EXHIBIT B
Physical Processes and Geological Resources

Appendix H

Exhibit B

Physical Processes and Geological Resources

Table of Contents

CONTENTS CONTINUED

CONTENTS CONTINUED

CONTENTS CONTINUED

LIST OF FIGURES

Figures Follow Exhibit B Text

CONTENTS CONTINUED

LIST OF FIGURES

Figures Follow Exhibit B Text

PLATES

Follow Figures

LIST OF TABLES

Appendix H
EXHIBIT B - Physical Processes and Geological Resources

EXECUTIVE SUMMARY

Geographic Location: Northwest Pacific Coast of continental United States, deep draft ocean entrance to the Columbia River along Oregon and Washington.

Organizational Oversight: U.S. Army Corps of Engineers - Portland District.

Project Features Addressed: Ocean Dredged Material Disposal Sites 2 to13 miles Offshore of the Mouth of the Columbia River.

Exhibit B describes the physical evaluation of dredged sediment placed at Ocean Dredged Material Disposal Sites (ODMDS) offshore the Mouth of the Columbia River (MCR). This exhibit presents assessments highlighting the limitations of existing ODMDSs and describes physical processes and design criteria to facilitate optimal selection of new ODMDS locations. This exhibit was compiled during FY 1997-98 in support of the Columbia River Channel Deepening Feasibility Study.

Siting criteria used to assess new ODMDSs (capable of providing 50-years of disposal capacity) are identified based on physical assessments of open water dredged material disposal and considerations of insitu conditions at proposed ODMDS sites. The siting and design criteria presented in this exhibit are not intended to define ODMDS management procedures.

The report is composed of 9 sections. Section 1 summarizes the physical environment at MCR and introduces the activity of ocean disposal of dredged material as a means of maintaining reliable navigation at MCR. Section 2 reviews the previous management of MCR ODMDSs and identifies limitations of existing ODMDSs. Section 3 assesses bathymetric change at existing MCR ODMDSs and related affects on the local wave climate. Section 4 identifies the need for new larger ODMDSs and formulates site selection criteria, in terms of physical processes and site capacity, required for successful long-term ODMDS management. Section 5 introduces the fate modeling approach used to assess proposed new ODMDSs in terms of physical processes. Section 6 describes fate modeling results, specifies proposed ODMDS dimensions, and summarizes physical impacts of ODMDS use. Sections 7 and 8 describe the oceanographic processes affecting MCR ODMDSs. Section 9 describes the geologic resources at existing and proposed MCR ODMDS locations.

Appendix H
Exhibit B - Physical Processes and Geological Resources

Section 1
INTRODUCTION

Mouth of the Columbia River - Physical Setting

The Columbia River flows into the Pacific Ocean at the boundary between Oregon and Washington (figure B-1) and is the second largest in the United States in terms of annual river discharge. The course of the Columbia River is 1,210 miles long, dropping over 2,600 feet from its Canadian headwaters to the sea, draining an area of approximately 250,000 square miles. The Columbia River accounts for 60% (winter) to 90% (summer) of the total freshwater discharge into the ocean between the Canadian border and San Francisco. The Columbia River estuary is the largest fluvially dominated estuary in the Pacific Northwest [CREDDP 1984] and its tidal prism is about 1,390 mi^2-ft [Jarrett 1976]. The upriver limit for the Columbia River estuary, defined in terms of salt water intrusion, varies between river mile (RM, measured from the mouth) 28 and 38 and is a function of fluvial flow and sequencing of the tidal cycle. Current reversal due to tide can occur as far inland as RM 70. Tidal effects (fluctuation of water surface elevation) extend upriver to Bonneville dam (RM 145).

The river's annual discharge is marked by a high seasonal variability, typically ranging from 100,000 to 400,000 cfs. Highest discharges occur during May through July due to snowmelt and rain runoff. Lowest flows occur during late summer and early fall [Neal 1972]. The average (regulated) river discharge is presently about 265,000 cfs. Peak river flow at the Dalles dam during the freshet of May 1997 was at about 600,000 cfs, which corresponded to a 3 percent chance of exceedence (35-year) regulated flow event. The physical characteristics of the Columbia River estuary differ from those of most North American estuaries: River discharge is much greater, salinites are much lower, tidal forcing is greater, and bottom sediment is less stable. Flushing time for the Columbia River's estuarine waters is 2-5 days, whereas the flushing time for many other estuaries may require weeks or months: The average flushing time for Chesapeake Bay is about 1 year [CREDDP 1984].

Although the Columbia River is known for its low turbidity, swift river currents move a significant amount of bedload sediment and produce sand waves up to 10-foot tall on the channel bottom. Presently, the amount of sediment contributed by the upper Columbia River (above Bonneville Dam, RM 145) is very small compared to the net water discharge. Between 80-90% of the Lower Columbia River's sediment throughflow is composed of suspended sediment, yet relatively little suspended sediment is retained in the main stem of the estuary. The predominate sediment type in the main channels of the estuary is sand and small gravel which is transported as bedload, with finer silts and clays prevalent in peripheral bays and within limited areas of the main estuary [Roy et al 1982]. In terms of the overall estuary, average bottom sediments have been characterized as having 1% gravel, 84% sand, 13% silt, and 2% clay [Hubbell and Glenn 1973 and Roy 1982]. Fine sediment, which is normally transported in suspension, comprises only a small percentage of the sediment deposited in the main channels of the estuary.

Approximately 67% of the suspended sediment (generally, silt-size and finer) discharged from the Columbia River is estimated to be transported to the continental shelf of Washington, 17% of which is estimated to be transported beyond the shelf break, down into submarine canyons [Sternberg 1986]. Previous studies indicate that some of the sand-sized sediments within the lower Columbia River estuary may have been transported into the estuary from adjacent nearshore and shelf regions of the Washington and Oregon coasts [Lockett 1962 and Roy et al 1983]. The Columbia River estuary is being filled not only by river transported sediment, but also by marine sediment entering the MCR by tidally-induced movements of bottom water entering the estuary from the ocean. On the ocean side of the estuary, marine sand from the coast is transported to the MCR by the north and southbound littoral currents. Refer to section 7, *Oceanographic Processes*, for definition of littoral currents.

The Columbia River entrance is characterized by exceptionally strong wave-current interactions. As a consequence, the river entrance has been recognized as one of the most dangerous coastal inlets in the world. The seastate at the river entrance during storm conditions can be characterized by high swell incident from the northwest to southwest combined with locally generated wind waves from the south to southwest. Such combined seas can be particularly dangerous to the mariner at the river mouth, especially when opposing ebb currents can cause dramatic wave growth, steepening and breaking of incoming waves [Gonzalez 1984]. Compared to the Atlantic seaboard, the transition from coastal regime to oceanic along the Washington and Oregon Coast is abrupt: The continental shelf break lies approximately 20 miles offshore (figure B-2). Note that due to the proximity of Astoria Canyon, the shelf break is within 11 miles of the Columbia River entrance.

MCR Navigation Project Background – Dredging and Disposal

The present deep draft navigation project located at the ***Mouth of the Columbia River*** (MCR) consists of a dredged navigation channel 5 miles long which extends through a jettied entrance between the Columbia River and the Pacific Ocean (figure B-1). The MCR navigation project extends from river mile (RM) –2 to +3 and its present condition is the result of continuous improvement and maintenance efforts. These efforts have been conducted by the U.S. Army Corps of Engineers, Portland District (USACE) since the initial project authorization in 1885.

Prior to 1885, the natural channel through the ebb tidal delta at MCR had averaged about 25 feet deep and shifted frequently on a seasonal and annual basis. Figure B-3 documents the high degree of natural channel variability that had taken place between 1839-1885 at the MCR entrance (note the southward migration of the channel at Baker Bay). The ebb and flood tidal deltas at MCR entrance were distributed over a large area, immediately seaward and upstream of the river mouth.

To reliably maintain a congressionally authorized 30-foot channel across the MCR bar, the south side of the river entrance was jettied between 1885-1889. The alignment of the south jetty was northwestward along Clatsop Spit. Westward extension of the south jetty was begun in 1905 and by 1913, the south jetty had been extended to a total length of 6.6 miles and construction of the north jetty had begun. In 1917, the 2.5 mile-long north jetty was completed. The north jetty's alignment was southwestward along Peacock spit (see figure B-4). At the time of north jetty construction, Peacock Spit was completely submerged with elevations ranging form 0 to -25 ft MLLW: The subareal part of Peacock Spit now known as Benson beach did not exist before construction of the north jetty in 1913. The intended, and for the most part, realized effects of jetty construction at MCR were:

- Constrict the MCR entrance to 2 miles wide at the estuary mouth, at which point the velocity of tidal flow would be increased minimizing the formation of shoals within the MCR entrance channel.
- Prevent channel-ward encroachment of existing entrance shoals: Peacock Spit along the north side of the MCR entrance channel, and Clatsop Spit along the south side of the channel.
- Secure a stable and consistent navigation channel ½ mile wide with a project depth of 40 feet (based on 1913 project authorization).

Construction of the north and south jetties at MCR resulted in the ebb-tidal delta being displaced more than 10,000 ft toward the west (offshore) during the period 1885-1950 [Sternberg 1977]. Refer to figures B-3 and B-4 for the graphical description of MCR bathymetry change during 1885-1950.

Dredging and Ocean Disposal Prior to 1945

Dredging of the MCR bar by hopper dredge was first conducted in 1904, to maintain a 30-foot navigation channel across the entrance bar, formed by Clatsop spit. During this time, dredging was needed to remove intermittent shoals formed by Clatsop and Peacock spits. Between 1905 and 1940, approximately 8 million cubic yards (cy) of sediment had been dredged from the MCR entrance bar and placed in open water by hopper dredge. Table B-1 lists the volume per year dredged at the MCR bar bewteen 1904 and 1945.

Table B-1. MCR bar dredging volume per year between 1904 and 1945. MCR dredging was not performed for years not included below.

Fiscal Year	Amount Dredged at MCR Bar (cy)
1904	386,000
1912	542,000
1913	77,000
1915	1,188,000
1916	1,500,000
1917	814,000
1918	1,071,000
1919	344,000
1932	548,000
1939	501,000
1940	1,320,000
1941-44	none
Total	8,291,000 cy
(Average for each year of dredging 1904-1944 =	753,000 cy/yr)

Before 1945, MCR dredging was performed on an intermittent basis; being a function of shoaling severity, bar conditions, and hopper dredge availability. During this period of the MCR project, some degree of shoaling was tolerated within the channel and depths across the bar were attained without continual maintenance dredging. Dredged material disposal was typically conducted offshore at an area 1 to 2 miles southwest of the south jetty in water depths of 60 feet (figure B-5), near the modern-day ocean dredged material disposal site A [Lockett 1965]. It was assumed in this exhibit that 70% of the sediment dredged at MCR between 1904 and 1944 (5.8 million cy) was placed at the offshore location in vicinity of disposal site A. The other 30 % of MCR dredged material was assumed to be placed at estuarine disposal sites.

MCR Dredging and Disposal After 1945

Consistent annual maintenance dredging at MCR (and use of specific ocean sites for the disposal of dredged sediment) began in 1945 and has continued to the present. Dredging at MCR is performed by hopper dredges. The need for annual dredging at MCR was based upon deeper draft requirements of modern ocean-going vessels and the need for reliable channel dimensions conforming to the authorized project. Between 1945 and 1955, approximately 13 million cy (an average of 1.2 million cy/yr) was dredged at the MCR bar and placed in ocean or estuarine disposal sites (table B-2). To address the needs of modern ocean navigation, the MCR channel entrance was deepened (by dredging) to 48 feet in 1956. Beginning in 1977, the MCR navigation channel was maintained to its full authorized dimensions and advance maintenance dredging was conducted to a depth of 52 ft (48 ft plus 5 ft for advance maintenance). In 1984, the channel was deepened to its present authorized depth of 55 feet below MLLW. The present authorized MCR deep draft navigation project (Rivers and Harbor Act of 1884, 1905, 1954; and Public Law 98-63) provides for a 2,640-foot-wide channel across the Columbia River Bar. The northerly

2,000 feet of the channel is maintained at -55 feet MLLW (plus 5-feet for advance maintenance dredging), and the southerly 640 feet of the channel is maintained at -48 feet MLLW (plus 5-feet for advance maintenance dredging).

Table B-2. MCR bar dredging volume per year between 1945 and 1955.

Fiscal Year	Amount Dredged at MCR Bar (cy)
1945	393,000
1946	186,000
1947	483,000
1948	1,030,000
1949	1,042,000
1950	927,000
1951	1,000,000
1952	1,267,000
1953	2,796,000
1954	2,141,000
1955	1,749,000
Total	13,014,000 cy
(Average for each year of dredging 1945-1955 =	1,183,000 cy/yr)

The present MCR project is affected by two principle shoaling areas (figure B-5 and B-6). The outer (ebb tidal) bar, influenced by Peacock Spit on the Washington (north) side of the channel and Clatsop Spit on the Oregon (south) side of the channel, extends from approximately RM -2 to RM -1. The inner (flood tidal) shoal, influenced mainly by Clatsop Shoal, is located on the south side of the channel extends from approximately RM 0 to RM 3 [Siipola & Braun 1995]. In its present configuration, the entrance channel at MCR requires annual average dredging of 4.5 million cy of shoaled sediment to maintain the navigation channel at the authorized depth. The sediment dredged at MCR is sand, most of which is transported into the navigation channel from Clatsop Spit.

From 1904, the initiation of hopper dredging at MCR, until 1958 dredged material was placed primarily offshore at an area 1 to 2 miles southwest of the south jetty in water depths of 60 feet, near the present ocean dredged material disposal site A (figure B-5). This area had historically been the primary location of dredged material disposal because it was located beyond the navigation channel in deep water where the wind and wave conditions were favorable for hopper dredges to transit during the dredging season. It was assumed in this exhibit that 70% of the sediment dredged at MCR during 1945-1955 (8.3 million cy or 828,000 cy/yr) was placed in vicinity of disposal site A [Lockett 1965]. For the other 30% of MCR dredged material, it was assumed that 10% was placed at the offshore location in vicinity of disposal site B, and 20% at estuarine disposal sites.

In 1958, use of disposal area A (and vicinity) was discontinued based on recommendations of the USACE Committee on Tidal Hydraulics [1957]. These recommendations were based on: A) Field observations of bottom current in vicinity of disposal area A indicating a bottom flow predominately toward the navigation channel,

TABLE B-3. Disposal of Dredged Material at Mouth of the Columbia River ODMDSs (1956-1998)

(MCR & Tongue Point Dredged Material Deposited at Cited Disposal Areas)

Disposal Site	A	B	C*	D *	E	F	G	Total cubic yards
Fiscal Year	cy	cy	cy	cy	cy	cy	cy	cy
1956	12,096,000	1,296,000	504,000	504,000	0	0	0	14,400,000
1957	1,605,643	1,221,307	422,071	838,428	0	0	0	4,087,449
1958	6,135	2,274,704	0	326,753	0	0	0	2,607,592
1959	0	1,914,964	0	661,021	0	0	0	2,575,985
1960	0	1,927,208	0	612,636	0	0	0	2,539,844
1961	0	1,837,879	0	297,066	0	0	0	2,134,945
1962	0	2,322,256	2,838	632,618	0	0	0	2,957,712
1963	0	1,725,851	724,630	234,735	0	0	0	2,685,216
1964	0	514,900	1,459,186	683,151	0	0	0	2,657,237
1965	0	675,921	1,205,090	1,606,671	0	0	0	3,487,682
1966	0	2,010,673	29,891	2,437,451	0	215,002	0	4,693,017
1967	0	1,463,573	1,067	354,700	0	422,066	0	2,241,406
1968	0	1,919,199	0	109,592	0	0	0	2,028,791
1969	0	2,021,562	0	89,042	0	0	0	2,110,604
1970	0	1,489,795	0	3,060	0	0	0	1,492,855
1971	51,047	1,439,042	13,818	241,689	0	0	0	1,745,596
1972	12,995	2,579,688	0	287,646	0	1,886	0	2,882,215
1973	0	3,051,662	0	409,640	291,439	3,060	0	3,755,801
1974	0	994,059	0	506,711	2,168,543	29,123	0	3,698,436
1975	0	333,462	0	895,594	4,886,792	27,539	0	6,143,387
1976	2,574	1,017,100	0	758,743	4,257,150	53,250	602,895	6,691,712
1977	2,867,393	1,868,579	0	710,373	3,678,429	0	0	9,124,774
1978	3,060	187,704	0	312,635	3,925,986	0	0	4,429,385
1979	0	116,502	0	158,466	4,930,840	0	0	5,205,808
1980	11,142	118,686	0	0	2,675,722	0	0	2,805,550
1981	2,254,321	9,180	0	0	3,042,896	0	0	5,306,397
1982	971,209	12,240	0	0	3,086,514	0	0	4,069,963
1983	1,124,466	199,969	0	0	606,218	0	0	1,930,653
1984	4,060,853	3,864,247	0	0	989,600	0	0	8,914,700
1985	1,326,150	2,068,927	0	0	4,126,429	0	0	7,521,506
1986	2,037,455	3,387,376	0	0	2,926,412	0	0	8,351,243
1987	1,593,550	1,209,358	0	0	1,183,050	0	0	3,985,958
1988	1,447,240	4,533,756	0	0	478,864	0	0	6,459,860
1989	647,458	3,456,285	0	0	568,522	2,030,954	0	6,703,219
1990	2,729,358	1,119,663	0	0	507,201	0	0	4,356,222
1991	1,486,938	1,956,570	0	0	380,142	0	0	3,823,650
1992	874,700	2,888,028	0	0	796,198	0	0	4,558,926
1993	0	1,629,208	0	0	988,208	2,288,431	0	4,905,847
1994	408,924	1,002,668	0	0	397,621	1,500,407	0	3,309,620
1995	0	2,480,664	0	0	988,547	0	0	3,469,211
1996	0	1,693,145	0	0	726,336	2,205,113	0	4,624,594
1997	0	326,824	0	0	1,171,246	174,883	0	1,672,953
1998	0	0	0	0	3,444,656	820,722	0	4,265,378
Totals	37,618,611	68,160,384	4,362,591	13,672,421	53,223,561	8,776,831	602,895	187,412,899
Volume of **sediment** placed in Ocean Dredged Material Disposal Sites for 1956-1998 (cy)								***173,740,478***
Annual Avg 1990-1998	ODMDS A **611,102**	ODMDS B **1,455,197**			ODMDS E **1,044,462**	ODMDS F **776,617**	Annual avg. for 1990-1998	3,887,378
Note 1 : ODMDSs receive *Interim* designation in 1977 .							1986-1989	6,375,070
Note 2: Final designation of ODMDSs in 1986 .							1977-1985	5,478,748
Note 3: * Estuarine disposal site.							1956-1976	3,696,071

and B) An assumption that shoaling on the outer bar was due to the return of dredged material placed at disposal area A. Between 1958-71, area A was not used for dredged material disposal. Other disposal areas located further offshore (area B and F) were used more extensively. After 1971, the vicinity of area A has been used intermittently for dredged material disposal. At present, the sandy dredged material is placed in EPA-designated ocean dredged material disposal sites, as has been the case since 1977. The annual volume of dredged material placed at MCR dredged material disposal sites since 1956 is summarized in table B-3 and figure B-7. The total volume of material dredged from the MCR channel between 1904 and 1998 is estimated to be 209 million cy.

Past and Present MCR Dredged Material Disposal Sites

Figure B-5 illustrates the general layout of the 7 open water sites that were used for dredged material disposal ***prior*** to 1977. Sites A, B, E, F, and G were classified as *ocean disposal sites*. Sites C and D were classified as *estuarine disposal sites*. Prior to EPA's 1977 *interim* site designation, the location of MCR ocean disposal sites was not precisely specified and the placement of dredged material was not strictly controlled, in terms of hopper dredges being positioned within the disposal area during release of dredged material.

Estuarine Dredged Material Disposal Sites

In the past, estuarine disposal sites C and D have been used for open water placement of sediments dredged from the MCR channel when wind and wave conditions precluded the dredge from leaving the entrance. Estuarine disposal site C was located just inside and along the north jetty and site D was located in the estuary adjacent to Desdemona Sands channel. Site C received moderate amounts of dredged material until 1971, at which time disposal in this site was discontinued, due to concerns that the site's capacity to accept dredged material had been exceeded. Refer to Section 4 of this exhibit for the definition of disposal site capacity. It was believed that dredged material placed at site C was being transported eastward into the estuary and navigation channel. Site D was used for disposal of sediment dredged from the MCR channel and locations further in the estuary. Use of Site D was curtailed in 1980 due to concerns of placed dredged material being transported northward into Baker Bay. At present, sediment dredged from the MCR project is not placed in estuarine disposal sites: All MCR dredged material is placed in ocean disposal sites. Use of site C may resume in the future, depending upon environmental clearances and permit issues (addressed under the Clean Water Act, section 404). If site C is used, the site will be managed within context of its limited capacity (estimated to be 500,000 cy per year). Use of site C (also known as the "north jetty" site) will not be addressed in this exhibit.

Designation of Ocean Dredged Material Disposal Sites

In January 1977, ocean disposal sites A, B, E, and F received *Interim* designations when EPA issued the final Ocean Dumping Regulations (40 CFR 228). At the time of *Interim* site designation, the boundaries for these rectangular disposal sites were fixed geographically in terms of corner coordinates. Figure B-6 denotes the boundaries for the EPA-designated interim disposal sites A, B, E, and F (thin solid line defining the smallest boundary shown for each disposal site). The *Interim* sites were "sized" based on the perceived need to minimize the areal extent over which dredged sediments would affect the receiving water column and seabed during disposal. Smaller sites were considered more environmentally acceptable than larger sites. Sediment dredged from the MCR navigation channel is composed of sand and contains very little fine-grained material (less than 4% by weight, smaller than 0.0625 mm).

An environmental impact statement (EIS) recommending the final designation of the four interim sites was completed in February 1983 [EPA 1983]. Due to findings reported in the above EIS, long-term disposal site capacity was not considered to be a driving factor in the development of MCR ODMDS layout. Refer to Section 4 of this exhibit for the definition of ODMDS capacity. Shoaling at site B due to dredged material disposal during 1945-1975 was 20 ft (or 0.67 ft/yr over 30 years). The 1983 EIS stated that "mounds of accumulated dredged sediment tend to spread laterally and flatten under the influence of bottom currents and wave-induced turbulence" [EPA 1983 and Sternberg, et al 1977]. The 1983 EIS acknowledged that the "loading-up" of disposal site A during 1956 (12 million cy was placed in one year) did create a mounding problem and that concentrating dumping in one specific disposal site may aggravate sediment accumulation [EPA 1983]. The 1983 EIS concluded that continuation of ocean disposal of sediment dredged from MCR (approximately 6 million cy/yr, estimated in 1983) would have few if any significant adverse impacts, as long as dredged material disposal was not limited to one specific disposal site.

Ocean **d**redged **m**aterial **d**isposal **s**ites (***ODMDS***) A, B, E, and F received final designation in August 1986 (51 FR 29923-29927). At the time of final designation, the size of the designated ODMDS was based on the need to minimize the area of potential benthic impacts. Shoaling of dumped dredged material was not considered to pose a problem to navigation. The rationale employed for designation of ODMDS A, B, E and F was based on the 1983 EIS. Consequently, the areal extent of the final designated ODMDSs was the same as the *Interim* sites, shown in figure B-6.

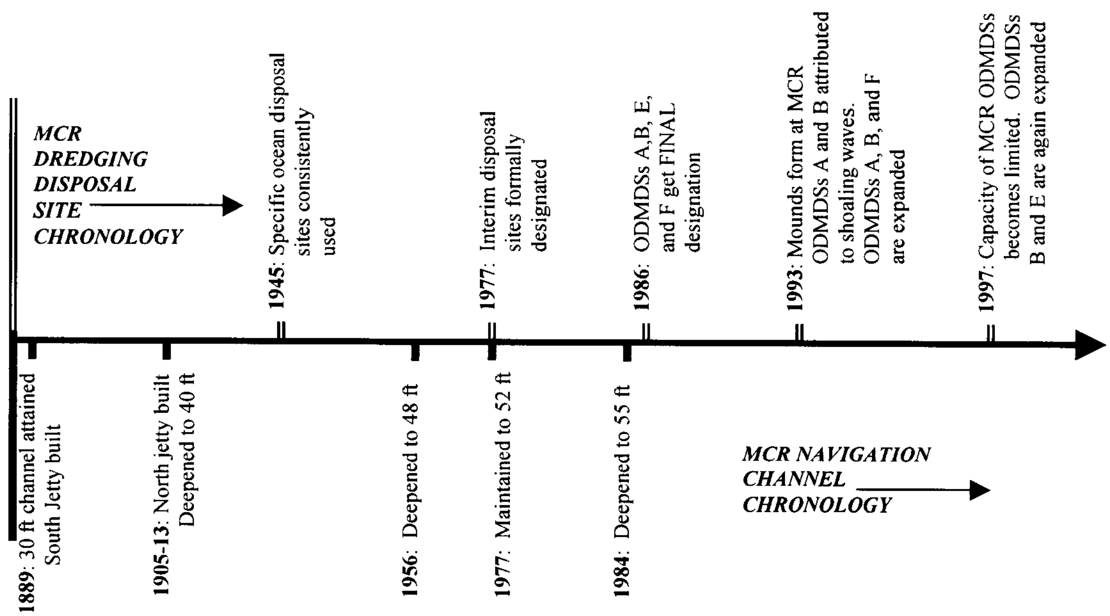


Figure B-8. Timeline for development of the navigation channel and ODMDSs at MCR

Between 1980 and 1998, all sediment dredged from the MCR project was placed at sites A, B, E, and F. In 1993, ODMDS A, B, and F were expanded to meet dredged material disposal capacity needs (figure B-6, bold solid line). In 1997, ODMDS B and E were temporarily expanded to meet dredged material disposal capacity needs, until an appropriately sized ODMDS can be designated (figure B-6, bold dashed line). A project timeline linking MCR navigation channel development to disposal site designation is shown above in figure B-8.

Summary of Present ODMDS Use

Since 1977, ODMDSs A, B, E and F have been the ***primary*** locations where MCR dredged material (sand) has been placed. These four ODMDSs are located on the seaward flank of the MCR ebb-tidal shoal and are economical (in terms of haul distance) for disposal of sediments dredged from both the outer and inner bars at MCR. ODMDSs at MCR have been used in varying degrees, through time expanded to address disposal site management issues. Between 1977 and 1987, most of the sediment dredged at MCR was placed in ODMDS A and E. Beginning in 1984, use of ODMDS B was increased as use of ODMDS E was reduced. In 1988, the volume of dredged material placed in ODMDS E was restricted to 1 million cubic yards/year to prevent dredged material accumulation (mounding) and limit possible transport of placed dredged material eastward back into the estuary or southward into the MCR channel. ODMDS E is located immediately seaward of the north jetty, within the throat of the Columbia River entrance. The continual use of ODMDS E is partially in response to a request from the

Washington Department of Ecology to enhance sand by-passing and retard erosion of the coastal beaches north of MCR.

During 1991 and 1996, ODMDS B had received most of the MCR dredged material as concerns arose that sediment placed in ODMDS A were accumulating, creating an adverse wave climate, and might migrate northward back into the entrance channel. Recent use of ODMDS F began in 1989, motivated by the need to: A) Disposal of sediments dredged from locations other than MCR [such as fine-grain sediment dredged from Tongue Point channel in 1989] and, B) Meet MCR disposal site capacity requirements for maintenance dredging without overloading sites A, B, and E. ODMDS F is located immediately offshore of the MCR ebb-tidal shoal within the alignment to the MCR entrance channel.

Section 2
MANAGEMENT OF OCEAN DREDGED MATERIAL DISPOSAL SITES AT MCR

Since 1945, five openwater disposal sites have been utilized by the Portland District for ocean placement of channel sediments dredged at the MCR. The rational for ODMDS use and management has changed significantly since 1945, the year that marks the beginning of consistent annual maintenance dredging at MCR. The transition in the year to year management of MCR ODMDS is characterized by three (3) important shifts in USACE and EPA policy which are outlined below. The average annual volume of sediment dredged at MCR (and placed in open water) has also varied through time, as shown in tables B-1, B-2, the bottom right of table B-3.

MCR Ocean Dredging Disposal Before 1977

Prior to formal designation of *Interim* dredged material disposal sites in 1977, dredged material disposal areas at MCR were sited only in terms of general location and areal configuration. Placement of dredged material within the disposal areas was governed by the need to minimize navigational impact (from dumped dredged material being transported back into the navigation channel) and minimize haul distance. Mounding of dumped dredged material did not appear to be a concern due to the spatial variability of dredged material disposal within a given site: The site boundaries were not fixed and it was not required to place material strictly within the disposal site. The operational "flexibility" of disposal site boundaries and vessel control during material placement resulted in a higher degree of dredged material dispersal than at present. Prior to 1977, average annual dredging at MCR was 3.7 million cy and the dredged material was placed over a wider areal expanse than the configuration of the disposal areas indicate.

MCR Ocean Dredging Disposal: 1977 to 1985

Between 1977 and 1985, the management of the *Interim* dredged material disposal sites at MCR was characterized by the transition from unregulated ocean dredged material disposal to a regulated program. In January 1977, four active ocean disposal sites at MCR received interim designations when EPA issued the final Ocean Dumping Regulations (40 CFR 228). The *Interim* configuration for each disposal site (figure B-6, smallest configuration for each site) was governed by the requirement to minimize the benthic area of impact due to openwater disposal of dredged sediments. The size of *Interim* sites A and B was 2,000 ft x 5,000 ft. *Interim* site E was 1,000 ft x 4,000 ft. *Interim* site F was 1,800 ft x 1,800 ft. The areal size of *Interim* disposal sites at MCR was based on:

ODMDS length = average dumping run for one dump
= (disposal vessel speed while dumping) **x** (time to empty disposal vessel)

ODMDS width = average turn during one dump = disposal vessel turning radius while dumping

ODMDS long axis orientation = preferential approach-heading during dredged material disposal. (site orientation is set by disposal vessel operators and is based on dumping efficiency and vessel sea-keeping due to incident wave direction)

Prior to the 1980's, sediment dredged at MCR and placed in open water disposal sites was accomplished using government hopper dredges. ***Government*** hopper dredges utilize a series of "doors" located on the hull bottom to release each load of dredged material. The bottom doors are sequentially opened during disposal until the entire load of dredged material is released form the vessel, resulting in a gradual release of dredged material from the vessel.

After 1980, approximately half of the material dredged at MCR was accomplished using contractor split-hull hopper dredges. ***Contractor*** split-hull hopper dredges release their load of dredged material by opening (splitting) the entire hull of the vessel. The split-hull method of disposal is more rapid (efficient) than bottom-door hopper dredges. While the use of split-hull hopper dredges reduces the time required for material disposal, split-hull dredges reduce the horizontal dispersal of dumped dredged material on the seabed while increasing the vertical extent of accumulation per dump.

To comply with the Ocean Dumping Regulations (40 CFR 228), the Portland District contract specifications required ***contract*** dredges to place dredged material entirely within the *Interim* disposal boundaries. The disposal site corner coordinates and a single disposal coordinate were given as a reference for disposal position within the ODMDSs. No reference was made regarding uniform spreading of dredged material placed within the ODMDSs. Conceptually, placement of dredged material was done randomly at some "radius" about the specified disposal coordinate. Similar methods of disposal control were also used to position ***government*** dredges within the *Interim* sites during dredged material disposal at MCR. Efficiency-oriented dredging contractors likely placed dredged material on the extreme channel-side of the disposal area (or buoy location) to shorten the haul distance while minimizing the aerial extent of dispersal. This method of dredged material disposal is referred to as "point-dumping" (repeated placement of dredged material at a fixed location). Point-dumping enhanced the vertical accumulation of dredged material within the small area of the *Interim* disposal sites. Although ***government*** dredges produced a more dispersive foot-print on the seabed (per dump) than contractor dredges, restricting disposal operations to the small area of the *Interim* sites likely resulted in point dumping. Utilizing the *Interim* disposal sites as described above, resulted in a faster rate of vertical accumulation of dredged material placed within the sites than periods before 1977. Note that during 1977 to 1985, the average annual volume of sediment dredged at MCR was 5.5 million cy, which was 49% higher than the period from 1945 to 1977.

MCR Ocean Dredging Disposal: 1986 to Present

In August 1986, the MCR *Interim* disposal sites A, B, E, and F received final EPA designation as ocean dredged material disposal sites (ODMDS). After final ODMDS designation, disposal site management at MCR became increasingly proactive in the year to year operation of ODMDSs. Proactive disposal site management was required to achieve maximum utilization of site capacity within the restricted area of EPA designated ODMDSs. The average annual volume of sediment dredged at MCR during 1986 to 1989 was 6.4 million cy, which was 13% higher than the period from 1977 to 1985 (73% higher than 1945-1977). In 1990, highly accurate navigation and positioning control became available for hopper dredges operating on the open coast. Vessel position was known to several meters accuracy, on a real-time basis. Hence, the hopper dredges could reliably place dredged material within the assigned ODMDS locations during all times of operation [Soderlind 1995]. Instead of placing material within some marginal "radius" of a pre-determined location, hopper dredges could return to the exact assigned dump coordinate and place dredged material within a very limited area. The average annual volume of sediment dredged at MCR during 1990 to 1997 was 3.8 million cy, equivalent to the average for 1956-1976. Even though the rate of dredging at MCR had decreased after 1990, the repetition of dredged material disposal at specific locations within small ODMDSs resulted in continued accumulation (mounding of placed material) at sites A and B.

The unintended consequence of "aggressively" using areally restricted ODMDSs at MCR was the rapid accumulation of dredged material placed within ODMDS A and B. Rapid accumulation of dredged material placed within ODMDS A and B resulted in the formation of large mounds, which may potentially interact with incoming waves to create hazards to navigation at the MCR entrance (described in Section 3, Recent Bathymetric Change at MCR ODMDSs). The reason for rapid accumulation (mounding) of dredged material placed within the ODMDS A and B, since 1977, has been attributed to four factors:

(A) The restriction of dredged material disposal within small EPA-designated ODMDSs (beginning in 1977).

(B) The improvement in vessel navigation (beginning in 1990), allowing for precise positioning control during disposal and repeated dumping at the same location.

(C) Increased use of contractor operated split-hull hopper dredges (beginning in the 1980's), which enhanced the vertical extent, per dump, of dredged material placed on the seabed within the ODMDSs.

(D) The annual volume of sediment dredged from the MCR and placed in ODMDSs during 1977-1990 was 60% greater than 1956-1976. The reason for higher dredging and disposal volume at MCR during 1977-90 is attributed to the MCR channel deepening of 1977 and 1984, and related channel side-slope adjustments.

If ODMDSs A and B had any potential for dispersing placed dredged material, the volume of dredged material placed at these sites far exceeded the dispersvie capability. It must be noted, that continual use of ODMDS E (from 1973-97) has not resulted an any persistent mounding or related navigation impacts. ODMDS E has exhibited substantial dispersion with respect to the volume of dredged material placed at this site. In this regard, ODMDS E has been successfully managed for dredged material disposal purposes.

Recent Management Actions for MCR ODMDSs

Since 1985, unanticipated bathymetric mounding has occurred at ODMDSs A and B due to rapid accumulation of placed dredged material. In 1992, the mounding of dredged material placed at ODMDSs A and B began to adversely affect navigation at the MCR entrance. To avoid hazards associated with dredged material mounding, temporary expansion of sites A, B and F were coordinated with regional resource agencies in 1993 and an operational policy of uniform placement (vs. point disposal) of dredged material was implemented. Since 1992, ODMDSs have been managed to achieve maximum site capacity while avoiding additional impacts to navigation, due to mounding [Siipola and Braun 1995].

An important facet of ODMDS management includes consistent site monitoring. Bathymetric surveys serve as the method of choice to monitor the physical environment at the ODMDSs. Consistent annual bathymetric surveys have been conducted at MCR ODMDSs and vicinity since 1983; the x,y,z data has been digitally stored. Since 1992, ODMDS surveys have been conducted twice annually, before and after the dredging season (June-October). The semi-annual monitoring is necessary to track bathymetric change at the ODMDSs, ensure that the Corps of Engineers does not un-intentionally worsen the mounding problem, or place dredged material outside of the active ODMDS boundaries. Based on the bathymetric monitoring of MCR ODMDSs, the specified location of dredged material disposal has been shifted throughout a given ODMDS on an annual basis to avoid "hitting" high spots created by the previous years' disposal operation. Despite the effort to evenly distribute dredged material within MCR ODMDS A and B, dredged material has slowly accumulated within these sites since 1992. The mounding of dredged material placed at ODMDS A and B during 1986 to 1997 was much greater than expected, when these sites were designated as ODMDS sites in 1986 [EPA 1983].

Present Configuration of MCR ODMDS

In 1997, additional temporary expansion of ODMDSs B and E was coordinated with regional resource agencies and special management options implemented [USACE 1997]. ODMDS B was expanded to avoid placement of dredged material on the existing mound, located within the 1993 site boundary (figure B-6). ODMDS E was expanded to promote the dispersion of placed dredged material; to avoid mounding and promote bottom transport of placed dredged material into the littoral sediment budget. The lineal dimensions, boundary coordinates, and water depth variation for the present MCR ODMDSs (expanded A, B, E, and F) are described below. Disposal boundary coordinates are in state plane, Oregon north zone, NAD 27 (ft) and geographic coordinates (NAD83). These boundaries apply to the 1997 ODMDS configuration, as shown in figure B-6 (outer boundary). Refer to the main report of Appendix H, for description of the originally designated (1986) ODMDS boundaries.

ODMDS "A": dimensions = 6,000 ft x 4,000 ft, azimuth = 225°, average depth = 70 ft
1994 elevation variation = -90 MLLW to -42 MLLW

Northwest corner -	Easting=1,083,484 ft,	Northing=946,096 ft	Lat=46 12 18 N,	lng=124 07 18 W
Northeast corner: -	Easting=1,087,695 ft,	Northing=950,370 ft	Lat=46 13 02 N,	lng=124 06 21 W
Southwest corner: -	Easting=1,086,334 ft,	Northing=943,289 ft	Lat=46 11 52 N,	lng=124 06 36 W
Southeast corner: -	Easting=1,090,544 ft,	Northing=947,563 ft	Lat=46 12 36 N,	lng=124 05 39 W

ODMDS "B": dimensions = 12,000 ft x 24,000 ft, azimuth = 62°, average depth = 150 ft
1994 elevation variation = -220 MLLW to -50 MLLW

Northwest corner -	Easting=1,051,147 ft,	Northing=959,676 ft	Lat=46 16 10 N,	lng=124 10 01 W
Northeast corner: -	Easting=1,073,123 ft,	Northing=970,017 ft	Lat=46 14 32 N,	lng=124 08 40 W
Southwest corner: -	Easting=1,056,318 ft,	Northing=948,688 ft	Lat=46 14 18 N,	lng=124 15 07 W
Southeast corner: -	Easting=1,078,294 ft,	Northing=959,029 ft	Lat=46 15 31 N,	lng=124 13 46 W

ODMDS "E": dimensions = 2,000 ft x 10,000 ft, azimuth = 229°, average depth = 55 ft
1994 elevation variation = -75 MLLW to -46 MLLW

Northwest corner -	Easting=1,082,928 ft,	Northing=962,314 ft	Lat=46 15 35 N,	lng=124 05 15 W
Northeast corner: -	Easting=1,092,272 ft,	Northing=966,392 ft	Lat=46 13 02 N,	lng=124 06 21 W
Southwest corner: -	Easting=1,085,149 ft,	Northing=959,481 ft	Lat=46 14 58 N,	lng=124 07 37 W
Southeast corner: -	Easting=1,093,020 ft,	Northing=965,649 ft	Lat=46 14 31 N,	lng=124 07 03 W

ODMDS "F": dimensions = 10,000 ft x 10,000 ft, azimuth = 225°, average depth = 125 ft
1994 elevation variation = -180 MLLW to -90 MLLW

Northwest corner -	Easting=1,068,886 ft,	Northing=944,684 ft	Lat=46 11 58 N,	lng=124 10 45 W
Northeast corner: -	Easting=1,076,130 ft,	Northing=951,578 ft	Lat=46 13 09 N,	lng=124 09 07 W
Southwest corner: -	Easting=1,075,780 ft,	Northing=937,440 ft	Lat=46 10 49 N,	lng=124 09 03 W
Southeast corner: -	Easting=1,083,024 ft,	Northing=944,334 ft	Lat=46 12 00 N,	lng=124 07 24 W

Section 3
RECENT BATHYMETRIC CHANGE AT MCR AND RELATED NAVIGATION IMPACTS

This section is composed of three parts. First, ***large-scale bathymetric change*** of the MCR entrance channel and ebb-tidal shoal is discussed for the time period between 1985 and 1997. Following the large-scale bathymetry change discussions, ***site specific bathymetric change*** at MCR ODMDSs is discussed in terms of the mounding of placed dredged material. Recent utilization of expanded ODMDS E is specifically addressed. Finally, the change in ***wave conditions*** at the MCR entrance due to recent the mounding of dredged material placed within the ODMDSs is discussed. The accuracy standards of bathymetry data used in this exhibit is described in Section 8, *Measured Oceanographic Data*.

Regional Bathymetric Change at MCR

Three survey years were used to assess *recent* regional bathymetry change at MCR: 1985, 1994, and 1997. The left graphic in figure B-9 describes the approach bathymetry at MCR for 1985. The right graphic of figure B-9 describes the approach bathymetry at MCR for 1994. The boundaries (1993 configuration) for ODMDSs A, B, E, and F are shown in figure B-9. The 1997 bathymetry for MCR and vicinity is shown in figure B-10 along with the expanded boundaries (1997) for MCR ODMDS B and E. The bold dashed rectangle shown in the center of figures B-9 and B-10 defines the feature area of analysis for the regional bathymetry change and wave amplification assessment, discussed later in this section. Note the change in bathymetry (mounding) within the 1993 boundaries of ODMDS A and B between 1985 and 1994 (figure B-9). Between 1985 and 1997, note the decrease in seabed elevation (depth increase) at the MCR entrance, just offshore of the jetties.

To fully delineate recent bathymetric change at MCR, "difference" plots were obtained by subtracting different year surveys of the approach bathymetry. The left graphic shown in figure B-11 is the result of subtracting the 1985 MCR approach bathymetry from the 1994 approach bathymetry. The bold dashed boarder defines the feature area of bathymetry change analysis, as referenced in figure B-9. Note the significant mounding (of placed dredged material) that occurred within ODMDS A and B between 1985 and 1994. ODMDS F experienced limited mounding.

The vicinity of the MCR entrance channel (including ODMDS E) underwent a significant increase in depth due to a combination of erosion and dredging. The right graphic shown in figure B-11 is the result of subtracting the 1994 approach bathymetry from the 1997 approach bathymetry. Note the depth increase that occurred at specific areas within ODMDS A and B between 1994 and 1997. During this time, limited mounding occurred along the western flank of ODMDS B, while Peacock Spit (north of ODMDS E) experienced an increase in depth due to seabed erosion.

Figure B-12 shows the regional bathymtric change that occurred at MCR between 1985 and 1997. Two extremes of bathymetric change are present in figure B-12. Significant mounding is evident in ODMDS B, and to a lesser extent, the eastern and western perimeter of ODMDS A. The middle area of ODMDS A experienced net erosion between 1985 and 1997. Modest mounding occurred in ODMDS F during 1985 to 1997. Significant deepening occurred within the MCR entrance and adjacent areas to the north and south. Note that the entire area of expanded ODMDS E is contained within a region that experienced 5-10 feet of erosion between 1985 and 1997. Based on the regional bathymetry change shown in B-8 and B-9, areas near the MCR (ODMDS A and E) appear to be more favorable for the dispersion of placed dredged material than areas offshore MCR (ODMDS B and F). The above finding infers that ODMDS E has the highest potential to disperse placed dredged material, with ODMDS A demonstrating moderate dispersion potential. The area near the top of the mound in ODMDS B appears to be moderately dispersive. ODMDS F does not appear to be dispersive with respect to the dredged material placed at this site.

Potential Impacts of Regional Bathymetric Change on Navigation at MCR

Existing navigation conditions at MCR are, in part, a function of the bathymetry. From year to year, the bathymetry at MCR can experience significant change (5-10 ft or more) due to environmental forcing caused by episodic events such as high Columbia river flow due to freshets, El Nino, and La Nina. Additionally, the bathymetry near the MCR is continually re-adjusting to the influence of jetties constructed at the estuary mouth. Figure B-4 shows the bathymetry re-adjustment that took place at MCR during 1916-1950 in response to jetty construction. While most of the bathymetry re-adjustment due to jetty construction has already occurred, the MCR bathymetry is still attaining equilibrium. Note that since 1950, the leading edge of ebb-tidal shoal has continued to be displaced toward the northwest at the expense of the shoal's crest (ie. the crest of the ebb-tidal shoal has been eroded while the seaward edge migrates toward the northwest). During 1985 and 1997, the seabed in vicinity of Peacock spit was lowered 5-10 ft (by estuarine scour and dredging), allowing larger ocean waves to propagate further into the MCR entrance. Although increased depth (due to natural causes-erosion) in and around the MCR entrance channel is desirable from a maintenance dredging perspective, the propagation of potentially larger waves through MCR entrance channel may degrade navigation and adversely affect the structural integrity of the north and south jetties.

Small-vessel traffic patterns in and around ocean entrances to estuaries tend to be a function of the bathymetry and attendant wave conditions. Since small-vessel navigation at MCR is affected by natural modification of the bathymetry, so then small vessel patterns may be required to change with time (due to the natural redistribution of shoal material on Peacock Spit).

Site Specific Bathymetric Change at MCR ODMDS

Bathymetric change at MCR ODMDSs, in terms of the mounding of placed dredged material, is discussed below. Analyses were limited to time periods in which reliable survey data was available. The time period of bathymetric change analysis for ODMDS A was from 1957 to 1995, with graphical results are shown for the time period 1981 to 1995 in terms of the 1993-expanded ODMDS boundary. The time period of bathymetric change analysis for ODMSD B and F was from 1981 to 1997, with graphical results shown in terms of the 1993-expanded ODMDS boundaries. The time period of analysis used for ODMSD E was from 1990 to 1997 with graphical results shown in terms of the originally-designated 1986 ODMDS boundaries. Recent (1997-98) bathymetric change observed within the 1997-expanded boundary at ODMDS E is also described.

ODMDS A

Prior to formal designation as an *Interim* ocean disposal site in 1977, about 28 million cy of dredged sediment had been placed within or in vicinity of Site A (1904 to 1976). The average annual volume of dredged material placed in Site A between 1945-1958 was 1.6 million cy/yr. About 49% of the dredged material placed at Site A during 1945-58 (13.7 million cy), occurred within a 2 year period (1956-57) and resulted in rapid mounding. Consequently, use of Site A was discontinued from 1959 to 1971.

A small volume of dredged material was placed at Site A during 1971-1976. Based on a 1975 MCR bathymetry survey, there was little indication of dredged material mounding at Site A as a result of the 1956-57 high volume disposal [Sternberg 1977]. Apparently, much of the dredged material placed at Site A during 1956-57 had been dispersed during the period of 1958-1975. This would infer a maximum dispersion rate of 800,000 cy/yr (13.7 million cy/17 years), assuming all dredged material placed during 1956-57 was dispersed out of Site A by 1975. It is likely that a lesser amount of dispersion took place, since there was some indication of mounding in the 1975 survey. The fact that most of the dredged material placed at site A (during 1956-57) had dispersed within a 20-year time frame likely contributed to consideration of Site A as an *Interim* site in 1977.

At the time of final *ODMDS* designation in 1986, Site A was not considered to have a mounding problem [EPA 1983]. The above assessment was based on MCR bathymetry surveys conducted in 1975 and 1978. Between 1977 and 1991, approximately 22.5 million cy of dredged material was placed within ODMDS A boundaries (average of 1.6 million cy/yr); 20% of which was placed by Contractor-operated split-hull hopper dredges. Based on a 1985 survey (left caption, figure B-9), mounding of dredged material Site A was beginning to occur in 1985. By 1992, significant mounding of dredged material was reported within ODMDS A.

In 1993 ODMDS A was expanded (figure B-6) and placement of dredged material within that site was restricted to a maximum of 1.5 million cy annually. Only the western third of this site was used, and only during the summer months when nearshore currents are believed to flow southward [Siipola and Braun 1995]. Even though ODMDS A was expanded in 1993, the site has received only 408,000 cy of dredged material since that time. In May 1993 mounding at ODMDS A, due to dredged material placement, reached -36 ft MLLW. The mound was 36 ft high relative to the 1981 bathymetry. Instances of steepened, amplified, and breaking wave conditions in vicinity of ODMDS A were reported, by navigation interests transiting the MCR entrance channel. The wave effects were attributed to the mound at ODMDS A. Consequently, the disposal of dredged at ODMDS A has not occurred since 1994. Between May 1993 and July 1997, the maximum mound height at ODMDS A was reduced by 15 feet, from 36 ft to 21 ft (about 4 ft/yr), through sediment dissipation by waves and currents [Siipoal and Braun 1995(98)]. In 1997, the minimum bottom elevation within ODMDS A remained at -42 ft MLLW.

The left graphic in figure B-13 illustrates the accumulation of dredged material at ODMDS A from 1981 to 1995. Note that the height and areal coverage of the dredged material mound had dramatically increased since 1981. In 1995, the dredged material mound at ODMDS A was 25 ft high and extended 1,500 ft beyond the site boundaries, with respect to the 1981 bathymetry. The total volume gain associated with bathymetric change at ODMDS A (for entire area within left graphic) between 1981-1995 was calculated to be 15.4 million cy (based on differencing of 1981 and 1995 surveys). The actual volume of dredged material placed in ODMDS A during 1981-95 was estimated to be 21 million cy (dredge logs). Based on the above data, approximately 26% of the dredged material placed at site A (5.5 million cy) can not be accounted using bathymetric survey calculations. This volume "under-estimate" could be the result of: (A) an average vertical survey error of 1.7 ft – which is possible, (B) consistent over-reporting of dredged volumes in the logs - unlikely, or (C) erosion-transport of placed dredged material out of the ODMDS and vicinity (to an apron thickness undetectable by surveys) - likely. It is likely that ODMDS A is somewhat dispersive, as shown in figure B-11 (right caption) and B-9, but not to a sufficient level to handle to consistent dredged material disposal exceeding 360,000 cy/yr (5.5 million cy placed over 15 yrs). The net direction of dredged material dispersion at ODMDS A appears to be northward toward the MCR entrance channel.

Although there appears to be a moderate rate of dispersion at ODMDS A, this site is considered to be non-dispersive with respect to the amount of dredged material which has been historically placed there during active site use (1.6 million cy/yr). Placement of dredged material in ODMDS A is currently restricted, due to the present mounding and potentially related adverse (wave shoaling) effects upon navigation. ODMDS A is near its capacity to handle additional dredged material disposal. If dredged material disposal at ODMDS A was indefinitely restricted, the dredged material mound (shown in the left caption of figure B-13) would be dispersed out of the site boundaries within 20-40 years from 1995. This conclusion was based on the estimated range in dispersion rate at Site A: 360,000 cy/yr (1981-95) to 800,000 cy/yr (1958-1975). It is assumed in this exhibit that the dispersion rate for ODMDS A is 360,000 cy/yr.

ODMDS B

Prior to formal designation as an *Interim* ocean disposal site in 1977, approximately 34 million cy of dredged sediment had been placed within or in vicinity of Site B (1945 to 1975). The year to year volume of dredged material placed at Site B during this time period was consistent with the average annual disposal volume of 1.8 million cy/yr.

Based on a 1975 MCR bathymetry survey, the accumulation of dredged material placed at Site B had resulted in a mound about 20 ft high with respect to the 1945 bathymetric condition [Sternberg 1977]. The accumulation of dredged material placed at Site B represented a shoaling rate of 0.67 ft/yr (between 1945 and 1975). In 1975, bathymetry within Site B varied between 80-140 ft, below MLLW. Given that the observed shoaling rate (due to dredged material disposal during 1945-75) was less than 1 ft/yr and that water depths in Site B were for the most part greater than 90 ft, continued use of Site B was not considered to present a problem to navigation. This finding likely contributed to consideration of Site B as an *Interim* site.

At the time of formal *ODMDS* designation in 1986, Site B was not considered to have a mounding problem and continued use of Site B was not considered to present a problem to navigation [EPA 1983]. The above assessment was based on a 1978 MCR bathymetry survey. Between 1977 and 1991, approximately 24.2 million cy of dredged material was placed within the ODMDS boundaries (average of 1.7 million cy/yr); 50% of which was placed by Contractor-operated split-hull hopper dredges. In 1992, significant mounding of dredged material was reported within ODMDS B.

In 1993 ODMDS B was expanded to 4,000 ft x 6,000 ft (figure B-6) and the site was divided into six 2,000'x2,000' cells. Dredged material disposal was managed by designating specific cells available for placement each year. Since 1993, dredged material placement has been restricted to the deeper portion of ODMDS B (the 3 western-most cells) to avoid placement on the mound that had formed within the *Interim* site boundaries. In September 1994, mounding at ODMDS B, due to dredged material placement, reached -42 ft MLLW: The dredged material mound had accumulated over 75 ft in height relative to the 1981 bathymetry [Siipola and Braun 1995]. Instances of steepened, amplified, and breaking wave conditions in vicinity of ODMDS B were reported, by navigation interests transiting the MCR entrance channel. The wave effects were attributed to the mound at ODMDS B. To minimize potential interference with navigation, the mound at ODMDS B was reduced 5-12 ft by dredging the top from –42 ft MLLW to -53 ft MLLW. The material was placed in the 3 western-most cells of the site. Between Fall 1994 and Summer 1997, the highest mound elevation at ODMDS B (located in the eastern half of the site) was further reduced by 7 feet, from -53 ft MLLW to -60 ft MLLW through sediment dissipation by waves and currents. The reduction in mound height represents an erosion rate of about 2 ft/yr, applicable for the top of the mound at ODMDS B. The equivalent volume of annual erosion was estimated to be

300,000 cy/yr [USACE 1997]. The above erosion "effect" at ODMDS B is considered to be confined to the shallow area of the site near the top of the dredged material mound.

The right graphic in figure B-13 illustrates the accumulation of dredged material at ODMDS B from 1981 to 1997. In 1997, the dredged material mound at ODMDS B was 55 ft high and extended more that 2,500 ft beyond the 1993-expanded site boundaries, with respect to the 1981 bathymetric condition. Note that prior to 1981, the accumulation of dredged material previously placed at Site B had formed a mound approximately 20 ft high with respect to the 1945 bathymetry [Sternberg 1977 and EPA 1983]. The total volume gain associated with bathymetric change at ODMDS B between 1981-1997 was calculated to be 37.6 million cy. This volume estimate was based on survey differencing and applies to the entire area shown in the right graphic of figure B-13. According to USACE-Portland District dredged logs, the actual volume of dredged material placed in ODMDS B during 1981-97 was estimated to be 31.5 million cy. Based on the above data, approximately 19% more "material" appears to be on the seabed than was placed at ODMDS B. This volume "overestimate" could be the result of: (A) an average vertical survey error of 1.7 ft - possible, (B) consistent under-reporting of dredged volumes in the logs - unlikely, or (C) a region-wide accumulation of sediment due to natural processes - possible. In either case, ODMDS B is ***not*** considered to be a dispersive site, with respect to the volume of dredged material placed (1.8 million cy/yr for 1990-1996, table B-3).

During 1993-1996, much of the dredged material that would have been placed at ODMDS B was diverted to ODMDS F to prevent further mounding at ODMDS B. Future disposal within the 1993 boundaries of ODMDS B has been limited since 1996, due to potential mounding effects on waves and navigation. In FY 1997, only 332,000 cy was placed in the western quarter of ODMDS B (relative to the 1993 site boundaries) to avoid wave amplification due to mounding. Due to the reliance on ODMDS B as a primary disposal site (68.2 million cy placed at this site since 1956, table B-3), Site B was temporarily expanded in 1997 [USACE 1997]. The 1997-expaned boundary of ODMDS B was intended to provide more than sufficient disposal capacity for a 3-5 year period while providing for the operational flexibility of disposal at nearshore (50-70 ft depth) and offshore areas (160-200 ft depth). A utilization plan for the 1997-expanded ODMDS B was developed to minimize benthic impacts [USACE 1997].

ODMDS E

Because ODMDS E is 1,000 ft north of the MCR entrance channel, this site has typically been used during early summer or fall when the littoral transport of dredged material placed at this site was thought to be northward toward Peacock Spit, and away from the MCR entrance channel. Between 1988-1996, the volume of dredged material placed at ODMDS E was restricted to a maximum of 1 million cy annually. This was done to prevent overloading the site (reduce the likelihood of placed dredged material being transported back into the navigation channel) due to the small ODMDS boundaries. It was estimated that placement of 1 million cy within the original ODMDS E boundary would have resulted in a mound 3-4 ft in height; if the placed material did not disperse during disposal. A 4-foot high mound at ODMDS E was determined NOT to have an affect on incident waves [USACE 1998].

The right graphic in figure B-14 illustrates the lack of accumulation of dredged material at ODMDS E from 1990 to 1997. Note that only the eastern ¼ of ODMDS E appears to have accumulated any sediment, and that this localized accumulation is within the detection limit of bathymetric surveys (1 ft). Between 1990 and 1997, most of ODMDS E (within the 1986 boundaries) had experienced at net ***decrease*** in seabed elevation. The seabed within the western 1/2 of ODMDS E had eroded by 2 ft or more. The total volume ***loss*** associated with bathymetric change at ODMDS E between 1990-1997 was calculated to be –310,000 cy (based on survey differencing). According to USACE-Portland District dredge logs, the actual volume of dredged material placed in ODMDS E (1986 boundaries) during 1990-97 was estimated to be 5.1 million cy. Based on the above data, none of the "material" that was placed at ODMDS E appears to have accumulated on the seabed. The total ODMDS E volume "loss" of 5.4 million cy (between 1990-97) could be the result of: (A) an average vertical survey error of -36 ft – impossible, (B) consistent under-reporting of dredged volumes in the logs - unlikely, or (C) a region-wide transport or erosion of sediment due to natural processes - likely. The dredged material placed at ODMDS E each year appears to be completely transported out of the site by the following year. This indicates that ODMDS E is a highly dispersive site, with respect to the volume of dredged material placed. Based on the above survey data, the dispersive capacity within the 1986 boundary of ODMDS E is considered to be about 1 million cy/yr.

Utilization of Expanded ODMDS E during 1997-1998

Due to the high dispersion rate observed at ODMDS E , its close proximity to the MCR entrance channel (short haul distance), reliance on the site as a primary disposal site (50 million cy placed since 1956), and the potential for dredged material placed at ODMDS E to be re-introduced into the littoral environment of the Washington coast; ODMDS E was temporarily expanded in 1997 [USACE 1997]. The 1997 boundary of expanded ODMDS E was intended to maximize the site's dispersion of dredged material (see figure B-12 and B-15). A site utilization plan for the 1997-expanded ODMDS B was developed to minimize navigation impacts [USACE 1997]. The ***dispersive*** capacity for the entire 1997-expanded boundary of ODMDS E was estimated to be 1 to 2.3 million cy/yr [USACE 1998 and Section 7 of this Exhibit].

During June–August 1997, approximately 550,000 cy of dredged material was placed within the original boundaries (dashed line) of ODMDS E during and 450,000 cy of dredged material was placed within the expanded area of ODMDS E. Immediately following dredged material disposal (in August 1997), a 3-4 ft accumulation (mound, not shown) was observed on the seabed within ODMDS E. Figure B-15 shows the bathymetric change observed within the 1997-expanded boundary of ODMDS E (during May 1997-May 1998). Figure B-15 demonstrates that during the ensuing fall, winter, and spring, the accumulated dredged material was dispersed: There was little accumulation of placed dredged material within expanded ODMDS E in May 1998, despite placement 1 million cy during the 1997 dredging season.

Figure B-16 shows the bathymetry at ODMDS E as of 19 May 1998 and documents the 1998 pre-disposal condition of ODMDS E. During June 1998 – August 1998, approximately 3.5 million cubic yards (cy) of sand was placed within ODMDS E (1997 configuration). A government-operated hopper dredge placed 1.95 million cy of dredged material within the western half of ODMDS. A contractor-operated hopper dredged placed 1.5 million cy of dredged material in the eastern half of ODMDS E. To maintain safe distance between the two hopper dredges and avoid overlapping usage of ODMDS E, the middle part of the site was not used. To avert excessive mounding of placed dredged material within ODMDS E, dredged material was distributed uniformly throughout the site using a series of grid-cells to control the release point for each disposal event: The goal was to prevent mound-induced wave amplification at or near ODMDS E by limiting the vertical accumulation of placed dredged material to 4-6 ft, with respect to the baseline bathymetry of ODMDS E [USACE 1998b]. Figure B-17 documents the bottom accumulation of dredged material that occurred within ODMDS E during 19 May 1998 - 16 Sept 1998.

