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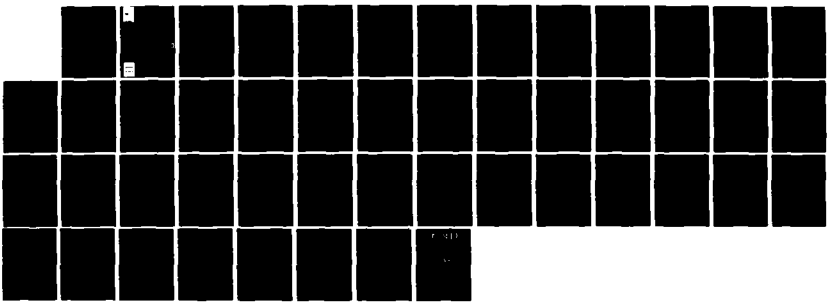

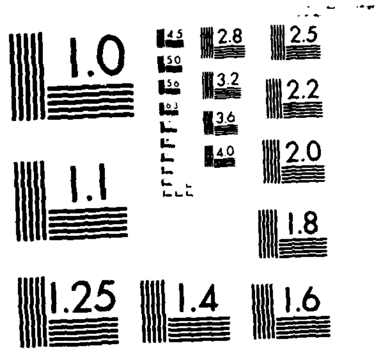

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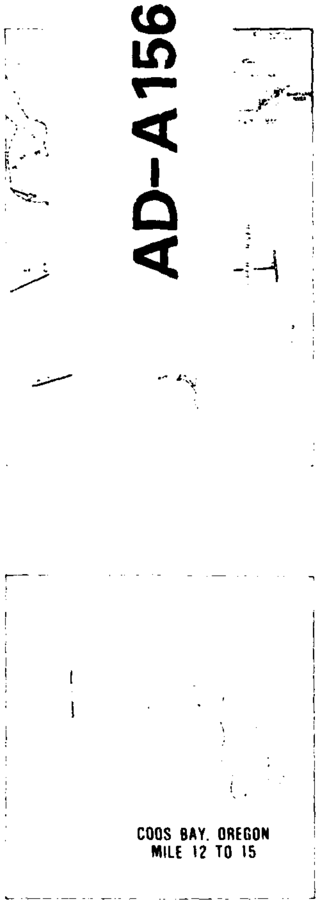

HYDRAULICS LABORATORY

(2)

TECHNICAL REPORT H-78-5

EFFECTS OF DEPTH ON DREDGING FREQUENCY

Report 3

EVALUATION OF ADVANCE MAINTENANCE PROJECTS

by

Rutherford C. Berger, Jr., Jesse A. Boyd, Jr.

Hydraulics Laboratory

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Overall costs of maintaining authorized or required project depths in the navigation channels and harbors of the United States by dredging have increased dramatically during the last decade. To reduce these costs by extending the interval between maintenance dredging operations--and to provide full project dimensions for a greater period of time--advance maintenance is performed at critical shoaling areas of many navigation projects. Advance maintenance is dredging done beyond the existing authorized depth of a project

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to provide a predetermined amount of catchment capacity below design depth. It is exclusive of the allowable dredging tolerance (usually 1 to 2 ft) common to most dredging operations which compensates for inaccuracies inherent to the practice. This report, the third of a series, examined and evaluated the effectiveness of advance maintenance dredging in producing desired results for six selected navigation channel segments. These segments are: Shipyard River, S. C., Coos Bay, Oreg. (miles 0 to 1 and 12 to 15), and three reaches of the Columbia River, Oreg.-Wash. between miles 73 and 84. This was accomplished by comparing shoaling rates and distributions and dredging frequencies resulting from maintenance operations on these projects which included advance maintenance with others which did not. Data used were obtained from predredge and postdredge surveys and other pertinent dredging information from Corps district offices and annual reports of the Chief of Engineers. Results indicated that advance maintenance was beneficial in some, but not all, cases and that it should be evaluated on a case-by-case basis.

PREFACE

The study reported herein was conducted by personnel of the Hydraulics Laboratory, US Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, under the Improvement of Operations and Maintenance Program, Office, Chief of Engineers, US Army. This is the third report in a series dealing with the results of an in-depth investigation of the practice of advance maintenance dredging.

The study was conducted during the period 1978 to 1982 under the direction of Messrs. H. B. Simmons and F. A. Herrmann, Jr., former and present Chiefs of the Hydraulics Laboratory; R. A. Sager, Chief of the Estuaries Division; R. A. Boland, Chief of the Hydrodynamics Branch; and M. J. Trawle, Project Manager. This report was prepared by Messrs. R. C. Berger, Project Engineer, and J. A. Boyd with the assistance of Messrs. Boland and Trawle.

Commanders and Directors of WES during the investigation and the preparation and publication of this report were COL John L. Cannon, CE, COL Nelson P. Conover, CE, COL Tilford C. Creel, CE, and COL Robert C. Lee, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, US CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

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

Multiply	By	To Obtain
acre-feet	1233.482	cubic metres
cubic feet	0.02831685	cubic metres
cubic feet per second	0.02831685	cubic metres per second
cubic yards	0.7645549	cubic metres
feet	0.3048	metres
miles (US nautical)	1.852	kilometres
miles (US statute)	1.609344	kilometres
square miles (US statute)	2.589988	square kilometres
tons (2,000 lb, mass)	907.1847	kilograms

EFFECTS OF DEPTH ON DREDGING FREQUENCY

EVALUATION OF ADVANCE MAINTENANCE PROJECTS

PART I: INTRODUCTION

Background

1. One of the Corps of Engineers responsibilities is that of improving and maintaining navigation channels and harbors in the United States. Recently, the cost of maintenance dredging in estuaries has grown rapidly as a result of many factors including: increased environmental awareness, urban expansion and previous dredging eliminating disposal sites, increased traffic calling for more closely maintained channel, and labor cost increases.

2. In view of this, utilization of any equipment, operation and maintenance procedures, or methodology that improves the cost-effectiveness of maintenance dredging should be considered. The subject of this report involves one such methodology, "Advance Maintenance."

3. Advance maintenance is a maintenance procedure in which the channel section is deepened (sometimes widened) to allow a reduced dredging frequency. If the shoaling rate is not increased significantly maintenance costs will be reduced because of less frequent mobilization and demobilization of dredging plant. A typical channel cross section with no advance maintenance is shown in Figure 1. The required depth here is generally the authorized project depth; however, it may be less. The dredging tolerance (usually only 1 to 3 ft*) is provided due to dredging inaccuracies. Figure 2 shows a channel with provisions for advance maintenance. The required channel depth is the authorized depth plus the depth of advance maintenance.

4. Advance maintenance should provide additional time before redredging is needed, which would mean a savings in the costs associated with starting and completing dredging operations--mobilization, demobilization, survey costs, and others. These costs will be referred to as mobilization costs. A brief list of potential advantages and difficulties of advance maintenance are shown below.

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* A table of factors for converting US customary units of measurement to metric (SI) units is presented on page 3.

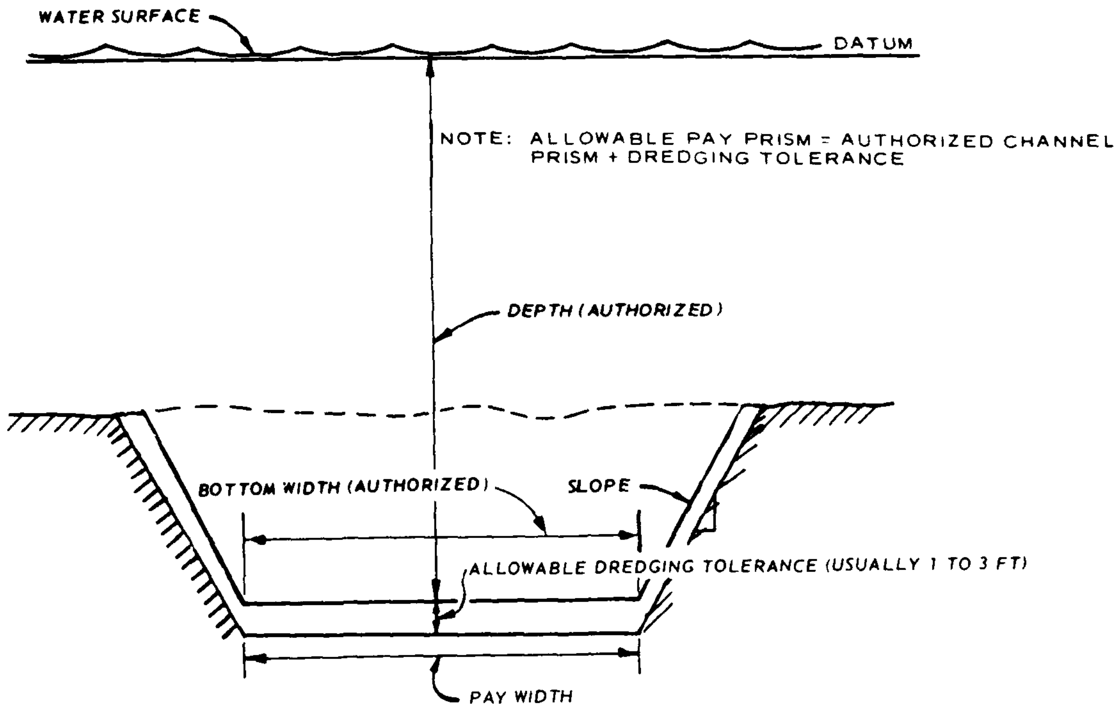

Figure 1. Typical dredged channel cross section

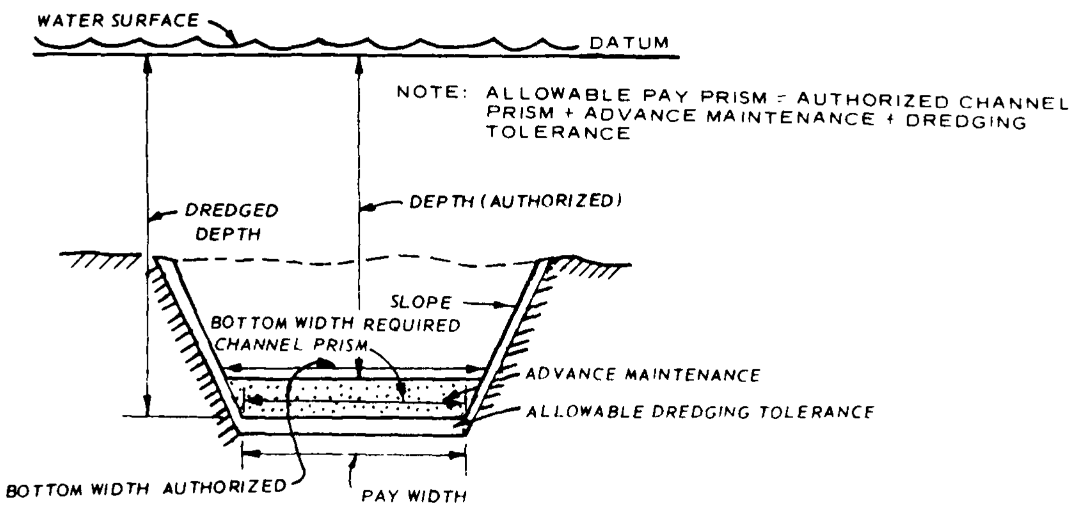

Figure 2. Dredged channel cross section with advance maintenance included

a. Possible advantages

(1) Reduced expenditures for mobilization

(2) Increased scheduling flexibility for dredging

(3) Allowed project dimensions for a greater length of time

(4) Increased dredge efficiency due to larger cut

b. Possible difficulties

(1) Cost of the initial advance maintenance (including utilization of disposal sites)

(2) If shoaling rate increases due to advance maintenance, disposal areas would be used more rapidly

(3) A shift in the shoaling distribution to a less advantageous region due to the enlargement

(4) Dredging operations could take longer

These factors would have to be evaluated from an economic standpoint.

