Proceedings of the Thirteenth Dredging Seminar

Prepared by

Center for Dredging Studies

J. B. Herbich, Ph.D., P.E., Director

CDS Report No. 253

TAMU-SG-82-102
September 1981

Texas A&M University **Sea Grant College Program**

College Station, TX 77843

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MOUNT ST. HELENS ERUPTION

Restoration of Columbia, Cowlitz and Toutle River Channels for Navigation and Flood Control

by

J. F. Bechly[1]

ABSTRACT

On 18 May 1980, Mount St. Helens, Washington experienced a major volcanic eruption. Resulting eruptive flows consisting mainly of a large portion of the former mountain top were displaced into the upper reaches of the Toutle River. Large volumes of these sands, gravels and silts reached the Cowlitz and Columbia Rivers. At an estimated cost of $221 million, a massive water and land fleet of dredging equipment was mobilized by the Portland District, U.S. Army Corps of Engineers, to begin the restoration. Flood control work requires significant completion by late October 1980, and navigation depths are being restored in increments to alleviate delays to vessel traffic.

[1]Chief, Waterways Maintenance Branch, Navigation Division, Portland District, U.S. Army Corps of Engineers.

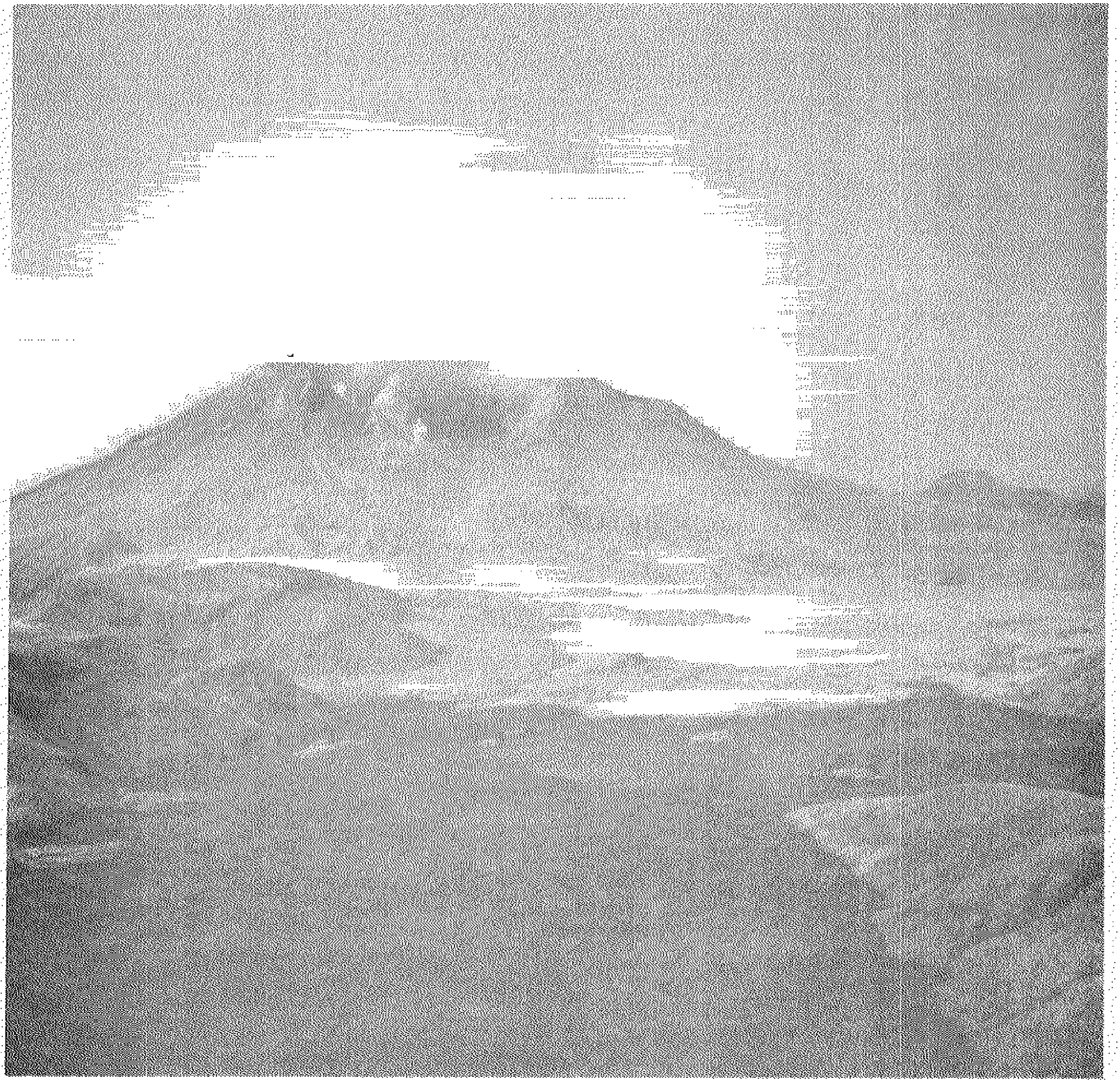
1. General

In early April 1980, Mt. St. Helens in southwestern Washington State began exhibiting earthquakes, minor steam and ash ejections and other activities signaling a new era of activity in recent times for this longtime inactive volcano. Minor eruptions continued, becoming larger and 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 several hundred feet, 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.

Shock waves created by the explosion were felt and heard in faraway places such as Vancouver, B. C., eastern Washington and Oregon into the Willamette Valley. However, nearby communities to the south and west of the mountain including Vancouver, Washington, Portland, Oregon and Longview and Kelso, Washington, did not feel or hear the blast. The gas cloud and blast zone impacted by the mountain ranged from 12 to 15 miles to the north and west of the volcano. Temperatures within the zone of devastation are estimated to have reached more than 500 degrees centigrade.

The eruption and blast removed an estimated 4 billion cubic yards of material from the top and center of the mountain, lowering its height by more than

MOUNT ST. HELENS AND SPIRIT LAKE BEFORE ERUPTIONS



MOUNT ST. HELENS AND SPIRIT LAKE AFTER MAJOR ERUPTIONS

1200 feet and forming a huge crater more than a mile in diameter. It is estimated approximately one quarter of the 4 billion cubic yards 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. Thicknesses as deep as two and three inches are recorded in some communities of eastern Washington, with thicknesses of a sixteenth to an eighth of an inch recorded in communities in Idaho, Montana and Wyoming. As shown on Figure 1, the blast and resultant mud and pyroclastic flows also impacted the river basins of the Toutle, Cowlitz and Columbia rivers. It is estimated that approximately 3 billion cubic yards of the material settled in the upper 14 miles of the north fork of the Toutle River, with an additional 58 million cubic yards settling in the upper reaches of the south fork of the Toutle River. Mudflows in the following 24 hours, buoyed by melting ice and waters displaced out of the upper river channels, carried more than 50 million cubic yards into the 21 miles of the Cowlitz River from the mouth of the Toutle downstream and deposited an additional 45 million cubic yards in the Columbia River, upstream and downstream, of the mouth of the Cowlitz River. These flows and volumes occurred in less than a 24-hour period after the blast. The Toutle and Cowlitz rivers experienced three successive flood crests. The third crest occurred early on the 19th of May at Castle Rock and equaled a 250-year frequency. This flow came from less than one-fourth of the drainage area. Columbia River infill took place between the hours of midnight and five A. M. on 19 May. It is difficult to imagine these tremendous volumes of material moving into these river basins and 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

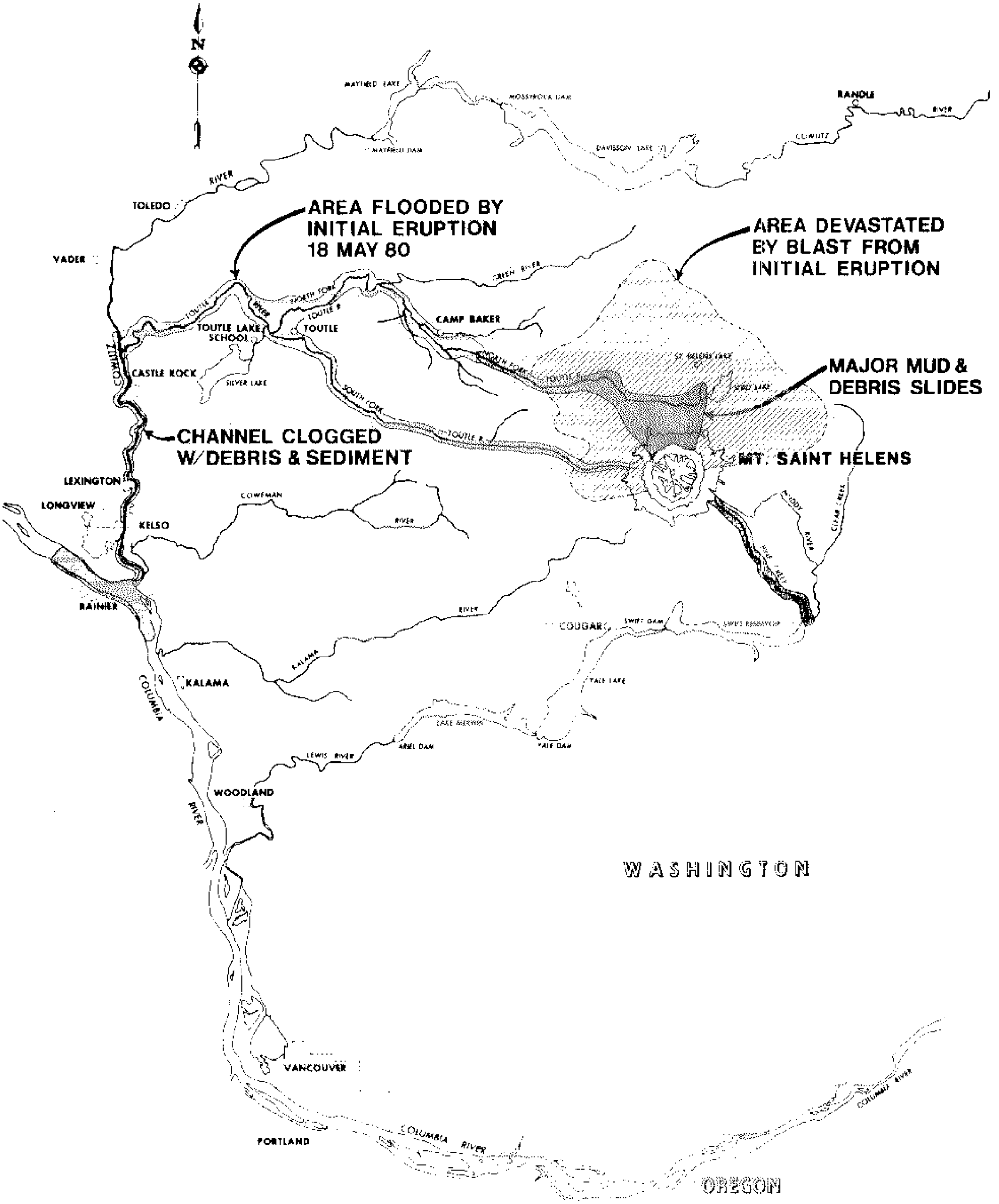
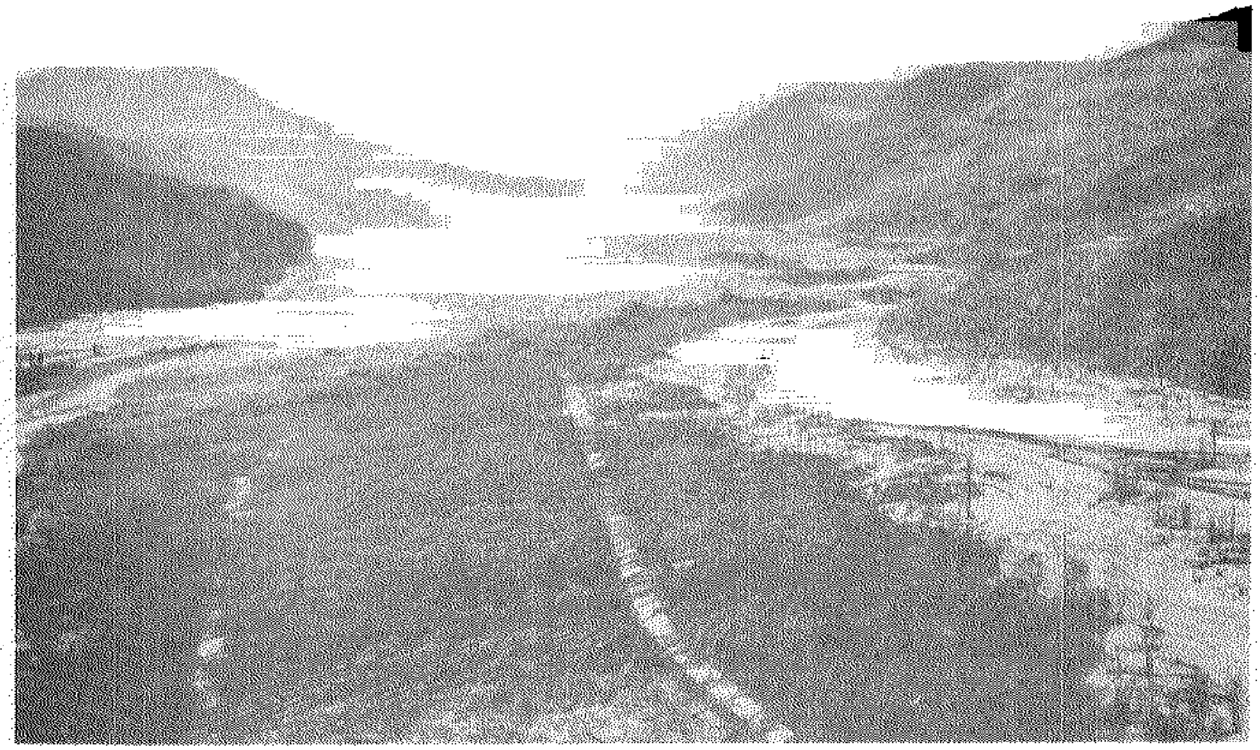
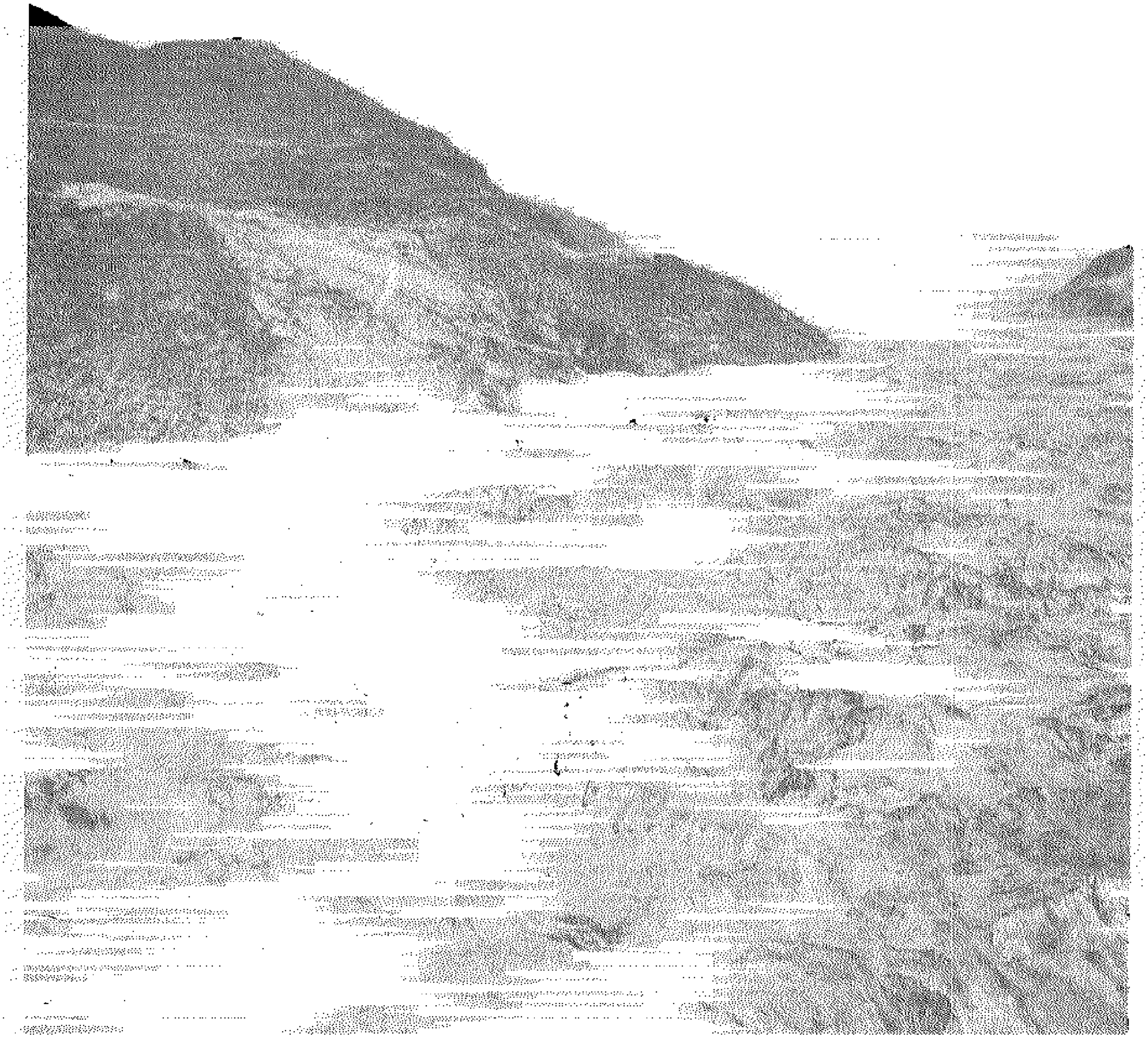

N
AREA FLOODED BY
INITIAL ERUPTION
18 MAY 80
AREA DEVASTATED
BY BLAST FROM
INITIAL ERUPTION
MAJOR MUD &
DEBRIS SLIDES
CHANNEL CLOGGED
W/DEBRIS & SEDIMENT
MT. SAINT HELENS
TOLEDO
VADER
TOUTLE LAKE
SCHOOL
TOUTLE
CAMP BAKER
CASTLE ROCK
LEXINGTON
LONGVIEW
KELSO
RAINIER
KALAMA
COUGAR
WOODLAND
VANCOUVER
PORTLAND
RANDLE
COLUMBIA RIVER
WASHINGTON
OREGON

FIGURE 1



VIEW OF NORTH FORK TOUTLE RIVER
(Note mudflow and Mount St. Helens in background)



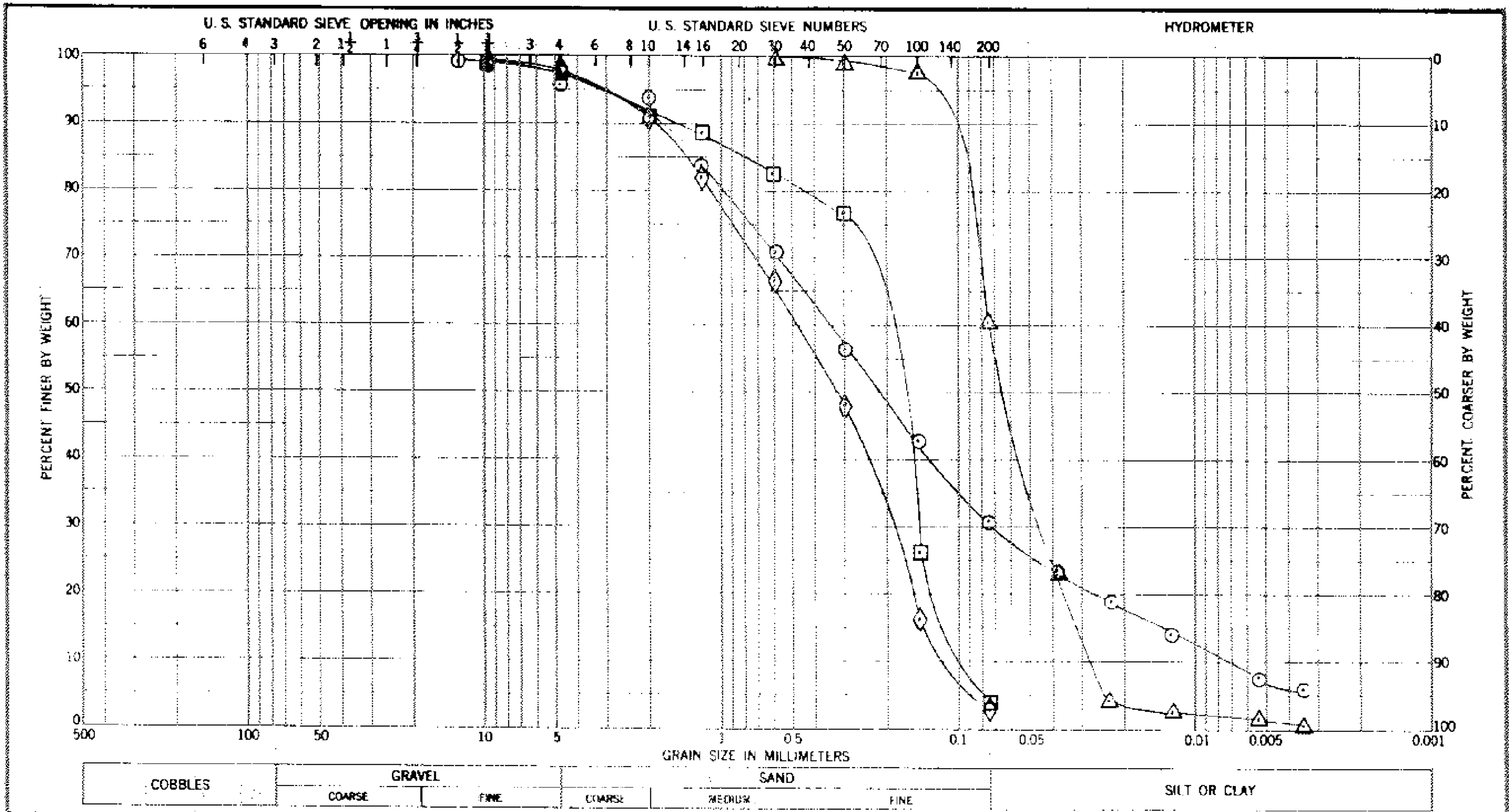
VIEW OF MUDFLOW IN NORTH FORK TOUTLE RIVER VALLEY

Kelso. Mudflows did not build up at any locations, but resulted in uniform layers of sand and gravel and other debris being deposited throughout the floodplain of the lower Toutle and the lower Cowlitz River valleys; instead of the normal-stained high-water marks such as experienced in rainfall floods, almost everywhere the water flowed in the lower Cowlitz and Toutle Rivers a hard dense layer of sand and gravel was left.

This event could be likened to a similar volume of material and consistency of "pancake batter" flowing at a high rate of speed along the floors of these river valleys and simply leveling out and settling as the flows continued downstream. Trees were caked with up to several inches of material along their trunks as well as everything within the flow zone on these rivers. Tests on 19 May after the peak flows had passed still indicated 50% solids. JTU levels in the Toutle ranged upward from 8000 and in the Cowlitz were recorded at 5600 on 19 May. Normal levels are 3 to 10 JTU's. Figures 2 and 3 show mechanical analysis results of samples for Cowlitz and Columbia River channels. Densities in place range from 1801 gms/liter to 2086 gms/liter. Normal Columbia River sand densities are about 1850 to 1900 gms/liter. The infill material is very angular and tends to cling together, resulting in considerably less daily capacities and distances. Wear of dredge components were also found to be increased by up to 25%.

2. Flood Control Impact

Twenty-one miles of the Cowlitz River from the mouth of the Toutle River downstream were essentially filled in, eliminating natural channel capacities.



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
River Mouth	20 May 80 ⊙	Silty SAND (SM)	In place density =			1801 gm/liter
R.M. 0.2	20 May 80 △	Sandy SILT (ML)	" (NON-PLASTIC)			1801
R.M. 3.5	20 May 80 ⊡	SAND (SP)	"			2087
R.M. 8.5	20 May 80 ◇	SAND (SP)	"			2026

Project: RIVER SEDIMENT ANALYSIS

Area: Cowlitz River, WA

Boring No

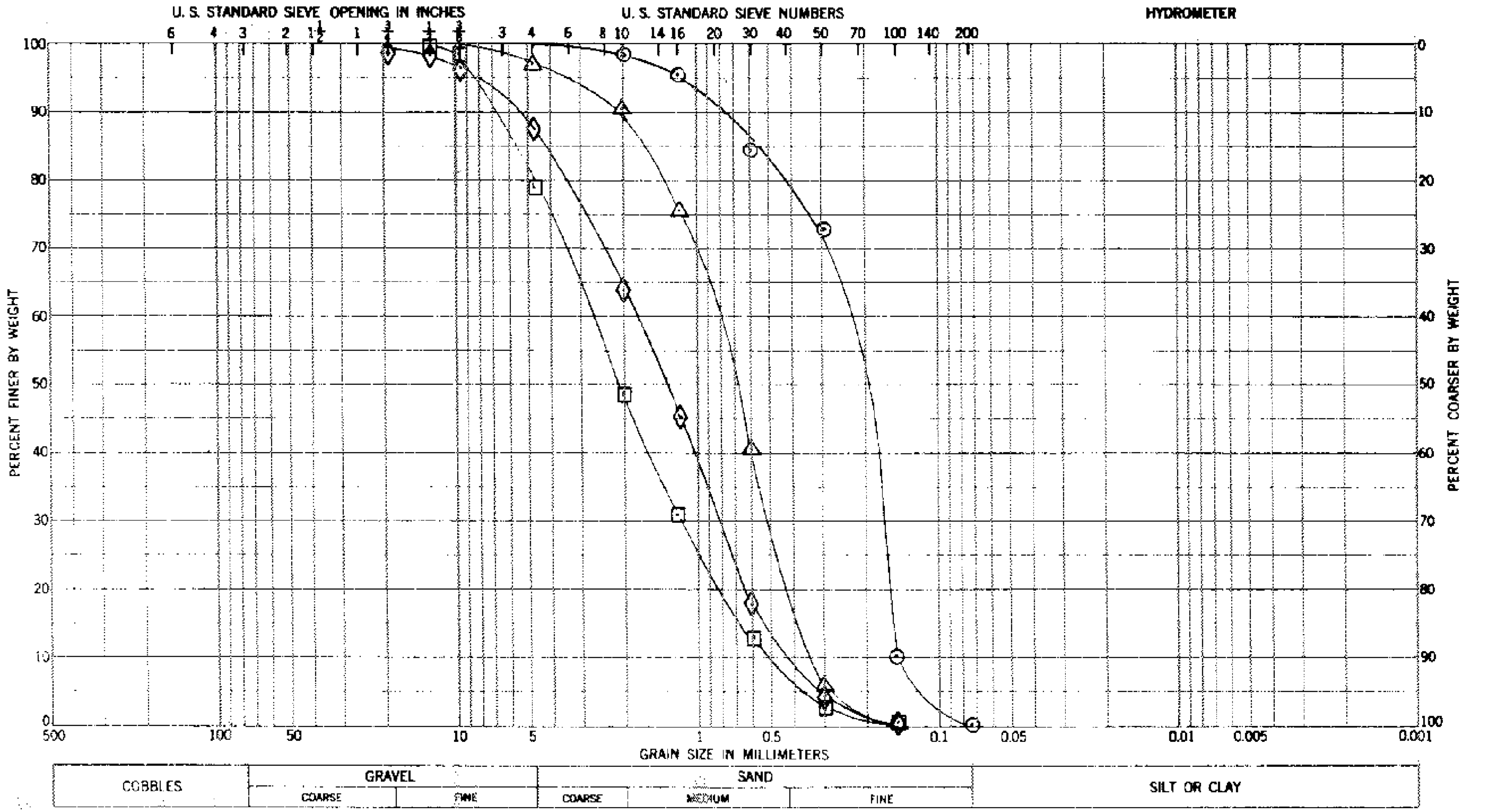
Date: 17 Jun 80 (80-S-649)

GRADATION CURVES

NPD

ENG FORM 1 MAY 63 2087

FIGURE 2



Sample No.		Elev or Depth	Classification	Nat w %	LL	PL	PI
CRM	⊙	67+05	SAND (SP)	in place density =		1903 gm/liter	
CRM	△	67+40	SAND (SP)	"		1896 "	
CRM	□	68+10	Gravelly SAND (SP)	"		1982 "	
CRM	◇	68+40	Gravelly SAND (SP)	"		1967 "	

GRADATION CURVES NPD

Project: RIVER SEDIMENT ANALYSIS

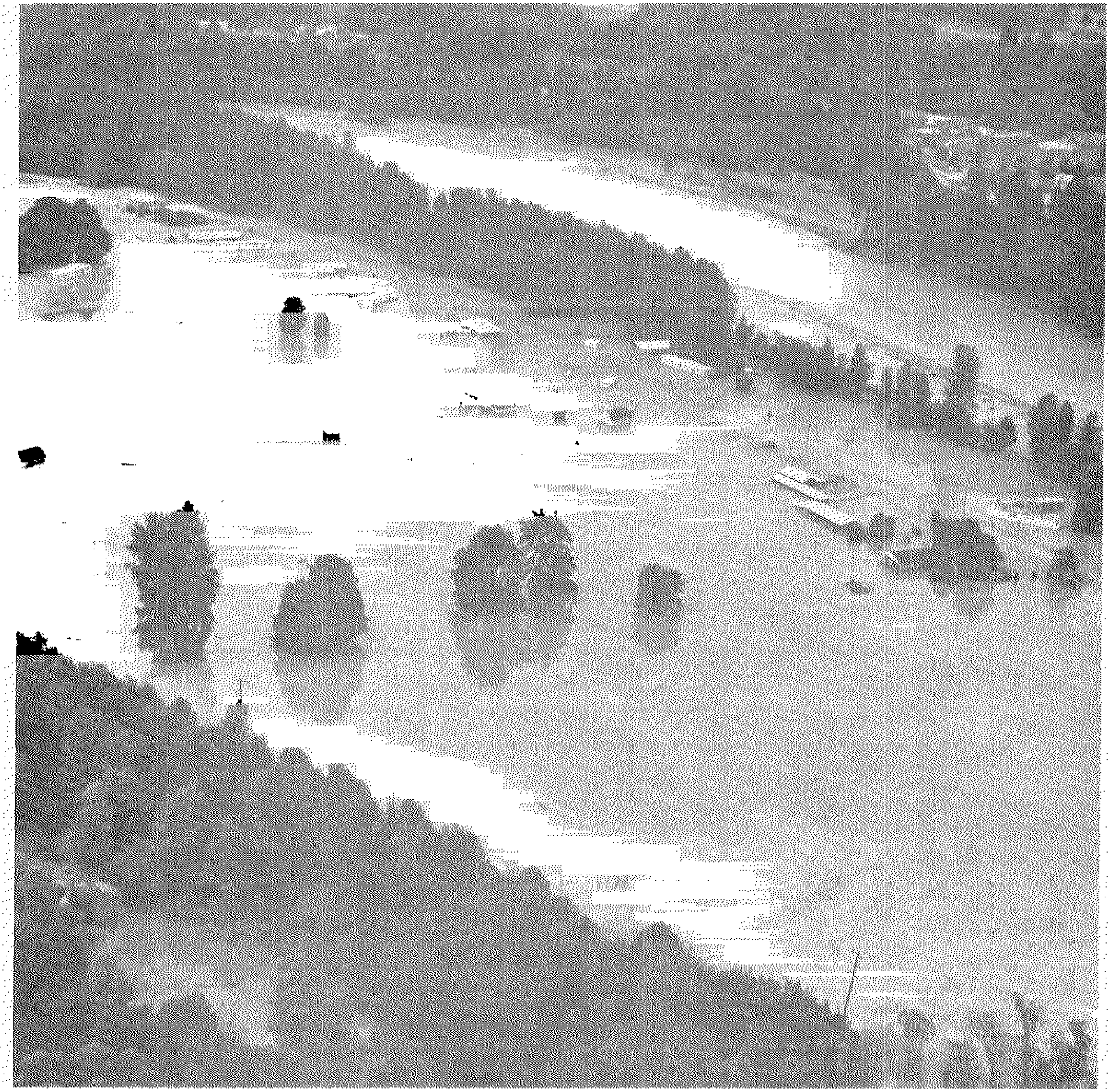
Area: Columbia River

Boring No.: Sampled 18 June 1980

Date: 25 June 1980 (80-S-649)

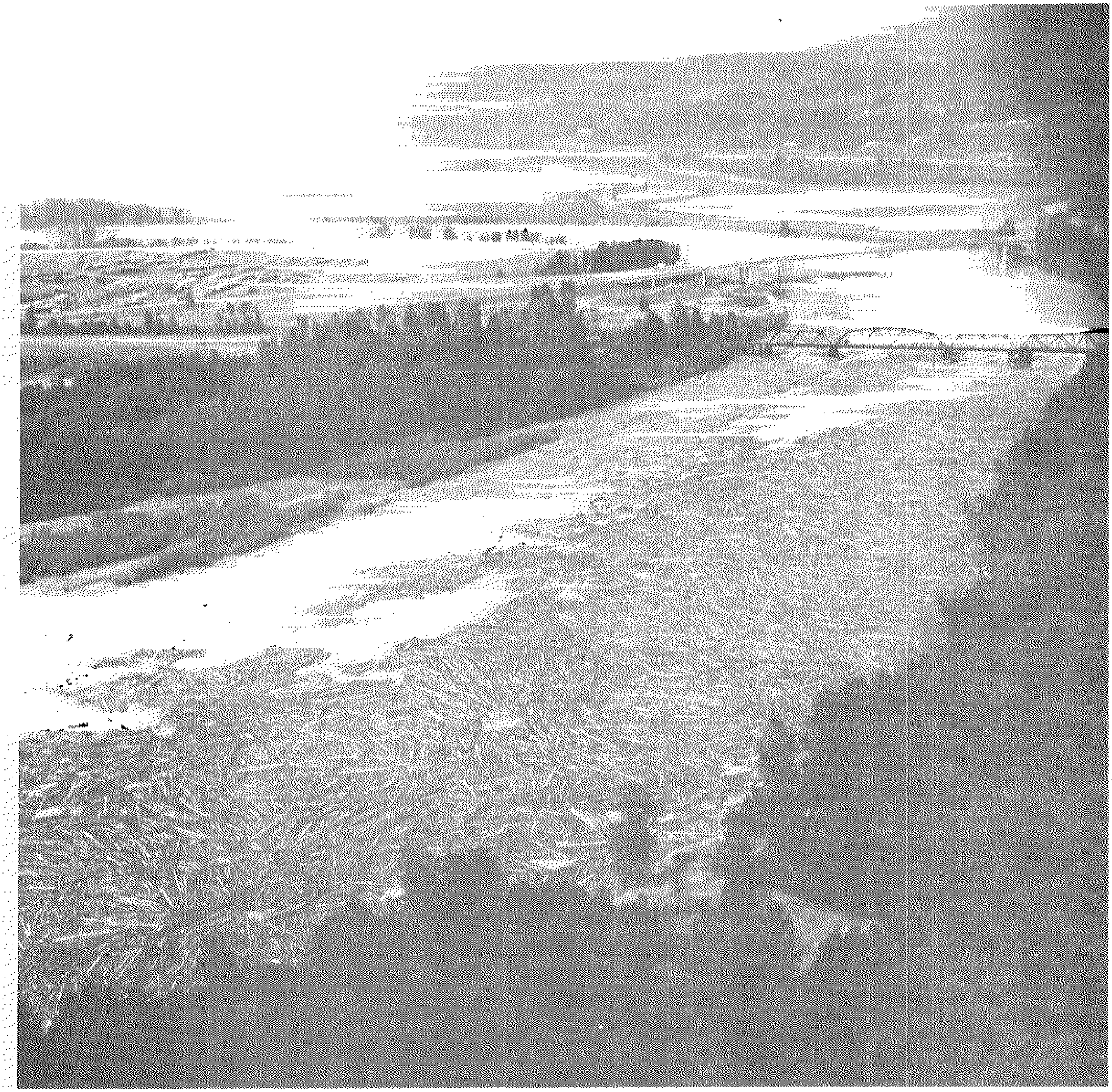
ENG FORM 1 MAY 63 2087

FIGURE 3



UPPER COWLITZ RIVER

(Typical view of how mudflow impacted Cowlitz Valley)



DEBRIS IN COWLITZ RIVER ONE DAY AFTER ERUPTION.

Figure 4 provides profiles of the Cowlitz River before and after the mudflows. At the time of the eruption, Cowlitz River flows were in the neighborhood of 8 to 10,000 cfs and these flows after the resultant mudflows on 18 and 19 May were essentially at bank-full capacity. In addition, because mudflow materials remained in essentially all areas they inundated, valley storage capacities for the normal floods were severely impaired. Communities of Lexington and Castle Rock, as well as the large communities of Kelso and Longview, were left virtually without flood protection and would experience millions of dollars in damage during the coming winter months if urgent measures were not undertaken immediately. In the Columbia River, flood control impacts were not nearly so severe. It is estimated 45 million cubic yards of infill material would have raised flood levels on the Columbia River upstream of the Longview area more than a foot for several miles. However, there were no extensively developed areas in this affect-impacted reach that would experience severe damages because of the increased flood levels.

3. Navigation Impacts

Columbia River navigation channel is normally 40 x 600 feet Columbia River low-water datum. This channel traverses the Columbia River from the ocean to the Portland, Oregon metropolitan area. The Cowlitz River enters the Columbia River at the Columbia River Mile 68, and the mouth of the Willamette River which serves the Portland harbor area at Mile 101. In addition, there is routinely maintained navigation channel in the lower four miles of the Cowlitz River with dimensions of 10 by 150 feet. This latter channel served primarily tug and barge traffic; whereas, the Columbia River navigation channel serves tug and barge and deep draft vessel traffic and experiences commerce in excess of 25 million tons per year in these reaches.

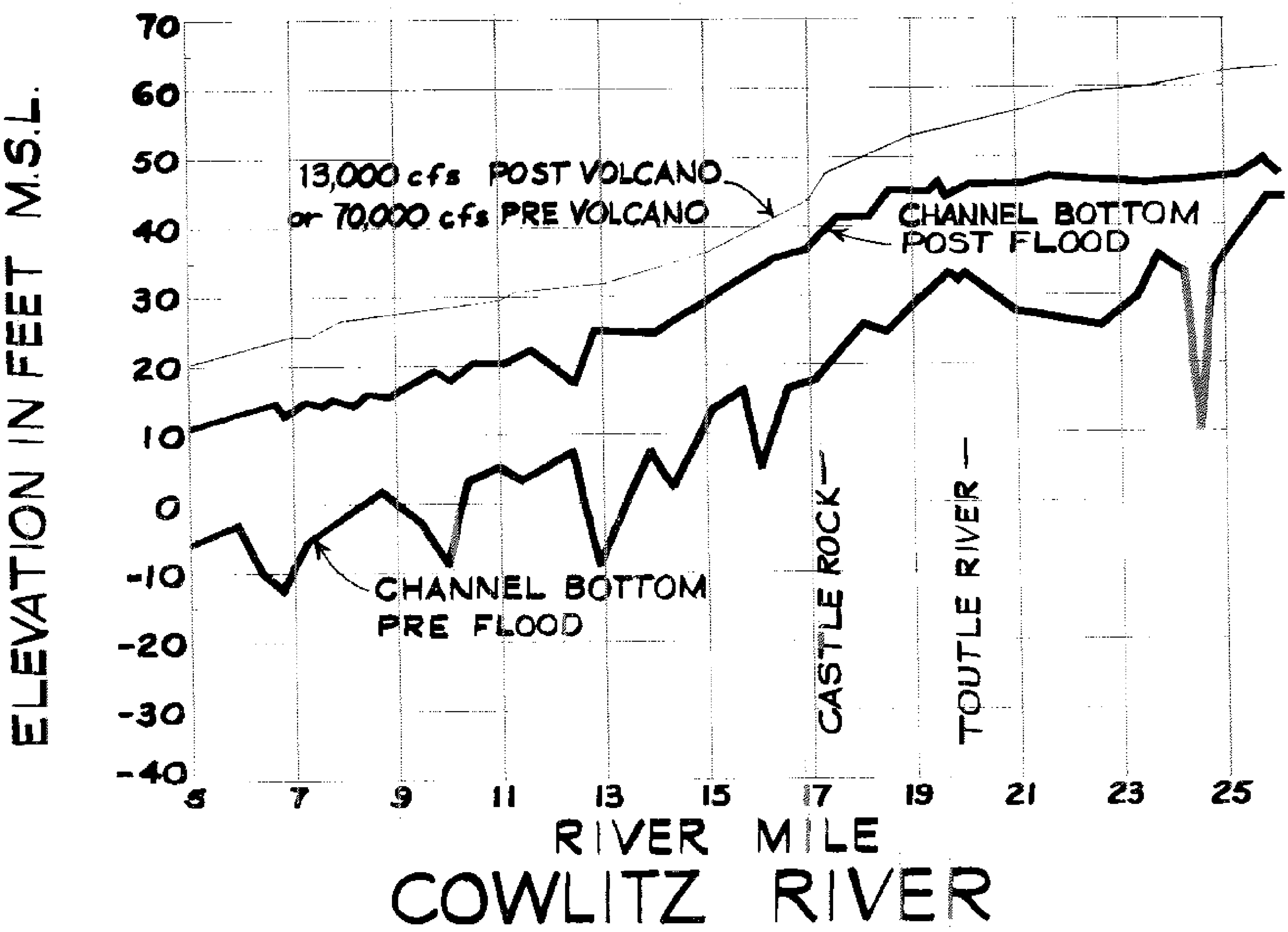
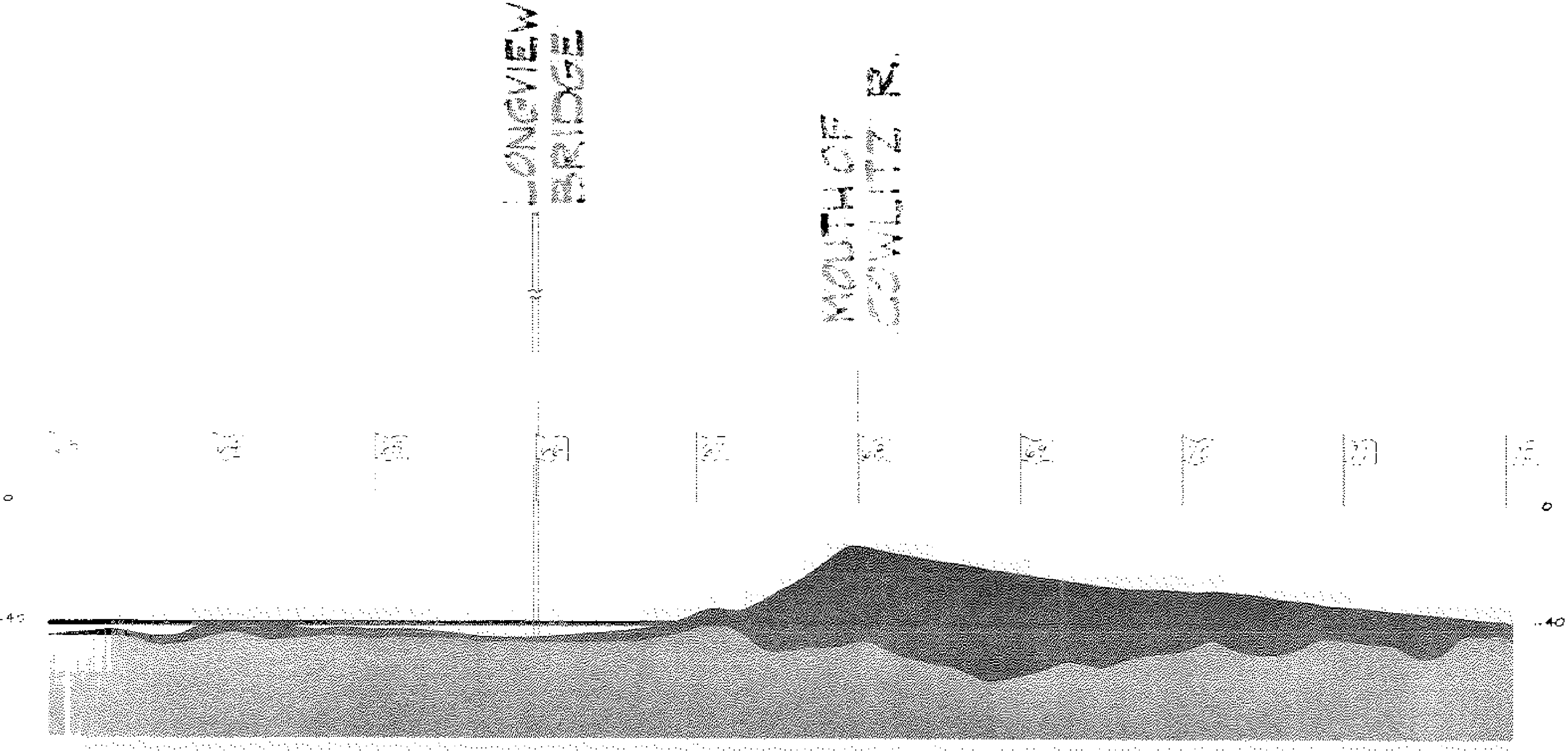

70
60
50
40
30
20
10
0
-10
-20
-30
-40
ELEVATION IN FEET M.S.L.
13,000 cfs POST VOLCANO
or 70,000 cfs PRE VOLCANO
CHANNEL BOTTOM
POST FLOOD
CHANNEL BOTTOM
PRE FLOOD
CASTLE ROCK
TOUTLE RIVER
5
7
9
11
13
15
17
19
21
23
25
RIVER MILE
COWLITZ RIVER

FIGURE 4

As reported by the Columbia River pilots, a deep draft vessel traversed the Columbia River channel in the vicinity of River mile 68 in an upstream direction without incident at 3 A. M. on 19 May. However, at 5 A. M. on 19 May another vessel progressing upstream ran hard aground at River mile 68 adjacent to the mouth of the Cowlitz River and had to be assisted off by tugs later in the day. Hydrographic surveys accomplished late on 19 May after turbidity levels subsided sufficiently enough to allow penetration of electronic Fathometer signals, revealed navigation depths in the Columbia River had been reduced to 15 feet CRD and navigation depths in the Cowlitz River were virtually nonexistent. These depths essentially closed the Columbia River channel from upstream of Longview to deep draft-vessel traffic. Thirty-one deep draft vessels were trapped upstream of the area in the Portland-Vancouvèr and Kalama harbor areas. In addition, 50 ships enroute to the area were forced to stand off the mouth of the Columiba River or seek other ports. Impacts to the 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 Mile 63 upstream to River Mile 72. Figure 5 illustrates the distribution of the material in comparison with normal channel depths. Based on surveys, approximately 14 million cubic yards of material infilled the 40 by 600 foot navigation channel in this reach alone.