ODMDS E monitoring results indicate that at the conclusion of 1998 dredged material disposal operations, only 35% (or 1.2 million cy) of all dredged material placed at ODMDS E during 1998 was observed to have accumulated on the seabed within the site. This result indicates that during the 1998 dredging-disposal season, the wave/current environment at ODMDS E had dispersed 65% (or 2.3 million cy) of the 3.5 million cy of dredged material placed at this site. During the 1998 disposal operations, the eastern and western areas of ODMDS E exhibited similar dispersion rates [USACE 1999]. Based on surveys conducted during 1998 (figure B-17), the placed dredged material that was dispersed out of ODMDS E did not appear to be accumulating (to a detectable height, ±1 ft) either within the MCR navigation channel or on Peacock Spit.

ODMDS F

Prior to 1989, ODMDS F was rarely used for the disposal of sediments dredged from the MCR due to established preferences for utilizing ODMDSs A, B, and E. Additional factors that discouraged the aggressive use of ODMDS F are that the site lies directly in the path of vessels approaching the MCR navigation channel and that site F is located at the bar pilot transfer area. The presence of two dredges simultaneously operating in ODMDS F was perceived to be detrimental to safe navigation at MCR entrance. In 1992, it became apparent that ODMDS F must be used more extensively to avert additional mounding (due to dredged material disposal) at ODMDSs A and B. Due to the small areal extent (as originally designated in 1986), ODMDS F was expanded by a factor of 30-fold in 1993. The Portland District has minimized the interference of dredging disposal activities with shipping/commerce at ODMDS F by allowing only one dredge to utilize disposal site during a given disposal season.

In 1993, the expanded ODMDS F was divided into sixteen 2,000'x2,000' cells. ODMDS F is surrounded by a 1,000-foot buffer zone: Placement of dredged material is not permitted within or outside the buffer zone. Dredged material disposal is managed by designating a limited number of cells available for placement each year. Beginning in 1993, ODMDS F has been used more extensively to reduce the amount of dredged material placed in ODMDSs A and B.

The right graphic in figure B-11 illustrates the accumulation of dredged material at ODMDS F from 1981 to 1997. Recent use of ODMDS F formally began in 1989 (see table B-3). The recent placement of dredged material at ODMD F has resulted in multiple mounds 8-12 ft high distributed throughout the southeastern half of site F. The total volume gain associated with bathymetric change at ODMDS F between 1981-1997 was calculated to be 11 million cy (based on survey differencing). The actual volume of dredged material placed in ODMDS F during 1981-97 was estimated to be 8.3 million cy (NWP dredge logs). Based on the above data, approximately 9% more "material" appears to be on the seabed than was placed at ODMDS F. This volume "overestimate" could be the result of: (A) an average vertical survey error of 0.6 ft - likely, (B) consistent under-reporting of dredged volumes in the logs - unlikely, or (C) a region-wide accumulation of sediment due to natural processes - possible.

In either case, ODMDS F is ***not*** considered to be a dispersive site with respect to the volume of dredged material placed at the site per year (924,000 cy/yr). This finding corroborates with previous investigations [EPA, 1983, Siipola et al 1993, and USACE 1997] which stated that dredged material placed at site F is not subject to significant annual dispersal.

The capacity of ODMDS F to handle additional dredged material disposal beyond 1997 has been limited to 10 million cy [USACE 1997]. Dredged material placement in ODMDS F has been restricted to the northwestern half of the site: The southeastern half of site F is effectively filled, based on the limiting mound height of 10-15 ft for the potential onset of adverse wave conditions. If more than 10 million cubic yards is placed at ODMDS F(after 1997), the resultant accumulation of dredged material could adversely affect the wave environment at the approaches to the MCR entrance channel.

Experimental Dredged Material Disposal Site G

As part of the Corps of Engineers Dredged Material Research Program (DMRP) an experimental area - site G - was selected for field investigation in June 1975. Site G was located 1 mile south of ODMDS A in an average water depth of 80 ft (figure B-5). During a two-month period beginning in mid-July 1975, 600,000 cubic yards of dredged material (fine-medium sand: D_{50}=0.2 mm) was placed at site G. A 5-foot high mound with 1,500-foot base diameter was formed in response to dredged material accumulation during disposal. Bathymetric surveys conducted immediately after the disposal operation

(2-3 September 1975) could account for 364,000 cy (61%) of the 600,000 cy placed on the seabed [Borgeld 1978]. It is likely that some of the dredged material was dispersed away from the immediate point of disposal, forming a thin apron of accumulation around the mound base. The bathymetric surveys lacked the precision to detect the thin apron of dredged material along the mound base.

A bathymetric survey conducted 6 months after disposal at site G (February 1976) could account for 260,000 cy (71%) of the 364,000 cy observed on the bottom immediately after disposal in September 1975, or about 43% of the total volume placed at site G (600,000 cy). The height of the dredged material mound at site G was reduced from 5 feet to 3 feet between September 1975 and February 1976. The above results do not infer that dredged material was transported completely off of the mound. It is likely that the dredged material was dispersed off of the high point of the mound toward the base. The bathymetric surveys lacked the precision to detect the thin apron of dredged material along the mound base. The mound appeared to be transported toward the northwest, parallel with the ambient bathymetry contours [Boone 1978].

Based on the above observations, the environment at site G is considered to be moderately dispersive for the volume and type of material placed at there during 1975. The dispersion rate for dredged MCR material placed at site G was estimated to be 100,000 - 340,000 cy/yr. It is assumed that the dispersion rate at site G is 100,000 cy/yr.

Observed Sediment Dispersion at MCR ODMDSs

MCR ODMDSs A and E and experimental site G are considered to be dispersive disposal sites. These three sites are located in water depths between 50 to 80 ft. ODMDS E is the most dispersive site, with 100% of the dredged material placed since 1990 (about 1 million cy/yr) being transported out of the site or dispersed to a thickness undetectable by surveys. Since 1981, 26% (or 360,000 cy/yr) of the dredged sediment placed at ODMDS A has been transported out of the site. Waves and currents at site G had dispersed 17 % (100,000 cy) of the dredged material placed at that site within 6 months after disposal.

ODMDS B and F are not considered to be dispersive disposal sites. In fact, more "material" appears to be within each site (and immediate vicinity) than was placed during 1981 to 1996. Sites B and F are located at the base of the ebb-tidal delta of MCR, in water depths between 100 to 180 ft. Although ODMDS B (1993 boundaries) is not considered to be net dispersive, the top of the mound has exhibited localized erosion (2 ft/yr or 300,000 cy/yr of erosion during 1995-96). In 1998, the top of the ODMDS B mound was about -65 ft MLLW. A summary of estimated annual dispersion and related net bathymetric change for ODMDSs A, B, E, F, and experimental site G is summarized in table B-4.

Table B-4. Observed dispersion potential at MCR ODMDSs, based on survey differencing.

MCR Disposal Site	Estimated Vertical Erosion Rate, (ft/yr)	Estimated Net Erosion Volume, (cubic yards/yr)	Average Water Depth at Erosion Area, (ft)
ODMDS A *	>3	360,000	45
ODMDS B *	2	0 (300,000 cy at top of mound)	65
ODMDS E * #	>4	1 million * - 2.3 million #	55
ODMDS F *	0	0	130
Site G ^^	2	100,000	80

* = ODMDS boundaries are based on 1993 extent.
# = ODMDS boundaries are based on 1997-expansion
^^ = Experimental site used in 1975

Littoral Zone Placement of Sediment Dredged from MCR

The nominal water depth above which littoral transport is expected to occur at MCR was estimated to be 59 ft [Section 5 of this exhibit]. Based on ODMDS bathymetry change and observed sediment dispersion discussed above and summarized in table B-4, it is assumed that dredged material placed in ODMDS A and E is either transported to the MCR entrance or to the littoral environment of the Oregon and Washington coasts. This assumption is also based on previous studies [Hermann 1972, Lockett 1965, and USACE 1957]. Between 1904 and 1997, approximately 61% of the material dredged from MCR has been placed in vicinity ODMDS A and E or estuarine disposal sites.

Most of the dredged material placed at ODMDS B and F is likely impounded on the MCR ebb tidal shoal for a long period of time (> 20 years). Since 1904, approximately 39% of the material dredged from MCR has been placed in vicinity ODMDS B and F. Assuming that the above data are nominally correct, about 2/3 of ALL sediment dredged at MCR has been placed within the active sediment budget of the Columbia River mouth or adjacent nearshore (littoral) areas.

Present Wave Conditions at MCR: Dredged Material Mounding vs. Site Capacity

Since 1986, dredged material placed within ODMDS A and B has accumulated at a rate faster than the Portland District had anticipated when the disposal sites were formally designated by EPA. ODMDSs A and B were intended to be moderately dispersive and have a 20 year life-cycle. Sites A and B (1986 designated boundaries) have reached capacity within 10 years of initial operation. ODMDS capacity is defined as that quantity of material that can be placed within the legally designated disposal site without extending beyond the site boundaries or interfering with navigation [Poindexter-Rollings 1990]. Presently, exceedence of capacity within the 1986 boundaries of ODMDSs A and

B has created a significant operational problem for the Portland District and users of the navigation project:

- The overall footprint of dredged material contained within existing ODMDSs extends beyond the sites' formally permitted boundaries, by as much as 3,000 feet in some cases.

- Dredged material within the ODMDS A and B has accumulated to an areal and vertical extent which may create adverse sea conditions. In some cases, mounds rise 50-70 ft above surrounding bathymetry. Mariners report that the ODMDS "mounds" cause waves to steepen or break in vicinity of the ODMDSs and that these wave conditions are hazardous to navigation at MCR.

The creation of potentially hazardous wave conditions at the MCR entrance, by mounding of placed dredged material, is illustrated in figure B-18. Figure B-18 shows the potential change (amplification) in wave height due to the change in bathyemtry at MCR ODMDSs A and B between 1985 and 1997. Refer to figure B-12 for a graphical description of MCR bathymetric change for 1985-1997. Results shown in figure B-12 are for 12-second period waves approaching MCR from the west (230-290° azimuth). Based on the above results, existing (1997) dredged material mounds at ODMDSs A and B could potentially increase the height of incident waves by 50%, as compared to the 1985 bathymetry. The method used to estimate the above wave amplification is discussed in Section 5, *Simulating the Fate of Dredged Material Placed at ODMDSs.*

Capacity Limitations for Present ODMDSs

To avert additional mounding and related navigation consequences at ODMDS A and B, dredged material disposal in ODMDS A has been discontinued and disposal within ODMDS B has been limited to areas beyond the existing mound foot-print. Recent concerns of adverse environmental impact within the expanded area of ODMDS B (1997 boundary), have dictated that all dredged material disposal within ODMDS B be halted.

At present, only ODMDS E and F are available for disposal of material dredged from the MCR channel. The ***total remaining*** disposal capacity for expanded ODMDS F (1993 configuration) is estimated to be 10 million cy [USACE 1997]. Based on bathymetry monitoring conducted during 1997-1998, the ***annual*** disposal capacity for ODMDS E (1997 expanded configuration) was estimated to be 1-2.3 million cy/year. This means that if 2.3 million cy of dredged material were placed at ODMDS E (1997-configuration) in a given year, all of the placed material is expected to be dispersed out of the site before the next year's disposal operation. This is due to the dispersive nature of this site [USACE 1997 and 1998].

The volume of sediment annually dredged from the MCR channel (MCR maintenance dredging) is approximately 4.5 million cy/yr, based on an average for 1987-1998 (table B-3). The remaining time for which sufficient ODMDS capacity is available at existing MCR sites (E and F, as of 1998) was determined below:

- Annual volume of sediment presently dredged at MCR = 4.5 million cy/yr
  REQUIRED annual capacity for MCR ODMDSs, for disposal of MCR maintenance dredging = 4.5 million cy.

- Remaining capacity ***AVAILABLE*** in ODMDS A = 0

"	"	"	ODMDS B = Use of site halted
"	"	"	ODMDS E = 1 - 2.3 million cy/yr
"	"	"	ODMDS F = 10 million cy total

- Expected time in years, beginning in 1998, that adequate ODMDS capacity is available for disposal of sediment dredged from the MCR channel =

Existing MCR ODMDS capacity, in years = 10 /(4.5 – 2.3) = 4.5, say 5 years, from 1998.

If utilization of ODMDS E is limited to 1 million cy/yr, then there is only 3 years of adequate disposal capacity remaining at present MCR ODMDSs. Likewise, *if* ODMDS E can be utilized at 3.5 million cy/yr, then there is 10 years of adequate disposal capacity remaining at present MCR ODMDSs. The above estimates assume that an average of 4.5 million cy/yr is dredged at MCR and only ODMDSs E and F are available for dredged material disposal.

To summarize, an average of 5 years of adequate disposal capacity (commencing from 1998) is estimated to remain within expanded MCR ODMDSs E (1997 configuration) and F (1993 configuration). By the year 2003, it is estimated that the required dredging volume for MCR maintenance (4.5 million cy/yr) will exceed the available disposal capacity within existing ODMDSs E and F. The above estimates assume that ODMDSs A and B are not available for dredged material disposal. It is obvious, based on recent performance of MCR ODMDSs A and B, that the new disposal sites must be much larger (than the originally 1986-designated boundaries) to reliably handle 50-years of dredging disposal without mounding (or other capacity-related) concerns.

Section 4
SITING and MANAGEMENT REQUIREMENTS FOR NEW ODMDS AT MCR

The recent operational performance of MCR ODMDSs (mounding at A and B) indicates that if ODMDSs with insufficient capacity are selected, expensive re-designation (or temporary expansion) efforts may still result in unacceptable future conditions (mounding). The key to successful ODMDS designation and long-term management is knowing in advance (or reliably predicting) the fate of dredged material placed at the ODMDS. This is especially true if new ODMDSs are required to have the minimum dimensions necessary to provide adequate site capacity for a 50-year life-cycle. Future MCR ODMDSs will be required to provide sufficient disposal capacity for:

- ongoing MCR maintenance dredging.
- maintenance dredged for the existing 40-foot Columbia River channel (in the Columbia River estuary), if the Columbia River is not deepened to 43 ft.
- new work dredging for the Columbia River Channel deepening (to 43 ft deep in the Columbia River estuary).
- maintenance dredging associated with the deepened navigation channel (in the Columbia River estuary).

Operational Aspects

The operational requirements for future ODMDS use were assessed to ensure that new MCR ODMDSs fulfill a minimum life-cycle of 50 years. The total volume of dredged material expected to be placed within MCR ODMDSs for the next 50 years is estimated to be between 225-262 million cy (or 4.5-5.2 million cy/yr). Future ODMDS site capacity must be sufficient to handle the expected volume of placed dredged material without negatively impacting navigation or the environment at MCR. Operational requirements for successful siting and management of future ODMDSs at MCR will:

♦ Provide ODMDS capacity for disposal of new work and maintenance dredging material originating from MCR, estuarine, and riverine dredging sites. The annual volume of dredged sediment estimated to be placed in MCR ODMDSs, could range from 4.5 million cy/yr (present average MCR channel maintenance) to 8 million cy/yr (MCR maintenance and CRCD new work within the estuary). The high value of 8 million cy/yr would apply for 2 years, during deepening of the Columbia River channel. The average annual volume of dredged material expected to be placed in MCR ODMDSs during the next 48 years (assuming that the Columbia River channel is deepened to –43 ft MLLW), is about 5 million cy/yr. Over the next 50 years, the total volume of dredged material to be placed in ODMDSs is expected to range between 225 million cy (MCR maintenance) – 262 million cy (MCR maintenance+CRCD+Columbia River maintenance).

♦ Locate new ODMDSs within the zone of siting feasibility: Conduct dredging disposal activities in an efficient manner by minimizing haul (transit) time for hopper dredges and scows from point of dredging to point of disposal. The ZSF for MCR maintenance dredging is a 4.5 mile radius offshore of RM -1. The ZSF for Columbia River dredged material is a 13 mile radius offshore of RM 0.

♦ Where practical, facilitate re-introduction or dredged material placed at ODMDSs into the littoral zone. At MCR, the offshore limit for littoral transport of placed dredged material corresponds to a water depth of 60 ft (section 5 of this exhibit). Dredged material placed at water depths shallower than 60 ft are expected re-worked by bottom transport (waves/currents) to the littoral zone of Oregon-Washington. To facilitate introduction of dredged material into the littoral zone, portions of new or expanded ODMDSs should be located in water depths equal to or less than 60 ft, where possible.

♦ Avoid navigation impacts at ODMDSs due to excessive cumulative build-up of placed dredged material, over the life-cycle of the proposed ODMDSs (see section 6 of this exhibit). Designate ODMDSs with large areal configuration and manage sub-units of an ODMDS on an annual rotational basis.

♦ Where needed, enhance the dispersal of dredged material placed at ODMDSs by evenly distributing dredged material on the seabed. This may be desirable at ODMDS located close to shore (ODMDS E). Conversely, if the disposal footprint (seabed area covered per disposal season) is required to be small, an ODMDS may be managed to promote vertical accumulation of placed dredged material rather than dispersing dredged material over a large area. Dredged material mound height must be managed to prevent excedance of wave shoaling criteria. An ODMDS would be divided into several sub-areas and each sub-area would be used until the height of accumulated dredged material reaches the maximum vertical limit.

♦ Ensure that new or expanded MCR ODMDSs conform to the five general criteria for the selection of ocean disposal sites (40 CFR 228.5), as specified in tables 1 and 2 of the main report (Appendix H).

Proposed ODMDS Site Selection Criteria

Dredging and disposal practices at the MCR must continually balance the competing interests of providing a safe navigation channel, minimizing adverse impacts to the environment, optimizing dredging and disposal efficiency, and maximizing dredged material as a littoral resource. The over-riding considerations governing the selection of a new ODMDS include the avoidance of (dredged material) mound-induced wave amplification, avoidance of impacts to sensitive benthic areas, and locating new ODMDSs within the ZSF. For sediment dredged at locations upstream of the MCR project (upstream of RM +3), the ZSF is a 13 mile radius extending offshore from RM 0. For sediment dredged within the MCR project (RM –2 to +3), the ZSF is a 4.5 mile radius extending offshore from RM -1. Refer to figure B-6 for specification of the ZSF at MCR.

Collectively, the MCR ODMDS must be large enough to permit the distribution of 50-years of dredged material disposal (facilitate the distribution of 225-262 million cy of dredged material on the seabed) without allowing the accumulated material to exceed a height which would cause wave amplification. Management of new MCR ODMDS's will avoid the amplification of incoming waves, due to the presence of large dredged material mounds. The disposal of dredged material will be controlled in terms of limiting the extent (plan-form and height) of its accumulation on the seabed. At any given location within a proposed ODMDS, accumulation of dredged material will be controlled so that incident waves are not significantly amplified as compared to the baseline condition, due to dredged material mounding. **The *baseline condition* for new ODMDSs refers to pre-ODMDS bathymetry and associated wave environment.**

Determination of the size for new ODMDSs sufficient to handle between 225-262 million cy and successfully locating potential new ODMDSs in terms of the required size vs. other competing criteria was the objective of this exhibit. Consideration of proposed ODMDSs in terms of size and location is described in Section 6, *Fate Modeling Results and Impact Assessment for the Proposed ODMDS.* Development of a life-cycle management plan for proposed ODMDSs, to ensure that new sites meet operational requirements, is described in the *Management and Monitoring Plan.*

ODMDS Capacity – General Considerations

The total site capacity for a given ODMDS consists of two components; static site capacity and dynamic site capacity.

Total ODMDS site capacity = dynamic site capacity + static site capacity

Dynamic ODMDS ***capacity*** is defined as the volume of placed dredged material which is transported out of an ODMDS, by waves and currents. The shallower a given ODMDS location, the greater its potential for dispersing placed dredged sediments and the higher its dynamic capacity. Generally, the deeper a given site, the lower its dynamic capacity. For a given water depth, dynamic capacity may be higher for areas closer to a estuary inlet (such as ODMDS E near the MCR entrance), than at open coast areas (Long Beach, Washington).

Dynamic capacity is specified in terms of a volume rate (cubic yards per year, cy/yr) at which sediment leaves a given site. Dynamic capacity at a given site can change with time based on changes in site bathymetry or changes in waves/currents. Results of dynamic capacity estimates are presented in the *Management and Monitoring Plan.*

Static ODMDS ***capacity*** is defined as the limiting volume of dredged material which can be placed within a given area before the resultant mound feature begins to have a negative impact on either navigation of the ambient environment. Navigation impacts associated with static capacity, include reducing vessel keel clearance to an unsafe margin or degrading the sea state by causing waves to steepen, amplify in height, or break. Environmental impacts associated with static capacity, include exceeding a pre-determined burial depth over the site's pre-disposal substrate or promoting downslope distribution of placed material onto areas beyond the designated ODMDS boundaries.

For the case of MCR ODMDSs, static site capacity is governed by the need to avoid navigation impacts. This includes vessel keel clearance and wave shoaling constraints: The most restrictive constraint applies. To meet wave amplification constraints, a given ODMDS mound must not amplify incident waves with respect to a baseline (pre-disposal) bathymtric condition. The wave amplification criteria is generally more restrictive than keel clearance. Generally, the shallower a given ODMDS location, the lower its static capacity and vice-versa. Results of static capacity estimates are presented in Section 6 , *Fate Modeling and Impact Assessment for the Proposed ODMDS.*

Section 5
FATE SIMULATION OF DREDGED MATERIAL PLACED AT ODMDSs
Coupled Strategy of Numerical Modeling and ODMDS Management

A key to successful ODMDS designation and management is knowing in advance (or reliably predicting) the fate of dredged material placed at the ODMDS. Section 103 of the Ocean Dumping Act and section 404 of the Clean Water Act require that field-verified, state of the art procedures be used for the assessment of possible physical impacts due to the operation of proposed ODMDSs

During the USACE Dredging Research Program (DRP), several sediment fate (FATE) numerical models were developed or enhanced in order to improve the reliability of ODMDS management. These FATE models incorporate state-of-the-art techniques for simulating the behavior of dredged material placed in open water, and account for a variety of disposal operations and environmental conditions. Results from FATE model application at MCR were used to guide site selection for new ODMDSs and are described in section 4, *Siting and Management Requirements for New ODMDSs at MCR*. Site impact assessments focused on:

Wave conditions - The use of new ODMDSs would not increase (worsen) the wave environment at the ODMDS location or adjacent areas, with respect to the site's baseline condition.

Impacts to benthic in-fauna - The use of new ODMDSs would minimize potential impacts to benthic in-fauna (refer to Appendix A, *Living Resources*). Proposed sites were located to avoid placement of dredged material on a seabed substrate that is significantly different from the sediment dredged at the navigation channel. The goal is to place dredged sediment on a similar type of insitu seabed sediment. If needed, proposed ODMDSs may be managed to prevent more than 10 inches (25 cm) per year of dredged material accumulation on the seabed.

Transport of dredged material into the littoral zone – It would be desirable for new ODMDSs to promote the littoral re-introduction of placed dredged material along the Oregon and Washington Coasts. The nearshore part of new ODMDSs may be located in water depths of 30-60 ft to facilitate shoreward movement of placed material. After placement in the nearshore part of new ODMDSs, dredged material would be transported by waves and currents to the littoral zone. Nearshore placement of dredged material would be performed within the context of minimizing navigation and environmental impacts.

FATE model results that were used to assess the long-term suitability of proposed ODMDS locations are described in Section 6, *Fate Modeling Results And Impact Assessment for the Proposed ODMDS.* The following paragraphs describe FATE model components and the strategy for using the FATE models in this ODMDS assessment.

The Fate of Dredged Sediment Placed in Open Water

The physical processes affecting dredged material placed in open water include gravity, surface waves, and currents. At the point of release from the disposal vessel, dredged material falls through the water column, convects/diffuses laterally, and eventually comes to rest on the seafloor. This scenario characterizes the ***short-term fate*** of dredged material placed in open water. Figure B-19 illustrates dredged material behavior, when placed in open water by a hopper dredge or split-hull barge. During the disposal operation, dredged material can be spread out on the seabed to varying degrees, depending upon the speed of the disposal vessel, water depth, water column current, ambient bathymetry, and other variables. The time-frame for processes affecting the short-term fate of placed dredged material is: During and immediately after the disposal operation (minutes to hours).

After dredged material has come to rest on the seabed, it can be eroded by waves and currents. If the dredged material is cohesive, it can experience self-consolidation due to gravity. If many loads of dredged material are placed one on top of another such that a steep aggregate mound develops on ambient bathymetry, the mound will avalanche and material will be transported downslope. The combination of these processes define the ***long-term fate*** of dredged material placed in open water. The time-frame for processes affecting the long-term fate of placed dredged material is: After the disposal operation (days to years).

Predictive Methods: Applicable Numerical Models

STFATE, LTFATE, and MDFATE are numerical models which incorporate state-of-the-art techniques for simulating short- and long-term bathymetric change due to dredging disposal operations and environmental processes. The models were developed at USACE, Waterways Experiment Station (WES) and are briefly described below.

Short-Term FATE: Predicts the distribution of dredged material thru the water column and bathymetric distribution of dredged material on the seabed after it has passed through the water column, on an individual "dump" (disposal vessel load) basis. The time-frame of interest for the STFATE model is on the scale of minutes to hours, during dredged material disposal. The model accounts for various disposal vessel, water column, and material parameters. In this investigation, STFATE will be used in a 2 dimension capacity.

Long-Term FATE: Simulates bathymetric change due to self-weight consolidation and sediment transport arising from the interaction of waves and currents. The time-frame of interest for the LTFATE model is from days to years, after dredged material disposal. The model accounts for waves, currents, tidal, and material parameters. LTFATE is a 2 dimensional model.

Multiple-Dump FATE: Predicts the change in bathymetry at an ODMDS resulting from a series of "dumps" and simulates long-term change of the resultant bathymetry. MDFATE uses components of STFATE and LTFATE to simulate a disposal operation which could extend over a year and consist of hundreds of "dumps". The model accounts for overall disposal operation and long-term environmental processes. The time-frame of interest for the MDFATE model is from minutes to years, and simulates processes during and after dredged material disposal. MDFATE is a 2 dimensional model and uses the same parameters as used in STFATE and LTFATE.

Predictions of dredged sediment behavior, when it is placed into the open waters of the ocean, can only be as good as the poorest estimate for the forcing environment (i.e. waves, currents, and other processes). To address this need for input data, tide and wave prediction techniques were developed by WES to provide realistic wave and current data to the FATE models.

The programs **HPDPRE** and **HPDSIM** were used to simulate a time series representation for wave height, period, and direction [Borgman and Scheffner 1991]. The **ADCIRC** model was used to simulate equilibrium Newtonian tide in terms of ocean surface elevations and current [Hench et al 1994].

The numerical model **RCPWAVE** [Ebersol et al 1986] was used in this investigation to assess the effect of bathymetry change (dredged material mounds) upon the wave environment at proposed MCR ODMDSs. RCPWAVE is a 2 dimensional numerical model which simulates behavior of waves as they are refracted and diffracted by the bathymetry that the waves pass over.

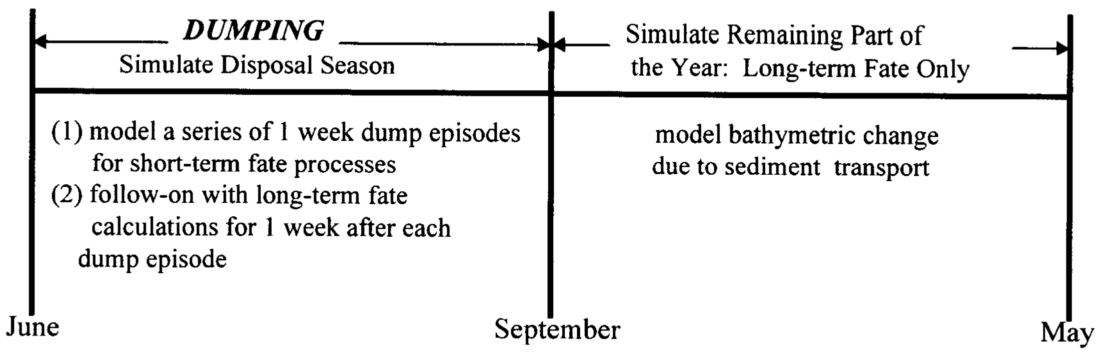
The above models have been calibrated, verified, and successfully applied at several locations within and outside the Portland District [USACE 1997 and 1995, Clausner et al 1998 (a and b), Moritz and Randall 1995, Johnson 1978, Johnson and Fong 1995, Thevenot and Johnson 1994, Scheffner 1992, EPA 1978, and Schubel et al 1978]. Collectively, the above numerical models were used to resolve future ODMDS site management issues at MCR related to physical aspects.

MCR-ODMDS Modeling Strategy

As a first step toward modeling sediment fate at MCR ODMDSs, existing oceanographic information was consolidated for use in the modeling effort. The year 1997 was chosen as the "base year" for simulating the behavior of dredged material mounds at proposed MCR ODMDSs and was based on the availability of the most recent bathymetric survey for the MCR approaches and ODMDSs.

For modeling purposes , the annual dredging and disposal season at MCR was broken into two (2) discrete time periods. Dredging disposal at the MCR ODMDS normally begins during June and continues through the summer until September. After September, ODMDSs are not used and are affected by the energetic wave/current environment until the following June time-frame when dredged material disposal again commences. The schematic shown below describes how the MDFATE model was applied to simulate dredged material disposal at the proposed MCR ODMDS.

Modeling of the Annual Dredged Material Disposal Cycle at MCR ODMDS



During a given ODMDS operational year, short-term fate processes (dredged material disposal) were simulated for a 4-month period (June - September). Long-term fate processes were then simulated for a 8-month period, until the following year when the annual cycle was repeated.

Short-term Fate

The STFATE model was used to estimate the geometry of dredged material deposited on the seafloor, on an individual dump basis. These results determined whether flat or peaked "mounds" are produced from dredged material disposal, on an individual dump basis. The above estimates were be performed for the two dredging vessels which have been most used at MCR. Results are described in Section 6 of this exhibit. STFATE results were used to optimize ODMDS capacity based on the need to distribute dredged material within the site in terms of thickness, deposition rate, and areal extent per load placed. The STFATE model was also used to guide Battelle-MSL laboratory-based tests for evaluating the response of juvenile flatfish and Dungeness crab to deposited sediment (as related to dredged material disposal, see Exhibit A).

Long-term Fate

The LTFATE and MDFATE models were used to estimate the capacity of proposed ODMDSs for a 50-year life-cycle. The definition of ODMDS site capacity is discussed in section 4 of this exhibit. The MDFATE model was used to simulate the long-term accumulation of dredged material placed at various locations within proposed ODMDSs. MDFATE results were used to determine the ODMDS dimensions required to “acceptably” operate a site over the life-cycle. MDFATE model results were also used to ensure that life-cycle management of the proposed ODMDS would meet operational requirements (based on the need to distribute dredged material within a given site, in terms of verifying accumulation thickness and areal extent per year). Results are described in the *Management and Monitoring Plan.*

Future management of MCR ODMDS's will prevent the amplification (shoaling) of incident waves due to the formation of new dredged material mounds by limiting the size (height and plan-form) of new dredged material mounds. Dredged material mound accumulation will be restricted to prevent wave amplification. The RCPWAVE model was used to assess wave shoaling characteristics of various dredged material mound sizes vs. water depth and wave parameters. The wave amplification criteria was used for purposes of minimizing hazardous wave conditions due to excessive accumulation of dredged material mounds. Results are described in Section 6, *Fate Modeling Results and Impact Assessment for the Proposed ODMDS* and in the *Management and Monitoring Plan.*

Calculating Bottom Sediment Transport Potential

The calculation of closure depths [Hallemeier 1981] gives a ***qualitative*** indication of the depth limit for sediment transport due to incident waves for average and storm wave conditions. Sediment transport closure depths give a general indication for the extent (water depth) of sediment transport, but do not define how much sediment transport will occur.

Hallermeier Sediment Transport Limits

The nearshore region of the seabed can be divided into different transport zones based upon relative rates of littoral sediment transport (see Section 7). Two (2) water depth zonal limits, $\mathbf{d}_\ell$ and $\mathbf{d_s}$ are typically used to describe the transportability of sediment at the seabed due to shoaling waves [Hallemeier 1981]. These depth values are commonly referred to as *closure depths.*

(1) The water depth corresponding to $\mathbf{d}_\ell$ gives a seaward limit for sediment transport associated with highly turbulent surf-zone (or littoral) effects. This depth is a function of the annual mean significant wave height ($H_{1/3}$) and defines the *littoral* zone for which all significant alongshore/cross-shore transport occurs. Algebraically, the littoral closure depth ($\mathbf{d}_\ell$) for typical nearshore sand is defined as:

$\mathbf{d}_\ell = 2H_{1/3} + 11\sigma$ where, $H_{1/3}$ = average annual significant wave height applicable at $\mathbf{d}_\ell$
σ_h = annual standard deviation of $H_{1/3}$

The $H_{1/3}$ used for the $\mathbf{d}_\ell$ calculation at MCR was determined by transforming the deepwater $H_{1/3}$ (specified by WIS-II station 46, $H_{1/3}$= 9.0 ft and σ_h =4.2 ft) to a water depth of 60 ft. The resultant annualized nearshore $H_{1/3}$ = 8.8 ft with σ_h =3.8 ft. Using the nearshore wave criteria, $\mathbf{d}_\ell$ was calculated to be 59 ft.

(2) The water depth corresponding to $\mathbf{d_s}$ gives the extreme seaward (outer) limit of wave-induced sediment motion due to extreme waves (storm effects) and is a function of annual mean significant wave height, the annual mean significant wave period, and

median sediment grain size. The nearshore zone located seaward of $\mathbf{d}_\ell$ and landward of $\mathbf{d_s}$ (between the two depths) defines the *shoal* zone. The shoal zone between $\mathbf{d}_\ell$ and $\mathbf{d_s}$ is a "gray" area where typical waves have neither a strong nor negligible effect on the bottom sediment transport during a typical year of wave action [Hallemeier 1981].

$\mathbf{d_s} = (H_{1/3} - 0.3\sigma)T_s(g/5000D_{50})^{1/2}$ where, $H_{1/3}$ = 9 ft, estimated average annual significant wave height applicable at $\mathbf{d_s}$
T_s = wave period (associated with $H_{1/3}$) = 11 sec
g = 32.2 ft/sec^2
D_{50} = median sediment grain size = 0.15-0.25 mm = 0.000492 – 0.00082 ft

The median grain size for dredged material to be placed at MCR ODMDSs was estimated to be 0.22 mm (Section 8, Measured Oceanographic Data). The median grain size for in "native" situ material at existing ODMDSs was estimated to be 0.15 mm. The corresponding values for MCR closure depths were calculated to be:

$\mathbf{d}_\ell$ = seaward limit of active littoral zone at MCR (all sediments) = -59 ft MSL
$\mathbf{d_s}$ = extreme seaward limit for wave-induced sediment motion (0.15mm) = -250 ft MSL.
$\mathbf{d_s}$ = extreme seaward limit for wave-induced sediment motion (0.25mm) = -200 ft MSL

In terms of closure depth, ODMDSs A, B and E should experience littoral sediment transport at locations shallower than $\mathbf{d}_\ell$ = -59 ft MSL (about –55 ft MLLW). This in fact has been documented at ODMDS A, E, and the top of the dredged material mound at ODMDS B as described in Section 3, Observed Dispersion Rates at MCR ODMDSs. In general, the ambient depths at MCR ODMDSs B and F (100-150 ft) should experience limited movement of placed dredged materials, since they are located in water depths less than $\mathbf{d_s}$. Using closure depths as general criteria for selecting an ODMDs is illustrated as follows. If a new MCR ODMDS was needed to prevent any long-term transport of placed dredged material, then the non-dispersive site should be located in water depths deeper than -200 ft MLLW. This criteria would provide for a completely ***non-dispersive*** ODMDS at MCR, if the placed dredged material had a median grain size of 0.25 mm . Conversely, if a ***dispersive*** ODMDS was required to promote rapid transport of placed dredged material back into the littoral environment, then the proposed site should be located in water depths equal to or shallower than -55 ft MLLW. This is presently the case with ODMDS E.

It must be noted that the Hallemeier limits give a ***generalized*** indication of sediment transport due to annual average wave conditions. The Hallemeier closure depth criteria do NOT include the effect of current on sediment transport nor quantify the dispersal rate of sediment.

Ackers-White Sediment Transport Estimates

To obtain a more detailed description of sediment behavior, several relationships have been developed to ***quantitatively*** estimate sediment transport rates [Ackers and White 1973]. The LTFATE model uses the Ackers and White [1973] equations as the basis for the non-cohesive sediment transport model. The equations are applicable for uniformly graded noncohesive sediment in the range of 0.04-0.4 mm and estimate the transport rate of sediment based on a depth-averaged current. A modification of the Ackers-White equations was made to reflect an increase in the transport rate when ambient currents are accompanied by surface waves [Scheffner et al 1995]. The net direction of sediment transport is governed by current direction.

Several sensitivity tests were conducted to demonstrate the sensitivity of the sediment transport rate at MCR with respect to wave height, current speed, water depth, and sediment grain size. Results of the of the Ackers-White "tests" are shown in figure B-20 (six graphs).

Wave height and current are governing parameters for sediment transport (upper left and bottom two graphs). If wave height is increased from 7 ft to 20 ft in 48-foot water depth, sediment transport potential increases by a factor of 10 for a current of 1.5 ft/sec. For water depths less than 100 ft, wave height controls the magnitude of sediment transport (upper right and bottom two graphs), assuming other parameters remain constant. For water depths greater than 100 ft, sediment transport potential due to the combined effect of waves and currents diminishes rapidly. For a water depth of 48 ft (high point of ODMDS A mound in 1995) and current of 1.5 ft/sec, the sediment transport rate is about 7 times higher than at 125-foot depth. Note that regardless of the wave height or water depth, if the depth-averaged current is lower than a threshold value of 0.5 ft/sec, there is no ***net*** calculated sediment transport. Based on the sensitivity of sediment transport potential at MCR (with respect to water depth), a water depth of 60 ft was used to define the limit of littoral transport.

Sediment grain size has some effect upon sediment mobility (middle right graph of figure B-20), but only at high values of depth-averaged current. Since the range in sediment grain size for dredged material at MCR is 0.15 mm to 0.25 mm (Section 8, *Measured Oceanographic Data*), the transport rate could be significantly higher for dredged materials placed in the shallow water areas (<60 ft depth). This would be the case at ODMDS E for most of the year (due to its proximity to the jettied entrance of the Columbia River) and on the top of the mounds in ODMDSs A and B during significant storm events. The variability in wave period (middle left graph, figure B-20) does not appear to have an appreciable effect upon sediment transport rates.

Limitations of Simple Sediment Transport Estimates

Even though the modified Ackers-White equations may provide a realistic estimate of sediment transport potential, the result is only 1-dimensional. The actual (2-dimensional) response of the dredged material would still remain uncertain, until hindsight from the actual disposal operation is gained through post-disposal condition surveys.

Reliance on 1-dimensional estimates for characterizing sediment transport can be a costly proposition for disposal site selection, if ODMDS designation efforts do not provide an disposal site with intended dispersive properties. The FATE sediment fate models use the Ackers-White and other equations to estimate physical processes affecting 2-dimensional sediment transport on the seabed. Application of the FATE numerical models provide the needed predictive means to reliably select a new site or expand an existing ODMDS. The FATE models can also be used to optimize dredged material management at ODMDSs.

It must be noted that the FATE models are only tools that provide estimates of sediment behavior and related processes. The accuracy of FATE model-generated results is highly dependent upon the parameters input to the models. Controlling parameters are physical characteristics of the dredged material, disposal operation sequencing, and forcing environment (waves and currents). As discussed in Section 7 and 8 of this exhibit, much effort was expended to develop reliable input for FATE modeling. Based on previous applications of FATE models and data development outlined above, it is assumed that FATE model results obtained for MCR will meet an accuracy standard of 80% (the difference between predicted and actual conditions is expected to be within ± 20%).

FATE Model Data Requirements

Before reliable modeling of dredged material fate could be conducted, environmental processes which govern sediment transport at MCR had to be defined. The following prioritization of various environmental parameters is given in terms of the requirement for FATE model result accuracy:

First Priority = depth-averaged current magnitude and direction, resolve into seasonal regimes
Second Priority = Wave height time series, year-long data record with 3-hour record interval
Third Priority = Characteristic physical properties for dredged sediment and ambient bottom sediments at ODMDSs
Fourth Priority = Wave period time series, year-long data record with 3-hour record interval

Section 7, *Oceanographic Processes* provides a general description of regional oceanographic process at MCR. Section 8, *Measured Oceanographic Data* quantitatively describes site specific parameters relevant to FATE modeling.

Section 6
FATE MODELING AND IMPACT ASSESSMENT FOR PROPOSED *ODMDS* LOCATIONS

This section describes procedures that were used to generate "generic" ODMDS site selection criteria based on physical processes relevant to MCR. The "generic" physical process criteria was used, in conjunction with other considerations, to evaluate proposed MCR ODMDS locations. Proposed ODMDSs were assessed for life-cycle performance, in terms of physical processes, using the fate models. Results of life-cycle analysis for proposed ODMDSs are reported in the *Management and Monitoring Plan.*

Life-Cycle Assessment for a Proposed ODMDS

Selection of new proposed ODMDSs within required ZSF limits was accomplished by unbiased consideration of operational, biological, physical, economic constraints. Selection of proposed ODMDSs is discussed in the main report. After consensus-based selection of proposed ODMDSs was performed, the utility of proposed ODMDSs was determined by using the MDFATE model to assess the 50-year life-cycle for each proposed site. The MDFATE life-cycle assessment used criteria described in Section 4, *Siting and Management Requirements for New ODMDSs At MCR* to ensure that life-cycle management of the proposed ODMDS would meet operational requirements. MDFATE life cycle simulation results are described in the *Management and Monitoring Plan*.

Maximum Height for Dredged Material Mounds

The areal size of new MCR ODMDSs was determined based upon the site requirement to provide static capacity for 262 million cy of dredged material over a 50-year life-cycle ***without affecting present wave conditions***. Management of new MCR ODMDS's will avoid the amplification of incident waves (sea and swell), due to the formation of large dredged material mounds. At any given location within a proposed ODMDS, accumulation of dredged material will be controlled so that incident waves are not amplified over the baseline (pre-disposal) condition. The RCPWAVE model was used to assess the wave interaction (amplification) of various dredged material mound sizes vs. water depth and wave parameters.

Figure B-21 summarizes RCPWAVE results for estimating the limiting mound height for several mound geometries in water depths from 40 to 200 ft. The lower bold solid line applies to a large mound feature (2,000 ft wide x 4,000 ft long, with 1.2° or 1V:50H sideslopes) and was used to determine to maximum mound height applicable for candidate ODMDS locations at MCR.

Areal Configuration of ODMDSs vs. Site Capacity

Specification of the proposed ODMDS water depth determines the limiting mound height for the site, based on figure B-21. Once the limiting mound height is determined, the areal extent of a proposed ODMDS can be calculated from geometric constraints based on the desired volume of static capacity. Refer to Section 4 of this exhibit for the definition of static capacity. All that is needed to begin the ODMDS size calculation is the water depth at the candidate ODMDS location. An example is shown below.

Given:
Water depth at a hypothetical ODMDS = D = 75 ft
Desired static capacity volume = Vs = 10 million cy = 270 million cubic feet
Side slope for accumulated dredged material = theta = 1.2 ° =1V:50H = 0.020

Required:
Maximum limiting mound height = Hm
Areal Dimensions for ODMDS (assume square site boundaries, length=width) = Ls = Ws.

Solution:

Hm = 5 ft (obtained form figure B-21, lower curve using 75 ft water depth)

Vs = 1/6*Hm*(A +4B+C), where A = (Ls-2*Hm/theta)* (Ws-2*Hm/theta)
= volume of a prismatoid B = [(Ls-2*Hm/theta)+Ls]* [(Ws-2*Hm/theta)+Ws]/4
C = Ls*Ws
≈ 0.95 * Volume of a solid trapezoid
Volume of a solid trapezoid = ½*Hm[Ws+(Ws-2*Hm/theta)]*Ls
Vs ≈ 0.95* {½*Hm[Ws+(Ws-2*Hm/theta)]*Ls}, since Ws = Ls
Vs ≈ 0.95* {Ls^2*Hm – Hm^2 *Ls/theta}, at this point Vs can be solved for, or if Vs is known then Ls can be determined by 0 = Ls^2 – Hm*Ls/theta – Vs/(0.95*Hm), by solving for Ls in terms of the quadratic solution for the root.
for this example, Ls = {5/0.02 + [$(5/0.02)^2$ + 4*270,000,000/(0.95*5)]$^{1/2}$ }/2 = 7,665 ft

The length of each side (assuming a square ODMDS layout), = Ls = 7,700 ft = 1.26 nautical miles

Hypothetical Capacity for Dredged Material Disposal within the MCR ZSF

A similar approach was used to determine the total static capacity (volume) available for dredged material disposal within the 4.5 mile MCR ZSF. The following site capacity calculation is presented for hypothetical purposes only, and is not intended to influence the selection of specific areas for consideration as proposed ODMDSs. Areas omitted from the above volume calculation included locations where water depth was less than 50 ft, present ODMDSs, and regions which may pose a potential ODMDS siting conflict. Potential ODMDS locations within the 4.5 miles ZSF were divided into "units" with similar water depth, as shown in figure B-22. Candidate areas located within the 4.5 Mile ZSF correspond units I-VII. Candidate areas (between 50-100 ft depth) located beyond the 4.5 mile ZSF, but within the 13 mile ZSF were also included in the estimate for static capacity volume. These areas correspond to "units" VIII-IX. A two step process was used to determine available static capacity for each unit: 1) Determine allowable mound height for each "unit" based on average water depth, using figure B-21, and 2) Calculate static capacity volume based on allowable mound height and "unit" dimensions. Results are shown below in table B-5. These results were originally developed for the MCR ODMDS "Overlay Process working group".

Table B-5. Estimated static capacity within selected "units" of MCR zones of siting feasibility (ZSF). Refer to figure B-22 for "unit" locations.

Unit	Average Depth (ft)	Area (acres)	Square Dimension (ft)	Allowable Mound Height (ft)	Unit Volume Capacity (Mcy)
I	60	2,500	10,350	4	14.8
II	75	2,300	10,000	5	17.2
III	125	2,600	10,700	15	55.3
IV	175	2,000	9,300	30	76.8
V	180	1,500	8,000	30	54.7
VI	180	1,700	8,600	30	64.5
VII	75	3,500	12,200	5	25.8
				4.5 mile ZSF Subtotal	308 million cy
Shallow Water "UNITS" Outside of 4.5 mile Radius, but within 13 mile ZSF					
VIII	75	25,200	33,200	5	202.1
IX	75	15,600	26,000	5	124.6
				13 mile ZSF Subtotal	326 million cy

Based on the above volume estimates, there is 308 million cy of static capacity within the 4.5 miles ZSF. Within nearshore areas located *between* the 4.5 and 13 mile ZSF, there is an estimated 326 million cy of static capacity. The combined static site capacity for "units" I-IX is estimated to be 634 million cy. The total volume of dredged material expected to be placed offshore MCR over the next 50 year is between 225-262 million cy. Assuming that siting constraints do not prevent consideration of the above units as potential ODMDSs, it appears that sufficient static site capacity is available for dredged material disposal within the 4.5 mile ZSF and along the nearshore areas within the 13 mile ZSF.

Short-Term Fate Modeling: Bathymetry Impact Assessment

When dredged material is released in open water by a disposal vessel, the material falls through the water column, mixes with ambient water, and forms a plume. This process is called convective descent. When the diluted dredged material plume encounters the seabed, the plume spreads radially along the seabed. This process is called dynamic collapse. After the plume has expended all of its momentum along the seabed, the dredged material slowly settles under the influences of gravity and the ambient current environment. This process is called passive transport and diffusion. Figure B-19 illustrates dredged material behavior, when placed in open water by a hopper dredge.

The STFATE model [Johnson 1990, 1995] estimates the behavior of dredged material as it is dumped in open water, passes through the water column, and encounters the seabed; on an individual dump (disposal vessel load) basis. The STFATE model accounts for various disposal vessel, water column, and dredged material parameters. Through its 25-year period of development, the STFATE model has been calibrated and successfully applied at numerous locations [Koh and Chang 1973, Brandsma and Divoky 1976, Bokuniewicz at al 1978, Bowers and Goldenblatt 1978, Johnson and Holliday 1978, Thevenot and Johnson 1994, Moritz and Randall 1995, Lillycrop and Clausner 1997, and Johnson et al 1998]. It must be noted that the FATE models (including STFATE) are only tools that provide estimates of sediment behavior and related processes. The accuracy of STFATE model-generated results is highly dependent upon the parameters input to the model. Controlling parameters which must be properly specified within the STFATE model are physical characteristics of the dredged material, disposal operation sequencing, and forcing environmental conditions within the water column (waves, currents, density structure). With respect to application within the Portland District USACE, much effort was expended to develop reliable input for STFATE modeling. Based on previous applications of STFATE, it is assumed that the STFATE model results obtained for MCR will meet an accuracy standard of 80% (the difference between predicted and actual conditions is expected to be within ± 20%).

The objectives of ***this*** short-term fate assessment were:

- **Estimate the disposal foot-print geometry in terms of thickness and areal extent after the placed material comes to rest on the seabed**: This data describes the coverage of dredged material on the seabed.

- **Estimate the distance that placed dredged material is displaced away from the point of release**: This parameter describes the ODMDS "buffer" which ma be needed to keep material within the disposal site boundary while the placed material is falling through the water column.

- **Estimate the fall speed, density, and detailed areal extent of dredged material as it encounters the seabed during disposal**: These parameters describe physical process of dredged material travelling downward through the water column and impacting the seabed. This data provides insight to the potential bathymetric impacts in the immediate vicinity of disposal.

Short-term fate simulations were conducted for the disposal of dredged material from two types of hopper dredges: (A) a split-hull hopper dredge - *NEWPORT*; and (B) a multiple bottom door hopper dredge - *ESSAYONS*. The operating parameters for each dredge (and others used at MCR) are shown below.

Table B-6. Operating parameters for hopper dredges commonly used at MCR.

DREDGE	OVERALL DIMENSIONS length (ft)	beam (ft)	draft(ft) loaded/empty	WORKING CAPACITY average (cy)	VESSEL SPEED during disposal (knots)	DISPOSAL vessel type (# of doors/size of each)	DURATION placement of each load (minutes)
Newport	300	55	20/10	3,000	2 to 6	split-hull/ 200x30 ft	4 to 8
Manhattan Island	281	52	19/8	2,600	2 to 5	split-hull/ 190x30 ft	4 to 8
Padre Island	281	52	19/8	2,600	2 to 5	split-hull/ 190x30 f t	4 to 8
Essayons	350	68	27/15	4,500	2 to 8	bottom doors(12)/ 8x8 ft	6 to 15
Stuyvesant	372	72	29/17	6,800	2 to 8	bottom doors (40)/4x4 ft	6 to 15

Since 1990, about half of all dredging disposal at MCR ODMDSs has been performed by the *ESSAYONS*. The *NEWPORT* has performed about 30% of the MCR dredging disposal. Other split-hull dredging/disposal vessels similar to the *NEWPORT*, have performed the remainder of the dredging and disposal at MCR. For simulation purposes, the vessel speed during disposal was assumed to be 2 knots (3.5 ft/sec) for both dredges. The duration of placement for an individual load of dredged material was assumed to be 5 minutes for the *NEWPORT* and 8 minutes for the *ESSAYONS*. Short-term fate simulations were conducted for disposal water depths ranging from 40 to 200 ft. Three types of current conditions were also tested: No current, a 1 ft/sec current , and a 4 ft/sec current. Currents were modeled as being oriented 45 ° into the heading of the disposal vessel. The current regime at existing MCR ODMDSs and candidate sites ranges from 0.5 ft/sec to 5 ft/sec. The characteristics of sediment dredged from the MCR project and placed at ODMDSs are described in Section 8, *Measured Oceanographic Data*.

Depositional Geometry

The time required for dredged material to fall to the seabed and completely settle out of suspension (passive transport and diffusion) is largely dependent upon the water column environment and the material type placed at a given disposal site. At MCR ODMDSs, approximately 97% of dredged material placed is composed of sand and 3% is composed of fines (silt), on a per load basis (Section 8, *Measured Oceanographic Data*). Based on STFATE results for typical MCR conditions, the time required for ***sand*** to completely settle out of the water column during dredged material disposal and deposit onto the seabed is approximately 200 seconds (after the completion of the disposal operation). The time required for ***silt*** to completely settle out of the water column and deposit onto the seabed is approximately 2,000 seconds (after the completion of the disposal operation). The above results were obtained for 100-foot water depth with no current. Short-term fate (STFATE) estimates for passive transport and diffusion are summarized graphically in figures B-23 to B-27 and are described in terms of mound height, mound width-length, and displacement distance. Operational factors that govern the depositional foot-print geometry (on the seabed) include:

- Speed of hopper dredge while dumping
- Current speed and direction in the water column
- Water depth (and bathymetry) at disposal location

Mound length is a function of ***vessel speed*** (figure B-24). For normal operating conditions in water depth of 70 ft without a current, the *ESSAYONS* (*NEWPORT*) produces a dump foot-print 600 to 3,200 ft long (900 to 4,300 ft) for vessel speeds ranging from 1 to 10 ft/sec, respectively. Recall that the *ESSAYONS* requires more time to place dredged material per load than split-hull hopper dredges (Table B-6). ***Mound thickness*** is also affected by vessel speed (figure B-24). For normal operating conditions in water depth of 70 ft without a current, the *ESSAYONS* (*NEWPORT*) produces a dump foot-print 1.2 to 0.2 (1.5 to 0.3) ft thick for vessel speeds ranging from 1 to 10 ft/sec, respectively.

For similar operating conditions (vessel speed, water depth, and currents), the ***split-hull*** hopper dredges such as the *NEWPORT* ***produce a thicker*** (higher) ***resultant mound*** foot-print than the ***multiple bottom-door*** hopper dredge *ESSAYONS*. This is shown in figure B-24,25. For average operating conditions in 70 feet of water without a current, the dredge *ESSAYONS* will produce a deposition mound with maximum height of 0.9 ft. The *NEWPORT* will produce a mound with maximum height of 1.2 ft.

The most significant parameter affecting ***mound geometry*** (width and height) ***is water depth.*** Increasing the ***water depth*** by a factor of 3 (60 ft to 180 ft) will decrease disposal ***mound height*** for a single dump by a factor of 2 for both types of hopper dredges. Increasing the water depth by a factor of 3 (60 ft to 180 ft) will increase disposal ***mound width*** for a single dump by a factor of 2.5 for both dredges (figure B-26). This applies to dredges disposing in all current conditions tested.

Increasing ***current speed*** from 1 to 4 ft/sec (in 70 ft of water) reduces mound height by a factor of 2 for both dredges. Currents displace placed dredged material away from the location of release, before the material impacts the seabed (figure B-26). For disposal in a water depth of 180 ft, a 1 ft/sec current could displace dredged material 400 ft from the site of disposal before most of the material encounters the seabed. For the same water depth, a 4 ft/sec current could displace dredged material more than 2,000 ft from the site of disposal before most of the material settles onto the seabed.

The nominal configuration of a dredged material mound resulting from disposal of one load by the dredge *NEWPORT* in 60 ft (and 160 ft) water depth with a current of 1 ft/sec is shown in figure B-23. The estimated areal coverage of a mound resulting from a single load placed in 60 ft water depth is about 10 acres with maximum mound height of 0.8 ft with, 90% of the mounded area is less than 0.3 ft. The estimated areal coverage of a mound resulting from a single load placed in 160 ft water depth is about 26 acres with a maximum mound height of 0.4 ft, with 98% of the mounded area is less than 0.3 ft.

For locations offshore of MCR where water depths are between 100-200 ft and currents are approximately 1 ft/sec, the mound resulting from an ***individual dump*** could be expected to have the following configuration:

Mound Length: 1,300 - 2,100 ft
Mound Width: 400 - 800 ft
Maximum Mound Thickness: 0.2 - 0.8 ft
Displacement of Mound during Disposal: 100 - 400 ft (up to 2,000 ft for strong currents)

For locations on the MCR ebb-tidal shoal where strong currents are present, the mound resulting from an ***individual dump*** could be expected to have the following configuration:

Mound Length: 1,200 - 1,600 ft
Mound Width: 800 - 1,500 ft
Maximum Mound Thickness: 0.2 - 0.6 ft
Displacement of Mound during Disposal: 400 - 1,200 ft

Dredged Material Bottom Encounter Processes

Table B-7 summarizes physical parameters of dredged material, as it impacts the receiving seabed, during placement in open water by a split-hull hopper dredge. The bottom deposition parameters (describing the convective descent and dynamic collapse phases) were estimated using the STFATE model. Operational input used in the STFATE model pertain to typical disposal of MCR dredged material using the split-hull dredge *NEWPORT* (3,000 cy per dump) on a flat seabed with a current of 1 ft/sec applied at 45 degrees across the disposal heading. Other input data are the same as used for the assessment of *Depositional Geometry*, described above.

Table B-7. Estimated parameters describing the bottom encounter of dredged material placed in open water by split-hull hopper dredge (5 minute dump run with vessel moving at 4 ft/sec).

	(A)							(B)		
Disposal Water Depth (ft)	**Time for Plume[1] to Affect Seabed** (sec)		**Plume[2] Width**	**Plume Fall Speed[3] at Seabed** (ft/sec)		**Plume Density[4] at Seabed** (gr/cc)		**Vertical[5] Extent** (ft)		**Coverage[5] Area on Seabed** (acre)
	descent	**collapse**	**descent** (ft)	**descent**	**collapse**	**descent**	**collapse**	**98%**	**50%**	
50	3	35	55	8	3	1.17	1.046	0.85	0.25	10
100	11	72	110	5	2	1.07	1.030	0.55	0.15	20
150	25	120	170	3	1	1.03	1.025	0.35	0.10	25
200	43	170	250	2	1	1.027	1.025	0.20	0.05	30

Notes:
1. Time needed for dredged material to reach the seabed after release (for descent) and to completely expend all energy associated with the disposal operation and bottom encounter (for collapse). Descent = *convective descent processes,* during which time the dumped material falls through the water column under the influence of gravity and accounts for the motion of dredged material to the point of bottom impact. Collapse = *dynamic collapse processes,* during which time the descending plume impacts the seabed (bottom encounter) or arrives at a level of neutral buoyancy and

expends its potential and kinetic energy in lateral/vertical spreading of the dredged material plume. The duration for the collapse phase is determined by subtracting the descent time from the collapse time, as shown in table B-7 (for the 100-ft water depth, the duration of the collapse phase is estimated to be 72-11=61 seconds.)
2. Dimension of the plume transverse to the vessel heading during disposal, applicable at instant of bottom encounter.
3. Downward speed of dredged material plume just before bottom encounter (for descent) and average fall speed of plume as it encounters seabed (for collapse).
4. Density of seawater = 1.024 gr/cc (64.2 lbm/cf), density of dredged material in hopper dredge = 1.79 g/cc (112 lbm/cf) = density of dredged material on the seabed, after deposition .
5. Final configuration of dredged material on seabed after completion of the passive transport and diffusion phase. "98%" = 98th percentile thickness of accumulation on seabed, only 2% of the foot-print is thicker. "50%" = average thickness of foot-print. "Coverage" = total area of foot-print on seabed greater than 0.01 ft (0.12 in) thick.

Results shown in table B-7 indicate that if the *NEWPORT* dumped 1 load of dredged material in a water depth of 50 ft (vessel was moving at 4 ft/sec during a 5 minute dump run), the following would occur at the seabed.

It would take 3 seconds for the dumped material plume to initially encounter the seabed after being released from the hopper dredge and falling through the water column. As the dredged material plume is released from the hopper dredge, it gains downward momentum (due to the plume falling through the water column). Just before impacting the seabed, the dredged material plume would be: falling downward at 8 ft/sec, have a width of 55 ft (direction transverse to heading of hopper dredge), and have a density of 1.17 gr/cc. The dredged material plume would have been diluted by a factor of 5 from the initial density within the dredge. The total area of the seabed affected by the convective descent phase (during the entire 5 minute dump) would have been, 55 ft (wide) x 5 min x 60 sec/min x 4 ft/sec (long) = 1.5 acres.

Just after impacting the seabed, the average downward speed of the dredged material plume would be 3 ft/sec. It would take 32 seconds (35-3, table B-7) for the plume to expend its downward momentum and complete the dynamic collapse phase. This is the period when crabs, flatfish, and other organisms located on the seabed directly beneath the disposal vessel are the most likely to be affected by the disposal process. After completion of the dynamic collapse phase, the dredged material plume would have been diluted by a factor of 17 from the initial density in the dredge: Approximately 90% of the dredged material placed into the water column would have been deposited on the seabed. After completing the dynamic collapse phase, the process of passive transport and diffusion, would begin and the dredged material would settle-out of the water column and accumulate on the seabed according to the results described in figures B-23 to B-27.

