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October 1993

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Station

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Ship Navigation Simulation Study, Lorain Harbor, Lorain, Ohio

Volume I: Main Text

by *Michelle M. Thevenot, Carl J. Huval, Larry L. Daggett*
Hydraulics Laboratory

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Prepared for U.S. Army Engineer District, Buffalo

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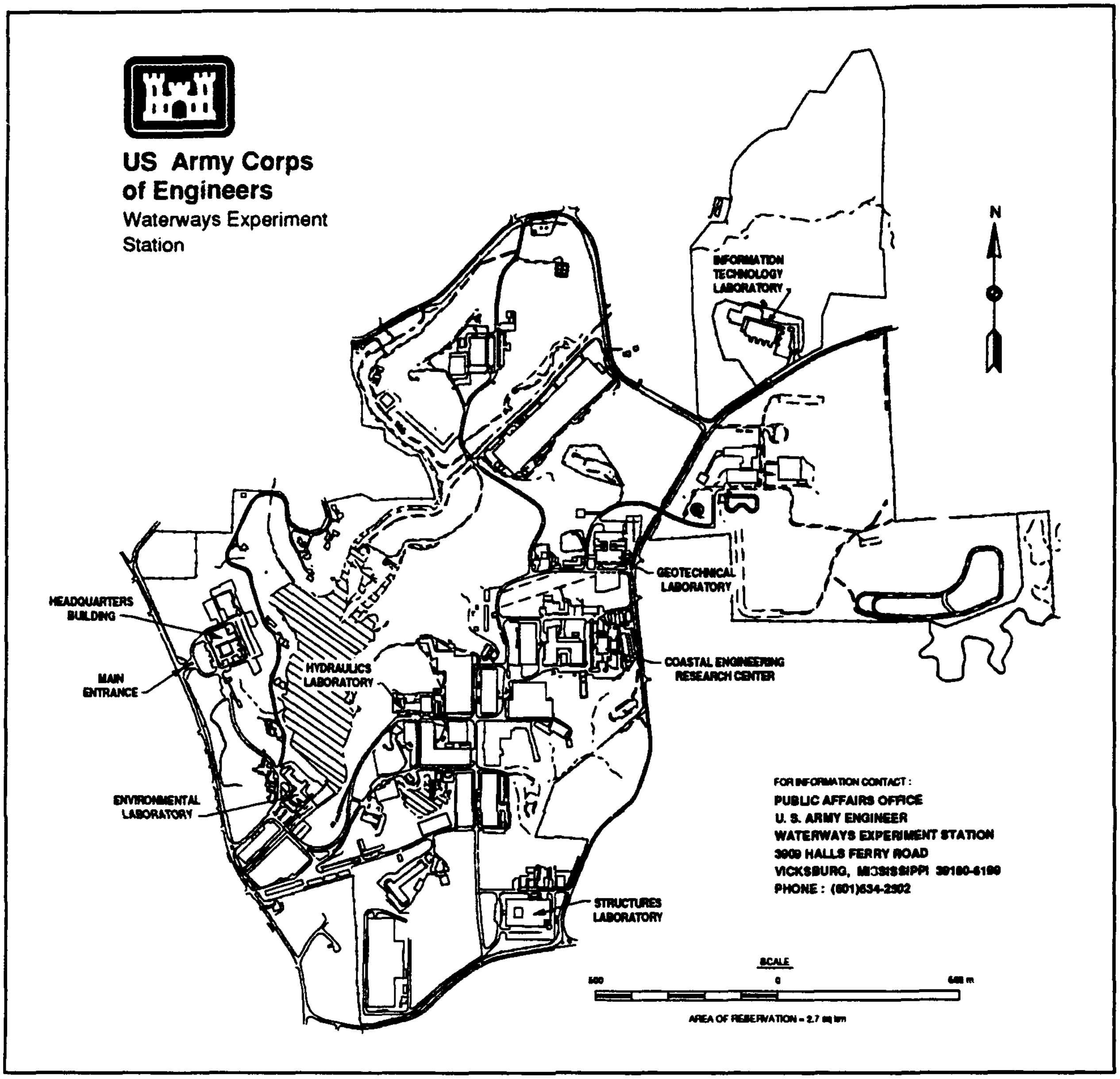

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PREFACE

This investigation was performed during the period December 1987 to October 1989 by the Hydraulics Laboratory of the US Army Engineer Waterways Experiment Station (WES) as authorized by the US Army Engineer District, Buffalo (NCB). The study was conducted with the WES research ship simulator. NCB provided the essential field and model data required.

The investigation was conducted by Ms. Michelle M. Thevenot, Mr. Carl J. Huval, and Dr. Larry L. Daggett of the Navigation Branch, Waterways Division, Hydraulics Laboratory, under the general supervision of Mr. Frank A. Herrmann, Jr., Director of the Hydraulics Laboratory; Mr. R. A. Sager, Assistant Director of the Hydraulics Laboratory; and Mr. M. B. Boyd, Chief of the Waterways Division.

Acknowledgment is made to Mr. Ted Valerio, Project Management, NCB, for cooperation and assistance at various times throughout the investigation. Special thanks should go to Great Lakes Fleet, American Steamship Company, and Rouge Steel Company for furnishing professional shipmasters to con the ship during the simulator tests on the WES Ship Simulator: John Gezcynski, Patrick Owens, John McDonough, John Szczerowski, George Palmer, Albert Nelson, John Nelson, and Richard Peacock. Gratitude is also extended to the shipmasters who participated in the simulation.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

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* A limited number of copies of Appendices A and B were published under separate cover. Copies are available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

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

Multiply	By	To Obtain
acres	0.4047	hectares
degrees (angle)	0.01745329	radians
feet	0.3048	metres
inches	2.54	centimetres
miles (US statute)	1.609347	kilometres

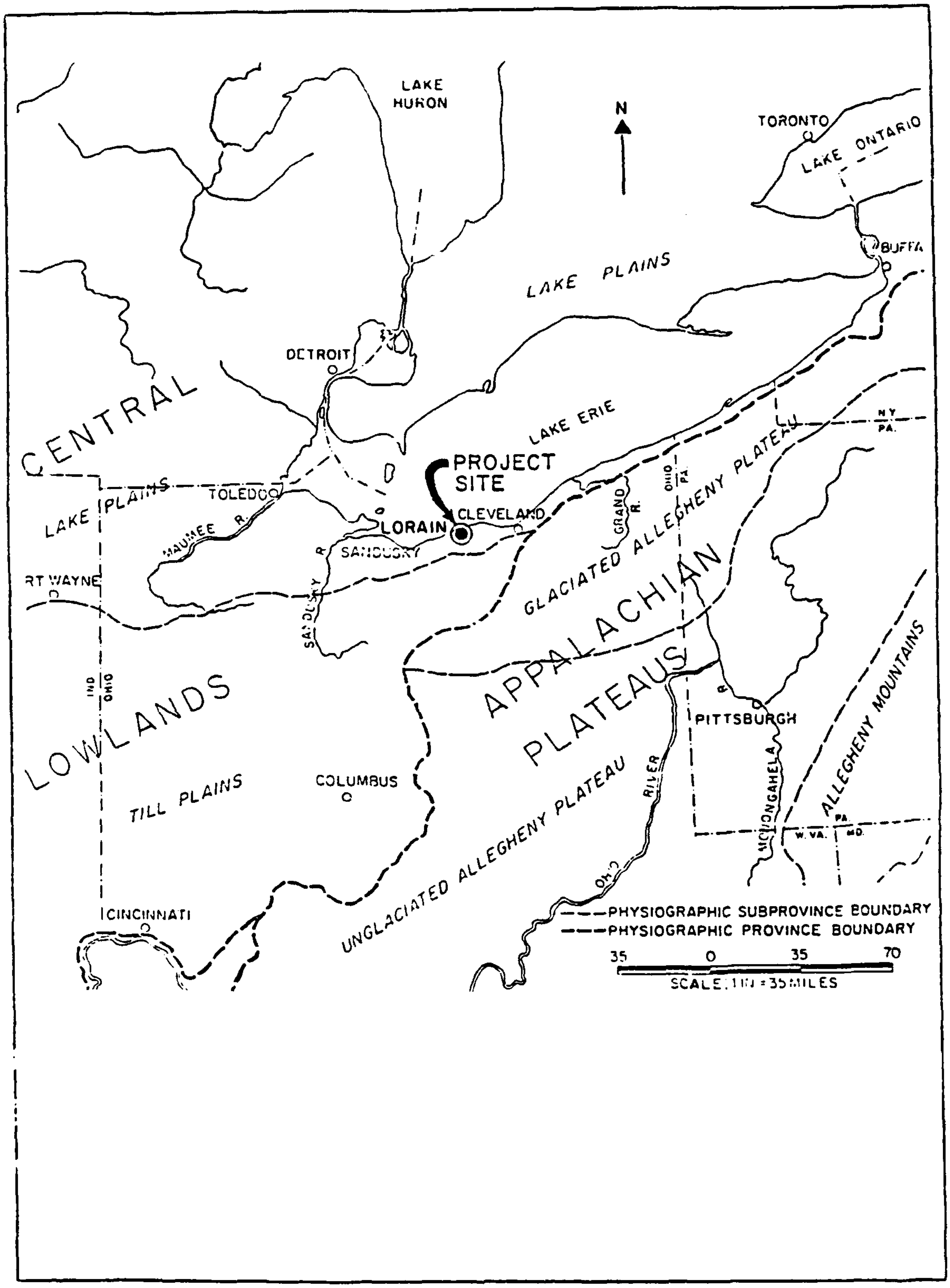

Figure 1. Project location

SHIP NAVIGATION SIMULATION STUDY

LORAIN HARBOR, LORAIN, OHIO

PART 1: INTRODUCTION

Physical Description

1. Lorain, OH, is located on the south shore of Lake Erie approximately 25 miles* west of Cleveland, OH, and 90 miles east of Toledo, OH (Figure 1). The harbor accommodates the waterborne movement of bulk cargo to and from the city of Lorain and points inland. This harbor services local industry within Lorain and interior industrial and commercial areas in the hinterland of Ohio and adjacent states. Iron ore and limestone are the major cargoes handled.

2. On 23 September 1976, the following resolution was passed:

> Resolved by the Committee on Public Works and Transportation of the House of Representatives, United States, that the Board of Engineers for Rivers and Harbors is hereby requested to review the report on Lorain Harbor, Ohio, published in House Document No. 166, 86th Congress, 1st Session, and other pertinent reports, with view of determining whether any modification to the recommendations contained therein is advisable at the present time, including consideration of the passage and safe navigation of new and larger ships operating on the Great Lakes.**

This resolution is the study authorization.

3. Lorain Harbor consists of a lake approach channel, an outer harbor, and a navigation channel in the Black River, which serves as the inner harbor, as shown in Figure 2. The authorized channel at present is 800 ft wide in the lake approach channel and 29 ft deep.† The outer harbor consists of an irregular shaped area of about 60 acres protected by four breakwater structures. The authorized depth is 28 ft for an 800-ft width. The remainder of the outer harbor is 25 ft deep except in the west outer harbor in the channel to the municipal pier, which is 16 ft deep. The inner harbor consists of an

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* A table of factors for converting non-SI units of measurement to SI (metric) units is found on page 3.

** US Army Engineer District, Buffalo. 1984. "Feasibility Report (Lorain Harbor, OH)," Buffalo, NY.

† All elevations (el) and depths cited in this report are referenced to low-water datum (lwd). Lake Erie lwd is 568.6 ft above mean water level at Father Point, Quebec, Canada (International Great Lakes Datum 1955 or IGLD 1955).

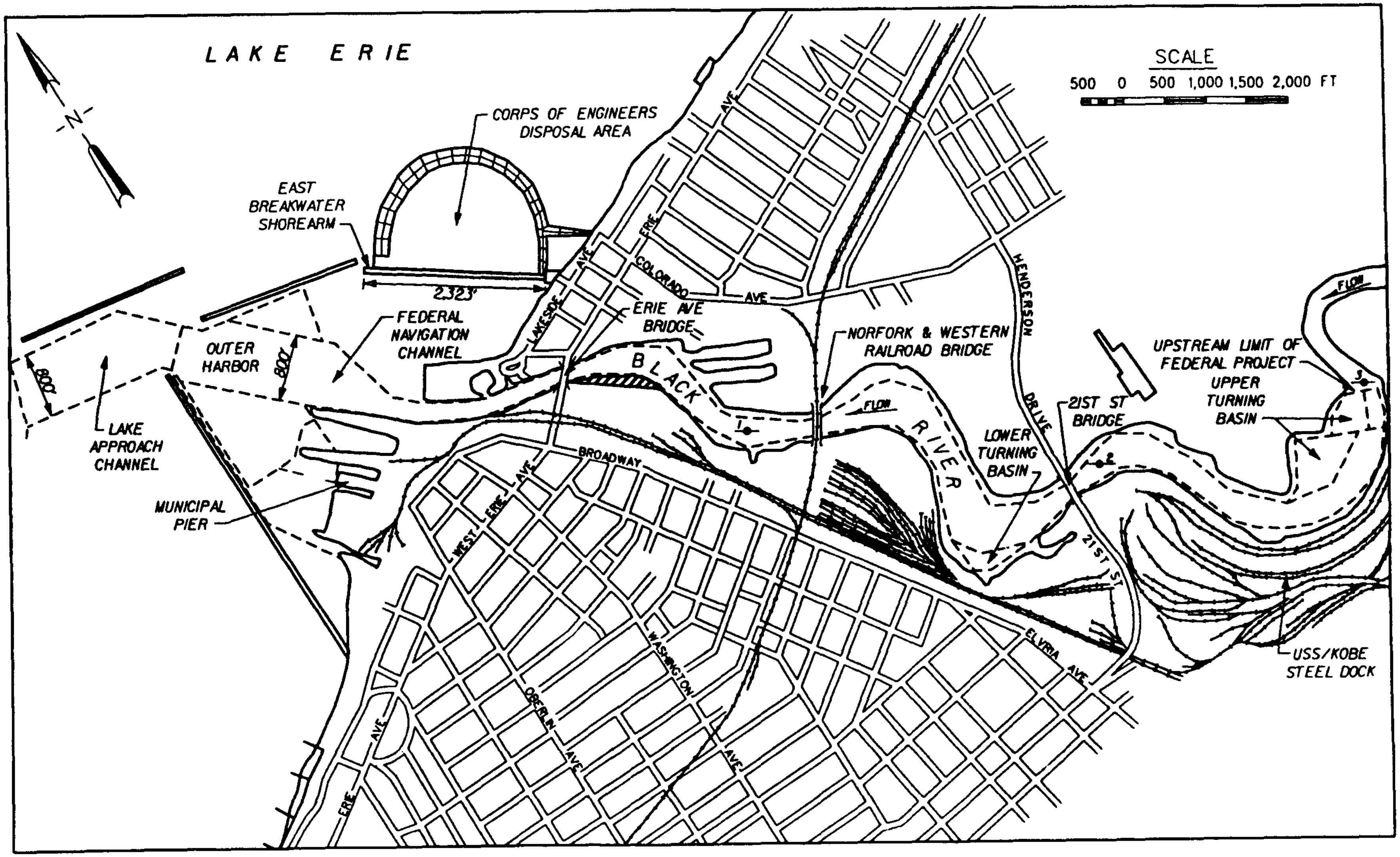

Figure 2. Study area

improved navigation channel extending approximately 3 miles up the Black River. In the river channel, the width is governed by the distance between banks. The lower 2,200 ft of the river channel is 28 ft deep. The remainder of the river channel to within 500 ft of the upstream project limit is dredged to 27 ft. The last 500 ft is 24 ft deep. The lower turning basin located downstream of the 21st Street Highway Bridge is 27 ft deep, and the upper turning basin has depths of 21 and 17 ft.

4. The water levels in the outer harbor in the lower Black River to the upper limit of the Federal project vary with and are approximately the same as the levels of Lake Erie. The lake level is subject to a seasonal rise and fall usually consisting of high levels in May and June and low levels in January and February. Yearly and seasonal fluctuations are caused by variations in precipitation rates within the Great Lakes Basin. Short-term fluctuations lasting from a few hours to several days are caused by meteorological disturbances. Differences in barometric pressure and winds blowing over the surface of the lake create temporary water level fluctuations which vary locally. Astronomical tides are assumed to have a negligible influence on water levels at the project site.

5. The authorized river channels were designed for safe and efficient operation of 730-ft vessels loaded to a maximum draft of 25.5 ft. Presently, 767-ft vessels with 70-ft beams are able to enter Lorain Harbor at static drafts of about 27 ft using high lake levels. According to the vessel captains, the existing river configuration does not allow for the smooth and continuous operation of the 767-ft vessels up or down the river. The existing channel requires that shipmasters maneuver a great deal in order to navigate around the bends between the Norfolk and Western Railroad Bridge and the 21st Street Highway Bridge. This maneuvering consists of a "backing and filling" operation: a shipmaster noses his vessel ahead, reverses engines to halt forward progress, pivots using bow and stern thrusters, and then puts the engines forward again. This type of maneuver takes more time than driving through in a smooth and continuous motion. Vessel operators indicate that backing and filling to navigate around these bends causes an inbound transit delay of 40 min. Bow and stern thrusters have been added to the 767-ft vessels to assist in the maneuvering of the prototype ships.

6. Backing and filling requires a high degree of control of the vessel and makes the rudder and propeller of the vessel more vulnerable to damage.

Shipowners' policy dictates that in order to maintain the level of control necessary to navigate the 767-ft vessel in the existing Black River channel and to provide additional protection for the rudder and propeller, a total of 30 in. of underkeel clearance is required. As lake levels begin to drop and approach low-water datum, the 767-ft vessels have to begin to light-load in order to maintain the required underkeel clearances to be able to maneuver up the channel. Reductions in capacities require an increase in the number of trip deliveries and increase the total transportation costs. Channel improvements should minimize the amount of light-loading of 767-ft vessels, thus maximizing the benefits of using these larger vessels. Channel improvements should also reduce the transit time delay due to bend restrictions by eliminating backing and filling, thus allowing the shipmasters to navigate the channel using smooth and continuous operations.

7. Navigation problems due to bend restrictions are made worse by the three bridges crossing the Black River within the limits of the Federal Navigation Channel (Figure 2). The Erie Avenue Bridge, constructed in the late 1930's, has a total length of about 1,050 ft and consists of a twin-leaf bascule main span with eight steel girder approach spans on the west river bank and one on the east river bank. The main span is 295 ft long and provides approximately 147.5 ft horizontal clearance, with 33.5 ft of vertical clearance above mean water elevation at the bridge center when in the closed position. The Norfolk and Western vertical lift bridge provides an understructure clearance of 123.7 ft and channel width of 205 ft. The 21st Street Bridge, constructed in the 1940's, is a six-span 1,700-ft through truss with a 400-ft river crossing span. The understructure clearance, based on Lake Erie low-water datum of 568.6 ft, is 99.6 ft for approximately 250 ft in the center river crossing span. Structural changes to these bridges, which would widen the Federal Navigation Channel, were determined not to be cost-effective.

Proposed Channel Improvements

8. The authorized project as presented in the project's final feasibility report* calls for channel improvement involving three bank cuts. Two of the cuts would be located at consecutive bends in the river and the third

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* US Army Engineer District, Buffalo, op. cit.

would be located at the upper turning basin as shown in Figure 3. Bank cuts B and C would be constructed to the existing 27.0-ft lwd. The upper turning basin cut would be constructed to the existing basin depth of 21.0 ft. Bank cut B, immediately upstream of the Norfolk and Western Railroad Bridge, would widen the existing channel an average of about 150 ft and would be approximately 1,500 ft long. The lengths here are measured along a straight line from one end of the cut to the other. Bank cut C would widen the existing channel an average of about 100 ft and would be approximately 700 ft long. This cut would be located immediately downstream of the 21st Street Highway Bridge. The upper turning basin cut would widen the channel by up to 200 ft and would be about 400 ft long. Bank slopes were planned to be 1V on 4H. Detailed drawings of these cuts, provided by the US Army Engineer District, Buffalo, are shown in Figures 4, 5, and 6.

Purpose and Scope of Investigation

9. The specific purpose of the ship simulation study was to test the proposed authorized project and recommend design modifications that would allow safe and efficient use of the channel by the 767-ft vessels currently used in Lorain Harbor. The simulator tests were designed to determine if the proposed bank cuts would provide an acceptable level of reduction of the backing and filling maneuvers currently required and also to estimate the reduction in transit times that can be expected as a result of the proposed improvement. In addition, the simulation tests were used to determine if increased drafts of these vessels through reduced underkeel clearances from 30 in. to 18 in. can be safely accommodated with the proposed channel alignment.

10. The vessel simulation study consisted of two phases. Phase 1 of the study provided data pertaining to the economic feasibility of the project by conducting a series of low-cost, radar-based simulation tests. Phase 2 was a more thorough study that included the visual scene in the simulation.