4. Funding

After a survey of the impacted area and consideration of available alternatives for restoring the flood control and navigation channels of the Columbia and Cowlitz rivers together with measures necessary to minimize future impacts of winter flood and erosion of the huge mudfills in the Toutle River basin, a funding program was determined and submitted to the



COLUMBIA RIVER
LONGITUDINAL PROFILE
R.M.63 to R.M.72

HORIZONTAL SCALE: 1"=16,000'
VERTICAL SCALE: 1"=160'
(DISTORTED VERTICAL SCALE)

FIGURE 5

Congress. This program resulted in $221 million being made available to accomplish restorative measures for the Corps of Engineers activities resulting from the St. Helens eruption. $176 million of this money was in Public Law 99 funds and the remaining $45 million in O & M funds for the Columbia River channel. Figure 6 illustrates a breakdown of funding program for Fiscal Year 1980. It is estimated an excess of $55 million additional funds may be required through Fiscal Year 1985 based on current conditions and reasonable estimates of future impacts from eruptive activities already experienced. Further eruptions could alter our restoration program and probable funding requirements.

5. Environmental Impact Statement

In an unprecedented effort, Portland District staff embarked on preparation of an EIS for the Mount St. Helens recovery operations to provide the public, Federal and State agencies an opportunity to review the alternatives considered and probable impacts to the environment of the actions underway and proposed to be accomplished. The draft Environmental Impact Statement was completed in preliminary form on 25 July 1980 and sent to interested Federal, State and local agencies for review. The final draft Environmental Impact Statement was submitted to the Environmental Protection Agency 19 September 1980. The time frame for production of the initial draft was only twenty days and many procedural steps were obviously abbreviated. The time table did not permit detailed and in-depth review of each topic discussed. However, it is simply not possible to be complete due to the unstable conditions and incomplete data available at the time. The EIS was written in the spirit of the NEPA and will be supplemented in the future as updated information clarifies the many options or alternatives that are considered as conditions develop.

Columbia - Cowlitz Rivers

Navigation and Flood Control Channel Restoration

Funding Program	1980
Cowlitz River Channel Excavation	113.1
Toutle River Sediment Stabilization Basins	2.9
Debris Retaining Structures	15.2
Seeding Disposal Areas	1.0
Green River Fish Hatchery Protection	1.7
Mossyrock Storage Agreement	8.0
Assistance to Resource Agencies	.2
Flood Protection	
a. Levees	15.5
b. Bank Protection	4.0
c. Local Assurances	10.3
Engineering and Design	4.0
Hydrology-sediment Studies	0
Columbia River Dredging	45.0
Total	221.1

FIGURE 6

6. Restoration efforts.

Immediately after the eruption the blockage to the navigation channels of the Columbia and lower Cowlitz Rivers was clearly evident. On 19 May District hopper dredge plant was ordered mobilized to the site and a search began for contractor-owned dredging equipment. On 23 May a letter contract was awarded for movement of most of the large pipeline dredges of the West Coast to the worksite. In the following days, several tributary-stream drainage channels completely blocked by the mudflow in the Cowlitz River were the scene of activity by Corps of Engineers emergency excavation activities and minor improvements were made to existing levee systems to provide minimum flood protection.

In following days and weeks as more data of the extent and impacts of the St. Helens eruptions were made known, planning efforts for a variety of alternatives to provide both navigation in the Columbia River and flood control protection to the communities in the Cowlitz River basin were developed. Additional dredges for restoration of the Cowlitz River channel, debris retaining structures in the upper Toutle River basin, levee construction for urban areas in the lower Cowlitz River and other alternatives were conceived, considered and initiated as soon as their scope could be firmed and invitations for bid processed. The following paragraphs briefly outline the efforts involved in the various alternatives for these restoration activities.

a. Navigation on the Columbia River. Figure 7 illustrates the River from Mile 63 to River Mile 72 together with the location of the mouth of the Cowlitz River. As shown on Figure 5, the major portion of the infill occurred in this reach of the Columbia River. After preliminary surveys on 19 May three government hopper dredge plant vessels operated by the Portland District were ordered to this vicinity. In addition, the Port of Portland

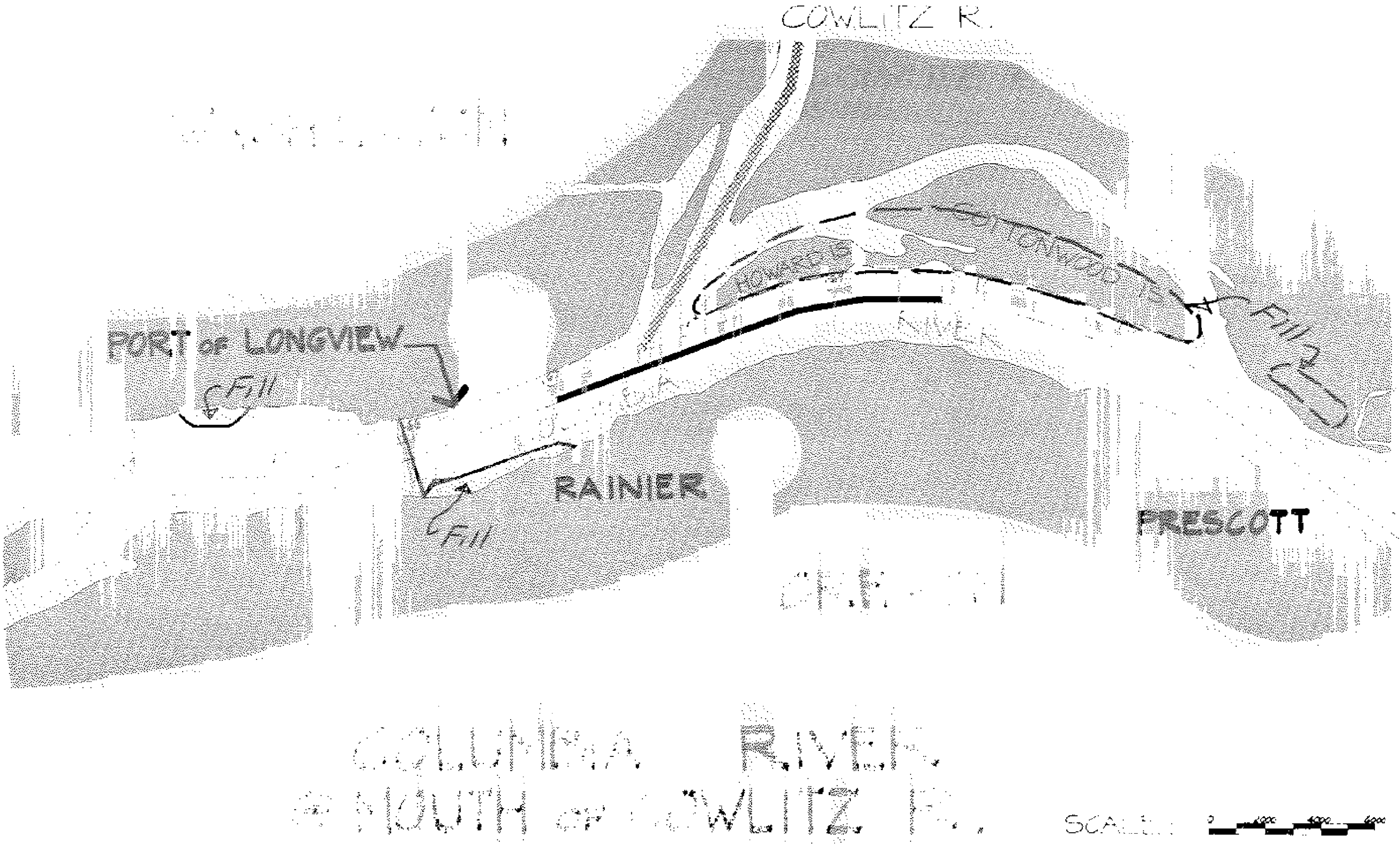
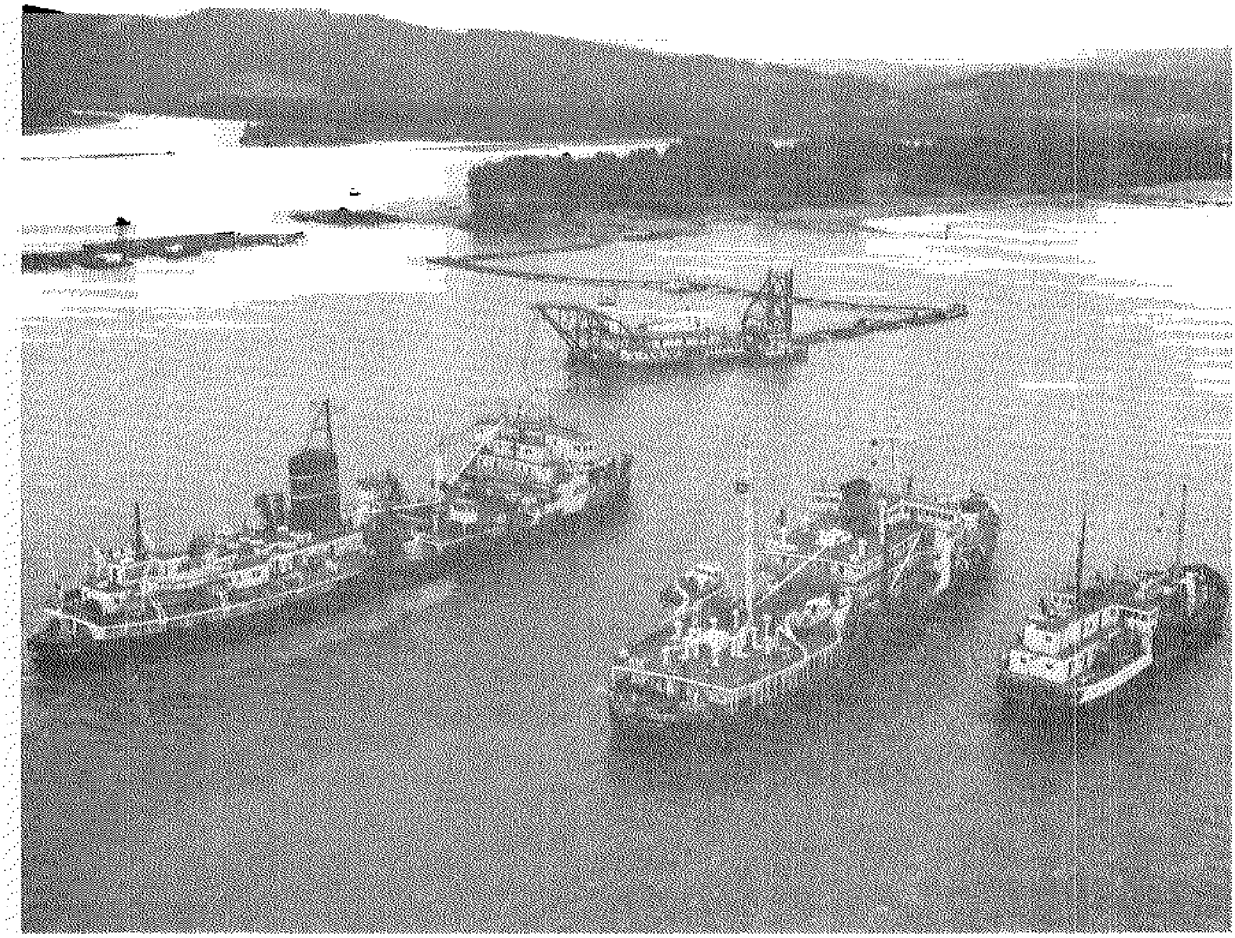

COWLITZ R.
PORT of LONGVIEW
Fill
Fill
RAINIER
HOWARD IS
COTTONWOOD IS
Fill
RIVER
PRESCOTT
COLUMBIA RIVER
@ MOUTH of COWLITZ R.
SCALE

FIGURE 7

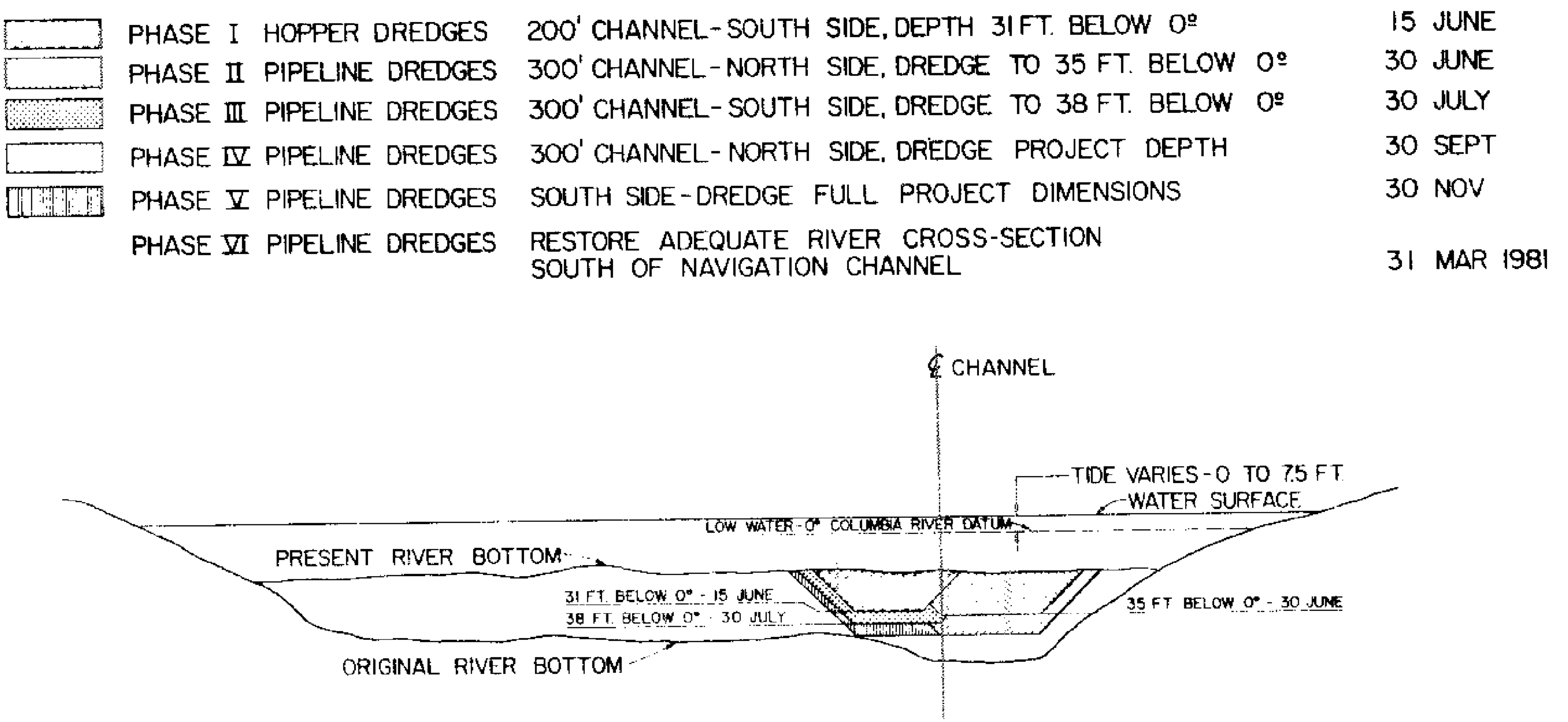


HOPPER DREDGES BIDDLE, HARDING AND PACIFIC AND

30" PIPELINE DREDGE OREGON
(Note Mouth of Cowlitz River in background)

AERIAL VIEW OF COLUMBIA RIVER
COWLITZ RIVER MOUTH AT LOWER LEFT.
(Note three pipeline dredges at work)

30-inch pipeline dredge OREGON, working under Corps of Engineers contract at another location in the lower Columbia River, was ordered to proceed to the area. As additional survey data was accumulated over the next forty days, contractors on the West Coast and throughout the nation were canvassed by phone to determine the amount of large pipeline dredging plant that was active and available to be mobilized to the area within a short period of time. A contract was negotiated immediately with the largest dredging contractor on the West Coast. At the same time determination of the location and extent of a large amount of disposal area capacity necessary was underway. This effort required maximum cooperation between contractors, local authorities, environmental interests, a large number of Federal, State and local agencies. Because of the urgent nature of the restoration activities, environmental requirements were relaxed if necessary, as long as all reasonable efforts were made to reduce impacts from the activities. Figure 8 illustrates the phased plan of excavation of the Columbia River navigation channel that was conceived and accomplished on a timely basis to provide utilization of the channel by deepdraft vessels on a priority basis. Columbia River pilots and the U.S. Coast Guard cooperated complet-ly in controlling the passage of deepdraft vessels through this area during high-tide periods and daylight hours only on a fully coordinated basis to provide for a maximum of vessel traffic passage with a minimum of disruption and danger to the equipment and dredging crews in the area. Table 9 provides a summary of the dredges utilized to restore the Columbia River navigation project channel depths together with the listing of pertinent data. The 14 million cubic yards of infill in the federal project will be removed by about 30 November 1980.



TYPICAL SECTION
COLUMBIA RIVER AT LONGVIEW

FIGURE 8

COLUMBIA RIVER - PIPELINE DREDGES - PERTINENT DATA

Dredge	Work Start	Size Inches	Pump Hp	c.y./day	Eff Hrs/day	Non Eff Hrs/day	Repair Hrs/day	Max Pump Dist to date
OREGON	23 May	30	4985	24,500	18.91	4.55	.54	6,310'
O. Riedel	7 Jul	26	4200	20,600	17.19	4.63	2.18	4,620'
MCCURDY	7 Jun	24	3000	15,800	16.64	5.11	2.25	3,450'
LOFGREN	6 Jun	24	2900	15,800	17.19	5.08	1.73	3,790'

NOTE: Figures are averages

Figure 9

Upon determination thereof, nearly 45 million cubic yards of material had infilled into this reach of the Columbia River channel, and it was evident that more than restoration of the navigation project itself would have to be accomplished in the near future. Otherwise, continued normal river flows would erode the remaining infilled material and move significant amounts downstream to cause disruptions to navigation channel depths for the foreseeable future. Soon after the magnitude of the problem was determined, the services of a consultant were secured with the view towards determining the extent of additional dredging outside federal project limits that should be accomplished to minimize the impacts of future flows to navigation channel depths in the Columbia River. Figures 10, 11 & 12 are maps illustrating the results of the consultant efforts. Excavation to the limits shown on the maps will result in an additional 8 million cubic yards of material being removed from the Columbia channel. The removal of the additional 8 million cubic yards is not as urgent and will be accomplished over the next years.

b. Lower Cowlitz. Within the first few days after the May 18 eruption as surveys and field reconnaissance confirmed a massive infill into the Cowlitz River channel, it became apparent that the lower 9 miles of the river presented special problems as far as restoration of the flood control and navigation channel. The navigation channel in the Cowlitz River existed previously from River Mile 4 downstream. Upstream to River Mile 9, areas adjacent to the river channel were heavily urbanized and disposal areas were sparse and often times several hundred to several thousand feet from the river channel. Upstream of River Mile 9, population densities dropped drastically and areas adjacent to the river channel were primarily farmland that had been inundated and infilled considerably as a result of the mudflows.

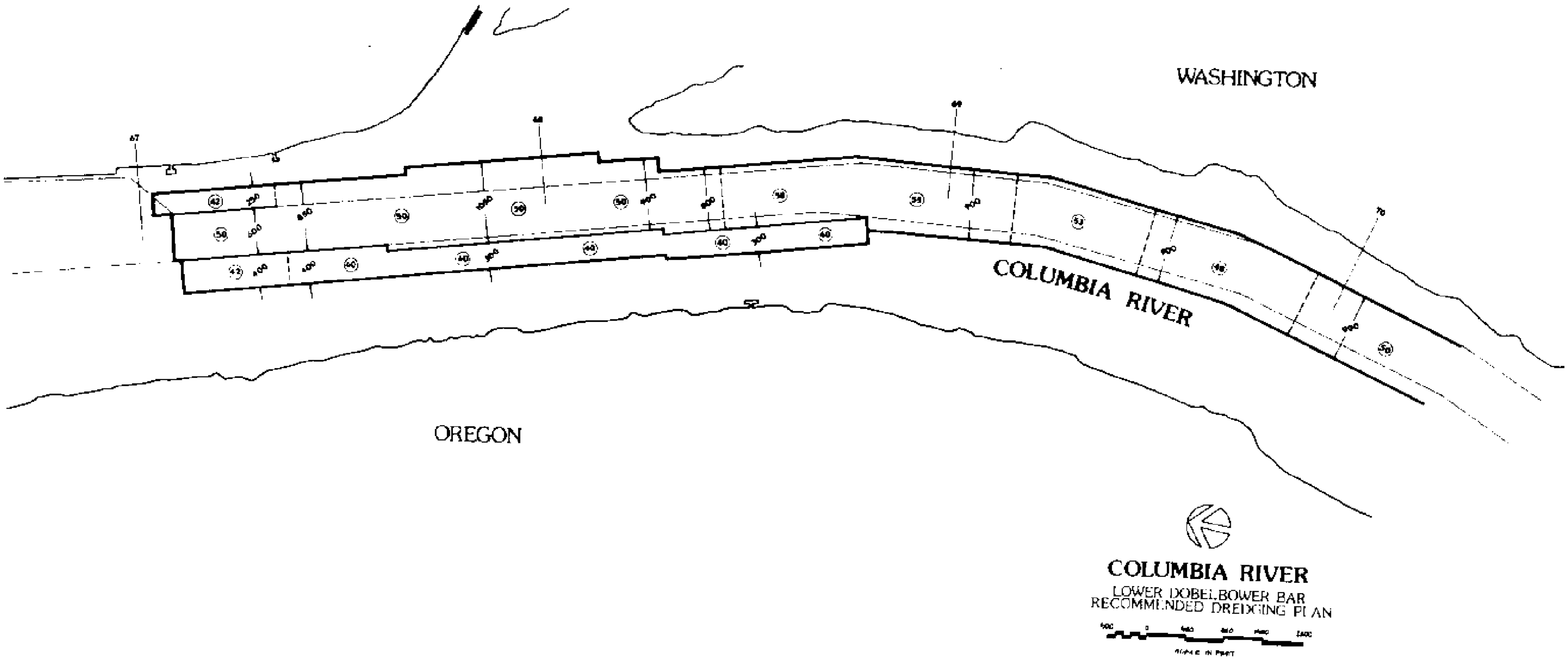

WASHINGTON
COLUMBIA RIVER
OREGON
COLUMBIA RIVER
LOWER DOBELBOWER BAR
RECOMMENDED DREDGING PLAN

FIGURE 10

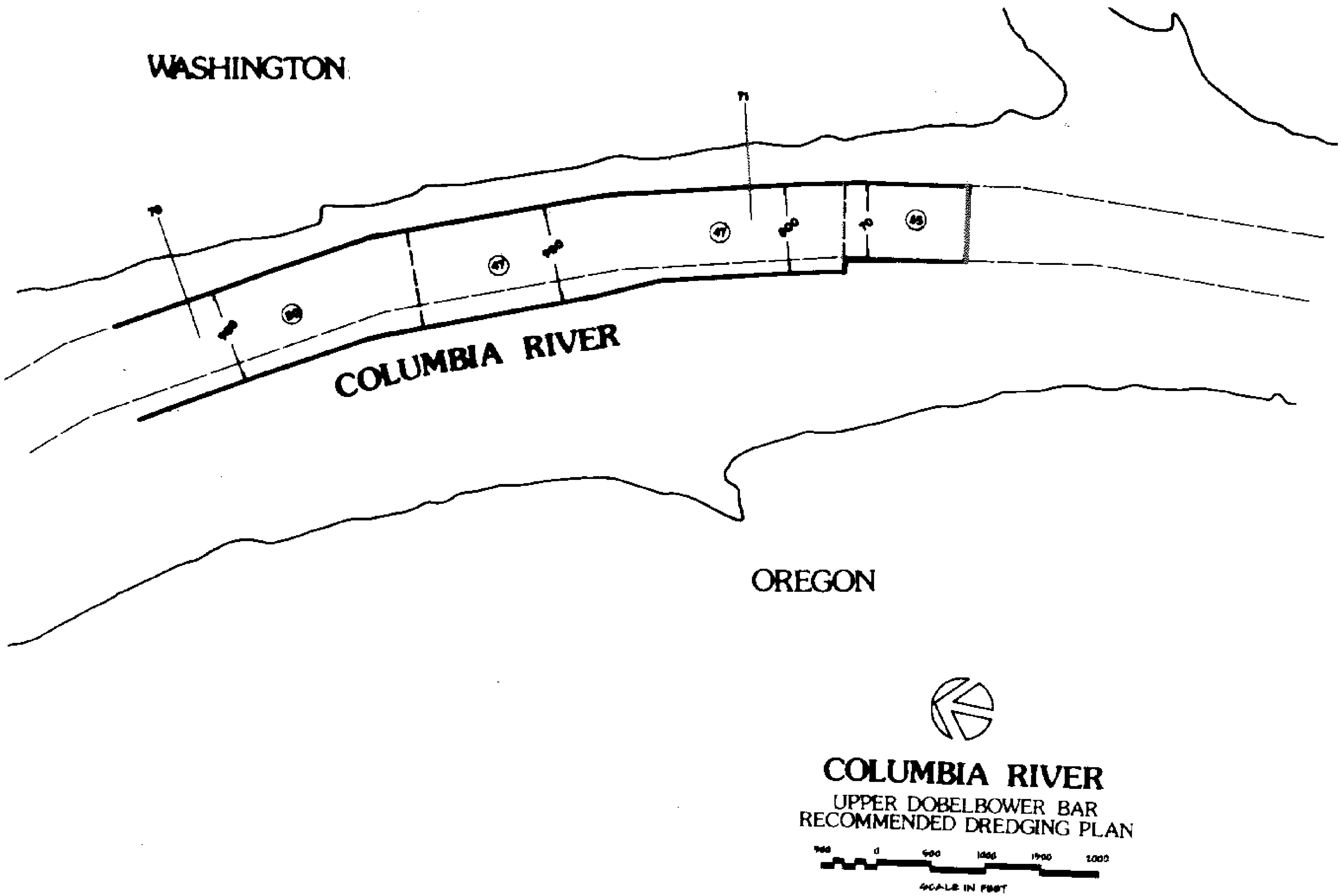

WASHINGTON
COLUMBIA RIVER
OREGON
COLUMBIA RIVER
UPPER DOBELBOWER BAR
RECOMMENDED DREDGING PLAN
SCALE IN FEET

Figure 11

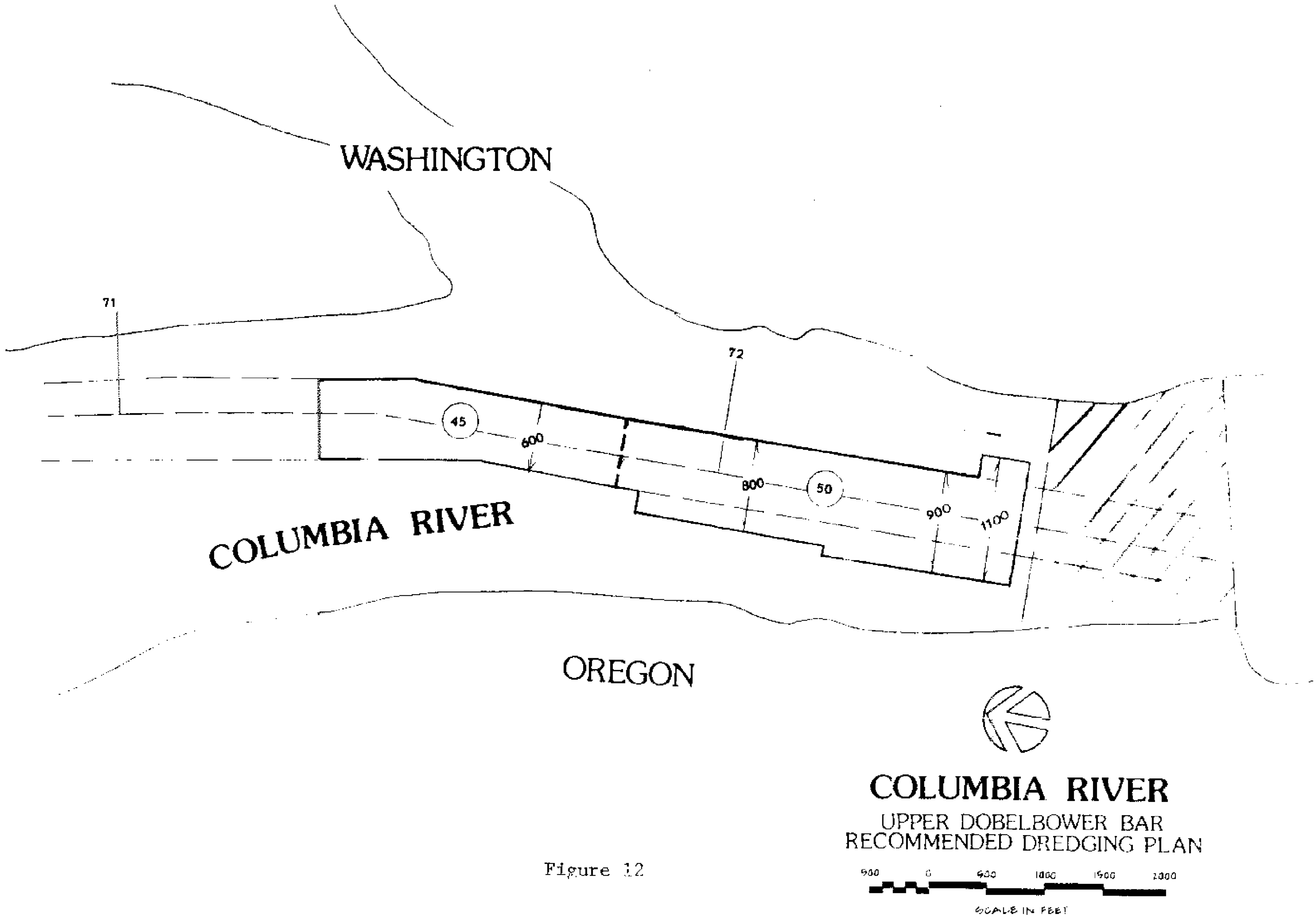

WASHINGTON
71
72
45
600
800
50
900
1100
COLUMBIA RIVER
OREGON
COLUMBIA RIVER
UPPER DOBELBOWER BAR
RECOMMENDED DREDGING PLAN
SCALE IN FEET

Figure 12

Accomplishment of restoration of the channel reach from River Mile 9 downstream appeared to be most feasible by medium and large pipeline dredge plant. It was also determined that nearly all of this type of plant on the West Coast would have to be utilized for this restoration operation. Therefore, normal competition by advertised bid to get the equipment to the site quickly was not possible and letter contracts were negotiated with the companies involved. This type of procurement enabled West Coast dredging plant to be mobilized to the area quickly and work to begin at an early date to provide maximum channel dimensions prior to the Fall rainy season. Work on the lower Cowlitz River was targeted to be accomplished to the maximum extent by 1 November 1980. In later weeks it became apparent that more large pipeline dredge plant would be required to accomplish channel excavation desired in the lower Cowlitz River by 1 November. Invitation for bids were prepared for mobilization for plant from other areas of the nation and two more dredges were secured by this method. Table 13 summarizes dredges utilized in the lower Cowlitz River, their capacities and other pertinent data.

One unique operation that took place as part of the mobilization of these large dredges in the lower Cowlitz River included the overland haul of the dredges ART RIEDEL and HERB ANDERSON from River Mile 1.5 to River Mile 6 to enable work to be accomplished quickly in the more critical area of the river channel. The picture illustrates one of these dredges being moved without being dismantled to save more than a month's dredging time up-river.

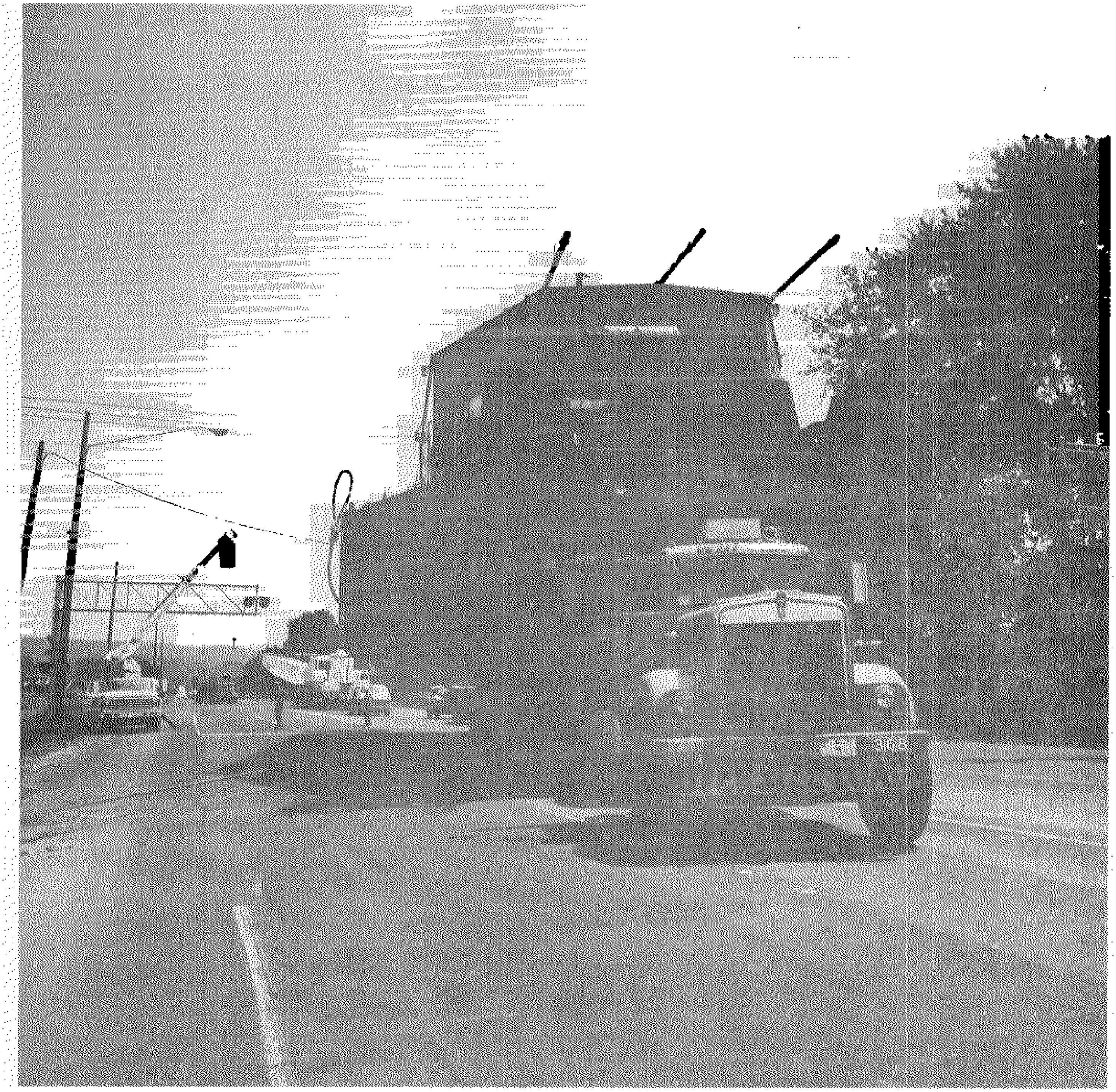
As mentioned previously, disposal in the lower reaches of the Cowlitz River were few and sometimes isolated from the river area. The photos

LOWER COWLITZ RIVER - PIPELINE DREDGES - PERTINENT DATA

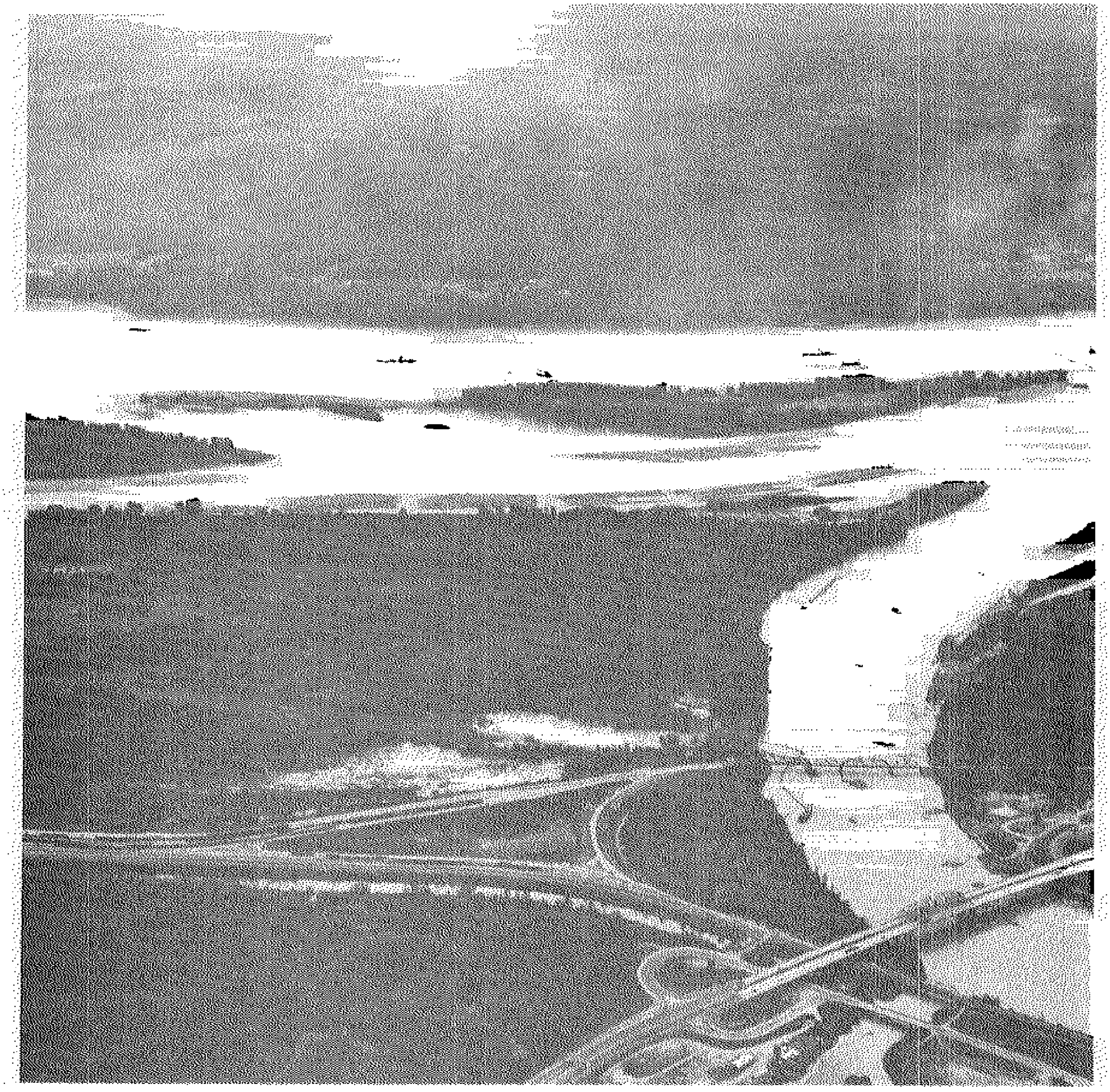
Dredge	Work Start	Size (inch)	Pump HP	CY/day (Avrg)	Eff. hr/day	N. Eff. hr/day	Repair hr/day	Max Pump to date	Mob-Demob Cost	Eff. cost/hr	N. Eff. cost/hr
MISSOURI	23 Jun	24	2500	24,700	18.22	3.40	2.39	3670'	NA	NA	NA
HUSKY	18 Jun	20	2800	19,200	20.21	2.59	1.20	4345'	302,800	983.	688.
A. RIEDEL	8 Jun	20	1850	19,400	17.47	4.10	2.43	3450' (20 Sept)	NA	NA	NA
H. ANDERSEN	19 Jun	20	1850	13,400	16.11	2.40	5.49	3020'(w/o booster) 5980'(with booster) 8 Sep, 18 Aug	NA	NA	NA
CORNELLIA B.	13 Sep	20	1900	13,200	18.49	2.62	2.89	1580'	250,000	1000.	700.
MR. GUS	20 Aug	16	700	8,000	17.26	3.07	3.67	1000'	170,000	640.	580.
HOWARD	7 Sep	16	2700	10,000	17.48	4.22	2.30	1940'	550,000	625.25	625.25

