CEWES-HE-P 13 May 1993

MEMORANDUM FOR RECORD

SUBJECT: Mobile Bay Channel, Advance Maintenance Analysis and Testing

Summary

1. Mobile Bay and River Channel maintenance has involved longer dredging times and more frequent dredging since the 1989 channel deepening. Since channel maintenance dredging volumes have been affected little by historical changes in channel geometry, application of advance maintenance dredging procedures may be economical. Advance maintenance can reduce dredging frequency and costs while maintaining controlling depth. About four million cubic yards of additional advance maintenance may eventually be economical. As a first phase of implementation, three advance maintenance sections testing three configurations (over-depth, over-width, and wing-cut) are proposed. Test sections should be monitored to guide further advance maintenance construction.

Introduction

2. This memorandum results from a meeting at the US Army Engineer District, Mobile (CESAM), Mobile Area Office held 17 December 1992. The meeting was initiated by Pat Langan, CESAM-OP-O. Representatives from CESAM and the Waterways Experiment Station (CEWES) Hydraulics Laboratory discussed problems with the Mobile River and Bay Channel maintenance and the set of possible measures put forth in a Dredging Operations Technical Support (DOTS) program memorandum "Mobile Harbor, Bay Channel Maintenance Dredging" dated 22 September 1992. Of those previously identified measures, advance maintenance (AM) options appear to have the best potential for alleviating maintenance problems. It was the consensus of those present at the meeting that CEWES should examine AM in more detail and, if found to be economically feasible, field tests should be planned.

3. This memorandum outlines an analysis of the suitability of AM procedures for reducing dredging frequency and costs for Mobile Bay Channel, and proposes full scale field tests as a first step in the development of a permanent AM plan. In the sections that follow: maintenance problems and the bay setting are described; the history of channel development and maintenance dredging volumes are presented leading to a evaluation of AM effects on dredging requirements; alternate configurations are described, discussed, and a test plan proposed; and a monitoring plan is recommended.

Problem Description

4. The Mobile Bay Channel project has recently been deepened to 45-ft deep and 2 ft of AM was applied over the entire channel area. The present channel is dredged to 47-ft depth by a nominal 400-ft width and extends from Stations 85+00 to 1577+50 relative to the Highway 90 bridge. The project has been authorized for 55-ft deep by 550-ft wide for future expansion.

5. Some operational problems have been experienced with channel maintenance since the 1988-1989 deepening of the Mobile Bay Channel from 40 ft to 45 ft. The problem is not necessarily the drastic increase in the total shoaling or maintenance dredging volumes, but rather is related to the long dredging times for a reach caused by the new requirement for disposal of maintenance material seaward of the bay entrance. Dredging times have been as long as six months. Furthermore, it is imperative that the controlling channel depth be maintained at 45 ft to accommodate frequent visits by world-class colliers. The combination of long mechanical/hopper dredging times and low allowable accumulation thicknesses of material in the channel requires constant maintenance of this project.

6. Dredging is now required over shorter channel reaches than before the deepening to maintain controlling depth. While it is too early to determine whether shoaling distributions have been changed by the deepening, shoaling is not uniform and shoals have intruded above 45-ft depth quickly and required rapid dredging responses. Recourse has been made to rental hopper dredges. Mobilization costs are high and advance planning of dredging requirements is difficult.

7. The required channel maintenance since the deepening has been about five to six million cubic yards (M cu yds) per year (Dyess, personal communication). However, the exact amount dredged cannot be estimated with certainty because of the method of dredging and dredge contracting. A short term increase in dredging volumes would be expected due to the disturbance of channel and channel side-slopes during dragging operations. Dragging was used during the deepening to bring the center of the channel and channel side slopes to grade.

Circulation and Sedimentation in the Bay

8. Mobile Bay is a large shallow estuary with a significant freshwater and sediment inflows from fluvial drainage. Figure 1 shows the layout of the bay and the bay channel. The area of tidal influence is 409 sq mi while the bay proper has an area of about 380 sq mi. The average bay width is 13.8 mi and average depth is 9.6 ft. The long-term average annual inflow is 79.3 thousand cubic feet per second (kcfs) and monthly averages range from 179 to 29 kcfs. Tide range is 1.3 ft at the entrance and 1.4 ft at mid- and upper-bay areas. The tidal prism is 585 M cu yds (15.8 billion cu ft).

9. Mobile Bay adjoins Mississippi Sound and the Gulf of Mexico at two wide entrances (2.5 and 3.2 mi, respectively). The drainage basin for the bay is about 40,000 sq mi. The bay is composed of a small saltwater zone near the entrance, and a mixing zone covering the remainder of the bay area. The bay is moderately to highly stratified depending on the level of freshwater inflow.

10. With respect to coastal sedimentation, the bay, with its relatively weak tidal flows, can be classified as wave dominated. Wave energy in the Gulf of Mexico supplies sediment to the seaward end from where it can be transported headward by a combination of tidal currents and gravitational circulation. Because of the size of the bay, internally generated waves are important as an energy source that mobilizes sediments for redistribution around the bay by currents.