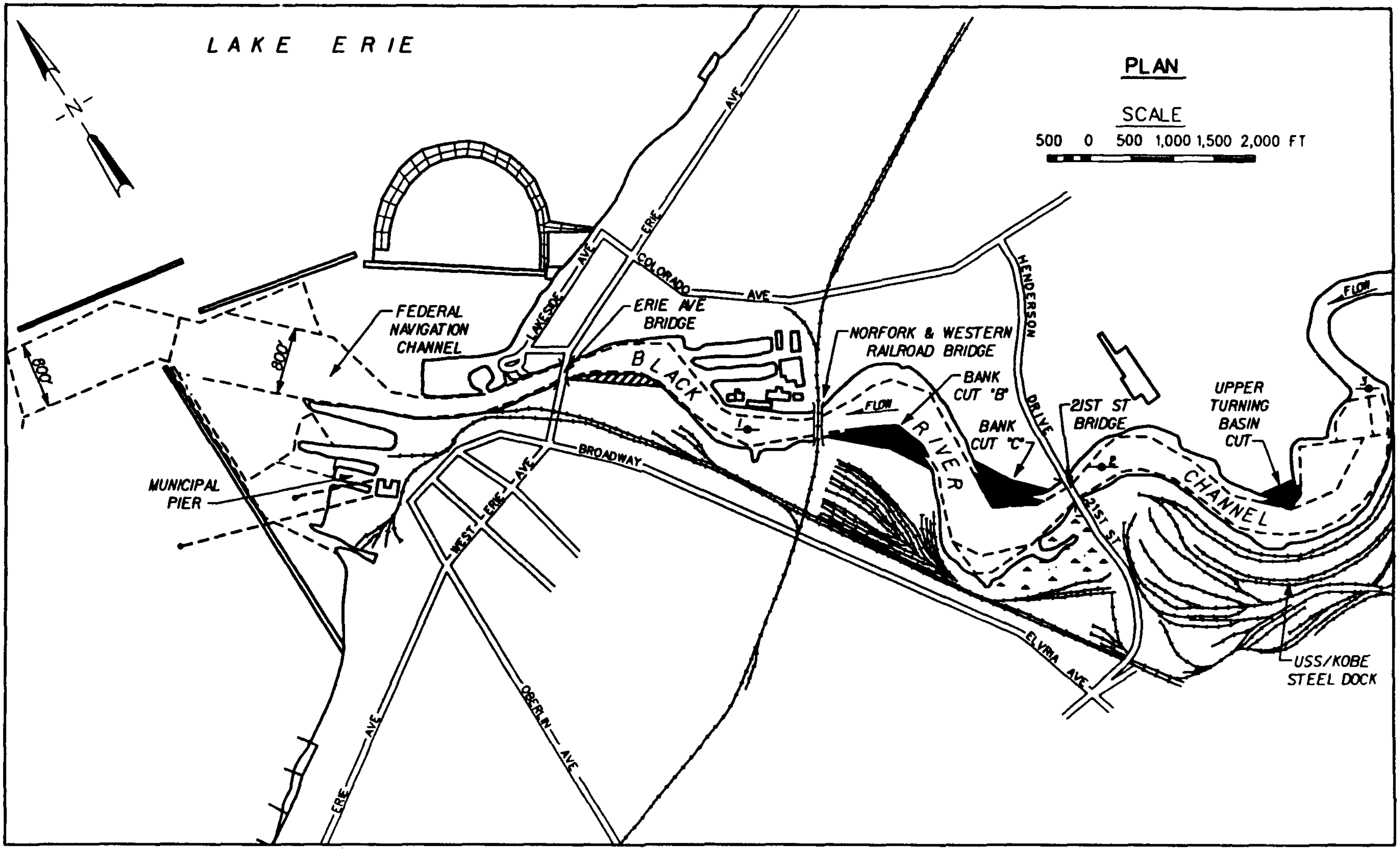

Figure 3. Proposed bank cuts

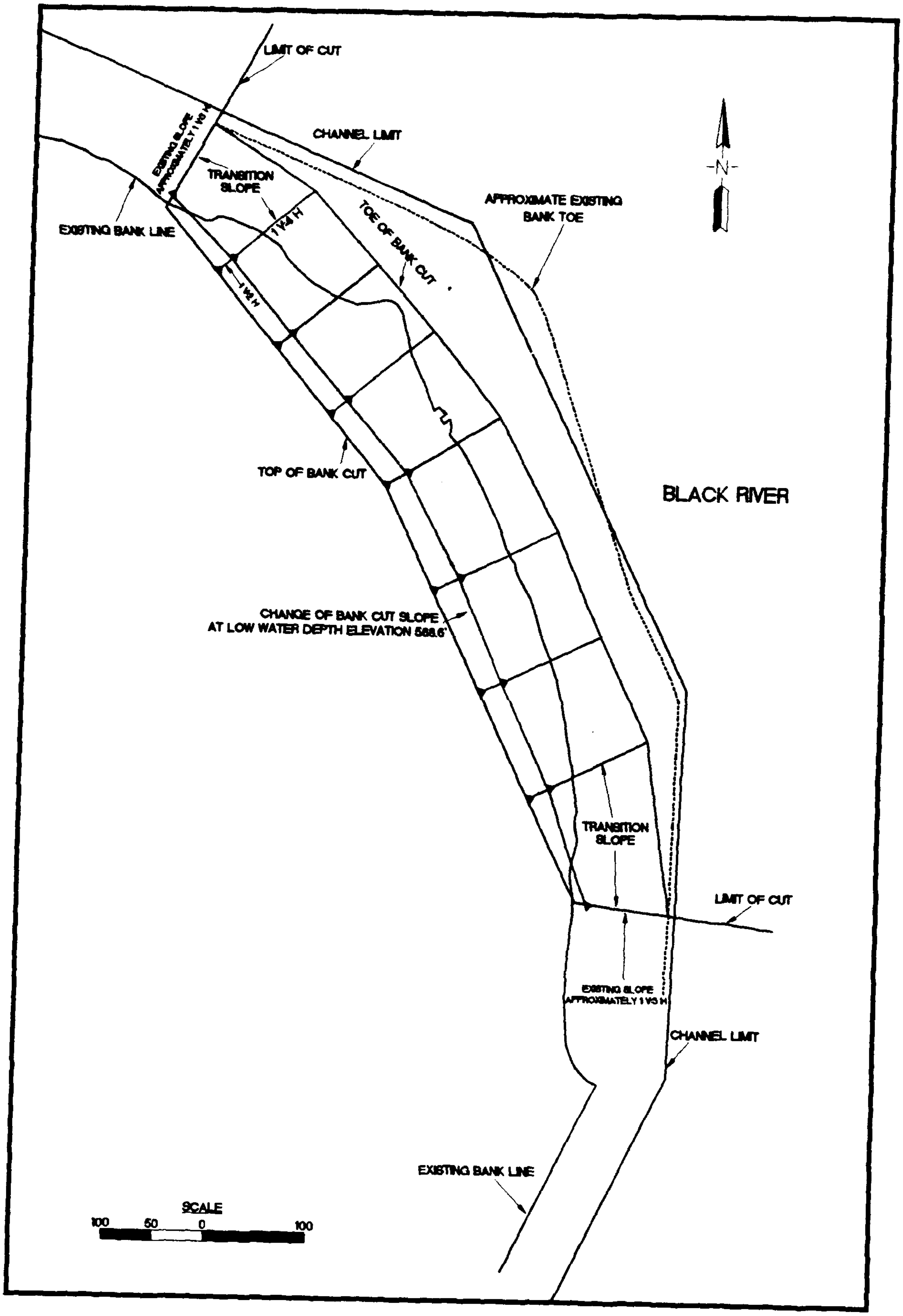

Figure 4. Details of proposed bank cut B

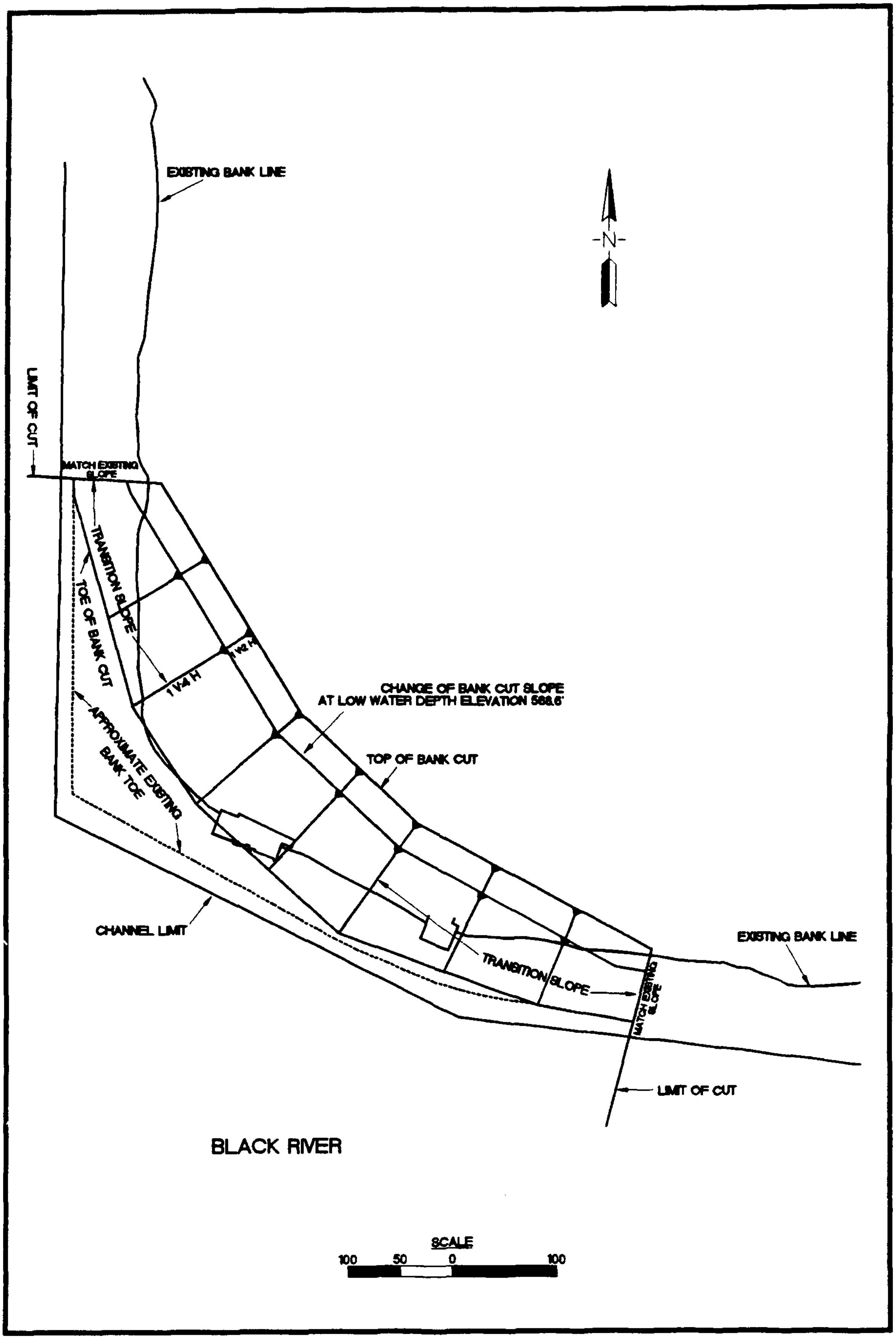

Figure 5. Details of proposed bank cut C

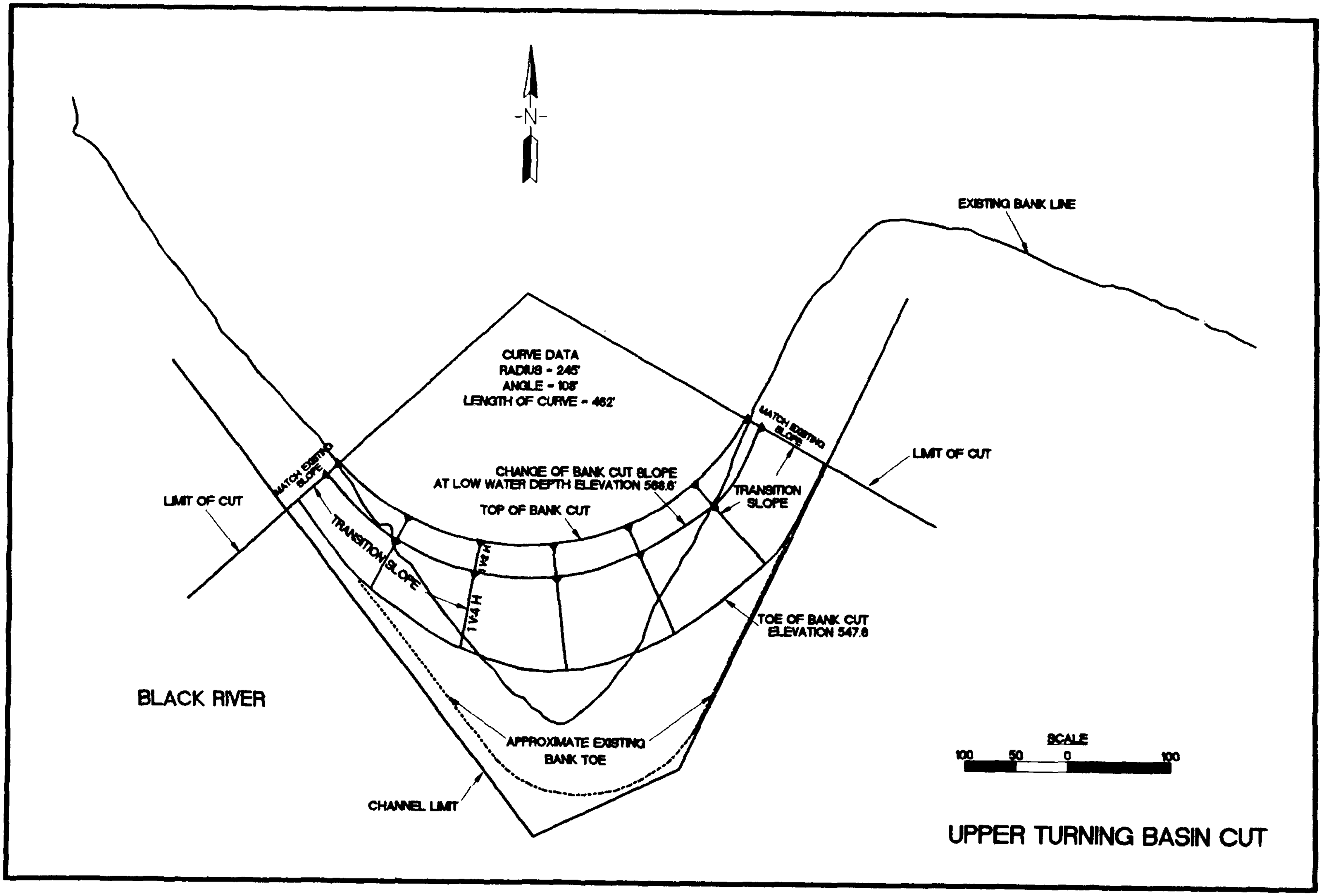

Figure 6. Details of the upper turning basin cut

PART II: DATA DEVELOPMENT

11. In order to simulate a study area, it is necessary to develop information relative to five types of input data:

- a. The channel database contains dimensions for the existing channel and the proposed channel modifications. It includes the channel cross sections, slope angle, overbank depth, and autopilot track-line definition.
- b. The radar database contains the features for the plan view of the study area.
- c. The ship data file contains characteristics and hydrodynamic coefficients for the test vessels.
- d. The file for current pattern data in the channel includes the magnitude and direction of the current for each cross section defined in the channel database.
- e. The visual scene database is composed of principal features of the simulated area, including the aids-to-navigation, buildings, and loading facilities.

The data discussed in a, b, and c were required for both Phase 1 and Phase 2 of the simulation. The e data were necessary for Phase 2 only. Since the simulation took place in slack water, d was not needed for any part of this study.

Channel

12. The information used to develop the channel database came from the District-furnished hydrographic survey charts, topographic maps, and National Oceanic and Atmospheric Administration (NOAA) Chart No. 357. This was the latest information available concerning the dimensions of the channel. State planar coordinates as shown on the annual survey were used for the definition of the data.

13. The simulator channel, which began at the outer harbor and continued to the turning basin, had 65 cross sections. Channel cross sections were placed at each bend in the channel and at each surveyed cross section. Figure 7 shows the defined channel for the existing condition. Cross sections A, B, and C were located at each of the bank cuts to illustrate the dimensions of the proposed cuts. Figures 8, 9, and 10 present the layout of cross sections A, B, and C, respectively, as examples of the cross-section definitions used in this study. The upper plot is exaggerated vertically to show the

