June 1995

US Army Corps
of Engineers

Review of Long-Term Maintenance Plans for the South Jetty, Grays Harbor, Washington

by *Special Subcommittee of the Committee on Tidal Hydraulics and Coastal Engineering Research Board*

Prepared for U.S. Army Engineer District, Seattle

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3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Final report

Prepared for U.S. Army Engineer District, Seattle
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Preface

A request to the Committee on Tidal Hydraulics (CTH) and the Coastal Engineering Research Board (CERB) was presented to the Chairman, CTH, by LTC Rex N. Osborne, District Engineer, U.S. Army Engineer District, Seattle, for assistance in planning the design of protection measures to stabilize the breach of a sand spit adjacent to the east end of the south jetty at the entrance to Grays Harbor, Washington, which occurred during a storm on 10 December 1993. He requested that a special meeting of consultants composed of CTH and CERB members convene at Westport to (a) provide a review and technical advice to the district on the erosion and estuary hydraulics at the project; (b) review an engineering report prepared for the city of Westport; and (c) comment on a draft plan of future studies for the area.

Mr. Frank A. Herrmann, Director, Hydraulics Laboratory, WES, Chairman of the CTH, formed a subcommittee of members and consultants of the CTH and Professor Robert Dean of the CERB, chaired by Mr. W. H. McAnally, Jr., Chief, Waterways and Estuaries Division, Hydraulics Laboratory, to respond to LTC Osborne's request. Members of this subcommittee are listed in Appendix A. The subcommittee, hereinafter called "committee," met in Westport 28 and 29 June 1994.

Mr. Samuel Powell is Headquarters, U.S. Army Corps of Engineers, Liaison for the CTH.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
cubic yards	0.7645549	cubic meters
degrees (angle)	0.01745329	radians
feet	0.3048	meters
inches	2.54	centimeters
miles (U.S. statute)	1.609344	kilometers
square feet	0.09290304	square meters
square miles	2.589988	square kilometers
tons (2,000 pounds mass)	907.1847	kilograms

1 Introduction

1. A breach of the sand spit adjacent to the east end of the south jetty at the entrance to Grays Harbor, Washington, occurred during a storm December 10, 1993. The breach widened rapidly, exposing the landward end of the jetty and eroding portions of Westhaven State Park. The sand spit, the evolving breach, and the exposed east end of the south jetty are shown in Photos 1-10. Residents of the nearby City of Westport were alarmed by the catastrophic character of the breach and expressed concern for further loss of land, impacts on water wells, and the possibility that further erosion would cause the entrance channel on the north side of the jetty to exit through the breach. Further erosion may also threaten the stability of the south jetty, and the eroded material may impact the entrance channel. The Seattle District will fill the breach with sand prior to the 1994-95 winter storm season. This fill is expected to be a temporary remedy that will provide time for the consideration of more permanent structural or operational protection of navigation facilities and land resources.

2. A request to the Committee on Tidal Hydraulics (CTH) and the Coastal Engineering Research Board (CERB) was presented to the Commander, Waterways Experiment Station (WES), by LTC Rex N. Osborne, District Engineer, Seattle District, for assistance in planning the design of protection measures. He requested that a special meeting of consultants composed of CTH and CERB members convene at Westport to:

a. Provide a review and technical advice to the district on the erosion and estuary hydraulics at the project.

b. Review an engineering report prepared for the City of Westport.

c. Comment on a draft plan of future studies for the area.

3. Mr. Frank A. Herrmann, Chair of the CTH, formed a subcommittee of members and consultants of the CTH and Professor Robert Dean of the CERB, chaired by W. H. McAnally, Jr., to respond to Col. Osborne's request. Participants in this subcommittee are listed in Appendix A. The subcommittee, hereinafter called "committee," met in Westport June 28 and 29.

4. In preparation for this meeting, the Seattle District prepared an excellent summary of historical hydrographic surveys, history of jetty construction and repair, history of beach changes, reports to the Congress on needs for the jetties, the breach fill plan, and plans for additional studies. Letters and news clippings pertaining to the breach and the planned temporary fill were also provided together with the following documents: CTH (1967), Battelle/Marine Sciences Laboratory (1992), Hartman Associates (1994), and Hosey and Associates (1994).

5. The preparatory material also included a detailed list of "Items for Consideration:"

I. Review overall erosion process based on available information
- a. Evaluate threat to jetty structural integrity and to navigation channel
- b. Evaluate threat posed by the breach to the City of Westport
- c. Estimate long-term (50-year) erosion effects on South Beach (to 1 mile[1] south of jetty)

II. Review NPS alternatives for addressing long term actions
- a. Suggested additions and/or deletions
- b. Based on available information, rank alternatives on technical viability

III. Review Hartman Associates' report
- a. Review relationship between maintenance dredging and channel alignment and erosion
- b. Evaluate feasibility of channel realignment alternative
- c. Comment on the conclusion that there is an immediate need for breach filling

IV. Review NPS breach fill plan
- a. Review placement location and quantity
- b. Estimate breach fill contribution to jetty integrity
- c. Review Hartman recommendation to place fill material into "wave breaking zone"
- d. Estimate life of temporary fill (time until next breach)

V. Review NPS draft Plan of Study
- a. Discuss whether or not model tests are recommended
- b. Review prototype data requirements for model studies and sand budget study
  - i. tidal current measurements
  - ii. water surface elevations
  - iii. other

[1] A table of factors for converting non-SI units of measurement to SI units is found on page v.

6. The committee met in Westport for a day and a half. During the first day of the meeting the committee was briefed by representatives of the Seattle District, the City of Westport, and Hartman Associates in a public meeting. A tour of the breach area and adjacent beaches and an inspection of the south jetty aboard the *Shoalhunter* were also completed the first day. An executive session the second day included discussions of sediment transport, the causes of the breach, its possible continuing growth and consequences, design of the immediate fill, and the "Plan of Study, Long Term Maintenance of the Grays Harbor South Jetty."

7. This report responds to the charge to the committee. It is based on the written information described above and the meetings at Westport, and it has been reviewed by correspondence among all committee members.

2 Brief History of Grays Harbor Entrance

8. Grays Harbor entrance is located on the Washington coast about 45 miles north of the mouth of the Columbia River and 110 miles south of the entrance to the Strait of Juan de Fuca. A vicinity map and the navigation facilities in the entrance are shown in Figure 1. The Harbor broadens gradually from the river channel at Aberdeen to a large pear-shaped shallow estuary encompassing North and South Bays. An entrance is formed by sand spits extending from north and south. The Harbor is about 11 miles wide near the entrance and extends about 15 miles from Aberdeen to the entrance. The water surface of the shallow Harbor is 91 square miles at mean higher high water and 38 square miles at mean lower low water.

9. The configuration of the entrance in 1894, prior to construction of jetties, is presented in Figure 2. A deep entrance channel is shown in the figure. This channel was maintained by strong ebb currents resulting from constriction of tidal flows by sand encroaching from both north and south. An outer bar and deposits inside the entrance formed where ebbing and flooding tidal current velocities slowed. This figure is a "snap-shot" of a very dynamic natural entrance that changed its configuration with changing wind, wave, and sediment supplies. Shifting sands and shallow water at the outer bar created severe hazards to navigation, including grounding of ships and steepened wave conditions. Construction of jetties to stabilize the position of the entrance channel, to provide a protected entrance, and to create eroding currents at the outer bar began in 1898 and were completed in 1916. Alignments of the jetties are shown in Figure 3.

Construction

10. The south jetty was constructed during the years 1898 to 1902 to a length of 13,734 ft and elevation of +8 ft MLLW. Deterioration lowered the outer 12,000 ft to elevations between -5 and -10 ft MLLW by 1933, and the entire jetty was reconstructed to a top elevation of +20 ft during the years

1935 to 1939. By 1962 the outer 8,500 ft had deteriorated to a top elevation of about -1.5 ft MLLW. The innermost portion remained at +20 ft. Four thousand feet of the inner portion of the damaged jetty was restored to elevation +20 ft, leaving the outer 7,000 ft in its degraded condition. No maintenance work has been done since 1966, and the outer 7,000 ft has continued to lower. The 1990 survey shows that the top elevation was between -10 and -20 ft MLLW.

11. Construction of the 17,204-ft-long north jetty was completed to a top elevation of +8 ft in 1916. The outer 7,000 ft deteriorated to a top elevation of about -0.5 ft MLLW by 1933, while the inner portion remained at about +8 ft. The degraded portion was raised to a top elevation of +20 ft during the years 1941-42, but by 1960 the restored portion had again degraded to an average top elevation of +14 ft over an outer length of 6,500 ft with a minimum elevation of +3 ft. The outer 6,000 ft of the north jetty was rehabilitated to +20 ft in 1975, and is in good condition. The outer (west) ends of the jetties are 6,500 ft apart.

12. Erosion of the shore of Point Chehalis in the 1940's led to the construction of groins in 1950 and a revetment in 1952 to protect the City of Westport. An additional 540 ft of revetment was constructed along the west shore in 1954. This revetment was extended 560 ft in a southerly direction in 1956. Extensive repair of the revetment and groins was made during 1970-73. The seven original groins were replaced with six all-rock structures; all of the north revetment and 550 ft of the west shore revetment were raised to +25 ft MLLW, and an additional 200 ft of the west shore revetment received minor repair but was not raised. Minor rehabilitation work along the northern portion of the revetment was carried out during 1980-92. During a storm in 1992, the southern portion of the revetment was overtopped and failed, causing significant flooding of the Westport business district. This portion (800 ft) was rehabilitated in the Fall of 1993.

Dredging

13. Prior to construction of the jetties, water depths over the outer bar were as shallow as 15 ft, and early navigation charts warn of breakers across the entire width of the entrance. Constraint of the entrance by the original jetties was inadequate to maintain project dimensions, particularly when the jetties were in a deteriorated condition. Dredging of the bar commenced in 1916 and continued at regular intervals until the jetties were reconstructed in 1942. No maintenance dredging was required in the bar and entrance channels between 1942 and 1990. The bar channel was deepened to -46 ft MLLW as part of the Grays Harbor Navigation Improvement Project in 1990. Maintenance dredging has been required since that time in the bar and entrance channels to maintain this depth.

14. Material dredged in the bar channel is disposed in deep water near the west end of the channel. Material dredged in the entrance channel has been

disposed in the entrance channel near the east end of the south jetty. More recently it has been disposed off South Beach and in Half Moon Bay to retard erosion.

Evolution of the Jettied Entrance

15. Figure 3 shows the configuration of the entrance in 1915, the time when the jetties were nearly completed. The entrance channel is broader than the channel was prior to construction, shown in Figure 2, and has about the same depth. It emerges near the center of the outer ends of the jetties. Material had been scoured from the entrance and deposited on the outer bar. Sand was deposited along the south side of the south jetty (then 13 years old).

16. Figure 4 shows the configuration of the entrance in 1930. Comparison with Figure 3 shows that the entrance channel is deeper but narrower,and the north side of the entrance channel has moved south. Depths of water over the outer bar were greater, and Point Brown extended further south and west. The west shore of Point Hanson (South Beach) was eroded.

17. Figure 5, showing the configuration of the entrance in 1940, indicates a continuation of the trends described above. The entrance channel was hard against the south jetty and still narrower than it was in 1930. The inner bar deposit south of the north jetty, across the jetty from Point Brown, has accumulated more sediment, as had the deposit at the north tip of Point Hanson -- now Point Chehalis. South Beach was eroded further.

18. Figure 6, dated 1950, shows continuing evolution as described above. The entrance channel was still narrower and deeper, the inner bar deposit north of the channel had accumulated more sediment, and North Beach on Point Brown had advanced toward the outer end of the north jetty. It appears that there was some deposition at the north end of South Beach. This plot shows the first indication of erosion at the east end of the south jetty and of the Point Chehalis shoreline.

19. Figure 7, dated 1960, when compared with Figure 6, shows erosion of the outer bar and widening of the entrance channel. There was slight erosion of North Beach and some deposition on South Beach. Erosion at the east end of the south jetty had progressed, forming Half Moon Bay. Further erosion of the Point Chehalis shoreline had occurred.

20. Figure 8, dated 1966, when compared with Figure 7, shows additional deposition on the inner bar deposit south of the north jetty and some erosion of the east shore of Half Moon Bay. There was further erosion of the outer bar.

21. Figure 9 shows the December, 1993 configuration of the entrance including the recent breach at the east end of the south jetty. The trends

shown in the previous figures continued. South Beach was eroded, Half Moon Bay was enlarged, and North Beach was filled westward nearly to the outer end of the north jetty. The shallowest contour on the outer bar is -42 ft (the contour interval is 6 ft).

22. The breach occurred during a storm on December 10, 1993. The storm started on the evening of December 8 and lasted until December 15 (Hartman Associates 1994, p 7). The maximum significant offshore wave height was recorded by the Grays Harbor buoy at 0230 December 10. The wave height was 25 ft and the period was 13 seconds. The direction of offshore waves varied from 33 to 91 degrees relative to the shore. Hartman & Associates calculated the largest wave height at the 33-ft depth to be 16.7 ft with a length of 450 ft. They calculated a wave recurrence interval of two years. Evidently, setup from south winds combined with high waves caused overtopping of the narrow portion of the spit between South Beach and Half Moon Bay. Much of the material that was washed out of the breach has deposited in Half Moon Bay. Figure 10 shows details of the breach in May, 1994.

23. Trends shown by this succession of figures include erosion of material on the outer bar, accumulation of material on North Beach, accumulation of material on the inner shoal and narrowing of the entrance channel as it migrated southward, erosion of South Beach, and erosion to form Half Moon Bay including the west shore of Point Chehalis.

3 Regional Sediment Transport

24. Evaluation of the causes of the breach at the south jetty and of means for cost effective long term maintenance of the jetty and entrance channel require examination of the effects of the jetties on waves and currents and the resulting sediment movement. The description that follows is based on the information included in the sources available for this report. It should be verified and refined by data obtained during the current studies, as described in paragraphs 57 on.

25. Time series of wave height, period, and direction obtained from the Wave Information Studies (WIS) by the USACE Coastal Engineering Research Center (Jensen, Hubertz, and Payne 1986) are plotted in the Battelle report (Battelle/Marine Sciences Laboratory 1992, p 42) and are shown in Figure 11. This figure shows that winter waves having significant heights on the order of 20 ft and significant periods of 16 seconds approach the entrance from the southwest to west directions. Summer waves have significant heights on the order of 4 to 5 ft, periods of 5 seconds, and approach from west to northwest.

26. Winds during winter are typically from the southwest or south and are strong. Gale force winds occur 5 to 8 percent of the time (Battelle/Marine Sciences Laboratory 1992, p 33). Summer winds have generally lower speeds and blow from the north or northwest directions. Coastal currents respond to winds and are variable. Mean velocities in winter are 10 to 20 cm/s from south to north, and mean summer currents average 5 cm/s flowing from north to south. Hickey (1989) shows the Davidson Current flowing northward on the shelf during winter, and the California Current flowing southward in summer.

27. Bottom drifters placed off the mouth of the Columbia River indicate a northward drift during winter. It was noted that bottom drifters placed where depths are less than 100 ft tend to drift onshore, whereas drifters placed at greater depths tend to move north.

28. Tides at the Grays Harbor entrance are mixed semi-diurnal and have a mean diurnal range of 9.0 ft. The mean spring range (the highest of the 14-day spring - neap cycle) is 12.0 ft.

29. Figures 3 through 9 show continuing erosion of the outer bar and contours that trail from the outer bar northward. Sixteen second waves having 20-ft significant heights can easily suspend sand at the depths of the outer bar, and the winter coastal current would transport the suspended material northward. The more frequent 5-ft, 5-second waves and southward drift during summer may also produce southward transport on the outer bar material. Bed shear stresses calculated at the 40-ft depth for these wave conditions are 1.1 N/m^2 under winter waves and 0.05 N/m^2 under summer waves. From these data it must be concluded that the eroding bar material is moving northward. This observation is supported by similar observations at the mouth of the Columbia River by Beeman and Everts.

