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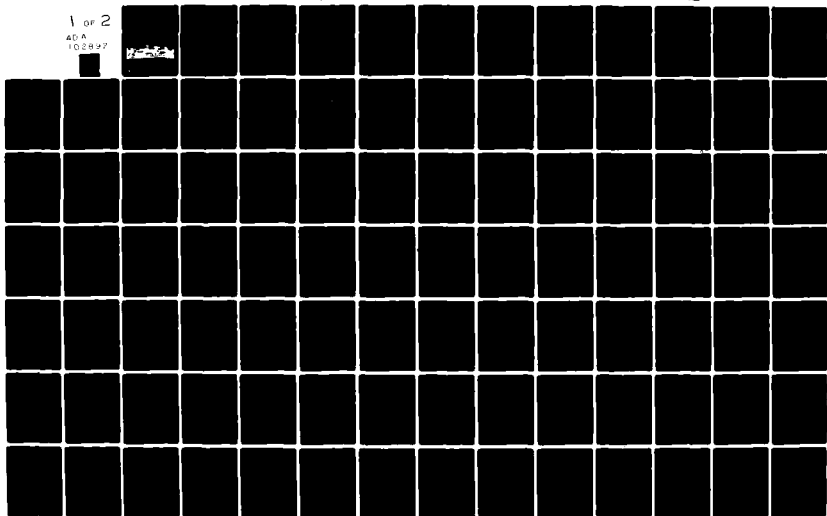
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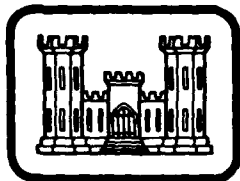
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TECHNICAL REPORT H-78-5

EFFECTS OF DEPTH ON DREDGING FREQUENCY

Report 2

METHODS OF ESTUARINE SHOALING ANALYSIS

by

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July 1981

Report 2 of a Series

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20. ABSTRACT (Continued).

The overall objective of this investigation was to evaluate the effectiveness of advance maintenance dredging in reducing dredging frequency and/or costs in the maintenance of coastal channels and harbors and to establish necessary guidelines for governing the practice. This report, the second of a series, presents an empirical method of shoaling analysis based on historical dredging and shoaling records that results in reliable predictions of future shoaling for deepened channel conditions resulting from either an increase in authorized channel depth or advance maintenance. The method presented was designed to be general enough so that it can be applied to most navigation projects without difficulty. The procedure was described step by step using an example (fictitious) project. To demonstrate how the method would be applied to real navigation projects and to point out problems that occur when evaluating real projects, selected Galveston Bay, Texas, navigation projects were evaluated and the results discussed.

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PREFACE

The study reported herein was conducted by personnel of the Hydraulics Laboratory, U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, under the Improvement of Operations and Maintenance Program, Office, Chief of Engineers, U. S. Army.

The study was conducted during the period 1 July 1976 to 31 March 1978 under the direction of Messrs. H. B. Simmons, Chief of the Hydraulics Laboratory; F. A. Herrmann, Jr., Assistant Chief of the Hydraulics Laboratory; R. A. Sager, Chief of the Estuaries Division; R. A. Boland, Chief of the Interior Channel Branch; and W. H. McAnally, Technical Advisor for Estuaries Research Projects, Estuaries Division. This report was prepared by Mr. M. J. Trawle, Project Engineer, with the assistance of Messrs. Boland and McAnally.

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

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

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

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
feet	0.3048	metres
cubic yards	0.7645549	cubic metres
miles (U. S. statute)	1.609344	kilometres

EFFECTS OF DEPTH ON DREDGING FREQUENCY
METHODS OF SHOALING ESTUARINE ANALYSIS

PART I: INTRODUCTION

Objective

1. The overall objective of this investigation is to evaluate the effectiveness of advance maintenance dredging in reducing dredging frequency and costs in estuarine channel and harbor maintenance and to establish guidelines necessary for governing this practice.

2. The objective of this report is to present an empirical method of shoaling analysis based on historical dredging and shoaling records that results in reliable predictions of future shoaling for deepened channel conditions. Deepened conditions can result either from an increase in the authorized channel depth or from advance maintenance dredging.

Background

3. A typical dredged channel with no provision for advance maintenance dredging is illustrated in Figure 1. Basic specifications for the dredged dimensions are authorized depth, authorized bottom width, and authorized side slopes which describe the authorized channel prism. Where advance maintenance dredging is not utilized, the authorized channel is the same as the required channel prism. The inclusion of allowable dredging tolerances for the bottom and side slopes of the channel to compensate for dredging inaccuracies provides for adjusted channel dimensions which define the allowable pay prism of the channel.

4. Allowable dredging tolerance should not be confused with advance maintenance dredging (Figure 2). Allowable dredging tolerance, usually 1 to 3 ft,* is simply a margin of error that allows the contractor to be

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

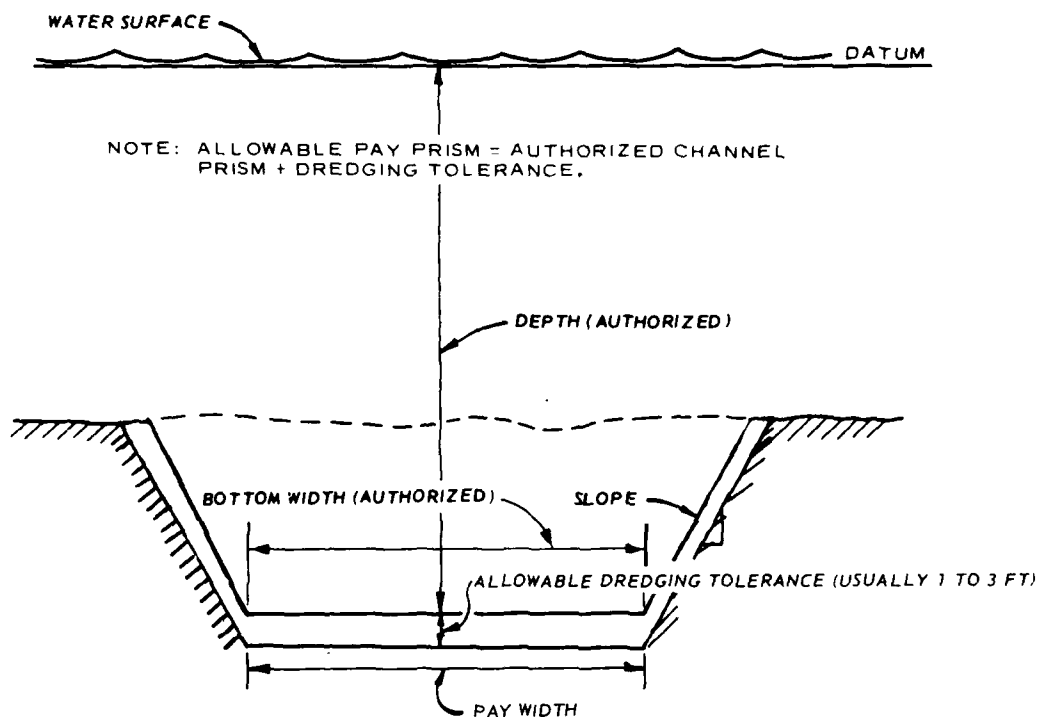


Figure 1. Typical dredged channel cross section

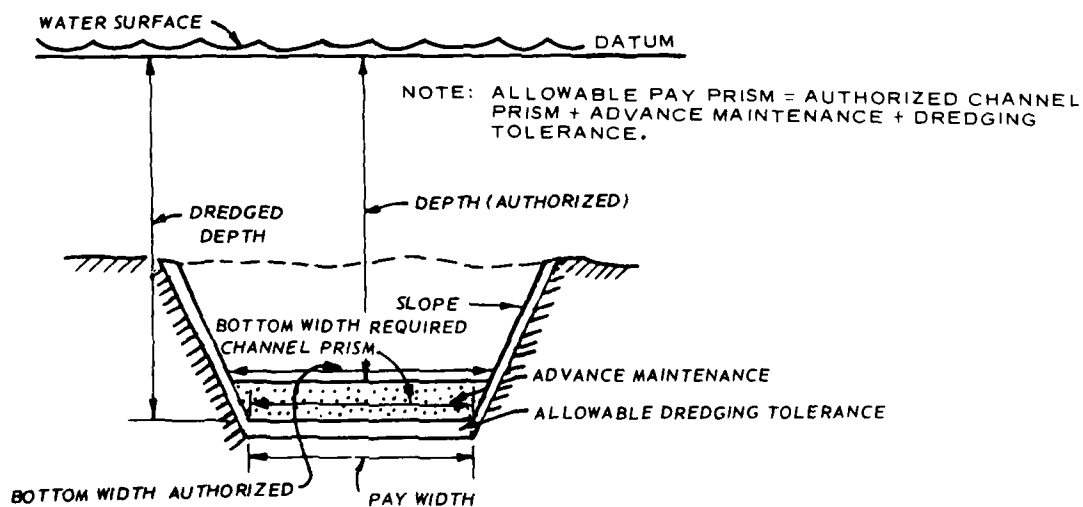


Figure 2. Dredged channel cross section with advance maintenance included

paid for material dredged within a specified depth (usually 1 to 3 ft) below the authorized depth. Allowable dredging tolerance is necessary to allow for dredging inaccuracies. Factors that contribute to the need for a tolerance for industry and for Corps dredges include wave action, tidal forecast variances, and equipment conditions and controls.

5. Whenever deepening of a dredged channel is being investigated, a prediction must be made as to the effect of the deepening on the existing dredging requirements. If the deepening is related to advance maintenance dredging rather than to an increase in the authorized depth, the prediction becomes even more difficult because the project is allowed to shoal over a wide range of depth. As a result of the environmental regulations created within the last decade, dredging has become a much more expensive operation than in the past, and costs will be felt even more heavily in the future. For this reason, predictions of shoaling for deepened conditions, whether advance maintenance dredging or increase in authorized depth, should be reliable. Currently a variety of procedures are followed by Corps districts for predicting the effect of depth on dredging requirements. Four of the most used procedures in the past are presented in the following subparagraphs:

- a. Increase in cross-sectional area. The basic premise in this procedure is that for any dredged navigation channel, the percent increase in the shoaling rate caused by deepening is proportional to the percent increase in cross-sectional area of the channel below natural depth (Figure 3) or, presented in equational form,

$$S_d = S \left(\frac{A_d}{A} \right)$$

where

S = existing channel shoaling rate

S_d = deepened channel shoaling rate

A = existing channel cross-sectional area

A_d = deepened channel cross-sectional area

- b. Increase in wetted perimeter. The basic premise in this procedure is that for any dredged navigation channel, the percent increase in the shoaling rate caused by deepening

is proportional to the percent increase in the wetted perimeter of the channel below natural depth (Figure 3) or, presented in equational form,

$$S_d = S \frac{x_d + y_d + z_d}{x + y + z}$$

where

S = existing channel shoaling rate

S_d = deepened channel shoaling rate

x = length of existing channel side slope (left)

y = length of existing channel bottom

z = length of existing channel side slope (right)

x_d = length of deepened channel side slope (left)

y_d = length of deepened channel bottom

z_d = length of deepened channel side slope (right)

c. Experience in nearby areas. When navigation channels in nearby areas have already been deepened to the depth being considered for the channel under investigation, results of the deepening in the nearby channel may be used to predict the future dredging requirements for the channel in question. It should be noted that this procedure has considerable potential for distorted results when comparison areas have included engineered modifications such as diking, bank protection, variable flows from dam releases, or any other engineering modifications which would create significant dissimilarities.

d. Limited historical dredging or shoaling data. Often the prediction of shoaling for a deepened channel is made on the basis of limited historical dredging or shoaling data. For example, based on hydrographic surveys of a navigation channel, suppose it's determined that for a period between dredging (say 3 yr) for the existing channel depth, the shoaling rate was X cu yd per year. For a period between dredging for the previous channel depth (say 4 ft less than that existing), the shoaling rate was Y cu yd per year. The percent increase in shoaling from the previous to existing depth is simply

$$\text{Percent increase in shoaling} = \frac{100(X - Y)}{Y}$$

The rate of increase can then be extrapolated to the greater depths being considered. If a few more data points are available, a predictive equation can even be generated that allows for other than a linear extrapolation.

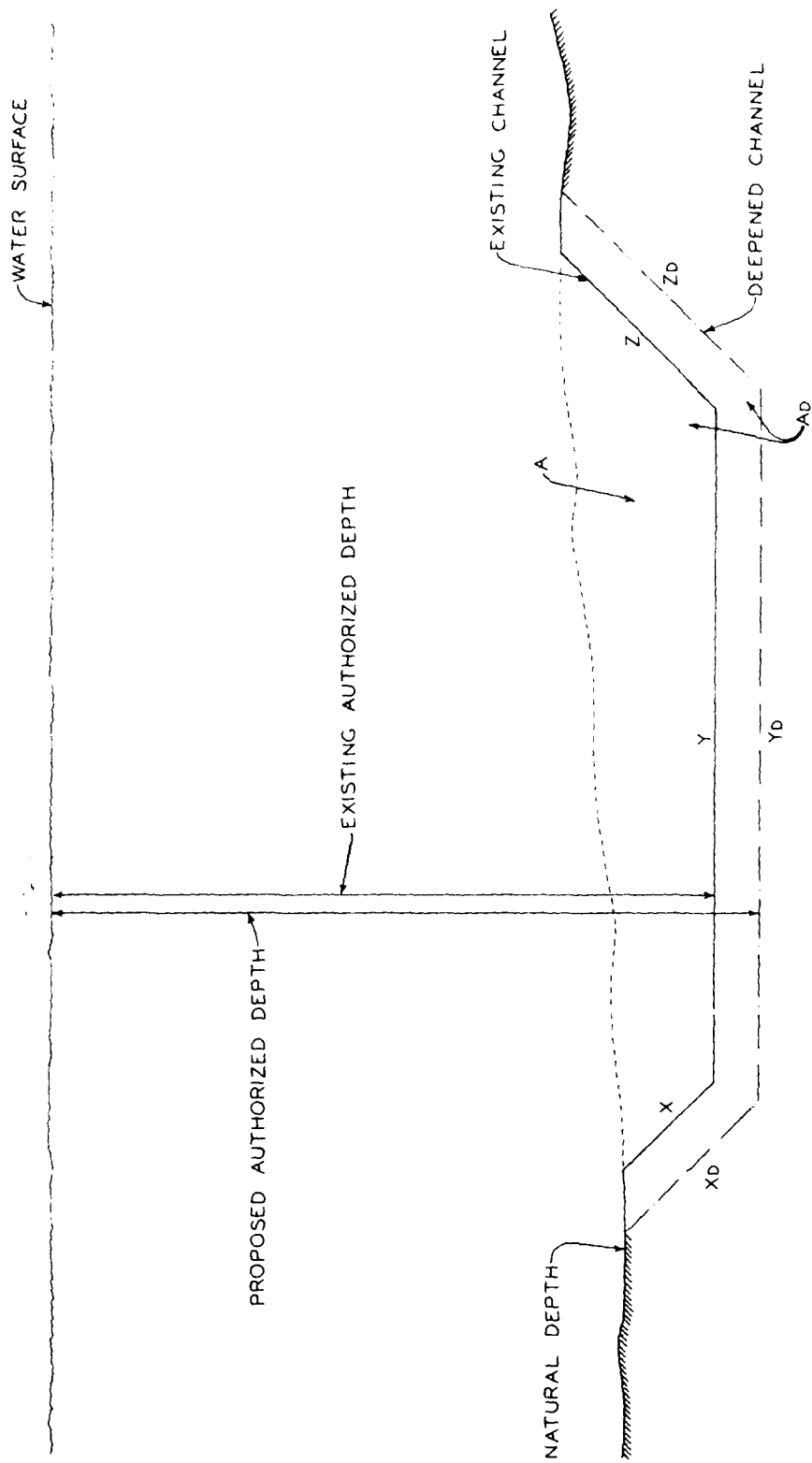


Figure 3. Channel cross section for existing and enlarged dimensions

6. Of the four procedures above, the first two--increase in cross-sectional area and increase in wetted perimeter--are based on the assumption that all navigation channel shoaling increases with depth can be related, at least approximately, to some function of channel geometry such as cross-sectional area or wetted perimeter. The problem with this approach is that the assumption is often not valid. Each navigation channel should be treated as unique, since shoaling depends on a multitude of factors, including such factors as sources and types of shoaling material, wind and wave action, ship traffic, past dredging practices, floods, droughts, storms, and changes in density currents, as well as geometry. To assume that shoaling can be predicted on the basis of channel geometry alone is a gross oversimplification and should not be considered reliable. This procedure should not be utilized by Corps personnel.

7. The third method, presented in subparagraph 5c, can be a valid method of prediction if the channel in the nearby area is indeed similar to the channel being evaluated. However, one cannot assume that a channel will behave the same as a nearby channel based on proximity alone. Again this is an oversimplification resulting in a prediction that should not be considered reliable.

8. The fourth method of shoaling analysis, presented in subparagraph 5d, differs from the others presented in that the prediction is based on historical dredging or shoaling data. The problem with the approach usually lies in the fact that the amount of data used in the evaluation is insufficient to determine representative shoaling rates. The nature of shoaling phenomena requires that long periods of time be evaluated because the variance in short-term shoaling for most projects is tremendous. In many cases, a few short time periods with one set of channel dimensions are compared with a few short time periods at another set of dimensions; and a prediction for deepened condition is made based on the limited historical data evaluated. The approach can result in (a) shoaling rates not representative of the corresponding channel dimensions and (b) a poor predictive model. As a general rule, the more historical dredging and shoaling data used in the evaluation of a project,

the more likely a predictive model that extrapolates the data will be valid.

Approach

9. The method of shoaling analysis presented will be first described step by step in PART II of this report, using an example project. The example project is fictitious and was created to be typical of many estuarine dredged navigation projects maintained by the Corps of Engineers. In PART III of this report the method will be applied to several real dredged navigation projects maintained by the Corps.

10. For any dredged navigation project, shoaling rates are considered to vary in both time and space. For example, the shoaling rate at one location and depth is not constant over time. The shoaling rates at the same location and time but at different depths are not necessarily the same. The shoaling rates at the same depth and time but at different locations within the project are not the same. The variation of shoaling with time may be cyclical in nature as in the case of seasonal changes; there may be a long-term, man-induced, or natural change which gradually affects the shoaling rates within the project; or there may be abrupt changes caused by shocks to the system such as storms or man-made modifications in nearby areas such as dams, locks, flow diversions, and so on. All of these factors should be considered in the analysis of shoaling for any dredged navigation project.

Assumptions

11. Ideally, a predictive scheme for deepening and subsequent shoaling analysis would include all factors that affect the shoaling rates within a dredged navigation channel, a goal which is generally not achievable. In the method of shoaling analysis presented in PARTS II and III of this report, the following simplifying assumptions were made:

- a. The variation in shoaling rates within a project can be

discretized to form a reasonable number of sections. For example, a 6000-ft-long channel could be divided into six 1000-ft sections and an average shoaling rate for each section for a given depth used in subsequent computations, as long as the shoaling within each section was relatively evenly distributed. This discretization procedure could tie in quite nicely with the frequently used dredging clause which indicates that the project is divided into "acceptance sections" with lengths ranging from 1000 to 3000 ft or so.

- b. The variation in shoaling rate with depth for a given location can be discretized to form a reasonable number of depth intervals. For example, if shoaling was being considered at depths from 40 to 50 ft, the variation in shoaling with depth for a given location could be discretized to form 1- to 4-ft intervals (40 to 44 ft, 44 to 46 ft, 46 to 49 ft, and 49 to 50 ft) for computational purposes.
- c. Short-term variation in shoaling, such as seasonal variation, is not considered, since most shoaling intervals (periods between dredging activity) to be investigated in estuarine navigation projects are at least 1 yr in length. However, if the shoaling is highly seasonal and sufficient data are available to develop shoaling rates with respect to depth for each appropriate period (for example, April through October and November through March), the method in this report could be applied to each period and results coupled.
- d. Channel depth changes within the range considered do not significantly affect the distribution of shoaling material within the project. The validity of this assumption for a particular project can be addressed by inspection of the shoaling distribution patterns during previous project depth increases.

PART II: DISCUSSION OF METHODS

12. In order to demonstrate the methods to be used in shoaling analyses, an example estuarine navigation project has been created as an example and will be evaluated. The project is fictitious and not based on any specific real project. The project was initiated in FY 1930 with new work dredging of 1.52 million cu yd in FY 1930, 1.57 million cu yd in FY 1931, and 0.47 million cu yd in FY 1932, resulting in a 10-mile-long channel of 30-ft depth* and 300-ft width. Maintenance dredging was performed periodically between FY 1932 and FY 1943, ranging in volume from none to 1.42 million cu yd in FY 1943. During FY 1943, new work dredging of 1.35 million cu yd was conducted to deepen the project, resulting in a 10-mile-long channel of 32-ft depth and 300-ft width. Periodic maintenance dredging was performed between FY 1944 and FY 1959, ranging in volume from none to 1.40 million cu yd in FY 1959. During FY 1960 and FY 1961, new work dredging of 3.03 and 1.24 million cu yd, respectively, was conducted to deepen and widen the project, resulting in a 10-mile-long channel of 34-ft depth and 400-ft width. Periodic maintenance dredging was performed between FY 1960 and FY 1966, ranging from none to 2.03 million cu yd in FY 1963. During FY 1967, new work dredging of 1.89 million cu yd was conducted to deepen the project, resulting in a 10-mile-long channel of 36-ft depth and 400-ft width. Periodic maintenance dredging was performed from FY 1967 to FY 1975, ranging from none to 2.81 million cu yd in FY 1975. The dredging history for the project, similar to information that can be extracted from the Corps of Engineers Annual Reports and including both new work and maintenance dredging volumes, is presented in Table 1. It is assumed that advantage is taken of the 2-ft dredging tolerance allowance each time the channel is dredged (new work or maintenance). Thus, the channel depth immediately after each dredging operation would be 1 or 2 ft greater than the authorized project depth.

13. In order to determine the effectiveness of advance maintenance

* All depths cited herein are in feet below mean low water (mlw).

for any maintenance dredging project, the relation between shoaling characteristics of that project and project dimensions must first be determined. The shoaling characteristics of a project can usually be investigated as follows:

- a. Analysis of maintenance dredging records from the Corps of Engineers Annual Reports (Phase 1).
- b. Analysis of shoaling rates as determined from dredging records from the Corps of Engineers Annual Reports (Phase 1-Modified).
- c. Analysis of shoaling rates as determined from periodic hydrographic surveys (Phase 2).

14. The analysis of maintenance dredging records from Corps Annual Reports (Phase 1) is the easiest to apply, but also the least accurate. The analysis of shoaling rates as determined from dredging records from the Corps Annual Reports (Phase 1-Modified) is an extension of Phase 1, but requires additional information. Analysis of shoaling rates as determined from periodic hydrographic surveys computes shoaling rates directly and is therefore the most accurate; but the surveys required are usually not available for the entire history of the project. The three approaches will be demonstrated with the example channel described in paragraph 12. The use of Phase 1 or Phase 1-Modified combined with Phase 2 analysis is required for predictive purposes.

Phase 1

15. The annual report dredging data for the example channel presented in Table 1 are graphically displayed as dredging volume versus fiscal year in Figure 4. The variance in yearly dredging activity is quite large. Years in which no dredging occurred are plotted as zero. Another factor contributing to variances is that dredging periods which straddled two fiscal years, i.e., began in one fiscal year but ended in the next, are plotted as two separate dredging activities, rather than as one dredging activity as actually was the case. Inspection of Table 1 indicates that dredging activity may have straddled fiscal year boundaries during FY 1943-44, FY 1950-51, FY 1954-55, FY 1959-60, and

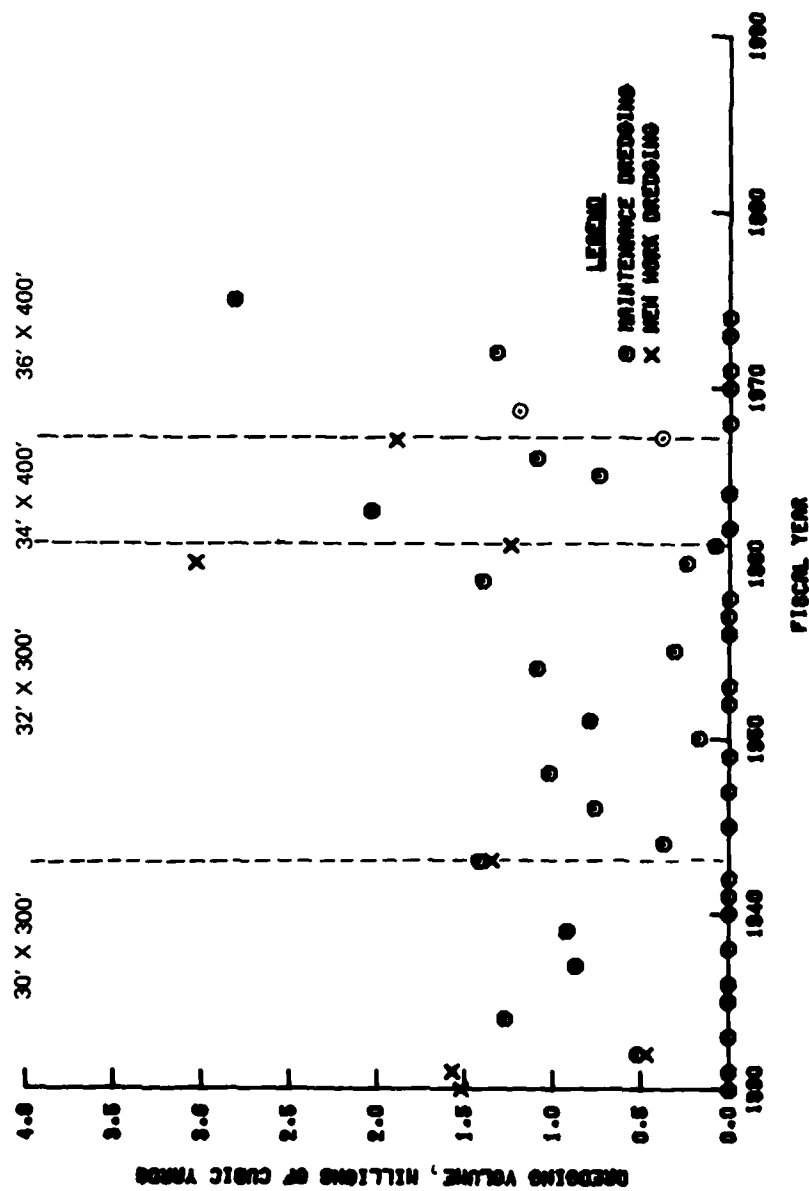


Figure 4. Example channel dredging history

FY 1965-66, resulting in two data points for one period of dredging activity.

16. In order to more quantitatively determine the relation between dredging requirements and channel size, a second plot of the same data is presented in Figure 5, where the annual maintenance dredging volumes are plotted against accumulated new work volume. In order to be as general as possible, accumulated new work is the parameter used to represent increasing channel dimensions. If the project is such that the channel width has not varied over several channel deepenings, then plots of dredging or shoaling versus depth can also be generated. A regression curve, $Y = AX^2 + BX$, is least-square fitted to the data as a guideline for the shoaling behavior (rate of dredging) as a function of channel dimensions. As can be seen from Figure 5, the regression curve is almost linear for the example project and indicates an average annual maintenance dredging volume of 0.30 million cu yd for the original project (30 x 300 ft). The average annual maintenance dredging volume is increased to 0.40 million cu yd for the 32- x 300-ft project, an increase of 33 percent compared with the 30- x 300-ft project. The average annual maintenance dredging volume is increased to 0.67 million cu yd for the 34- x 400-ft project, an increase of about 68 percent when compared with the 32- x 300-ft project. The average annual maintenance dredging volume is increased to 0.77 million cu yd for the 36- x 400-ft project, an increase of 13 percent when compared with the 34- x 400-ft project.

17. The above results indicate that increases in project depth of 2 ft caused increases in annual maintenance dredging of about 13 to 33 percent, while the deepening and widening of 2 ft and 100 ft, respectively, resulted in a substantial increase of about 68 percent. Therefore, a major portion of the 68 percent increase caused by the deepening and widening could reasonably be expected to have been caused by the widening alone. This is not an unexpected result, since the dredged volume would increase with the greater bottom area even if the shoaling rate (depth deposited/time) remained constant.

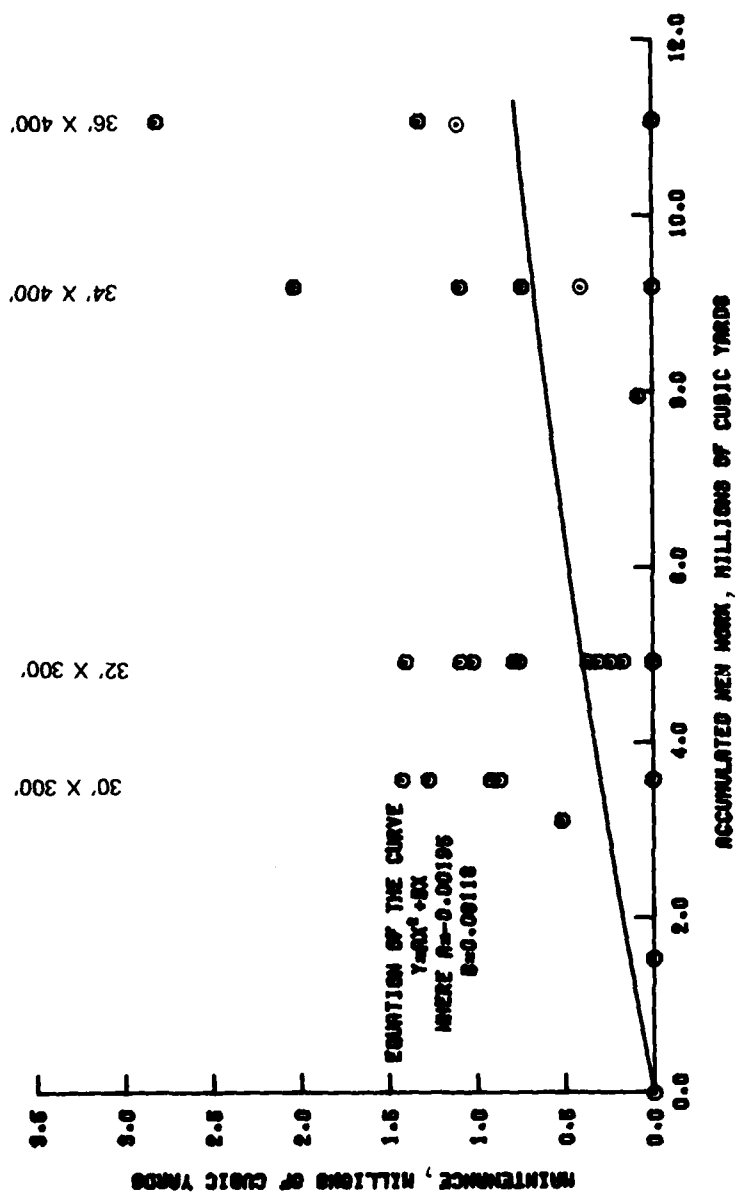


Figure 5. Example channel annual maintenance plotted as a function of accumulated new work volume

Phase 1-Modified

18. The preceding analysis was based only on fiscal year dredging volumes from the Corps Annual Reports. If the actual dates of dredging activity are also provided in the Annual Reports or are available from district files, the analysis can be refined to increase its predictive capability by computing shoaling rates based on dredging volumes and the actual time intervals rather than intervals restricted to whole years as in Phase 1. For example, Table 2 gives the dates of dredging activity for the example navigation channel described previously. Using this information, the average shoaling rates based on dredging volumes and the associated time intervals can be computed as shown in Table 2. In order that the relation between shoaling and accumulated new work volumes (channel dimensions) can be determined as was done in Phase 1 previously, the average shoaling rate for each accumulated new work volume (channel dimension) is computed. For example, the average shoaling rate for the 32- x 300-ft channel (an accumulated new work volume of 4.91 million cu yd) is computed in the following manner. From Tables 1 and 2, the total volume of dredging to maintain the 32- x 300-ft channel (4.91 accumulated new work volume) was 5.86 million cu yd ($0.76 + 1.02 + 0.96 + 1.40 + 1.64 + 0.08 = 5.86$). From Table 2, the period of time in which the 32- x 300-ft channel existed was from 10 August 1943 to 2 March 1961 (17.55 yr). Therefore, the average shoaling rate based on dredging volumes for the 32- x 300-ft channel was 0.33 million cu yd per year ($5.86 \text{ million cu yd} / 17.55 \text{ yr}$).

19. The average shoaling rate is computed for each of the different channel dimensions as was demonstrated for the 32- x 300-ft channel. The regression curve obtained using shoaling rates determined from Phase 1-Modified is shown in Figure 6. It should be noted that the average shoaling rates for each channel dimension were weighted according to the number of times the project was dredged for maintenance. The reason for weighting the shoaling rates is that the greater the number of times the project is dredged, the more likely the computed shoaling rates are representative of the actual shoaling rates. Therefore, for

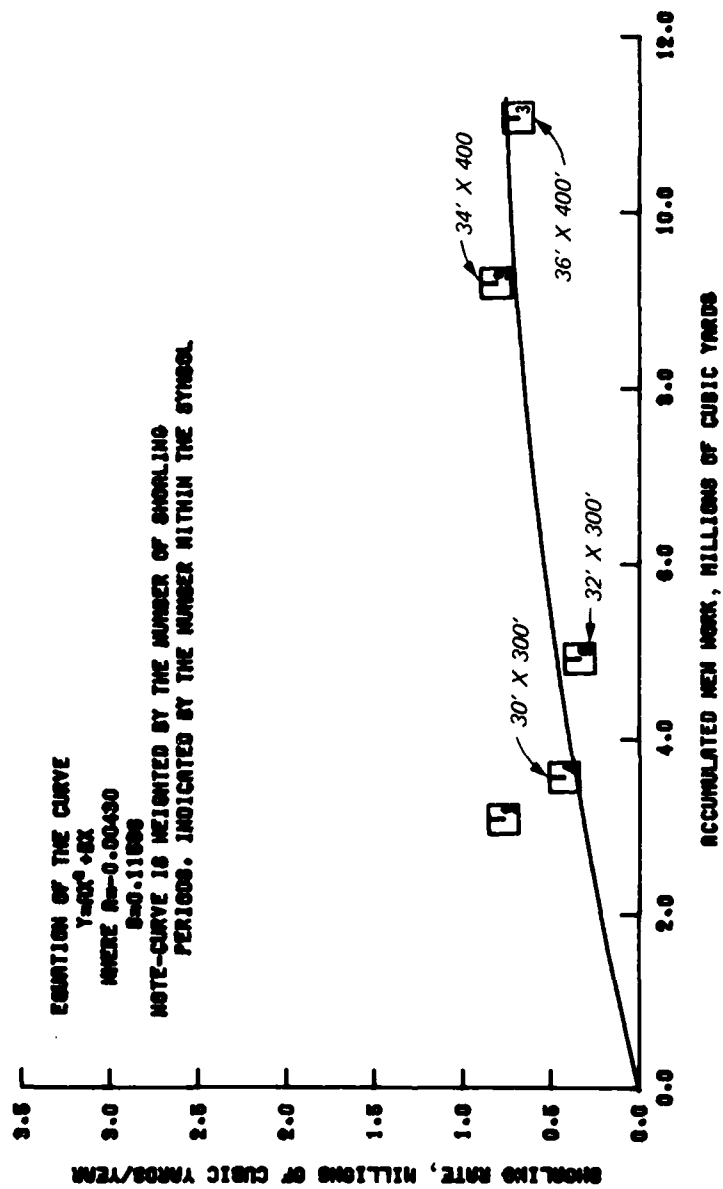


Figure 6. Example channel average shoaling rates (computed from dredging volumes) plotted as a function of accumulated new work volume

the regression curve in Figure 6, the average shoaling rate for the 30- x 300-ft channel was actually considered as four data points; the average shoaling rate for the 32- x 300-ft channel was considered as six data points; the average shoaling rate for the 34- x 400-ft channel was considered as three data points; and the average shoaling rate for the 36- x 400-ft channel was considered as three data points. Therefore, the 30- x 300-ft, 32- x 300-ft, 34- x 400-ft, and 36- x 400-ft channel average shoaling rates had weighting factors of 1.33, 2.00, 1.00, and 1.00, respectively. The resulting regression curve (Figure 6) indicates an average shoaling volume of 0.36 million cu yd/yr for the original project (30 x 300 ft). The average shoaling volume is increased to 0.47 million cu yd/yr for the 32- x 300-ft project, an increase of 31 percent compared with the 30- x 300-ft project. The average shoaling volume is increased to 0.70 million cu yd/yr for the 34- x 400-ft project, an increase of about 49 percent when compared with the 32- x 300-ft project. The average shoaling volume is increased to 0.76 million cu yd/yr for the 36- x 400-ft project, an increase of 9 percent when compared with the 34- x 400-ft project.

20. The above results indicate that increases in project depth of 2 ft caused increases in average shoaling volumes of about 9 to 31 percent, while the deepening and widening of 2 ft and 100 ft, respectively, resulted in a substantial increase of about 49 percent.

21. The regression curve obtained using Phase 1-Modified differs only slightly from the curve obtained using Phase 1 for the example channel. For the subsequent shoaling prediction the results from the Phase 1 analysis will be used.

Phase 2

22. Phase 2 differs from Phases 1 and 1-Modified in that shoaling volumes are computed directly from hydrographic survey data rather than indirectly through dredging volumes. The use of survey sheets allows one to analyze the shoaling distribution within the project, i.e., the project can be segmented and the shoaling determined for each segment. Dredging data from annual reports are not usually broken down extensively.

The disadvantage with hydrographic survey data is that usually they are available only for the more recent history of the project. For the example channel, the hydrographic survey data are available only as far back as 1960. No survey data are available from 1930 to 1960. Phase 2 results, which provide shoaling rates for each of the selected segments within the project for the more recent conditions, will be coupled with the results provided by Phases 1 or 1-Modified to predict the effectiveness of advance maintenance dredging. The following survey data are available for the example project:

- a. January 1961 - Predredge survey.
- b. March 1961 - Postdredge survey.
- c. October 1962 - Predredge survey.
- d. February 1963 - Postdredge survey.
- e. March 1965 - Predredge survey.
- f. November 1965 - Postdredge survey.
- g. January 1967 - Predredge survey.
- h. June 1967 - Postdredge survey.
- i. July 1968 - Predredge survey.
- j. December 1968 - Postdredge survey.
- k. December 1971 - Predredge survey.
- l. June 1972 - Postdredge survey.
- m. July 1974 - Predredge survey.
- n. December 1974 - Postdredge survey.

23. Using these survey data, six shoaling periods (postdredge survey to following predredge survey) were considered, i.e., from March 1961 to October 1962 (19 months), from February 1963 to March 1965 (25 months), from November 1965 to January 1967 (14 months), from June 1967 to July 1968 (13 months), from December 1968 to December 1971 (36 months), and from June 1972 to July 1974 (23 months). The first three survey periods occurred when the authorized dimensions were 34 ft x 400 ft, and the second three periods occurred when the authorized dimensions were 36 ft x 400 ft.