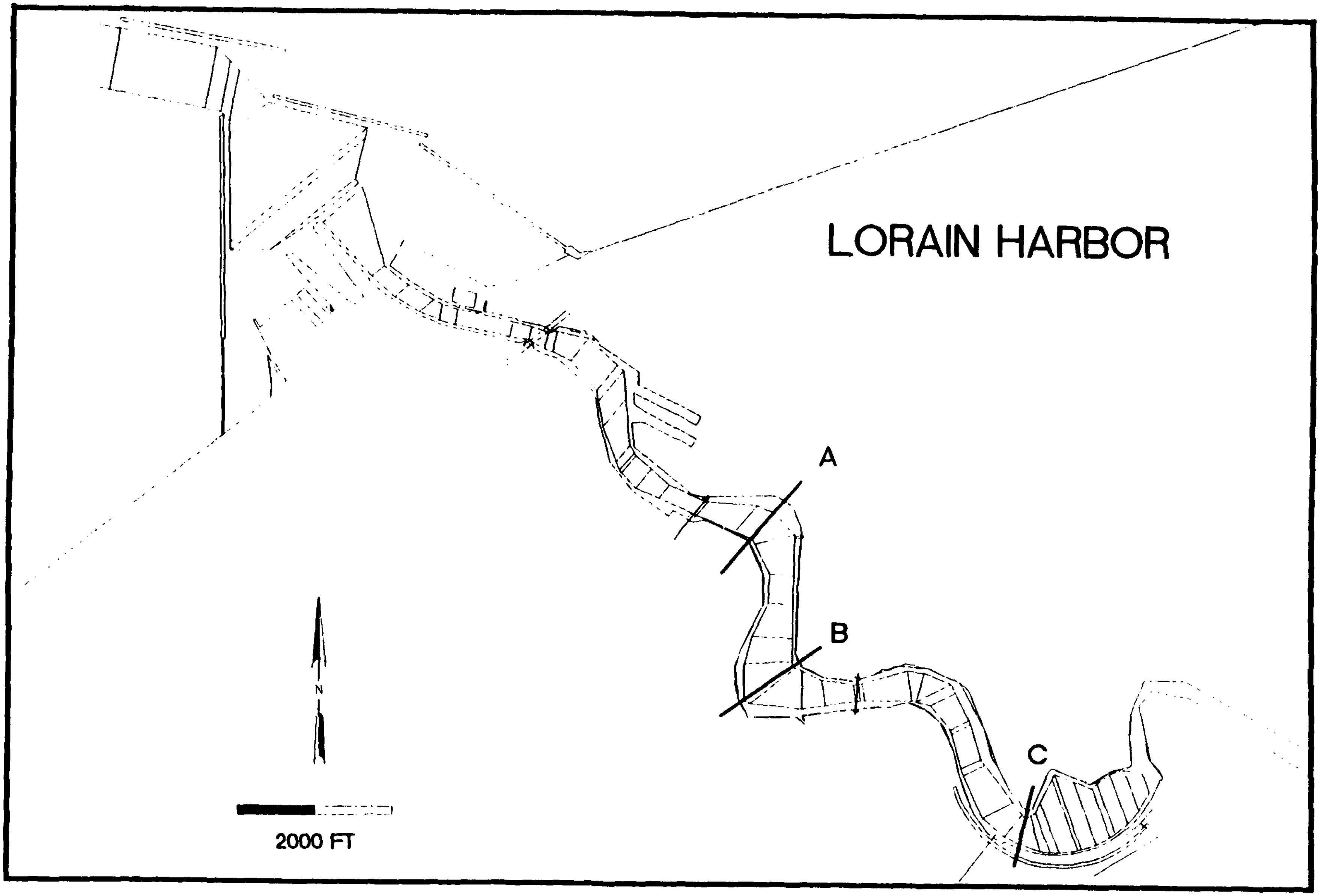

Figure 7. Locations of typical cross sections at each of the proposed bank cuts

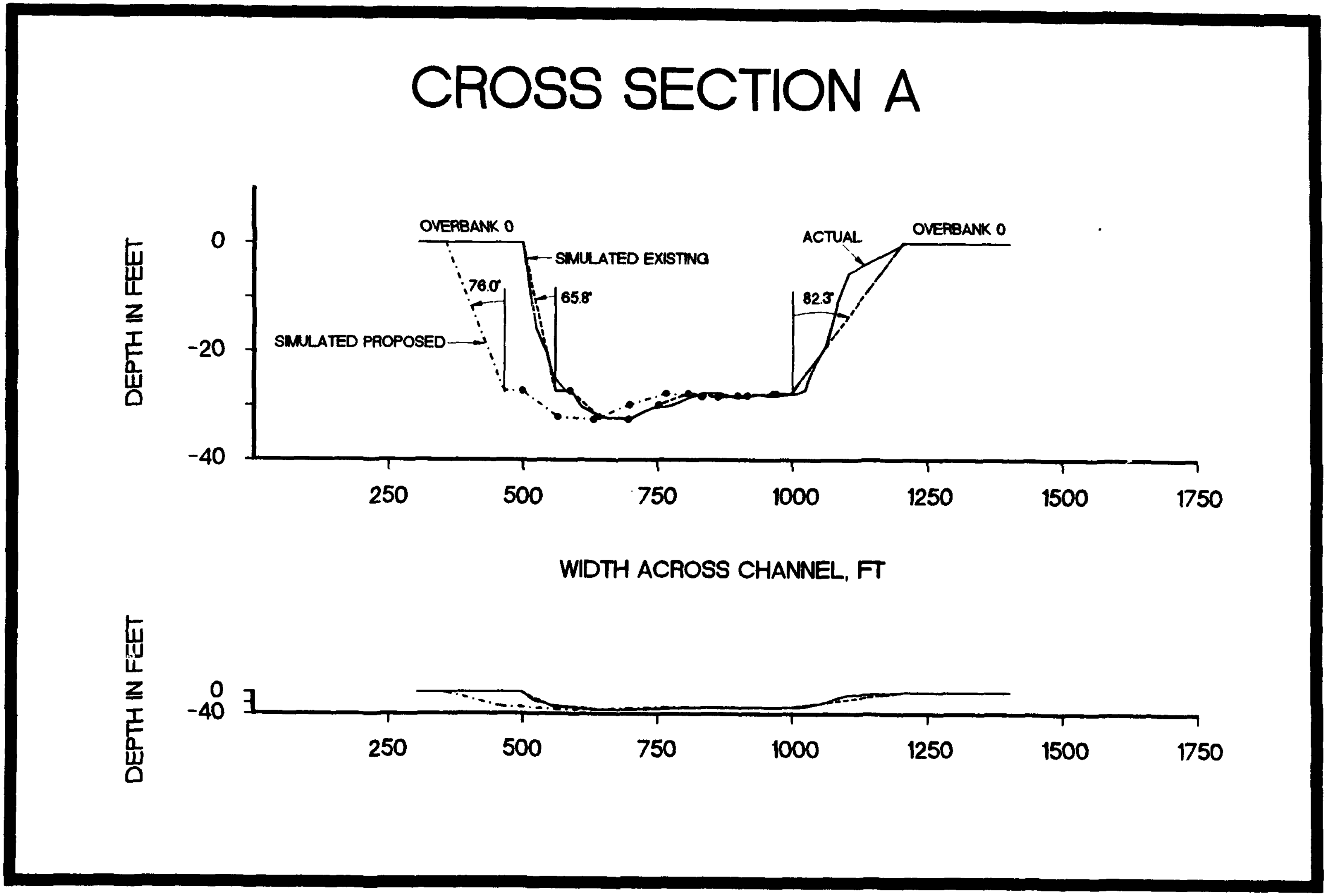

Figure 8. Cross section A

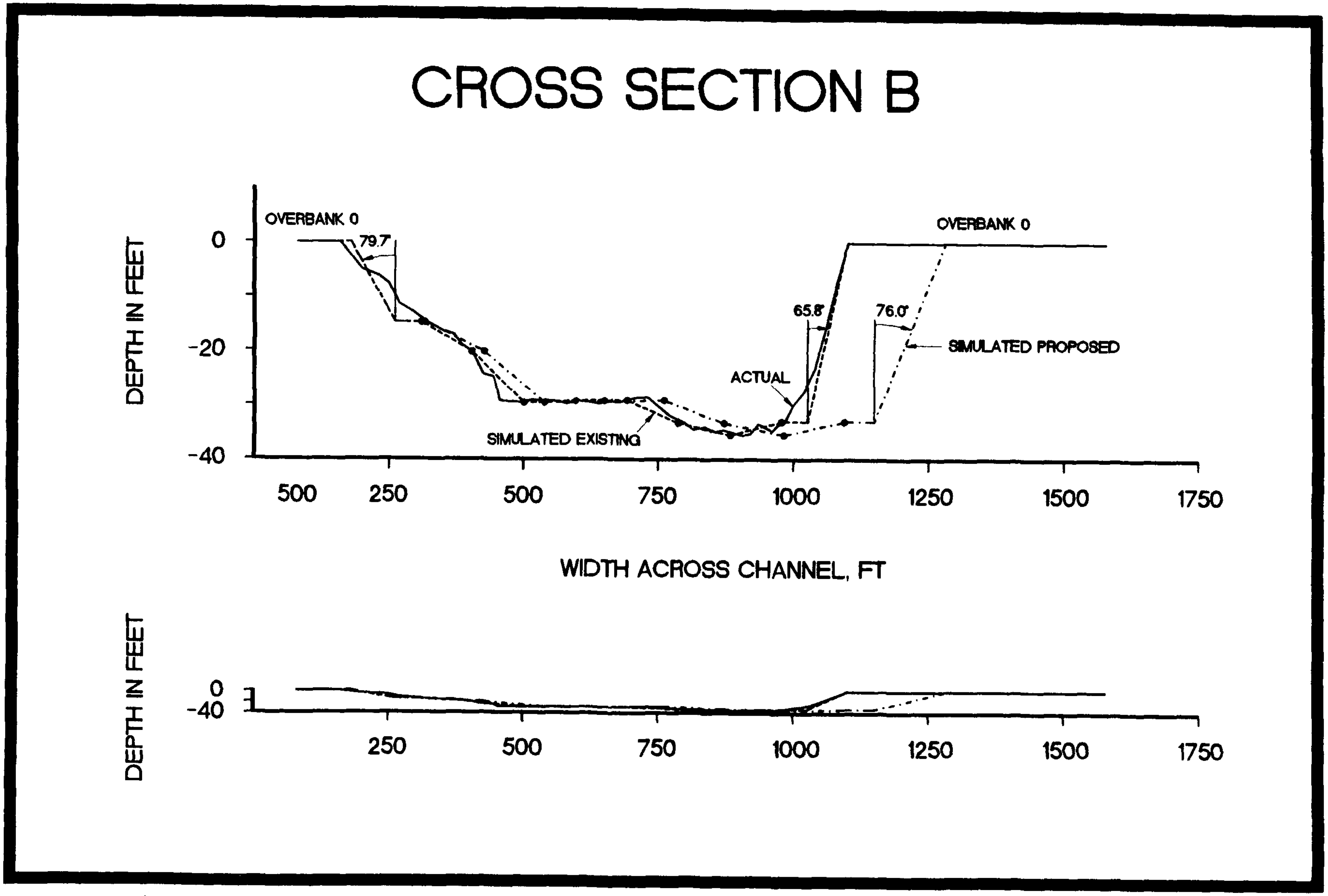

Figure 9. Cross section B

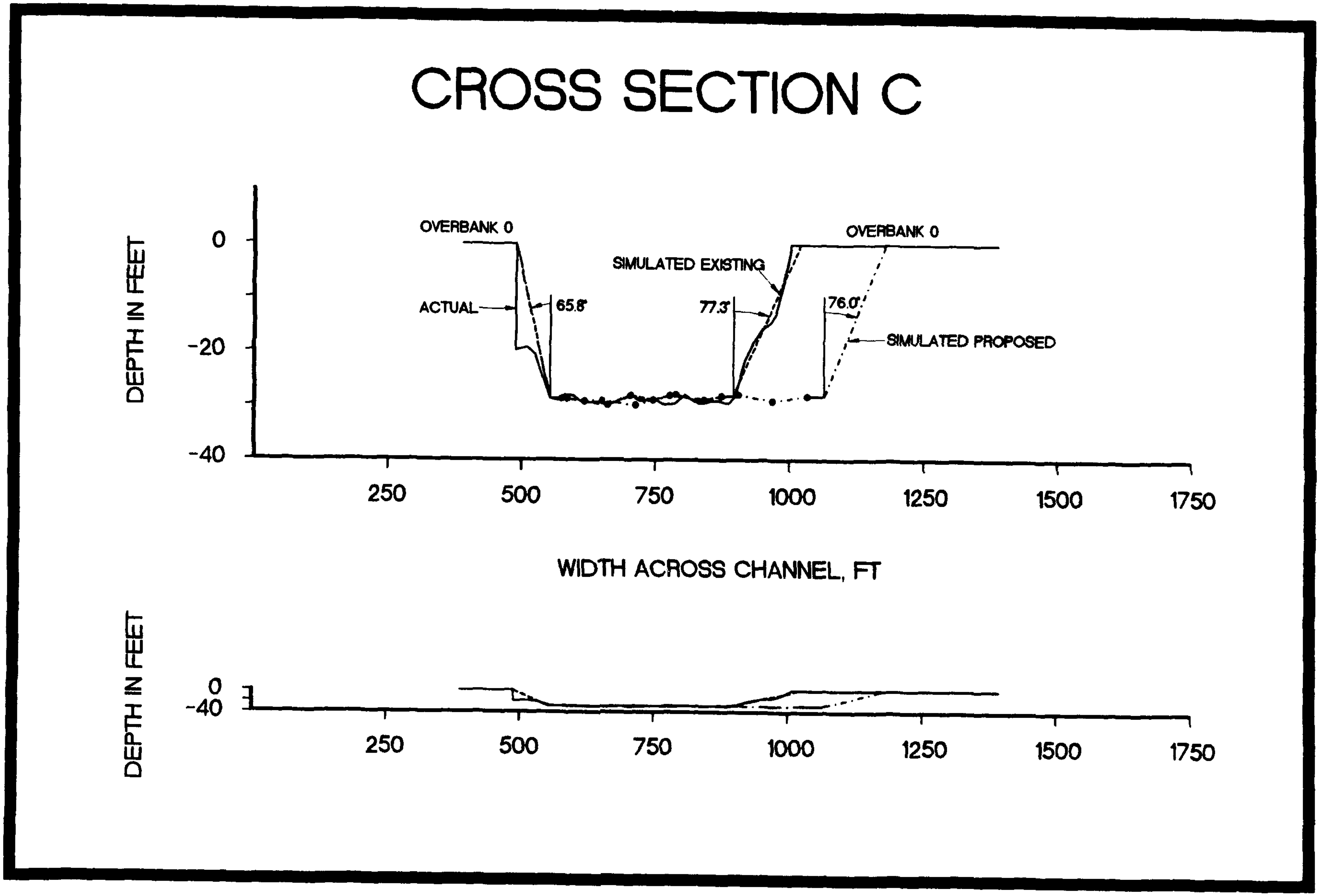

Figure 10. Cross section C

differences between the simulated and the actual channel cross sections.

14. The ship simulator model allows eight equally spaced points to define each cross section. At each of these points a depth is required. For each cross section, the width, right and left bank slopes, and overbank depth must be input. These data were obtained from the hydrographic survey data provided by the Buffalo District for use in the main program for calculating bank suction forces. Figures 8, 9, and 10 show the eight points, the bank slopes, and the overbank depths for cross sections A, B, and C, respectively. Each of these figures shows the bank slope for the proposed cut is 76.0 deg; this corresponds to the 1V on 4H slope as planned in the project's feasibility study. The depths for the proposed channel were the same as the existing channel spread along the length of the entire cross section to approximate the natural topography of the channel.

Radar

15. The radar database is used by a graphic image generator to create a simulated radar for use by the test shipmasters. The radar database contains X- and Y-coordinates that define the border between land and water. The file also contains coordinates for any major physical feature deemed important such as buildings, bridges, tanks, docks, and aids-to-navigation. In short, these data define what a shipmaster would actually see on a shipboard radar. The radar image is a continuously updated view of the vessel's position relative to the surrounding area. Three different scales were programmed to enable the shipmaster to choose which scale he preferred.

Current

16. A current database contains current magnitude and direction at eight points across the channel at each of the cross sections defined in the channel. No current data were necessary since all tests were made in slack water. When the tests were being planned, inquiries about flow conditions in the Black River were made. Information received indicated the only currents of consequence result from upland storm runoff, which was of short duration. High flows occurred infrequently during the sailing season and ships waited for flows to abate before transiting the river. The study was designed to

evaluate the relative effectiveness of the alternative bank cut plans. Simulations with current would not improve the bank cut impacts; on the contrary, currents would tend to obscure any effects.

Test Ship

17. The ship data base consists of the ship characteristics and coefficients used in the hydrodynamic program for calculating forces on the laker used in the testing program. In addition, because the stern of the ship would also be seen in the visual scene by the shipmaster from the ship bridge when he turned and looked aft (this is done with the look-around switch, paragraph 20), a visual image of the ship stern had to be created for Phase 2 of the study.

18. The design ship used in the simulation was the *A. M. Anderson*, which was 767 ft long and had a 70-ft beam. Four ship drafts were used in the simulation. Outbound runs were made with the ship ballasted or an 18.2-ft draft with a large (greater than 8 ft) underkeel clearance. Inbound runs were made in high and low water conditions. The inbound runs with the high water condition had the ship loaded to a 27.0-ft draft with a 2.5-ft underkeel clearance. For the inbound runs with the low water condition, the ship was loaded to a 24.5-ft draft again with a 2.5-ft underkeel clearance for the existing condition and a 25.5-ft draft with a 1.5-ft underkeel clearance for the proposed channel. A description of the ship model is included in Ankudinov.*

Visual Scene

19. The visual scene data base, which was used in Phase 2, was created from the same maps and charts noted in the discussion of the channel source. Areal and still photographs obtained during a reconnaissance trip to Lorain Harbor constituted another source of information for the scene. These combined with comments made by shipmasters in meetings at the US Army Engineer

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* V. Ankudinov. 1988 (Aug). "Hydrodynamic and Mathematical Models for the Ship Maneuvering Simulations of the Great Lakes Ore Carrier 'A. M. Anderson' in Support of the West Lorain Harbor Study," Technical Report 87005.0324-1, Tracor Hydronautics, Inc., Laurel, MD.

Waterways Experiment Station (WES) and Lorain allowed inclusion of the significant physical features the shipmasters use for informal ranges and location sightings. During validation additional informal navigation aids were incorporated.

20. All docks, buildings, and tanks are included in the visual scene. The information requires generating the visual scene in three dimensions: north-south, east-west, and vertical elevation. Again the state planar coordinate system is used. As the ship progresses through the channel, the three-dimensional picture is constantly transformed into a two-dimensional perspective graphic image representing the relative size of the objects in the scene as a function of the vessel's position and orientation and the relative direction and position on the bridge for viewing. The graphics hardware used for the Lorain Harbor project was a stand-alone computer (Silicon Graphics-Iris 2300) connected to the main computer to obtain information for updating the viewing position and orientation of the ship. Also, the viewing angle is passed to the graphics computer for the look-around feature on the simulator console. This feature enables the shipmasters to look at objects outside of the straight-ahead view, which encompasses only a 40-deg arc, and simulates the shipmaster's ability to see any object with a turn of his head. The shipmaster's position on the bridge can also be changed from the center of the bridge to the edge of the ship at the bridge wing or anywhere in between to obtain a better view.

21. It may be noted that the creating of a scenario for the project area is very demanding in terms of engineering judgment. The goal of the scenario is to provide all the required data without excessive visual clutter, bearing in mind the finite memory storage and computational resources available on the minicomputer.

PART III: NAVIGATION STUDY

Phase 1

Test conditions

22. The Lorain Harbor scenario as implemented on the WES ship simulator included the navigation channel beginning at the lake approach channel and continuing on to the upper turning basin (Figure 2). This channel follows the meanders of the Black River, and therefore contains many bends. The Phase 1 testing was conducted with three different channel designs (Figure 11): (a) the existing condition; (b) the authorized project as presented in the Feasibility Report,* Plan 1; and (c) a design suggested by an active shipmaster who navigates in the river regularly, Plan 2. This design included cut B of Plan 1 and the upper turning basin cut as well as a slightly enlarged version of cut C. This design also included three other bank cuts. Bank cut 1, which was initiated but not completed, was one of these additional cuts. This cut was upstream of the Erie Avenue Bridge. Another was bank cut D, which was considered by the District but determined not feasible. This cut was upstream of the 21st Street Bridge. The last of the additional cuts was another cut in the upper turning basin.

23. As stated in paragraph 18, the design ship was based on the *A. M. Anderson*, which is 767 ft long, has a 70-ft beam, and has both bow and stern thrusters, which were available in all Phase 1 tests. The ship was loaded to 24.5-ft draft with 2.5-ft underkeel clearance in the existing condition and to 25.5-ft draft with 1.5-ft underkeel clearance in the proposed conditions for inbound runs. The turning maneuver was simulated in the upper turning basin with a draft of 18.2 ft (the ballasted condition). Phase 1 tests were conducted with simulated radar available to the shipmaster. Other instrumentation normally used by the shipmaster aboard the ship was also accessible. The visual scene was not used during Phase 1. All runs were made in slack water and no wind.

Test procedure

24. Two retired shipmasters from the USS Great Lakes Fleet (USS GLF) participated in Phase 1, which was designed as a low-cost study providing a

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* US Army Engineer District, Buffalo, op. cit.

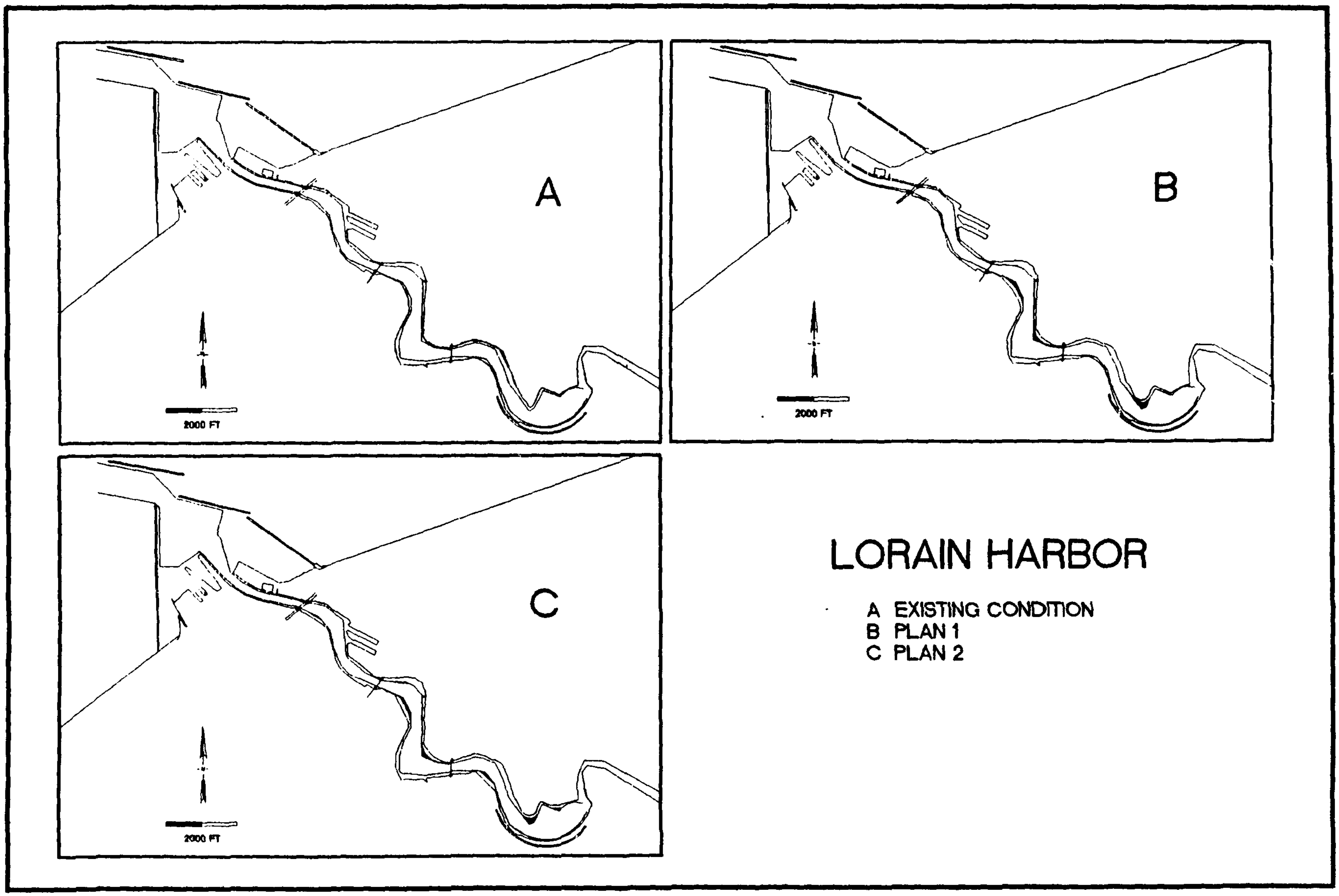


Figure 11. Three channel alignments tested in Phase 1

rapid assessment of the proposed design changes and potential project benefits. The first retired shipmaster, A, conducted several preliminary runs to verify the ship simulator model. Despite a malfunction with the bow thruster, causing it to lose power periodically when commanded and decrease the ship's maneuverability, a decision was made to proceed with testing. This decision was based on the premise that Phase 1 was to be a low-cost preliminary study. Shipmaster A then began actual testing. Shipmaster B was briefed on the study and introduced to the equipment after which he conducted a familiarization run in the simulated existing channel. Normally, several preliminary runs are made; however, due to the time restrictions it was necessary to proceed with testing immediately. Shipmaster B stated that he thought more time for such familiarization was needed.

25. For each of the three Phase 1 channel conditions, two scenarios were tested: inbound transits and turning maneuvers. For inbound runs, the existing condition was run with a draft of 24.5 ft. Shipmaster A's existing channel run was a combination of two incomplete runs. Shipmaster B made two existing condition runs: one complete run beginning at the outer harbor and one partial run starting at the Norfolk and Western Railroad Bridge. The proposed channels were tested with a draft of 25.5 ft. Shipmaster A made one run of each channel. Shipmaster B made one complete run and one partial run similar to his existing condition runs. A total of 15 runs were made over 3 days of testing. A complete list of test runs along with a comparable transit time for each is presented in Table 1.

26. During each run, the characteristic parameters were automatically recorded every 10 sec. These included the position of the ship's center of gravity, speed, revolutions per minute (rpm) of the engine, heading, drift angle, rate of turn, rudder angle, and port and starboard clearances.

Test results

27. The simulator tests were evaluated based on shipmaster ratings and ship tracks. In addition, a time analysis was made to determine the transit time benefit from the plans. The following sections will discuss these methods of analysis.

28. Shipmaster's ratings. To obtain the shipmasters' comments about the simulator, the proposed deepening, and the runs, two questionnaires were prepared. One was given to the shipmasters after each run, and a final debriefing questionnaire was given to the shipmasters upon completion of the test

period. An example of the questionnaire given after each run and a completed final debriefing questionnaire are shown in Appendix A. For each run, the shipmasters were asked to give a rating on the difficulty of the run, the amount of bank effects, the amount of thruster used, the maneuverability of the ship, and the danger of grounding for different areas. The following areas were rated: A, from the outer breakwater to the Norfolk and Western Railroad Bridge; B, from the Norfolk and Western Railroad Bridge past the bend in the river at the gypsum dock; C, from the gypsum dock to the 21st Street Highway Bridge; and D, the 21st Street Highway Bridge to turning basin. In addition, the turning basin was divided into areas 1 and 2 as shown in Figure 12.

29. Plates 1 and 2 show the average scores of the shipmasters' ratings for the inbound and outbound conditions, respectively. In general, a lower rating indicates a safer channel. The expected results—the existing channel having the highest ratings, Plan 1 having significantly lower ratings than the existing channel, and Plan 2 having a rating slightly lower than Plan 1—were seen in few of the rating categories. The ratings shown were obtained by averaging two or three numbers coinciding with the number of runs made of that condition. Due to the preliminary nature of the Phase 1 testing, an adequate sampling was not acquired to provide significant averages. However, on an individual basis, the data were useful in determining the economic feasibility of the project.

30. Plate 3 illustrates the overall ratings of the inbound and outbound runs. These values were determined by averaging the ratings of the areas involved. Since more individual ratings were used, these ratings seem to have a greater degree of accuracy. There is very little difference between the overall ratings of the inbound runs for the channel conditions. However, the outbound runs show the expected pattern. It was determined that the reason the inbound ratings did not show this expected pattern as previously discussed was that the draft of the vessel was increased from 24.5 ft in the existing condition to 25.5 ft in the two proposed conditions with no increase in underkeel clearance. This negates most, if not all, of the benefits obtained from widening the channel. This conclusion was confirmed in Phase 2.

31. Track plots. For the inbound runs, the shipmasters appeared to increase ship speed up to approximately 3 mph in the straight channel segments. Thrusters were ineffective at ship speeds greater than this.

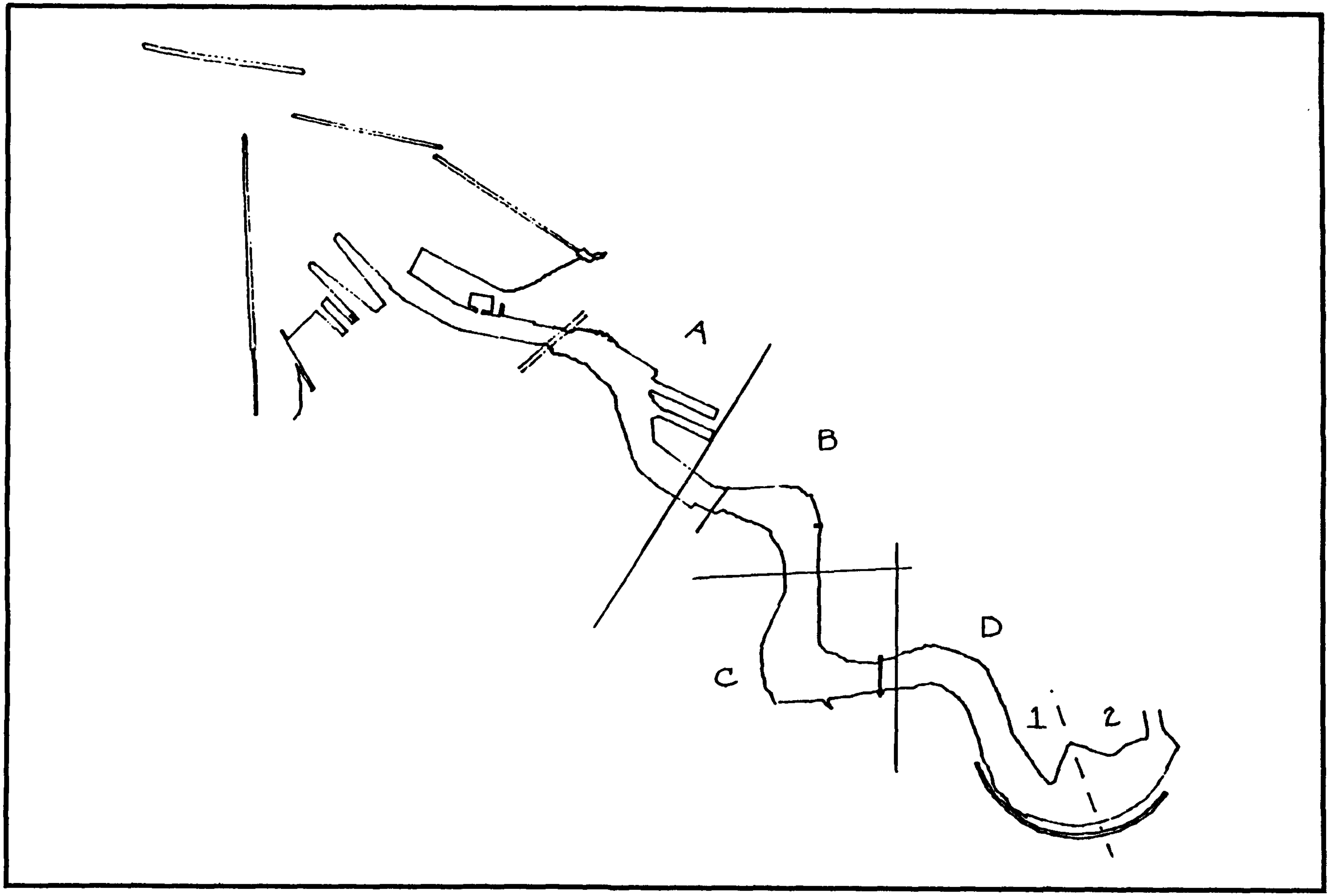


Figure 12. Channel divisions for Phase 1 pilot ratings

Approaching a turn, the shipmaster activated the thrusters and reduced forward speed by reversing the engine. Thrusters were normally used on maximum thrust and ` ¬ was set to full reverse. Minimum ship transit times were obtained by maintaining forward motion. A complete set of individual track plots is presented in Appendix B.