30. The milder summertime waves from the northwest tend to promote onshore movement and to transport sand southward along the shore. North Beach is supplied with southward littoral transport during summer, and bar material north of the jetty has been gradually transported to North Beach. The north jetty obstructs southward transport, and sand has accumulated on its north side.

31. South Beach has no supply of sand in summer except that moving onshore. Advances of the shore of South Beach coincided with initial completion of the south jetty and with its rehabilitation (CTH 1967, p 4). This coincidence suggests that material supplied to the bar by erosion of the entrance contributed to South Beach. It is common for portions of an outer bar that are isolated from the seaward jet by construction of a jetty to move ashore when no longer exposed to the ebb jet. An example is the beach adjacent to the south jetty of Ponce de Leon Inlet, Florida. As bar material was depleted by winter transport, a steeper slope toward deep water gradually developed and the supply of sand for onshore transport became limited.

32. Sand accumulated on the north side of the north jetty until the depths at the jetty end were shallow enough for summer transport around it. There may also have been transport over the north jetty while it was in a deteriorated condition. Transport of this material into the entrance and deposition on the north side of the space between the jetties - the inner bar - caused narrowing of the entrance channel and its migration to the present location hard against the south jetty. The high velocity currents that result from the narrowing of the channel appear to be sufficient to carry most of the sediment that passes around the north jetty inward and outward with tidal currents.

33. As described above, the sand supply to South Beach is limited. Erosion rates during winter are exceptionally high immediately south of the south jetty because of the steep slope of the bed near shore that allows waves to impact the shore with little dissipation, wind and wave setup against the jetty and shore, and possibly reflections of southwesterly waves off of the south jetty. These factors also contributed to the overtopping that caused the breach. Prior to the breaching, wind and wave setup from southwest winds created a seaward current along the south side of the jetty. This current,

combined with suspension of sand in the violent mixing that must occur during storms, provided a conveyance that carried sand to sea.

34. Erosion of the tip of Point Chehalis and the formation of Half Moon Bay can be attributed to several combined causes. Prior to construction of the jetties, sand was transported into the entrance on flooding tidal currents and Point Chehalis received a continuing supply of sand that compensated erosive events. Construction of the jetties and migration of the entrance channel to its location against the south jetty reduced the rate of accumulation of sand on the Point and increased the exposure of the region to transmitted ocean waves. Further, erosion of the outer bar facilitated propagation of waves having increasing heights into the entrance. The shape of Half Moon Bay is that which would result from diffraction of waves around the exposed east end of the south jetty. The entrance channel bends at that location, contributing erosion from secondary currents associated with the outside of a bend. And finally, once the proto-Half Moon Bay erosion was initiated, the strong currents in the channel created an eddy that would transport sand suspended by waves into the nearby navigation channel. Overall, erosion of Half Moon Bay and the tip of Point Chehalis are the consequences of depleted supplies of sand and increased exposure to waves and currents.

35. Erosion of South Beach near the jetty and erosion creating Half Moon Bay created a narrow neck of sand that could be overtopped with enough flow to cross the neck and initiate a channel. Failure then was rapid.

36. Information was developed by the CTH and Battelle studies that further illuminates the trends described above. Areas encompassing North Beach, the bar, entrance, and South Beach were blocked off and changes in sand volume for each block were calculated from hydrographic surveys. The areas used in the Battelle study are shown in Figure 12. Figure 13 shows the composited (CTH 1967 and Battelle/Marine Sciences Laboratory 1992) results. Fluctuations of the plots may be due in part to uncertainties of water surface elevations during the surveys. The plots show clear trends, however. The plot for North Beach shows that sand accumulated until the capacity of the north jetty to retain it was exceeded. The rate of onshore movement of sand from the offshore deposit to North Beach diminished as the offshore material became depleted, and the slight decrease of volume in later years shown in Figure 13 may continue. The volume of sand in the entrance diminished early as the result of constriction of ebb flows by the jetties, then changed only slowly. The volumes of sand on the bar and on South Beach continued downward trends.

37. Further description of transport on the beaches is provided by estimating transport due to waves. As shown in Figure 1, North and South Beaches have different alignments, and transport is sensitive to the angles of wave approach. Estimates using *Shore Protection Manual* methods and WIS Station 48 wave data yielded the following annual littoral transport rates, in millions of cubic meters.

Beach	Northward	Southward	Net
North	12.0	11.0	1.0 Northward
South	10.5	14.7	4.2 Southward

Not only is the South Beach deprived of a source of sediment; its orientation contributes to the rate of southward transport. The orientation of North Beach is due to the obstruction by the north jetty and possibly to onshore transport from the bar. If the supply from the bar diminishes, as suggested above, the south end of this beach may regress until its orientation causes no net transport.

38. The plot of total volumes in Figure 13 shows continuing loss of sand from the region over a period of ninety years. This period is too long to attribute the loss to cyclic causes, such as variability of winter weather. It is most likely a result of the impacts of the jetties on the areas included in the computation. The jetties first caused erosion of sand from the entrance and its deposition on the bar, where it was subsequently eroded by waves and coastal currents. Sand that entered the entrance from North Beach crowded the entrance channel until velocities were sufficient to carry additional sand seaward or landward beyond the areas included in the calculation. Waves in the entrance must also have contributed to movement of sand. And finally, South Beach was deprived of a sand supply and subjected to erosion as described in paragraph 31.

39. External supplies of sand to the region have probably diminished. Decreased discharge of sand from the Columbia River due to the construction of dams has been mentioned, and the bar deposit following construction of the jetties there was depleted during this period. (See section 4.3.5, Battelle 1992.) Presently available information is insufficient to evaluate effects of changes of these sources on Grays Harbor entrance. If diminishing supply of sand from these sources is a factor, however, *it is evident that the supply of sand provided initially from these sources will not return in the foreseeable future.* Erosion of the shore and cliffs south of the Grays Harbor entrance must also supply sand to the entrance, and varying wave climate may have contributed to the South Beach shoreline fluctuations. Barring new supplies of littoral material, however, the loss of sediment shown in Figure 13 can be expected to continue until a new steady state is established.

40. This description is a rational scenario that logically explains the features and evolution observed at the entrance to Grays Harbor. It is based on only hydrographic surveys of a limited portion of the coast, jetty history, and very limited oceanographic data, however, and should be verified by both detailed review of wave, wind, and hydrographic data and acquisition of additional hydrographic and oceanographic data over an extended region. Similar winter offshore northward and summer onshore transport is described at the entrances to Humboldt Bay, California (Bodin 1980; Costa 1984), and the Columbia River (Beeman, personal communication; Everts, personal communication).

4 Impacts of Further Erosion of the Breach

41. At the time of the committee's inspection, the lowest elevation of the breach was next to the south jetty and an upward sloping beach extended south about 500 ft to a bluff. The breach was a continuation of South Beach into Half Moon Bay beach. Material eroded from the breach and continuing longshore sediment supply from the south had created a large deposit in Half Moon Bay having a shape similar to that of a flood delta. The elevation of the sand near the jetty was such that shallow flood flow occurred. The tidal flow did not appear sufficient to erode sand. Over time, however, storm conditions, including setup and high waves impacting the jetty, as described in paragraph 33, and a lessening supply of sand from the south, could deepen the breach to an elevation such that tidal flows through the breach would be sufficient to transport sand. The proximate deep waters off of South Beach and in the entrance channel near the east end of the jetty are sinks for eroded sand, and when sand begins to be transported to these sinks by tidal currents the passage will become unstable. In any case, the breach is a threat to the landward end of the jetty.

42. Existing ebb flows in the navigation channel near Half Moon Bay are sufficient to transport sand that is carried into it from the breach. If the depth of the breach reaches the point of instability, however, flows in the navigation channel will diminish as an increasing portion of ebb flows exit the short path to the ocean through the breach, and the capacity of the entrance channel to carry sand would be reduced. The performance of the jetty system could be compromised and increased dredging of the entrance could be required.

43. It should be emphasized that the *elevation* of the lowest passage through the breach bed relative to the tides at the site will determine its stability against capturing the navigation channel and that the elevation will be determined by the sediment supply to and loss from the breach during storms.

44. Erosion of the shoreline of Half Moon Bay prior to the breach was 11 ft/year. That rate of erosion was due to waves that were transmitted down the channel and diffracted around the end of the breakwater, as well as to locally generated waves and local currents. Similar "crenulate" or "spiral" bays are found along the Pacific coast down-drift of coastal prominences,

"tombolos," and are due to diffraction of waves around them and the eventual adjustment of the shore normal to the diffracted waves. The deposit in Half Moon Bay that appeared after the breach and the changed shoreline has altered wave and current conditions and winter alongshore sand transport so that future rates of erosion along the shore of Half Moon Bay are difficult to predict with presently available information.

45. Without intervention, the long term rate of erosion of South Beach south of the breach shown in Figure 13 can be expected to continue. Annual changes of shoreline have fluctuated since the last rehabilitation of the south jetty in 1967, but the changes have been mostly erosion, and rates have increased during recent years. The annual shoreline erosion rate ranged from 26 to 62 ft along the shore since the mid-1980's (Battelle/Marine Sciences Laboratory 1992, p 12). Figure 13 indicates a ninety year annual average sediment loss of 0.7 million cubic yards over the area included in the computation. As noted above, the supply of sediment to the beach has diminished, and the estimate for 1987 to 1990 is slightly over one million cubic yards (Hosey and Associates 1994, p 4). The loss of sand carried by the seaward current along the south side of the jetty that occurred prior to the breach due to wind and wave setup should no longer occur, but littoral transport through the breach may compensate this change. The projected 2043 shoreline shown in Figure 14 is a reasonable guess; there is uncertainty about future rates of shoreline regress, but there is little doubt that erosion will continue in the absence of intervention.

5 Protection Measures

Alternative Remedies

Beach revetment

46. This alternative is shown in Figure 15. It includes revetment along South Beach and extension of the revetment in Half Moon Bay. In addition to a very high initial cost, erosion of sand at the base of the revetment down South Beach would cause continuing requirements for expensive maintenance.

Revetment and jetty extension

47. This alternative is shown in Figure 16. It includes a 2500-ft eastward extension of the jetty to the junction of a 1500-ft southward extension of the Westport revetment. Protection against erosion in the Half Moon Bay area and of Point Chehalis against waves and currents in the entrance would be provided. This plan would also provide assurance that the entrance channel would not be captured by South Beach erosion in the breach area. Curvature of the jetty near its junction with the revetment extension to provide a smooth alignment along the channel bend would reduce construction and maintenance costs. No means of reducing erosion of South Beach is shown.

South jetty spur groin

48. This alternative is presented in Figure 17. It includes a 2000 ft groin perpendicular to and on the south side of the South Jetty located about 2000 ft from its east end. No direct closure of the breach is indicated; however, the intent of the groin is to interrupt the seaward current along the jetty and to facilitate accumulation of sand in the breach area and out along the south jetty. This alternative could provide long term protection of the jetty but would require expensive maintenance. It would not diminish erosion in Half Moon Bay. Its efficacy depends on a supply of sand from the south, possibly augmented by placement of dredged material. Design of such a groin should include computations of northward littoral transport and possibly a physical model study to determine optimum location and length of the groin.

Reinforcement of the jetty

49. This alternative is presented in Figure 18. It includes reinforcement of 2000 ft of the east end of the south jetty. It would maintain stability of the structure in the presence of continuing erosion of South Beach and Half Moon Bay. Continuous monitoring of the beach would be required, and risk of capture of the navigation channel by erosion of the breach would persist.

Nearshore berms

50. Annually resupplied nearshore berms shown in Figure 19 would be placed in Half Moon Bay and near the north end of South Beach. The purposes of these berms would be to reduce wave action and supply sand to the beaches. Up to 500,000 cubic yards a year of sandy dredged material could be placed between the -20 and -40 ft contours near South Beach. The berm would cover an area 5000 ft long by 500 ft wide. An initial berm 2000 ft long containing 385,000 cy of sand was placed at the 40-ft contour during September and August, 1993, and an additional deposit is planned at the 30-ft contour in September, 1994. An initial 185,000 cy berm was placed in Half Moon Bay in 1992 and an additional 200,000 cy was added in May, 1994. Placement of these berms costs little above the cost of the previous disposal operations, and the practice should be continued to retard shoreline erosion.

Direct nourishment

51. Placement of dredged material directly on the beach in the breach area as shown in Figure 20. The elevation of the top of the fill would be above that of the jetty to reduce the prospect of overtopping and to allow for settlement, and the width in the direction of the breach would be nearly twice that of the pre-breach sand neck. The eastern edge of the should extend from the eastern end of the jetty as shown in Figure 20 to protect the park facilities from erosion by waves diffracted by the end of the jetty. Approximately 500,000 cy of suitable material is dredged annually from the Entrance, Pt. Chehalis, and South reaches that could be placed at this location at a cost of $4 to $5 per cubic yard above present maintenance costs. The quantity of material dredged from these reaches is becoming smaller each year as the system adjusts to the 1990 channel modifications. Additional material, in diminishing amounts, is dredged from the bar, but the cost of transporting it to the beach would be prohibitive. Timing of this alternative is subject to fishery concerns, dredging schedules, and weather. To be a viable long term solution, this alternative would require a commitment to supplement sand from diminishing maintenance dredging with material dredged for nourishment.

Relocation of the entrance channel

52. Relocation of the channel midway between the jetties was recommended by the City of Westport's consultants, Hartman Associates, Inc., to reduce the exposure of Half Moon Bay and Point Chehalis to ocean waves. In order to reduce wave propagation along the south jetty, however, channel relocation would have to be accompanied by decreasing water depths along the south jetty, e.g., by placement of dredged material. Material dumped there in the past has been transported out of the area, so additional structural measures may be needed to retain it. If the region next to the south jetty could be stabilized at a shallower depth, it would both reduce wave penetration to Half Moon Bay and reduce exposure of the jetty to strong currents.

53. It should be noted that at the time the jetties were completed, 1916, the entrance channel paralleled the south jetty, it was about 4,000 ft wide between the 6-fathom contours west of Point Chehalis (Figure 3), and the south side was about a thousand feet north of the south jetty. The north side of the channel has migrated south about 1500 ft to its present location (Figure 9). This migration is attributed above to sand that enters the entrance by wave and current transport around the end of the north jetty. Continuing supply of sand from this source can be expected (see paragraph 32), and a relocated channel would again move southward unless its position is retained by continual maintenance dredging, possibly augmented by structures. If this option were selected, it could be combined with direct nourishment or nearshore berm options described in paragraphs 50 and 51. However, the Committee considers that the annual costs of maintaining the entrance channel along the central axis between the jetties, plus annualized cost of the structures along the south jetty required to hold sand placed there for the purpose of shoaling the existing navigation channel, would far exceed the annualized costs of other promising alternatives.

Relocation of the bar channel

54. Factors that determine the location of the bar channel include safety of navigation, the need for continuous access, and cost of maintenance. An additional consideration is the location of the entrance channel. Relocation of the bar channel from its present alignment should only be considered if relocation of the entrance channel is a selected option.

Comparison of Options

55. The options described above are distinguished by the several hard structures and various dredging options. Of the several structures, *extension of the south jetty eastward to join an extension of the Point Chehalis revetment* is clearly a means of protecting the jetty and navigation channel. It would have little benefit to South Beach. Initial cost would be appreciable, and

maintenance costs per lineal foot would be comparable to those for existing structures. The *groin on the south side of the jetty* has potential for reducing the erosion rate immediately south of the jetty. As noted in paragraph 48, selection of this option should only follow calculations of littoral transport to the site and model studies to determine location and length of the groin. *Reinforcement of the east end of the jetty* is the "do nothing" alternative as far as the breach and erosion of Half Moon Bay are concerned and perpetuates the risk of navigation channel capture. It would be the least costly of the structural alternatives. *Revetment along South Beach* would prevent further loss of land behind the structure. It would not improve conditions along the shore of Half Moon Bay. This option appears to have the highest construction and maintenance costs of the structural alternatives.