During the passive transport and diffusion phase, about 10% of the dredged material would still be suspended in the water column, where the material would be advected by currents away from the point of disposal, and begin to settle on the seabed at the periphery of the dredged material foot-print. The concentration of solids (sand) within the dredged material plume would be equal to that of the ambient environment near the seabed during normal conditions of transient sediment transport as caused by waves/currents. At the end of the passive transport and diffusion phase, it is estimated that 98% of the disposal foot-print area would be less than 0.85 ft thick (10.2 in). The thickest 2% of the foot print was estimated to cover an area of 0.3 acres. The average thickness would be less than 0.25 ft (or 3 in). The total area of the foot-print on the seabed, having a thickness greater than 0.01 ft (0.12 in), was estimated be about 10 acres.

STFATE results summarized in table B-7 were used to guide Battelle-MSL laboratory-based tests for evaluating the response of juvenile flatfish and Dungeness crab to deposited sediment (as related to dredged material disposal, see Exhibit A). The following STFATE data (via table B-7) were used to establish parameters for the dredged material burial lab tests conducted by Battelle-MSL:

- ***Rate of burial** (the time needed for the plume to affect the seabed after "descent", was based on 1/3-2/3 of the "collapse phase" duration) – column (A) of table B-7.*
- ***Depth of accumulation** (the 98% thickest vertical extent) - column (B) of table B-7.*

The intent of the burial tests was to reproduce the accumulation process of dredged material disposal, at a location corresponding to directly underneath the hopper dredge during the first few minutes of disposal. The above scenario was deemed the worst case, in terms of depth and rate of deposition (i.e. the thickest and fastest rate of accumulation). The rate of burial used in the lab tests was based on the assumption that most of the dredged material impacting the seabed directly underneath the disposal vessel (thickest area of deposition) would have accumulated within:

1/3 of the total collapse phase time period for the 50-ft disposal water depth
1/2 of the total collapse phase time period for the 100-ft disposal water depth
1/2 of the total collapse phase time period for the 150-ft disposal water depth
2/3 of the total collapse phase time period for the 200-ft disposal water depth

STFATE Conclusions

The thickest area of bottom accumulation for an individual dump represents a small fraction (10% or less) of the overall foot-print coverage. For a typical disposal event, most of the disposal foot-print area is composed of a thin apron of dredged material (less than 0.25 ft thick, depending on disposal water depth). Measurements of seabed change at MCR, due to ambient sediment transport process by waves and currents at seabed locations less than 120 ft deep, indicate that seabed elevation normally fluctuates 0.05-0.50 ft on an hourly basis [supporting data are shown in *Section 8 "Measured Oceanographic Data"*, Lund 1998]. A typical dredged material disposal event at MCR would produce a foot-print with average thickness of less than 0.25 ft (equal to normal seabed fluctuation due ambient MCR transport processes).

Based on the characteristics of dredging vessels typically used at MCR, split-hull hopper dredges (*NEWPORT*) are estimated to produce a disposal foot-print per dump that has a maximum thickness 40% greater than the multiple bottom-door hopper dredge (*ESSAYONS*). Dredged material can be dispersed (spread-out on the seabed) by increasing the speed of the disposal vessel while it is placing the dredged material. If the hopper dredge speed is increased while dumping, the mound thickness of individual dumps can be significantly reduced at the expense of increasing mound length. Mound height can be reduced by 60% by increasing the speed of the disposal vessel from 3.5 ft/sec (2 knots) to 8 ft/sec (5 knots). Based on STFATE results for displacement of placed dredged material from the point of release, a 500-foot ODMDS buffer is recommended to prevent inadvertent placement of dredged material outside of formal ODMDS boundaries for nearshore sites (water depth less than 70 ft). For ODMDSs proposed in water depths greater than 150 ft, it is recommended that a minimum buffer of 2,000 ft be employed. If an ODMDS is proposed for 300 ft water depth, then a 3,000 ft buffer is recommended.

The bottom encounter processes associated with dredged material disposal (convective descent and dynamic collapse) are a function of disposal water depth. For shallow water disposal (in 50 ft depth), the "impact" of the dredged material plume on the seabed is more concentrated (in terms of dredged material plume velocity and density at the seabed) than for disposal in 100 ft of water. However, disposal at deeper water depths increases the areal extent of bottom impact as compared to disposal in shallower water depths. The seabed area affected by the convective descent phase is about 10% of the total dredged material foot-print (resulting from completion of the passive transport and diffusion phase). Figure B-27 is a compilation of all STFATE results (for the dredge *NEWPORT*) and shows the how effect of disposal water depth acts to reduce mound thickness for dredged material accumulation on the seabed.

Estimating the Size, Capacity, and physical Impacts for Candidate MCR ODMDSs

The areal dimensions required for new (proposed) MCR ODMDSs were determined based on the need to provide volume capacity for a 50-year dredging-disposal life cycle. This means that new MCR ODMDSs must provide site capacity to receive 225-262 million cy of sandy dredged material over a 50-year period without adversely affecting navigation or the environment. The general areas under consideration for new MCR ODMDSs are shown in figure 20 of the main report of Appendix H.

ODMDS E

ODMDS E (as expanded in 1997) was one of the candidate areas considered as a new formally EPA-designated ODMDS. ODMDS E is located about 0.25 miles seaward of the MCR north jetty and within 1,500 ft of the MCR navigation channel (figure B-6 and B-10). ODMDS E is the only previously used dredged material disposal site which is being considered for future dredged material disposal. Continued use of ODMDS E is desirable due to:

The dispersive nature of the site - dredged material placed at ODMS E is quickly transported to the littoral environment of MCR. This permits for the renewal of disposal capacity at ODMDS E while using the disposal operation as a method to place dredged material within the nearshore littoral environment of Washington.

The proximity of the site with respect to the MCR navigation channel – haul distance from location of MCR dredging to location of disposal (ODMDS E) is short, making ODMDS E cost-effective to utilize.

The capacity of expanded ODMDS E is associated with the site's ability to temporarily accumulate placed dredged material without negatively affecting navigation due to mounding. The total capacity for a given ODMDS is composed of static capacity and dynamic capacity. Refer to Section 4 for definition of ODMDS capacity.

Calculated Capacity for ODMDS E

The estimate for static capacity within ODMDS E is based on the volume of dredged material that can be accumulated within the site without amplifying wave conditions (due to mound shoaling). The static capacity volume for ODMDS E was estimated based on the following mound dimensions of:

Volume 1 – within 1977 ODMDS boundary = 4,000 ft long x 1,000 feet wide, avg. height of 5 feet, and side- slope of 1V:50H= 530,000 cy for the original (1977) ODMDS E boundaries.

Volume 2 – within 1997- expanded area of ODMDS boundary = 6,000 ft long x 1,800 feet wide, avg. height of 5 feet, and side-slope of 1V:50H = 1.6 million cy for the expanded area (1997) of ODMDS E .

The total static capacity of expanded ODMDS E was estimated to be 2.1 million cy, 530,000 cy of which is associated with the original (1977) site boundary [USACE 1997]. The estimate for **static capacity** within ODMDS E is based on the volume of dredged material that can be accumulated within the site without amplifying wave conditions (due to mound-induced effects), with respect to the "baseline" condition (figure B-10). The static capacity estimate is based on a maximum mound height of 5 feet , with respect to the May 1997 (baseline) bathymetry, and assumes that dredged material is not transported out of the site (dynamic capacity =0). This is a conservative assumption (transport of accumulated material will likely occur during the winter due to high wave and current conditions that will act upon the accumulated dredged material). Past experience at ODMDS E shows that the site does not accumulate dredged material over time. If the placed dredged material is transported out of the site (by waves and currents), which is anticipated, the total static capacity of the site may be renewed every year. The 5-foot mound height criteria was based on a non-impact requirement for ODMDS wave conditions.

Based on findings reported in USACE [1997], the accumulation of placed dredged material on the seabed at ODMDS E during CY 1997 was estimated to be about 60% of the volume placed. This means that about 40% of the dredged material placed at ODMDS E during 1997 was immediately dispersed to areas either beyond the survey boundaries or accumulated to a thickness less than the vertical detection threshold of the survey. In either case, it was estimated that 60% of the material placed at ODMDS E will accumulate on the seabed in terms of a distinguishable mound feature. This inferred that the **dynamic capacity** of ODMDS E was assumed to be 40% of the total site capacity. The *total* ODMDS site capacity = static + dynamic. Accounting for the 60%

retention estimate as described above, the total volume of dredged material that could potentially be placed within ODMDS E for 1 year utilization is estimated to be 3.5 million cy. This infers a dynamic capacity of 1.4 mcy for ODMDS E. The estimate for total capacity (1 year utilization) at ODMDS E is shown below:

Total site Capacity for ODMDS E = Static site capacity / percent of placed material that is retained in site
= 2.1 million cy / 0.60 = 3.5 million cy (entire ODMDS E).

The above results indicate that the ***maximum*** volume of dredged material that can be placed within ODMDS E during a given year is 3.5 mcy; the results do not indicate that ODMDS E can be used for the disposal 3.5 million cy of dredged material per year. After placing 3.5 million cy at ODMDS E (during a given disposal year), 1-2 years time would be required to completely disperse the accumulated dredged material out of the site boundaries. Alternatively, 1.4 million cy per year could be placed at ODMDS E, following the 3.5 mcy disposal event.

Observed Capacity for ODMDS E

The observed dynamic capacity for ODMDS E during 1998 was determined to be 2.3 million cy/yr, and indicates the actual volume of dredged material that can be placed at ODMDS E per year without accumulating (see Section 3 of this exhibit). The above capacity estimate was based on one year of site monitoring and is subject to change based on the variability of the MCR environment. The reliability of the dynamic capacity estimate for ODMDS E precludes its use for long-term site management forecasting. Although ODMDS E has been successfully used for the dispersal of up to 3.5 million cy/yr of dredged material into the littoral environment, ODMDS E should not be assumed to continually provide this volume of dynamic capacity (per year) over a 50-year period. It is likely that the long-term capacity for annual disposal at ODMDS E is between 1.4-2.3 million cy (per year).

Physical Impacts due to Dredged Material Disposal at ODMDS E

Accumulation of Placed Dredged Material. The seabed at ODMDS E would be subjected to various degrees of dredged material accumulation (burial) during dredged material disposal operations. On a per dump (individual disposal vessel load) basis, the seafloor at ODMDS E could be subjected to individual burial events ranging from 0.01 – 0.8 ft thick and covering 5-15 acres of seafloor. On a seasonal basis (after an entire dredging-disposal season), the seabed within ODMDS E could be subjected to dredged material accumulation ranging between 1-6 ft thick covering an area of up to 0.5 sq. mile. It should be noted that the bathymetry of ODMDS E is presently subjected to "natural" modification by waves and currents, producing seabed change which may exceed 5 ft vertical (deposition or erosion by waves-currents) during any given year. Short-term (during a ½ hour period) "natural" seabed change has been observed to exceed 4 inches.

All dredged material placed within ODMDS E is expected to be transported away from the location of disposal (during and after deposition on the seabed) by waves and current. The length of time required for waves and currents to transport deposited dredged material out of ODMDS E is based on the volume placed. Estimated dispersal rates range from 1.4 to 2.3 million cy/yr. The magnitude and the direction of sediment transport is expected to vary throughout any given year. Over time, the net direction of transport for dredged material placed in the nearshore zone is expected to be toward the north, with onshore and offshore components. Refer to Section 7 for the description of littoral transport at MCR.

It is possible, after several years of placing dredged material at ODMDS E, that some of the placed dredged material will be transported onto Peacock spit and accumulate to various degrees. Areas on Peacock Spit may over time, experience enhanced shoaling due to dredged material disposal at ODMDS E. While this may be a desirable consequence of using ODMDS E for "littoral" purposes, the potential of dredged material shoaling in areas of "off-channel" navigation at MCR is not desirable. Unacceptable shoaling on Peacock Spit, due to use of ODMDS E, will be kept to a minimum as specified in the "Management and Monitoring Plan".

Modification of In-Situ Surface Sediment Gradation. There could be a slight change of the surface sediment texture (grain size) on the seafloor of ODMDS E, in response to dredged material disposal. Specifically, the average grain size of seabed sediment within the ODMDS E may increase due to the placement of dredged material that is coarser than in situ sediments. The overall physical properties of the pre-disposal seabed sediment within ODMDS E would NOT be changed: Sand (sediment dredged from MCR and the Columbia River) will be placed on sand (in situ sediment residing on the seabed of proposed ODMDSs). The mean grain-size of in situ seabed sediment within ODMDS E varies between 0.2-0.25 mm and has a fine-grain material content of 0-10%. The mean grain-size of dredged sediment to be placed within ODMDS E varies between 0.19-0.37 mm and has a fine-grain material content of 1-4%.

Modification of Existing Wave Environment. Use of ODMDS E will not degrade the existing wave or current environment either within or outside the ODMDS boundaries.

Modification of Existing Current Environment . Placement of dredged material within ODMDS E (1997 expanded configuration) is not expected to affect circulation of the Columbia River plume, within or outside of the site boundaries. Accumulation placed dredged material on the seabed will be limited to a height of 4-6 ft with respect to the site's baseline condition. The placed dredged material is expected to be dispersed within 1-3 years, depending upon the volume placed per year. A vertical accumulation of 4-6 ft of dredged material within a water depth of 45-65 ft will affect less than 10% of the water column: This not expected to modify currents at ODMDS E.

"North" and "South" Proposed ODMDSs – *Initial* Configuration

To provide a conservative estimate for future site capacity at MCR, ODMDS E was not included in the 50-year site capacity analysis for proposed new sites. The proposed new ODMDS(s) were "sized" based on the site capacity estimating method described earlier in this section, with consideration given to criteria enumerated in the main report of Appendix H and the *Management and Monitoring Plan.*

Initially, two (2) proposed ODMDSs (figure 16 of the main report, Appendix H) were evaluated using assumptions enumerated below

1) With respect to placing dredged material within the littoral environment, proposed ODMDSs should facilitate equal distribution of dredged material placement along the Oregon and Washington coasts. This assumption is based on the lack of certainty for estimating the net direction of littoral transport in vicinity of MCR (see ***Section 7, Oceanographic Processes).***

2) The dynamic capacity for proposed "north" and "south" sites was assumed to be 0. Although the nearshore areas of these sites are within the littoral zone, the sites were assumed to be non-dispersive as a conservative measure for ensuring sufficient life-cycle capacity.

3) At least half of all dredged material to be placed offshore of MCR should be placed in nearshore areas, to permit introduction of dredged material into littoral zone. To allow placement within the littoral zone, the nearshore area of a proposed site was considered to extend from 30 ft water depth to 100 ft water depth.

4) Half of all dredged material may be placed in offshore areas. Since ocean disposal of dredged sediment is not recommended in water depths greater than 200 ft (due to detrimental benthic impacts – Exhibit A), offshore ODMDS locations were considered between water depth of 100-200 ft.

5) Seabed surface sediment in vicinity of MCR , tends to become finer (smaller grain size) as one moves offshore: The grain size of seabed sediment nearshore is larger than sediment offshore. Refer to Section 8 of this exhibit for elaboration. To facilitate the matching of dredged material textual properties (grain size) with the in-situ surface sediment at proposed ODMDSs, it is assumed that coarser dredged material (larger sized sand dredged upstream of the MCR channel) will be placed exclusively within the nearshore zone of ODMDSs. Finer dredged material (sand dredged from MCR) may be placed in nearshore and offshore zones of ODMDs.

6) Each proposed MCR ODMDS should facilitate redundant site capacity. For example: If at sometime in the future, ocean disposal of dredged material is restricted within ODMDSs located offshore Oregon, ODMDSs offshore Washington must have sufficient capacity to handle all MCR dredged material disposal and vice-versa. Proposed ODMDSs located along Oregon were assumed to provide 230 million cy of static capacity. The same requirement was applied to Washington proposed ODMDSs.

Based on the above assumptions, site capacity estimates were developed for 2 proposed ODMDSs (North and South sites). The "north" and "south" proposed ODMDSs were expected to have a 50-year life-cycle capacity of 230 million cy. As proposed, the proposed "north" ODMDS located along the Washington coast included only a nearshore zone. The proposed "south" ODMDS, proposed along the Oregon coast will include a nearshore and offshore zone. Therefore, there were three (3) areas considered for site capacity purposes: Two (2) *nearshore* areas, one each located along Oregon and Washington; and one (1) *offshore* area, located along Oregon.

Based on present MCR bathymetric conditions (figure B-6), the cross-shore dimension for the *nearshore* zone of the proposed ODMDS along Oregon was fixed at 2.8 miles (the distance between –30 and –100 ft MLLW contour). The cross-shore dimension for the *nearshore* zone of the proposed ODMDS along Washington was fixed at 3.2 miles. The cross-shore distance for *offshore* zone of the proposed ODMDS along Oregon was fixed at 3.2 miles (the distance between –100 and –200 ft MLLW contour).

Static Capacity Requirements for *Initial* "North" and "South" Sites

The following calculations were used to "size" proposed new MCR ODMDSs to provide redundant life-cycle capacity per site = 230 million cy. After determining the "life-cycle capacity" dimensions for each site, additional consideration was given to providing enough ODMDS area for distributing dredged material to a sufficiently thin accumulation on an annual basis. This approach was considered for minimizing benthic impacts due to accumulation resulting from repeated disposal at one location.

Given:

Two proposed ODMDSs, 2 zones in each = 4 ODMDS zones - 2 nearshore and 2 offshore.
Average water depth at proposed nearshore ODMDS = D = 70 ft
  Cross-shore dimension for OR nearshore area = 3.2 miles
  Cross-shore dimension for WA nearshore area = 4.5 miles
Average water depth at proposed offshore ODMDS = D = 150 ft
  Cross-shore dimension for OR offshore area = 3.2 miles
Required static capacity volume for each zone in the ODMDS proposed along the Oregon coast = Vs
  = 115 million cy = 3,105 million cubic feet
Required static capacity volume for the ODMDS proposed along the Washington coast = Vs
  = 230 million cy = 6,210 million cubic feet
Side slope for accumulated dredged material = theta = 1.2 ° =1V:50H = 0.020

Required:

Maximum limiting mound height for each ODMDS = Hm
Areal Dimensions for each ODMDS (at first assume square site boundaries, length=width) =Ls= Ws.

Solution:

Hm = 5 ft for depth = 70 ft (obtained form figure B-21, lower curve using 70 ft water depth)

Hm = 25 ft for depth = 150 ft (obtained from figure B-21, lower curve using 150 ft water depth)

$Ls = \{Hm/0.02 + [(Hm/0.02)^2 + 4*Vs/(0.95*Hm)]^{1/2}\}/2$ = required square dimension for ODMDS

For the ***nearshore Oregon ODMDS*** location, Ls = 4.2 nautical miles per side, since cross-shore dimension is fixed at 3.2 miles, the alongshore dimension = 4.2*4.2/3.2= 5.5 miles
Minimum site dimension for 50-year life-cycle capacity = 3.2 (cross) mi x 5.5 mi (along)

For the ***nearshore Washington ODMDS*** location, Ls = 6.0 nautical miles per side, since cross-shore dimension is fixed at 4.5 miles, the alongshore dimension = 6.0*6.0/4.5= 8 miles
Minimum site dimension for 50-year life-cycle capacity = 4.5 (cross) mi x 8 mi (along)

For the ***offshore Oregon ODMDS*** location, Ls = 2.0 nautical miles per side, since cross-shore dimension is fixed at 3.2 miles, the alongshore dimension = 2.0*2.0/3.2= 1.2 miles
Minimum site dimension for 50-year life-cycle capacity = 3.2 (cross) mi x 1.2(along)

As specified in Section 4, "*Siting and Management Requirements for New ODMDSs at MRC*", new ODMDSs should be sized to provide sufficient area to promote the distribution of dumped dredged material, where needed. Based on the initial findings presented in Exhibit A (of Appendix H), it was determined that the annual operational foot-print (area affected by disposal) should be minimized for *offshore* parts of proposed ODMDSs (water depths greater than 100 feet). This would concentrate dredged material within a small foot-print, on an annual basis. For *nearshore* parts of proposed ODMDSs (water depths less than 100 ft), the the annual operational foot-print (area affected by disposal) should be maximized. This would diffuse dredged material over a wide area, prevent significant accumulation, and promote benthic recovery in the energetic nearshore area. Collectively, these measures intended to minimize the overall benthic impact of dredged material disposal throughout a given ODMDS.

ODMDS Sizing Considerations to Address Non-Repetitive Dumping

For nearshore ODMDS areas, the annual distribution of dredged material could be enhanced by evenly distributing individual loads of dredged material on the seabed during disposal. If required, the nearshore areas of proposed ODMDSs could be managed to minimize repeat dumping in one location and prevent more than 10" of annual dredged material accumulation on the seabed. This measure would promote benthic recovery. To facilitate the above, an ODMDS could be divided into several sub-areas and each sub-area would be used on an annual rotational basis. This management rational is based on the siting requirements stated in Exhibit A of this report.

The following calculations were used to determine the *nearshore* ODMDS area that is required to meet the dispersal requirements stated above. The potential need for minimizing the annual rate of dredged material accumulation at nearshore disposal sites is assumed not to apply to offshore sites.

Over the 50 year life-cycle, the average annual volume of dredged material expected to be placed into MCR ODMDSs is 4.5 million cy/yr (this includes MCR and Columbia River channel dredged material). Assuming an average unit disposal volume (per hopper dredge load = average of *Newport* and *Essayons*) of 3,700 cy, about 1,170 dumps per year would be required to place 4.5 million cy of dredged material at MCR ODMDSs. To prevent significant overlap of individual dumps (hopper dredge loads) and excedence of the 10" annual vertical accumulation limit, a per dump separation distance was determined based on the areal coverage associated with a per dump seabed accumulation thickness of 2.5" (applicable for disposal in 60 ft water depth).

Based on the estimated areal configuration of an individual dump performed in 60 ft of water (figure B-27), the portion of dredged material deposition on the seabed greater than 2.5 " thick is expected to occupy 35% of the total per dump foot-print area (or 200 ft x 700 ft). Summarizing the above:

> In 60 ft of water, the per dump areal coverage associated with an accumulation thickness of 2.5 " (or more) is 200 ft x 700 ft, which is about 3 acres.

The total areal coverage needed (in 60 ft water depth) to distribute 4.5 million cy of dredged material to a thickness of 10" or less = 1,170x200x700 = 4.4 sq miles. The equivalent square dimension is 2.1 miles. To provide enough ODMDS area for a 3-year rotational disposal plan, an ODMDSs with area of (2.1 mi. x 2.1mi.)x 3 years = 13.2 sq. mi. would be needed. For the proposed nearshore ODMDS locations, the bounding site dimensions were determined by : 13.2 sq. mi. divided by the fixed cross-shore dimension.

For the proposed "south" nearshore site: Fixed cross-shore dim. = 3.2 mi.
Calculated along-shore dimension for "non-repetitive" requirement =13.2/3.2 = 4 mi.

For the proposed "north" nearshore site: fixed cross-shore dim = 4.5 mi.
Calculated along-shore dimension for "non-repetitive" requirement = 13.2/4.5 = 3 mi.

Areal Dimensions for *Initial* "North" and "South" Sites

Since the dimensions required for static site capacity are larger than the dimensions required for distributing dredged material, the static site capacity dimensions will be used to size the nearshore area for each ODMDS. Suggested dimensions for proposed nearshore sites are summarized in table B-8.

Table B-8. Estimated areal dimensions and corresponding site capacity for neashore and offshore areas of proposed new ODMDSs located along Oregon (OR) and Washington (WA) coasts. Dimensions consider both total site capacity and annual accumulation considerations.

Disposal Area	**Depth Range, (ft) [Average Depth]**	**Bounding* Dimensions (n.mi.)**	**Mound** Height (ft)**	**Disposal Area Static Capacity (Mcy).**
Nearshore-OR	30-100 [70]	3.2(cross-shore) x 5.5(alongshore)	5	115
Offsshore-OR	100-200 [150]	3.2(cross-shore) x 1.2(alongshore)	25	115
Nearshore- WA	30-100 [70]	4.5(cross-shore) x 8.0(alongshore)	5	230

Note: static capacity estimates are with respect to 1994 (baseline) conditions.
* = For nearshore sites, dimensions were determined based on the cross shore distance from the –30 to –100 ft MLLW contour and the need to distribute placed dredged material for preventing excessive

accumulation per annum (10 inches per year accumulation). For offshore sites, dimensions were determined based on the cross shore distance from the –100 to –200 ft MLLW contour.
** = maximum mound height based on RCPWAVE criteria, for avoiding wave amplification, see figure B-21.

If dredged material is placed within ODMDS E during a given year, then the entire site will likely be used. If dredged material is placed within the proposed "North" or "South" sites, only a small part of the site would be used for dredged material disposal.

The calculated dimensions for initially-proposed sites (summarized in table B-8) are intended to function only as a general guide for determining the initial configuration of "North" and "South" sites. Site dimensions (specified in table B-8) are large enough to accommodate a 500-ft "buffer" zone for the nearshore areas and a 2,000 ft buffer for the offshore area. The rational and assumptions used to develop table B-8 were not intended to dictate ODMDS management procedures.

Revised Configuration for "North" and "South" Sites

Based on comments received from MCR stakeholders (main report, Appendix H), the size of initially-proposed "north" and "south" sites was deemed too large. Stakeholders feared that the large areal extent of the initially-proposed "North" and "South" sites would impact fisheries and other resources. The initially-proposed sites (discussed above) were subsequently reduced in size (by a factor of one-half) to address stakeholder concerns (see figure 22, in Appendix H). The size of the initially-proposed sites was reduced by revising several of the siting assumptions listed in the section *"North" and "South" Proposed ODMDSs – Initial Configuration*.

Assumption #2 regarding zero dynamic capacity for nearshore sites, was changed to include dynamic capacity in the sizing of proposed nearshore sites.

Assumption #3 regarding the maximum depth limit of nearshore areas, (for littoral transport) was changed from 100 ft to 60 ft. Nearshore areas of the revised "north" and "south" sites were considered to be within the 30-60 ft water depth.

Assumption #4 regarding the minimum depth limit of the offshore area, was changed from 100 ft to 150 ft. The offshore area of the revised "south" site were considered to be within the 150-200 ft water depth.

Assumption #6 regarding redundant site capacity of "north" and "south" sites was revised. Nearshore areas of the "north" and "south" sites were revised to accept 1 million cy/year (each) over a 50 year life-cycle. The offshore area of the "south" site was assumed accept 4.5 million cy/yr over a 50-year life-cycle.

The following calculations were performed to determine the "revised" size for the ***offshore*** area of the "south" site. This approach was considered for minimizing the area of the offshore site. A buffer for the "offshore" site was not included in the following size determination. If a buffer were applied, it would have added 2,000 ft to each side of the "offshore" site.

Given:
Average water depth at revised offshore area of the "south" site = D = 175 ft
Cross-shore dimension for OR offshore area (distance between 150-200 ft contour) = 1.5 miles
Required static capacity volume for the revised offshore area of the "south" site = Vs
= 4.5 mcy *50 yrs = 225 mcy
Side slope for accumulated dredged material = theta = 1.2 ° =1V:50H = 0.020

Required:
Maximum limiting mound height for each ODMDS = Hm
Areal Dimensions for the revised offshore area of the "south" site (at first assume square site boundaries, length=width) =Ls= Ws.

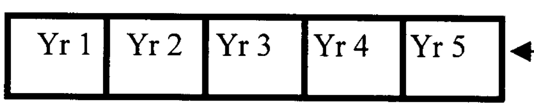
Solution:

Hm = 35 ft for depth = 175 ft (obtained from figure B-21, lower curve using 175 ft water depth)

$Ls = \{Hm/0.02 + [(Hm/0.02)^2 + 4*Vs/(0.95*Hm)]^{1/2}\}/2$ = required square dimension for ODMDS

For the ***offshore "south"*** location, Ls = 2.4 nautical miles per side, since cross-shore dimension is fixed at 1.5 miles, the alongshore dimension = 2.4*2.4/1.5 = 3.8 miles
Minimum site dimension for 50-year life-cycle capacity = 1.5 nmi (cross-shore) x 3.8 nmi (alongshore)

The following calculations were performed to determine the "revised" size for ***nearshore*** areas of the "North" and "South" sites. This approach was used to minimize the size of the nearshore sites while enhancing littoral transport of dredged material placed within the "revised" nearshore areas. This approach would also utilize the dispersive capacity of the nearshore sites. An additional consideration included the need to promote benthic recovery following dredged material placement, while avoiding the formation of excessively high dredged material mounds. The above requirements were met by splitting the "North" and "South" sites into 5 separate cells. The cells would be used on a 5 year rotational basis. A buffer was determined for each cell.



Revised nearshore placement area, 5 placement "cells" aligned alongshore

One cell would be used (1 mcy of disposal) in any given disposal year, after which the cell would be left "fallow" for 4 years until it would again be used for dredged material disposal. This would allow benthic recovery within each cell following disposal and facilitate the dispersion of placed dredged material out of the cell, avoiding the mounding of dredged material.

Given:
Average water depth at revised nearshore area of the "north" and "south" sites = D = 50 ft
Average cross-shore dimension for OR and WA nearshore areas (between 30-60 ft) = 1.5 miles
Required static capacity volume for each placement cell (5 total) within the revised nearshore areas = Vs

Vs = 1 mcy, placed every 5 years

Required *dispersive* capacity for each placement cell (5 total) within the revised nearshore areas = Vd

Vd = 1 mcy/4 years = 225,000 cy/yr

Side slope for accumulated dredged material = theta = 1.2 ° =1V:50H = 0.020

Required:

Maximum limiting mound height for each ODMDS = Hm

Areal Dimensions for the revised nearshore area of the "north" and "south" sites (assume square boundaries for each placement cell, (length=width) =Ls= Ws. Placement cells are arranged side by side in the alongshore direction, between the depth contours of 30-60 ft.

Solution:

Hm = 3 ft for depth = 50 ft (obtained from figure B-21, lower curve using 50 ft water depth)

$Ls = \{Hm/0.02 + [(Hm/0.02)^2 + 4*Vs/(0.95*Hm)]^{1/2}\}/2$ = required square dimension for 1 placement cell to hold 1 mcy.

Ls = for each nearshore placement cell, per side, Ls = 3,100 ft.

Based on analysis of the nearshore area of Coos Bay ODMDS [USACE 1998], the dispersion rate of sandy dredged material placed at this site was observed to be 200,000 cy per year applicable over 2,000 ft x 8,000 ft. This translates into a unit dispersion rate of 0.013 cy/sf per year. Assuming the Coos Bay dispersion rate would apply to similar locations at MCR, the 4-year disperison rate for each 3,100 ft x 3,100 ft nearshore placement cell = 480,000 cy. This is less than 1 mcy, which is the volume of dredged material expected to be placed within each cell every 4 years. The placement cells need to be larger than 3,100 ft x 3,100 ft to facilitate the required 1 mcy dispersion every 4 years.

The disposal cell area needed to disperse 1 mcy every 4 years at revised nearshore sites was estimated by:
Cell Area = 1 mcy/(0.013 cy/sf *4 yrs) = 4,500 ft * 4,500 ft. Ld = 4,500 ft

To ensure that dredged material placed at one cell does not infringe on neighboring cells, add a 1,000 ft buffer to Ld. Dredged material would not be placed within the buffer area. Thus, each placement cell within the revised nearshore areas is 6,500 ft x 6,500 ft. . This is less than cross-shore dimension between 30-60 ft depth contours (1.5 miles). If 5 cells were aligned alongshore, the overall dimensions of the nearshore disposal sites would be 6,500 ft (cross-shore) x 32,500 ft (alongshore).

Taking advantage of the 1.5 mile cross-shore distance between 60-30 ft countours, the overall dimensions for the "revised" nearshore areas of the "north" and "south" sites are: Ld x 5Ld, or 9,100 ft (cross-shore) x 22,000 ft (alongshore).

Physical Impacts due to Dredged Material Disposal at Revised "North" and "South" Sites

Accumulation of Dredged Material Placed. The seabed at the revised "north" and "south" ODMDSs may be subjected to various degrees of dredged material accumulation (burial) during dredged material disposal operations. On a per dump (individual disposal vessel load) basis, the seafloor at the "revised" ODMDSs could be subjected to individual burial events ranging from 0.01 – 0.8 ft thick and covering 5-15 acres of seafloor. On a seasonal basis (after an entire dredging-disposal season), the nearshore area of the "revised" (north and south) sites may be subjected to dredged material accumulation ranging between 1-3 ft thick covering an area of up to 0.6 sq. miles. The offshore area of the "revised" south site may be subjected to discrete locations of mounded dredged material of 1-5 ft thick covering an area up to 0.25 sq. miles.

All dredged material placed within the nearshore zone of the "revised" sites (between 30 ft and 60 ft water depth) is expected to be transported away from the location of disposal (after deposition on the seabed) by waves and currents after a period of 4-5 years. The magnitude and the direction of sediment transport is expected to vary throughout any given year. Over time, the net direction of transport for dredged material placed in the nearshore zone is expected to be along shore (toward the north and south), with a slight onshore component. Refer to Section 7 for the description of littoral aspects at MCR. It should be noted that the nearshore bathymetry of MCR is presently subjected to "natural" modification by waves and currents, producing seabed change which may exceed 5 ft vertical (deposition or erosion) during any given year. Short-term (within a ½ hour period) "natural" seabed change has been observed to exceed 4 inches.

Dredged material placed in the offshore zone of the "revised" south site, between 150 ft and 200 ft water depth, is not expected to be transported (in significant quantities – on an annual basis) away from the location of disposal by waves and currents.

Modification of In-Situ Surface Sediment Gradation. There could be a slight change of the surface sediment texture (grain size) on the seafloor of the "revised" sites, in response to dredged material disposal. Specifically, the average grain size of seabed sediment within the "revised" sites will likely increase due to the placement of dredged material that is coarser than in situ sediments. The overall physical properties of the pre-disposal seabed sediment within the "revised" ODMDSs would NOT be changed: Sand (sediment dredged from MCR and the Columbia River) will be placed on sand (in situ sediment residing on the seabed of proposed ODMDSs). The mean grain-size of in situ seabed sediment within the "revised" "north" and "south" ODMDSs varies between 0.09-0.15 mm and has a fine-grain material content of 0-10%. The mean grain-size of dredged sediment to be placed within "revised" ODMDSs varies between 0.19-0.37 mm and has a fine-grain material content of 1-4%.

Modification of Existing Wave and Current Environment. Use of revised "north" and "south" ODMDSs will not degrade the existing wave or current environment either within or outside the ODMDS boundaries.

Modification of Existing Current Environment. Placement of dredged material within the nearshore areas of the revised "north" and "south" sites is not expected to affect circulation within or outside of the site boundaries. Accumulation placed dredged material on the seabed will be limited to 3 ft per "cell" (every 4 years). The placed material is expected to be dispersed before the "cell" is used again (after 4 years). A vertical accumulation of 3 ft of dredged material within a water depth of 30-60 ft will affect less than 10% of the water column: This not expected to modify currents at the nearshore areas.

Due to the size of the mound resulting from accumulated dredged material placed in the revised "offshore" site (20-35 ft high covering a 5.7 sq. mile area), it is possible that currents in vicinity of the revised "offshore" site could be affected by disposal operations. A vertical accumulation of 35 ft of dredged material within a water depth of 175 ft will affect 20% of the water column: This may modify currents at the revised "offshore" disposal site. If realized, the effects upon the site's current field would not occur until a substantial volume of dredged material has been placed a the site (45 mcy, or 10 years disposal). The area of enhanced mixing between the surface water of the Columbia River plume and ambient coastal water is believed to be north of the "offshore site. It is unknown whether changes in circulation at the "offshore" south site could potentially affect the distribution of the Columbia River plume, and deposition of suspended sediment and detritus in vicinity of the "offshore" site.

"Deepwater" ODMDS

After presenting the revised "north" and "south" sites to MCR stakeholders, USACE and EPA determined that the stakeholders' concern of potential adverse impacts was not mitigated by the reduced size of the revised sites. It was agreed by USACE, EPA, and MCR stakeholders to examine a "deepwater" site, instead of the "north" and "south" sites. The "deepwater" site would be located in water between 180 and 280 ft deep and facilitate the disposal of 4.5 mcy of dredged material per year for 50 years. Once placed at this proposed location, the dredged material would be inert – it would be permanently removed from the littoral system of MCR.

The "deepwater" site would be used such that during each annual disposal operation, the drop-zone (and subsequent seabed accumulation) of placed dredged material would be confined to as small an area as possible. The process would be repeated at the same disposal location until placed dredged material had accumulated to the maximum allowable height, at which point the drop-zone would be moved to another location within the "deepwater" site. This measure is intended to confine potential benthic impacts to the minimum area possible.

The following calculations were performed to determine the size for the proposed "deepwater" site. This approach was considered for minimizing the area of the "deepwater" site.

Given:

Average water depth at deepwater area of the "south" site = D = 230 ft

Required static capacity volume for the deepwater site = Vs
= 4.5 mcy *50 yrs = 225 mcy

Side slope for accumulated dredged material = theta = 1.2 ° =1V:50H = 0.020

Required:

Maximum limiting mound height for deepwater ODMDS = Hm

Areal Dimensions for the deepwater site (assume square site boundaries, length=width) =Ls= Ws.

Solution:

Hm = 40 ft for depth = 230 ft (obtained from figure B-21, lower curve using maximum water depth on chart). Although a 40-ft high mound in 230 ft water depth is not expected to affect incident waves on the surface, a mound this size could potentially affect circulation (currents), since the mound would extend through 20% of the water column.

$$Ls = \{Hm/0.02 + [(Hm/0.02)^2 + 4*Vs/(0.95*Hm)]^{1/2}\}/2$$ = required square dimension for ODMDS

For the ***"deepwater"*** site, Ls = 2.14 nautical miles (or 13,000 ft) per side.
Minimum site dimension for 50-year life-cycle capacity = 2.1 nmi (cross-shore) x 2.1 nmi (alongshore)

To ensure that no material placed within the "deepwater" site moves outside of the site boundaries (either during or after disposal), a 3,000 ft buffer was added to each side of the site. This made the "deepwater" site 19,000 ft x 19,000 ft (3.12 nmi x 3.12 nmi). Refer to figure 25 in Appendix H for the location of the proposed "deepwater" site.

Physical Impacts due to Dredged Material Disposal at "Deepwater" Site

Accumulation of Dredged Material Placed. The seabed within the "deepwater" ODMDS will be subjected to dredged material accumulation (burial) during dredged material disposal operations. On a per dump (individual disposal vessel load) basis, the seafloor at the "deepwater" ODMDSs would be subjected to individual burial events less than 0.5 ft thick and covering 20-50 acres of seafloor. On a seasonal basis (after an entire dredging-disposal season), the seabed of the "deepwater" ODMDS could be subjected to accumulation of dredged material of 15-20 ft high covering an area of 0.5 sq. miles. Over time, the offshore area of a proposed ODMDSs could be subjected to discrete locations of mounded dredged material of 20-40 ft thick.

Sediment Budget of the MCR Littoral Environment. Dredged sandy material placed at the "deepwater" site would be rendered inert. The placed dredged material would not be transported back to the littoral environment of MCR.

If the "deepwater" site is used as intended (4.5 mcy of MCR sand placed per year for 50 yrs), the implications on the littoral sediment budget at MCR and adjacent coastal areas could be profound. The removal of 225 mcy of sand from MCR (via dredging) and subsequent placement at the "deepwater" site would be equivalent to removing the above and below water portions of Peacock spit. The result of such a mass removal of littoral sand would likely be adverse: Local and possible regional coastal erosion may result. The stability of MCR jetties may be reduced due to increased toe scour, resulting from such a littoral sediment deficit.

Modification of In-Situ Surface Sediment Gradation. In response to dredged material disposal at the "deepwater" ODMDSs, there could be a significant change of the surface sediment texture (grain size) on the seafloor within the site. Specifically, the average grain size of seabed sediment within the proposed ODMDSs will increase due to the placement of dredged material that is coarser than in situ sediments. The overall physical properties of the pre-disposal seabed sediment within the proposed ODMDSs would be changed: Sand (sediment dredged from MCR and the Columbia River) will be placed on very fine sand, silt, and mud (in situ sediment residing on the seabed of proposed ODMDSs). The mean grain-size of in situ seabed sediment within the "deepwater" site varies between 0.002-0.12 mm and has a fine-grain material content of 10-15%. The mean grain-size of dredged sediment to be placed within proposed ODMDSs varies between 0.19-0.37 mm and has a fine-grain material content of 1-4%.

Modification of Existing Wave Environment. Use of the proposed "deepwater" ODMDSs will not degrade the existing wave or current environment either within or outside the ODMDS boundaries.

Modification of Existing Current Environment. The "deepwater" site is located on the mid-continental shelf in water depths between 200 and 300 ft. The area in vicinity of the "deepwater" site is where surface water from the Columbia River plume is significantly modified by ambient coastal water, promoting the rapid deposition of suspended sediment and detritus from the Columbia River plume.

Due to the size of the mound resulting form accumulated dredged material (20-40 ft high covering a 4 sq. mile area), it is possible that currents in vicinity of the "deepwater" site could be affected by disposal operations. A vertical accumulation of 40 ft of dredged material within a water depth of 200 ft will affect 20% of the water column: This may modify currents at the proposed "deepwater" disposal site. If realized, the effects upon the site's current field would not occur until a substantial volume of dredged material has been placed a the site (45 mcy, or 10 years disposal). Since the mixing zone for the plume of the Columbia River frequently passes over the area of the proposed "deepwater" site, changes in circulation at the "deepwater" site could potentially affect the distribution of the Columbia River Plume and detritus in vicinity of the proposed site.

Section 7
OCEANOGRAPHIC PROCESSES

Offshore Regional-Scale Circulation

Circulation of the coastal waters near the mouth of the Columbia River (MCR) results from an interaction of regional oceanic circulation, astronomical tides, local wind-generated surface waves and current, swell, and Columbia River flow as affected by inland meteorological events. Time scales for MCR coastal circulation processes range from seconds for wind generated waves to months for seasonal weather patterns to years for large-scale events such as El Nino. These processes act on ebb tidal shoal sediments at MCR (depths <120 ft) to produce the bathymetric condition observed at any particular time. In summary, the time-varying circulation of MCR coastal waters controls the transport and seasonal distribution of suspended material within the water column and bottom sediments.

From a sediment transport point of view, the Oregon-Washington continental shelf can be divided into three cross-shore (from offshore to onshore) regions [Sternberg 1986]. The first of these regions is the outer shelf (depth >300 ft) where shoaling internal waves and seasonally-modified regional currents affect the movement of bottom sediments. The second cross-shore region is the mid-shelf (120-300 ft depth), over which wind-driven currents are the most important factor. The third and most active region is the inner shelf (depth <120 ft), over which shoaling wind waves and swell, shelf-modified tidal currents, and estuarine-induced currents are at least as important as wind-driven currents for promoting the transport of bottom sediments.

Circulation of the continental shelf waters off Washington and Oregon is thought to be nearly geostrophic, i.e. friction plays a minor role in determining the water column circulation when compared to sloping sea surfaces, sloping internal density surfaces, and the rotation of the earth. Consequently, mean circulation on the shelf tends to be along the bathymetric contours.

Circulation of coastal (inner shelf) waters is subject to seasonal reversal, generally being northward during winter and southward during summer. On time scales of several days, coastal circulation can be highly variable in direction and speed with fluctuations correlating with changes in sea level and the alongshore component of wind [Huyer 1977]. The alongshore component of the coastal current regime is substantially stronger and more responsive to changes in wind conditions than is the onshore-offshore component of current [Collins 1970]. Fluctuations in the mean alongshore circulation appear to be coherent over distances of 125 miles and are independent of depth in both phase and magnitude to approximately 70 ft depth [Huyer 1977]. The magnitude of alongshore current fluctuations decreases rapidly with distance offshore and increasing water depth. Currents averaged over very long periods, e.g., longer than 50 days, correlate better with sea level changes than with winds to depths of 120 ft. By 250 ft depth, the influence of both sea level and winds appears to be substantially diminished and other processes such as tides, regional circulation, and internal waves control the current regime.

<u>California and Davidson Currents</u>

Net regional circulation along the continental shelf of the Washington and Oregon coasts has been characterized in terms of two seasonal current regimes: summer and winter [Bourke 1971]. Offshore of the continental shelf break (>20 miles from the coast), surface flow down to 500 ft depth is dominated by the California current. The California current is a broad, shallow, slow moving current which flows southward throughout the year at speeds of 0.1-0.7 ft/sec as a diffuse band about 300 miles wide. Inshore (east) of the California is a seasonally varying flow called the Davidson Current.

The Davidson current is a northward flowing current attaining speeds of 0.3 to 1.0 ft/sec over extensive distances along shore. In the surface waters of the continental shelf, this current responds to the seasonal wind patterns of the northeast Pacific: The Davidson current develops off of the Oregon-Washington coast in September and becomes well established in January in response to southerly winds. The seasonal directionality of surface winds offshore of the Pacific northwest coast is shown in figure B-28. Inshore of the California current, the surface expression of the Davidson current diminishes towards the spring, and is incorporated into the permanent California current by May [Bourke 1971]. The subsurface part of the Davidson current is believed to flow northward throughout the year.

Generalized Shelf Circulation

A generalized model for the seasonal changes in the alongshore and offshore circulation along the Pacific Coast of Washington and Oregon has been developed [Huyer 1977]. The *summer circulation* of surface water on the continental shelf is influenced by the southward flowing California current which attains maximum strength during the summer when surface winds are consistently from the north-northwest. *Winter circulation* of shelf waters is dominated by the northward flowing Davidson current which attains maximum strength due to winter storm (wind stress) patterns. The subsurface part of the Davidson current (below 300 ft depth) is believed to flow northward throughout the year, although the surface waters respond to seasonally varying wind stress patterns (reversals). Thus, the net direction of bottom currents on the mid- and outer continental shelf is believed to be northward and along shore.

Maximum surface current speed over the midshelf (5-10 miles offshore) occurs during June-Aug when the southward flow is reinforced by strong northerly winds. During summer, a strong vertical gradient (shear) of the alongshore current can be found over the middle and outer shelf. The subsurface current is northward while the surface current is southward. The bottom current along the mid-shelf is reduced, due to the high gradient between surface and bottom waters.

The transition from summer to winter for middle and inner-shelf circulation is gradual. The offshore shear zone between the northward flowing bottom waters of the outer-shelf and the southward flow of nearshore coastal waters migrates upward through the water column and shoreward under the influence of fall and winter southerly winds. Reversal of surface water circulation over the shelf occurs when the winter regime of northward flow (Davidson current) is re-established throughout the water column [Sobey 1977].

Inner-Shelf Circulation

The bottom current for inner shelf waters is dominated by surface circulation ands tends to be stronger and more consistently southerly (during the summer) than the bottom circulation further offshore. During periods of sustained wind direction, wind-generated surface current affects flow throughout the water column along the inner shelf.
The transition from the winter circulation regime to the spring and summer regime is abrupt along the middle and inner shelf, occurring only in about a week during a strong northerly wind event. The transition is the result of a large cumulative offshore transport

of surface water caused by local wind stress and the establishment of strong offshore density gradients in the shelf waters. Upwelling is associated with the spring current transition and continues into July or August. The offshore density gradients are associated with the persistent southward surface current and upwelling due to the summer oceanographic season.

Along the inner shelf, open coast surface currents can approach 1.3 ft/sec during the summer. Reversals in current direction rarely occur during summer. With onset of northerly summer winds (southward coastal current), surface coastal waters are directed offshore due to Coriolis deflection resulting in upwelling along the coast: Bottom water is directed onshore. The Coriolis (offshore) deflection of summer surface currents forces the estuarine plume and associated suspended sediments of the Columbia River to be transported offshore while the plume flows southward from the MCR (figure B-29). The Columbia River plume is a major source of relatively warm, low salinity water to the coastal region, and promotes the formation of biologically active oceanic fronts.

With the onset of southerly winter winds resulting in northward flow, surface coastal waters are directed northward (and landward due to Coriolis deflection) resulting in downwelling along the coast. This flow scenario displaces inner-shelf bottom water offshore. The mean alongshore circulation of surface coastal waters during winter is northward at 0.3 - 0.8 ft/sec. The inner shelf current can be highly variable over periods of several days: Southerly flow (north to south) can sometimes occur during the winter. Under the influence of southerly winter winds, and Coriolis (onshore) deflection of surface currents, the plume of the Columbia River is confined inshore while flowing northward from the MCR. The seasonal configuration for the Columbia River surface plume is shown in figure B-29.

Vertical mixing of the inner shelf waters is at a maximum during the winter (December - March) when currents are nearly uniform in speed and direction throughout the water column. Significant wind-generated currents develop in response to strong southerly storm winds during the winter. Wind-induced currents may exceed 60 cm/sec flowing northward with event persistence of 5 to 7 days. Wind-driven currents develop within a few hours of the onset of strong winds, then decrease slowly over several days following cessation of the winds. Vertical mixing (through the water column) may be retarded during the winter for coastal areas such as the MCR, where low salinity plume water discharged from the Columbia River estuary creates stratified conditions. Plume density gradients near MCR can be up to 1 o/oo (for salinity) per meter depth and plume thickness can range from 16-66 ft depth from the ocean surface [Hickey 1998]. Most of the "dynamics" in the Columbia River plume are primarily confined to the upper 16 feet of the water column. Plume-induced currents have been observed at 3.2 ft/sec on the plume surface, 0.66 - 1.65 ft/sec at 16 ft depth, and decrease to 0.16 - 0.50 ft/sec at 33 ft depth [Hickey 1998].

Cross-shore Circulation

The upwelling and downwelling circulation effect due Coriolis deflection induces seasonally varying cross-shore transport of shelf bottom water (Ekman transport). Offshore bottom transport occurs during winter and onshore bottom transport occurs during summer. Ekman transport may affect the fate of fine-grain bottom sediments. Within the immediate vicinity of MCR, estuarine circulation also induces cross-shore transport in water depths less than 70 ft during ebb-tide (offshore flow), flood-tide (onshore flow), and freshets (offshore flow).

Based upon results of a seabed drifter study [Morse et al 1968], the annualized mean alongshore flow of the mid-shelf bottom waters has been estimated to be in a northerly direction. Seabed drifters released offshore of MCR between the 120 and 300 ft contours drifted northward at 0.03 to 0.10 ft/sec, either parallel to the shelf contours or with a very slight offshore component. Many drifters ultimately entered the Straits of Juan de Fuca.

Seabed drifters released inshore of the 120 ft depth (the inner shelf) typically have moved toward the beach under the influence of shoaling waves, wind driven currents, or Ekman transport. Based on previous seabed drifter studies conducted near MCR [Morse 1968], the net direction for cross-shore current on the inner shelf is onshore.

Summary of Seasonal Changes in Circulation

In general, there are three oceanographic seasons for circulation of coastal waters near the Columbia River mouth [Borgeld 1978]. These seasons are briefly defined as:

Fall -Winter - characterized by moderate discharge of the Columbia River, caused by rainfall in the coast ranges, and a winter oceanic regime along the Oregon-Washington continental shelf. Onset of the Davidson current occurs and the coastal current is directed northward by southerly winds. The Fall-Winter season is generally defined as November - March.

Spring - Characterized by the highest discharge of the Columbia River, caused by snow melt in the higher elevations of the catchment basin, and the onset of the upwelling regime along the continental shelf. Transition between the Davidson and California current regimes occurs in offshore waters. The coastal current begins reversal from northward to southward flow. The Spring season is defined as April - June.

Summer - characterized by low discharge of the Columbia River accompanied by the southerly circulation of shelf waters induced by the California current. The coastal water is directed southward by northerly winds. The Summer season is generally defined as July - October.

Long-Period Waves

Superimposed upon the slowly varying regional or seasonal circulation are periodic currents due to tides, inertial currents, and internal waves. While variations in wind speed and direction at duration longer than 2 days are reflected in surface currents, shorter duration wind events can give rise to inertial currents that have 17 hour periods and speeds exceeding 0.33 ft/sec [Huyer 1977].

Continental shelf waves are long waves typically generated by atmospheric pressure/system movements. These waves have periods of 4 - 6 days and propagate toward the north along the western coast of North America. The magnitude of the current associated with shelf waves is on the order of 0.10 ft/sec [Moores 1968]. Shelf-wave flow is uniform throughout the water column and is directed along the shelf, this type of flow may have a significant long-term effect on the rate of transport on fine-grained (silt-clay) sediments sited in water depths greater than 120 ft.

Astronomical tides at MCR have diurnal inequality typical of the North American Pacific Coast with a long ebb from higher high to lower low water. The mean tidal range at MCR is 6.5 ft, the range from mean lower low water (MLLW) to mean higher high water (MHHW) is 8.5 ft. Extreme tide ranges form -2.5 ft MLLW to +11.5 ft MLLW [Lockett 1959]. At MCR, tidal currents are believed to account for more than half of the water motion over periods of several days [Stevenson 1974].

The tidal current for a given coastal location can be described in term of two components: (A) The **shelf tidal current** driven by the approach and passage of the tidal wave over the continental shelf and is uniform throughout the water column, and (B) The **estuarine tidal current** generated by flood and ebb flow from a nearby estuary/embayment. Offshore of MCR, the shelf tidal current is rotary. The estuarine (or plume) driven tidal current at the ODMDSs and other locations close to MCR is significant due to the size and proximity of the Columbia River. The shelf tidal current at MCR surface waters may at times be partially or entirely masked by wind-driven, river discharge, or estuarine tidal currents.

Offshore Rotary Currents

Rotary currents are tidal currents that continually change direction, periodically with time, so that in 12.5 hours the current will have set in all directions of the compass. The rotary current regime at MCR has been documented through observation at the Columbia River lightship for a 2-year period during the months of February, May, August, and November [USNHO 1954]. The MCR lightship was located about 5 miles south of ODMDS B and was decommissioned in 1978. The lighted horn entrance ***bouy "CR"*** is currently positioned near the same location as was the lightship. The rotary current at MCR rotates clockwise with a period of 12.5 hours and has little diurnal inequality (residual or time-averaged component).

The rotary current at MCR generally sets 20° (True) during maximum flood and 200° (T) during maximum ebb. Rotary currents at MCR average about 0.50 ft/sec at strength. A graphical representation of the rotary current at MCR is shown in figure B-30. The fortnightly neap-to-spring tidal cycle causes rotary currents to respectively decrease and then increase 20 percent relative to rotary currents under the mean tidal conditions [USNHO 1954]. Although the rotary tidal current described in figure B-30 applies to the open coast offshore MCR, the rotary current likely includes some "estuarine" effect due the Columbia River plume (i.e. flood and ebb flow from the Columbia River).

Estuarine Effects

In coastal waters immediately offshore of MCR, the offshore circulation of the Columbia River estuary exerts its influence, tending to draw bottom marine waters into the estuary while discharging low salinity waters (the plume) at the surface. For example, at 1 mile SW of the MCR south jetty (seabed = 70 ft depth, figure B-6) near ODMDS A, mean bottom currents flowed eastward during June 1967 [Morse 1968]. This onshore circulation pattern has been documented to extend 6 miles offshore by observing that seabed drifters released offshore MCR tend to enter the estuary and ground at Clatsop Spit, as shown in figure B-31. General observations made at the Columbia River lightship indicate a seasonally variable non-tidal current induced by a combination of river discharge and nearshore current, as shown in figures B-32 [USNHO 1954]. During observation from the lightship, the average set for non-tidal currents induced by the net river flow changed from 235°(T) during Spring -Fall to 295°(T) during Fall-Spring in response to the seasonal shift in the regional current pattern. In absence of any oceanographic circulation, the ebb-flow plume of the Columbia River would tend to extend oceanward in the southwest direction (250°T) due to the orientation of the entrance channel between the jetties.

The observed non-tidal current speed at the MCR lightship ranged between a monthly average of 0.5 ft/sec in March to 1.3 ft/sec in June. During periods of high river discharge, the combined tidal and non-tidal surface current can exceed 3.4 ft/sec in a set to 225° (T) at the lightship (lighted horn ***bouy "CR"***) location. The greatest surface current speed observed at the MCR lightship was 5.9 ft/sec. As a comparison, the surface currents measured at the channel entrance between the north and south jetties were 9.8 ft/sec on ebb and 3.9 ft/sec on flood during a freshet (river flow, 570,000 cfs) in June 1959 [USACE 1960]. In September 1959 (normal Fall river flow condition, 160,000 cfs), the surface currents at the same jetty location were 7.9 ft/sec on ebb and 5.9 ft/sec on flood.

At the jettied entrance to the Columbia River estuary, ebb flow in the northern side of the ***river entrance*** (near jetty "A") is seaward, both at the surface and seabed. During flood tide, saltwater tends to intrude along the southern side of the river channel (along the south jetty and Clatsop spit) [Sternberg 1977]. Consequently, sediments tend to enter the estuary with the marine waters through the ***southern*** side of the MCR during flood tide. Estuarine water and sediments tend to exit the entrance through the ***northern*** side of the entrance and are carried offshore during the ebb tidal flow, when mid-depth ebb currents exceed 6 ft/sec in the entrance channel [USACE 1960 and Sternberg 1977]. The asymmetry of tidal flow in vicinity and through the river mouth is evident by the orientation of bathmetry contours offshore of Peacock and Clatsop spits (figure B-6 and B-10).

Littoral Sediment Supply and Transport

Along the inner- and mid-shelf zone of the coast (water depths less than 300 ft), currents induced by wind, waves, and tides are primarily responsible for sediment transport through the water column and on the seafloor. Wave-induced currents tend to diminish inversely with (water depth)$^{1/2}$ [Komar et al 1972]. The closer one moves toward shore (the shallower the water depths), the more energetic the effects of wave shoaling will be throughout the water column. Increased wave shoaling accompanied by an ambient current can produce a high sediment transport potential (see Section 5, *Simulating The Fate Of Dredged Material Placed At ODMDSs* of this exhibit). In water depths less than 60 ft along the Washington and Oregon Coasts, wind- and wave-induced currents dominate the transport of sediment along the seabed. This area is called the ***littoral*** (or nearshore) ***zone***. Within the littoral zone of Washington and Oregon, the seabed sediment is primarily composed of sand, gravel, and cobbles. Sediment smaller than sand (silt and clay) generally does not reside within the littoral zone of the Pacific NW due to the high mobility of fine-grain sediment. Near MCR, littoral sediments are composed of fine-medium sand.

The transport of bottom sediment within the littoral zone, due to waves and currents, is called ***littoral transport***. In general, littoral transport is a function of wave height and period, bottom sediment size, and strength of ambient current. There are two directional components of littoral transport: cross-shore or perpendicular to shore (onshore-offshore) and alongshore (updrift-downdrift). As waves approach the coast, water depth becomes progressively shallower causing the waves to shoal. Eventually, the shore incident waves break due to bottom friction and conservation of momentum. The dissipation of energy due to wave shoaling and breaking acts to transport bottom sediment, (usually) in the direction of wave propagation. The angle at which waves approach the coast dictates the degree of alongshore and cross-shore littoral transport. For example, waves that approach the shore obliquely tend to produce more alongshore transport than waves which approach the shore straight-on. Cross-shore transport is more complex than alongshore transport: Under some wave conditions bottom sediment can be transported offshore while at other times bottom sediment can be transport onshore. In general, the direction of cross-shore transport for sand-sized sediments along coastal areas of the Pacific Northwest is assumed to be onshore during summer and both onshore and offshore during winter.

Historically, the Columbia River has been a major source of sediment to the northwest coast. On the oceanside of MCR, the mouth of the river is flanked by broad sandy beaches. To the immediate south, lies Clatsop spit where the beach is backed by substantial dunes. To the north, lies Peacock spit and a rocky headland (Cape Disappointment) which anchors the shore (figure B-6). The sandy sediment on the southwest Washington and northeast Oregon coastal beaches originated from the Columbia River.

A difference of opinion exists regarding the predominant direction of littoral trasnport in the vicinity of the MCR entrance [Lockett 1967]. Several observations have been advanced which indicate that the net direction of littoral transport at MCR is from south to north [Ballard 1964]:

- Wave analyses indicate a net northerly wave energy flux is predominate in the winter months.
- A smaller median grain size of beach sand is found south of the MCR entrance.
- The *presence* of the massive shoal formation (Peacock spit) to the immediate north.
- The migration of Sand Island toward the north (during 1839-1885, figure B-3 and B-4).