32. All inbound runs during Phase 1 were made with a lake level of 568.6. The test ship was equipped with both bow and stern thrusters. For the existing condition, the ship was loaded to a draft of 24.5 ft with an underkeel clearance of 2.5 ft. As shown in Plate 4, transits of the existing condition illustrate a lot of backing and filling. Navigation problems occur in the area of each of the proposed channel cuts. The shipmasters had little difficulty entering the Black River and maneuvering through the Erie Avenue Bridge. However, making the turn upstream of the Erie Avenue Bridge, shipmaster B (Plate 5) during his first run was required to back and fill, causing him to go out of the channel at the small-boat harbor and hit the docked ship. Downstream of the Norfolk and Western Railroad Bridge, both shipmasters had trouble (Plate 4). Plate 6 shows shipmaster A backing and filling to align for the bridge and in doing so backing into a docked barge. In his first run, shipmaster B (Plate 5) turned too sharply and went slightly out of the channel just upstream of the Norfolk and Western Railroad Bridge. As shown in Plate 7, at this location, shipmaster B was starting his second run. Because of the defined initial conditions, the ship transited through the Norfolk and Western Bridge with no problems. Plate 4 shows no groundings occurring in the area of the B cut. However, in the area of the C cut, all three runs are shown to have exceeded the channel limits. Shipmaster A, as shown in Plate 8, made a turn that was too wide and exceeded the southern channel boundary slightly. As shown in Plate 9, shipmaster B lost control while backing and filling in his first run, causing him to back out of the channel. In his second run, he turned too sharply causing him to cut the corner on the interior of the turn (Plate 10). Much backing and filling was necessary in this area. Upstream of the 21st Street Highway Bridge gave the shipmasters little problem (Plate 4). At the turn entering the turning basin, shipmaster B had trouble with his first run. As shown in Plate 11, backing and filling caused him to go out of the channel. This does not occur in the other test runs.

33. The Plan 1 condition was run with the design ship loaded to 25.5 ft

with an underkeel clearance of 1.5 ft in all of the inbound runs. More backing and filling was observed in Plan 1 than in the existing condition at the locations of cuts B, C, and D (Plate 12). In the area of cut D, no changes were made between the existing channel alignment and Plan 1. This difference must be due to the increased draft and decreased underkeel clearance.

34. Shipmaster A (Plate 13) navigated from the outer harbor past the Erie Avenue Bridge with no incidents. However, shipmaster B (Plate 14) hit the bridge pier with the port bow of the ship. Both shipmasters navigated from the Erie Avenue Bridge to the Norfolk and Western Railroad Bridge without accidents (Plate 12). As shown in Plate 15, shipmaster A did a small amount of backing and filling at the B cut and then exceeded the channel limit at the C cut. In his first run, shipmaster B remained inside of the channel in the area of both the B and C cuts. However, in his second run (Plate 16), he maintained a smooth and continuous motion around the B cut area but then had to back and fill at C and still went slightly out of the channel. Upstream of the 21st Street Bridge, shipmaster A, shown in Plate 17, grounded slightly on the port bow. As shown in Plate 18, shipmaster B did a substantial amount of backing and filling and still seriously grounded in his first run. However, in his second run he remained within the channel limits. This may be due to the fact that he was not given adequate time to familiarize himself with the equipment.

35. The Plan 2 condition was run with the design ship loaded to 25.5 ft with an underkeel clearance of 1.5 ft, similar to the Plan 1 condition. As seen in Plate 19, a more smooth and continuous motion occurred in the area of the B and C cuts as compared to the other conditions. More backing and filling was done in the area of cut 1 and cut D. This is thought to be caused by a change in bank effects that was not anticipated by the shipmasters.

36. As shown in Plate 20, shipmaster A left the channel slightly downstream of the Erie Avenue Bridge. He was then required to back and fill near the small-boat harbor, where he backed into a docked ship. Shipmaster B navigated to the Erie Avenue Bridge without incident but was also required to back and fill between the Erie Avenue Bridge to the Norfolk and Western Railroad Bridge, and in doing so, went out of the channel twice (Plate 21). Plate 22 shows that in the area from the Norfolk and Western Railroad Bridge to the 21st Street Highway Bridge, shipmaster A's run of this condition was very similar to his run of the Plan 1 condition. He did a small amount of backing

and filling at the B cut and then exceeded the channel boundary in the area of the C cut. Shipmaster B (Plate 23) came in contact with the channel boundary at the area of the B cut in his first run. However, his second runs illustrated a smooth and continuous motion around these two bends. This, again, could be due to his learning to operate the simulator. Both shipmasters A (Plate 24) and B (Plate 25) encountered serious problems navigating downstream of the 21st Street Bridge. As stated previously, this is thought to be caused by the slope of the bank cut in this area. However, as shown in Plate 26, the second run of shipmaster B shows smooth and continuous motion throughout the channel. This illustrates that, if the shipmasters were aware of the bank effects, they could adjust accordingly.

37. All of the turning basin maneuvers were run with a draft of 18.2 ft with a large underkeel clearance (8.8 ft). The shipmasters backed their ships at a heading of 70 deg into the largest part of the turning basin. They then rotated counterclockwise and headed down the Black River.

38. In the existing condition, serious groundings occurred (Plate 27) in the turning basin. As shown in Plate 28, shipmaster A was responsible for both of the groundings. Shipmaster B did not exceed the channel limits.

39. Similar to the existing condition, Plan 1 showed several groundings (Plate 29). Whereas shipmaster A grounded in the existing condition, he did not in Plan 1. Shipmaster B was responsible for the groundings in this condition (Plate 30). It should be pointed out that due to the lack of formal validation of Phase 1, shipmaster A did not start from the proper initial condition (Plate 31). This may have caused somewhat different results.

40. In the Plan 2 condition as in Plan 1, shipmaster A started from a different initial condition. Both shipmasters were able to make the required turn without grounding (Plate 32).

41. Time analysis. For the time analysis of the inbound runs of Phase 1, the channels were divided into three areas (Figure 13). Area 1 was defined as the Erie Avenue Bridge to the Norfolk and Western Railroad Bridge; this isolated cut 1 of Plan 2. Area 2 included cuts B and C. It started at the Norfolk and Western Railroad Bridge and ended at the 21st Street Highway Bridge. Area 3 contained cut D of Plan 2 starting at the 21st Street Highway Bridge and stopping at the farthest point of the shortest run. The partial runs of shipmaster B that made up his second set of runs contained areas 2 and 3. Run times for each area are given in Table 2.

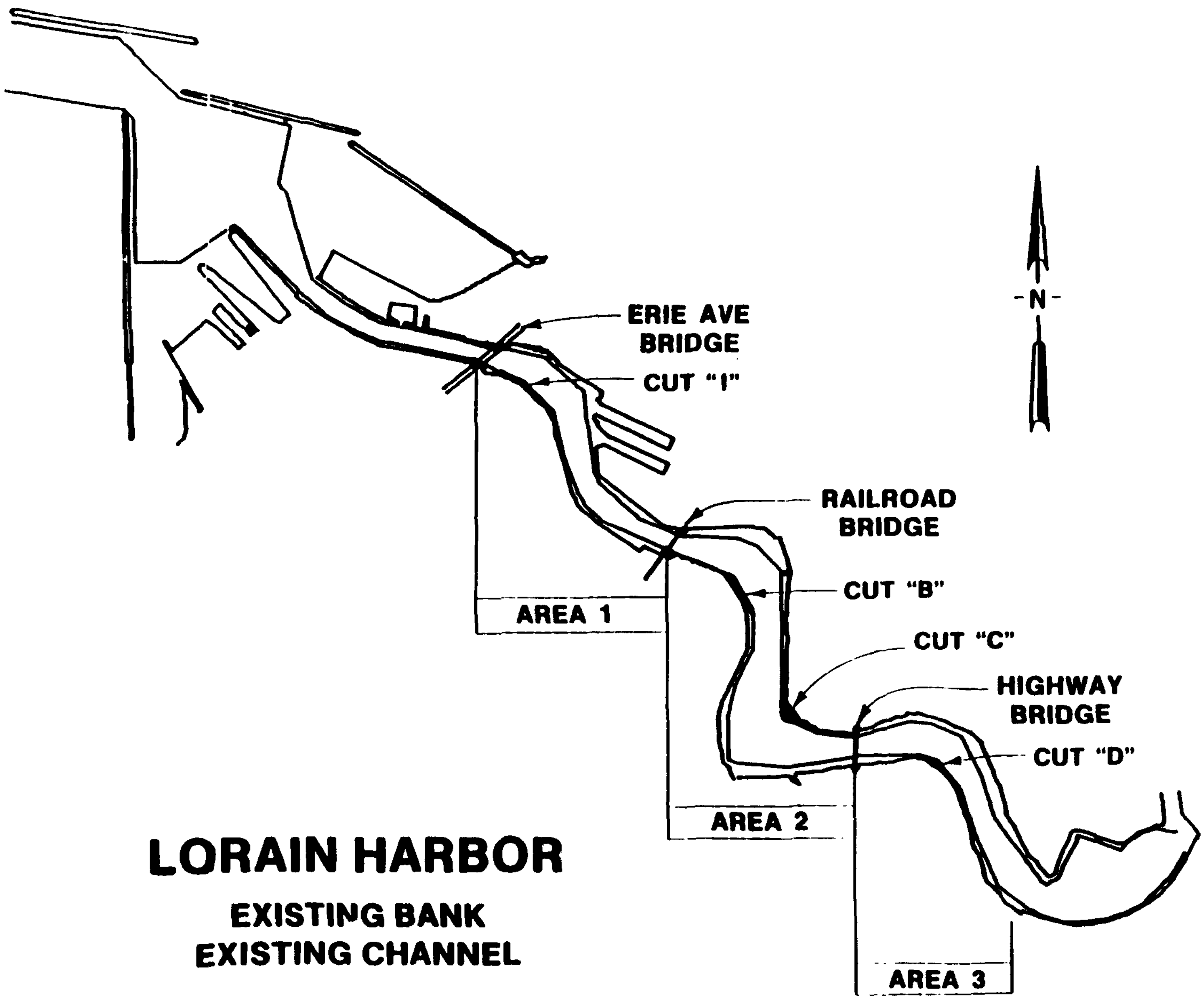


Figure 13. Three areas defined for time analysis

42. Plan 1, which had no cuts in area 1, took longer than the existing condition due to the additional draft. There was a slight decrease in time for Plan 2 compared to Plan 1 but not enough to show a time savings over the existing condition. The shipmasters were not able to navigate through the additional channel available due to cut 1 because of the alignment required to clear the Erie Avenue Bridge. Therefore, no advantage could be accredited to the proposed widening.

43. As shown in Plate 22, shipmaster A did not take advantage of the cuts available to him in area 2. This may be due to the problems with the bow thruster. When commanded, the bow thruster would lose power periodically, causing the ship's maneuverability to decrease (Figure 14). Shipmaster B also had a problem with the bow thruster during his first run of Plan 2. However, Figure 15 shows that in his other runs he managed to obtain a decrease in transit time of approximately 5 min.

44. The transit time in Plan 1 and the existing channel were nearly the same in area 3 (Figure 16). Since there were no cuts in this area of Plan 1, this suggests that the additional draft caused no problems with navigation. The transit time was increased in area 3 of Plan 2. It appears that the design of cut D caused bank forces that were not anticipated by the shipmasters. As shown in Plate 25, this resulted in the ship being pulled toward the port-side bank. Backing the vessel was necessary to get it returned to its proper course.

45. In the turning basin, the shipmasters backed into the largest area and then implemented the thrusters, causing rotation to the port. Once properly located in the turning basin, they used the rpm to return the ship to minimum speed. From then on, the rpm was used only to avoid the banks until it was time to come out of the turn.

46. Both shipmasters took advantage of the turning basin cut in Plan 1. Shipmaster A stated that the additional cut in Plan 2 was not necessary. However, in the existing channel (Plate 28), this is an area where he had trouble. Therefore, it was determined that both cuts were beneficial.

47. Due to time restraints, shipmasters were not given long enough in the turning basin tests to bring their ships out of the turning basin and under control sufficiently to consider time differentials between runs. It was determined that more testing was necessary to measure time savings attributed to the proposed turning basin cuts.

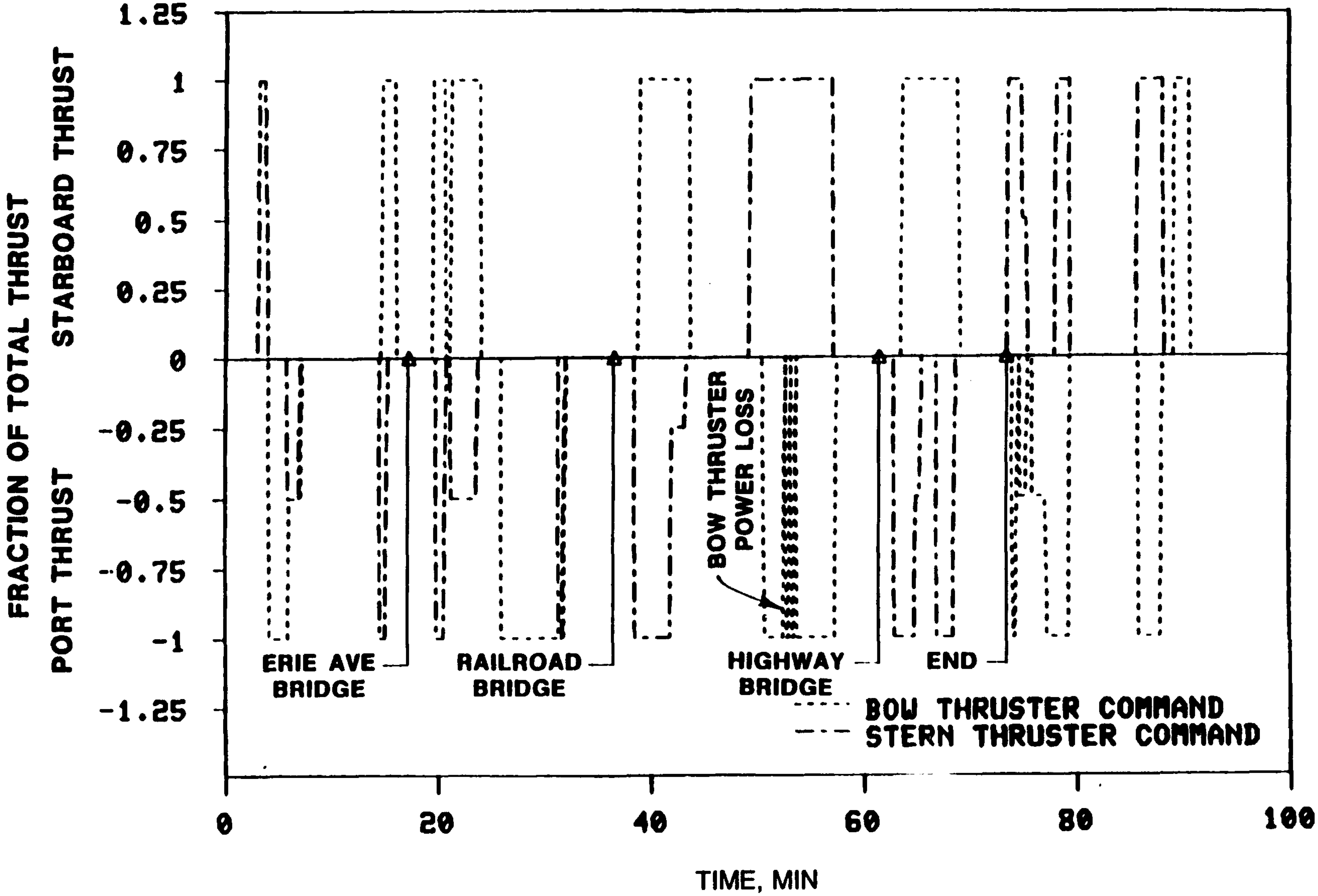


Figure 14. Bow thruster periodically losing power

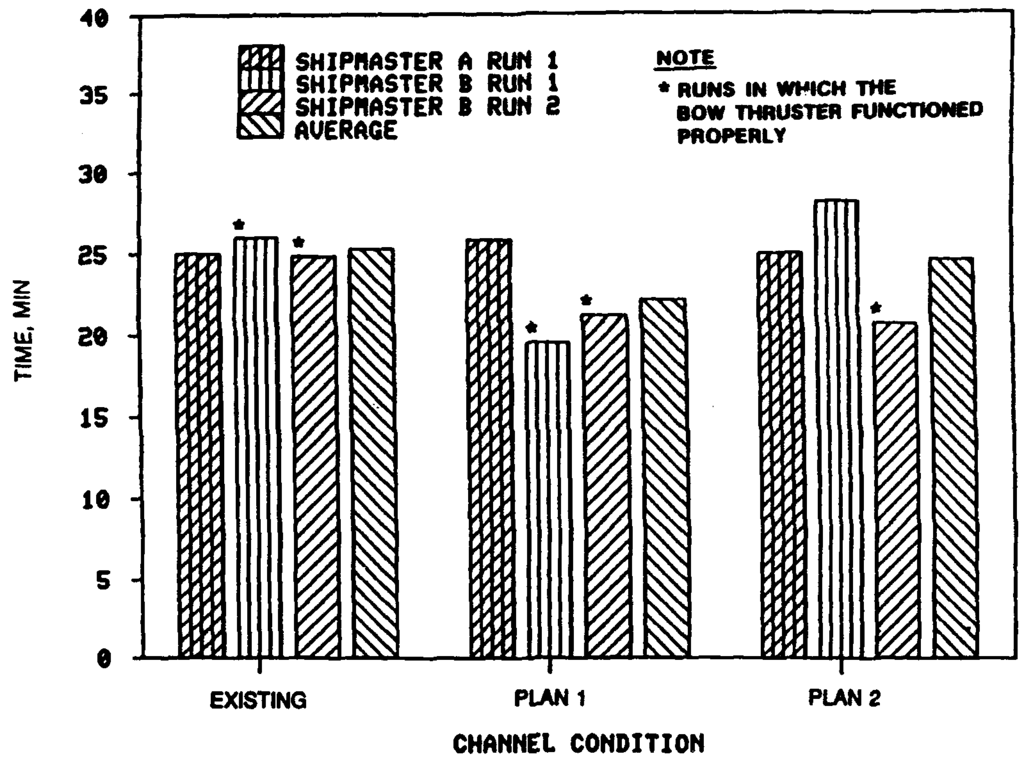


Figure 15. Time to navigate area 2

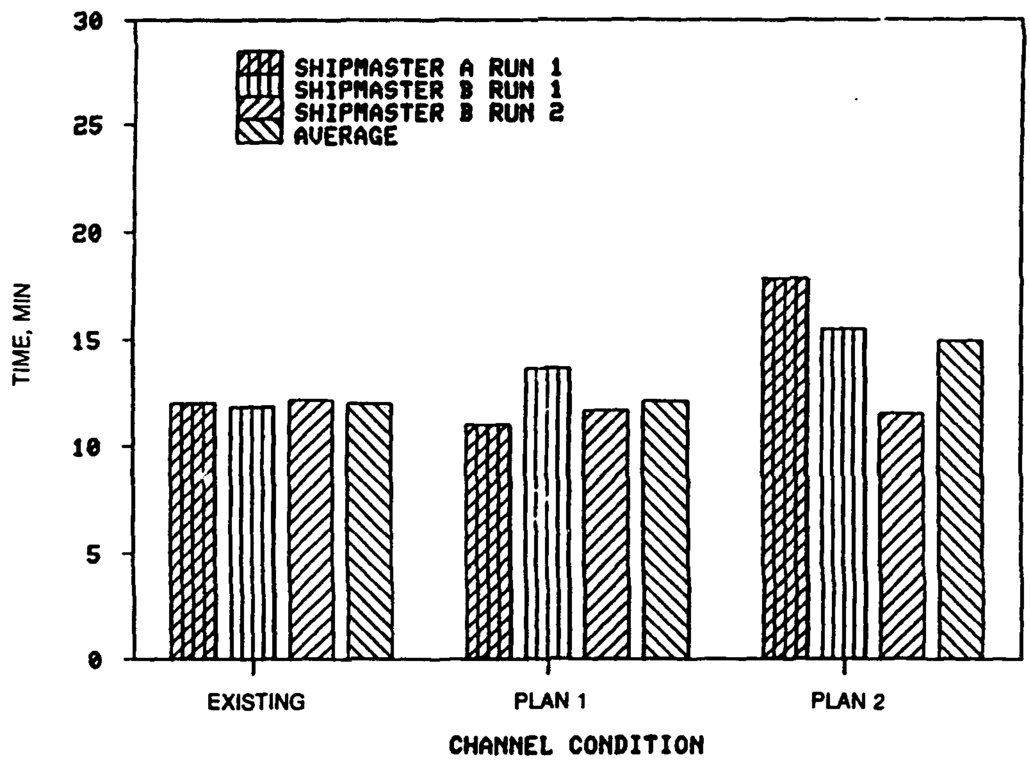


Figure 16. Time to navigate area 3

Conclusions

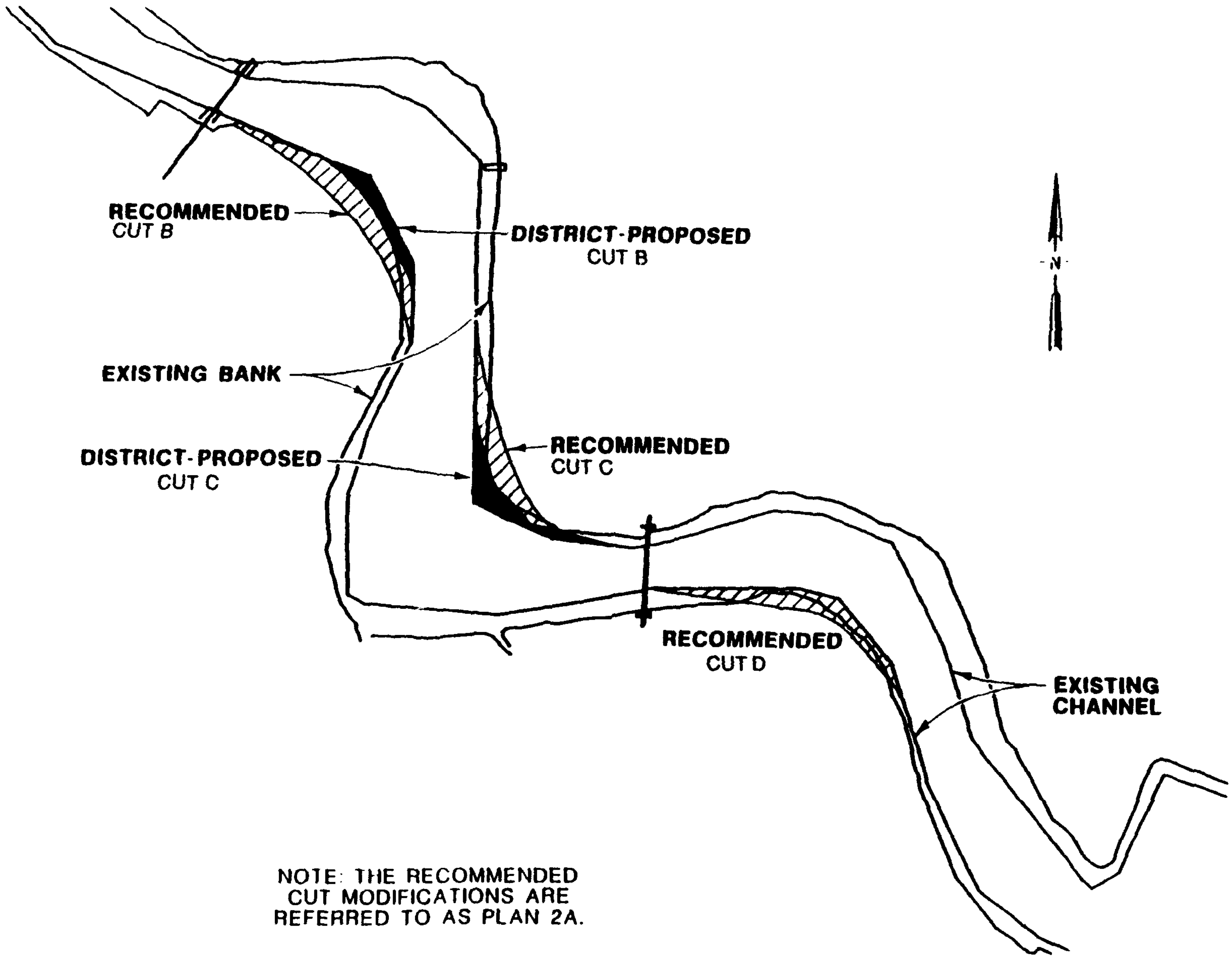
48. At the completion of Phase 1, it was determined that the data available were not adequate to make any definite conclusions. More testing was recommended.