NOTE: Figures are averages

Figure 13

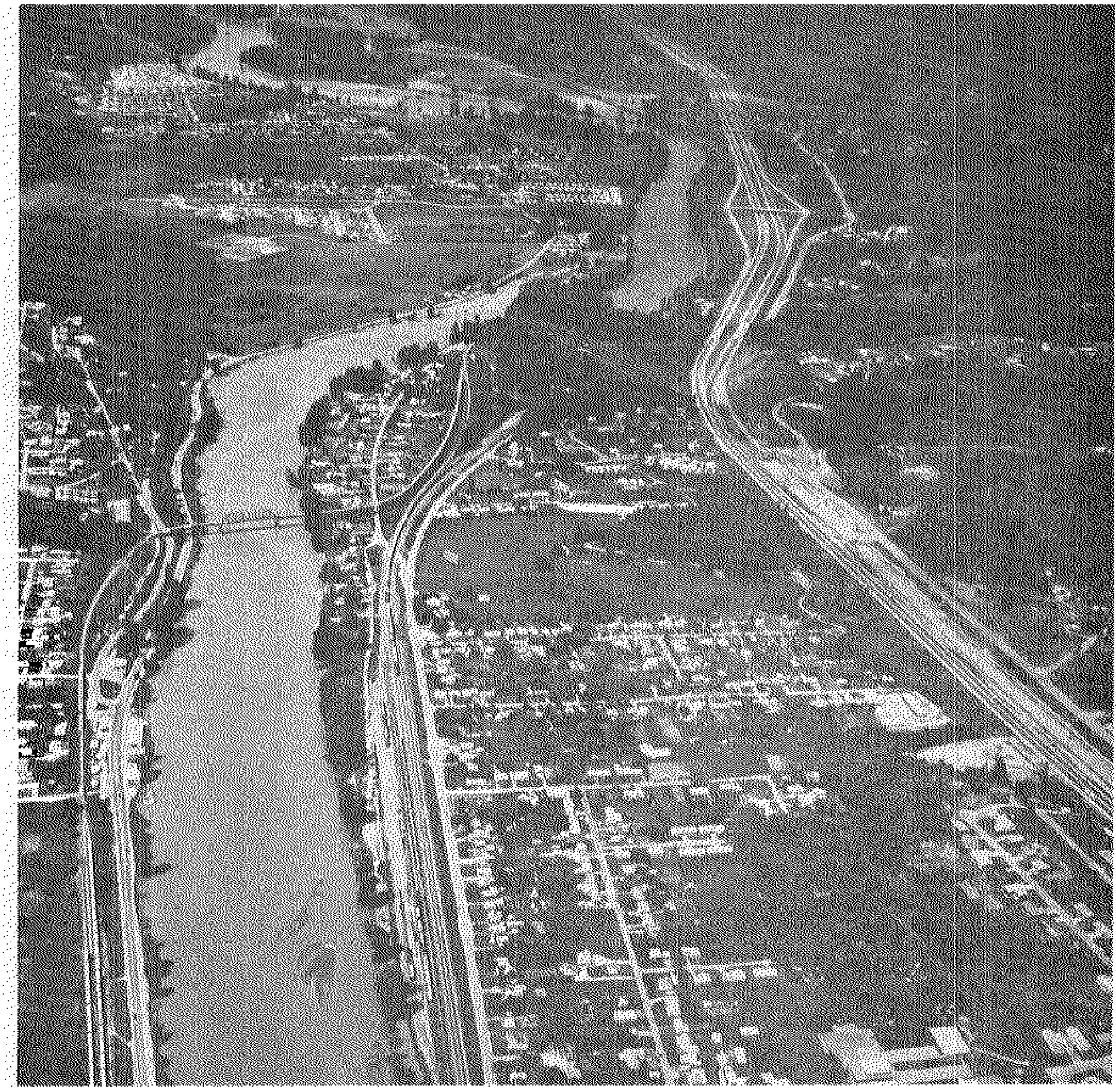


OVERLAND MOVE OF 20" PIPELINE DREDGE



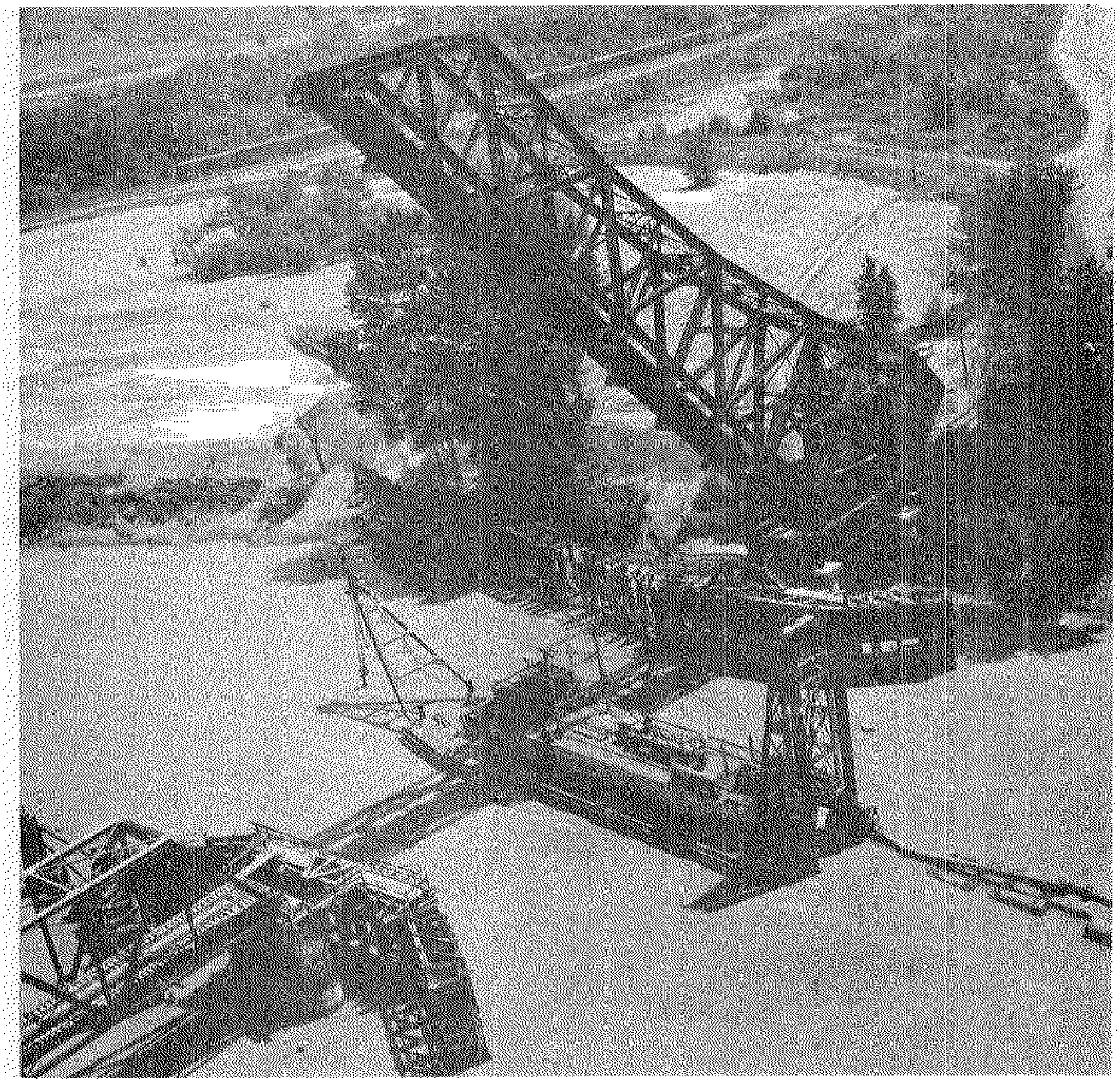
GENERAL VIEW OF DISPOSAL AREAS PRIOR TO USE

(Mouth of Cowlitz River at right—Columbia River in background)

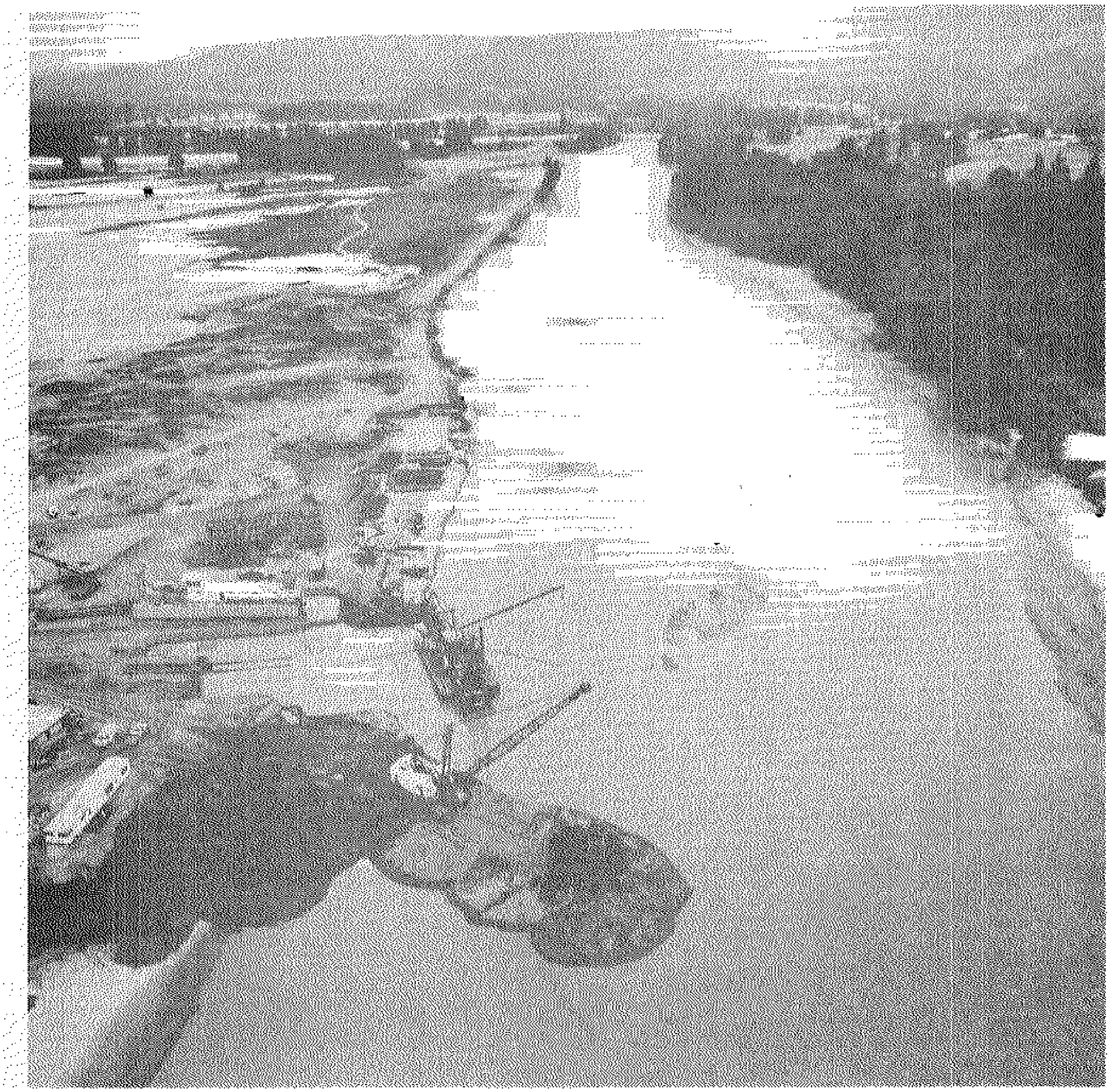


GENERAL VIEW OF COWLITZ RIVER - MILES 5-9

(Most clear areas became disposal sites)

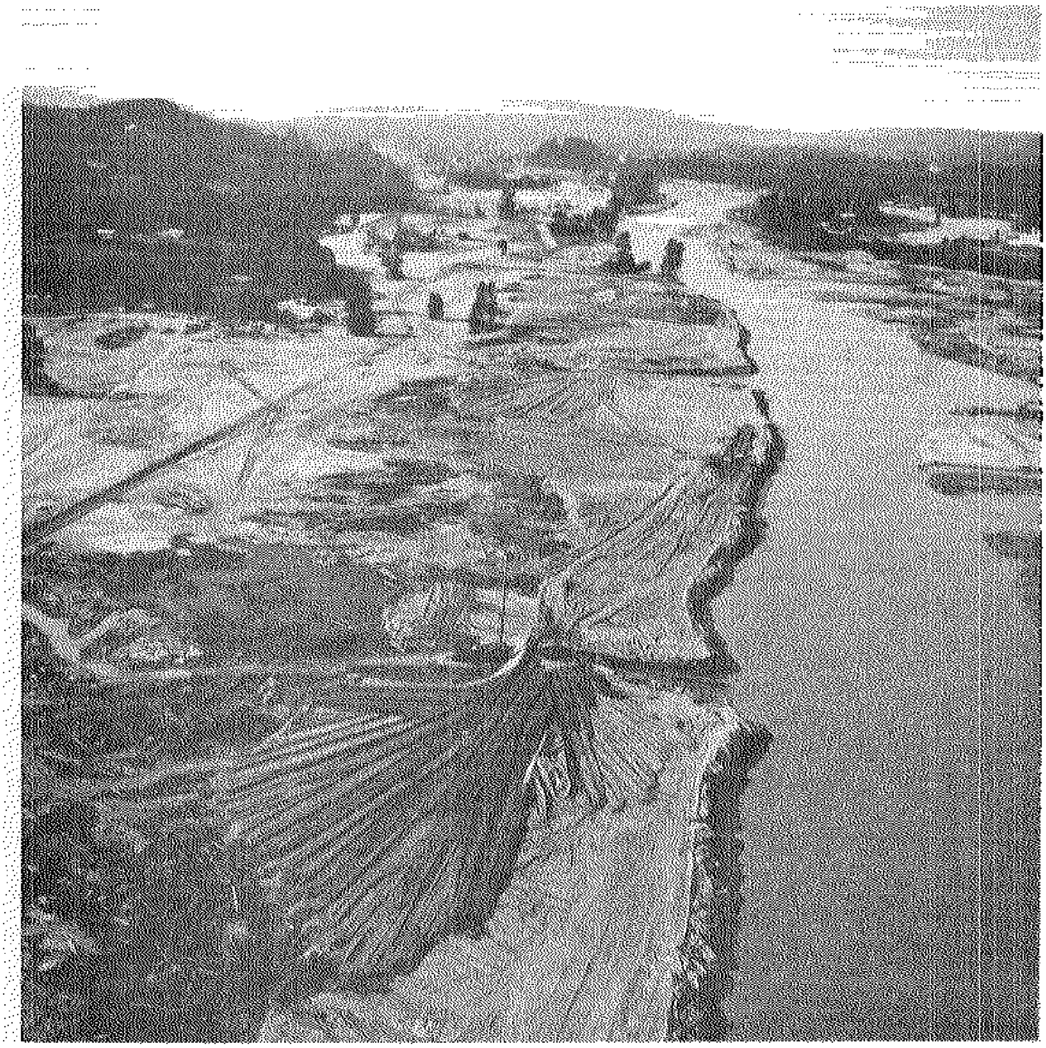


20" DREDGE AT WORK IN LOWER COWLITZ RIVER

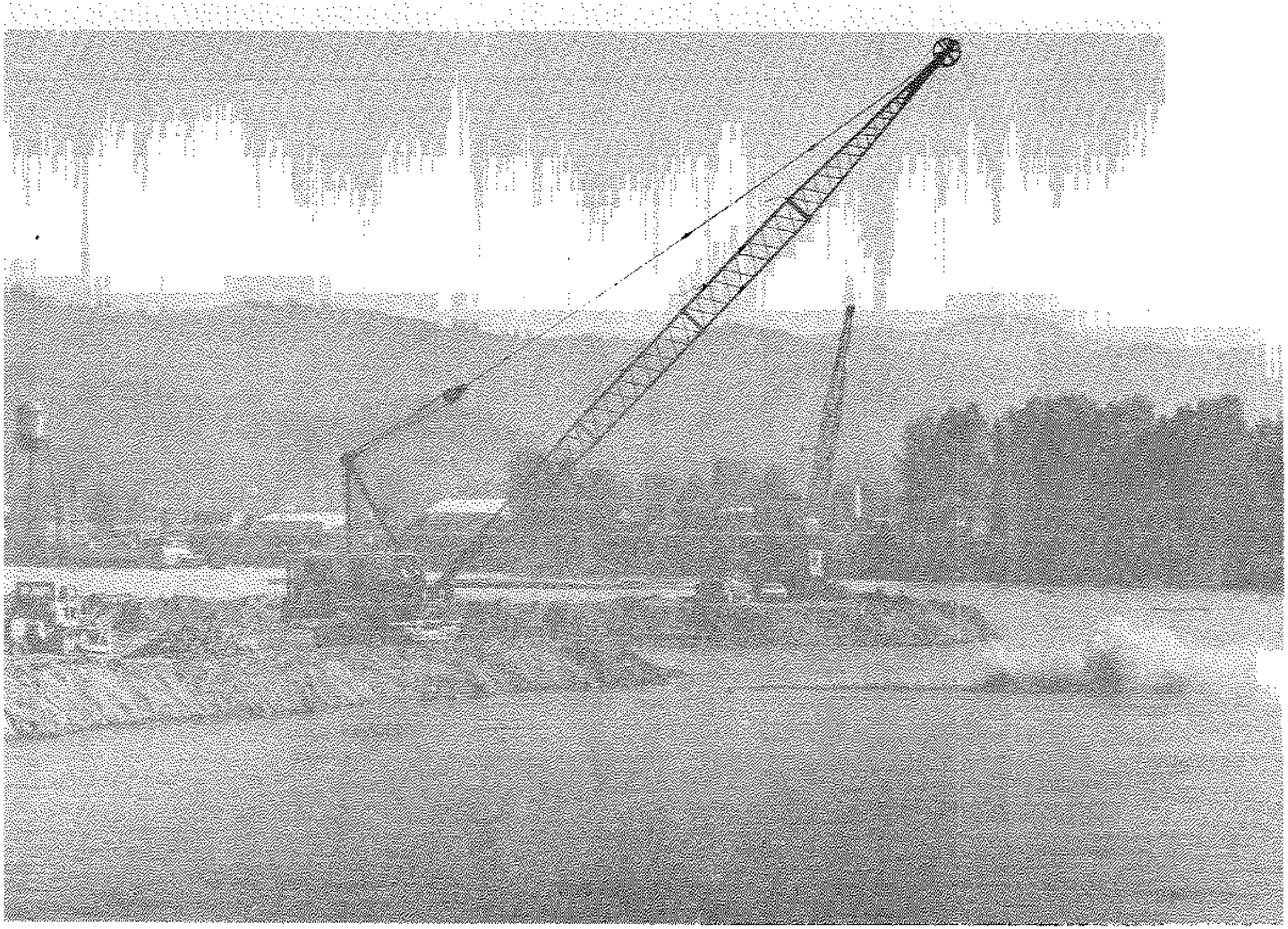


LAUNCHING OF 24" AND 18" PIPELINE DREDGES

(on Upper Cowlitz River)



GENERAL VIEW OF UPPER COWLITZ RIVER SHOWING HIGHLINE OPERATIONS



(Jan Fardel Photo)

DRAGLINES IN LOWER COWLITZ RIVER
(Note Dredge HUSKY in background)

illus[illegible] the potential disposal sites determined early in planning efforts. Most of the green undeveloped areas in these photos were considered and eventually secured for dredged material. All of the disposal areas secured for the dredging activities in the Columbia and lower Cowlitz Rivers, both upper and lower, were secured at no cost to the Government.

c. Upper Cowlitz. Since nearly all of the medium and large pipeline dredging plant had been secured in early recovery efforts for work in the lower Cowlitz and Columbia Rivers, other methods for excavation of the channel upstream of River Mile 9 and the Cowlitz River through River Mile 21, and in the Toutle River, had to be considered. These reaches were divided into several sections of two and three miles each and put out on an invitation to bid basis with payment for the excavation being accomplished by measurement of the disposal area. In these reaches, disposal areas were large and located immediately adjacent to the river channel which lended channel excavation activities to be accomplished by a large variety of equipment at the whim of the individual successful low bidders. Figure 14 illustrates typical contract drawing as utilized for this channel excavation activity. The drawing and text are small but provide general scope of invitation for bids and drawing prepared on an expedited basis. Table 15 lists contracts, equipment utilized and other pertinent data. Pictures show a variety of the type of dredging plant utilized by the various contractors in this area.

d. Toutle River. In additon to the dredging contract in the lower one mile of the Toutle River, planning efforts determined several alternatives to minimize impacts of erosion of the large mudflows in the Toutle River Valley in future years. Figure 16 shows a map of the Toutle River drainage and major features, including sediment basins and debris retaining structures, determined necessary to retain as much of the mudflow materials

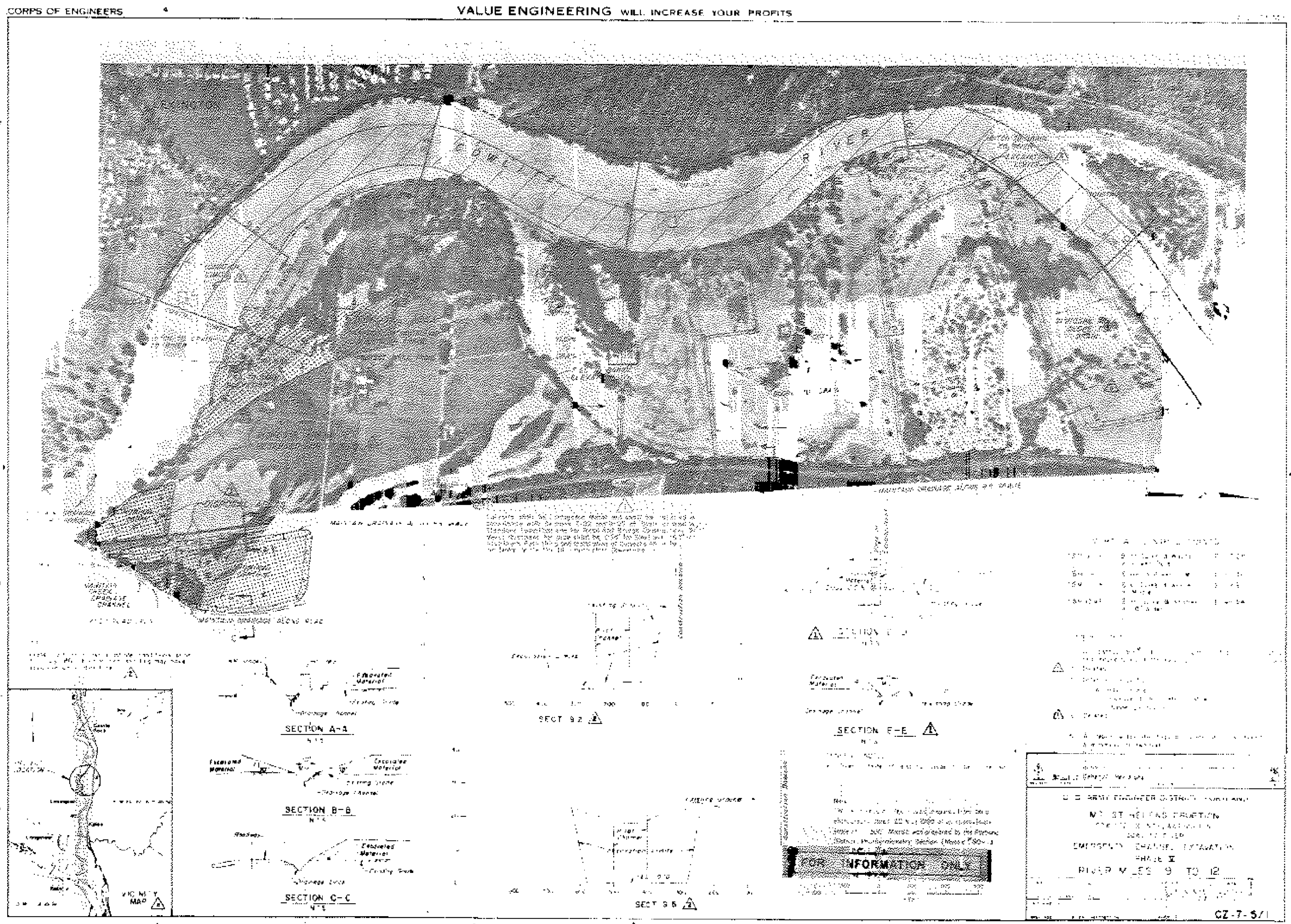

CORPS OF ENGINEERS
VALUE ENGINEERING WILL INCREASE YOUR PROFITS
SECTION A-A
SECTION B-B
SECTION C-C
SECT 9.2
SECT 9.5
SECTION E-E
FOR INFORMATION ONLY
MT. ST. HELENS ERUPTION
EMERGENCY CHANNEL EXCAVATION
RIVER MILES 9 TO 12
VICINITY MAP
CZ-7-5/1

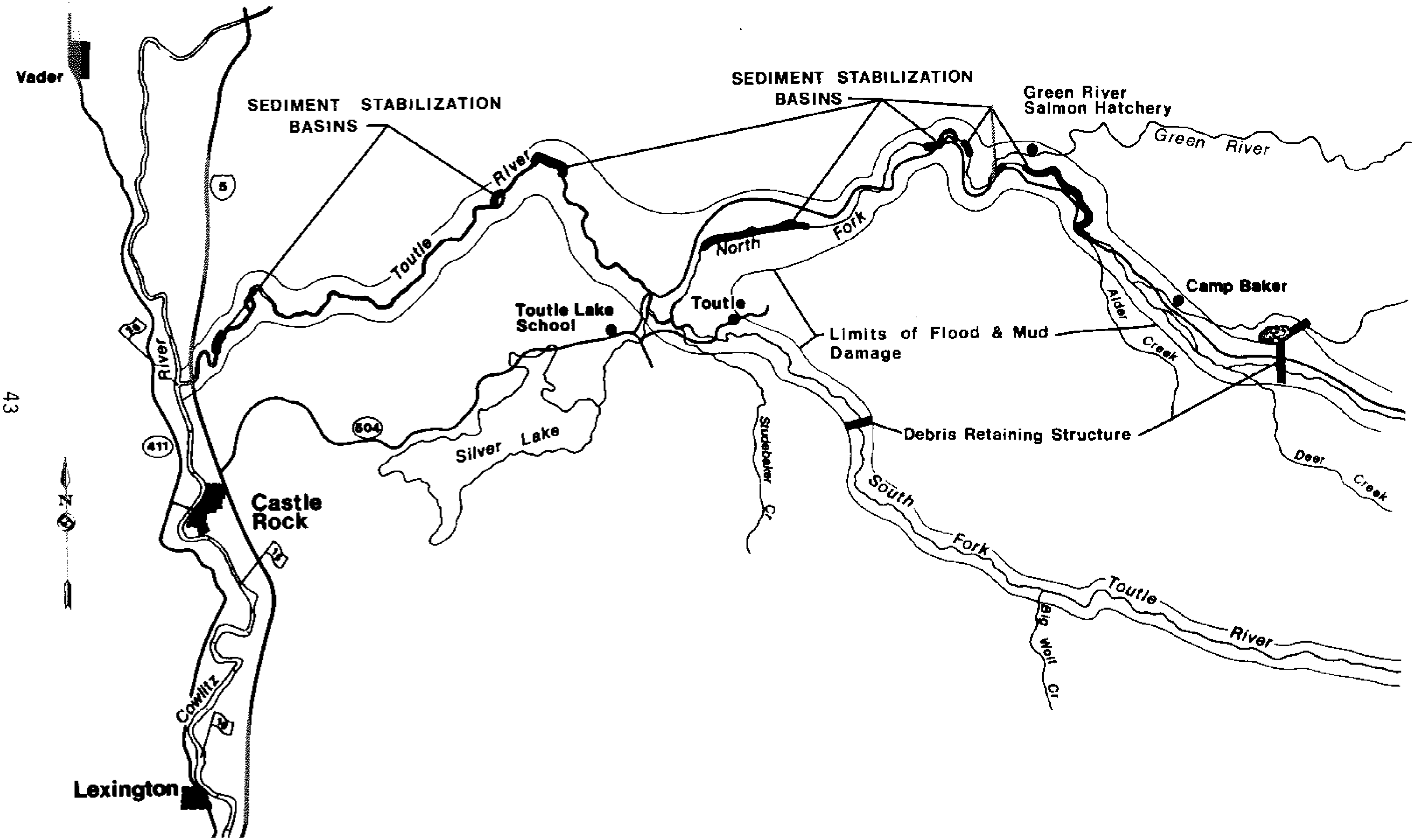
Figure 14

UPPER COWLITZ RIVER

Dredging Contracts and Equipment

R. M.	Contractor	Approximate Quantities	Contract Amount	Description of Equipment
9-13	Canonie South Heron, MI		$19,903,500	24", 18", 16", 14", & 12" pipeline dredges (6); 6 & 8 cy draglines (2)
13-14	Winston	Rental	99,225	4 cy dragline, 4 cy highline
	General Const.	Rental	2,734,966	16" pipeline dredge
	La Duke	Rental	67,702	1½" cy dragline
	Ross Island	Rental	1,449,890	16" pipeline dredge
14-16	Capital Lacey, WN	3,500,000cy	7,958,000	4 to 11 cy highline (15) 3 to 8 cy dragline (8) 3 - 8" pipelines
16-18	Segale Tukwila, WN	3,500,000cy	7,440,000	2, 4, 5, & 8 cy draglines (7) 9 cy Sauerman 8 cy front loaders (2) 20 cy end dumps, scrapper
18-21.5	Claterbos Astoria,OR	5,500,000cy	14,764,000	4 to 10 cy backhoe (4) 3 to 8 cy dragline (8) 6 to 12 cy front end loaders (3) 8 belly dumps, 3 end dumps, Sauerman
Toutle 1 Mile ±	Brusco Longview, WA	550,000cy	984,000	2, 4, & 5 cy draglines (4)

Figure 15



Vader
SEDIMENT STABILIZATION BASINS
SEDIMENT STABILIZATION BASINS
Green River Salmon Hatchery
Green River
Toutle River
North Fork
Camp Baker
Toutle Lake School
Toutle
Limits of Flood & Mud Damage
Alder Creek
Debris Retaining Structure
Silver Lake
Studebaker Cr
Deer Creek
South Fork Toutle River
Big Wolf Cr
Castle Rock
River
Cowlitz
Lexington
5
504
411
N

Figure 16

in this area as possible. Figure 17 is a contract drawing of the north fork debris retaining structure. Pictures shown illustrate the progress at the time of preparation of the paper on the north fork and the south fork debris retaining structures. Table 18 illustrates contracts awarded and the pertinent data for the sediment basins and debris retaining structures in the Toutle River Valley. It is hoped those constructions will minimize the erosion and displacement of the mudflow material from the Toutle River into the Cowlitz and Columbia Rivers during winter storms in the next several years.

e. Levees. Final planning efforts were directed towards providing levee protection or increased levee protection as necessary around developed urban areas in the lower Cowlitz River. Figure 19 shows the location of the levees planned to be constructed to protect those areas. Figure 20 is a typical X section of the levee construction. Table 21 provides a listing of contracts advertised and pertinent data regarding levee improvements. Rights-of-way for levee construction involved a large number of property owners, particularly in the urban areas, and were difficult to obtain. Local authorities were assigned by the Federal Government for attaining rights-of-way for the levee project, because of its urgency in nature and the massive amount of damages that could occur if construction was delayed.

f. Flow Reductions. Two large power storage reservoirs exist on the upper reaches of the Cowlitz River. Because it was uncertain that all construction outlined briefly in the above paragraphs could be accomplished in a timely manner to insure full protection against winter storms, particularly those occurring in late October or early November, arrangements were made to purchase flood storage in those reservoirs. As a result of these efforts, reservoirs are being drawn to provide for 360,000 acre feet of additional flood control storage. It is anticipated construction measures

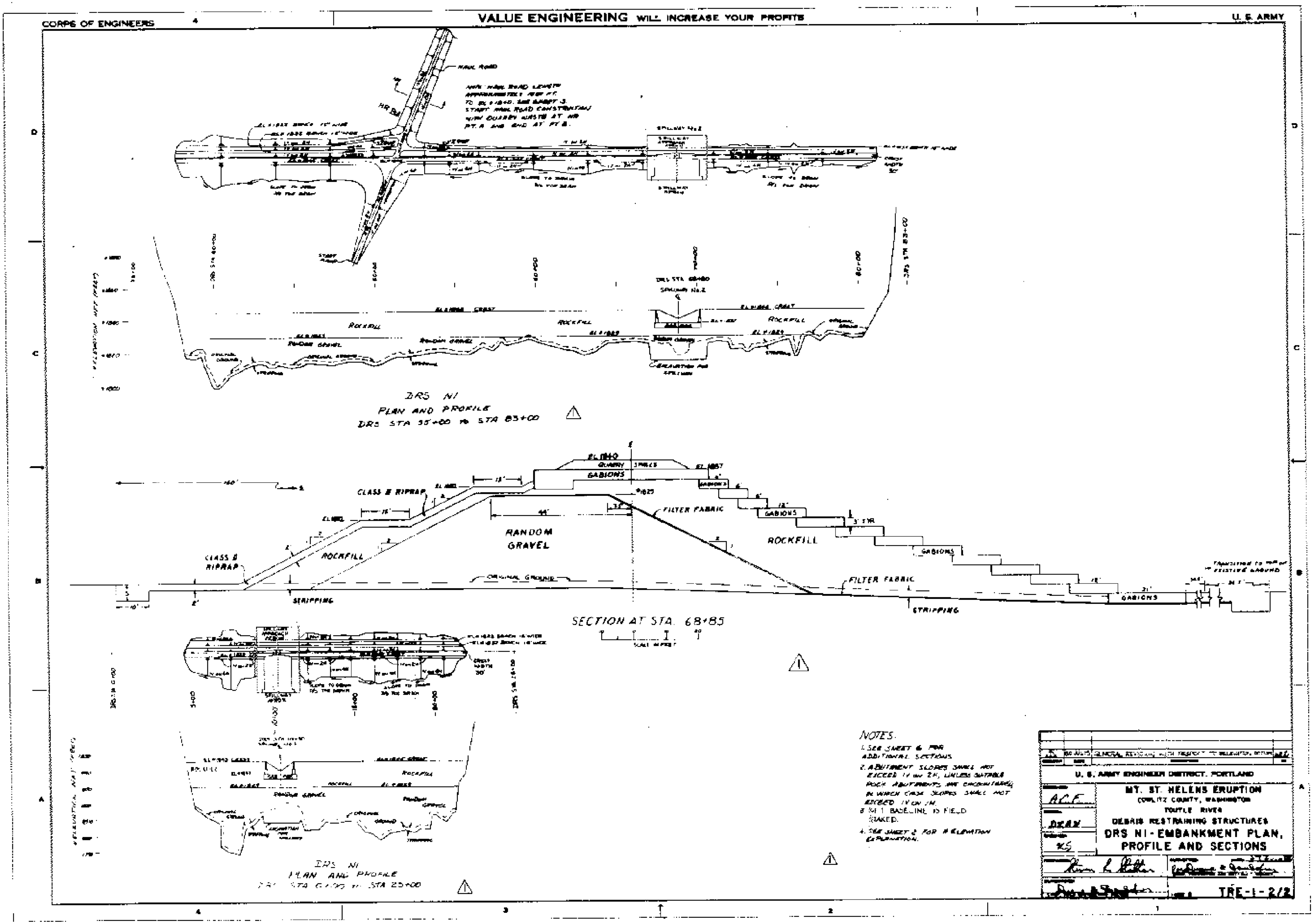
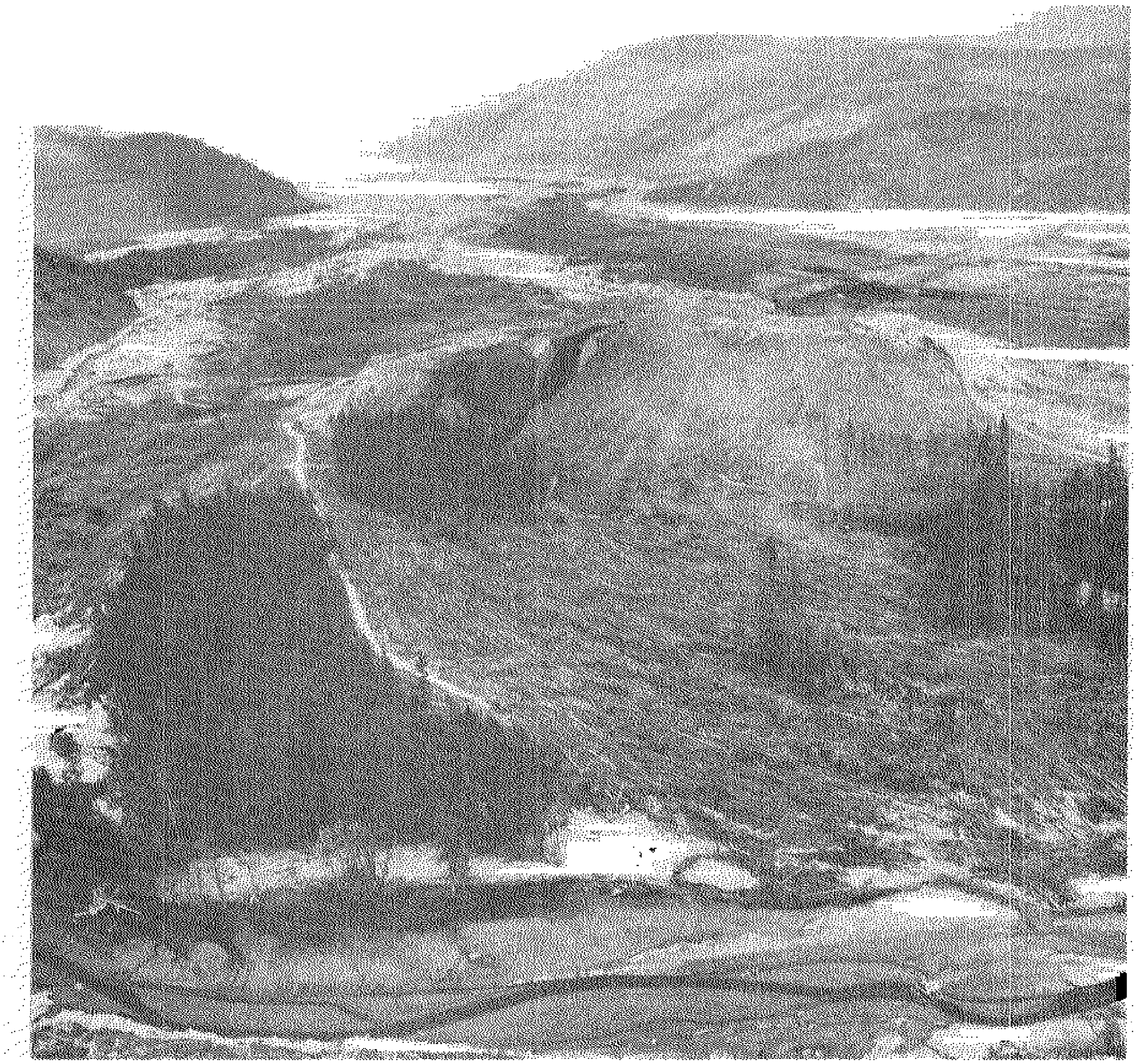
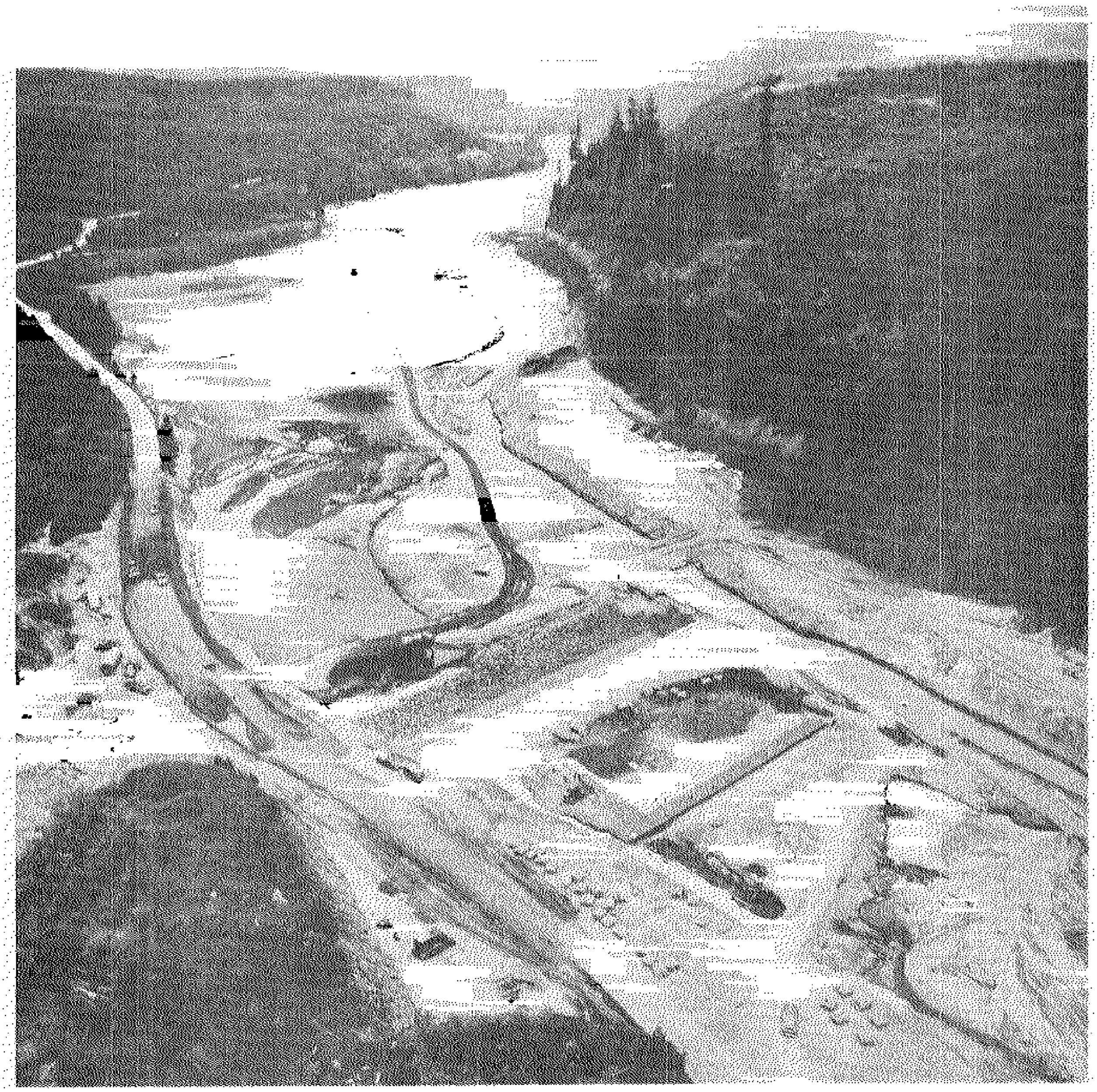

CORPS OF ENGINEERS
VALUE ENGINEERING WILL INCREASE YOUR PROFITS
U. S. ARMY
DRS NI
PLAN AND PROFILE
DRS STA 35+00 TO STA 83+00
ROCKFILL
RANDOM GRAVEL
CLASS II RIPRAP
CLASS II RIPRAP
RANDOM GRAVEL
ROCKFILL
FILTER FABRIC
GABIONS
STRIPPING
ORIGINAL GROUND
SECTION AT STA. 68+85
DRS NI
PLAN AND PROFILE
NOTES:
1. SEE SHEET 6 FOR ADDITIONAL SECTIONS.
2. ABUTMENT SLOPES SHALL NOT EXCEED 1V ON 2H, UNLESS SUITABLE ROCK ABUTMENTS ARE ENCOUNTERED, IN WHICH CASE SLOPES SHALL NOT EXCEED 1V ON 1H.
3. NI 1 BASELINE IS FIELD STAKED.
4. SEE SHEET 2 FOR ▲ ELEVATION EXPLANATION.
U. S. ARMY ENGINEER DISTRICT, PORTLAND
MT. ST. HELENS ERUPTION
COWLITZ COUNTY, WASHINGTON
TOUTLE RIVER
DEBRIS RESTRAINING STRUCTURES
DRS NI-EMBANKMENT PLAN, PROFILE AND SECTIONS
TRE-1-2/2

FIGURE 17



VIEW OF NORTH FORK TOUTLE RIVER DEBRIS RETAINING STRUCTURE UNDER CONSTRUCTION

(Note St. Helens mudflow in background)



VIEW OF SOUTH FORK TOUTLE RIVER DEBRIS RETAINING STRUCTURE

TOUTLE RIVER

Contracts

Description	Contractor	Amount
Sediment Basins, North Fork	Canonie	$1,577,606 (1,500,000 cy)
Sediment Basins, Main Stem	Peterson	$837,850 (475,000 cy)
Debris Control Structure, North Fork	Washington	$10,558,100
Debris Control Structure, South Fork	Mountain Engineer and Cardee, Bozeman, MT	$1,656,000
Diversion levee and channel stabilization to protect Green River Fish Hatchery (just off N.F. Toutle R.)	" "	$165,600
Cleanout of Debris Retaining Structure on S.F. Toutle R.	Nestaval Corp. Kelso, Wn.	$1,493,000

Figure 18

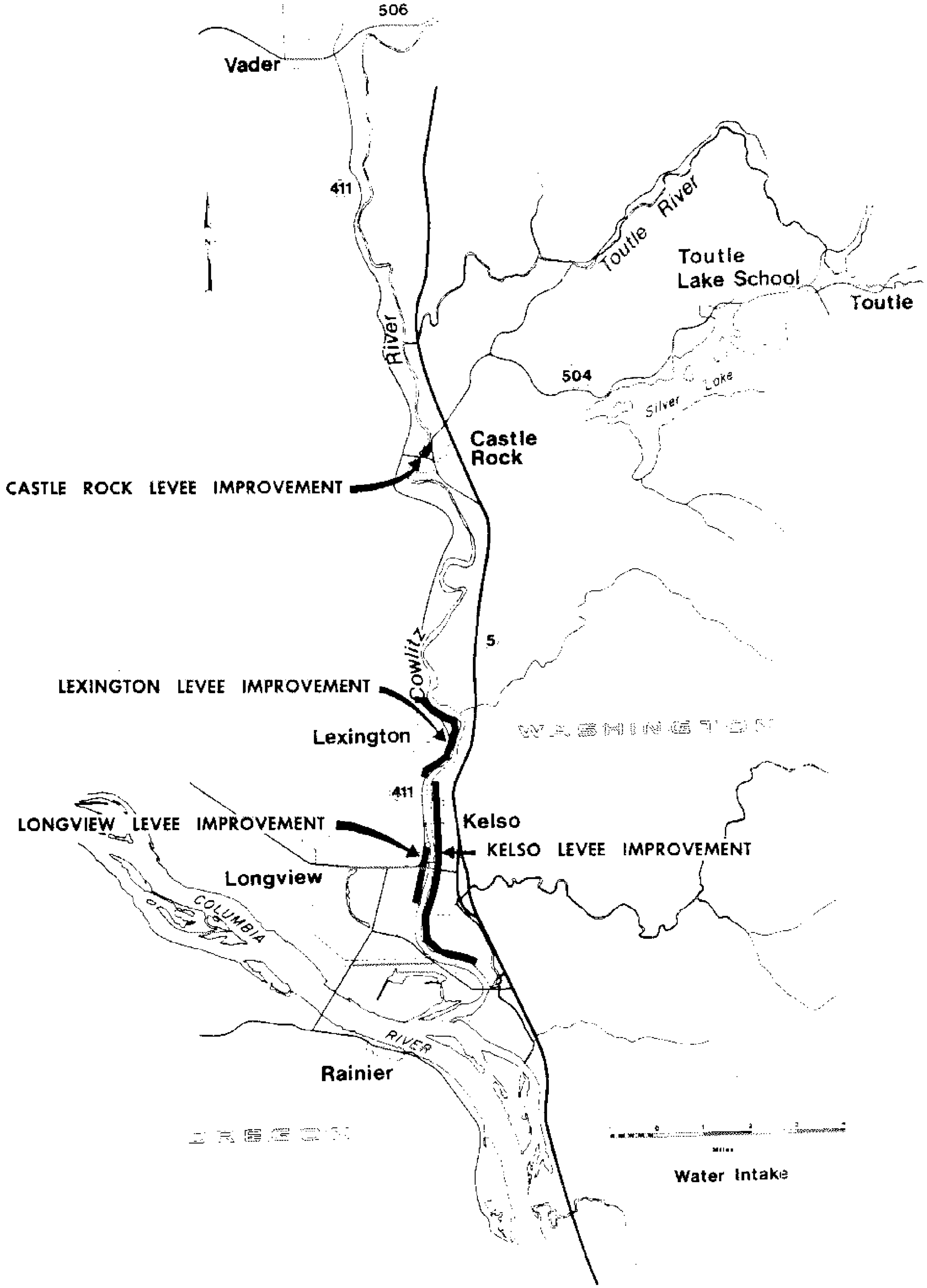
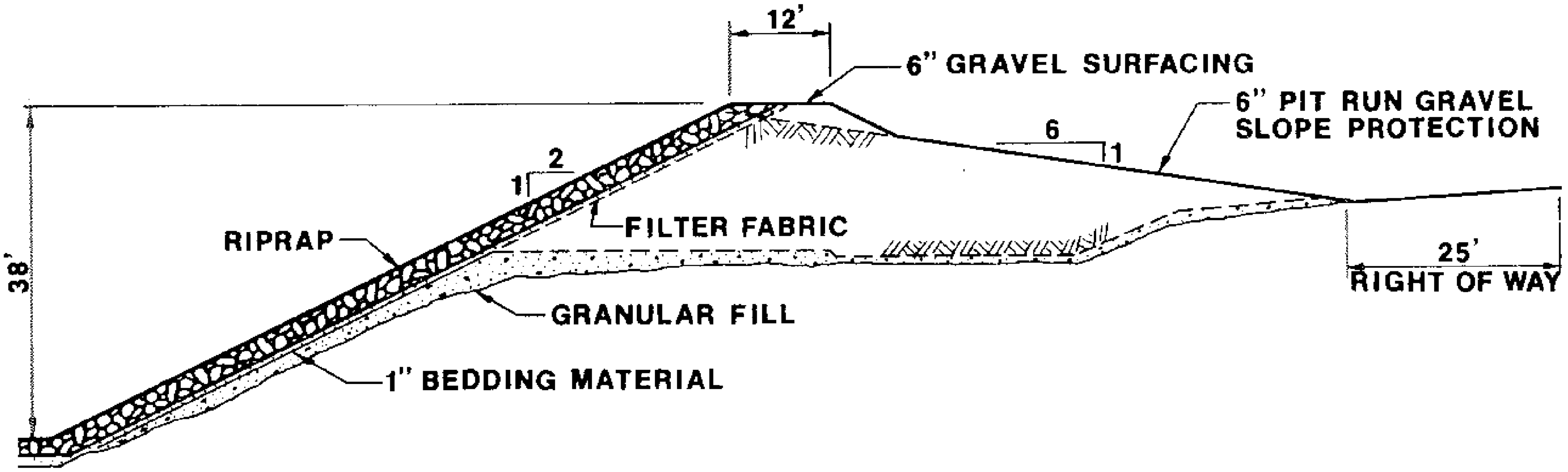

506
Vader
411
Toutle River
Toutle
Lake School
Toutle
River
504
Silver Lake
Castle
Rock
CASTLE ROCK LEVEE IMPROVEMENT
5
Cowlitz
LEXINGTON LEVEE IMPROVEMENT
Lexington
WASHINGTON
411
LONGVIEW LEVEE IMPROVEMENT
Kelso
KELSO LEVEE IMPROVEMENT
Longview
COLUMBIA
RIVER
Rainier
OREGON
Water Intake

FIGURE 19



TYPICAL SECTION THRU LEVEE

FIGURE 20

COWLITZ RIVER

Levee Improvements

Description	Contractor	Amount	Estimated Completion Date
Lexington	Peter Kiewit Vancouver, WA	$5,730,000	10 Dec 80
Castle Rock	Kerco, Lakeview, OR	$ 559,700	30 Nov 80
Longview	Grady Const, Longview, WA	$ 582,446	15 Nov 80
Kelso	Out for Bid	$3,000,000±	

FIGURE 21

described above and their maintenance in the foreseeable future will preclude further requirements for purchase of flood control storage in those reservoirs.