Contrary observations which could lead one to conclude that the net littoral transport is from north to south have also been advanced [Lockett 1967]:

- The *shape* of Peacock Spit bulges seaward and curves toward the south , past the north jetty. The north jetty and associated estuarine flow would be presumed to act as a littoral barrier for sediment moving south.
- The shoreline for approximately 3 miles south of the MCR has experienced periods of recession and erosion since construction of the entrance jetties.
- During the period from 1877 to 1958, the area to the immediate north of the MCR entrance had shoaled approximately 317,000,000 cy, while the area to the immediate south had lost 504,000,000 cy of sedimentary material. This indicates that the littoral sediment supply immediate south of MCR was interrupted, while the area to the immediate north of MCR was augmented.

Although the dominance of southerly waves (and associated northward littoral current) during the 5-month period of December - March is a documented fact, the remainder of the year is characterized by northerly waves and an attending southward littoral current. It is possible that the wave and current regime present during a period of 7 months could generate littoral transport that approaches the transport experienced during the more energetic 5-month period of the year.

Littoral Transport Implications for Dredged Material Placed at MCR ODMDSs

The onset of long-term climatic perturbations such as El Nino and La Nina can modify the directionality of waves making landfall on the Northwest US coast, greatly affecting the directionality and strength of the littoral current. Long-term changes in the littoral environment are likely responsible for whether littoral sediment (sand) is transported north or south along the Northwest US coast.

The issue of "north vs. south" littoral transport at MCR is an important consideration for life-cycle analyses of existing or proposed ODMDS. The "governing littoral question" relating to ODMDS siting and management at MCR is: Which alongshore direction will dredged sand be transported, when placed at a nearshore ODMDS – north or south? The net direction of littoral transport is believed to be toward the north [Ballard 1964], with significant excursions toward the south [Lockett 1967]. Estimates for gross alongshore transport (direction independent) along the Oregon-Washington Coast exceed 1 million cy per year. A conclusive description for the net direction and magnitude of alongshore transport along coastal areas north and south of MCR is not available.

Within this exhibit, the assessment of littoral transport at MCR ODMDS has assumed that there is equivalent potential for north and south alongshore littoral transport at MCR: To hedge against the uncertainty of littoral transport direction. This assumption implies that dredged (sand-sized) sediment that is placed at nearshore ODMDSs (excluding sites ON the ebb-tidal delta) has an equal chance of being transported toward the north or south of MCR.

In summary, it is assumed that dredged material placed at proposed MCR ODMDSs (in water depth shallower than 60 ft) will have an equal chance of being transported toward the north or the south. Based on the grain size of dredged material (D = 0.2-0.3 mm) that is to be placed within the nearshore areas of MCR ODMDSs, the placed dredged material is expected be transported onshore; thus benefiting the littoral environment.

The littoral transport issue has been indirectly addressed within the physical evaluation analysis for the nearshore areas of proposed ODMDSs at MCR. Figure B-33 is a schematic for the estimated seasonal sand transport patterns near MCR. Note complex littoral circulation indicated near the north jetty offshore of Benson Beach (Cape Disappointment). According to figure B-33, the 60 ft contour line is shown to be annual limit of significant seasonal offshore/onshore transport.

Section 8
MEASURED OCEANOGRAPHIC DATA

Predictions of future MCR ODMDS capacity requirements are highly dependent upon the quality of oceanographic data available. Analyses of the fate of dredged material placed in open water, can only be as accurate as the poorest estimate for the forcing environment and dredged sediment composition. Relevant oceanographic data used in this exhibit to simulate dredged material disposal at MCR include:

- Bathymetric surveys at existing and proposed proposed ODMDS locations
- Physical/textural properties for native seabed sediments at MCR and dredged materials to be placed at MCR ODMDSs
- Wind-generated surface wave characteristics
- Ocean tidal signal (for surface elevation and currents)
- Residual bottom currents for each oceanographic season

Hydrographic Survey Data

Hydrographic surveys at the MCR "approaches" and ODMDSs "A", "B", "E", and "F" have been digitally recorded since 1981. Areal coverage of the ***approach surveys*** is from RM -1 to 5 miles offshore (in the cross-shore direction) and 3 miles north and south of the navigation channel (in the alongshore direction). The approach survey frequency is about once every 2 years. Areal coverage of ***disposal site*** surveys typically extends 1,000 feet beyond the sites' formal boundary and the survey frequency is usually two times per year (spring and fall). Elevation (z) values for all hydrosurvey data are recorded in ft, MLLW which is -3.05 ft NGVD at Fort Stevens, 1947 adjustment. The horizontal datum (x,y) is Oregon State Plane (ft), north zone, NAD 27.

Survey Error Assessment

Horizontal control (x,y) for the MCR surveys is presently ±3.3 ft (±10 ft before 1987). The vertical accuracy of the wave-motion compensator is 5% of the vertical displacement: For a 6-foot swell, this is about ±0.5 ft. The vertical accuracy of the fathometer is approximately 1% of the total water column. The combined accuracy for reported vertical data (z), corrected for heave-pitch-roll, at 100-foot water depth is ±1.5 ft. This represents the **random error** inherent in the depth data (z) for MCR hydrosurveys. Random error is averaged-out (or reduced to a mean value of 0) when comparing two different surveys of the same area.

Depth data were converted to elevation (z, MLLW) using a time-varying NOAA tidal corrector (for zone 1), based on the Hammond tide gauge located 7 miles within the estuary. Possible sources of **systematic error** (bias from year to year) for survey data (z) collected at MCR could be due: (A) mis-calibration of the fathometer/supporting equipment, or (B) misapplication of the tidal elevation corrector. Changes in river discharge or coastal circulation could introduce bias into the tidal corrector. It is assumed that the fathometer and supporting equipment were properly calibrated for each hydrographic survey.

Systematic error due to the tidal corrector would likely arise from phase differences (errors due to predicted vs. actual arrival time of tide). A phase error of 1 hour, between the ***actual*** higher high tide signal at 2 hours after high high water and the ***predictor*** tidal signal $|(HH+2hr)-(HH+3hr)|$, would produce a bias of ±2 ft in tidal elevation. It is reasonable to assume that the phase error of the tidal corrector should be less than 1 hour: This would correspond to a systematic error of ±1 ft . In summary , the estimated accuracy statistics for the MCR hydrographic surveys are:

Random error for X,Y data = ±3.3 ft (±10 ft before 1987)
Random error for Z data = ±1.5 ft
Systematic error for Z data = ±1 ft

Digital hydrographic survey data were used in this exhibit to assess past and future bathymetric change at MCR ODMDSs (see Section 3, *Recent Bathymetric Change at MCR and ODMDSs*). All results involving bathymetry change assessment were determined within the data accuracy limits stated above.

Textural Characteristics of Sediments to be Placed at MCR ODMDSs

The type of dredged materials historically placed at the MCR ODMDSs has been poorly graded sand (SP sand, ASTM D 2487). The grain size of the dredged material placed at the ODMDSs depends upon where the material was dredged from (figure B-3), with grain size diameter ranging between 0.13-0.35 mm [Paxton 1990 and Lockett 1959]

Sand dredged from the "inner bar" (RM 1 to 3) tends to be coarser (median grain diameter, D_{50}=0.25 mm) than material dredged from the "outer bar" (RM-2 to 1, D_{50}=0.19) [Sternberg 1977, Lockett 1959, and Paxton 1992]. Overall, the "fines" content (silt or clay, D<0.062 mm) of sediment dredged from the MCR channel entrance is about 3%. Based on previous bottom sediment sampling programs [USACE 1960, Sternberg 1977, and Paxton 1990], an average sediment grain size of D_{50}=0.22 mm was assumed to apply to both inner and out bar sediments at MCR.

Existing ODMDSs are used exclusively for disposal of material dredged from MCR. MCR dredged material is believed to originate from marine and estuarine sources (see Section 1). For future dredging disposal operations (proposed Columbia River channel deepening and related maintenance dredging), dredged material placed within MCR ODMDSs is expected to originate from sources within the Columbia River estuary. For the proposed *Columbia River channel deepening* (-43 ft CRD deep and 600-ft wide channel), new work dredged material to be placed in ODMDSs could originate from as far inland as RM 28. New (proposed) ODMDSs will be used for disposal of future maintenance dredging from the MCR and the Columbia River projects.

The percent of fine-grain material (silt and clay) in MCR channel sediments is similar to Columbia River estuarine and riverine channel sediments. However, the D_{50} (mean grain size) for Columbia River channel sediments becomes progressively coarser as one moves upriver from MCR. Within the scope of ODMDS sediment fate analyses, sandy dredged material originating from RM -2 to 28 will be assumed to have similar physical characteristics.

About 4-6 miles offshore (west) of the river entrance, locations north of MCR have higher fines content than areas south of MCR. Figure B-34 shows the textural (or size) distribution of bottom sediments near MCR. Although not shown in figure N-34, bottom sediments inshore of the 60 ft depth contour are predominately composed of sand (see Section 7, *Littoral Sediment Transport*). The percent fine-grain material (silt and clay) in native sediments offshore of MCR increases directly with depth, and the average grain size for the sand-sized sediments tends to decrease with depth for locations north and south of the MCR entrance. The greatest variation in median grain size for bottom sediments sampled offshore MCR is associated with the northern flank of the ebb tidal delta, toward the northwest and in vicinity of ODMDS B [Sternberg 1977 and Siipola 1992]. This area is known to local fishermen as the "mud-hole".

Seasonal Variation of Bottom Sediments Offshore of MCR

The seasonal variation in bottom sediment texture at MCR and offshore areas has been described in numerous reports [Sternberg 1977 and Roy 1982]. Within this exhibit, MCR bottom sediments were grouped into 4 textural categories based on a range in median diameter (D_{50}).

Factor 1: D_{50} = 0.19-0.28 mm
Factor 2: D_{50}= 0.13-0.18 mm
Factor 3: D_{50} = 0.0625-0.12 mm
Factor 4: D_{50}= finer than 0.0625 mm (fine-grain material)

Factor 1 and factor 2 bottom sediments are present at the Columbia River entrance during all oceanographic seasons. Although factor 3 (0.063-0.12 mm) sediment is often observed at the MCR channel, factor 3 sediments are transitory and more common during the summer than winter [Roy et al 1982]. Factor 3 sediment texture is characteristic of native marine sands observed along the inner-shelf at MCR (excluding the coarser ebb-tidal shoal sediments associated with the Columbia River).

It has been observed that winter storms winnow the silt fraction , factor 4, from sediments between the MCR entrance and the outer edge of the ebb-tidal shoal (120 ft depth). The seaward advance of factor 2 sediments has been observed to occur with onset of the spring freshet (high river discharge) [Roy et al 1982]. The silt size fraction returns to the MCR sediment regime in the spring and increases markedly through the summer in the form of intermittent and ephemeral patches. The area offshore of the MCR ebb-tidal shoal (deeper than 120 ft) is believed to receive sediments from adjacent inner-shelf areas during the summer.

The primary distinction between native seabed sediments and placed dredged material is based on textural and mineralogical properties. Most of the sediment dredged from the MCR channel (factor 1, factor 2, and some factor 3) and placed at ODMDSs is different from the ambient seafloor sediments on the inner shelf (factor 3).

Bottom Sediments Observed Near Existing MCR ODMDSs

Some of the sediments dredged from the MCR are texturally identical (factor 3) to the modern marine sands of the inner shelf and the ambient sediments at ODMDSs A, B, and F [Borgeld 1978]. Consequently, dredged factor 3 sediments placed in ODMDSs behave similarly to ambient seafloor sediments in terms of transportability. Coarser estuarine/riverine sediments (factors 1 and 2) behave differently than ambient seafloor sediments (factor 3). Factor 1 and 2 sediments are less mobile than factor 3 and 4 sediments and tend to remain stationary when placed at deep water disposal sites such as ODMDSs B and F.

For ODMDSs A, B, and F (depths greater than 70 ft), sediments larger than factor 2 are relatively stable and are believed to move slowly northward as bedload under the influence of the winter nearshore circulation regime. Sediments finer than factor 2 are frequently re-suspended throughout the year and are believed to move by suspended load transport toward the north [Borgeld 1978 and Sternberg et al 1977].

Dredged material placed at ODMDSs B is identifiable in terms of the sediments observed on the seafloor, due to placed dredged material being coarser than the ambient seafloor sediment [Borgeld 1978, Sternberg 1977, and Siipola 1992, 1996]. In figure B-34, the distribution of bottom sediment with $D_{50} \geq 0.2$ mm (factor 1) is coincident or immediately to the southeast of ODMDS B. ODMDS A is located within the slug of factor 2 sediment from the upper reach of the ebb tidal shoal. Likewise, factor 1 sediment is located near ODMDS E. Figure B-34 and B-35 show that within 2 miles from ODMDS B, significant amounts of factor 4 material ($D_{50} \leq 0.0625$mm) are consistently observed on the seabed. This area of fine grained material forms a northwest trending deposit on the seabed that is bordered on the east, south and west by coarser material [Siipola 1992, 1996]. A concentrated area of fine-grain material (40% composition – silt and clay) has been observed 1-2 miles northwest of ODMDS B, during recent benthic monitoring performed by NMFS in 1992-1996. The fine-grain sediment at ODMDS B is believed to originate from two potential sources:

- **Dredged sediments placed at the disposal site**. Fine materials (3% of the total volume) within dredged sediments placed at the disposal site are stripped away and transported northwestward by the prevailing bottom currents at the disposal site. These fine grained materials are observed in relatively close proximity to ODMDS B, within 1-2 miles northwest from the site .

- **Natural deposition of Columbia River "plume" suspended sediments**. During winter and spring, when the Columbia River discharge (and sediment load) is high, the suspended (fine-grain) sediments within the Columbia River plume are transported northwest from MCR and deposited as the plume water mixes with ambient ocean water. The deposited fine grain materials are located on the seabed 1-10 miles northwest from ODMDS B.

The percent of fine-grain material contained in MCR dredged sediments is low (3% by mass); the annualized amount of factor 4 sediment in dredged material placed ODMDS B is about 40,000 cy/year. Since 1945, the cumulative amount of fine-grain material placed at ODMDS B is estimated to be 1.5 million cy. The amount of fine sediment observed to the northwest of ODMDS B far exceeds the volume of fine sediment placed during dredged material disposal. Therefor, the concentration of fine-grain sediment to the northwest of ODMDS B is believed to be the result of deposition of suspended sediments and detritus from the Columbia River plume. Recall that between 80-90% of the Lower Columbia River's sediment throughflow is composed of suspended sediment, yet relatively little suspended sediment is retained in the main stem of the estuary (Section 1). Approximately 67% of the suspended sediment (generally, silt-size and finer) discharged from the Columbia River is estimated to be transported to the continental shelf of Washington. The interaction (mixing) of surface water from the Columbia River plume with the ambient coastal currents promotes the rapid deposition of suspended sediments and detritus from the Columbia River plume. Apparently, the onset of enhanced mixing between the MCR plume and coastal waters is to the west-northwest of MCR or about 1-2 miles northwest of ODMDS B. Additional description of the seabed and substrate offshore MCR is described in Section 9 *"Geologic Features"*, of this exhibit.

Physical Properties of Dredged Material Placed at MCR ODMDSs

The specific gravity of the material dredged from the entrance channel at the MCR was determined to be 2.71, for the both inner and outer bar locations [Paxton 1990]. The resuspended density (ρ_{ss}) for the dredged material was determined to be 1,835 g/ℓ [Portland District dredge logs and Paxton 1990]. The term "re-suspended" , relates to sediment that has bee recently deposited on the seabed (after being suspended within the water column). Within context of this discussion, "re-suspended" specifically refers to dredged material recently deposited on the seabed after being placed in open water during dredged material disposal. The resulting re-suspended void ratio (e_{ss}) for sand dredged from the MCR channel entrance was calculated to be 1.062 using a volumetric method outline below:

$\forall t = \forall s + \forall v$, assume $\forall t = 1.0$ units for subaqueous sediment

where $\forall v$ = volume of voids (entrained water) in sample

$\forall s = 1 - \forall v$ — $\forall s$ = volume of solids (sediment constituent) in sample

$\forall t$ = total unit volume of sediment in sample

relating volume ($\forall$) to mass (M),

$M_t = M_s + M_v$, — M_v is due to entrained water $= \rho_v * \forall v$

$\rho_t \forall t = \rho_s \forall s + \rho_v \forall v$ — $\rho_t = \rho_{ss} = 1835$ g/ℓ

$\rho_t = \rho_s \forall s + \rho_v \forall v$ — $\rho_v = 1024$ g/ℓ, $\rho_s = 2710$ g/ℓ (S.G = 2.71)

$\rho_t / \rho_s = (1 - \forall v) + \rho_v \forall v / \rho_s$ — = S.G. *1,000 g/ℓ

$0.677 = (1 - \forall v) + 0.378 * \forall v$

$\forall v = 0.518$

$\forall s = 1.0 - 0.518 = 0.481$

$e_{ss} = \forall v / \forall s$

$e_{ss} = 1.062$

The insitu void ratio for loose to dense uniform dry sand typically ranges between 0.85 to 0.51, respectively. The higher value calculated for MCR sediments (1.062) is due to the sediment being resuspended in a subaqueous environment.

Dredged Material Solids Content and Void Ratio

Normally, hydraulically dredged sediment has a low solids content. The concentration of solids for hydraulically dredged sediments (Cs, by volume) varies between 0.18 to 0.35. Since hopper (hydraulic) dredges are used to remove channel sediments from MCR, it could be concluded that the solids content for each load of dredged material placed at MCR ODMDSs would be lower than 0.35. However, the operating practice of overflow dredging is used at MCR for ***clean*** sand-based dredged material placed at the ODMDSs. This allows for water to be drained out of the hopper bins as dredged sediment is pumped in. The practice of overflow dredging can substantially increase the solids content of each load of dredged material placed at the ODMDSs. The concentration of solids for sand in the hopper dredges operating at MCR ($Cs_{\text{in dredge}}$) was assumed to be the same as for the re-suspended sediment tests (i.e. ρ_{ss} = 1,835 g/l and e_{ss}=1.062) and was calculated by:

$Cs_{\text{in dredge}} = \forall s_{\text{in dredge}} / \forall t_{\text{in dredge}}$ = concentration of solids by volume in the hopper dredge

$e_{ss} = \forall v / \forall s = 1.062, \quad \forall v_{\text{in dredge}} = \forall s_{\text{in dredge}} * 1.062$

e_{ss} = resuspended void ratio

e_{insitu} = insitu void ratio at site of dredging in channel
= 0.68 (assumed value based on typical range)
= (0.85+0.51)/2

in a volumetric analysis, $\forall t = \forall s + \forall v$, assume $\forall t$ = 1.0 units

$\forall t = \forall v_{\text{in dredge}} + \forall s_{\text{in dredge}}$

$= 1.062 \forall s_{\text{in dredge}} + \forall s_{\text{in dredge}}$

$= \forall s_{\text{in dredge}} (1+1.062)$

Since $\forall t = 1.0$, $\forall s_{\text{in dredge}} = 1.0/(1+1.062) = 0.481$

$Cs_{\text{in dredge}} = \forall s_{\text{in dredge}} / \forall t = 0.481/1.0 = 0.481$ similarly, $C_{s(insitu)} = 0.595$ ($e_{insitu} = 0.68$)

Usually, the volume of sediment placed at an ODMDS is different from the volume of sediment removed from the site of dredging. This is due to the cumulative difference between the: (a) the insitu void ratio of the sediment before dredging, 0.51 to 0.85; (b) the resuspended void ratio of the dredged sediment after being placed into the disposal vessel, 1.062 in this case; and (c) the depositional void ratio of the dredged sediment after placement at an ODMDS. The change in specific volume of dredged material from the site of dredging to the site of disposal is commonly referred to as a "bulking factor". The bulking factor for dredged sediments placed at MCR ODMDSs can be calculated by noting the relationship between the volume of sediment removed from the channel ($\forall$insitu), the volume of dredged material in the disposal vessel ($\forall$in dredge), and volume deposited on the seabed ($\forall$d).

The depositional void ratio for dredged material placed on the seabed (ed) for MCR sand-based dredged material placed at ODMDSs was assumed to be equivalent to the resuspended case (ed=ess).

$\forall t_{SS} = C_{s(insitu)} * \forall t_{insitu} (1+e_{ss}) = \forall t_{\text{in dredge}}$

$\forall t_{\text{in dredge}} = C_{s(\text{in dredge})} * \forall t_{\text{in dredge}} (1+e_d)$

$= C_{s(insitu)} C_{s(in\ dredge)} \forall t_{insitu}(1+ess)(1+ed) = (0.485)(0.595) \forall t_{insitu}(1+1.062)(1+1.062)$

$= 1.227 \forall t_{insitu}$ where, ed = depositional void ratio

Bulking Factor from dredging site to disposal vessel = 1.227

Bulking Factor from disposal vessel to disposal site = 1.000, or $\forall_{seabed} = \forall_{disposal}$

The volume of dredged material hauled to the ODMDS is based on the "dredge logs" for each disposal vessel. The dredge log volume is the volume of dredged material in the disposal vessel before placement at a disposal site ($\forall_{disposal}$): It is not equivalent to the undisturbed volume of insitu sediment ($\forall_{insitu}$). The "dredge log" volume is equal to the volume of material placed on the seabed at the ODMDSs. Therefore, the dredging volume statistics reported in tables B-1 to B-3 indicate the "actual" volume of dredged material placed at ODMDSs. After the placed dredged material has deposited on the seabed, the depositional void ratio (e=1.06) may be reduced to the in-situ void ratio (e=0.68), by a "consolidation" effect. The potential volume change associated with reducing the void ratio from 1.06 to 0.68 is approximately 30%. It is unlikely that deposited dredged material will be completely "consolidated", although some volume change is expected to occur.

Subaqueous Angle of Repose - Slumping of Dredged Sediments

As dredged sediments are continually placed (load by load) within a specific open water area, the material builds laterally and vertically. Geometrically, the extend at which the material accumulates is limited by the steepest angle at which the material can attain before gravity (and environmental forces) forces the material to slump and redistribute downslope. The avalanched sediment comes to rest when some equilibrium angle is reached. The limiting angle of repose (shearing angle, φ_s) for subaqueous dredged sediments is steepest angle the material can attain before slumping. The post-sheared angle (φ_{ps}), defines the slope of the slumped dredged material after is has come to rest [Larson and Krause 1989 and Allen 1970]. The areal and vertical configuration of aggregate dredged material mounds at ODMDSs are controlled by the shearing angle and post-sheared angle of the dredged material.

The range in slumping angles vary considerably with material type and the forcing environment. The angle of repose for dry loose sand is 26°-30°, from horizontal [Hough 1957]. Reported values for the subaqueous angle of repose (shearing angle) for sand placed on the seabed range from 1.8°- 8° [USACE 1995 and Johnson 1995]. Reported values for the angle of repose for highly disturbed and minimally disturbed cohesive sediments placed on the seabed are 0.3° and 10°, respectively.

At the MCR ODMDS "B", the angle at which sandy dredged material begins to slump (shearing angle, φ_s) varies between 1.8° and 2.5° ($\tan\varphi = \Delta z/\Delta x = \Delta z/\Delta y$). These values are based upon the assessment of recent bathymetric surveys of the dredged material mound at ODMDS "B". The angle at which slumping stops (post-sheared angle, φ_{ps}) once it has begun was estimated to be 1.5°. These values will define the steepness at which dredged material is permitted to accumulate during the MDFATE simulation.

Summary of MCR Dredged Material Parameters

The following dredged material parameters will be used in the FATE models for simulation activities described in Section 6 of this exhibit:

Dredged material type = fine to medium sand, SP
D_{50} material dredged from estuary = 0.25 mm
D_{50} material dredged from MCR = 0.22 mm
Fines content (D<0.0625 mm) = 3 % (silt)
S.G.of dredged material solids = 2.71
$C_{s(disposal)}$ = concentration of solids by volume in the disposal vessel = 0.481
ed = depositional void ratio = 1.062
φ_s = subaqueous shearing angle = 1.8° - 2.5°
φ_{ps} = subaqueous post-shearing angle = 1.5°

Surface Waves - Simulated Data

Wave data observed 30 km offshore MCR (depth = 370 ft) during 1984-1993 defines the following short-term summary statistics applicable for MCR: Annual average $H_{1/3}$ and T_p = 7.2 ft and 10.5 sec, average $H_{1/3}$ and T_p for May-Sept = 4.9 ft and 8.9 sec, average $H_{1/3}$ and T_p for Oct-Apr = 8.5 ft and 11.7 sec. During intense winter storms, $H_{1/3}$ can exceed 30 ft.

To develop an unbiased estimate for the long-term wave statistics (greater than 10 yrs), a synthetic time series for the annualized wave environment at the MCR was generated using HPDSIM [Borgman and Scheffner 1991]. The program uses a finite length wave record to compute a matrix of coefficient multipliers that can be used to generate arbitrarily long time sequences of simulated wave data which preserve the primary statistical properties of the source finite data set. The wave height, period, and direction for the synthetic data set are based upon the 20-year Wave Information Study (WIS) station 46 - Phase II database [Corson et al 1987]. WIS station 46 is located about 25 miles offshore MCR. The summary statistics for station 46 are:

Mean WIS Parameters
Shoreline and mean bathymetric contour alignment = 158° (True)
Water depth at WIS II-46 = 1000 ft
$H_{1/3}$ = average annual significant wave height =9.0 ft
σ_h = annual standard deviation of $H_{1/3}$ = 4.2 ft
T_s = wave period (associated with $H_{1/3}$) = 11 sec
σ_T = annual standard deviation of T_s = 2.4 sec
Most frequent wave direction band = 292°(T), Northwest
Average Direction of largest waves = 213°(T), Southwest

An example of the simulated wave environment for wave height ($H_{1/3}$) for a 1-year duration (time = 0 corresponds to January 1) is shown in the top of figure B-36. Note that the waves are more severe during the late fall, winter, and early spring than summer. The maximum and minimum significant wave heights ($H_{1/3}$) for the synthetic wave year were about 28 ft and 2.5 ft, respectively. The average significant wave height was 9.0 ft. Since, the synthetically generated wave data (WIS) and observed wave data (NOAA) for MCR have been documented as matching fairly well [USACE 1995], the WIS data were considered adequate for simulating the wave environment at MCR and for use as input for sediment fate modeling.

Simulated Tidal Elevations and Currents at MCR

The shelf tidal signal (elevation and current) at the MCR was simulated using the 5 primary tidal constituents generated from the ADCIRC-derived database for the Eastern North Pacific Coast [Hench et al 1994 and Luettich 1995]. ADCIRC (Advanced CIRCulation) is a two-dimensional finite-element model developed under the DRP to simulate hydrodynamic circulation (tides) along shelves and coasts. The time series shown in the top of figure B-37 represents a simulated equilibrium shelf tide 6 miles offshore MCR for 1 month (720 hours). The referenced tidal datum is MLLW (+3.56 ft MLLW = 0.0 ft NGVD). An equilibrium tide is harmonically correct to the actual case, but is not referenced to a specific date or time. The maximum tidal range for the simulated tide shown in figure B-37 is 11 ft, which agrees with the observed range for MCR. The tidal phasing of the simulated and observed tidal elevation data also compared favorably.

Simulated depth-averaged tidal currents, applicable offshore of MCR, are shown in the bottom of figure B-37 (in terms of principal components u,v). The tidal current shown in figure B-37 was produced using the ADCIRC model and accounts only for the **shelf tidal current**, based only on the approach and passage of the tidal wave. The current generated by flood and ebb flow from the Columbia River estuary is not included in the ADCIRC-predicted tidal current. The u-component (x, or east-west) of the simulated tidal current at MCR is about twice as large as the v-component (y, or north-south). The maximum +u is 0.2 ft/sec, the maximum -u is -0.15 ft/sec. The v-component is equally distributed about 0.1 ft/sec and -0.1 ft/sec. The net flow (or residual) of current shown in figure B-37 is toward the east, at about 0.05 ft/sec.

Measured Currents at MCR

Definition of currents at MCR ODMDSs is of prime importance, since currents significantly affect the short-term fate of dredged material and completely control the long-term fate (direction of transport). For MCR inner-shelf waters (depths <120 ft), the current regime is influenced by wind-stress, waves, tidal, and estuarine processes. In vicinity of MCR, the discharge from the Columbia River estuary dominates nearshore circulation from the surface to depths of 20-70 ft [Hickey 1998]. Large scale oceanic currents such as the California or Davidson currents generally influence the net alongshore direction (north or south) of the inner shelf current regime, but do not directly affect the magnitude of inner shelf currents. Considerable effort was invested to reliably specify the residual current regime at MCR. Residual current data relevant to MCR ODMDS designation and management are summarized below.

The term *residual* refers to a long-term net result (time-averaged over days, weeks, or months), which does not include short-term (hours to days) variations. A residual current describes the net flow (direction and speed) for a given location within a specific time interval and averages-out sort-term signals such as shelf tidal currents, storm-induced currents, and other episodic events.

The MCR current data presented in this exhibit were obtained from extensive monitoring work performed by the USN Hydrographic Office [1954 and 1960], University of Washington [Sternberg 1977 and Hickey et al 1998], and USACE [1998]. The USNHO data were measured in vicinity of the Columbia River Lightship and at several sites offshore of the MCR (figure B-38). The U of W current data were obtained in vicinity of MCR ODMDS A, B and E. The USACE data was obtained at ODMDS E and B. Current data was obtained throughout the water column using a variety of measurement techniques.

Currents Measured by USN Hydrographic Office - MCR Lightship Location

Long-term residual *surface currents* were measured at the MCR lightship ("CR" buoy, 5 miles offshore of MCR) during 1951-54. During the spring and summer months, the residual surface current was reported as 0.85 ft/sec @ ≈225°(T). During the autumn and winter months, the residual surface current was reported as 0.51 ft/sec @ ≈315°(T) at the lightship. The ambient bathymetric contours at the lightship location were estimated to be oriented at 335°(T).

On a seasonal basis, the residual surface current at the MCR lightship was greater in the summer (and less aligned with the bathymetric contours) than during winter months. This is due to northwest summer winds generating southerly coastal current, which reinforces the southerly discharge of the Columbia River freshet (plume). During summer the Columbia River plume is directed toward the southwest. Southwest (winter) winds tend cause the weakest residual *surface* currents at MCR, due to the opposing direction of the northward coastal current with southward discharge of the Columbia River [USNHO 1954].

During 10-13 February 1958, the USNHO conducted current measurements from the Columbia River lightship at 2/3's water depth (100 ft) and near bottom (150 ft) locations using an Ekman current meter. Fifty-five current observations were taken at 1-2 hour intervals. Time-averaged results were obtained for the 10-13 February data and are shown below. These values represent the time-average of the *total current*, due to river discharge, tides, regional circulation at the site of measurement. Columbia River discharge (The Dalles) was 146,000 cfs during 10-13 February 1958. Since the currents were time-averaged, the result is considered to represent a "short-term" residual current for the 3-day period of record.

Time-averaged currents at USNHO current measurement station ***Columbia River lightship***

V at 100-foot depth = 1.3 ft/sec @ 333°

V at 150-foot depth = 0.7 ft/sec @ 336°

Based on sub-surface observations at the lightship during 10-13 February 1958, the short-term residual current at 100 feet depth was almost 2 times greater than along the bottom (150 feet). The current direction for the two observations was the same, NNW. Throughout the water column, the short-term residual current was parallel with the ambient bathymetry, as was the long-term surface residual current for the winter time frame. The *3-day* residual (mid-depth) current during 10-17 February 1958 was 2 times greater than the *long-term* residual surface current for winter (1952-1954). The difference between *long-term* and *short-term* residual current at the lightship may be due to more energetic periods of flow being averaged "out" for the long-term surface current observations.

Currents Measured by USN Hydrographic Office - ODMDS A, B, and F

During 7-20 February 1958, current measurements were taken at two locations offshore of the MCR [USNHO 1960]. These locations were near ODMDS A, B, and F. For each location, data was taken for approximately 2 days duration at 4 hour intervals and 3 depths through the water column: 10 ft, 50 ft, and 100 ft for ODMDS B; and 10 ft, 50 ft, and 85 ft for ODMDS A and F. Current data was measured using a Roberts radio current meter. The threshold of operation for the Roberts current meter was 0.3 ft/sec. Direction validity checks were made using an Ekman current meter. Time-averaged results of the USNHO current data were obtained for site **C-2** (within ODMDS B, for 7-8 February) and site **C-3A** (within ODMDS F and 3000 ft southwest of ODMDS A, for 19-20 February). Long-term inferences based on the C-2 and C-3A data are limited, due the short duration of measurement (2-days). Time-averaged results for both stations are discussed below.

Site C-2 was situated in the southeastern corner of the present ODMDS B. At the time of current measurement, the ambient bathymetric contours at C-2 were estimated to be oriented at 310°(T). The ambient bathymetric contours at C-3A were estimated to be oriented at 320°(T). The values summarized below represent the time average of the total current at C-2 and C-3A, due to the combined effect of river discharge, ocean tides, regional circulation at the site of measurement. Since the currents were time-averaged, the result is considered to represent a residual current for the 2-day period of record. The (±) values given for current magnitude and direction are based upon the 95% confidence interval (student-t distribution) for the 45 values contained in each data set.

Time-averaged currents at USNHO current measurement station ***C-2*** (ODMDS B)

V at 10-foot depth = 1.0 ±0.42 ft/sec @ 255 ±16°
V at 50-foot depth = 1.6 ±0.18 ft/sec @ 263 ±5°
V at 100-foot depth = 1.3 ±0.24 ft/sec @ 283 ±6°

Based on the above data, the surface current at C-2 (ODMDS B) was the least aligned with the ambient bathymetry (55° W offset) and was most variable in terms of speed and direction. The mid-depth current speed was greater than currents at the surface or bottom of the water column (95% level of confidence). In terms of direction, the surface and mid-depth currents were statistically equivalent. The bottom current at C-2 followed the bathymetric contours the most closely (25° W offset) and was statistically different, in terms of direction, from the surface and mid-depth currents. The meteorological conditions at MCR during the 7-8 February 1958 current observations were: sea surface temp=48-51°F, air temp=48-55°F, average wind speed/direction = 0-10 kts @ 180°(T), combined waves = calm-3 ft @ 240°(T), and Columbia River discharge (The Dalles) was 104,000 cfs.

Time-averaged currents at USNHO current measurement station ***C-3A*** (ODMDS A and F)

V at 10-foot depth = 0.85 ±0.23 ft/sec @ 294 ±11°
V at 50-foot depth = 0.55 ±0.14 ft/sec @ 288 ±10°
V at 85-foot depth = 0.74±0.16 ft/sec @ 272±7°

Based on time-averaged results for currents observed at C-3A (ODMDS A and F), the bottom current was the least aligned with the ambient bathymetry (90° W offset) and was the most consistent in terms of speed and direction. The speed of the bottom current was greater than the mid-depth current and was equivalent to the surface current (95% level of confidence), during the time of measurement. The surface current followed the bathymetric contours the most closely and was statistically equivalent to the mid-depth current in terms of direction. The meteorological conditions at MCR during the 19-20 February 1958 current observations were: sea surface temp=49-53°F, air temp=55-63°F, average wind speed/direction = 2-4 kts @ 270°(T), combined waves = calm-1 ft @ 230°(T), and Columbia River discharge (The Dalles) was 176,000 cfs.

Comparison of USNHO Current Stations C-2 and C-3A

Although the measurement periods for stations C-2 and C-3A were separated by a span of 11 days, meteorological conditions were similar. It is inferred that oceanographic conditions during the two periods of measurement were also similar. In this exhibit, it was assumed that the USNHO observations are indicative of the typical seasonal current during February (winter). The surface currents at USNHO stations C-2 and C-3A are statistically equivalent (95% level of confidence) in terms of speed, but differ significantly in terms of direction. Mid-depth and bottom currents at the two locations are statistically different in terms of speed and direction.

The depth-averaged currents at stations C-2 and C-3A, obtained from the 3 vertical observations, are shown below. The results are considered to represent residual depth-averaged currents for the 2-day period of record. Note that the depth-averaged current speed at station C-2 is about twice that of station C-3A. The depth-averaged current direction at C-2 is almost due west (270°) whereas the current direction at C-3A is WNW. It appears that during February 1958, station C-2 was modified by the Columbia River plume to a greater extent than C-3A.

Depth Averaged Current at C-2, V_{avg} = 1.3 ft/sec @ 267°
Depth Averaged Current at C-3A, V_{avg} = 0.7 ft/sec @ 285°

Currents Measured by University of Washington: 1975-1976

During various oceanographic seasons between 1975-1976, current observations were measured at nine MCR sites with water depths ranging between 79 and 102 feet (figure B-38). Current data was collected by bottom mounted and tethered instruments. The measured bottom currents ($U_{3.3}$) were obtained 3.3 ft from the bottom every 30 minutes and time-averaged over 30 minute periods.

Three bottom mounted current meters (savonius rotor type on tripod) were deployed at the vicinity of: ODMDS B (**station 1** @ depth = 98 ft, **station 2** @ depth = 102 ft, and **station 6** @ depth = 78 ft); and ODMDS A (**station 3** @ depth = 78 ft and **station 4** @ depth = 93 ft). **Station 5** (@ depth = 103 ft) was deployed about 2 miles south of ODMDS A. Several tethered current meters were also deployed: A1 near ODMDS "B"; and A2 and A3 at the seaward ends of the north jetty and south jetty, respectively. Deployment and retrieval dates for U of W current measurements during 1975 -76 are shown below [Sternberg 1977]:

Station Location	Deployment Dates	Current Measurement Duration
1 and 2	12 April - 6 May 1975	565 hours
3	15 June - 8 July 1975	543 hours
4 and 5	19 Aug - 12 Sept 1975	570 hours
6	12 Dec 75 - 26 Jan 1976	351 hours (instr damage)
A1	9 June - 20 June 1975	240 hours (lost instr)
A2	9 June - 20 June 1975	288 hours
A3	9 June - 20 June 1975	288 hours

Currents were measured 3.3 ft from the seabed at stations 1-6, 38 feet from the seabed at station A1, 9 ft and 26 ft above seafloor for A2, and 15 ft and 31 ft above seafloor for A3. Time series data for the u,v current components at stations 1 and 2 are shown in figure B-39. The **tidal** influence on stations 1-6 was significant. The tidal component of current amplitude observed at stations 1-6 was about 0.3-0.5 ft/sec. Sustained currents

(30-minute time-average) at stations 1 and 2 were generally less than 0.66 ft/sec (68% and 61% of the sampling duration, respectively). The sustained current at station 3 did not exceed 0.82 ft/sec during the sampling period. Sustained currents at stations 4 and 5 were generally less than 0.6 ft/sec, corresponding to the typical amplitude of tidal currents in the area. Sustained currents at station 6 were on the order of 0.98 ft/sec.

Bottom currents were generally aligned with bathymetric contours. At stations 1 and 2 (northern most stations), the bottom current direction was toward the northwest during flood and toward the southeast during ebb. The bottom contour trend at station 1 was SSW and at station 2 it was NNW. At stations 3-6 (southern most stations), the bottom current direction was toward the north during flood and toward the south during ebb. The bottom contour trend at stations 3-6 was about NW.

The residual current for stations 1-6 was obtained in terms of progressive current diagrams [Sternberg 1977]. The residual current does not include the tidal component. Results are described below for stations 1-6. The residual bottom currents at stations 1 and 2 were aligned with the bathymetry contours. The speed and direction of these currents, may indicate the influence of the Columbia River plume at station 1 (westward flow at a speed twice that of station 2). Maximum values for current were due to passage of a storm and had duration of about 2 days.

April-May 1975

Station 1: $V_{3.3}$ = 0.28 ft/sec @ 200°(T), maximum $V_{3.3}$=2.1 ft/sec @ 315°
Station 2: $V_{3.3}$ = 0.13 ft/sec @ 354°(T), maximum $V_{3.3}$=2.1 ft/sec @ 315°

The residual current magnitude for station 3 was low. The direction of the residual current at station 3 was perpendicular to the isobaths and may indicate flood-dominated flow into the estuary at this location.

June-July 1975

Station 3: $V_{3.3}$ = 0.04 ft/sec @ 90°(T)

The current for station 4 was consistent, in terms of speed and direction. Flow at station 5 was more complex with long-term reversals in current direction. At both locations, the residual current was aligned with the bathymetry contours. It appears the maximum values for current at stations 4 and 5 were due to a sea level fluctuation with duration of about 5 days [Sternberg 1977].

Aug-Sept 1975

Station 4: $V_{3.3}$ = 0.21 ft/sec @ 321°(T), maximum $V_{3.3}$=1.4 ft/sec @ 330°
Station 5: $V_{3.3}$ = 0.04 ft/sec @ 300°(T), maximum $V_{3.3}$=1.2 ft/sec @ 300°

The "background" current speed at station 6 was 0.98 ft/sec and equally distributed about 270° and 340° with significantly higher peaks occurring during storm events. On 25-26 December 1975, the current reached 2.63 ft/sec set @ 260°(T) due to an intense storm. The trend of the isobaths at station 6 was estimated to be 315°(T).

Dec 1975

Station 6: $V_{3.3}$ = 0.98 ft/sec @ 305° (T),

A tethered current meter array (station A1, near ODMDS B) was deployed in 96 feet water depth with four current meters located throughout the water column. The dates of data collection were 9-20 June 1975. Two days into the data collection program, the top 3 current meters were lost. These current meters were later retrieved about 150 miles south of MCR. Only the results from the lowest current meter were recorded (located 38 ft above the seabed).

Bottom currents measured at mooring station A1-A3 exhibited a dominant tidal component. At station A1 (ODMDS B), flow varied between 0.7 ft/sec@90°T during flood and 1.5 ft/sec@225°T during ebb. At station A2 (north jetty), flow varied uniformly through the water column from 1.6 ft/sec@60°T during flood to 4.9 ft/sec@260°T during ebb. Net flow at A2 was seaward (west), both at the surface and bottom, indicating that flow along the north jetty is ebb dominated. At station A3 (south jetty), flow varied from 1.0 ft/sec@40°T during flood to 2.7 ft/sec@230°T during ebb. Net flow at A3 was northward, both at the surface and bottom, indicating that flow along the south jetty is flood dominated. The residual bottom current for the **A1** mooring was:

June 1975

Mooring Station A1: V_{38} = 0.60 ft/sec @ 213° (T)

The currents at U of W stations 1, 2, and 4-6 were generally aligned with the ambient bathymetry. The residual current at station 3 was perpendicular to the ambient bathymetry contours. Even though stations 1 and 2 were separated by only 1.5 miles, the bathymetry contours and the observed current speed and direction for the two stations were significantly different. While the current directions (and isobath directions) at stations 1 and A1 were similar, the current speed at A1 was almost twice that at station 1. The observations at stations 1 and A1 were less than 1 mile apart, within 35 ft vertically, but account for different seasons of coastal flow.

Currents Measured by Oregon State University: Summer-Fall 1997

During August–October 1997, Oregon State University under contract to the U.S. Army Corps of Engineers and U.S. Environmental Protection Agency acquired oceanographic data at three locations offshore MCR, in flow regimes spanning from estuarine-dominated to ocean-dominated (figure B-40). Data were measured concurrently at each location. Measured data included currents (complete vertical structure, including bottom: u-v components reported every 30 min), waves, tide, bottom sediment concentration, and vertical displacement of the seabed (bedform activity). Collectively, this data set is the most detailed obtained at MCR. Bottom current data is discussed below.

Each instrument suite was installed on a 6-foot tall aluminum-frame tripod that was deployed on the seabed. Deployment water depths ranged from 50 ft to 120 ft. Site E1 was located 2 miles southwest of the north jetty, near the throat of the MCR entrance at a water depth of 50 ft (figure B-38). Circulation at site E1 was considered to be estuarine-dominated throughout the water column. Site B1 was located 4 miles southwest of the north jetty, on top of the 60-foot high dredged material mound, at ODMDS B in a water depth of 65 ft (top of mound). Site DP1 was located 4.5 miles southwest of the estuary at the seaward base of the 60-foot high dredged material mound, in water depth of 120 ft. Bottom circulation at DP1 was considered to be ocean-dominated.

Deployment of instruments at sites E1, B1, and DP1 occurred during onset of a strong El Nino Event. Therefore, the measured currents were assumed indicative of a Fall-Winter season, in terms of current directionality and magnitude. Deployment and retrieval dates for OSU current measurements during August-October 1997 are shown below [Solitt 1997]. Average discharge of the Columbia River during the monitoring period was about 160,000 cfs (at the Dalles).

Station Location	Deployment Dates	Reported Current Measurement Duration
Site E1	19 August - 21 October 1997	840 hours
Site B1	18 August - 20 October 1997	840 hours
Site DP1	19 August - 15 October 1997	480 hours

Refer to figure B-38 for instrument locations. Bottom currents were recorded in terms of principal components (u and v) at each site using an acoustic doppler velocimeter (ADV) instrument located 1.5 ft from the seabed. The bottom current (**$V_{1.5}$**) at each station location was concurrently recorded every 30 minutes, based upon a 10 minute sampling period with sampling rate of 1 hz. Results of Aug-Oct 1997 OSU bottom current measurement are summarized in figures B-40 and B-41.

Variation of Bottom Current along MCR Ebb Tidal Shoal

During the measurement period, the bottom current at Site E1 was dominated by the tidal signal associated with the estuary flow. Note the fortnightly modulation in the u and v components of bottom current at site E1, shown in the top two graphs in figure B-40 (neap currents at day 8 and 22 with spring currents at day 14 and 28). The u-component at site E1 was highly biased toward the offshore (-) direction due to net discharge of the Columbia River. The bottom current at site B1 was consistent with tidal forcing due to the Columbia River estuary flow (middle two graphs in figure B-40). The magnitude of both u and v components at site B1 were less than site E1 and the v-component for site B1 was less correlated with the tidal signal than at site E1. The data record for bottom current observed at site DP1 began on day 15 (last two graphs in figure B-40). The u and v components for site DP1 bottom current were at best weakly correlated with the tidal forcing of the Columbia River estuary. The bottom current at DP1 appears to be more correlated with offshore flow process than those of the Columbia River.

The coastal influence on bottom currents is apparent during day 25-30 at sites E1, B1 and DP1; when the u component was displaced in the offshore (–, west) direction and the v component was displaced toward the north (+). A strong southerly wind event lasting about 5 days, coinciding with day 25-30, was responsible for creating an enhanced northward coastal current which influenced the flow at MCR. The net direction of coastal current forcing measured at sites E1, B1, and DP1 was toward the northwest (combined effect of a -u and +v bias). The site E1 record shows this effect again during day 43-46 in the bottom of figure B-40. Figure B-41 shows the spatial distribution of bottom current (in terms of east-west and north-south components) measured at stations E1, B1, and DP1 during the Aug-Oct 1997 OSU deployment. Note the strong bias of observed bottom current toward a specific direction, depending on location. The speed and direction of these currents, indicate the dominating influence of the Columbia River plume at site E1. Note that there is little bottom flow toward the southeast at site E1.

Time-Averaged OSU Current Data

The residual current for sites E1, B1, and DP1 was obtained by vector averaging the time series data shown in figure B-40. The residual current does not include the tidal component. Results are described below. The residual bottom current at site E1 was almost perpendicular to the ambient seabed contours (aligned at 240°). The residual bottom current at sites B1 and DP1 was parallel with the ambient seabed contours (aligned at 330°). Although the water depth at site B1 was half that of site DP1, the residual and maximum bottom current *speed* at site B1 and DP1 were equivalent. Maximum values for current were due to passage of a high wind event that had duration of about 5 days.

August-October 1997
Site E1: $V_{2.5}$ = 0.55 ft/sec @ 310° (T), maximum $V_{2.5}$=3.0 ft/sec @ 240°
Site B1: $V_{2.5}$ = 0.37 ft/sec @ 309° (T), maximum $V_{2.5}$=2.0 ft/sec @ 243°
Site DP1: $V_{2.5}$ = 0.37 ft/sec @ 326° (T), maximum $V_{2.5}$=2.1 ft/sec @ 294°

Discussion of Measured Current Data

The currents measured in vicinity of MCR by the USNHO, University of Washington and Oregon State University are summarized below. The data are indicated as single-point values and represent residual currents of varying duration.

Based on the U of W current statistics for 1975 and USNHO data for 1958, bottom currents measured during the fall-winter (U of W station 6, USNHO stations C2 and C3A, and OSU E, B, and DP1) were 2-3 times faster than the currents measured during the spring-summer (U of W stations 1-5 and A1). Surface currents observed at the CR lightship were stronger during the Spring-Summer time frame than Fall-Winter, which is opposite of the bottom current observations at MCR. The difference between surface and bottom currents at MCR is due to the influence of the Columbia River plume and estuarine tidal exchange. Since the Columbia River plume is less saline (dense) than ambient coastal waters, plume water discharged seaward of the estuary tends to be confined to the upper 60 ft of the water column offshore of MCR [Hickey 1998]. The Columbia River plume affects the ambient coastal waters at the surface to a greater extent than bottom water (i.e. bottom current), although for areas near the MCR, the momentum exchange from surface plume water can affect flow at the bottom. During Columbia River freshets (April-July), the surface currents near MCR are likely to be stronger and more directionally dependent on the Columbia River plume, than currents below depths of 60 ft. For areas directly within the Columbia River entrance, the current throughout the water column is dominated by the Columbia River plume during all ebb flow conditions. During significant offshore wave or wind (storm) events, bottom currents are likely to be stronger and more directionally independent from surface currents near MCR.

Table B-9. Residual Currents obtained from Measured Data at MCR during 1954, 1958, 1975, and 1997.

Recording Period	Source	Water Column Location	Time Averaged Speed & Direction (T)
Spring-Summer	C.R. lightship (USNHO)	surface	0.85 ft/sec @ ≈225°(T)
Fall-Winter	C.R. lightship (USNHO)	surface	0.51 ft/sec @ ≈315°(T)
Feb 1958	C.R. lightship (USNHO)	V at 100-foot depth	1.3 ft/sec @ 333°(T)
		V at 150-foot depth	0.7 ft/sec @ 336°(T)
Feb 1958	ODMDS B USNHO	(C-2) V at 10-foot depth	1.0 ±0.42 ft/sec @ 255 ±20°
		(C-2) V at 50-foot depth	1.6 ±0.18 ft/sec @ 263 ±4°
		(C-2) V at 150-foot depth	1.3 ±0.24 ft/sec @ 283 ±8°
Feb 1958	ODMDS A USNHO	(C-3A) V at 10-foot depth	0.85 ±0.23 ft/sec @ 294 ±11°
		(C-3A) V at 50-foot depth	0.55 ±0.14 ft/sec @ 288 ±10°
		(C-3A) V at 85-foot depth	0.74 ±0.16 ft/sec @ 272±7°
Apr-May 1975	ODMDS B U of W	(1) V at 3.3 ft above bottom	0.28 ft/sec @ 200°(T)
		(2) V at 3.3 ft above bottom	0.13 ft/sec @ 354°(T)
June-July 1975	ODMDS A U of W	(3) V at 3.3 ft above bottom	0.04 ft/sec @ 90°(T)
Aug-Sept 1975	ODMDS A U of W	(4) V at 3.3 ft above bottom	0.21 ft/sec @ 321°(T)
		(5) V at 3.3 ft above bottom	0.04 ft/sec @ 300°(T)
Dec 1975	ODMDS B U of W	(6) V at 3.3 ft above bottom	0.98 ft/sec @ 305°(T)
June 1975	ODMDS B U of W	(A1) V at 38 ft above bottom	0.60 ft/sec @ 213°(T)
June 1975	North Jetty U of W	(A2) V at 9-26 ft above bottom	1.60 ft/sec @ 60°(T)-flood
		V at 9-26 ft above bottom	4.90 ft/sec @ 260°(T)-ebb
June 1975	South Jetty U of W	(A3) V at 15-30 ft above bottom	1.0 ft/sec @ 40°(T)-flood
		V at 15-30 ft above bottom	2.70 ft/sec @ 230°(T)-ebb
Aug-Oct 1997*	ODMDS E OSU	(E1) V at 2.5 ft above bottom	0.55 ft/sec @ 310°(T)
Aug-Oct 1997*	ODMDS B top OSU	(B1) V at 2.5 ft above bottom	0.37 ft/sec @ 309°(T)
Aug-Oct 1997*	ODMDS B bottom OSU	(DP1) V at 2.5 ft above bottom	0.37 ft/sec @ 326°(T)

* = deployment during onset of a strong El Nino Event. Measured currents are considered indicative of a Fall-Winter season, in terms of current direction and magnitude.

Bottom currents at MCR tend to be **aligned with the seabed contours** during normal climatic conditions, except in close proximity to the MCR entrance where Columbia River bottom currents can flow perpendicular to the local seabed contours (site E1). Figure B-38 highlights the directionality of the bathymetric contours at MCR. The river's ebb flow has a pronounced effect on the orientation of the ebb tidal shoal at MCR. Since bottom **current direction** at MCR is modified by the local bathymetry (and vice-versa), bottom current direction at MCR is expected to vary with location on the ebb-tidal (outer) shoal. During non-storm and non-freshet conditions, bottom currents are more closely aligned with the bathymetry contours than currents at the surface. Surface current direction, in vicinity of MCR, is modified by the Columbia River plume. The **magnitude** of surface and bottom currents at MCR is controlled by relative location with respect to the Columbia River plume.

Bottom currents at MCR tend to be less aligned with the ambient bathymetry during storm or high wind events, when wind-driven currents dominate and can produce currents **perpendicular** to the MCR bathymetry contours. This situation appeared to be the case for currents measured at U of W station 6. The perpendicular flow condition of bottom currents, with respect to contour alignment of the seabed, likely produces the most pronounced transport of bottom sediments on the ebb-tidal shoal at MCR [USACE 1995].

The vertical structure of the **water column** at MCR can be **significantly** stratified due to the Columbia River plume, as shown in a series of vertical profiles from USNHO current station C-2 on 8 Feb 1958. In the top graphic of figure B-42, the salinity varies from 20.8 o/oo at the surface to 32.0 o/oo at 100-foot depth and the surface current is 3 times that of the mid-depth or bottom current. The bottom graphic in figure B-42 shows the bottom current being 60% greater than the surface current. There can be a 50° difference in current direction through the water column at any given time.

Summary of Measured Current Data and Related Inferences

At the MCR, current velocity varies considerably with respect to vertical location through the water column and geographic location relative to the ebb-tidal shoal and Columbia River plume. Within close proximity to the MCR entrance, where estuarine-induced flow is the strongest, surface and bottom currents are dominated by the tidal exchange of the estuary and the Columbia River plume. This appears to be the case for ODMDS E.

At locations further from the MCR entrance (ODMDSs A, B, and F), surface currents are controlled by the seasonal influence of the Columbia River plume and its interaction with the nearshore coastal current. Bottom currents can be affected by the Columbia River plume, but to a lesser degree than surface currents. Along the open coast of northern Oregon and southern Washington, away from the MCR flow influence, the nearshore coastal current is generally consistent through the water column and tends to be northward during Fall-Winter and southward during Summer.

Consideration of proposed locations for ODMDSs must account for the spatial variability of current at MCR to fully realize disposal site dynamic capacity. Using the current data presented above, a seasonally varying residual bottom current was determined for four locations along the ebb-tidal shoal at MCR. Results of the dynamic capacity estimate for proposed ODMDSs are described in the "*Management and Monitoring Plan*".

Residual current at southern half of the ebb-tidal shoal

2 miles South-southwest of south jetty

Spring = 0.38 ft/sec @ 288°(T), maximum 1.5 ft/sec@288°(T)
Summer = 0.08 ft/sec @ 325°(T), maximum 1.3 ft/sec@315°(T)
Winter = 0.74 ft/sec @ 272°(T), maximum 1.7 ft/sec@262°(T)

Residual current at northeast quadrant of the ebb-tidal shoal.

Peacock Spit, between #7 entrance buoy and the north jetty

Spring = 0.93 ft/sec @ 315°(T) does not include freshet effect
Summer = 0.93 ft/sec @ 225°(T)
Winter = 0.93 ft/sec @ 315°(T)

Residual current at north quadrant of the ebb-tidal shoal.

Peacock Spit, 2 miles SW of north jetty, between entrance buoy #7 and #3

Summer-Fall, during El Nino = 0.55 ft/sec @ 310°(T)

Residual current at northwest quadrant of the ebb-tidal shoal.

4 miles WSW of north jetty, ½ mile north of entrance buoy #1

Spring = 0.09 ft/sec @ 320°(T)
Summer = 0.60 ft/sec @ 213°(T)
Summer-Fall, during El Nino = 0.37 ft/sec @ 309°(T)
Winter = 0.96 ft/sec @ 294°(T)

The **total** bottom current for the above areas at MCR was "constructed" by adding the seasonal residual bottom current (shown above) to the simulated depth-averaged tidal current (described in *Simulated Tidal Elevations and Currents at MCR*). This provided a realistic estimate for seasonally varying bottom currents; data which was used to simulate the fate of dredged material to be placed at proposed MCR ODMDSs.

Measured Seabed Change at MCR

During August – October 1997, Oregon State University measured the fluctuation of the seabed at three locations (E1, B1, and DP1) along the ebb-tidal shoal at MCR concurrently with the bottom current measurements described previously. Data collection sites are shown in figure B-42. Measurement of seabed fluctuation at each site was obtained by an ADV, the same instrument used to measure bottom current (reported in *Currents Measured by Oregon State University: Summer-Fall 1997*). The ADV was used as an altimeter, for measuring relative vertical displacement (or bedform activity) of the seabed with respect to the ADV instrument. Data was recorded every 30 minutes.

The top graphic of figure B-43 shows a compilation of wave, current, and seabed change data obtained at Site E1. Site E1 was located 2 miles SW of the north jetty, within the throat of the MCR entrance at a water depth of 50 ft. Circulation at Site E1 is considered to be estuarine (or current)-dominated. At time 0, the distance between the ADV and the seabed was 72 cm (2.2 ft). The data sequence in the top graphic of figure B-43 shows that seabed displacement exceeded 10 cm (0.33 ft) on several occasions (within a period of ½ - 2 hours). Both short-term deposition (decrease in distance between ADV and seabed) and short-term erosion (increase in distance between ADV and seabed) are evident in figure B-43. The seabed at Site E1 is composed of fine sand. The rapid (short-term) vertical fluctuation of the seabed at E1 is due to the transport (deposition or erosion) of bottom sediment caused by waves and currents. Data obtained at Site E1 indicate that "seabed change" is positively correlated with changes in wave height and bottom current speed. During the 35 day record shown in figure B-43 (top), the vertical distance between the seabed and the ADV was reduced by 50 cm due to long-term settlement of the instrument platform into the seabed.

The bottom graphic of figure B-43 compares data (for vertical seabed displacement) at each of the three deployment locations. Site B1 was located 4 miles offshore of the Columbia River estuary, on top of a 60 ft high dredged material mound, in water depth of 65 ft. Site DP1 was located 4.5 miles offshore of the Columbia River estuary at the oceanward base of a 60 ft high dredged material mound, in water depth of 120 ft. Bottom circulation at Site DP1 is considered to be ocean-dominated. The time-varying displacement of the seabed at sites E1 and B1 is similar, whereas the seabed displacement at Site DP1 is less variable. The above trend indicates that less seabed change occurs at locations offshore of MCR where the water depth is relatively deep and is less affected by wave-induced sediment transport processes.

Section 9
GEOLOGICAL RESOURCES

Introduction

The confluence of the Columbia River and Pacific Ocean has prompted numerous surveys and scientific studies. The earliest comprehensive navigation chart was published in 1885. Studies of the physical environment began in the 1930's with publications by Hickson [1930], Hodge [1934], and O'Brien [1936], among others, concerning sediments and sediment transport. There was renewed interest in the area in the 1960's by both the Corps of Engineers and the University of Washington. Publications by Kidby and Oliver [1965], Lockett [1963,1967] and others, related to shoaling and beach erosion near the entrance. Research by Ballard [1964], Gross and others [1963], Andrews [1964], White [1967], and Burnett [1968] concerned continental shelf sedimentation. Numerous studies related to Hanford, begun in the 1960's, were also completed [Pruter and Alverson, 1972]. An interest by the Corps of Engineers in dredging and disposal at the mouth of the Columbia River resulted in a series of publications by Sternberg and others [1977], Borgeld and others [No date], Roy and others [1979, 1982], Walter and others [1979] and other University of Washington researchers concerning the sedimentary environment. Studies of continental shelf sediments off Oregon, by Oregon State University researchers, include Runge [1966], Scheidegger and others [1971], Harlett [1972], and Kulm and others [1975]. Kulm [1977] prepared a detailed review of activities of oceanographers at both the University of Washington and Oregon State University. A more extensive bibliography is included in this exhibit.