49. Cut 1 showed no time savings and was eliminated from further testing. Cuts B and C illustrated a trend toward decreasing transit time. These cuts along with cut D were refined in an attempt to increase the time savings. The recommended cut modifications, illustrated in Figures 17 and 18, were tested in Phase 2 as Plan 2a.

50. Analyzing only the runs during which the bow thruster functioned properly, inbound runs showed a decrease in transit time by approximately 5 min. In the existing channel, using the bow and stern thrusters, the shipmasters' average speed was 1.85 mph. The channel cuts as tested allowed shipmaster B to increase his average speed to approximately 2 mph. It was thought that time savings could reach 15 min, which would correspond to an average speed of about 2.5 mph. This was estimated to be the maximum average speed at which the shipmasters can operate safely in this channel. The transit time will not decrease by 40 min as discussed in the feasibility study because this would require an average speed of over 6 mph, which would render both bow and stern thruster useless. This was proven to be accurate in Phase 2. It was assumed at the completion of Phase 1 that the addition of the stern thruster to the design ship subsequent to the completion of the feasibility study reduced the time savings portion of the benefits. However, Phase 2 showed that the stern thruster did not decrease transit time significantly.

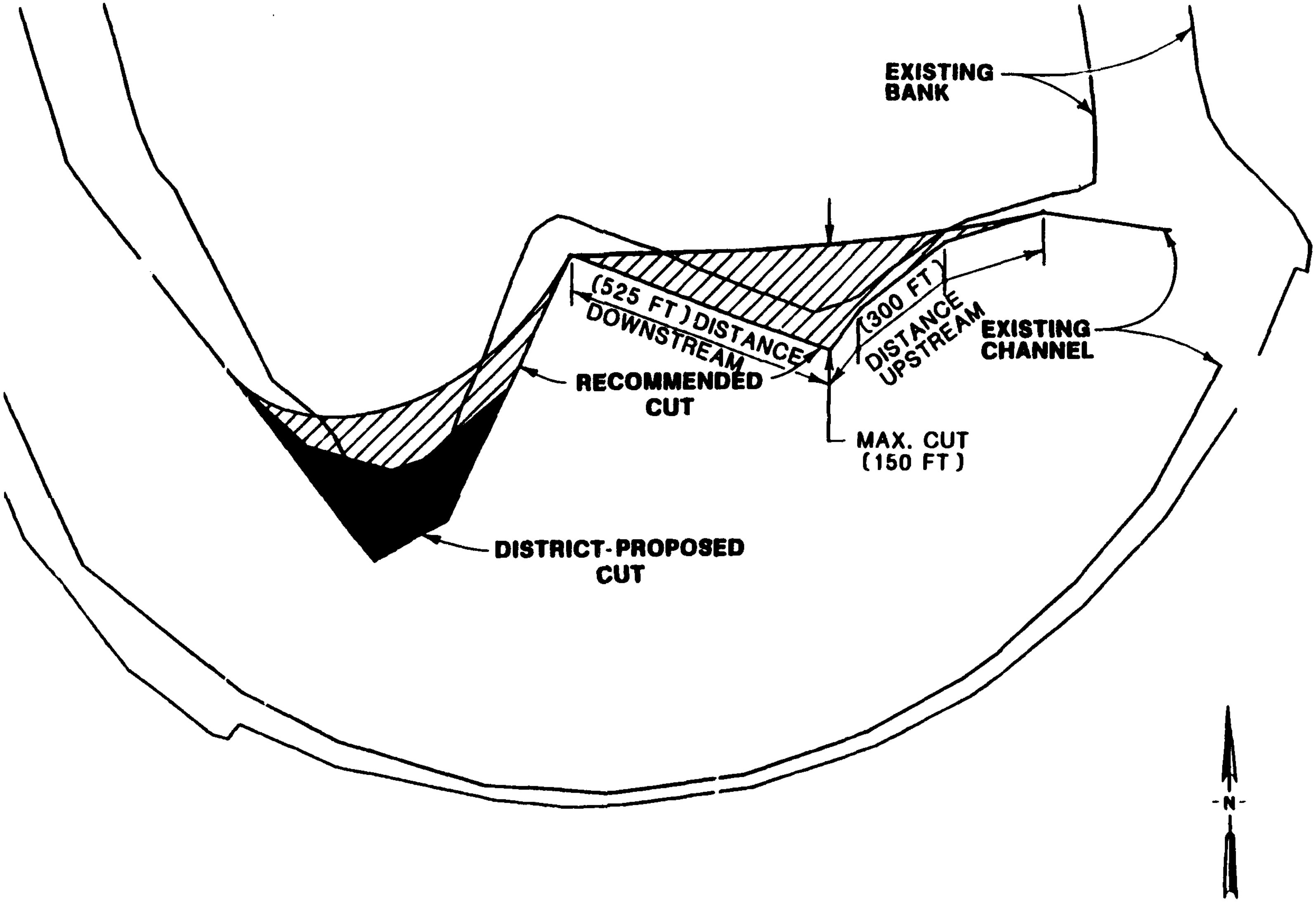
51. The 12-in. increase in draft created no detrimental effect on ship navigation. This part of the project benefits is an issue concerning safety that will require a change in USS GLF policy and cannot be addressed solely by this research.

52. The turning basin tests suggested that benefits could be achieved from bank cuts due to time savings to turn the ballasted ship. If the cuts were increased slightly, it was thought that the shipmasters could make the turn without going out of the channel or requiring backing. The recommended turning basin cuts, shown in Figure 18, were implemented as part of Plan 2a, which was tested in Phase 2 of the project.



NOTE: THE RECOMMENDED CUT MODIFICATIONS ARE REFERRED TO AS PLAN 2A.

Figure 17. Recommended channel versus Plan 1



NOTE: THE RECOMMENDED CUT MODIFICATIONS ARE REFERRED TO AS PLAN 2A.

Figure 18. Recommended turning basin versus Plan 1

Validation tests

53. For the purpose of validating Phase 2 of the Lorain Harbor Ship Simulation Study, two active shipmasters from the Great Lakes made simulation runs prior to testing. The purpose of the validation test was to verify and adjust, as necessary, model parameters such as bank effects, ship coefficients, and objects in the visual scene based on the shipmaster's experience and familiarity with the study area.

54. The validation tests were conducted on the ship simulator for the existing channel scenarios. Because there are no aids-to-navigation in this reach of channel, the shipmasters use physical features as informal ranges and location sightings. Attempts were made to incorporate these features in the visual scene prior to validation; however, many were not included. Both shipmasters validating the simulation spent much time adding tanks, poles, and buildings to the visual scene since they used different landmarks as guides. In addition, thruster horsepower and bank effect factors were adjusted based on the shipmasters' comments. Upon leaving, the shipmasters remarked how close to reality the simulation had become following these changes.

Test conditions

55. During Phase 1, it was determined that cut 1 showed no benefits and it was eliminated from Phase 2 testing. This allowed the testing for Phase 2 to begin at the Norfolk and Western Railroad Bridge instead of at the outer harbor. Cuts B and C demonstrated a trend toward decreasing transit time. These cuts, along with cut D, were refined to work together to increase the time savings. The turning basin tests suggested that benefits can be achieved from bank cuts due to time savings to turn the ballasted ship. If enlarged slightly, it is possible that the cuts will allow the shipmasters to make the turn without going out of the channel or requiring extra backing operations. The recommended cut modifications to Plan 2 are shown in Figures 17 and 18. These recommended bank cuts were implemented in the simulator for Phase 2 testing and are referred to as Plan 2a. A summary of the two plans tested during Phase 2 is shown in Table 3. This table gives the maximum cut as well as the distances downstream and upstream measured along the toe of the cut. Figure 18 shows how these measurements were taken. This method differs from that of Plan 1, since in paragraph 8 the average cut is given and the length

is measured using a straight line from one end of the cut to the other.

56. The simulation study was designed to test both channel alternatives for comparison with the existing condition. Figure 19 shows the three channel alignments that were tested in Phase 2: existing, Plan 1, and Plan 2a. The ship used in the simulation was the *A. M. Anderson*, described in paragraph 18. Some of the tests involved both bow and stern thrusters as the ships are presently configured, while other tests involved only the bow thruster as these ships were configured during the feasibility study. Since increasing the draft of the ship is one of the benefits of the project, it was necessary to run tests of the ship at different drafts. Tests were run with the present high-water condition at lake level 571.1 ft IGLD, +2.5 ft lwd. The draft of the ship during an inbound run at this elevation was 27.0 ft, the maximum design draft of this vessel, and the underkeel clearance was 2.5 ft. Tests were also run at lake level 568.6 ft IGLD. The draft of the ship during an inbound run at this elevation was different for the existing condition than for the two proposed conditions. For the existing condition, the draft of the ship during an inbound run was 24.5 ft and the underkeel clearance was again 2.5 ft. For the two proposed conditions, the draft of the ship during an inbound run was 25.5 ft with only 1.5 ft of underkeel clearance. This takes into account the 12-in. decrease in underkeel clearance that results in the increase in draft that is discussed as one of the project benefits in the feasibility study.* Since the normal operating procedure is to transit inbound to the United States Steel/Kobe Steel (USS/Kobe Steel) terminal, unload iron ore, and leave the dock unloaded, all outbound runs were made with the ship in a ballasted condition. This corresponds to a ship draft of 18.2 ft. For this condition the underkeel clearance was large (greater than 8 ft).

57. All tests were run with slack water and no wind. Since astronomical tides were said to be negligible at the project site in the project's feasibility report, it was tentatively proposed that the simulations be done in slack water.** The test conditions were confirmed at a meeting on 3 March 1988 by a representative of USS GLF, Captain John McDonough. At this meeting,

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* US Army Engineer District, Buffalo, op. cit.

** Personal Communication, 3 December 1987, to Commander, US Army Engineer Division, North Central, from Robert W. Whalin, US Army Engineer Waterways Experiment Station, Subject: Vessel Simulation Study of the Lorain, Ohio, Deep-Draft Commercial Harbor.

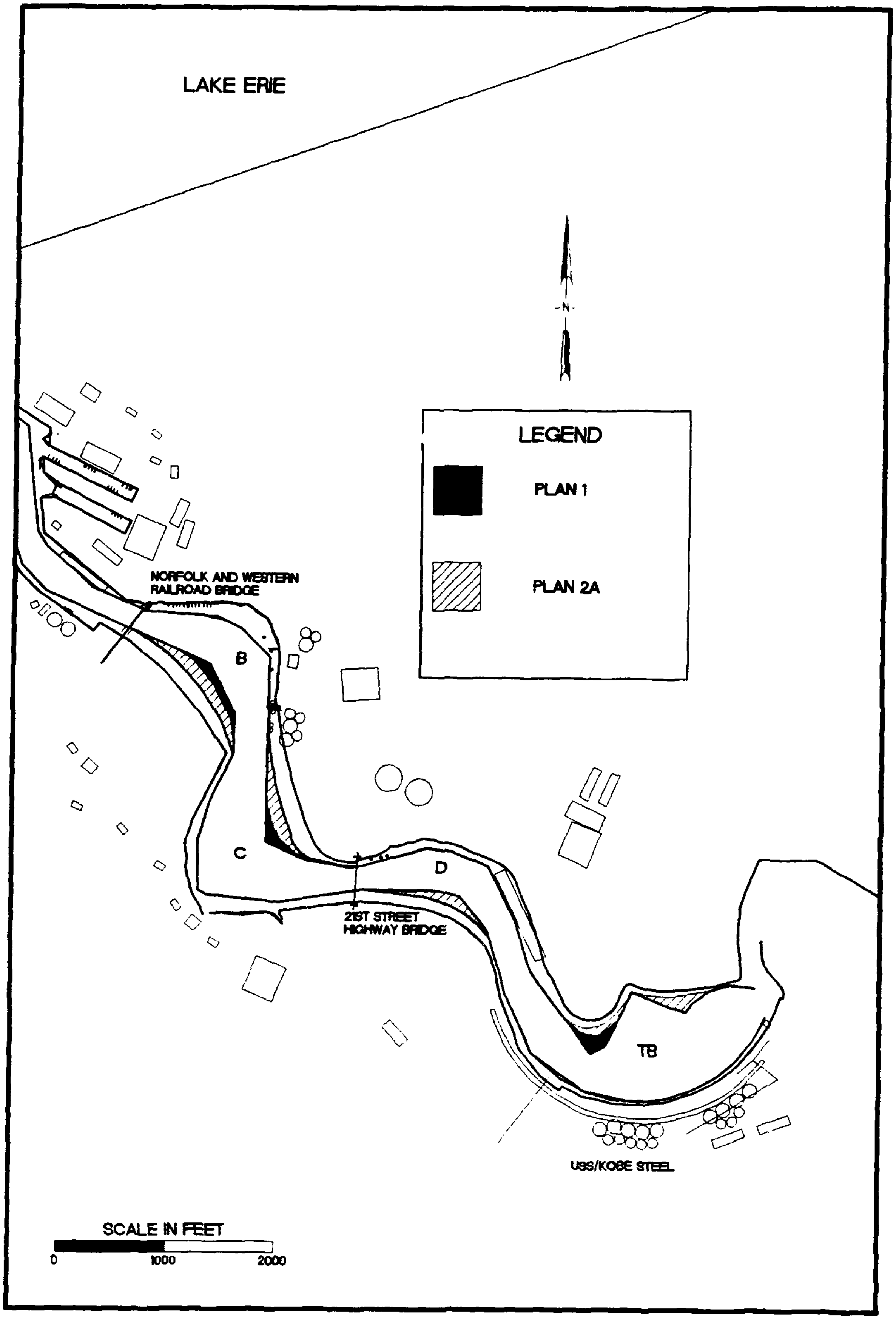


Figure 19. Plans tested during Phase 2

it was indicated that the only currents of consequence result from upland storm runoff, which is of short duration. High flows occur infrequently during the sailing season and ships wait for flows to abate before transiting the river. The study was designed to evaluate the relative effectiveness of the alternative bank cut plans. Simulations with current effects would not improve the bank cut impacts; on the contrary, currents would tend to obscure any effects. Wind effects on the ships are small due to the high topography along the channel.

<u>Test procedures</u>

58. Four shipmasters (C, D, E, and F) assisted in the Phase 2 simulation test runs. Shipmasters A and B participated in the Phase 1 testing. Three of the four involved with Phase 2 are active shipmasters on the Great Lakes with experience in using the stern thruster. The fourth, D, is a retired shipmaster from the Great Lakes. Prior to retiring, this shipmaster frequently transited the Black River; however, he did not have the aid of a stern thruster. Shipmaster E had experience with the class of ship used in this study; however, since the company he works for has scrapped the 767-ft-long ships, he navigates a 658-ft-long ship. He has experience in the Black River only up to the gypsum plant located upstream of the 21st Street Bridge. Shipmaster F has experience with the 767-ft-long ships; however, he has no experience navigating the Black River. Shipmaster C navigates the design vessel into the terminal at the upper end of the project. This shipmaster has a more appropriate experience base for this study than the others. Two additional shipmasters validated the ship simulator model. They have similar background to the test shipmaster C.

59. Twenty-four combinations of conditions were tested. Inbound runs started from the Norfolk and Western Railroad Bridge with a heading of 120 deg and proceeded up the Black River to the USS/Kobe steel mill dock. Outbound runs began at the dolphin at the eastern end of the USS/Kobe dock with a heading of 70 deg. The shipmaster backed into the turning basin, rotated counterclockwise, and then headed downstream. The run ended at the Norfolk and Western Railroad Bridge. A total of 113 runs were made in 16 days spanning a 5-week testing period. A complete list of test runs is presented in Table 4.

<u>Test results</u>

60. <u>Shipmaster's rating.</u> As in Phase 1, two questionnaires were prepared to document the shipmasters' comments and rate each run. One was given

to the shipmasters after each run, and a final debriefing questionnaire was given to the shipmasters upon completion of the testing period. For each run, the shipmasters were asked to rate the difficulty of the run, the likelihood of grounding, damage caused to docked ships by the wake or thruster wash, the accuracy of the simulated bank effects and ship, and the controllability in areas B, C, and D, as shown in Figure 19. These areas were defined as follows: B, from the Norfolk and Western Railroad Bridge past the bend in the river at the gypsum dock; C, from the gypsum dock to the 21st Street Highway Bridge; and D, the 21st Street Highway Bridge to the turning basin. Area A was not included in Phase 2 testing and therefore was not rated. The turning basin was rated as a whole and not broken into two areas as shown in Figure 12. The simulator accuracy was rated above average as shown in Plate 33.

61. Inbound transits. For the other categories, a lower rating generally indicated a safer channel. It was anticipated that the existing channel would have the highest ratings, Plan 1 would have significantly lower ratings than the existing condition, and the Plan 2a rating would be slightly lower than Plan 1.

62. The shipmasters' ratings for the controllability in all areas for conditions 1 through 6 defined in Table 4, inbound runs with the stern thruster available for navigation, are shown in Plate 34. All of these ratings show the anticipated results, i.e., Plan 2a better than Plan 1, which is much better than the existing condition. Plate 35 shows the ratings of difficulty of run, danger of grounding, and damage to docked ships for these conditions. The expected results are observed for all conditions with the exception of condition 3 in Table 4, the Plan 2a transit with a lake level of 571.1 ft IGLD for the rating damage to docked ships. As discussed in paragraph 70, test results for this condition showed plenty of clearance compared to the existing as well as the Plan 1 conditions. Shipmaster F rated this condition 9 out of 10 while the other shipmaster ratings ranged from 0 to 3 out of 10. He gave high ratings to the similar existing and Plan 1 conditions; however, he did in fact give a lower rating to Plan 1 than Plan 2a. It seems that shipmaster F, being unfamiliar with the Black River, did not know the extent of damage that would be caused to docked ships.

63. The ratings for the controllability of the ship for inbound runs without the stern thruster, conditions 7 through 12 in Table 4, are shown in Plate 36. The only area that did not exhibit the expected results was the

turning basin. Shipmaster D gave this area much higher ratings than did the other shipmasters. He gave Plan 2a a lower rating than Plan 1 and the existing turning basin; but since he made two runs of Plan 2a and only one run of the existing and Plan 1 conditions, the rating for Plan 2a has been raised noticeably. As shown in Plate 37, the ratings for difficulty of run and danger of grounding both illustrate the expected results for these conditions. However, for both the 571.1-ft-IGLD and the 568.6-ft-IGLD lake levels, the ratings for damage to docked ships are not consistent with expectations. Shipmaster D, on his first run, gave an unusually high rating for the Plan 1 condition with a lake level of 571.1 ft IGLD. This seems to be an accurate assessment of this run since he did come close to the dock upstream of the 21st Street Bridge. In his subsequent run of this condition he gave a much lower rating. In the similar condition with a lake level of 568.6 ft IGLD, shipmaster E rated Plan 1 very high (10 out of 10) on damage to docked ships. This run was similar to the one discussed previously in which shipmaster D came too close to the dock upstream of the 21st Street Bridge.

64. The overall averages of the inbound runs are shown with and without the stern thruster in Plates 38 and 39, respectively. It is observed that the shipmasters rated the runs with the stern thruster lower than the runs without the stern thruster. The shipmasters also rated the existing condition lower with the 24.5-ft draft than with a 27-ft draft in both cases. It was easier to navigate the lighter ship with the same underkeel clearance. However, the Plan 1 and Plan 2a channels were given only slightly lower ratings when the draft was decreased from 27 ft to 25.5 ft. Not only was the decrease in draft smaller, 1.5 ft in Plans 1 and 2a as opposed to 2.5 ft in the existing condition, but the underkeel clearance was smaller: 1.5 ft in Plans 1 and 2a as opposed to 2.5 ft in the existing condition. This is a subtle indication that reducing the underkeel clearance cancels the benefits of increasing the draft.

65. Outbound transits. The outbound runs at lake levels of 571.1 ft and 568.6 ft were combined since both were run with a draft of 18.2 ft and an underkeel clearance of over 8 ft. With the stern thruster available to aid in navigation, the controllability ratings in areas B, C, and D exhibit the expected results (Plate 40). These ratings are for conditions 13 through 18 in Table 4. For the turning basin, the Plan 2a channel got a higher rating than anticipated. Shipmaster D gave this condition a very high rating (10 out of 10) for a run determined to be poor and eliminated from further analysis

(paragraph 83). By eliminating this run, the average rating would be reduced from 4.22 to 3.50 out of 10, which would be within the limits of the expected value. Plate 41 shows that the danger of grounding for Plan 2a of this condition was higher than anticipated. This same run was the problem. If it were eliminated, the average rating would fall from 3.89 to 3.37 out of 10, which is slightly less than the 3.57 rating of Plan 1.

66. The outbound runs without the stern thruster, conditions 19 through 24 in Table 4, were rated on controllability as shown in Plate 42. The ratings were higher than anticipated for the Plan 1 channel of this condition in area D. This was because shipmasters D and E gave high ratings, 9 and 7 out of 10, respectively. These shipmasters did have problems in this area; however, no changes were made in this area and they did not have this problem in the existing conditions. This illustrates how the cuts cannot be analyzed separately but the channel must be judged on the design as a whole. This is discussed further in paragraph 114. Plate 42 also shows that the Plan 2a turning basin got higher ratings than the Plan 1 turning basin. Shipmaster E had a run of Plan 2a which was eliminated from analysis for reasons discussed in paragraph 92. If this run is removed, the rating will be lowered to within the expected level. However, eliminating this run does not lower the danger of grounding and the damage to docked ships ratings, shown in Plate 43, to within the range of anticipated values.

67. The overall ratings for the outbound runs (Plates 44 and 45) indicate that without the stern thruster, Plan 1 was slightly preferred as the channel alignment. However, with the stern thruster, Plan 2a was preferable. As expected, Plans 1 and 2a show considerable reduction in rating with the stern thruster when compared to tests without the stern thruster. However, the existing condition is rated about the same with and without the stern thruster.