5. It would seem apparent that potential economically beneficial advance maintenance candidates would have one of the following characteristics:

a. High associated mobilization costs.

b. Dredge scheduling difficulties.

c. Critical shoaling primarily in a short reach; this reach could use advance maintenance with the rest of the channel dredged normally. This would reduce initial costs.

d. A project which has historically not shown tremendous increase in shoaling with channel enlargement.

Approach

6. This report discusses the use of advance maintenance on a few particular sites that might point out some general uses of advance maintenance in practice. The primary factors that are of concern are the shoaling rate and distribution and the dredging frequency before and after application of advance maintenance.

7. Maintenance histories of six navigation channel segments are presented and evaluated in this report with regard to the effects of advance maintenance on dredging frequency, shoaling or dredging rate, and shoaling distribution. The channel segments are located at Shipyard River, S. C.; Coos Bay, Oreg.; entrance (miles 0 to 1) and inner channel (miles 12 to 15), and three reaches of the Columbia River, Oreg.-Wash., between miles 73 and 84 (Kalama, Lower Martin Island, and Upper Martin Island). Effects of advance

maintenance were analyzed by comparing the results of dredging operations that included advance maintenance with those that did not. Data used in this report are based on predredge and postdredge survey sheets and other pertinent dredging information obtained from the Corps District Offices and the history of dredging operations contained in the Corps Annual Reports.

8. Analysis of maintenance requirements was based primarily on information from the Corps Annual Reports. The initial dredging of advance maintenance on a project was considered new work instead of maintenance in this report, so this amount usually had to be estimated from hydrographic survey results. Average maintenance requirements and dredging period values with and without advance maintenance conditions were compared. The "period" is the length of time from the completion of one dredging operation to the completion of the next. The inverse of this parameter indicates the number of times dredging was necessary within a specified time, or the dredging frequency.

9. The average values used for these comparisons were determined using data that contained a certain amount of variability. This variability or variance requires that the determination of the effectiveness of advance maintenance is a statistical exercise. The 10 percent level of significance was chosen for this task. This means that if a condition were judged to be significantly different from another there is only a 10 percent chance that in reality the two conditions were identical; but due to the particular samples chosen to represent each condition, a difference was noted as being significant. The student's t-test (Owen 1962) was used where possible to make the evaluation. The value of "t" was calculated as follows:

$$t = \left[\frac{(\bar{x}_1 - \bar{x}_2)}{\sqrt{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}}\right] \left[\frac{n_1 n_2 (n_1 + n_2 - 2)}{n_1 + n_2}\right]$$

where:

$\bar{x}_1$ and $\bar{x}_2$ are the means of samples 1 and 2

n_1 and n_2 are the sample sizes of samples 1 and 2

S_1 and S_2 are the standard deviations of samples 1 and 2

If the absolute value of the calculated "t" was greater than the student's "t" found in standard statistical tables for a significance level of 0.10 for $(n_1 + n_2 - 2)$ degrees of freedom, the difference was considered significant.

10. The student's t-test assumes that the samples are from normally distributed populations and that the population variances are equal. In order to use the t-test, the variances of the two samples must be shown not to be significantly different. This was done by dividing the larger sample variance by the smaller. The resulting value would indicate a significant difference if greater than the value of "F" in an F distribution table (Owen 1962) for the appropriate significance level.

11. In the event that the difference in the sample variances was too great to use the student's t-test, a nonparametric method known as the Mann-Whitney U test (Owen 1962) was used. This method is not as effective as the t-test but can be applied to samples with unequal variances. To perform the Mann-Whitney test, data from the two samples are ranked jointly in increasing (or decreasing) order of magnitude. From this ranking the statistic "U" can be calculated.

$$U = n_1 n_2 + \frac{n_1(n_1 + 1)}{2} - R_1$$

where:

n_1 and n_2 are sample sizes of samples 1 and 2

R_1 is the sum of the ranks assigned to the values of the first sample

If ($U_{0.95} \leq U_{calculated} \leq U_{0.05}$) then the samples were considered significantly different at the 0.10 significance level.

12. The distribution of shoaling within a project for conditions with and without advance maintenance was developed from hydrographic surveys. The shoaling rate for each section along the project was determined as the average difference in elevation across a range of a hydrographic survey after a dredging operation (postdredge) and a survey prior to the next dredging operation (predredge). No analytic evaluations of advance maintenance effects on shoaling distribution were made but qualitative characteristics were observed.

PART II: ANALYSIS OF SPECIFIC PROJECTS

Shipyard River, South Carolina

Description

13. Shipyard River is a saltwater tidal tributary of Charleston Harbor, South Carolina. From its source, the river flows southerly about 3 miles and empties into Cooper River about 3/4 mile above Drum Island. Current velocities in Shipyard River are low, and the mean tidal range is 5.2 ft (OCE 1960).

14. Material depositing in this river is predominantly clay (97 percent by volume passing the 200 mesh sieve). This is considerably finer than the material normally deposited in the adjacent Charleston Harbor project.

Background

15. The existing Shipyard River navigation project provides for a channel 30 ft deep at mean low water and 200 ft wide, widened at the entrance, and two turning basins 30 ft deep. One basin is at the upper end of the project and the other, near its entrance (Figure 3).

16. The existing project was completed in June 1951. Table 1 lists the maintenance dredging operations in Shipyard River from that time through FY 75. The information in this table was gathered from the Corps Annual Reports.

17. Advance maintenance has been performed on this project from November 1961 to the present. Four feet of advance maintenance was dredged over the entire project between November 1961 and January 1962. Each subsequent maintenance dredging included 4 ft of advance maintenance until this was increased to 6 ft in July-August 1966. Since initial advance maintenance dredgings are considered "new work" in this report, the volumes of material removed during both the first 4 ft and the first 6 ft advance maintenance operations were estimated using hydrographic surveys, then removed from maintenance and placed under new work in Table 1.

Analysis and results

18. The behavior of the project as reflected by the maintenance dredging required for various conditions of advance maintenance is shown in Table 2. This table contains information derived from data in Table 1. Results are compared for advance maintenance of 4 ft, 6 ft, and their combination, with no advance maintenance, or "Base" conditions, using methods described earlier

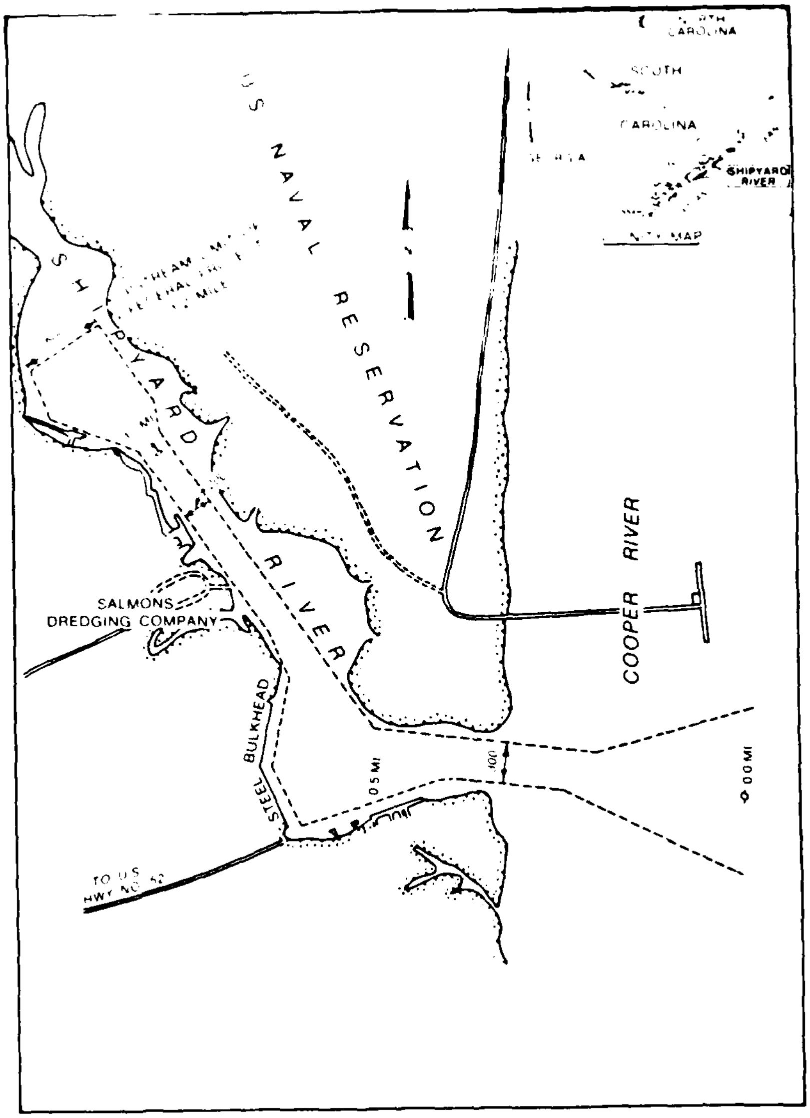

Figure 3. Shipyard River project

under Approach. The third column lists the average values of period and the average dredging rate for all conditions. The differences between these average values and the Base mean value were evaluated as to their significance and the judgment is registered in the last column. The 4 ft advance maintenance condition registered no significant change from Base. However, the 6 ft advance maintenance condition showed an increase in dredging period from 9.1 to 16.0 months and a decrease in dredging volume from 44,900 to 30,500 cu yd/month compared with Base. There were 14 periods under Base conditions and only 6 each for 4 and 6 ft of advance maintenance. To compare results of about the same length of time, 4 and 6 ft of advance maintenance were combined to compare directly with Base conditions. These results showed an increase in required dredging period from 9.1 to 12.6 months with no significant change in maintenance dredging requirements.