7. Future Impacts.

The Mt. St. Helens' eruption and subsequent mudflow impacts to the navigation and flood control channels as mentioned occurred in May 1980. The date of the eruption was fortunate in several respects. It provided several months of time for large-scale operations by the Corps of Engineers and other agencies to be initiated and completed to the extent possible before the winter flood season, which normally begins about 1 November and extends through February of any given winter season. It also provided for these recovery operations to be accomplished during the dry season when construction activities are implemented most expeditiously and efficiently.

Even if massive restoration efforts underway are successful, there will be literally millions of cubic yards of material remaining within the normal flood zones of the Cowlitz and Toutle Rivers. Efforts underway now are to minimize the impacts of the erosion of these materials into the river channels which could result in filling and reducing the flood-carrying capacity of the Cowlitz River channel. Funding targeted for future years will be directed towards further minimizing these impacts, so that the economies and stabilities of the areas can be preserved as much as possible.

8. Summary.

The above paragraphs briefly outline a massive recovery effort undertaken by the Corps of Engineers to provide restoration of the flood control and navigation channels in the Cowlitz and Columbia Rivers. As discussed, the efforts appear to be logical, straightforward and easily accomplished. However, a tremendous number of hours by more than 300 employees of the Portland District and North Pacific Division, together with energetic assistance by many other government agencies, local agencies, local interests, property owners, contractors, etc., have been required to get this large program underway and on toward successful completion. Many alternatives were considered and considerable "midnight oil" was burned in an effort to make the right decisions in a timely manner so that work could be accomplished on an expedited basis. The short time frame involved in accomplishing the assembly and preparation of the EIS draft is an example. Directions of effort had to be altered many times as surveys, real estate requirements, environmental problems, fiscal availability or channel excavation plant, etc., became known.

Approximately 40,000,000 cubic yards of material will have been excavated in this effort from the Columbia and Cowlitz River navigation channels by 1 December 1980. The major portion of this material will have been removed by 1 November 1980. An additional 9 million cubic yards or more will be removed during Fiscal Year 1981 and several million more yards will be removed from the basins behind the debris-retaining structures on the Toutle River. When one considers that most of this excavation was accomplished from a standing start, in a six-month period of time by one government agency, the magnitude of the effort involved in planning and implementing is apparent.

OPERATING CHARACTERISTICS OF CUTTERHEAD DREDGES

by

John B. Herbich[1]

ABSTRACT

A survey was made to evaluate the operating characteristics of cutterhead dredges in this country and overseas. The survey was made (1) to determine the physical characteristics of the dredges: (2) to find out how many cutterhead dredges are equipped with modern instrumentation; (3) to determine the average crew size on the dredges; (4) to determine the estimated percentage of maintenance time required; (5) to find out whether cutterhead dredges presently owned can operate in waves and swells; (6) to determine the type of pipelines used; and (7) to compare the dredging practice of the U.S. and Canada with those of Europe and Asia.

The results of the survey are presented in two sections, one for U.S. and Canada, and the other for foreign cutterhead dredges. It was discovered that relatively few dredges are able to operate under wave conditions over five feet, and that few of the U.S. and Canadian dredges have adequate instrumentation, but a majority of foreign dredges have magnetic flow meters, density meters and total production meters. Other findings deal with dredging operation methods, operating time, etc.

INTRODUCTION

There were several reasons for making a survey of the cutterhead dredges operating characteristics, namely:

1. to determine the physical characteristics of the dredges,
2. to find out how many cutterhead dredges are equipped with modern instrumentation,

---

[1]Director, Center for Dredging Studies, Texas A&M University, College Station, Texas

3. to find out the average crew size on the dredges,
4. to determine the estimated percentage of maintenance time required,
5. to find out whether cutterhead dredges presently owned can operate in wind waves and swells,
6. to determine the type of pipelines used, and
7. to compare the dredging practices of the U.S. and Canada with those of Europe and Asia.

RESULTS OF A SURVEY CONDUCTED BY THE CENTER FOR DREDGING STUDIES TEXAS A&M UNIVERSITY

Operating Characteristics of Cutterhead Dredges - United States and Canada

1. Do you operate cutterhead dredges? Yes [X] No [ ]

   If not, please return this questionnaire unfilled.

2. What is the size of cutterhead dredges that you operate? (circle size of dredges)

6" - 6	16" - 12	27" - 4
8" - 3	18" - 11	28" - 1
10" - 6	20" - 10	30" - 8
12" - 15	22" - 6	36" - 1
14" - 6	24" - 6	42" - 2
15" - 3		

3. Do you have any self-propelled cutterhead dredges?

   Yes - 1 No - 47

4. Do you have any dredges with a pump on the ladder to increase dredging depth?

   Yes - 5 No - 48

5. Do you have any dredges equipped with a swell-compensating device on the ladder?

   Yes - 0 No - 48

6. Do you have the following instrumentation installed on your dredges?

Magnetic flow meter	Yes - 1	No - 45
Density meter	Yes - 1	No - 44
Total production meter	Yes - 3	No - 45

   If answer is yes to any of these questions please specify the size of dredge, size of meters and the make of the meters:

   Ellicott: 36" - details of instruments unavailable.

7. Size of crew on an 8-hour shift. Give answers for short pipeline operation and for long pipeline operation:

   Summary:

Average size of crew for short pipeline:	8.98
Range in crew size for short pipeline:	2-37
Average size of crew for long pipeline:	14.41
Range in crew size for long pipeline:	2-55

8. Estimate percentage maintenance time required on your dredges

Summary:

Smaller size	12"-18":	14.45%
Medium size	20"-27":	12.92%
Larger size	over 28":	11.83%

9. Estimate the net operating time in calm waters and waves up to 3 ft.

Summary:

Calm waters	%	hrs/day
Ave.	81.5	17.9
Range	20-100	8-24
Waves		
Ave.	57.94	15.94
Range	4-80	4-24

10. Estimate average breakdown time for new and old equipment.

Summary:

New equipment	%	hrs/day
Ave.	6.89	2.03
Range	1-20	.25-4
Old equipment		
Ave.	12.5	2.8
Range	1-37	.48-8.88

11. Can you operate the dredge in

2-3 ft:		
waves (swell)	Yes - 25	No - 18
wind waves	Yes - 31	No - 8
3-4 ft:		
waves (swell)	Yes - 14	No - 26
wind waves	Yes - 14	No - 21
over 5 ft:		
waves (swell)	Yes - 4	No - 38
wind waves	Yes - 4	No - 32

12. Can you operate a floating pipeline in

2-3 ft:		
waves (swell)	Yes - 31	No - 11
wind waves	Yes - 32	No - 6
3-4 ft:		
waves (swell)	Yes - 12	No - 23
wind waves	Yes - 14	No - 18
over 5 ft:		
waves (swell)	Yes - 4	No - 31
wind waves	Yes - 4	No - 27

13. Do you operate with spuds? Yes - 45 No - 2

or on wires and anchors in exposed areas? Yes - 20 No - 11

14. Have you used a floating buoyant pipeline (which floats without supporting pontoons)? Yes - 5 No - 44

Successfully? Yes - 5 No - 7

15. Have you generally used ball joints in floating pipelines?

Yes - 36 No - 13

16. Have you used rubber sleeves instead of ball joints in floating pipelines? Yes - 32 No - 16

17. Any additional comments?

Listing of Comments:

In operating in swells of 2-3 ft, good pipelines and pontoons are required.

Operating time is pumping time.

We do marine work other than dredging.

Keep up the good work.

Maintenance time on our rig is high due to the fact that we are doing a complete overhaul of our rig.

I doubt that too many generalization characteristics can be determined because size of dredge, weather, and material each have a bearing on production, lost time, etc.

Considering operational down time, debris, weather and changing location of a dredge on job site only about 50% of time is spent actually dredging.

We have a "Thomas" jet assist on our 185' long ladder.

Our dredges work exclusively on inland waterways and are constructed for that type of work.

Breakdown time may be governed by type of work, i.e., silt, clay, sand, rock. Also, number of boosters required for today's requirement for long lines.

Our dredge operates in a 30-40 acre pond and is not subjected to swells or waves over 1½ ft. We have found that rubber sleeves with clamps are very economical and fairly easy to maintain.

We also operate 2 booster pumps mounting in barges equipped with 18" discharge pumps.

Can't have material any faster, cheaper, more accurate, than hydraulic dredging. Even cleanest way for EPA people.

We do not operate channel dredge -- just shell dredge.

We pump sand and gravel for our own use in protected manmade lakes of up to 10 acres -- our lines are short and ice is about our only trouble (in wintertime). Most all dredges in this area are used as ours is for sand and gravel production. Most are in the 8 x 10 size.

Percentagewise, few have cutterheads and waves are not a problem.

18. Average number of employees: from 2 to 10,000.

Average number of cutterhead dredges: from 1 to 6.

Operating Characteristics of Cutterhead Dredges - Overseas Countries

1. Do you operate cutterhead dredges? Yes [X] No [ ]

If not, please return this questionnaire unfilled.

2. What is the size of cutterhead dredges that you operate? (circle size of dredges)

6" - 2	18" - 5	28" - 5
8" - 2	20" - 10	30" - 6
10" - 3	22" - 2	32" - 10
12" - 11	24" - 13	34" - 1
14" - 3	26" - 2	36" - 6
16" - 11	27" - 8	40" - 1
		42" - 1

3. Do you have any self-propelled cutterhead dredges?

Yes - 6 No - 33

4. Do you have any dredges with a pump on the ladder to increase dredging depth?

Yes - 9 No - 30

5. Do you have any dredges equipped with a swell-compensating device on the ladder?

Yes - 3 No - 37

6. Do you have the following instrumentation installed on your dredges?

Magnetic flow meter	Yes - 17	No - 22
Density meter	Yes - 16	No - 23
Total production meter	Yes - 15	No - 22

If answer is yes to any of these questions please specify the size of dredge, size of meters and the make of the meters:

Size of discharge pipe: .850 meters made by IHC-Holland, the Netherlands.

Dredge 30"/Meters 28", Make: Altometer Sliedrecht, the Netherlands.

30" discharge pipe x 3600 HP, Ellicott Machine Co., USA

28" and 32" dredges - 26" and 28" pipelines, respectively. All meters by IHC-Holland, the Netherlands.

Dredge 32" -- size 28" -- IHC-Holland, the Netherlands.

Diameter of suction pipe (mm): 700-850-1000/diameter of meters (mm): 600-750-950/IHC-Holland, the Netherlands.

Yes, on 30" dredges and larger, when soil conditions permit the use; Make: flow: Alto - density/production - IHC-Holland, the Netherlands.

20", 24", IHC-Holland, the Netherlands.

16" - Honeywell

Only with 34" size dredge. Standard meters, IHC-Holland, the Netherlands.

28" dredge; Solids Optimizer, Ellicott

26" -- 42" --

Two dredgers; each one with magnetic flow meter. Hokushin Electric Works, Ltd.

24" suction dredge/24" Foxton Magnetic Flow Transmitter/24" Ohmort Density Base.

22"-22" - Hokushin Electric Co., Ltd.; 28"-28" - Hokushin Electric Co., Ltd.; 30"-30" - Toshiba Electric Co., Ltd.

7. Size of crew on an 8-hr. shift. Give answers for short pipeline operation and for long pipeline operation:

Summary:

Average size of crew for short pipelines: 9.6
Range in crew size for short pipelines: 1-35

Average size of crew for long pipelines: 10.8
Range in crew size for long pipelines: 2-40

8. Estimate percentage maintenance time required on your dredges.

Summary:

Smaller size	12" - 18"	15.00%
Medium size	20" - 27"	15.75%
Larger size	over 28"	17.34%

9. Estimate the net operating time in calm waters and waves up to 3 ft.

Summary:

Calm waters	%	hrs/day
Ave.	72.34	17.74
Range	10-100	2.5-2.4
Waves		
Ave.	58.50	17.16
Range	50-70	12-24

10. Estimate average breakdown time for new and old equipment.

Summary:

New equipment	%	hrs/day
Ave.	13	11.54
Range	1-80	2-24

Old equipment

	%	hrs/day
Ave.	18.56	10.06
Range	1-50	1.1-24

11. Can you operate the dredge in

2-3 ft:

waves (swell)	Yes - 22	No - 8
wind waves	Yes - 25	No - 5

3-4 ft:

waves (swell)	Yes - 6	No - 26
wind waves	Yes - 10	No - 21

over 5 ft:

waves (swell)	Yes - 0	No - 26
wind waves	Yes - 1	No - 27

12. Can you operate a floating pipeline in

2-3 ft:

waves (swell)	Yes - 23	No - 7
wind waves	Yes - 22	No - 6

3-4 ft:

waves (swell)	Yes - 9	No - 24
wind waves	Yes - 9	No - 23

over 5 ft:

waves (swell)	Yes - 2	No - 22
wind waves	Yes - 2	No - 22

13. Do you operate with spuds? Yes - 33 No - 6

or on wires and anchors in exposed areas? Yes - 24 No - 10

14. Have you used a floating buoyant pipeline (which floats without supporting pontoons)? Yes - 10 No - 29

Successfully? Yes - 10 No - 7

15. Have you generally used ball joints in floating pipelines?

Yes - 32 No - 11

16. Have you used rubber sleeves instead of ball joints in floating pipelines? Yes - 34 No - 15

17. Any additional comments?

Listing of Comments:*

Net operating time means dredging time and break time means the time which is lost by difficulties.

Dredgers we use only work in rivers.

As we are working on river and canals, we do not work in swells over 2 feet.

---

*Answers were corrected for grammatical errors only.

We operate two 24" dredges in enclosed ponds for recovery of mineral sands; therefore, we do not encounter wave conditions. We operate 24 hours per day, 7 days per week.

Answers are rough approximations. In most cases it is hard to answer with a simple yes or no. Much depends upon soil and external conditions.

Both dredges employed on harbour maintenance work. 12" uses booster pump beyond 3000 line. 10" uses booster beyond 1,800 line. 12" cutter suction dredge "Thomas Markinnon" operates on harbour maintenance in Port Whang area. Pump "Warman" 12/14 driver by 450 BHP Dutz engine, can dredge to 42 ft. Operates 12 hrs. per day, 5 days per week. 10" cutter suction dredge 12 hrs. per day, 5 days per week. 10" cutter suction dredge "Te Kau" (Maori work for 10) operates on shallow maintenance and capital works such as new yacht marinas and associated construction work. Pump "Gwynn" 10/12 driven by 150 BHP Papman 4 rph engine can dredge to 21'. Both dredges use spuds at all times.

It is surely not often that we get a questionnaire such as this one, and I will be most interested to learn of your findings in due course. Besides straight dredging we do seem to require unusual jobs of our cutter suction dredge (it's an L.M.G.). For instance, we have devised a diffuser to discharge into a hopper barge instead of to a pipeline. We then transport the spoil to a holding area and later repump it into the reclamation. We also have a device which enables us to dredge around and in between the piles in our wharves which are reinforced concrete piled structures, not solid quays which I understand is the more usual construction in your part of the world.

This dredge, at the present moment is used to maintain the river for drainage purposes. It can only be operated at high tide hours.

We work 12-hr. shifts, because in this way we operate more efficiently instead of having 3 crews.

Ladder pump is scheduled to be installed later.

No experience with 5 foot swells in our area.

Answers as follows: 8000 HP dredger.

Dredge pump is actually 20 x 24 but we use 24-inch discharge line starting close to the pump.

Hull has only 12 inches to winch opening in front.

These data relative to suction cutter dredgers of 27 inches. P.S. Sending the results of your study would be very much appreciated.

18. Number of employees in the Respondent's company: from 2 to 10,000

Number of cutterhead dredges in the Respondent's company: from 1 to 6

SUMMARY AND CONCLUSIONS

Tables I and II summarize the most important points uncovered in the survey.

1. There are more self-propelled dredges in use overseas.
2. Ladder-installed pumps are becoming more popular, particularly overseas.
3. Only about 8 percent of foreign dredges are equipped with swell-compensating devices.
4. Overseas dredges are much more extensively instrumented than U.S. and Canadian dredges.
5. U.S. and Canadian dredges can operate under slightly higher swell and wind wave conditions.
6. A greater use is made of floating buoyant pipelines overseas.

RECOMMENDATIONS

1. To install the necessary instrumentation and measuring devices on U.S. and Canadian dredges to maximize production and reduce fuel consumption.
2. To develop sea-going cutterhead dredges which can work in 6-ft waves and which can withstand 12-ft waves.[1,2,3] The capital investment in cutterhead dredges is considerably lower than hopper dredges. Most offshore dredging must at present be performed with hopper dredges.
3. To develop methods employing submerged pipelines or a combination of flexible floating and semi-rigid submerged pipelines to eliminate damage caused by waves to conventional pontoon-supported pipelines.

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2. Herbich, J. B. and Y. K. Lou, "Stable Catamaran Hulls for Cutterhead Dredges", Paper OTC 2290, Proc. Offshore Technology Conference, 1975.

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TABLE I. SUMMARY - EQUIPMENT, INSTRUMENTATION, CREW SIZE AND MAINTENANCE

	U.S. & Canada		Overseas		Notes
	Number	%	Number	%	
Self-propelled cutterhead dredges	1/47*	2.1	6/33	18.2	There are more self-propelled dredges overseas.
Dredges with pump on the ladder	5/48	10.4	9/30	30.0	To increase digging depth, dredges equipped with ladder pumps are becoming more popular, particularly overseas.
Swell-compensating device on the ladder	0/48	0	3/37	8.1	Swell-compensating devices are not in use at all in the U.S. and Canada, but 8% of foreign dredges are equipped with the device.
Instrumentation					
Magnetic flow meter	1/45	2.2	17/22	77.2	Overseas dredges are much more instrumented than U.S. and Canadian dredges.
Density meter	1/44	2.3	16/23	69.6	
Total production meter	3/45	6.6	15/22	68.2	
Size of crew on an 8-hour shift					
Short pipeline	9.0		9.6		No significant differences.
Range	2-37		1-35		
Long pipeline	14.4		10.8		
Range	2-55		2-40		
Percentage maintenance time required					
12-inch to 18-inch size		14.45		15.00	More maintnenace time allowed for larger dredges overseas.
20-inch to 27-inch size		12.92		15.75	
over 28-inch		11.83		17.34	

*1/47 means that one out of 47 dredges is self-propelled.

TABLE II. SUMMARY - OPERATIONAL CHARACTERISTICS OF CUTTERHEAD DREDGES IN OPEN WATER

	U.S. & Canada		Overseas		Notes
	Number	%	Number	%	
Dredge operation in waves (swell)					
2-3 ft	25	58.1	22	73.3	U.S. and Canadian dredges can operate under slightly higher wave (swell) conditions.
3-4 ft	14	35.0	6	18.8	
over 5 ft	4	9.5	0	0.0	
Dredge operation in wind waves					
2-3 ft	31	79.5	25	83.3	U.S. and Canadian dredges can operate under slightly higher wind wave conditions.
3-4 ft	14	40.0	10	32.3	
over 5 ft	4	11.1	1	3.6	
Operation of a floating pipeline in waves (swell)					
2-3 ft	31	73.8	23	76.7	U.S. and Canadian contractors operate floating pipelines under slightly higher wave (swell) conditions.
3-4 ft	12	34.3	9	27.3	
over 5 ft	4	12.9	2	8.3	
Operation of a floating pipeline in wind waves					
2-3 ft	32	84.2	22	78.6	U.S. and Canadian contractors operate floating pipelines in slightly higher wind waves.
3-4 ft	14	43.8	9	28.1	
over 5 ft	4	12.9	2	8.3	
	Yes	No	Yes	No	
Use of floating buoyant pipeline	5	44	10	29	Greater use of floating buoyant pipelines overseas.
Use of ball joints in floating pipelines	36	13	32	11	No significant differences.
Use of rubber sleeves in floating pipelines	32	16	34	15	No significant differences.

DREDGING WORK IN THE U.S. ARMY, CORPS OF ENGINEERS

by

Carl C. Cable[1]

ABSTRACT

The paper will document some of the experiences of the U.S. Army Corps of Engineers Districts in performing their responsibilities involving dredging. With the impact of environmental laws, the major emphasis is being placed on new and innovative ways to dispose of dredged material.

Several examples will be presented to illustrate the various methods used to provide beneficial and acceptable disposal of dredged material. These examples will serve to highlight the increased concern being given to dredging and its disposal methods.

INTRODUCTION

Congress' concern over dredging activities in the United States, as expressed in the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500) (FWPCA) has had a great impact on how we conduct our dredging work in the Corps of Engineers. The FWPCA, which had as an objective "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters," in Section 404 established a program to regulate the discharge of dredged or fill material into water. The Clean Water Act of 1977 (PL 95-217) (CWA), updates and continues the Section 404 review and permit requirements with respect to the construction, operation, and maintenance of water resources projects involving the discharge of dredged or fill material. Note the continued emphasis on the discharge or disposal of dredged material. This emphasis has led our managers in the Corps of Engineers to devise new and novel methods of disposing of dredged material

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to meet the demands of these and other laws. Some examples of these methods are presented herewith.

"CAPPING" OF DREDGED MATERIAL

The New England Division, U.S. Army, Corps of Engineers conducted maintenance dredging of Stamford and New Haven Harbor channels from April 23, 1979 to May 1, 1980. 100,000 cubic yards of fine grained material was removed from Stamford, 230,000 cubic yards of lithologically similar, but cleaner material from New Haven and 77,300 cubic yards of sand from New Haven. Bucket dredges and scows were used for the fine material and the Hopper Dredge ESSAYONS was used to deposit the sand material.

The particular aspect of disposal with which the Corps of Engineers has been concerned at Stamford and New Haven Harbors is the handling of materials from highly industrialized harbors. "Industrialized" has become synonymous with "enriched" in the sense of potential contaminants in dredged material. The more developed harbors have the worst condition and the greatest need for frequent dredging, usually. Hence, a do--nothing is rarely acceptable, and a mitigation program is looked toward as the only operative alternative.

Public perception of open water disposal is such that there is little choice but to apply the most conservative management techniques available. The plethora of laws and regulations issued during the seventies has done little to advance the better understanding of cause-effect relationships in the area of dredged material management. The Corps approach therefore has been to work within the rules as best they can be defined, and to develop practical techniques for handling dredged material in a manner which is environmentally conservative and still maintains cost effectiveness.

As background, Long Island Sound lies between the States of New York and Connecticut and is defined as an estuary with two layered flow and with a salinity gradient of five parts per thousand between eastern and western extremities. Net drift in any location is affected by tidal currents, wind-driven circulation, and river inflow and fresh water influx. The Connecticut shoreline is highly developed, having three deep-draft (35 feet) and five medium-draft (about 15 feet) harbors which receive raw materials for manufacturing, with a predominance of petroleum cargos. Long Island Sound has long been noted for its shellfish production (oysters) and is the recreation area for a hugh concentration of sporting vessels in the affluent New York-Connecticut region. Conflicts between the needs of commerce and fisheries/recreation are a matter of history.

Long Island Sound has been used for disposal of dredged material since early times, and as recently as 1972, there were 19 separate disposal sites identified, most in close proximity to particular harbors being serviced. The most heavily used site had been in the western end where New York and western Connecticut harbors had sent about 20 million cubic yards over a 40-year period. Since 1973, the number of sites in active use has been limited to three, with the aforementioned western end site having been restricted by public attention generated in a political context. The site is now the most heavily fished for lobster of all regions in Long Island Sound.

The need to perform maintenance dredging in the 12 foot (MLW) East Branch channel of Stamford Harbor had been the subject of much contention since 1972. This narrow, poorly flushed estuary had received untreated domestic and industrial wastes without benefit of dredging since 1940. Bottom sediments, largely organic silt, exhibited high concentrations of heavy metals as well as various forms of detritus associated with its industrial character. Land disposal or other means of treatment were not available locally.

When a shoaling condition was detected in the 35-foot channel of New Haven Harbor in early 1979, the states and other agencies were consulted on the possibility of linking the New Haven dredging needs with those of Stamford in a demonstration of a "capping" procedure. New Haven materials ranged from organic silt-clay to silty fine sand, and were in a moderate range from standpoint of background or enrichment.

Since the Stamford material has a higher concentration of heavy metal contaminants than the New Haven material, the disposal plan used was to cover the Stamford material with that dredged from New Haven. Disposal of dredged material from both harbors was in the Central Long Island Sound disposal area. A monitoring study was developed to address the potential environmental impacts resulting from disposal and to evaluate the effectiveness of the capping operation. Surveys of the disposal site completed on June 22, 1979, indicated the capping operation had been extremly successful. The precision disposal of Stamford material 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.

Further monitoring of the disposal sites is planned to assess the longer term effects of these capping procedures. However, the history of disposal at the Central Long Island Sound Site indicates that these deposits will be stable and the capping will be effective. Should this be the case, capping of undesirable spoils can be an important, beneficial technique for future disposal operations.

Follow-on studies will yield important data relating to the health of benthic communities which colonize the mounds, and, if possible, will give an increase of differences, or lack thereof, of contaminants to the surrounding area.

The value of this "capping" procedure to dredgers lies in the potential for dealing with varying quantities of materials which may otherwise be unacceptable for disposal into the marine environment. Through opportunistic scheduling and management, it may be possible to isolate objectionable materials at reasonable cost. It is conceivable that an improvement in marine habitat can also result from such practice.

"FLOW LANE" DISPOSAL

Another technique used by the Corps of Engineers to optimize dredge material disposal is "flow lane" disposal as practiced in the Columbia and Lower Willamette Rivers project. The Portland District, U.S. Army, Corps of Engineers, is responsible for providing adequate depth in this navigation system.

This project encompasses the main deep-draft navigation channel of the Columbia River from just inside the entrance bar at its mouth of River Mile 104 at Vancouver, Washington, and River Mile 8 in the Willamett River at Portland Harbor, Oregon. The channel is forty feet deep by six hundred feet wide. There are about twenty-six traditional shoals that have to be maintained periodically. Some of these shoals are maintained on an annual basis, others not for 3-5 year intervals. Annually the Corps does maintenance dredging on approximately one dozen of the shoals in the 100-mile plus reach. This involves pipeline dredging plant and hopper dredging plant and average annual removal in recent years is approximately 3,789,000 cubic yards at a cost to the United

States of about $1,729,000. Hopper dredging accounts for another 2,385,000 cubic yards and an additional cost of $1,114,000.

Although the Corps has improved the hydraulic characteristics of the channel since the early 1900's by the construction of several hundred flow control structures (pile dikes) and strategic placement of dredged material along shorelines, closing off or narrowing side channels, etc., maintenance dredging as noted above still takes place in substantial quantities. Over the years, disposal areas have become a premium and recent environmental legislation and policy including nonfilling of wetlands, etc., severely limited upland disposal potentials. The Portland District has developed, along with resource agency inputs and cooperation, a method of what is called "flow lane" disposal. In this process, at many locations where upland or beach erosion area disposal is not availalbe for a particular bar, the dredged material is placed in water downstream of the dredging site ususally alongside the navigation channel. Placement is in at least 25 feet of water at areas where the hydraulic characteristics would indicate gentle erosion of the material and subsequent redeposition at downstream locations. Ultimately, some rehandling will be accomplished, but overall benefits are greater than alternatives. The material is placed in a thin blanket to minimize interference with fish drifts and natural flow characteristics. This could be analogous to the "cut and fill" approach used in other areas, but at this time, placement of the materials within the limits of the navigation channel downstream which would result in a true "cut and fill" operations is avoided. The Corps does utilize stockpile or other upland disposal sites near heavily populated areas as much as possible to take advantage of the productive uses of clean, Columbia River sands normally dredged.

"WHEEL WASH" DISPOSAL

Another dredging practice used in the Portland District is a channel flushing vessel to accomplish "wheel wash" dredging and disposal.

The Channel Flusher SANDWICK is a modified LCM-8 vessel that is utilized in the Portland District to accomplish an improved form of "wheel wash" dredging and disposal. Modifications to the SANDWICK include a 12-foot by 24-foot hydraulically operated door attached to the stern of the vessel. When this door is lowered it deflects the prop wash of the vessel in a downward direction, which significantly increases its capacity to sweep isolated shoal areas clean at depths of 18 to 20 feet. The SANDWICK is held in place by a four-point mooring system of which two points operating from the stern of the vessel are utilized almost exclusively. The Portland District experiences great difficulty in maintaining the entrance bars at six smaller projects. These projects have entrance depths of from 22 to 10 feet M.L.L.W. because of winter weather conditions maintenance is done through the months of May through September. The Hopper Dredge PACIFIC is severely taxed in attempting to maintain these projects and is the only conventional piece of plant available that can operate safely and effectively on the bars. The SANDWICK has been used at various locations, but since the summer of 1979 it has been the Rogue River Bar Entrance Project, which is the most difficult to maintain because of winter conditions experienced even during the summer months. This freed the Dredge PACIFIC to concentrate on other more commercially important coastal projects. The SANDWICK accomplished this mission in keeping at least half channel widths so that recreational and commercial fishing craft could utilize the entrance during the normal summer season.

BEACH NOURISHMENT DISPOSAL IN FLORIDA

The Jacksonville District, U.S. Army, Corps of Engineers, has utilized dredged material for beach nourishment disposal for a number of years. A recent job at Fernandia Harbor, Florida, optimized the harbor improvement project dredging by placing dredged material on a badly eroded beach. The dredging involved the deepening of the entrance channel to 40 feet for the Naval Submarine Support Base, Kings Bay, completed in June 1979. Deepening of the exposed entrance channel was performed by the Hopper Dredge McFARLAND with assistance from the Hopper Dredge GOETHALS. Of a total of approximately 2.3 million cubic yards removed by both dredges in the deepening project for the U.S. Navy, approximately 500,000 cubic yards of suitable material was placed by means of a direct pump-out system on the ocean beach south of the entrance channel at Fernandia, Florida. The operational methods employed were to obtain a load of material in the hoppers and then tie up to a mooring barge located just outside the channel near the south jetty and pump the dredged material through submerged pipeline and shoreline down the beach approximately 6,000 feet to the start of the beach fill area. With the addition of two booster pumps in the line at this point on the beach, the beach fill area extended south another 7,000 feet for a total pumping distance from the dredge of approximately 13,000 feet. Due to the existing irregular shore alignment the width of the beach fill area varied from 60 to 600 feet so as to provide a relatively continuous shore alignment with a berm elevation of +10 feet M.L.W.

While the disposal of material from the channel deepening project on the eroded beach was more costly ($6.68/c.y.) than disposal at sea

($2.64/c.y.), alternative source of beach fill would now cost considerably more ($5.08/c.y.). The management decision to use this method of beach nourishment enable reuse of valuable sand as well as saving $1.64/c.y.

Another vital beach nourishment disposal project being performed by the Jacksonville District is the Dade County erosion and hurricane (tidal flooding) protection project. For this nourishment project, sand was obtained from suitable sources offshore and pumped on the beach at Miami Beach.

The Dade County Beach erosion and hurricane (tidal flooding) protection project provides for an initial placement of 13.5 million cubic yards of material to form a beach and protection dune for 9.3 miles of shore between Government Cut and Bakers Haulover Inlet. It also provides for beach erosion control by the initial placement of 0.7 million cubic yards of material to form a protection and recreational beach along 1.2 miles of shore and Haulover Beach Park.

Between Bakers Haulover Inlet and Government Cut, the plan provides for a dune 20 feet wide at an elevation of 11.5 feet above mean low water. Seaward of the dune a berm at an elevation of 9.0 feet above mean low water extends for 50 feet, thence a natural slope extends to the water. The beach would be nourished periodically as needed to compensate for erosion losses.

The present estimated project costs, including a 10-year beach nourishment, are about $56 million. The Federal share would be about $31,000,000 and non-Federal at about $25,000,000.

The first contract which included Haulover Park and 96th Street to 80th Street was completed November 17, 1978. Approximately 716,000 cubic yards were placed on Haulover Beach and about 2,424,000 cubic yards from 96th Street to 80th Street. The second contract from 80th Street to 63rd Street was completed August 31, 1979. This stretch of beach was nourished using approximately 1,271,000 cubic yards of material. The third contract from 63rd Street to 41st Street calls for disposal of approximately 3,177,000 cubic yards. A fourth contract will cover from 41st Street to Lincoln Road and a fifth contract from Lincoln Road to Government Cut.

Material for these projects is from areas 6 to 12 thousand feet offshore. The preceding and present contractors were and are being done by Hydraulic Pipeline Dredges, transporting the material through mostly submerged pipeline.

The first contract was performed by first the Hydraulic Cutter Head Dredge ILLINOIS which was later replaced by the Hydraulic Cutter Head Dredge ALASKA. Both of the dredges are owned by Great Lakes Dredge and Dock Company. The dredges are powered by 7200 HP on their pumps and 1600 HP on their cutterheads. The suction is 34 inches and the pump and discharge pipe is 27 inches in diameter. The ILLINOIS moved material through an average of 12,000 feet of pipe line, of which 9,700 feet was submerged. The ALASKA used an average of 11,000 feet of which 7,900 feet was submerged.

The second contract was performed by the electric powered Dredge SENSIBAR SONS owned by Construction Aggregates Corporation. The dredge is supplied 13,200 volts from the shore to the transformer located on the reel barge which is near the dredge. The transformer reduces the current to 7,200 volts. This voltage provides power for the 6000 HP pump and the 1400 HP cutter head motor. The suction pipe is 34 inches in diameter, the pump and discharge is 30 inches in diameter. Material was moved through an average of 9,000 feet of pipeline, of which 6,650 feet was submerged.

DISPOSAL IN NEARSHORE ZONE

The Wilmington District, U.S. Army, Corps of Engineers, has converted the CURRITUCK to provide dredging capability for use of the vessel in beach nourishment disposal. Results of disposal material at New River Inlet, N.C., in the offshore zone indicated a favorable impact on the nourished beaches.

The "CURRITUCK" has been used in two phases of a research project at New River Inlet, N.C., to study the feasibility of disposal of clean sandy dredged material in the nearshore zone and having it move onshore as a method of beach nourishment. During the first phase in the summer of 1976, 34,775 cubic yards of dredged material was placed in 8 feet of water and the second phase involved placing 55,120 cubic yards of material in 10 and 12 feet of water. The rationale for Phase II was to determine the optimum and maximum pumping depths in terms of mechanical placement and bypassing benefits. The shallower the placement depth the longer it takes the CURRITUCK to dump its load and return to refill. Thus, if the same desired results are obtained by dumping in deeper water, costs will be reduced.

Results show that material placed in the shallowest water (8 feet) in both phases responded similarly, that is the material moved shoreward into the higher energy inshore and beach zone and then alongshore in the littoral transport system. Results also show that material placed in deeper water in the second phase moved landward, but that transport rates and amounts were much less than for shallow water. There was slow shoreward movement of the deepwater bars until the onset of winter wave conditions in January and February resulted in a flattening of the bars by accretion on the outer flank of the mound. During the same time period the beach and shoreface seemed to maintain their shape although sand was eroded from the area just landward of the disposal bars and assumed to move seaward. Although a general shoreward movement of material placed in depths of 10 - 12 feet looks promising, the sand transport rates appear to be quite slow. This general interpretation is tenuous and can only be substantiated by additional offshore surveys.

In summary, even though the results of Phase I and II are favorable, a careful assessment of all factors should be made before designing a beach nourishment project using this method.

DISPOSAL AREA REUSE

Numerous examples exist around the U.S.A. of reuse of disposal areas, usually by removal of deposit material for other beneficial uses.

The Detroit District, U.S. Army, Corps of Engineers, has utilized this reuse principle at two diked disposal areas. The upstream reaches of the Saginaw River, mainly the 27 foot depth project area which commences within the city limits of Bay City, Michigan, and extends to Saginaw, Michigan, a distance of about 13 miles, shoals in an irregular manner throughout this entire length. An area to receive the maintenance dredgings along this portion of the river was desirable without traveling outside of these 13 miles of river, and as near the center of this reach as possible. The City of Bay City, Michigan, provided a site with dikes at Skull Island in calendar year 1970. This site was utilized three consecutive seasons and was more than satisfactory. However, the site was not convenient to Bay City in regards to their reuse of the material. Thus, a new site at Middleground Island was utilized beginning in 1973.

The site at Middelground Island has the capacity to hold only one season's dredgings. Between dredging periods, the material is removed by Bay City for various beneficial uses. Thus, the site is continuously available on a seasonal basis. Beneficial use of the material dredged placed in the Middleground Island disposal area includes cover for the City's nearby sanitary landfill operations. In addition, the material has been effectively utilized for a mat and partial backfill in connection with the installation and maintenance of the City's sewer collection system. This method of disposal and cooperation has been very beneficial to both the Detroit District and the City of Bay City.

The Harsen's Island diked disposal site is a state-provided disposal area which is located on a State of Michigan Wildlife Preserve. Unpolluted St. Clair River sediments are stockpiled by a Corps Hopper dredge for use by the Michigan Department of Natural Resources (MDNR) in state projects such as dike and road foundation repairs within the confines of the wildlife reservation on Harsen's Island. The site has been used by the Corps since 1977.

It is proposed to continue these types of programs whenever possible and to improve upon them as experience is gained and local interests become more aware of potential benefits. It is anticipated that other local interests will become interested as well, based on the excellent response of those now working, cooperating, and benefiting from these alternate disposal practices.

The Sacramento District, U.S. Army, Corps of Engineers provides yet another example of disposal area reuse.

During a five year period, approximately from 1967 to 1972, the Interstate Highway system was under construction in and near the City of

Sacramento. Good road building materials were scarce in the Sacramento Valley. However, the sand annually dredged as part of the Sacramento River Shallow Draft Project proved to meet Interstate specifications. As a result, a combination of maintenance dredging by the Corps and dredging under Department of the Army permit by the contractors for the California Division of Highways supplied millions of cubic yards of suitable material. In many cases the material was pumped by cutter-head suction dredge directly into the roadway alignment.

In addition, an agreement was signed in 1967 between the Secretary of Army and the Secretary of Transportation which provided for the removal of some twelve million cubic yards of material from Government-owned disposal areas for use in the Interstate system. Through this agreement, some disposal areas which had been filled were emptied and once again made available for years to come. Development continues along the rivers making it prohibitive to locate and develop new disposal areas. The benefits of reuse are real, as our mission of maintenance dredging would be greatly complicated were we to lose the use of certain critically located disposal areas.