Regional Setting

The Columbia River estuary appears as a broad, low-lying embayment between rugged headlands at Tillamook Head to the south and Cape Disappointment to the north. A wide, sandy beach and dune expanse extend south from the river mouth and north from Cape Disappointment. The principal physical influences on the area are regional or global in nature. Seasonal river flow in the Columbia River depends upon weather and other factors over the entire Columbia River Basin, which includes over 250,000 square miles of the continental Northwest (figure B-44). Also shown on the figure B-44 is the extent of freshwater influence offshore which is affected by seasonal atmospheric and oceanic circulation patterns. High river discharge in summer, coupled with predominantly southern winds and near-surface waves and currents, produce a very large plume of fresher water offshore. Winter weather conditions produce a series of storms with high waves and wind from the southwest which are responsible for a predominant nearshore sediment transport to the north and locally severe beach erosion. On a scale of days and weeks the astronomical tide exerts a continuously changing force combining with other forces near the mouth of the river.

Geological Framework

The coastal area of Oregon has been influenced by a combination of tectonic forces and glacial effects during the past few million years. Regional uplift, coupled with a fluctuating sea level, are shown by marine terraces up to 100 feet above present sea level and Astoria Canyon, more than 300 feet below sea level. Beneath deposits of recent sands are rocks up to 40 million years old. These are mostly marine deposits with volcanic outcrops forming such features as North Head, Tongue Point, and Tillamook Head. About 20 million years ago these rocks were uplifted and deformed into a "trough" along the course of the present river. Erosion as uplift produced massive sedimentary deposits which were subsequently partially eroded and overlain by younger deposits. Volcanic activity associated with the uplift produced submarine basalt deposits and intrusions intermingled with the sedimentary deposits.

Beginning about 2 million years ago, glacially-induced sea level fluctuations were superimposed upon the continued regional uplift. At the maximum extent of the continental glaciers sea level was as much as 400 feet below present and the mouth of the Columbia River was up to 10 miles offshore. During this time a series of shelf-edge canyons were formed, including Astoria Canyon, which channeled sediments into deeper water. Delta-like features formed from massive amounts of sediments, estimated up to 10 times present volumes [Nelson, 1968]. The Astoria fan is one such feature, shown on figure B-44. As the glaciers retreated, sea level rose up to 100 feet above its present elevation. Coastal forces extensively reworked unconsolidated sediments and formed marine terraces during relative still-stands. The last episode of glacial retreat began less than 20,000 years ago with sea level rising rapidly until 5,000 to 6,000 years ago. Estuaries at the mouth of the Columbia River and elsewhere are "drowned" river valleys, and coastal features such as extensive sand spits and dune complexes resulted from marine forces reworking sediments relict from earlier times.

Figure B-45 shows the general geology of the area around the mouth of the Columbia River. Upland areas are mostly ancient sedimentary rocks which are folded, faulted and overlain by younger basalts. Overlying these rocks are occasional remnants of once extensive Pleistocene marine terraces. Filling the valley bottoms and the estuary are modern river sediments. These grade into marine sands near the river mouth which continue offshore. Extensive coastal dunes and beaches have been formed in modern times by wind forces acting upon river/marine sands. Figure B-46 presents two cross sections of the study area based upon onshore drilling. These sections are displayed on figure B-45. Section A-A runs north-south along Clatsop Spit and Section B-B runs perpendicular to the shoreline near Gearhart. These sections demonstrate the extent of the sediment layer above bedrock, averaging 100 feet near Gearhart and thickening to over 200 feet at the mouth of the Columbia River.

Geologic Units Beneath the Columbia River Mouth Study Area

No bedrock outcrops were found during Corps investigations within the Columbia River mouth study area. Pleistocene and Holocene sediments extend across the entire continental slope and are exposed on the sea floor only on large banks such as Heceta and Nehalem which are south of the study area. By projection of bedrock units mapped in the Astoria 15' Quadrangle by Schlicker and others [1972], it appears that the study area is underlain by an undifferentiated sequence of sedimentary rocks of Oligocene to middle Miocene age. These beds are estimated to be approximately 5000 feet thick and consist of thin-bedded to massive tuffaceous siltstone and claystone with lesser amounts of sandstone and shale locally. These beds are mildly deformed, typically dipping 40 degrees or less. No known faults mapped on land project into the study area. A west-trending strike slip fault through the Columbia River mouth and extending offshore is known from either aeromagnetic data or seismic reflection profiling. It occurs in the older rocks, being concealed by the younger strata.

Several wells have been drilled in the Clatsop plains area south of the south jetty within a few miles of the study area [Frank, 1970]. Near the surface, these wells encountered a variety of unconsolidated dune, beach, and shallow marine sands interbedded with alluvium, all of Pleistocene and Holocene age. These young deposits extend to depths of between 250 and 300 feet below sea level and rest unconformably on a sandy unit that extends to depths of approximately 400 feet below sea level. This second unit was tentatively identified as Astoria Formation by Frank [1970], but has subsequently been called Upper Miocene Sandstone by Schlicker and others [1972]. This unit is typically buff-colored, medium- to coarse-grained, semi-consolidated sandstone of marine origin. The Oligo-Miocene beds which are called the Astoria Formation underlie the Upper Miocene Sandstone.

Recent Geophysical Investigations

Geophysical investigations consisting of side scan sonar and subbottom profiling, have been conducted by the Corps in the offshore Columbia River within the last 12 years. These were conducted to provide general data for interpretation of ocean bottom and subbottom conditions.

The first study in 1985 utilized both side scan and subbottom profiling techniques. Plates 5 and 2 show a geologic map of the 1985 study area produced by side scan sonograph records. The subbottom acoustic data provided a clear differentiation between the unconsolidated fine to medium sand of the present sea bottom and underlying semi-consolidated to consolidated sediment beneath. Table B-10 shows the seismic-stratigraphic units identified by the subbottom profiling. The top layer of sediment defined between the base of the water column and the first subbottom reflector has a variable thickness averaging from 20 to 40 feet thick. This material is of Holocene age with the upper part consisting of the sediment currently being deposited by the Columbia River and subsequently redistributed by oceanic currents. The basal reflector of this unit is very irregular, suggesting that the underlying unit might be large scale sand waves or dunes. This unit averages 90-120 feet thick and is thought to consist of unconsolidated and semi-consolidated sand with minor silt and clay. This correlation is based solely on depth and geometry of these contacts with those found in nearby wells.

Side scan data from 1985 revealed a general uniformity of the sea floor, which appears to be composed of silty sand to sandy silt. No rock outcrop exposures were found in the area surveyed. Small east-west trending ripple marks were consistently apparent over the entire area surveyed, decreasing somewhat north of the river mouth. The extreme northern portion of the study area showed a notable increase in bottom debris and bottom growth. At and south of the river mouth there was a marked absence of typical sea floor growth and debris. Sand waves were noted south of the active disposal site A. Long period sand waves with wave lengths of up to 500 feet, crest to crest, and heights of up to five feet, trough to crest, were noted on the fathometer records and located where indicated on the side scan map. The wave crests parallel the east-west axis of the local grid. These long period sand waves were practically invisible on the side scan records

Table B-10

SEISMIC-STRATIGRAPHIC SUB-BOTTOM UNITS FROM THE COLUMBIA RIVER MOUTH

Seismic Stratigraphic Unit	Depth (feet below MLLW)		Thickness (feet)	Tentative Correlation	Lithology	Depositional Environment	Probable Age
	Upper Contact	Lower Contact					
1	-38 to -132	-45 to -283	<10 to >170 20-40 average	————	Unconsolidated fine to medium sand	Inner shelf to estuarine (to the east)	Holocene
2	-45 to -283	-192 to -302	<35 to >165 90-120 average	Marine and Dune Sands (Schlicker and others, 1972)	Unconsolidated to semi-consolidated sand with minor silt and clay	Shallow marine, dune and fluvial	Pleistocene and Holocene
3	-197 to -295	-203 to -376	0 to >140 60-80 average	————	Probably alluvium	Fluvial and estuarine (?)	Pleistocene
4	-125 to 433	-237 to -570	<30 to >290 170-210 average	Upper Miocene Sandstone (Schlicker and others, 1972)	Soft clay, sand, and sandstone	Marine	Upper Miocene
5 and 6	-237 to -570	base of these units is not well defined		Astoria Formation (Frank, 1970); Oligocene to middle Miocene sedimentary rocks, undifferentiated (Schlicker and others, 1972)	Tuffaceous siltstone, shale, and sandstone	Marine	Oligocene to middle Miocene

due to their long wave length and small wave height. Eight large objects were located on the side scan map. Location and dimensions of the objects are given on Plate 5.

Side scan data from 1996 was collected from areas not covered by the 1985 survey. Data from the combined surveys provides fairly complete coverage out to about 5 miles from the river mouth with overlap noted primarily in the river mouth area (Plate 1). Plate 3 shows the majority of the material in the 1996 coverage area is interpreted to be sand/silt which is equivalent to the fine to medium sand identified in the earlier survey. A large area between the jetties and immediately offshore shows numerous sand waves. Beyond that is a large area described as possible scour/ submerged rock, however, rock is not likely to be found within the study area. A few large unidentifiable objects were found on the bottom. None of these targets exhibited a shadow indicating there was little bottom relief. These are located in a table on Plate 3.

Bottom changes noted since the 1985 survey

Most of the area of overlap between the 1985 and 1996 surveys appears to be unchanged. Plate 4 shows contours of the differences between bathymetric data from the 1985 survey and the 1996 survey. Positive values indicate material added since 1985. The major differences found between the two studies are as follows:

- Sand waves are no longer present in Area "F".
- Less scour was observed in the channel between the jetties and was replaced by sand waves.
- More scour was observed west of approximately X=1,090,000. This interpretation is consistent with the bathymetric changes indicated on Plate 4 which shows the removal of one to two feet of material in the scoured areas.
- Five "Other Submerged Targets" were detected at the mouth of the jetties and do not appear in the 1985 Study.
- Three objects shown in the 1985 study as "Shipwreck or Other Large Object on Sea Floor" were not detected by the 1996 Survey.
- Significant amounts of material have been added to Areas "B", "F", and "A" as shown on Plate 4. Area "B" appears to be as much as 25 feet shallower in 1996 than in 1985.

Section 10
REFERENCES

Ackers, P., and White, W.R. (1973). "Sediment transport: a new approach and analysis." Journal of Hydraulics Division ASCE 99(11), 2041-2060.

Allen, J.R.L. (1970). "The avalanching of granular solids on dune and similar slopes", *Journal of Geology*, Vol 78, No 3, pp 326-351.

Andrews, R.S. (1964). "Modern Sediments of Willapa Bay, WA: A coastal plain estuary.", Thesis, University of Washington, Seattle, WA.

Burnett, T.L. (1968). "Bottom sediment data from the continental shelf of Washington – Grays Harbor to Cape Flattery, 1964. University of Washington, Department of Oceanography, Seattle, WA, Spec. Rep. 39

Barnes, C.A., Duxbury, A.C., and Morse, B.A. (1972). "Circulation and selected properties of the Columbia River effluent at sea", The Columbia River estuary and adjacent waters. (A.T. Pruter and D.L. Alverson, eds) University of Washington Press, Seattle, WA

Ballard, R.L. (1964). "Distribution of beach sediment near the Columbia River", Technical Report No. 98, University of Washington, Department of Oceanography, Seattle WA.

Boone, C.G., Granat, M.A., Farrell, M.P. (1978) "Aquatic disposal field investigations Columbia River disposal site, Oregon, Executive Summary", Technical Report D-77-30. U.S. Army Engineer Waterways Experiment Station, Vicksburg, Ms

Borgeld, J.C., , Creager, J.S., Walter, S.R., Roy, E.H. (1978). "An investigation to determine the sedimentary environment at Sites E, G, and H near the Mouth of the Columbia River entrance". Contract number DACW57-77-C0035, Final Report to the U.S. Army Corps of Engineers, Portland District, Portland Oregon.

Borgman, L.E., and Scheffner, N.W. (1991). "Simulation of time sequences of wave height, period and direction", Technical Report DRP-91-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Ms.

Bourke, R.H. and Glennne, B. (1971). "The nearshore physical oceanographic environment of the Pacific northwest coast". Report 71-45, Oregon State University, Department of Oceanography. Corvallis, Oregon.

Brandsma, M.G., and Divoky, D.J. (1976). "Development of models for prediction of short-term fate of dredged material discharged in the estuarine environment". CR-D-76-5, U.S. Army Waterways Experiment Station, Vicksburg, MS.

Bokuniewicz, H. J., Gebert, J., Gordon, R. B., Higgins, J. L., Kaminsky,P., Pilbeam,C. C., Reed, M., and Tuttle, C. (1978). "Field Study of the Mechanics of the Placement of Dredged Material at Open-Water Disposal Sites. Volume 1:Main Test and appendices A-I," Technical Report D-78-7, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Bowers, G.W. and Goldenblatt, M.K. (1978). "Calibration of a Predictive Model for Instantaneously Discharge Dredged Material". EPA Report R-804994, Covalllis Environmental Research laboratory, Ecosystems Modeling and Analysis Branch, Corvallis, OR 97330.

Clausner, J. E., Lillycrop, L. S., McDowell, S. E., and May, B. (1998). "Overview of the 1997 Mud Dump Capping Project," Proceedings XVth World Dredging Congress 1998, CEDA, Amsterdam, The Netherlands.

Clausner, J.E., Gailani, J. Z., and Allison, M.C. (1998). "MDFATE Modeling of Contaminated Sediment Placement in the Eastern Section of the North Energy Island Borrow Pit", Draft Report prepared for the U.S. Army Engineer District, Los Angeles, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Collins, C.A., and Patulla, J.G. (1970). "Ocean currents above the continental shelf off Oregon as measured with a single array of current meters." Journal of Marine Research, 28(1), pp 51-68.

Corson, W.D., Abel, C.E., Brooks, R.M., Farrar, P.D., Groves, B.J., Payne, J.B., MvAnney, D.S., and Tracy, B.A. (1987). "Pacific coast hindcast phase II wave information", WIS Report No. 16, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Ms.

Columbia River Estuary Data Development Program, Cooperative study between Columbia River Estuary Study Taskforce, NOAA, and US Dept of Commerce. (1984).

Ebersole, B.E., Cialone, M.A., and Prater, M.D. (1986). "Regional coastal processes numerical modeling system, RCPWAVE - a linear wave propagation model for engineering use." Technical Report CERC-86-4, U.S. Army Waterways Experiment Station, Vicksburg, MS.

EPA (1978). "Calibration of a Predictive Model for Instantaneously Discharged Dredged Material", EPA-600/3-78-089, Environmental Research Laboratory, Corvallis, OR.

Gonzalez, F.I. (1984). "A case study of wave-current-bathymetry interactions at the Columbia River entrance", *Journal of Physical Oceanography*, Vol 14

Gross, M.G., Mcmnaus, D.A., and Creager, J.S. (1963). " Preliminary report on the sediments and radioactivity in the vicinity of the Columbia River effluent." University of Washington, Dept. of Oceanography, Seattle WA, TR 84.

Hallermeier, R. 1981. "Seaward limit of significant sand transport by waves: An annual zonation for seasonal profiles", CETA 81-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Ms.

Hench, J.L., Luettich, R.A., Westerink, J.J., and Scheffner, N. W. (1994). "ADCIRC: An advanced three-dimensional circulation model for shelves, coasts, and estuaries", Technical Report DRP-92-6, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Ms.

Hermann, F.A. (1972). "Model Studies of Navigation Improvements, Columbia River Estuary" Report 2, Entrance Studies, Fixed-Bed Studies of Disposal Areas C and D. Technical Report 2-735, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Ms.

Hickey, B.M., Pietrafesa, L.J., Jay, D.A., and Boicourt, W.C. (1998). "The Columbia River plume study: Subtidal variability in velocity and salinity fields", Journal of Geophysical Research, Vol 103, No. C5, pp 10339-10368.

Hickson, R.E. (1930). "Shoaling on the Lower Columbia River." The Military Engineer Vol. 22, pp 217-219.

Harlett, J.C. (1972). "Sediment trasnport on the northern Oregon continental shelf." Thesis, Oregon State University, Corvallis, Oregon.

Hodge, E.T. (1934). "Geology of beaches adjacent to the mouth of the Columbia River and petrology of their sands." Unpublished report, U.S. Army Corps of Engineers, Portland District, Portland Oregon.

Hough, B.K. 1957. "Basic soils engineering", Ronald Press Company, New York, New York.

Hubbell, D.W. and Glenn, J.L. (1973). "Distribution of radionuclides in bottom sediments of the Columbia River estuary. U.S.G.S. Professional Paper 433-L, GPO, Washington, D.C.

Huyer, A. and Smith, R.L. 1977, "Physical characteristics of Pacific Northwest coastal waters." *The marine and plant biomass of the Pacific northwest coast*. R. W. Krauss, ed., Oregon State University Press, Oregon State University, Corvallis, OR.

Jensen, R., Hubertz, J., 1989. "Pacific coast hindcast phase III north wave information", WIS Report No. 17, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Ms.

Johnson, B. H. (1978). "Evaluation and Calibration of the Tetra Tech Dredged Material Disposal Models Based on Field Data," Technical Report D-78-47, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Johnson, B. H. (1990). "User's guide for models of dredged material disposal in open water", Technical Report DRP-90-5, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Johnson, B. H. And Fong, M. T. (1995). "Development and Verification of Numerical Models for Predicting the Initial Fate of Dredged Material Disposed in Open Water, Report 2, Theoretical Developments and Verification Results," Technical Report DRP-93-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Johnson, B.H. (1995). Personal communication regarding construction of subaqueous sill for preventing salt wedge intrusion on lower Mississippi River. U.S. Army Engineer Waterways Experiment Station, Vicksburg, Ms.

Johnson, B. H., and Holiday, B.W. (1978). "Evaluation and Calibration of the Tetra Tech Dredged Material Disposal Models Based on Field Data," Technical Report D-78-47, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Johnson, B.H., Moritz, H.R., Teeter, A.M., Cerco, C.F., and Wang, H.V. (1998). "Modeling the Fate and Water Quality Impact of Dredged Material Placed at Site 104, Chesapeake Bay", U.S. Army Engineer Waterways Experiment Station, Vicksburg, Ms.

Knutson (1996). Personal communication regarding UNET simulation for Lower Columbia River. U.S. Army Engineer District Portland, Portland, Oregon.

Komar, P.D., Neudeck, R.H., and Kulm, L.D. (1972). "Observations and significance of deep-water oscillatory ripple marks on the Oregon continental shelf", Chapter 25, Shelf Transport. Ed. by Swift, Duane, and Pilkey.

Kidby, H.A. and Oliver, J. G. (1965). "Erosion and accretion along Clatsop Spit." Technical Report, U.S. Army Corps of Engineers, Portland District, Portland Oregon.

Koh, R.C.Y., and Chang, Y. C. (1973). "Mathematical model for barged ocean disposal of waste." Envir. Protection Serv. EPA 660/2-73-029, U.S. Environmental Protection Agency, Washington, D.C.

Kulm, L.D., Roush, R.C., Harlett, J.C., Neudick, R.H., Chamber, D.M., and Runge, E.J. (1975). "Oregon continental shelf sedimentation: Interrelationships of facies distribution and sedimentary processes." Journal of Geology, Vol. 83(2): pp 145-175.

Kulm, L.D. (1977). "Coastal morphology and geology of the ocean bottom – the Oregon region.", In Krauss, ed. The marine plant biomass of the Pacific Northwest.

Larson, M. and Krause, N.C. (1989). "SBEACH: Numerical model for simulating storm induced beach change, Report 1: Theory and model foundation", Technical Report CERC-89-9, Coastal Engineering Research Center, U.S. Army Waterways Experiment Station, Vicksburg, MS.

Lillycrop, L. and Clausner, J. (1997). "Numerical Modeling of the 1997 Capping Project at the MDS Site," Proceedings Xth World Dredging Congress 1998, CEDA, Amsterdam, The Netherlands.

Luettich, R.A. (1995). Personal communication. Institute of Marine Sciences, University of North Carolina at Chapel Hill.

Lockett, J.B. (1959). " Interim consideration of the Columbia river entrance". *Journal of Hydraulics Division*, Proceedings of the American Society of Civil Engineers.

Lockett, J.B. (1965). "Some indications of sediment transport and diffusion in the vicinity of the Columbia River estuary and entrance, Oregon and Washington". Presented before the International Association of Hydraulic Research, Portland, USACE.

Lockett, J.B. (1967). " Sediment transport and diffusion : Columbia estuary and entrance". *Journal of the Waterways and Harbors Division*, Proceedings of the American Society of Civil Engineers. Vol 93, No WW4.

Lund, C.R. 1998. "Analysis of Currents at the Mouth of the Columbia River Dredged Material Disposal Sites", Submitted to OSU/Dr. Charles Sollitt as a Thesis for M.S in Civil Engineering.

Moores, C.N.K. and Smith, R.L. (1968). "Continental shelf waves off Oregon" *Journal of Geophysical Research*. 73(2):549-557

Moritz, H.R. (1994). "User's Guide for the MDFATE model", prepared under Contract No. DACW39-94-1304, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Ms.

Moritz, H.R. and Randall, R.E. (1995). "Simulating dredged material placement at open water disposal sites", *Journal of Waterway, Port, Coastal, and Ocean Engineering*, Vol 121, No. 1.

Morse, B.A., Gross, M.G., and Barnes, C.A. (1968). "Movement of seabed drifters near the Columbia River". Proceedings of the American Society of Civil Engineers, *Journal of Waterways and Harbors*, 99WWI:91-103

National Ocean Survey (1994). Personal Communication

Nelson, C.H. (1968). "Marine geology of the Astoria deep-sea fan." Ph. D. thesis, Oregon State University, Corvallis, Oregon.

Neal, V.T. (1972). "Physical aspects of the Columbia River and its estuary". In: Pruter, A.T and Alverson, D.L., ed. The Columbia River estuary and adjacent ocean waters. University of Washington Press, Seattle.

O'Brien, M.P. (1936). "Mouth of the Columbia River – beach erosion investigations, summary of observations and results, July 1935 – August 1936." Tech memo 20. U.S. Tidal Model Lab., Berkley, California.

Paxton, J. A. (1990). Portland District USACE memorandum for the commander: Results from W.O. #90-SH-1734, report of sediment test samples at MCR.

Poindexter-Rollings, M.E. (1990). "Methodology for analysis of subaqueous mounds". Technical Report D-90-2, Environmental Laboratory, U.S. Army Waterways Experiment Station, Vicksburg, MS.

Pruter, A.T and Alverson, D. L., editors (1972). "The Columbia River estuary and adjacent ocean waters", University of Washington Press, Seattle, WA.

Roy, E.H., Creager, J.S., Gelfenbaum, G.R., Sherwood, C.R., and Stewart, R.J. (1982). "An investigation to determine the sedimentary environments near the entrance to the Columbia River entrance". Contract number DACW57-80-C0012, Final Report to the U.S. Army Corps of Engineers, Portland District, Portland Oregon.

Roy, E.H., Creager, J.S., Walter, S.R, and Borgeld, J.C. (1979). "An investigation to determine the bedload and suspended sediment transport over the outer tidal delta and monitor the sedimentary environment at sites E and D near the mouth of the Columbia River entrance". Contract number DACW57-78-C0042, Final Report to the U.S. Army Corps of Engineers, Portland District, Portland Oregon.

Runge, E.J. (1966). "Continental shelf sediments , Columbia River to Cape Blanco, Orgeon.", M.S. thesis, Oregon State University, Corvallis, Oregon.

Scheidegger, K.E. Kulm, L.D., and Runge, E.J. (1971). "Sediment sources and dispersal patters of the Oregon continental shelf sands." Journal of Sed. Pet., Vol 41, pp 1112-1120.

Scheffner, N.W., Thevenot, M.M., Tallent, J.R., and Mason, J.M. (1995). "LTFATE: A model to investigate fate and stability of dredged material disposal sites", Technical Report DRP 94-xx, Coastal Engineering Research Center, U.S. Army Waterways Experiment Station, Vicksburg, MS.

Schubel, J.R., Carter, H.H., Wilson, R.E., Wise, W.M., Heaton, M.G., and Gross, M.G. "Field Investigations of the Nature, Degree, and Extent of Turbidity Generated by Open-Water Disposal Operations". TR-D-78-3, U.S. Army Waterways Experiment Station, Vicksburg, MS.

Sherwood, C.R. (1989). "Use of sediment transport calculations in dredged material disposal site selection", Battelle Marine Sciences Laboratory, Sequim, Washington.

Siipola, M.D. and Braun, E.P. (1995). "Management/monitoring program for the ocean dredged material disposal sites of the U.S. Army Corps of Engineers, Portland District", Department of the Army, Corps of Engineers, Portland District, Portland, OR

Siipola, M.D. (1992). " Reconnaissance level benthic infaunal, sediment, and fish study: Offshore fom the Columbia River, July 1992". Department of the Army, Corps of Engineers, Portland District, Portland, OR and U.S. Environmental Protection Agency, Region 10, Seattle, WA.

Schlicker, H. G., Deacon, H.G., Beaulieu, J.D., and Olcott, G.W. (1972). "Environmental geology of the coastal region of Tillamook and Clatsop counties, Oregon", ODGMI bull. 74.

Sobey, E.J.B. (1977). "The response of Oregon shelf waters to wind fluctuations: Differences and the transition between winter and summer". Ph.D. thesis, Oregon State University, Corvallis, OR.

Scheffner, N., W. (1992). "Dispersion Analysis of Humbolt Bay, California, Interim Offshore Disposal Site." Misc. Paper DRP-92-1. U.S. Army Waterways Experiment Station, Vicksburg, MS.

Sternberg, R.W. (1986). "Transport and accumulation of river-derived sediment on the Washington continental shelf, USA" Journal of the Geological Society, London, Vol. 143, pp 945-956.

Soderlind, K. (1995). Personal communication - Memorandum for record (PE-HY). Army Engineer District Portland. Portland, Oregon.

Sternberg, R.W., Creager, J.S., Glassley, W., and Johnson, J. (1977). "Aquatic disposal field investigations Columbia River disposal site, Oregon, Exhibit A: Investigation of the hydraulic regime and physical nature of bottom sedimentation.", Technical Report D-77-30. U.S. Army Engineer Waterways Experiment Station, Vicksburg, Ms

Stevenson, M.R., Garvine, R.W., and Wyatt, B. (1974). "Lagrangian measurements in a coastal upwelling zone off Oregon" *Journal of Physical Oceanography*, 4(3):321-336.

Thevenot, M.M and Johnson, B.H. "Verification of Numerical Modelling of the Fate of Disposed Dredged Material", Dredging '94 – Proceedings of the Second International Conference on Dredging and Dredged Material Placement, Vol 1. ASCE.

U.S. Army Engineer District, Portland (1995a). "Simulation of dredged material disposal at Coos Bay ocean dredged material disposal site "F". Department of the Army, Corps of Engineers, Portland District, Portland, Or.

U.S. Army Engineer District, Portland (1960). "Summary of interim report on 1959 current measurement program, Columbia River mouth at Oregon and Washington, Corps of Engineers, Portland District, Portland, Or.

U.S. Navy Hydrographic Office (1954). "Inshore survey project: Preliminary report on the Columbia river mouth and its approaches", U.S. Navy Hydrographic Office, Washington 25, D.C.

U.S. Navy Hydrographic Office (1960). "Inshore survey results: Columbia river mouth and its approaches", H.O. Misc. 15359-21S, Oceanographic Survey Branch Division of Oceanography, U.S. Navy Hydrographic Office, Washington 25, D.C.

Walter, S.R., Roy, E.H., Creager, J.S., and Borgeld, J.C. (1979). "an investigation to determine the bedload and suspended load sediment transport over the outer tidal delta and monitor the sedimentary environment at sites A, E, and D near the mouth of the Columbia River.", Annual Report, U.S. Army Corps of Engineers, Portland District, Portland Oregon.

White, S.M. (1967). "The mineralogy and geochemistry of sediments on the continental shelf off of the Washington-Oregon coast.", Thesis, University of Washington, Seattle, WA.

Figures

050

CORPS OF ENGINEERS U. S. ARMY

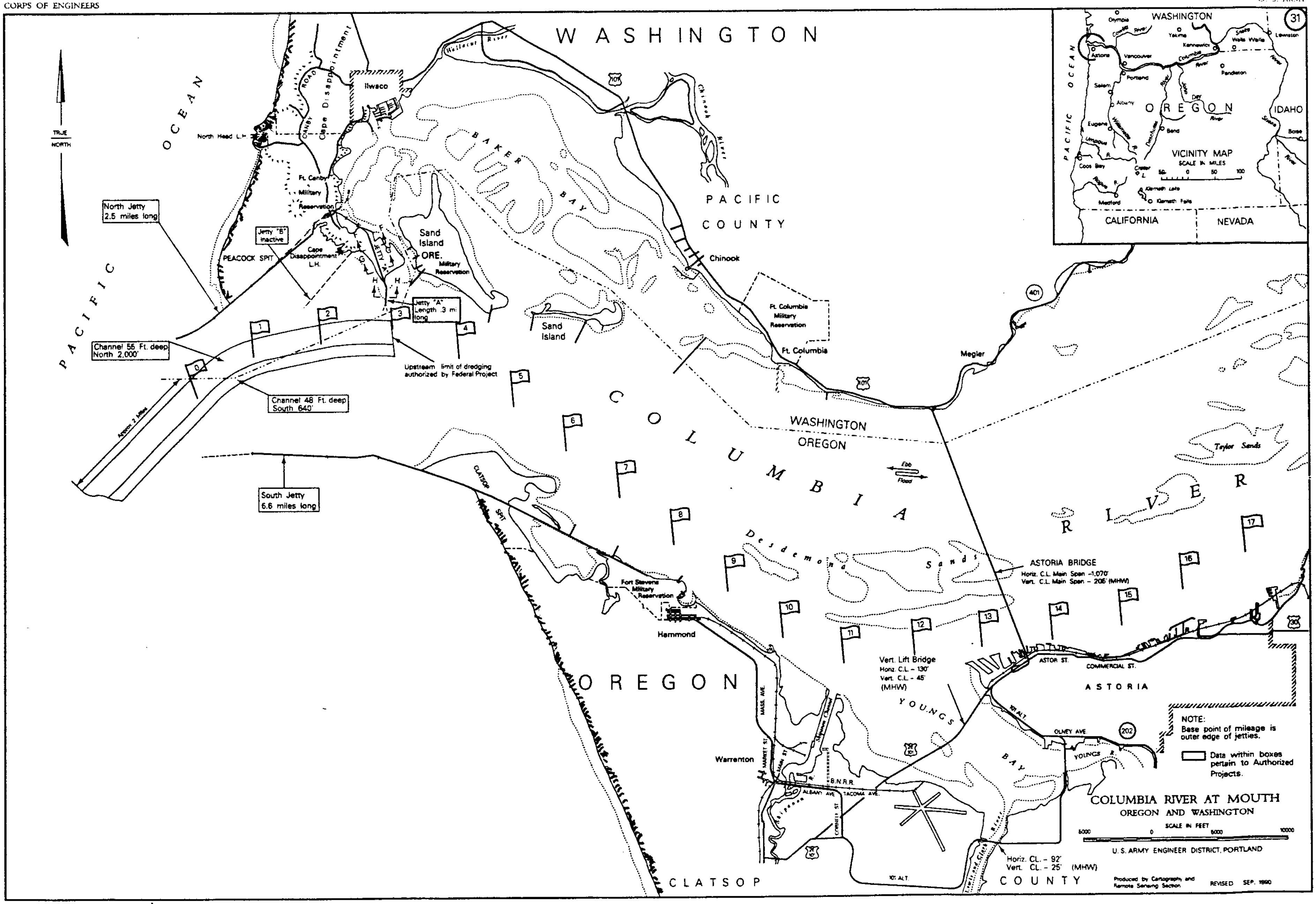


Figure B-1 Mouth of Columbia River project map.

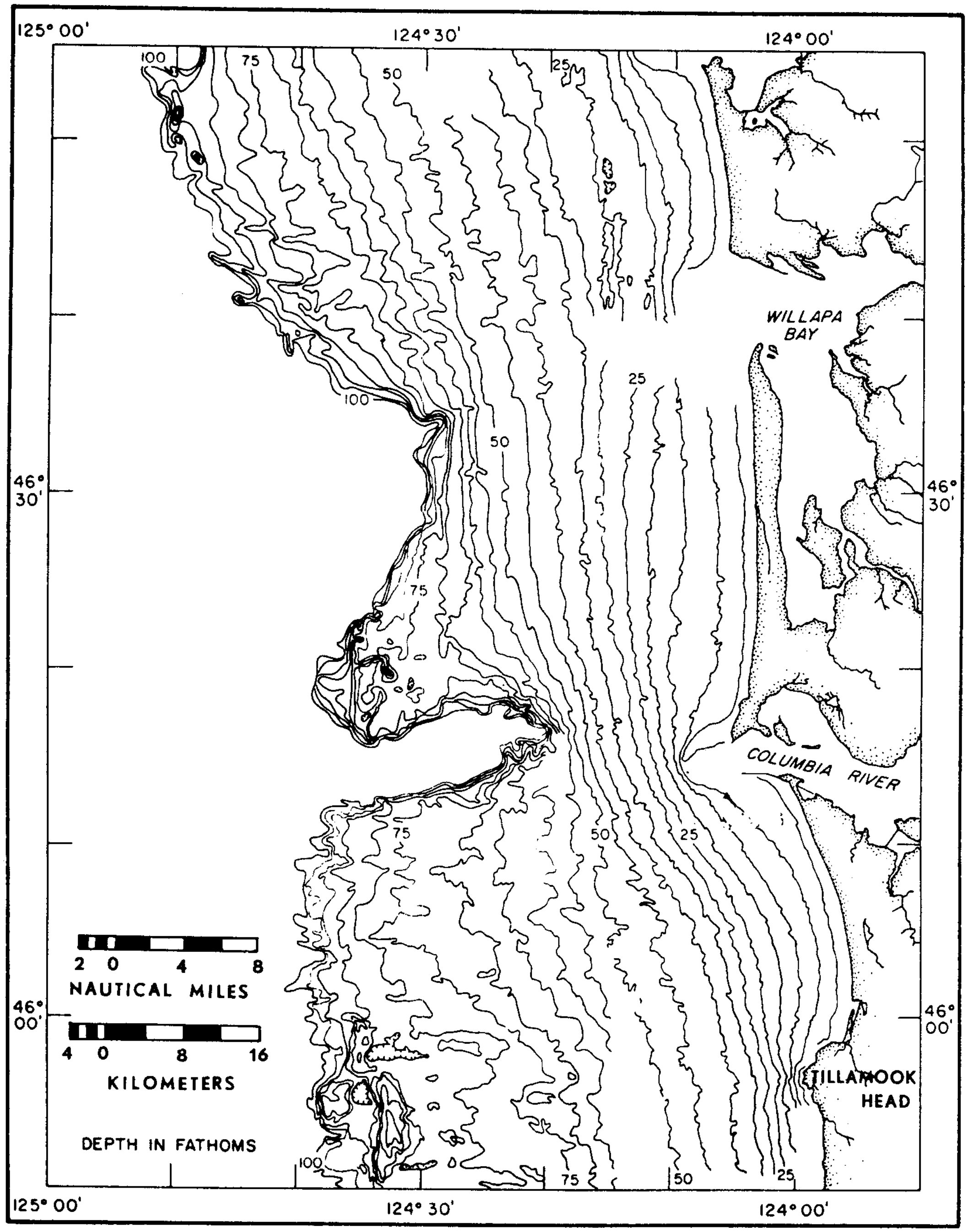
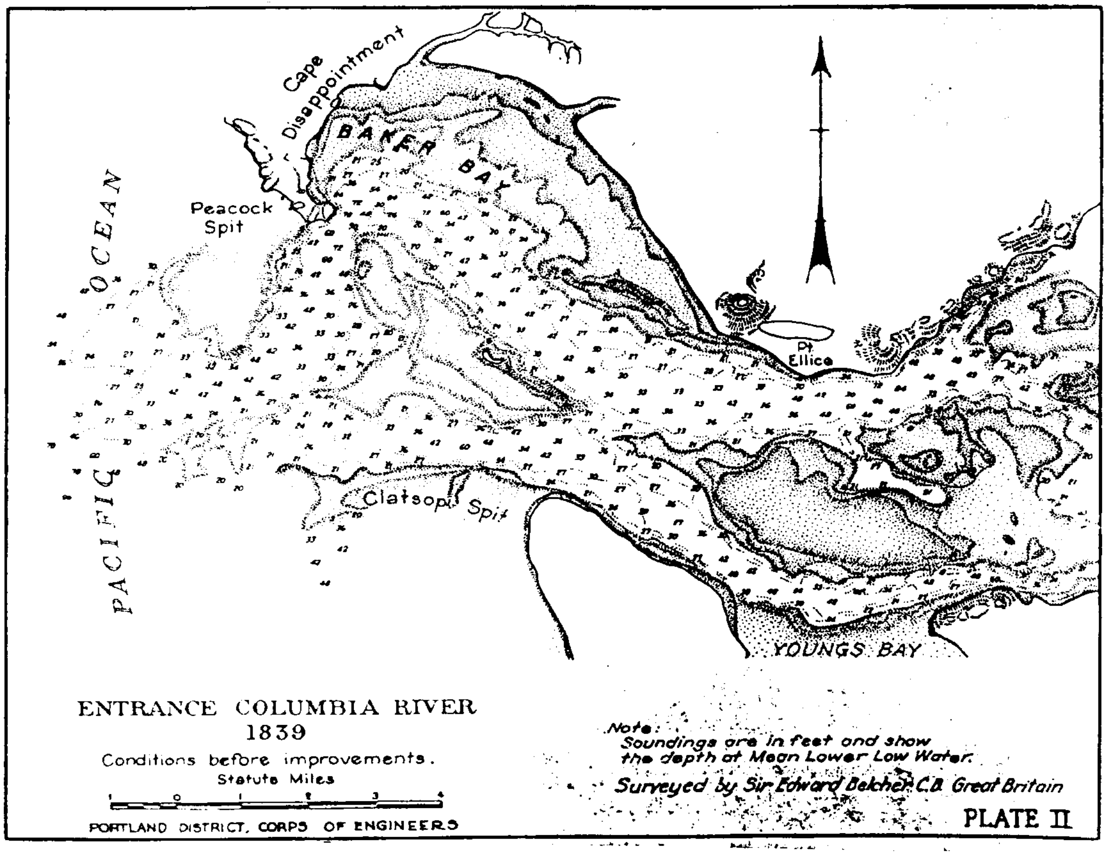


Figure B-2 Bathymetry of the continental margin near the Mouth of the Columbia (USCGS).



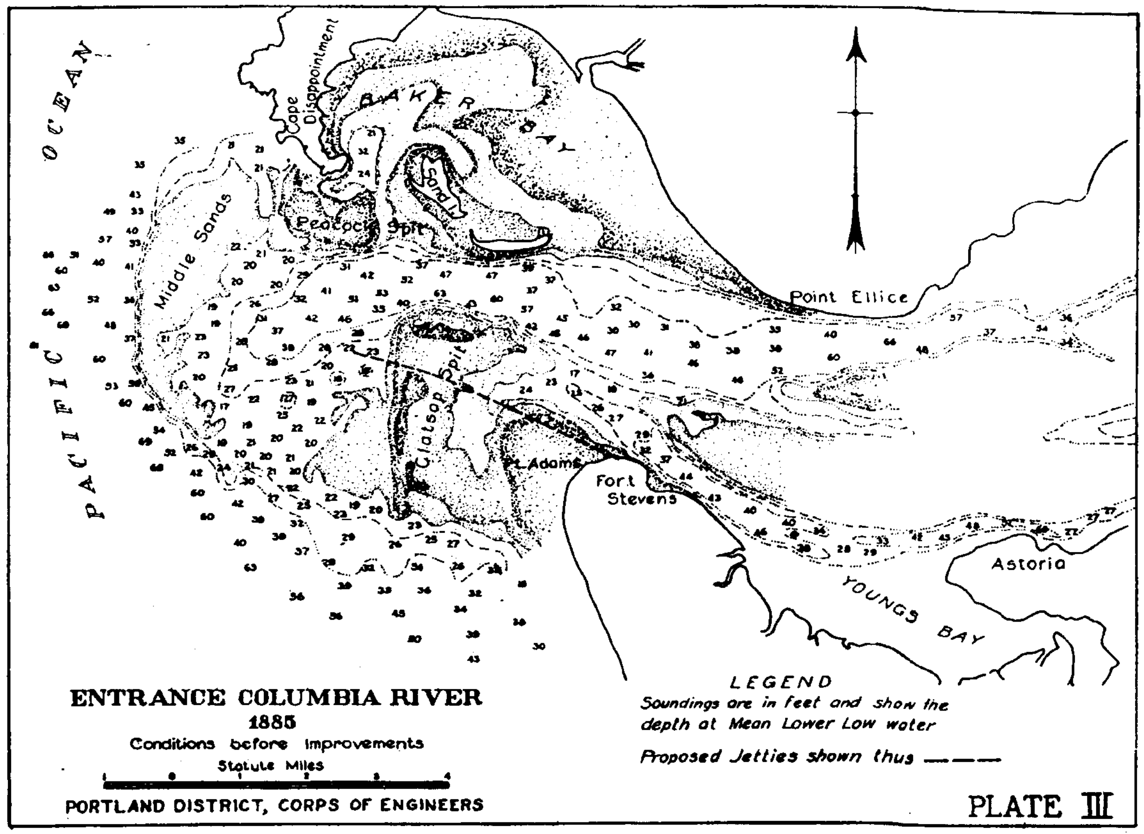
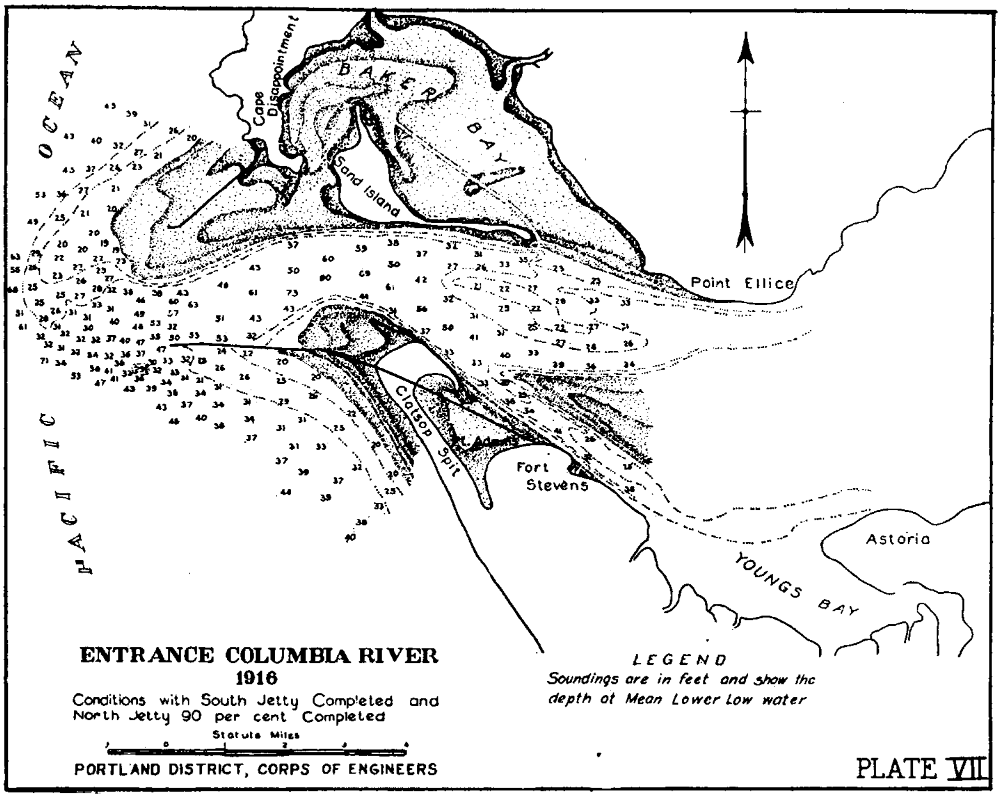


Figure B-3. Mouth of the Columbia River bathymetry change during 1839-1885, before navigation improvements.



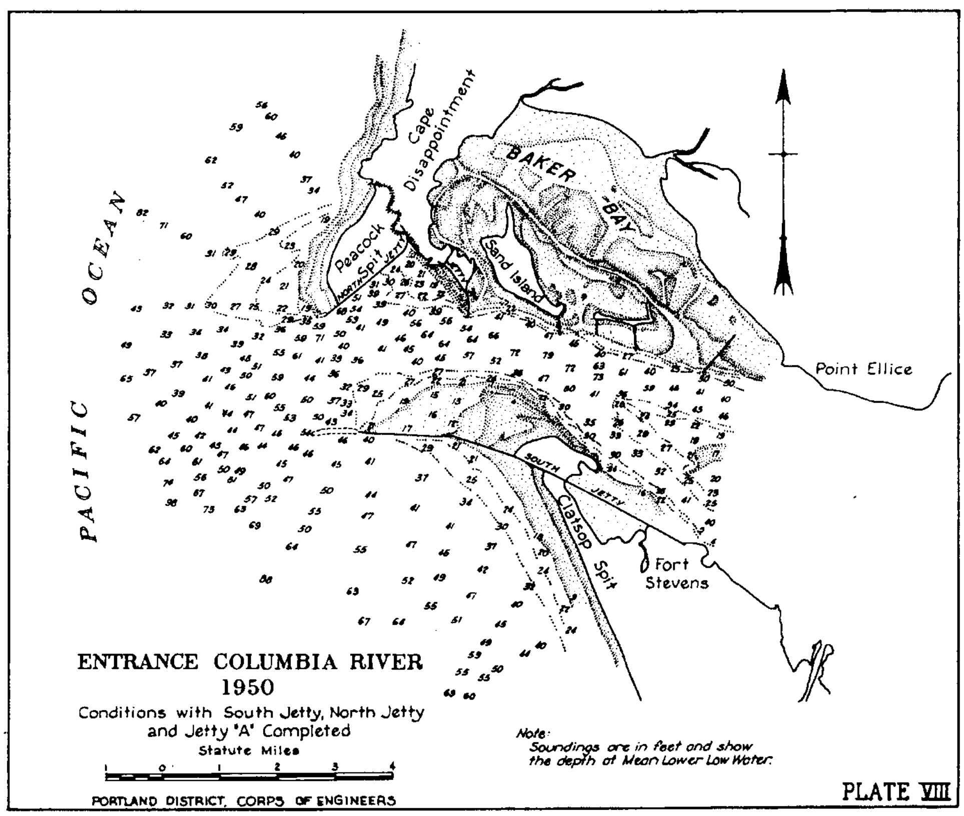


Figure B 4 Mouth of the Columbia River bathymetry change during 1916-1950, after navigation improvements.

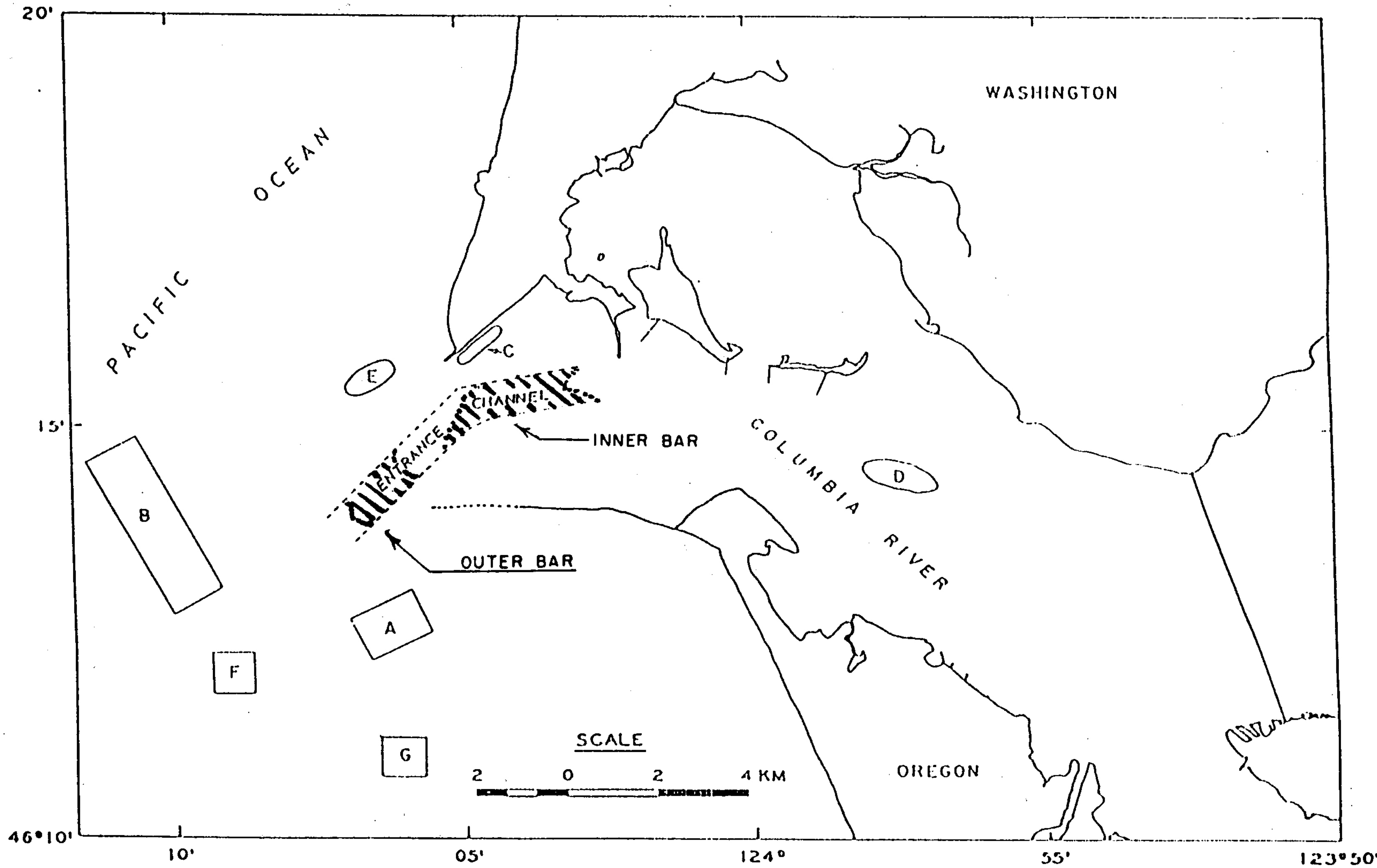


Figure B-5 Configuration of ODMDSs at MCR before formal designation in 1977.

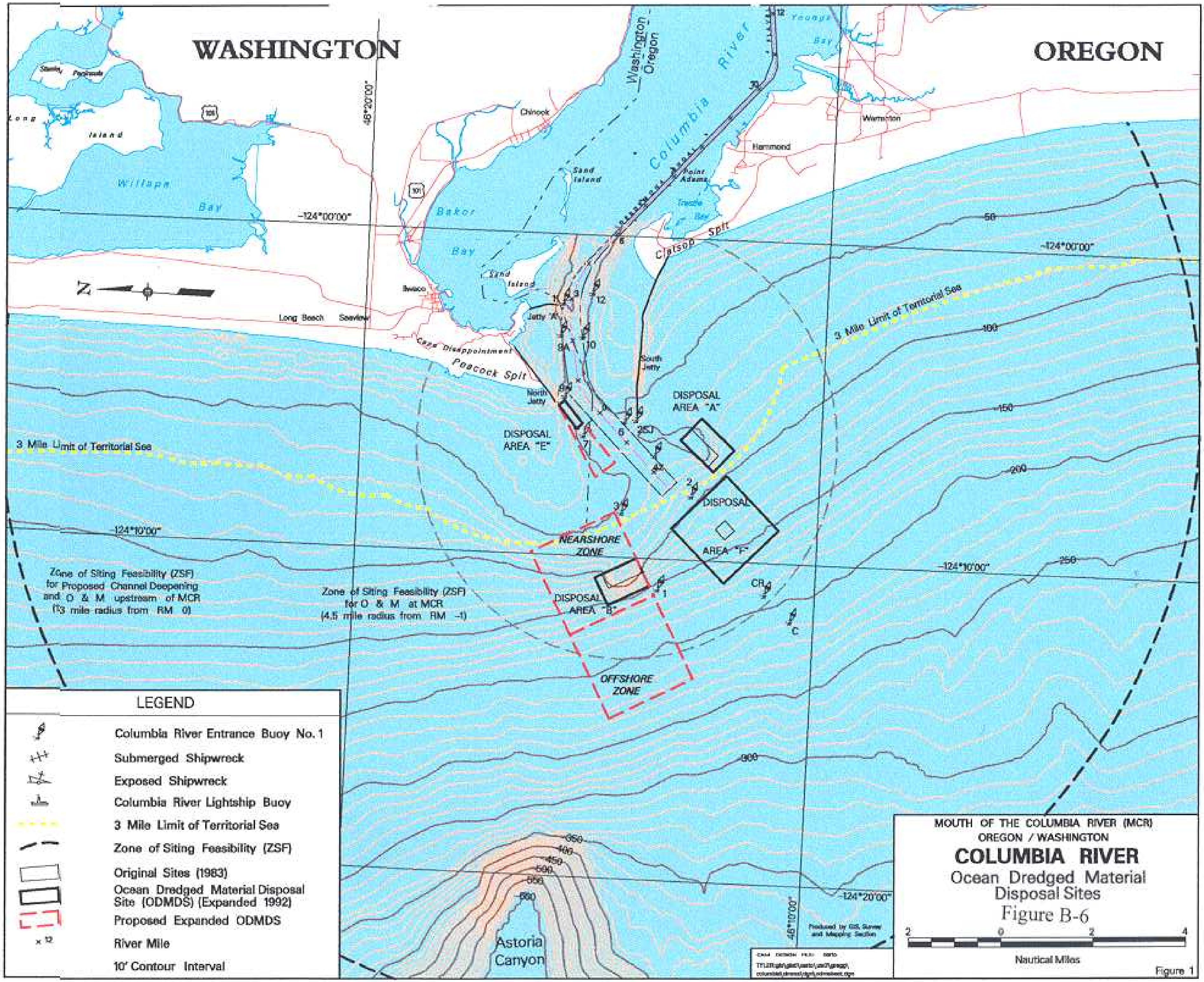
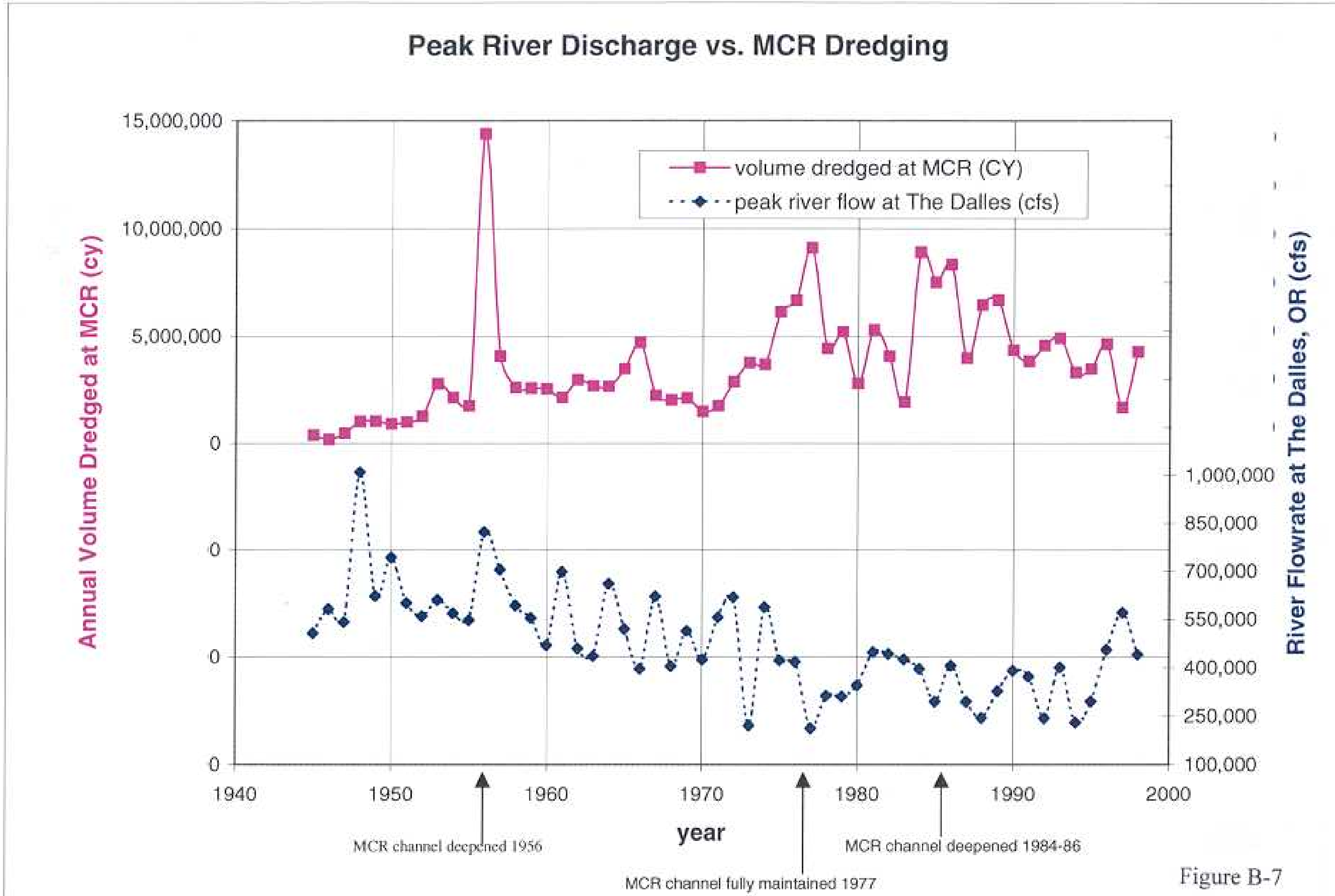

WASHINGTON
OREGON
Columbia River
Washington
Oregon
Willapa Bay
Baker Bay
Long Island
Chinook
Ilwaco
Long Beach
Seaview
Hammond
Warrenton
Youngs Bay
Point Adams
Trestle Bay
Clatsop Spit
Sand Island
Cape Disappointment
Peacock Spit
North Jetty
South Jetty
Jetty "A"
-124°00'00"
-124°10'00"
-124°20'00"
46°20'00"
46°10'00"
3 Mile Limit of Territorial Sea
DISPOSAL AREA "A"
DISPOSAL AREA "B"
DISPOSAL AREA "E"
DISPOSAL AREA "F"
NEARSHORE ZONE
OFFSHORE ZONE
Zone of Siting Feasibility (ZSF) for Proposed Channel Deepening and O & M upstream of MCR (3 mile radius from RM 0)
Zone of Siting Feasibility (ZSF) for O & M at MCR (4.5 mile radius from RM -1)
Astoria Canyon
LEGEND
Columbia River Entrance Buoy No. 1
Submerged Shipwreck
Exposed Shipwreck
Columbia River Lightship Buoy
3 Mile Limit of Territorial Sea
Zone of Siting Feasibility (ZSF)
Original Sites (1983)
Ocean Dredged Material Disposal Site (ODMDS) (Expanded 1992)
Proposed Expanded ODMDS
River Mile
10' Contour Interval
MOUTH OF THE COLUMBIA RIVER (MCR)
OREGON / WASHINGTON
COLUMBIA RIVER
Ocean Dredged Material Disposal Sites
Produced by GIS Survey and Mapping Section
Nautical Miles
Figure 1

Figure B-6



Peak River Discharge vs. MCR Dredging
volume dredged at MCR (CY)
peak river flow at The Dalles (cfs)
Annual Volume Dredged at MCR (cy)
15,000,000
10,000,000
5,000,000
0
0
0
0
River Flowrate at The Dalles, OR (cfs)
1,000,000
850,000
700,000
550,000
400,000
250,000
100,000
1940
1950
1960
1970
1980
1990
2000
year
MCR channel deepened 1956
MCR channel fully maintained 1977
MCR channel deepened 1984-86

Figure B-7

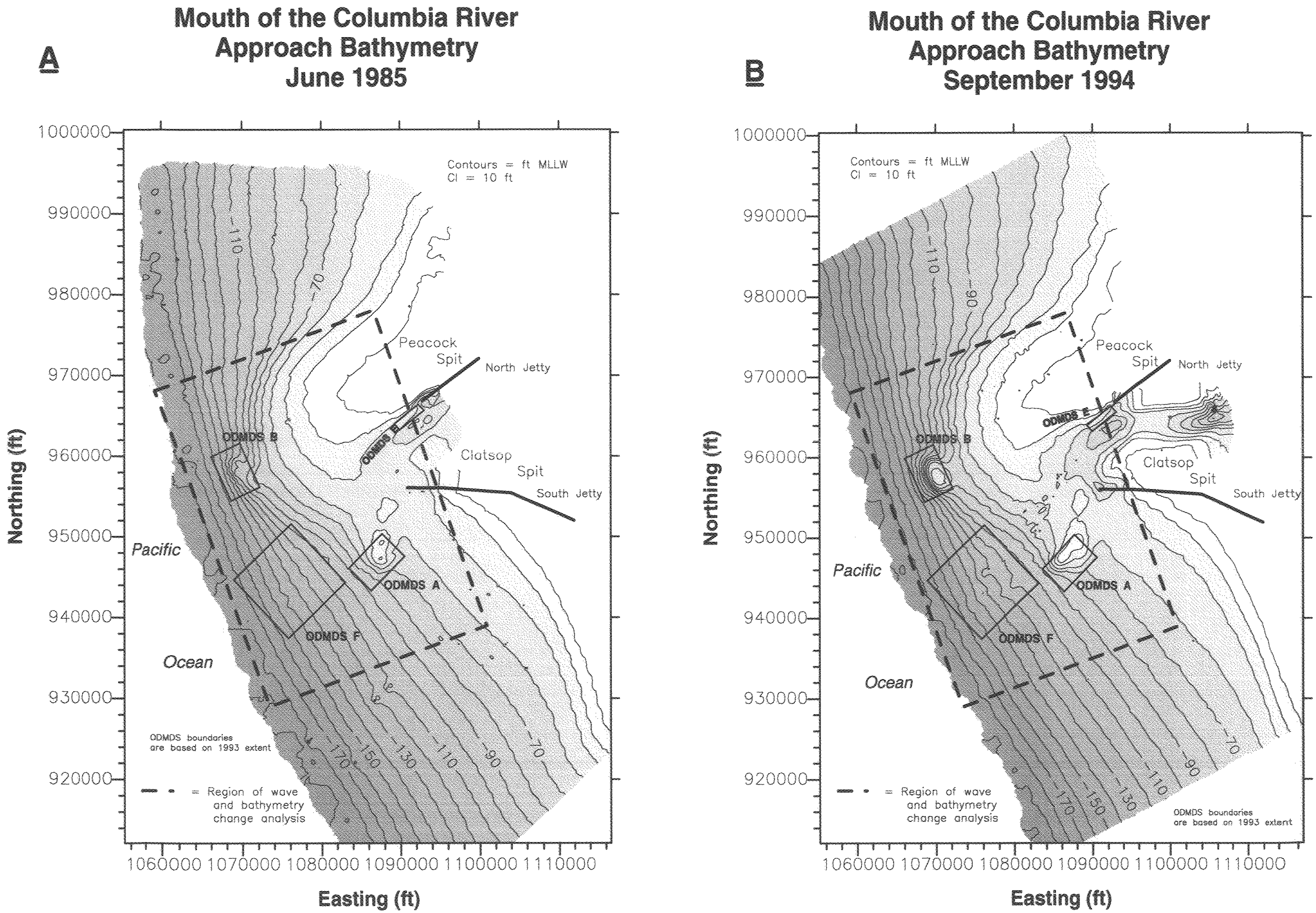


Figure B9. Regional (approach) bathymetry offshore the Mouth of the Columbia River for 1985 (A) and 1994 (B).