Composite ship-track plot

68. Inbound transits. Plate 46 shows a composite ship-track plot of all inbound runs of the existing condition. This condition had a lake level of 571.1 ft IGLD and both bow and stern thrusters were available to aid in navigation. This test case is described as condition 1 in Table 4. It was determined that this test condition would be run first since this was the condition that is most familiar to the shipmasters who navigate in Lorain Harbor. Also, the high-water condition was considered to be of importance since this will

more readily display the transit time differential than the low-water case because of the 1-ft differential in draft in the latter case. Shipmaster F did not run this condition first because he had not navigated the Black River and therefore would not be confused by the differences. Plates 47 and 48 are more detailed drawings of the composite ship-track plot of test condition 1. In two out of six runs, groundings are observed. These groundings can be attributed to learning to operate the simulator. On shipmaster C's first run of this condition, he went out of the channel and came dangerously close to the small-boat harbor just upstream of the Norfolk and Western Railroad Bridge, as seen in Plate 47. This plate also shows shipmaster C going out of the channel while backing and filling in the area of cut C. The other grounding shown in this plate and all the groundings in Plate 48 can be attributed to the first run of shipmaster D. Both of these shipmasters reran these conditions, and Plates 49-52 show that the shipmaster's familiarizing himself with the simulator is an important aspect of the testing procedure. Plate 53 shows the composite ship-track plot eliminating these two runs. Shipmaster E, who also ran this condition first, did not exceed the channel limits; however, he did have an unusually slow transit time.

69. Plate 54 shows a composite ship-track plot of Plan 1 (shown in Table 4 as test condition 2) inbound transits with both bow and stern thrusters, and a lake level of 571.1 ft IGLD. Fewer groundings occurred in this condition. This was due to the additional room in which the shipmasters had to navigate. The runs were made in a random order after the first run for each shipmaster so that learning the simulator was not a factor as in the previous test condition. As seen in Plate 55, a very serious grounding occurred just downstream of the 21st Street Highway Bridge. Shipmaster F, who made this run, states, "Excessive speed caused grounding in 'C' area." This is the shipmaster who had not navigated the Black River; however, this was his fifth run and he should have learned how to navigate this river by this run. Plate 56 shows the composite ship-track plot of this condition excluding this run. The transits are much smoother than those in the existing channel condition shown in Plate 53.

70. Plate 57 shows the composite ship-track plot of inbound transits through Plan 2a with both bow and stern thrusters available and a lake level of 571.1 ft IGLD (test condition 3 in Table 4). The shipmasters seem to have had plenty of room in this channel alignment. Plate 58 shows that the same

shipmaster that had trouble in the previous test condition, F, had trouble at the turn entering the turning basin. One explanation for this could be that he was tired since this was the last run of a day that consisted of no successful test runs. His comments were, "Vessel was aground on turn into the basin. Assumed vessel would be far enough off corner when turn was commenced. The trip was easy except for the grounding."

71. Another set of runs was made at elevation 568.6 ft IGLD. Plate 59 shows a composite track plot of inbound runs with the existing channel alignment. Again, bow and stern thrusters were available for aiding navigation. This is shown as test condition 4 in Table 4. No serious groundings occurred; however, it should be noted that a lot of backing and filling was required in the areas of each of the proposed bank cuts. It can be seen in Plate 60 that shipmaster C needed more room to get around the turn at the proposed cut D to remain in the channel as well as to stay clear of the dock.

72. Similar to the existing channel alignment of this condition, Plan 1 required a lot of backing and filling. This is shown in Plate 61, the composite ship-track plot. This test condition involved inbound transits with both bow and stern thrusters and a lake level of 568.6 ft IGLD, labeled condition 5 in Table 4. A reduction in the amount of backing and filling is observed in the area of cut D in this plan from the existing condition even though no cuts have been implemented in this area. While navigation conditions improved, they did not improve as much as hoped with the bank cuts. These runs were made with a 1-ft increase in ship draft, thus reducing the underkeel clearance that was tested in the existing condition and making the vessel less maneuverable.

73. The composite ship-track plot of inbound transits with both bow and stern thrusters at a lake level of 568.6 ft IGLD implementing the Plan 2a design is shown in Plate 62 (test condition 6 in Table 4). This plate illustrates more of a smooth and continuous ship track than appears in the other conditions. On the more detailed drawing (Plate 63) a problem does appear near the 21st Street Bridge. The shipmasters were able to navigate past cut C much more quickly than before; therefore, they were overshooting the 21st Street Bridge and were just outside the southern boundary of the channel when passing through it. It can be seen in Plate 64 that the shipmasters are aided in this problem by cut D. If this cut was not implemented, the track-lines would remain outside the southern channel boundary for over 500 additional

feet. Cut D also relieved the bank effects and enabled the right turn in the bend to be accomplished more effectively.

74. All of the previously discussed runs were also tested without the stern thruster available for navigation. The ship-track plot of the existing condition is shown in Plate 65. This plot corresponds with test condition 7 in Table 4 and involves inbound transits at a lake level of 571.1 ft IGLD. From the track-lines, it can be seen that these runs are more difficult than those previously discussed. This is to be expected since the ship has been made less maneuverable. Plate 66 shows shipmaster C causing substantial damage to the bow of the ship by striking a dolphin just outside of the channel line. Shipmaster C gave no indication as to why this occurred; however, it appears from his single track-line plot (Plate 67) that he did not initiate backing soon enough upon exiting the Norfolk and Western Bridge span. Since he has been using a stern thruster in recent years, he may have not adjusted his strategy to the approach used prior to adding the stern thrusters. It appears he did not allow for the lack of turning power at the stern. Plate 68 shows the composite ship-track plot of this test condition eliminating that run.

75. Inbound transits with bow thrusters only at a lake level of 571.1 ft IGLD with the Plan 1 design (shown in Plate 69) are listed as test condition 8 in Table 4. This channel alignment appears to require less backing and filling than the existing condition (Plate 68). However, much more backing and filling was done in this condition than in the similar condition with the stern thruster available to the shipmasters (Plate 56). The only point of difficulty appears to be turning into the turning basin as seen in Plate 70. Shipmaster D appeared to be transiting too quickly approaching the turning basin. Backing and filling became necessary and the ship went out of the channel when attempting to back. Because this was the 32nd run made by shipmaster D in one week, it is possible he was tired.

76. For test condition 9 from Table 4, Plan 2a bank cuts were implemented with inbound runs at a lake level of 571.1 ft IGLD with no stern thrusters. The composite ship-track plot of this test condition is shown in Plate 71. Much variance is seen in the area of cut C (Plate 72). This was caused by shipmaster E not being able to make a smooth and continuous transit around cut C and losing control during backing and filling. This run was hampered by a hardware error that allowed only 25 deg starboard rudder, which

seriously hindered the shipmaster's ability to maneuver the ship.

77. The Plan 2a bank cuts allowed smoother ship transits than the other channel alignments for this same condition. Plate 73 shows that in order to take advantage of the wider channel at the point at cut C, the ship came close to the starboard bank at the downstream end of cut D. In fact, some runs went outside the channel just upstream from the 21st Street Bridge. This is similar to the situation discussed in paragraph 73. This indicates that cut D should be extended downstream through the 21st Street Bridge. Cuts C and D are closely related and the advantages of one cannot be gained without implementing both cuts.

78. Proceeding to the low-water runs without the stern thruster available, the ship-track plot of the existing condition is shown in Plate 74. This corresponds to test condition 10 in Table 4. There are no obviously bad runs of this condition despite the excessive amount of backing and filling required to navigate upstream.

79. Because of the 1-ft increase in draft, the Plan 1 design appeared to require the same amount of backing and filling as the existing channel alignment for this condition. This is shown in Plate 75, the composite track plot of the inbound transits with no stern thruster at a lake level of 568.6 ft IGLD, identified as test condition 11 in Table 4. Plate 76 shows shipmaster E encountering significant problems in the cut D area. He apparently gained too much speed while navigating through the 21st Street Bridge span and lost control while recovering from the turn.

80. Unlike the runs using the stern thruster, with Plan 2a the shipmasters were still required to do much backing and filling. Plate 77 shows the ship-track plot of these inbound transits at lake level 568.6 ft IGLD, described by test condition 12 in Table 4. Plate 78 again shows shipmaster E gaining too much speed and losing control in a turn. The only apparent explanation for this accident and the one discussed previously seems to be that this particular shipmaster may have been too concerned with speed and forfeited safety. This is contrary to the attitude expressed by other shipmasters.

81. Outbound transits. All twelve runs previously discussed were run outbound as well as inbound. With the lake level 571.1 ft IGLD and the stern thruster, the existing condition track-line plot is shown in Plate 79. This corresponds with test condition 13 in Table 4. Since the ships were

ballasted, the shipmasters could exceed the channel limit without grounding; therefore, each run that went out of the channel will not be noted. However, as seen in Plate 80, shipmaster D seemed to have a problem with the second half of this run. The shipmaster appeared to have a problem judging the ship's motion. This probably was due to the failure of the projector, which displays the visual scene of the simulation, to operate properly during this run. Without the projector, the shipmaster used a 14-in. monitor for the visual scene display with the radar image to guide him.

82. The projector was not working for this shipmaster's run of the Plan 1 design either. These transits with both bow and stern thrusters at lake level of 571.1 ft IGLD are test condition 14 in Table 4, and the composite ship-track plot is shown in Plate 81. A smooth and continuous transit with little variance between runs is shown around cut C. It can be seen in Plate 82 that shipmaster D hit the bank in the first part of the turning basin. He stated after completing this run: "Did not back up far enough in turning basin." This was probably because he did not have the visual cues that he had been using.

83. Problems with the projector continued to hamper shipmaster D with the Plan 2a channel design. On the ship-track plot of outbound transits with bow and stern thrusters available at a lake level of 571.1 ft IGLD (test condition 15 in Table 4), a lot of grounding is evident (Plate 83). During this run the radar went down on shipmaster D. His run of this condition is shown in Plate 84. Plate 85 shows the composite ship-track plot eliminating this run. This condition demonstrates a smooth and continuous track from the cut D area to the end of the run.

84. For the lake level 568.6 ft IGLD condition, the composite ship-track plot of the existing channel alignment is shown in Plate 86. Plate 87, the first half of the condition described as test condition 16 in Table 4, shows three severe groundings. Shipmaster E grounded leaving the turning basin. As seen in Plate 88, this is an overall bad run. He was using excessive speeds for this channel. Possible reasons for this are discussed in paragraph 80. Shipmaster F got into trouble at the 21st Street Bridge and the run continued poorly from then on. This was his second run, and not being familiar with Lorain Harbor, he must have been still involved in the learning process. Plates 89 and 90, which show his first and second runs, respectively, of this condition, indicate that the first is very unusual. Plate 91 shows this

condition, eliminating the bad runs of shipmasters E and F. Observe the backing and filling done near the area of cut C.

85. The Plan 1 runs of this condition (test condition 17 of Table 4) are shown in Plate 92. In this condition, a smooth and continuous track-line is seen up to cut B where a small amount of backing and filling is necessary. In this condition, cut C seems to have been improved.

86. Transits with stern thrusters available at lake level 568.6 ft IGLD with the Plan 2a channel alignment are shown in Plate 93. This corresponds to test condition 18 in Table 4. Again, a smooth and continuous motion of the ship is possible through the proposed channel. In Plate 94, shipmaster E is shown to have exceeded the southern channel boundary by more than half a ship's beam in the 21st Street Highway Bridge span. If the channel were enlarged as discussed in paragraph 77, this would not be a problem. In fact, the track-lines might even remain inside the channel.

87. These runs appear more difficult when the stern thruster is not available. The composite ship-track plot of the existing condition is shown in Plate 95. This corresponds to test condition 19 in Table 4. Shipmaster D had an overall bad run in this condition. His comments were that the ship had a very slow response on backup. Yet he rates accuracy of the simulated ship behavior as 10, the best possible grade. A single track plot of this run is shown in Plate 96.

88. Tests of Plan 1 with this condition are defined as test condition 20 in Table 4. Once again, shipmaster D shows deviation from the norm. Plate 97 shows the composite ship-track plot of this test condition. The three locations in which shipmaster D encountered trouble can be seen more readily in Plate 98.

89. Shipmaster C seems to have had problems with these conditions in the Plan 2a channel alignment (test condition 21 in Table 4). The composite ship-track plot of this condition is shown in Plate 99. Despite hitting the gypsum terminal, he rates this run as very easy. A single track plot of this run (Plate 100) shows that this is the only location in which he encounters a problem. By not having a stern thruster, he lost control of the stern of the ship and hit the dock. All three channels require backing and filling under this condition.

90. For the low-water runs of the existing condition, a composite track plot (Plate 101) shows very little excursion beyond the channel boundary.

This corresponds to test condition 22 in Table 4.

91. Test condition 23, the Plan 1 design, is shown as a composite ship-track plot in Plate 102. The ship tracks in Plates 103 and 104 that include extensive backing and filling belong to shipmaster E and reflect again the hardware problem limiting starboard rudder to a maximum of 25 deg (discussed in paragraph 76).

92. Ship tracks for the Plan 2a design, test condition 24, are shown on the composite track plot (Plate 105). After a run of this condition, shipmaster E expressed fatigue and his testing was terminated. It is his track plot that hits the concrete dock opposite the turning basin with the stern of the ship (Plate 106). Shipmaster E does not normally turn in this turning basin, and it does not appear that this collision is related to the turning basin design.

93. It may be of concern that the reason for bad runs seems to be repetitive. For example, many of the runs conducted without the projector were not successful. One may inquire as to whether all the runs made while the projector was down should be discarded. However, 13 runs were made without the projector and eliminating them would mean eliminating over 10 percent of the total runs. Also, it was apparent from the inbound runs of Plan 1 (test condition 8 listed in Table 4) that shipmaster D made one good run not using the projector (Plate 107), and then later made a run with the projector that was much worse (Plate 108).

94. The same type of question arises with shipmaster E's runs in which he was limited to 25 deg starboard rudder. In this case, only two out of the five runs with this problem were unsuccessful. Shipmaster E had four runs that had problems for other reasons. Some of the runs with only 25 deg starboard rudder (Plate 109) are better than the ones with the full 45 deg starboard rudder (Plate 88). Since shipmaster E made the fewest runs, it is important to keep as much of his data as possible so that his runs have approximately the same weight as each of the other shipmasters. Therefore, all runs that can be judged as acceptable were used for analysis.

95. Time analysis. Four reaches were defined for conducting a time analysis and are shown in Figure 19. The average times to transit these reaches were determined. The computed averages for all runs are shown in Table 5. As discussed previously, 9 of the 113 runs were anomolous and have been eliminated from analysis. Table 6 shows the inbound runs that were

included. The inbound average transit times computed from these runs are shown in Table 7. It can be seen from this table that, for the existing condition, the runs with lake level 571.1 ft IGLD took longer than the runs with lake level 568.6 ft IGLD. The reason for this is that the draft was 2.5 ft greater in the condition with lake level 571.1 ft IGLD. This condition was run with a ship draft of 27.0 ft, whereas the condition with lake level 568.6 ft IGLD was run with a draft of 24.5 ft in the existing condition. Since the ship had a greater draft, it had more mass and momentum and was therefore harder to slow and change its course. The ships therefore had to move at a slower speed to maintain control. The difference in time between these conditions is 9 min.

96. Unlike the existing condition, the proposed conditions do not show the transit time differential between lake levels 571.1 ft IGLD and 568.6 ft IGLD. This is due to the draft differential being 1.5 ft instead of 2.5 ft. Also, the underkeel clearance was different. The condition with lake level 571.1 ft IGLD was run with a ship draft of 27.0 ft with underkeel clearance of 2.5 ft, but the proposed channel with lake level 568.6 ft IGLD was run with 25.5-ft draft with underkeel clearance of 1.5 ft. Since the ship drafts were closer, the transit time differential was less. Also, since less maneuvering was necessary, the increase in draft did not have such a detrimental effect on navigating. With the stern thruster, there was a decrease in time in the condition with lake level 571.1 ft IGLD compared with the 568.6-ft IGLD lake level. This indicates that reducing the underkeel clearance increases transit time; therefore, high water is very beneficial in conjunction with either of the proposed channels.

97. During Phase 1, it was assumed that the addition of the stern thruster detracted greatly from the transit time benefits discussed in the feasibility report. However, the simulation study showed that the stern thruster saved less than 4 min on inbound transits. It is important to note a trend. The feasibility study based the decrease in transit time on the estimate of a shipmaster. Similarly, the assumption that the stern thruster saved a lot of time during inbound transits was based on shipmaster input. The shipmasters seemed to consistently overstate the time savings. The reason for this might be that time is distorted when one is put into a dangerous situation. Since the shipmasters feel more secure with the stern thruster, the time seems to go by faster. This results in a perceived exaggeration of

the time savings and an indication of a larger safety factor.

98. Comparing the existing to each of the proposed channel alignments uses two separate conditions, lake level 571.1 ft IGLD and 568.6 ft IGLD. These conditions vary greatly with respect to time saving because the condition with lake level 571.1 ft IGLD was run with the same ship draft and underkeel clearance for all channel alignments, whereas in the condition with lake level 568.6 ft IGLD, the proposed channels were run with 1 ft more draft on the ship and 1 ft less underkeel clearance.

99. For lake elevation 571.1 ft IGLD with the stern thruster available to aid in navigation, the simulation study shows the time savings due to Plan 1 is 13 min. Four minutes were saved by cut B. Cut C contributed 6 min. In the reach from the 21st Street Bridge to the turning basin 3 min were saved. There was no cut in this reach; therefore, the time savings must be attributed to the shipmasters being able to better align themselves in this area due to previous cuts. Without the stern thruster, only 4 min were saved. This is because the shipmasters were not able to transit this channel alignment without the stern thruster as smoothly as they did the same alignment with the stern thruster, as discussed in paragraph 75.

100. For lake level 568.6 ft IGLD, the Plan 1 bank cuts provide a time savings of 1 min. This is attributed to cut C. Two minutes are saved by the Plan 1 bank cuts at this lake level without the stern thruster. More time is saved without the stern thruster than with the stern thruster because the existing condition takes more maneuvering than the proposed condition. Therefore, not having the stern thruster has a greater effect on the time to transit the existing condition, causing the time differential to increase.

101. The Plan 2a bank cuts for lake level 571.1 ft IGLD with the stern thruster available show a time savings of 15 min. Cut B shows a reduction of transit time of 5 min. Six minutes are contributed by cut C and 4 min of time savings are attributed to the area from the 21st Street Bridge to the turning basin. Without the stern thruster, the Plan 2a bank cuts save 10 min. This is what is expected—a savings close to but slightly less than the savings with the stern thruster.

102. For lake level 568.6 ft IGLD, the Plan 2a bank cuts provide a time savings of 5 min. Cuts B and C each show a reduction in transit time of 2 min. A 1-min time savings is attributed to the final reach. Without the

stern thruster, a time savings of 4 min is observed. Again, this is as expected.

103. All outbound runs were made with a ship draft of 18.2 ft, in ballast. Since the underkeel clearance was large in both the lake levels, there was no need to separate the two conditions as in the inbound runs. The runs that were kept as adequate are shown in Table 8. Note that the two lake levels have been combined. The average transit times for these outbound runs are shown in Table 9.

104. The addition of the stern thruster saved approximately one minute in the outbound runs for all conditions tested. When asked, shipmaster C stated that the stern thruster saved him 20 min in the turning basin. However, the simulation study shows a decrease in time to complete the turning maneuver of only 0.5 min. This is again an example of the distortion of time to the shipmaster when navigating in dangerous water as discussed in paragraph 97.

105. With the stern thruster available for navigation, the time savings due to the Plan 1 bank cuts is 5 min. Two minutes are saved in the turning basin. No time is saved from the turning basin to the 21st Street Bridge. One minute of time savings is attributed to cut C. Two minutes are saved in reach B. Without the stern thruster, the Plan 1 channel alignment saves 2 min.

106. The Plan 2a channel design using the stern thruster saves 7 min for the outbound runs. Four minutes are saved in the turning maneuver. No decrease in time is shown from the turning basin to the 21st Street Bridge. Cut C contributed 1 min of time savings to the total. Two minutes' decrease in transit time is attributed to cut B. Without the stern thruster, 3 min of transit time are saved.

107. Assuming the drafts are the same in the existing and proposed conditions, the total round trip transit time saving for the Plan 1 bank cuts is 18 min and for the Plan 2a bank cuts, 22 min. The time savings for the Plan 2a bank cuts may increase slightly if the addition to cut D as discussed in paragraph 77 is implemented; however, it is not possible to specify this time savings without additional tests of this condition.

108. It can be seen in Table 10 that there is a 9-min time differential between conditions 1 and 4. That is, keeping the same underkeel clearance but increasing the load by 2.5 ft of draft results in a significant increase in transit time. From the outbound runs of the proposed conditions with the

stern thruster, it can be seen (Table 9) that for reaches B, C, and D the time is fixed at 25 min. Since the minimum underkeel clearance of these runs is 8.8 ft and the load is 18.2 ft, it can be assumed that the minimum time to navigate inbound is approximately 25 min. From analyzing test conditions 1-6 (Table 4), the minimum transit time, 25 min, is indicated to be a good approximation for Plans 1 and 2a if the draft is 24.5 ft and underkeel clearance is 2.5 ft. Using linear interpolation, the transit times for the 25.5-ft draft with a 2.5-ft underkeel clearance were calculated. From this it can be seen that the Plan 1 transit time decreases by 5 min due to the increase in underkeel clearance, whereas the Plan 2a transit time decreases by 2 min.

Conclusions

109. The simulation tests showed that navigation is more difficult without the stern thruster This is illustrated by all plans requiring backing and filling without the stern thruster. However, the time savings obtained by implementing the stern thruster are not as great as previously expected. A time savings of approximately 40 min was anticipated, whereas the ship simulation showed a decrease in transit time of only 4 min.

110. For outbound runs, the difference between high- and low-water operations was insignificant since they were all run at the same draft and the underkeel clearance was large. The existing conditions require backing and filling operations for all outbound runs. However, with the stern thruster implemented, Plans 1 and 2a generally show no backing and filling during outbound transits. Plan 2a requires 2 min less for the turning maneuver than Plan 1. Otherwise, Plans 1 and 2a both require the minimum transit time of 25 min from the turning basin to the Norfolk and Western Railroad Bridge.

111. For inbound runs with the stern thruster, no significant backing and filling was observed in Plan 1 or Plan 2a when tested in the high-water case. In the low-water case, Plan 1 required almost as much backing and filling as the existing condition, whereas Plan 2a showed no significant backing and filling. This indicates that Plan 2a maintains good ship handling characteristics with increased load and decreased underkeel clearance.

112. By comparing the high- and low-water conditions for the inbound runs with the stern thruster, the effects of draft, load, and underkeel clearance on time can be ascertained. Increasing the load but keeping the underkeel clearance constant in the existing condition results in a significant increase in time (9 min). Thus, it can be said that increasing the load but

maintaining the underkeel clearance increases the transit time for the same channel conditions. It is observed from comparing the high- and low-water conditions for inbound runs with the stern thruster for the two plans that the benefits of increasing the load are negated because the underkeel clearance is reduced. Continuing with the comparison of low- and high-water conditions for inbound runs with the stern thruster, Table 10 shows that the Plan 2a transit times seem to remain within 3 min of the minimum time set by the maximum speed to navigate this channel. The Plan 1 and the existing channel transit times fluctuate two to three times this much.

113. Plan 2a can be transited using a smooth and continuous motion in any of the conditions if the stern thruster is used. This is important because maintaining continuous forward motion is safer than backing and filling since backing decreases the control of the ship and increases risk of damage to the propeller, rudder, and/or engine. Also, smooth motion requires fewer operations, therefore allowing less chance of error.