OPTIMUM DREDGING DEPTH - IMPACT ON DISPOSAL NEEDS

Another area wherein innovative procedures have been undertaken to provide desired channel conditions with minimum impact on the environment (less disposal needed) is in the Upper Mississippi River. The St. Paul District, U.S. Army, Corps of Engineers, maintains 284.2 miles of the 9-foot channel on the Mississippi, Minnesota, St. Croix and Black Rivers. Historically, dredging and disposal requirements on the Mississippi average 1.5 million cubic yards annually. Channel maintenance has been accomplished with the 20 inch hydraulic dredge WM. A. THOMPSON and four cubic yard clamshell Derrick Barge HAUSER.

Before 1974, dredging was normally programmed to a depth of 13 feet below low control pool level; the two exceptions to this norm were the Minnesota River 9-foot Channel Project and the Mississippi River emergency dredging in 1965 and 1969. The original design of the Minnesota River 9-foot Channel Project limited dredging to 11 feet in consideration of riverbank stability. During 1965 and 1969, Mississippi River 9-foot Channel Project dredging depths were limited to 12 feet, and channel widths were restricted to allow timely completion of dredging for allowance of navigation. Full channel widths with a 13-foot dredging depth were implemented the following years.

The following are the channel widths maintained on tangent (straight) sections of the rivers:

River	Location	Widths
Mississippi River	Pool 3-10	300 feet
Mississippi River	Lock and Dam 2 to head of navigation, mile 857.6	200 feet
St. Croix River		300 feet
Black River		300 feet
Minnesota River		100 feet

The channel width on river bends was increased up to 550 feet. This width was determined through experience considering the bend radius, river current conditions, and motor vessel operation comments.

Additional overwidth or advance dredging was accomplished as equipment and funding capability allowed to increase the channel width longevity. This practice was considered essential to insure adequate channel width during the absence of the Dredge THOMPSON; it provided capacity for future shoaling during high flow periods. Advance dredging is very efficient with a large hydraulic dredge which, once mobilized and set up at dredging locations, is able to dredge the additional volume required with a relatively small increase in dredging time.

Channel condition surveys were conducted by one hydrographic survey crew; three additional crews provided assistance following the annual spring runoff. Sonar surveys were utilized to establish areas of shoaling, and manual detail surveys were conducted for detail channel condition. Channel condition surveys were conducted after open river flow conditions passed and pools were reestablished. Channel maintenance dredging was scheduled when the channel depth shoaled to 11 feet or less below low control pool elevations.

Channel maintenance under the preceeding conditions has proven very successful in providing a reliable navigation system. The unit cost of dredging was very low as the average resulting dredging face of approximately 3 feet allowed efficient equipment operation, dredged material placement sites adjacent to the channel were used and the workload was adequate to provide excellent plant usage.

Enactment of the National Environmental Policy Act in 1970 required preparation of an Environmental Impact Statement (EIS) for the Upper Mississippi River 9-foot Channel System. The EIS found the historic method of dredged material placement was having a significant adverse impact on the environment. Additional selectivity in dredged material placement was implemented in 1975 as concluded necessary in the EIS Statement of Findings. The Water Pollution Control Act of 1972 required full consideration of the material placement impact on water quality and wetlands. The 1977 Clean Water Act required dredged material placement to comply with State requirements as well as Federal. Disposal of 1.5

million cubic yards of dredged material annually places an excessive demand on available beneficial uses, rapidly depletes the capacity of reasonable disposal sites and the volume makes alternate disposal sites and methods very costly. In 1975, the St. Paul District joined in a Federal-State effort under the Upper Mississippi River Basin Commission to develop a total resource management plan for the Upper Mississippi River. This team effort was entitled GREAT (Great River Environmental Action Team). The Corps of Engineers headed a Work Group of GREAT, the Dredging Requirement Work Group (DRWG), with the primary purpose of reducing channel maintenance dredging quantity. One of the parameters designated for an intensive review was dredging depth and its resultant impact on disposal needs.

The optimum dredging depth must take into consideration many interrelated factors. The quantity of dredging, of course, can be affected by the choice of depth - dredging to 13 feet resulted in an average dredging face of 3 feet. Dredging to lesser depths will obviously reduce the face and quantity dredged at that site. Since the depth of dredging affects the storage capacity for future shoaling, reducing the depth of dredging would affect the frequency of dredging. The depth of dredging face has an impact on the type and size of equipment selected for required dredging. Smaller dredging requirements at more frequent locations could require deployment of an increased number of smaller dredges to allow time and cost effectiveness. The bottom line in all of this is channel reliability. If the dredging equipment capability is not increased to meet an increase in dredging frequency, the channel reliability could be reduced.

The DRWG recognized the complex inter-relationship of the factors and the scope of work involved with 284 miles of channel with 122 separate historic channel maintenance sites. Three basic methods of attacking the investigations were identified:

a. Field Testing. The advantage of documented field tests is that they have the best reliability; the disadvantages are that the test conditions are limited by the hydrologic cycle experienced, variables cannot be tested under identical reoccurring conditions, the study period is short, and any failures pose a risk to continuing commerce.

b. Physical Modeling. This method has proven reliability to predict the impact of parameter modification. It has an advantage over field tests as one can repeat tests with all parameters constant except test parameter variation. The primary disadvantages are cost, aerial scope, and time requirements.

c. Mathematical Modeling. A mathematical model is a computerized program of hydraulic and sediment transport mechanics equations which attempt to describe the river flow, including water and sediment, and its interaction with the river bed. This method is relatively new and untested as only recent development of computer capability allowed initiation of a mathematical solution. A math model has a great advantage over a physical model because the model does not have to be built after each test. It is more time and cost effective than field testing or physical modeling but lacks full development and reliability.

The Corps of Engineers accomplished reduced depth dredging (depth of 11 to 12 feet below low control pool) at 35 of 49 sites dredged on the Mississippi River during the period 1974-1978.

During the GREAT program (1975-1978) 23 percent, 53 percent, and 24 percent of the dredging based on volume was accomplished at 13, 12 and 11 feet of depth, respectively. During the overall period of 1974-1978, 42 percent, 38 percent, and 20 percent of the dredging was accomplished to 13, 12 and 11 feet, respectively. The GREAT program resulted in an overall reduction of 940,350 cubic yards or 23.7 percent of the main channel maintenance on the Mississippi River 9-foot Channel Project, based on initial dredging requirements at each site.

Analysis of the 1960-1973 period indicated that a reduction of depth to 12 feet would have resulted in a 25 percent reduction in individual dredging requirements without consideration of impact on frequency of dredging.

The tests sites had an average annual dredging requirement of 402,400 cubic yards during the 1975-1978 period. The 1956-1974 historical average annual dredging requirement adjusted 12 percent for the 1975 low control pool level change was 629,300 cubic yards. This represents a reduction of 36 percent in dredging quantity. This comparison is considered optimistic as the base period included record floods in 1965 and 1969.

Overall, during the GREAT period, 52 percent of the sites subject to reduce depth dredging were dredged in one year. For these same sites, 39 percent were dredged in an average year for the period 1956-1974, with 13 foot dredging in all but two years. This is a 34.1 percent increase in frequency of dredging. This would tend to illustrate that the decrease in quantity was offset by a increase in frequency.

Existing dredging capability was utilized to accomplish the maintenance dredging. Additional plant was acquired to allow material placement with longer transport distances. Increases in mobilization, setup time, disposal site shutdown requirements, and mechanical downtime reduced the existing equipment capability. These reduction in capability are not attributable to the depth of dredging. However, it does illustrate that channel maintenance was feasible during 1974-1978 with the reduced depth dredging program. Increased frequency of dredging at the test sites did not exceed existing plant capability. However, due to the short period of record, this conclusion is tempered for long-term or extreme flow conditions.

In summary, the field records of 1974-1978 do not indicate an increase of channel closures with reduced depth dredging. However, a much greater risk of channel closure results particularly with 11-foot versus 12- of 13-foot dredging for the following reasons. Field documentation has shown that channel closure can occur within a few days of the channel reaching a depth of 10 feet. The 1974 closure at Reads Landing demonstrated that the channel closed within 4 days with channel depths not less than 10 feet without any change in river stage. When dredging is limited to 11 feet, the Corps of Engineers, St. Paul District, is hesitant to initiate dredging when isolated depths at a site approach 10 feet. Many thousands of dollars of cost are required with the existing equipment to improve the channel depth a few tenths of a foot. Channel maintenance as exemplified by Reads Landing in late 1976 is deferred with increase site monitoring. This poses a definite increased risk to the channel relibility. Development of equipment with high efficiency in dredging extremely shallow face of material would improve the viability of reduced depth dredging. In addition, development of capability to predict whether the site will continue to shoal shallower or scour deeper would be a significant tool to define dredging needs. This predictive and equipment capability would minimize dredging cost, quantities dredged, and improve the channel reliability.

The past 5 years' performance of the Dredge WM. A. THOMPSON and Derrick Barge HAUSER was analyzed to determine the impact of reduced depth dredging. This cost can be aggravated if the frequency of dredging increases. In both examinations, only actual dredging time was considered to minimize the impact of placement site conditions on overall productivity. Alternate equipment could not be evaluated as the Dredge THOMPSON and Derrick Barge HAUSER accomplished all pilot efforts.

(1) Dredge THOMPSON. The following tabulation illustrates the Dredge THOMPSON without application of the Booster Barge MULLEN:

Dredging Depth (Feet)	Average Face (Feet)	Production/Pumping Hour	
		Sq. Yds/Hr.	Cu. Yds/Hr.
11	1.32	1341	589
12	1.77	1347	794
13	2.90	982	984

This clearly indicates that the average 11 foot project costs the same as the average 12 foot project. Therefore, it is just as economical to dredge to 12 as to 11 feet with the Dredge THOMPSON; an increase in frequency increased the costs. The aerial production drops considerably with 13-foot dredging, and an increase in frequency is acceptable. Assuming an average mobilization of 2 days with an average job requirement of 4 days with 13 foot dredging, the frequency of dredging at 12 feet could increase 22 percent without reducing the cost effectiveness of the Dredge THOMPSON. Use of a 20 percent factor is recommended as the average face at 12 feet may increase. The production of the Dredge

THOMPSON with the Booster Barge MULLEN was slightly higher, but significant mobilization and setup time is an overriding factor.

(2) Derrick Barge HAUSER. A similar tabulation for the Derrick Barge is as follows:

Dredging Depth (Feet)	Average Face (Feet)	Production/Pumping Hour Sq. Yds/Hr.	Production/Pumping Hour Cu. Yds/Hr.
11	1.81	288	174
12	2.50	230	192
13	3.67	166	202

Considering the aerial production data, an average job size of 9 days at 13 feet, 1 day of mobilization, and 10 percent stepping time, the frequency of dredging could increase 28 percent with 12-foot dredging and 52 percent with 11-foot dredging without increasing the dredging cost.

A trial effort was made in an effort to improve the production of the derrick barge in shallow face dredging. The derrick barge clamshell will take up to a 2-foot face in a single pass. When the face is less than 2 feet, the clamshell in only partially loaded, but the cycle time remains nearly uniform. Therefore, a concept of dredging a cut face 1-foot deep by dredging 2 feet deep but skipping 50 percent of the area in the checkerboard pattern was considered. This methodology was tested on the outside cut of Below the Head of Raft Channel, Pool 8 in 1976. The dredge cut was located on the inside of a river bend. The derrick barge production increased, but unfortunately the dredged area did not level out. It remained uneven throughout the balance of the 1976 season. The river flow was insufficient to level the area, and the motor vessel propellor was not effective as it was directed to the outside of the bend. Any future attempt should include trial applications of a drag bar or beam to level the area.

SUMMARY

The examples presented herein tend to illustrate the emphasis being placed on the disposal of dredged material. This is not to say that the optimization of dredging techniques is not receiving its share of technical effort. It is increasingly evident that the total dredging cycle needs to be addressed, with all elements being considered very carefully.

EFFECTS OF SEDIMENT PARTICLE SIZE DISTRIBUTION AND RELATED FACTORS ON SURVIVAL OF THREE AQUATIC INVERTEBRATES:

IMPLICATIONS FOR THE CONDUCT OF

DREDGED SEDIMENT BIOASSAYS

by

VICTOR A. MCFARLAND[1]

ABSTRACT

The influence of sediment particle size distribution on the survival of three invertebrate species was investigated. A simple nondisruptive procedure for combinating natural uncontaminated sediments, which provided control sediments of predicted particle size distribution, was developed. The tubicolous polychaete, Diopatra cuprea and the grass shrimp Palaemonetes pugio survived equally well on all sediment types ranging from 00 percent coarse-textured to 100 percent fine-textured sediment during the 12-day investigations. Survival of the burrowing polychaete, Neanthes arenaceodentata declined linearly as silt/clay content of the sediment increased; however, this decreased survival was not statistically significant at the a = 0.05 level. The implications of the lack of prior knowledge of the compatibility of test organisms with the sediment type under investigation in a sediment bioassay are discussed.

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INTRODUCTION

1. The criteria governing ocean disposal of dredged material under Section 103 of the Marine Protection, Research, and Sanctuaries Act of 1972 (Public Law 92-532) require that potential for environmental harm be assessed by a three-phase bioassay (U. S. EPA, 1977). These bioassays must measure the toxicity of the liquid, suspended particulate, and solid phases of a dredged sediment being considered for ocean disposal to "appropriate sensitive marine organisms."

2. An implementation manual describing suggested procedures for complying with these regulatory requirements was prepared by the Environmental Protection Agency/Corps of Engineers Technical Committee on Criteria for Dredged and Fill Materials (EPA/CE 1977), and is used routinely by coastal Corps District and EPA Regional offices in regulatory evaluations of dredged material proposed for ocean disposal. The liquid and suspended particulate phase tests are conducted in the manner of the traditional 96-hr aquatic bioassay. The solid phase test, however, is an innovation in which survival of the test organisms is determined after 10-days' exposure to a deposited layer of the dredged material at in situ sediment density. This is compared with survival in identical systems containing deposited layers of reference or control sediments.

3. Many benthic surveys have related the distribution of organisms to sediment type (Driscoll 1975; Dexter 1978; Nichols 1970; Sanders 1958; Stickney and Stringer 1957; EPA 1975; Young and Rhoads 1971). Sanders (1958) related the sediment preference of many organisms to feeding type. In that study, most epifauna and filter-feeding infauna were associated with sandy sediments. Fine-grained sediments were characterized by deposit-feeding infauna. Sanders (1958) found a sand bottom community characterized by

amphipods of the genus Ampelisca, one of which was Ampelisca spinipes. Stickney and Stringer (1952) found amphipods of this species characterized the muddy central core of Greenwich Bay. While it appears that at least in the case of Ampelisca spinipes, the same organism may characterize either sandy or muddy bottoms, very few species show such an ubiquitous distribution in the field. Many factors such as larval settling preference, inter-specific competition, adult mobility, phototaxis, water currents, and variable responses to changes in temperature or salinity operate to affect the distribution of juvenile and adult organisms in the field (Gray 1974). Since factors such as these are controlled in laboratory testing, the occurrence of an organism in a particular substrate in the field does not necessarily mean that species can not survive acceptably in the laboratory in other sediment types for the duration of a bioassay.

4. A related concern is the nature of a suitable control sediment. The particle size distribution of the dredged material in a particular channel is beyond the control of the investigator. The particle size distribution of the reference material can be selected only within the range available near the dump site and a choice is often limited. However, a control sediment of any desired particle size distribution can be selected by the investigator, and can be made intermediate between size distributions of the dredged and reference sediments. The location and collection of a demonstrably nontoxic sediment of a particular particle size distribution can be time-consuming and logistically difficult. This paper describes a method whereby a very natural control sediment of any desired particle size distribution can be easily prepared in the laboratory, and describes the effect on survival of three organisms of various size distributions of sediments so prepared.

MATERIALS AND METHODS

Sediments

5. The mud used in this study was taken with a Peterson grab from the deepest part of East Bay, Pensacola, Florida, an area with no apparent nearby sources of pollution. It was transported to the laboratory in fiberglass ice

chests and stored at $4^{o}C$. Before use in the experiments, it was strained through a 1.0 mm polyethylene screen without the addition of water and was mixed thoroughly with a large wooden paddle. Particle size distribution analysis was performed using the modified hydrometer method of Patrick (1958). A quartz sand was obtained from an area of Santa Rosa Sound, Florida, well removed from apparent sources of pollution. In the laboratory this sand was sieved, air-dried, and sized using U. S. Standard sieves.

6. The mud and sand were mixed by incorporation of the sand in the wet mud using stainless steel spatulas and a plastic covered slab. This procedure involved spatulating a small, workable-size mass (500-700 g) of the mud on the slab into a thin layer. A proportionate amount of sand was added to this mass and worked into it until the sand was evenly distributed in the mud. Two spatulas were used, one to do the mixing and moving and the other to clean the first. When the components were well mixed, the mass was set aside and a second batch prepared in the same way. This was mixed with the first batch and the procedure was repeated until all the sand had been mixed with all the mud. The small mixed batches were then combined and mixed thoroughly in an ice chest using a wooden paddle. No water was added at any point in the process.

Chemical Analyses

7. Standard procedures were used for chemical analyses performed on the mud sediment used in this study (US-EPA, 1969; US-EPA, 1979a and 1979b; Rand, M. C. et al., 1975; Mills, et al., 1972). Parameters included heavy metals, polynuclear aromatic hydrocarbons, polychlorinated biphenyls, chlorinated hydrocarbon pesticides, nutrients, oil and grease, and miscellaneous sediment characteristics.

8. With the exception of Hg, metals were digested in concentrated nitric acid. Metals other than Pb that were present in concentrations greater than 50 ppb were analyzed by argon plasma emission spectroscopy using a Spectrametrics multielement system, Spectrospan Model III. Lead and all

metals in concentrations below 50 ppb were analyzed on a Perkin-Elmer Model 5000 atomic absorption spectrometer using a heated graphite atomizer system. Mercury was analyzed by the cold vapor method, wherein the sample is digested and reduced to the elemental form and the vapor is passed through a chamber mounted on a Perkin-Elmer atomic absorption spectrometer, Model 305.

9. Samples for PCB analysis were extracted in hexane/acetone, cleaned on Florisil™, and concentrated using a Kuderna-Danish system. Analysis was completed on a Hewlett-Packard Model 5840 gas chromotograph equipped with an electron capture detector.

10. Polynuclear aromatic hydrocarbons were extracted with the PCB's and cleaned on Florisil™. Analysis was by flame ionization using a Perkin-Elmer Model 990 gas chromatograph.

11. Colorimetric methods were used for the analysis of CN, TKN, TP, and COD using a Technicon AutoAnalyzer, Model AAII for the first three parameters and a Hitashi Spectrophotometer, Model 100-60 for the COD. TOC was analyzed on an Oceanographic International IR detector following persulfate digestion. Oil and grease, TVS, and TS were analyzed by gravimetric procedures. In the case of oil and grease, the sediment was extracted using hexane. For TVS, the sediment was ashed in a muffle furnace at 550°C. NH_3-N was analyzed by distillation into acid, adjustment of the pH to 10.5 and back-titration.

Experimental Organisms

12. Three species were used in the investigation. The tubicolous polychaete, *Diopatra cuprea* was collected by divers on the Texas coast. The worms were found living in a sandy substrate, and when brought to the laboratory they were placed in large fiberglass tanks containing 10 cm of sand with artificial seawater adjusted to 33 ‰ salinity, and maintained at an ambient temperature of 20 ± 2°C. The acclimation period was three weeks and the worms were fed during this period on a diet of dried, ground *Thallasia sp.*

13. Another polychaete species which builds a burrow or inhabits crevices and is a different feeding type, *Neanthes arenaceodentata*, was cultured in our laboratory from a strain originally obtained from D. Reish[2]. This worm was cultured in flat plastic trays in artificial seawater at 25 $^{o}/oo$ salinity and a temperature maintained at 20 $\pm$ 2^{o}C. A thin layer of sand in the trays allowed the worms to form burrows. The water was aerated, checked daily for increased salinity, and partially replaced every 2 weeks. The food was dried alfalfa.

14. The third species tested was the estuarine grass shrimp, *Palaemonetes pugio*. These shrimp were collected by dip net in *Thallasia* beds at Shoreline Park in Escambia Bay, Florida. In the laboratory, they were maintained in glass aquaria equipped with subgravel/airlift filters. Salinity was maintained at the collection level of 25 $^{o}/oo$ and temperature was controlled at 20 $\pm$ 2^{o}C. The shrimp were fed daily on 48-hr nauplii of *Artemia salina*.

Experimental Design

15. Experimentation with polychaetes was conducted in 190 x 100 mm acid-washed crystallizing dishes. Containers for the grass shrimp were 5.7ℓ battery jars. Treatments consisted of clear water with no sediment added, 100 percent sand, 50 percent sand/50 percent mud, 20 percent sand/80 percent mud, and 100 percent mud. All containers were randomly assigned a position in the same temperature-controlled water bath.

16. Two procedures were followed for addition of the sediment to the aquaria. Procedure A, which was nondisruptive of the sediment, consisted of placing the sediment to a depth of 30 mm in each empty container and slowly siphoning water into a petri dish placed on the surface. Water flowed over the sides of the dish onto the sediment and filled the containers without

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suspending the sediment. In Procedure B, the sediment was slurried in water, poured into containers partially filled with water, and allowed to settle for 1 hr. About 75 percent of the water was siphoned off after this settling period and replaced with clear water using the petri dish to avoid additional disturbance. Sufficient slurry was added to produce a sediment depth of 15 mm. Once temperature had stabilized at 20°C, 10 organisms were added to each container. Aeration was provided by bubbling filtered compressed air into each dish through a small bore glass pipet. After 24 hrs, water was again changed in containers representative of the second procedure, and after an additional 24 hrs, part of the water in each container was removed and sufficient additional slurried sediment was added to bring the settled sediment depth to 30 mm. Water was again changed after a 1-hr settling period and at 48-hr intervals thereafter. The experiment was terminated after 12 days and surviving organisms in all aquaria were counted and the results analyzed by two-way analysis of variance, Duncan's multiple range test for variable survival, and linear regression analysis.

RESULTS AND DISCUSSION

17. Results of the chemical analyses of the East Bay mid-channel sediment are given in Table 1. The earth's average crustal abundances of the metals analyzed in this sediment are shown in parentheses. Concentrations in the sediment were generally near or below the earth's crustal averages. Most of the miscellaneous sediment characteristics which are generally related to sediment toxicity and to adsorption-desorption of lipophilic pollutants are low. Total volatile solids is an exception. All the organic contaminants measured which would tend to be associated with organic or volatile solids, however, were below analytical detection limits or present in very low concentrations. Particle size analysis showed the mud contained 2 percent sand, 78 percent silt, and 20 percent clay. The sand was not analyzed chemically. The sand contained less than 0.01 percent by weight of particles smaller than 63 μm. Two-thirds of the particles fell between 63 um and 300 μm and one-third were between 300 μm and 1.0 μm.

18. On the basis of these determinations the mid-channel sediment and the sand were considered to be nonpolluted and physically suitable for mixing to form "control" substrates in which the survival of organisms exposed would not likely be affected by chemical toxicity.

19. For none of the three species were there any statistically significant differences in survival due to the procedure by which sediment was added to a test container (Table 2). Treatment x procedure interactions were also insignificant, and for these reasons data from both procedures were pooled in calculating treatment effects. Survival of the three species investigated is shown in Figure 1.

20. Palaemonetes pugio survived equally well regardless of the presence or nature of sediment. Survival was 90 percent or better in all treatments where sediment was present and slightly less than 90 percent in clear water without sediment.

21. The survival of D. cuprea was higher in all sediment treatments than that of the other two organisms. Survival of this organism approached 100 percent on sediments, but was reduced to 65 percent in the absence of a sediment.

22. The survival of N. arenaceodentata decreased linearly from a high of 95 percent in 100 percent sand to a low of 77.5 percent in 100 percent mud (r^2 = 0.95) in the treatments where sediment was present. However, the difference between the survivals in any treatment in which a sediment was present were not statistically significant at the 0.05 level. The 40 percent survival in clear water without the presence of sediment was statistically lower than in the presence of any sediment and was lower for this animal than for either of the others.

23. In this study, P. pugio and D. cuprea survived equally well in the presence of a pure mud substrate as when pure sand was present. These two organisms appear to be acceptable for use in bioassays in which reference and test sediments are of widely differing particle size distribution. While the differences are not statistically significant, N. arenaceodentata showed decreasing survival with increasing mud content. This suggests a possible

sensitivity of this animal to some toxic property of the test mud. More likely, however, in view of the uncontaminated nature of the mud, is a general decrease in physical compatibility with muddy sediments. This would limit the species usefulness in bioassays involving high mud content sediments. The two polychaetes clearly require a sediment substrate. Their poor survival in sediment-free water is highly significant when compared to survival in the presence of a sediment of any particle size distribution. The grass shrimp, however, survives as well without a sediment as it does when any sediment is present.

24. In regulatory dredged sediment bioassays, the reference sediment is intended to represent conditions at the proposed disposal site had dumping never taken place there, and is collected near the disposal site in an area not affected by previous disposal operations. For purposes of regulatory evaluations, survival in the dredged material being tested is compared to survival in the reference material to assess whether disposal is likely to degrade sediment conditions beyond those presently existing in the vicinity of the disposal site. The control sediment is intended to be similar in sedimentological characteristics to the dredged sediment and to the reference sediment and must be demonstrably nontoxic. Its sole purpose is to provide quality assurance regarding the conduct of the bioassays. In the case in which the reference sediment is pristine and physically similar to the dredged material, it can also serve as the control sediment.

25. Problems may arise when the physical nature of the dredged material is markedly different than that of the sediment in the vicinity of the dump site, and therefore, different from the reference sediment. Frequently, the material to be dredged from a ship channel is predominately silt-clay, while the sediments in and around a dump site are sand, or vice versa. Since the intent of the tests is to determine dredged material toxicity as distinct from physical effects, one qualification of an appropriate test organism clearly must be the ability to survive equally well in sediments of different particle size distributions. Otherwise, physical incompatibility with the sediments can make the determination of toxicity impossible. This is critical since the

decision whether to grant a permit to dump is strongly influenced by the predicted toxicity of the dredged sediments.

26. All factors other than toxicity of the test sediment which may influence the outcome of the test must be the same for the control, reference, and test organisms. Therefore, a species which would not survive equally well in a variety of sediment types would be unsuitable for use in a bioassay in which the reference and test sediments were of widely different particle size distributions. The present study describes a simple method for determining the suitability of potential test species for use in laboratory bioassays in which the reference and test sediments have different particle size distributions.

27. Tests of this type are not difficult to perform and can provide a data base which can aid in choosing the most suitable organisms for use in sediment bioassays. Such information should be of use both to the contractor who performs the bioassays, and, as quality assurance, to the contracting officers who must select a contractor and must make regulatory decisions on the bioassay results provided them. Once the physical compatibility of potential test species with particle sizes of the test and reference sediments has been verified, the technique described here can be used to prepare a non-toxic control sediment with natural texture and any desired particle size distribution.

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Table 1

Chemical Analysis of East Bay, Pensacola, Florida, Mid-Channel Sediment. All Values are mg/kg, Dry-Weight Unless Otherwise Indicated. Values in Parentheses are Earth's Average Crustal Abundances of Metals.[3]

Parameter	Concentration		Parameter	Concentration
Cd	2.36	(0.2)	Napthalene	0.073
Cr	118.0	(200.0)	1-me-Napthlene	<0.010
Cu	19.8	(70.0)	2-me-Napthlene	<0.010
As	6.83	(5.0)	Aroclor 1242	<0.010
Pb	21.8	(16.0)	1248	<0.010
Mn	57.8	(1000.0)	1254	<0.010
Ni	32.2	(100.0)	1260	<0.010
Zn	88.8	(80.0)	α-BHC	<0.001
Hg	<0.0021		Heptaclor	0.002
TP	504.0		Heptaclor epoxide	0.001
NH_3-N	15.0		Lindane	<0.001
TOC	6630.0		Aldrin	0.001
CN	<0.5		Dieldrin	<0.001
TKN	2890.0		Endrin	<0.001
COD	3.69%		p, p^1-DDE	0.005
Oil & Grease	500.0		p, p^1-DDD	<0.001
TS	21.4%		p, p^1-DDT	<0.001
TVS	24.8%		o, p^1-DDT	<0.001
S	35.0			

3 After V. M. Goldschmidt, Courtesy A. Muir, editor, and Clarendon Press, Oxford, Publishers of "Geochemistry."

Table 2

Analysis of Variance Results for Each Species Tested Comparing Effect on Survival of Procedure, Treatment, and Procedure × Treatment Interaction

Source	DF	Anova SS	F	P > F
Palaemonetes pugio				
Procedure	1	5	0.03	0.8610
Treatment	4	70	0.11	0.9751
Procedure Treatment	4	270	0.44	0.7803
Diopatra cuprea				
Procedure	1	45	1.29	0.2833
Treatment	4	3370	24.70	0.0001
Procedure Treatment	4	130	0.93	0.4853
Neanthes arenaceodentata				
Procedure	1	20	0.13	0.7226
Treatment	4	7570	12.62	0.0006
Procedure Treatment	4	730	1.22	0.3631

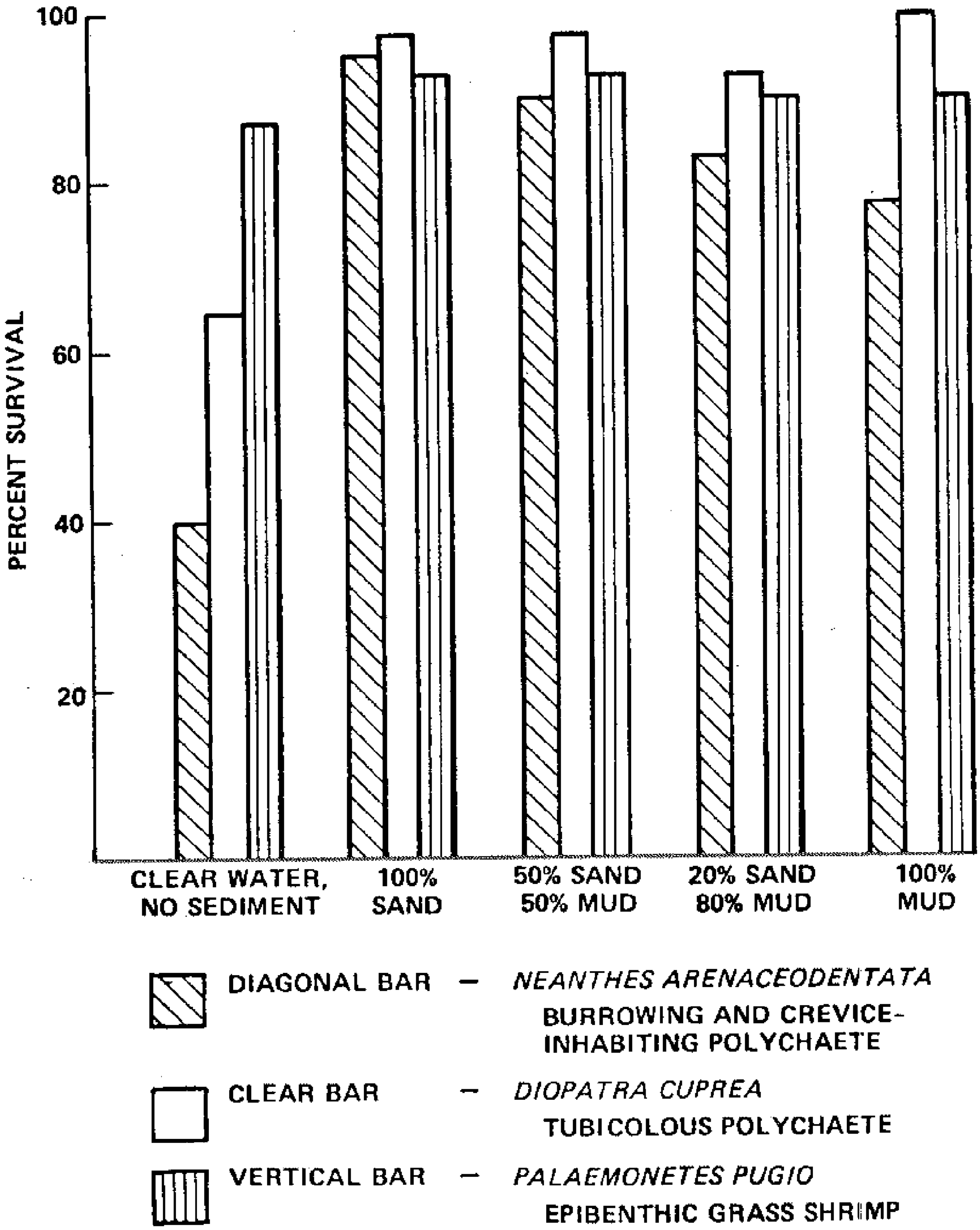

Figure 1. Survival after twelve days exposure

DREDGING AND THE NATIONAL WATERWAYS STUDY

by

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ABSTRACT

The National Waterways Study was authorized by Congress directing the Corps of Engineers to make a comprehensive study and report on the system of waterway improvements. The study shall include a review of the existing system and its capability for meeting the national needs, including emergency and defense requirements and an appraisal of additional improvements necessary to optimize the system and its intermodal characteristics through the year 2003. This study has been assigned to the Institute of Water Resources.

The first task of the National Waterways Study has been to develop an inventory of the existing system and the commodities which move on the waterways, and to prepare a description of that system. The development of future scenarios precedes the second group of major activities which include projecting commodity flows and assessing the capability of the existing system to meet these flows. This is followed by assessment under the future conditions. Development and evaluation of alternative strategies follow the identification of constrained segments of the nation's system.

Part of the National Waterways Study has been devoted to the history of dredging, present status of dredging technology, and a projection of future technology and fleet utilization.

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INTRODUCTION

There has been speculation about what is to become of America's waterways, much of it focused on the socio-economic, institutional and environmental impacts of using waterways and water-related resources to provide transportation benefits for the American people. In addition, the growing complexity of water resources management has tended to obscure the attention given to any single function, such as transportation, for which water is used. In evaluating the current and potential role of waterways in the national transportation scheme, it is necessary to consider a number of factors which have an impact--directly or indirectly--upon the maintenance and development of the network in meeting a level of waterborne transportation needs. One of the more critical functions in the operation of our waterway system is dredging. What shape America's waterways will take in the future is going to be influenced significantly by decisions made today concerning the dredging activities to be performed in this system.

A decision-making basis as to what the waterways could and should become in the overall context of our national transportation system is being developed in the National Waterways Study. The United States Congress, acting in Section 158 of the Water Resources Development Act of 1976, directed the U.S. Army Corps of Engineers to undertake a navigation-oriented study. The overall NWS objective is to identify and analyze alternative strategies for providing a navigation system to serve the nation's current and projected transportation needs. In achieving this objective, one function of the study is to assess the capability of the existing waterway system to meet both current and projected national transportation needs. The study is examining the capability of the current navigation system to handle present and future traffic. System level constraints are being identified. Such constraints may be specific in nature, such as capacity problems at Lock & Dam 26 on the Mississippi, or they may be more general, such as reduced levels of maintenance or new work dredging system-wide. This latter potential constraint to waterborne commerce is gaining increasing attention as the National Waterways Study proceeds apace.

The preliminary findings to date highlight the continued and growing importance of the waterway network in the national transportation scheme, and lend credence to expressions of concern over potentially serious constraints to this role, such as the long-term impacts of reduced levels of dredging. Although continuing pressures for national and regional growth spur on moves to expand transportation capabilities, it seems apparent that the mission of institutions involved in water transportation is focusing more on improved operations and maintenance--modernization of existing waterways and replacement of outmoded facilities--not on major system development and expansion. There are also questions about the safety of navigation facilities and the reliability of the system in sustained use. Many improvements were installed decades ago, and breakdowns at sensitive points are another concern.

THE WATERWAY SYSTEM TODAY

In assessing the significance of a potential constraint to waterborne commerce, such as reduced dredging volumes, it is important to understand the magnitude of the waterway network and associated facilities. One of the first tasks of the National Waterways Study was to perform an inventory of the component parts and functions of the existing waterway system in order to develop this characterization of the system as a basis for further study.

Currently, nearly 26,000 miles of commercially navigable waterways are in use, in addition to the shipping lanes of the Great Lakes and the coastal trade routes. Ninety-five percent of the Unites States population lives in states served by this system. These waterways are served by more than 230 commercial harbors and ports operated by private industry or by local or state governments.

Navigation improvements along the waterways include locks at 265 sites, channel alignments, bank stabilization, cut-offs, dredging, and clearing and snagging operations. The Corps of Engineers operates most of the locks, maintains most of the improved waterways and is also responsible for a portion of the dredge fleet capacity required for maintaining the channels and ports.

Since 1824 the Federal government has invested about $10 billion in the development and maintenance of the inland and intracoastal waterways and in the Great Lakes and coastal harbors. Present annual maintenance costs for these facilities range from $350 to $400 million.

Approximately 1.9 billion tons of freight move along the waterways and through the ports each year. The foreign trade component is nearly equal to the domestic flow and is growing at an accelerating rate. Both foreign and domestic commerce each approached one billion tons in 1977. The waterway system provides effective transportation for movement of crude and refined petroleum, coal, grains and fertilizers, industrial chemicals, iron ore, iron and steel products as well as other bulk commodities. Energy commodities, petroleum and its products and coal, dominate foreign and domestic waterborne trade and accounted for 61 percent of all waterborne commerce in 1977. Most of the movement is of foreign origin. The next largest domestic commodity group moving by water--grains--is predominately for export.

In the three decades between 1947 to 1977, the volume of waterborne commerce increased from 700 million tons to 1.9 billion tons. Domestic commerce has shown consistent growth, beginning with the movement of 579 million tons in 1947 and leveling off within a range of 970 to 990 million tons between 1973 and 1977. Foreign commerce has grown at a much more rapid pace, from 188 million tons in 1947 to 935 million tons in 1977. Foreign trade represented about 25 percent of total waterborne commerce in 1947, but it currently accounts for about 50 percent of the total.

In addition to characterizing the existing waterway system, its facilities and traffic patterns, a major function of the National Waterways Study is to project future commodity flow volumes and patterns on this system through 2003. Among the most significant growth commodities foreseen are coal and grain, with waterborne movement potentially increasing nearly three-fold and two-fold, respectively, over the time frame. Such projections illustrate the growing importance of the waterway system in moving vital commodities; they also illustrate its growing vulnerability to disruptions of this traffic flow. Important constraints to the realization of projected traffic growth are being identified in the National Waterways Study. Reduced levels of dredging in channels and ports has surfaced as one of a number of potential constraints on the system. The United States has not attempted to develop a deepwater port capability that would be competitive with European facilities. Moreover, a variety of factors have resulted in reduced volumes of dredging nationwide, with the result that certain locations are not effectively maintaining existing depths, much less improving them.

THE PLIGHT OF DREDGING

Prior to 1978, the dredging program of the Corps of Engineers was accomplished under the provisions of 33 U.S. Code (USC) 622 and 33 USC 624. These laws required that the Federal dredging workload be performed in the most economical or advantageous manner by use of either Corps dredging plant or industry plant.

Through the end of World War II, the Nation experienced a continuous development of the waterway system to meet expanding commercial, recreational and national defense requirements. In order to meet the growing needs for maintaining and improving the waterway system, the Corps acquired the dredges necessary to assure that this work was accomplished in a timely manner and at a reasonable cost.

Since World War II however, there have been few instances in which the channels of the Nation's ports and inland waterways have been widened and deepened to any significant extent. During the past 16 years alone, the overall annual dredging workload in the United States has decreased 41% from 480 million cubic yards in 1963 to 282 million cubic yards in 1979 (Table 1). Although there has been a slight net increase (8%) in the maintenance dredging workload during this time period, the new work or improvement dredging workload has experienced a dramatic 82% reduction from 263 million cubic yards in 1963 to 48 million cubic yards in 1979.

This reduction in workload is directly related to three factors. Foremost among these is the sudden and intense public interest and concern with environmental protection and preservation, which is reflected by the enactment of a series of environmentally-oriented statutes; e.g., National Environmental Policy Act, Federal Water Pollution Control Act, the Marine Protection, Research and Santuaries Act, and Clean Water Act.

TABLE 1: RECENT CHANGES IN THE NATIONAL DREDGING WORKLOAD (1963-1979)

Dredging Program	Workload Cubic Yards Millions 1963	1979	Percent Change
Improvement	263	48	-82
Maintenance	217	234	+ 8
TOTAL	480	282	-41

One of the major constraints to dredging in this age of environmental awareness is the disposal of dredged material. Prior to 1966 open water disposal was acceptable in most cases. Now it is increasingly more difficult to use as a method of disposal. This has resulted in stopping some dredging projects and severely limiting others. The problems associated with the obtaining suitable disposal areas have significantly delayed dredging projects because of:

a. The time required to perform an EIS.

b. The time and funds required to design, build, and procure disposal areas.

Environmental constraints and stringent new disposal practices have made obsolete much of the dredging fleet which was already out-dated and marginal in performance. Some of the dredging fleet could be modified, but with the cut back in dredging, industry is reluctant to make the capital investments for a shrinking and uncertain work load.

Another blow to dredging has come with the rigid enforcement of the "Seagoing Barge Act." The majority of the cutterhead dredges were designed and constructed for use in interior waterways and would require extensive modifications to meet the requirements of the "Seagoing Barge Act" prior to their working in exposed coastal waters. In many cases, these modifications would be so extensive that rehabilitation will not be economically feasible. Recently, the Coast Guard has been given increased latitude in interpreting this Act. The impact this will have upon the dredging industry remains to be seen.

A third factor contributing to diminution of the U.S. dredging fleet is the fact that U.S. channel depths have not kept up with those of the rest of the world. Outdated port dimensions will increasingly play a role in our balance of trade because the country is currently not able to efficiently export coal in deepdraft vessels.

The above three factors are predominantly responsible for the significant decrease in the annual dredging workload in the United States. The Federal dredge fleet has mirrored this fact by a significant decrease in size. Worse yet, the 82% reduction in the annual improvement dredging yardage had a substantial adverse impact on the industry, because the industry had traditionally performed about 85% of this type of work. While there have been a large number of deep draft channels and harbors constructed for large supertankers and bulk cargo ships in many parts of the world, there have been no such facilities constructed in the United States since World War II. That coupled with the large decrease in the total workload since 1963, have deteriorated the financial condition of many of the dredging companies.

As the volume of the workload available to the industry decreased, the industry, through its national organization, the National Association of Dredging Contractors, approached the Congress and the Corps of Engineers with a proposal that all of the dredging workload be performed with industry plant. This was not possible under the provisions of 33 USC 622 and 33 USC 624, nor was it in the public interest due to the large capital investment in the existing Federal dredges. Nevertheless, in recognition of the industry's plight, Congress decided that a comprehensive review of the national dredging program was needed. This decision led to a series of congressional actions.

In 1967, Congress directed the Corps of Engineers to defer acquisition of new dredging equipment and to advertise through competitive bidding some of the work performed by Corps hopper dredges. In 1972, Congress placed a moratorium on all plans for the replacement or modification of Corps dredges pending completion of a comprehensive study of the national dredging program. The purpose of the study was to determine the procedures for accomplishing the Corps' dredging requirements in the most efficient, economical and timely manner. The study, which is known as the "National Dredging Study," was conducted by a management/engineering firm and was completed in August 1974.

The National Dredging Study concluded that the industry's dredging fleet was generally obsolete and that there was little prospect of the industry improving its productivity without the introduction of new equipment and technology. Although industry has constructed one new dustpan dredge and three new pipeline and three new split hull dredges, in part in response to the ongoing Industry Capability Program, there had been little overall improvement to its dredging productivity.

Following a review of the National Dredging Study, the moratorium on the addition to, modification of, or replacement of the Corps of Engineers dredge fleet was lifted by the Congress in fiscal year 1976 but funds were only appropriated for the construction of three new Corps of Engineers hopper dredges. However, the majority of the Corps of Engineers' existing non-hopper dredges are antiquated and must be retired in the near future. But, considering the present status of industry's non-hopper fleet, the retirement of the out-dated Corps dredges must be carefully considered until it is clear that the industry dredges, which average 25 years in age, are capable of extended timely, economical and efficient performance.

Presently, the industry non-hopper fleet includes 293 cutterhead dredges, 174 clamshell dredges, 13 dipper dredges, and one dustpan dredge. The Corps of Engineers' existing fleet of active dredges consists of 13 hopper dredges, two large class cutterhead dredges, five dustpan dredges, one dipper dredge, three sidecasting dredges, three bucket dredges and one special purpose split-hull dredge. Several small hydraulic dredges with discharge diameters 12-inches and less are too small for use on major navigation projects or for emergency and national defense purposes. These small dredges are operated by the Corps for maintenance of breakwaters at hydroelectric or flood control project reservoirs, in remote locations, in areas in which the volume of work is limited, and in areas where industry equipment is not available.