24. The project, shown on the location map in Figure 7, was segmented into 10 equal 1-mile sections and the section shoaling rates for

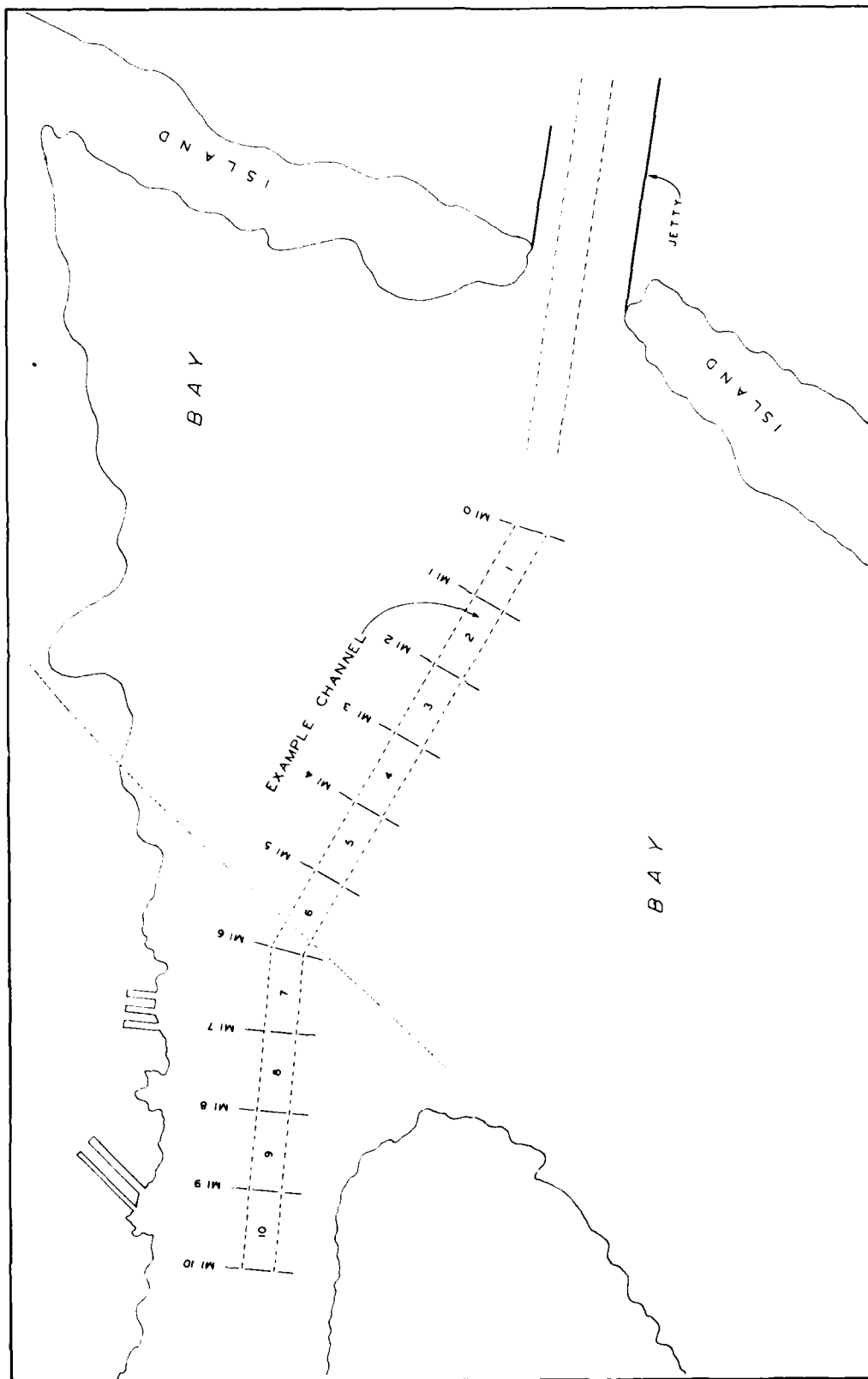


Figure 7. Example channel location map

each of the 6 shoaling periods were computed and are presented in Table 3. Project shoaling for the three periods with the 34-ft authorized depth, computed by Phase 2 analysis, totaled about 600, 620, and 660 thousand cu yd/yr for a time-weighted average of 625 thousand cu yd/yr. Project shoaling for the three periods with the 36-ft authorized depth, computed by Phase 2 analysis, were about 780, 740, 760 thousand cu yd/yr for a time-weighted average of 759 thousand cu yd/yr.

Comparison of Results

25. The shoaling results for the example channel obtained from the regression curves of Phases 1 and 1-Modified and the direct computations of Phase 2 are summarized as follows:

Phase	<u>Shoaling in Thousands of cu yd/yr for Channel Dimensions</u>			
	<u>30 x 300 ft</u>	<u>32 x 300 ft</u>	<u>34 x 400 ft</u>	<u>36 x 400 ft</u>
1	300	401	673	770
1-Mod	358	465	701	756
2	--	--	625	759

26. Results from the Phase 2 analysis indicate that the use of historical dredging volumes to determine the effect of increasing dimensions on shoaling rates was reasonable. If the Phase 2 analysis had yielded shoaling rates which differed significantly from Phase 1 or 1-Modified, a further exploration of the data to determine their adequacy would be required.

Shoaling Predictions

27. Table 2 shows that the average dredging interval for the existing project is 3.0 yr (6.0 yr : 2). Table 3 shows that the highest average shoaling rate of 1.6 ft per year for the existing project occurred in section 6. Therefore, the representative controlling depth for the existing project, assuming the full 2 ft of allowable dredging tolerance is used, can be determined as follows:

Shoaling in section 6 = 1.6 ft per year $\times$ 3.0 years = 4.8 ft

Controlling depth = 36 ft + 2 ft allowable dredging tolerance

- 4.8 ft shoaling = 33.2 ft

28. Based on the data in Table 3, the existing shoaling pattern for the example project is shown in Figure 8. Advance maintenance can be applied either to reduce dredging frequency while maintaining the controlling depth at 33.2 ft, or to increase the controlling depth to authorized depth (36 ft) while maintaining or reducing the dredging frequency. The procedure used to investigate these objectives will now be discussed.

29. The increase in the shoaling rate for the 2-ft depth increase from 34 to 36 ft (from 9,180 to 11,070 thousand cu yd accumulated new work) indicated by the Phase 1 regression curve was about 13 percent. The curve also indicates a decreasing rate of increase with depth. For the following evaluation of overdepth dredging, the increase in shoaling rate will be held constant at 13 percent per 2-ft increment rather than decreased. The resulting predictions should tend to be on the conservative side.

30. Using the 13 percent rate of increase for each 2-ft increment from 2 to 10 ft of advance maintenance (40- to 48-ft depth, including 2 ft of allowable dredging tolerance at each increment), the incremental shoaling rates for each of the 10 sections are:

Depth ft	Predicted Incremental Shoaling Rates, ft/yr, for Sections									
	1	2	3	4	5	6	7	8	9	10
Less than 38*	0.5	0.7	0.8	0.9	1.2	1.6	1.4	1.2	0.8	0.5
38 to 40	0.6	0.8	0.9	1.0	1.4	1.8	1.6	1.4	0.9	0.6
40 to 42	0.7	0.9	1.0	1.1	1.6	2.0	1.8	1.6	1.0	0.7
42 to 44	0.8	1.0	1.1	1.2	1.8	2.3	2.0	1.8	1.1	0.8
44 to 46	0.9	1.1	1.2	1.4	2.0	2.6	2.3	2.0	1.2	0.9
46 to 48	1.0	1.2	1.4	1.6	2.3	2.9	2.6	2.3	1.4	1.0

* Shoaling rates for this depth are taken directly from Table 3 for the 36-ft project depth.

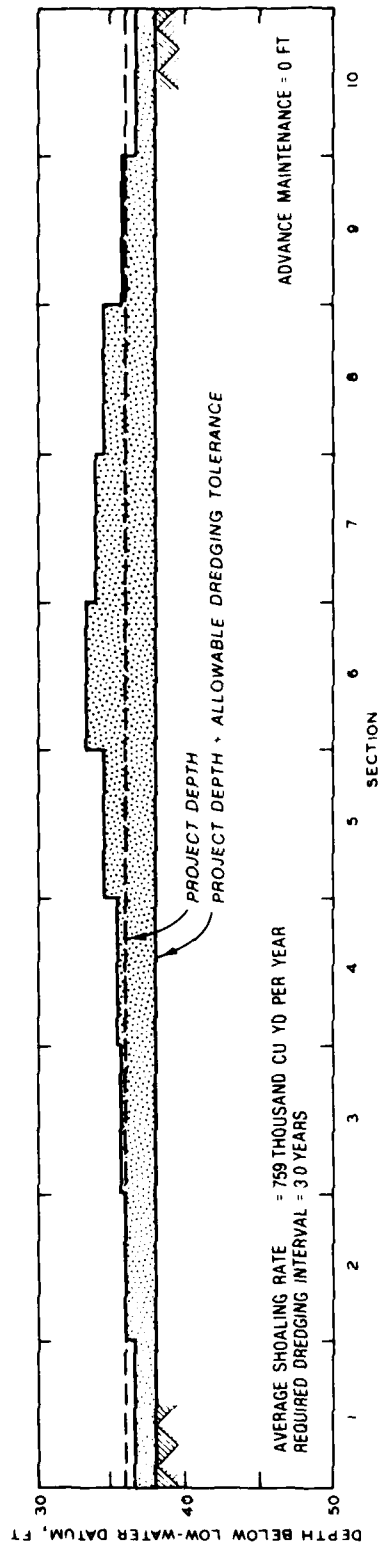


Figure 8. Existing shoaling pattern for example channel

The above incremental shoaling rates will be applied to all advance maintenance evaluations of the example project.

Reduction in Dredging Frequency While Maintaining Controlling Depth

31. Advance maintenance of 2, 4, 6, 8, and 10 ft along the entire length of the channel will now be considered.

Two feet of advance maintenance

32. Two feet of advance maintenance will increase the after-dredging depth to 40 ft (36 ft authorized plus 2 ft advance maintenance plus 2 ft allowable dredging tolerance). The first section to be evaluated must be the section with the highest shoaling rate, section 6. Since the after-dredging depth is set at 40 ft, and the shoaling rate for section 6 from 40 to 38 ft is 1.8 ft/yr, section 6 will shoal from 40 to 38 ft in 1.1 yr (2 ft/1.8 ft per yr). Since the shoaling rate for section 6 from 38 to 33.2 ft (controlling depth) is 1.6 ft/yr, section 6 will shoal from 38 to 33.2 ft in 3.0 yr (4.8 ft/1.6 ft per yr). Therefore, section 6 will shoal from 40 to 33.2 ft in 4.1 yr (1.1 yr + 3.0 yr), which then becomes the time interval to be used in evaluating the remaining nine sections. Section 1 will shoal from 40 to 38 ft at the rate of 0.6 ft/yr in 3.3 yr (2 ft/0.6 ft per yr). For the remaining 0.8 yr (total = 4.1 yr), section 1 will shoal above 38 ft depth at the rate of 0.5 ft/yr, or 0.4 ft (0.8 yr $\times$ 0.5 ft/yr). Total shoaling for section 1 in 4.1 yr equals 2.0 ft (40 to 38 ft) plus 0.4 ft (38.0 to 37.6) or 2.4 ft. Since the bottom area is known, the shoaling volume for the 4.1-yr period can also be determined, excluding the amount deposited outside the channel prism on the side slopes. For section 1 this is 188 thousand cu yd (400 ft $\times$ 5280 ft $\times$ 2.4 ft/27 ft³ per yd³). The same procedure can be followed for sections 2, 3, 4, 5, 7, 8, 9, and 10, resulting in the shoaling pattern shown Plate 1a profile. The overall average annual shoaling rate listed in Plate 1a profile is determined by computing the volume of shoaling in each of the 10 sections, summing, and then dividing by the computed dredging interval (4.1 yr).

Four feet of advance maintenance

33. Four feet of advance maintenance will increase the postdredge depth to 42 ft (36 ft authorized plus 4 ft advance maintenance plus 2 ft allowable dredging tolerance). As was the case for 2 ft advance maintenance, the first section to be evaluated is section 6. Since the postdredge depth is 42 ft, and the shoaling rate for section 6 from 42 to 40 ft is 2.0 ft/yr, section 6 will shoal from 42 to 40 ft in 1.0 yr (2.0 ft/2.0 ft per yr). As previously determined (paragraph 32), section 6 will shoal from 40 to 38 ft in 1.1 yr and from 38 to 33.2 ft in 3.0 yr. Section 6 will shoal from 42 to 33.2 ft in 5.1 yr (1.0 yr + 1.1 yr + 3.0 yr), which becomes the time interval to be used for the remaining nine sections. Section 1 will shoal from 42 to 40 ft at the rate of 0.7 ft/yr in 2.9 yr (2.0 ft/0.7 ft per yr). For the remaining 2.2 yr (total = 5.1 yr) section 1 will shoal at the rate of 0.6 ft/yr or 1.3 ft (2.2 yr $\times$ 0.6 ft/yr). Total shoaling for section 1 in 5.1 yr equals 2.0 ft (42- to 40-ft depth) plus 1.3 ft (40- to 38.7-ft depth), or 3.3 ft. Shoaling volume for the 5.1-yr interval is 258 thousand cu yd (3.3 ft $\times$ 400 ft $\times$ 5280 ft/27 ft³ per yd³). The same procedure can be followed for sections 2, 3, 4, 5, 7, 8, 9, and 10, resulting in the shoaling pattern shown in Plate 1b profile.

Six feet of advance maintenance

34. Six feet of advance maintenance will increase the after-dredging depth to 44 ft (36 ft authorized plus 6 ft advance maintenance plus 2 ft allowable dredging tolerance). Since the postdredge depth is 44 ft and the shoaling rate for section 6 from 44 to 42 ft is 2.3 ft/yr, section 6 will shoal from 44 to 42 ft in 0.9 yr (2.0 ft/2.3 ft per yr). As previously determined in paragraph 33, section 6 will shoal from 42 to 33.2 ft in 5.1 yr. Section 6 will therefore shoal from 44 to 33.2 ft in 6.0 yr (5.1 yr + 0.9 yr), which becomes the time interval to be used for the remaining sections. Section 1 will shoal from 44 to 42 ft at the rate of 0.8 ft/yr in 2.5 yr (2.0 ft/0.8 ft per yr) and from 42 to 40 ft at the rate of 0.7 ft/yr in 2.9 yr (2.0 ft/0.7 ft per yr). For the remaining 0.6 yr (total = 6.0 yr) section 1 will shoal at the rate of 0.6 ft/yr, or 0.4 ft (0.6 yr $\times$ 0.6 ft/yr). Total shoaling for

section 1 in 6.0 yr equals 2.0 ft (44- to 42-ft depth) plus 2.0 ft (42- to 40-ft depth) plus 0.4 ft (40- to 39.6-ft depth), or 4.4 ft. Shoaling volume for the 6.0-yr interval is 344 thousand cu yd ($400 \times 5280 \text{ ft} \times 4.4 \text{ ft} / 27 \text{ ft}^3 \text{ per yd}^3$). The same procedure can be followed for sections 2, 3, 4, 5, 7, 8, 9, and 10, resulting in the shoaling pattern shown in Plate 1c profile.

Eight feet of advance maintenance

35. Eight feet of advance maintenance will increase the after-dredging depth to 46 ft (36 ft authorized plus 8 ft advance maintenance plus 2 ft allowable dredging tolerance). The shoaling rate for section 6 from 46- to 44-ft depth is 2.6 ft/yr, which means section 6 will shoal from 46- to 44-ft depth in 0.8 yr ($2.0 \text{ ft} / 2.6 \text{ ft per yr}$). As previously determined in paragraph 34, section 6 will shoal from 44 to 33.2 ft in 6.0 yr. Section 6 will therefore shoal from 46 to 33.2 ft in 6.8 yr ($0.8 \text{ yr} + 6.0 \text{ yr}$), which becomes the time interval to be used for the remaining nine sections. Section 1 will shoal from 46- to 44-ft depth at the rate of 0.9 ft/yr in 2.2 yr ($2.0 \text{ ft} / 0.9 \text{ ft per yr}$) and from 44- to 42-ft depth at the rate of 0.8 ft/yr in 2.5 yr ($2.0 \text{ ft} / 0.8 \text{ ft per yr}$). For the remaining 2.1 yr (total = 6.8 yr), section 1 will shoal at the rate of 0.7 ft/yr, or 1.5 ft ($2.1 \text{ yr} \times 0.7 \text{ ft per yr}$). Total shoaling for section 1 in 6.8 yr equals 2.0 ft (46- to 44-ft depth) plus 2.0 ft (44- to 42-ft depth) plus 1.5 ft (42- to 40.5-ft depth), or 5.5 ft. Shoaling volume for the 6.8-yr interval is 430 thousand cu yd ($400 \text{ ft} \times 5280 \text{ ft} \times 5.5 \text{ ft} / 27 \text{ ft}^3 \text{ per yd}^3$). The same procedure can be followed for sections 2, 3, 4, 5, 7, 8, 9, and 10, resulting in the shoaling pattern shown in Plate 1d profile.

Ten feet of advance maintenance

36. Ten feet of advance maintenance will increase the after-dredging depth to 48.0 ft (36 ft authorized plus 10 ft advance maintenance plus 2 ft allowable dredging tolerance). The shoaling rate for section 6 from 48- to 46-ft depth is 2.9 ft/yr, which means section 6 will shoal from 48- to 46-ft depth in 0.7 yr ($2.0 \text{ ft} / 2.9 \text{ ft per yr}$). As previously determined in paragraph 35, section 6 will shoal from 46 to 33.2 ft in 6.8 yr. Section 6 will therefore shoal from 48 to 33.2 ft in 7.5 yr

(0.7 yr + 6.8 yr), which is also the time interval to be used for the remaining nine sections. Section 1 will shoal from 48- to 46 ft depth at the rate of 1.0 ft/yr in 2.0 yr (2.0 ft/1.0 ft per yr) and from 46- to 44-ft depth at the rate of 0.9 ft/yr in 2.2 yr (2.0 ft/0.9 ft per yr) and from 44- to 42-ft depth at the rate of 0.8 ft/yr in 2.5 yr (2.0 ft/0.8 ft per yr). For the remaining 0.8 yr (total = 7.5 yr), section 1 will shoal at the rate of 0.7 ft/yr, or 0.6 ft (0.8 yr $\times$ 0.7 ft/yr). Total shoaling for section 1 in 7.5 yr equals 2.0 ft (48- to 46-ft depth) plus 2.0 ft (46- to 44-ft depth) plus 2.0 ft (44- to 42- ft depth) plus 0.6 ft (42- to 41.4-ft depth), or 6.6 ft. Shoaling volume for the 7.5-yr interval is 516 thousand cu yd (400 ft $\times$ 5280 ft $\times$ 6.6 ft/27 ft³ per yd³). The same procedure is followed for sections 2, 3, 4, 5, 7, 8, 9, and 10, resulting in the shoaling pattern shown in Plate 1e profile.

37. The average shoaling rates and required dredging intervals for advance maintenance dredging from 2 to 10 ft are shown as follows:

Advance Maintenance ft	Average Shoaling Rate Thousands of cu yd/yr	Required Dredging Interval yr
0 (existing)	759	3.0
2	800	4.1
4	858	5.1
6	917	6.0
8	986	6.8
10	1,043	7.5

As can be seen, any increase in the required dredging interval is accompanied by the undesirable increase in shoaling rate. Since the shoaling rate for the example channel exhibits higher shoaling rates in sections 5 through 8 and lesser shoaling rates in the remaining sections, various combinations of advance maintenance will now be investigated with the intent of keeping the increased shoaling rates which accompany the example channel advance maintenance to a minimum.

Varied advance maintenance

38. A procedure that is termed "varied advance maintenance" in this report will be investigated here. Varied advance maintenance is defined as the application of different amounts of advance maintenance

along a dredged channel, according to need. For the example channel, the shoaling rates of the 10 sections are divided into high-rate-of-shoaling and low-rate-of-shoaling sections. Sections 5 through 8 are considered to have high rates of shoaling, and sections 1, 2, 3, 4, 9, and 10 are considered to have low rates of shoaling. The advance maintenance applied to sections 5 through 8 (high shoaling rates) will be greater than the advance maintenance applied to sections 1, 2, 3, 4, 9, and 10 (low shoaling rates).

39. The computational procedure for the varied advance maintenance schemes are the same as previously described, except that the after-dredging depths in the high-rate-of-shoaling sections and the low-rate-of shoaling sections are different because the amounts of advance maintenance are different. For example a scheme with 6 ft advance maintenance in the high-rate-of-shoaling sections and 4 ft advance maintenance in the low-rate-of-shoaling sections has an after-dredging depth in sections 5 through 8 of 44 ft (36 ft authorized plus 6 ft advance maintenance plus 2 ft allowable dredging tolerance) and in sections 1, 2, 3, 4, 9, and 10 of 42 ft (36 ft authorized plus 4 ft advance maintenance plus 2 ft allowable dredging tolerance).

40. The shoaling patterns for 2 ft advance maintenance in the high-shoaling-rate sections and 2 or 0 ft advance maintenance in the low-shoaling-rate sections are shown in Plate 2. The shoaling patterns for 4 ft advance maintenance in the high-shoaling-rate sections and 4, 2, or 0 ft advance maintenance in the low-shoaling-rate sections are shown in Plate 3. The shoaling patterns for 6 ft advance maintenance in the high-shoaling-rate sections and 6, 4, 2, or 0 ft advance maintenance in the low-shoaling-rate sections are shown in Plate 4. It should be noted that the shoaling pattern for 6 ft advance maintenance in the high-shoaling-rate sections and no advance maintenance in the remaining sections coupled with the 6-yr dredging interval, shown in Plate 4, resulted in depths in sections 4 and 9 slightly less than the controlling depth of 33.2 ft. The shoaling patterns for 8-ft advance maintenance in the high-shoaling-rate sections and 8, 6, 4, or 2 ft advance maintenance

in the low-shoaling-rate sections are shown in Plate 5. The shoaling patterns for 10 ft advance maintenance in the high-shoaling-rate sections and 10, 8, 6, 4, or 2 ft advance maintenance in the low-shoaling-rate sections are shown in Plate 6. It should be noted that the shoaling pattern for 10 ft advance maintenance in the high-shoaling-rate sections and 2 ft advance maintenance in the remaining sections coupled with the 6-yr dredging interval, shown in Plate 6, resulted in a depth in section 4 slightly less than the controlling depth of 33.2 ft. The average shoaling rates and required dredging intervals for each of the above advance maintenance schemes are summarized as follows:

Advance Maintenance ft	Average Shoaling Rate Thousands of cu yd/yr	Required Dredging Interval yr
0 (existing)	759	3.0
2	800	4.1
0 and 2	773	4.1
4	858	5.1
2 and 4	820	5.1
0 and 4	798	5.1
6	917	6.0
4 and 6	876	6.0
2 and 6	842	6.0
0 and 6	820	6.0
8	986	6.8
6 and 8	933	6.8
4 and 8	902	6.8
2 and 8	871	6.8
10	1,043	7.5
8 and 10	1,001	7.5
6 and 10	960	7.5
4 and 10	924	7.5
2 and 10	895	7.5

41. For a given dredging interval, the application of varied advance maintenance can result in a significant reduction in the dredging volume compared with the same depth of advance maintenance applied uniformly to the channel. Figure 9 presents the shoaling rate-dredging interval curve developed from the most efficient of the combinations of

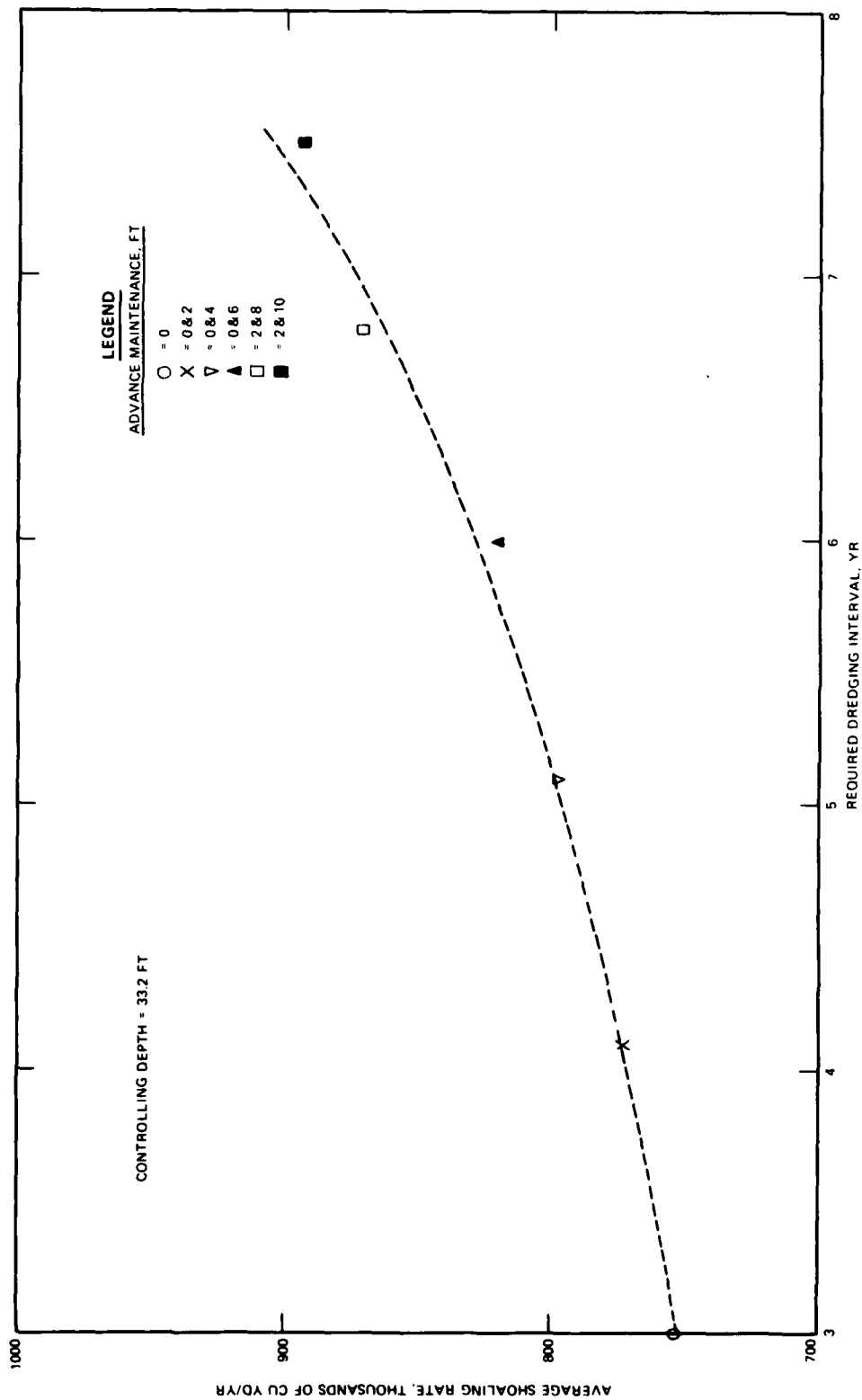


Figure 9. Example channel dredging interval-shoaling relation for various schemes of advance maintenance with a controlling depth of 33.2 ft

advance maintenance investigated for the example project. This curve would be used for any subsequent economic analysis to determine the applicability of advance maintenance.

Increase in Controlling Depth While Maintaining or
Reducing Dredging Frequency

42. For the example project the existing dredging interval is 3 yr, but the controlling depth (at section 6) is only 33.2 ft, which is considerably less than the 36-ft authorized depth. The objective here is to determine the amount of advance maintenance required to increase the controlling depth to 36 ft while maintaining or reducing the required dredging frequency. Advance maintenance of 2, 4, 6, 8, and 10 ft will be evaluated. The shoaling rates and the computational procedure are the same as described previously. The only difference is that the controlling depth is 36 ft rather than 33.2 ft. The resulting shoaling patterns for 0, 2, 4, 6, 8, and 10 ft advance maintenance are shown in Plates 7-12. The average shoaling rate and required dredging intervals are summarized as follows:

Advance Maintenance ft	Average Shoaling Rate Thousands of cu yd/yr	Required Dredging Interval yr
0	759	1.3
2	829	2.4
0 and 2	783	2.4
4	894	3.4
2 and 4	854	3.4
6	961	4.3
4 and 6	920	4.3
2 and 6	880	4.3
8	1,030	5.1
6 and 8	986	5.1
4 and 8	943	5.1
10	1,099	5.8
8 and 10	1,054	5.8
6 and 10	1,015	5.8
4 and 10	969	5.8

43. As can be seen from the results, for a given dredging interval the application of varied advance maintenance can result in a significant reduction in the dredging volume compared with the same depth of advance maintenance applied uniformly to the channel. Figure 10 represents the shoaling-rate dredging interval curve developed from the most efficient of the schemes investigated for the example project. The curve would be used for any subsequent economic analysis to determine the applicability of advance maintenance.

44. At the present time very limited use of varied advance maintenance procedures exists. As these procedures may be applied to navigation channels, the need to continuously update predictions is important. The variable depths could change the shoaling rates in various portions of the channel to the extent that the effectiveness of advanced maintenance could change.

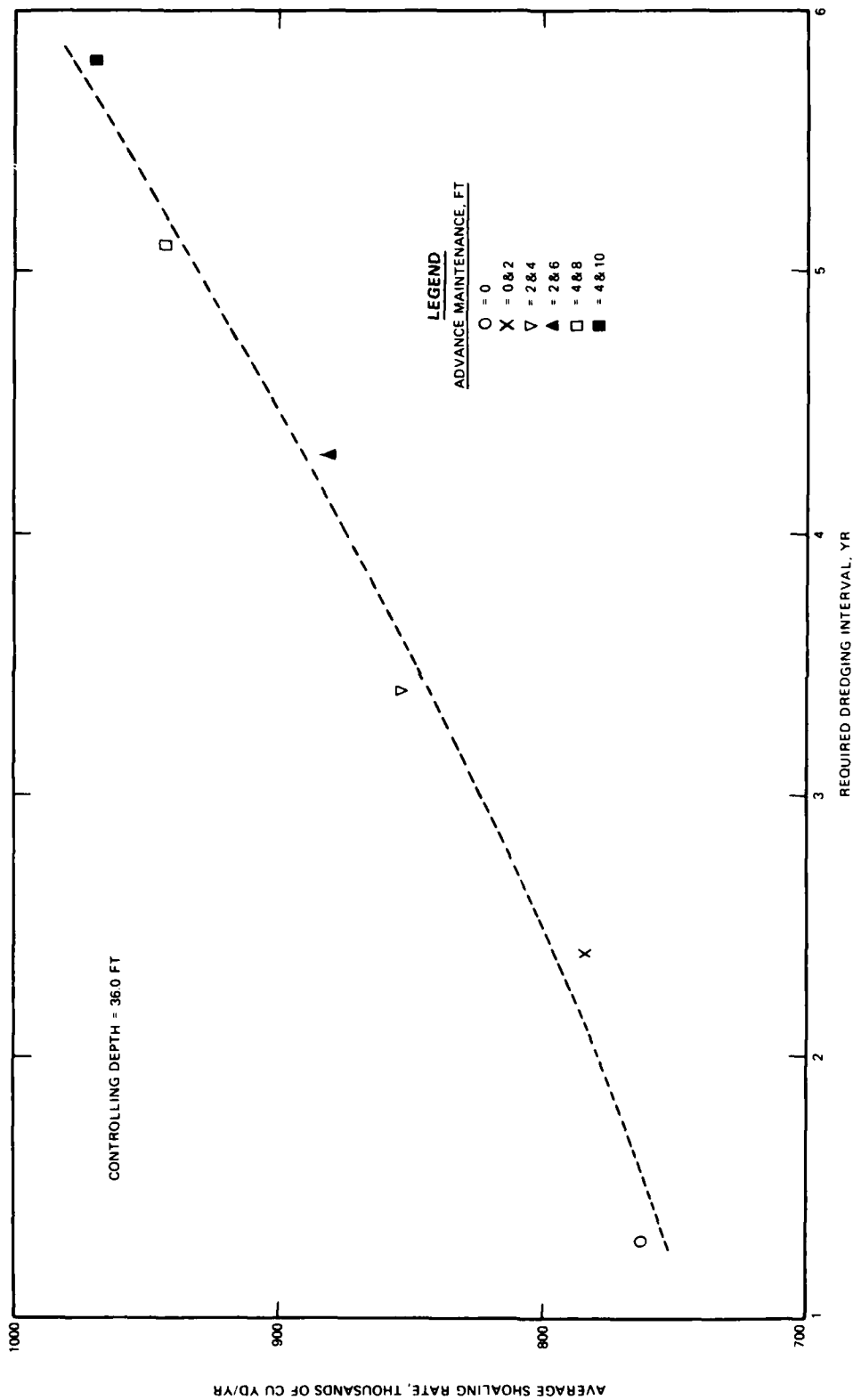


Figure 10. Example channel dredging interval-shoaling relation for various schemes of advance maintenance with a controlling depth of 36.0 ft

PART III: ANALYSES OF SELECTED GALVESTON BAY PROJECTS

45. The shoaling analyses described in PART II of this report will now be applied to selected navigation projects in Galveston Bay, Texas. The Galveston Channel, Texas City Channel, and Houston Ship Channel (Phases 1 and 1-Modified only) will be analyzed and shoaling predictions made for various amounts of advance maintenance dredging.

Bay Description

46. Galveston Bay, located in the southeastern part of Texas on the Gulf of Mexico (Figure 11), is approximately 60 miles west of Port Arthur, Texas, and 50 miles south of Houston, Texas. With the exception of the area between Galveston Island and Bolivar Peninsula, known as Bolivar Roads, the bay is relatively shallow and varies generally from 7 to 9 ft in depth, except for the deepened channels that are maintained by dredging. Bolivar Roads is connected to the various ports in or near Galveston Bay by Galveston, Houston Ship, and Texas City Channels and is connected to the Gulf of Mexico by the Galveston Harbor entrance or jetty channel. The improvements to the natural pass between Galveston Bay and the Gulf of Mexico include a jettied entrance channel from deep water in the gulf to Bolivar Roads, a distance of about 7 miles, and north and south rock jetties, about 5 and 7 miles long, respectively.

47. Currents in the channels and bays are largely the result of Gulf of Mexico tides. The mean diurnal range is about 2 ft in the Gulf of Mexico at Galveston Bay and about 0.5 ft in the San Jacinto River and Buffalo Bayou. The normal water-surface elevation at the entrance to Galveston Bay has been lowered by amounts up to 4.3 ft below mean low tide by strong north winds in the winter season, and has been raised by amounts up to 15 ft above mean low tide by tropical hurricanes which approach from the south, usually in late summer or early fall.

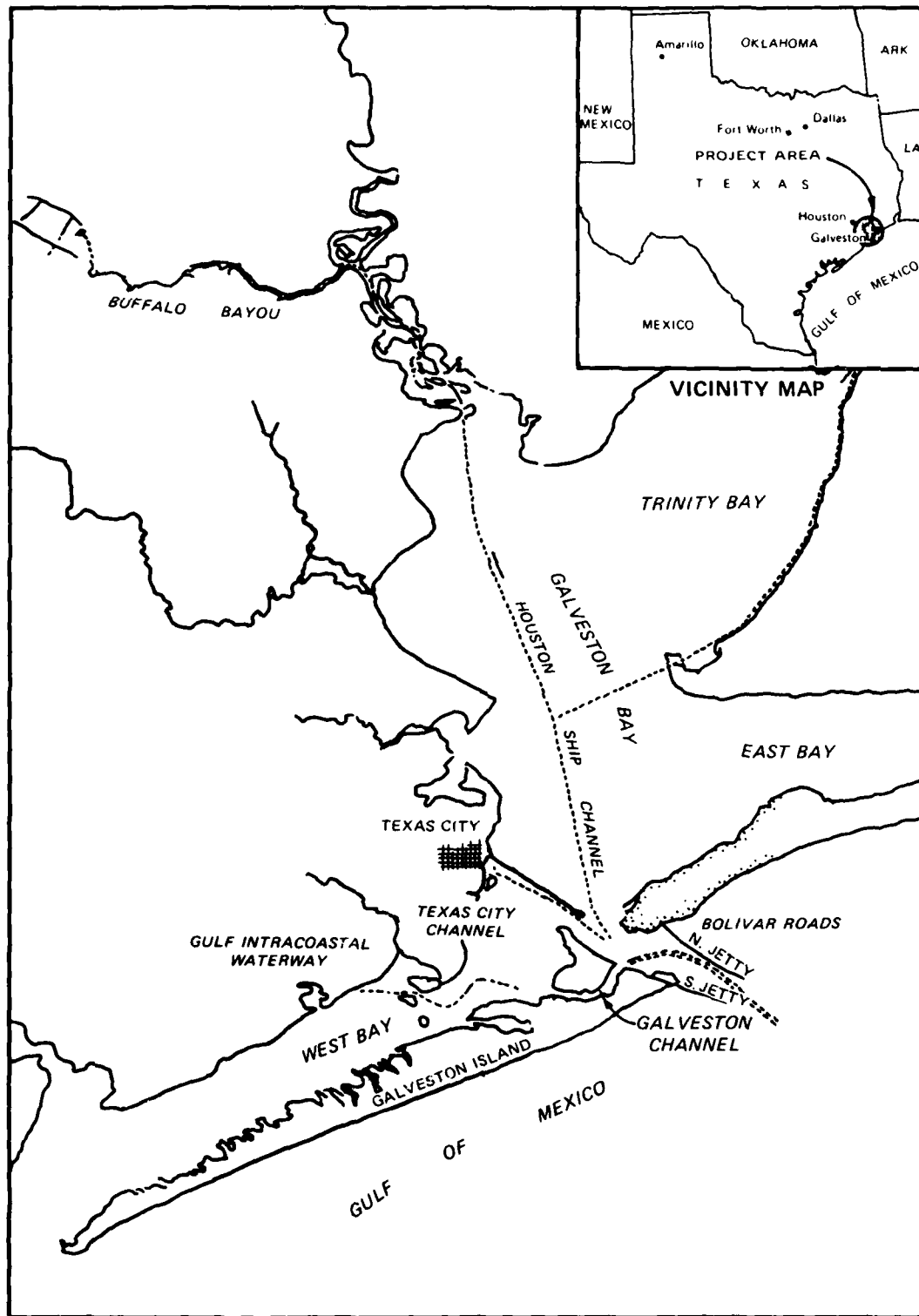


Figure 11. Location map

Galveston Channel

48. Galveston Channel, located between Pelican Island and the Galveston waterfront (see Figure 12), was originally authorized by Congress in 1886. The natural condition consisted of a narrow channel with depths generally between 20 and 30 ft. Between 1905 and 1913, the project was deepened to a depth of 30 ft at mlw with a 1200-ft width. By 1940, the depths were being maintained between 32 and 34 ft. The predredge and postdredge survey sheets for Galveston Channel from 1960 to 1975, obtained from the Galveston District, indicated that from 1960 to 1962 the contract dredging depths were 34 ft at mlw plus 2 ft allowable overdepth and no advance maintenance; from 1962 through 1966, the depths were 34 ft at mlw plus 2 ft allowable dredging tolerance and 2 ft advance maintenance; and from 1966 through 1974, the depths were 36 ft at mlw plus 3 ft advance maintenance plus 2 ft allowable dredging tolerance. These design depths and the actual average postdredge depths for this period are shown in Plate 13. The channel depth is presently authorized for 40 ft at mlw plus 3 ft advance maintenance plus 2 ft allowable dredging tolerance, but definitive results from this recent depth increase will not be available for several years.

Phase 1

49. Using the procedures described in PART II for Phase 1 analysis, the annual report dredging data for Galveston Channel are tabulated in Table 4 and graphically displayed in Plate 14 as maintenance dredging volume versus fiscal year. The second plot of the data, annual maintenance versus channel dimensions (accumulated new work), is presented in Plate 15. A 2nd degree regression curve, fitted to the second plot, serves as a guideline for the shoaling behavior as a function of channel dimensions. For Galveston Channel, since the increases in channel dimensions involve only increases in depth, not widening, the regression curve describes the relation of channel depth to required dredging

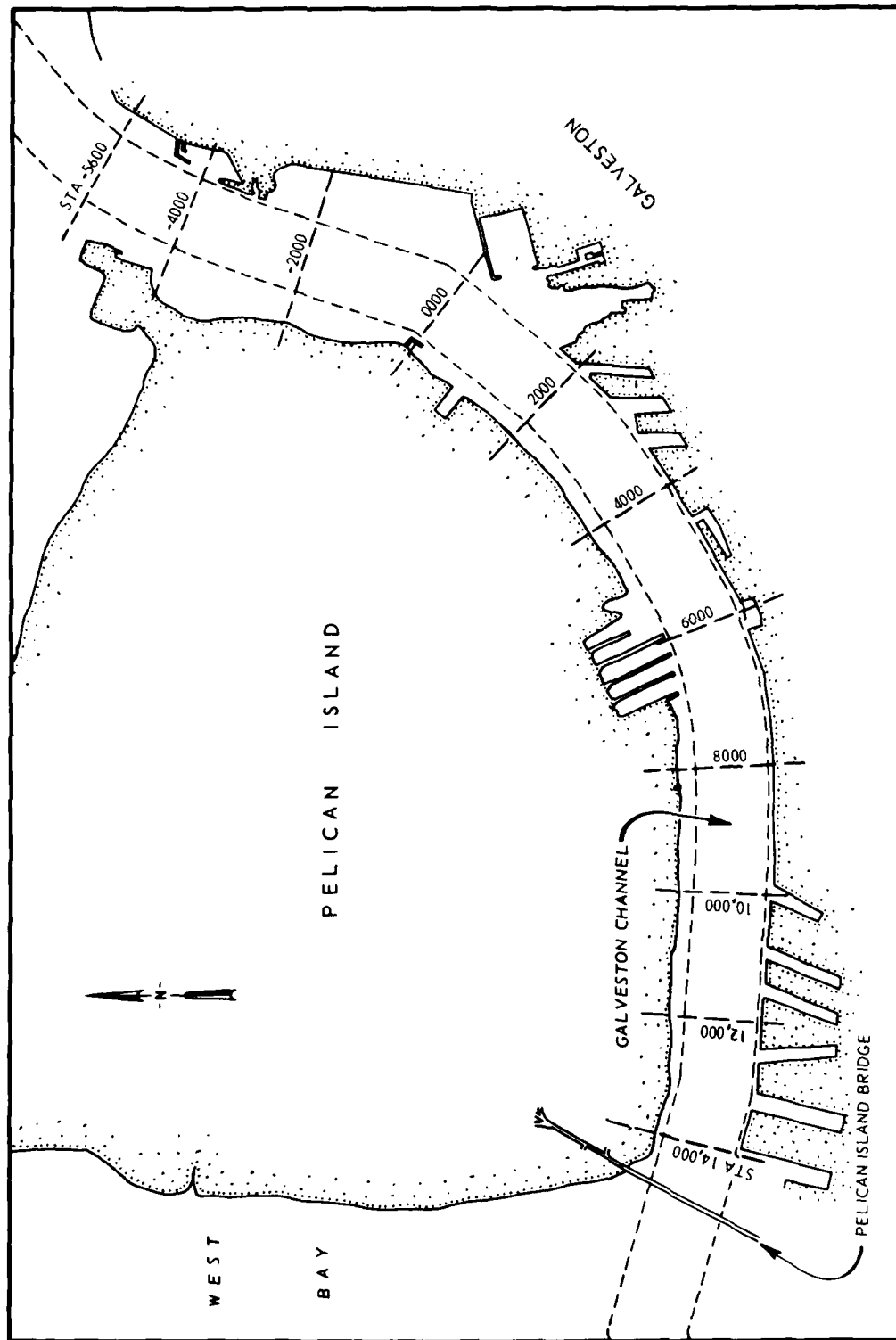


Figure 12. Galveston Channel location map

volume. The regression curve indicates the required dredging volumes for the Galveston Channel as follows:

<u>Project</u>	<u>Total Depth*</u>	<u>Required Dredging Volume, Millions of cu yd/yr</u>	<u>Percent Change**</u>
30 x 1200	32	1.87	
32 x 1200	34	1.94	+4
34 x 1200	36	1.93	-1
34 x 1200	38	1.90	-2
36 x 1200	41	1.71	-10

* Includes allowable dredging tolerance and advance maintenance.