11. Tidal currents in the channel decrease from the bay entrance toward the central portion of the bay and then increase (as ebb tidal currents) toward the bayhead delta. Thus, the middle bay is the locus above which the sediments are expected to coarsen and have more riverine character. At the seaward end of the bay, sediments coarsen and have more marine or coastal character. The middle bay is expected to contain the greatest fraction of fine-grained sediments in the system. A bayhead delta has formed over geologic time filling the northern portion of the bay, mainly by fluvial sediments. Thus, the bay is filling toward its middle from the landward end with riverine sediments and from the seaward end with marine sediments.

History of Dredging and Channel Maintenance in Mobile Bay

12. The period 1871 through 1913 saw drastic channel expansion in Mobile Bay. The natural 12.7-ft deep bay channel was deepened, widened, and lengthened in stages to the dimensions of 27 ft by 200 ft by 177,000 ft. Total new-work dredging was 63 M cu yds while the total maintenance dredging was only 6.2 M cu yds total for this period of construction. The bay channel was brought to its full length, often a critical point with respect to maintenance requirements (C. Berger, personal communication). Following this period of channel expansion, annual maintenance dredging volumes became substantially larger.

13. Annual maintenance dredging volumes for the Mobile River and Bay Channel were compiled for the period 1915 through 1987 to help predict the possible effects of AM on shoaling. Annual maintenance dredging volumes for the bay channel were obtained from annual reports by the Chief of Engineers, and are shown in Figure 2. (Volumes reported for 1983, 1985, and 1987 unavoidably include Theodore Ship Channel dredging, and for 1985 also include Outer Bar Channel dredging.) There were four channel configurations and two initial channel configuration phases in the period of record. However, the initial 30 ft by 220 ft phase was short and was combined with the 30 ft by 300 ft configuration. Mean values for the channel configurations were calculated over periods starting the second year after major new-work dredging (to allow equilibration). The results were as follows:

Channel		Year		Mean Dredging Volume,
Depth	Width	Start	End	M cu yds per yr
27'	200'	1915	1920	3.68
30'	300'	1928	1931	7.07
32'	300'	1935	1955	4.05
36'	400'	1959	1964	4.10
40'	400'	1967	1987	3.68

14. Annual variations in maintenance dredging volumes were large and standard deviation of all values is 2.64 M cu yds per year. Because variability is so high, differences between mean values in the table above are not statistically significant. The mean value of all data is 4.00 million cu yds per year. In addition to individual annual values, a smooth trend fit to the data is shown in Figure 2. That trend line shows no relationship to channel configuration. Any number of other trend lines could be fit to the data, but there is much scatter in the data and no trend associated with channel geometry can be discerned visually. A linear least-squares regression fit to the data shows a negative slope with time, bisecting the trend line shown in Figure 2.

15. As evidenced by the above table and the data in Figure 2, there has been no clear relation between required maintenance dredging and channel dimensions. The conclusion of the historic dredging volume analysis is that channel geometry has had only a second-order (small) effect on channel dredging requirements.

16. The historic maintenance dredging data show that factors other than channel dimensions dominate the year-to-year variations and probably the long-term trend. For instance, following the flood of 1927, heavy channel maintenance was required for several years resulting in a spike in the annual dredging volumes. Other short-term fluctuations may reflect annual fluvial sediment inflow, coastal wave energy, as well as dredging operational, budgetary, and environmental considerations. The long-term decreasing trend may be due to decreasing sediment yield from the Mobile River, decreases in the bay volume, and/or improvements in dredging procedures. It seems unlikely that the dominant factors contributing to short- and long-term variations in shoaling could be identified with sufficient accuracy to allow quantification of secondary effects, such as channel geometry, using historic data.

17. From experience in other estuaries and an understanding of estuarine processes, channel dimensions generally do effect shoaling and maintenance dredging volumes, sometimes in unexpected ways. Thus, while historic data indicate Mobile Bay and River Channel is suitable for AM, it is prudent to develop a plan slowly while monitoring the response of the system over time.

While the annual variability in dredging volumes is likely to continue and obscure the response, monitoring information in addition to total volumes could be used to gage AM field test results, as will be described in a latter section.

Advance Maintenance Concepts

18. Advance maintenance can be used to reduce dredging frequency and costs while maintaining controlling depth and/or width. Advance maintenance can be applied by channel deepening and/or widening, in a uniform or varied amount along a channel. The first step in the scoping of AM is a prediction of the shoaling response of the channel. In most cases, this is best done by an analysis of the shoaling history over a period when the channel underwent changes in geometry, as done in the last section. For AM to be successfully applied, the increase in shoaling volume associated with the expansion of the channel prism must be more than offset by the economy gained by reduced dredging frequency.

Advance Maintenance Requirements

19. Advance maintenance creates storage volume for channel shoaling and thereby increases the time interval between required dredging. As indicated in the earlier section, annual shoaling volumes can be expected to average about 4 M cu yds per year, but will vary considerably year-to-year. To accommodate shoaling in most years, 6.6 M cu yds (the annual mean plus standard deviation) is suggested as an appropriate planning volume. The channel currently has 2 ft of AM, and since the controlling depth is 45 ft, this amounts to 4.6 M cu yds of sediment storage distributed over the entire length of the channel. However, channel shoaling is not uniform along its length. The first maintenance dredging covered 119,000 ft of channel length and the second dredging covered about 38,000 ft of channel. On average (so far) about 78,500 channel-ft shoals annually to the extent that it requires maintenance. The present storage volume over this portion of the channel is only 2.3 M cu yds, indicating that insufficient storage volume is available to allow annual dredging. It is anticipated that additional AM on the order of 4 M cu yds may eventually be economical.