DREDGING TRENDS

The National Waterways Study first undertook the task of providing an inventory of the national waterway system from which much of the previous statistics were presented. The field offices provided to a central data base various catagories of data including the dimensions of navigable waterways along with dredging costs and corresponding volumes, both applied and deferred. Further surveys provided information on the commercial dredging fleet. This information helps provide a baseline to both define the relationship of dredging to the waterway system and serve as a barometer.

Over the period of 1963 to 1979 the total volume of dredged material decreased from 480 to 282 million yards with a corresponding cost increase from $166 million to $324. Table 2 below shows that the unit cost did not advance dramatically until 1971 when environmental constraints and escalating fuel prices began being applied. Not only have environmental constraints resulted in reduced dredging but they have affected the disposal of dredged material.

TABLE 2

DREDGING COST TRENDS

1963 TO 1979

CORPS AND INDUSTRY

Fiscal Year	Total Cost Dollars (millions)	Total Cubic Yards (millions)	Average Unit Cost (cents/cu.yds)
1963	166	480	34.6
1964	142	409	34.7
1965	148	416	35.6
1966	137	390.	35.1
1967	110	327	33.6
1968	112	338	33.1
1969	115	342	33.6
1970	128	392	32.7
1971	141	357	39.5
1972	141	315	44.8
1973	157	312	50.3
1974	176	386	45.6
1975	207	332	62.3
1976	240	287	83.6
1977	237	298	79.5
1978	307	280	109.6
1979	324	282	114.9

Tables 3 and 4 below give some indication of types of dredging performed and the methods of disposal. Open water disposal appears to have been reduced, which would be a logical result of environmental constraints, while the decrease in confined disposal would represent the unavailability of (a) funds, (b) space and/or (c) judiciary approval.

TABLE 3

MAINTENANCE DREDGING VOLUME BY TYPE OF EQUIPMENT

Method Dredged	1966 - 1979[1] Million Cu. Yds.	%	1973 - 1977[2] Million Cu. Yds.	%
Hopper	70.7	23.7	88.2	30.4
Sidecast	0.3	0.1	0.3	0.1
Pipeline	205.9	69.0	154.0	53.1
Bucket	3.6	1.2	6.4	2.2
Dipper	0.7	0.2	1.7	0.6
Mixed	17.2	5.8	39.4	13.6
TOTAL	298.4	100	290.0	100.0

1. Average annual maintenance dredging total developed in June 1971 incuded only those projects requiring maintenance at least once each five years from WES TR H-72-8, pages 4,6.

2. Average maintenance dredging volume over 3-5 years, 1973-1977, from National Waterways Inventory.

TABLE 4

MAINTENANCE DREDGING VOLUME BY TYPE OF DISPOSAL

Method Disposed	1966 - 1979[1] Million Cu. Yds.	%	1973 - 1977[2] Million Cu. Yds.	%
Confined	67.1	22.5	50.1	17.3
Open	182.1	61.1	169.7	58.5
Undifferentiated	49.2	16.4	70.2	24.2
TOTAL	298.4	100	290	100.0

1. Average annual maintenance dredging total developed in June 1971 included only those projects requiring maintenance at least once each five years from WES TR H-72-8, pages 4,6.

2. Average maintenance dredging volume over 3-5 years, 1973-1977, from National Waterway Inventory.

The real impact of environmental and economic constraints is, of course, not only the lack of waterway development but also a deterioration of the existing system. During the period 1973-1977 about 28.9 million cubic yards or 10% of the total maintenance dredging was deferred for either insufficient funding or environmental reasons. From a cost point of view the deferred dredging represented 27.6% of the dredging costs. Mr. Herbert Haar, chairman of the American Association of Port Authorities Ad Hoc Committee on dredging further emphasizes the lack of maintenance by recently reporting that "The U.S. Corps of Engineers had a need for dredging in the amount of $478 million in Fiscal Year 1980 whereas the budget provided only $284 million. The shortfall in funds will continue in Fiscal Year 1981 where requirements are $452 million and the proposed budget provides only $307 million." This implies the need for non-partial allocation of funding.

For the reader to pursue that thought trend, the summary of Corps wide dredging activities covering the period 1973 - 1977 is presented below. The data in Tables 5 and 6 account for the total reported "average annual" dredging of 290,016,500 cubic yards ranked by percentage showing that the greatest amount of dredging is performed in the Lower Mississippi River.

TABLE 5

DISTRIBUTION OF DREDGING VOLUME BY REGION

Regions	Percent Volume
Miss. River & Trib.	38.0
Gulf	28.5
Atlantic	16.4
Pacific	14.6
Great Lakes	2.3

TABLE 6

DISTRIBUTION OF DREDGING VOLUME BY CORPS DIVISION

Corps Division	Percent Volume
Lower Mississippi Valley	44.4
South Atlantic	16.0
Southwestern	13.1
North Pacific	9.0
North Atlantic	6.2
South Pacific	5.5
North Central	2.8
Missouri River	1.6
Ohio River	.9
New England	.3
Pacific Ocean	.1

Lending itself more to analysis is Table 7 which shows by waterway segment, the (a) average cost per mile of dredging, (b) average dredging volume per mile and (c) the average cost per cubic yard of dredging. While the Lower Mississippi River from New Orleans to the Gulf requires by far the most dredging, 16% by volume, on a unit cost it is one of the least expensive. Further scrutiny shows that the most expensive dredging projects are, logically, those requiring confined disposal.

The National Waterways Study is concerned with the role that dredging plays in the development and maintenance of the waterway system. Over the past 30 years waterborne commerce has risen 175% and current projections to the year 2000 for unconstrained waterways are 2.4 billion tons. These projections will be hard to realize if constraints are not eliminated and parts of the system improved. Dredging will play an integral part in the development and maintenance of the nation's waterways.

With shrinking resources allocated to the waterway system, the system will have to be approached as a whole. Data above will have to be considered along with data on commerce to help plan for future maintenance or development. The National Waterways Study is presently addressing this problem.

TABLE 7

Summary of Dredging by Analytical Segment

Reporting Region	Segment Name	Ave. Annual Vol. Latest 3-5 yrs.(1) CY X 10^2	Ave. Annual Cost Latest 3-5 yrs. $ X 10^3	Ave. Cost $/Cu. Yd.	Length of Seg.-ment (1) Miles	Ave. Cost Mile	Ave. Vol Per Mile Cubic	Type of Waterway	Types Dredging	Types Disposal	Dredging COE	Equipment Private
1	Up. Miss. River	27291	2737	1.00	673	4067	4055	C	C,D,T	B,C,O,Z	2T,2T	1D
2	Lower Up. Miss R.	0	0	-	22.6	0	0	C	-	-	-	-
2	Mid. Miss. River	60386	3163	0.52	267	11846	22616	FEC	T,U	C,O	IT, IU	16D,1B
3	Lower Mid. Miss. R.	220000	5790	0.26	356	16264	61798	F	T,U	O	3U	3D
3	Upper L. Miss. River	109211	2534	0.23	426	5948	25636	F	U	O	IU,1T	TD
3	L. Miss. Old R.-B.R.	14805	889	0.60	69	12884	21457	F	T,U	O	-	-
4	Miss. R.B.R. To N.O.	58446	1999	0.34	127	15740	46070	S	C,E	O	-	19D,1B
4	Miss. R.-N.O.-Gulf	475897	20608	0.43	202	102020	235593	S	H,T,U,Z	A,C.O,P	1H	26D,10B
5	Illinois W/W	25124	1711	0.68	349	4903	7199	CECA	T,Z	O,Z	1T	3D
6	Missouri River	48484	4017	083	621	6469	7807	F	U	O	1T,1U	
7	Upper Ohio River	1908	488	2.56	359	1359	531	C	C,T	C,Z		3D,2B
7	Mid. Ohio River	7275	862	1.18	288	2993	2433	C	C,T	O,Z	-	-
7	L. Ohio River III	4666	396	0.85	238	1664	1961	C	T	O	-	3D
7	L. Ohio River II	9660	1090	1.13	151	7218	6397	C	T	O	-	1D
7	L. Ohio River I	20	2	1.00	46	43	43	C	T	O	-	-
7	Monongahela R.	710	211	2.97	129	1636	500	C	C	C	-	-
7	Allegheny R.	100	111	2.78	72	1541	568	C	C	C	-	-

(1) Source: Inventory of Waterway Physical Charactcteristics
(2) 1978 Costs

Summary of Dredging By Analytical Segment (con't)

Reporting Region	Segment Name	Ave. Annual Vo. Latest 3-5 yrs. (1) CY X 10^2	Ave. Annual Cost Latest 3-5 yrs. \$ X 10^3 (2)	Ave. Cost \$/Cu.Yd.	Length of Seg.-ment (1) Miles	Ave. Cost Mile	Ave. Vol. Per Mile Cubic	Type of Waterway	Types Dredging	Types Disposal	Dredging COE	Equipment Private
7	Kanawha R.	110			91	2198	121	C	C,T	Z		
7	Kentucky R.	1100	119	1.08	255	467	431	C	C	O		
7	Green R	750	97	1.29	212	458	354	C	C	O		
7	Cumberland R.	892	181	2.03	381	475	234	C	C,T	O,C		2D
8	U.Tenn & Clinch Rivers	0	0	-	499	0	0	C	-	-		
8	L. Tenn. R.-Ohio River	300	52	1.73	215	242	140	C	-	10		
9	Ark. Verd. Wht. & Blk. Rivers	32942	2420	0.78	701	3442	4686	C,F	T	B,C		
9	Quachita-Blk & Red Red	24493	1271	0.50	566	2246	4328	C,F	T	C,O		
9	Old & Afch.	52219	1410	0.27	168	8392	31081	C	T,Z	C,O,Z		
9	B. Rge. Morg City By-pass	6350	295	0.46	64	4909	9922	C	T	C,O		
10	GIWW-West I & Tribs	41567	2914	0.70	489	5959	8500	I,S	C,H,T	C,O,P,Z		4D,2B
10	GIWW W. II & Tribs	48131	13497	0.31	698	19337	61623	I,S	H,T	C,O,P,Z		
10	GIWW W. III & Tribs	50575	5390	1.07	260	20731	19452	I,S	H,T,Z	C,O,P,Z		5D
10	Houston Ship Canal	87460	4679	0.53	175	26731	49977	C	H,T,Z	C,O,P,Z,	1H	10D,6B
11	GIWW E I & Tribs	45078	2381	0.50	539	4417	8474	I,C,S	H,T	C,O	2T	21D,1B
11	GIWW E II	17304	1300	0.75	467	2784	3705	I,C,	H,T,Z,	C,O,Z		1D
11	Florida Gulf Coast	16580	3358	2.03	017	5487	2700	I,C,S	H,P,Z	C,O,Z		17D

(1) Source: Inventory of Waterway Physical Characteristics
(2) 1978 Costs

Summary of Dredging by Analytical Segment (con't.)

Reporting Region	Segment Name	Ave. Annual Vol. Latest 3-5 yrs.(1) CY X 10^2	Ave. Annual Cost Latest 3-5 yrs. $ X 10^3(2)	Ave. Cost $/Cu.Yd.	Length of Seg.-ment (1) Miles	Ave. Cost Mile	Ave.Vol. Per Mile Cubic	Type of Waterway	Types Dredging	Types Disposal	Dredging Equipment COE	Dredging Equipment Private
12	Blk. Warrior & Tomb.	63843	3289	0.52	452	7277	14125	C	H,T,Z	B,C,U,Z	-	-
12	Ala. Coosa River	16344	631	0.39	798	791	2048	C	T	O	-	-
12	Tenn. Tom W/W	-	-	-	314	-	-	C	-	-	-	-
11	Apal. Chat. Flint	17015	1276	0.75	283	4509	6012	C	T	C,O	-	-
13	Fla. Ga. Coast	119795	9814	0.82	1956	5017	6124	I,E,F	H,T,Z	B,C,P,Z	2H	25D,2B
13	Carolina Coast	167628	15746	0.94	1434	10987	11690	I,C,E,F	H,S,T,Z	B,C,M,O,P,Z	25ISP	16D,5B
14	Chesap. & Del Bays	58937	11894	2.02	1437	8277	4101	I,S,E,F	C,H,O,R,S, T,Z	B,C,M,O,P,Z	3H,IS	33D,15B
14	N.Y. N.J. Coast	57689	11892	2.06	778	15285	7415	I,S,E,F	C,H,O,S,Z	B,O,P,Z	-	19D,6B
16	N.Y. State W	12291	15530	8.09	781	18885	2170	C,A	C,H,T,Z	C,P,Z	-	1D
15	U. Atlantic	8221	2507	3.05	-	-	-	S,D,F	C,H,S,T,Z	B,C,O,P,Z	-	11D,14B
16	L. Ont. St. Lawr.Sea.	4263	515	1.21	-	-	-	L,E,S	C,H	O,Z	-	1D,2B
16	L. Erie	42921	5902	1.38	-	-	-	L,E,S	C,H	C,O,Z,	3H	6D,10B
16	L. Huron	7164	5431	7.58	-	-	-	L,E,S	C,H,I,T,Z	B,C,O,Z	1H	16D,21B
16	L. Michigan	13443	2778	2.07	-	-	-	L,D,S	C,H,T,Z	B,C,O,Z	-	2D,27B
16	L. Superior	2308	556	2.41	-	-	-	L	C,H,I,Z	C,Z	-	7D,3B
17	Puget Sound	6040	755	1.25	-	-	-	-	C,P	C,O	-	3D,7B
18	U. Col-Snake W/W	0	0	-	315	0	0	0	-	-	-	7D,1B

(1) Source: Inventory of Waterway Physical Characteristics
(2) 1978 Costs

Summary of Dredging by Analytical Segment (con't)

Reporting Region	Segment Name	Ave. Annual Vol. Latest 3-5 yrs.(1) CY X 10^2	Ave. Annual Cost Latest 3-5 yrs. \$ X 10^3(2)	Ave. Cost \$/Cu.Yd.	Length of Seg.-ment(1) Miles	Ave. Cost Mile	Ave. Vol. Per Mile Cubic	Type of Waterway	Types Dredging	Types Disposal	Dredging COE	Equipment Private
18	L. Col.-Snake W/W	199915	7548	0.38	150	50320	133270	P,L,E,S	D,H,P	B,O,P	3H,1T	7D,1B
18	Oregon Wash. Coast	61902	4978	0.81	167	29800	37007	F,S	C,D,H,T,Z	B,O,P	-	4D,1B
19	Northern Calif.	4789	600	1.26	2	300000	237400	-	C,H,Z	C,P,Z	-	-
19	San Fco. Bay Area	59439	96856	16.30	559	173266	106331	S	C,H,T,Z	C,O,P,Z	-	3D,3R
19	Central S. Calif.	101063	18362	1.82	-	-	-	-	T,Z	B,O,P	-	3D,3B
20	S.E. Alaska	0	0	0	0	0	0	-	C	C	-	1D,2B
20	S. Central Alsk. Coast	825	247	2.99	-	-	-	-	C	O	2T	-
20	W & N. Coast of Alask.	110	50	4.55	-	-	-	-	C	C	-	-
21	W. Pacific Incl. H.I Guam Latin Am.	1518	206	1.36	-	-	-	-	C,D,H,P	C,P	-	1B
22	Carribean Incl. P.R.	2050	289	1.41	-	-	-	-	C,H	O	-	5D,2B
Totals		2909108	303817	1.04	-	-	-	-	-	-	-	-
	U. Miss-St. Paul Dist.	5682	1522	2.68	278	5475	2044	C	O,T	B,C,O,Z	2T,1I	1D
	U. Miss-Rock Is. Dist.	6203	2143	0.68	318	2147	2143	C	T,D	B,O,Z	-	-
	U. Miss-St. Louis Dist.	14355	17506	0.52	82	9085	17500	C	T	O	-	-

(1) Source: Inventory of Waterway Physical Characteristics
(2) 1978 Costs

TABLE 7 (cont'd)

Summary of Dredging by Analytical Segment

KEY

Type of Dredging or Dredge (COE)

D - Dragline
I - Dipper
L - Ladder
U - Dustpan
C - Clamshell
O - Orange Peel
H - Hopper
P - Plain Suction
T - Cutterhead
S - Side Casting
Z - Other

Type of Disposal

A - Agitation
B - Beach Nourishment
C - Confined
M - Marsh
O - Open Water
P - Ocean
Z - Other

Type of Dredge (Private)

D - Dredge
B - Barge

Type of Waterway

C - Channelized
F - Free Flowing River
S - Seaway (Doep Draft)
CA - Canal
I - Intracoastal Waterway
L - Lake

HIGH SPEED HYDROGRAPHIC SURVEYING

by

Adam Heineman[1] and Jack Bechly[2]

Abstract

Increasing budget limitations, rising fuel costs, environmental concerns for wetlands, together with continually changing shoaling patterns are some of the motivating parameters toward the goal of increasing the coverage and frequency of hydrogrpahic surveys. The Portland District, U.S. Army Corps of Engineers, has in recent years procured electronic and floating plant equipment that is within the present "state of the art," so that goals can be realized within the mission assignment of their river and harbor channel maintenance program.

Introduction

As shown on Figure 1, Portland District encompasses most of the State of Oregon and that part of the State of Washington which includes the drainage of the Lower Columbia River. Portland District, Navigation Division, is responsible for maintenance of over 700 river miles of Federal navigation project channels. These miles represent a large variety of navigation projects ranging from entrance channels for small boat basins to the large vessel channels, such as the Columbia River 40' x 600' channel which is coupled with an entrance bar of forty-eight feet by one-half mile. To meet the needs for producing adequate information for channel users and for monitoring our dredging operations, "state of the art" equipment improvements to enhance the efficiency of producing surveys has been underway for several years.

[1]Chief, Navigation Division, Portland District, U.S. Army Corps of Engineers.

[2]Chief, Waterways Maintenance Branch, Navigation Division, Portland District, U.S. Army Corps of Engineers.

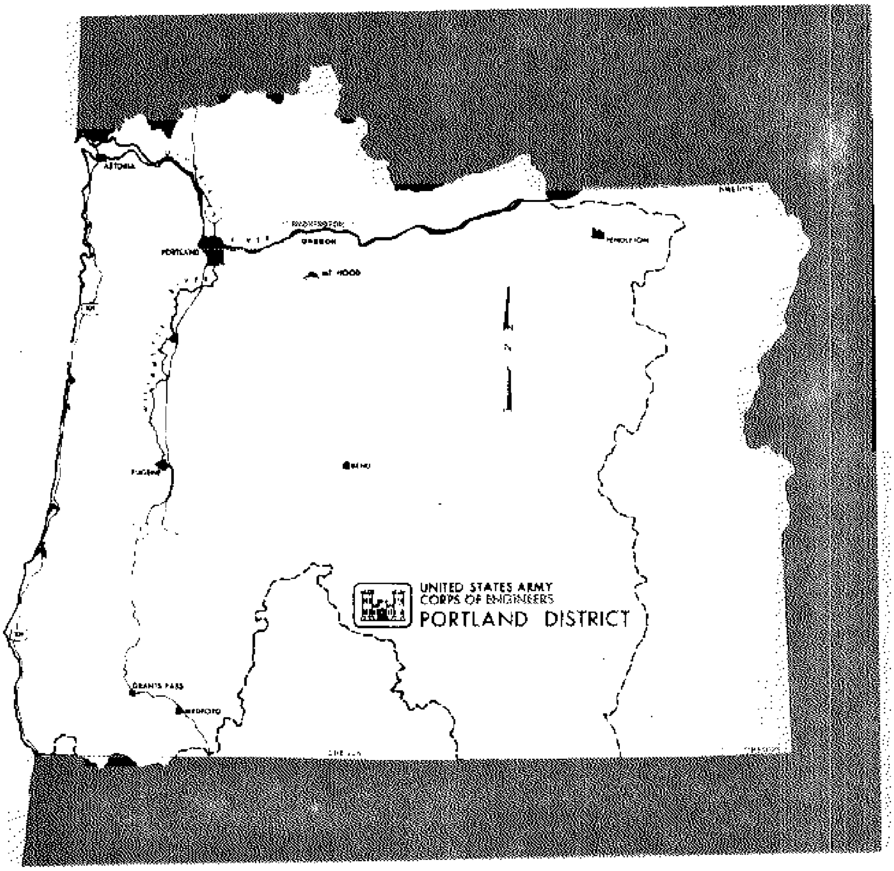

Figure 1. District Map

Hydro-Survey Needs

Emphasis on minimizing expenditures for all Federal civil works programs and maximizing the efficiencies of our operations has resulted in increased significance of our hydro-survey activities. To insure that only the most critical shoals are scheduled for maintenance, surveys must necessarily be increased in scope and frequency to provide planning personnel with timely and accurate information.

Environmental concerns in recent years have also modified the direction of our disposal operations in many aspects and have again placed increasing loads on our hydrographic survey staff. Additional information needed to increase inwater disposal operations, and thus reduce impacts to the environment by avoiding filling wetlands bordering our tidal areas is needed by many interests. Rapidly accelerating fuel costs for dredging plant have also impacted to a general extent the increased importance of expanding hydrographic surveying efforts.

As the surveying increases, consideration must be given to measures which will improve our daily survey miles produced and fuel efficiencies for the large number of surveying vessels in operation. Increased hydrographic needs in many cases also means increased use of our vessels near marine structures and equipment such as marinas, boat house moorages, public beaches, etc. Minimizing the wake and wave actions while maintaining the maximum speed possible becomes increasingly important.

Because of the number of river miles the Portland District is required to monitor, in most cases several times a year, we have long utilized a survey method whereby most sounding lines are run parallel with the channel direction. This method permits our displacement hull survey vessels to operate at full speed for more than half of the survey miles required. General categories of hydrographic surveying in Portland District are: 1. Condition surveys, which are run for large sections of each project on a frequent basis depending on shoaling patterns (parallel lines). 2. Cross line surveys are run on a less frequent basis from bank to bank, including those areas outside the limits of the Federal projects, to provide information on adjacent shoals and shoaling patterns together with information required for location of "flowlane" or other types of inwater disposal sites. 3. Pre- and post-dredge surveys, which are run similar to condition surveys but only for selected reaches, provide extra lines both within and outside the channel limits to enable accurate computation of yardage quantities.

For condition surveys, normally a "five line" type of survey is utilized. That is, lines are run along the channel centerline, along the channel quarterlines, and along the channel sidecut lines to provide a quick reference for the location of shoaling areas for our Navigation Division planning staff and channel users. Pre- and post-dredge surveys are run in a similar manner with additional survey lines provided in- and out-side the channel for those areas that are planned to be dredged or have been maintained. Examples of the three types of surveys are shown in Figures 2, 3, and 4.

Our Present Approach

Portland District currently operates six hydrographic survey crews. Those crews range from a field crew which primarily establishes and maintains shore-based control points throughout the District's project areas, to the remaining five crews which conduct hydrographic surveys at varying locations. One crew is based in Salem, Oregon, south of Portland. This crew travels throughout the entire District conducting the smaller scope surveys such as marine entrance channels, etc. There are two crews with trailerized 26'

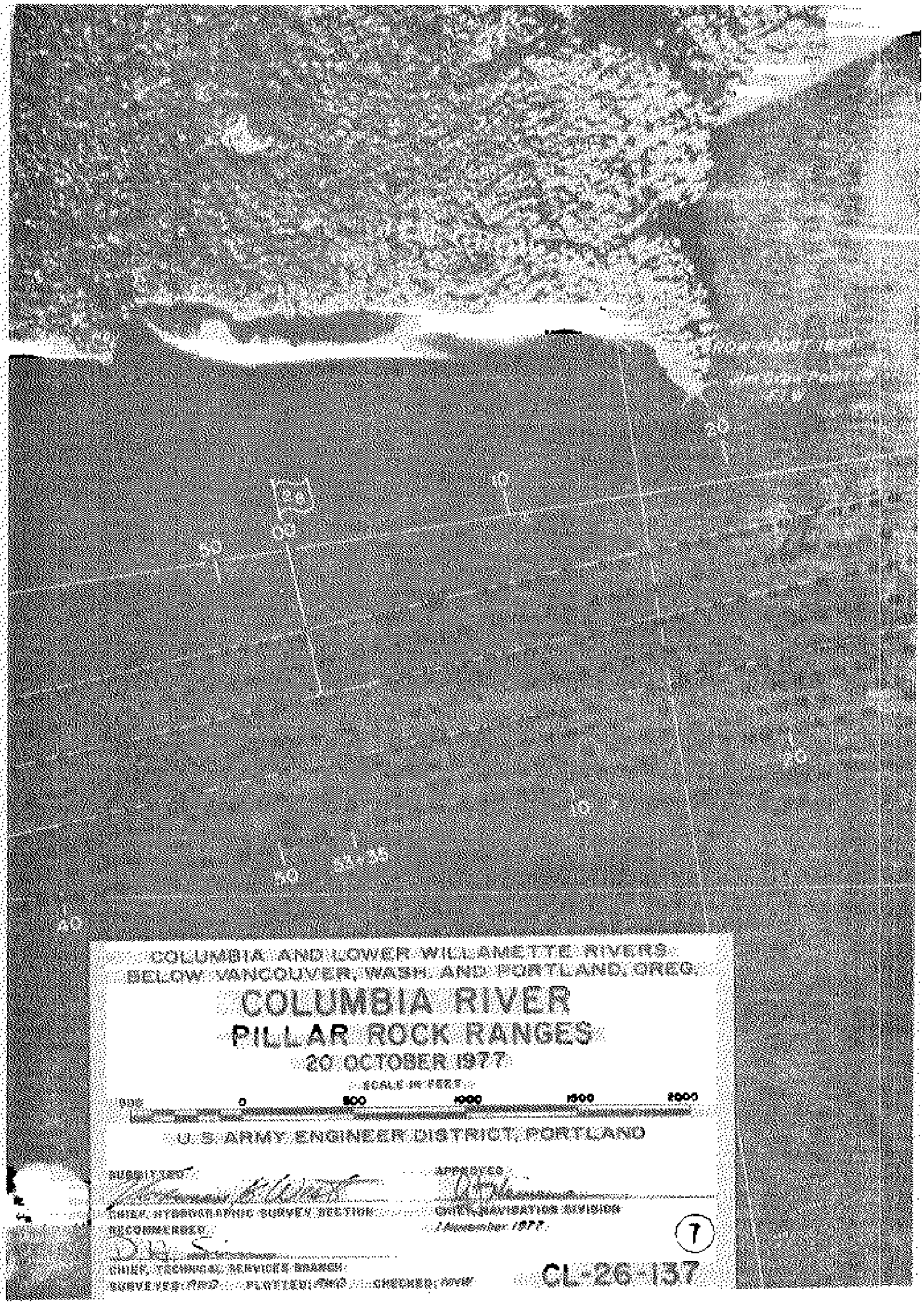

Figure 2. Condition

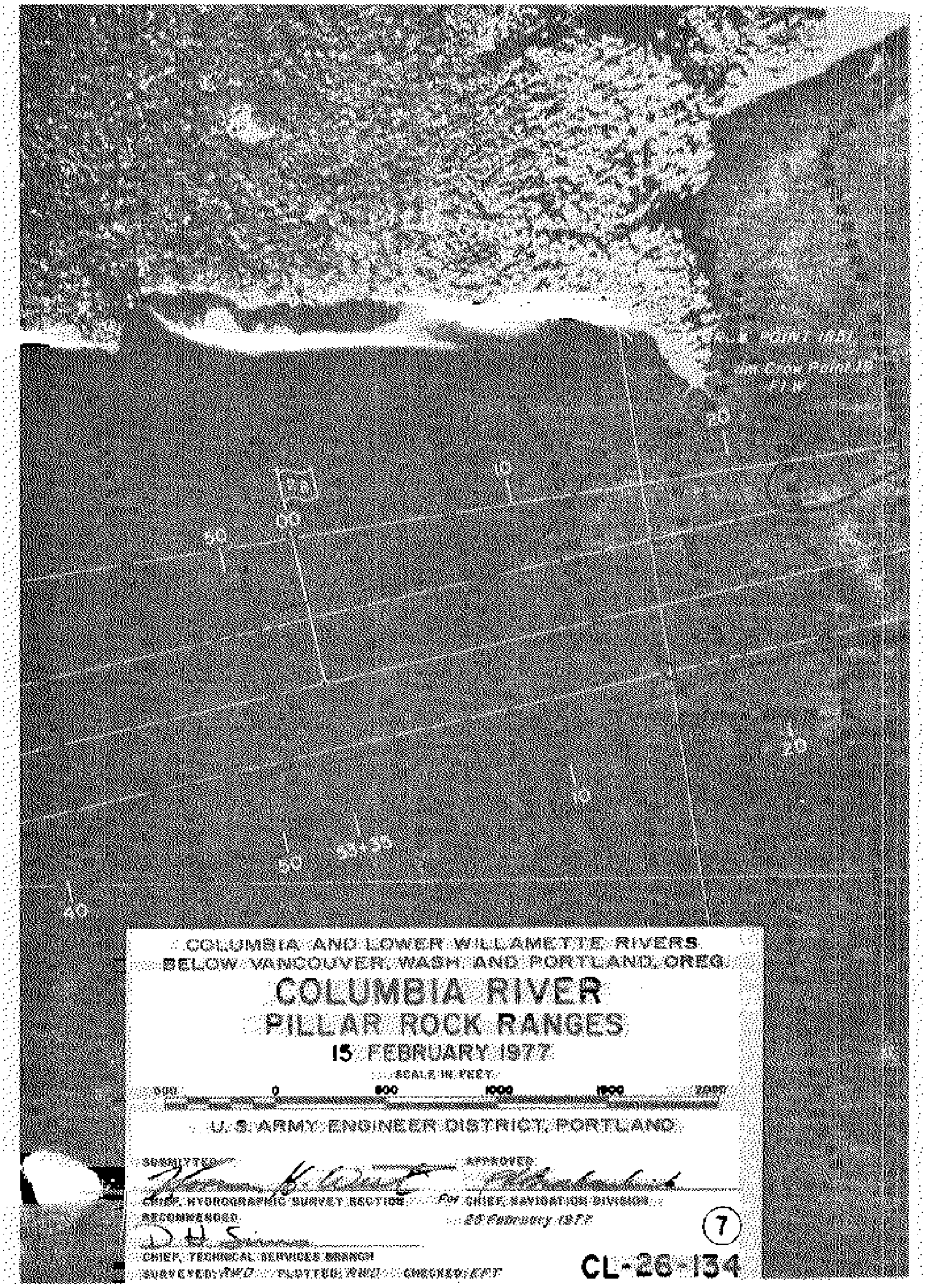

Figure 3. Crossline

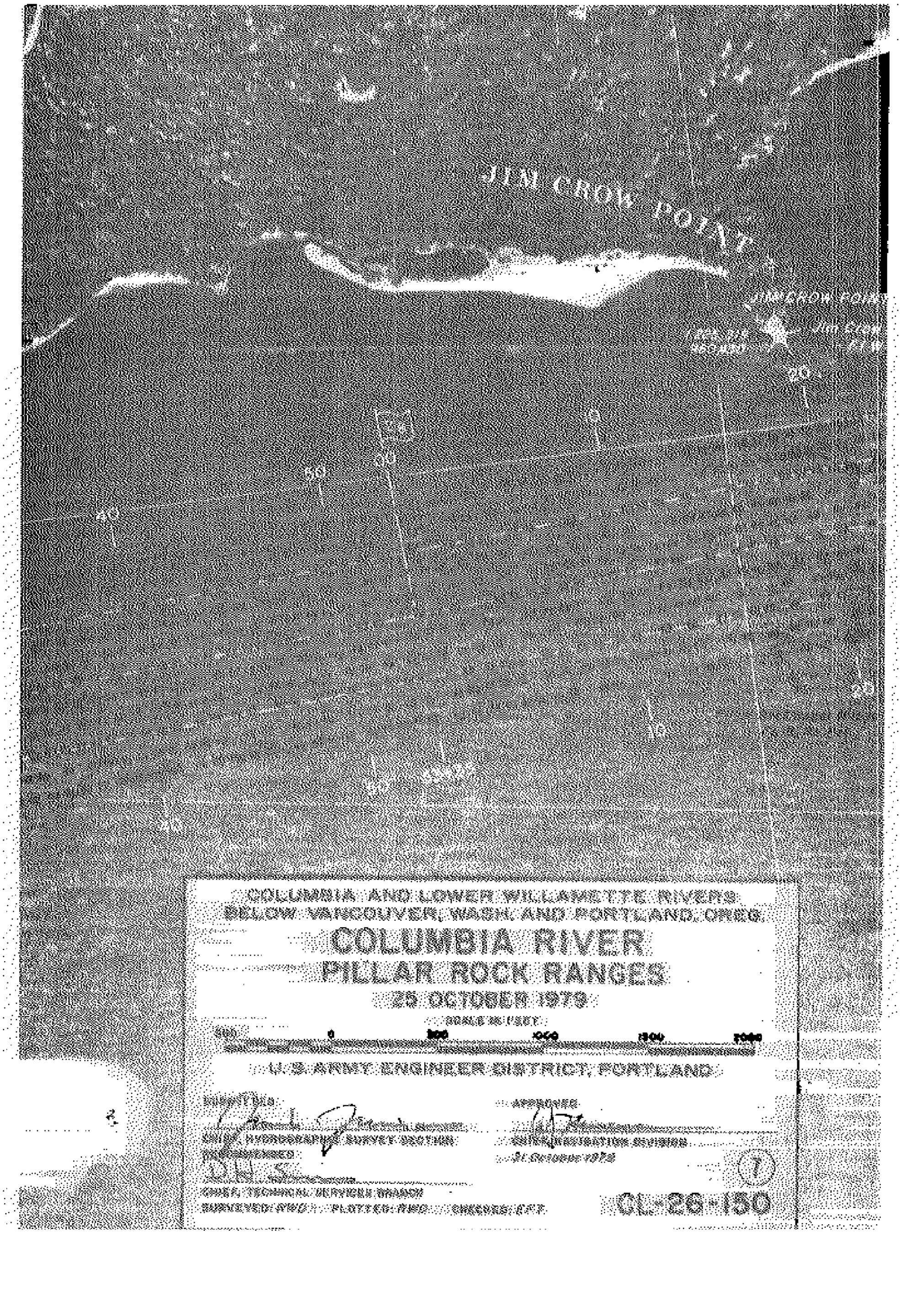

Figure 4. Post Dredge

boats that work on the next level of small and shallow projects and there are two large boat crews, one of which operates the 65-foot HICKSON and the other, the recently delivered 48-foot, high-speed survey boat RODOLF (Surface Effect Vessel).

The integrated electronics age for the Portland District began in the early 1970's with the purchase of one of the first of the original versions of the DECCA AURO-CARTA systems. Since that time the small survey vessels have been equipped with electronic positioning components and the HICKSON and RODOLF with updated and expanded versions of the most recent AUTO-CARTA systems. Some of the features in these later integrated systems are unique and exist only in the HICKSON and RODOLF equipment. The RODOLF is considered the final item of hardware required to develop the most efficient and economical survey system available.

Columbia and Lower Willamette (C&LW) Project and the RODOLF

The Columbia and Lower Willamette Rivers project consists of a 40' deep by 600' wide deep-draft navigation channel that covers 104 miles of the Columbia River from its mouth to Vancouver, Washington and eight miles up the Willamette River to the Portland Harbor. There are about twenty-six areas in the 104-mile C&LW project that experience periodic shoaling. Some of the shoals require maintenance annually while others only have to be dredged every three or four years. Maintenance dredging in recent years on this project has required removal of about 5,000,000 cubic yards of material. This quantity, coupled with the approximate 4,500,000 to 5,000,000 yards removed from the mouth of the Columbia River entrance bar, comprise about 30% of the total channel maintenance dredging quantities for the Portland District.

Maintenance of the C&LW project is accomplished using Corps of Engineers hopper dredges HARDING and BIDDLE, the 30" pipeline dredge OREGON owned by the Port of Portland, and by contractor-owned pipeline dredges. Generally, hopper dredges are utilized to maintain the entrance bar, lower estuary bars and "spot" shoals. Dredging of the shoals in the lower estuary is performed when weather conditions preclude work on the entrance bar. Pipeline dredge plant is used to maintain those shoals that are more substantial in nature.

Efficient maintenance of the Columbia River project requires frequent hydrographic surveys of all three types to ensure timely shoal removal, removal of the minimum amount of material necessary to provide a clear project, enough "pictures" of the river bottom area to provide insight into traditional shoaling patterns and information for the Corps. This is done in order to select a number of inwater or "flowlane" disposal areas necessary to supplement land disposal operations with the assistance of concerned environmental agencies. In the early 1970's, it was apparent that improvements in both the electronics data acquisition and vessel performance would have to be accomplished to cope with continuing manpower and budget restrictions. Planning began in 1975 to research the current "state of the art" for both surveying systems and surveying platforms. Current versions of the Decca Auto-Carta systems aboard the HICKSON and aboard the RODOLF were procured in late 1976 and in 1979. Efforts at that time were initiated for the acquisition of an aircushion-assisted catamaran survey vessel to provide the speed and wake characteristics desired to increase our hydrographic surveying capabilities. The system acquired for the planned high-speed survey vessel was placed aboard our 52-foot NORMAN BRAY in 1979. The BRAY was recently placed in a standby status after delivery of the survey boat RODOLF. The remainder of this paper describes the electronics utilized for the RODOLF, the capabilities of the RODOLF itself, and the outputs realized from the successful mating of system and vessel.

Electronics

Survey charts normally utilized for the Columbia River channel are at a scale of 1:5,000. Charts have a standard sheet size of 28 x 54 inches in length. Therefore, approximately 32 charts are utilized to cover the Federal navigation channel from the mouth of the Columbia River to the Portland and Vancouver harbor areas. A Lambert projection and coordinate system is utilized. A general view of the system as previously mounted in the vessel NORMAN BRAY is shown in Figure 5. Components for the data acquisition system are discussed in the following subparagraphs.

1. Positioning. Electronic positioning is provided by a Del Norte Trisponder Model 202A. It provides a one second update on position based on a 100 sum of average interrogations from each of several shore remote trisponders. It can be utilized on a time-sharing mode with another base unit on another vessel.

2. Depth Sounder. A Ross Fineline Model 200 provides ten digitized soundings per second together with an analog trace. This depth sounder also writes a preselected number series of fix marks on the analog trace during the data acquisition process. The numbering system on the fix marks matches the fix mark numbering system utilized on the track plotter.

3. Plotter. A Houston Instrument model DP-3 plotter with a twenty-two inch wide movable feed fixed bed provides on-board survey plots.

4. Keyboard Printer. A Digital Equipment Corporation model LA-36 keyboard printer is provided for operator control of program routines to be discussed later and provide for operator input of time, location of shore remotes, and other parameters required to initiate and continue with data acquisition process.

5. Keyboard Display. A keyboard/digital display unit, providing for secondary access of programmed routines and to provide

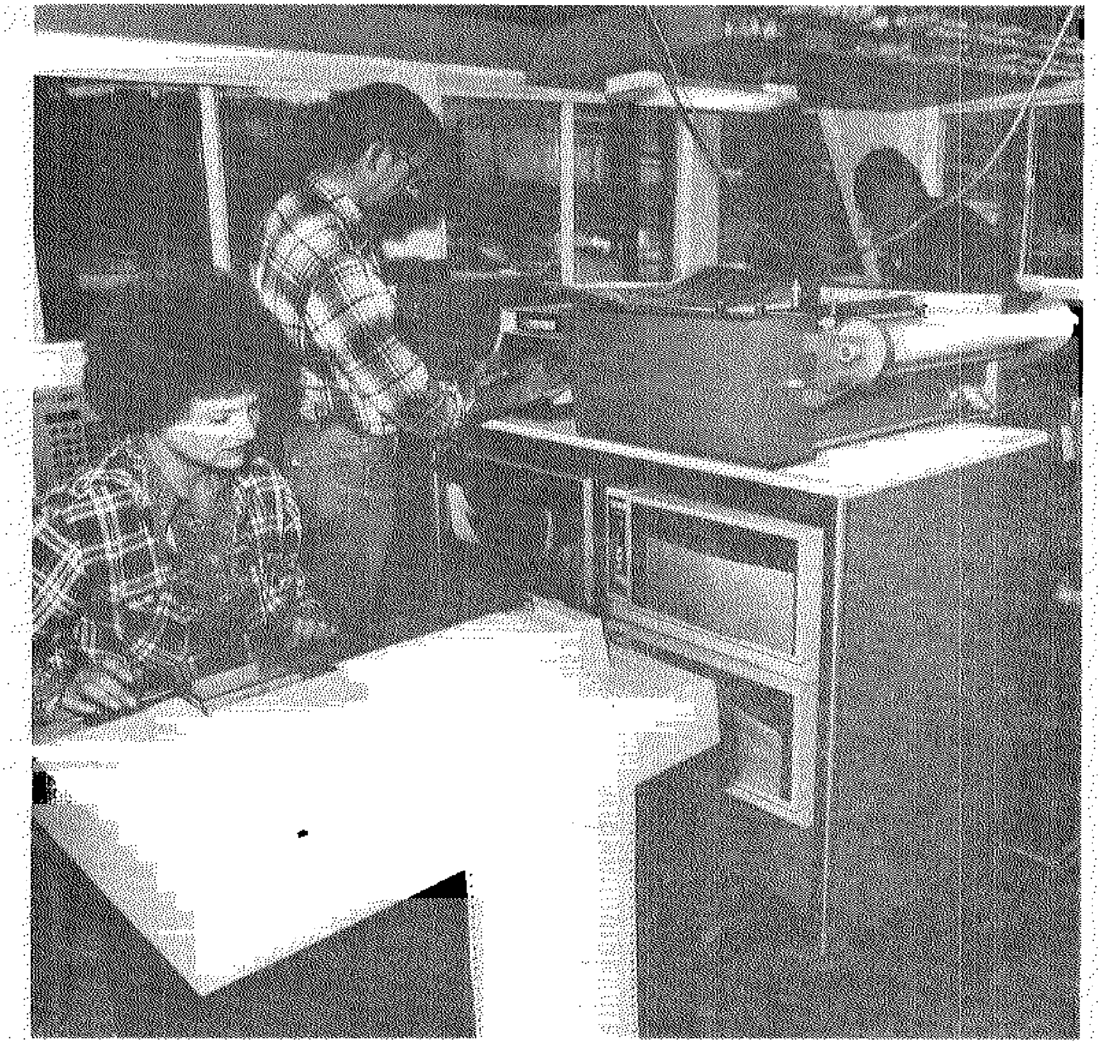

Figure 5. Integrated Hydrosurvey System

register call-ups, is included with the system. The keyboard display is a Digital Equipment Corporation RT model 02.

6. Left/right Console. Two identical left/right consoles are utilized. One is for the boat operator and one for the survey system operator. Each console has needle indication of left/right distances from a preselected course in units of feet on a scale graduated from 0-90 feet in both directions. It has a switch to enable the operator to switch the scale to a multiple of ten with an indicator light to show the latter mode when the 90-foot scale is exceeded. The console also displays the on-course speed of knots updated at least every two seconds and provides a digital display of the various register call-ups demanded by the survey system operator. These call-ups include, but are not limited to, distance from the end of the course, distance form the beginning of the course, etc. A switch is provided on the left/right console to manually change needle orientation if required when survey courses are run in both directions in series. Figure 6 illustrates the left/right console.

7. Tape Units. Two magnetic tape drives and the paper tape drive are included with the system. Magnetic tape drives are utilized to input data acquisition and data editing routines and to provide the output tape to be sent to the District office for production of the survey charts. Paper tape drive is utilized to input parameters for each particular survey chart such as chart orientation, chart skew, location of point of beginning, channel limits, etc. that are peculiar and preprogrammed for each area to be surveyed.

8. Hand-held control unit. A hand held control unit is also provided to facilitate the final chart-editing process. This unit can be seen resting on the left/right console in Figure 6.

9. Central Processing Unit. All of the above-mentioned hardware components are interfaced into a Digital Equipment Corporation PDP 11-34 computer to complete the survey system electronics.

Generally the system utilized a "two-pass" technique. Data accumulation and track plotting are accomplished in an on-line mode, and data outputs, including chart plotting, quantity computations, etc., are provided in the "off-line" mode. The system has two basic and separate capabilities. First, it can acquire data and output an edited sounding chart, as illustrated on Figures 2, 3, and 4. Secondly, when utilized in a cross-line type survey, the off-line routine can utilize the data acquired to plot cross-sections based on every digitized sounding (10 per second) and compute volumes and show them on the plotted cross-sections on an accumulated basis on board the vessel. An example of this is shown in Figure 7.