** Compared with the immediately previous project.

50. The above results indicate that increases in the project depth of Galveston Channel have not caused increases in the overall project shoaling and also that the period which included 3 ft of advance maintenance dredging did not involve increased overall dredging. In fact, the results indicate that after deepening beyond 32 ft, average annual maintenance requirements actually decreased slightly. It is possible that other factors not addressed by this analysis such as differing maintenance practices, stabilization of Pelican Island, changes in traffic density and draft of vessels, or changes in sediment loading to Galveston Channel could have affected shoaling.

Phase 1-Modified

51. The preceding analysis was based only on fiscal year dredging volume from the Corps Annual Reports. Since for the Galveston Channel project the dates of dredging activity are also provided in the Annual Reports, the analysis was refined to enhance its predictive capability by computing shoaling rates based on dredging volumes and the actual time intervals rather than intervals restricted to whole years as in Phase 1. The shoaling rates based on dredging volumes for each shoaling interval are shown in Table 5. Using the procedure described in paragraphs 18 and 19 in PART II results in the regression curve shown

in Plate 16, which indicates the shoaling rates for the Galveston Channel as follows:

<u>Project</u>	<u>Total Depth*</u>	<u>Shoaling Rate Millions of cu yd/yr</u>	<u>Percent Change**</u>
30 x 1200	32	1.94	
32 x 1200	34	2.02	+4
34 x 1200	36	2.01	0
34 x 1200	38	1.98	-1
36 x 1200	41	1.78	-10

* Includes allowable dredging tolerance and advance maintenance.

** Compared with the immediately previous project.

52. The above results, as was the case for Phase 1 analysis, indicate that increases in the project depth of Galveston Channel have not caused increases in the overall project shoaling and that 3 ft of advance maintenance dredging did not result in increased overall shoaling. Again, the results indicate that after deepening beyond 32 ft, maintenance dredging slightly decreased.

Phase 2

53. Hydrographic survey data were available from the Galveston District from 1960 through 1975. Phase 2 results will be compared with results obtained by Phases 1 and 1-Modified and will be used to determine the shoaling rates along Galveston Channel.

54. The survey data associated with the dredging activity occurring during May-December 1960; January-July 1962; April-May 1964; June 1971-October 1972; and January-June 1974 were available from the Galveston District. Using these survey data, the project was segmented into 10 sections (Figure 12), and the section shoaling rate for each the shoaling periods was computed as shown in Table 6. Project shoaling for the one period with the 34-ft authorized depth plus 2 ft of allowable overdepth was 1.79 million cu yd/yr. Project shoaling for the shoaling periods with an authorized depth of 34 ft plus 2 ft of

allowable dredging tolerance and 2 ft of advance maintenance averaged 1.78 million cu yd/yr. The averaging technique applied was to determine the time-weighted average for each section, then sum the section averages to obtain the total. For example, the section average for section 1 was determined as follows:

$$\begin{aligned}\text{Section 1 average} &= \left(190 \times \frac{25}{49}\right) + \left(283 \times \frac{13}{49}\right) + \left(246 \times \frac{11}{49}\right) \\ &= 227 \text{ thousand cu yd/yr}\end{aligned}$$

The section 5 average was computed as follows:

$$\begin{aligned}\text{Section 5 average} &= \left(139 \times \frac{36}{47}\right) + \left(172 \times \frac{11}{47}\right) \\ &= 147 \text{ thousand cu yd/yr}\end{aligned}$$

The section averaging allows one to compute a total project average even though the entire length of the project was not dredged each time dredging occurred, as was the case for Galveston Channel during 1962 through 1965. It should be noted that whenever a project is analyzed in which the same length of project is dredged each time, it makes no difference whether the sections are averaged first and then totaled or whether the shoaling for each period is totaled and then averaged. Project shoaling for the four shoaling periods with an authorized depth of 36 ft plus 2 ft allowable dredging tolerance and 3 ft of advance maintenance were 1.81, 1.76, 1.82, and 1.87 million cu yd/yr for a time-weighted average of 1.81 million cu yd/yr.

55. Both Phases 1 and 1-Modified analyses of dredging data indicated no increase in shoaling when the channel was deepened from 34 to 36 ft, and also no increase in shoaling after 3 ft of advance maintenance was added to the 36-ft authorized depth channel. Phase 2 shoaling analysis agrees with the Phase 1 and 1-Modified results, as shown below:

Phase	Shoaling in Thousands of cu yd/yr				
	Channel Depth, ft*				
	30	32	34	34**	36†
1	1,870	1,940	1,930	1,900	1,710
1-Mod	1,940	2,020	2,010	1,980	1,780
2	--	--	1,788	1,781	1,811

* Channel width - 1200 ft for all depths.

** With 2 ft advance maintenance.

† With 3 ft advance maintenance.

Therefore, it would be projected that increased channel depth would not increase the average annual maintenance requirement. Thus, it is shown a priori that calculations for increased advance maintenance will indicate no change in annual dredging volumes.

56. The average dredging interval for the existing channel, determined from the data in Table 5 (see "Shoaling Interval" column), was 2.51 yr. Based on the shoaling rates from Table 6, the existing shoaling pattern at 2.51 yr after dredging is shown in Figure 13, indicating a controlling depth of 34.0 ft (in section 1).

Shoaling predictions

57. The controlling depth, which occurs in section 1, is assumed to be 34.0 ft to agree with the shoaling pattern in Figure 13. Increased advance maintenance can be evaluated either to reduce the dredging frequency while maintaining the 34.0-ft controlling depth in section 1 or to increase the controlling depth to 36 ft (authorized depth) while maintaining or reducing the frequency of dredging.

58. The existing conditions shoaling rates for sections 1 to 10 (Table 6) will be used for evaluation of 5, 6, and 9 ft of advance maintenance.

Reduction in dredging frequency while maintaining controlling depth

59. Increased advance maintenance of 5, 7, and 9 ft along the entire length of the channel will be investigated. Varied advance maintenance (lesser amounts of advance maintenance in the low shoal sections than in the high shoal sections) will also be investigated.

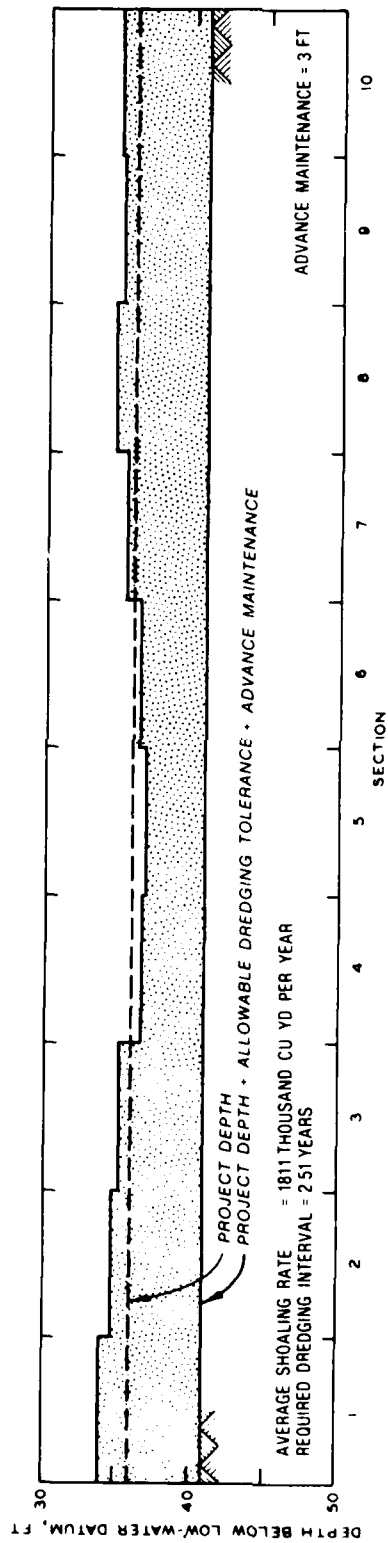


Figure 13. Galveston Channel existing shoaling pattern

60. Five feet of advance maintenance will increase the after-dredging depth to 43.0 ft (36 ft authorized depth plus 5 ft advance maintenance plus 2 ft allowable dredging tolerance). The first section which requires evaluation is the controlling section 1. Since the after-dredging depth is 43 ft and the shoaling rate for section 1 is 2.8 ft/yr, the section will shoal from 43.0 to 34.0 ft in 3.21 yr, which is also the time interval to be used for the remaining sections. The resulting shoaling pattern is shown in Plate 17a profile.

61. Seven feet of advance maintenance will increase the after-dredging depth to 45.0 ft (36 ft authorized plus 7 ft advance maintenance plus 2 ft allowable dredging tolerance). Section 1 will shoal from 45 to 35.1 ft in 3.93 yr. The resulting shoaling pattern is shown in Plate 18a profile.

62. Nine feet of advance maintenance will increase the after-dredging depth of 47.0 ft (36 ft authorized depth plus 9 ft advance maintenance plus 2 ft allowable dredging tolerance). Section 1 will shoal from 47 ft to 35.1 ft in 4.64 yr. The resulting shoaling pattern is shown in Plate 19a profile.

63. Since shoaling rates are not increased with depth, the only advantage of using varied advance maintenance in Galveston Channel would be to reduce the new work dredging volume created by the initial advance maintenance dredging. Variation in advance maintenance of 2 and 4 ft between the high and low shoaling sections will be investigated. The project will be grouped into sections 1, 2, 8, 9, and 10 (high shoaling) and sections 3, 4, 5, 6, and 7 (low shoaling). Resulting shoaling patterns with varied advance maintenance are shown in Plate 17b, Plate 18b and c, and Plate 19b and c profiles.

64. The average shoaling rates and required dredging intervals are summarized as follows:

<u>Advance Maintenance ft</u>	<u>Average Shoaling Rate Thousands of cu yd/yr</u>	<u>Required Dredging Interval, yr</u>
3 (existing)	1,811	2.51
5	1,811	3.21
3 and 5	1,811	3.21

(Continued)

<u>Advance Maintenance ft</u>	<u>Average Shoaling Rate Thousands of cu yd/yr</u>	<u>Required Dredging Interval, yr</u>
7	1,811	3.93
5 and 7	1,811	3.93
3 and 7	1,811	3.93
9	1,811	4.64
7 and 9	1,811	4.64
5 and 9	1,811	4.64

As stated before, advance maintenance does not increase the average shoaling rate for Galveston Channel. Therefore advance maintenance can be used effectively to reduce dredging frequency without any increase in the long-term dredging volume.

Increase in controlling
depth while maintaining
or reducing dredging frequency

65. The situation is that the existing dredging interval is 2.51 yr, but the controlling depth at section 1 is 34.0 ft rather than the authorized depth of 36 ft. The problem is to increase the controlling depth to 36 ft while maintaining or reducing the dredging frequency. Advance maintenance of 5, 7, and 9 ft along the entire length of the channel as well as varied advance maintenance will be investigated. The shoaling rates and the computational procedures are the same as previously described, except that the controlling depth has been increased from 34.0 to 36 ft. Since the shoaling rates for each section are independent of depth for the depth range under consideration, the average shoaling rate remains unchanged for each scheme evaluated. The only change is that the required dredging interval is reduced compared with the shallower controlling depth. The resulting shoaling patterns for 3, 5, 7, and 9 ft of advance maintenance are shown in Plates 20-23. The average shoaling rate and required dredging intervals are summarized as follows:

<u>Advance Maintenance ft</u>	<u>Average Shoaling Rate Thousands of cu yd/yr</u>	<u>Required Dredging Interval, yr</u>
3	1,811	1.79
1 and 3	1,811	1.79
5	1,811	2.50
3 and 5	1,811	2.50
7	1,811	3.22
5 and 7	1,811	3.22
3 and 7	1,811	3.22
9	1,811	3.94
7 and 9	1,811	3.94
5 and 9	1,811	3.94

For the existing channel maintenance scheme (3 ft of advance maintenance) an attempt to increase the before-dredging controlling depth from the current 34 ft to 36 ft would result in a reduction in the required dredging interval from 2.51 yr to 1.79 yr with no change in the average shoaling rate. To increase the controlling depth while maintaining a required dredging interval of 2.5 yr requires either the 5-ft advance maintenance scheme or the varied advance scheme of 3 and 5 ft. To increase the controlling depth to 36 ft while increasing the required dredging interval beyond the 2.5 yr requires advance maintenance greater than 5 ft.

Hindcast

66. In order to demonstrate the capability of the prediction techniques presented in this report, the dredging requirement (both volume and frequency) for the existing Galveston Channel will be "predicted" using only information from previous conditions. The prediction can then be compared with the actual dredging requirement observed for the existing condition to determine the adequacy of the method in this case.

67. The existing condition (1975) for Galveston Channel is 36 ft deep $\times$ 1200 ft wide with 3 ft of advance maintenance. The previous condition was 34 ft deep $\times$ 1200 ft wide with 2 ft advance maintenance. Thus, the technique will be employed to "predict" the effect of 3 ft of advance maintenance and the 36-ft-deep channel on dredging requirements.

68. Using Phase 1-Modified analysis from the years 1905 through

1966 (all the available data except for existing condition) results in a regression curve shown in Plate 24, which indicates the shoaling rates for the Galveston Channel as follows:

<u>Project</u>	<u>Total Depth*</u>	<u>Shoaling Rate Millions of cu yd/yr</u>	<u>Percent Change**</u>
30 × 1200	32	1.90	
32 × 1200	34	2.03	0
34 × 1200	36	2.03	0
34 × 1200	38	2.02	0

* Includes 2 ft allowable dredging tolerance.

** Compared with immediately previous project.

69. The above results indicate that the increases in the depth of Galveston Channel beyond 34 ft (32-ft project) have not caused increases in the overall project shoaling.

70. Using the Phase 2 analysis for Galveston Channel as discussed in paragraphs 53 and 54 results in the data presented in Table 6 for the 34- and 34-ft (with 2 ft advance maintenance) projects. Based on the tabulation in paragraph 68, it will be projected that increased channel depth by advance maintenance will not increase the average annual maintenance requirement. Thus, it is shown a priori that calculations for 3 ft of advance maintenance will indicate no change in annual dredging volumes.

71. The average dredging interval for the "existing channel" (34 ft project depth with 2 ft advance maintenance), determined from the data in Table 5 (see "Shoaling Interval" column), was 1.98 yr. Based on the shoaling rates from Table 6, the "existing" shoaling pattern at 1.98 yr after dredging indicates a controlling depth of 32.9 ft (in sections 1, 2, and 3).

72. The 3 ft of advance maintenance and 36 ft channel depth will be evaluated with an increased controlling depth from 32.9 to 34 ft (actual observed controlling depth for 3 ft of advance maintenance condition from 1967 through 1975). Three feet of advance maintenance

and 36 ft channel depth increases the after-dredging depth from 38 to 41 ft. The first sections that require evaluation are the controlling sections 1, 2, and 3. Since the after-dredging depth is 41 ft and the shoaling rate for sections 1, 2, and 3 is 2.6 ft/yr, the section will shoal from 41 to 34 ft in 2.69 yr.

73. The average shoaling rates and required dredging intervals are summarized as follows:

Project Description Advance Maintenance ft	Controlling Depth ft	Shoaling Rate Thousands of cu yd/yr	Dredging Interval yr
34 ft project depth with 2 ft advance maintenance ("existing")	32.9	2,020	1.98
36 ft project depth with 3 ft advance maintenance (predicted)	34.0	2,020	2.69
(observed)	34.0	1,780	2.51

74. As can be seen, good agreement is achieved for the predicted required dredging interval with 3 ft of advance maintenance and 34 ft controlling depth (2.69 yr) and the observed required dredging interval (2.51 yr). The predicted shoaling rate was left unchanged from previous conditions at 2020 thousand cu yd/yr while the observed shoaling rate decreased slightly to 1780 thousand cu yd/yr. The hindcast is thus completed with the conclusion that the prediction scheme was satisfactory for both dredging volume and frequency in this case.

Texas City Channel

75. The Texas City Channel, located in the western part of lower Galveston Bay (Figure 11), was originally authorized by Congress in 1899 at dimensions of 25 ft x 100 ft. Natural depths varied from 4 to 8 ft. In 1915 and 1916, the channel was deepened and widened to 30 ft x 300 ft. In 1931 the turning basin was enlarged from 600- to 800-ft width. The change in turning basin dimensions was not considered

significant enough to prohibit comparison of pre-1931 project dredging data and post-1931 project dredging data. In 1937, the channel was deepened so that the dimensions were 34 ft x 300 ft. During 1959 and 1960, the channel was again deepened and widened to 36 ft x 400 ft. In 1966 and 1967, the channel was again deepened, resulting in the existing dimensions of 40 ft x 400 ft over a distance of 6.75 miles. The pre- and postdredge survey sheets for the Texas City Channel from 1962 to 1975, obtained from the Galveston District, indicated that from 1961 to 1965 the contract dredging depths were 36 ft plus 2 ft advance maintenance plus 2 ft allowable dredging tolerance; from 1965 to 1966 the depths were 36 ft plus 3 ft advance maintenance plus 2 ft allowable dredging tolerance; and from 1966 through 1975, the depths were 40 ft plus 3 ft advance maintenance plus 2 ft allowable dredging tolerance. These design depths and the actual average postdredge depths for the periods from 1962 to 1975 are shown in Plate 25.

Phase 1

76. Using the procedures described in PART II for Phase 1 analysis, the annual report dredging data for the Texas City Channel are tabulated in Table 7 and graphically displayed in Plate 26 as maintenance dredging and new work volume versus fiscal year. The second data plot, annual maintenance dredging versus accumulated new work, is presented in Plate 27. The regression curve indicates required dredging volumes as follows:

Project	Total Depth*	Maintenance Dredging Volumes Millions of cu yd/yr	Percent Change**
25 ft x 100 ft	27	0.40	--
30 ft x 300 ft	32	0.95	+138
30 ft x 300 ft†	32	1.05	+11
34 ft x 300 ft	36	1.14	+7
36 ft x 400 ft	40	1.35	+18
40 ft x 400 ft	45	1.47	+9

* Includes allowable dredging tolerance and advance maintenance.

** Compared with immediately previous project.

† Enlarged turning basin.

Phase 1-Modified

77. The preceding analysis was based only on fiscal year dredging volumes from the Corps Annual Reports. Since the dates of dredging activity for the Texas City Channel are also provided in the Annual Reports, the analysis can be refined to increase its predictive capability by computing shoaling rates based on dredging volumes and actual time intervals rather than intervals restricted to whole years as was the case for Phase 1. The average shoaling rates based on dredging volumes for each shoaling interval are shown in Table 8. The shoaling histogram as described in paragraphs 18 and 19 in PART II results in the regression curve shown in Plate 28, which indicates overall shoaling rates as follows:

Project	Total Depth* ft	Shoaling Rate Millions of cu yd/yr	Percent Change**
25 x 100	27	0.42	
30 x 300	32	0.99	+136
30 x 300†	32	1.10	+11
34 x 300	36	1.20	+9
36 x 400	40	1.44	+20
40 x 400	45	1.60	+11

* Includes allowable dredging tolerance and advance maintenance.

** Compared with immediately previous project.

† Enlarged turning basin.

Phase 2

78. Hydrographic survey data were available from the Galveston District from 1960 through 1975. Phase 2 results will be compared with the results obtained by Phases 1 and 1-Modified and will be used to determine shoaling rates along the Texas City Channel.

79. The survey data associated with the dredging activity occurring during November 1961-February 1962; May-June 1963; January-May 1965; May-August 1966; March-May 1968; February-April 1970; May-July 1972; and August 1974-January 1975 were available from the Galveston District. Using these survey data, the project was segmented into nine sections

(Figure 14), and the section shoaling rate for each of the shoaling periods was computed as shown in Table 9. Project shoaling for the three periods with the 36-ft authorized depth with 2 to 3 ft advance maintenance and 2 ft allowable dredging tolerance averaged 1.53 million cu yd/yr. Project shoaling for the four shoaling periods with an authorized depth of 40 ft with 3 ft advance maintenance and 2 ft allowable overdepth averaged 1.65 million cu yd/yr.

80. The average dredging interval for the existing channel, determined from the data in Table 8 (see "Shoaling Interval" column), was 1.89 yr. Based on the shoaling rates from Table 9, the existing shoaling pattern at 1.89 yr after dredging is shown in Figure 15, indicating a controlling depth of 36.7 ft (in section 8).

Shoaling predictions

81. The controlling depth, which occurs in section 8, is assumed to be 36.7 ft to agree with the shoaling pattern in Figure 15. Increased advance maintenance can be applied either to reduce the dredging frequency and maintain the 36.7-ft controlling depth in section 8 or to increase the controlling depth to 40.0 ft (authorized) while maintaining or reducing the dredging frequency. A summary of Phases 1, 1-Modified, and 2 results is as follows:

Phase	Shoaling in Thousands of cu yd/yr					
	25 x 100 ft	30 x 300 ft	30 x 300 ft (enlarged TB)	34 x 300 ft	36 x 400 ft	40 x 400 ft
1	400	950	1,050	1,140	1,350	1,470
1-Mod	420	990	1,100	1,200	1,440	1,600
2	--	--	--	--	1,533	1,640

82. Comparison of Phase 2 with Phase 1-Modified indicates that Phase 1-Modified is a reasonable estimation of the historical shoaling rates in the Texas City Channel.

83. The increase in the shoaling rate for the 4-ft increment from 36 to 40 ft (from 20,340 to 26,510 thousand cu yd accumulated new work) indicated by the Phase 1-Modified curve is 11 percent. The curve also indicates a decreasing rate of increase with depth. For the following

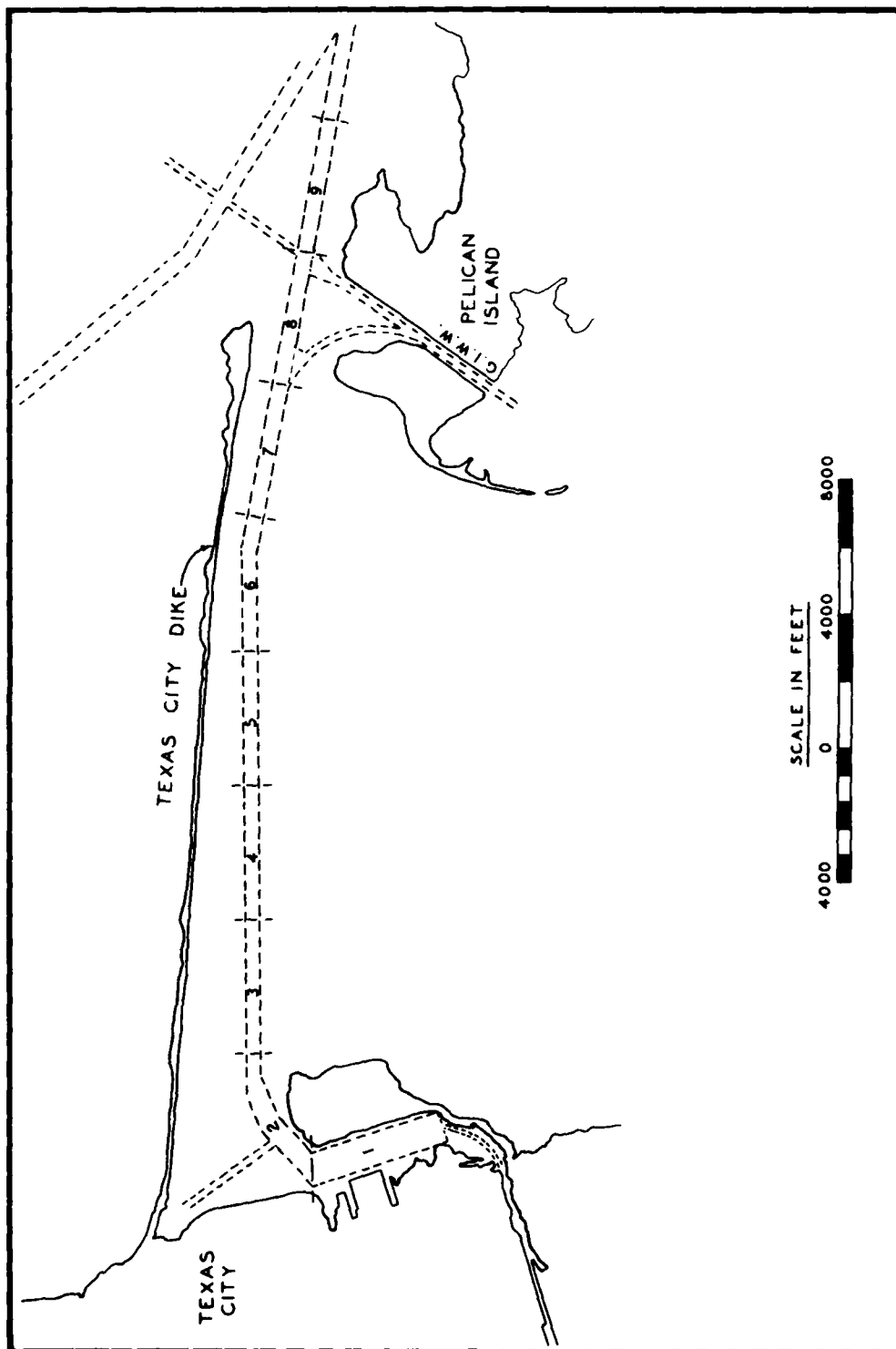


Figure 14. Texas City Channel location map

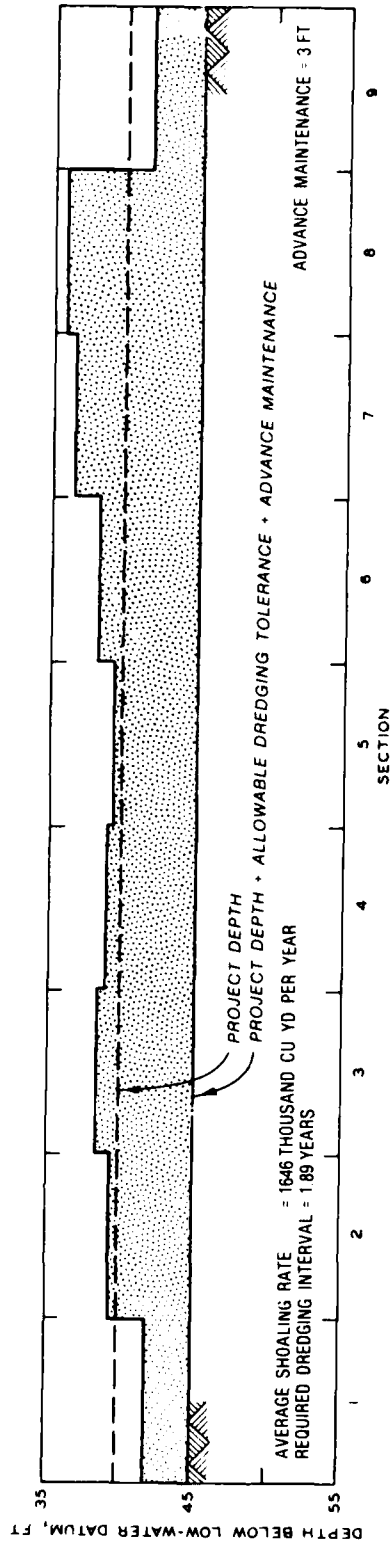


Figure 15. Texas City Channel existing shoaling pattern

evaluation of dredging tolerances, the increase in shoaling will be held constant at 5 percent (per 2-ft increment) rather than decreased.

84. Using the 5 percent rate of increase from 3 to 9 ft of advance maintenance, the shoaling rates for the nine sections (rounded to the nearest tenth of a foot per year) are:

Depth, ft	Predicted Shoaling Rates, ft/yr, for Sections								
	1	2	3	4	5	6	7	8	9
Less than 45*	1.5	2.7	3.2	2.9	2.7	3.2	4.1	4.4	1.6
45 to 47	1.6	2.8	3.4	3.0	2.8	3.4	4.3	4.6	1.7
47 to 49	1.7	2.9	3.6	3.2	2.9	3.6	4.5	4.8	1.8
49 to 51	1.8	3.0	3.8	3.4	3.0	3.8	4.7	5.0	1.9

* These shoaling rates are taken directly from Table 9.

The above incremental shoaling rates will be applied to all advance maintenance dredging predictions for the Texas City Channel.

Reduction in dredging frequency
while maintaining controlling depth

85. Increased advance maintenance of 5, 7, and 9 ft was evaluated along with varied advance maintenance using the procedure described in PART II for the example channel. Resulting shoaling patterns are shown in Plates 29-31. For varied advance maintenance, the high shoaling rate sections were considered to be sections 7 and 8; and the low shoaling rate sections were considered to be sections 1, 2, 3, 4, 5, 6, and 9. The average shoaling rates and required dredging intervals for each of the advance maintenance schemes investigated are summarized as follows:

Advance Maintenance ft	Average Shoaling Rate Thousands of cu yd/yr	Required Dredging Interval, yr
3 (existing)	1,646	1.89
5	1,677	2.32
3 and 5	1,655	2.32
7	1,712	2.74
5 and 7	1,681	2.74
3 and 7	1,663	2.74

(Continued)

<u>Advance Maintenance ft</u>	<u>Average Shoaling Rate Thousands of cu yd/yr</u>	<u>Required Dredging Interval, yr</u>
9	1,756	3.14
7 and 9	1,715	3.14
5 and 9	1,667	3.14

86. As can be seen, for a given dredging interval the application of varied advance maintenance can result in a slight reduction in the dredging volume compared with the same depth of advance maintenance applied uniformly to the channel. Figure 16 presents the shoaling rate-dredging interval curve using the most efficient of the combinations of advance maintenance evaluated. This curve would be used for any subsequent economic analysis to determine the applicability of advance maintenance.

Increase in controlling
depth while maintaining
or reducing dredging frequency

87. Increased advance maintenance of 5, 7, and 9 ft was evaluated along with varied advance maintenance using the procedure described in PART II for the example. Resulting shoaling patterns are shown in Plates 32-35. For varied advance maintenance the high shoaling rate sections were again considered to be sections 7 and 8, and the low shoaling rate sections were considered to be sections 1, 2, 3, 4, 5, 6, and 9. The average shoaling rates and required dredging intervals for each of the advance maintenance schemes investigated are summarized as follows:

<u>Advance Maintenance ft</u>	<u>Average Shoaling Rate Thousands of cu yd/yr</u>	<u>Required Dredging Interval, yr</u>
3	1,646	1.14
5	1,689	1.57
3 and 5	1,654	1.57
7	1,735	1.99
5 and 7	1,692	1.99
9	1,785	2.39
7 and 9	1,736	2.39
5 and 9	1,697	2.39

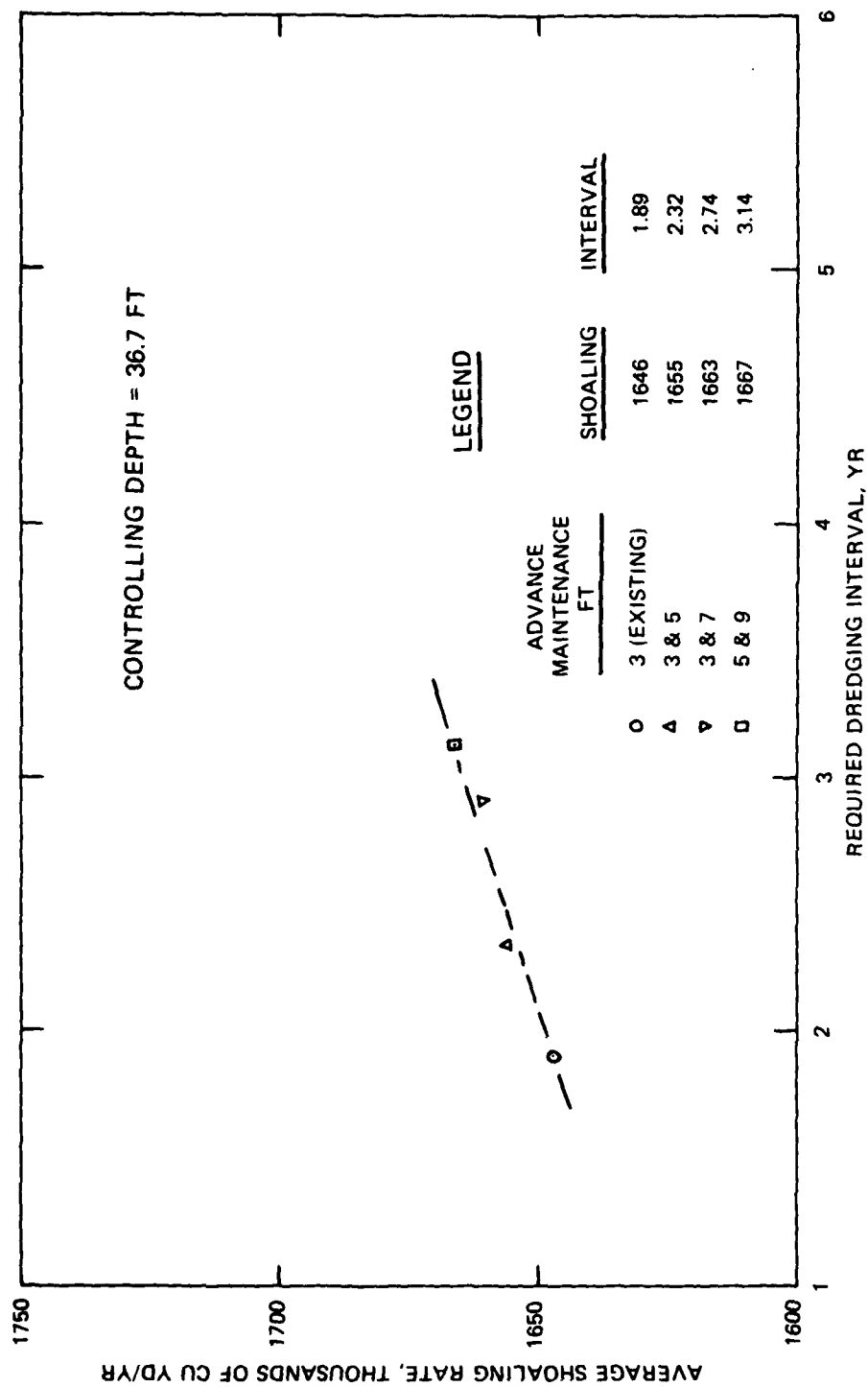


Figure 16. Texas City Channel dredging interval-shoaling relation for various schemes of advance maintenance with a controlling depth of 36.7 ft

88. As can be seen, for a given dredging interval the application of varied advance maintenance can result in a slight reduction in the dredging volume compared with the same depth of advance maintenance applied uniformly to the channel. Figure 17 presents the shoaling rate-dredging interval curve using the most efficient of the combinations of advance maintenance evaluated. This curve would be used for any subsequent economic analysis to determine the applicability of advance maintenance.

Hindcast

89. As was done for Galveston Channel, the dredging requirement (both volume and frequency) for the existing Texas City Channel will be "predicted" using only information from previous conditions. The prediction can then be compared with the actual dredging requirement observed for the existing condition to determine the adequacy of the method in this case.

90. The existing condition for Texas City Channel is 40 ft deep at mlw by 400 ft wide with 3 ft of advance maintenance. The previous condition was 36 ft deep at mlw by 400 ft wide with 2 ft of advance maintenance. Thus, the technique will be employed to "predict" the combined effect of channel deepening (36 to 40 ft) and increased advance maintenance (2 to 3 ft) on the project dredging requirements.

91. Using Phase 1-Modified analysis from the years 1906 through 1967 (all the available data except existing conditions) results in a regression curve shown in Plate 36, which indicates the overall shoaling rates for the Texas City Project as follows:

<u>Project</u>	<u>Total Depth*</u> ft	<u>Shoaling Rate Millions of cu yd/yr</u>	<u>Percent Change**</u>
25 x 100	27	0.44	
30 x 300	32	1.01	+139
30 x 300†	32	1.12	+11
34 x 300	36	1.20	+7
36 x 300	40	1.37	+14

* Includes allowable dredging tolerance and advance maintenance.

** Percent change from immediately previous project.

† Enlarged turning basin.

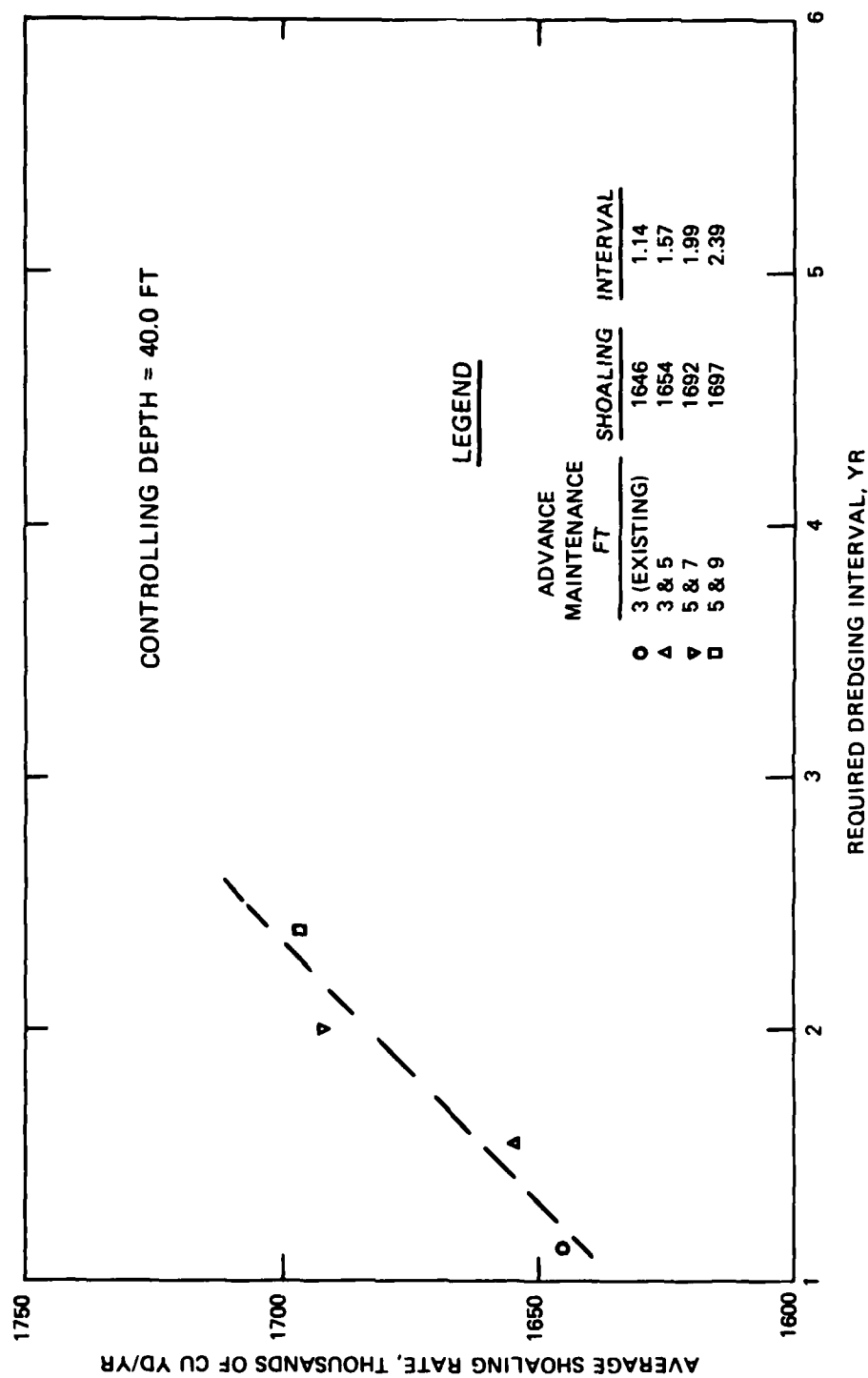


Figure 17. Texas City Channel dredging interval-shoaling relation for various schemes of advance maintenance with a controlling depth of 40 ft

92. The first step for the analysis is to estimate the shoaling rate for a 40-ft project by extrapolating the regression curve presented in Plate 36. Before the extrapolation can be made, however, the 40-ft depth condition must be converted to its equivalent new work dredging required to achieve the 40-ft depth condition. The estimated new work dredging to deepen the channel from 36- to 40-ft project depth is about 2.37 million cu yd for the channel bottom, based on 4-ft increase in depth times 400-ft width times 32,000-ft length (channel section) plus 4-ft increase in depth times 800-ft width times 4000-ft length (harbor section). Additionally, the estimated new work dredging along the channel side slopes (1 on 2) is roughly about 1.00 million cu yd. The total new work dredging to enlarge the project from 36- to 40-ft depth is roughly estimated at 3.37 million cu yd. Extrapolation of the regression curve presented in Plate 36 (equational form of $y = -0.00182X^2 + 0.10410X$) to include the additional 3.37 million cu yd estimated new work dredging results in a shoaling rate for the 40-ft depth project of 1.48 million cu yd/yr, or an increase of about 8 percent from the 36-ft channel. The increase of 8 percent for the 4-ft depth increment (2 percent per foot of depth) will be used to establish a shoaling rate-depth relation for the advance maintenance condition.