Selection Factors for Advance Maintenance Configuration

20. The AM configurations which were considered included over-depth, over-width, and wing-cut. Wing-cut AM is over-width dredging which is not carried to the full channel depth. A wing-cut could be used as an initial phase of an over-width configuration or as a more reversible test of the over-width approach. Over-depth AM is the most reversible configuration, as it will eventually shoal back to the original channel prism if AM were discontinued. Wing-cut AM would be intermediate, and over-width AM would be the least reversible.

21. Several factors were used to rate the three configurations and are defined next. Lateral shoaling storage is the efficiency of AM to store sediment which enter and deposit from lateral sediment sources. Longitudinal shoaling storage is the efficiency to store deposited sediments transported to the site in the channel. Efficiency here refers to the fraction of AM used by a deposit as it reaches the controlling depth. Channel sediment capture is here related to the decrease in local shear stresses attributable to AM section enlargement (ignoring transport gradient effects). Storage per unit section area is the AM area divided by the area of cross section enlargement attributable to AM construction. This is inversely related to another factor - construction cost (excavation per unit storage).

22. The following are relative ratings ascribed to the three AM configurations for Mobile Bay Channel:

Selection Factor Ratings

	Configuration		
	Over-depth	Over-width	Wing-cut
Lateral Shoaling Storage	low	high	high
Longitudinal Shoaling Storage	high	medium	low
Channel Sediment Capture	low	medium	medium
Storage per Unit Section Area	high	low	medium
Construction Costs	low	high	medium

Where sediment encroaches on a channel laterally, over-width and wing-cut have been successful at intercepting and storing sediment at other sites. Over-depth dredging is less effective in this case but most effective if the shoaling results from sediment carried by, and uniformly distributed across, the channel. Channel shoaling is never perfectly uniform across channels, but tends to concentrate near the toes of the side slopes where shear stresses and vessel disturbances are less severe. Sediments depositing on channel side slopes indicate a lateral sediment source, flows crosswise to the channel, or a combination of both.

23. Sediment capture is related to storage and to section area, but also includes the ability of the channel with AM to convey sediment longitudinally in the channel. One factor which cannot be easily quantified is the effect of ship disturbances. In channels frequently traversed by vessels with draft approaching the controlling depth for the channel, ship disturbances have a considerable effect on resident sediments near the center of channels. Commonly, sediments are slightly finer and fine-grained sediments more well-settled in the flanks of the channel compared to the area where ships tend to navigate. This being the case, a narrow channel will have a greater fraction of the channel disturbed by shipping and is most likely to transport

sediments longitudinally. Wider channels give more undisturbed storage area for sediments to deposit. For channels of equal cross section area, a deeper channel will have larger shear stress and transport a greater sediment load.

24. Over-depth dredging produces the greatest AM storage per unit cross section excavated (1:1) compared to over-width or wing-cut dredging. The initial construction costs for over-width AM are higher because of the necessity to remove side slope material.

Recommended Advance Maintenance Tests

25. A recommended test plan was developed to serve as a starting point for further discussions, refinement, and evaluation by CESAM. Formulation of the plan was based on the selection factors previously described and inspection of before- and after-dredging surveys from 1989 to January 1993. Given the possible total AM which may be required, the tests were scaled to represent a significant fraction of the anticipated AM. Three test sections are recommended to test the shoaling response of the channel, test the utility of various configurations, and begin to develop a plan for dredging frequency for various channel reaches. Figure 1. shows the approximate locations for the test reaches. The strategy was to create needed AM storage in appropriate areas while trapping the maximum amount of sediment in the middle bay area and thereby reduce overall dredged material haul distance. The proposed test sections have required frequent maintenance since the deepening.

26. All proposed AM cuts are within the authorized 55-ft by 550-ft channel prism. Channel side slopes were maintained at 1 vertical on 5 horizontal. Proposed over-depth and wing-cut AM sections were plotted and volumes computed based on usable channel bottom rectangles. It is anticipated that side slopes of approximately 1V:5H would develop after repeated dredging. Tests are described in the following paragraphs.

27. Stations 240+00 to 285+00. This reach contains a bend (Station 265+00) where the maximum channel width is 500-ft. Shoaling occurs on both sides of the channel, centered at the point of the bend. Depths are shallow outside of the channel. For this 4,500-ft reach, partial over-depth dredging to 52-ft depth is recommended over the central part of the channel inside 25 ft from each existing channel toe. Thus, the AM would vary from 350-ft to a maximum of 450-ft-width and represent a 319,456-cu-yd cut beyond the present channel prism. Figure 3 shows a typical section in this reach and the proposed AM.

28. Partial over-depth AM is recommended for this reach because of its location. In the upper bay, the channel is relatively confined, ebb-phase tidal flows dominate, and sediments are relatively coarse. Partial over-depth will not affect the channel side slopes which appear to be adjusting to the channel deepening. By not disturbing channel side slopes, the question of side slope adjustment effects on shoaling will be minimized and the analysis of test results will be simplified. Furthermore, maintaining a compact cross

section where ebb currents are strong and sediments are most likely to be disturbed by passing vessels will foster transport of sediment further down bay where dredging transport distances are shorter.