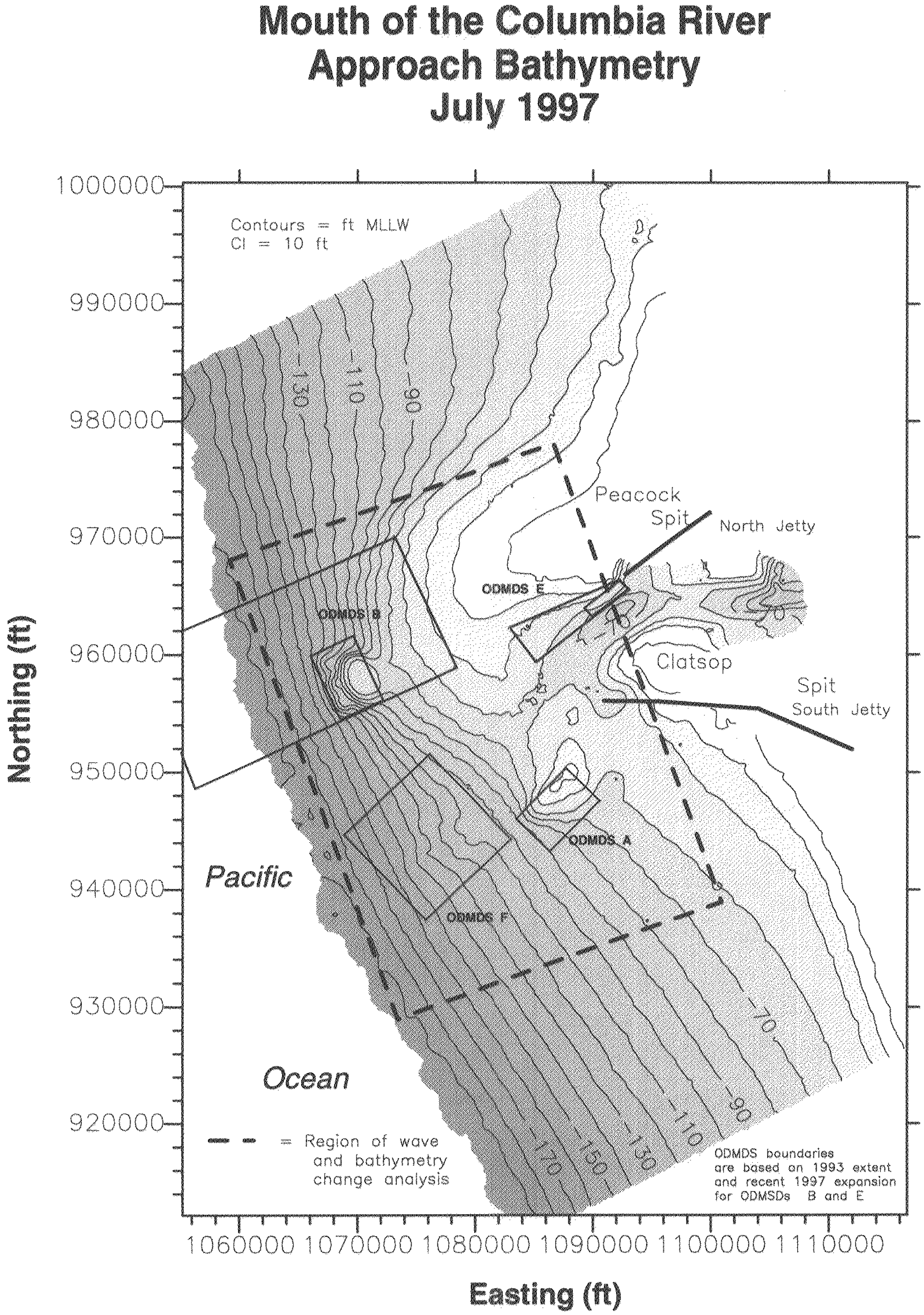


Figure B10. Regional (approach) bathymetry offshore the Mouth of the Columbia River for 1997.

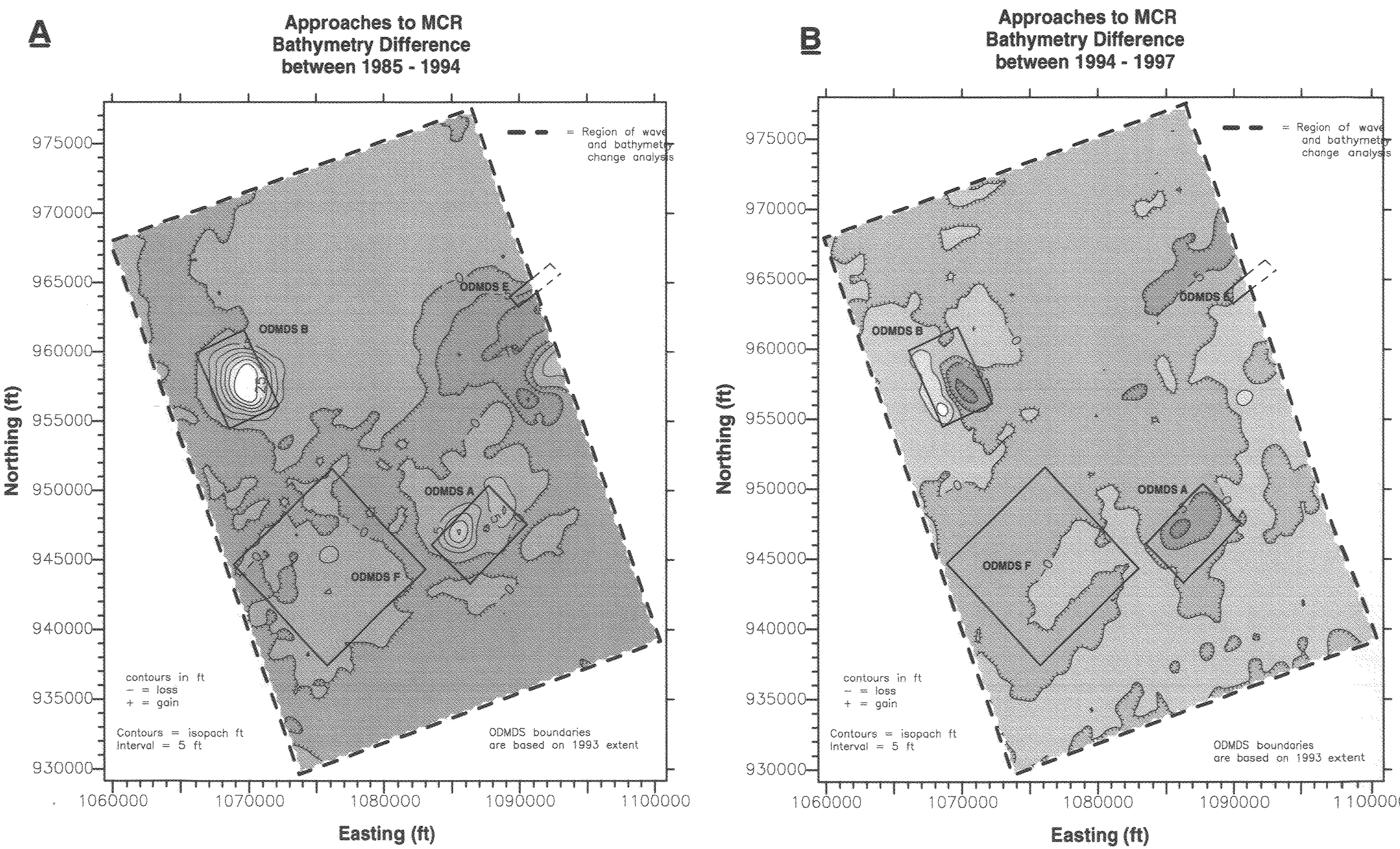


Figure B11. Regional bathymetric change offshore the Mouth of the Columbia River between 1985-1994 (A) and 1994-1997 (B).

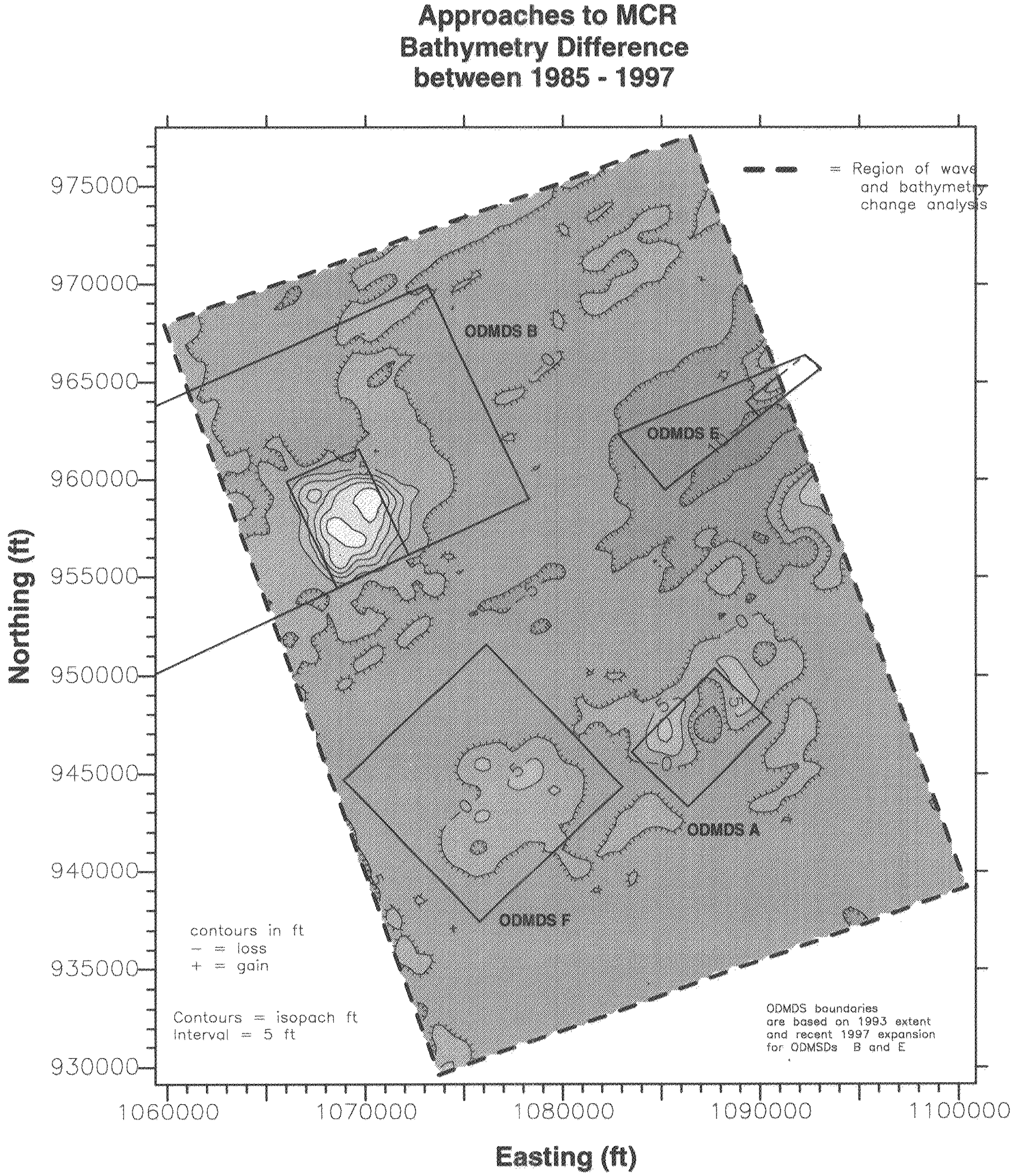
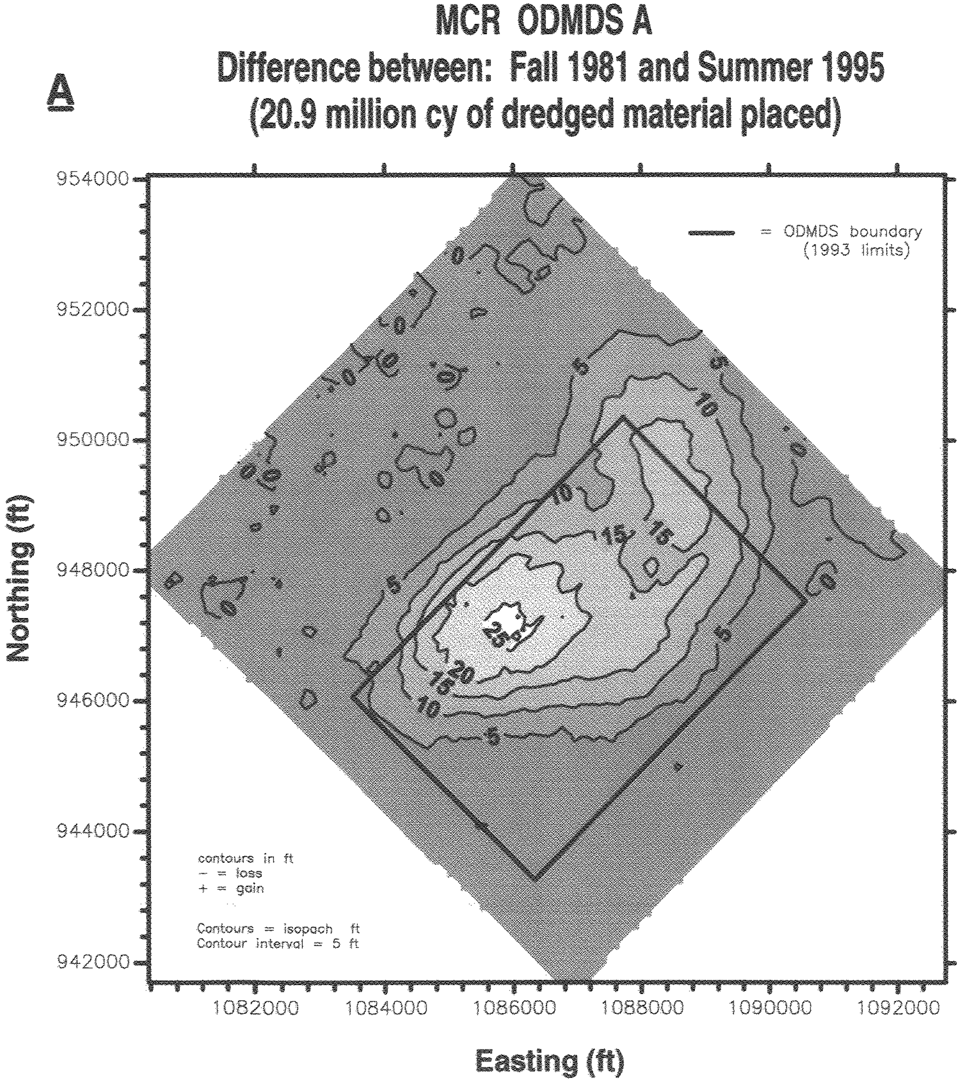
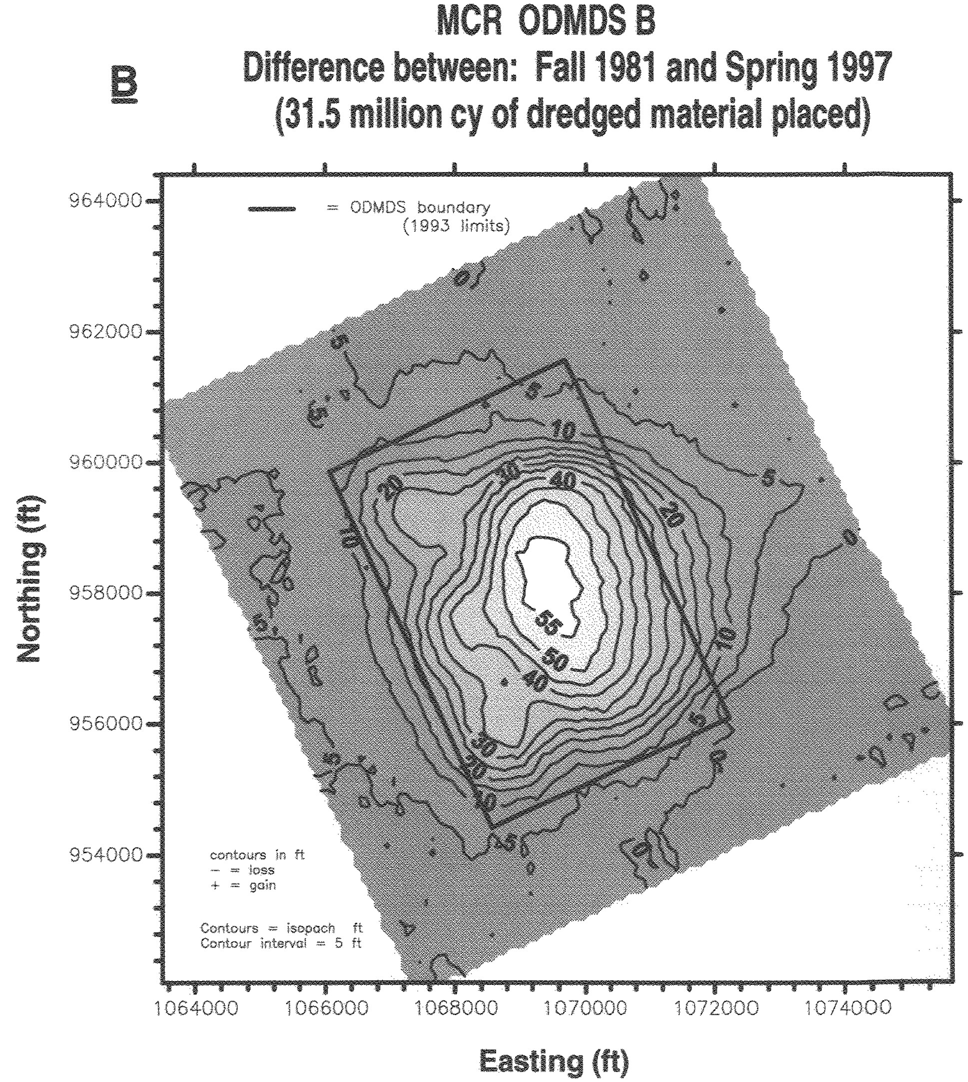


Figure B12. Regional bathymetric change offshore the Mouth of the Columbia River between 1985 and 1997.





Figire B-13. Bathymetric change at MCR ODMDS A and B. Batymetric change at ODMDS A between 1981-1995 (A) and bathymetric change at ODMDS B between 1981-1997 (B).

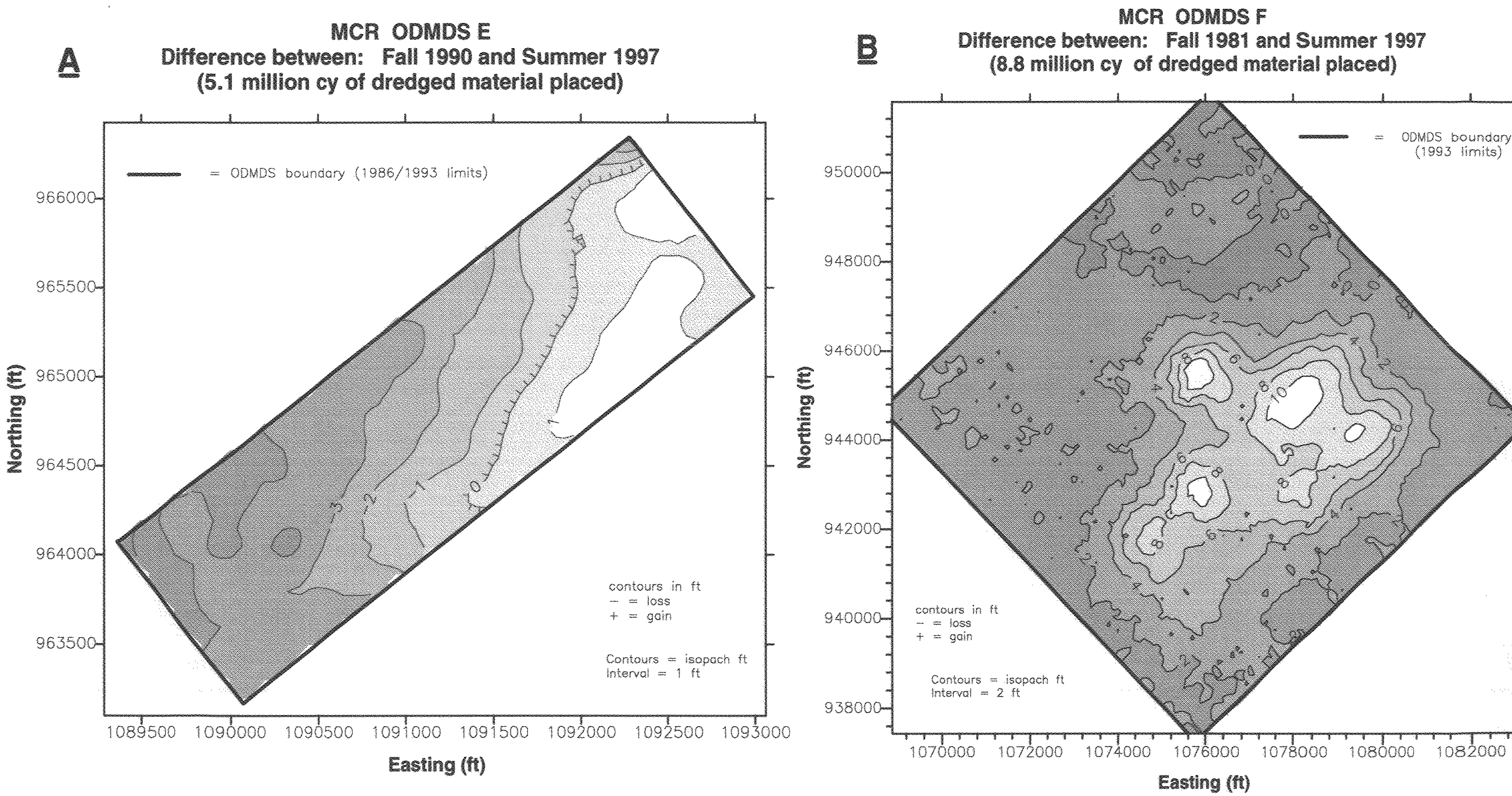


Figure B-14. Bathymetric change at MCR ODMDS E and F. Bathymetric change at ODMDS E between 1990-1997 (A). and bathymetric change at ODMDS F between 1981-1997 (B).

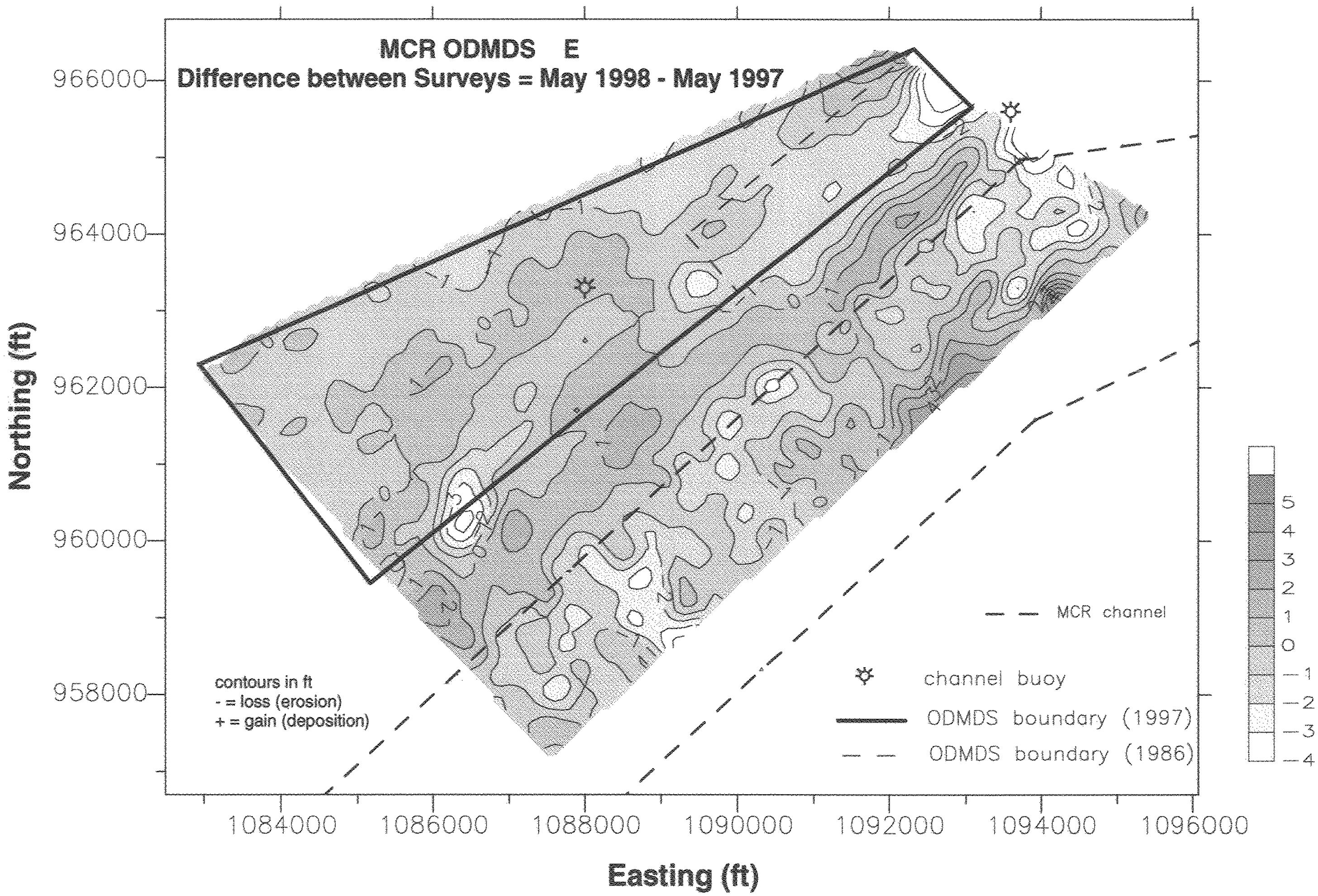


Figure B-15. Bathymetric change at ODMDS E during May 1997 and May 1998

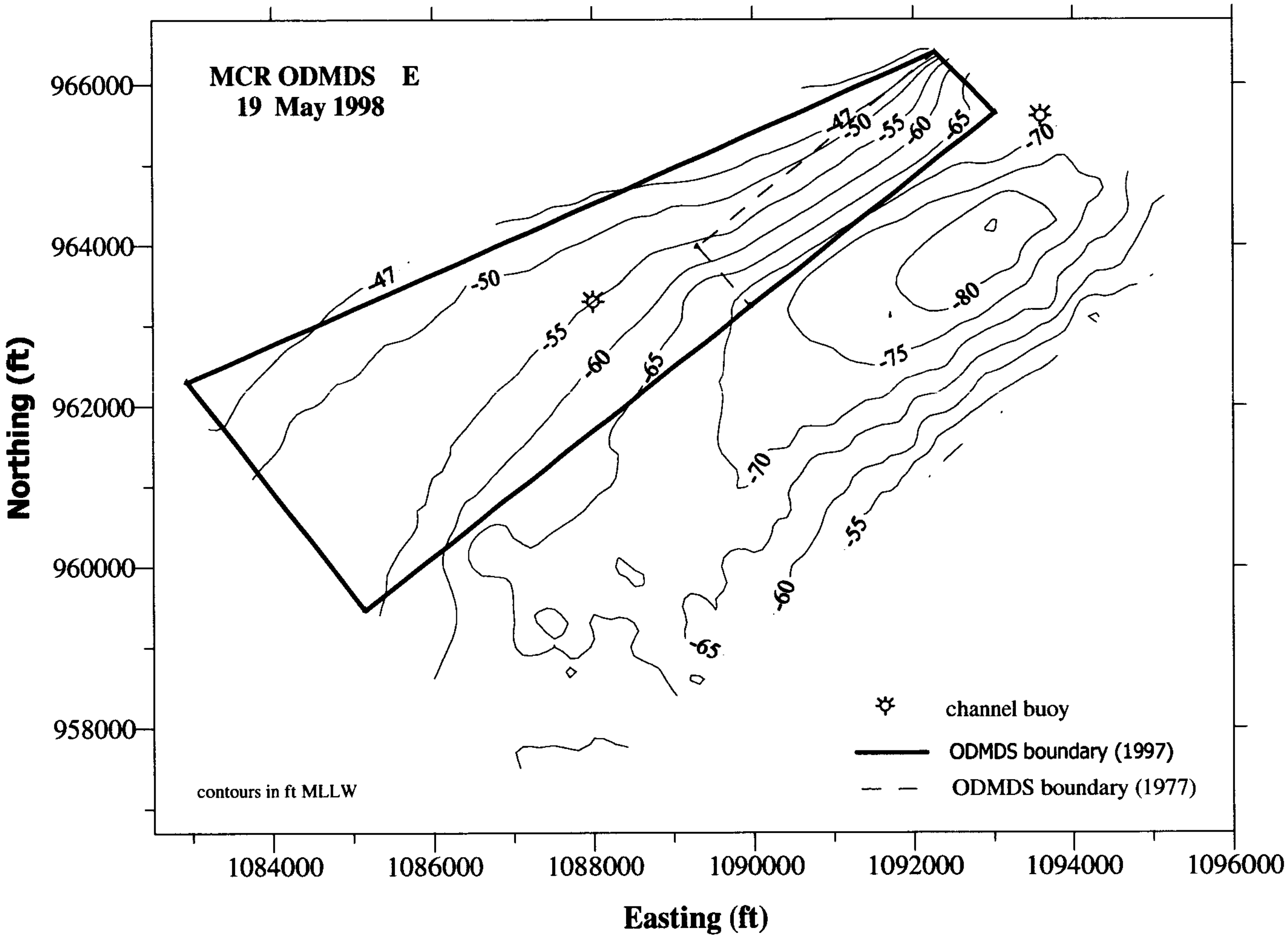


Figure B-16. Bathymetry at ODMDS E during May 1998 (before 1998 dredged material disposal).

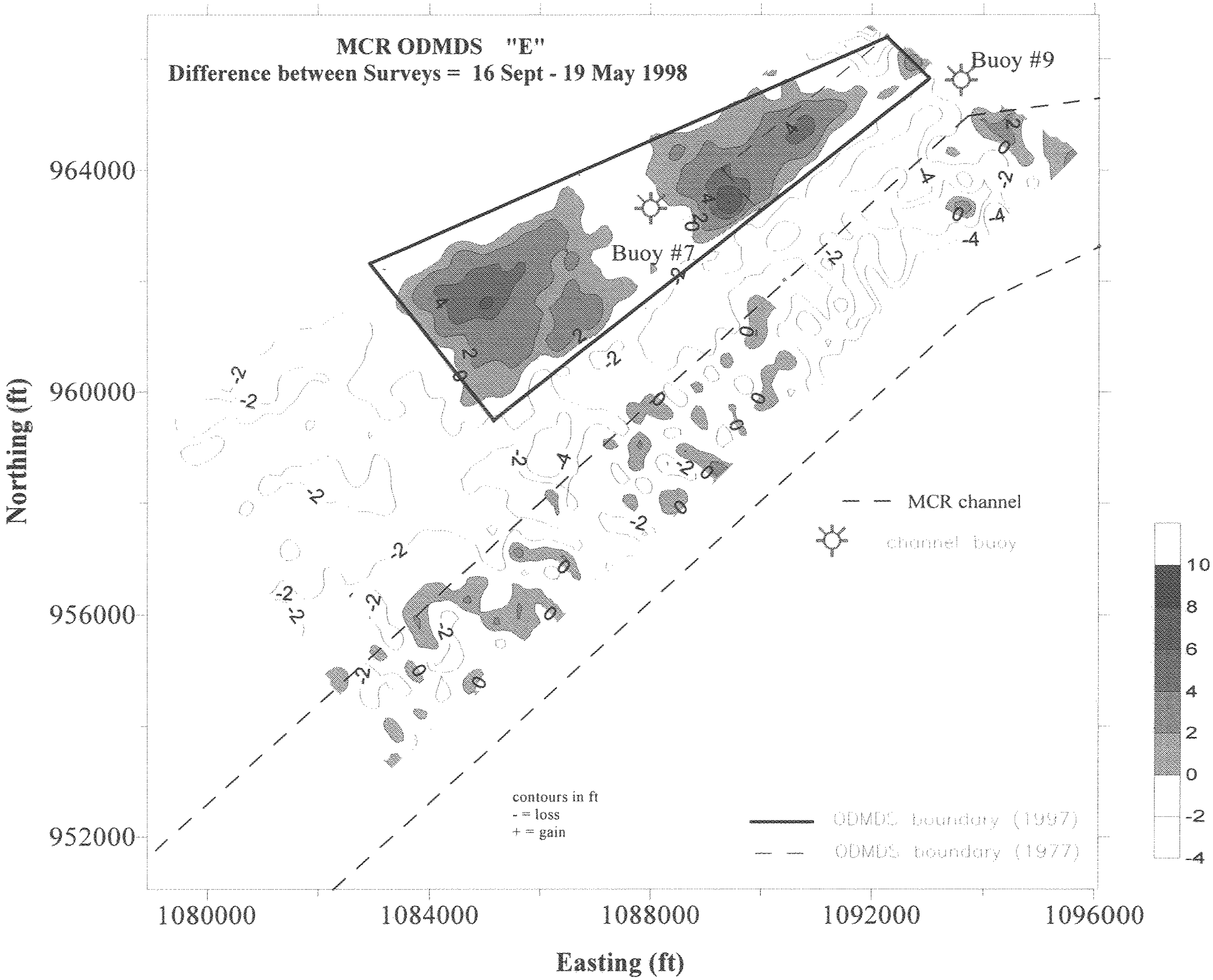


Figure B-17. Bathrymetry change at ODMDS E due to dredged material disposal during 1998.

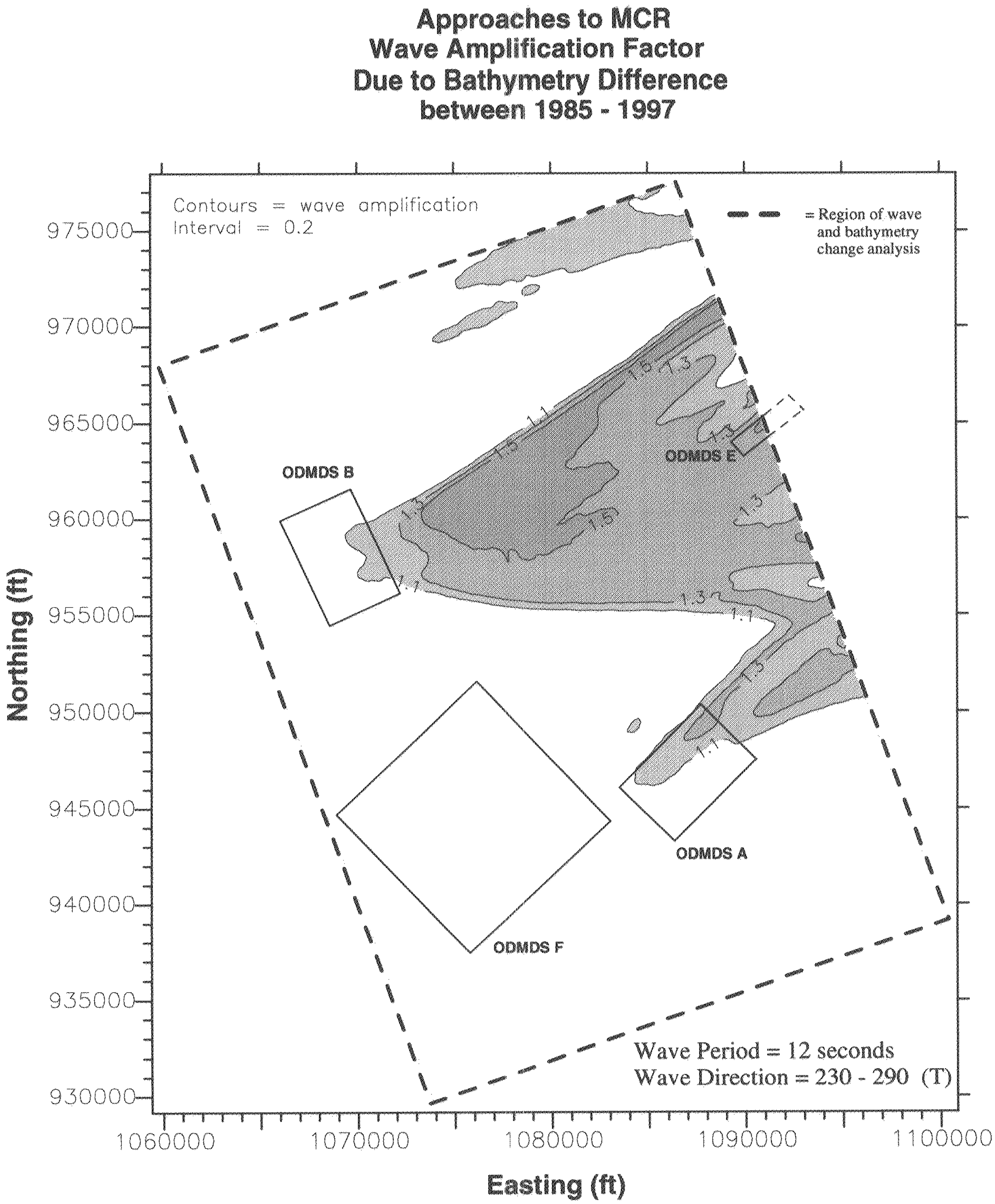
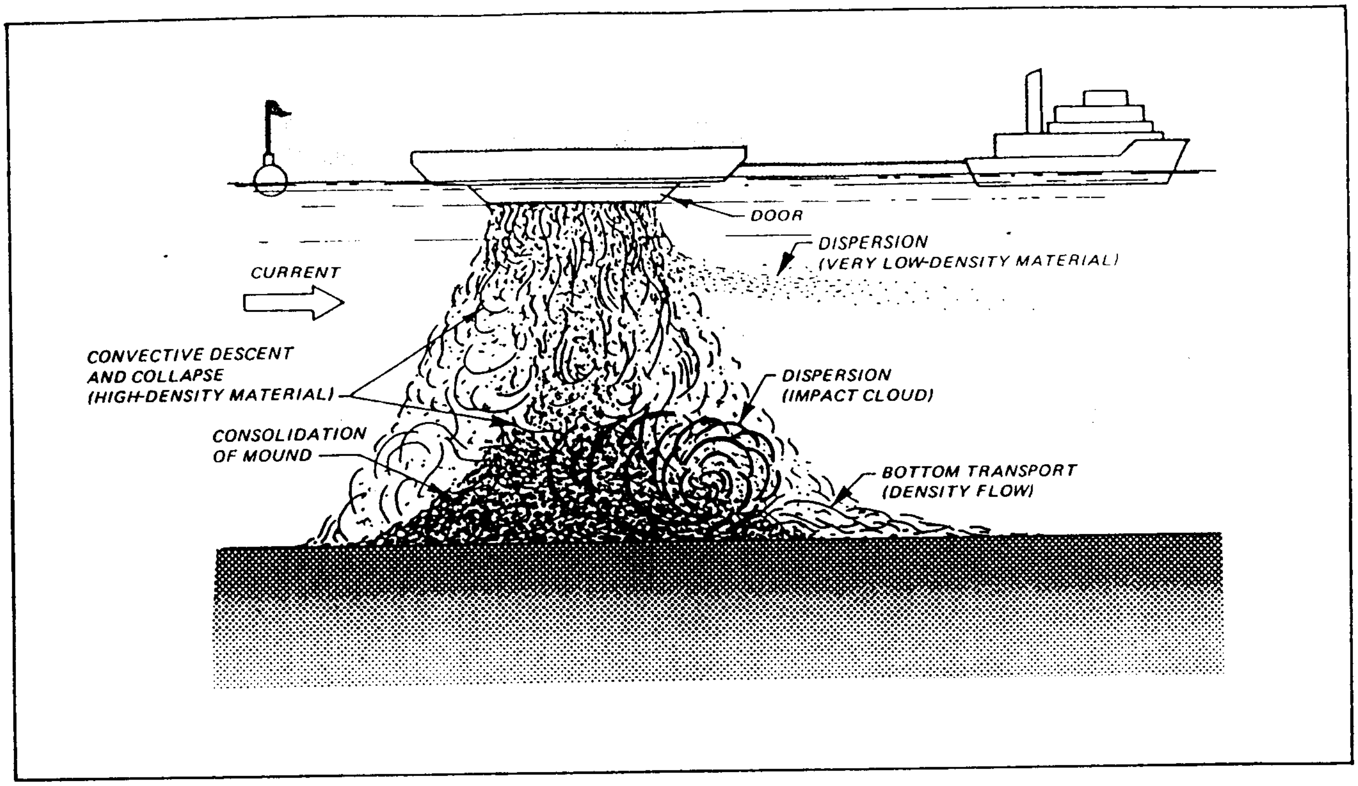


Figure B18. Estimated Wave Amplification at MCR Due to the Change in Bathymetry Between 1985 and 1997. Refer to Figure B12 for a Graphical Discription of Bathymetric Change for 1985-1997.



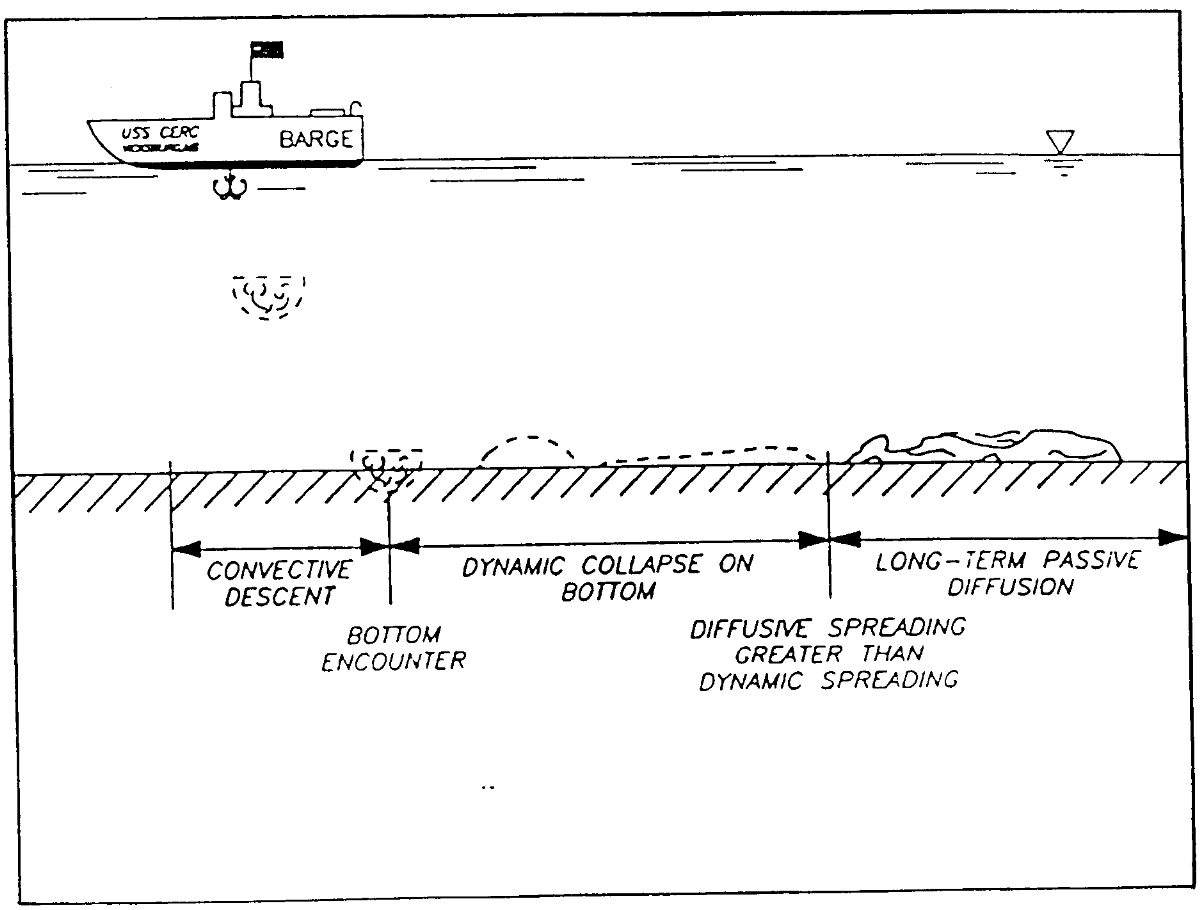


Figure B-19 (Top) Four phases of dredged material behavior when the material is discharged subaqueously (Bottom) Computational phases of the short-term fate model

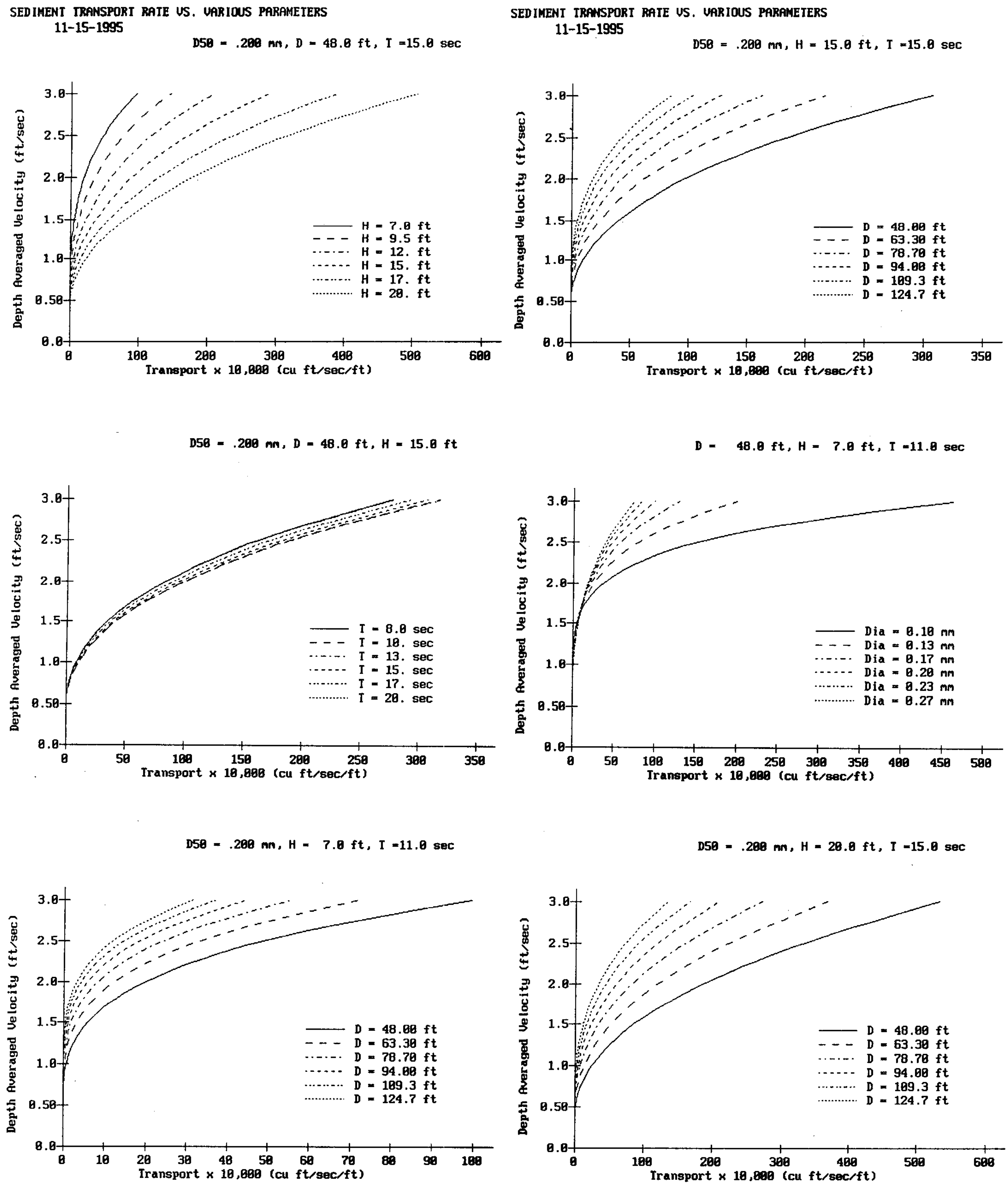


Figure B-20 Results form Ackers-White patch-test of point values for sediment transport potential

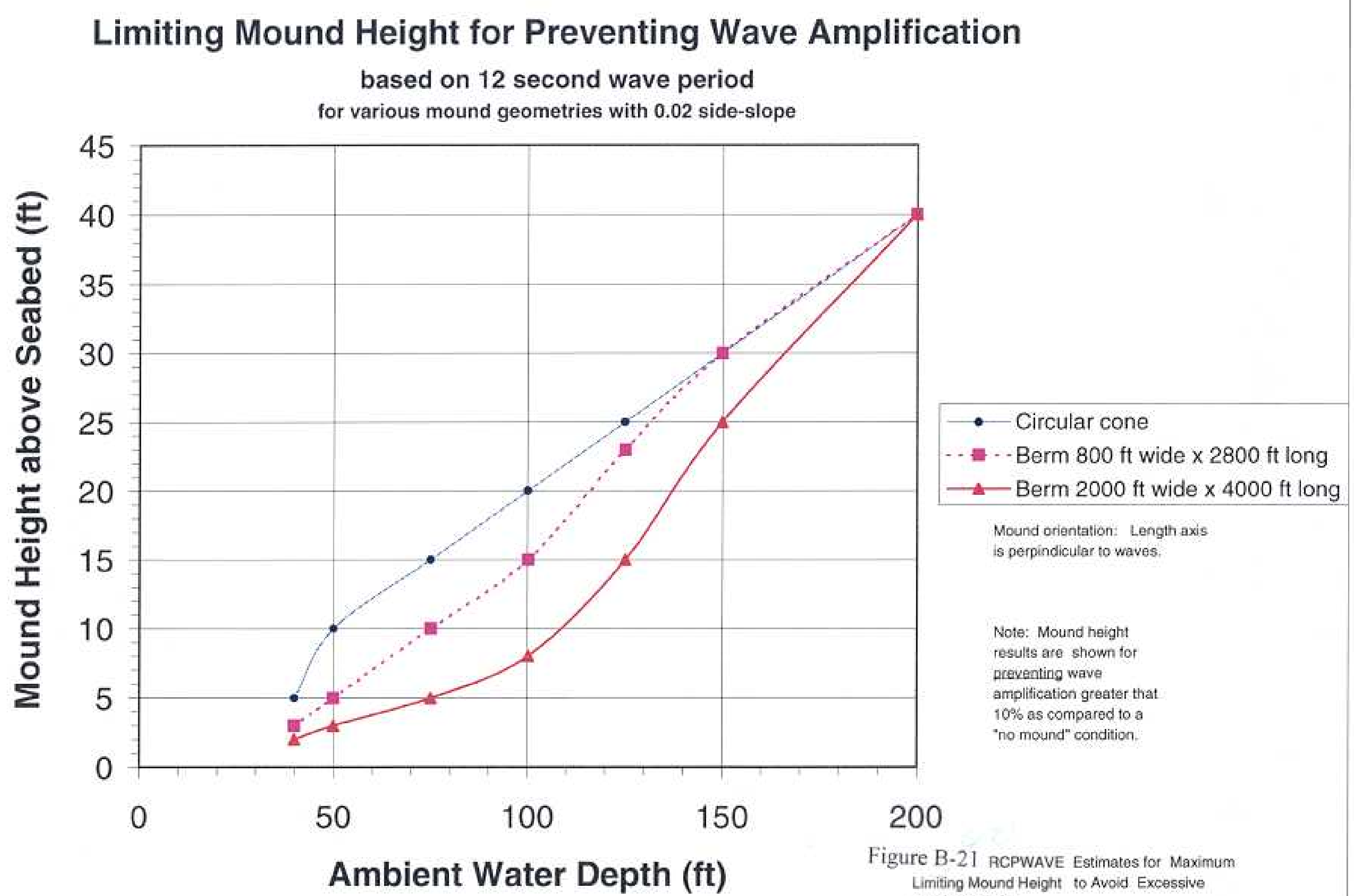
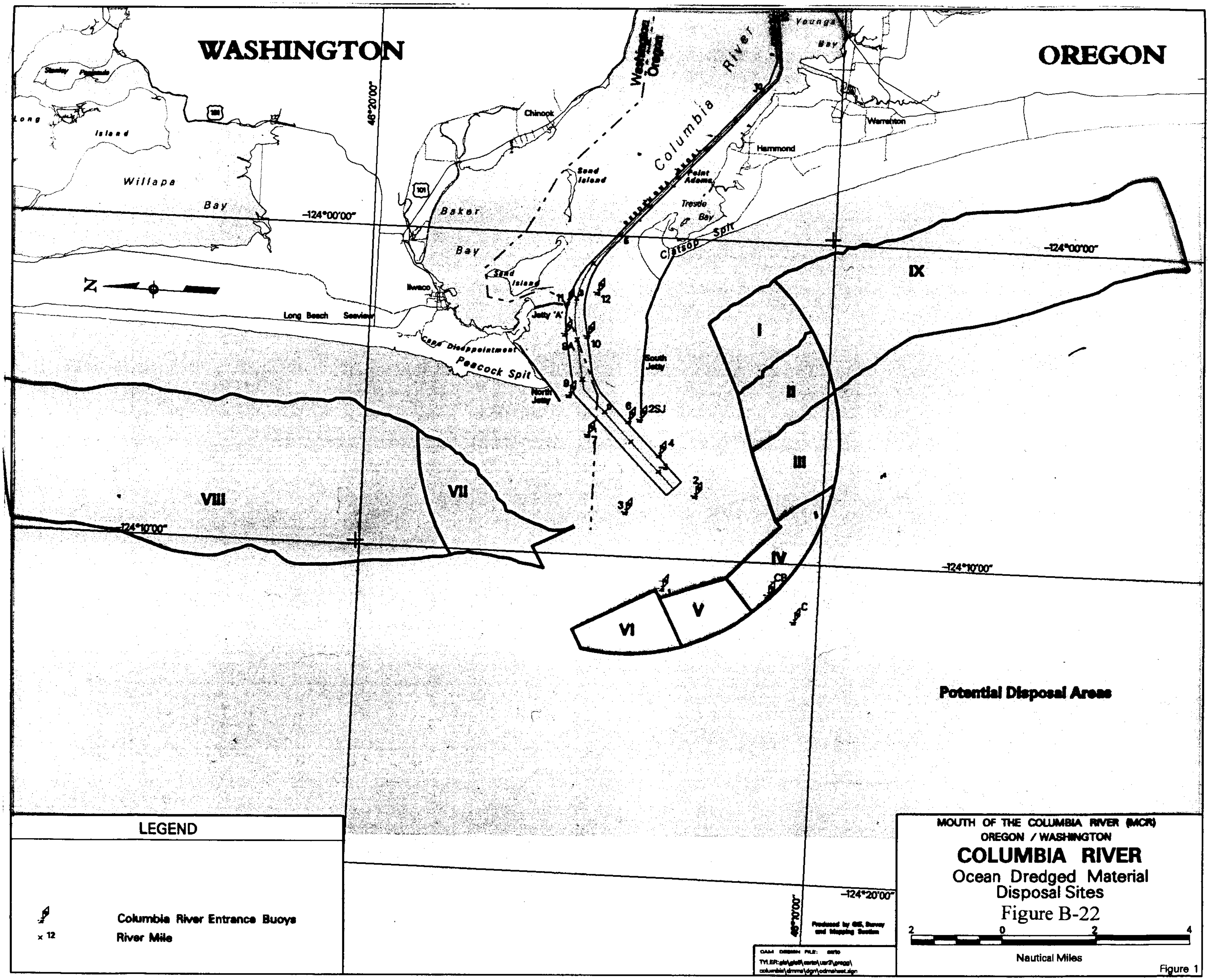


Figure B-21 RCPWAVE Estimates for Maximum Limiting Mound Height to Avoid Excessive Wave Shoaling.