93. Using the Phase 2 analysis for the Texas City project as discussed in paragraphs 77 through 79 results in the data presented in Table 9 for the 36-ft project.

94. The average dredging interval for the "existing channel" (36-ft project depth) determined from the data in Table 8 (see "Shoaling Interval" column) was 1.79 yr. Based on the shoaling rates from Table 9, the "existing" shoaling pattern of 1.79 yr indicates a controlling depth of 32.8 ft in section 8, or 3.2 ft less than project depth of 36 ft at mlw. The 3 ft of advance maintenance for the 40-ft project will be evaluated to reduce dredging frequency while maintaining the 36.7-ft controlling depth (observed) in section 8.

95. The predicted shoaling rates (based on the 2 percent increase per foot of depth in the range of consideration) for the nine sections shown in Figure 14 are:

	Predicted Shoaling Rates, ft/yr, for Sections								
	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>
Less than 40*	2.5	2.4	3.0	2.2	2.5	2.4	3.3	4.0	1.2
40 to 41	2.6	2.4	3.1	2.2	2.6	2.4	3.4	4.1	1.2
41 to 42	2.6	2.5	3.1	2.3	2.6	2.5	3.4	4.2	1.3
42 to 43	2.7	2.5	3.2	2.3	2.7	2.5	3.5	4.2	1.3
43 to 44	2.7	2.6	3.2	2.4	2.7	2.6	3.6	4.3	1.3
44 to 45	2.8	2.7	3.3	2.4	2.8	2.7	3.6	4.4	1.3

* These shoaling rates are taken directly from Table 9.

96. Using the above predicted shoaling rates and the procedure described in PART II for the example channel results in average shoaling rates and required dredging intervals as follows:

<u>Project Depth</u> <u>ft</u>	<u>Advanced</u> <u>Maintenance</u> <u>ft</u>	<u>Controlling</u> <u>Depth</u> <u>ft</u>	<u>Average</u> <u>Shoaling Rate</u> <u>Thousands of</u> <u>cu yd/yr</u>	<u>Required</u> <u>Dredging</u> <u>Interval</u> <u>yr</u>
36 ("existing")	2	32.9	1,370	1.79
40 (predicted)	3	36.7	1,480	2.01
40 (observed)	3	36.7	1,600	1.89

97. As can be seen, satisfactory agreement is achieved for the predicted required dredging interval (2.01 yr) and the observed required dredging interval (1.89 yr). It must be realized that the effect of channel deepening alone would be to reduce the dredging interval while the effect of increased advance maintenance would be to increase the dredging interval. The fact that the prediction scheme not only correctly indicated that the combined effect would cause an increase in the dredging interval, but also predicted the amount of increase in dredging interval reasonably well is encouraging. Good agreement was also achieved with regard to the average shoaling rate, with the prediction being slightly less than that observed (1.48 million cu yd/yr predicted versus 1.60 million cu yd/yr observed). Thus, the hindcast is completed with the conclusion that the prediction scheme performed satisfactorily in this case.

Houston Ship Channel

98. The existing project (Figure 11) was originally authorized by the Act of 5 March 1905 and modified by subsequent acts. In 1919, a 30-ft-deep channel was authorized. In 1935, authorization was given to deepen the channel to 32 ft and widen the channel through Galveston Bay to 400 ft. In 1935, authorization was given to further deepen the channel to 34 ft. In 1948, authorization was given to further deepen the channel to 36 ft. The existing authorization was given by Congress in 1958. It now provides for a channel 40 ft deep and 400 ft wide extending about 26 miles across Galveston Bay from Bolivar Roads, just within the entrance to Galveston Bay, and into Buffalo Bayou an additional distance of a little under 21 miles; thence, the project dimensions of the channel within Buffalo Bayou are 40 ft deep $\times$ 300 ft wide for a distance of a little less than 1 mile and 36 ft $\times$ 300 ft for an additional distance of about 3 miles to a turning basin 36 ft deep and having a width varying from 400 to 1000 ft. Since about 48 miles of the 51-mile-long channel are maintained at 40-ft depth, the project will hereafter be referred to as the 40-ft depth project. The total length of the channel described including the turning basin is approximately 51 miles. Present dredging procedure includes 2 ft of advance maintenance and 2 ft allowable dredging tolerance.

Phase 1

99. Since the Annual Report dredging data for the Houston Ship Channel lists dredging below Morgan Point (Galveston Bay section) separately from the dredging above Morgan Point (Buffalo Bayou section), Phase 1 analysis will be applied independently to the Galveston Bay section and to the Buffalo Bayou section.

100. The Annual Report dredging data for the Galveston Bay section and the Buffalo Bayou section are presented in Tables 10 and 11 and graphically displayed in Plates 37 and 38 as maintenance and new work dredging volume versus fiscal year. The annual maintenance versus accumulated new work (channel dimensions) graphs are presented in Plates 39 and 40. Regression curves, fitted to the data, serve as

guidelines for the shoaling behavior as a function of channel dimensions.

The regression curves indicate the required dredging volumes as follows:

<u>Project Dimensions ft</u>	<u>Total Depth* ft</u>	<u>Required Dredging Thousands of cu yd/yr</u>	<u>Percent Change**</u>
<u>Galveston Bay Section</u>			
25 x 100	27	1,833	--
30 x 250	32	2,320	+27
34 x 400	36	2,357	+2
36 x 400	38	2,210	-6
40 x 400	44	1,923	-13
<u>Buffalo Bayou Section</u>			
25 x 100	27	987	--
30 x 250	32	1,597	+62
32 x 400	34	2,049	+28
36 x 400	38	2,205	+8
40 x 400	44	2,071	-6

* Includes allowable dredging tolerance and advance maintenance.

** Compared with immediately previous project.

The above results indicate that after the more recent increases in project depth the overall shoaling volumes actually slightly decreased.

Phase 1-Modified

101. The preceding analysis was based only on fiscal year dredging volumes from the Corps Annual Reports. Since, for the Houston Ship Channel, the dates of dredging activity are also provided in the Annual Reports, an analysis can be made by computing shoaling rates based on dredging volumes for each shoaling interval shown in Tables 12 and 13. Using the procedure described in paragraphs 18 and 19 in PART II results in the regression curve shown in Plates 41 and 42, which shows the shoaling rates for the Houston Ship Channel as follows:

Project Dimensions ft	Total Depth* ft	Required Dredging Thousands of cu yd/yr	Percent Change**
-----------------------------	-----------------------	--	------------------

Galveston Bay Section

25 x 100	27	1,926	--
30 x 250	32	2,508	+30
34 x 400	36	2,672	+7
36 x 400	38	2,596	-3
40 x 400	44	2,397	-8

Buffalo Bayou Section

25 x 100	27	847	--
30 x 250	32	1,367	+61
32 x 400	34	1,751	+28
36 x 400	38	1,879	+7
40 x 400	44	1,751	-7

* Includes allowable dredging tolerance and advance maintenance.

** Compared with immediately previous project.

The above results, as was the case for the Phase 1 analysis, indicate that after the more recent increases in project depth, the overall project shoaling has slightly decreased.

102. Phase 2 analysis was not applied to the Houston Ship Channel because of the unavailability of adequate hydrographic survey data. However, based on the results from Phase 1 and 1-Modified, increased overdepth dredging beyond the current 2 ft probably would not cause any significant change in overall shoaling.

PART IV: CONCLUSION

103. Before a prediction of future dredging requirements for a proposed deepened or an advance-maintained channel can be attempted, a determination of the effect of depth on shoaling must be made. This report presented an empirical method, based on historical dredging and shoaling data, which provides a rational approach to the problem.

104. The approach included several simplifying assumptions, listed in paragraph 11. Before any project is evaluated as described in this report, it should be first determined that the assumptions made will not severely affect the results. If it is determined that an assumption is not valid for the project to be investigated, the procedure should be modified to avoid the offending assumption.

105. The method of shoaling analysis was described using an example project. The procedure basically involved two steps. The first step was to determine the effect of past changes in depth on shoaling. The second step was to extrapolate the shoaling-depth relation to the proposed advance maintenance or deepened condition to determine required dredging frequencies and volumes. The method was then applied to selected projects in Galveston Bay - Galveston Channel, Texas City Channel, and Houston Ship Channel. The purpose was to demonstrate how the procedure can be applied to real projects. Hindcasts performed on the Galveston and Texas City projects indicated that the technique gave satisfactory predictions for both dredging volumes and frequencies in these two cases. Problems can occur when dealing with real projects when reported dredging volumes are not in reasonable agreement with the observed shoaling volumes for the period investigated. Additional research is then required to determine the adequacy of available data before a predictive technique to define shoaling as a function of depth could be considered reliable.

106. In summary, the approach presented in this report requires considerably more effort than the arbitrary, rule-of-thumb procedures predictors described in paragraph 5; but the result should be a much more reliable prediction of the effect of advance maintenance dredging or

channel deepening on a dredged navigation project.

107. As these procedures may be applied to a navigation channel, each new set of data should be used to update the predictions on the effectiveness of advanced maintenance.

Table 1

Dredging History of Example Channel, Millions of Cubic Yards

<u>Fiscal Year</u>	<u>Annual New Work</u>	<u>Accumulated New Work</u>	<u>Annual Maintenance</u>
1930	1.520	0.	0.
1931	1.570	1.520	0.
1932	0.470	3.090	0.520
1933	0.	3.560	0.
1934	0.	3.560	1.270
1935	0.	3.560	0.
1936	0.	3.560	0.
1937	0.	3.560	0.870
1938	0.	3.560	0.
1939	0.	3.560	0.920
1940	0.	3.560	0.
1941	0.	3.560	0.
1942	0.	3.560	0.
1943	1.350	3.560	1.420
1944	0.	4.910	0.370
1945	0.	4.910	0.
1946	0.	4.910	0.760
1947	0.	4.910	0.
1948	0.	4.910	1.020
1949	0.	4.910	0.
1950	0.	4.910	0.170
1951	0.	4.910	0.790
1952	0.	4.910	0.
1953	0.	4.910	0.
1954	0.	4.910	1.090
1955	0.	4.910	0.310
1956	0.	4.910	0.
1957	0.	4.910	0.
1958	0.	4.910	0.
1959	0.	4.910	1.400
1960	3.030	4.910	0.240
1961	1.240	7.940	0.080
1962	0.	9.180	0.
1963	0.	9.180	2.030
1964	0.	9.180	0.
1965	0.	9.180	0.740
1966	0.	9.180	1.090
1967	1.890	9.180	0.350
1968	0.	11.070	0.
1969	0.	11.070	1.140
1970	0.	11.070	0.
1971	0.	11.070	0.
1972	0.	11.070	1.320
1973	0.	11.070	0.
1974	0.	11.070	0.
1975	0.	11.070	2.810

Note: Data taken from CE Annual Reports.

Table 2
Example Channel Shoaling Rates Computed from Dredging Volumes

Channel Dimensions ft	Accumulated New Work*	Maintenance Dredging		Volume*	Shoaling Interval		Computed Shoaling Rate*	Computed Average Shoaling Rate*
		FY	From To		From To	Years		
Pre 30 x 300	3,090	1932	2 Dec 31	520	1 Jul 31	4 Mar 32	0.68	768
30 x 300	3,560	1932-34	13 Feb 34	1,270	5 Mar 32	5 Jun 34	2.25	563
		1934-37	1 Sep 36	870	6 Jun 34	7 Jan 37	2.59	336
		1937-39	1 Jul 38	920	8 Jan 37	23 Oct 38	1.79	513
		1939-44	7 Apr 43	1,790	24 Oct 38	9 Aug 43	4.79	373
32 x 300	4,910	1944-46	15 Jan 46	760	10 Aug 43	4 May 46	2.73	278
		1946-48	18 Aug 47	1,020	5 May 46	29 Dec 47	1.65	616
		1948-51	25 May 50	960	30 Dec 47	14 Sep 50	2.75	349
		1951-55	2 Feb 54	1,400	15 Sep 50	10 Aug 54	3.86	363
		1955-60	24 Mar 59	1,640	11 Aug 54	29 Jul 59	4.97	330
		1960-61	13 Feb 61	80	30 Jul 59	2 Mar 61	1.59	50
		1961-63	12 Nov 62	2,030	3 Mar 61	5 Feb 63	1.93	1,051
34 x 400	9,180	1963-66	12 May 65	1,830	6 Feb 63	15 Oct 65	2.69	680
		1966-67	20 Feb 67	350	16 Oct 65	15 May 67	0.58	610
		1967-69	8 Aug 68	1,140	16 May 67	29 Nov 68	1.04	1,096
36 x 400	11,070	1969-72	1 Feb 72	1,320	30 Nov 68	18 May 72	3.47	381
		1972-75	13 Aug 74	2,810	19 May 72	24 Nov 74	2.52	1,115

Note: Dredging volumes are similar to data available in CE Annual Reports; dates of surveys may be in CE Annual Reports or in district files.
* In thousands of cubic yards.

Table 3

Example Channel Shoaling

Thousands of Cubic Yards per Year and in Feet per Year

Channel Section	34- x 400-ft Channel					36- x 400-ft Channel				
	Mar 61 to Oct 62	Feb 63 to Mar 65	Nov 65 to Jan 67	Avg		Jun 67 to Jul 68	Dec 68 to Dec 71	Jun 72 to Jul 74	Avg	
	thou cu yd	thou cu yd	thou cu yd	ft/yr	cu yd	thou cu yd	thou cu yd	thou cu yd	thou cu yd	ft/yr
1	41	47	34	0.4	41	35	45	39	40	0.5
2	62	58	71	0.9	64	57	51	62	57	0.7
3	59	67	70	0.9	65	58	65	63	62	0.8
4	53	61	75	1.0	63	64	72	81	72	0.9
5	98	89	102	1.5	97	95	84	102	94	1.2
6	87	94	95	1.2	92	124	110	131	122	1.6
7	71	75	74	0.9	73	129	118	89	112	1.4
8	50	52	57	0.7	53	100	92	84	92	1.2
9	41	39	48	0.6	43	71	65	61	66	0.8
10	35	37	31	0.4	34	42	40	45	42	0.5
Total	597	619	657		625	775	742	757	759	

Note: Data are similar to shoaling volumes which can be determined from hydrographic surveys (from a postdredge survey to the following predredge survey).

Table 4

Dredging History of Galveston Channel, Millions of Cubic Yards

<u>Fiscal Year</u>	<u>Annual New Work</u>	<u>Accumulated New Work</u>	<u>Annual Maintenance</u>
1902	0.102	0.	0.
1903	0.485	0.102	0.
1904	2.237	0.587	0.
1905	0.344	2.824	0.
1906	0.518	3.168	0.109
1907	0.535	3.686	0.604
1908	2.018	4.221	0.
1909	0.700	6.239	0.190
1910	0.138	6.939	2.186
1911	0.197	7.077	0.944
1912	5.511	7.274	1.541
1913	1.187	12.785	0.
1914	1.166	13.972	0.044
1915	0.	15.138	1.793
1916	0.	15.138	1.008
1917	0.	15.138	2.130
1918	0.	15.138	1.227
1919	0.	15.138	0.
1920	0.	15.138	0.273
1921	0.	15.138	1.002
1922	0.	15.138	1.321
1923	0.	15.138	1.795
1924	0.	15.138	3.095
1925	0.	15.138	1.709
1926	0.	15.138	3.220
1927	0.	15.138	5.322
1928	0.	15.138	5.271
1929	4.515	15.138	0.149
1930	0.	19.653	2.849
1931	0.	19.653	2.035
1932	0.	19.653	3.682
1933	0.	19.653	0.
1934	0.	19.653	4.725
1935	0.	19.653	0.889
1936	0.	19.653	3.172
1937	0.192	19.653	0.384
1938	0.848	19.845	3.247
1939	0.	20.693	0.828
1940	0.	20.693	3.646
1941	0.	20.693	0.

(Continued)

Note: Data taken from CE Annual Reports.

Table 4 (Concluded)

<u>Fiscal Year</u>	<u>Annual New Work</u>	<u>Accumulated New Work</u>	<u>Annual Maintenance</u>
1942	0.	20.693	0.
1943	0.	20.693	5.198
1944	0.	20.693	0.456
1945	0.	20.693	4.969
1946	0.	20.693	0.
1947	0.	20.693	6.083
1948	0.	20.693	0.
1949	0.	20.693	0.
1950	0.	20.693	5.005
1951	0.	20.693	0.
1952	0.	20.693	3.212
1953	0.	20.693	2.895
1954	0.	20.693	0.
1955	0.	20.693	2.733
1956	0.	20.693	1.169
1957	0.	20.693	0.
1958	0.	20.693	2.150
1959	0.	20.693	0.
1960	0.	20.693	1.601
1961	0.	20.693	2.431
1962	1.000	20.693	3.599
1963	0.	21.693	0.888
1964	0.	21.693	4.599
1965	0.	21.693	3.535
1966	2.273	21.693	0.233
1967	1.566	23.966	1.003
1968	0.	25.532	0.
1969	0.	25.532	4.313
1970	0.	25.532	0.
1971	0.	25.532	0.705
1972	0.	25.532	3.293
1973	0.	25.532	0.
1974	0.	25.532	3.483
1975	1.568	25.532	0.

Table 5

Galveston Channel Shoaling Rates Computed from Dredging Volumes

Channel Dimensions ft	Accumulated New Work*	Maintenance Dredging		Shoaling Interval		Computed Shoaling Rate*	Computed Average Shoaling Rate*
		FY	From To	From To	Years		
Pre 30 x 1200	3,168	1905-07	8 Aug 04 30 Jun 07	8 Aug 04 30 Jun 07	2.89	246	246
Pre 30 x 1200	7,077	1908-12	1 Jul 07 30 Jun 12	1 Jul 07 30 Jun 12	5.00	972	972
Pre 30 x 1200	13,972	1913-15	1 Jul 12 30 Jun 15	1 Jul 12 30 Jun 15	3.00	612	612
30 x 1200 (plus 2 ft allowable dredging tolerance)	15,138	1916	27 Oct 15 18 Apr 16	1 Jul 15 18 Apr 16	0.80	1,260	1,260
		1915-18	12 Aug 16 13 Dec 17	19 Apr 16 13 Dec 17	1.65	2,029	2,029
		1918-20	15 Nov 19 15 Jan 20	217 14 Dec 17 15 Jan 20	2.05	106	106
		1920	16 Jan 20 30 Mar 20	56 16 Jan 20 30 Mar 20	0.24	230	230
		1920-24	1 Jul 20 13 Apr 24	7,215 31 Mar 20 13 Apr 24	4.04	1,786	1,786
		1924-25	1 Jul 24 26 Oct 24	222 14 Apr 24 26 Oct 24	0.54	413	413
		1925	9 Oct 24 14 Jun 25	1,487 27 Oct 24 14 Jun 25	0.63	2,350	2,350
		1925-29	25 Jul 25 20 Jul 28	13,963 15 Jun 25 20 Jul 28	3.10	4,506	2,108
32 x 1200 (plus 2 ft allowable dredging tolerance)	19,653	1929-31	24 Mar 30 25 Sep 30	4,885 21 Jul 28 25 Sep 30	2.18	2,237	2,237
		1931-32	7 Dec 31 4 Mar 32	3,680 26 Sep 30 4 Mar 32	1.44	2,560	2,560
		1932-34	1 Sep 33 9 Feb 34	4,720 5 Mar 32 9 Feb 34	1.94	2,439	2,439
		1934-36	1 May 35 26 Oct 35	4,060 10 Feb 34 26 Oct 35	1.71	2,375	2,375
		1936-38	23 May 37 13 Nov 37	3,631 27 Oct 35 13 Nov 37	2.05	1,772	2,252
34 x 1200 (plus 2 ft allowable dredging tolerance)	20,693	1938-39	9 Mar 39 7 Jun 39	830 14 Nov 37 7 Jun 39	1.56	529	529
		1939-40	16 Jan 40 24 May 40	3,650 8 Jun 39 24 May 40	0.96	3,791	3,791
		1940-44	1 Oct 42 16 Jul 43	5,664 25 May 40 16 Jul 43	3.15	1,798	1,798
		1944-45	6 Sep 44 4 Nov 44	4,970 17 Jul 43 4 Nov 44	1.30	3,810	3,810
		1945-47	12 Dec 46 25 Jun 47	6,080 5 Nov 44 25 Jun 47	2.64	2,306	2,306
		1947-50	1 Jul 49 9 Jan 50	5,000 26 Jun 47 9 Jan 50	2.54	1,968	1,968

(Continued)

Note: Dredging volumes are similar to data available in CE Annual Reports; dates of surveys may be in CE Annual Reports or in district files.

* In thousands of cubic yards.

Table 5 (Concluded)

Channel Dimensions ft	Accumulated New Work	Maintenance Dredging			Shoaling Interval			Computed Shoaling Rate	Computed Average Shoaling Rate
		FY	From	To	Volume	From	To		
34 x 1200 (plus 2 ft allowable dredging tolerance) (Cont'd)	20,693	1950-52	17 Jul 51	23 Oct 51	3,210	10 Jan 50	23 Oct 51	1,798	
	(Cont'd)	1952-53	12 Feb 53	24 Apr 53	2,890	24 Oct 51	24 Apr 53	1,928	
		1953-56	31 Mar 55	21 Aug 55	3,900	25 Apr 53	21 Aug 55	1,678	
		1956-58	31 Mar 58	15 Jun 58	2,150	22 Aug 55	15 Jun 58	763	
		1958-61	6 Mar 60	11 Dec 60	4,030	16 Jun 58	11 Dec 60	1,619	
		1961-63	12 Jan 62	23 Jul 62	4,488	12 Dec 60	23 Jul 62	2,781	1,898
34 x 1200 (plus 2 ft allowable dredging tol- erance and 2 ft advance maintenance)	21,693	1963-64	1 Jul 63	30 Jun 64	4,606	24 Jul 62	30 Jun 64	2,374	
		1964-66	1 Jul 64	21 Jul 65	3,640	1 Jul 64	21 Jul 65	3,451	
		1966	22 Jul 65	20 Jun 66	128	22 Jul 65	20 Jun 66	139	2,140
Transition									
36 x 1200 (plus 2 ft allowable dredging tol- erance and 2 ft advance maintenance)		1967	1 Jul 66	21 Nov 66	1,003	21 Jun 66	21 Nov 66	2,377	2,377
		1967-69	20 Dec 68	2 Jun 69	4,310	22 Nov 66	2 Jun 69	1,706	
		1969-72	1 Jul 71	28 Oct 71	3,780	3 Jun 69	28 Oct 71	1,662	
		1972-74	28 Jan 74	1 Jun 74	3,480	29 Oct 71	1 Jun 74	1,344	1,567

Galveston Channel Shoaling

Thousands of Cubic Yards per Year and in Feet per Year

[illegible]

Note: -- Surveys not available (no data).
Excess allowable dredging tolerance.

Table 7

Dredging History of Texas City Channel, Millions of Cubic Yards

<u>Fiscal Year</u>	<u>Annual New Work</u>	<u>Accumulated New Work</u>	<u>Annual Maintenance</u>
1901	0.815	0.	0.
1902	0.967	0.815	0.
1903	1.105	1.782	0.
1904	0.684	2.887	0.
1905	1.010	3.571	0.
1906	0.	4.581	0.698
1907	0.	4.581	0.
1908	0.	4.581	1.001
1909	0.	4.581	0.273
1910	0.	4.581	0.700
1911	1.153	4.581	0.100
1912	0.	5.734	0.225
1913	0.072	5.734	1.155
1914	0.465	5.806	0.657
1915	3.639	6.271	0.353
1916	2.524	9.910	0.430
1917	0.	12.434	0.666
1918	0.	12.434	1.177
1919	0.	12.434	0.458
1920	0.	12.434	0.585
1921	0.	12.434	0.626
1922	0.	12.434	0.796
1923	0.	12.434	0.
1924	0.	12.434	0.287
1925	0.	12.434	2.226
1926	0.	12.434	4.240
1927	0.	12.434	0.056
1928	0.	12.434	2.396
1929	0.	12.434	1.940
1930	0.	12.434	2.451
1931	1.840	12.434	1.288
1932	0.	14.274	1.002
1933	0.	14.274	2.932
1934	0.	14.274	0.
1935	0.	14.274	1.921
1936	0.	14.274	0.
1937	1.846	14.274	0.980
1938	0.	16.120	0.
1939	0.	16.120	1.083
1940	0.	16.120	1.425

(Continued)

Note: Data taken from CE Annual Reports.

Table 7 (Concluded)

<u>Fiscal Year</u>	<u>Annual New Work</u>	<u>Accumulated New Work</u>	<u>Annual Maintenance</u>
1941	0.	16.120	0.385
1942	0.	16.120	1.973
1943	0.	16.120	0.173
1944	0.	16.120	0.659
1945	0.	16.120	1.879
1946	0.	16.120	0.
1947	0.	16.120	0.
1948	0.	16.120	3.348
1949	0.	16.120	0.
1950	0.	16.120	1.946
1951	0.	16.120	0.
1952	0.	16.120	1.329
1953	0.	16.120	0.
1954	0.	16.120	1.503
1955	0.	16.120	0.
1956	0.	16.120	1.250
1957	0.	16.120	0.
1958	0.	16.120	1.718
1959	2.145	16.120	0.
1960	3.884	18.265	0.818
1961	0.	22.149	0.
1962	0.	22.149	3.502
1963	0.	22.149	1.245
1964	0.	22.149	1.286
1965	0.	22.149	3.639
1966	1.143	22.149	0.058
1967	5.027	23.292	1.368
1968	1.143	28.319	2.923
1969	0.	29.462	0.
1970	0.	29.462	3.048
1971	0.	29.462	0.
1972	0.	29.462	1.700
1973	0.	29.462	1.045
1974	0.	29.462	0.
1975	0.	29.462	3.258

Table 8

Texas City Channel Shoaling Rates Computed from Dredging Volumes

Channel Dimensions ft	Accumulated New Work*	Maintenance Dredging		Shoaling Interval		Computed Shoaling Rate*	Computed Average Shoaling Rate*
		FY	From To	From To	Years		
25 x 100	4,581	1906	1 Jul 05	7 Jun 06	1 Jul 05	7 Jun 06	0.91
		1906-08	8 Jul 07	19 Sep 07	8 Jun 06	19 Sep 07	1.31
		1908-09	1 Nov 08	15 Nov 08	20 Sep 07	15 Nov 08	1.16
		1909-10	22 Sep 09	18 Apr 10	700	16 Nov 08	1.42
		1910-11	22 May 11	29 Jun 11	100	19 Apr 10	1.20
Transition	5,734	1911-12	2 Oct 11	24 Oct 11	225	30 Jun 11	0.32
		1912-13	8 Sep 12	17 Dec 12	1,039	25 Oct 11	1.15
		1913	8 Sep 12	15 May 13	116	18 Dec 12	0.41
Transition	5,806	1913-14	11 Aug 13	16 Jan 14	657	16 May 13	0.67
Transition	5,882	1914-15	12 Aug 14	9 Nov 14	353	17 Jan 14	0.81
Transition	9,910	1915-16	1 Jul 15	30 Jun 16	430	10 Nov 14	1.64
30 x 300 (plus 2 ft allowable dredging tolerance)	12,434	1917	28 Aug 16	4 Oct 16	666	1 Jul 16	0.26
		1917-19	1 Feb 18	23 Aug 18	1,635	5 Oct 16	1.88
		1919-20	27 Sep 19	18 Nov 19	409	24 Aug 18	1.24
		1920	29 Dec 19	31 Jan 20	176	19 Nov 19	0.20
		1920-21	19 Nov 20	9 Mar 21	626	1 Feb 20	1.10
		1921-22	1 Dec 21	30 Jun 22	796	10 Mar 21	1.31
		1923-24	24 Dec 23	16 Mar 24	287	1 Jul 22	1.71
		1924-27	1 Jul 24	6 Jul 26	6,522	17 Mar 24	2.31
		1927-29	1 Jul 28	11 Oct 28	3,061	7 Jul 26	2.27
		1929	1 Nov 28	21 Dec 28	1,177	12 Oct 28	0.19
		1929	21 May 29	7 Jun 29	98	22 Dec 28	0.46
		1929-30	12 Jul 29	30 Jan 30	2,451	8 Jun 29	0.65
		1930-31	23 Sep 30	15 May 31	1,288	31 Jan 30	1.29
		(Continued)					1,290

Note: Dredging volumes are similar to data available in CE Annual Reports; dates of surveys may be in CE Annual Reports or in district files.

* In thousands of cubic yards.

(Sheet 1 of 3)

Table 8 (Continued)

Channel Dimensions ft	Accumulated New Work	Maintenance Dredging		Shoaling Interval		Computed Shoaling Rate	Computed Average Shoaling Rate
		FY	From To	From To	Years		
30 x 300 (plus 2 ft allowable dredging tol- erance) harbor extended	14,274	1931-32	4 Mar 32	25 Mar 32	16 May 31	25 Mar 32	0.86
		1932-33	9 Nov 32	25 Jan 33	26 Mar 32	25 Jan 33	0.84
		1933-35	19 Nov 34	23 Jan 35	1,921	26 Jan 35	1.99
		1935-37	23 Oct 36	4 Feb 37	980	24 Jan 35	2.03
34 x 300 (plus 2 ft allowable dredging tolerance)	16,120	1937-39	1 Feb 39	15 Apr 39	5 Feb 37	15 Apr 39	2.19
		1939	1 May 39	30 Jun 39	16 Apr 39	30 Jun 39	0.21
		1939-40	14 Feb 40	30 Jun 40	1,425	1 Jul 39	1.00
		1940-41	7 Mar 41	4 May 41	385	1 Jul 40	0.84
		1941-43	27 Mar 42	5 Jul 42	2,146	5 May 41	1.17
		1943-45	17 May 44	23 Aug 44	2,538	6 Jul 42	2.13
		1945-48	23 Aug 47	5 Oct 47	2,925	24 Aug 44	3.12
		1948	10 Oct 47	28 Oct 47	423	6 Oct 47	0.06
		1948-50	31 Jan 50	28 Mar 50	1,946	29 Oct 47	2.41
		1950-52	27 Feb 52	12 Mar 52	1,329	29 Mar 50	1.96
		1952-54	13 Jan 54	25 Feb 54	1,503	13 Mar 52	1.96
		1954-56	20 Oct 55	20 Nov 55	1,250	26 Feb 54	1.73
		1956-58	9 Nov 57	18 Jan 58	1,718	21 Nov 55	2.16
		1958-60	1 Jul 59	10 Apr 60	818	19 Jan 58	2.22
		1960-62	18 Nov 61	14 Feb 62	3,502	11 Apr 60	1.85
		1962-64	26 May 63	30 Jun 64	2,531	15 Feb 62	2.37
36 x 400 (plus 2 ft allowable dredging tol- erance and 2 ft advance maintenance)	22,149	1965	19 Jan 65	7 May 65	3,639	1 Jul 64	0.85
		1965-67	16 May 66	13 Jun 67	1,368	8 May 65	2.10
		1967-68	1 Jul 67	30 Jun 68	2,923	14 Jun 67	1.05
		1967-68	1 Jul 67	30 Jun 68	2,923	14 Jun 67	1.05
Transition	28,319	1967-68	1 Jul 67	30 Jun 68	2,923	14 Jun 67	1.05
		1967-68	1 Jul 67	30 Jun 68	2,923	14 Jun 67	1.05
		1967-68	1 Jul 67	30 Jun 68	2,923	14 Jun 67	1.05
		1967-68	1 Jul 67	30 Jun 68	2,923	14 Jun 67	1.05

(Continued)

(Sheet 2 of 3)

Table 8 (Concluded)

Channel Dimensions ft	Accumulated New Work	Maintenance Dredging		Shoaling Interval		Computed Shoaling Rate	Computed Average Shoaling Rate
		FY	From	To	From	To	
40 x 400 (plus 2 ft allowable dredging tolerance and 3 ft advance maintenance)	29,462	1969-70	4 Feb 70	17 Apr 70	1 Jul 68	17 Apr 70	1,696
		1970-73	13 May 72	7 Jul 72	18 Apr 70	7 Jul 72	1,235
		1973-75	24 Aug 74	2 Jan 75	8 Jul 72	2 Jan 75	1,308
							1,390

Texas City Channel Shoaling

20-ft Channel with 2 to 3 ft Advance Maintenance										40-ft Channel with 3 ft Advance Maintenance													
Jan. 63 to Jul. 63				Jul. 63 to Sep. 64				Apr. 65 to Aug. 66				Mar. 68 to Mar. 70				Apr. 70 to Jun. 71				May 71 to Oct. 71			
thou cu yd	ft/yr	thou cu yd	ft/yr	thou cu yd	ft/yr	thou cu yd	ft/yr	thou cu yd	ft/yr	thou cu yd	ft/yr	thou cu yd	ft/yr	thou cu yd	ft/yr	thou cu yd	ft/yr	thou cu yd	ft/yr	thou cu yd	ft/yr	Avg	
1	239	2.0	261	2.2	368	3.1	291	2.5	--	--	6.7	173	1.5	--	--	--	--	173	1.5	--	--		
2	143	2.4	220	3.7	80	1.4	143	2.4	397	6.7	127	2.1	103	1.7	67	1.5	162	2.7					
3	212	3.6	163	2.8	156	2.6	177	3.0	370	6.2	133	2.2	182	3.1	129	2.2	190	3.2					
4	178	3.0	120	2.0	90	1.5	129	2.2	240	4.1	144	2.4	190	3.2	136	2.3	171	2.9					
5	173	2.9	159	2.7	111	1.9	147	2.5	215	3.6	125	2.1	179	3.0	133	2.2	158	2.7					
6	189	3.2	147	2.5	100	1.7	145	2.4	237	4.0	167	2.8	220	3.7	158	2.7	190	3.2					
7	230	3.9	180	3.0	167	2.8	193	3.3	269	4.5	240	4.1	273	4.6	201	3.4	241	4.1					
8	307	5.2	254	4.3	162	2.7	239	4.0	305	5.1	291	4.9	320	5.4	174	2.9	263	4.4					
9	92	1.6	42	0.7	69	1.2	69	1.2	204	3.4	106	1.3	49	0.8	44	0.7	93	1.6					
Total							1,533										1,646						

Note: -- surveys not available (no data).

Table 10

Dredging History of Houston Ship Channel, Galveston Bay SectionMillions of Cubic Yards

<u>Fiscal Year</u>	<u>Annual New Work</u>	<u>Accumulated New Work</u>	<u>Annual Maintenance</u>
1873	0.059	0.	0.
1874	0.	0.059	0.
1875	0.	0.059	0.
1876	0.134	0.059	0.
1877	0.	0.193	0.
1878	0.	0.193	0.
1879	0.075	0.193	0.
1880	0.629	0.268	0.
1881	0.	0.897	0.
1882	0.160	0.897	0.
1883	0.962	1.057	0.
1884	0.	2.019	0.
1885	0.	2.019	0.
1886	0.	2.019	0.
1887	0.	2.019	0.
1888	0.200	2.019	0.
1889	1.618	2.219	0.
1890	0.020	3.837	0.
1891	0.	3.857	0.
1892	0.	3.857	0.
1893	0.	3.857	0.
1894	0.	3.857	0.
1895	0.	3.857	0.
1896	0.	3.857	0.
1897	0.	3.857	0.
1898	0.	3.857	0.
1899	0.	3.857	0.
1900	0.	3.857	0.
1901	0.325	3.857	0.
1902	2.773	4.182	0.
1903	1.221	6.955	0.
1904	3.992	8.176	0.
1905	1.566	12.168	0.
1906	0.	13.734	0.
1907	0.	13.734	0.
1908	0.	13.734	1.315
1909	0.	13.734	2.540
1910	0.	13.734	0.
1911	0.	13.734	0.
1912	0.	13.734	0.

(Continued)

Note: Data taken from CE Annual Reports.

(Sheet 1 of 3)

Table 10 (Continued)

<u>Fiscal Year</u>	<u>Annual New Work</u>	<u>Accumulated New Work</u>	<u>Annual Maintenance</u>
1913	0.	13.734	0.
1914	15.153	13.734	0.
1915	0.004	28.887	0.187
1916	0.	28.891	2.928
1917	0.	28.891	3.908
1918	0.	28.891	1.879
1919	0.	28.891	0.
1920	0.	28.891	2.653
1921	10.599	28.891	0.
1922	6.538	39.490	1.877
1923	0.	46.028	3.383
1924	0.	46.028	0.
1925	0.	46.028	3.547
1926	0.	46.028	2.091
1927	0.	46.028	2.982
1928	0.	46.028	1.703
1929	0.	46.028	1.696
1930	0.	46.028	6.989
1931	0.	46.028	0.346
1932	0.	46.028	5.813
1933	0.043	46.028	0.028
1934	0.	46.071	0.457
1935	11.850	46.071	1.831
1936	0.	57.921	2.836
1937	5.615	57.921	3.858
1938	0.	63.536	1.308
1939	0.	63.536	3.044
1940	0.	63.536	3.901
1941	0.	63.536	3.352
1942	0.	63.536	3.133
1943	0.	63.536	5.519
1944	0.	63.536	3.842
1945	0.	63.536	5.198
1946	0.	63.536	0.
1947	0.	63.536	0.
1948	0.	63.536	10.958
1949	0.	63.536	0.
1950	0.737	63.536	0.559
1951	7.663	64.273	4.553
1952	0.	71.936	0.
1953	0.	71.936	4.477
1954	0.	71.936	0.
1955	0.	71.936	4.764

(Continued)

(Sheet 2 of 3)

Table 10 (Concluded)

<u>Fiscal Year</u>	<u>Annual New Work</u>	<u>Accumulated New Work</u>	<u>Annual Maintenance</u>
1956	0.	71.936	0.
1957	0.	71.936	0.
1958	0.	71.936	0.
1959	0.	71.936	0.
1960	0.228	71.936	4.130
1961	0.009	72.164	1.416
1962	0.	72.173	0.047
1963	4.472	72.173	0.759
1964	4.320	76.645	2.147
1965	0.	80.965	0.293
1966	0.213	80.965	5.888
1967	0.	81.178	0.244
1968	0.	81.178	0.
1969	0.	81.178	0.352
1970	0.	81.178	6.272
1971	0.	81.178	0.
1972	0.	81.178	3.720
1973	0.	81.178	2.724
1974	0.	81.178	1.393
1975	0.	81.178	0.494

Table 11

Dredging History of Houston Ship Channel, Buffalo Bayou SectionMillions of Cubic Yards

<u>Fiscal Year</u>	<u>Annual New Work</u>	<u>Accumulated New Work</u>	<u>Annual Maintenance</u>
1876	0.005	0.	0.
1877	0.	0.005	0.
1878	0.	0.005	0.
1879	0.	0.005	0.
1880	0.	0.005	0.
1881	0.	0.005	0.
1882	0.025	0.005	0.
1883	0.099	0.030	0.
1884	0.075	0.129	0.
1885	0.079	0.204	0.
1886	0.014	0.283	0.
1887	0.	0.297	0.
1888	0.065	0.297	0.
1889	0.	0.362	0.060
1890	0.007	0.362	0.
1891	0.026	0.369	0.
1892	0.	0.395	0.
1893	0.023	0.395	0.
1894	0.181	0.418	0.
1895	0.170	0.599	0.
1896	0.160	0.769	0.
1897	0.	0.929	0.
1898	0.	0.929	0.
1899	0.	0.929	0.
1900	0.	0.929	0.
1901	0.	0.929	0.
1902	0.	0.929	0.
1903	0.074	0.929	0.
1904	1.153	1.003	0.
1905	1.150	2.156	0.
1906	1.032	3.306	0.023
1907	1.260	4.338	0.040
1908	0.549	5.598	0.088
1909	0.991	6.147	0.185
1910	0.099	7.138	0.
1911	0.	7.237	0.
1912	0.039	7.237	0.
1913	8.339	7.276	0.
1914	6.277	15.615	0.
1915	0.277	21.892	0.