56. None of the non-structural alternatives -- the management of sand -- can maintain a closed breach and reduce erosion in Half Moon Bay without dredging in addition to that needed for maintenance. South Beach alone is estimated to lose close to a million cubic yards a year, and usable material from maintenance dredging is half that. However, if a purely non-structural solution is sought, then *direct nourishment* would provide the most protection per cubic yard of sand. This would be sacrificial material that would require continual monitoring and replacement. *Dredging a new entrance channel* north of the existing channel, and filling along the south jetty would reduce wave impact on Point Chehalis and Half Moon Bay, but would be expensive initially and would have maintenance dredging costs that are significantly above existing costs. This alternative might not be possible without structural means for retaining sediment along the south jetty. Placing dr edged material in *nearshore berms* retards erosion at these sites at low cost.

57. Combinations of options that should be evaluated for performance, costs, and environmental acceptability are recommended. These combinations are presented in order of the Committee's assessment of performance with consideration of costs:

a. Extension of the south jetty eastward in a curved alignment to join an extension of the Point Chehalis revetment together with placement of maintenance dredgings on South Beach. The cost of needed additional nourishment of South Beach should be included. This combination would clearly provide protection to the jetty and Point Chehalis, preclude capture of the navigation channel, and mitigate erosion of South Beach.

b. A groin on the south side of the jetty together with placement of maintenance dredgings in Half Moon Bay. This option would require direct nourishment initially and possibly additional nourishment later. It would only be feasible if there is enough northward sand transport to South Beach to maintain closure.

c. Reinforcement of the east end of the south jetty and placement of sand dredged for maintenance on the South Beach-Half Moon Bay beaches. This is the minimum cost alternative.

d. Relocation of the entrance channel together with direct nourishment. This option very likely would be the most expensive, would require continual maintenance dredging along the north side of the channel, and would require innovative and difficult construction. It amounts to sand bypassing. It would lessen the existing risk of undermining the south jetty. Its cost effectiveness, however, compared with other alternatives is doubtful.

Plan of Study

58. The NPS "Plan of Study, Long Term Maintenance of the Grays Harbor South Jetty," presented to the committee is shown in Appendix B. Development of plans were well advanced at the time of the committee meeting at Westport, and committee comments on the sections 1 through 3 are presented above. Computations and modeling, in section 4, will be needed to evaluate the plans listed in paragraph 57. These computations should yield: prospects of a stable or self-healing breach, conditions under which the breach would capture the entrance channel and the rate of capture and the resulting impacts on the navigation channel, anticipated sand transport northward and erosion of South Beach, wave and current conditions at Point Chehalis under continuing breach conditions and with the options above, and optimum placement of sand in Half Moon Bay and on South Beach. Evaluation of alternative 57-B. will require determination of optimum location and length of the groin. Measurements of tides, currents, and sediment properties would be needed, as well as collection of wind and wave data. Sediment input to the entrance from the north would be needed to evaluate the channel realignment alternative.

59. In addition, compilation, collection, and interpretation of data to verify and enhance the interpretations of entrance evolution presented in paragraphs 24 to 40 will support future management of the entire entrance and adjacent beaches, and should be a part of this study. The following investigations are needed:

a. A quantitative morphometric study of the entire entrance, the bed and beaches to well north and south of the entrance, and the bed to beyond the outer bar should be undertaken immediately. Subtraction of successive digitized plots will show areas of erosion and deposition in detail, and the changes and trends can be related to concurrent jetty modifications and external hydrologic, wind, and sediment supply changes.

b. A thorough evaluation of historical wind, wave, and tide data, including the recent Scripps gage data, is needed. Recurrence intervals of events, such as combinations of wave, wind, and tide, ranked in terms of onshore elevation, should be evaluated. Reduction of these data will be needed for calculating impacts on the sand bluff at the landward edge of the beaches as well as shoreline changes.

c. Offshore and northward winter transport is described in paragraphs 26 and 29. This description is based on reported wind-driven currents combined with sediment suspension by long waves. Verification of this transport, as well as transport in the entrance should be undertaken by a combined field and numerical model study. Modeling offshore bottom currents due to onshore winds will require a 3-dimensional model.

d. Onshore and southward summer littoral transport can be modeled by the model developed for (c).

e. Study of alternative 57-D was recommended with the understanding that Half Moon Bay was formed by diffracted and refracted ocean waves that arrived *via* the navigation channel. The possibility of other wave sources should be examined if this alternative is selected for detailed study. Video recordings of wave patterns, and an office evaluation of the temporal distribution of locally generated waves from wind data would support evaluation of alternative means of controlling erosion in Half Moon Bay.

60. Accumulation of more detailed wave and wind data would be valuable for future management of the entrance. Installation and maintenance of offshore wave direction and amplitude measuring equipment and a local wind station would enhance the accuracy of future littoral sand transport computation and beach erosion. Littoral current measurements during storms can be made by deploying a bottom mounted acoustic doppler current profiler on the bar on the alignment of the north jetty for a winter season.

61. Periodic extension of hydrographic surveys both north and south of the entrance would be valuable for future evaluation of entrance changes. These extensions could be transects normal to the shore and spaced only as closely as necessary to define significant changes in bottom profiles. They should be extended in shore as far as safety considerations allow.

6 Conclusions and Recommendations

62. The jetty system has been very effective in creating and maintaining water depths in the entrance to Grays Harbor for reliable transit of ships. In achieving this performance, however, the jetties have necessarily interrupted and redirected the littoral transport of sand. Long-term consequences include relocation and narrowing of the entrance channel to an alignment against the south jetty, erosion of the shore of Half Moon Bay and the north end of South Beach, and most recently a breach between Half Moon Bay and South Beach. The available information indicates that the erosion will continue. Without intervention, South Beach would extend through the former Half Moon Bay to the revetment west of Westport, and erosion of South Beach for some distance south from the jetty would continue.

63. The deep waters at either end of the breach are areas of active transport away from the breach and are sinks for sand eroded from the breach. There is concern that high waves from the southwest and west, accompanied by wind and wave setup, could provide episodic conditions that would erode the breach to depths where tidal flows would cause continuous erosion, and the navigation channel would branch through it. Such erosion could cause damage to the jetty and increasing deposition of sand in the navigation channel, both from the breach and from sand entering the north side of the channel. A contract has been let to refill the breach area with dredged sand. This fill is intended to provide temporary control while plans for long term management are developed and implemented. Without intervention the breach would be a threat to the jetty and to the entrance channel.

64. An eastern extension of the south jetty to a southern extension of the Point Chehalis revetment combined with placement of dredged sediment from maintenance operations on South Beach, possibly with additional nourishment, appears to be the most viable alternative for protecting the jetty, navigation channel, and west shore of Point Chehalis. Other alternatives that appear to be less viable but should be evaluated for cost and effectiveness include a groin on the south side of the south jetty combined with placement of dredged sand in Half Moon Bay and realignment of the entrance channel north of its present location combined with placement of dredged sand in Half Moon Bay and South Beach. A minimum cost alternative that includes reinforcing the east

end of the south jetty and placement of sand dredged during maintenance on the beach should also be evaluated. The analyses recommended above may indicate that additional alternatives should be evaluated.

65. Analysis of existing data, acquisition of additional data, and modeling are needed to evaluate long term maintenance alternatives. Quantitative morphometric analyses of inlet evolution are needed to verify relations of waves, currents, and jetty history to changes in sediment distribution. Field measurements of tides and currents, sediment analyses, and analyses of littoral transport north and south of the entrance are needed both for modeling and to relate to historical beach and bed changes. Additional measurements of wave patterns and their height and period at Half Moon Bay are needed to verify the processes responsible for creation of the bay. Gages for long term measurement of wave direction, amplitude, and period off of the entrance should be installed and maintained. Extension of the area covered by hydrographic surveys is recommended. Continuing measurements of winds, waves, currents, tides, and hydrography will aid in future management of the entrance.

66. A review by the Committee of the initial evaluation of data and of the wave patterns at Half Moon Bay recommended in paragraph 59 would be useful for refining the recommendations for further study and possibly for identifying additional alternatives.

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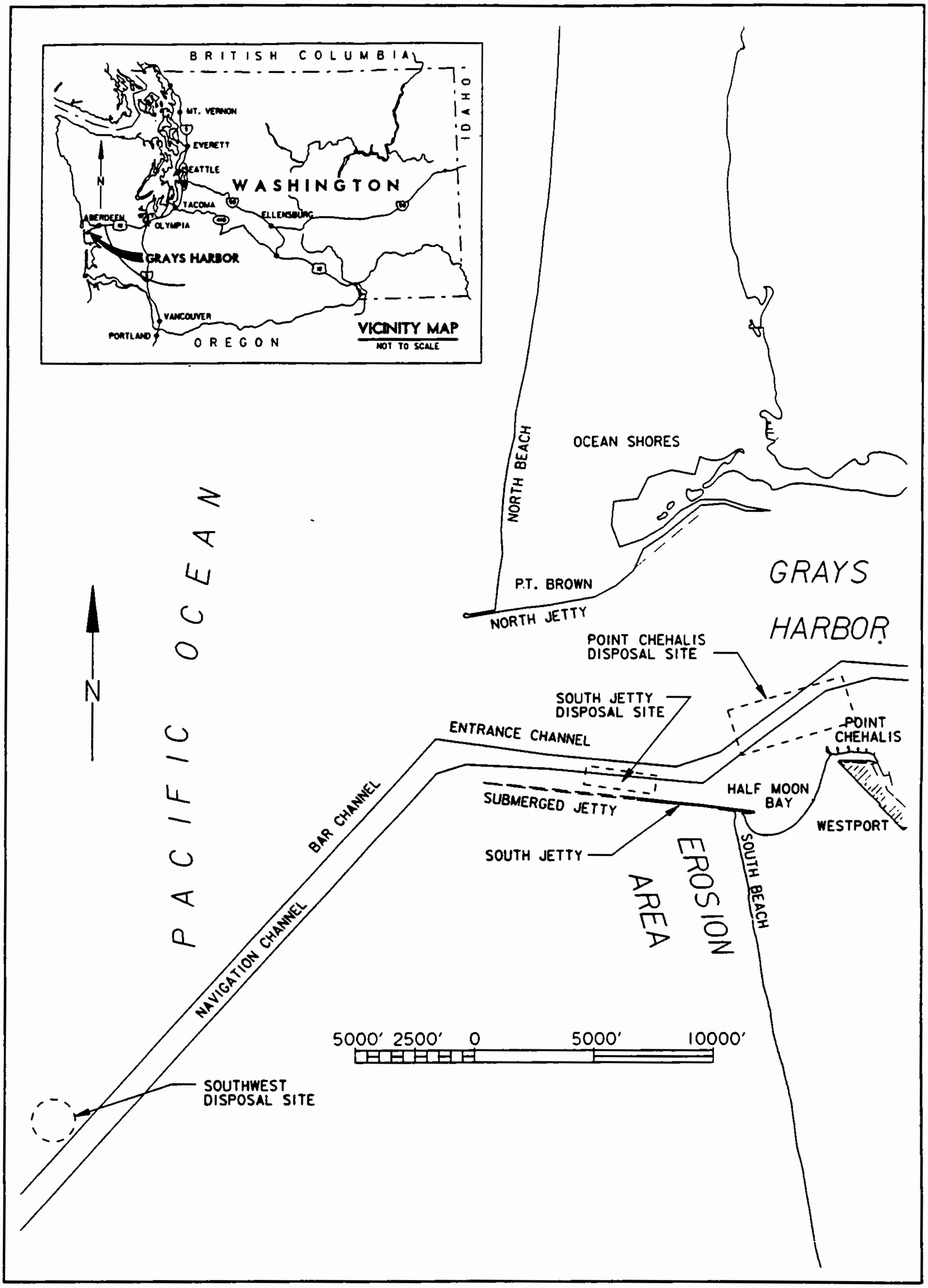