29. Stations 717+00 to 782+00. This reach is adjacent to the Gilliard Island disposal site near the Theodore Ship Channel. AM dredging is recommended to 52-ft depth. This AM would extend the entire channel width, and involve removal of material on channel side slopes. Figure 4 shows a typical section and the proposed over-depth AM. The proposed AM is shown in Figure 4 for a typical section, and would effectively increase channel width by 50 ft over existing conditions. The estimated volume of this cut is 784,051 cu yds.

30. Station 880+00 to 935+00. This reach contains a bend and maximum width of 505 ft. A wing-cut on the western channel slope, and partial over-depth are recommended. The partial over-depth AM is to 52-ft-depth, and over the 5,500-ft channel reach amounts to an estimated 383,056 cu yds. The proposed wing-cut consists of two cuts. First, a cut would be made at 30-ft depth from the existing channel prism 165 ft to the west, extending to the edge of the 55 ft by 550 ft authorized channel prism. The second cut is 100-ft wide starting 25 ft from the outside edge of the first, and is 5-ft deep. The proposed wing-cut is estimated to be 612,251 cu yds.

31. Figures 5 and 6 show typical sections in this reach, and the proposed AM. The wing-cut is a partial over-width AM intended to intercept sediment material from moving laterally into the channel. Before-dredging cross sections from this reach indicate that such lateral sediment movements have occurred. The two-cut configuration will provide a sill to better retain sediments. Increasing cross sections in the middle bay is least likely to increase total dredging requirements for the channel.

Advance Maintenance Test Monitoring and Analysis

32. Establishing a permanent AM system may require several dredging seasons and special monitoring is recommended during this process. The size, configuration, and distribution of AM storage must be tailored to the optimal dredging frequency for various individual reaches. As shown in the historical dredging analysis, total dredging volumes vary widely year-to-year. Thus, to assess AM performance and estimate future AM needs, shoaling by reach, as well as total shoaling, should be monitored. This will require more frequent comprehensive surveys than might otherwise be necessary. Channel-condition and before-dredging surveys should be carried out over the entire channel length about quarterly. This will allow computation of total shoaling volumes and volumes by reach over periods of 3-4 months.

33. Analysis of monitoring results will not be straightforward. If the shoaling in a test reach increases, it will not be immediately apparent whether this has resulted from an increase in total shoaling material supplied to the channel, an increase in the total sediment capture, or an increase in the local sediment capture of the channel. If local sediment capture

increases, then adjacent reaches may experience a decrease in shoaling. Eight combinations of test reach, adjacent reaches, and total shoaling increases or decreases are possible. Statistical tests of whether the test sections have increased or decreased total shoaling and increased local sediment capture may require about two years of monitoring data. Available data from after the deepening should be analyzed in the same manner to provide a baseline.

34. Channel deepening associated with the proposed AM would effect salinity distributions in the bay. Some additional evaluations of salinity intrusion and salinity intrusion effects might be necessary if previous evaluations did not include channel depths to 52 ft.

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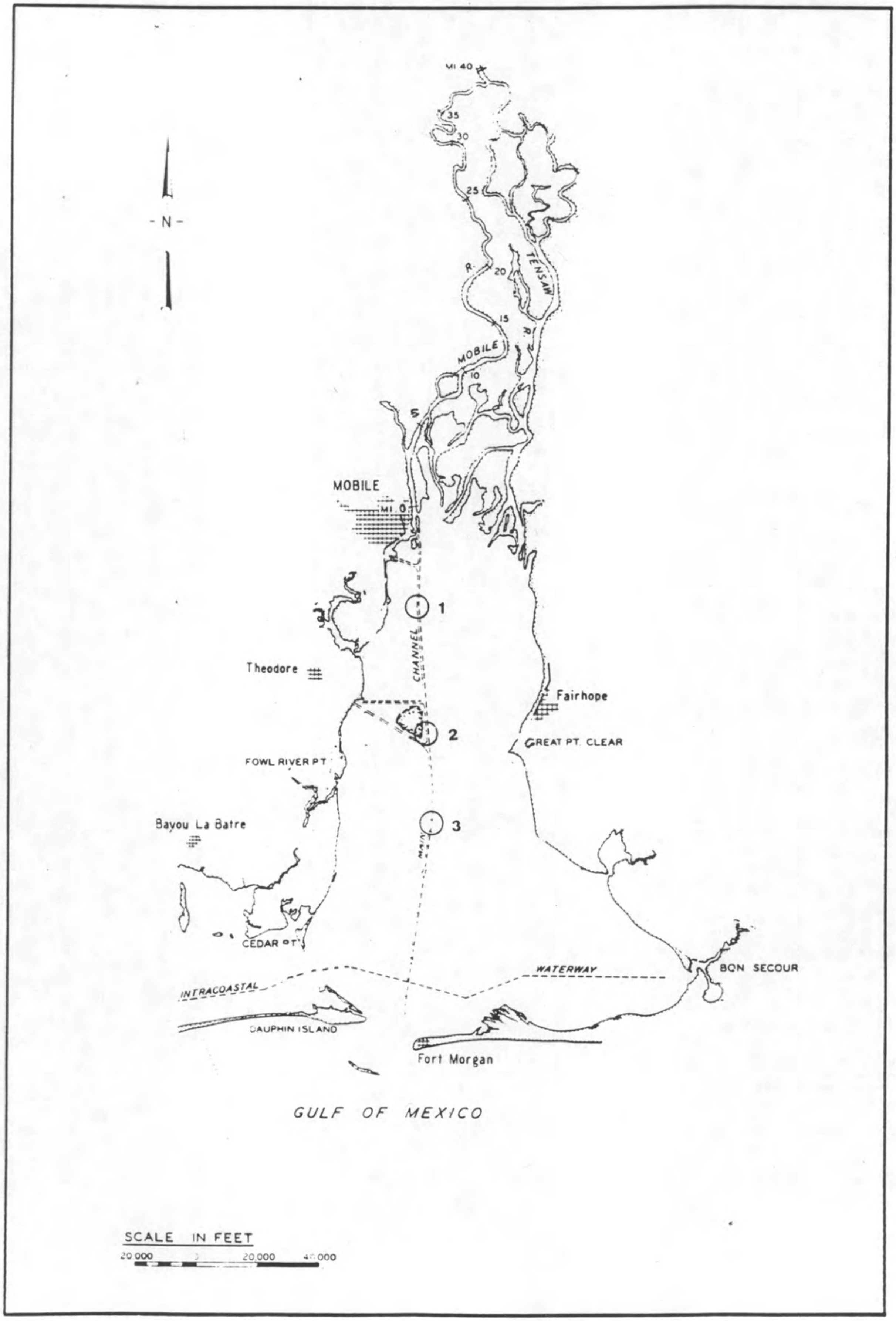