114. It has been observed by comparing the track-line plots of the existing condition and Plan 2a of similar test runs (Plates 53 and 57, respectively) that the shipmaster's strategy depends on the channel alignment. The shipmaster's approach to the 21st Street Bridge is much different in Plan 2a than in the existing condition. The transit time decreases in Plan 1 compared with the existing condition in a reach where there are no cuts. Also, at the exit to the bridge span, the ship track is much flatter in Plan 2a than in the existing condition. This indicates that the cuts are related and the benefits of one cut cannot be gained without the other cuts in that plan.

115. When the shipmasters were asked, they ranked the changes to the turning basin as the second most important cut area next to cut C. Shipmaster C states, "The proposed cut at the turning basin would be very helpful (Plan 1) - need not go to plan 2a." Referring to an inbound run with Plan 1 bank cuts, he says, "With the corner cut off on the turning basin in times of current in river - would be less current. Also would be able to start turn earlier. Vessels have had damage due to current entering basin." However, shipmaster F writes, "Remove corner, north point, also widen and deepen notch [see notch in Figure 20]. Vessel turning in wind and current would be able to handle the conditions easier. Also relieves the master on room for the stern to swing."

116. In the existing turning basin the shipmasters have less than one

ship beam (70 ft) of clearance from the point upstream, the point downstream, and the dock. A 767-ft turning circle superimposed on the turning basin is shown in Figure 20 to help visualize this. Since the dock is concrete, any contact between it and the stern of the ship could cause severe damage to the vessel. If the propeller and the rudder assembly are damaged, this would require dry-docking the ship and repair at great expense. Either of these cuts, the one upstream or the one downstream, would increase the clearance between the stern of the ship and the dock, thus improving conditions. However, the downstream cut has the added advantage of lessening the degree of turn necessary to exit the turning basin. This will allow the ship to leave the turning basin, where it is subjected to the forces of crosscurrent, sooner. Also, shipmaster C stated that this cut helped on inbound runs.

117. While the transit times do not indicate benefits that justify the cuts in the turning basin, it is apparent from the diagram (Figure 20) that there is little room for error in the present turning basin. It is believed that improvements to the turning basin will significantly increase the safety and should be implemented.

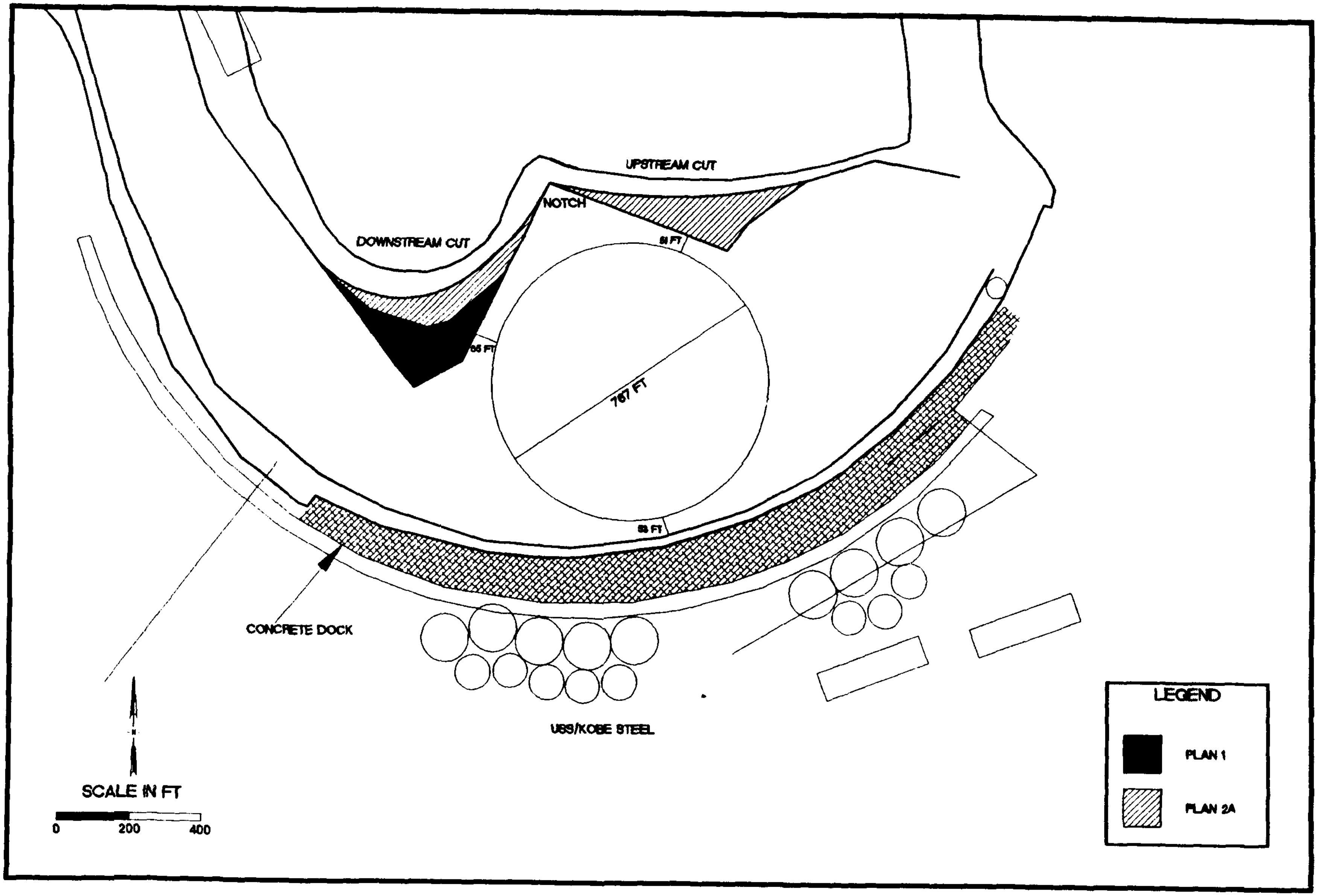


Figure 20. Existing turning basin inscribed with a 767-ft circle

PART IV: VERIFICATION

118. For the purpose of verifying the ship simulator modeling of Lorain Harbor, vessel trip information*,** was obtained from the shipping company. The vessel trip information is outlined in Table 11. Since times were taken only at the outer harbor and at the dock, it was necessary to determine a comparable ship simulator transit time to validate the simulator model.

119. For inbound runs, the simulator time was broken down into three parts in which different information needed to be analyzed. The first reach started at the outer harbor pier and continued to the Norfolk and Western Railroad Bridge. This reach was tested in Phase 1 of the study, but only two runs were simulated. The transit times were 35 and 37 min. The ship draft for these runs was 24.5 ft, which is less than the average ship draft on the trip information (26.5 ft). This means the simulated transits took less time than the actual transits, assuming underkeel clearance was the same. The time for a ship to transit from the Norfolk and Western Railroad Bridge to the entrance to the turning basin was determined for both the 27-ft draft and the 24.5-ft draft (Table 10). Multiplying the ratio of these two numbers by the 24.5-ft run of this first reach gives 46 min. The second reach started at the railroad bridge and ended at the entrance to the turning basin and was tested extensively in Phase 2. The high-water condition was used because the vessel trip information indicated that the ship was loaded to nearly 27 ft in most of the runs. However, some of the ships were not loaded to design capacity (27-ft draft); and as discussed as a conclusion of the simulation report, the transit time is dependent on the ship draft, as well as the underkeel clearance. The average simulated time to transit this reach was found to be 42 min.

120. The last reach started at the entrance to the turning basin and included slowing the ship down, easing it against the caisson, and aligning it with the dock. This is very time-consuming and was, therefore, excluded from testing. One run was made during Phase 1 that included this process and took

* Personal Communication, 28 August 1989, to Carl Huval, US Army Engineer Waterways Experiment Station, from Ted Valerio, US Army Engineer District, Buffalo, NY, subject: vessel trip information logs furnished by USS GLF.

** Personal Communication, 15 September 1989, to Michelle Thevenot, US Army Engineer Waterways Experiment Station, from Holly C. Hartmann, NOAA Great Lakes Environmental Research Laboratory, Ann Arbor, MI.

18 min. Again the ratio of the 27-ft draft and the 24.5-ft draft was multiplied by this figure to obtain an estimate of 23 min. Therefore, a simulator run comparable to that in the vessel trip information would take about 1 hr and 51 min. This is less than the average of the actual transits given in the vessel trip information of 2 hr and 22 min (Table 11). However, it is possible that many of these actual ship transits were subject to other kinds of unavoidable delays, such as other water traffic or a delay in bridge opening. This would explain the large range in the actual ship transit times.

121. The reach for the outbound runs was broken into two parts. The first reach was tested in Phase 2. The ship began at the caisson at the eastern end of USS/Kobe Steel Dock with a heading of 70 deg. The shipmasters backed into the turning basin, rotated counterclockwise, and then headed downstream. The simulations ended at the Norfolk and Western Railroad Bridge. Since no draft is given in the vessel trip information, it is assumed that the ship was ballasted (18.2-ft draft). The average transit time for the simulated runs of this reach took 51 min. For the remaining portion of the outbound transit, from the railroad bridge to the light pier, no simulations were done. This is because no project benefits were anticipated for an outbound run in this reach. An approximation was made using the ratio of the length of time of an outbound run to that of an inbound run with similar conditions. The average outbound transit leaving the turning basin to the railroad bridge took 28 min. An inbound run over the same reach took 42 min. Multiplying 46 min, the inbound time for the reach from the pier to the railroad bridge, by 28 and dividing by 42 gives 31 min. Therefore, the approximate total time for a simulated outbound run is 1 hr and 22 min. The average time of the actual transits is 1 hr 37 min. Again it is believed that some delays were included in these actual outbound ship transit times.

122. The vessel trip information does not include any data on underkeel clearance. As determined in the simulation study, the transit times depend on the draft and the underkeel clearance. It can be seen in Table 10 that decreasing the draft by 2.5 ft in the existing condition results in a 20 percent decrease in time. However, when the draft was decreased by 1.5 ft and the underkeel clearance was decreased by 1 ft in the plan conditions, there was an increase in transit time. This is to say that underkeel clearance could have more effect than draft on transit time. If the vessels had less than 2.5 ft underkeel clearance during an inbound transit, this would be

another reason for their average time to exceed that of the simulated time.

123. The contrived nature of the previous data did not satisfy the verification of the model. Therefore a trip was made to Lorain to get data regarding a ship transit. During this trip an inbound transit over the area simulated was timed. The condition of the high water was used for comparison since this corresponded to the conditions of the transit. The ship was loaded to a seasonal maximum draft with between 2 and 2.5 ft of underkeel clearance.

124. The timed transit took 51 min. The simulated runs ranged from 33 to 53 min. This range excluded the runs determined unacceptable in paragraph 68. One run took more and three runs took less than the 51 min. From discussions with shipmasters participating in the study, the information was acquired that the shipmaster who was timed during an actual transit took longer to navigate the channel than most of the others. Therefore, this information indicates that the simulator model was accurate. It has the actual time of a "slower" shipmaster toward the high end but still within the range of simulated ship transit times.

PART V: RECOMMENDATIONS

125. Plan 2a can be transited using a smooth and continuous motion in any of the conditions if the stern thruster is used. Maintaining continuous forward motion is safer than backing and filling since backing decreases the control of the ship and increases risk of damage to the propeller, rudder, and engine. Backing and filling creates more chance of error due to the increase in operations. In addition, Plan 2a transit times remain within 3 min of the minimum transit time set by the maximum speed to navigate this channel. The Plan 1 and existing channel transit times fluctuate two to three times as much. For these reasons, Plan 2a is recommended.

Table 1

Phase 1 Test Conditions

Run	Channel	Ship Draft, ft	Date, 1988	Time, min
		Shipmaster A		
Turning maneuver	Existing	18.2	27 April	24
	Plan 1	18.2	27 April	20
	Plan 2	18.2	27 April	20
Inbound run (upper)*	Existing	24.5	27 April	56
Inbound run (lower)*				
Inbound run	Plan 1	25.5	27 April	57
	Plan 2	25.5	27 April	63
		Shipmaster B		
Turning maneuver	Existing	18.2	28 April	19
	Plan 1	18.2	29 April	22
	Plan 2	18.2	29 April	19
Inbound run	Existing	24.5	28 April	56
	Plan 1	25.5	28 April	54
	Plan 2	25.5	29 April	63
Partial inbound run	Existing	24.5	29 April	37
	Plan 1	25.5	29 April	33
	Plan 2	25.5	29 April	32

* Two runs combined to form one run.

Table 2

Transit Time for Each Area

Run	Channel Condition	Transit Time, min		
		Area 1	Area 2	Area 3
	Shipmaster A			
Inbound run*	Existing channel	19.33	25.00	12.00
	Plan 1	20.34	25.83	11.00
	Plan 2	20.16	25.00	17.84
	Shipmaster B			
Inbound run	Existing channel	17.67	26.00	11.83
	Plan 1	20.83	19.50	13.67
	Plan 2	19.17	28.17	15.50
Partial inbound run	Existing channel	——	24.83	12.17
	Plan 1	——	21.17	11.67
	Plan 2	——	20.67	11.50

* Two runs combined to form one run.

Table 3

Cut Dimensions, ft

Measurement	Plan 1	Plan 2a
	Cut B	
Maximum cut	100	250
Distance downstream*	325	800
Distance upstream*	775	875
	Cut C	
Maximum cut	125	275
Distance downstream*	350	1,225
Distance upstream*	850	600
	Cut D	
Maximum cut	0	125
Distance downstream*	0	925
Distance upstream*	0	450
	Turning Basin, Cut 1	
Maximum cut	175	250
Distance downstream*	400	450
Distance upstream*	425	700
	Turning Basin, Cut 2	
Maximum cut	0	150
Distance downstream*	0	525
Distance upstream*	0	300

* Distances are measured along the toe of the cut following the existing channel limit from the maximum cut section to no cut. See Figure 18 for an illustration.

Table 4

Test Conditions

Test No.	Test Condition	Ship Transit	Lake El ft IGLD	Ship Draft, ft	Number of Tests per Pilot C	D	E	F	Number of Tests per Condition
1	Existing	Inbound with stern thruster	571.1	27	2	2	1	1	6
2	Plan 1		571.1	27	2	1	1	2	6
3	Plan 2a		571.1	27	2	1	1	2	6
4	Existing		568.6	24.5	2	2	2	2	8
5	Plan 1		568.6	25.5	2	2	2	1	7
6	Plan 2a		568.6	25.5	2	2	1	1	6
7	Existing	Inbound without stern thruster	571.1	27	1	1	1	1	4
8	Plan 1		571.1	27	1	2	1	1	5
9	Plan 2a		571.1	27	1	1	1	1	4
10	Existing		568.6	24.5	1	1	1	1	4
11	Plan 1		568.6	25.5	1	1	1	1	4
12	Plan 2a		568.6	25.5	1	2	1	1	5
13	Existing	Outbound with stern thruster	571.1	18.2	1	1	1	1	4
14	Plan 1		571.1	18.2	1	1	1	1	4
15	Plan 2a		571.1	18.2	1	1	1	1	4
16	Existing		568.6	18.2	1	2	1	2	6
17	Plan 1		568.6	18.2	1	1	1	1	4
18	Plan 2a		568.6	18.2	1	2	1	1	5
19	Existing	Outbound without stern thruster	571.1	18.2	1	1	1	1	4
20	Plan 1		571.1	18.2	1	1	1	1	4
21	Plan 2a		571.1	18.2	1	1	1	1	4
22	Existing		568.6	18.2	0	1	1	1	3
23	Plan 1		568.6	18.2	0	1	1	1	3
24	Plan 2a		568.6	18.2	0	1	1	1	3
								Total	113

Table 5

Computed Average Transit Times, min

Inbound or Outbound	Reach	Lake El, ft IGLD 571.1 Existing	571.1 Plan 1	571.1 Plan 2a	568.6 Existing	568.6 Plan 1	568.6 Plan 2a
		Stern Thruster Available					
Inbound		1*	2*	3*	4*	5*	6*
	B	13	9	8	10	10	8
	C	15	10	9	11	10	9
	D	14	11	10	12	12	11
	Subtotal	42	30	27	33	32	28
Outbound		13*	14*	15*	16*	17*	18*
	TB	24	22	20	22	19	19
	D	10	11	11	12	11	11
	C	11	10	9	11	9	9
	B	7	5	5	6	5	6
	Subtotal	52	48	45	51	44	45
Round Trip		94	78	72	84	76	73
		Stern Thruster Not Available					
Inbound		7*	8*	9*	10*	11*	12*
	B	13	11	8	11	10	9
	C	14	13	12	12	10	11
	D	15	14	12	13	14	12
	Subtotal	42	38	32	36	34	32
Outbound		19*	20*	21*	22*	23*	24*
	TB	24	20	19	22	22	19
	D	11	10	11	10	13	12
	C	11	10	9	10	10	9
	B	6	6	5	7	5	6
	Subtotal	52	46	44	49	50	46
Round Trip		94	84	76	85	84	78

* Run number; refer to Table 4.

Table 6

Inbound Run Test Conditions

Test No.	Test Condition	Ship Transit	Lake El ft IGLD	Ship Draft, ft	Number of Tests per Pilot C	D	E	F	Number of Tests per Condition
1	Existing	Inbound with stern thruster	571.1	27	1	1	1	1	4
2	Plan 1			27	2	1	1	1	5
3	Plan 2a			27	2	1	1	2	6
4	Existing		568.6	24.5	2	2	2	2	8
5	Plan 1			25.5	2	2	2	1	7
6	Plan 2a			25.5	2	2	1	1	6
7	Existing	Inbound without stern thruster	571.1	27	0	1	1	1	3
8	Plan 1			27	1	2	1	1	5
9	Plan 2a			27	1	1	1	1	4
10	Existing		568.6	24.5	1	1	1	1	4
11	Plan 1			25.5	1	1	1	1	4
12	Plan 2a			25.5	1	2	1	1	5

NOTE: Runs included in time analysis.

Table 7

Inbound Transit Times, min

Runs Included in Table 6

Reach		Lake El, ft IGLD					
		571.1			568.6		
		Existing	Plan 1	Plan 2a	Existing	Plan 1	Plan 2a
		Stern Thruster Available					
		1*	2*	3*	4*	5*	6*
B		13	9	8	10	10	8
C		15	9	9	11	10	9
D		14	11	10	12	12	11
	Total	42	29	27	33	32	28
	Time Savings**		13	15		1	5
		Stern Thruster Not Available					
		7*	8*	9*	10*	11*	12*
B		13	11	8	11	10	9
C		15	13	12	12	10	11
D		14	14	12	13	14	12
	Total	42	38	32	36	34	32
	Time Savings**		4	10		2	4

* Refer to Table 4.

** Difference between transit times for existing conditions and transit times for plan conditions.

Table 8

Outbound Test Conditions

Test No.	Test Condition	Ship Transit	Ship Draft, ft	Number of Tests per Pilot C	D	E	F	Number of Tests per Condition
13, 16	Existing	Outbound with stern thruster	18.2	2	3	1	2	8
14, 17	Plan 1		18.2	2	2	2	2	8
15, 18	Plan 2a		18.2	2	2	2	2	8
19, 22	Existing	Outbound without stern thruster	18.2	1	2	2	2	7
20, 23	Plan 1		18.2	1	2	2	2	7
21, 24	Plan 2a		18.2	1	2	1	2	6

NOTE: Runs included in time analysis.

Table 9

Average Outbound Transit Times, min

Runs Included in Table 8

Reach	Existing	Plan 1	Plan 2a
	Stern Thruster Available		
	13*, 16*	14*, 17*	15*, 18*
TB	23	21	19
D	11	11	11
C	10	9	9
B	7	5	5
Total	51	46	44
Time Savings**		5	7
	Stern Thruster Not Available		
	19*, 22*	20*, 23*	21*, 24*
TB	23	21	20
D	11	11	11
C	10	10	10
B	6	6	6
Total	50	48	47
Time Savings**		2	3

* Refer to Table 4.

** Difference between transit times for existing conditions and transit times for plan conditions.

Table 10

Transit Times, min

Maneuverability Parameters	Existing	Plan 1	Plan 2a
	Elevation 571.1 ft IGLD		
Draft 27.0 ft, underkeel clearance 2.5 ft	42 (1)	29 (2)	27 (3)
	Elevation 568.6 ft IGLD		
Draft 25.5 ft, underkeel clearance 1.5	—	32 (5)	28 (6)
Draft 25.5 ft, underkeel clearance 2.5	37*	27*	26*
Draft 24.5 ft, underkeel clearance 2.5 ft	33 (4)	25**	25**

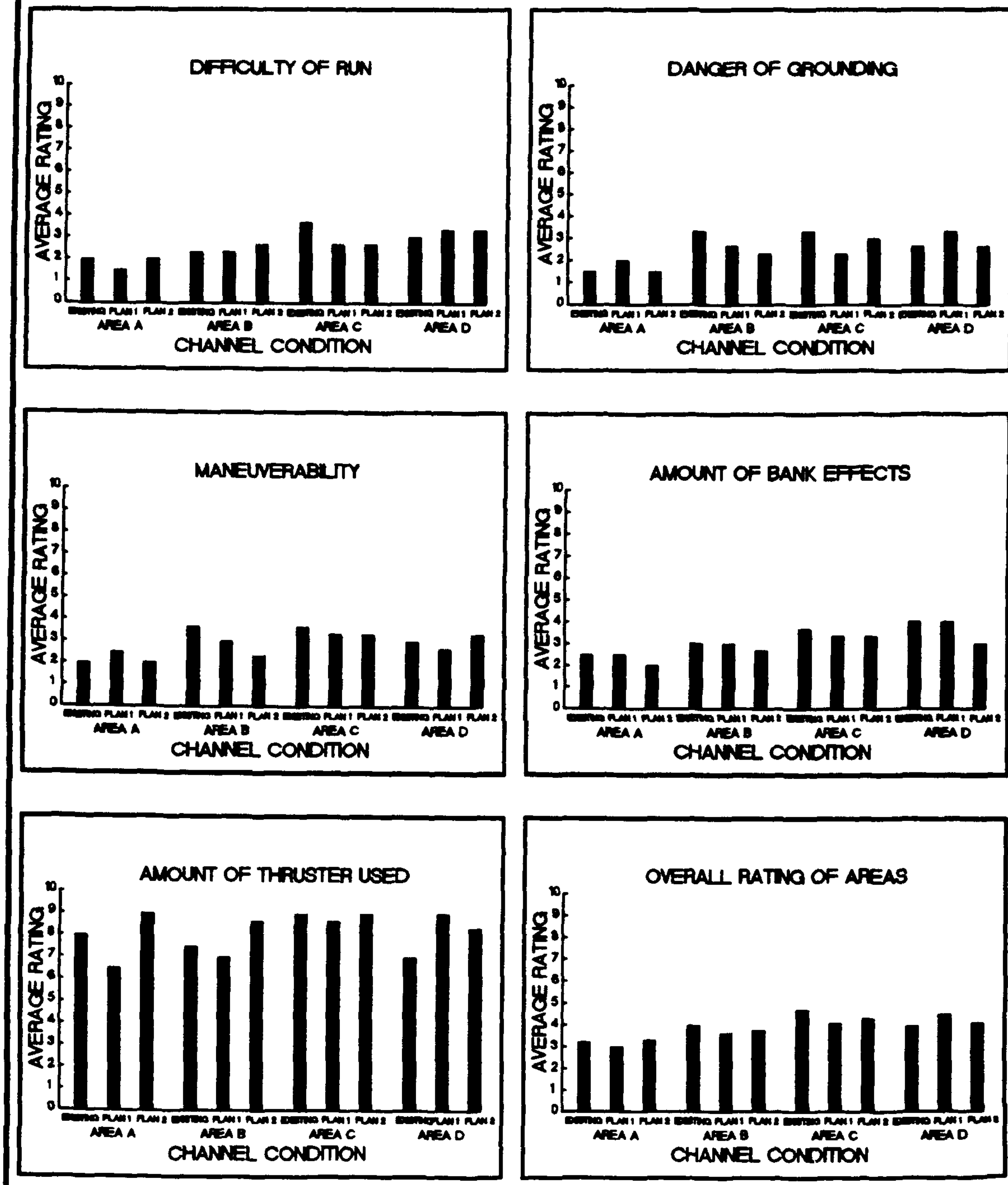
Note: Numerals in parentheses following values indicate the condition number (see Table 4).
* Value calculated using linear interpolation.
** Value projected from available data.