Figure 1. Grays Harbor entrance and vicinity

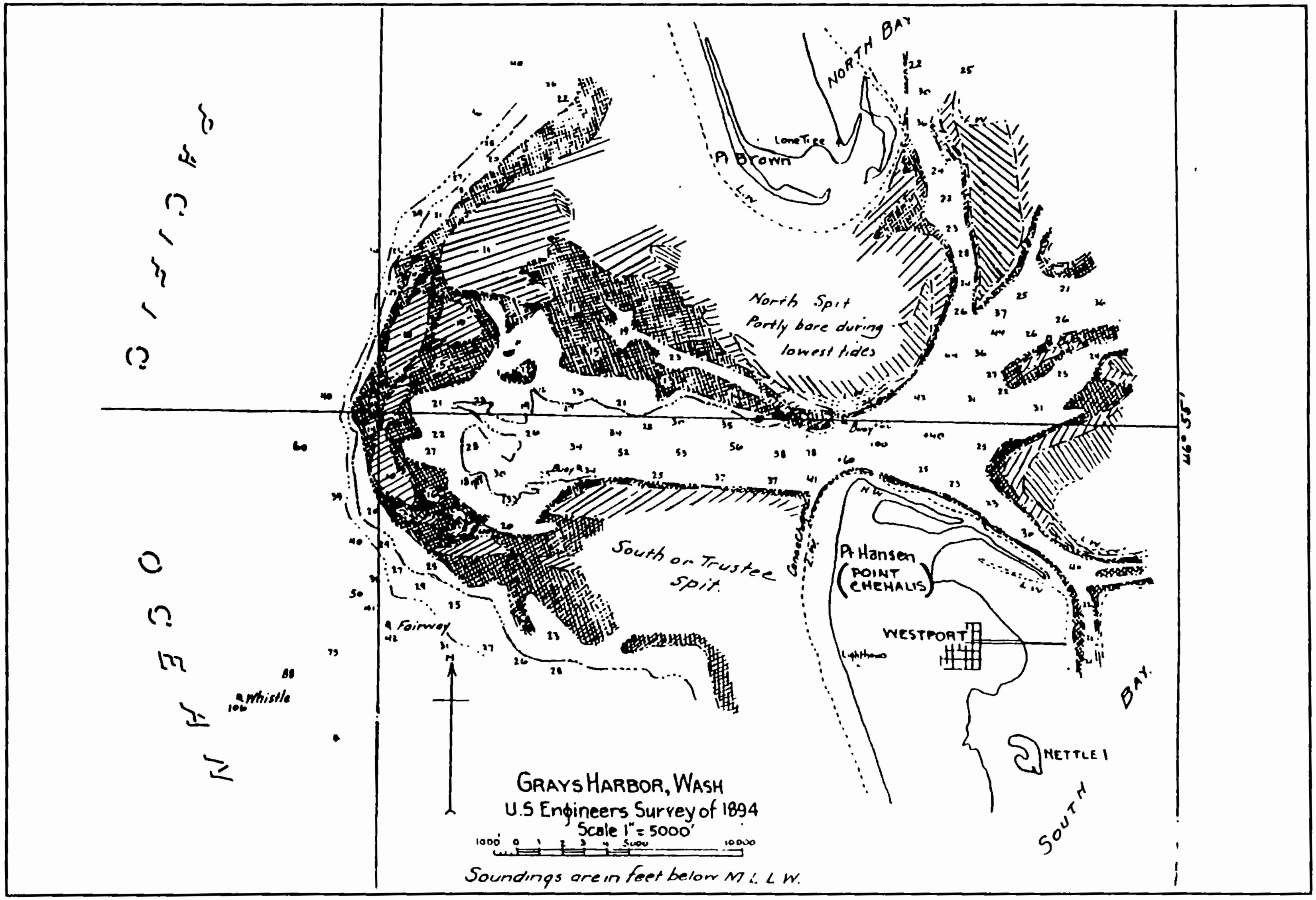


Figure 2. Entrance configuration before jetty construction

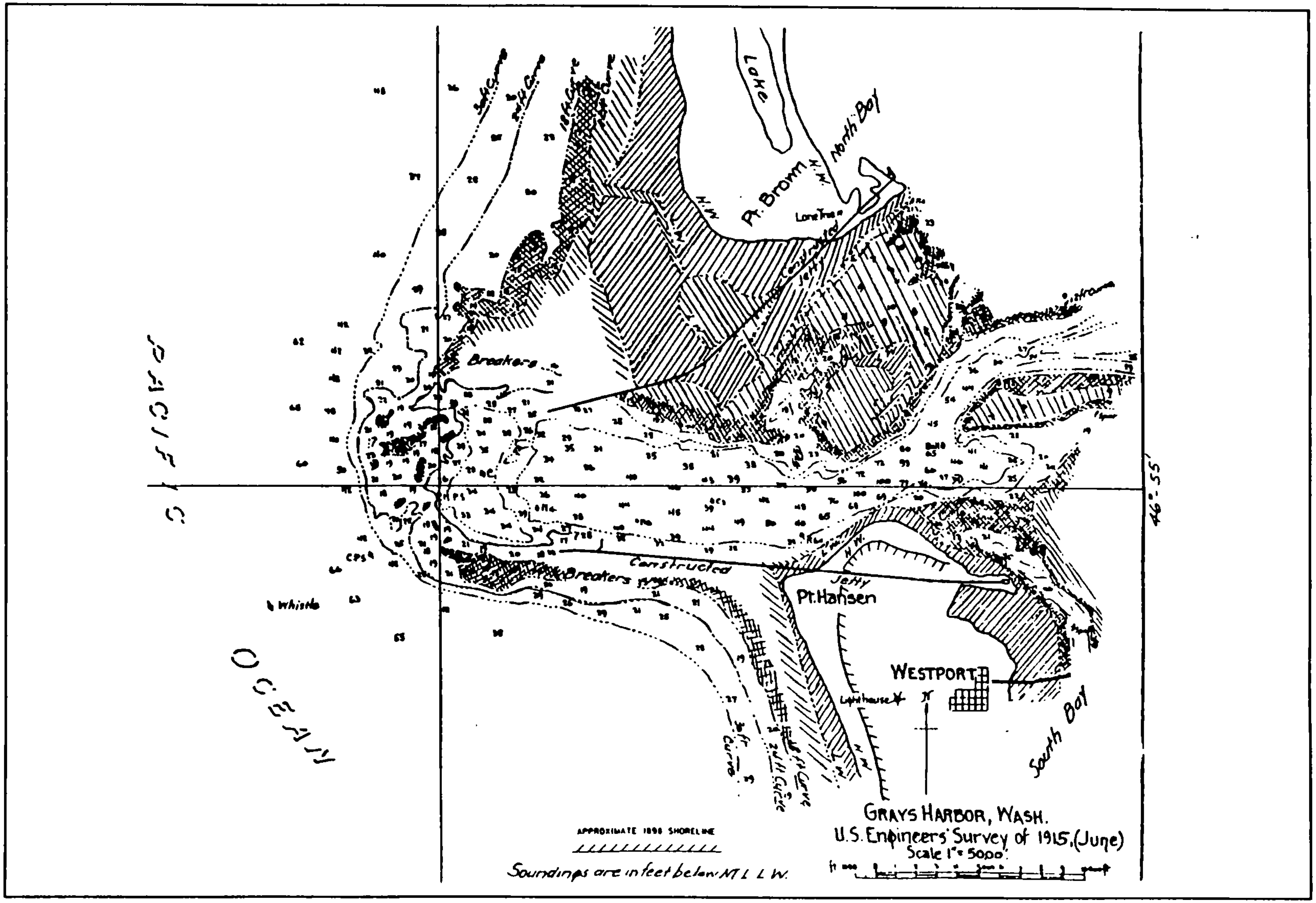


Figure 3. Entrance configuration on completion of jetties

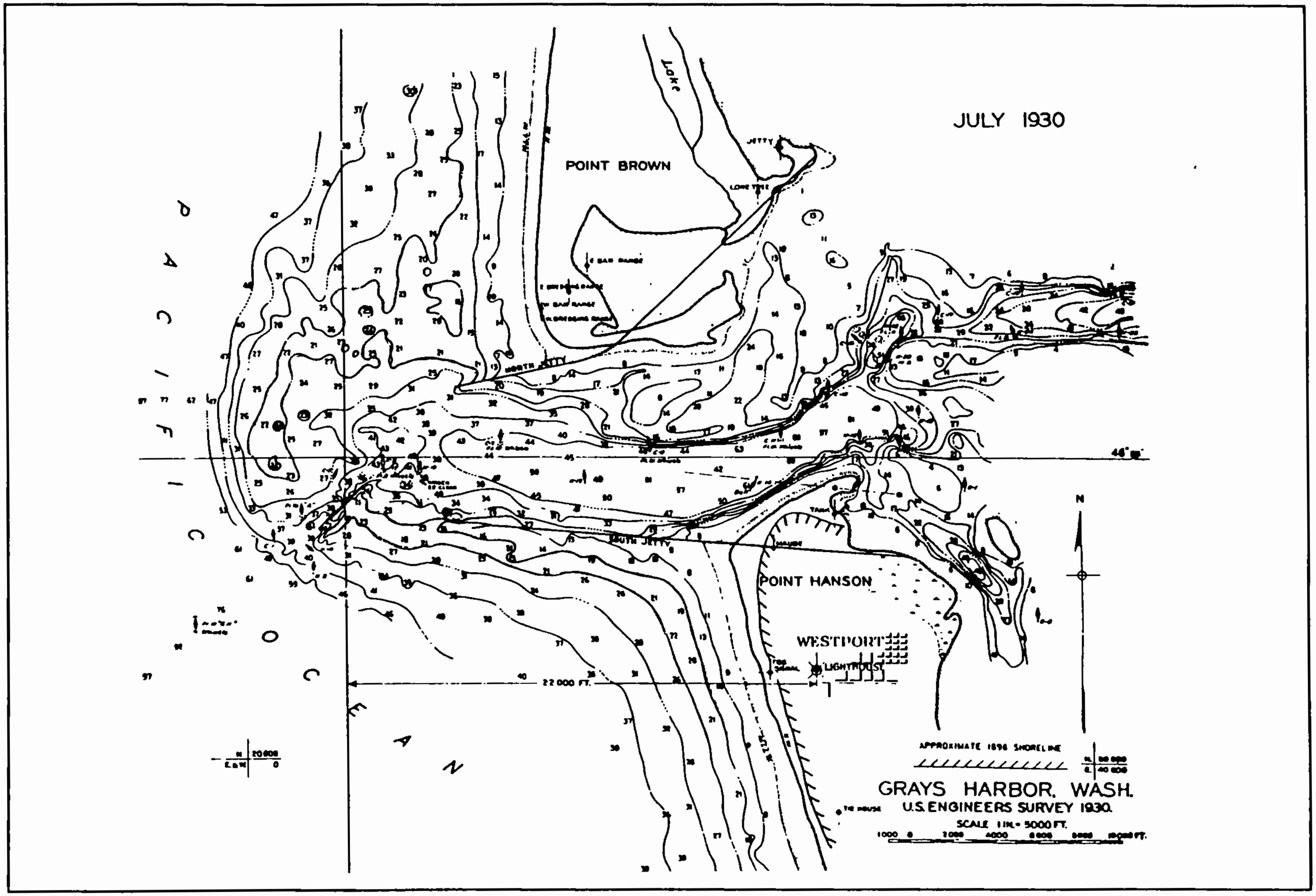


Figure 4. Entrance configuration in 1930

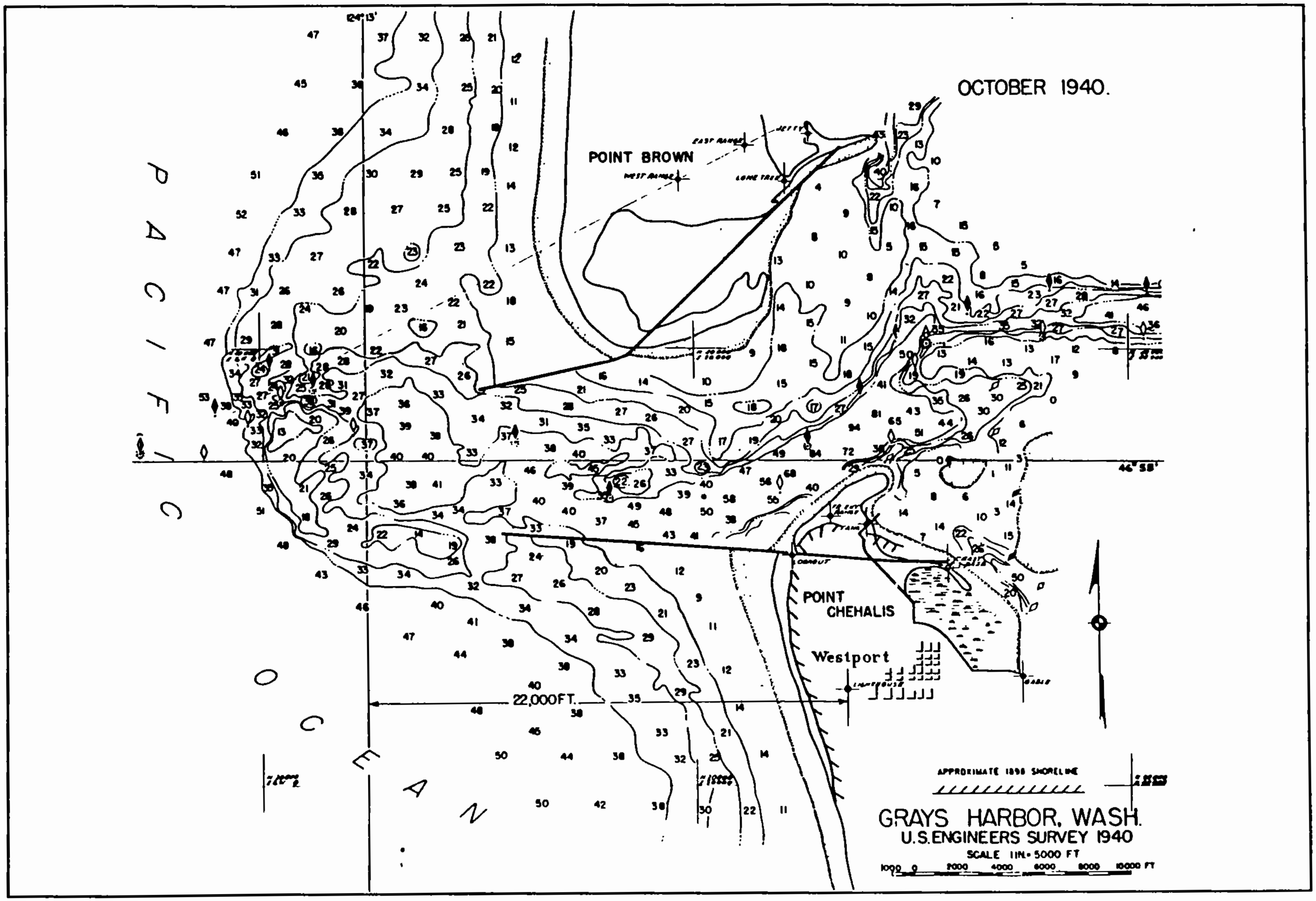


Figure 5. Entrance configuration in 1940

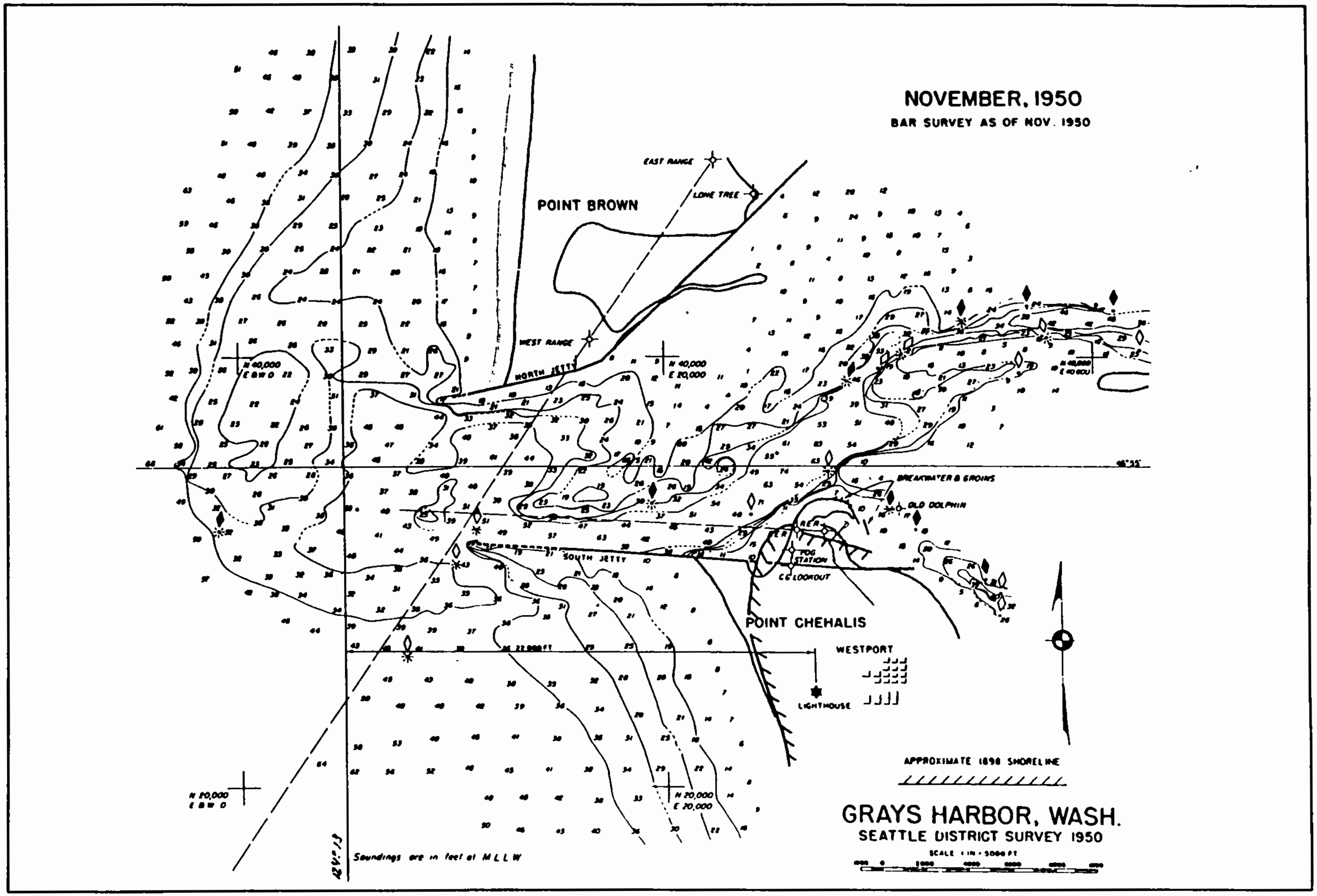