Figure 1. Mobile Bay showing approximate locations for test reaches Stations (1) 240+00-285+00 (2) 717+00-782+00, and (3) 880+00-935+00

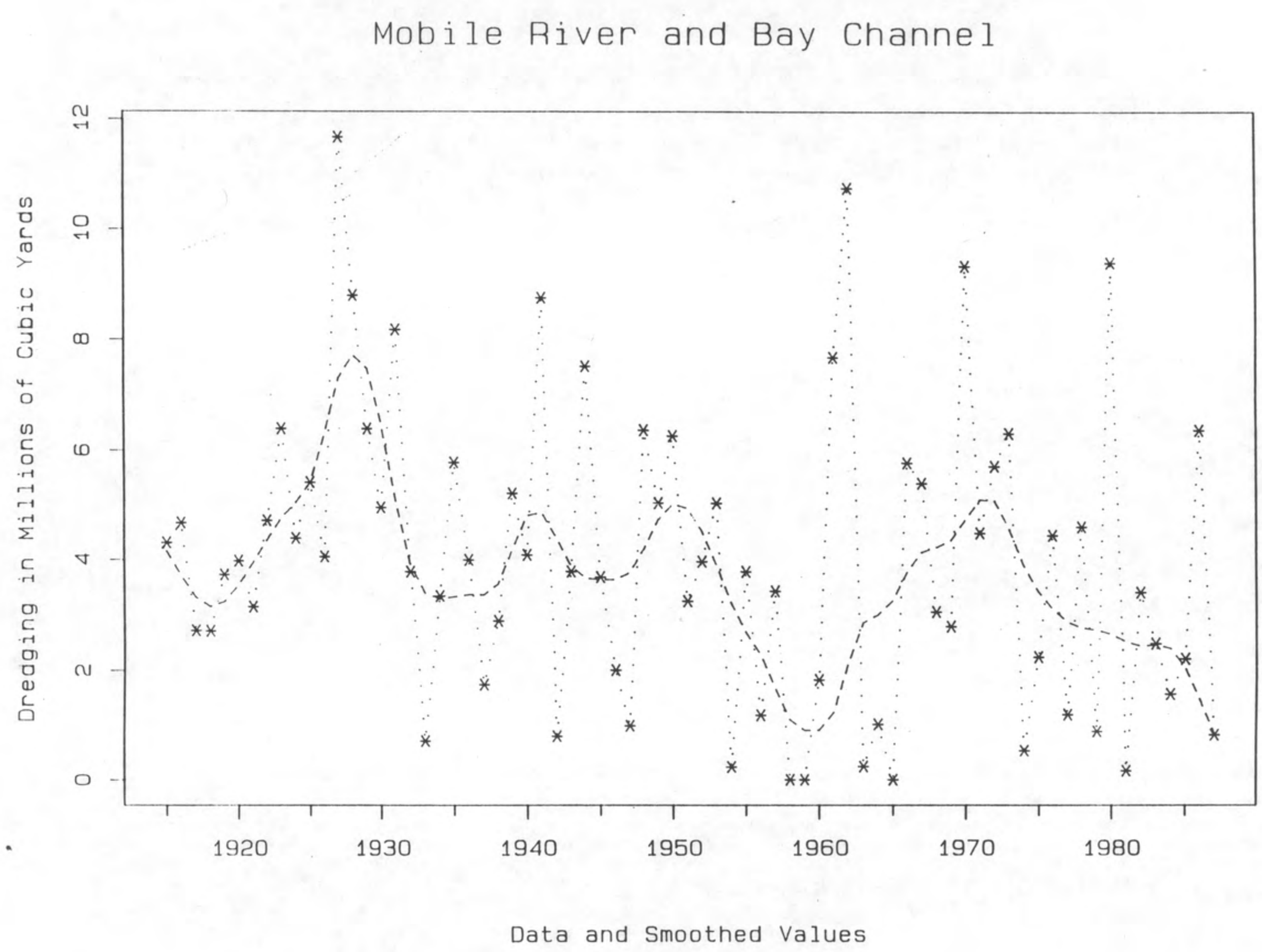