(Continued)

Note: Data taken from CE Annual Reports.

(Sheet 1 of 3)

Table 11 (Continued)

<u>Fiscal Year</u>	<u>Annual New Work</u>	<u>Accumulated New Work</u>	<u>Annual Maintenance</u>
1916	0.	22.169	1.706
1917	0.138	22.169	0.725
1918	0.	22.307	0.463
1919	0.	22.307	0.
1920	0.	22.307	0.444
1921	1.463	22.307	2.158
1922	2.643	23.770	0.325
1923	5.712	26.413	0.865
1924	4.965	32.125	2.479
1925	2.786	37.090	2.669
1926	0.506	39.876	2.228
1927	0.	40.382	2.895
1928	0.	40.382	2.698
1929	0.260	40.382	4.050
1930	0.	40.642	4.301
1931	0.	40.642	1.480
1932	2.110	40.642	1.393
1933	3.051	42.752	0.096
1934	0.105	45.803	0.366
1935	2.516	45.908	3.398
1936	0.826	48.424	1.032
1937	0.	49.250	0.450
1938	5.449	49.250	0.489
1939	3.752	54.699	0.
1940	2.163	58.451	0.048
1941	1.371	60.614	0.
1942	0.	61.985	0.650
1943	0.	61.985	2.304
1944	0.	61.985	0.478
1945	0.	61.985	0.
1946	0.	61.985	6.515
1947	0.	61.985	0.
1948	0.	61.985	5.219
1949	0.	61.985	3.896
1950	6.002	61.985	1.487
1951	2.209	67.987	0.527
1952	1.656	70.196	4.496
1953	2.329	71.852	1.150
1954	0.	74.181	3.908
1955	0.	74.181	0.575
1956	2.115	74.181	1.734
1957	0.832	76.296	2.403
1958	1.157	77.128	1.002

(Continued)

(Sheet 2 of 3)

Table 11 (Concluded)

<u>Fiscal Year</u>	<u>Annual New Work</u>	<u>Accumulated New Work</u>	<u>Annual Maintenance</u>
1959	0.074	78.285	2.926
1960	2.178	78.359	1.342
1961	1.163	80.537	2.648
1962	6.020	81.700	3.788
1963	7.386	87.720	2.782
1964	3.470	95.106	2.155
1965	6.678	98.576	5.017
1966	1.977	105.254	1.336
1967	0.	107.231	1.944
1968	0.	107.231	2.651
1969	1.383	107.231	2.874
1970	0.	108.614	2.989
1971	0.360	108.614	1.150
1972	0.	108.974	2.251
1973	0.	108.974	0.075
1974	0.	108.974	0.254
1975	0.	108.974	2.606

Table 12

Houston Ship Channel Shoaling Rates Computed from Dredging Volumes
Galveston Bay Section

Channel Dimensions ft	Accumulated New Work*	Maintenance Dredging		Volume*	Shoaling Interval		Computed Shoaling Rate*	Computed Average Shoaling Rate*		
		FY	From To		From To	Years				
25 x 100	13,734	1905-08	19 Jan 08	28 Mar 08	1,315	14 Dec 04	28 Mar 08	3.29	400	
		1908-09	1 Jul 08	31 Oct 08	2,440	29 Mar 08	31 Oct 08	0.59		4,272
		1909-16	11 Jun 15	16 Aug 15	1,305	1 Nov 08	16 Aug 15	6.79		
	28,891	1916	1 Sep 15	30 Sep 15	220	17 Aug 15	30 Sep 15	0.12	1,784	484
		1916	8 Dec 15	28 Feb 16	1,401	1 Oct 15	28 Feb 16	0.42	3,387	
1916-17		8 Mar 16	7 Mar 17	4,097	1 Mar 16	7 Mar 17	1.02	4,020		
30 x 250	46,028	1917-18	1 Jul 17	19 Feb 18	1,879	8 Mar 17	19 Feb 18	0.96	1,965	2,246
		1918-20	20 Aug 19	10 Mar 20	2,653	20 Feb 18	10 Mar 20	2.05	1,293	
		1920-23	1 Jul 21	30 Jun 23	5,260	11 Mar 20	30 Jun 23	3.31	1,591	
		1924-31	1 Jul 24	16 Sep 30	19,354	1 Jul 23	16 Sep 30	7.21	2,683	2,796
		1931-32	1 Jul 31	30 Jun 32	5,813	17 Sep 30	30 Jun 32	1.79	3,254	
34 x 400	57,921	1933-34	27 Jun 33	19 Feb 34	485	1 Jul 32	19 Feb 34	1.64	296	487
		1934-35	18 Nov 34	15 Feb 35	797	20 Feb 34	15 Feb 35	0.99	606	
		1935-36	7 Mar 35	6 Apr 36	3,870	16 Feb 35	6 Apr 36	1.14	3,404	3,295
		1936-37	4 Sep 36	21 Jun 37	3,858	7 Apr 36	21 Jun 37	1.21	3,193	
		1937-39	25 Feb 38	31 Jan 39	4,352	22 Jun 37	31 Jan 39	1.61	2,697	
30 x 250	46,028	1939-41	1 Jul 39	6 Mar 41	7,253	1 Feb 39	6 Mar 41	2.09	3,465	2,719
		1941-42	14 Aug 41	24 Mar 42	2,852	7 Mar 41	24 Mar 42	1.05	7,401	
		1942-43	1 Jun 42	4 Jan 43	5,799	25 Mar 42	4 Jan 43	0.78	242	
		1943-44	16 Oct 43	20 Nov 43	212	5 Jan 43	20 Nov 43	0.88		

(Continued)

(Continued)

Note: Dredging volumes are similar to data available in CE Annual Reports; dates of surveys may be in CE Annual Reports or in district files.

* In thousands of cubic yards.

Table 12 (Concluded)

Channel Dimensions ft	Accumulated New Work	Maintenance Dredging		Volume	Shoaling Interval		Computed Shoaling Rate	Computed Average Shoaling Rate	
		FY	From		To	From			To
34 × 400 (Con't)	63,536	1944-45	1 Feb 44	3 Jul 44	3,749	21 Nov 43	3 Jul 44	0.62	6,082
	(Con't)	1945	9 Aug 44	15 Dec 44	5,079	4 Jul 44	15 Dec 44	0.45	11,235
		1945-48	16 Jul 47	31 Oct 47	8,746	16 Dec 44	31 Oct 47	2.88	3,040
		1948	4 Nov 47	12 Jan 48	2,212	1 Nov 47	12 Jan 48	0.20	11,064
		1948-51	28 May 50	24 Feb 51	5,112	13 Jan 48	24 Feb 51	3.12	1,640
36 × 400	71,936	1951-53	1 Jul 52	30 Jun 53	4,477	25 Feb 51	30 Jun 53	2.35	1,909
		1954-55	22 Nov 54	30 Mar 55	4,764	1 Jul 53	30 Mar 55	1.75	2,725
		1955-62	18 Mar 60	23 Oct 61	5,593	1 Apr 55	23 Oct 61	6.57	852
		1962-64	16 Mar 63	30 Jun 64	2,906	24 Oct 61	30 Jun 64	2.68	1,082
40 × 400	80,965	1965	21 Jul 64	26 Jul 64	66	1 Jul 64	26 Jul 64	0.07	925
		1965	13 Mar 65	12 Apr 65	227	27 Jul 64	12 Apr 65	0.71	319
		1965-67	3 Jan 66	7 Jul 66	6,132	13 Apr 65	7 Jul 66	1.24	4,963
		1967-70	16 Jun 69	3 Dec 69	6,624	8 Jul 66	3 Dec 69	3.41	1,944
		1970-72	23 Jul 71	22 Dec 71	3,720	4 Dec 69	22 Dec 71	2.05	1,813
		1972-73	28 Oct 72	2 Feb 73	2,724	23 Dec 71	2 Feb 73	1.12	2,443
		1973-75	6 Feb 74	12 Aug 74	1,887	3 Feb 73	12 Aug 74	1.52	1,239
								1,847	

Table 13

Houston Ship Channel Shoaling Rates Computed from Dredging Volumes

Buffalo Bayou Section

Channel Dimensions ft	Accumulated New Work*	Maintenance Dredging		Shoaling Interval		Computed Shoaling Rate*	Computed Average Shoaling Rate*			
		FY	From To	Volume*	From To			Years		
25 x 100	362	1888-89	6 Dec 88	30 Jun 89	60	18 Feb 88	30 Jun 89	1.33	45	45
	929	1890- 1906	22 May 06	30 Jun 06	23	1 Jul 89	30 Jun 06	17.00	1	1
	4,338	1907	3 Jan 07	30 Jun 07	40	1 Jul 06	30 Jun 07	1.00	40	40
	5,598	1908	14 Dec 07	30 Jun 08	88	1 Jul 07	30 Jun 08	1.00	88	88
30 x 250	6,147	1909	16 Nov 08	17 Mar 09	185	1 Jul 08	17 Mar 09	0.71	260	260
	7,276	1909-17	1 Mar 16	19 Jan 17	2,431	18 Mar 09	19 Jan 17	7.84	310	310
	22,307	1917-18	27 Mar 18	7 May 18	200	20 Jan 17	7 May 18	1.30	154	154
		1918	11 May 18	17 Jun 18	263	8 May 18	17 Jun 18	0.11	2,344	2,344
		1918-20	1 Feb 20	28 Feb 20	37	18 Jun 18	28 Feb 20	1.70	22	22
		1920-31	25 Mar 20	28 Aug 30	25,402	29 Feb 20	28 Aug 30	10.50	2,420	2,420
		1931-32	19 Nov 30	5 Feb 32	2,316	29 Aug 30	5 Feb 32	1.44	1,607	1,607
		1932-33	29 Apr 32	29 Jul 32	326	6 Feb 32	29 Jul 32	0.48	684	684
		1933-34	1 Nov 33	31 Dec 34	338	30 Jul 32	31 Dec 34	1.42	237	237
		1934-35	25 Jun 34	3 Dec 34	1,762	1 Jan 34	3 Dec 34	0.92	1,908	1,908
		1935	4 Feb 35	30 Jun 35	1,664	4 Dec 34	30 Jun 35	0.57	2,907	2,907
		1935-38	14 Aug 35	15 Sep 37	1,647	1 Jul 35	15 Sep 37	2.21	745	745
32 x 400		1938	17 Sep 37	13 Feb 38	324	16 Sep 37	13 Feb 38	0.41	783	783
	54,699	1938-40	28 Aug 39	7 Sep 39	38	14 Feb 38	7 Sep 39	1.56	24	24

(Continued)

(Continued)

Note: Dredging volumes are similar to data available in CE Annual Reports; dates of surveys may be in CE Annual Reports or in district files.

* In thousands of cubic yards.

(Sheet 1 of 3)

Table 13 (Continued)

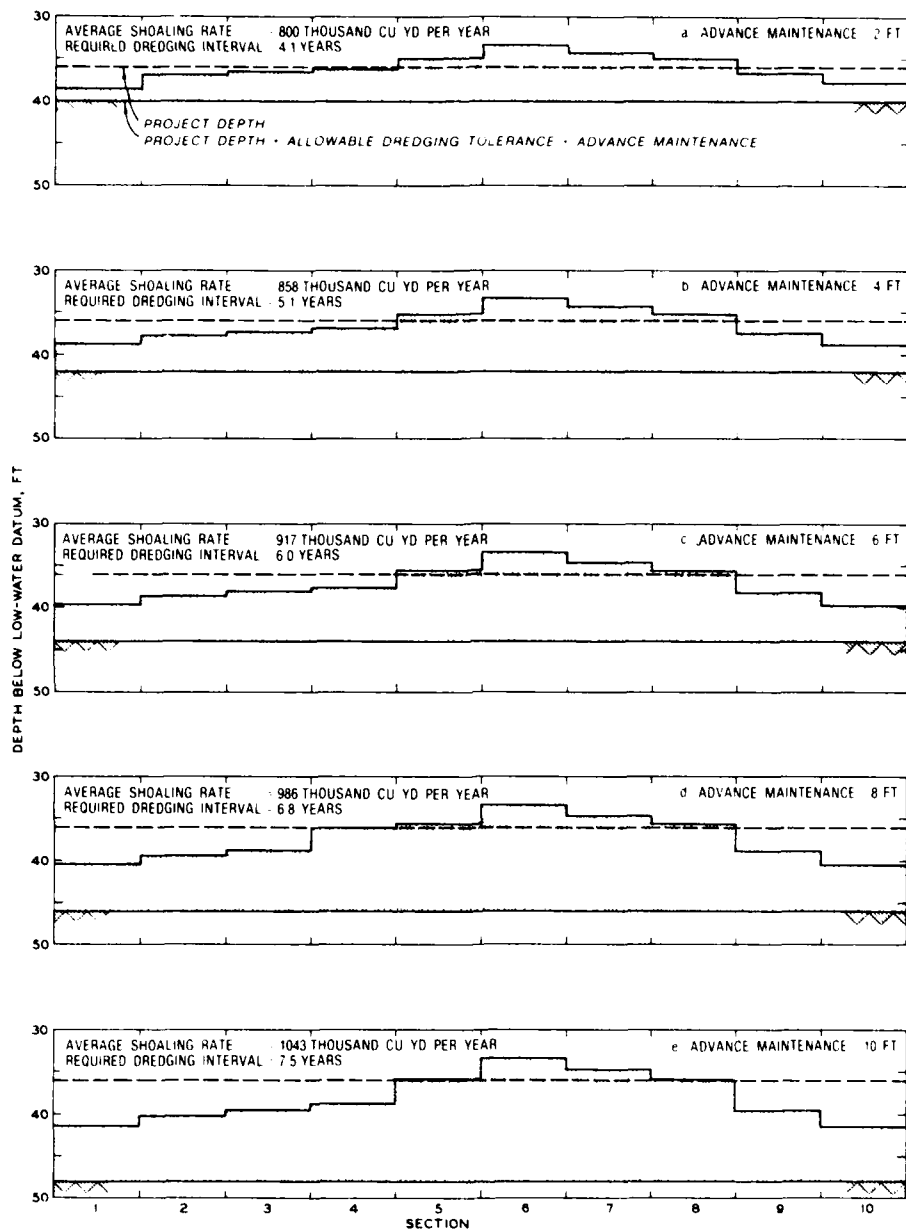
Channel Dimensions ft	Accumulated New Work	Maintenance Dredging		Shoaling Interval		Computed Shoaling Rate	Computed Average Shoaling Rate
		FY	From	To	From	To	
32 x 400 (Con't)	59,157	1940	8 Apr 40	17 Jun 40	8 Sep 39	17 Jun 40	13
	60,843	1940-42	14 Aug 41	6 Oct 41	18 Jun 40	6 Oct 41	244
	61,985	1942-43	15 Apr 42	26 Oct 42	7 Oct 41	26 Oct 42	1,098
		1943	1 Nov 42	25 May 43	17 Oct 42	25 May 43	2,557
		1943-44	17 Aug 43	15 Oct 43	26 May 43	15 Oct 43	1,220
		1944-46	1 Jul 45	3 Apr 46	6,515	16 Oct 43	2,642
		1946-48	4 Nov 47	23 Mar 48	4,125	4 Apr 46	2,094
		1948-49	22 May 48	13 Aug 48	2,193	24 Mar 48	5,599
		1949	19 Dec 48	9 Mar 49	1,528	14 Aug 48	2,681
		1949	12 Apr 49	28 Jun 49	1,269	10 Mar 49	4,175
36 x 400	65,123	1949-50	5 Dec 49	15 May 50	1,488	29 Jun 49	1,691
	70,196	1950-54	8 Feb 51	2 Sep 53	7,533	16 May 50	2,282
	74,181	1954	21 Dec 53	8 Apr 54	2,548	3 Sep 53	4,266
		1954-56	20 May 55	4 Aug 55	761	9 Apr 54	575
		1956	27 Oct 55	12 Dec 55	1,266	5 Aug 55	3,554
		1956	21 Dec 55	30 Jun 56	282	13 Dec 55	515
	76,574	1956-57	30 Aug 56	12 Mar 57	2,403	1 Jul 56	3,439
	77,128	1957-58	21 Oct 57	22 Dec 57	670	13 Mar 57	858
	78,285	1958-59	1 Jul 58	24 Sep 58	2,879	23 Dec 57	4,246
		1959	22 May 59	13 Jun 59	47	25 Sep 58	65
	78,359	1959-60	1 Jul 59	13 Oct 59	155	14 Jun 59	464
	79,135	1960-61	29 Oct 59	11 Oct 60	1,834	14 Oct 59	1,844
	87,720	1961-66	1 Jul 61	2 Jul 65	15,757	12 Oct 60	3,336
						2 Jul 65	

(Continued)

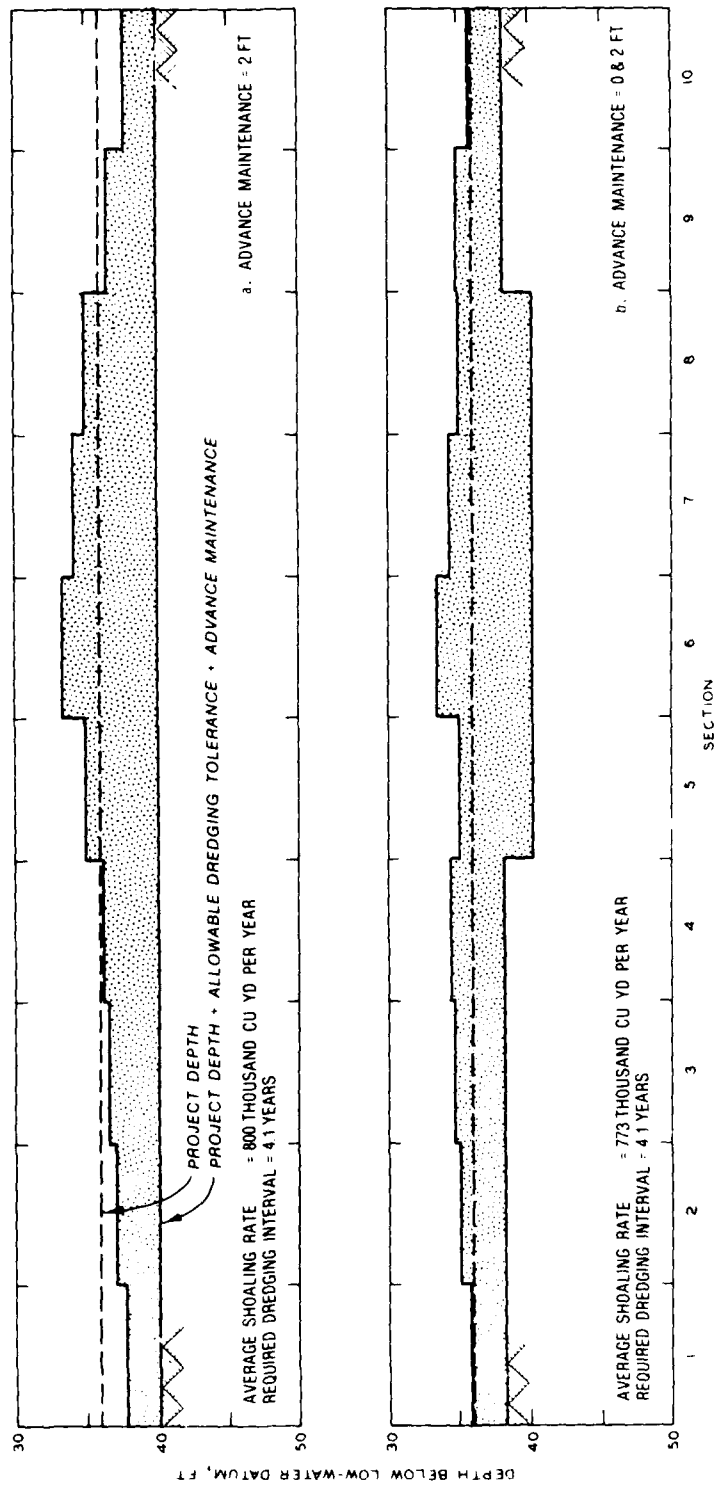
(Sheet 2 of 3)

Table 13 (Concluded)

Channel Dimensions ft	Accumulated New Work	FY	Maintenance Dredging		Volume	Shoaling Interval		Computed Shoaling Rate	Computed Average Shoaling Rate
			From	To		From	To		
40 x 400	105,254	1966	21 Jul 65	14 Oct 65	156	3 Jul 65	14 Oct 65	0.29	547
	107,231	1966-67	27 Apr 66	12 Oct 66	3,110	15 Oct 65	12 Oct 66	0.99	3,127
		1967-69	17 Jan 68	19 Sep 68	5,525	13 Oct 66	19 Sep 68	1.94	2,852
	108,614	1969-70	7 Aug 69	19 Oct 69	1,199	20 Sep 68	19 Oct 69	1.08	1,108
		1970	2 Jan 70	23 Jan 70	122	20 Oct 69	23 Jan 70	0.26	464
		1970-71	28 Apr 70	20 Jul 70	2,632	24 Jan 70	20 Jul 70	0.49	5,397
	108,974	1971	8 Aug 70	3 Feb 71	127	21 Jul 70	3 Feb 71	0.54	234
		1971-72	24 May 71	12 Dec 71	685	4 Feb 71	12 Dec 71	0.84	814
		1972	24 Apr 72	23 Jun 72	1,625	13 Dec 71	23 Jun 72	0.54	2,996
		1972-73	8 Jul 72	24 Aug 72	75	24 Jun 72	24 Aug 72	0.17	441
		1973-74	4 Jan 74	15 May 74	254	25 Aug 72	15 May 74	1.72	147
		1974-75	8 Apr 75	30 Jun 75	2,606	16 May 74	30 Jun 75	1.13	2,315
									1,086



EXAMPLE CHANNEL
SHOALING PATTERNS
UNIFORM ADVANCE MAINTENANCE



EXAMPLE CHANNEL SHOALING PATTERNS
UNIFORM AND VARIED ADVANCE MAINTENANCE

AD-A102 692

ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MS F/6 13/2
EFFECTS OF DEPTH ON DREDGING FREQUENCY. REPORT 2, METHODS OF ES--ETC(U)
JUL 81 M J TRAWLE

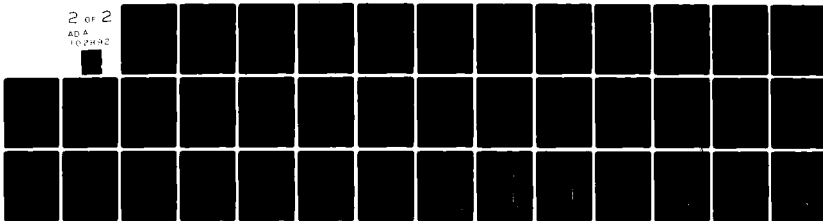
UNCLASSIFIED

WES-TR-H-78-5

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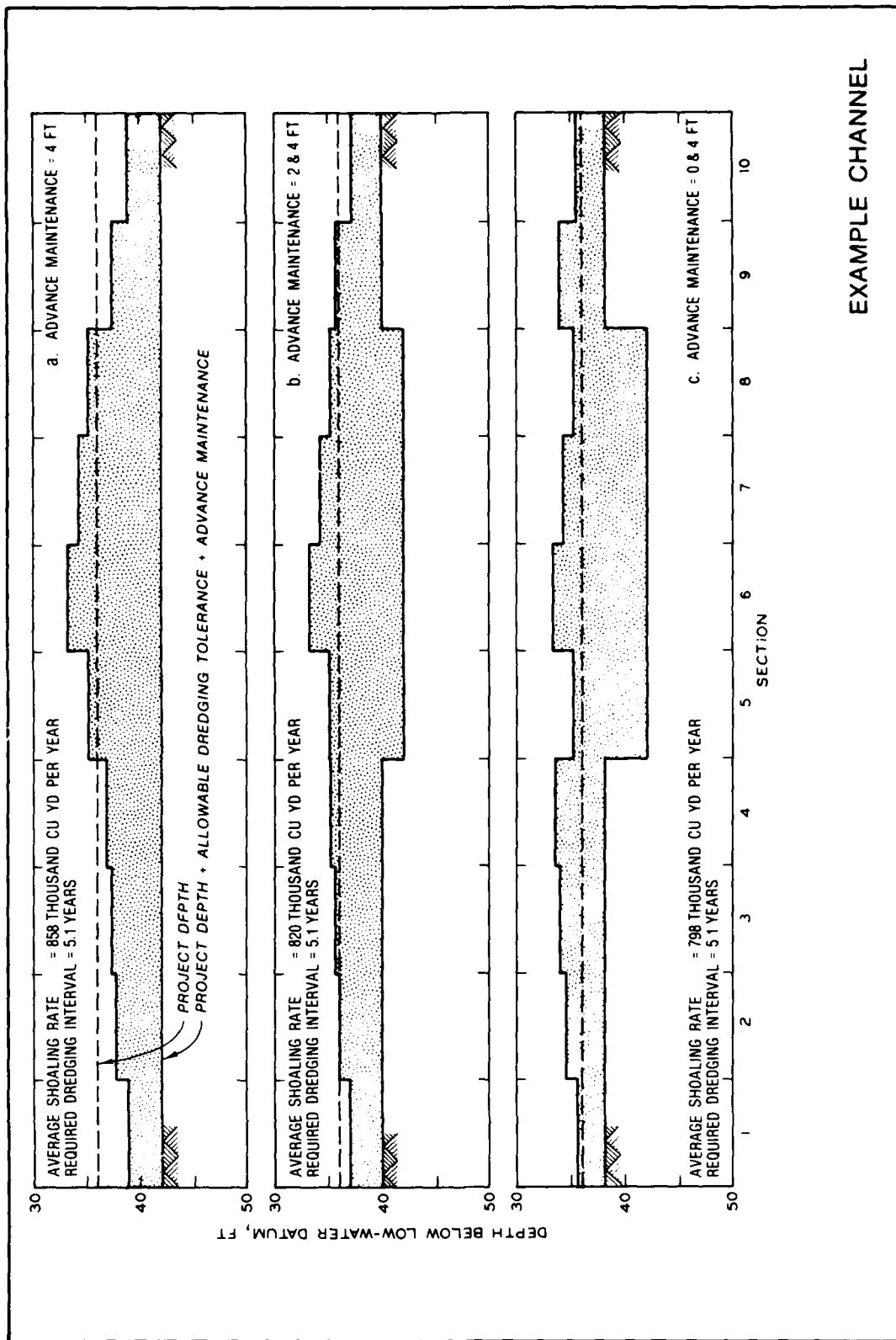
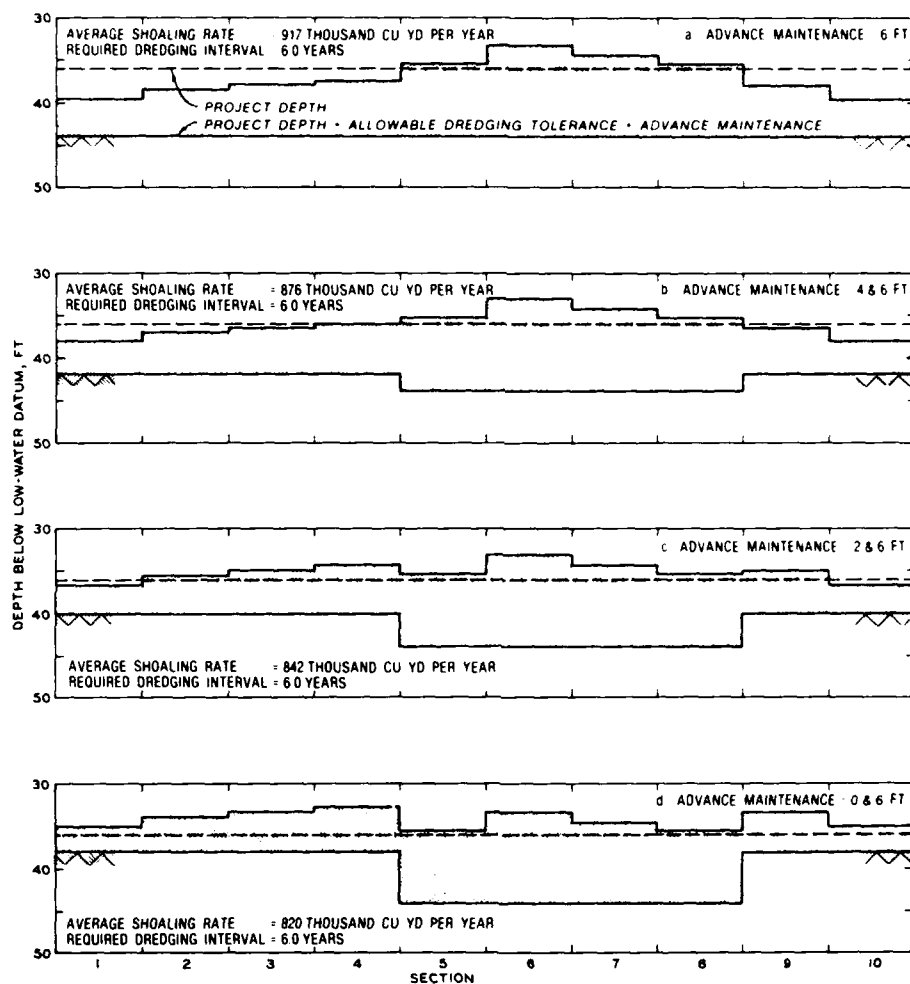
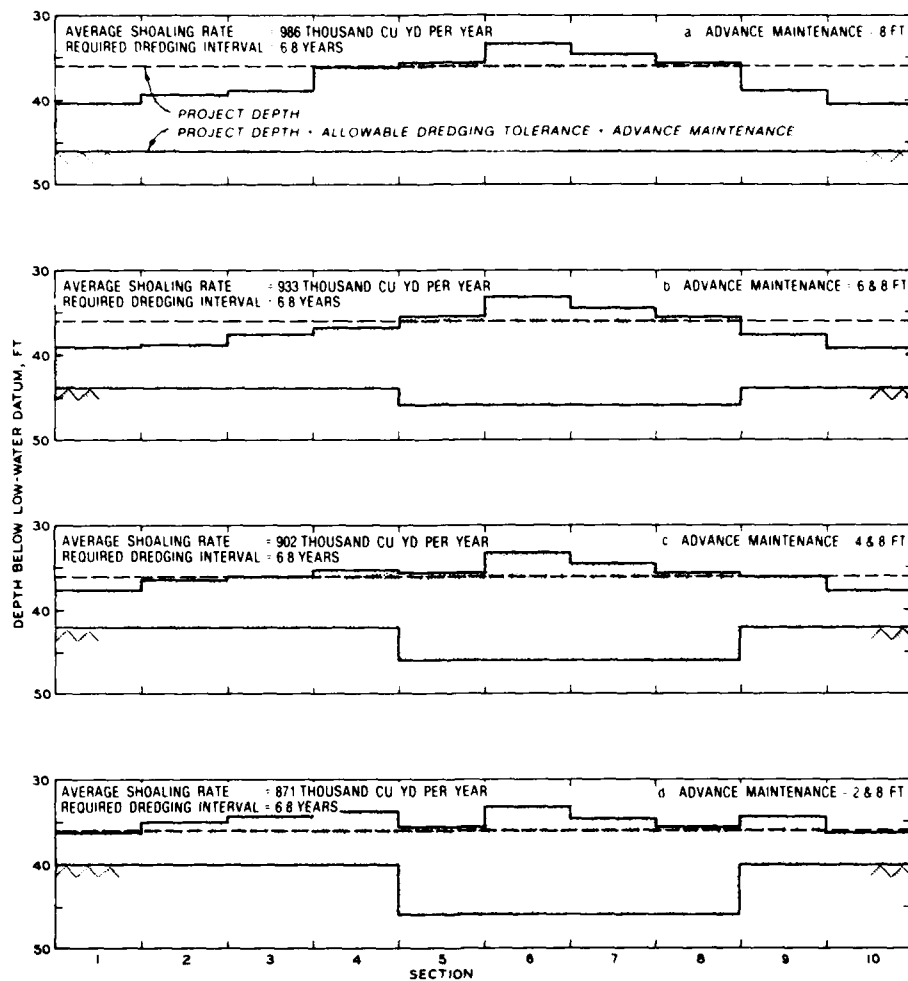


PLATE 3

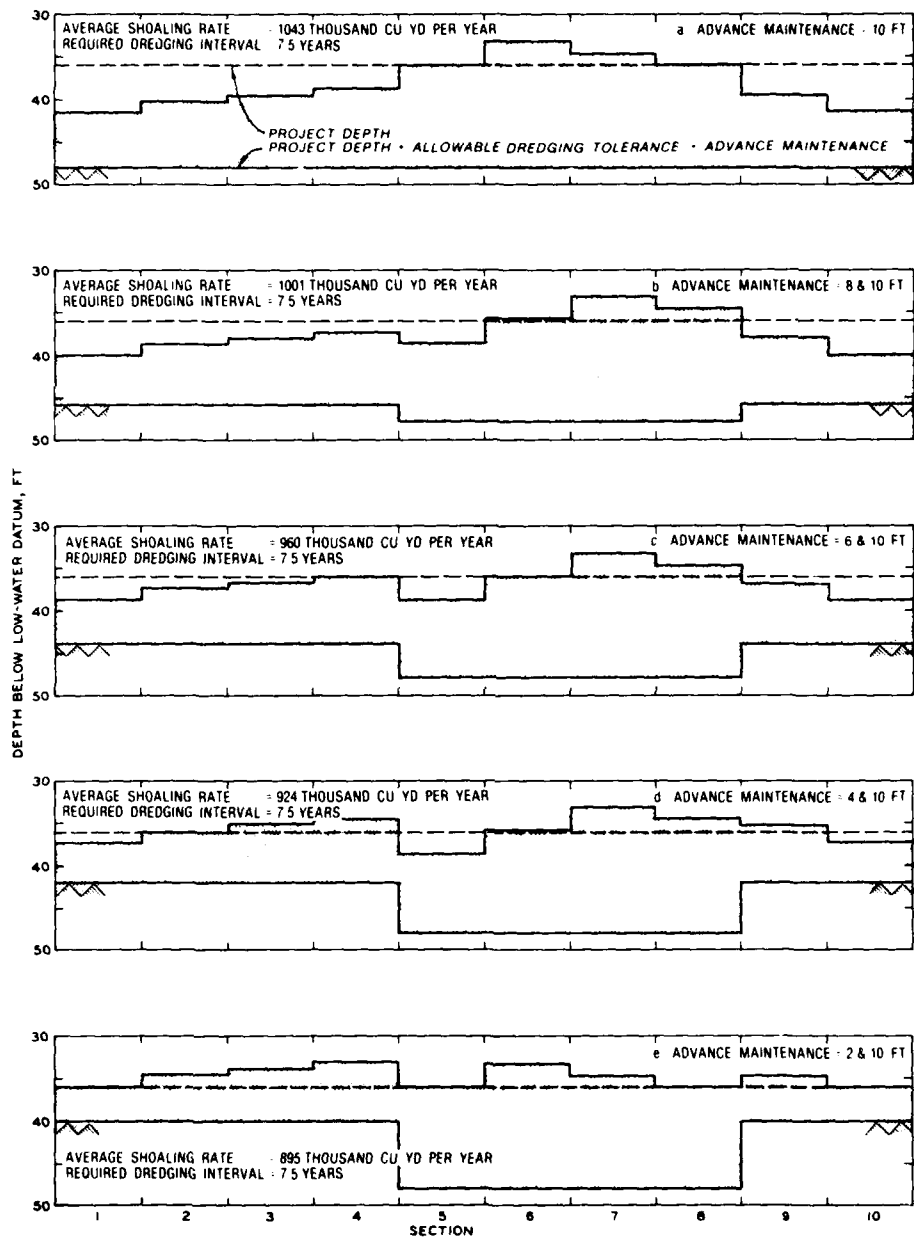
EXAMPLE CHANNEL



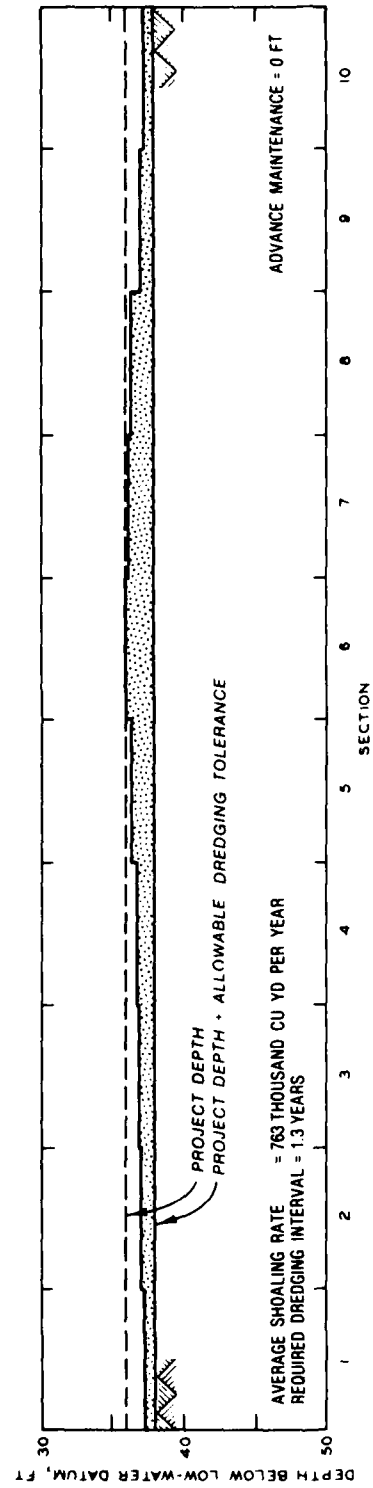
EXAMPLE CHANNEL
6.0-YR DREDGING INTERVAL



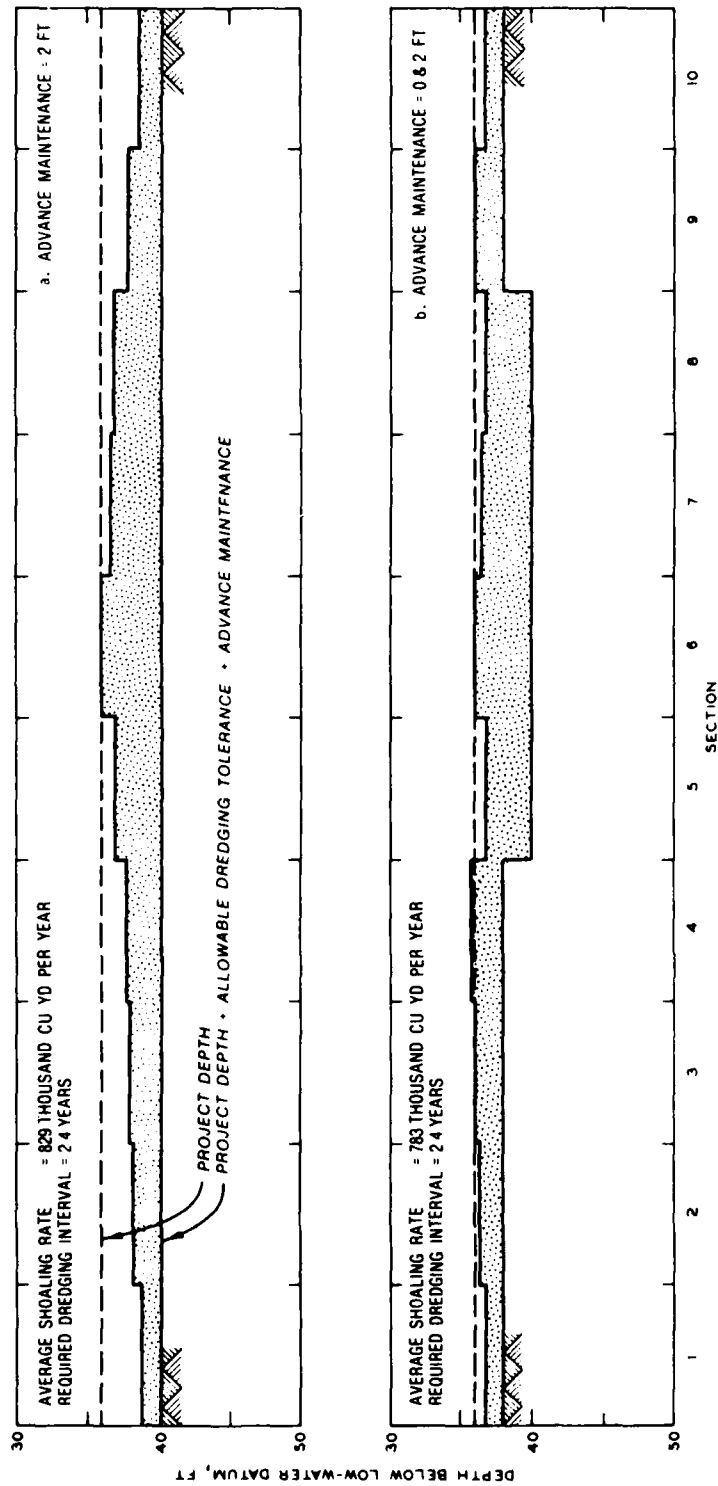
EXAMPLE CHANNEL
6.8-YR DREDGING INTERVAL