19. The drop in maintenance dredging required during the 6 ft advance maintenance condition could have been a result of a reduction in the freshwater sediment source. Figure 4, however, which shows the average yearly inflow for 1950 through 1975 for flow at Pinopolis Dam and maintenance dredging required, indicates no such reduction in flow for this period; in fact, the flow is somewhat higher than for Base condition.

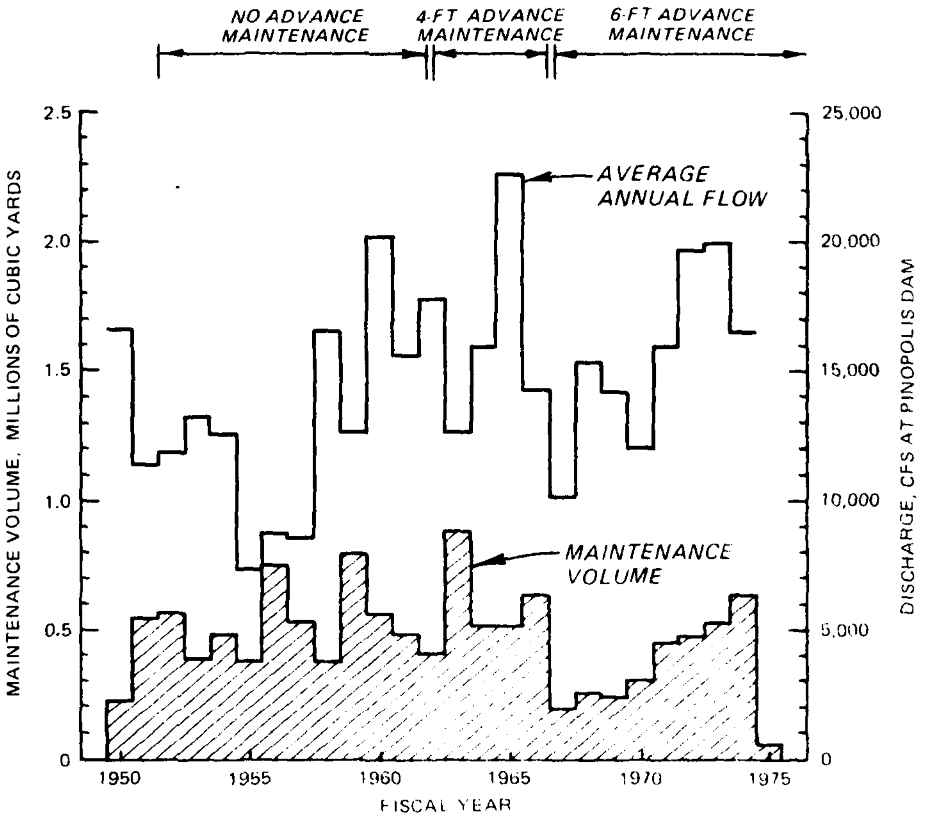

Figure 4. Average yearly inflow at Pinopolis Dam and yearly maintenance dredging in Shipyard River

20. The shoaling distribution within this project for all conditions was developed at 200-ft increments along the channel at the survey dates shown in Table 3.

21. Figure 5 reveals the results of this work. The loss of depth is

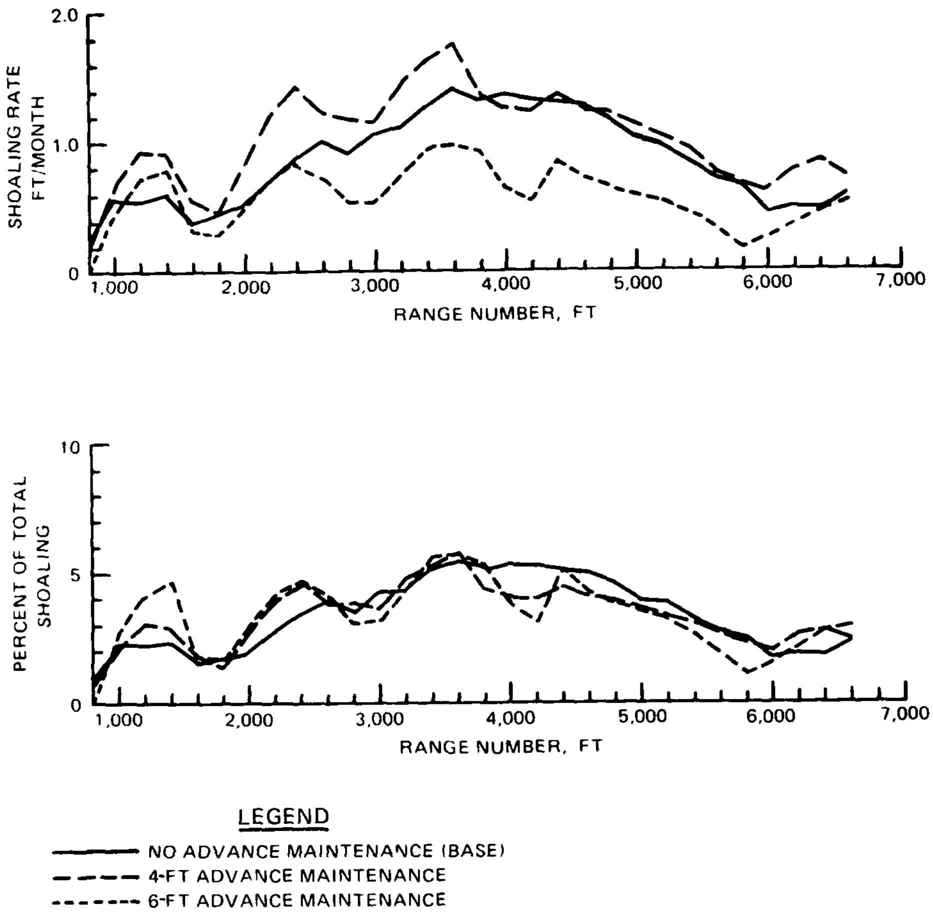

Figure 5. Shoaling distribution, Shipyard River

the criterion used here for evaluation of advance maintenance. Therefore the two diagrams shown in Figure 5 do not reflect volumes but loss of depth. The bottom diagram is the result of normalizing the top diagram by dividing each value by the total loss of depth. This will provide a direct means of comparing distribution. The peak shoaling location remained the same for all conditions at about range 3,600; however, advance maintenance seemed to shift the bulk of the shoaling slightly downstream. Overall, the shoaling distribution did not indicate much change.

22. Advance maintenance appears to have significantly reduced the frequency of maintenance dredging (increased the period) without causing significant changes in shoaling distribution or an increase in the maintenance volume required for the Shipyard River project. Provided the costs of implementation

of advance maintenance were not great enough to offset the savings realized by the reduction in dredging frequency, advance maintenance was effective on the project.

Coos Bay, Oregon

Description

23. Coos Bay, located on the Oregon coast about 200 miles south of the entrance of the Columbia River and 445 miles north of San Francisco Bay, is rather complex with nearly 30 tributaries feeding the system. The largest of these tributaries is the Coos River which has an average freshwater discharge of 2,200 cfs (Oregon State Water Resources Board 1971). Coos Bay has a drainage area of about 605 square miles which yields a total of 2,200,000 acre-ft of freshwater annually (OSWB 1971). Sediment transport to the estuary from this drainage basin is estimated to average 72,000 tons annually (Oregon State University 1971a, 1971b). The mean tidal range is 5.2 ft with a diurnal range of 7.0 ft (Oregon State University 1971b). The tidal prism of the estuary for mean and diurnal tidal range is 1.86×10^9 and 2.51×10^9 cu ft, respectively (Johnson 1972). The estuary is generally classified by salinity distribution as partly to well mixed.

Background

24. The Coos Bay navigation channel project is shown in Figure 6. During the period of concern for this study it consisted of: two rubble-mound, high-tide jetties at the entrance; an entrance channel across the outer bar 40 ft deep at mean lower low water (mllw) and approximately 700 ft wide near mile 0, gradually reducing to a depth of 30 ft and a width of 300 ft near mile 1; an inner channel 30 ft deep at mllw by 300 ft wide from mile 1 to mile 15; two turning basins; anchorage areas near channel miles 3.5 and 7.0; and several connecting channels (OCE 1960). The 30-ft-deep inner channel was completed in 1951 and dredging of the 40-ft-deep entrance channel was completed in 1952. The project was modified from 1976 through 1979 by a 5-ft deepening of the channels and turning basins, widening of the channel to 400 ft between miles 9 and 15, and abandonment of the anchorage areas.

25. This report considers only the entrance channel from mile 0 to mile 1 and the inner channel between miles 12 and 15. The reach between miles 1 and 12 is maintained on an irregular basis depending primarily upon weather conditions and dredge availability.