Figure 6. Entrance configuration in 1950

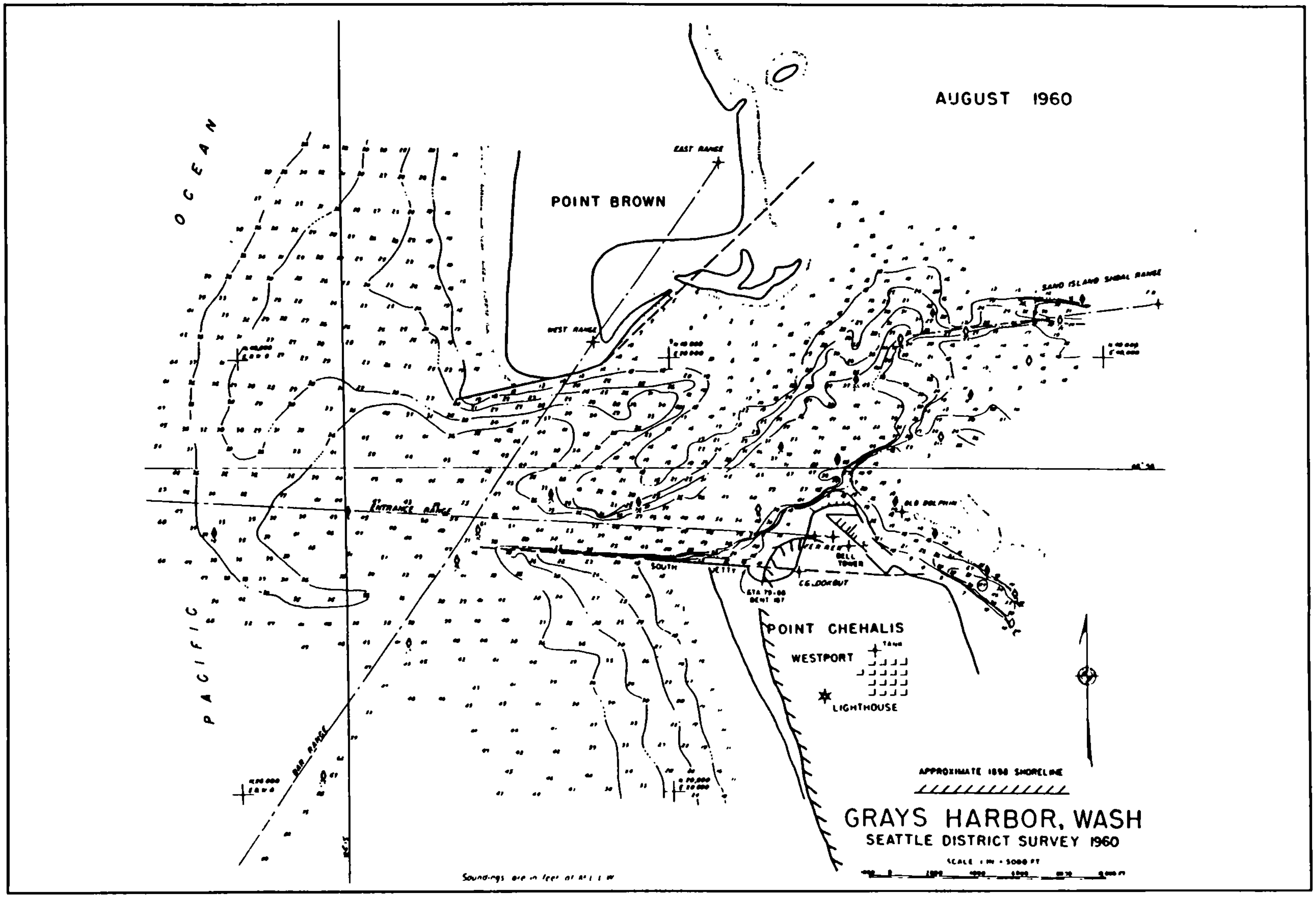


Figure 7. Entrance configuration in 1960

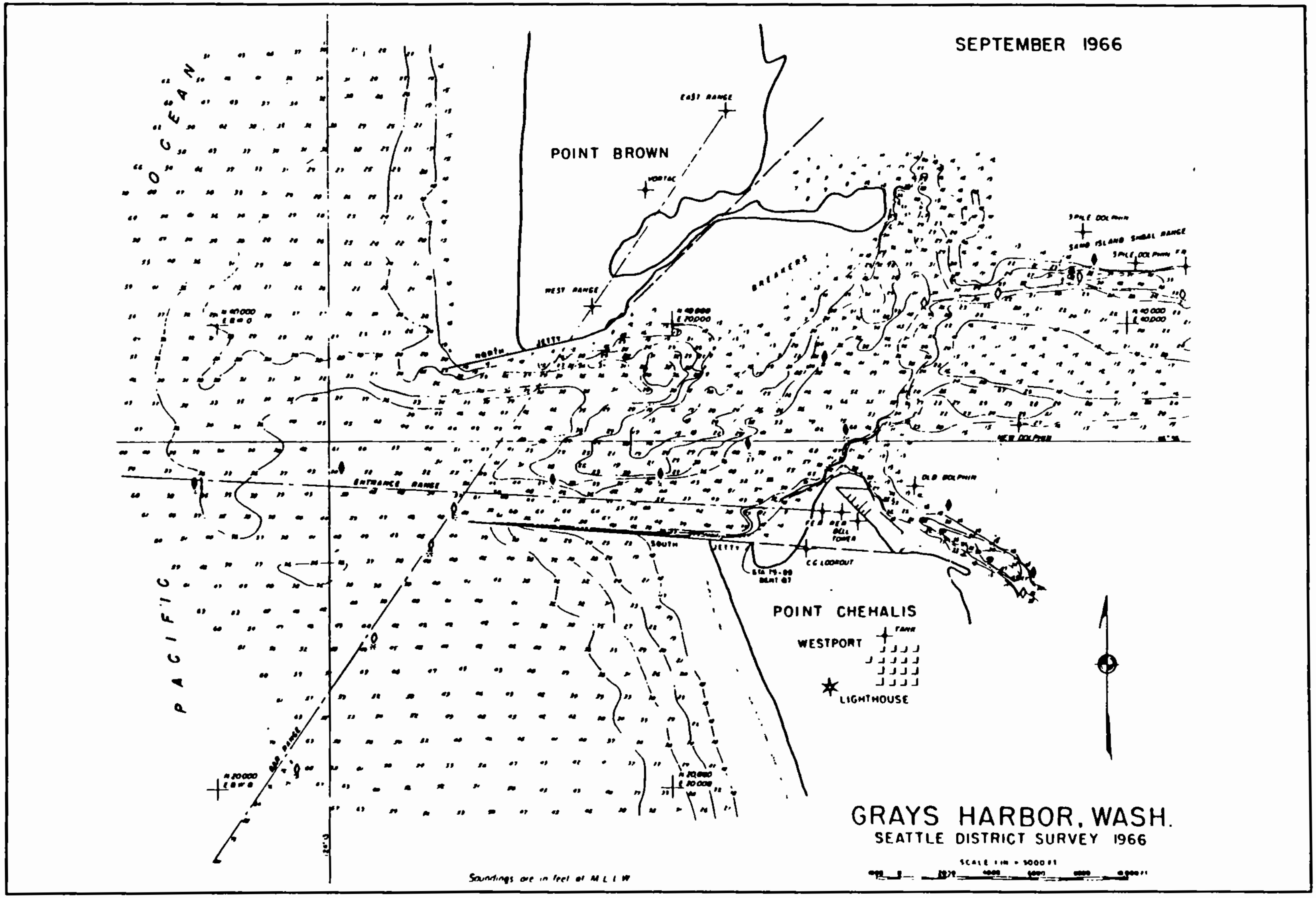


Figure 8. Entrance configuration in 1966

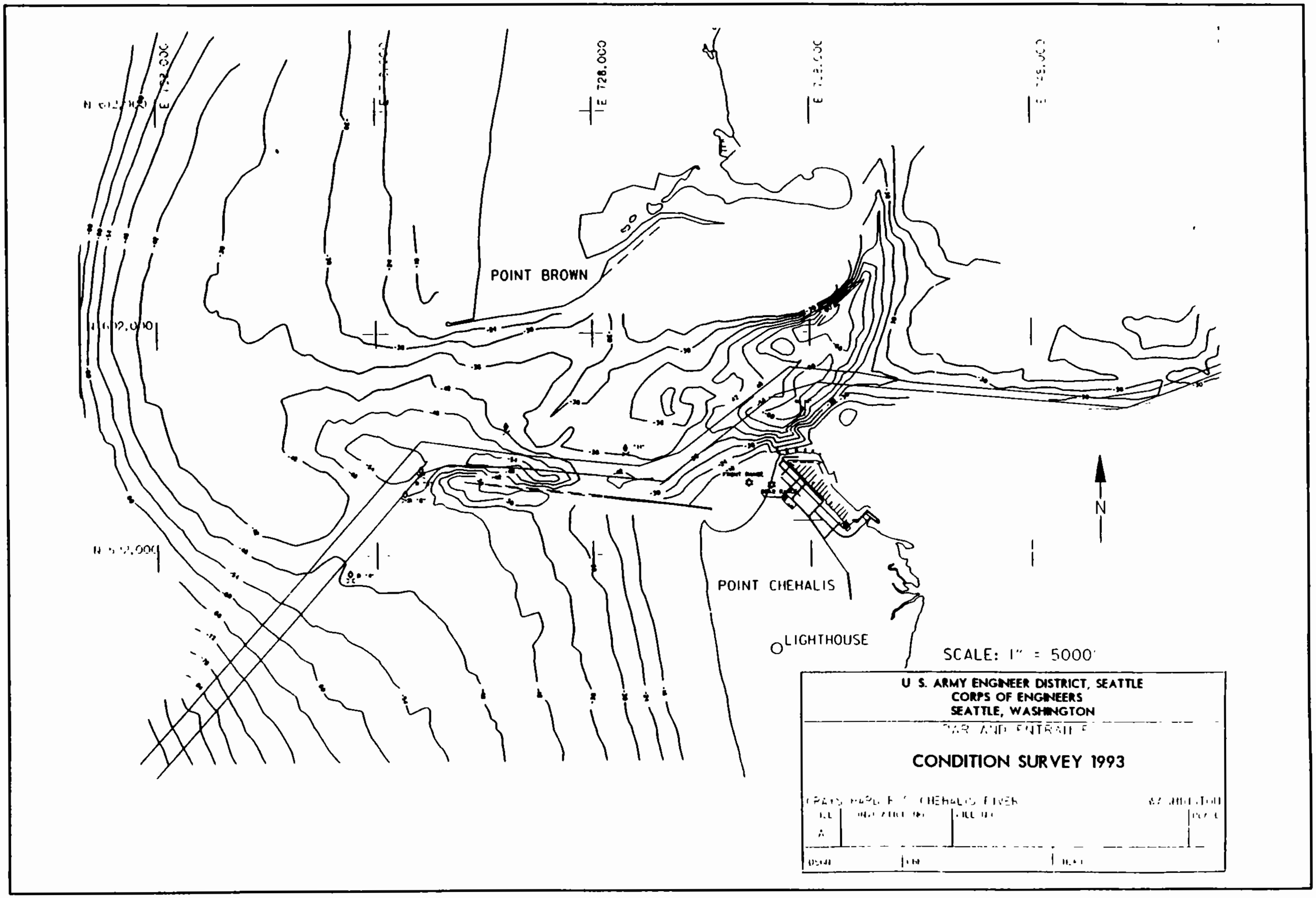


Figure 9. Entrance configuration in 1993

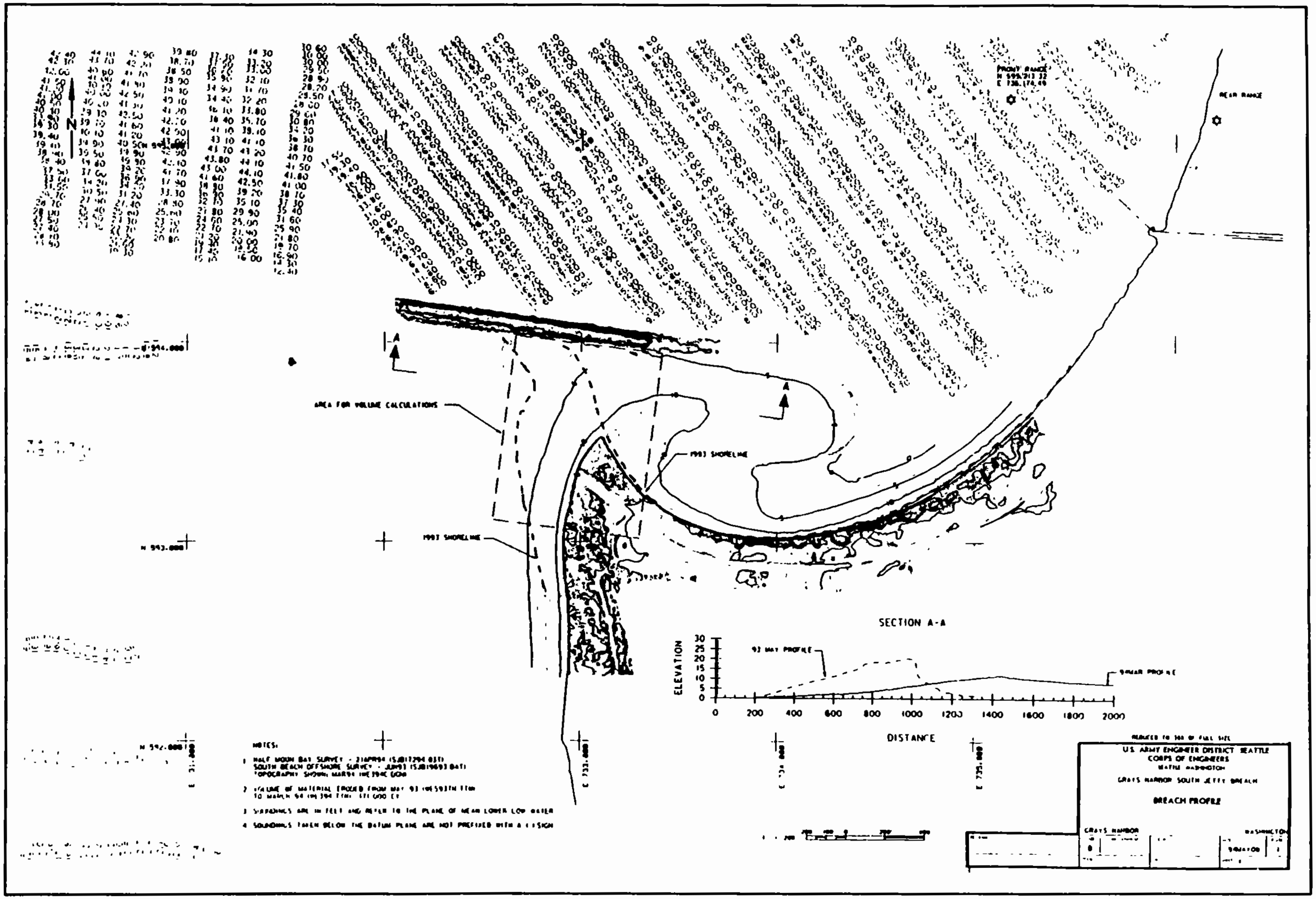
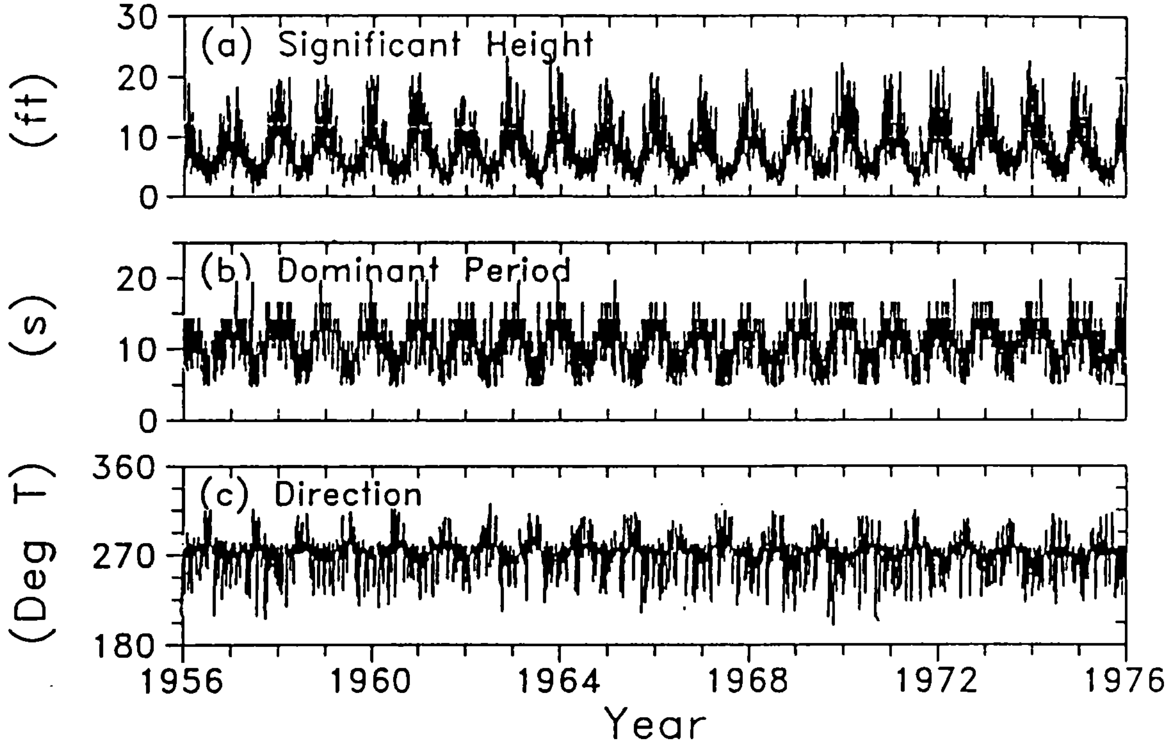
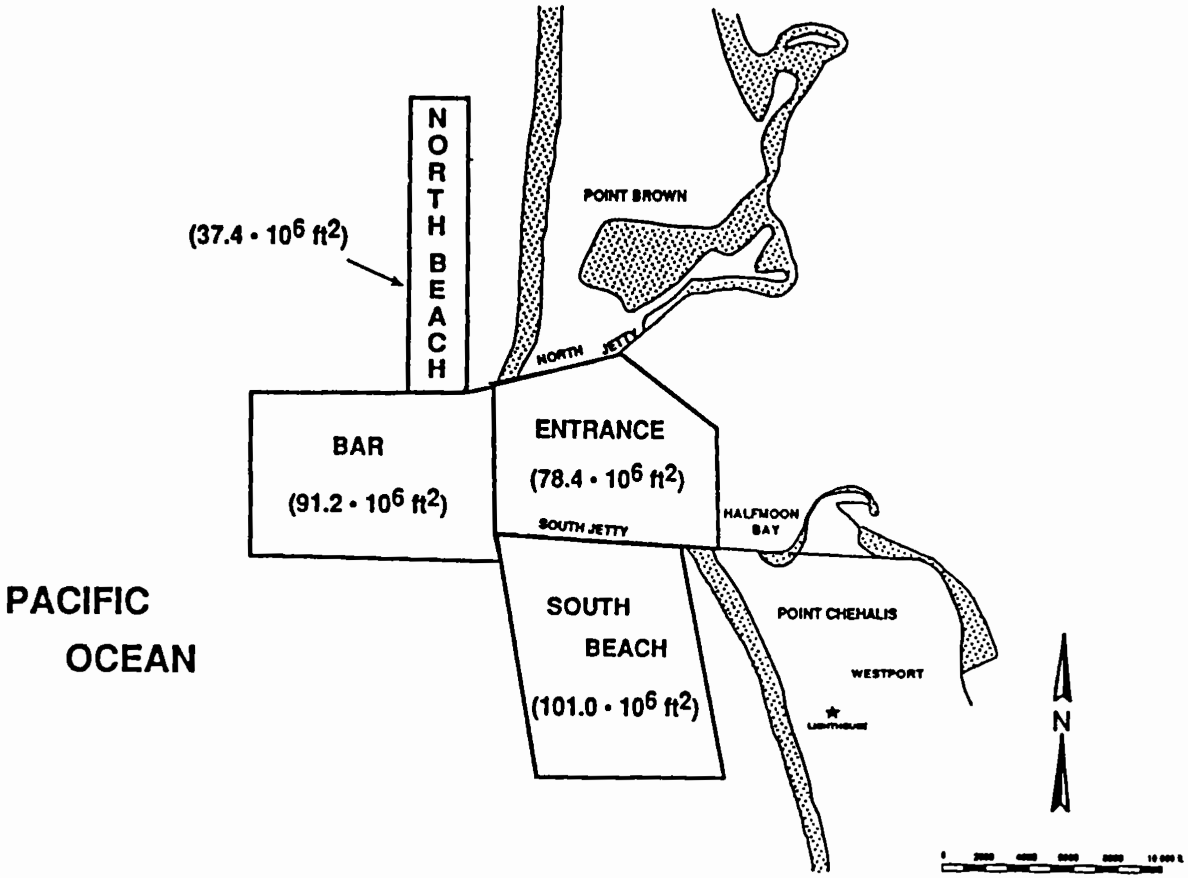