Figure 2. Annual dredging volumes and trend line

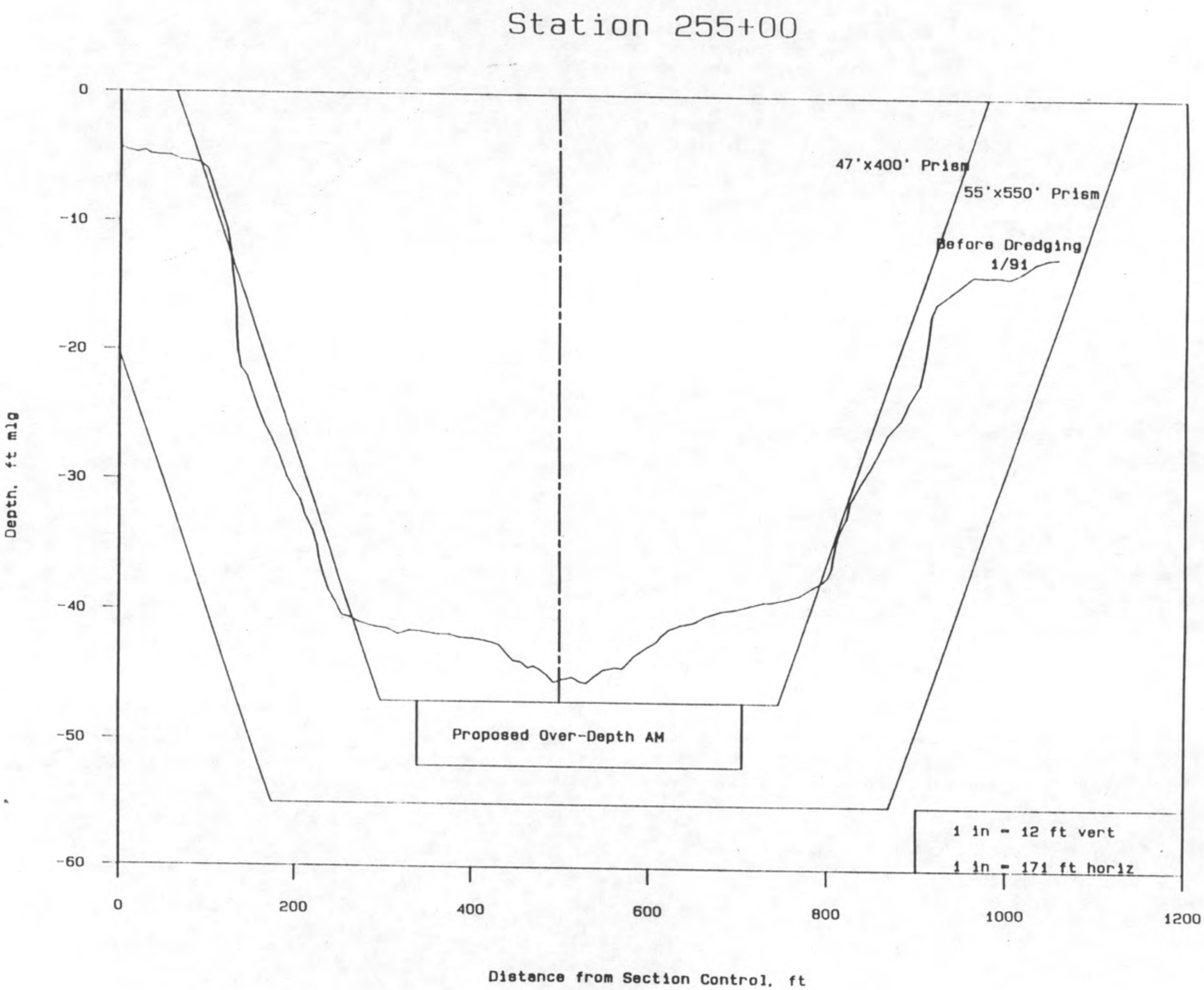

Figure 3. Typical section of the proposed test reach between Stations 240+00 and 285+00 with before dredging 1/91