WASHINGTON
OREGON
Willapa Bay
Long Island
Chinook
Baker Bay
Sand Island
Columbia River
Washington
Oregon
Youngs Bay
Warrenton
Hammond
Point Adams
Trestle Bay
Clatsop Spit
Ilwaco
Long Beach
Seaview
Jetty 'A'
Cape Disappointment
Peacock Spit
North Jetty
South Jetty
-124°00'00"
-124°10'00"
-124°20'00"
46°20'00"
46°10'00"
I
II
III
IV
V
VI
VII
VIII
IX
Potential Disposal Areas
LEGEND
Columbia River Entrance Buoys
River Mile
MOUTH OF THE COLUMBIA RIVER (MCR)
OREGON / WASHINGTON
COLUMBIA RIVER
Ocean Dredged Material
Disposal Sites
Figure B-22
Nautical Miles
Figure 1

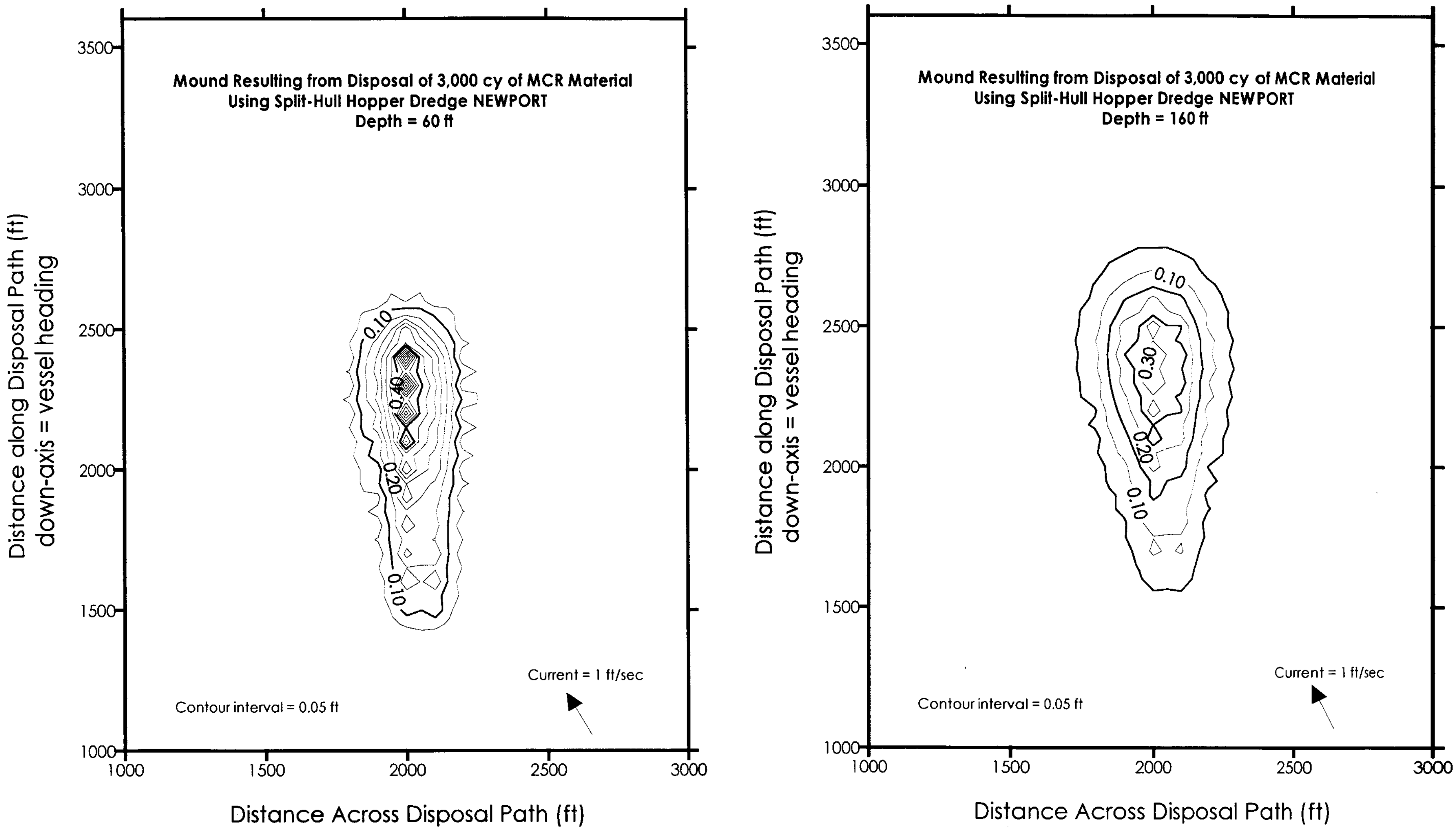
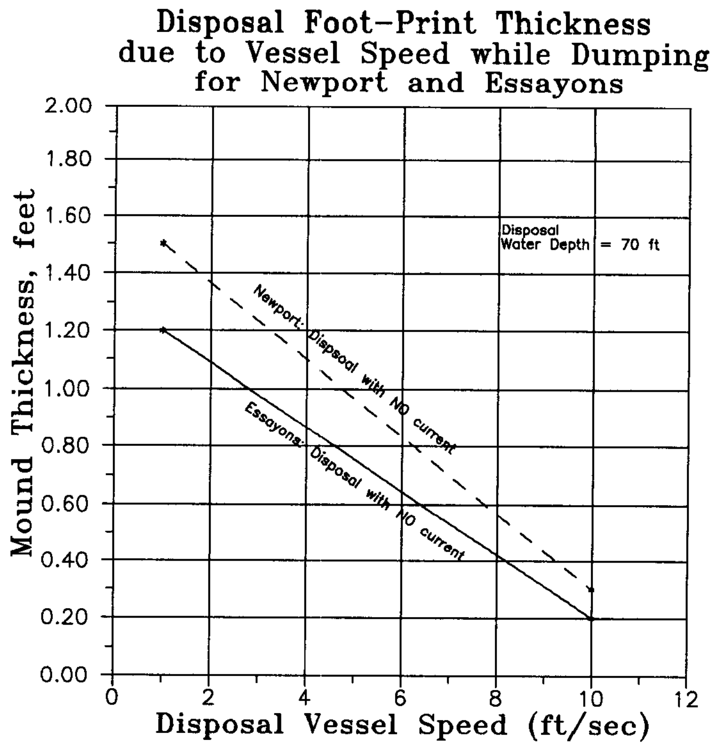


Figure B-23 Predicted Footprint for Mound Resulting from One Dump by the Dredge *Newport*. Left Caption Applies for Dredged Material Placement in 60-foot Water Depth. Right Caption is for Placement in 160-foot Depth.



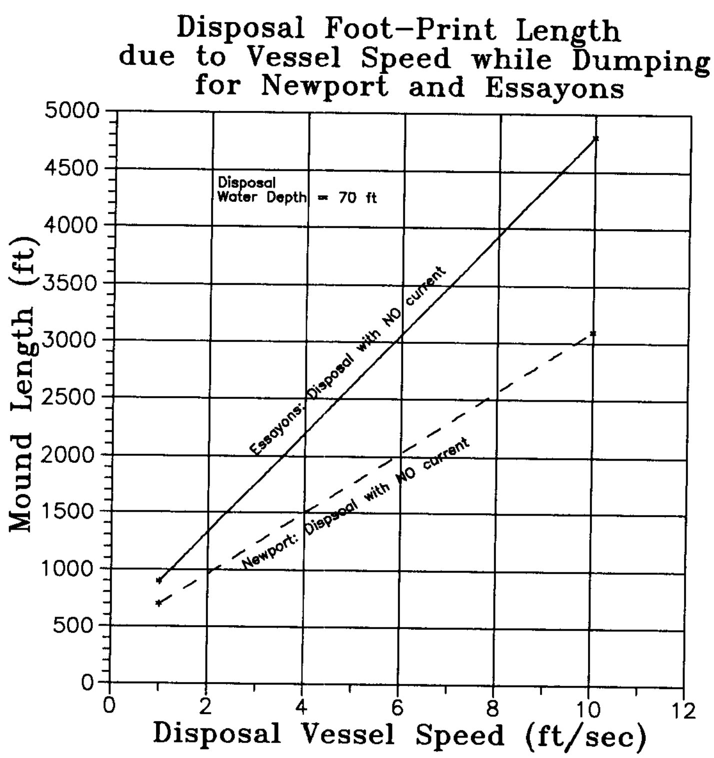
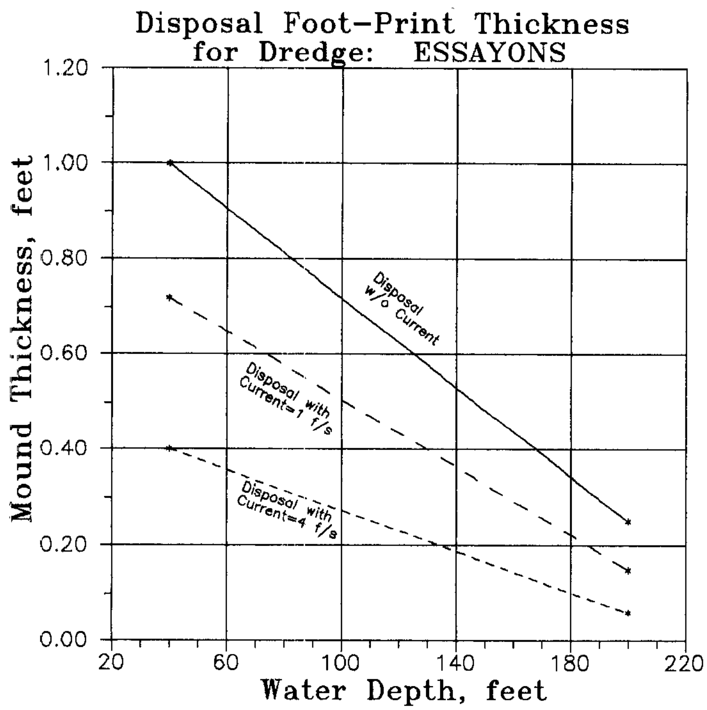


Figure B-24 Predicted Disposal Foot-print Geometry as a function of Disposal Vessel Speed. Top graphic is for *Mound Thickness* vs. Vessel Speed. Bottom graphic is for *Mound Length* vs. Vessel Speed.



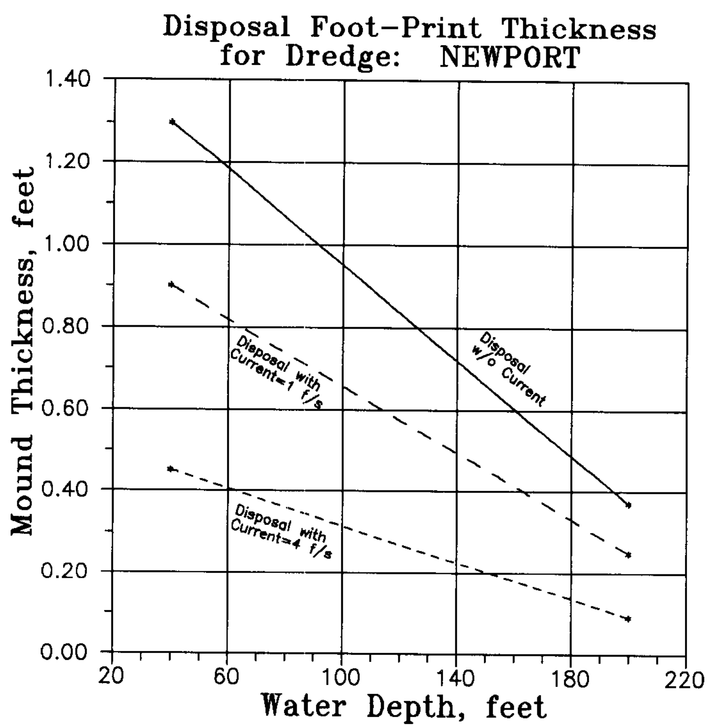
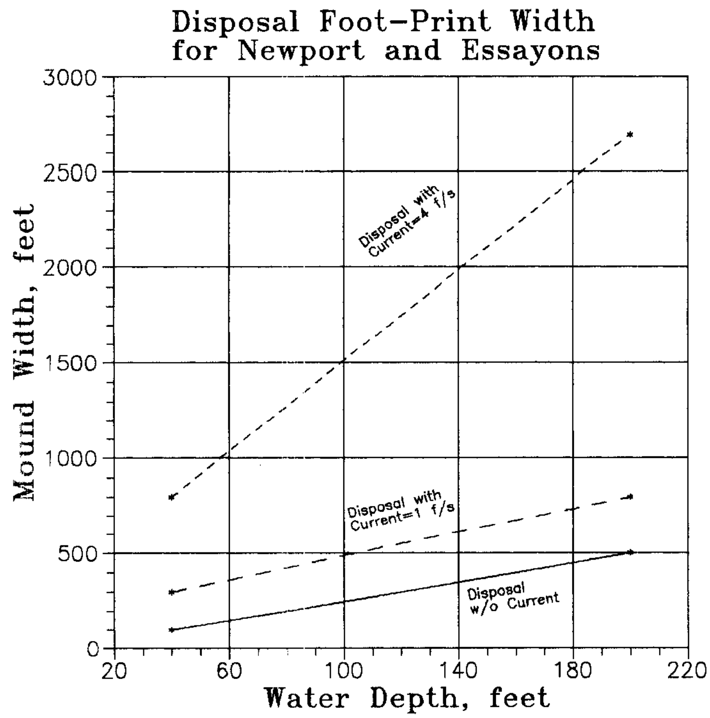


Figure B-25 Predicted Thickness for Disposal Footprint for Two Types of Hopper Dredges: Essayons (top) and Newport (bottom).



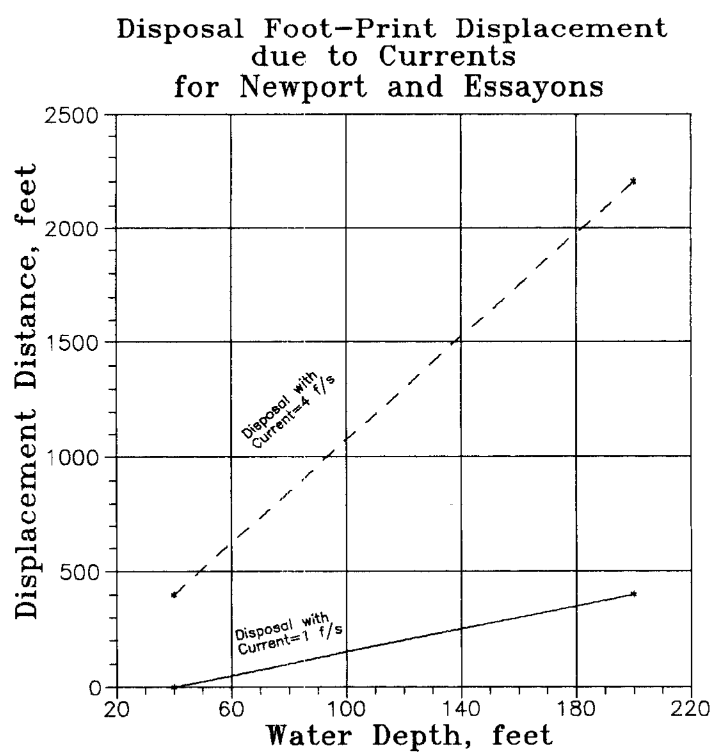


Figure B-26 Predicted Geometry for Disposal Footprint for Two Types of Hopper Dredges. Top caption describes dump foot-print width in terms of disposal water depth and current. Bottom caption describes displacement distance (offset) of dump foot-print due to current.

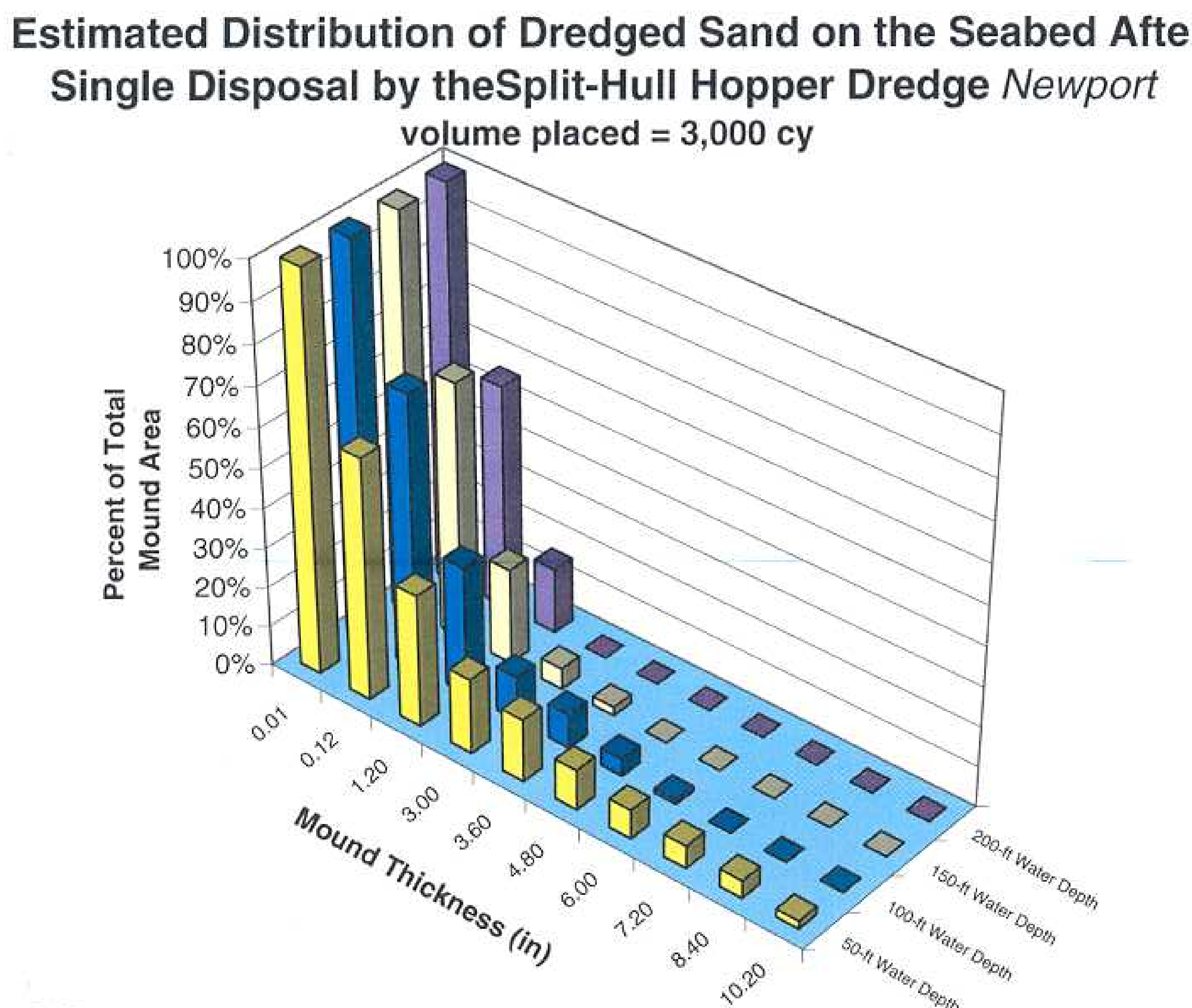

Estimated Distribution of Dredged Sand on the Seabed After Single Disposal by theSplit-Hull Hopper Dredge *Newport*
volume placed = 3,000 cy
Percent of Total Mound Area
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Mound Thickness (in)
0.01
0.12
1.20
3.00
3.60
4.80
6.00
7.20
8.40
10.20
200-ft Water Depth
150-ft Water Depth
100-ft Water Depth
50-ft Water Depth

Figure B-27

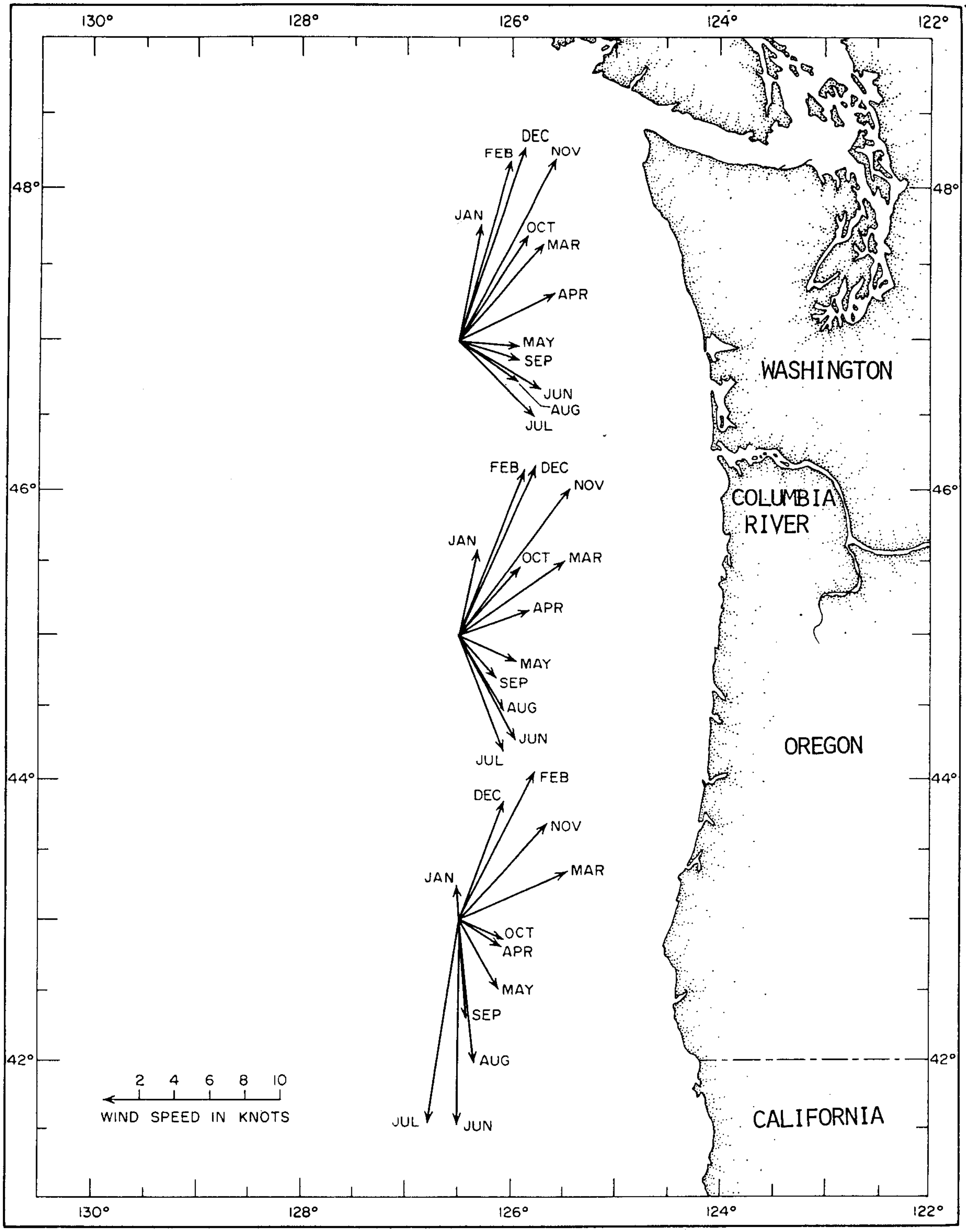
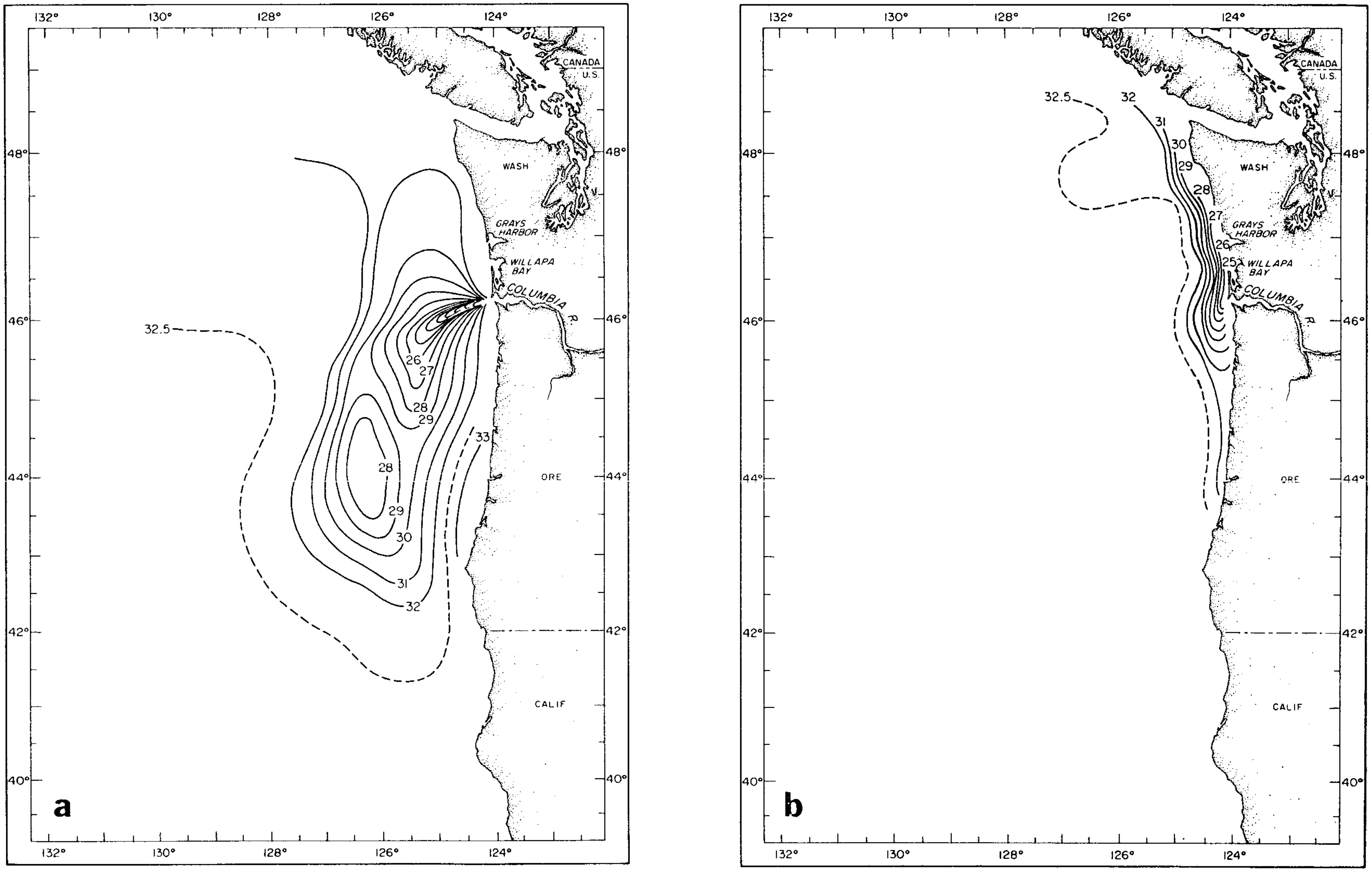


Figure B-28 Average speed and direction of monthly winds offshore Oregon for 1961-63 (Duxbury 1966).



FigureB-29 General salinity distribution (in ppt) offshore of MCR during summer (A) and winter (B) (Duxbury 1966).

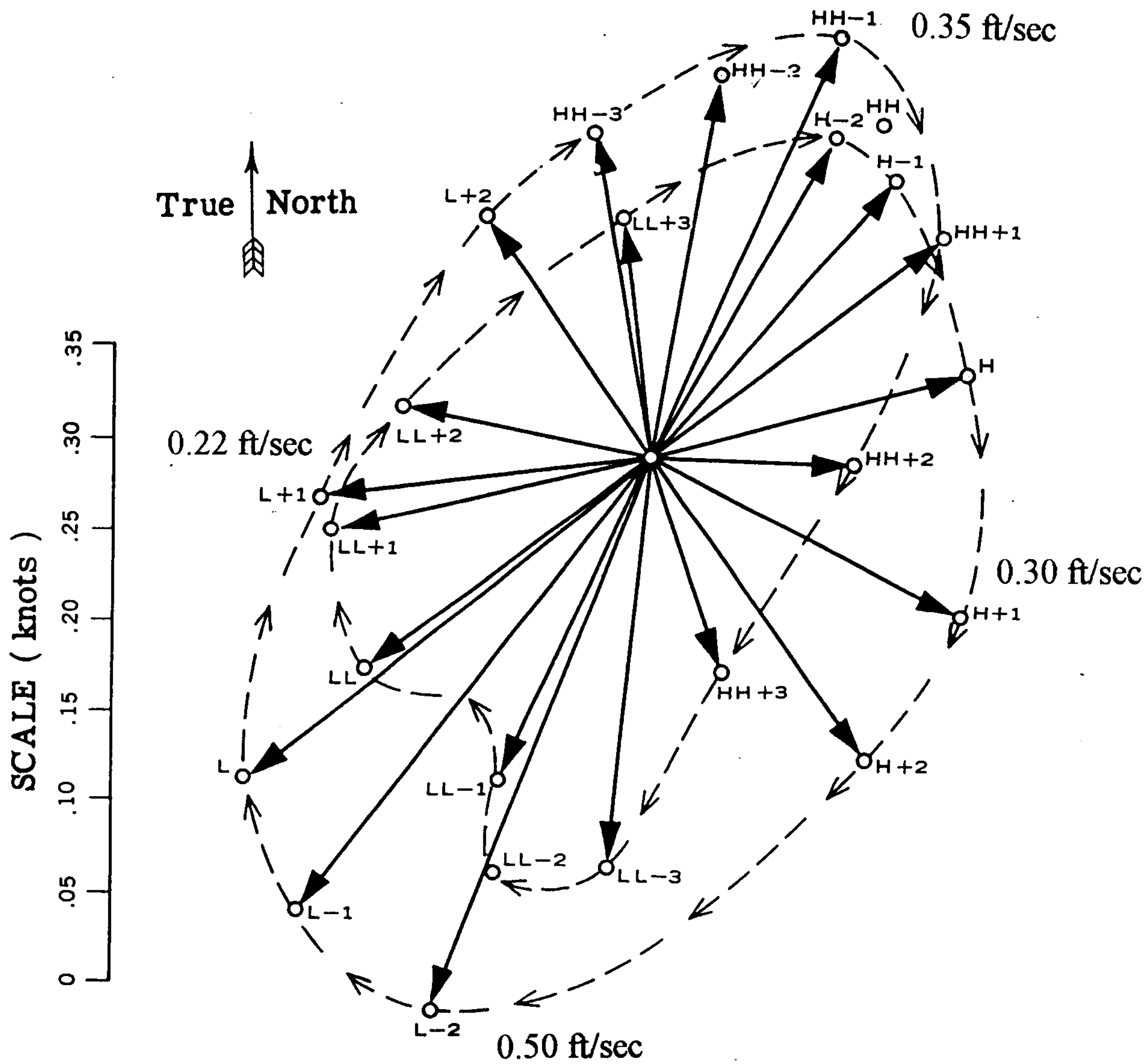


Figure B-30. Tidal current ellipse for the Mouth of the Columbia River.

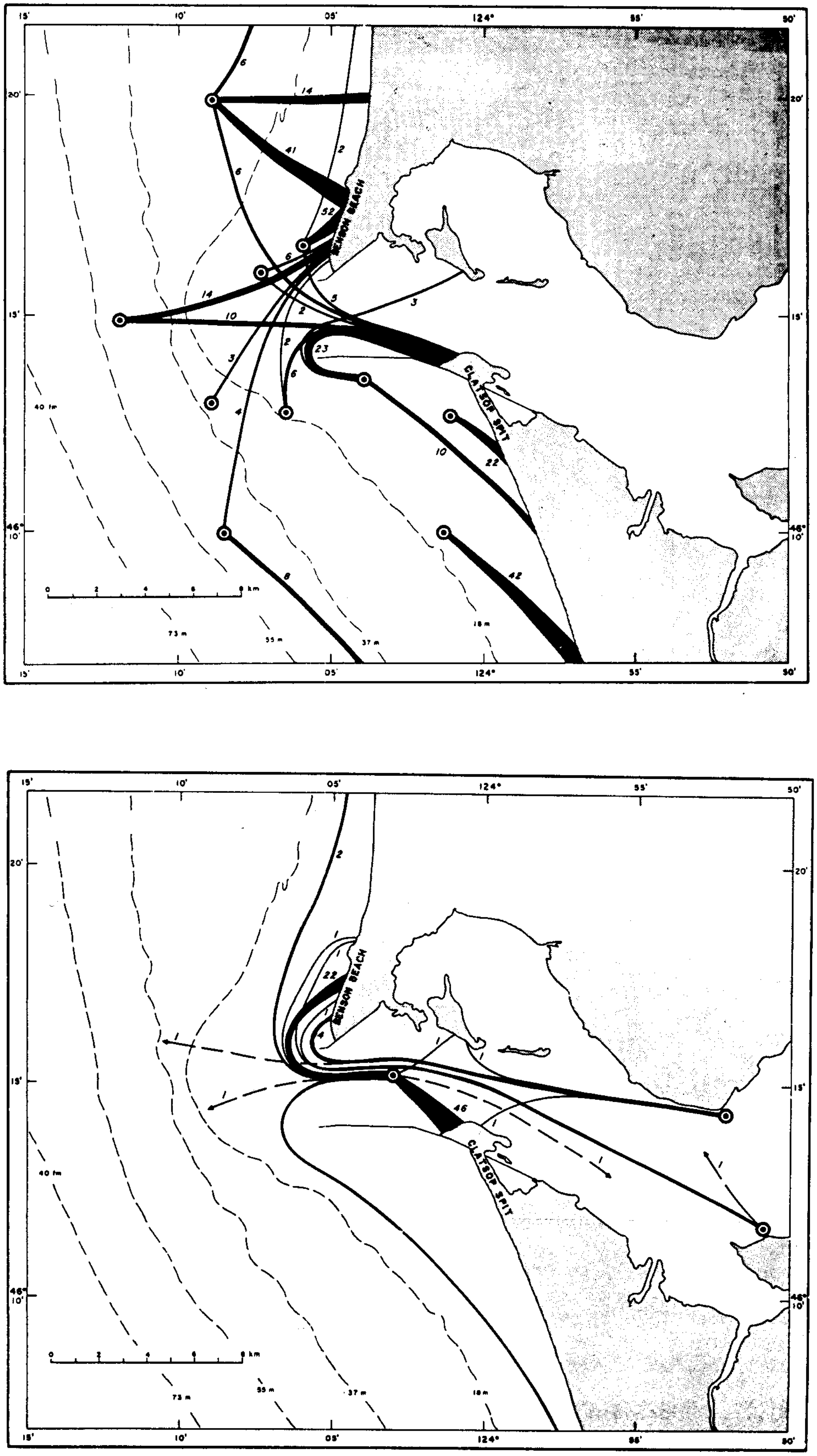
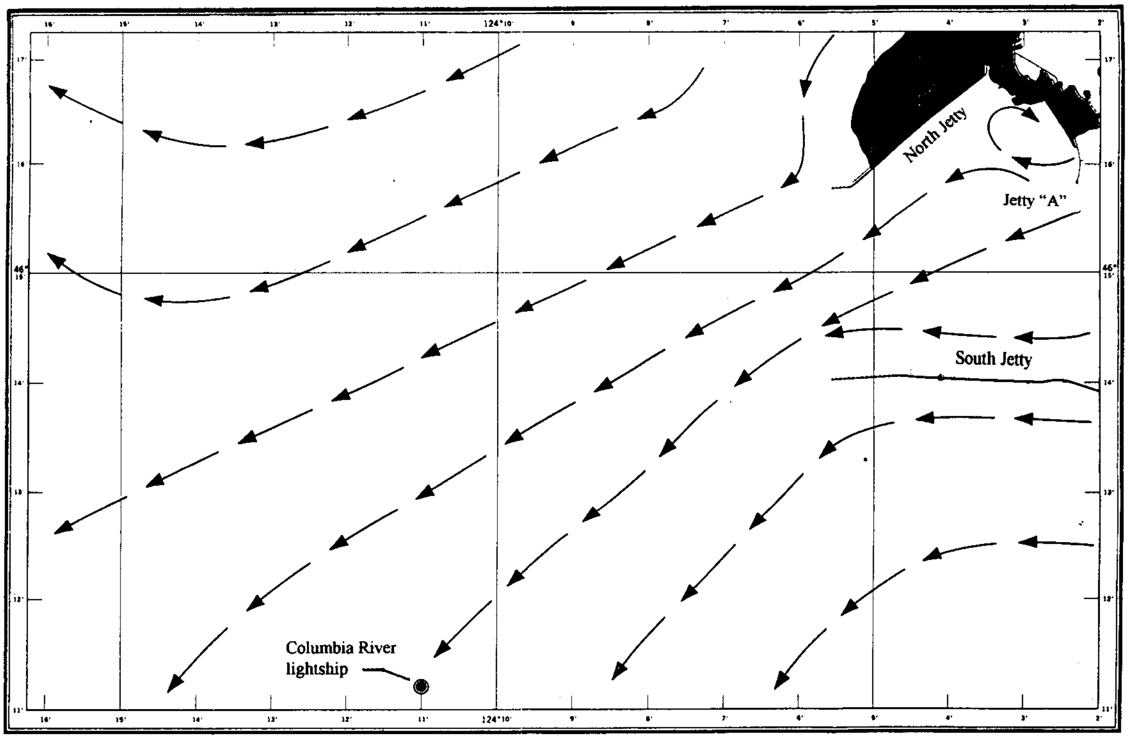
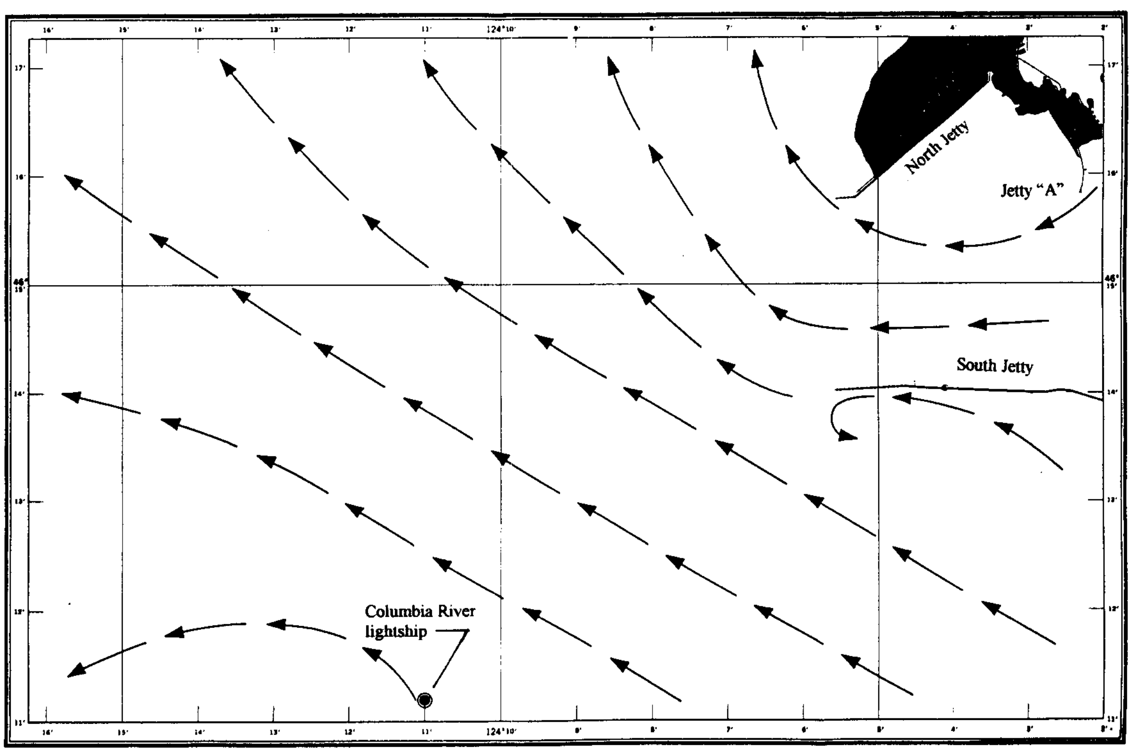


Figure B-31 Schematic paths of seabed drifters released <u>outside</u> of the MCR estuary (top) and paths of seabed drifters released <u>inside</u> the estuary (bottom) (Morse 1968).



Non-tidal currents due to river discharge and winds - spring/Summer (USNHO 1954).



Non-tidal currents due to river discharge and winds - fall/winter (USNHO 1954).

Figure B-32. Net direction for non-tidal coastal current near MCR during seasons of Fall/winter (bottom) and Summer/ Spring (top).

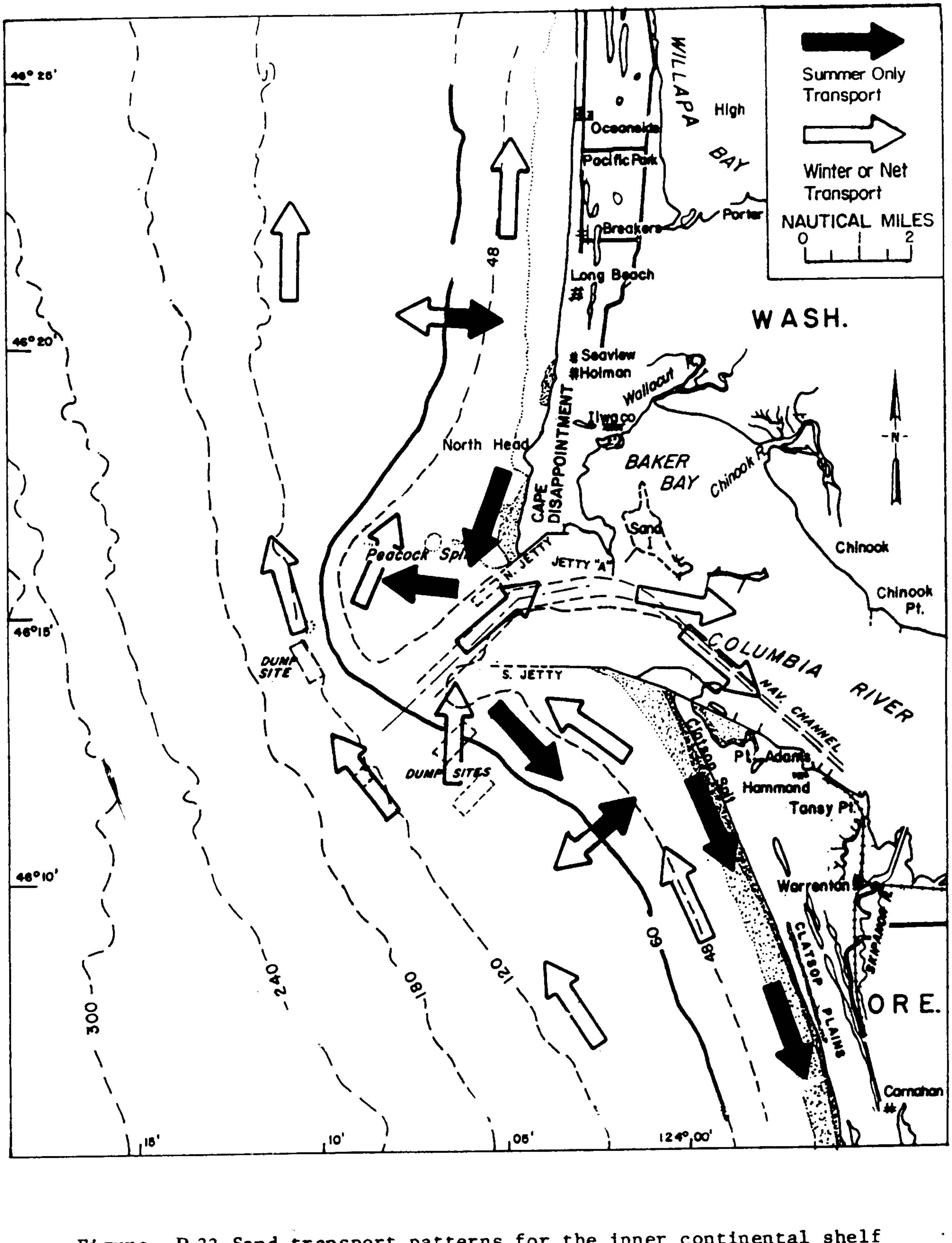
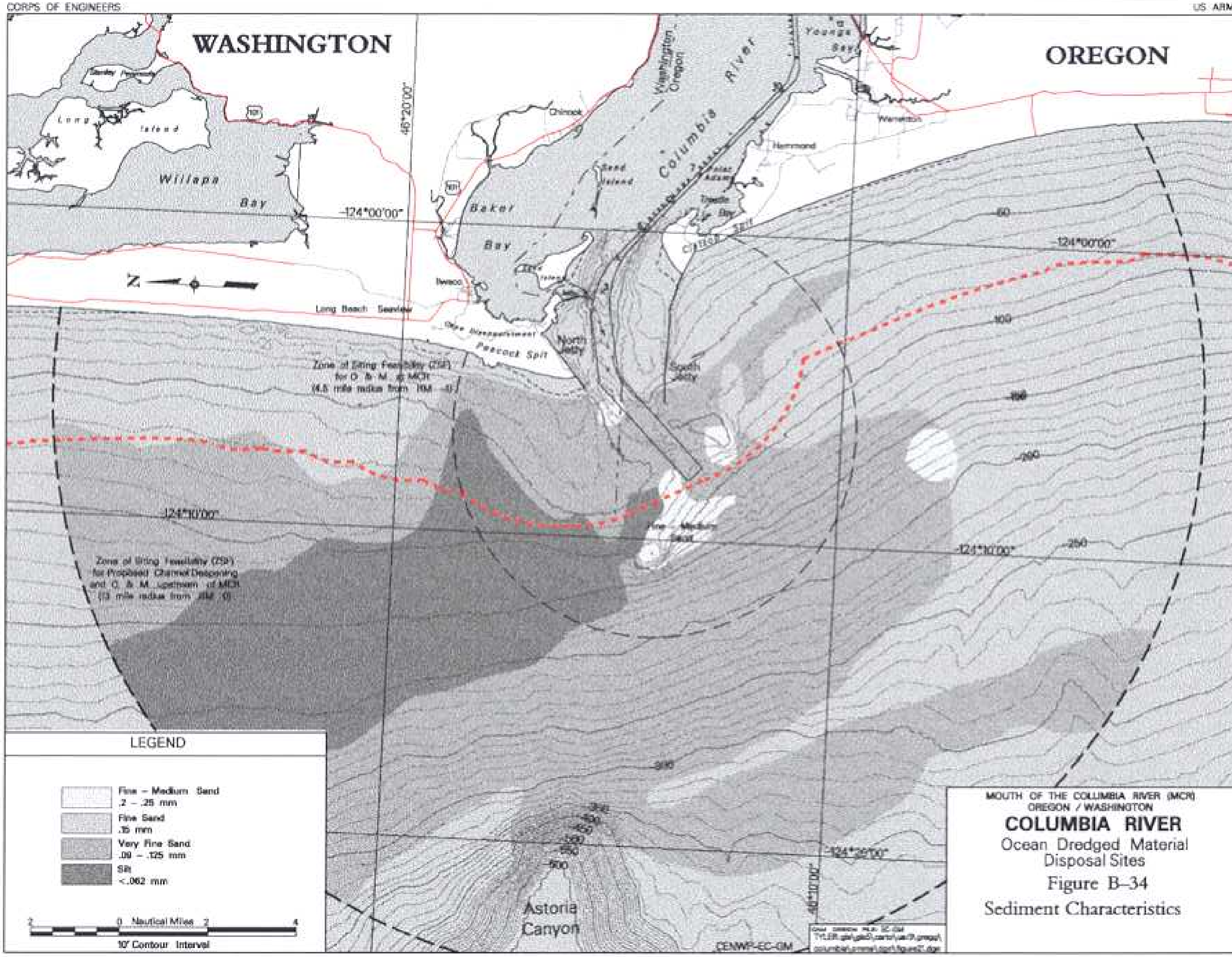
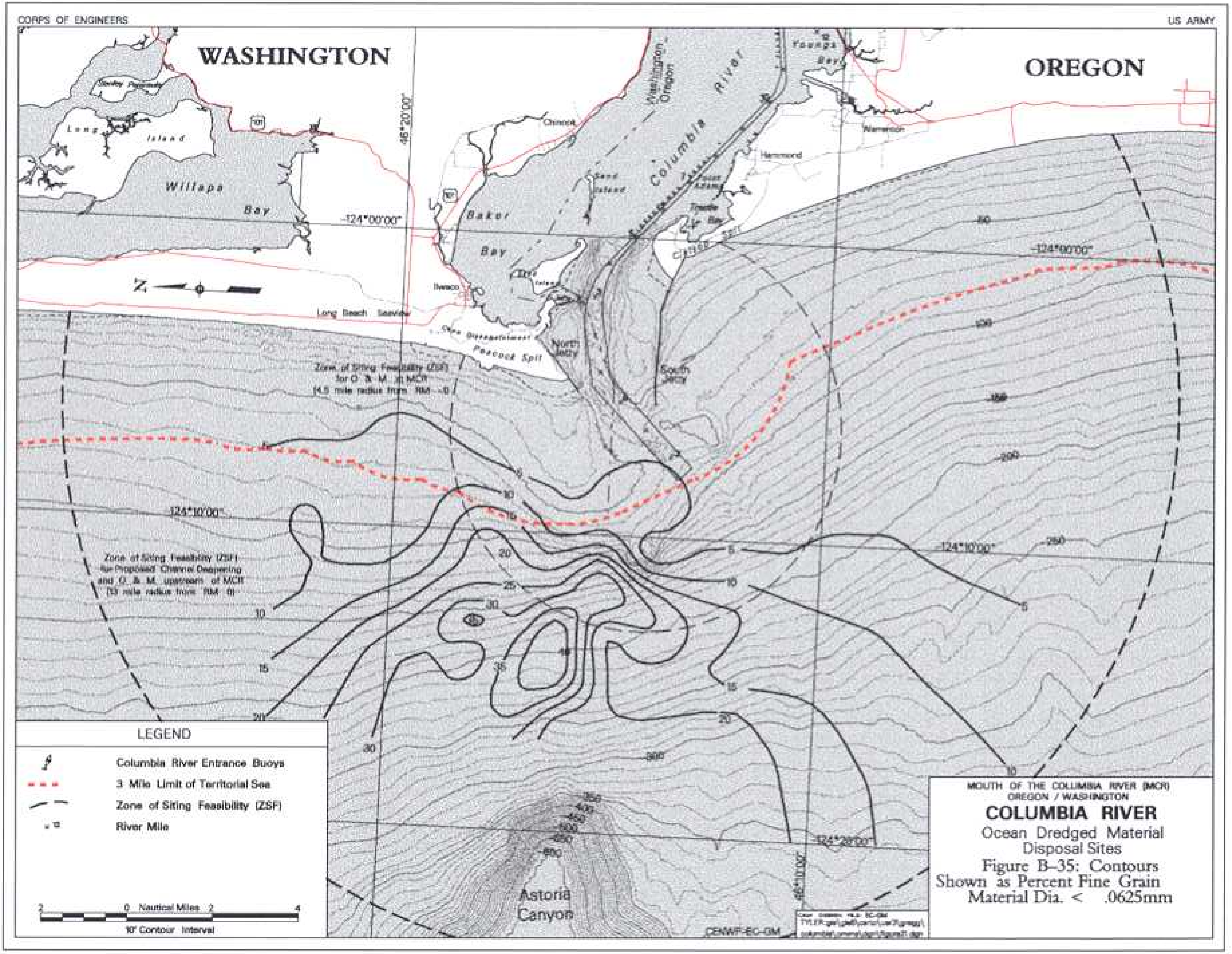


Figure B-33 Sand transport patterns for the inner continental shelf



MOUTH OF THE COLUMBIA RIVER (MCR)
OREGON / WASHINGTON
COLUMBIA RIVER
Ocean Dredged Material Disposal Sites

Figure B–34
Sediment Characteristics

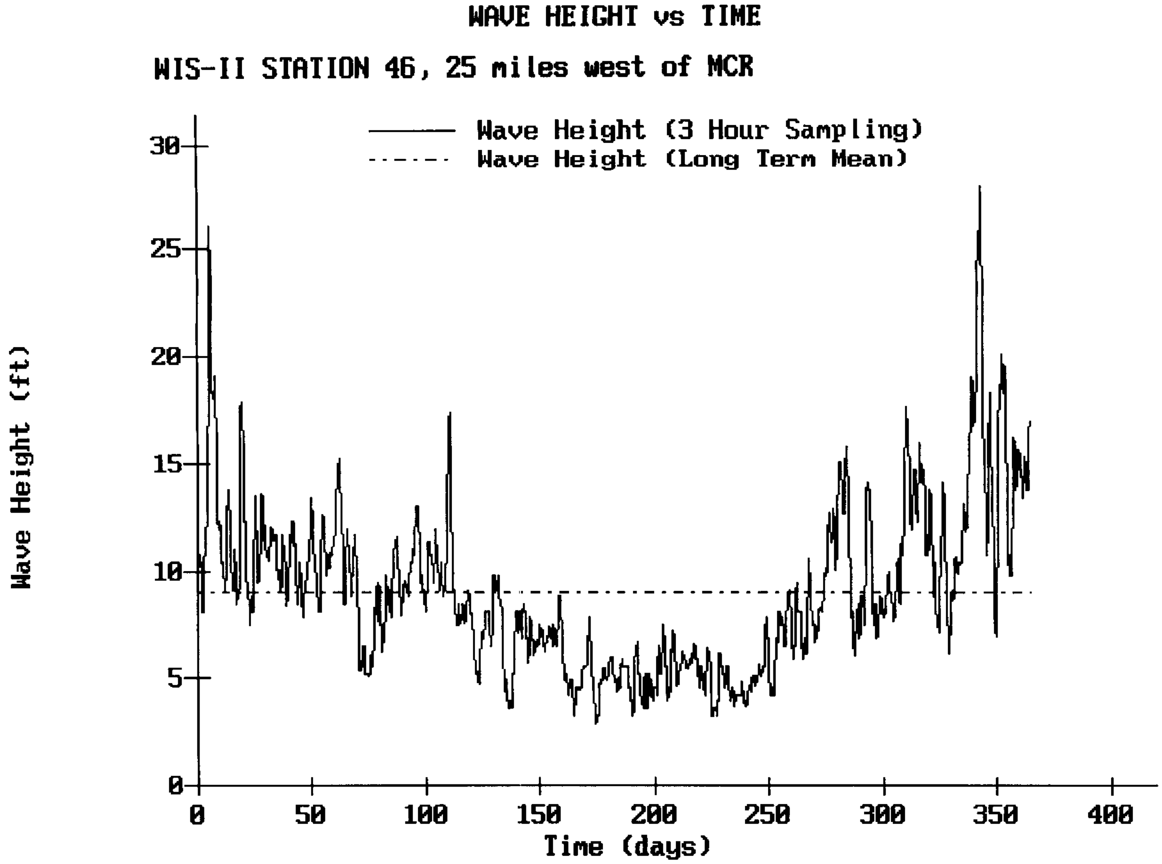


MOUTH OF THE COLUMBIA RIVER (MCR)
OREGON / WASHINGTON

COLUMBIA RIVER

Ocean Dredged Material Disposal Sites

Figure B–35: Contours Shown as Percent Fine Grain Material Dia. < .0625mm



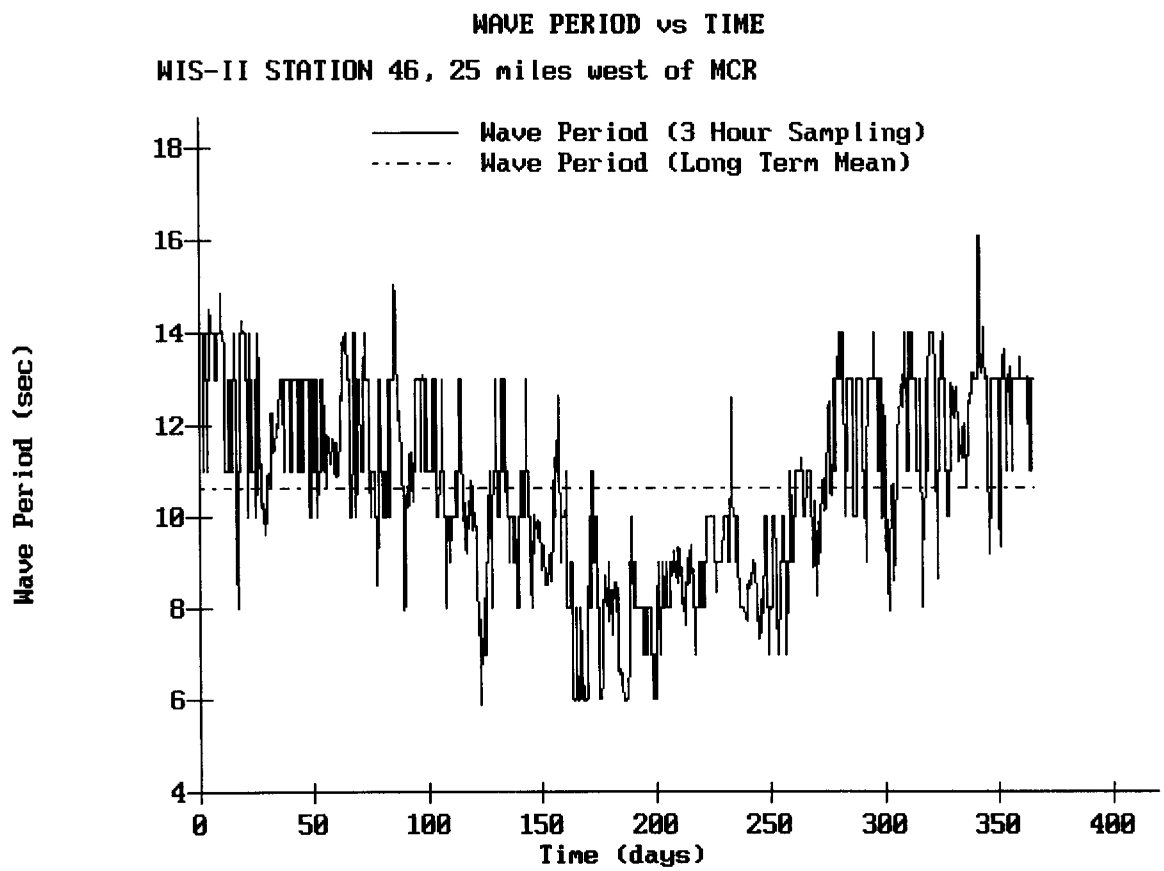
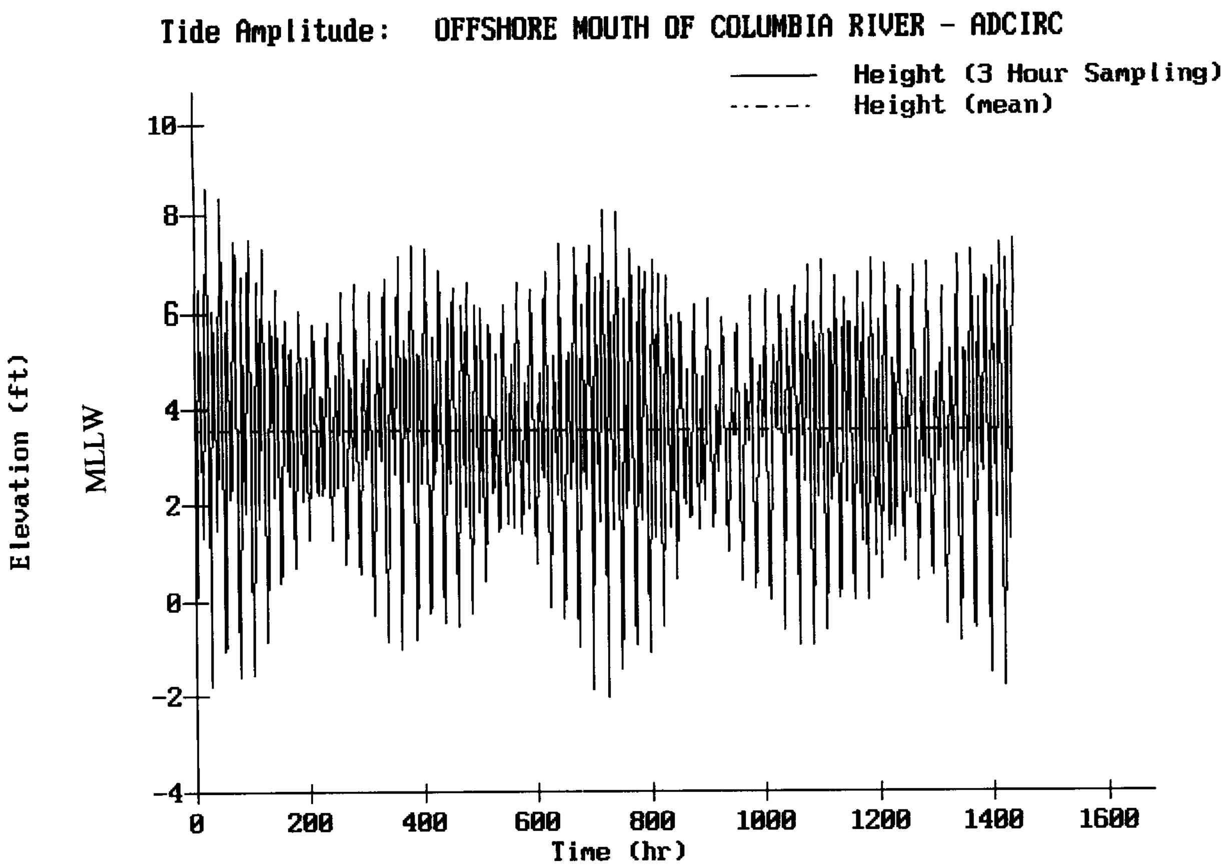


Figure B36. Simulated wave environment offshore MCR (WIS-II).