The system is currently utilized almost exclusively for data acquisition for hydrographic survey sounding plots. Data acquired during the on-line process is stored on tape and, at the end of the day's run, tide soundings are read into the computer

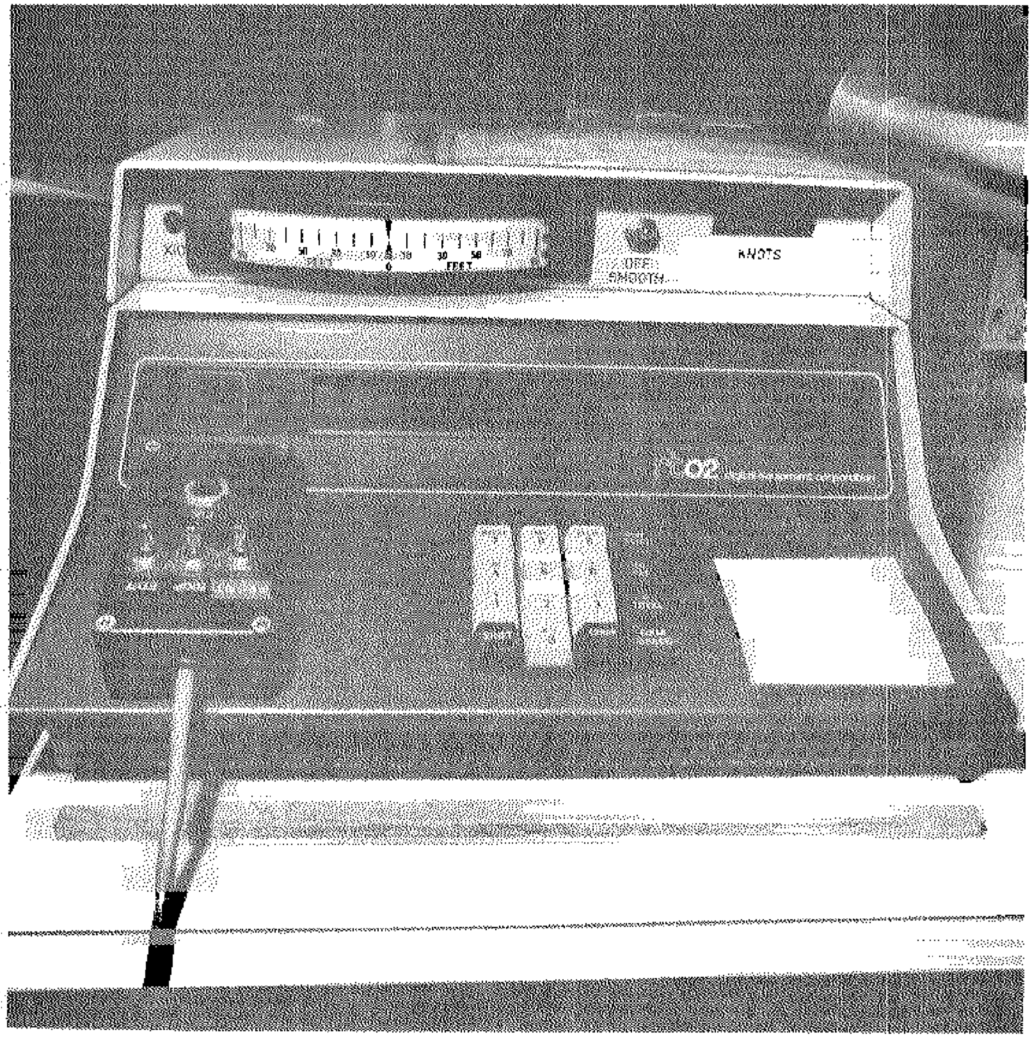

Figure 6. Right/Left Console

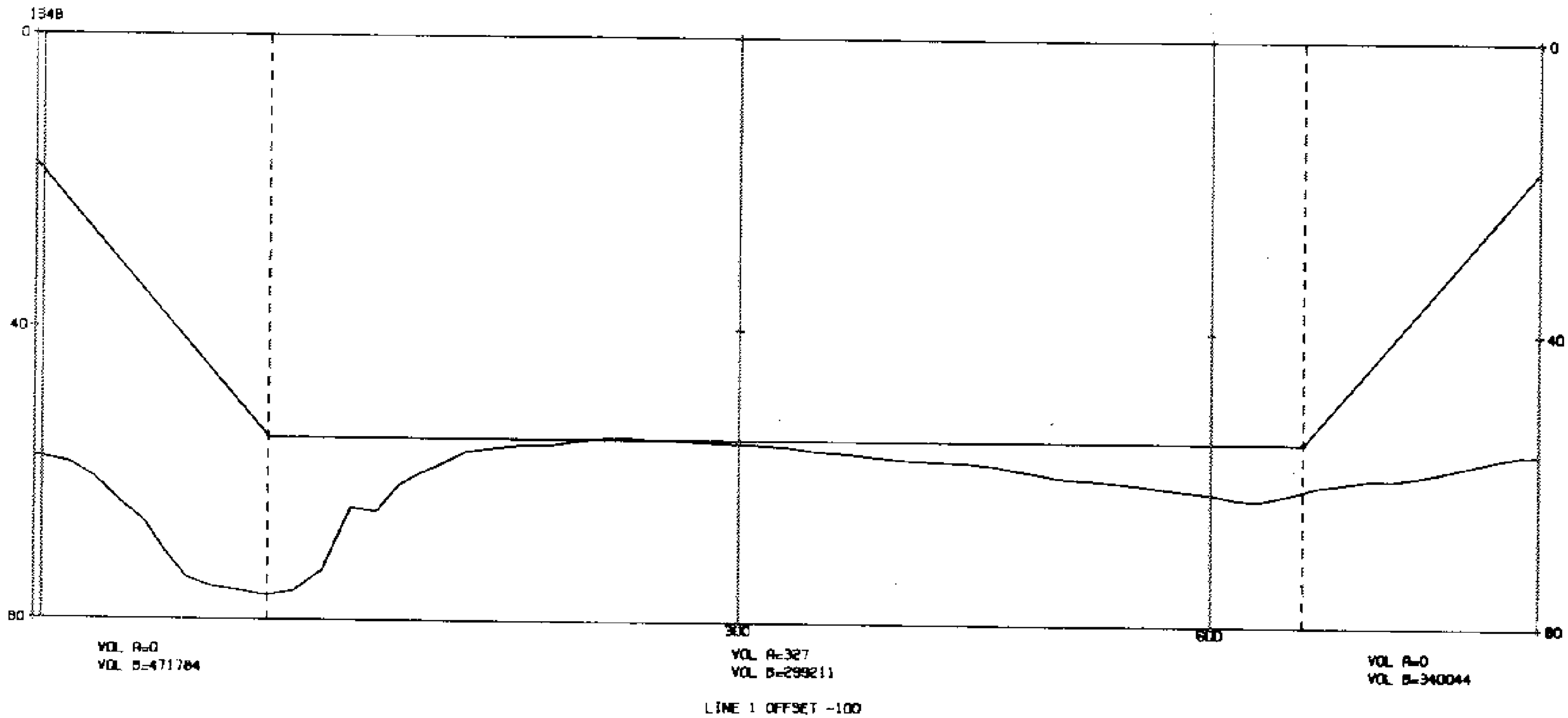

Figure 7. Volume Plot

and the off-line programming routine is inserted via magnetic tape to provide an edited sounding plot. During this last process, the surveyor on board scrutinizes the plot and reviews it for suspicious looking soundings. If some areas have been left blank due to momentary interruptions of the positioning system, the surveyor can interrupt the process and by examination of the analog trace, insert the soundings on an individual basis and/or delete erroneous soundings to provide for a final output tape to be sent to the District office.

Other features of the system to provide for uniform operation and for a complete and accurate sounding plot, include a smoothing routine on the right-left indicator by which the computer reviews the several previous distance measurements and applies a "proration" value to each so that the needle operates in a smooth and continuous manner without erratic movements that would be caused by utilizing only the one-second updates for each position.

For the digitized imputs form the fathometer, a routine is supplied that divides the digitized soundings in blocks of 1 to 20 seconds on 1 second intervals at the request of the surveyor. Normally we use blocks of from one to four seconds in length depending on the surface conditions of the water (swell lengths, etc.). These blocks are evaluated by the computer and then mean averaged to provide actual printed soundings closely and uniformly spaced. Sounding figures themselves are 7 millimeters in height. At the operator's selection, these soundings can be written on an orientation along the line or at right angles to the line being plotted. The system also includes a feature based on surveyor's selection to plot the mean depths where applicable but also to plot the least depths at the shoalest sounding in their correct location on the plotter output. In this case, the least depths take priority and adjacent soundings are displaced slightly to make room for the least depth shoal sounding in it actual position. This capability enables accurate location of the sand waves experienced routinely in the Columbia River project and enhances the ability for the reviewer in the District office to hand contour the sheets on an accurate basis and, also, insures more accurate quantity computation capabilities. An enlarged portion of a typical condition survey sheet showing the least depths plotted in their respective positions is shown in Figure 8.

During the on-line tract plot data acquisition process, the vessels's track is shown continuously on the track plotter. Numbered fix marks normally at approximately 2,5000-foot intervals are shown on both the plotter and analog trace, as previously mentioned. Our current method is to have these fix marks represent the time, in 4-digit numbers, for each of those preselected intervals. During the data acquisition process, the surveyor can use the keyboard register to call up various indicators, such as on-course distances, distances from the end of course, distance from the beginning of the course, distance to the right or left of the course, offset number or other information to facilitate both his and the vessel operator's performance during the data acquisition. These readouts, when left on register, are updated every 2 seconds

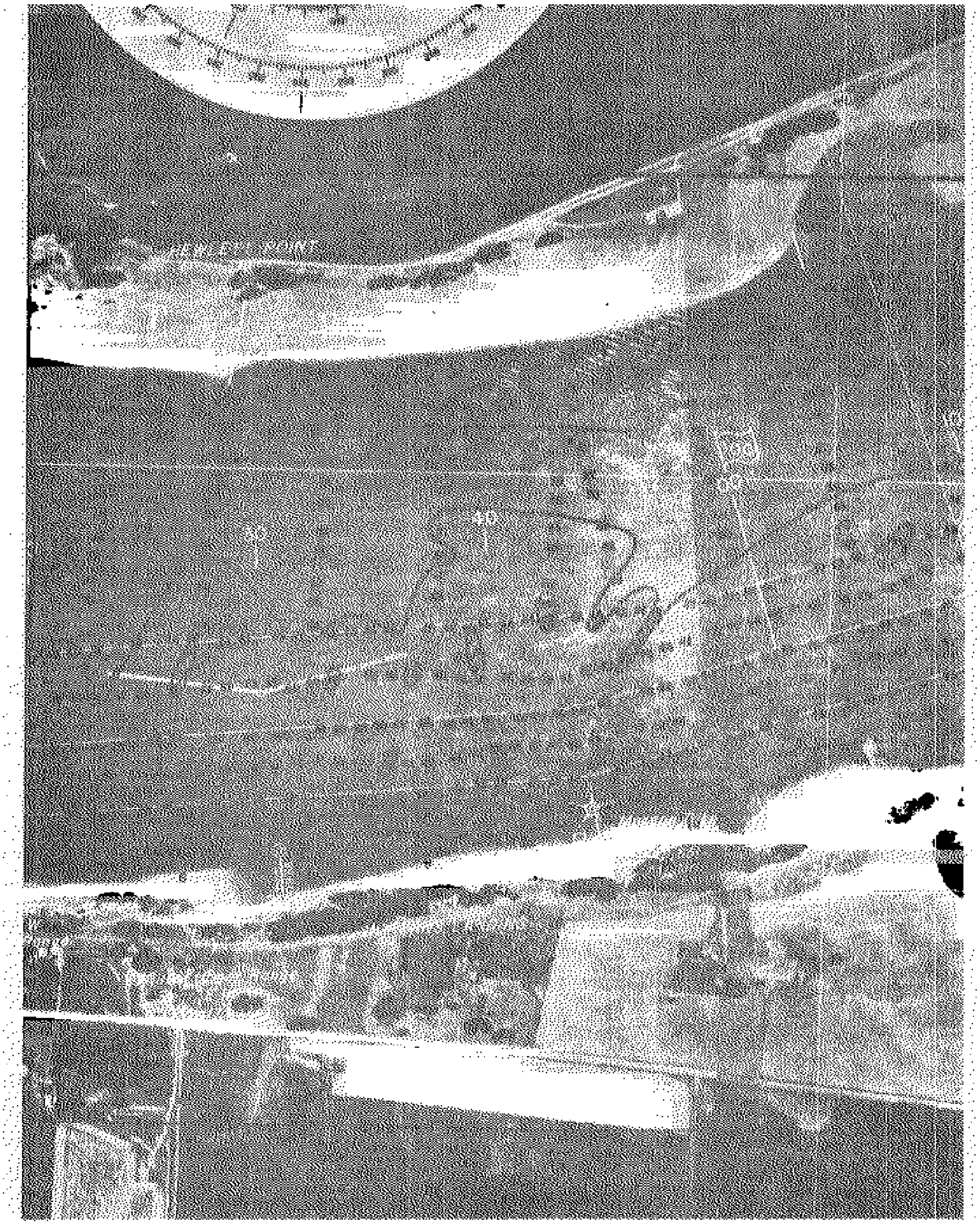

Figure 8. "Least" Depth Example

automatically until terminated or another register is called up. All of these readouts are produced by the system from a set of predetermined call-up numbers two digits in length. The sounding plot of the system has the capability to include tenths of foot as subscripts. These are normally not utilized in our Columbia River type surveys. Figure 9 is an example of a typical track plot (note fix marks) and Figure 10 is an example of a survey plot printed on the vessel.

10. Survey Vessel RODOLF. As mentioned previously, search for a "state of the art" high-speed vessel was begun in late 1975 to provide a platform to use the capabilities of the "state of the art" electronics. After analyzing various types of high-speed craft together with the desired requirements of the Columbia River project and also be capable of transit along the Oregon Coast, an air-cushion-assisted catamaran was selected as a type of vessel that would provide our optimum performance capabilities. A two-part procurement proposal was initiated, and through the results of the proposal process, Bell-Halter, Inc., of New Orleans, Louisiana, won the contract for providing the Portland District vessel. Bell-Halter is a joint venture of Bell Aerospace and Halter Marine Services Inc. The RODOLF is 48 feet in length, has a beam of 24 feet, and a maximum draft (off cushion) of 5 feet 10 inches. Clearance of the wet deck (off cushion) from the water surface is 1 foot. Clearance of the wet deck (on cushion) is 2.3 feet. The boat's displacement under full load is 55,000 pounds. The vessel has a continuous top speed of 35 miles an hour with a payload consisting of fuel for 6 hours operation at that speed, 7 persons, 50 percent water, all stores and electronic surveying system. The vessel has fuel tankage sufficient for a cruise at 25 miles per hour for 40 hours, without refueling, with the same crew and equipment loads. This fuel capability is to provide accomplishment of a normal week's data acquisition requirements without refueling. Off-cushion, the vessel has a continuous speed of 15 miles per hour with the same payload. Propulsion is provided by two 8V-92N Detroit Diesel marine engines, 350 shaft horsepower each. Propellers are 24-inch diameter, 4-bladed stainless steel protected by skegs. The lift fan engine is a 4-53N Detroit Diesel marine engine, 105 shaft horsepower. It has two Onan 7.5 kw auxiliary generators. Figure 11 shows the RODOLF under construction. Figure 12 is the vessel underway.

Special problems attendant with the use of the air-cushion-assisted vessel for hydrographic surveying, include determination of the location of transducers in the hull to provide for continuous data acquisition at speeds in excess of 25 miles an hour, and determination of the depth of the transducer below the water surface at varying speeds taking into account the impact of the captive air bubble between the hull of the vessel. Before the procurement for the vessel was initiated, tests of transducers located at several positions on a privately owned vessel with similar performance characteristics were accomplished. It was found that a transducer located nearly at midship provided continuous data acquisition in excess of 35 miles an hour. Preliminary tests with the RODOLF confirm this performance. Transducers

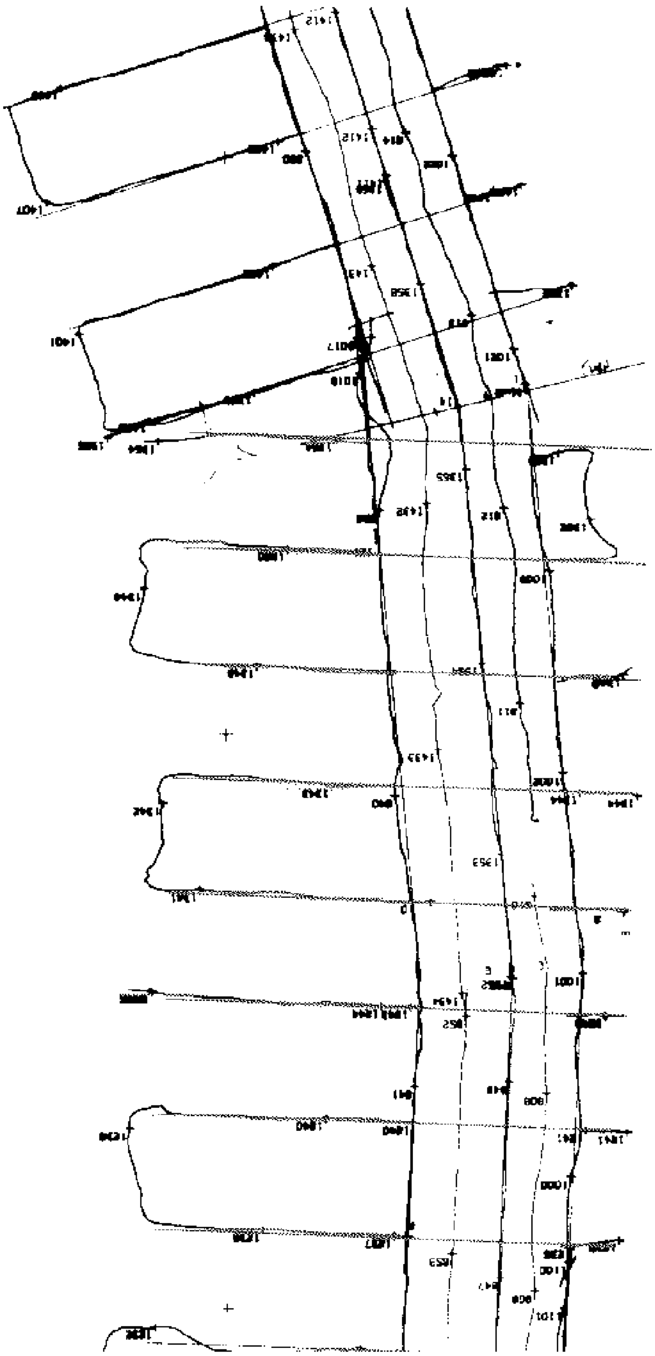

Figure 9. Track Plot

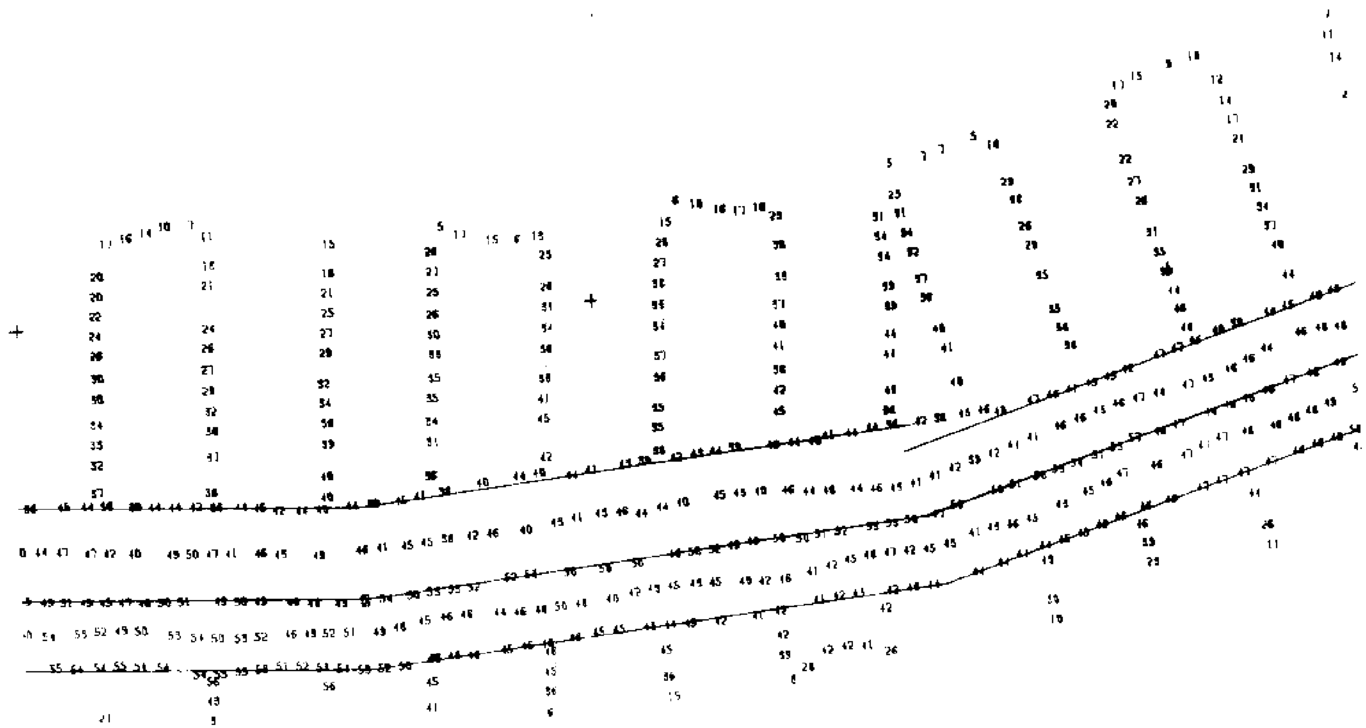

Figure 10. Sounding Plot

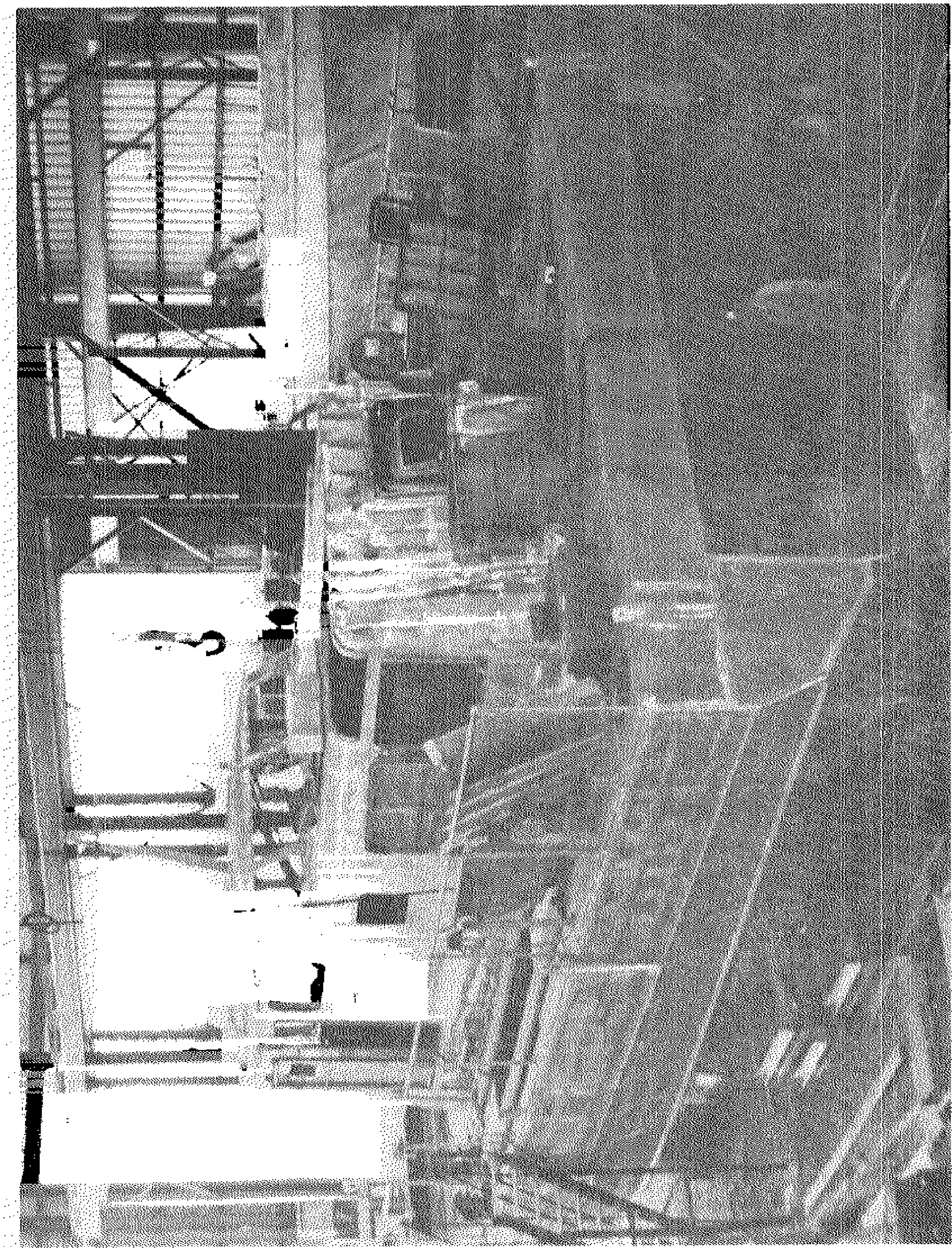

Figure 11. RODOLF Under Construction

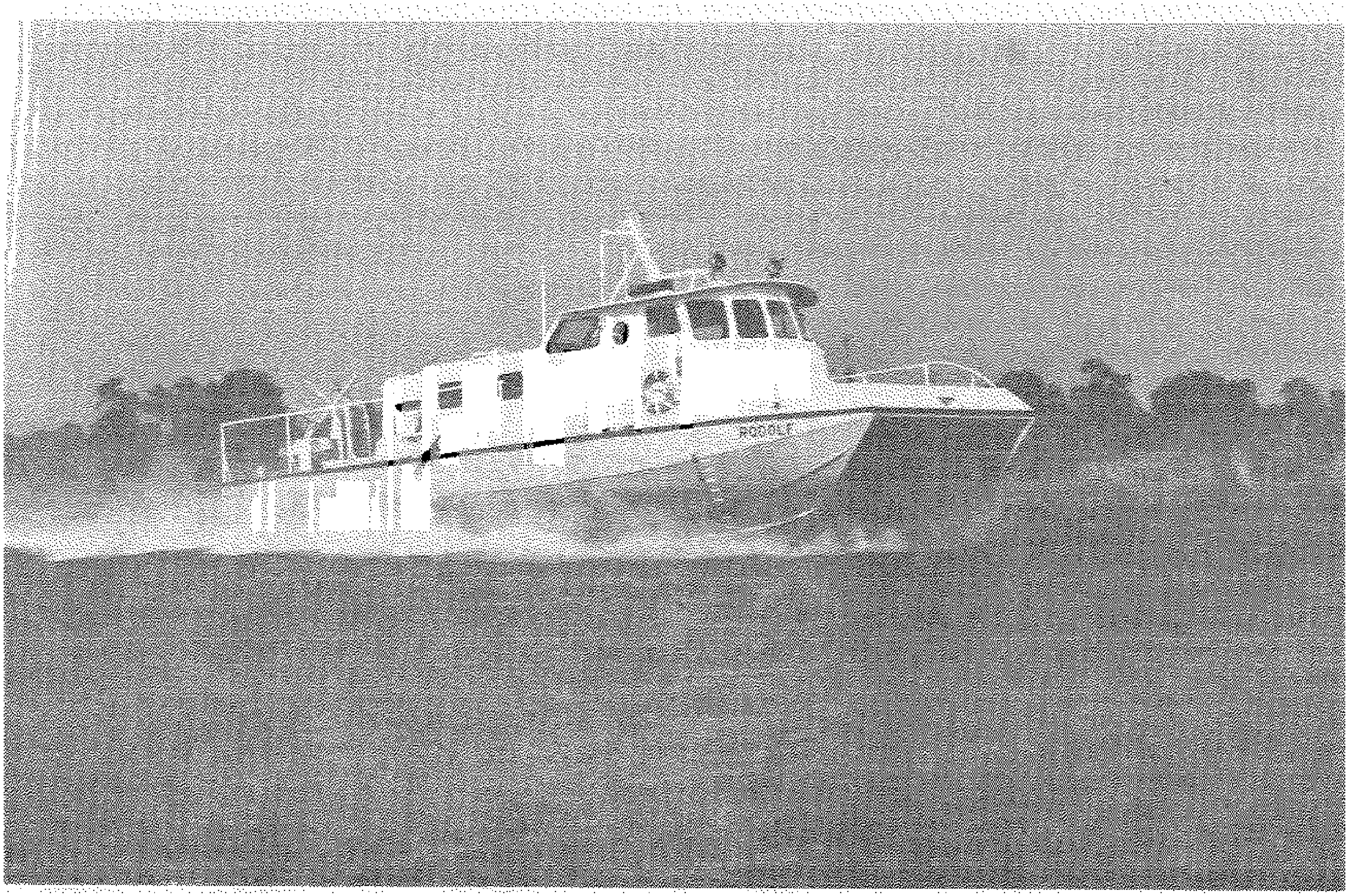

Figure 12. RODOLF Underway

located forward and aft of that position experienced some interference from air bubbles because of the surface effects of the vessel. Wake experienced with the vessel is very small as illustrated in Figure 13. This enables us to perform hydrographic surveys at speeds of 25 miles an hour routinely alongside marinas, boathouse moorages or other locations where previous surveys had to be accomplished at speeds of less than 5 miles an hour with displacement hull-type vessels. Fuel requirements of the RODOLF are about 25% below that of a similar size displacement hull vessel. The capabilities of the RODOLF to mobilize to the job site at speeds of 35 miles an hour also has greatly enhanced the productivity of the hydrographic survey crew and system.

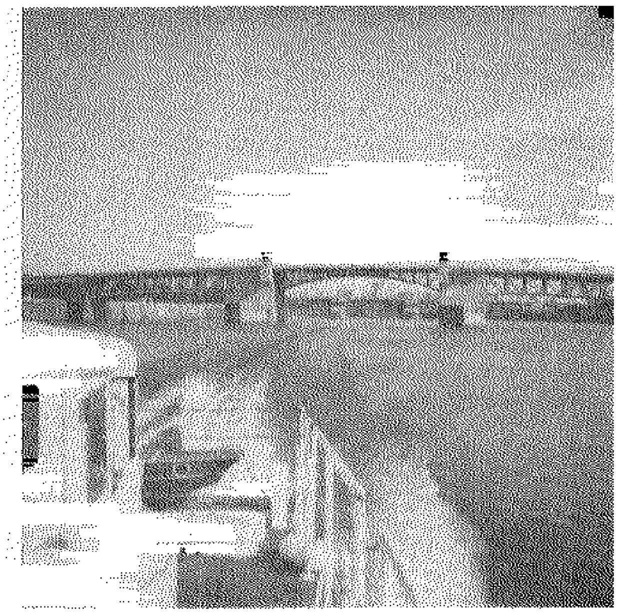

Figure 13. RODOLF Wake

11. Office Processing. Magnetic tape sent to the District office from the RODOLF is processed through the District computer to split it into a magnetic tape to be utilized for the District's large CALCOMP 72" flatbed plotter for the final surveying sheets on reproducible material and to a disc for use for office personnel in combination with prepared template information for quantity computations. Figures 2, 3, and 4 are examples of the final output of the overall system.

12. Future. We have assembled a sophisticated and complex electronic system together with the "state of the art" vessel for

hydrographic surveying in our District. Experience has shown that the remaining time loss to be eliminated is attributed to the type of positioning system utilized with the system. The present positioning system requires the survey crew to place several remote units at locations along the shore or on structures in the water at the beginning of each day's survey and to retrieve these units at the end of the day. Up to two hours lost time, out of a typical 10-hour surveying day can be attributed to this process.

The Corps of Engineers Waterways Experiment Station, in cooperation with a private company, has for several years participated in development of a passive radar reflector type positioning system, that will provide the accuracy desired for the hydrographic surveying process. This system is in the final stages of development and it is anticipated that it will be available to Corps of Engineers' districts for use for hydrographic surveying crews, hopper dredge and other marine plant within 18 months to 2 years. Completion of system development and the installation of required radar reflectors at permanent key points along the navigation projects will eliminate the time delays experienced now for setting up a shore-based line of sight positioning systems. Also eliminated will be the continuous maintenance of the required battery systems. We look forward to a productive future with the systems described.

BIOGRAPHY

Adam Heineman is Chief, Navigation Division, Portland District, U. S. Army Corps of Engineers. He received his B.S. degree in Civil Engineering from Oregon State University. He began his career with the Corps of Engineers and returned in 1972 to head the Navigation Division after 13 years with the Port of Portland.

Jack Bechly is Chief, Waterways Maintenance Branch, Navigation Division, Portland District, U. S. Army Corps of Engineers. He received his B. S. degree in Civil Engineering from Seattle University.

SIZING OF CONTAINMENT AREAS FOR DREDGED MATERIAL

by

Suzanne Lacasse[1]

ABSTRACT

The paper presents a method for sizing containment areas filled with dredged material. The technique aims at improving the bulking factor sizing method by taking into account (a) the properties of the channel sediment, (b) the behaviour of the dredged material in the disposal area, and (c) the components of the dredging operation that affect the volume of sediment entering the disposal area. The void ratio of the dredged material in the containment area represents the major unknown in the method. Laboratory sedimentation tests on channel sediment can lead to a prediction of void ratio versus depth and time in dredged material. Field investigations, including measurements of water content, rate of settling, excess pore pressure in the dredged material, and spatial distribution of solids in the containment area provide additional information on the material behaviour. The predicted void ratio versus depth distribution of dredged material compared well with measured values. The performance predicted at several containment areas agreed well with the field records available.

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[1] Civil engineer, Norwegian Geotechnical Institute, Oslo Norway. Formerly lecturer, Massachusetts Institute of Technology, Cambridge, Massachusetts.

I. INTRODUCTION

The increasing scarcity and cost of land-based disposal areas for dredged material and restrictions on open-water disposal create the need for efficient use of existing and future disposal sites. Whereas densification of the dredged material and design of containment areas to maximize settling effectiveness appear as possible means to reduce required containment volumes, the first priority remains the assessment of the volume actually occupied by a given volume of material dredged.

Two important variables set stringent conditions on land-based disposal projects: volume of channel sediment dredged and available containment volume. The empirical nature of existing sizing methods and the complex geotechnical aspects of channel sediment (before dredging) and dredged material (after disposal) render reliable assessment of performance of a containment area very difficult.

Bulking factors have been commonly used to estimate required volume capacity (Johnson, 1976; Huston , 1970). They generally vary with types of sediments and location. Lacasse et al. (1977a) presented a review of sizing practice based on interviews of a number of dredging specialists; in short the methods amount to refined but still empirical bulking factor techniques where sizing depends on a factor defined in terms of the type (i.e., sand, silt or clay) of the sediment. Containment area designers need however a rational sizing method that includes in a systematic manner all the parameters that affect the volume of dredged material in a disposal area.

The paper presents a method that predicts the volume occupied by a given quantity of channel sediment dredged. The method integrates various components of the dredging operation through a material balance equation and defines an equilibrium void ratio in the dredged material for excess pore pressures near complete dissipation. The technique provides specific and simple procedures that lead to more reliable results than the bulking factor approach. The following paragraphs also describe the behaviour of channel sediment and dredged material and apply the prediction methodology to five containment areas. In three instances, the predicted required containment volumes are compared to actual field performance.

II. CONTAINMENT AREA SIZING METHODOLOGY

2.1 METHODOLOGY

The sizing method quantifies the interrelationship among the components of a dredging project that affect volume predictions. The methodology proceeds in five steps (see also Diagram 1):

a. Determination of volume of solids effectively retained in the area through a material balance equation.

b. Prediction of state of dredged material in area (void ratio).

c. Prediction of required containment volume for dredged material.

d. Computation of settlement of foundation.

e. Computation of containment area dimensions.

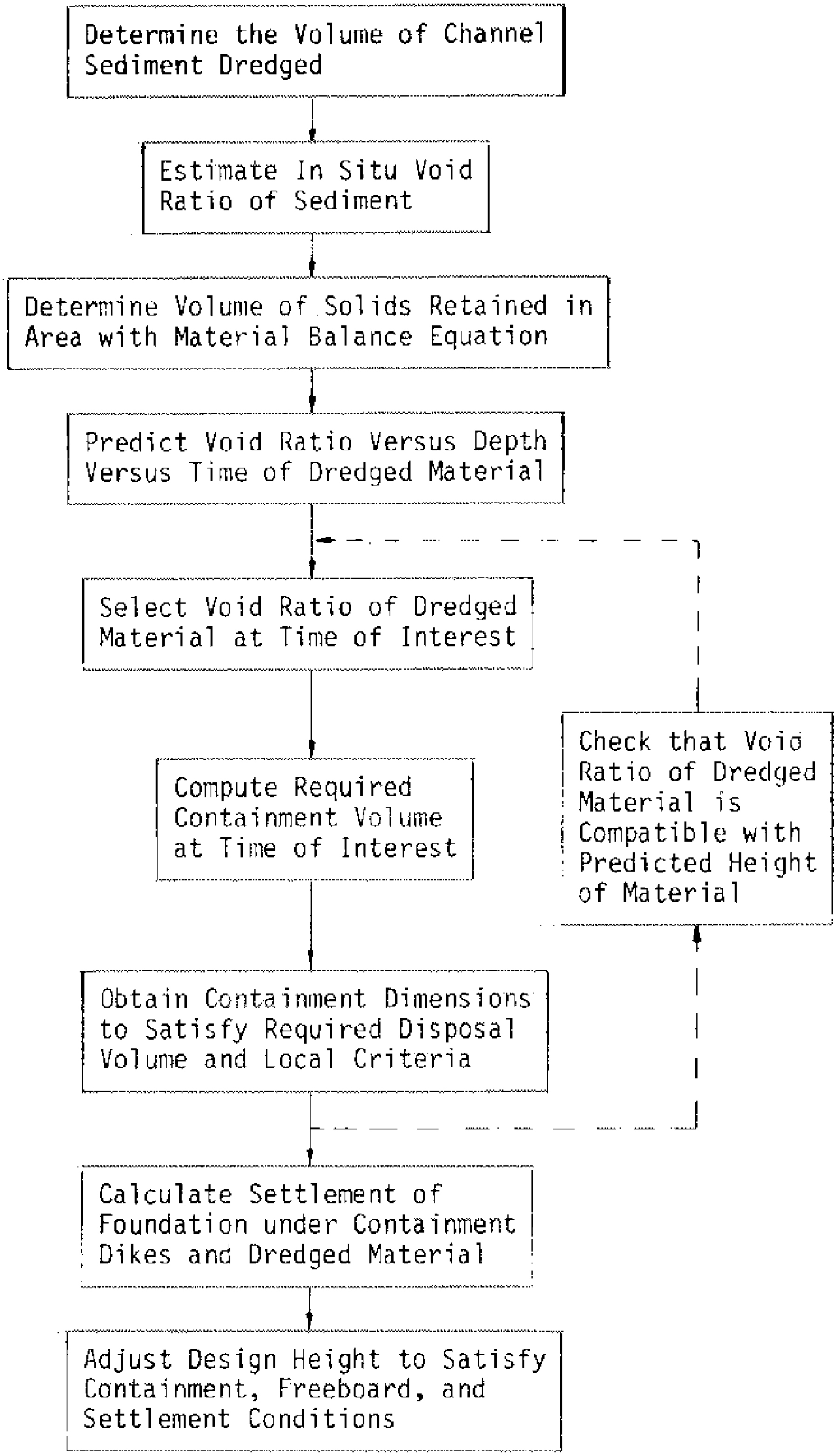

Diagram 1 Procedure for sizing containment areas.

The design volume of channel sediment to be dredged is determined by field investigations, past yearly records, and channel depth requirements. An assessment of the in situ sediment void ratio, e_o, from field investigations and/or correlations, yields the design volume of solids to be dredged:

$$V_p = \frac{V_t}{1 + e_o} \tag{1}$$

where V_p = design volume of solids to be dredged;

V_t = design volume of bottom sediment to be dredged;

e_o = void ratio of channel sediment.

A material balance equation ties in all the components of the dredging process that affect volume. The relationship states that the volume of solids in the containment area equals the volume of solids removed from the bottom minus losses:

$$V_c = V_p (1 + F_o) F_e F_p F_c \tag{2}$$

where V_c = volume of solids retained in containment area;

V_p = design volume of solids dredged;

F_o = overdredging factor;

F_e = efficiency of dredge removal action;

F_p = efficiency of transpost system;

F_c = efficiency of containment system.

The total volume of in situ solids removed includes possible overdredging by the contractor and is related to the design volume of solids to be removed, V_p, by the factor $(1 + F_o)$.

Efficiencies in Equations 1 and 2 express the ratio of volume of solids delivered by each component to volume of solids input to that component. For example, F_e includes losses of material upon removal of sediment *, and F_c possible losses of material through the containment system and over the effluent weir.

The state of the dredged material in the disposal area represents another variable required to estimate the containment volume. The sizing methodology predicts the void ratio versus depth distribution of the dredged material as a function of time (see next section). The required containment volume at a given time can then be expressed as:

$$V_{CA} = V_c \, (1 + e_{ave}) \qquad (3)$$

where V_{CA} = required containment volume;

e_{ave} = average void ratio of dredged material.

Substituting Equations 1 and 2 in Equation 3, the required containment volume becomes:

$$V_{CA} = \frac{V_t \, (1 + F_o) \, F_e \, F_p F_c \, (1 + e_{ave})}{(1 + e_o)} \qquad (4)$$

In the case of thick deposits of dredged material, settlement of the underlying foundation might occur and alter the disposal site capacity. In some cases, foundation settlements can be so small that neglecting them in the computations would not have appreciably impaired the predictions. Moreover, if erection of the containment dikes is recent, the dikes themselves may settle.

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* Pertains to all types of dredging actions (mechanical, suction, or combined).

2.2 PARAMETERS

Table I indexes the physical components considered in the sizing methodology and lists the significant parameters and the means available to assign values to these parameter.

Table I Index to Sizing Methodology Parameters

Physical Component	Parameter	Determination	Related parameters
Dredged Material	Average void ratio, e_{ave} (vs depth and vs time)	Past experience Best estimates Laboratory tests Field measurements Correlations	Grain size Plasticity Sedimentation/ consolidation rate
Sediment	In situ void ratio, e_o	Experience Channel sampling Correlations	—
Dredging Operation	Volume of material dredged, V_t	Channel surveys Yearly averages Physical requirements	Related to F_o and F_p
	Overdredging, F_o Removal efficiency, F_e Transport efficiency, F_p Containment efficiency, F_c	Experience Past case studies Best estimates Field measurements and control	—
Foundation Performance	Settlement	One-D settlement analysis Stress increase due to dredged material surcharge	Use conventional techniques

Containment areas are either filled in one continuous operation or designed for multiple-year usage. The assessment of the state of the dredged material necessitates, in each case, knowledge of the behaviour of the dredged material with time.

In summary, the prediction methodology establishes an inter-relationship between measurable soil characteristics and dredging operation parameters. A material balance equation determines the effective volume of solids entering the containment area and yields the required containment volume.

III. BEHAVIOUR OF CHANNEL SEDIMENT AND DREDGED MATERIAL

Very little data have been published on geotechnical properties of dredged material. Corps of Engineers (1969), Salem and Krizek (1976), Bartos (1976), Krizek et al. (1977) and MIT (1975) presented index properties and simplified behavioural patterns. Lacasse et al. [1977 a) and b)] described in depth the behaviour of dredged material placed in a containment area. They considered rate of settling, excess pore pressures, and void ratio versus depth and time, as measured in the laboratory and at several field sites through the U.S.A. They also presented detailed investigations of index properties and potential particle segregation in the containment area.

3.1 LABORATORY TESTS

Laboratory sedimentation-consolidation tests on dredged slurry at an initial solids concentration of 15% by weight enable prediction of field void ratio distribution of dredged material. Measurements with time of change in elevation of settling suspension, solids concentration versus depth and pore pressures in stillwater sedimentation cylinders defined void ratio-log effective stress relationships for low stress levels. Samples cut from the sedimented materials were then consolidated to higher effective stresses in a constant rate of strain consolidation apparatus.