Figure 10. Breach and deposit in Half Moon Bay



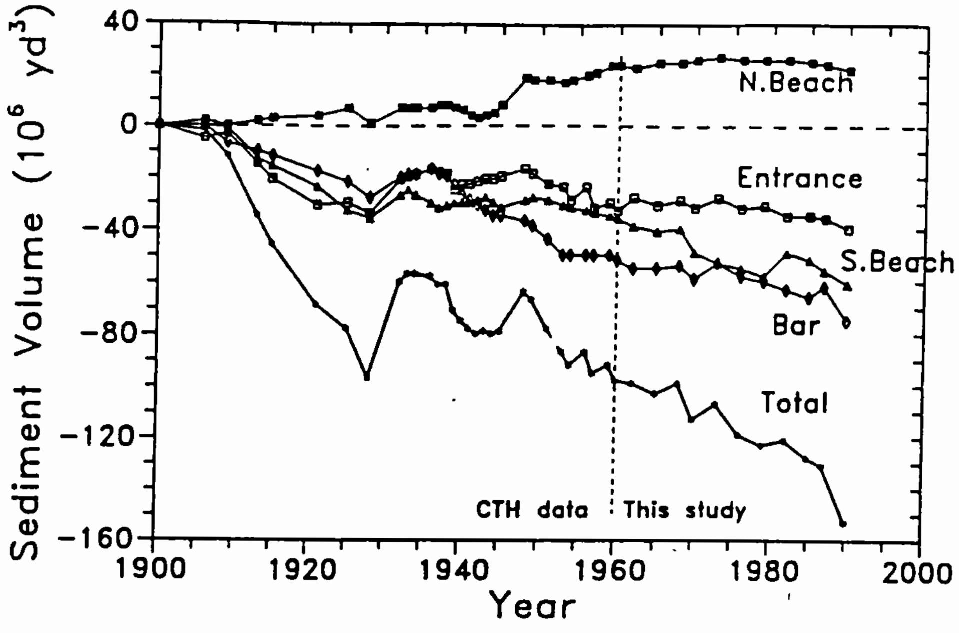
Time Series of Wave Information Studies Wave Model Hindcasts for Station 16 at 3-h Intervals from 1956 to 1976. (a) Significant wave height, (b) dominant wave period, (c) average wave direction.

Figure 11. Hindcast wave data for WIS station 16 (from Battelle/Marine Sciences Laboratory 1992)



Areas for Sediment-Volume Calculations. Numbers in parentheses indicate size of each area.

Figure 12. Areas selected for evaluation of volume changes (from Battelle/Marine Sciences Laboratory 1992)



Sediment-Volume Changes for the Period 1900 Through 1990 from Combined Data of the Committee on Tidal Hydraulics Report and This Study.

Figure 13. Historic volume changes for selected areas (from Battelle/Marine Sciences Laboratory 1992)