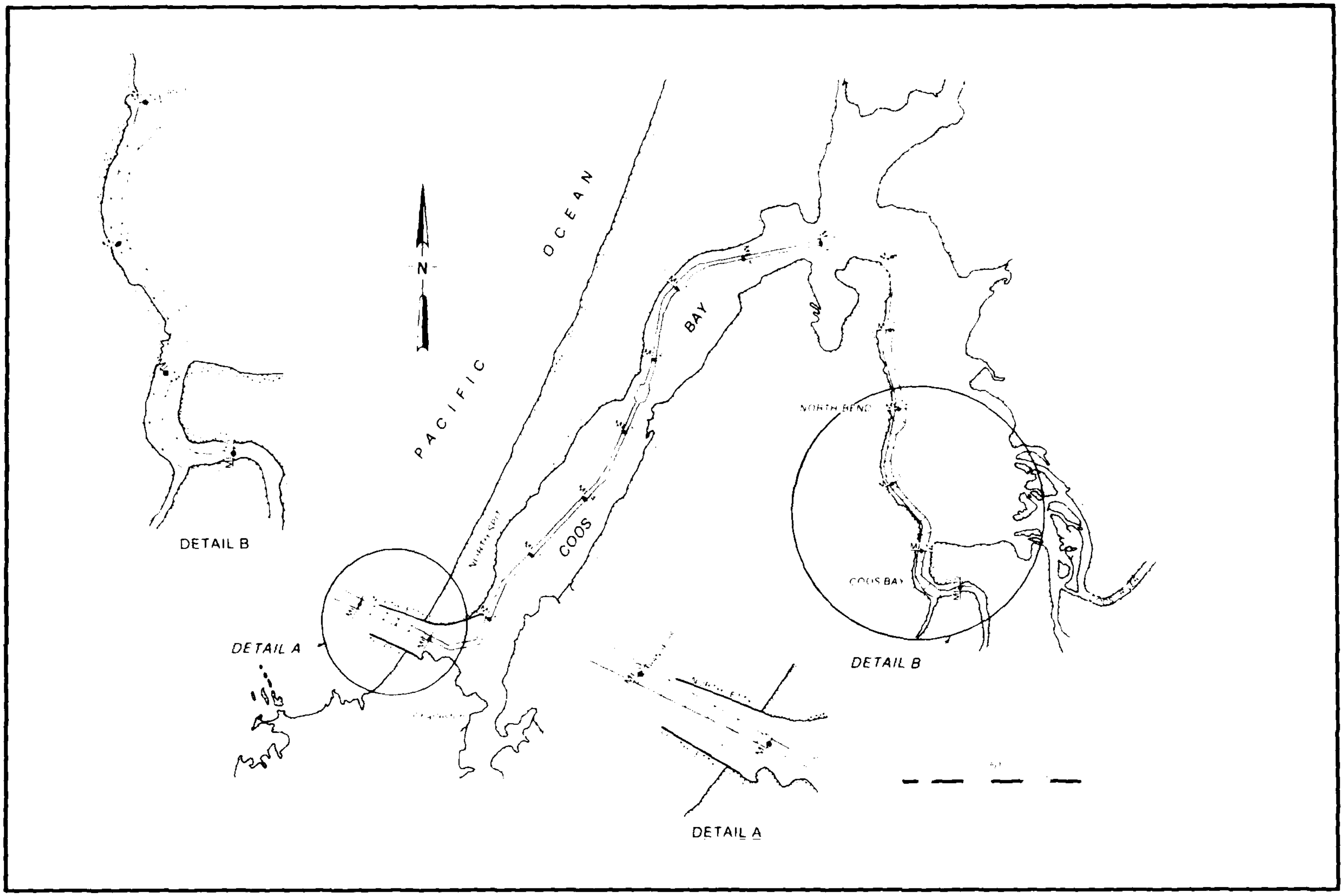

Figure 6. Coos Bay project

Coos Bay Entrance

26. The history of dredging activity in the entrance of Coos Bay since the last change of project dimensions is shown in Table 4. Advance maintenance of 3 and 5 ft was performed from 1 July 1962 through fiscal year 1975. The initial dredging of each advance maintenance condition should be considered new work; therefore these values were estimated based on the results of survey data. The remainder of the data was obtained from the Corps Annual Reports. The amount of advance maintenance performed was not consistent from year to year but shifted back and forth from 3 to 5 ft. Therefore all conditions of advance maintenance were combined in subsequent analyses.

27. Analysis of dredging period was made on data from dredging operations beginning 1 July 1958, because prior records did not include specific dates of operation. Table 5 shows that the average dredging period increased from 11.5 to 11.9 months following implementation of advance maintenance. This slight increase of about 2 weeks was neither statistically nor practically significant.

28. Figure 7 is a plot of dredging periods taken from Table 4. This

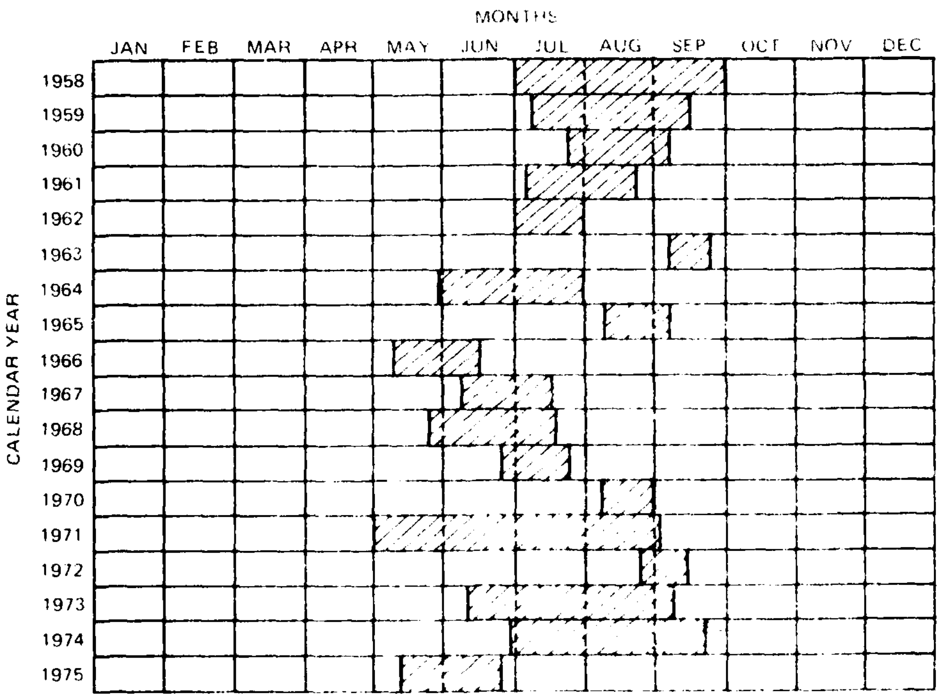

Figure 7. Dredging operations, Coos Bay entrance

figure shows that dredging operations occurred over a narrow band of time each year. The beginning of dredging operations varied from as early as 1 May to as late as 7 September, only slightly over 4 months. Perhaps such regularity indicates that the determination of the time to dredge was not based upon the lack of depth but possibly upon another factor, such as the availability of a dredge, or the only period in which the dredge can operate. As it turns out, the storms that frequent this area during the winter months force all dredging operations to be made during the summer. Since this restricts when dredging can take place, the advance maintenance provides assurance of project dimensions until operations can be resumed the following year. This also explains why no change in period was registered.

29. Maintenance volume was analyzed as maintenance per fiscal year rather than applying specific dates to calculate shoaling rates. This allows the use of additional data back to FY 53 for which dates were not given. As shown in Table 5, the maintenance required showed a drop from 1.03 to 0.79 million cu yd from Base to advance maintenance which was not a significant change.

30. The shoaling distribution was developed for six ranges 1,000 ft apart (Figure 8). The dates of the survey periods considered are shown in Table 6.

31. As shown on the location map in Figure 6, the channel widens from range 5,000 to range 0, so the distribution in Figure 8 does not reflect volumetric shoaling rate but the average loss of depth across a range. The distribution shows peak shoaling rates at range 3,000 for both conditions. Range 2,000 was near the tip of the jetties and a scour pattern was sometimes observed at this range; hence results at this range were quite sensitive to movement of the scour area, explaining some apparent difference between base and advance maintenance conditions. The deepened conditions did show an increased shoaling rate at the lower two ranges; in fact, at range 0 the shoaling rate was approximately doubled. Unfortunately, with the limited amount of base information the evidence is not conclusive.

32. Implementation of advance maintenance on the entrance of Coos Bay could not be shown to change the frequency of maintenance dredging, nor was there any conclusive evidence of a change in maintenance dredging required, or in the distribution of shoaling within the project. Though the peak shoaling remained at range 3,000 for both conditions, it did appear that shoaling for advance maintenance increased at the most downstream ranges. The use of

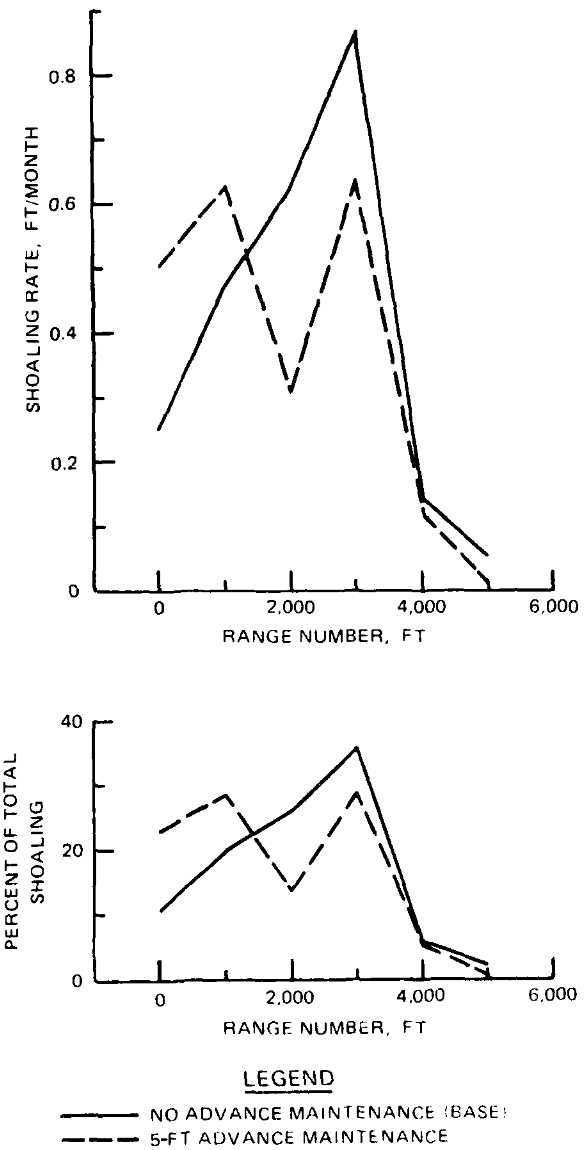

Figure 8. Shoaling distribution, Coos Bay entrance

advance maintenance was dictated on this project by the limited portion of the year in which dredging activity could take place. Advance maintenance was used here to assure appropriate channel depth until dredging could start again; therefore no decrease in dredging frequency was possible.

Coos Bay (Miles 12 to 15)

33. The dredging history of this channel before and after application

of 5 ft of advance maintenance is shown in Table 7. The volumes shown under new work volume were the initial dredging of advance maintenance in a portion of the channel. The amounts of initial advance maintenance were estimated using hydrographic dredging surveys, and the amount was subtracted from the maintenance volume reported by the US Army Engineer District, Portland.