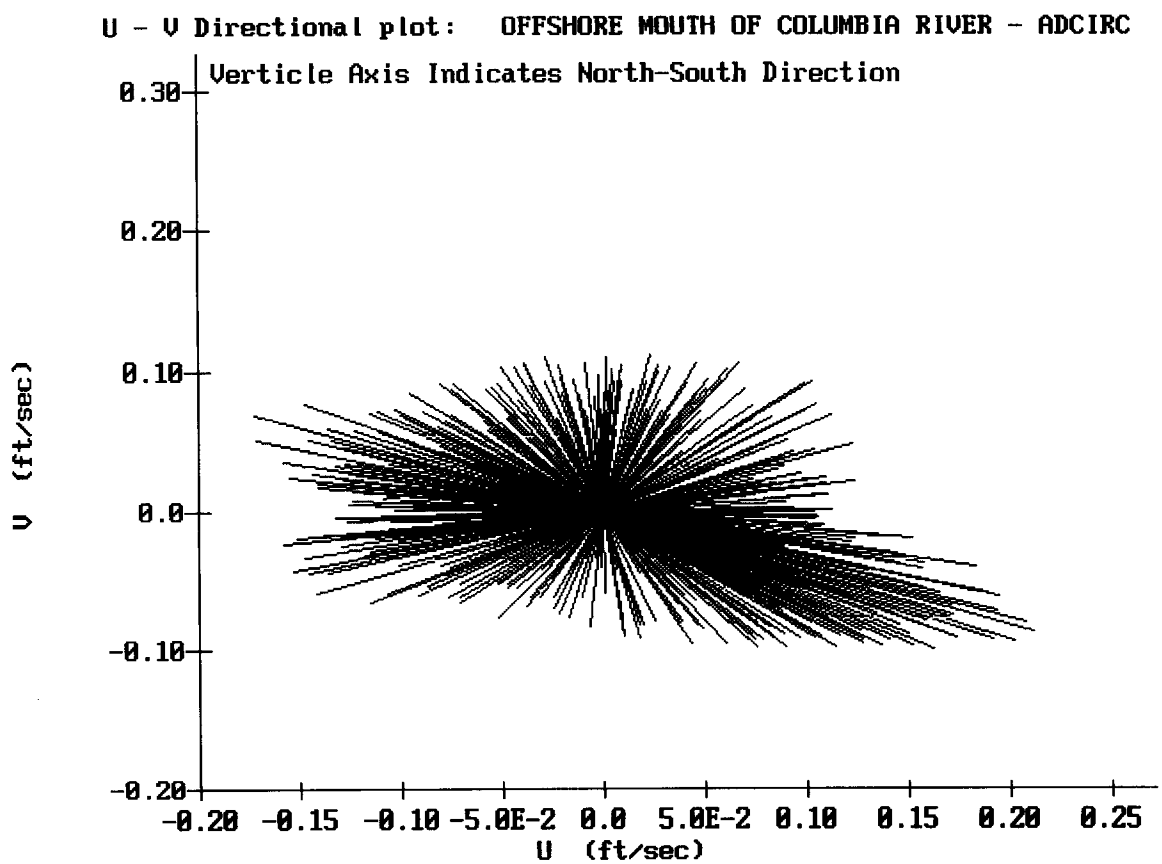


Figure B-37. Simulated open-coast tidal processes offshore MCR (ADCIRC).

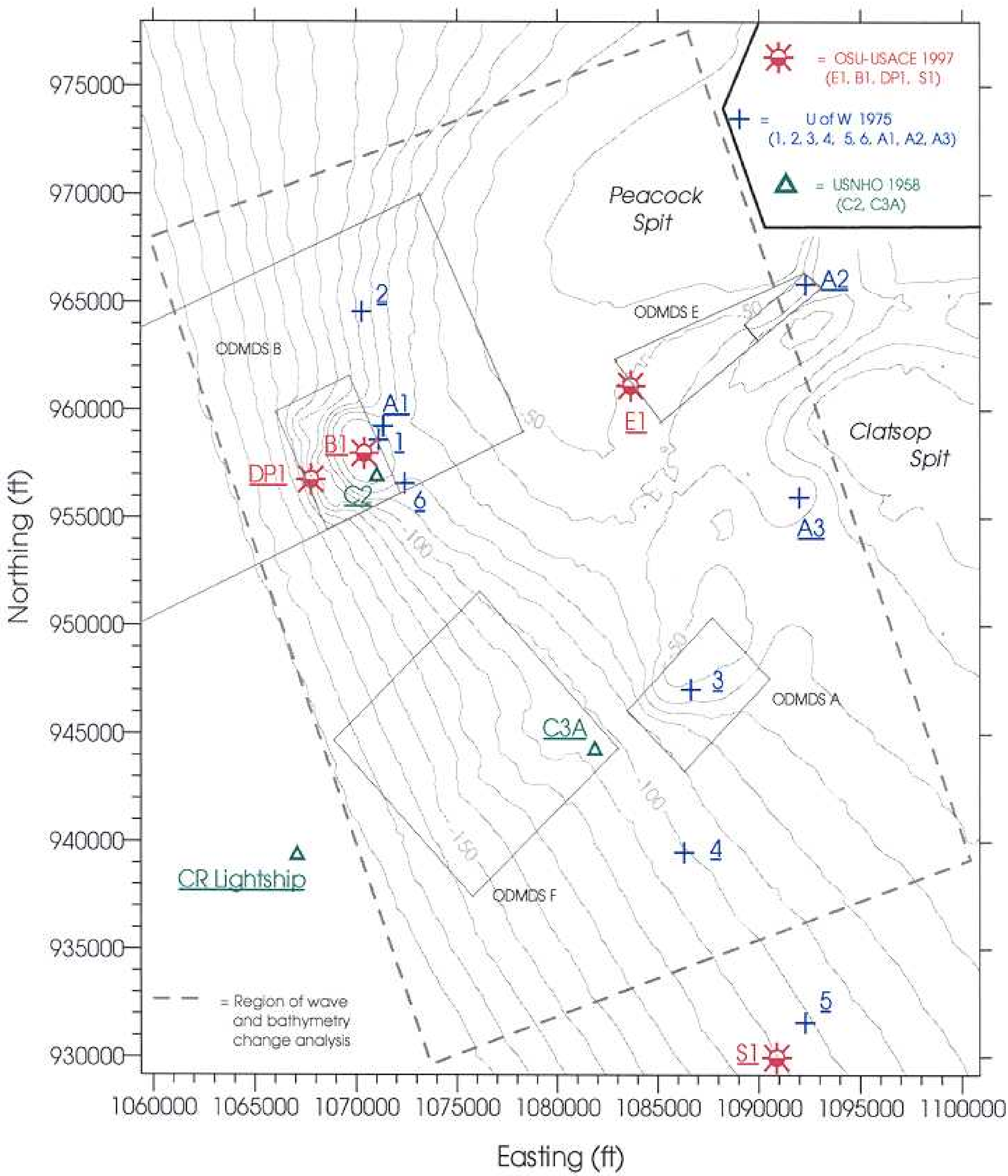


Figure B-38 MCR Current Measurement Locations

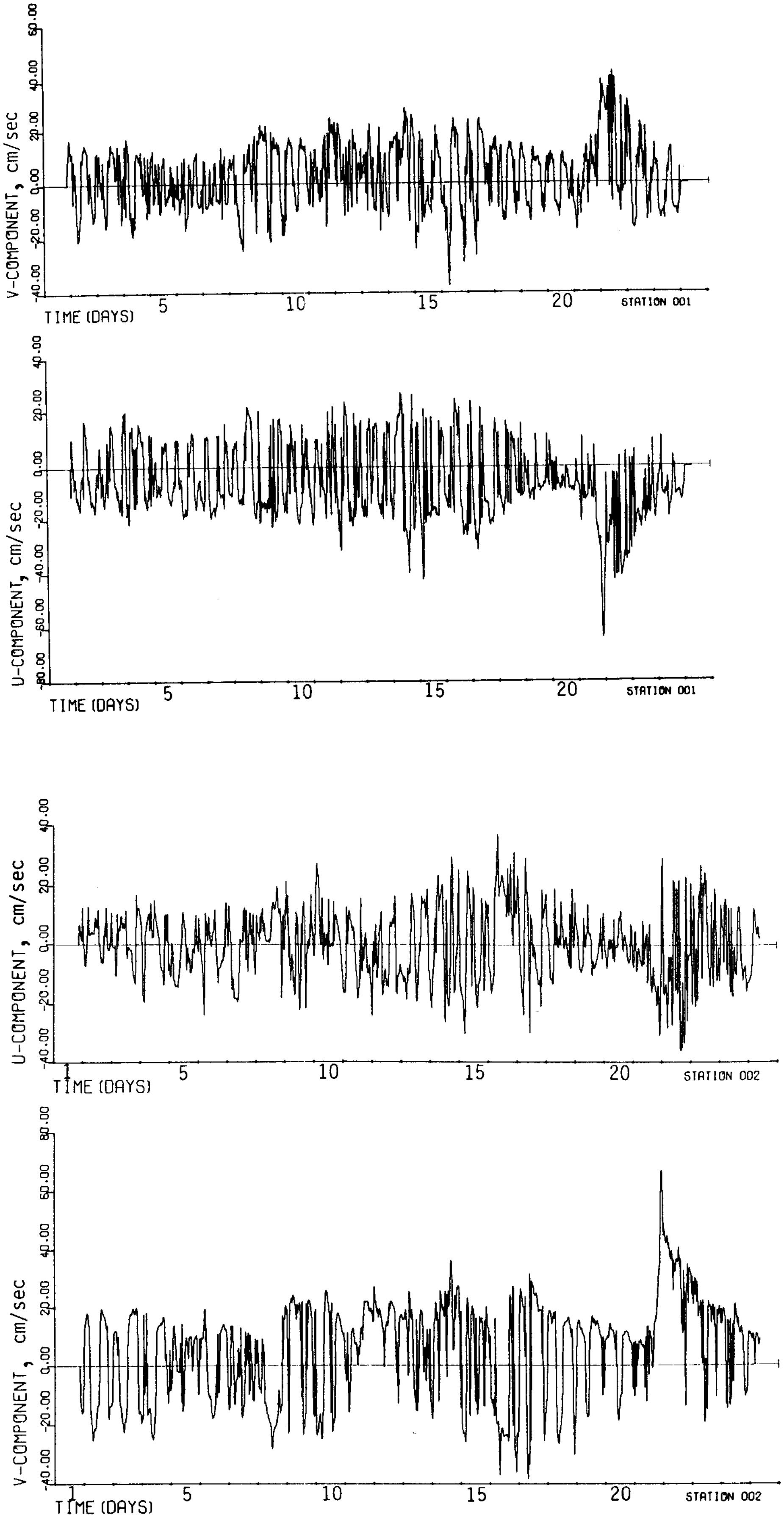


Figure B-39 Time-series data for U of W current stations 1 and 2

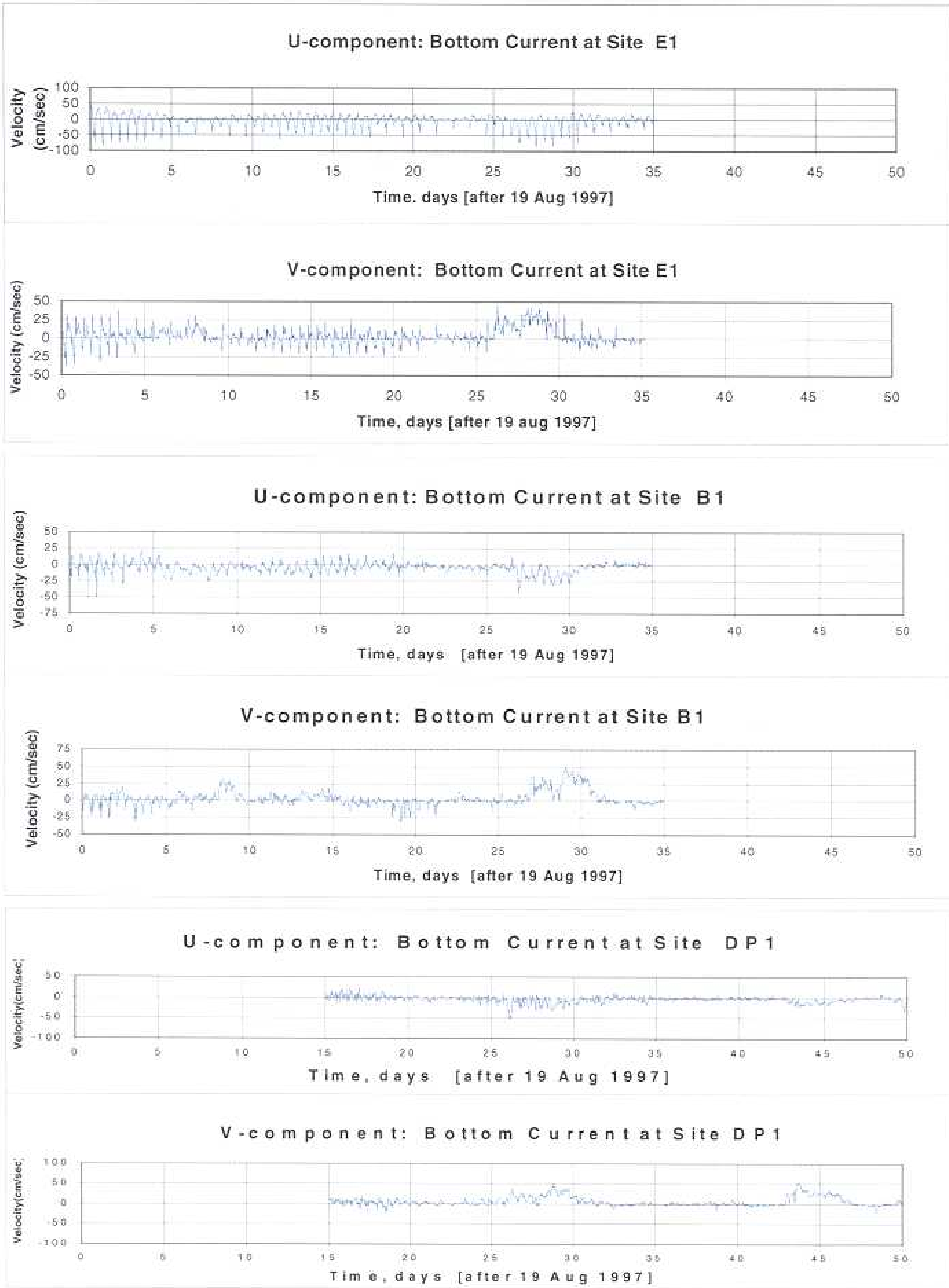


Figure B-40 Bottom currents observed at MCR during August – October 1997. Top two graphs apply to Site E1 (2 miles SE of north jetty), middle two graphs apply to Site B1 (on top of ODMDS B mound-4 miles SE of north jetty) , and bottom two graphs apply to Site DP1 (seaward base of ODMDS B mound-4.5 miles SE of north jetty).

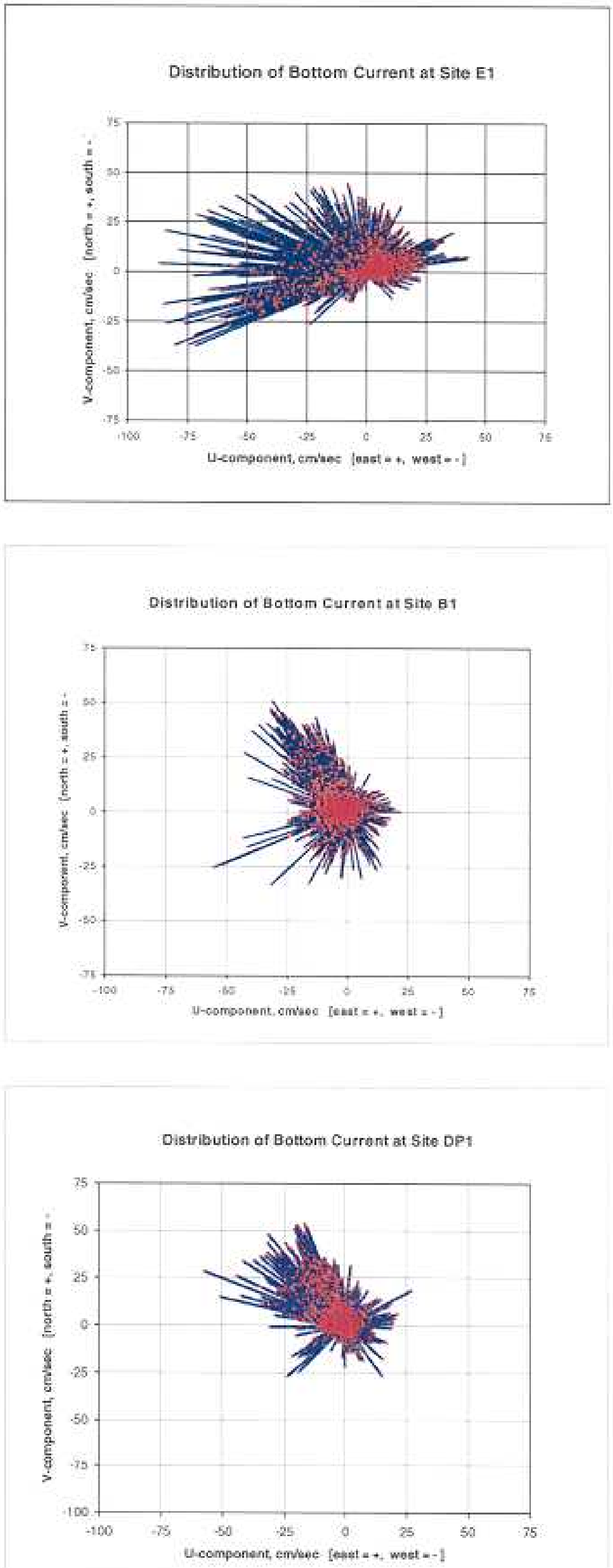


Figure B-41 Principal component distribution of bottom current measured at Site e1 (top), Site B1 (middle), and Site DP1 (bottom) during Aug-Oct 1997. Data provided by USACE-WES and OSU.

VESSEL	AREA	DATE	TIME
YF-854	Columbia River	8 Feb. 1958	0500 GMT

LOCATION NO	LATITUDE	LONGITUDE	DEPTH (ft)	WATER COLOR (Forel Scale)	TIDAL CURRENT STATE
26	46°14.0'N	124°10.3'W	125	—	— before — after —

								SECCHI (M)
89	111	A-1	C-2	—	—	—	—	D — (m) W — (m)

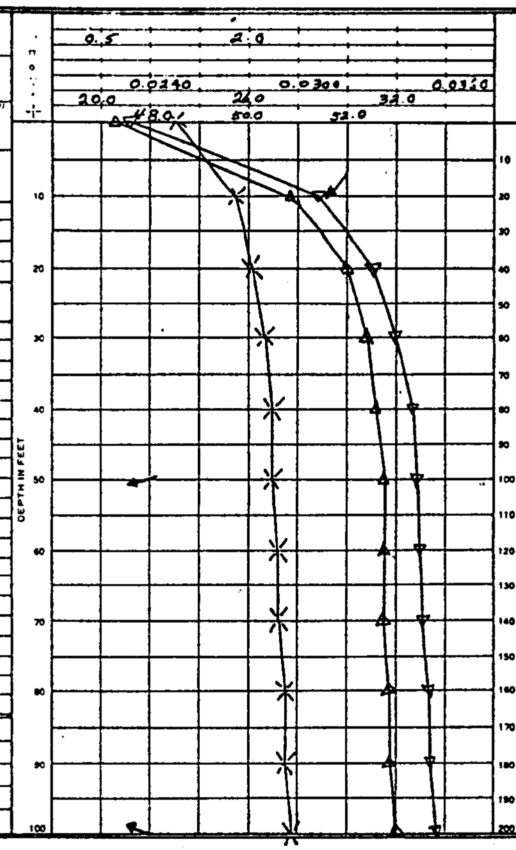
SEA SURF TEMP (°F)	WIND (ft) 42	AIR TEMP (°F)			CLOUDS	VISIBILITY
48.5	DIR 18 SPEED 09	WET 50.0 DRY 52.0	15	—	COVER — TYPE —	—

WAVES	SEA	SWELL	MARINE LIFE	TYPE	AMOUNT
DIRECTION (°T)	—	—	PLANT		
HEIGHT IN FEET	—	—	FISH		
PERIOD IN SEC	—	—	MAMMALS		

DEPTH (ft)	┼ TEMP (°F)	▽ E.C. (mhos)	Δ SAL (°/oo)	CLARITY K	CLARITY α	CURRENT SPEED (KTS)	CURRENT DIR (°T)
0	48.5	—	20.8				
0	48.5	.0229	20.5				
10	49.8	.0307	27.7			2.8	212
20	50.1	.0331	30.0				
30	50.3	.0340	30.8				
40	50.5	.0346	31.2				
50	50.5	.0348	31.4			0.9	264
60	50.6	.0349	31.5				
70	50.6	.0349	31.5				
80	50.7	.0352	31.8				
90	50.7	.0352	31.8				
100	50.8	.0355	32.0			0.9	282

REMARKS

Current Obs. at 0515 (GMT)



VESSEL	AREA	DATE	TIME
YF-854	Columbia River	8 Feb. 1958	1600 GMT

LOCATION NO	LATITUDE	LONGITUDE	DEPTH (ft)	WATER COLOR (Forel Scale)	TIDAL CURRENT STATE
26	46°14.0'N	124°10.3'W	125	—	— MINS before — after —

			CUR STA NO	PLANKTON NO	BOT SAMP NO		SURF (Light Level)	SECCHI (M)
100	122	A-1	C-2	—	—	—	—	D — (m) W — (m)

SEA SURF TEMP (°F)	WIND (ft) 42	AIR TEMP (°F)	BAROMETER	WEATHER	CLOUDS	VISIBILITY
50.8	DIR 18 SPEED 21	WET 48.2 DRY 49.2	12	14	COVER 9 TYPE 8	5

WAVES	SEA	SWELL	MARINE LIFE	TYPE	AMOUNT
DIRECTION (°T)	—	22	PLANT		
HEIGHT IN FEET	5	3	FISH		
PERIOD IN SEC			MAMMALS		

DEPTH (ft)	┼ TEMP (°F)	▽ E.C. (mhos)	Δ SAL (°/oo)	CLARITY K	CLARITY α	CURRENT SPEED (KTS)	CURRENT DIR (°T)	
0	50.8	—	*30.09					*Titration
0	508	—	30.4					
0	50.8	.0334	30.0					
10	50.9	.0340	30.4			0.6	293	
20	50.9	.0340	30.4					
30	50.9	.0340	30.4					
40	51.0	.0343	30.7					
50	51.0	.0343	30.7			0.8	246	
60	51.0	.0343	30.7					
70	51.0	.0346	31.0					
80	51.1	.0349	31.2					
90	51.1	.0349	31.2					
100	51.1	.0349	31.2			1.0	295	

REMARKS

Current obs. at 1616 GMT

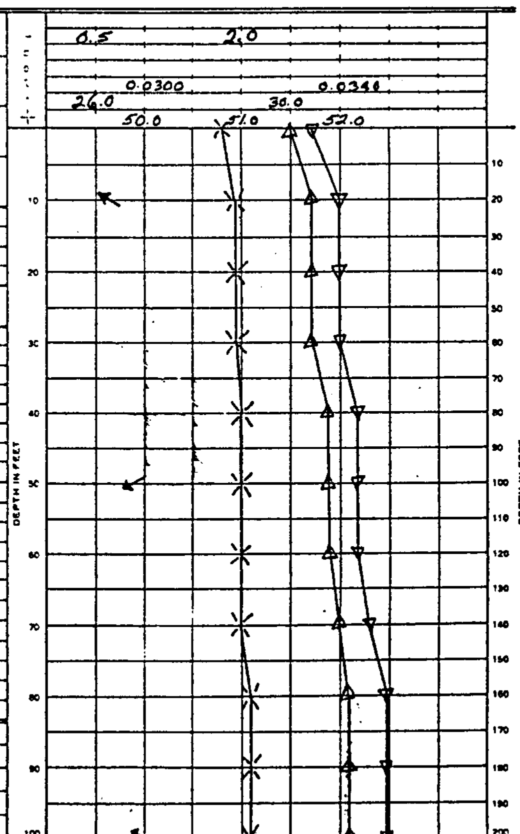
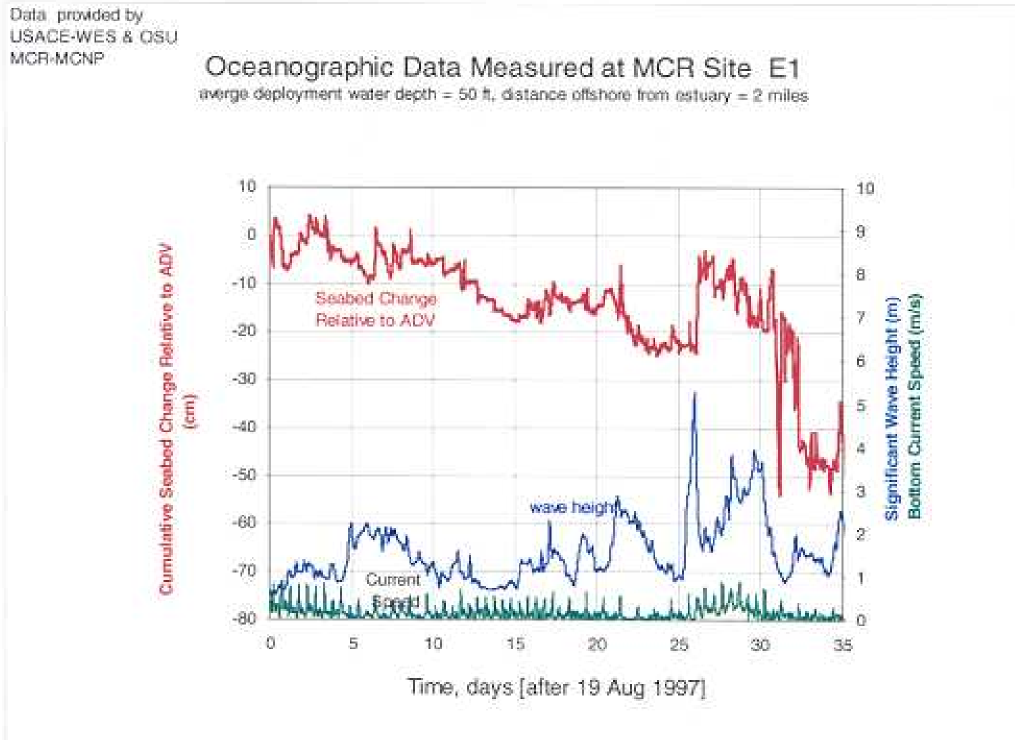


Figure B-42 Vertical profile measurements made by USNHO at station C-2



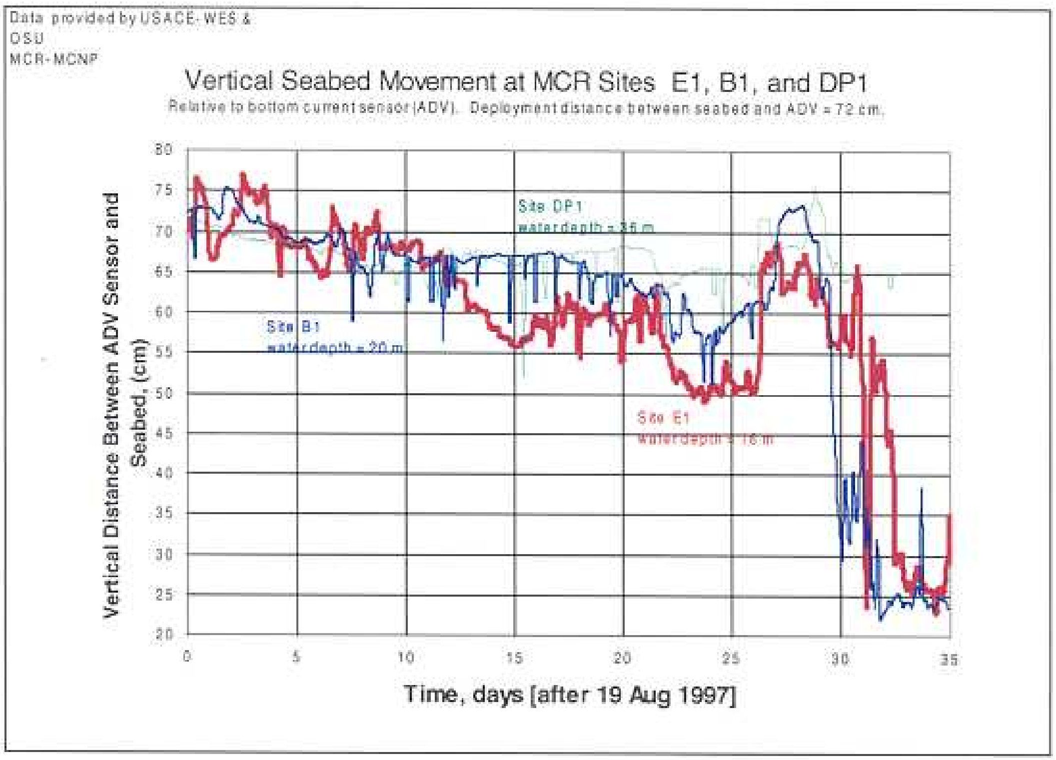


Figure B-43 Observed seabed fluctuation at locations offshore MCR during Aug-Oct 1997. Top graph shows seabed change and concurrent wave and bottom current process observed at monitoring Site E1 (see figure B38 for site location map). Bottom graph shows concurrent seabed change at Sites E1, B1, and DP1.

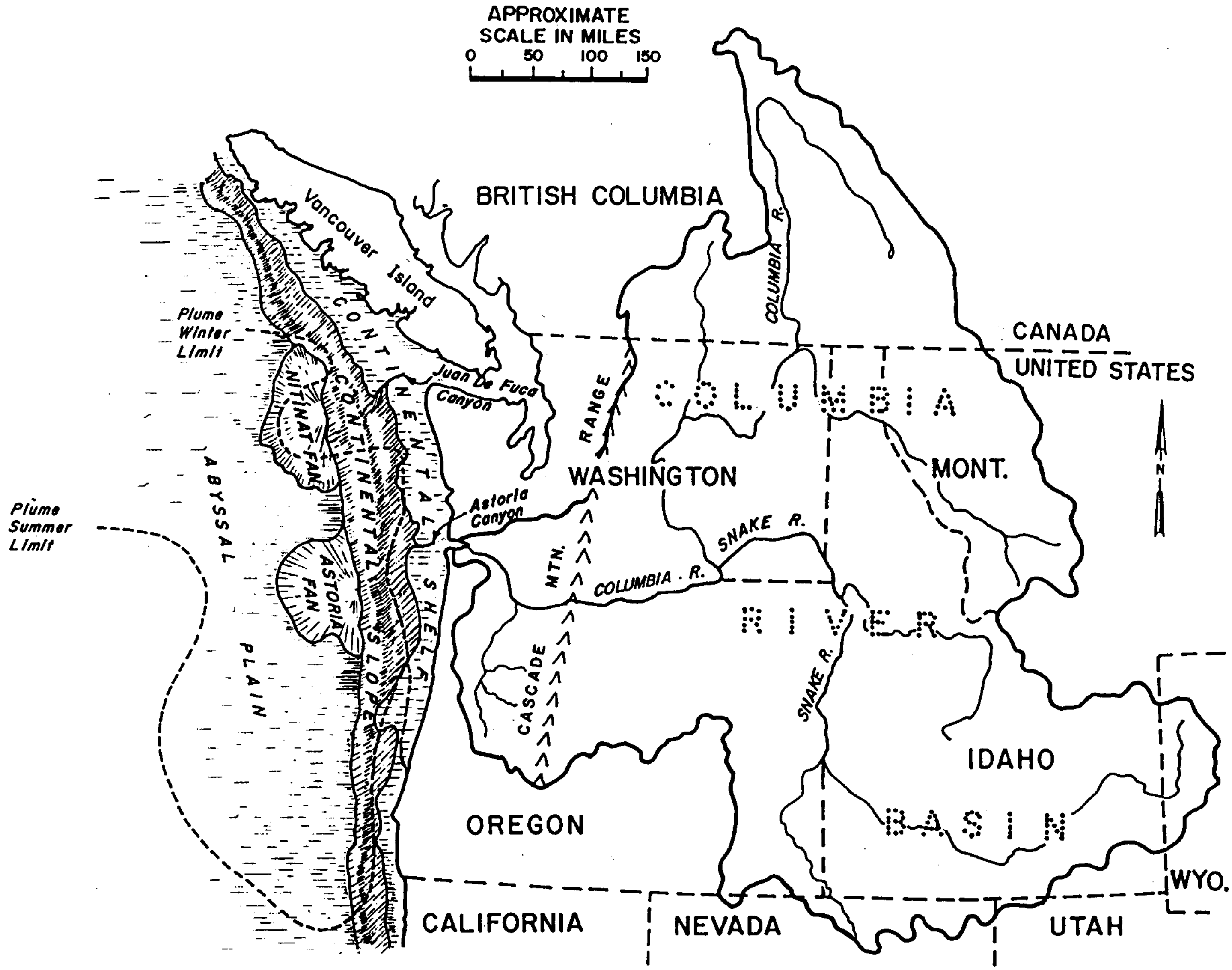


Figure B-44 Columbia River drainage basin and adjacent Pacific Ocean floor.

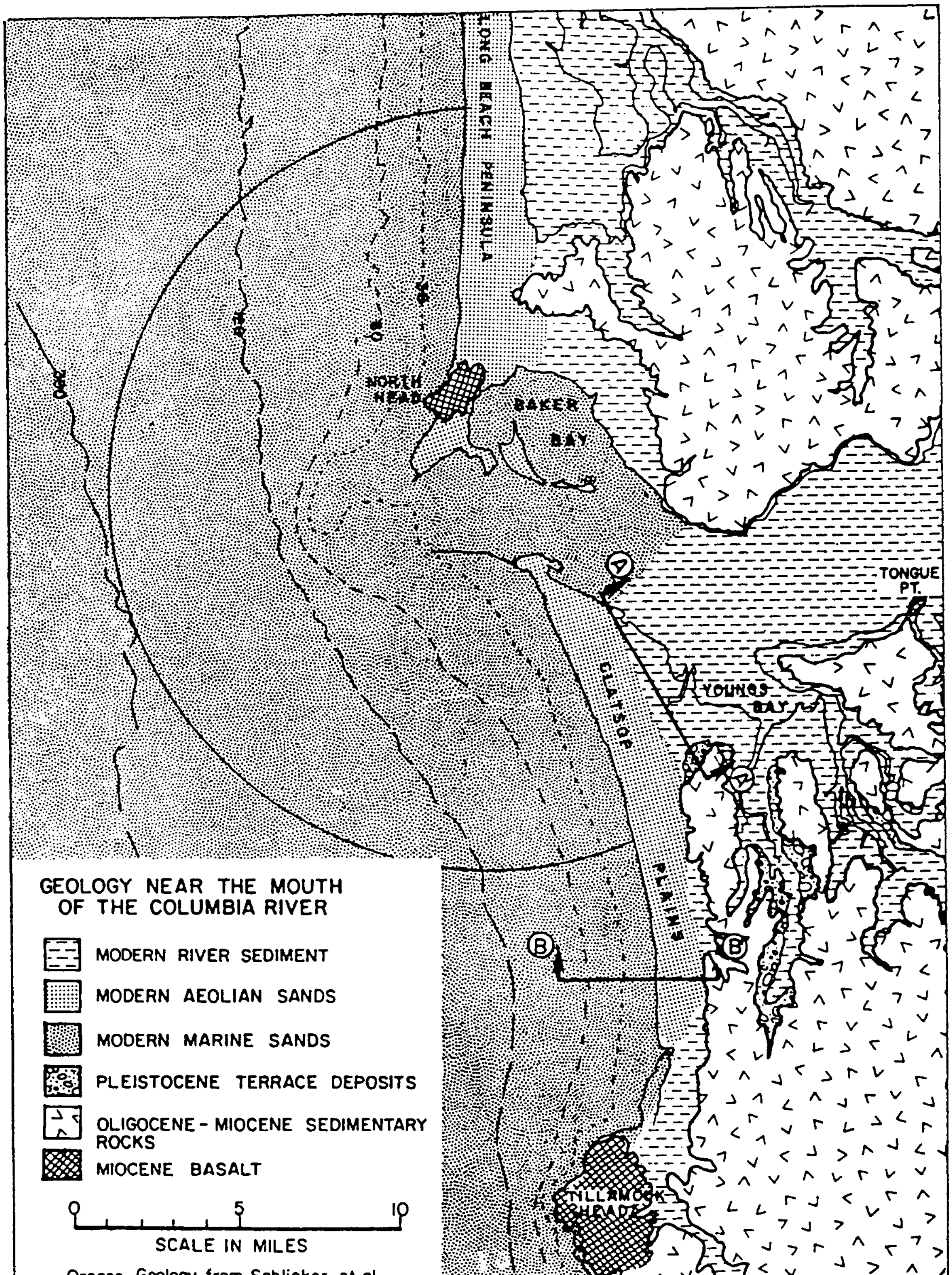


Figure B-45 Coastal geology near the Columbia River mouth.

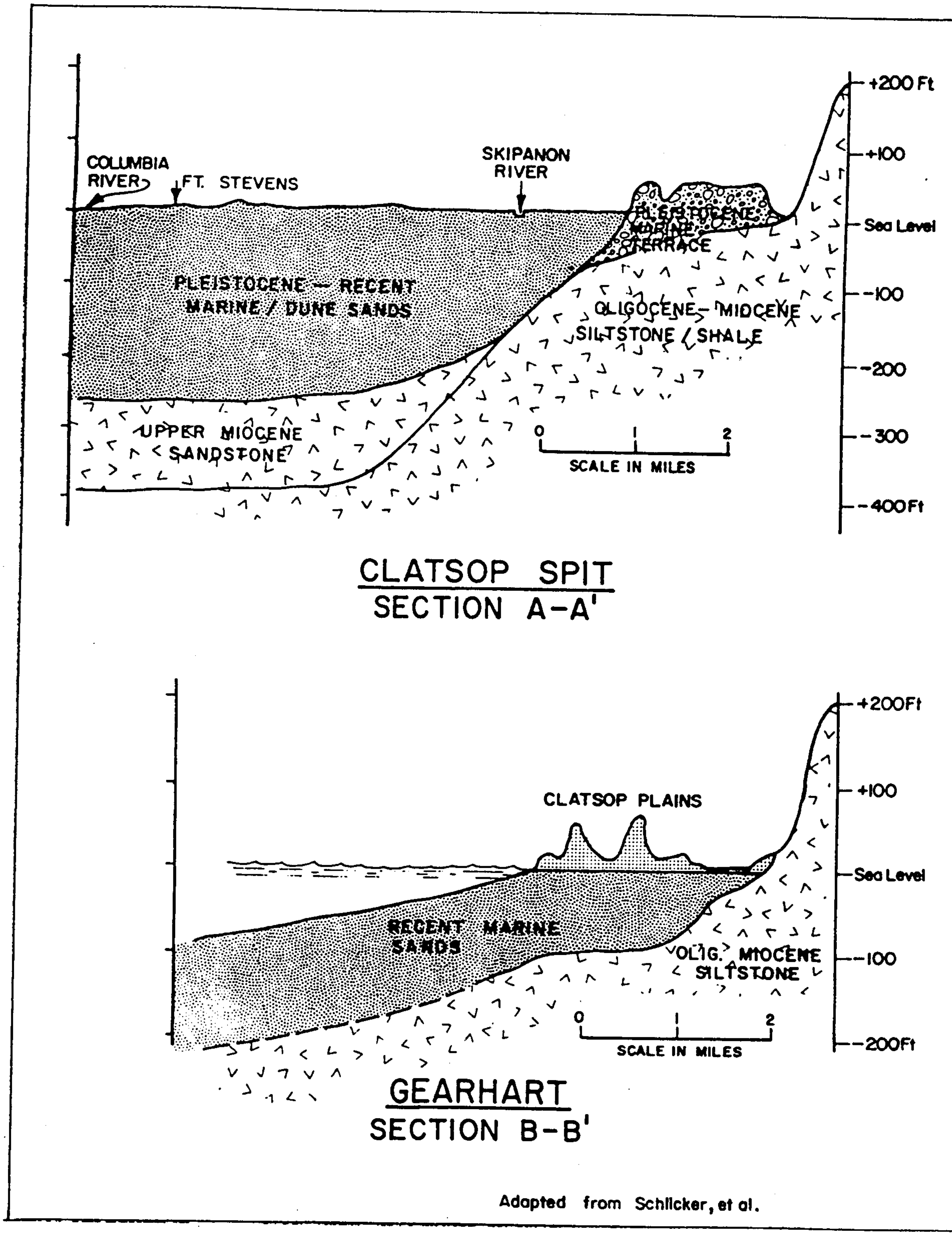
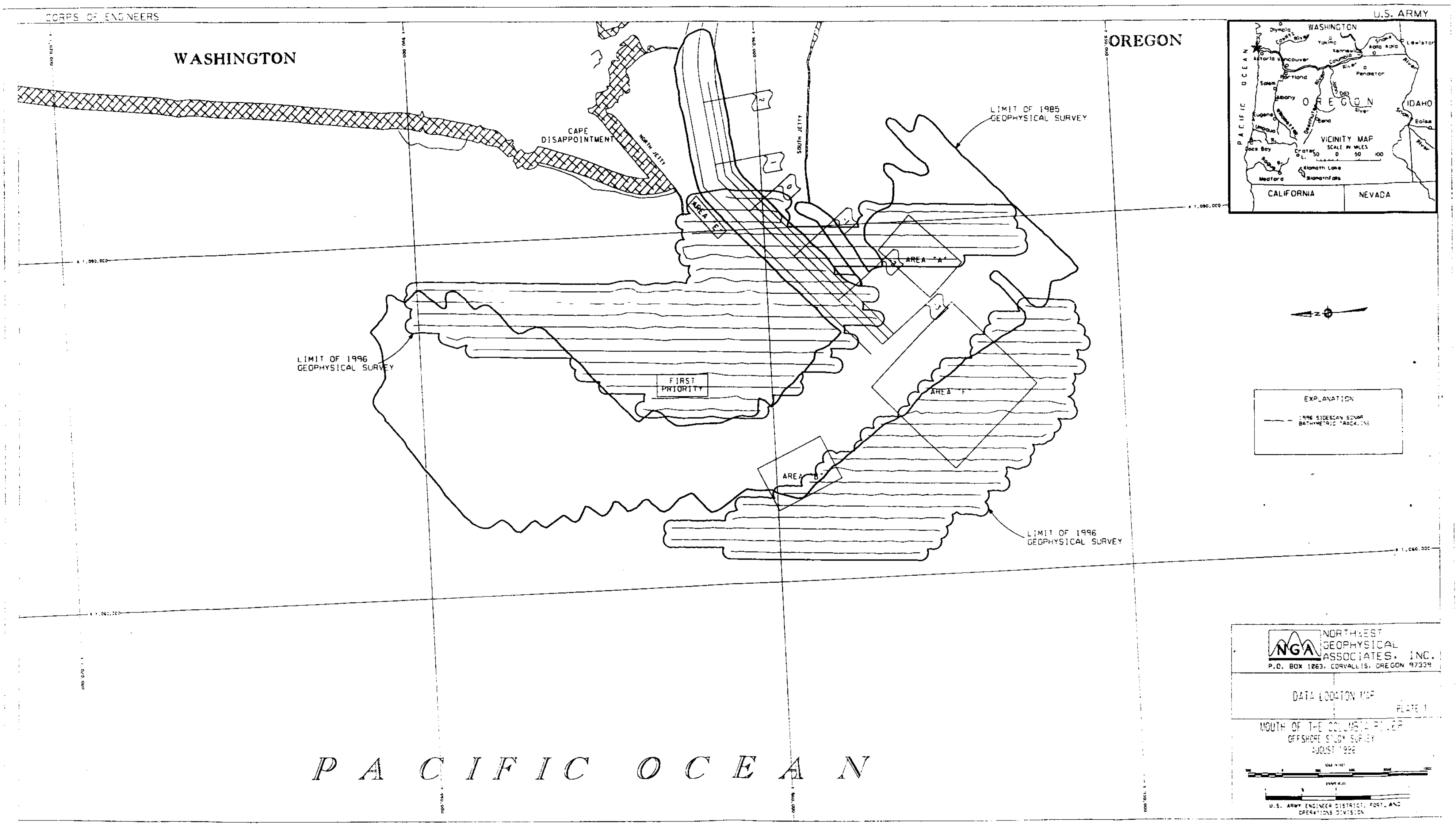
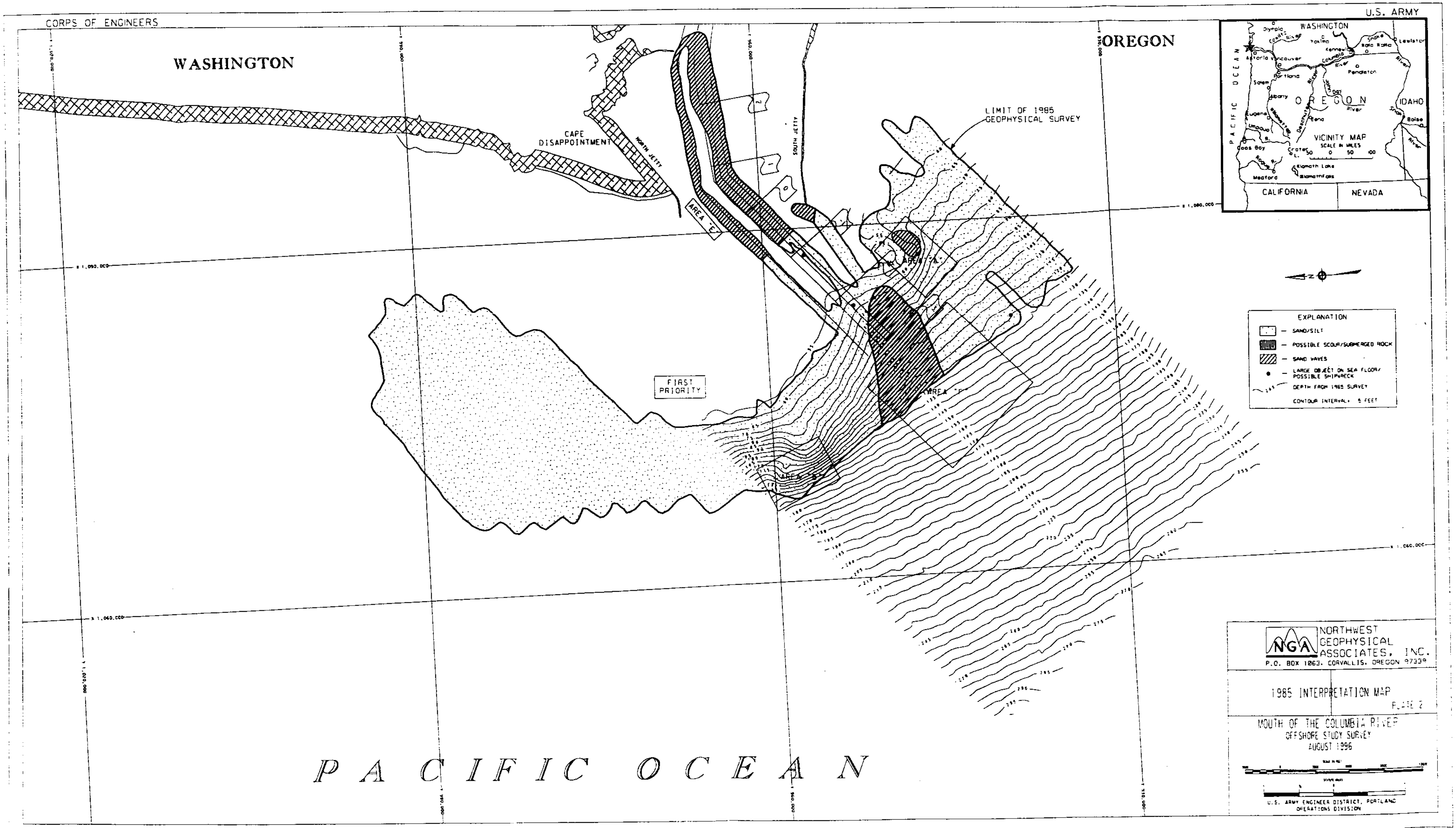


Figure B-46 Cross-sections of coastal areas near the Columbia River mouth. Sections shown in Figure B-2.



...\dgn\nwgeoassoc\nwgaplate1.dgn Jul. 07, 1998 07:13:57

Plate 1



...\dgn\nwgeoassoc\nwgaplate2.dgn Jul. 07, 1998 07:11:03

Plate 2

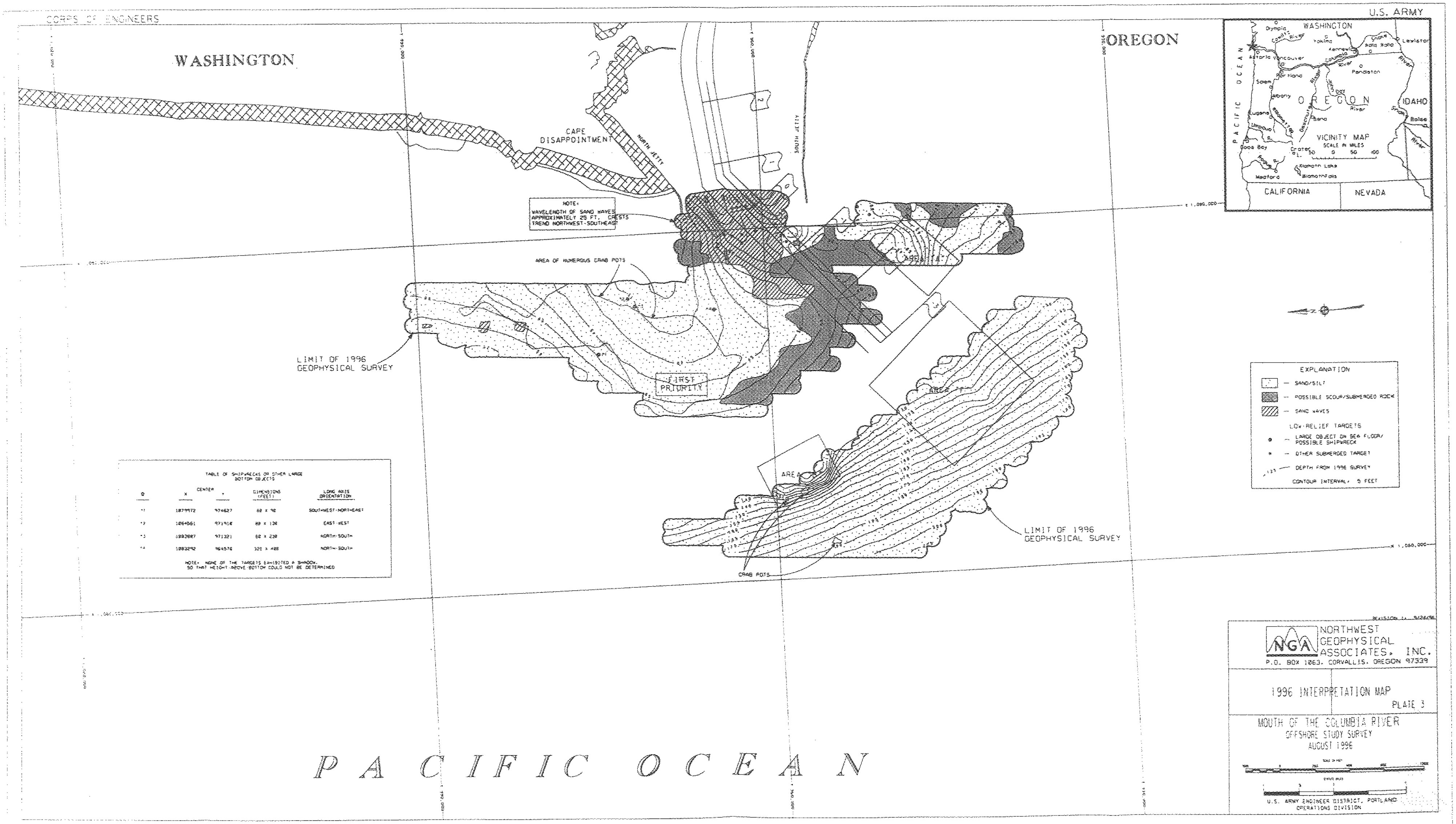


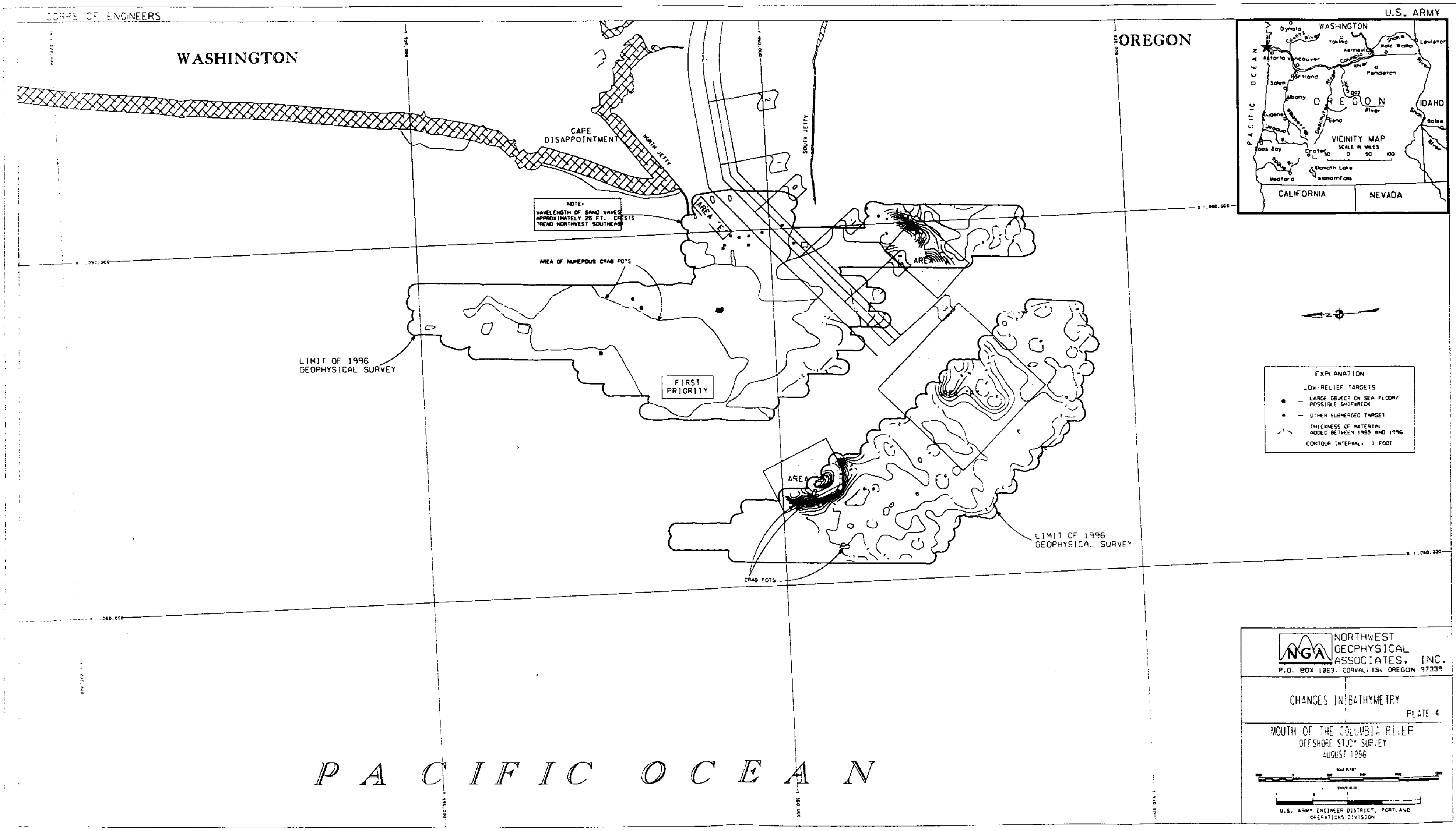
TABLE OF SHIPWRECKS OR OTHER LARGE BOTTOM OBJECTS

⊕	CENTER X	CENTER Y	DIMENSIONS (FEET)	LONG AXIS ORIENTATION
*1	1079972	974627	60 x 90	SOUTHWEST-NORTHEAST
*2	1064561	971918	80 x 130	EAST-WEST
*3	1083087	971321	60 x 230	NORTH-SOUTH
*4	1083292	964576	320 x 480	NORTH-SOUTH

NOTE: NONE OF THE TARGETS EXHIBITED A SHADOW, SO THAT HEIGHT ABOVE BOTTOM COULD NOT BE DETERMINED

...\dgn\nwgeoassoc\nwgaplate3.dgn Jul. 07, 1998 07:12:57

Plate 3



...\dmms\dgn\nwgaplate4.dgn Jul. 06, 1998 14:22:39

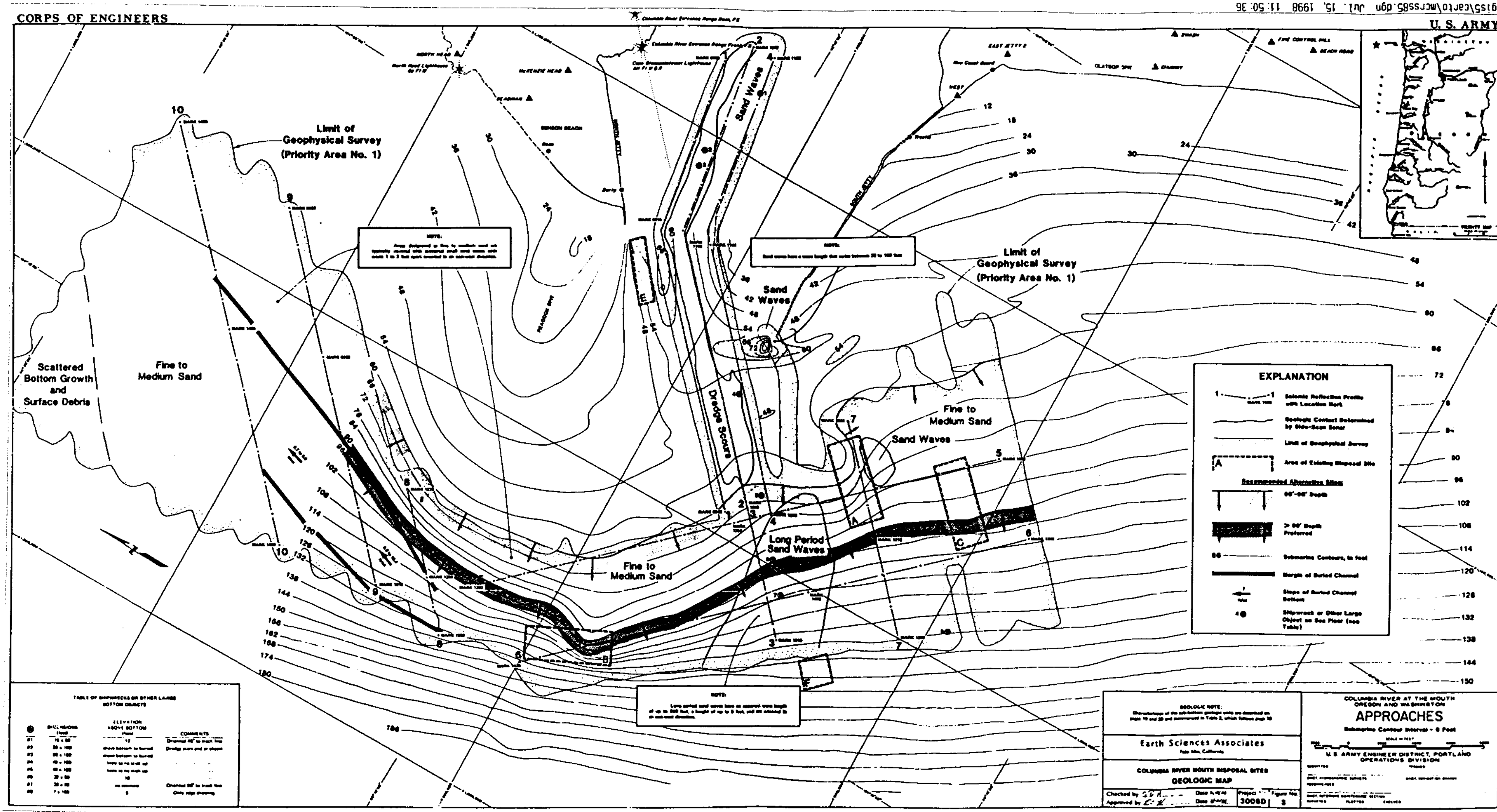

CORPS OF ENGINEERS
U. S. ARMY
Limit of Geophysical Survey (Priority Area No. 1)
Scattered Bottom Growth and Surface Debris
Fine to Medium Sand
Sand Waves
Dredge Scours
Long Period Sand Waves
EXPLANATION
APPROACHES
Earth Sciences Associates
GEOLOGIC MAP

Plate 5