Laboratory settling rates of channel sediment were initially very rapid for all materials (50 percent reduction in slurry height in less than a day). For annual deposits of dredged material of the order of less than 3 m thick, the time for dissipation of excess pore pressures is relatively short; it can be safely stated that self-weight consolidation will be well under way before the start of the next dredging season. One-dimensional compressibility curves for various dredged materials indicate that the compression index is very low at effective stresses equivalent to 1 to 5 m of dredged overburden and the change in void ratio during dissipation of the remaining pore pressures as well as that induced by additional loading will be small. For sizing purposes, consideration of the volume occupied by the material after sedimentation and self-weight consolidation is thus sufficient.

With respect to coefficient of consolidation data, Lacasse et al. (1977 a) summarized previous parametric studies done for dredged materials and slimes and presented coefficients measured from constant rate of consolidation tests.

3.2 PREDICTION OF IN SITU VOID RATIO OF DREDGED MATERIAL

The void ratio-effective stress curves (also called compressibility curves) enable prediction of the void ratio distribution versus depth in the field. The procedure consists of the following steps:

1. Divide depth of dredged material into several layers.

2. Assume an average void ratio for each layer.

3. With this void ratio calculate total and effective vertical stress in each layer.

4. Obtain new void ratio for each layer using calculated stresses and data from experimental compressibility curves.

5. Iterate through Steps 3 and 4 until void ratio versus depth remains constant after iteration (one or two iterations are generally sufficient).

This procedure was applied to four sites. Figures 1 to 4 illustrate the predicted void ratios. Measurement and compilation of field void ratios took place only after completion of the predictions and therefore did not influence the predictions. Computation of field void ratios considered water contents and total unit weights to take into account any incomplete saturation. In Browns Lake however, where field densities were not measured, the calculations used S = 100%.

Typically, void ratios below 50 cm remained constant with depth. In Branford Harbor, the predicted void ratio below a depth of 25 cm agreed well with the field void ratios measured ten years after disposal. In the one-year old James River-Windmill Point site, sampling difficulties impaired the reliability of the field measurements. Void ratios based on water contents averaged 1.30. However, during recovery, the cores underwent a volumetric compression of approximately 50%. Measured water contents were corrected to account for this volume change, leading to an estimated field void ratio of 2.5. The predicted void ratio averaged 3.0 below a depth of 60 cm. Two sites in Cleveland Harbor, one four year old, the other six months old, provided measurements of field void ratios very close to the predicted void ratio of 2.30. For Browns Lake, samples used for

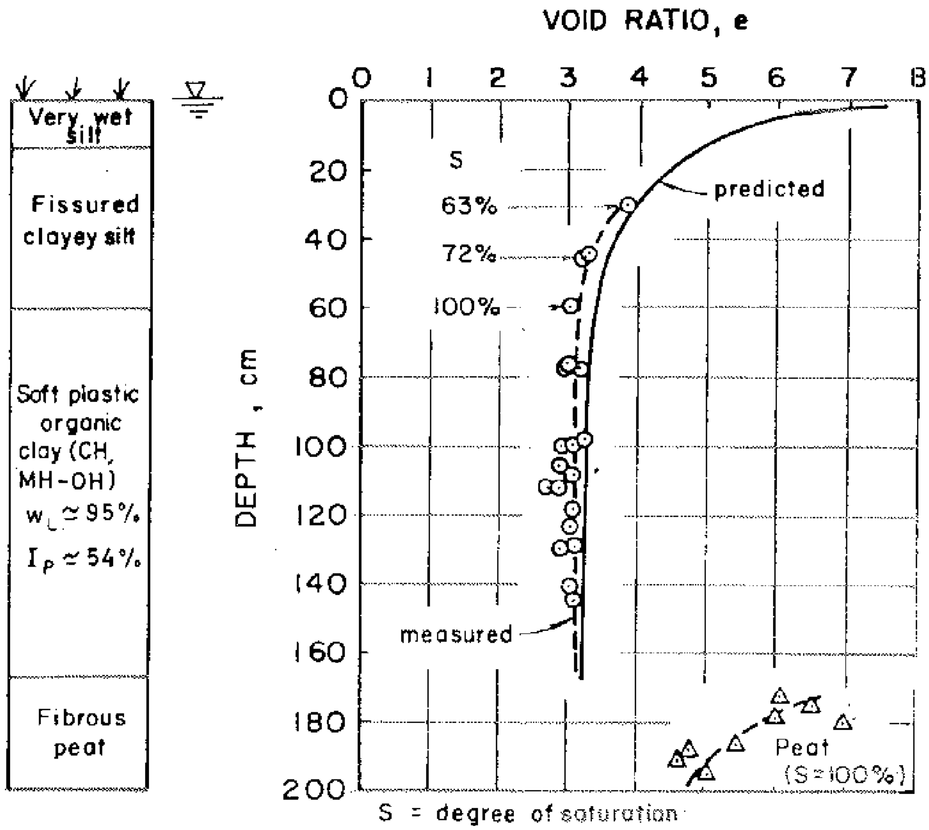

FIGURE 1. PREDICTED AND MEASURED VOID RATIO IN BRANFORD HARBOR UPLAND DISPOSAL SITE

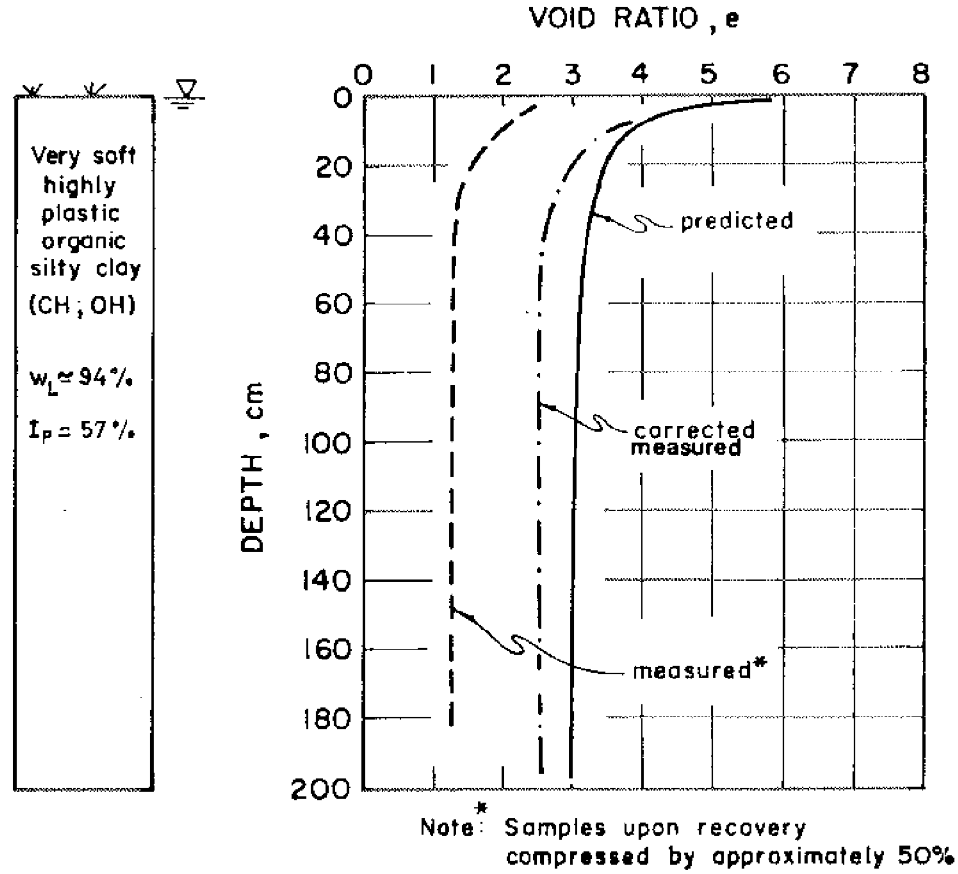

FIGURE 2. PREDICTED AND MEASURED VOID RATIO IN JAMES RIVER - WINDMILL POINT MARSH

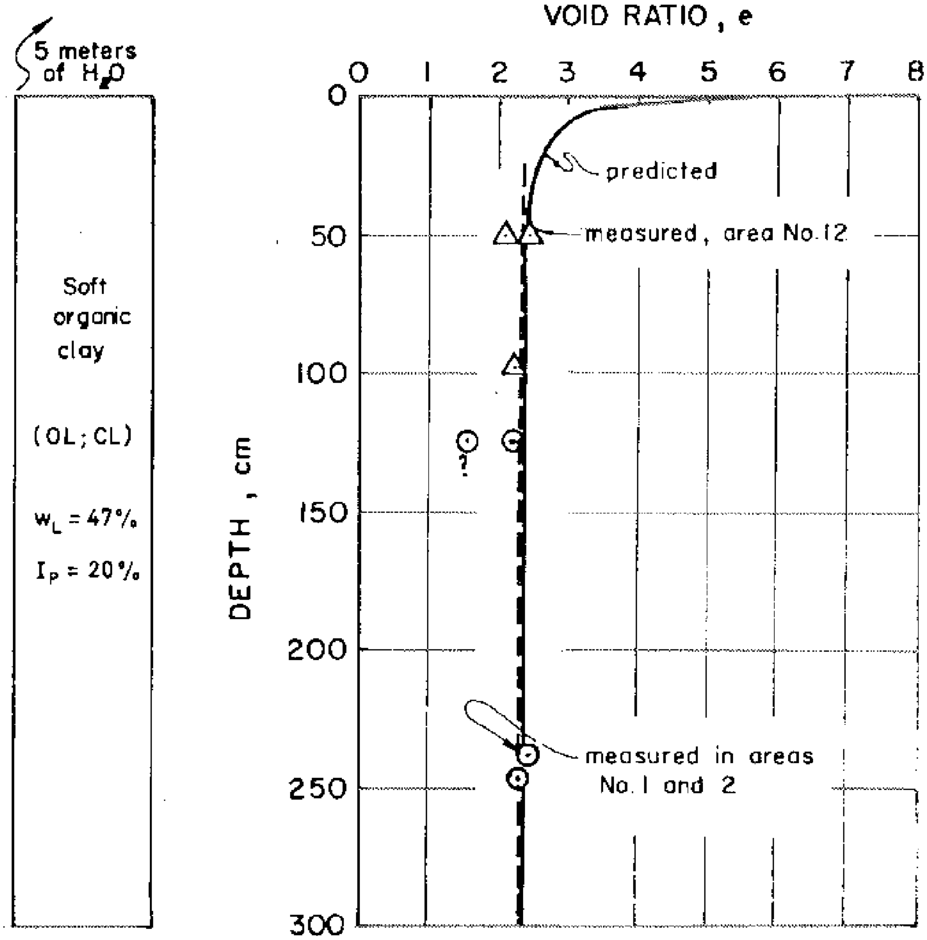

FIGURE 3. PREDICTED AND MEASURED VOID RATIO IN CLEVELAND HARBOR DISPOSAL SITES

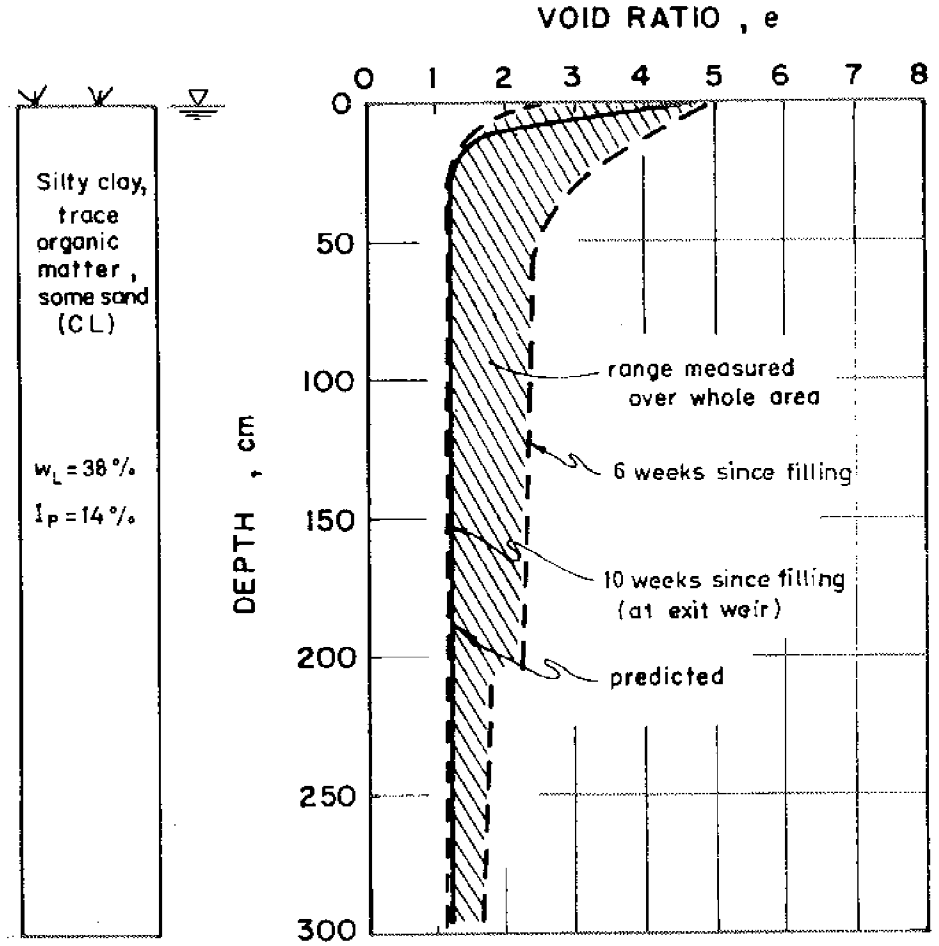

FIGURE 4. PREDICTED AND MEASURED VOID RATIO IN BROWNS LAKE DISPOSAL SITE

laboratory sedimentation-consolidation tests came from near the exit weir location. The data in the figure illustrate progression of the field settling. Void ratios will perhaps decrease further with time and agree more closely with predicted behaviour.

3.3 MEASURED IN SITU VOID RATIO OF CHANNEL SEDIMENT AND DREDGED MATERIAL

The void ratio* of the fine-grained channel sediment, the settling rate, total unit weight, and void ratio of the dredged material can be related to (1) ambient water environment, (2) grain size, and (3) plasticity of the material. Figure 5 plots measured field void ratios of channel sediment and dredged material versus plasticity index. Figure 6 compares these results with the sea bed and tidal flat deposits relationships proposed by Skempton (1970) for inorganic silts and clays.

Void ratios of *channel sediment* showed considerable scatter and should be determined preferably through fixed- piston sampling or as a minimum with disturbed sampling. However, Fig. 1 indicates higher void ratios for higher plasticity indices. Void ratios also increase with higher percentage of fines. The void ratio in the *disposal area* (after sedimentation and self-weight consolidation) also increased with salinity and plasticity.

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* Measurements of water content enable determination of the in situ void ratio by the equation:

$$G_s\, w = S\, e$$

where G_s = specific gravity of solids
w = water content
S = degree of saturation (see Lacasse et al., 1977 a, b)
e = void ratio

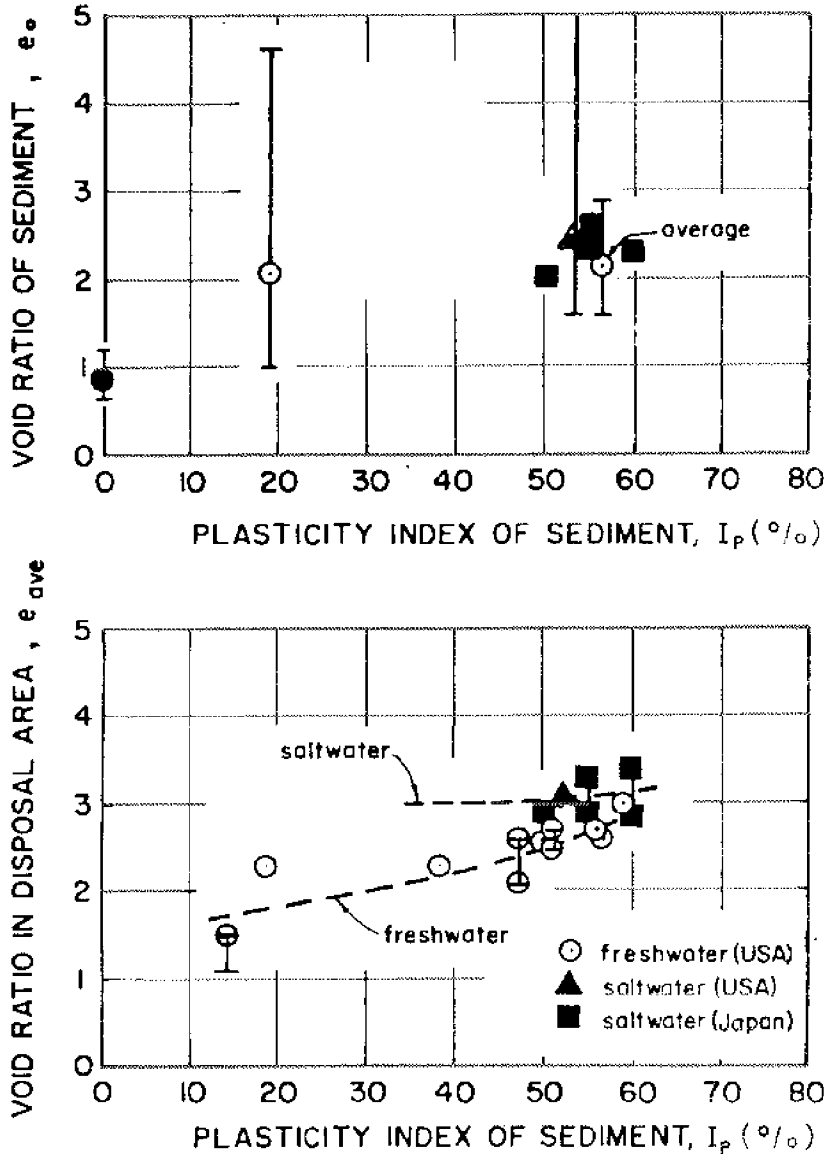

FIGURE 5. MEASURED VOID RATIOS OF CHANNEL SEDIMENT AND DREDGED MATERIAL

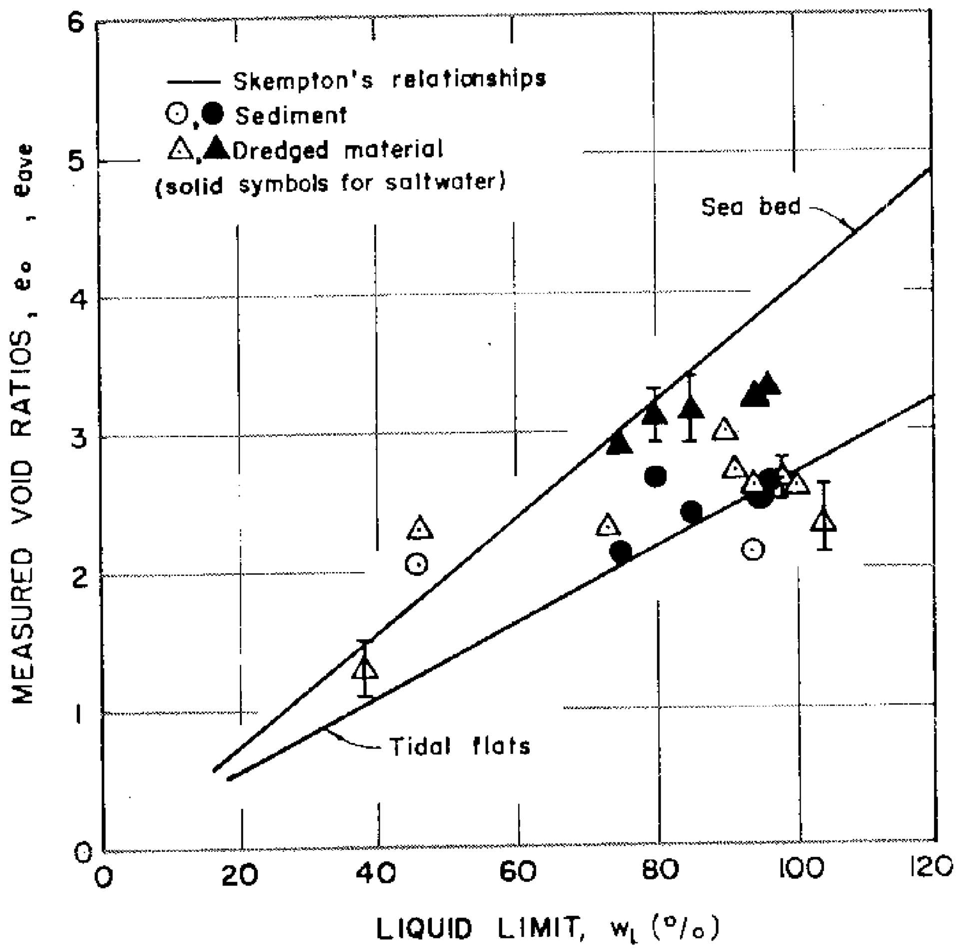

FIGURE 6. DEPOSITION VOID RATIO OF SEDIMENTS AND DREDGED MATERIALS

The examples presented indicate that the prediction method for void ratio versus depth distribution of dredged material yields acceptable results for fine-grained soils. The data show that void ratios of channel sediment and dredged material are related to ambient water environment, plasticity and grain size of the material.

Section VI presents guidelines for selection of the void ratios of channel sediment and dredged material for use in the sizing methodology.

IV. DREDGING OPERATION PARAMETERS

Four parameters of the dredging operation affect volume predictions: the overdredging factor, F_o, and the removal, transport, and containment efficiencies, F_e, F_p, and F_c. Determination of these parameters can be based on experience, "best estimates", past case studies, and field measurements. Control of the dredging and/or containment operation can also provide values for these variables, especially with respect to losses of material.

Overdredging depends on:

a. The type of sediment: F_o can vary with stiffness of the sediment. Maintenance and new dredged material are likely to have different F_o values.

b. Control of the dredge position: The ability of a dredge operator becomes important.

c. Instability of side slopes and other possible local characteristics.

Figure 7 illustrates a possible definition of overdredged volume. It is a highly variable parameter. In Mobile Alabama, overdredging factors backfigured from four dredging jobs varied from 31 to 78%.

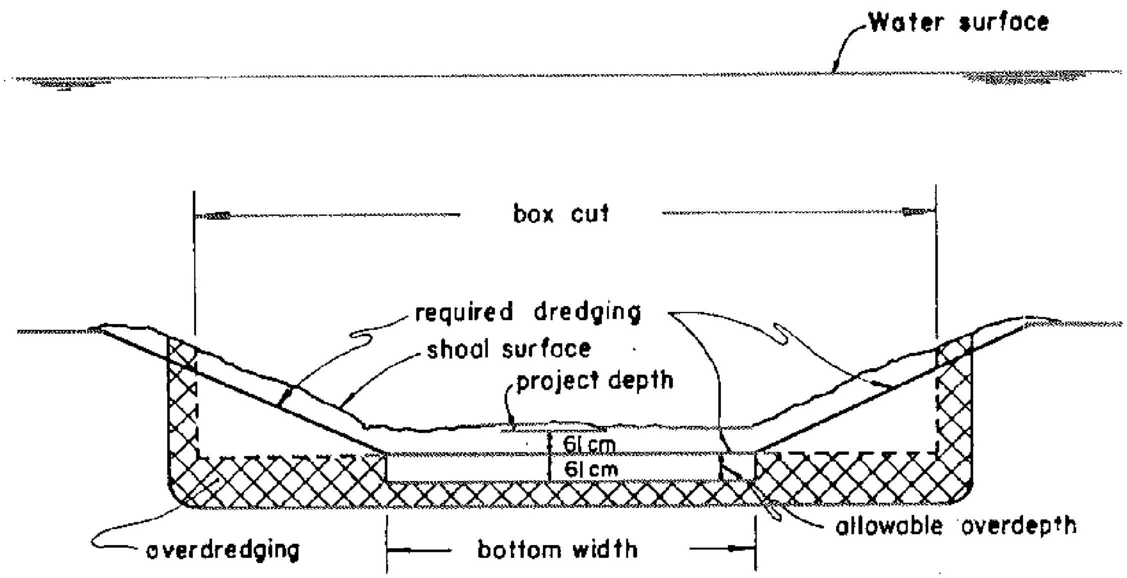

FIGURE 7. OVERDREDGING IN CHANNEL CROSS-SECTION

The dredging operation efficiency depends on a variety of factors.

For dredging currently done in the U.S.A., not all solids from the in situ sediment enter the mouth of the dredge; losses due to agitation or suspension of soil particles occur during removal. Values for the removal efficiency factor, F_e, depend on the type of sediment, the type of removal, the pumping rate, the rate of advance of the cutting tool, soil density, and tidal velocity. Specific values of F_e are generally determined from experience.

Solids can also be lost during transport from the dredge to the disposal area as a result of leaks or breaks in the pipeline. Values of the transport efficiency factor, F_p, depend on the amount of control exercised over the dredging contractor and the type of sediment. For large well-run operations, F_p will likely approach 1.0. Requirements for F_p equal to 1.0 could be established in dredging contracts.

The efficiency of the containment system, F_c, depends on the amount of solids lost from the containment structure and the amount of solids discharged through the effluent weir. Considerable material may be lost if dike freeboard is not designed to prevent breaching. Choice of adequate weir outflow and slurry inflow rates as a function of containment size and settling of solids should help keep F_c high.

Table II summarizes a review of current practice, based on interviews of selected dredging specialists. The average "best estimates" offered by all the specialists indicate that overdredging varies between 20 and 30% and that overall losses (during removal and transport and from the containment system) were less than 5% (F_e = 97%, F_p = 100%, F_c = 98%). Table II also summarizes the average and best estimate of each dredging operation parameter and lists the variables affecting each of them.

The selection of an overdredging factor should be based on local experience along a particular channel reach to be dredged. Use of an overdredging factor between 0 and 30%, with the value decreasing with increasing sediment consistency is recommended. For smaller jobs, slightly larger F_o values may be appropriate. Very strong winds or tides during dredging can decrease the removal efficiency, F_e, by 5 or 10%. Otherwise, F_e should remain near 100%. Values of F_e = 95%, F_p = 100%, and F_c = 100% are recommended for use in the sizing methodology unless local conditions indicate

Table II Estimate of Dredging Operation Parameters by Selected Dredging Specialists

Specialist	Overdredging Factor F_o (%)	Removal Efficiency, F_e (%)	Transport Efficiency, F_p (%)	Containment Efficiency, F_c (%)	Comments
A	10	100	100	100*	Hopper dredges
B	30 - 35	100	100	100*	$F_e \neq 100\%$ if very strong tides
C	30 - 78	80 - 100	>98	-	F_o backfigured from past jobs
D	0 - 10	>95	>98	100*	F_c decrease at end of operation, $F_p > 98$ if inspector present
E	10	>95	>95	-	
F	10 (in silt) 0 (in clay)	100	100	?	
G	-	100	100	100	
H	10 - 25	>98	>90	>95	
I	10	>98	>98	>95	
J	-	-	$F_e F_p F_c = 81$	-	Average value backfigured from 3 cases in Japan
Average	24	97	97	86	
Best-Estimate	20 - 30	97	100	98	Need inspection and control
Significant Factors	Operator Sediment Job Equipment	Operator Sediment Tides	Inspector Contractor Slurry Equipment	Environmental specifications Flow rate Weir design Freeboard	

* To be required

different values. The volume of sediment to be dredged should consider expected overdepths paid to the contractor since these are not included in the overdredging factor.

In the sizing equation (eq. 4), the components of the dredging operation, $(1+F_o)\, F_e F_p F_c$, would then account for a factor between 0.95 and 1.24.

V. APPLICATION OF THE PREDICTION METHODOLOGY

This section applies the prediction methodology to four disposal sites:

a. Cleveland Harbor combined disposal site nos. 1 and 2 (Michigan).

b. Cleveland Harbor disposal site no. 12 (Michigan), designed for multi-year usage.

c. Brandford Harbor (Connecticut).

d. Anacortes (Washington).

The information necessary for the solution of the sizing equation at each disposal site was not always available. In such cases, engineering judgment and experience with other dredged materials were used. Lacasse et al. (1977 a) described the layout and investigations at each disposal site. Table III summarizes the parameters and the results of each analysis.

In the use of the prediction method, available data are often scarce, but correlations with other dredged material can provide estimates for the missing data. In the three instances where predicted and measured volumes were compared,

Table III Application of Sizing Methodology

Parameter	Cleveland Harbor			Branford Harbor	Anacortes* Site
	Areas nos. 1 and 2	Area no. 12 (1975)	Area no. 12 (Future)		
Volume to be Dredged, V_t (m^3)	2,172,030	742,910	2,102,450 + 5% allowed overdepth	72,500 + 15% allowed overdepth	383,755
In Situ Void Ratio, e_o	2.05	2.05	2.05	2.50	SM = 0.90 ML = 1.80 CH = 2.25 Avg = 1.94
Overdredging, F_o (%)	0	0	20	30	15
Efficiency, $F_e F_p F_c$	0.95	0.95	0.95	0.90****	0.97
Average Void Ratio of Dredged Material, e_{ave}	2.30**	2.30**	2.30	3.20	SM = 0.90 ML = 2.30 CH = 3.00 Avg = 2.52
Predicted Containment Volume, (m^3)	2,232,560	763,615	2,722,915***	117,060	512,530
Measured Containment Volume, (m^3)	2,039,400	725,590	—	—	535,170
Relative Error on Predicted Volume, (%)	+ 9	+ 5	—	—	- 4

* Channel sediment included three soil types in the following proportions: SM = silty sand (5%)
ML = silt (55%)
CH = plastic clay (40%)

** Void ratio measured in field = predicted void ratio.

*** Given planar area of site, one can determine required height of dikes (after consideration of the potential settlements).

**** Losses are expected, based on past experience.

the results were generally satisfactory. The procedure reduced the uncertainty generally associated with containment volumes determined from traditional sizing techniques. Comparison of measured versus predicted volumes in Cleveland Harbor disposal sites agreed amazingly well. In the case of planning of future areas, one must also provide for sufficient freeboard on the retaining dikes.

VI. GUIDELINES FOR SELECTION OF SIZING PARAMETERS

6.1 CHANNEL SEDIMENT

Three approaches enable one to estimate the void ratio of channel sediment e_o: (1) obtain undisturbed samples and measure water contents, and total unit weights (to compute void ratio and degree of saturation), (2) obtain disturbed samples and measure water contents (assuming a degree of saturation), (3) use existing correlations. Figure 8 presents recommended values of void ratio for channel sediment as a function of plasticity index and liquid limit. The plot distinguishes between saltwater and freshwater deposits. One should note that limited data underlie the recommendations. Additional field measurements would greatly help refine selection of void ratio for channel sediment.

Determination of the void ratio of channel sediment by correlations should be done in three steps:

1. Find void ratio as a function of plasticity index and water salinity.

2. Find void ratio as a function of liquid limit and water salinity.

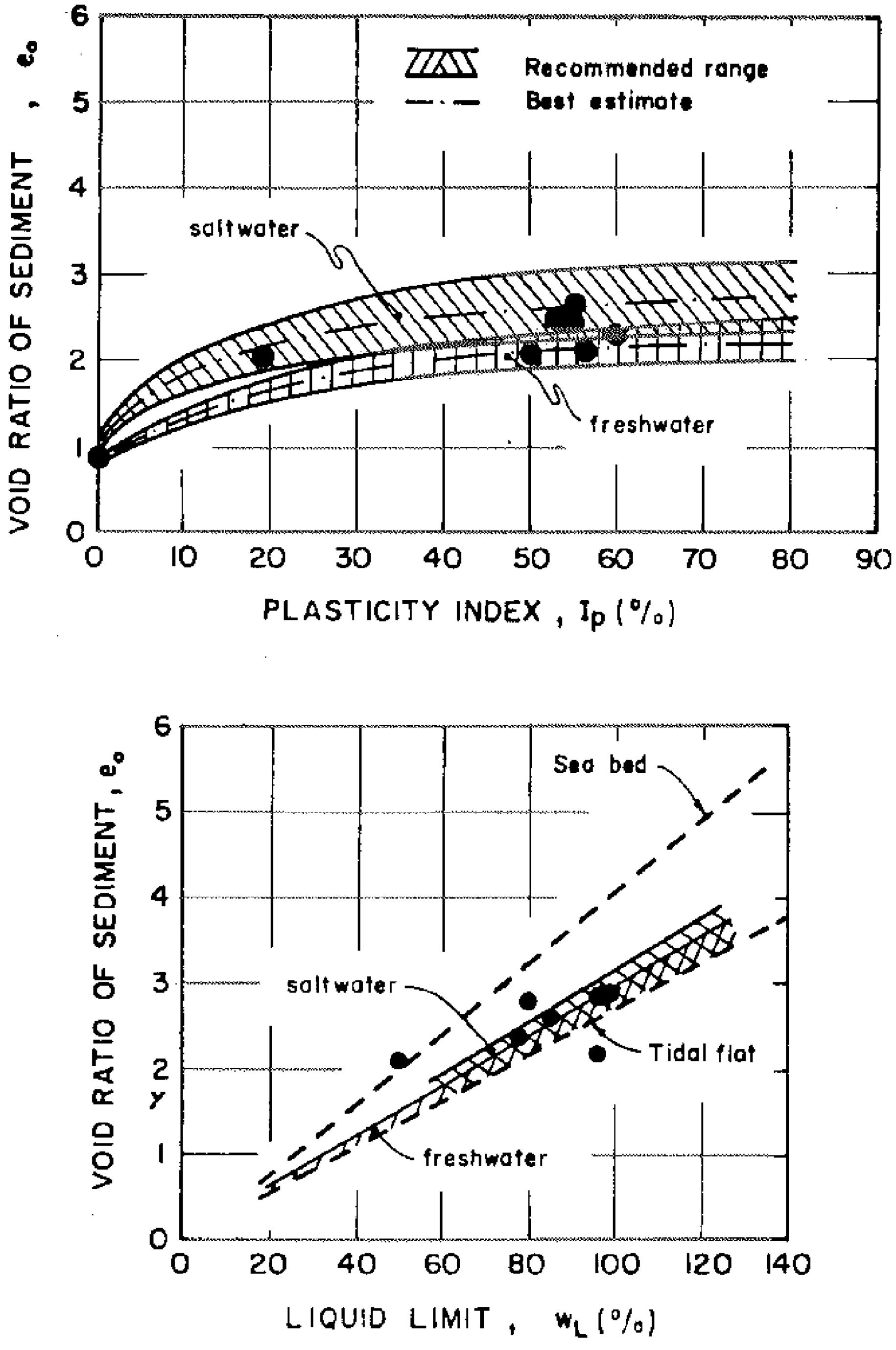

FIGURE 8. VOID RATIO AND INDEX PROPERTIES OF CHANNEL SEDIMENT

3. Compare values of void ratio and select best value (from experience, local conditions, special soil characteristics, etc.).

6.2 DREDGED MATERIAL

The measured void ratio of dredged material exhibited much less scatter than the void ratio of the channel sediment. Predicted values from laboratory sedimentation-consolidation tests have agreed amazingly well with field measurements. For sizing containment areas designed for multiple-year usage, it is recommended to consider the void ratio attained after sedimentation and self-weight consolidation, since dissipation of most excess pore pressures occurs during and between dredging seasons. Means of assessing the void ratio of dredged material include (1) laboratory sedimentation-consolidation tests and (2) correlations with plasticity index and/or liquid limit. If laboratory test results are not available, Fig. 9 provides an alternate way of obtaining void ratio.

The void ratios shown in Figs. 9 and 10 allow one to calculate the volume increase of the channel sediment after dredging, transport, and disposal. The volume increase is defined as $\frac{1 + e_{ave}}{1 + e_o} - 1.00$. Figure 10 shows the volume increase as a function of I_p for freshwater and saltwater deposits. A volume increase factor of 1.00 indicates no volume change. Volume increases computed from the field data presented appear as data points in the figure. For slightly plastic to non-plastic, fine-grained, freshwater materials ($I_p < 20\%$), the volume increase due to dredging and disposal (after sedimentation and self-weight consolidation) remains less than 10%, whereas for highly plastic, saltwater material ($I_p > 50\%$), the volume increase can reach

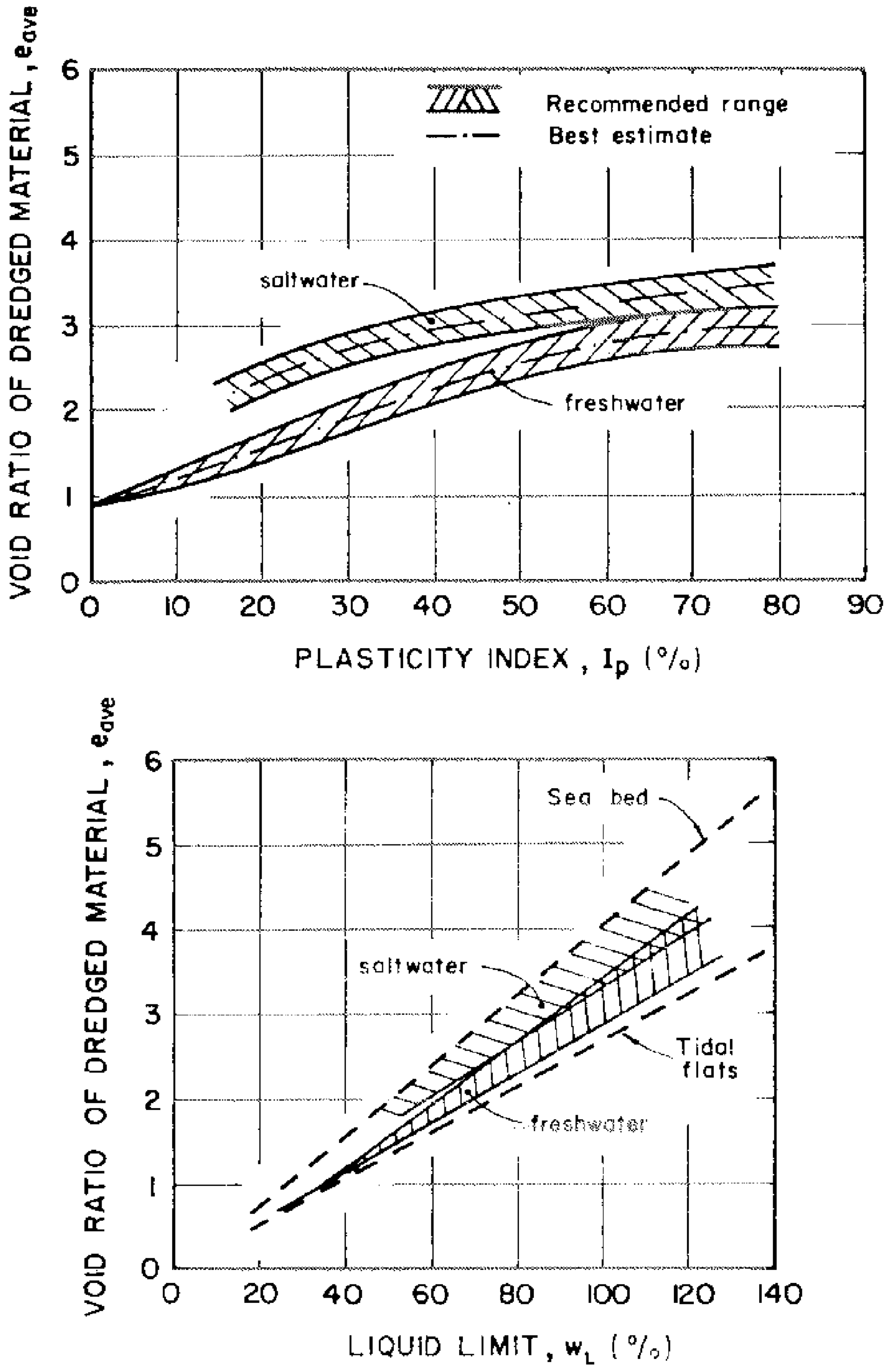

FIGURE 9. VOID RATIO AND INDEX PROPERTIES OF DREDGED MATERIAL

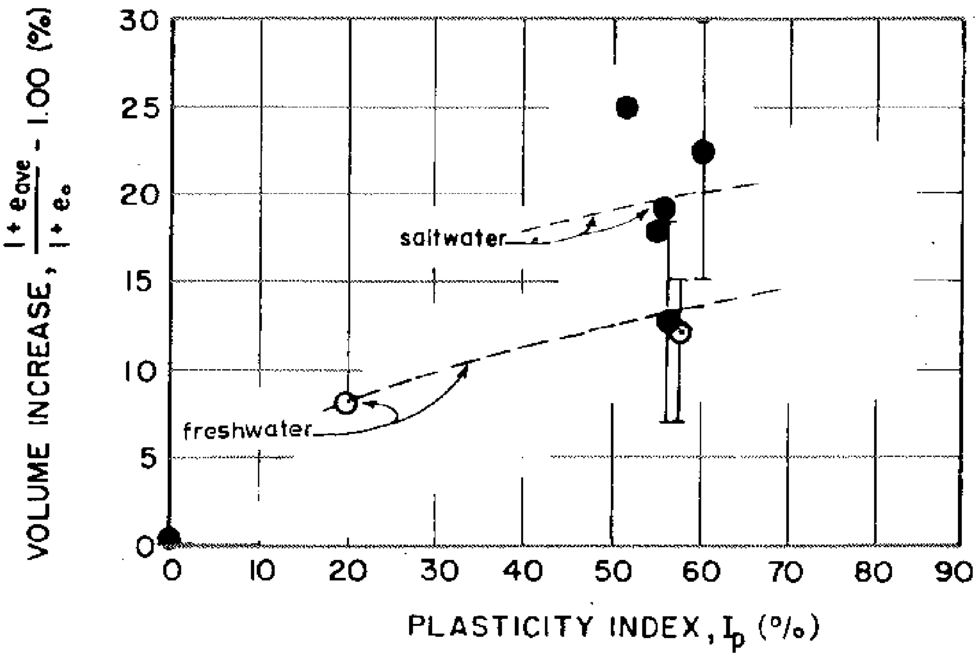

FIGURE 10. INCREASE IN VOID RATIO AFTER DISPOSAL

30%. The scatter emphasizes the need for additional field measurements.

VII. CONCLUSIONS

The containment area sizing technique presented aims at improving the bulking factor sizing method and takes into account (1) the properties of the channel sediment, (2) the behaviour of the dredged material in the disposal site, and (3) the components of the dredging operation that affect volume of sediment dredged. Void ratios of both channel sediment and dredged material are the major unknowns in the sizing technique.

The author proposes a technique to predict the void ratio of dredged material from laboratory column sedimentation-consolidation tests on channel sediment. Void ratios predicted at several disposal sites agreed well with measured values. In summary, the data indicate the following:

a. For slightly plastic to non-plastic fine-grained freshwater material ($I_p < 20$), the volume increase after dredging and disposal remains less than 10 percent.

b. For highly plastic saltwater material ($I_p > 50$), the volume increase after dredging and disposal can reach 30 percent.

Limited data underlie these relationships. Additional field measurements would greatly help refine selection of void ratios of sediment and dredged material.

An investigation of the dredging operation components indicates that the overdredging factor, F_o, is the most significant, since the loss of solids during the operation was observed (or is required) as very low.

Application of the sizing method to several actual field cases proved satisfactory. In two instances, the volume was overpredicted by less than 10 percent and in a third disposal site, the prediction was unsafe by 5 percent. To improve the reliability of the prediction method, one needs to:

a. Refine sampling procedures to obtain more reliable measurements of sediment void ratio.

b. Document further comparison of predicted versus field void ratios of both channel sediment and dredged material.

c. Investigate possible means of limiting uncertainty on the overdredging factor.

When selecting the parameters necessary to solve the sizing equation, the author recommends the following investigations:

a. Sampling of the sediment along length of channel.

b. Estimate of approximate consistency of sediment (penetration tests, for example).

c. Measurement of grain size and plasticity of sediment.

During the dredging operation, it is recommended to:

a. Observe dredging operation and any excessive losses.

b. After each dredging season (in a multi-year usage disposal area), verify the effective volume of dredged material and required containment volume.

In containment areas designed for multi-year usage, it it recommended to apply the sizing methodology at the end of each dredging year. This procedure will not only establish a bank of data for each methodology parameter and thus help reduce their uncertainty, but also enable one to reexamine volume predictions and, if necessary, modify either containment volume or volume to be dredged.

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