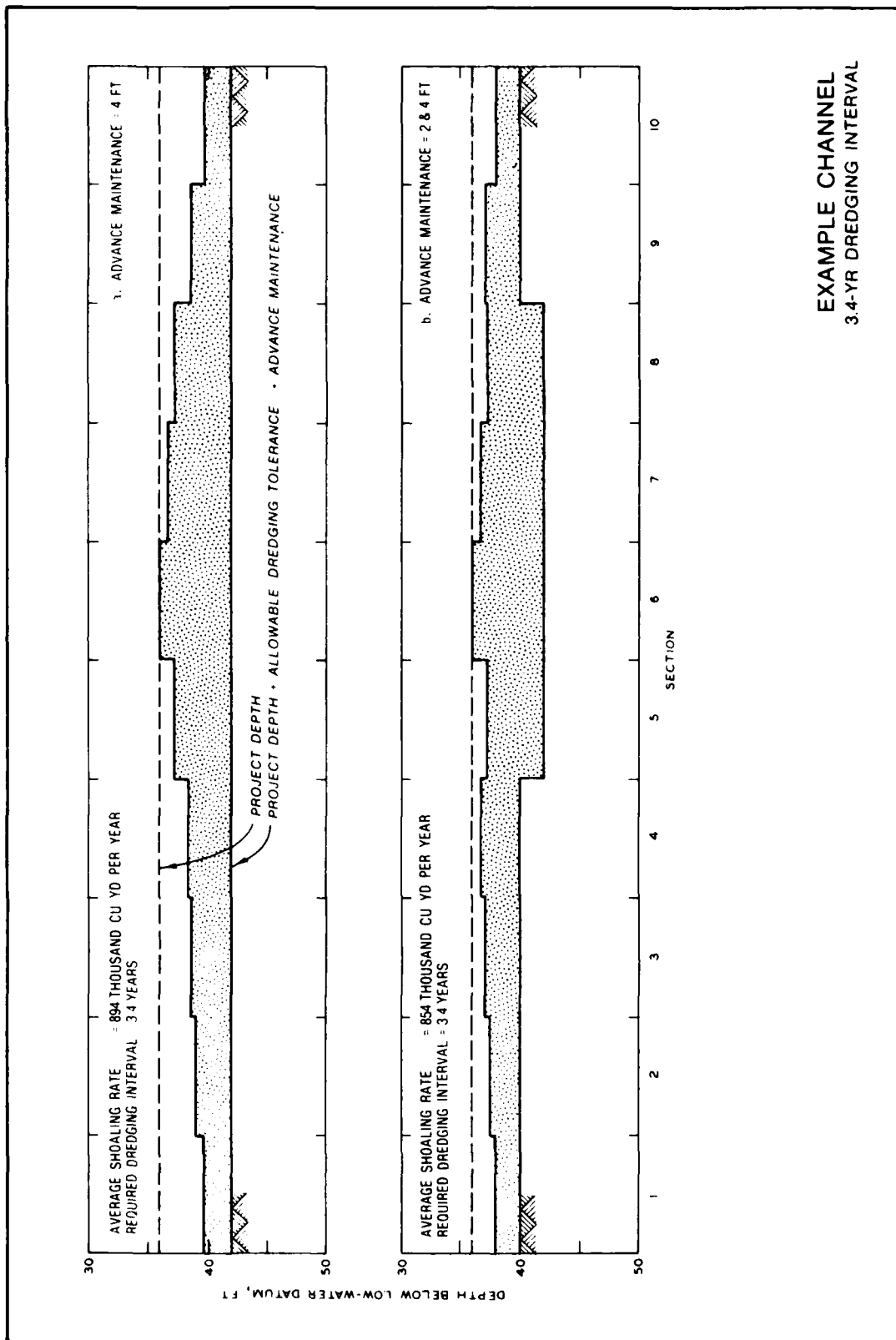
EXAMPLE CHANNEL
7.5-YR DREDGING INTERVAL



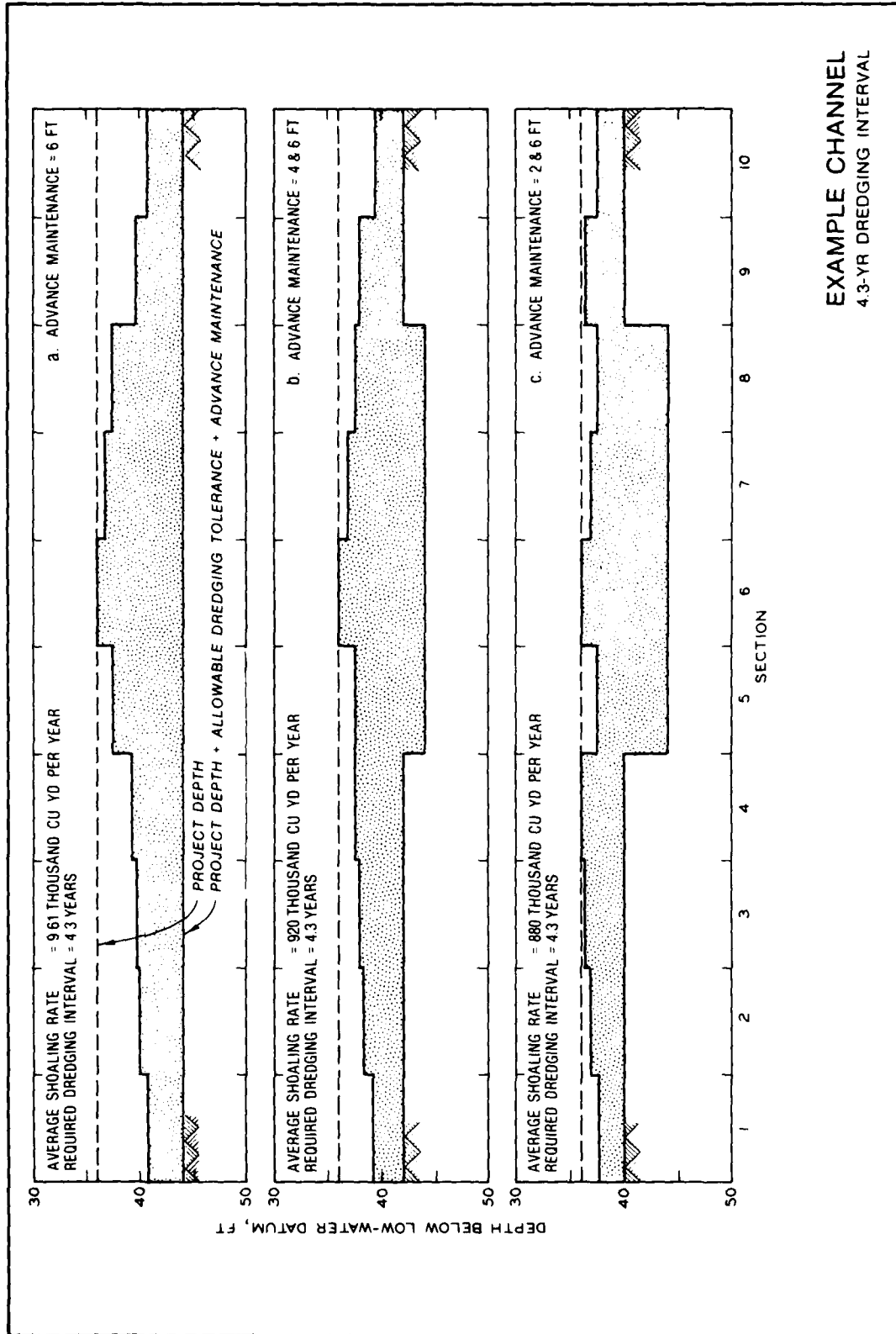
EXAMPLE CHANNEL
1.3-YR DREDGING INTERVAL



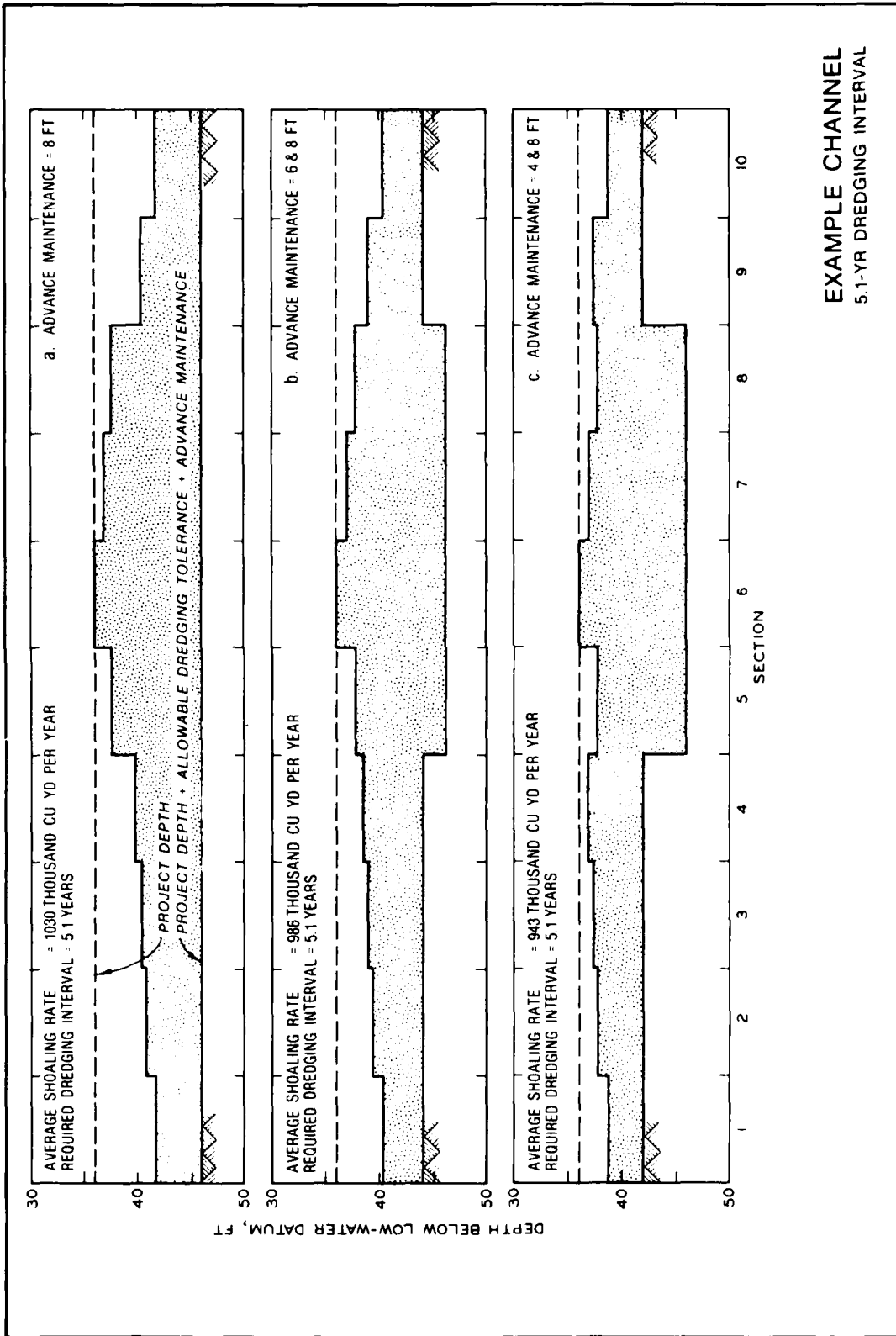
EXAMPLE CHANNEL
2.4-YR DREDGING INTERVAL



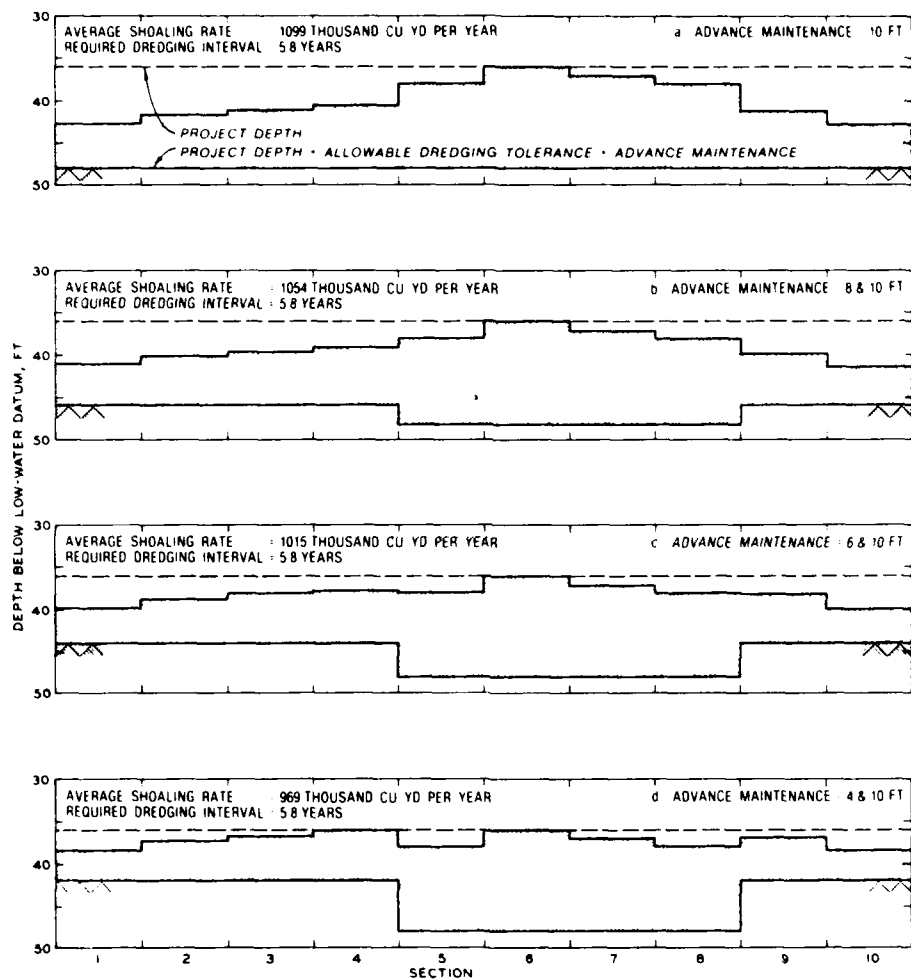
EXAMPLE CHANNEL
3.4-YR DREDGING INTERVAL



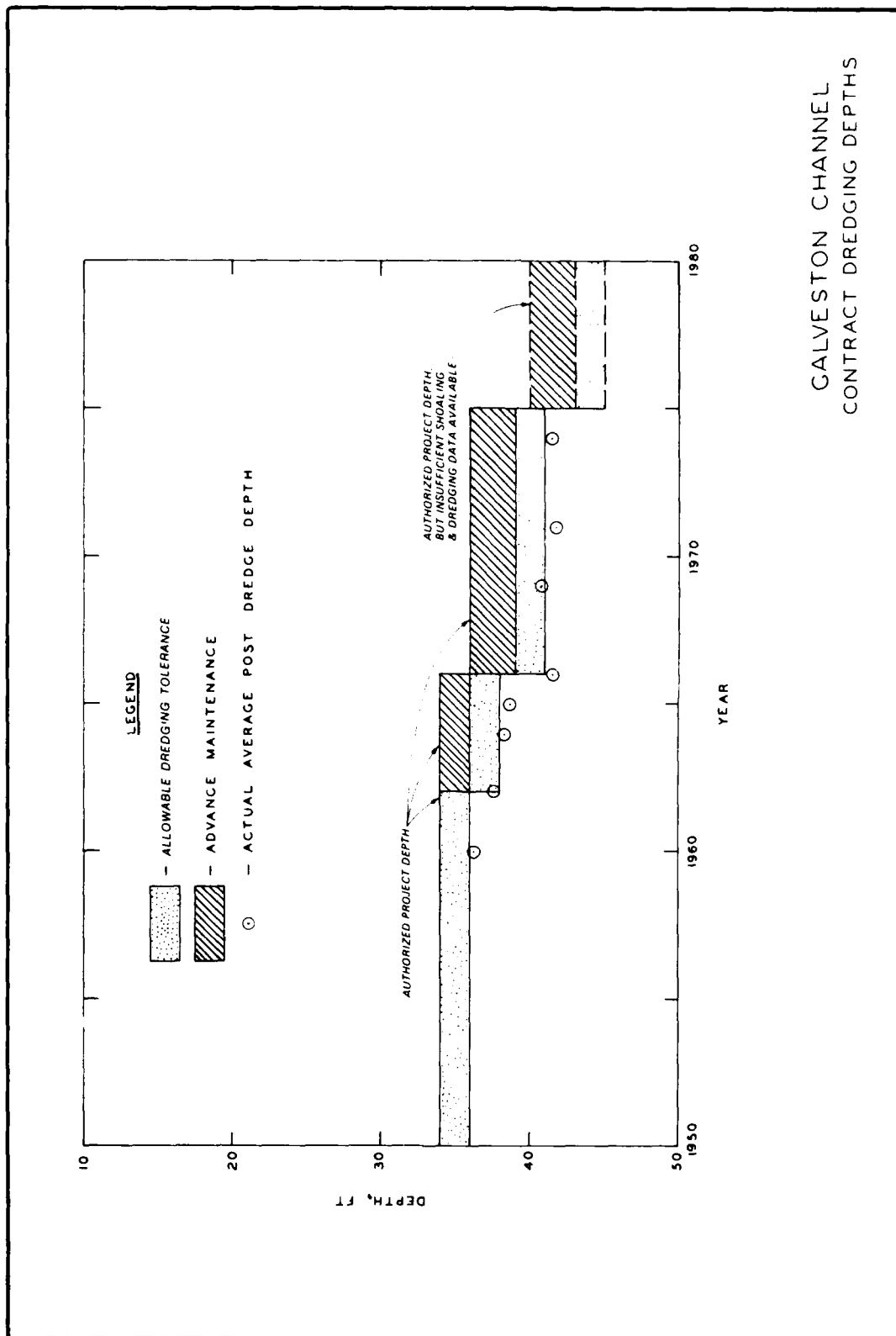
EXAMPLE CHANNEL
4.3-YR DREDGING INTERVAL



EXAMPLE CHANNEL
5.1-YR DREDGING INTERVAL



EXAMPLE CHANNEL
5.8-YR DREDGING INTERVAL



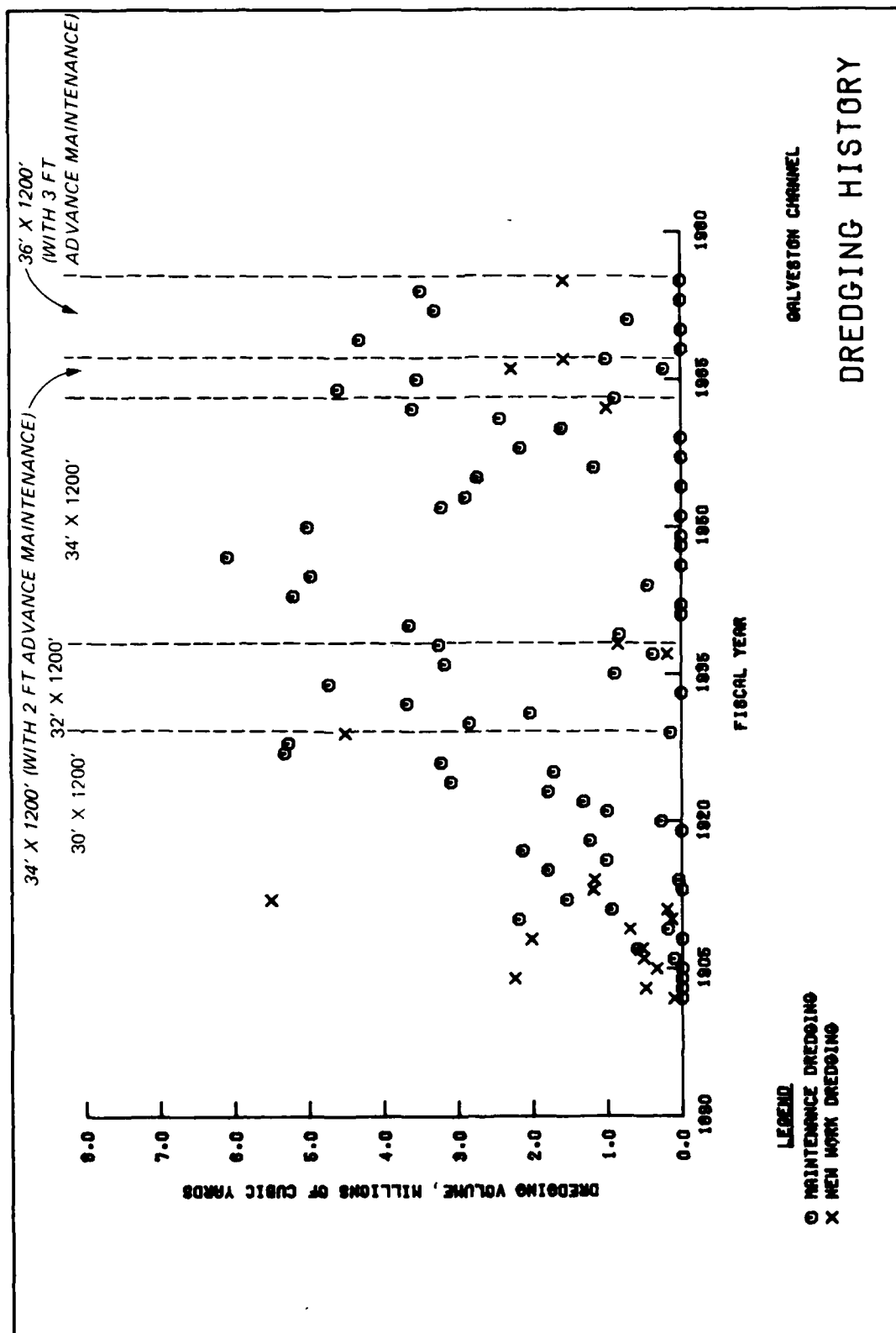
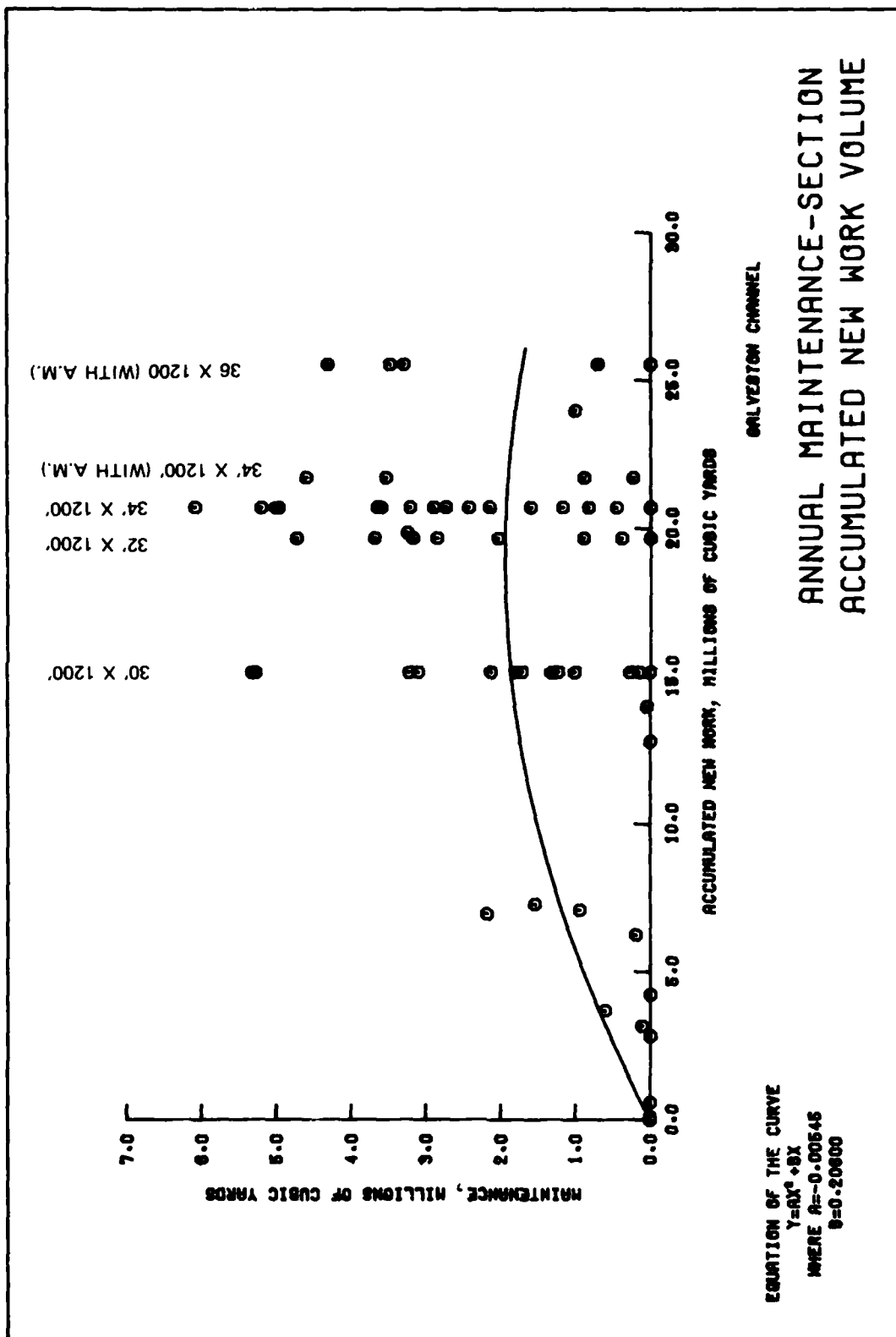
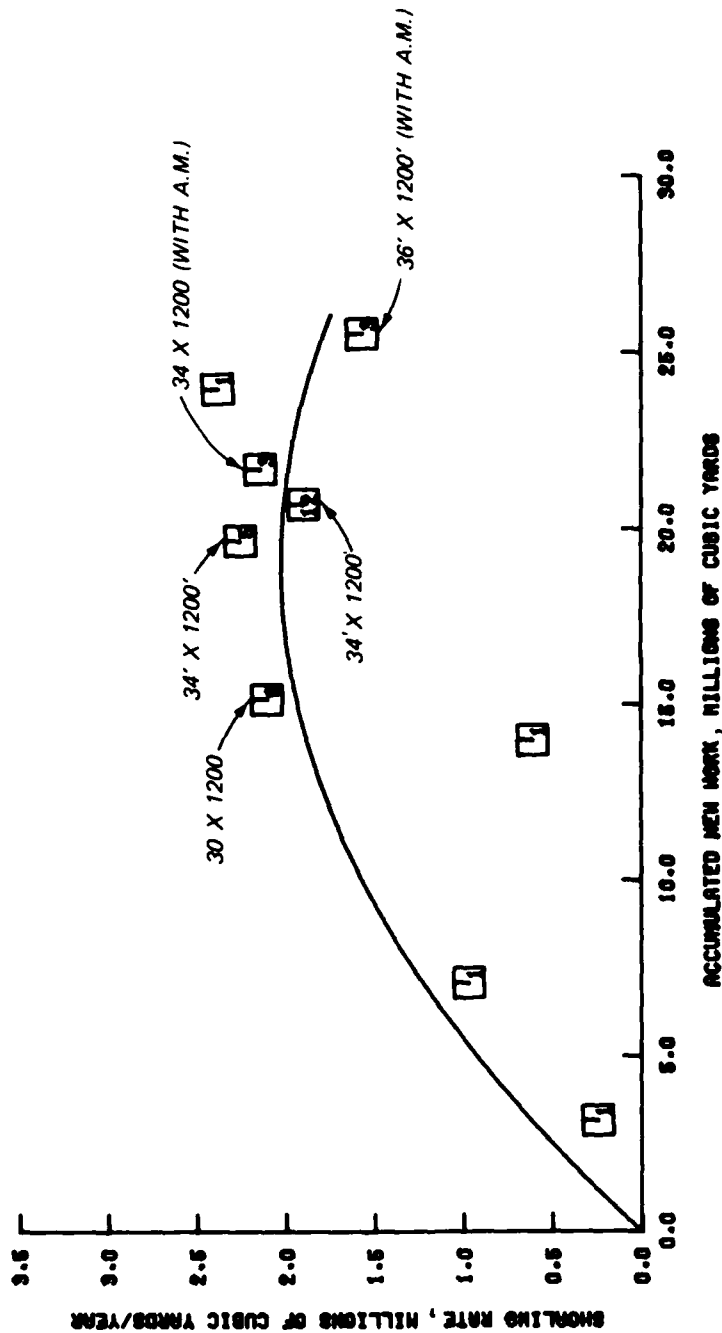


PLATE 14





EQUATION OF THE CURVE

$$Y = 0.0004 X^2 + 0.0004 X$$

WHERE $R = 0.0004$

$$B = 0.0004$$

NOTE-CURVE IS WEIGHTED BY THE NUMBER OF SHOALING PERIODS, INDICATED BY THE NUMBER WITHIN THE SYMBOL

GALVESTON CHANNEL

SHOALING RATE-SECTION ACCUMULATED NEW WORK VOLUME

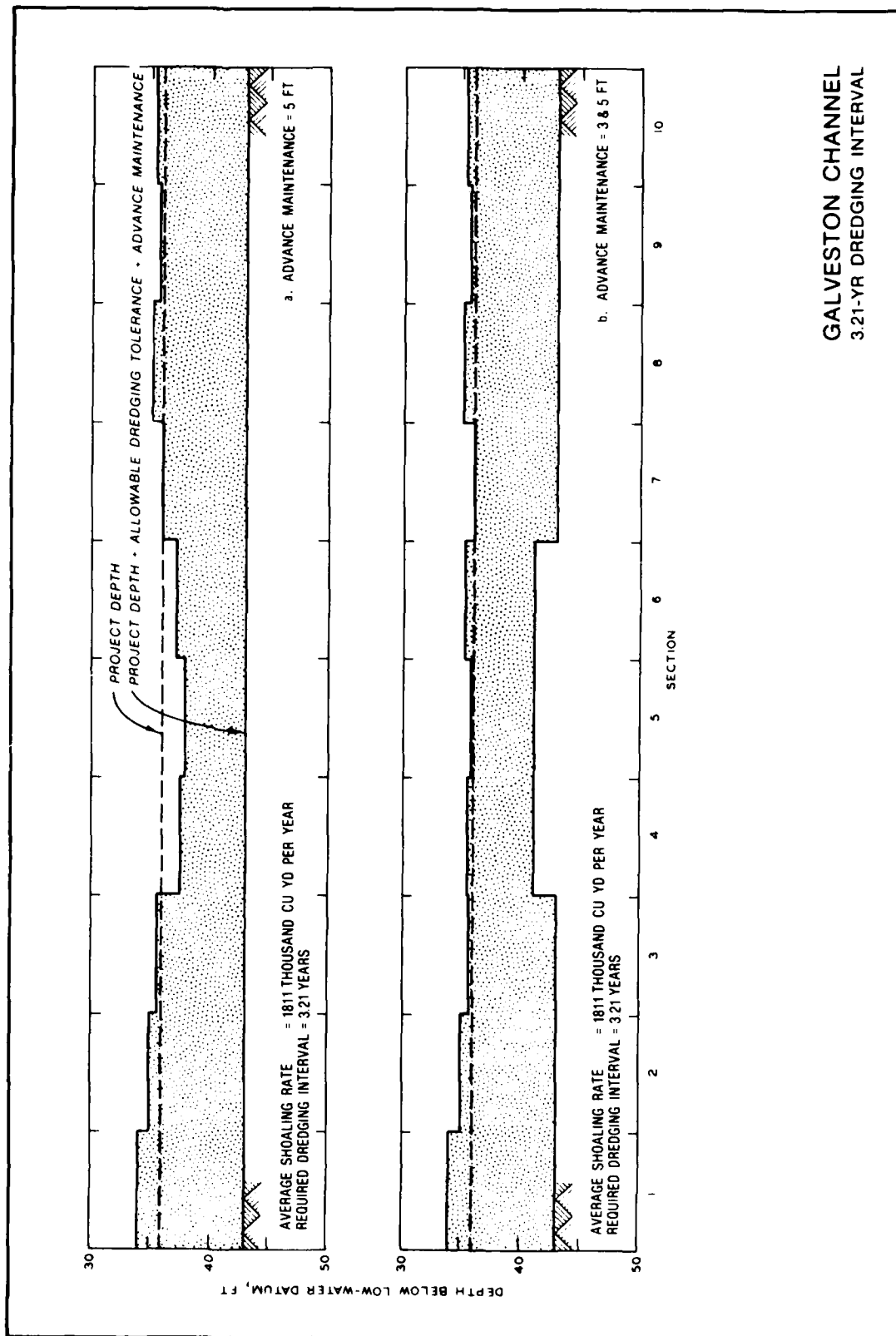
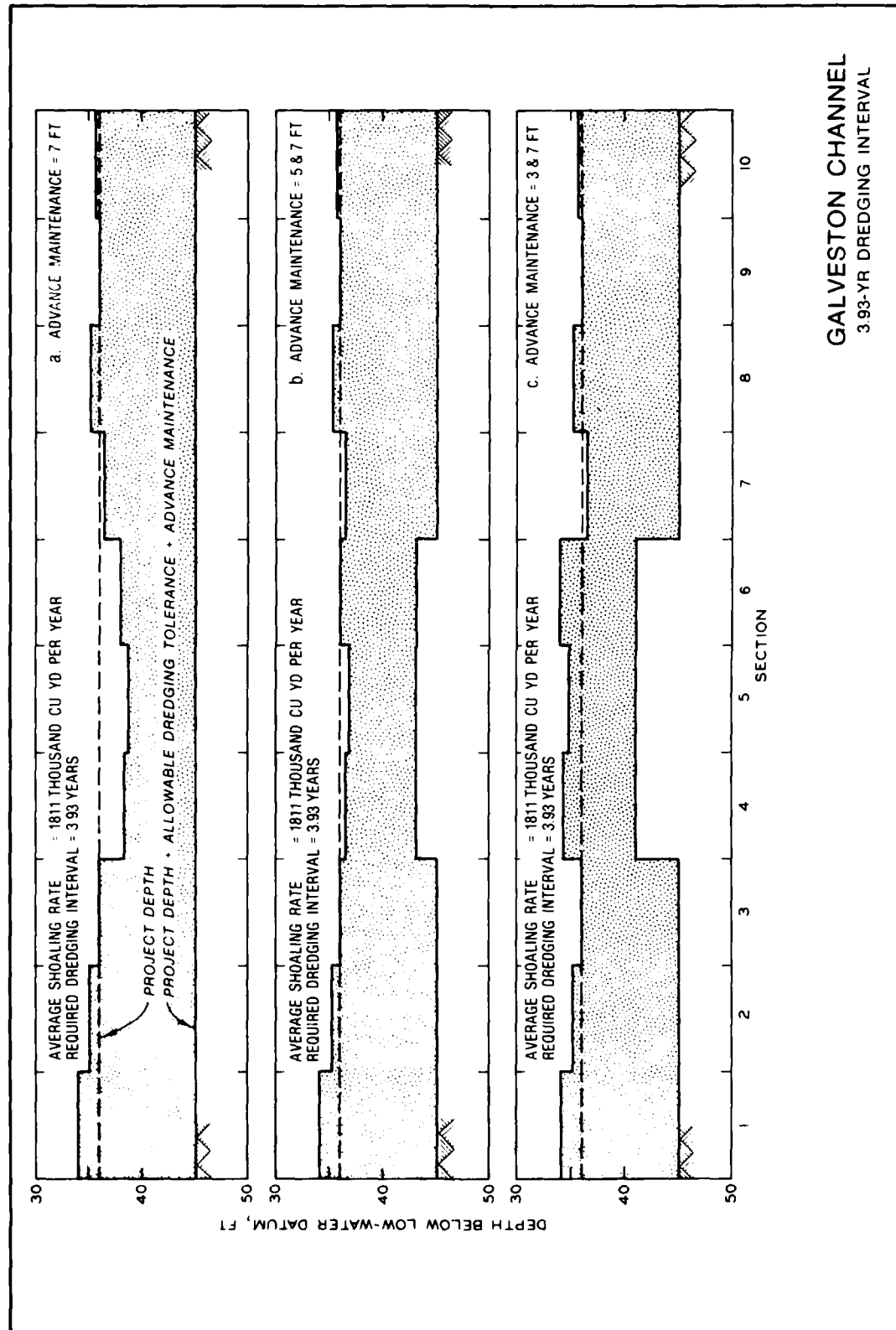
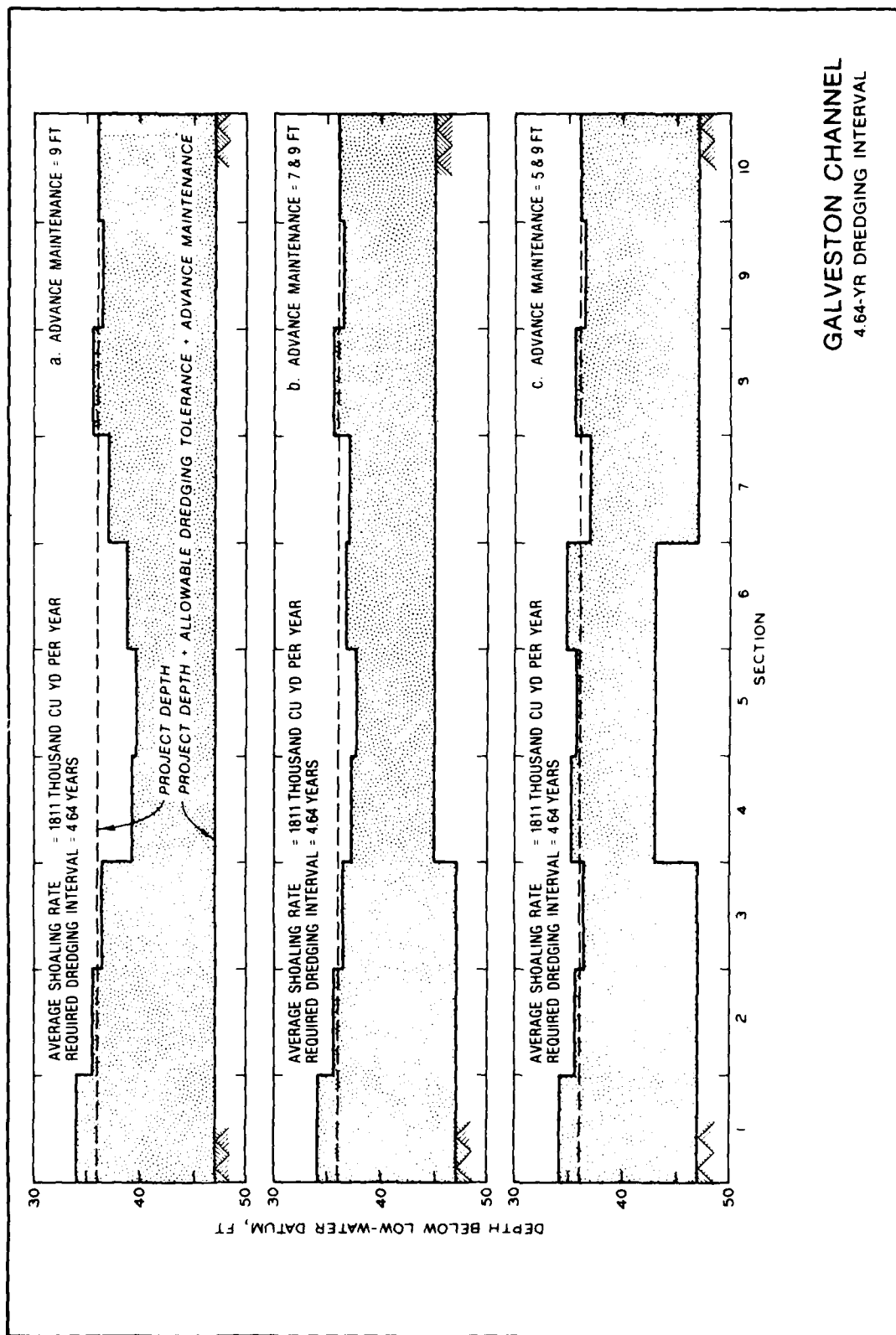