34. The dredging operation of 24 July 1963 to 9 September 1963 was not considered separately as a dredging event but was combined with the subsequent dredging. It seems quite unlikely that the small amount of material which apparently was within the navigation channel prism at that time was the cause of implementing the dredging operations. Instead, it seems likely that a small portion of the channel between miles 12 and 15 was dredged because of the availability of a hopper dredge which was operating primarily in the lower reaches of the estuary.

35. The majority of the project was deepened to the 5 ft advance maintenance condition by the dredging operation of 18 October 1962 to 20 December 1962, in removing about 960,000 cu yd from about mile 13 to mile 15. All operations which took place after that time were under advance maintenance conditions for this analysis.

36. Table 8 reveals the effect of the additional 5 ft of depth incorporated in the advance maintenance conditions. The required maintenance dredging period increased from an average of 22.2 months for Base to 45.7 months for advance maintenance conditions--more than double. The number of base periods and advance maintenance periods were just four and three, respectively; however, this increase was just significant at the 0.10 level. Advance maintenance appears to have made a significant decrease in dredging frequency.

37. The average volume of maintenance dredging in this portion of the navigation channel was 39,200 cu yd/month for Base and 35,000 cu yd/month for advance maintenance. This difference was not significant at the 0.10 level. Certainly, there was no indication of an increase in required maintenance.

38. In evaluating the effect of advance maintenance on the shoaling distribution some 17 ranges were considered (ranges 5,000 to 21,000 in 1,000-ft increments, Figure 6). The shoaling rates in feet/month of lost depth were calculated for base and advance maintenance conditions based on predredge and postdredge hydrographic surveys. If these were not available, condition surveys were used. Dates and locations of the surveys used are shown in Table 9.

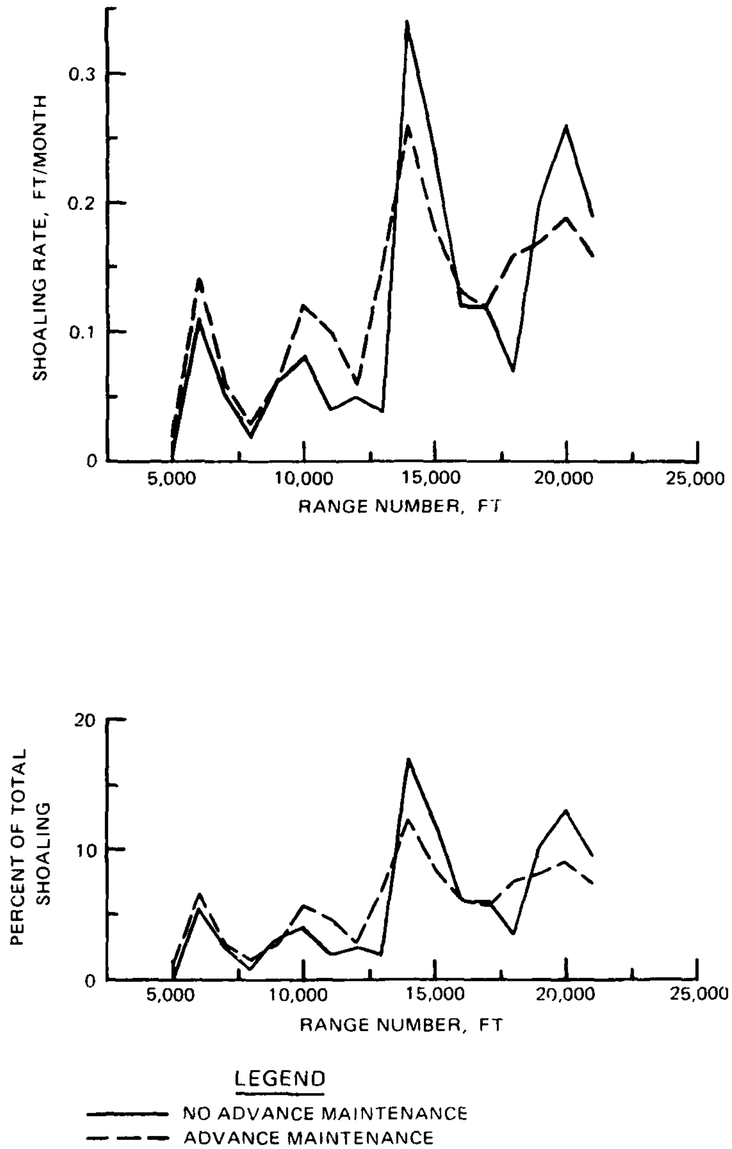

Figure 9. Shoaling distribution, Coos Bay (miles 12 to 15)

39. Figure 9 shows the results of determining average shoaling rates. This figure does not reflect volume of shoaling since the width varies as shown in Figure 6. The lower plot in this figure is the base and advance maintenance conditions normalized for the overall shoaling rates of each condition so that the distribution alone may be revealed. The dominant shoaling peaks occur at ranges 14,000 and 20,000 for both conditions. Additionally, two smaller peaks occur at ranges 6,000 and 10,000. All these high shoaling rate areas appear for both conditions, and the rank of each is the same for both

conditions. Thus the shoaling distribution is quite similar for base and advance maintenance conditions.

40. Advance maintenance of 5 ft in the channel region between miles 12 and 15 in the Coos Bay estuary appears to have significantly reduced the frequency of maintenance dredging without increasing shoaling rates or significantly altering the distribution of shoaling within this channel reach. If the cost of implementation of the initial advance maintenance was not too large, advance maintenance was quite effective here.

Columbia River

Description

41. The Columbia River has its source in Columbia Lake, British Columbia, and enters the United States near the northeast corner of the State of Washington. From here the river flows in a generally southerly direction for approximately 440 miles; then turns and flows westward about 305 miles, forming the boundary between Washington and Oregon; and discharges into the Pacific Ocean 153 nautical miles south of the Straits of Juan de Fuca and 535 nautical miles north of San Francisco Bay (Herrmann 1968).

42. Tides at Columbia River estuary have the diurnal inequality typical of the Pacific coast of North America with two unequal tides each day and a long runout to lower low water normally following higher high water. At lower stages of the river, tides cause a reversal of current as far as 90 miles above the mouth.

43. The three reaches of the Columbia River examined in this report--the Kalama, Lower Martin Island, and Upper Martin Island--extend approximately from river mile 74 to mile 84 (Figures 10, 11, and 12). For reference, Vancouver, Washington, is located about river mile 105. Although the water surface is subjected to tidal fluctuations in these reaches, the flow is usually unidirectional. Thus these are essentially riverine conditions.

Background

44. The original project for improvement of Columbia and lower Willamette Rivers from Portland to the sea was approved in 1877 and modified by subsequent acts. The existing project provides for a main channel 40 ft deep and 600 ft wide with various side channels. From 1955 through 1965, the period for which the effects of advance maintenance on this project were