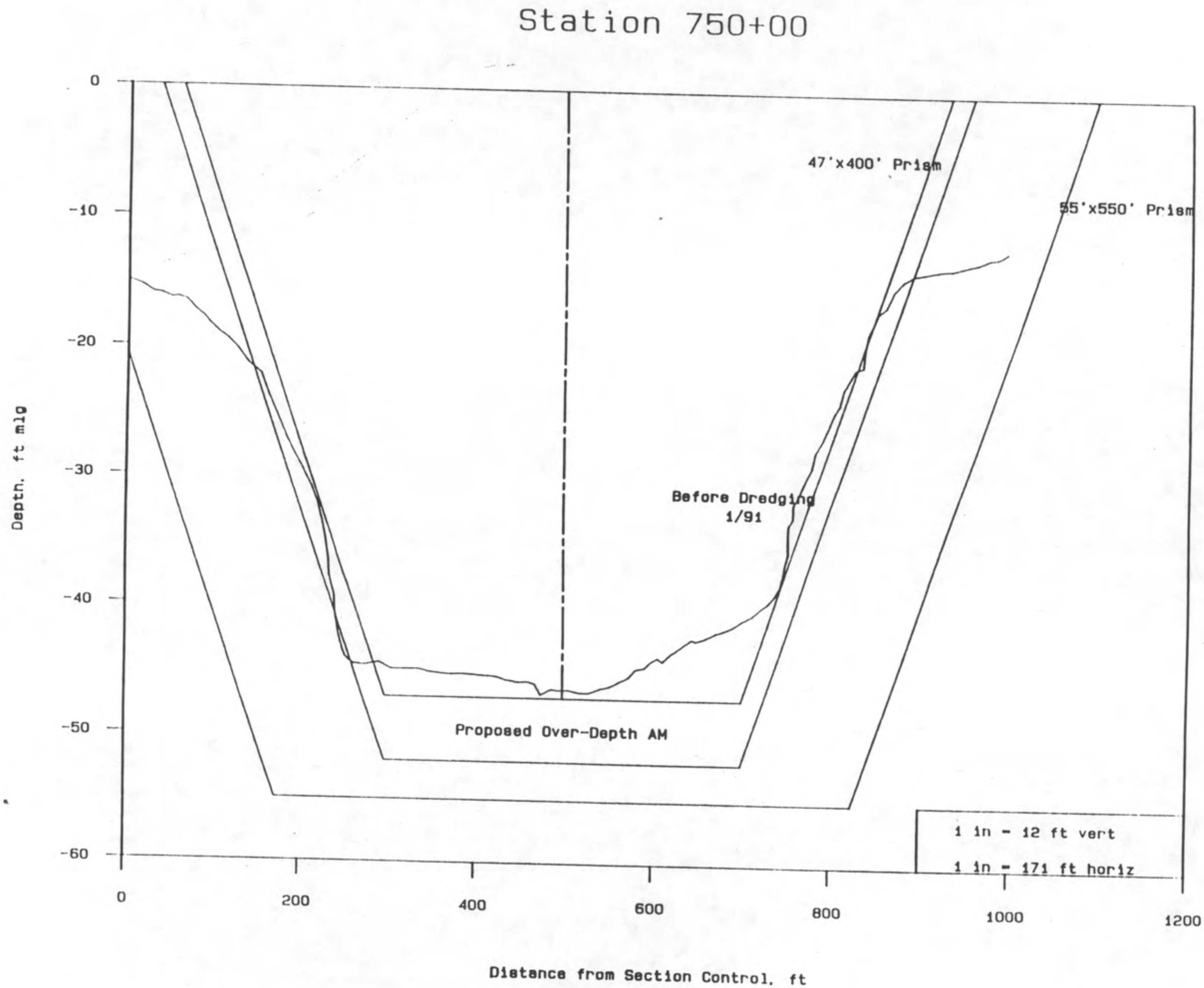

Figure 4. Typical section of the proposed test reach between Stations 717+00 and 782+00 with before dredging 1/91