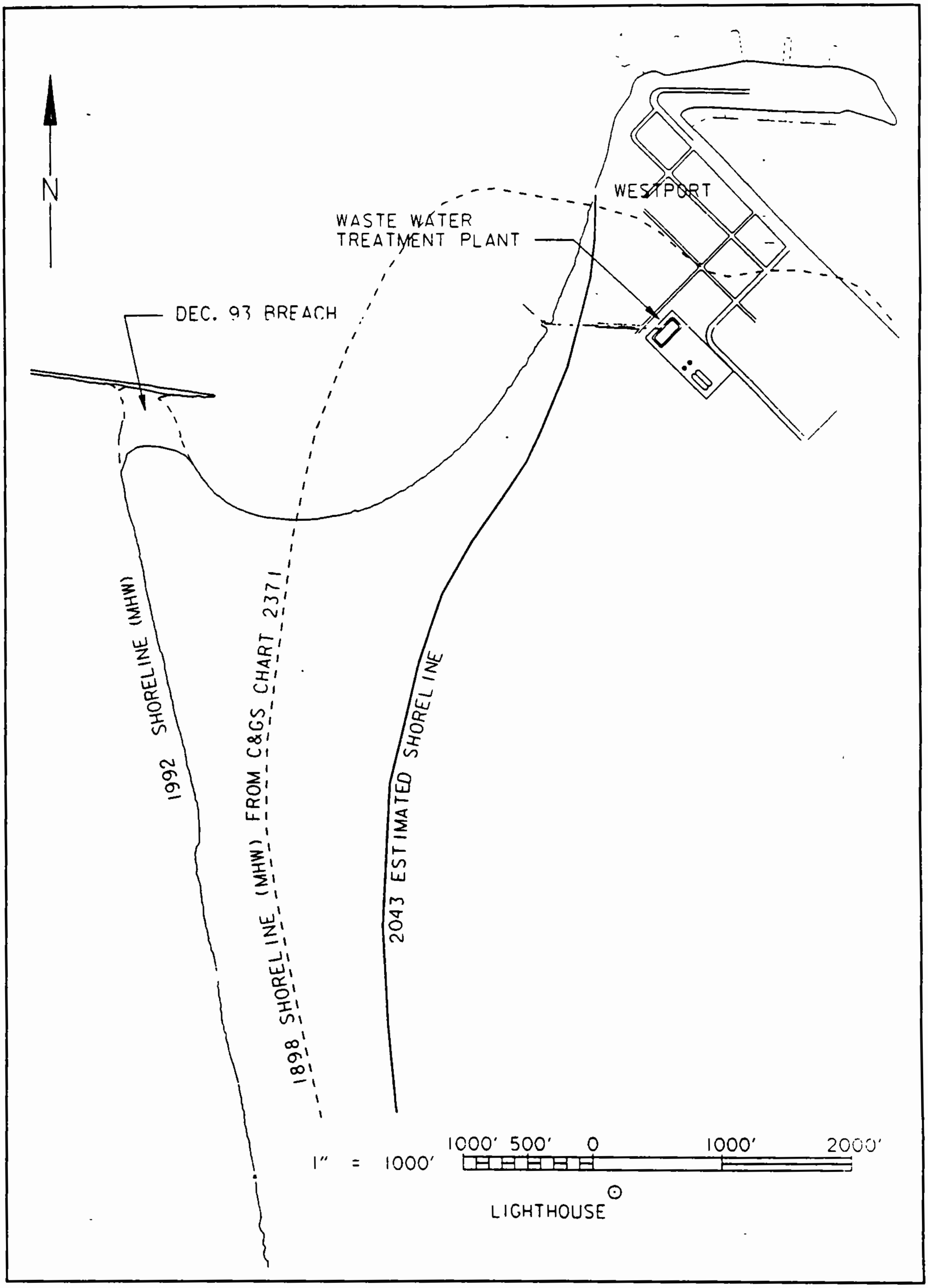


Figure 14. Projected 2043 shoreline estimated by the Seattle District

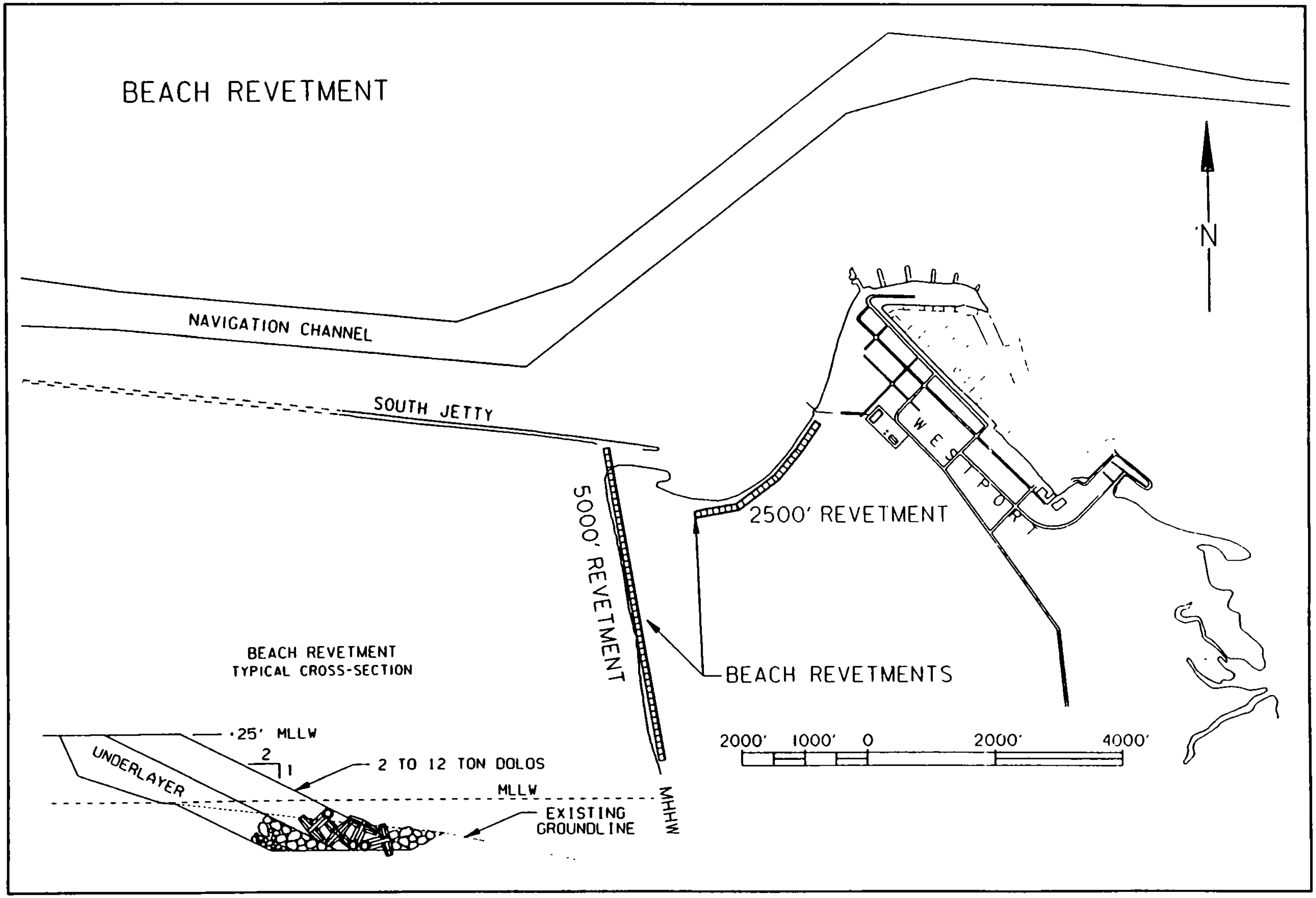


Figure 15. Beach revetment alternative

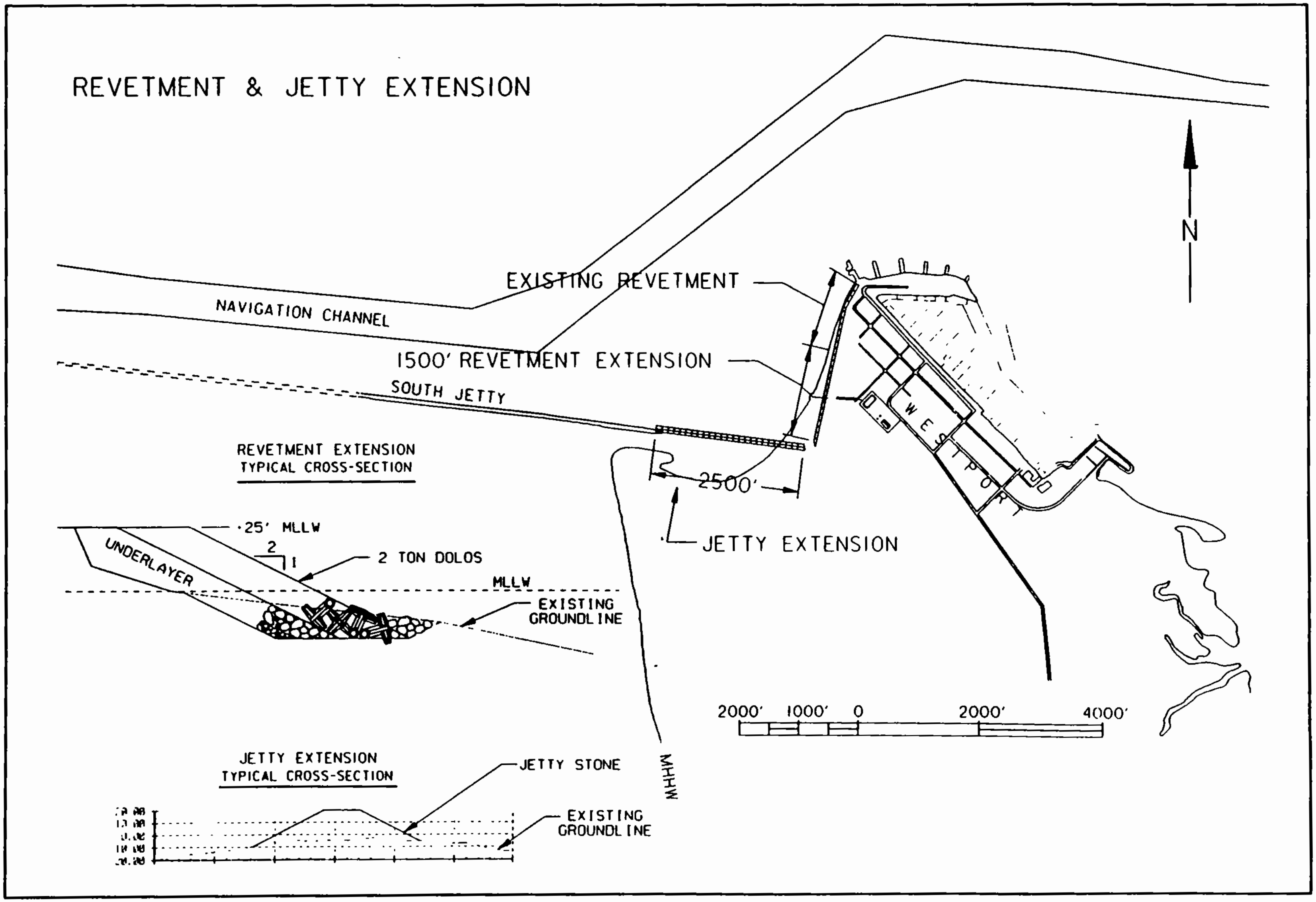


Figure 16. South jetty extension and revetment alternative

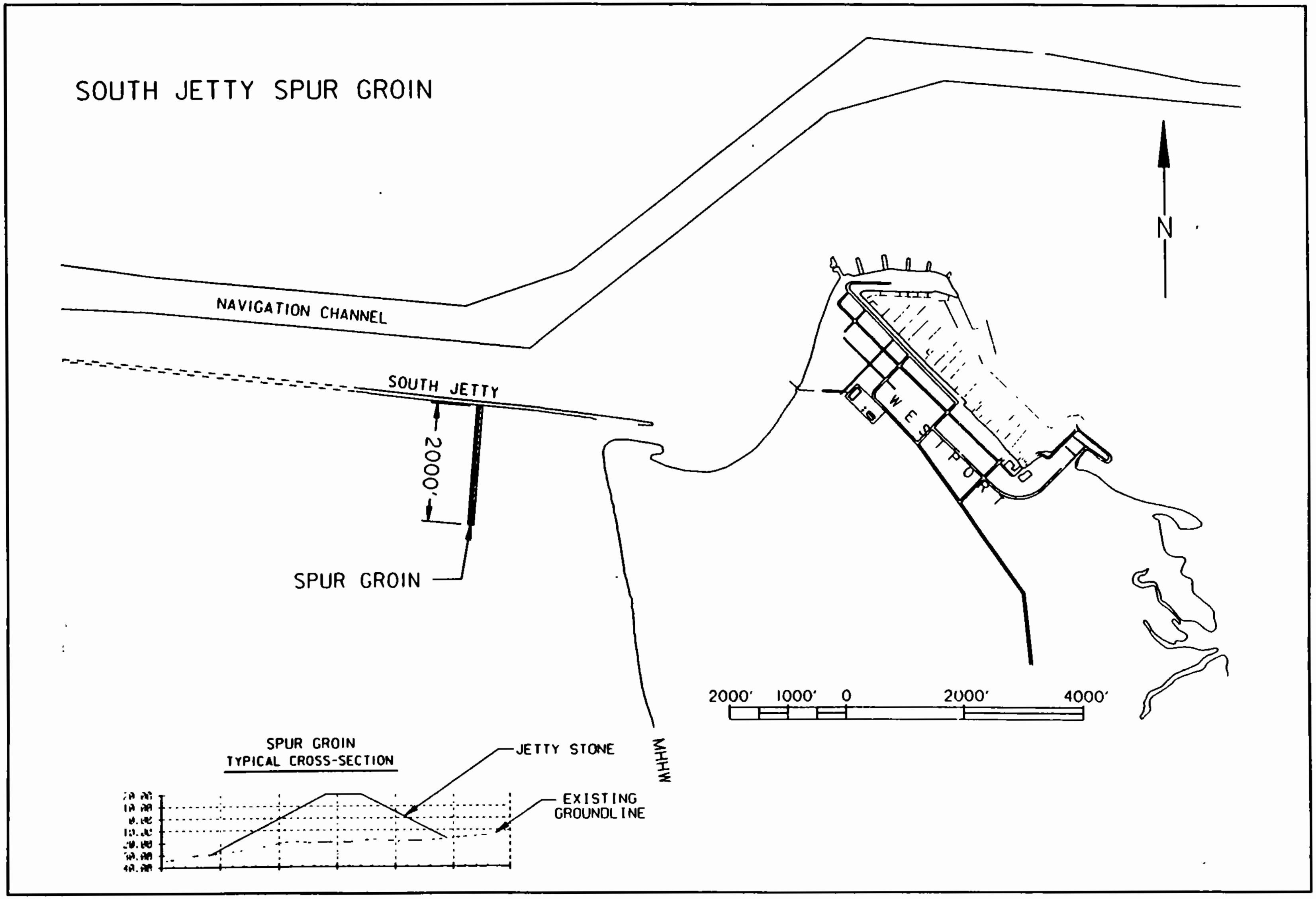


Figure 17. Spur groin alternative

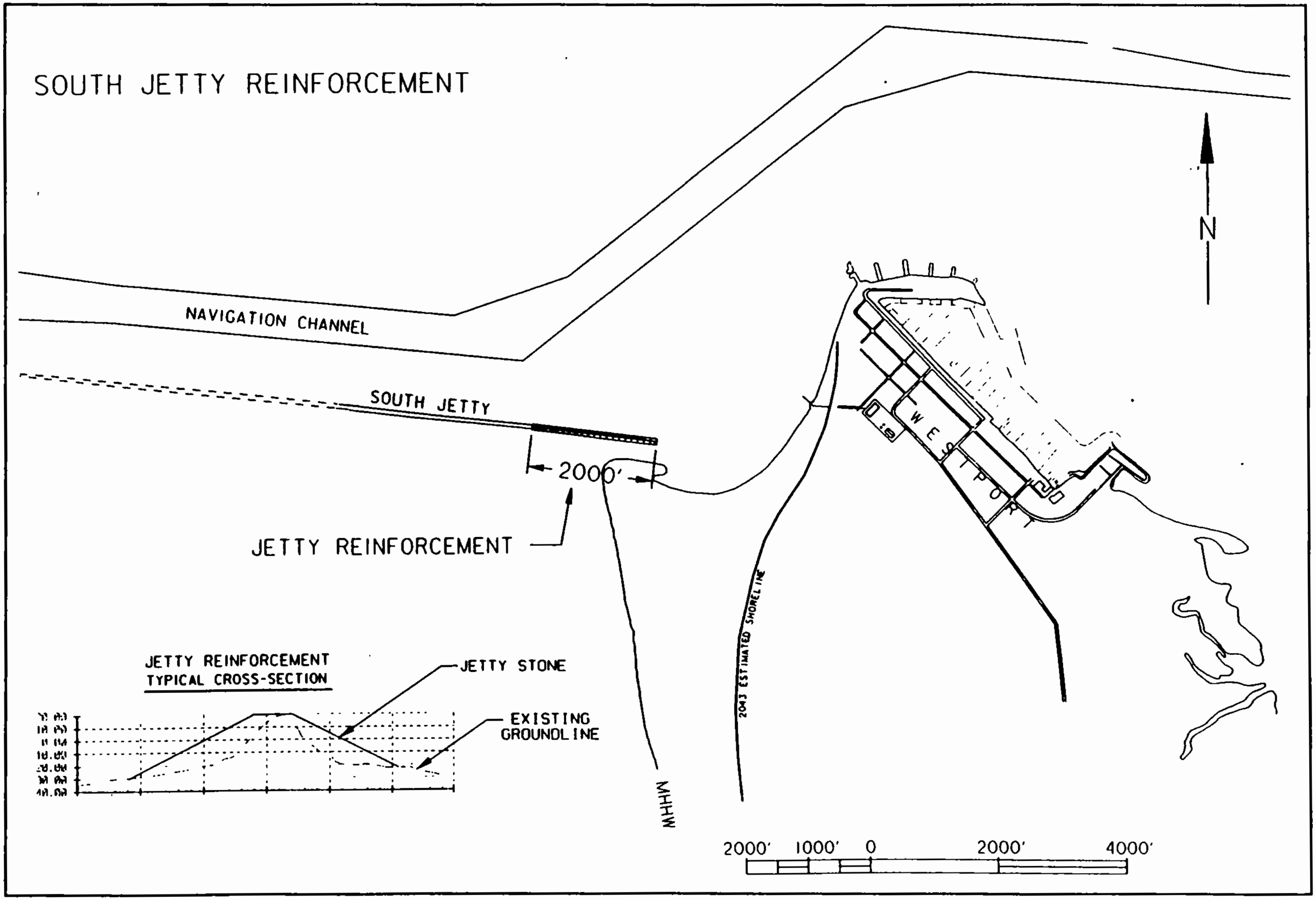


Figure 18. South jetty reinforcement alternative

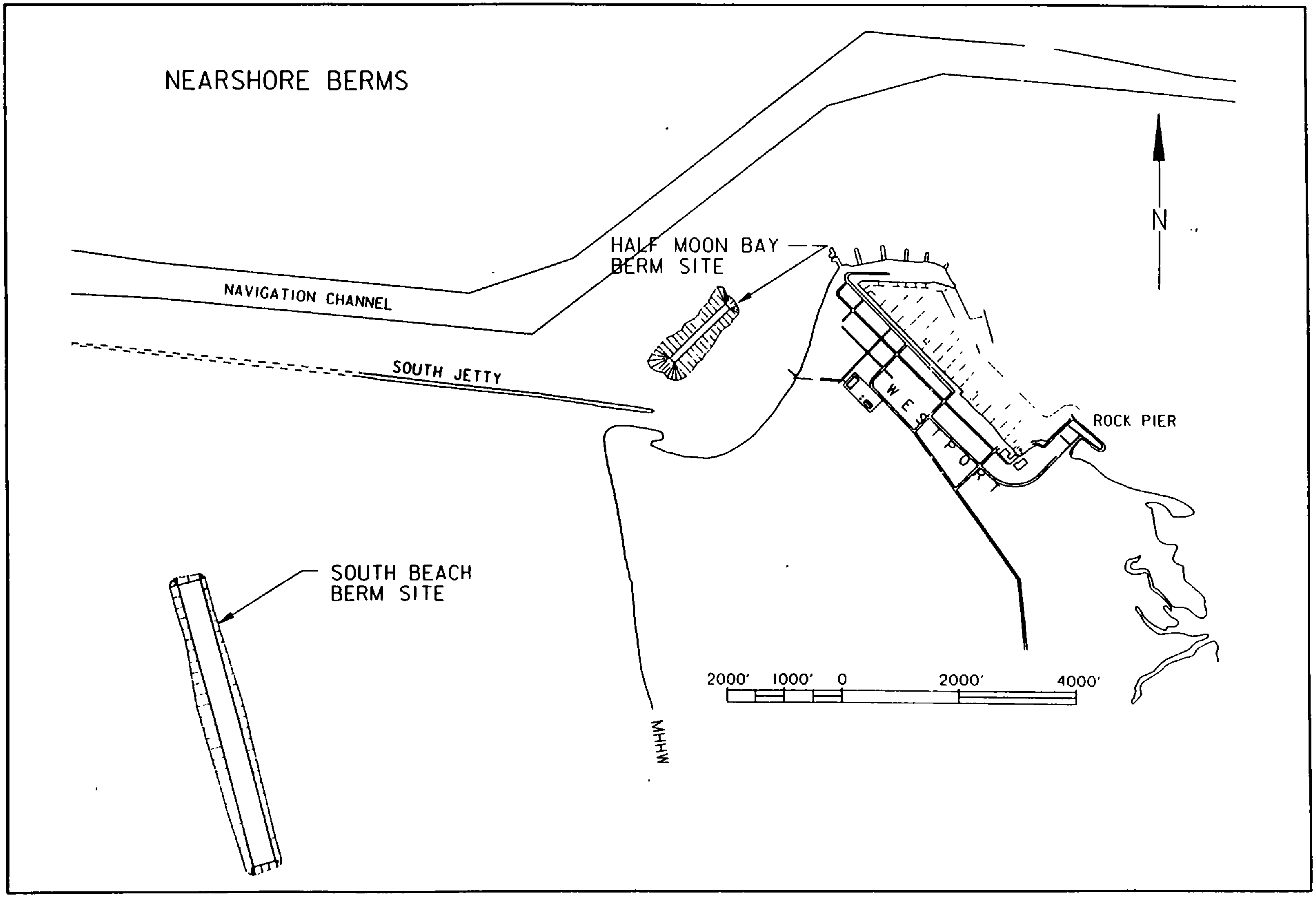


Figure 19. Nearshore berm alternative

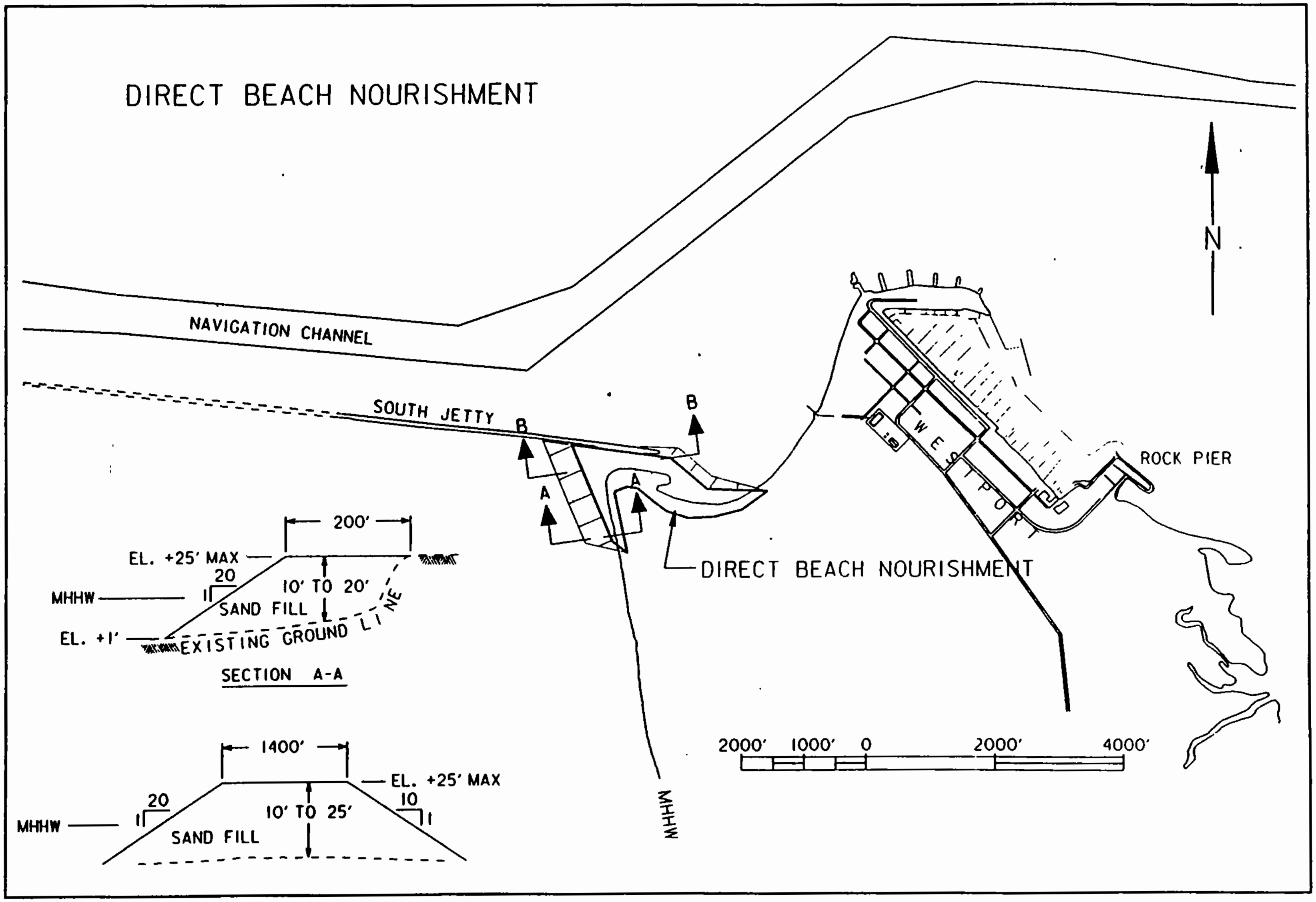


Figure 20. Direct beach nourishment alternative

Photo 1. Initial breach formation, looking seaward, 10 December 1993

Photo 2. Initial breach formation, looking landward, 10 December 1993

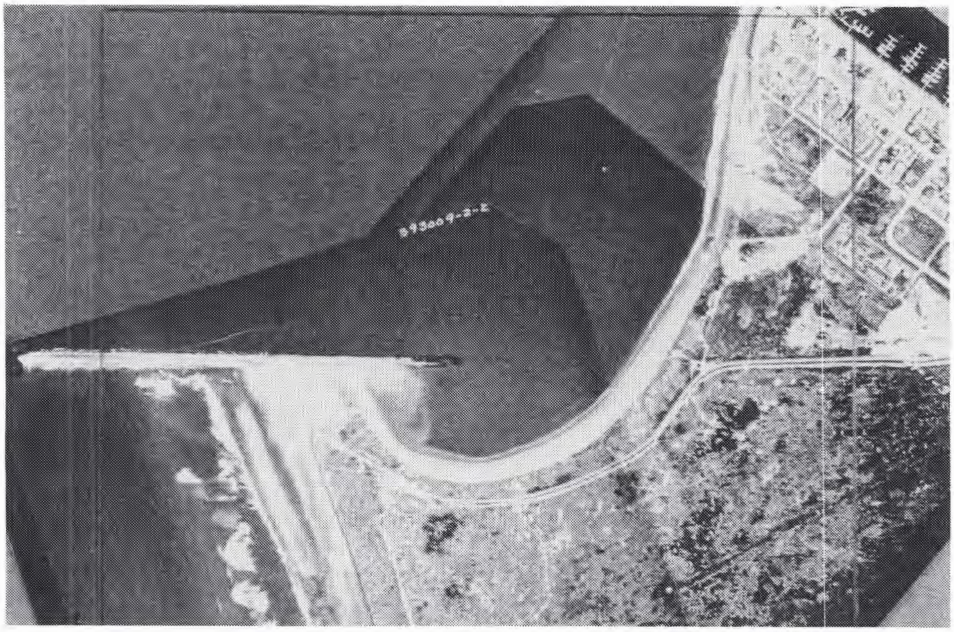


Photo 3. 23 May 1993, tide elevation -1.6 ft mllw, approximate scale 1 in. = 1,400 ft

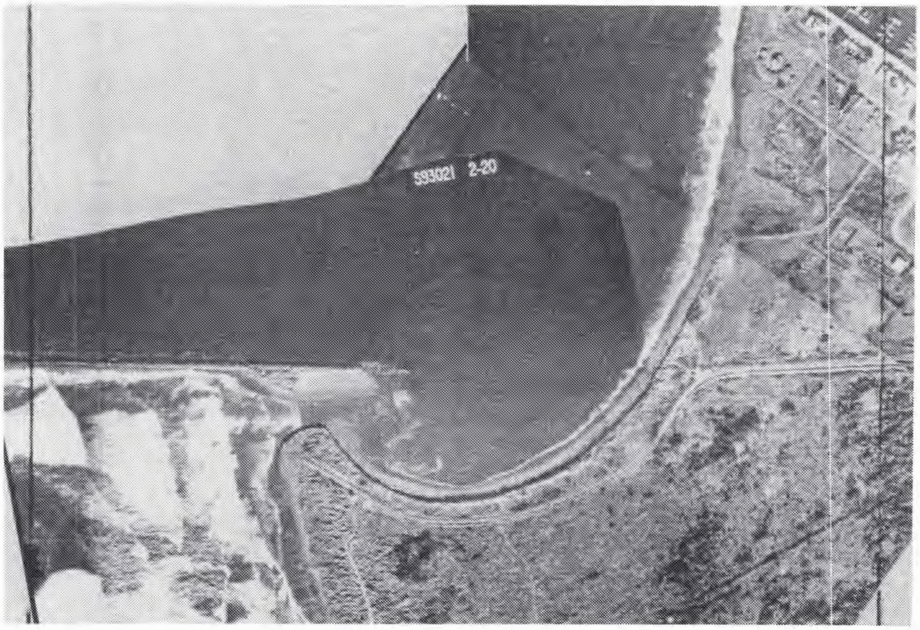


Photo 4. 17 December 1993, tide elevation +6.5 ft mllw, approximate scale 1 in. = 1,400 ft

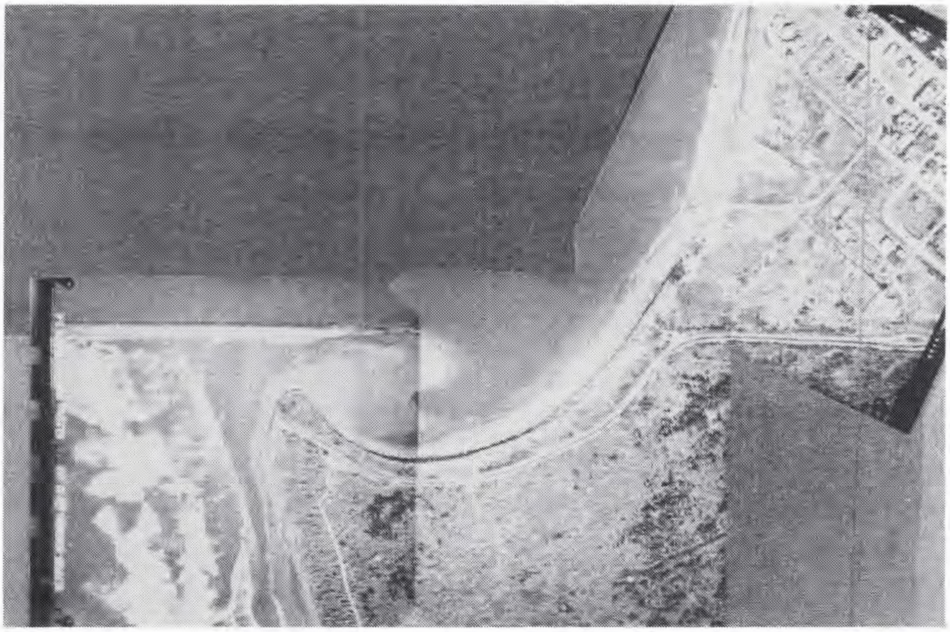


Photo 5. 2 February 1994, tide elevation +2.0 ft mllw, approximate scale 1 in. = 1,400 ft

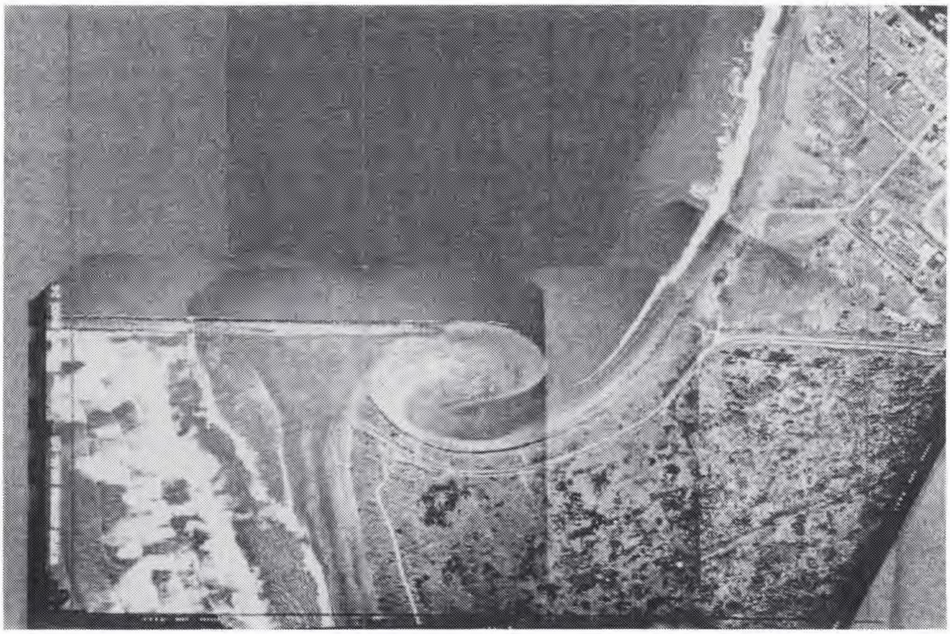


Photo 6. 6 March 1994, tide elevation +1.3 ft mllw, approximate scale 1 in. = 1,400 ft

Photo 7. Looking north, May 1994 (Photo courtesy of City of Westport)

Photo 8. Looking south, May 1994 (Photo courtesy of City of Westport)

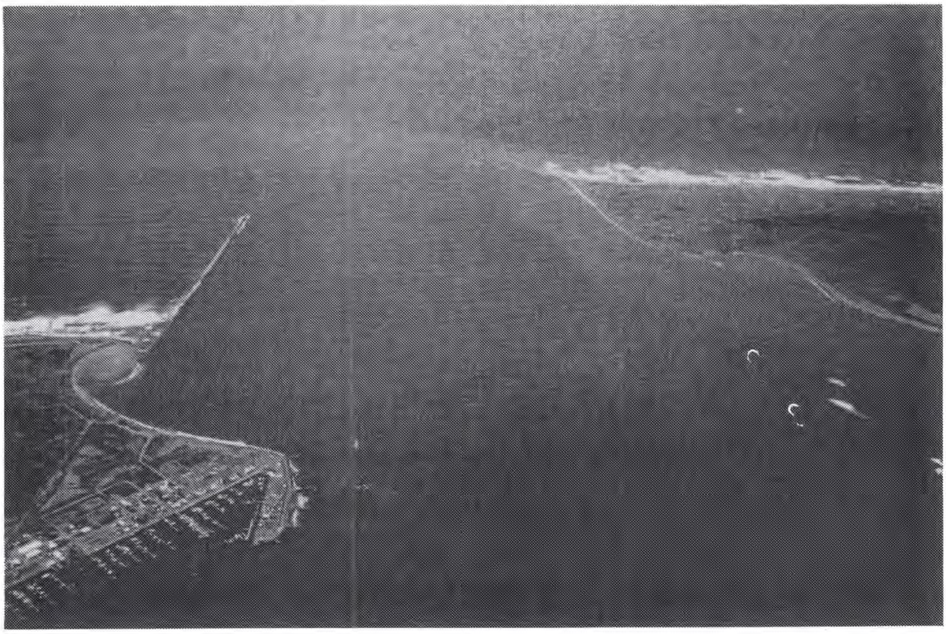


Photo 9. Looking west, May 1994 (Photo courtesy of City of Westport)

Photo 10. Looking east, May 1994 (Photo courtesy of City of Westport)

Appendix A
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Appendix B
Plan of Study
Long-Term Maintenance of the Grays Harbor South Jetty

1. Establish long term monitoring plan.
   a. Maintain control points for aerial surveillance.
   b. Make flights on a regular basis. (Bi-monthly at this time)
   c. Conduct offshore hydrographic surveys semi-annually.
   d. Conduct nearshore hydrographic surveys quarterly.
   e. Evaluate survey data on an as-needed basis.
   f. Conduct monthly site visits.

2. Prepare temporary closure plan for breach (Close by Nov. 4.)
   a. Coordinate with public, State and Federal agencies, Corps H.A., etc.
   b. Prepare plans and specifications for the temporary closure plan.
   c. Estimate quantities and costs for the closure plan.

3. Develop alternative methods to address long term erosion adjacent to the south jetty.
   a. Do nothing, allow erosion to continue.
   b. Structural alternatives:
      Reinforce east end of south jetty at present location.
      Extend south jetty eastward to Pt. Chehalis revetment.
      Construct a spur groin southward from the jetty.
   c. Beach nourishment:
      Determine volume requirements for beach nourishment only.
      Determine realistic volumes of maintenance dredged material that will be economically feasible to use for beach nourishment.
   d. Combined structure and beach nourishment, (incl. nearshore berms).
   e. Other (channel realignment, etc.).

4. Develop scope of work for NPS and/or WES for the following tasks:
   a. Collect tidal current and water level data for use in models.
   b. Optimize nearshore berm locations.

c. Investigate historical shoreline changes between the south jetty to Willapa Bay.

d. If required, conduct numerical or physical model studies to determine:
Breach size which will adversely affect the navigation channel.
Ebb and flood velocities in navigation channel for various sizes breach channel.
Shoaling rate in navigation channel for various breach sizes.
Hydraulic effects of alternative navigation channel alignments.
Optimum length and location of structural alternatives.

5. Develop recommended plan.
   a. Coordinate with resource agencies and select breach closure plan.
   b. Develop const. costs, schedules, funding (O&M, local cost sharing).
   c. Review of recommended plan by Corps' consultants.

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13. ABSTRACT *(Maximum 200 words)*
The purpose of monitoring the Demonstration Erosion Control (DEC) Project is to evaluate and document watershed response to the implemented DEC Project. Documentation of watershed responses to DEC Project features will allow the participating agencies a unique opportunity to determine the effectiveness of existing design guidance for erosion and flood control in small watersheds. The monitoring program includes 11 technical areas: stream gauging, data collection and data management, hydraulic performance of structures, channel response, hydrology, upland watersheds, reservoir sedimentation, environmental aspects, bank stability, design tools, and technology transfer.

This report includes detailed discussion of the eight technical areas that were investigated by the U. S. Army Engineer Waterways Experiment Station during Fiscal Year 1993, i.e., all of these areas except upland watersheds, reservoir sedimentation, and environmental aspects.

In the area of data collection and data management, installation of continuous stage gauge instrumentation at 33 sites and crest gauges at an additional 42 sites was completed and data collection initiated. The initial development of the engineering database on Intergraph workstations was completed and made available to the U.S. Army Engineer District, Vicksburg, for testing.

14. SUBJECT TERMS

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Coastal engineering	

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