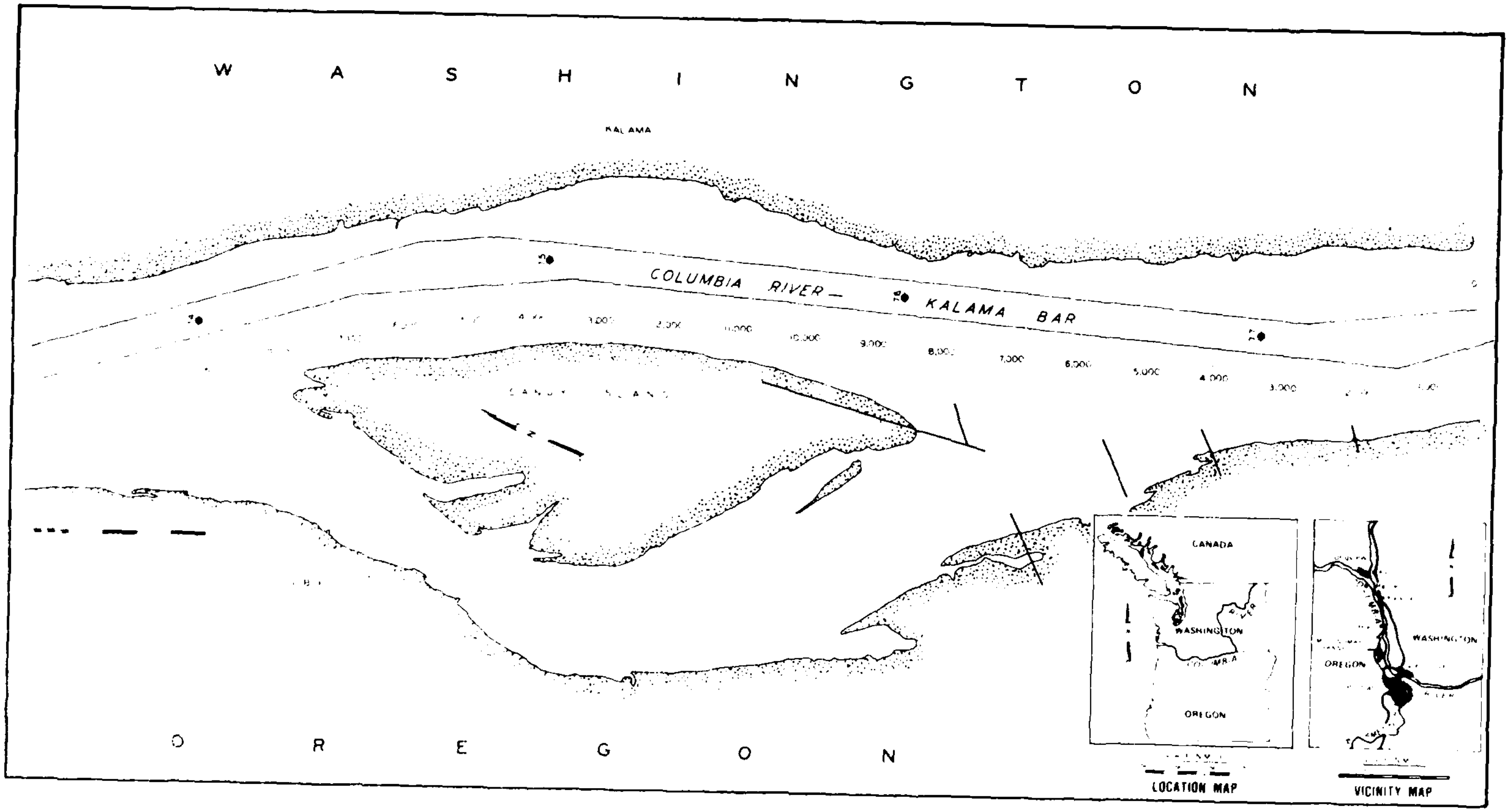

Figure 10. Kalama reach

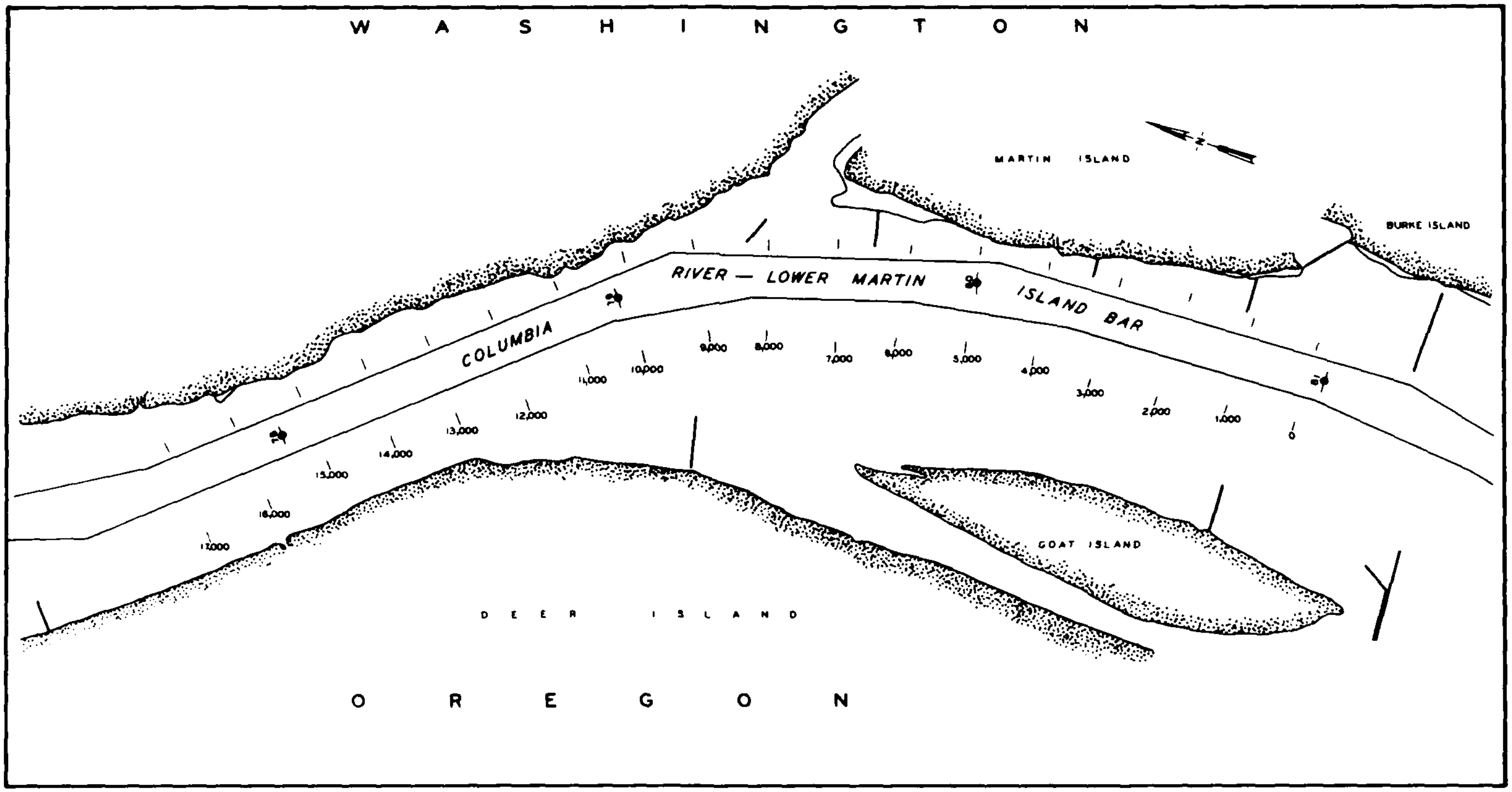

Figure 11. Lower Martin Island reach

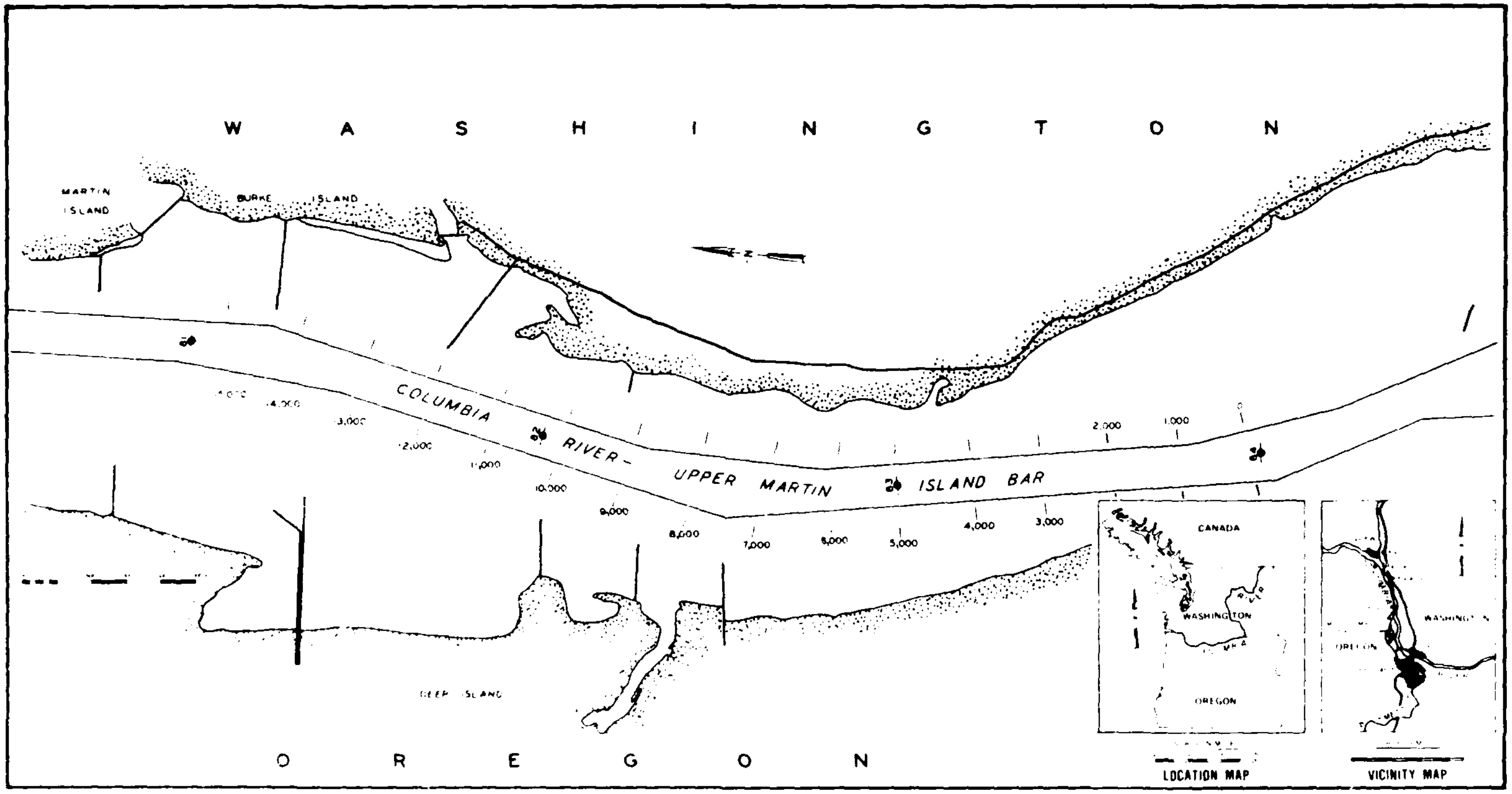

Figure 12. Upper Martin Island reach

analyzed, the Columbia River main channel was 35 ft deep by 500 ft wide. The dimensions of the entrance channel across the ocean bar are 48 ft by 2,640 ft.

45. These three shoals (Kalama, Upper and Lower Martin Islands) on the Columbia River shall be considered individually. Each of the reaches has a 35-ft navigation channel with 2 ft of dredging tolerance. Also each has had 3 and 5 ft of advance maintenance.

Analysis and results

46. On Kalama Bar, dredging data for no advance maintenance condition are shown in Table 10, from 4 August 1955 through 30 October 1959. New work for 3 ft of advance maintenance was conducted from 1 October to 30 October 1959 and was enlarged initially to 5 ft between 5 December 1960 and 20 January 1961. The amount of new work to accomplish the advance maintenance was estimated from hydrographic surveys and subtracted from the maintenance dredging volume reported by the Portland District. Advance maintenance condition data are presented beginning in October of 1959 and extending through December 1967.

47. As shown in Table 11 the average dredging period was 12.55 months before advance maintenance and 12.20 months after initiation of advance maintenance. This was not a significant change in period, nor was the change in maintenance dredging rate significant.

48. Advance maintenance of 3 ft was begun on the Lower Martin Island Bar with the dredging operation of 13-25 October 1961, and 5 ft of advance maintenance was initiated with the 17 September to 7 October 1962 operation. Table 12 lists the dredging history of Lower Martin Island Bar from August 1955 through November 1965. The new work volumes required in implementing the advance maintenance depths were again estimated.

49. As shown in Table 13 there were only three dredging periods with advance maintenance, so the variance of these data was high. The variances between the two sample populations were not similar and the Mann-Whitney test revealed no significant differences for either maintenance volume or dredging period.

50. The Upper Martin Island reach dredging history is shown in Table 14. Advance maintenance was implemented beginning in 1961 and was 3 ft in some years and 5 ft in others. The new work involved in deepening to include advance maintenance was estimated. Table 15 shows that the sample sizes were 6 and 4 for no advance maintenance and advance maintenance, respectively. The average dredging period remained about 1 year for both cases with no

significant difference noted. The average dredging rate for maintenance increased from 16,120 to 24,180 cu yd/month which was not a significant change.