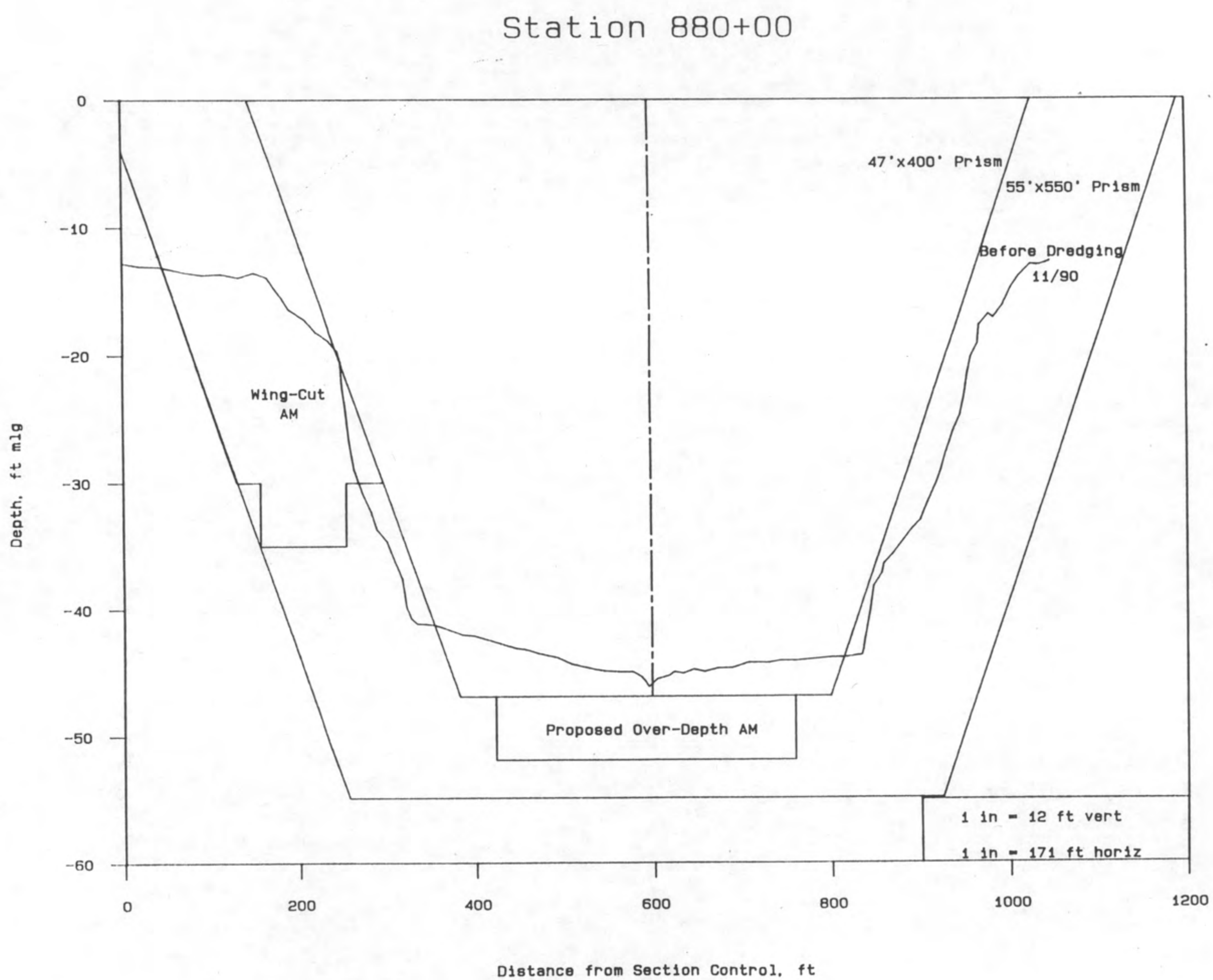

Figure 5. Typical section of the proposed test reach between Stations 880+00 and 935+00

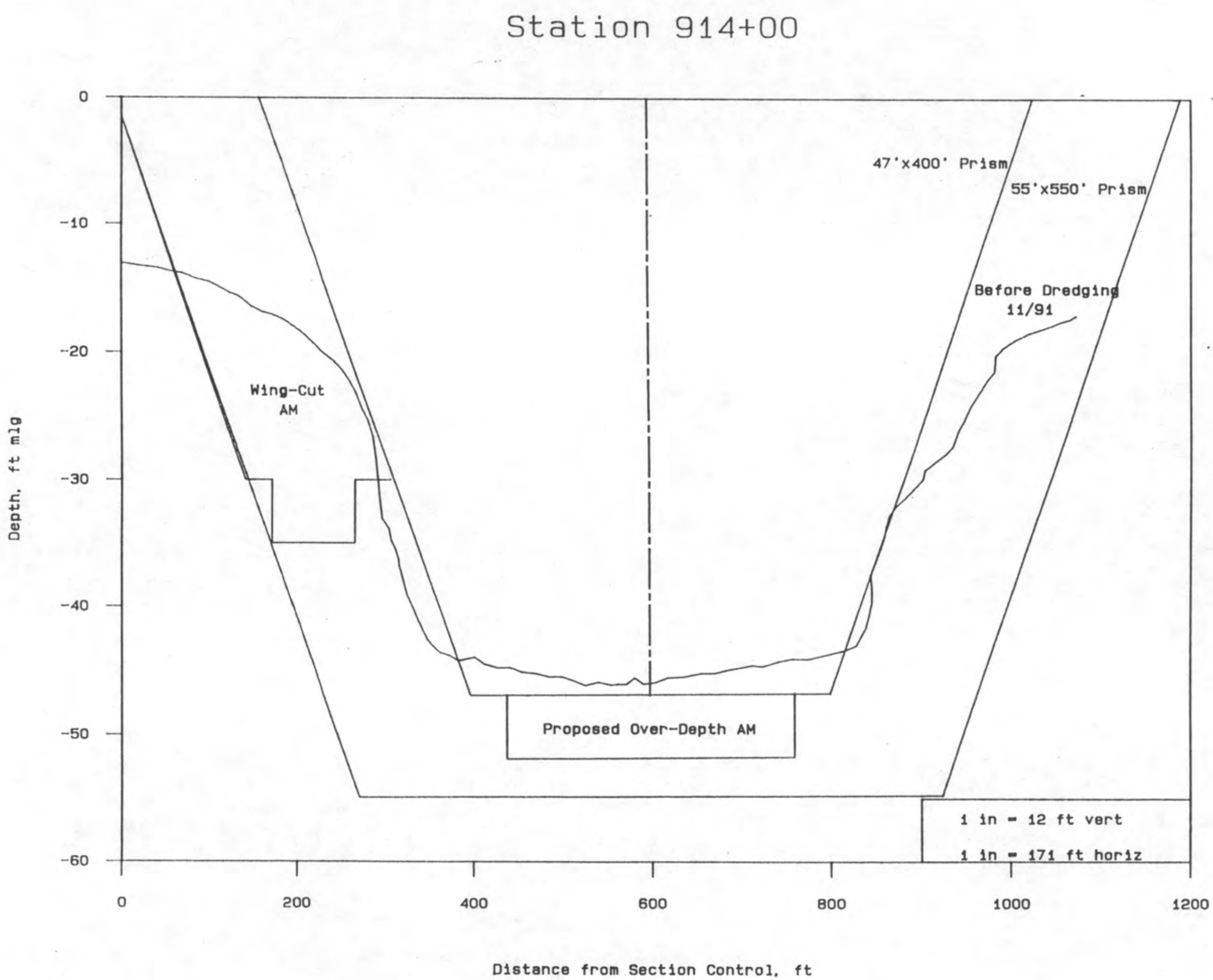

Figure 6. Typical section of the proposed test reach between Stations 880+00 and 935+00