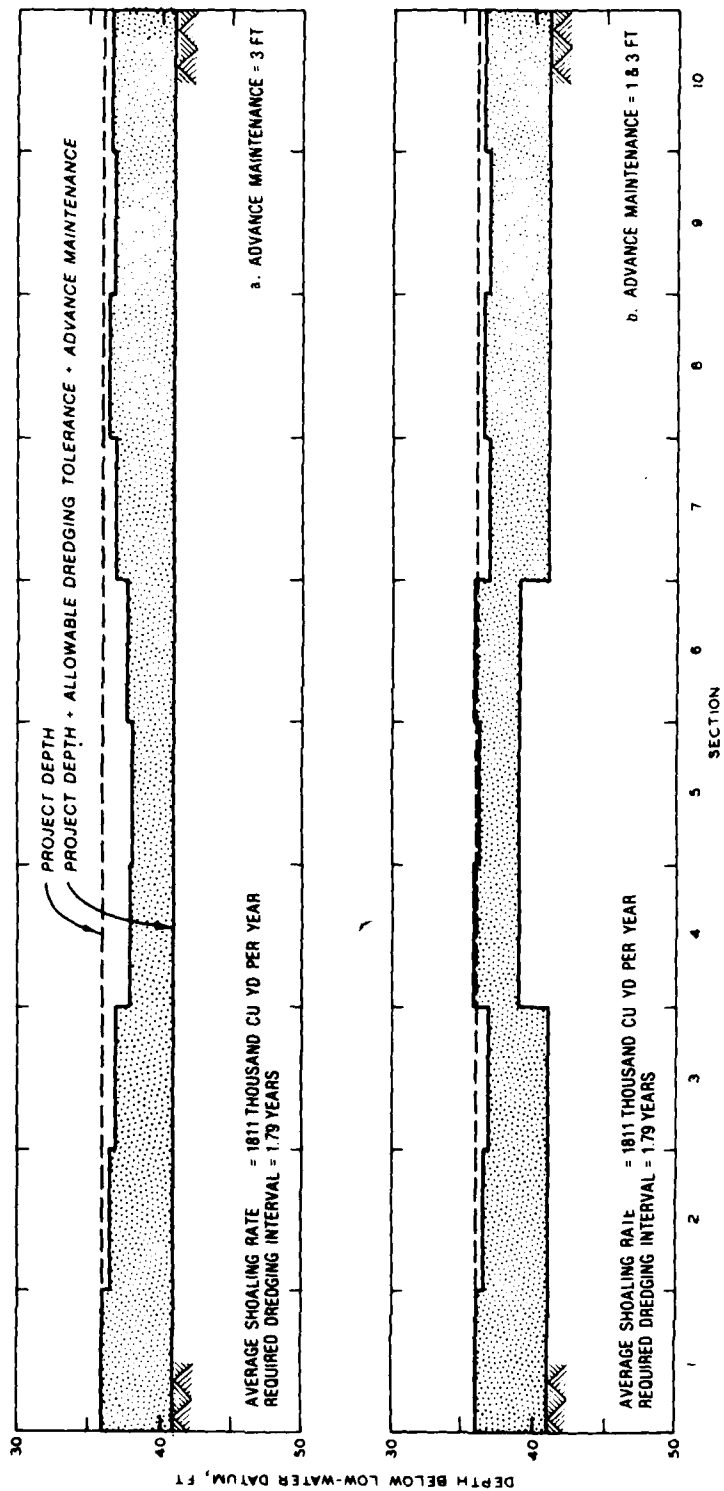
PLATE 17

GALVESTON CHANNEL
3.21-YR DREDGING INTERVAL

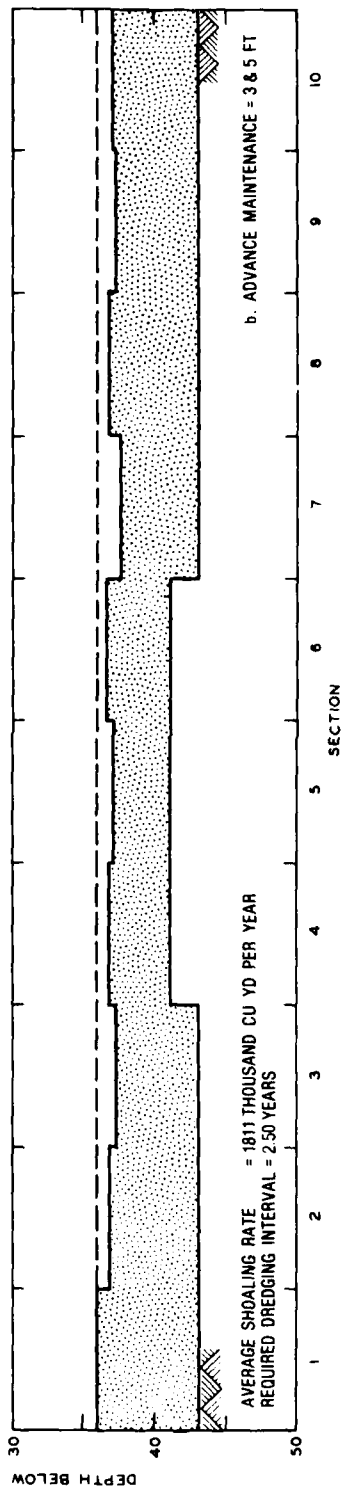
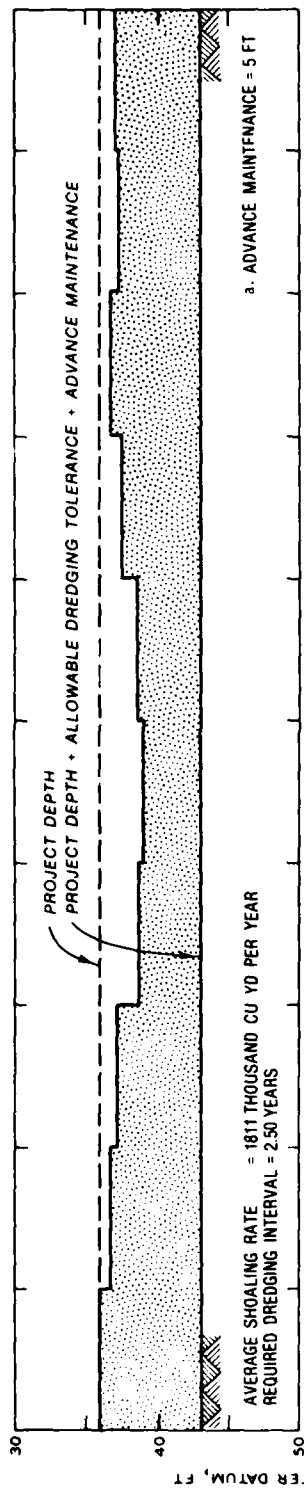


GALVESTON CHANNEL
3.93-YR DREDGING INTERVAL

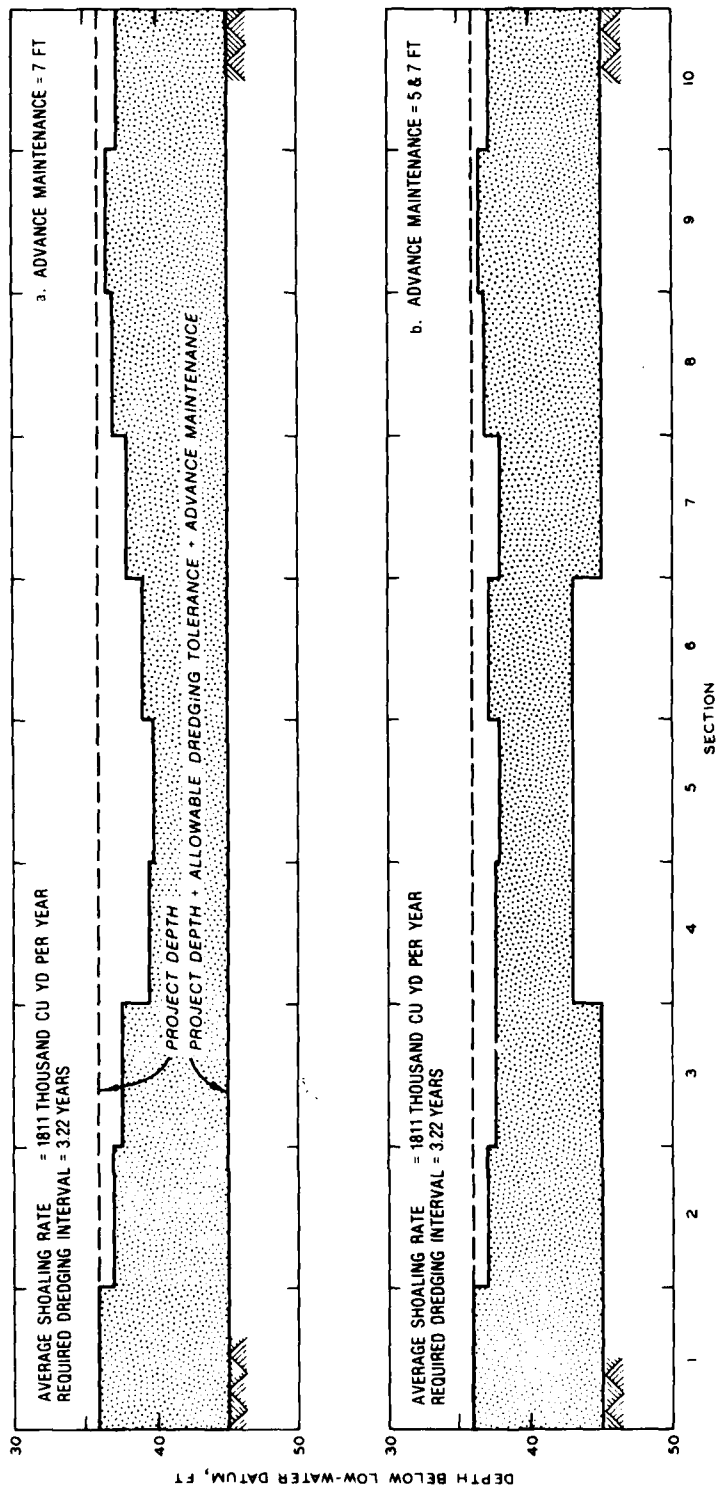




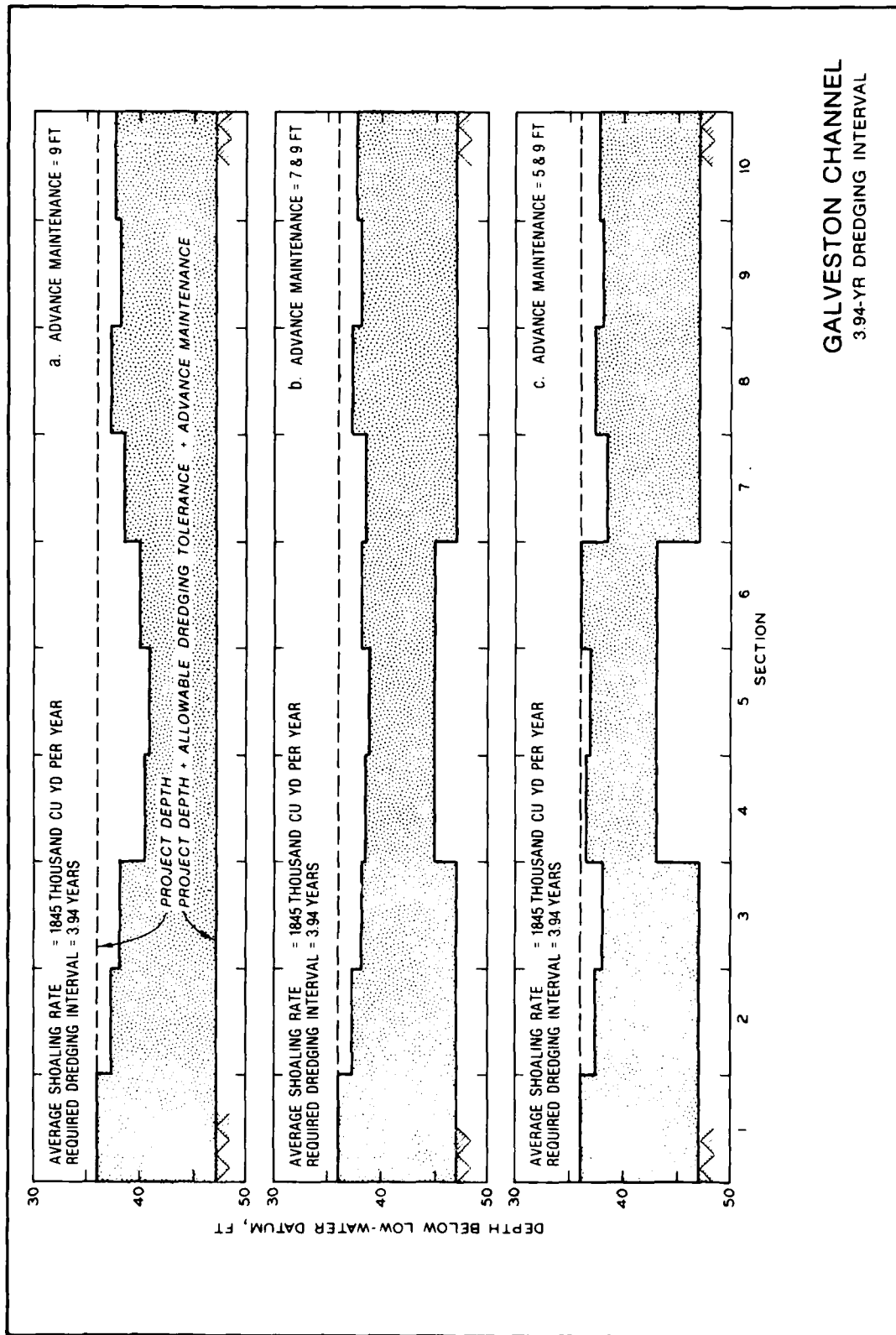
GALVESTON CHANNEL
1.79-YR DREDGING INTERVAL



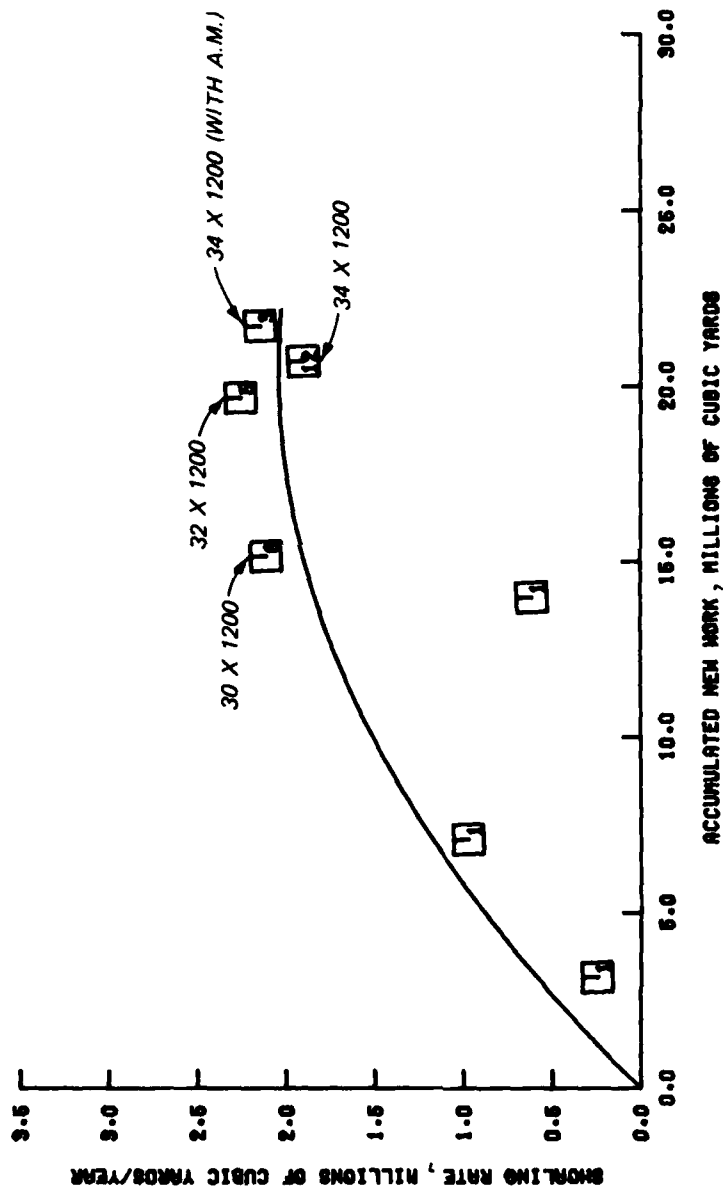
GALVESTON CHANNEL 2.50-YR DREDGING INTERVAL



GALVESTON CHANNEL
3.22-YR DREDGING INTERVAL



GALVESTON CHANNEL
 3.94-YR DREDGING INTERVAL



EQUATION OF THE CURVE

$$Y = AX^B + BX$$

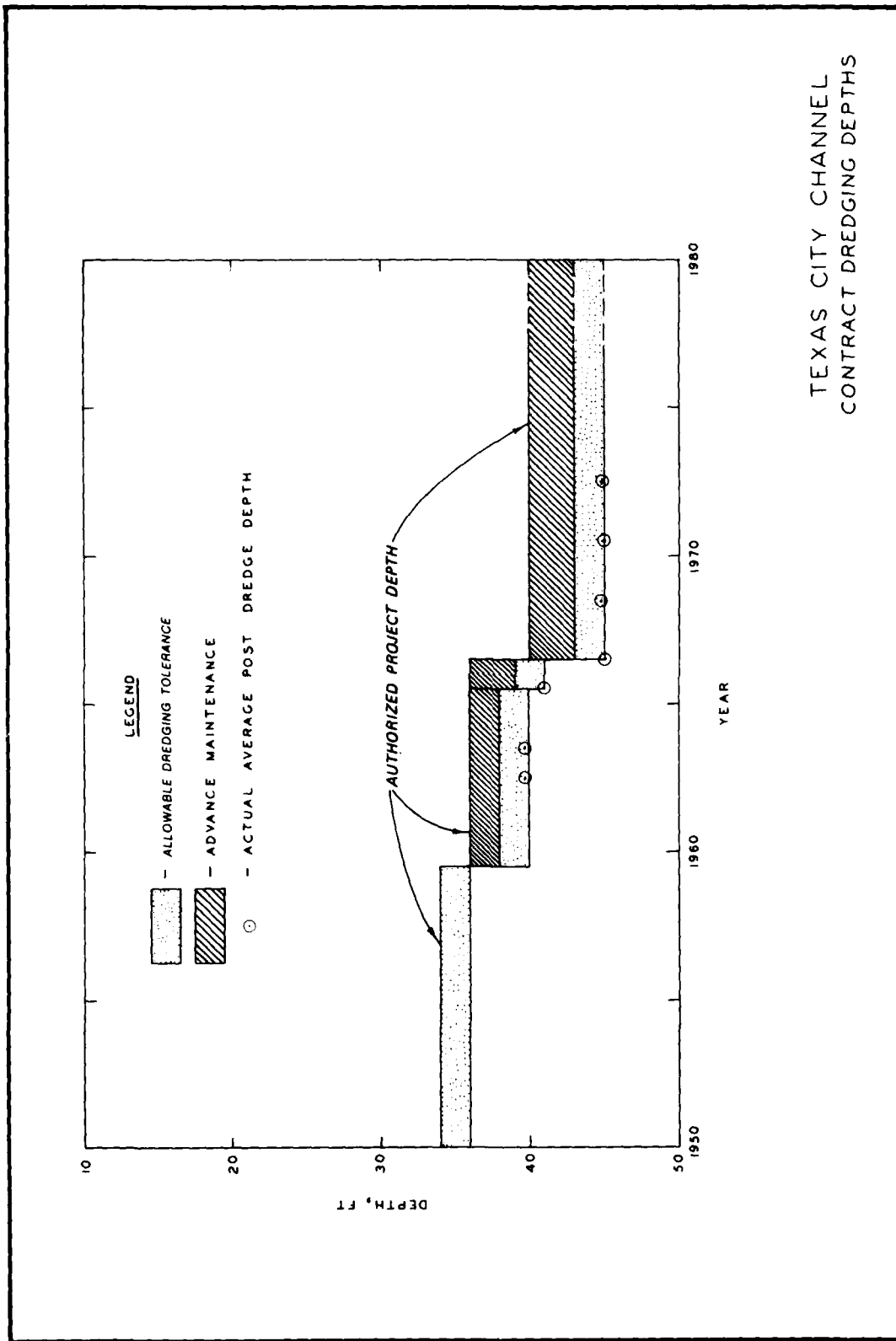
WHERE $A = -0.00483$

$B = 0.20027$

NOTE-CURVE IS WEIGHTED BY THE NUMBER OF SHOALING PERIODS. INDICATED BY THE NUMBER WITHIN THE SYMBOL

GALVESTON CHANNEL

SHOALING RATE-SECTION
ACCUMULATED NEW WORK VOLUME



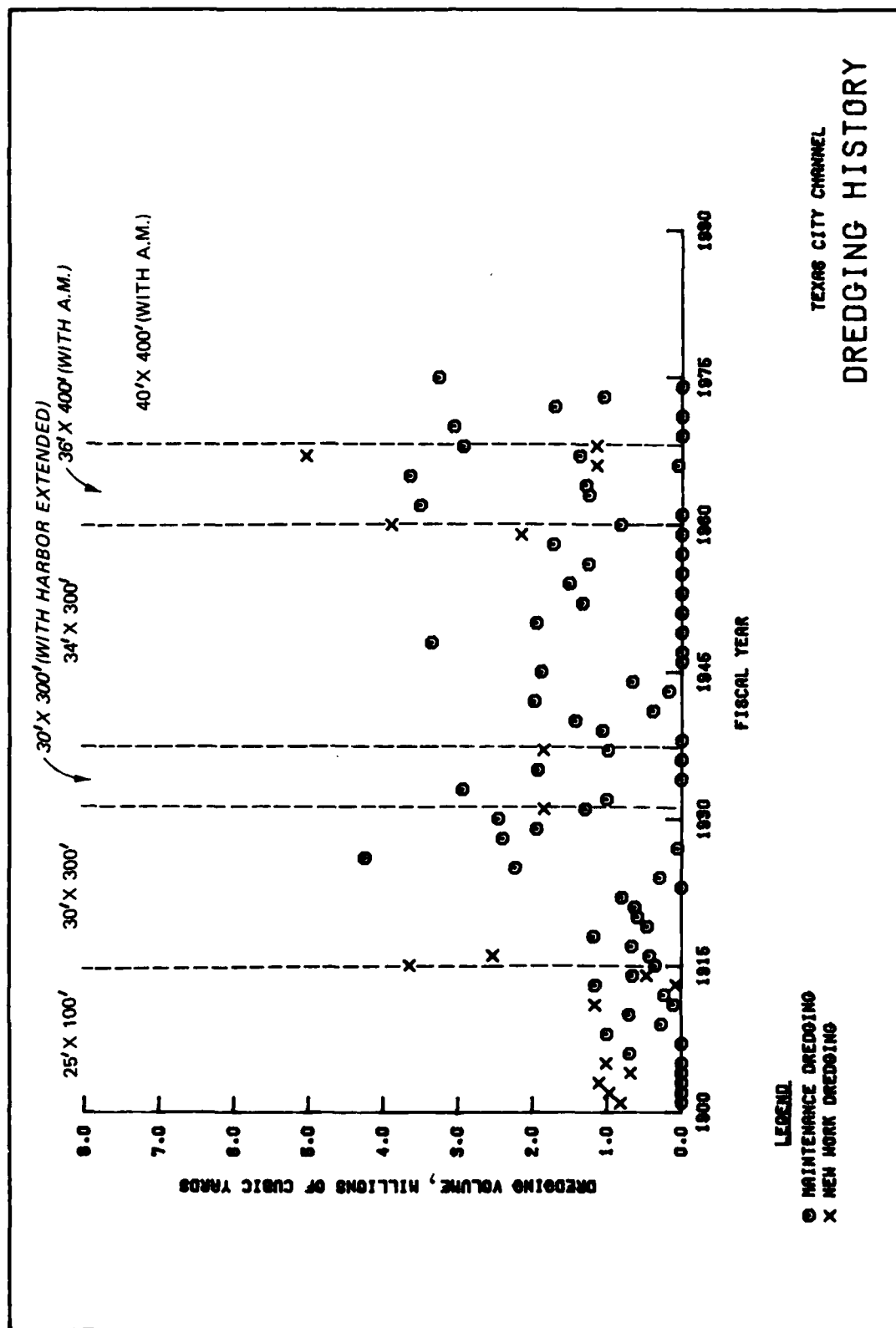
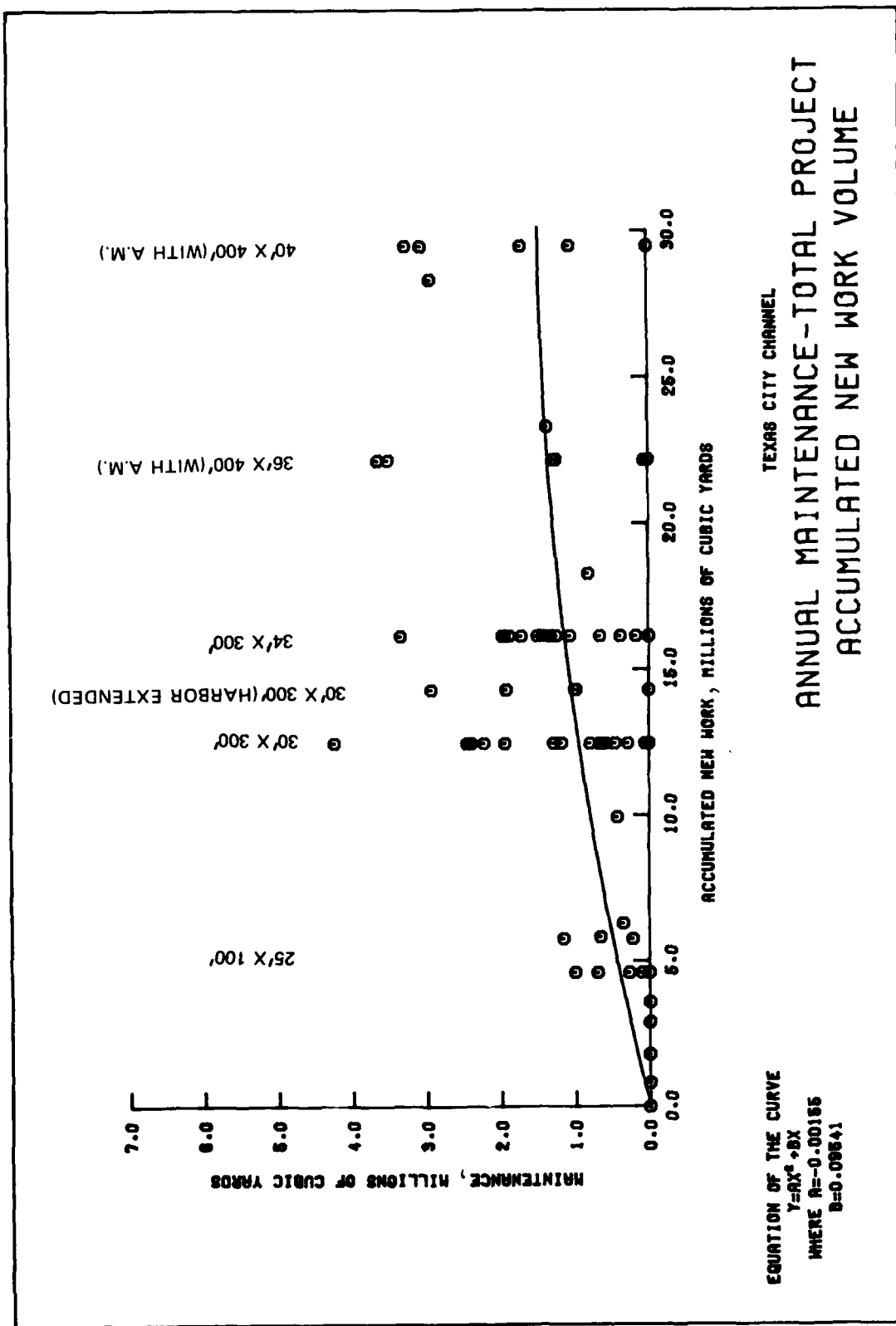
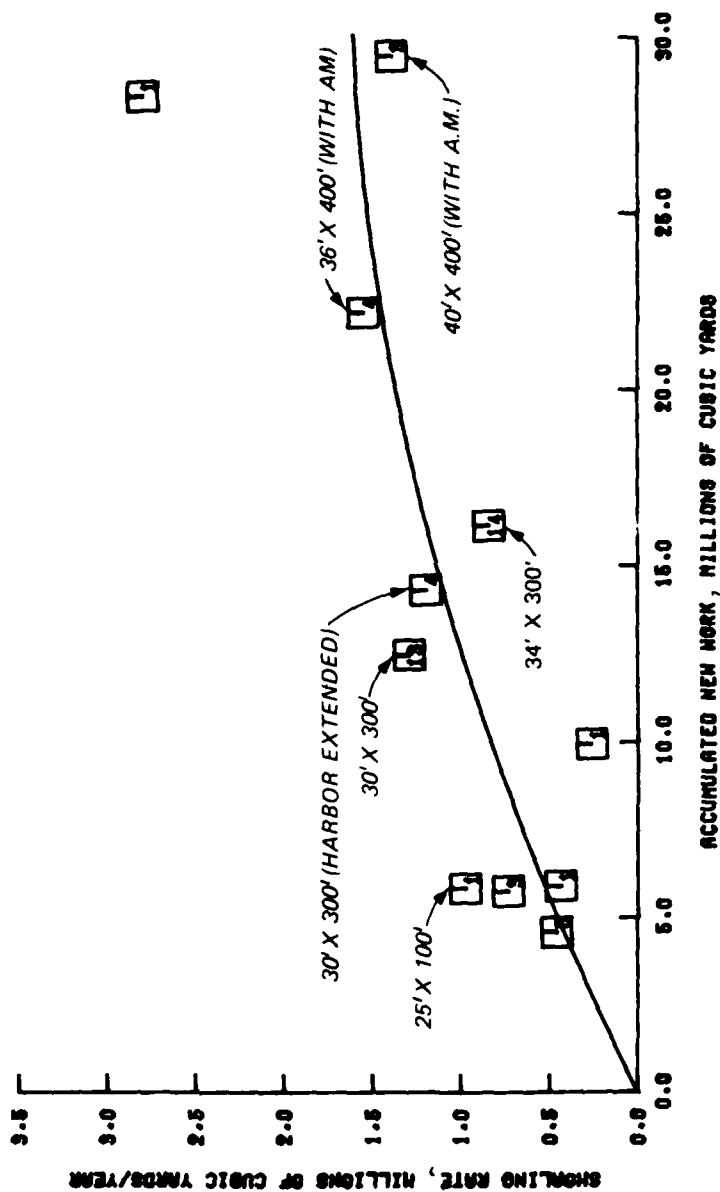


PLATE 26





EQUATION OF THE CURVE

$$Y = AX^B \cdot EX$$

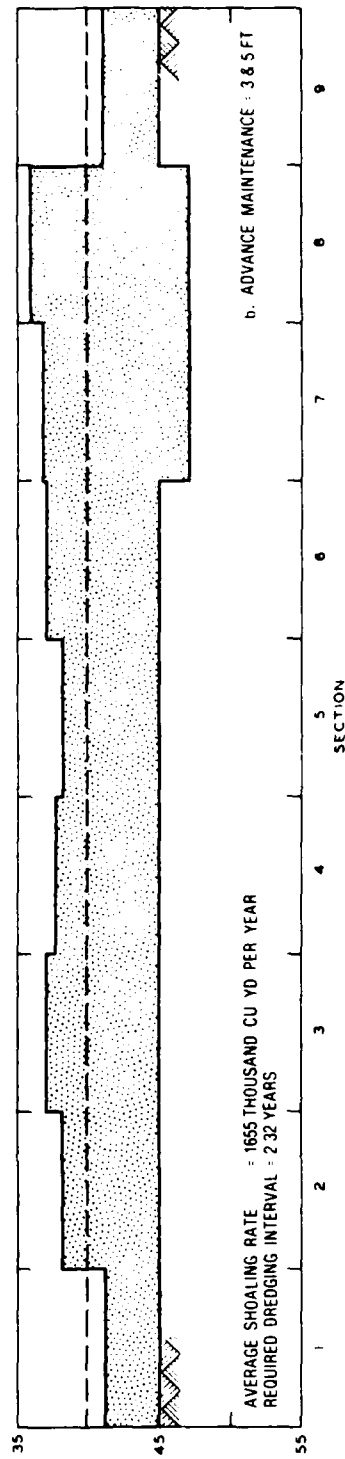
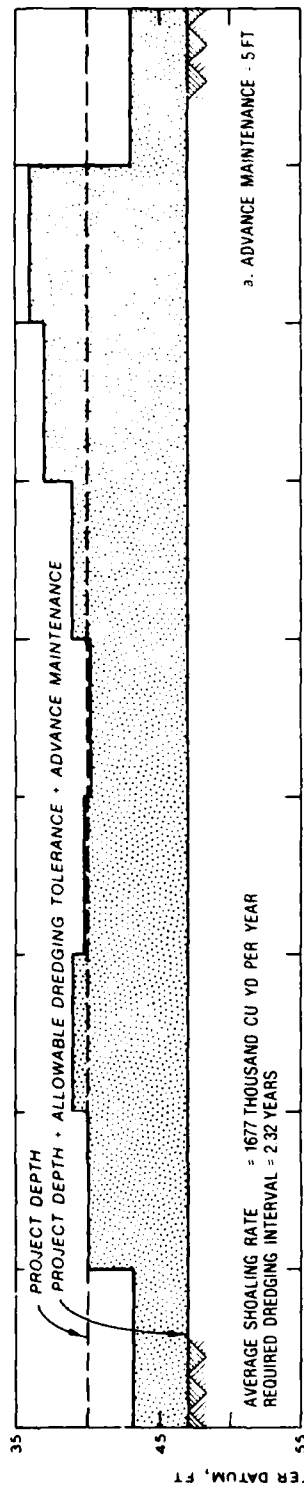
WHERE $A = 0.00149$

$B = 0.09920$

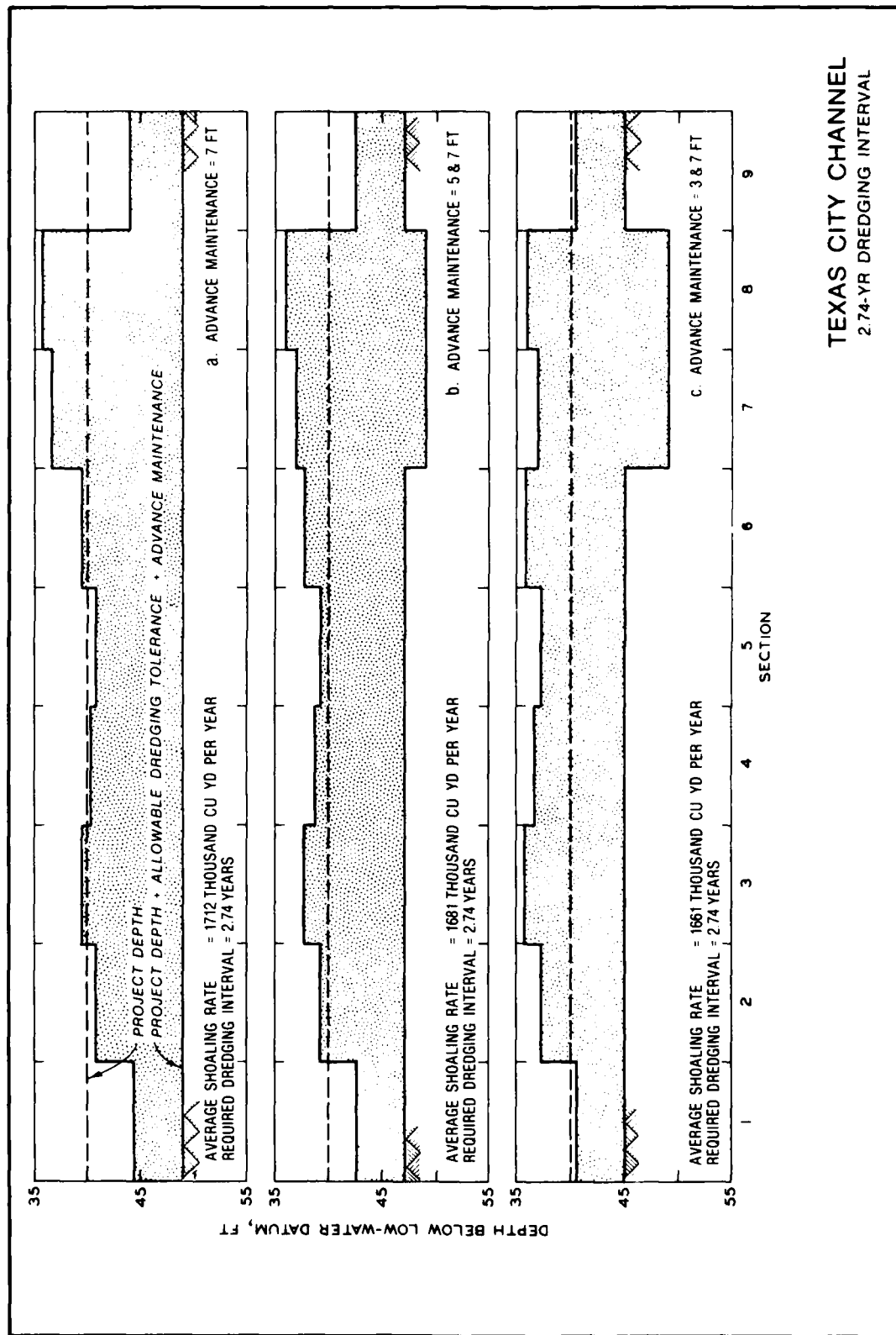
NOTE—CURVE IS WEIGHTED BY THE NUMBER OF SHOALING PERIODS. INDICATED BY THE NUMBER WITHIN THE SYMBOL