51. These three reaches of the Columbia River are indeed riverine reaches unlike the previous projects which were estuarine or coastal in character. Generally, riverine systems are dominated by seasonal flow fluctuations in which tremendous sediment transport will occur during the high flow season. The shoaling potential within certain flow periods, therefore, is quite large and certainly capable of completely filling the channel to critical conditions even with moderate enlargements. This forces the dredging period to remain somewhat constant, as was shown in this case, at about a 1-year period. The filling of the additional volume should result in an actual increase in maintenance dredging. The analysis of these reaches could not discern this effect. In a high energy situation such as this, the advantage of advance maintenance would be in providing some critical channel depth for a longer time period though probably not for the entire dredging period. An evaluation of this objective would require a series of surveys between dredging operations.

PART III: CONCLUSIONS

52. Two of the estuarine projects in this study, miles 12.0 to 15.0 of Coos Bay channel, Oregon, and Shipyard River channel, South Carolina, showed significant reductions in dredging frequency after the implementation of advance maintenance. Neither channel revealed any increase in shoaling due to advance maintenance or any significant shift in shoaling distribution, and advance maintenance seems to have been beneficial. Both of these reaches are in areas of low energy (the currents and wave conditions are low).

53. In the high energy environment of the coastal entrance of Coos Bay entrance channel and that of the riverine channels of Upper and Lower Martin Island Channel and Kalama Bar Channel in the Columbia River, the dredging frequency was not reduced; apparently the principal benefit of advance maintenance was to provide project dimensions a greater percentage of time. In the case of the Coos Bay entrance, storms are so severe that dredging operations for any reasonable period of time can only be conducted during one season of the year. In the three reaches of the Columbia River, the additional depth provided by the advance maintenance could allow the use of the channel at project dimensions for a greater length of time in spite of large seasonal variations in water levels and flows.

54. In some but certainly not all cases, the application of advance maintenance brings about a reduction in required dredging frequency resulting in reduced overall costs as well as an improved project. However, since advance maintenance is not always successful, the practice should be evaluated on a case by case basis, using an approach such as that described in Report 2 of this series (Trawle 1981).

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Table 1

Dredging Operations, Shipyard River

					Channel Condition at Completion of Dredging Operation		
Starting Date	Ending Date	Period Months	Maintenance Volume million cu yd	New York Volume million cu yd	Project Depth ft mllw	Allowable Overdepth ft	Advance Maintenance ft
FY 1951	Jun 1951	12.0	0.540	1.842	30	2	0
FY 1952	FY 1952	8.6	0.564		30	2	0
14 Dec 1952	16 Feb 1953	10.5	0.381		30	2	0
Nov 1953	Jan 1954	9.0	0.484		30	2	0
Sep 1954	Oct 1954	9.5	0.246		30	2	0
22 Jun 1955	17 Jul 1955	8.5	0.549		30	2	0
Mar 1956	Apr 1956	7.0	0.341		30	2	0
1 Oct 1956	31 Oct 1956	7.0	0.271		30	2	0
May 1957	Jun 1957	6.0	0.257		30	2	0
1 Nov 1957	30 Nov 1957	10.4	0.381		30	2	0
28 Aug 1958	13 Oct 1958	8.5	0.597		30	2	0
1 Jun 1959	30 Jun 1959	8.5	0.197		30	2	0
14 Feb 1960	14 Mar 1960	9.6	0.555		30	2	0
Dec 1960	Jan 1961	12.0	0.483		30	2	0
Nov 1961	Jan 1962	8.0	0.404	0.364	30	2	4
Aug 1962	Sep 1962	8.0	0.705		30	2	4
1 Apr 1962	30 Apr 1963	10.0	0.171		30	2	4
Jan 1964	Mar 1964	9.0	0.507		30	2	4
Oct 1964	Dec 1964	8.0	0.505		30	2	4
Jul 1965	Aug 1965	12.0	0.564		30	2	4
Jun 1966	Aug 1966	24.0	0.262	0.182	30	2	6
1 Jun 1968	31 Jul 1968	13.0	0.475		30	2	6
Aug 1969	Sep 1969	13.0	0.294		30	2	6
Sep 1970	Oct 1970	16.0	0.458		30	2	6
Sep 1971	Feb 1972	10.0	0.473		30	2	6
Nov 1972	Dec 1972	20.0	0.527		30	2	6
May 1974	31 Jul 1974		0.697		30	2	6

Table 2

Behavior of Project

Advance Maintenance ft	n Sample Size	$\bar{x}$ Average Period months	Standard Deviation months	S_2 Variance	S_L^2/S_s^2 F_{calc}	$F_{0.10}$	Type Test	t_{calc}	$t_{0.10}$	U_{calc}	$U_{0.10}$	Significant Difference
					Period							
Base	14	9.1	1.8	3.24	--	--	--	--	--	--	--	--
4	6	9.2	1.6	2.56	0.79	2.88	t	0.12	1.73	--	--	No
6	6	16.0	5.2	27.04	8.35	2.24	U	--	--	80	63	Yes
Combination 4 and 6	12	12.6	5.1	26.01	8.03	2.05	U	--	--	119.5	117	Yes
				Maintenance Dredging Rate								
		$\bar{x}$ Average Dredging Rate cu yd/month	S Standard Deviation cu yd/month									
Base	14	44,900	12,000	1.44×10^{8}	--	--	--	--	--	--	--	--
4	6	49,300	23,900	5.71×10^{8}	3.97	2.24	U	--	--	48	63	No
6	6	30,500	9,800	9.60×10^{7}	1.50	2.88	t	2.58	1.73	--	--	Yes
Combination 4 and 6	12	37,300	18,700	3.50×10^{8}	2.43	2.05	U	--	--	66.5	117	No

Table 3

Survey Period, Shipyard River

Postdredge Survey	Predredge Survey
No Advance Maintenance	
7/15/1955	1/12/1956
4/16/1956	7/19/1956
10/23/1956	2/14/1957
7/26/1957	11/08/1957
11/19/1957	6/19/1958
9/30/1958	4/21/1959
3/14/1960	8/05/1960
1/--/1961	7/17/1961
2/05/1962	5/29/1962
4 ft Advance Maintenance	
9/24/1962	2/13/1963
4/29/1963	7/24/1963
3/27/1964	7/28/1964
12/14/1964	4/08/1965
6 ft Advance Maintenance	
9/12/1969	4/04/1970
10/13/1970	5/06/1971
12/17/1971	5/16/1972
12/15/1972	4/24/1973
6/28/1974	10/22/1974
9/04/1975	1/07/1976
9/13/1976	4/01/1977

Table 4

Dredging Operations, Coos Bay Entrance

Starting Date	Ending Date	Period months	Maintenance Volume million cu yd	New Work Volume million cu yd	Channel Condition at Completion of Dredging Operation: Project Depth ft mllw	Allowable Overdepth ft	Advance Maintenance ft
FY 1952	FY 1952	12.0		0.177	40	2	0
FY 1953	FY 1953	12.0	1.750		40	2	0
FY 1954	FY 1954	12.0	1.041*		40	2	0
FY 1955	FY 1955	12.0	0.874		40	2	0
FY 1956	FY 1956	12.0	1.137		40	2	0
FY 1957	FY 1957	12.0	1.116		40	2	0
FY 1958	FY 1958	3.0	1.820		40	2	0
1 Jul 1958	30 Sep 1958	11.5	0.444		40	2	0
8 Jul 1959	15 Sep 1959	11.7	0.539		40	2	0
21 Jul 1960	6 Sep 1960	11.5	0.784		40	2	0
4 Jul 1961	22 Aug 1961	11.3	0.809		40	2	0
1 Jul 1962	31 Jul 1962	13.7	0.309*	0.378*	40	2	3
7 Sep 1963	21 Sep 1963	10.3	0.415		40	2	3
27 May 1964	31 Jul 1964	13.4	1.490		40	2	3
12 Aug 1965	12 Sep 1965	10.1	0.575*	0.144*	40	2	5
11 May 1966	15 Jul 1966	12.0	0.624		40	2	5
9 Jun 1967	16 Jul 1967	12.0	0.580		40	2	5
24 May 1968	17 Jul 1968	12.4	1.028		40	2	5
25 Jun 1969	24 Jul 1969	13.1	0.578		40	2	5
8 Apr 1970	27 Aug 1970	12.2	0.878		40	2	3
1 May 1971	2 Sep 1971	12.4	0.558		40	2	5
25 Aug 1972	13 Sep 1972	11.8	0.357		40	2	5
10 Jun 1973	8 Sep 1973	12.4	1.253		40	2	3
28 Jun 1974	20 Sep 1974	9.1	1.746		40	2	3
12 May 1975	23 Jun 1975		0.825		40	2	3

* Estimated.

Table 5

Coos Bay Entrance

Advance Maintenance ft	n Sample Size	$\bar{x}$ Average Period months	Standard Deviation months	S_2 Variance	S_L^2/S_s^2 F_{calc}	$F_{0.10}$	Type Test	t_{calc}	$t_{0.10}$	U_{calc}	$U_{0.10}$	Significant Difference from Base
Period												
Base*	4	11.5	0.16	0.027	--	--	--	--	--	--	--	--
3 or 5 ft	13	11.9	1.34	1.796	67.6	3.18	U	--	--	40	10-42	No
Maintenance Dredging Rate Volume in Fiscal Years												
		Million cu yd/yr										
Base**	10	1.03	0.46	0.212	--	--	--	--	--	--	--	--
3 or 5 ft	13	0.79	0.42	0.176	1.21	2.67	t	1.33	1.72	--	--	No

* Data began in 1958.
** Data began in 1952.

Table 6

Survey Periods, Coos Bay

Postdredge Survey	Predredge Survey
No Advance Maintenance	
10/06/1958	5/21/1959
9/09/1959	6/15/1960
10/03/1960	4/18/1961
10/03/1961	4/12/1962
Advance Maintenance	
8/01/1962	7/30/1963
9/30/1963	4/14/1964
8/06/1964	6/17/1965
9/14/1965	5/15/1966
9/29/1966	4/12/1967
8/14/1968	4/16/1969
8/19/1969	4/01/1970
8/28/1970	4/07/1971
7/12/1971	8/15/1972
9/27/1973	5/20/1974
6/19/1975	4/29/1976

Table 7

Dredging Operations, Coos Bay (Miles 12 to 15)

Starting Date	Ending Date	Period months	Maintenance Volume million cu yd	New Work Volume million cu yd	Channel Condition at Completion of Dredging Operation: Project Depth ft mllw	Allowable Overdepth ft	Advance Maintenance ft
16 May 1955	30 Jul 1955		0.976		30	2	0
		17.4					
27 Aug 1956	10 Jan 1957		1.473		30	2	0
		24.2					
30 Oct 1958	22 Jan 1959		0.493		30	2	0
		30.2					
29 Jun 1961	28 Jul 1961		1.152		30	2	0
		16.8					
18 Oct 1962	20 Dec 1962		0.360	0.962	30	2	5*
24 Jul 1963**	9 Sep 1963				30	2	5*
		43.8					
31 Jan 1966	16 Aug 1966		1.539	0.083	30	2	5†
		46.0					
9 Feb 1970	14 Jun 1970		1.601	0.320	30	2	5
		47.3					
14 Feb 1974	24 May 1974		1.667		30	2	5

* Advance maintenance completed from about mile 13 to mile 15.
** Not considered as a separate dredging event for this analysis.
† Advance maintenance completed except for North Bend Turning Basin.

Table 8

Coos Bay (Miles 12 to 15)

Advance Maintenance ft	n Sample Size	$\bar{x}$ Average Period months	Standard Deviation months	S_2 Variance	S_L^2/S_s^2 F_{calc}	$F_{0.10}$	Type Test	t_{calc}	$t_{0.10}$	U_{calc}	$U_{0.10}$	Significant Difference from Base
					Period							
Base	4	22.2	6.35	40.32	--	--	--	--	--	--	--	--
5	3	45.7	1.77	3.13	12.87	9.12	U	--	--	12	12	Yes
				Maintenance Dredging Rate								
		cu yd/ month	cu yd/ month									
Base	4	39,200	23,750	5.64×10^8	--	--	--	--	--	--	--	--
5	3	35,000	186.3	3.47×10^4	9.12	U	--	--	--	6	12	No

Table 9

Survey Period, Coos Bay

Survey Dates	Ranges
Ranges 5,000 to 7,000	
Base	
1/31/1957 to 5/16/1961	5,000-7,000
6/29/1961 to 6/25/1963	5,000-7,000
3/10/1964 to 7/15/1966	5,000-7,000
8/26/1966 to 3/15/1970	5,000-7,000
Advance Maintenance	
5/31/1970 to 4/18/1974	5,000-7,000
5/31/1974 to 12/30/1976	5,000-7,000
Ranges 7,000 to 15,000	
Base	
1/--/1957 to 4/20/1961	7,000-10,000
1/--/1957 to 12/19/1958	11,000-15,000
1/23/1959 to 3/30/1961	12,000-15,000
5/--/1961 to 12/--/1962	11,000-15,000
6/07/1961 to 6/10/1966	7,000-10,000
Advance Maintenance	
12/--/1962 to 4/12/1966	10,000-15,000
8/24/1966 to 3/05/1970	7,000-9,000
7/--/1966 to 2/06/1970	10,000-15,000
5/--/1970 to 4/18/1974	7,000-9,000
6/--/1970 to 3/01/1974	10,000-15,000
4/--/1974 to 1/04/1977	7,000-15,000
Ranges 15,000 - 21,000	
Base	
1/--/1957 to 10/24/1958	15,000-21,000
12/22/1958 to 3/22/1961	15,000-16,000
12/22/1958 to 3/02/1961	17,000-18,000
12/22/1958 to 1/26/1961	19,000-20,000
11/26/1958 to 1/26/1961	21,000
5/2/1961 to 9/24/1962	15,000-17,000
8/1/1961 to 10/23/1962	18,000
3/28/1961 to 10/23/1962	19,000
7/17/1961 to 10/23/1962	20,000
2/28/1961 to 10/23/1962	21,000

(Continued)

Table 9 (Concluded)

Survey Dates	Ranges
Advance Maintenance	
11/25/1962 to 3/09/1966	15,000-18,000
11/25/1962 to 12/01/1965	19,000-21,000
5/13/1966 to 12/18/1969	15,000-20,000
3/24/1966 to 12/18/1969	21,000
4/23/1970 to 2/27/1974	15,000-16,000
4/23/1970 to 1/23/1974	17,000-21,000
4/15/1974 to 1/04/1977	15,000-16,000
4/04/1974 to 1/04/1974	17,000-21,000

(Sheet 2 of 2)

Table 10

Dredging Operations, Columbia River, Kalama Bar

Starting Date	Ending Date	Period months	Maintenance Volume cu yd	New Work Volume cu yd	Channel Condition at Completion of Dredging Operation: Project Depth ft mllw	Allowable Overdepth ft	Advance Maintenance ft
4 Aug 1955	26 Aug 1955		425,000		35	2	0
		14.2					
10 Sep 1956	30 Oct 1956		684,000		35	2	0
		9.0					
8 Jul 1957	1 Aug 1957		458,000		35	2	0
		16.9					
22 Oct 1958	27 Dec 1958		637,000		35	2	0
		10.1					
1 Oct 1959	30 Oct 1959		165,000	456,000*	35	2	3
		14.7					
5 Dec 1960	20 Jan 1961		238,000	511,000*	35	2	5
		12.6					
5 Jan 1962	7 Feb 1962		354,000		35	2	3
		8.5					
8 Oct 1962	25 Oct 1962		175,000		35	2	3
		12.7					
24 Oct 1963	14 Nov 1963		261,000		35	2	3
		14.6					
7 Oct 1964	31 Jan 1965		725,000		35	2	5
		8.8					
9 Oct 1965	27 Oct 1965		259,000		35	2	5
		13.2					
1 Nov 1966	2 Dec 1966		491,000		35	2	5
		12.5					
8 Nov 1967	18 Dec 1967		288,000		35	2	5

* Estimated.

Table 11

Columbia River, Kalama Bar

Advance Maintenance ft	n Sample Size	$\bar{x}$ Average Period months	Standard Deviation months	S_2 Variance	S_L^2/S_s^2 F_{calc}	$F_{0.10}$	Type Test	t_{calc}	$t_{0.10}$	U_{calc}	$U_{0.10}$	Significant Difference
Period												
Base	4	12.55	6.35	13.40	--	--	--	--	--	--	--	--
3 and 5 ft	8	12.20	2.35	5.52	2.43	4.35	t	0.20	1.81	--	--	No
Maintenance Dredging Rate												
		Average Dredging Rate cu yd/month	Standard Deviation cu yd/month									
Base	4	47,809	21,077	4.44×10^8	--	--	--	--	--	--	--	--
3 and 5 ft	8	33,805	11,928	1.42×10^8	3.12	4.35	t	1.50	1.81	--	--	No

Table 12

Dredging Operations - Columbia River - Lower Martin Island Bar

Starting Date	Ending Date	Period months	Maintenance Volume cu yd	New Work Volume cu yd	Channel Condition at Completion of Dredging Operation: Project Depth ft mllw	Allowable Overdepth ft	Advance Maintenance ft
1 Aug 1955	4 Aug 1955		54,000		35	2	0
		14.2					
30 Sep 1956	9 Oct 1956		51,000		35	2	0
		12.3					
14 Oct 1957	17 Oct 1957		55,000		35	2	0
		11.2					
18 Sep 1958	22 Oct 1958		72,000		35	2	0
		13.0					
13 Oct 1959	21 Oct 1959		13,000		35	2	0
		11.8					
13 Oct 1960	24 Oct 1960		71,363		35	2	0
		12.4					
13 Oct 1961	25 Oct 1961		38,000	99,000*	35	2	3
		11.4					
17 Sep 1962	7 Oct 1962		65,000	119,000*	35	2	5
		13.7					
14 Nov 1963	28 Nov 1963		212,000		35	2	5
		23.5					
6 Nov 1965	11 Nov 1965		57,000		35	2	5

* Estimated.

Table 13

Columbia River - Lower Martin Island Bar

Advance Maintenance ft	n Sample Size	$\bar{x}$ Average Period months	Standard Deviation months	S_2 Variance	S_L^2/S_s^2 F_{calc}	$F_{0.10}$	Type Test	t_{calc}	$t_{0.10}$	U_{calc}	$U_{0.10}$	Significant Difference
					Period							
Base	6	12.48	1.04	1.08	--	--	--	--	--	--	--	--
3 and 5 ft	3	16.20	6.43	41.34	38.28	5.79	U	--	--	6	2-16	No
					Maintenance Dredging Rate							
		Average Dredging Rate cu yd/month	Standard Deviation cu yd/month									
Base	6	4,010	1,821	3.32×10^6	--	--	--	--	--	--	--	--
3 and 5 ft	3	6,872	5,545	3.07×10^7	9.27	5.79	U	--	--	7	2-16	No

Table 14

Dredging Operations - Columbia River, Upper Martin Island

Starting Date	Ending Date	Period months	Maintenance Volume cu yd	New Work Volume cu yd	Channel Condition at Completion of Dredging Operation: Project Depth ft mllw	Allowable Overdepth ft	Advance Maintenance ft
13 Oct 1955	24 Oct 1955		163,000		35	2	0
		11.2					
25 Sep 1956	30 Sep 1956		302,000		35	2	0
		12.5					
2 Oct 1957	14 Oct 1957		172,000		35	2	0
		11.1					
11 Sep 1958	17 Sep 1958		100,000		35	2	0
		12.9					
8 Oct 1959	15 Oct 1959		206,000		35	2	0
		11.7					
26 Sep 1960	4 Oct 1960		186,000		35	2	0
		12.3					
5 Sep 1961	13 Oct 1961		190,000	478,000*	35	2	3
		11.2					
16 Aug 1962	19 Sep 1962		252,000	150,000*	35	2	5
		14.5					
10 Nov 1963	5 Dec 1963		209,000		35	2	3
		10.1					
14 Sep 1964	7 Oct 1964		393,000		35	2	5
		13.7					
28 Oct 1965	27 Nov 1965		343,000		35	2	5

* Estimated.

Table 15

Columbia River, Upper Martin Island

Advance Maintenance ft	n Sample Size	$\bar{x}$ Average Period months	Standard Deviation months	S_2 Variance	S_L^2/S_s^2 F_{calc}	$F_{0.10}$	Type Test	t_{calc}	$t_{0.10}$	U_{calc}	$U_{0.10}$	Significant Difference
Period												
Base	6	11.95	0.73	0.53	--	--	--	--	--	--	--	--
3 and 5 ft	4	12.38	2.07	4.28	8.04	5.41	U	--	--	10.5	3-21	No
Maintenance Dredging Rate												
		Average Dredging Rate cu yd/month	Standard Deviation cu yd/month									
Base	6	16,120	5,220	2.72×10^7	--	--	--	--	--	--	--	--
3 and 5 ft	4	24,180	8,550	7.31×10^7	2.68	5.41	t	1.87	1.86	--	--	No

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