TEXAS CITY CHANNEL

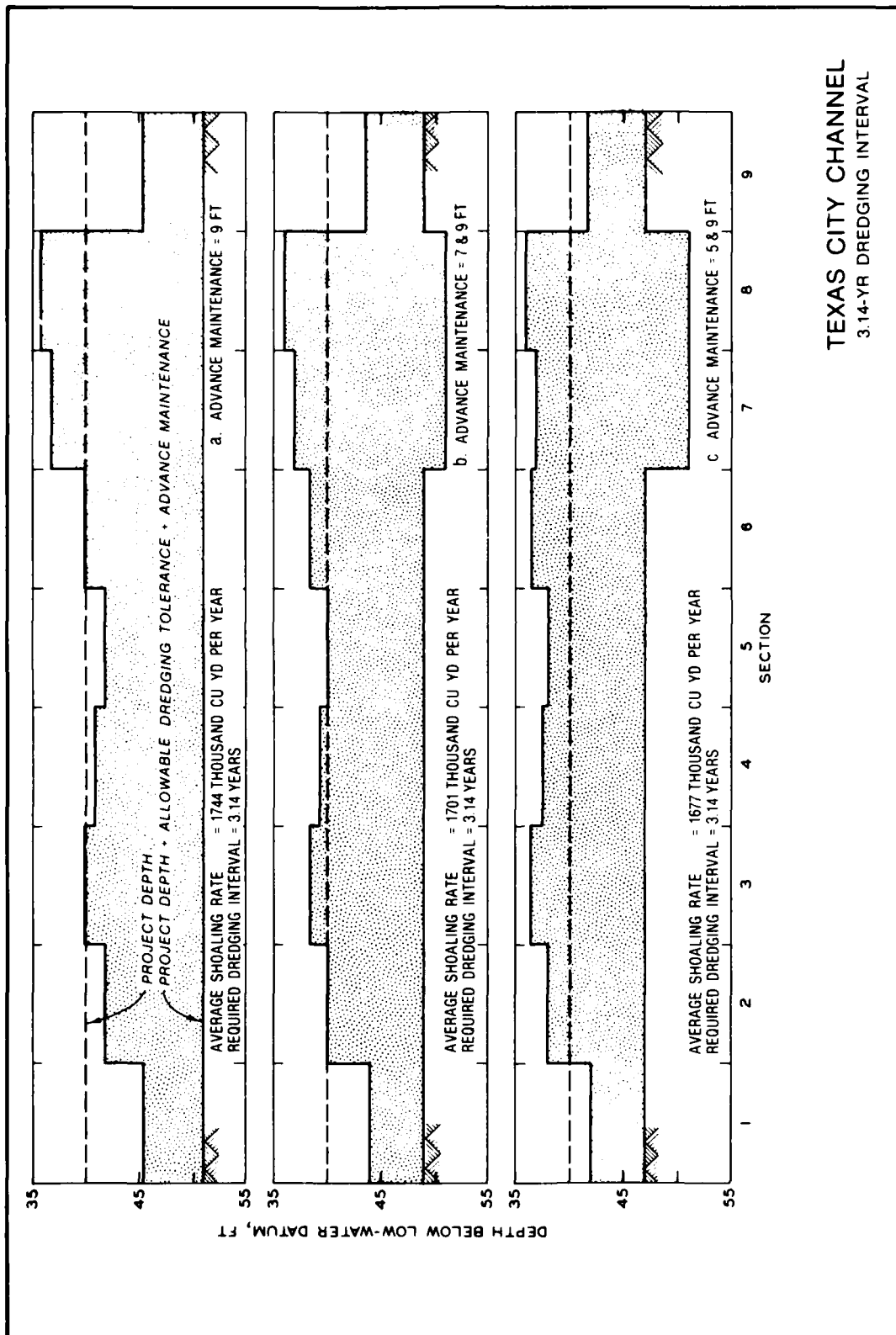
SHOALING RATE—TOTAL PROJECT
ACCUMULATED NEW WORK VOLUME



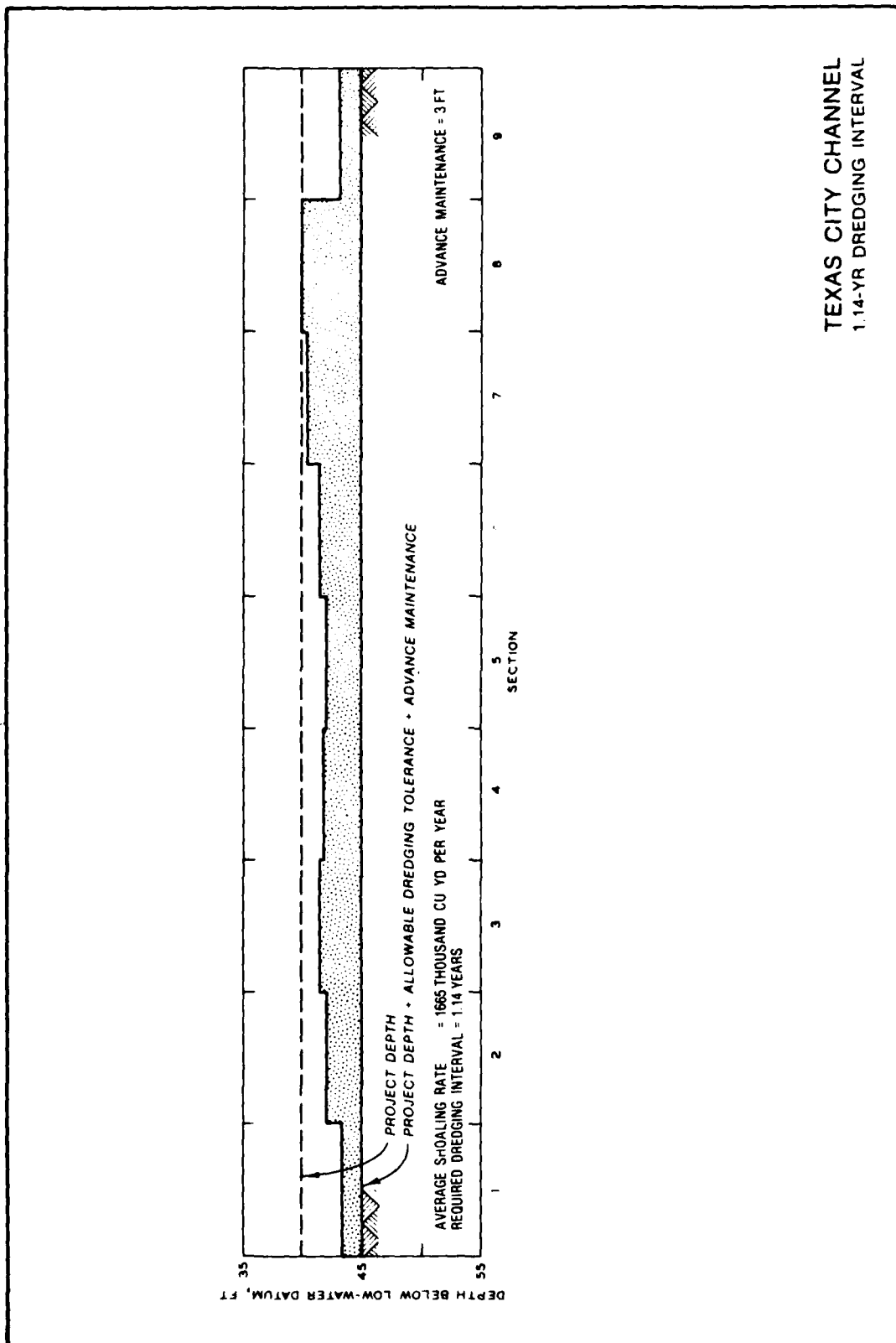
TEXAS CITY CHANNEL 2.32-YR DREDGING INTERVAL

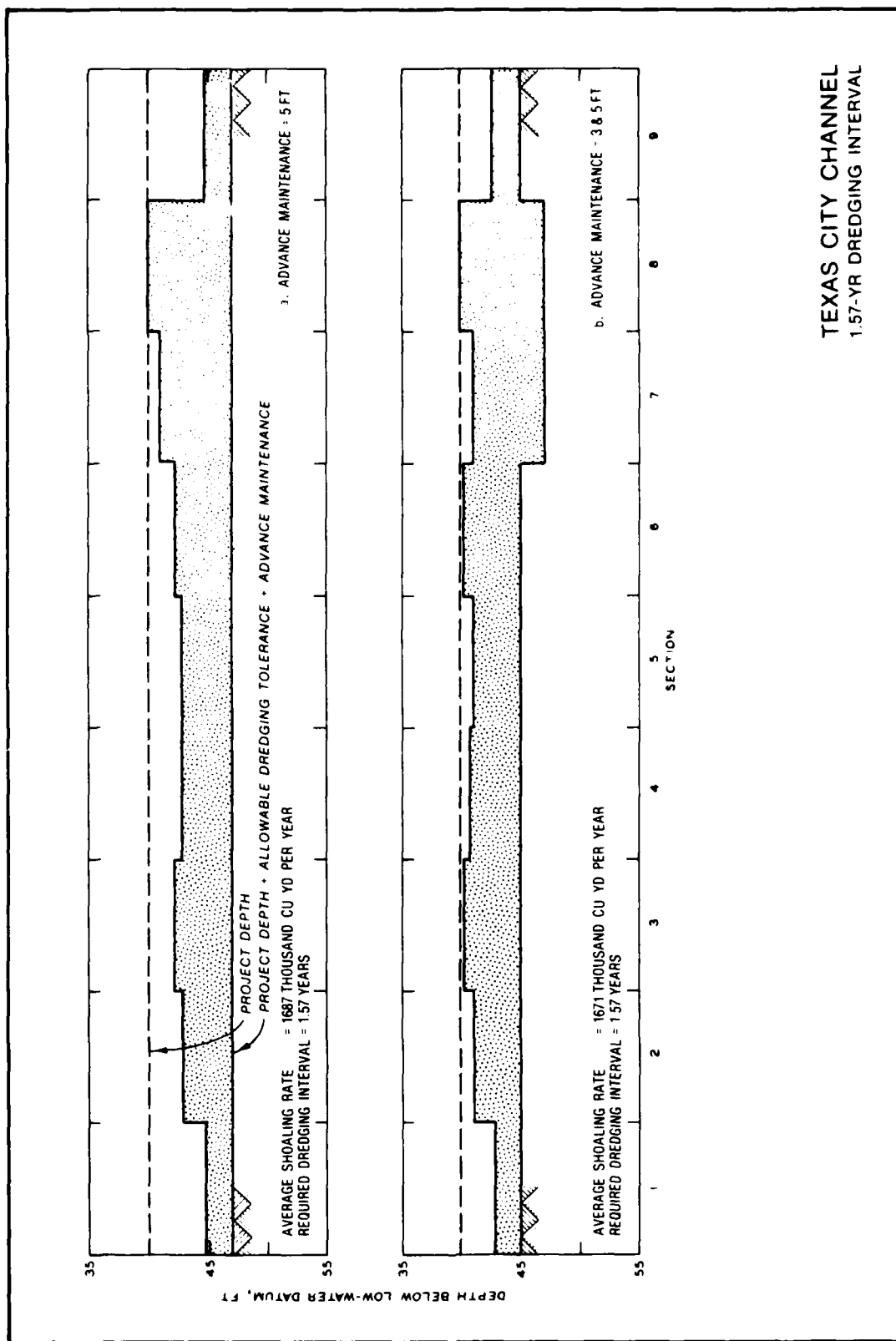


TEXAS CITY CHANNEL
2.74-YR DREDGING INTERVAL

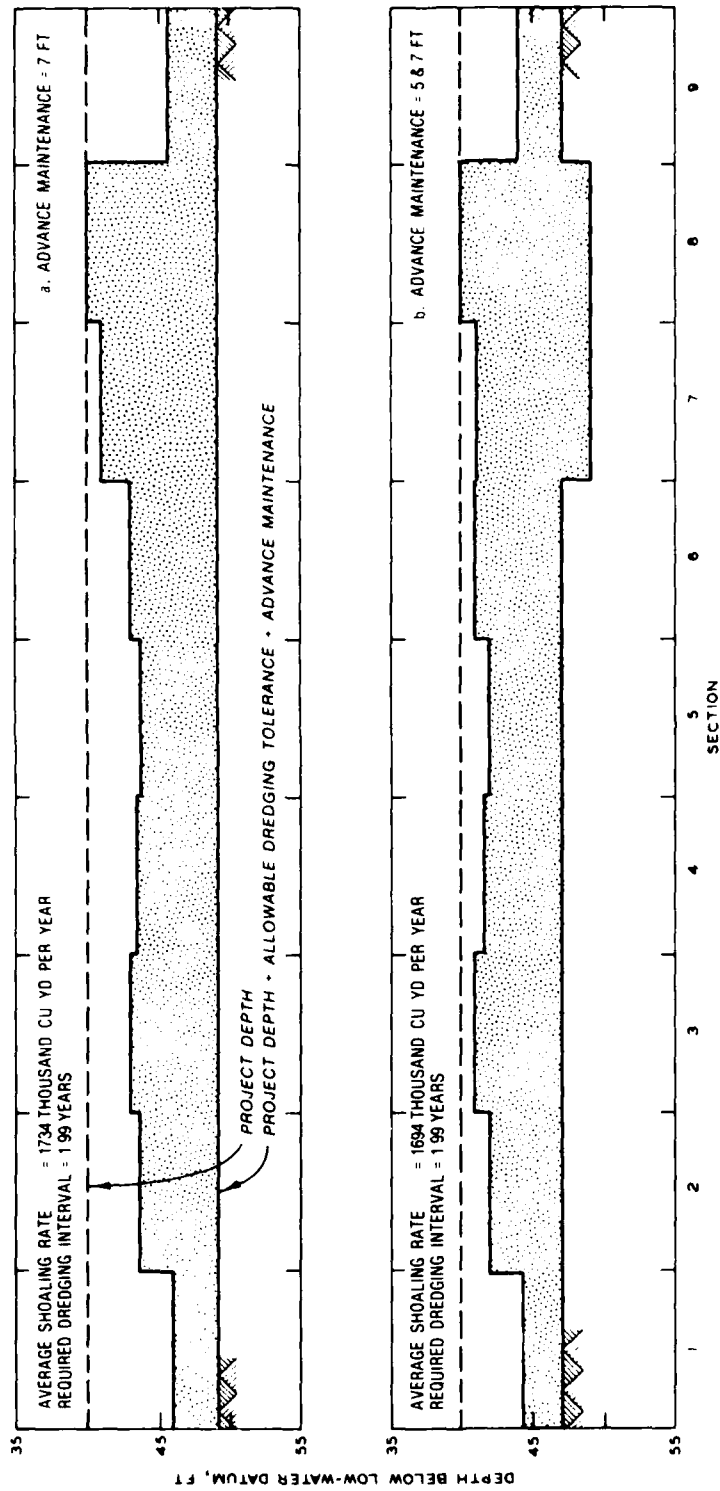


TEXAS CITY CHANNEL
3.14-YR DREDGING INTERVAL

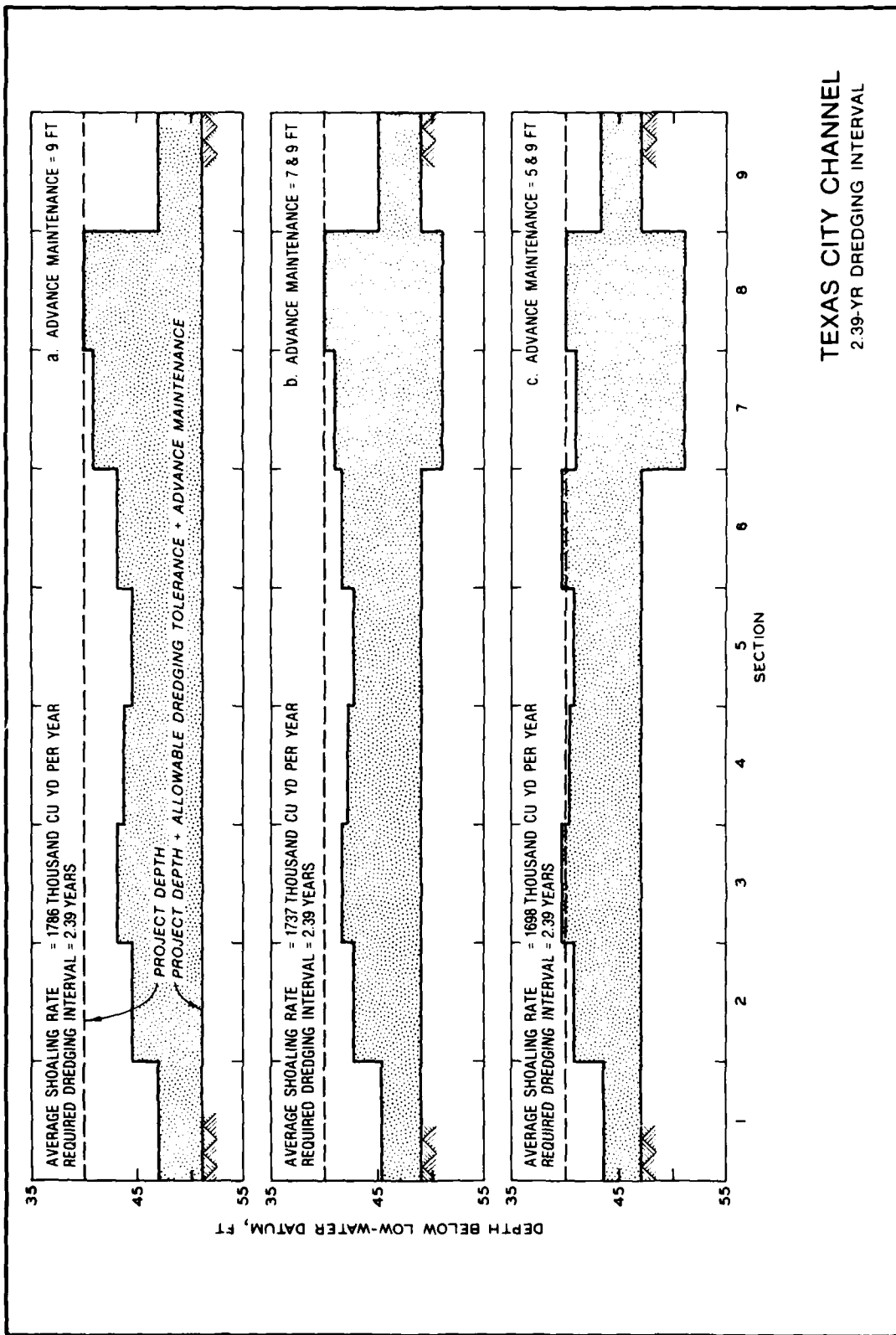




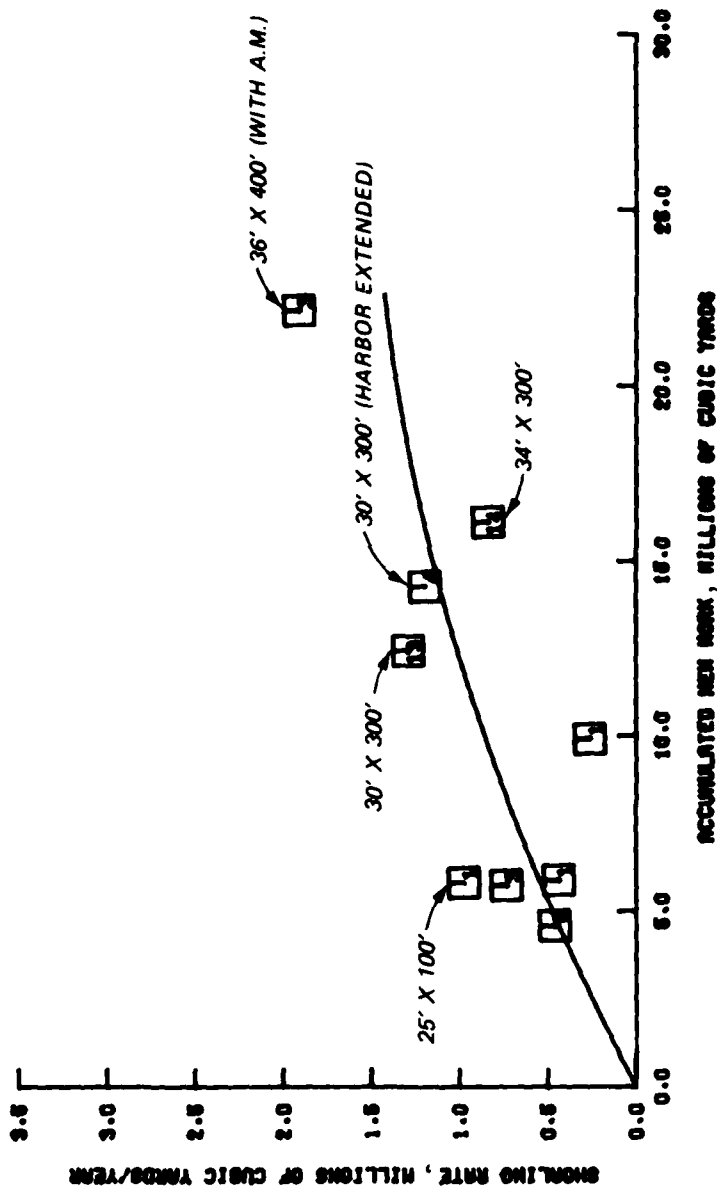
TEXAS CITY CHANNEL
1.57-YR DREDGING INTERVAL



TEXAS CITY CHANNEL
199-YR DREDGING INTERVAL



TEXAS CITY CHANNEL
2.39-YR DREDGING INTERVAL



EQUATION OF THE CURVE

$$Y = 0.00182 X^2$$

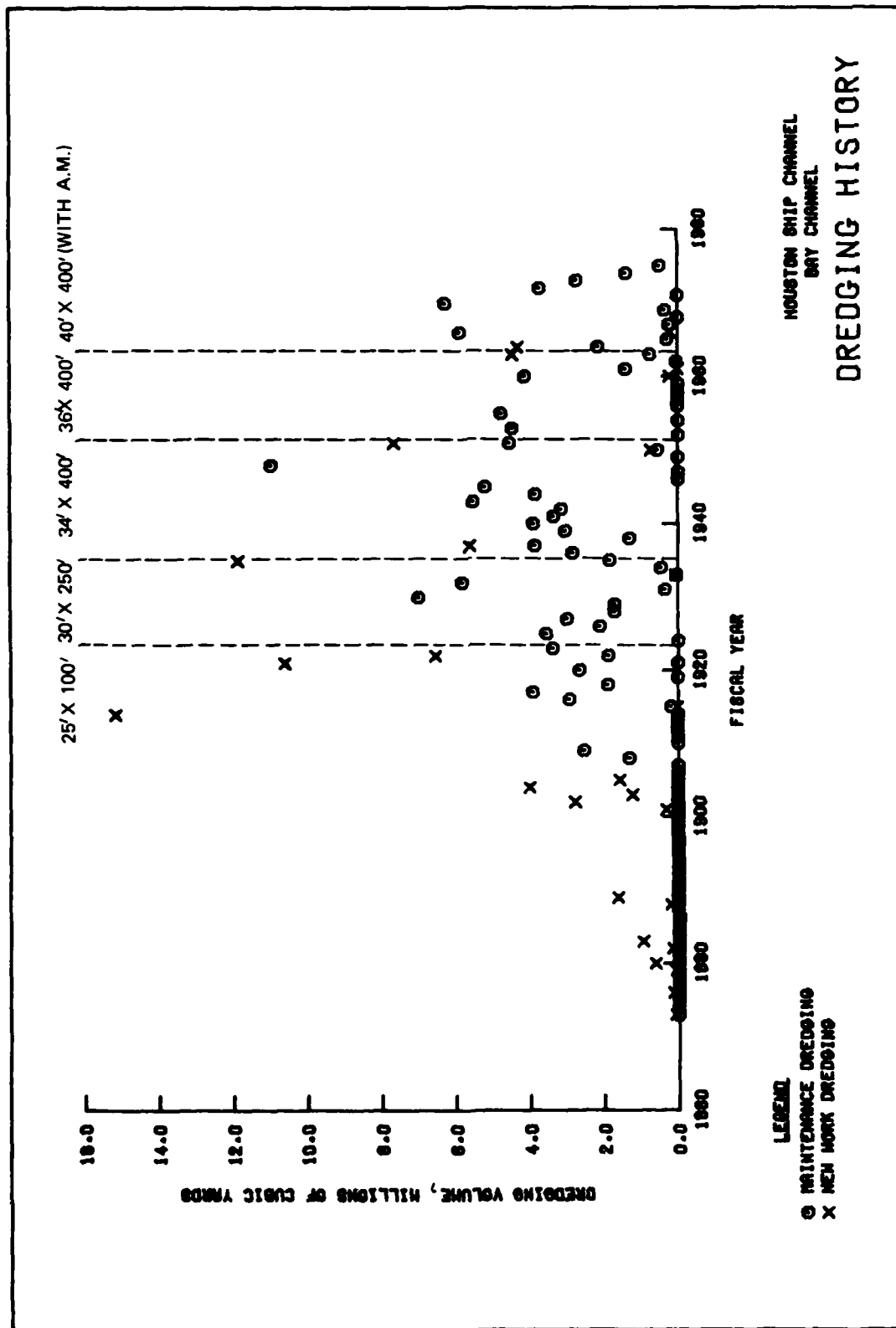
WHERE $R = 0.00182$

$$B = 0.10410$$

NOTE—CURVE IS WEIGHTED BY THE NUMBER OF SHOALING PERIODS. INDICATED BY THE NUMBER WITHIN THE SYMBOL.

TEXAS CITY CHANNEL

SHOALING RATE-TOTAL PROJECT ACCUMULATED NEW WORK VOLUME



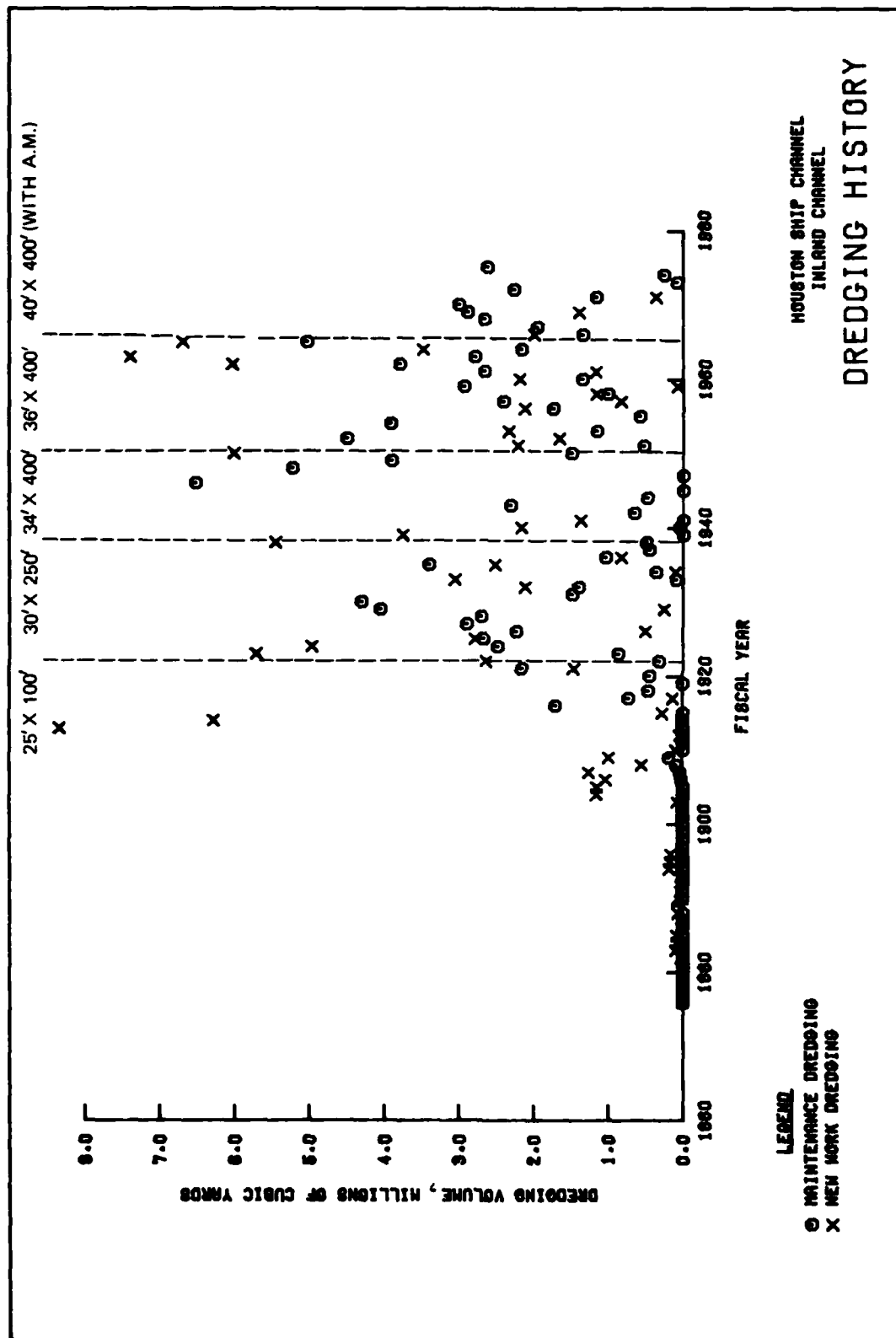
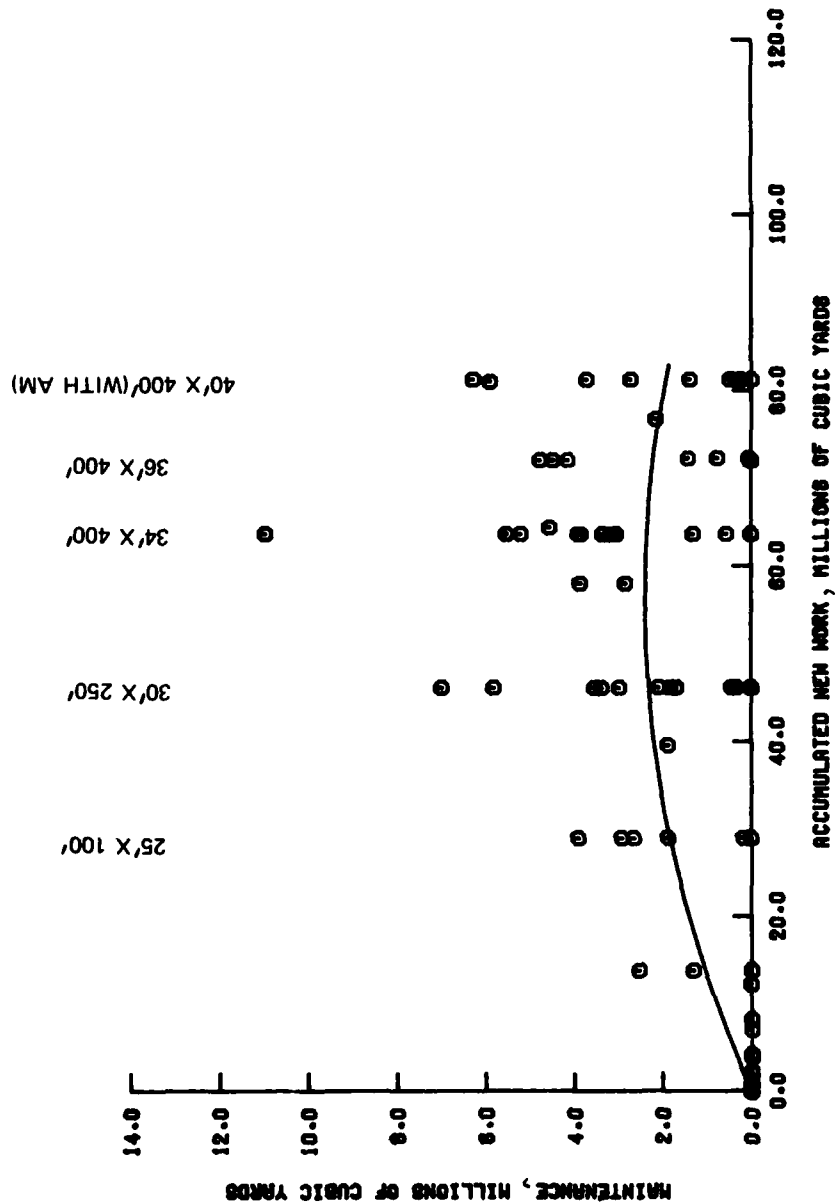
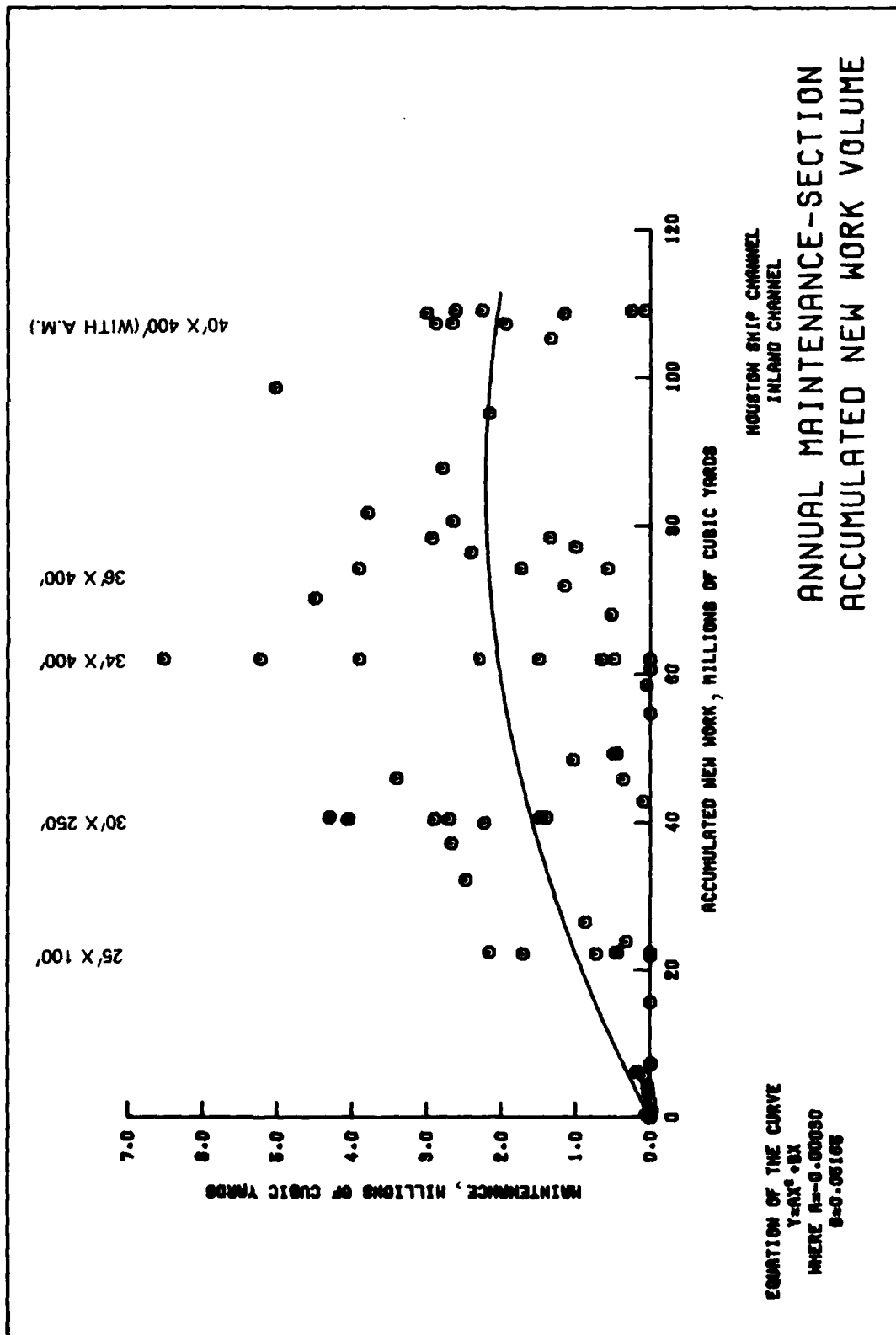
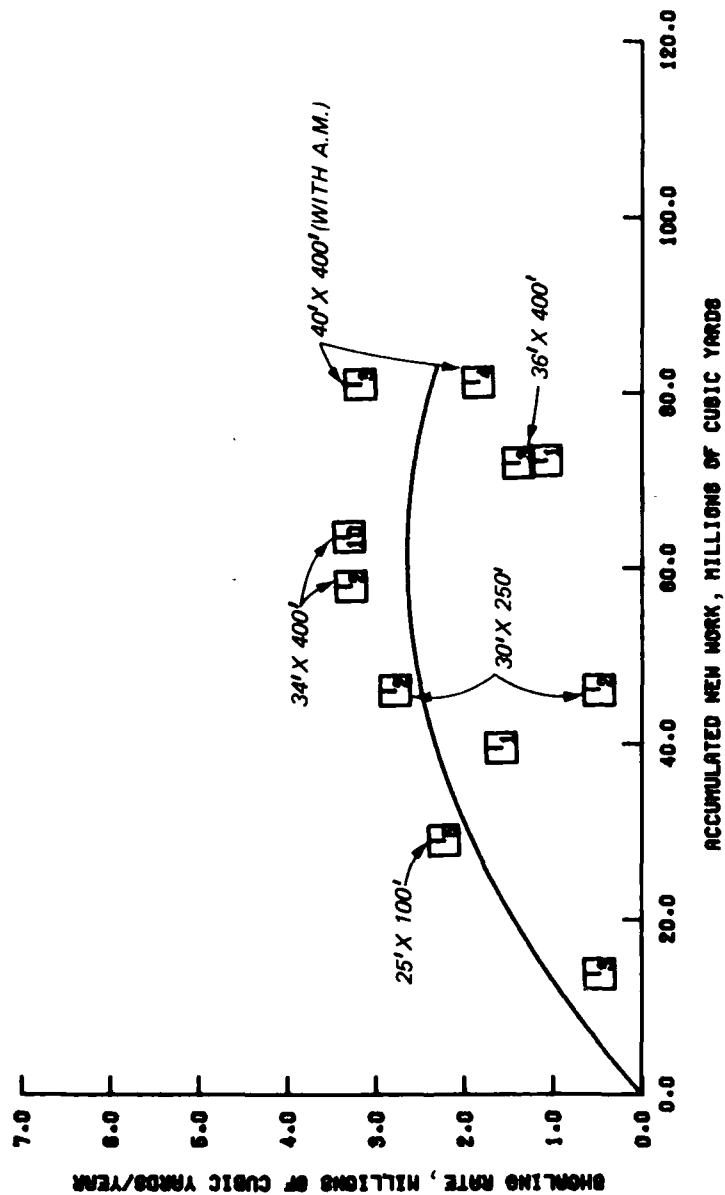


PLATE 38







EQUATION OF THE CURVE

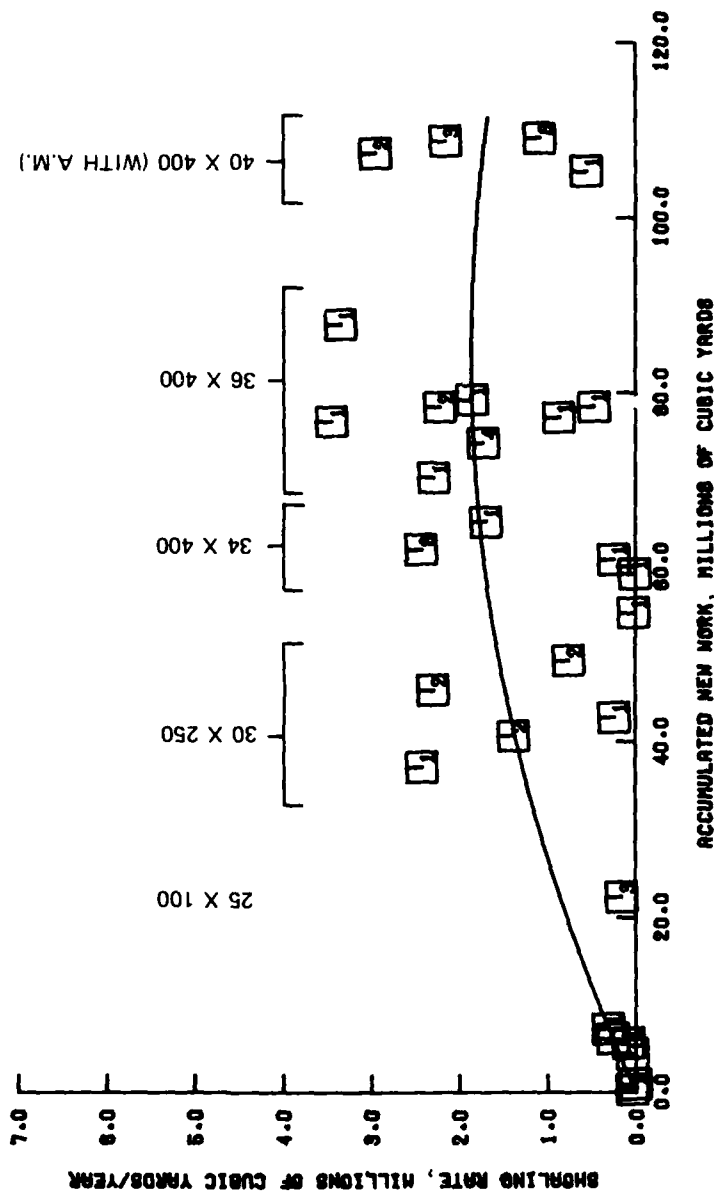
$$Y = AX^B + BX$$

WHERE $A = -0.00071$

$B = 0.08716$

NOTE-CURVE IS WEIGHTED BY THE NUMBER OF SHOALING PERIODS. INDICATED BY THE NUMBER WITHIN THE SYMBOL

SHOALING RATE-SECTION ACCUMULATED NEW WORK VOLUME



EQUATION OF THE CURVE

$$Y = AX^B + BX$$

WHERE $A = -0.00028$

$B = 0.04438$

NOTE-CURVE IS HEIGHTED BY THE NUMBER OF SHOALING PERIODS. INDICATED BY THE NUMBER WITHIN THE SYMBOL

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Trawle, Michael J.

Effects of depth on dredging frequency : Report 2 : methods of estuarine shoaling analysis / by Michael J. Trawle (Hydraulics Laboratory, U.S. Army Engineer Waterways Station). -- Vicksburg, Miss. : The Station ; Springfield, Va. : available from NTIS, [1981].

65 [25] p., 42 leaves of plates : ill. ; 27 cm. -- (Technical report / U.S. Army Engineer Waterways Experiment Station ; H-74-5, Report 2)

Cover title.

"July 1981."

"Prepared for Office, Chief of Engineers, U.S. Army."

1. Channels (Hydraulic engineering). 2. Dredging. 3. Harbors--Maintenance and repair. I. United States. Army. Corps of Engineers. Office of the Chief of Engineers. II. U.S. Army Engineer Waterways Experiment Station. Hydraulics Laboratory. III. Title IV. Series: Technical report (U.S. Army Engineer Waterways Experiment Station) ; H-78-5, Report 2.
TA7.W34 no.H-78-5 Report 2

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