Table 11

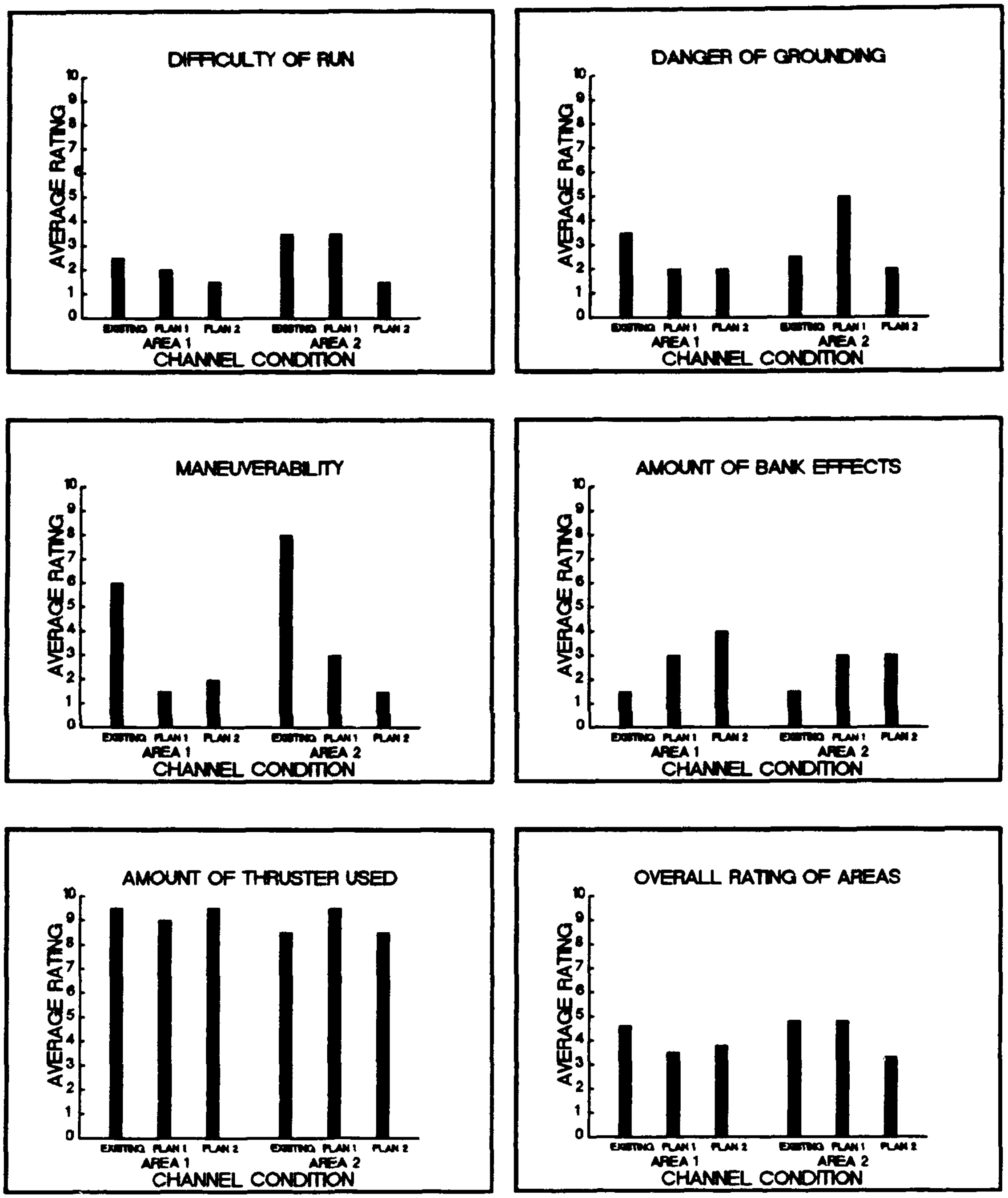
Transit Times From Vessel Trip Information

Date		Inbound	Outbound	Draft (Inbound)
27, 28 June		2 hr 0 min	1 hr 21 min	26 ft 11.50 in.
11, 12 June		2 hr 8 min	1 hr 32 min	26 ft 10.00 in.
4 June		2 hr 34 min	1 hr 26 min	26 ft 11.00 in.
27, 28 May		3 hr 29 min	1 hr 33 min	25 ft 11.00 in.
6, 7 May		1 hr 57 min	1 hr 16 min	26 ft 6.00 in.
24, 25 April		2 hr 3 min	1 hr 49 min	26 ft 2.00 in.
15 April		3 hr 20 min	1 hr 36 min	26 ft 0.00 in.
29 March		1 hr 39 min	1 hr 28 min	25 ft 9.00 in.
5 June		2 hr 15 min	1 hr 37 min	26 ft 11.75 in.
28 May		2 hr 42 min	1 hr 30 min	26 ft 10.00 in.
21 May		1 hr 47 min	1 hr 23 min	26 ft 10.00 in.
13 May		2 hr 13 min	1 hr 33 min	26 ft 7.00 in.
7 May		2 hr 41 min	1 hr 53 min	26 ft 8.00 in.
26 April		1 hr 15 min	2 hr 34 min	26 ft 4.00 in.
19 April		2 hr 13 min	1 hr 39 min	26 ft 3.00 in.
11, 12 April		1 hr 38 min	1 hr 21 min	26 ft 0.50 in.
24 June		2 hr 15 min	1 hr 33 min	27 ft 0.00 in.
13 June		2 hr 20 min	1 hr 44 min	27 ft 0.00 in.
24, 25 May		2 hr 50 min	1 hr 34 min	26 ft 8.00 in.
9, 10 May		2 hr 35 min*	1 hr 38 min	26 ft 6.00 in.
17, 18 April		2 hr 15 min	2 hr 28 min	26 ft 4.00 in.
28 March		3 hr 45 min	1 hr 50 min	25 ft 4.00 in.
4 April		3 hr 30 min	1 hr 52 min	26 ft 0.00 in.
31 May, 1 June		2 hr 6 min	1 hr 4 min	26 ft 11.00 in.
21 May		1 hr 34 min	1 hr 17 min	26 ft 9.00 in.
	Average	2 hr 22 min	1 hr 37 min	26 ft 6.27 in.
	Range	2 hr 30 min	1 hr 30 min	1 ft 8.00 in.

* Military time given as 2190.

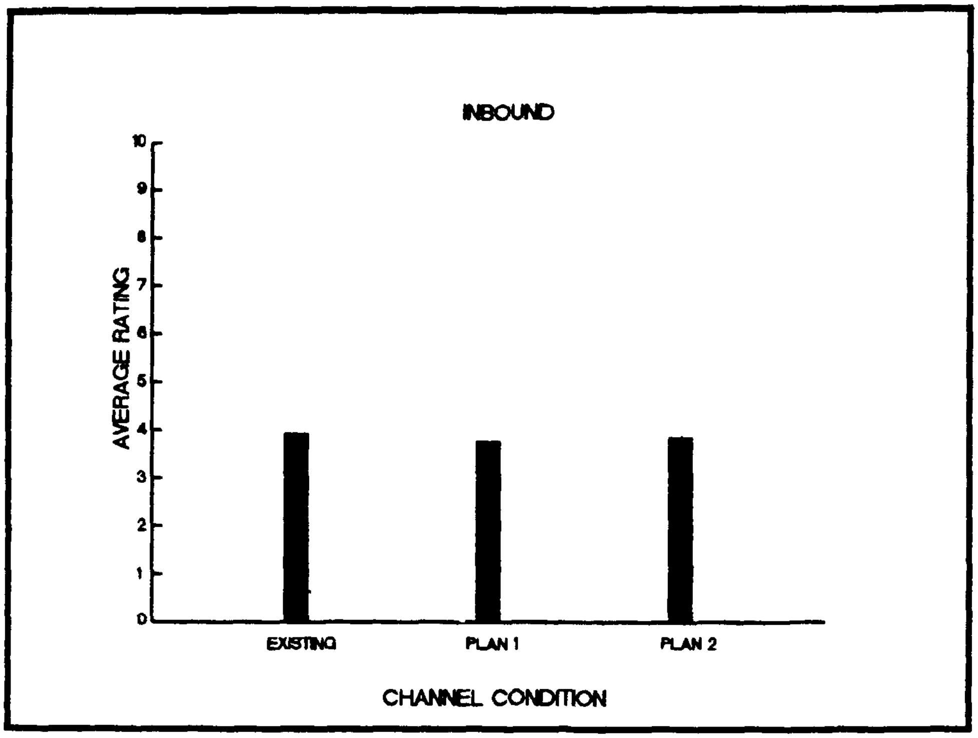


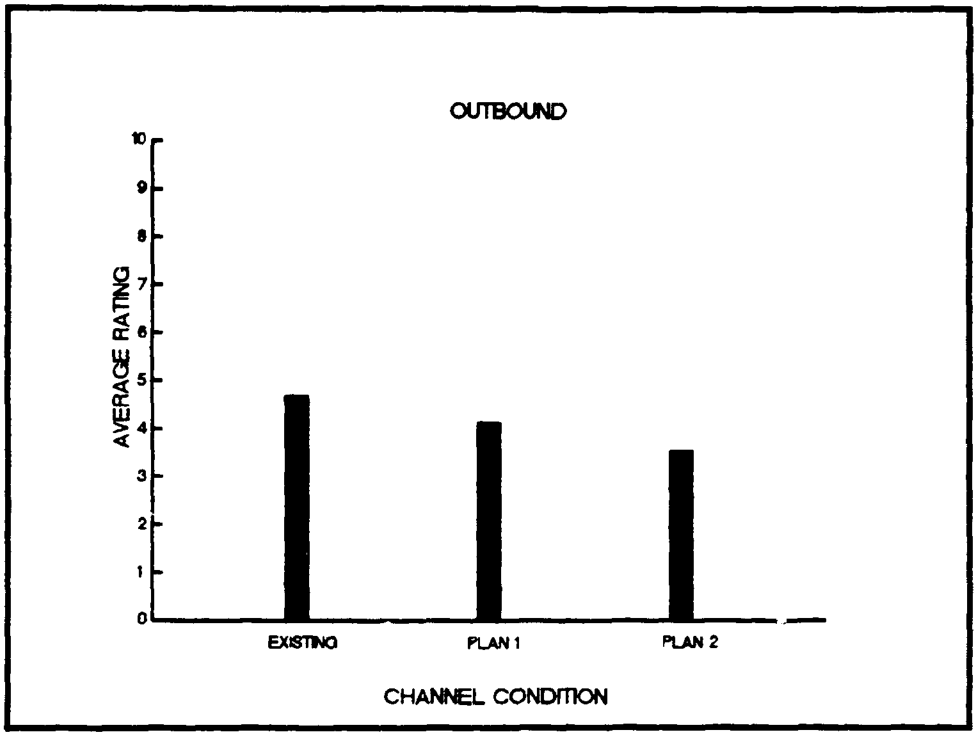
SHIPMASTER EVALUATION, PHASE 1
INBOUND RUNS



SHIPMASTER EVALUATION, PHASE 1
OUTBOUND RUNS

PLATE 2





SHIPMASTER EVALUATION, PHASE 1
OVERALL RATING OF PLANS

PLATE 3

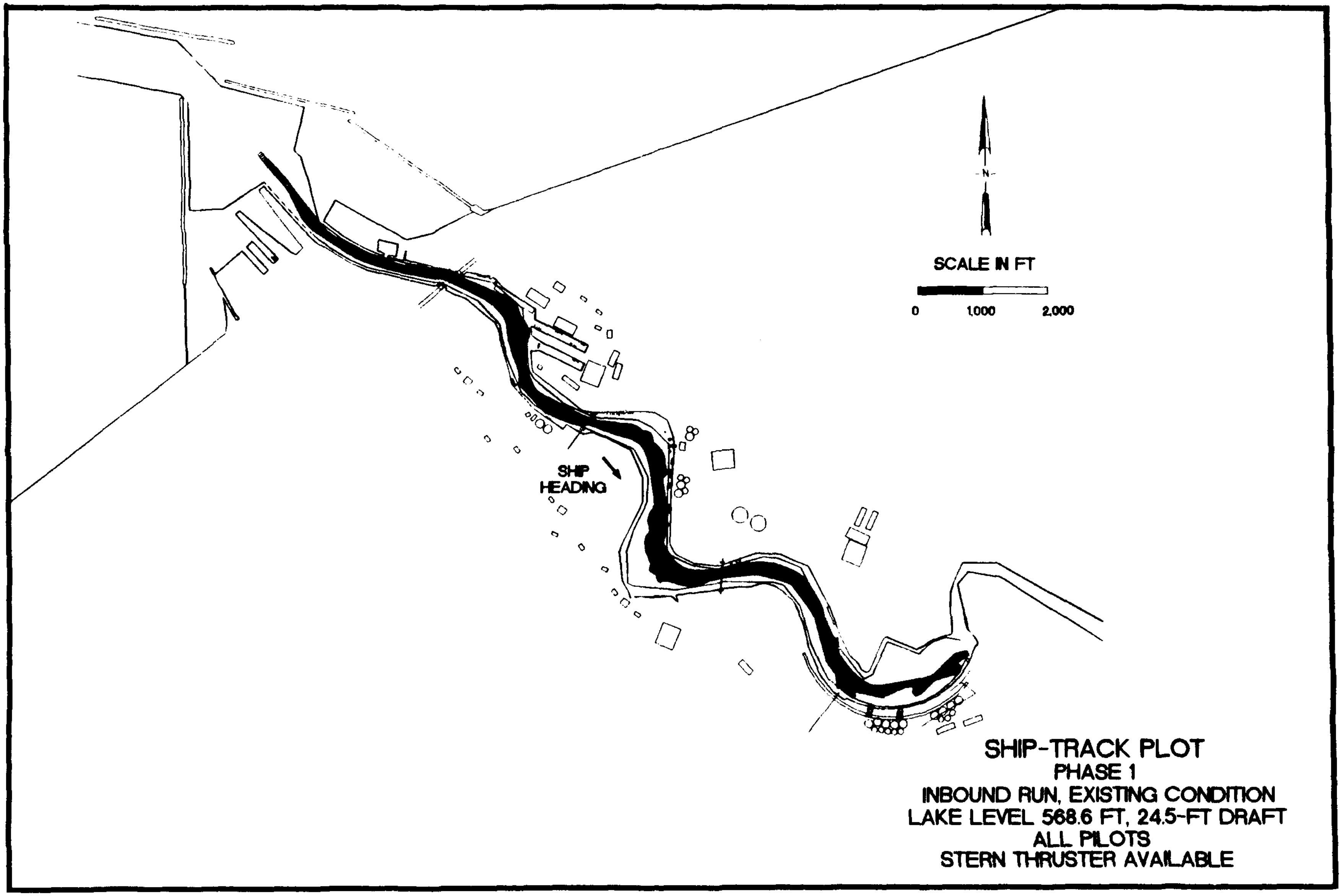
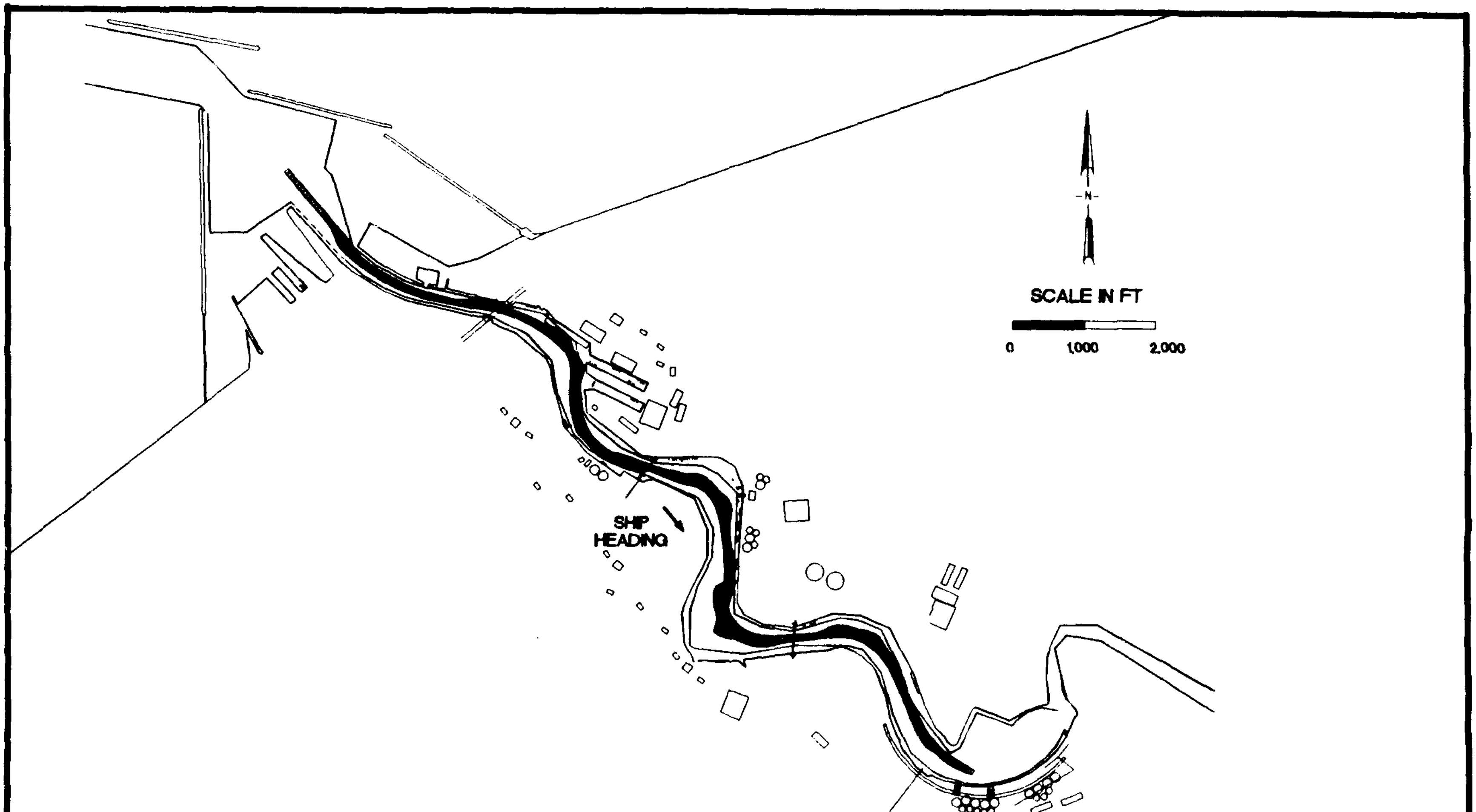
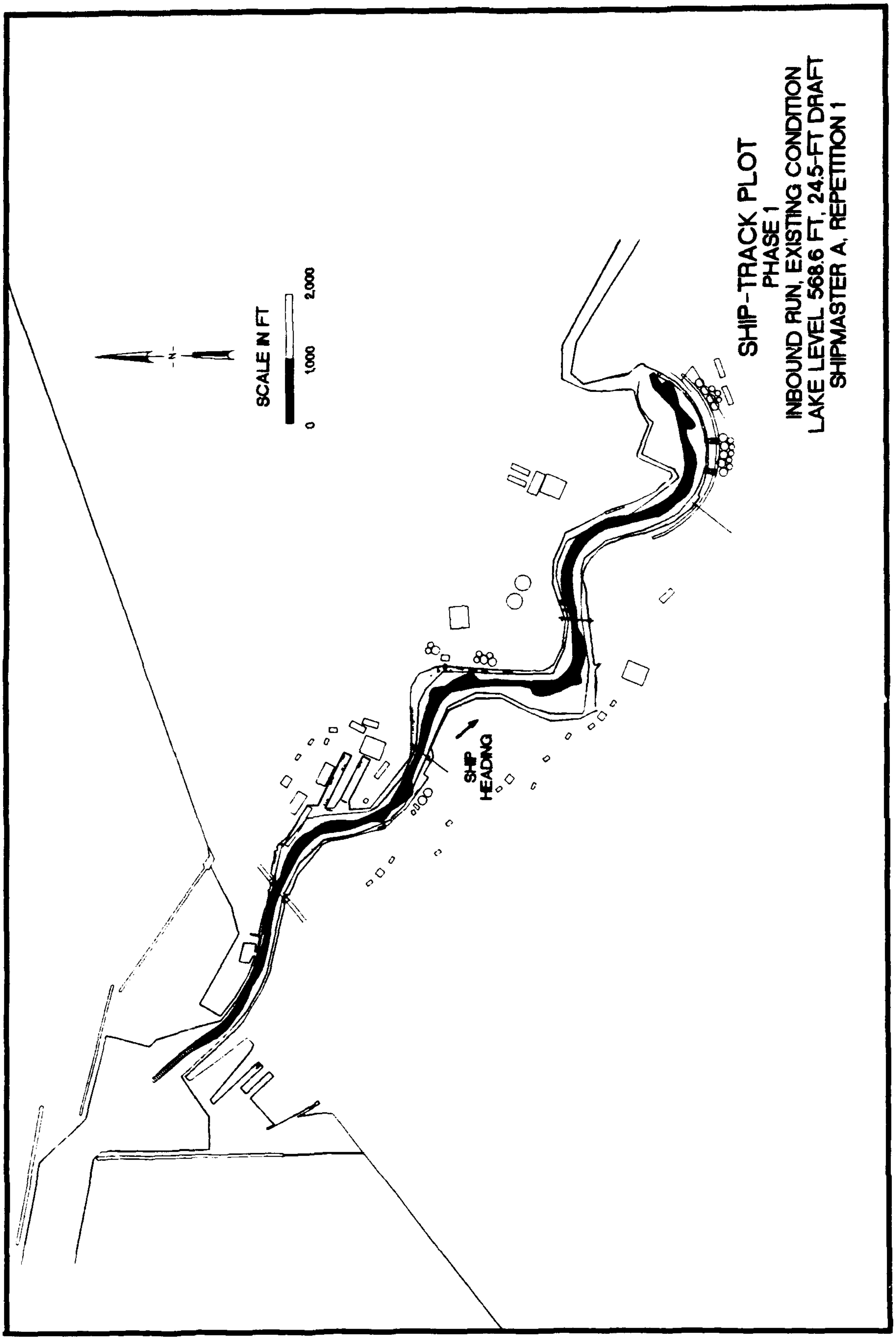

N
SCALE IN FT
0
1,000
2,000
SHIP HEADING
SHIP-TRACK PLOT
PHASE 1
INBOUND RUN, EXISTING CONDITION
LAKE LEVEL 568.6 FT, 24.5-FT DRAFT
ALL PILOTS
STERN THRUSTER AVAILABLE

PLATE 4



SHIP-TRACK PLOT
PHASE 1
INBOUND RUN, EXISTING CONDITION
LAKE LEVEL 568.6 FT, 24.5-FT DRAFT
SHIPMASTER B, REPETITION 1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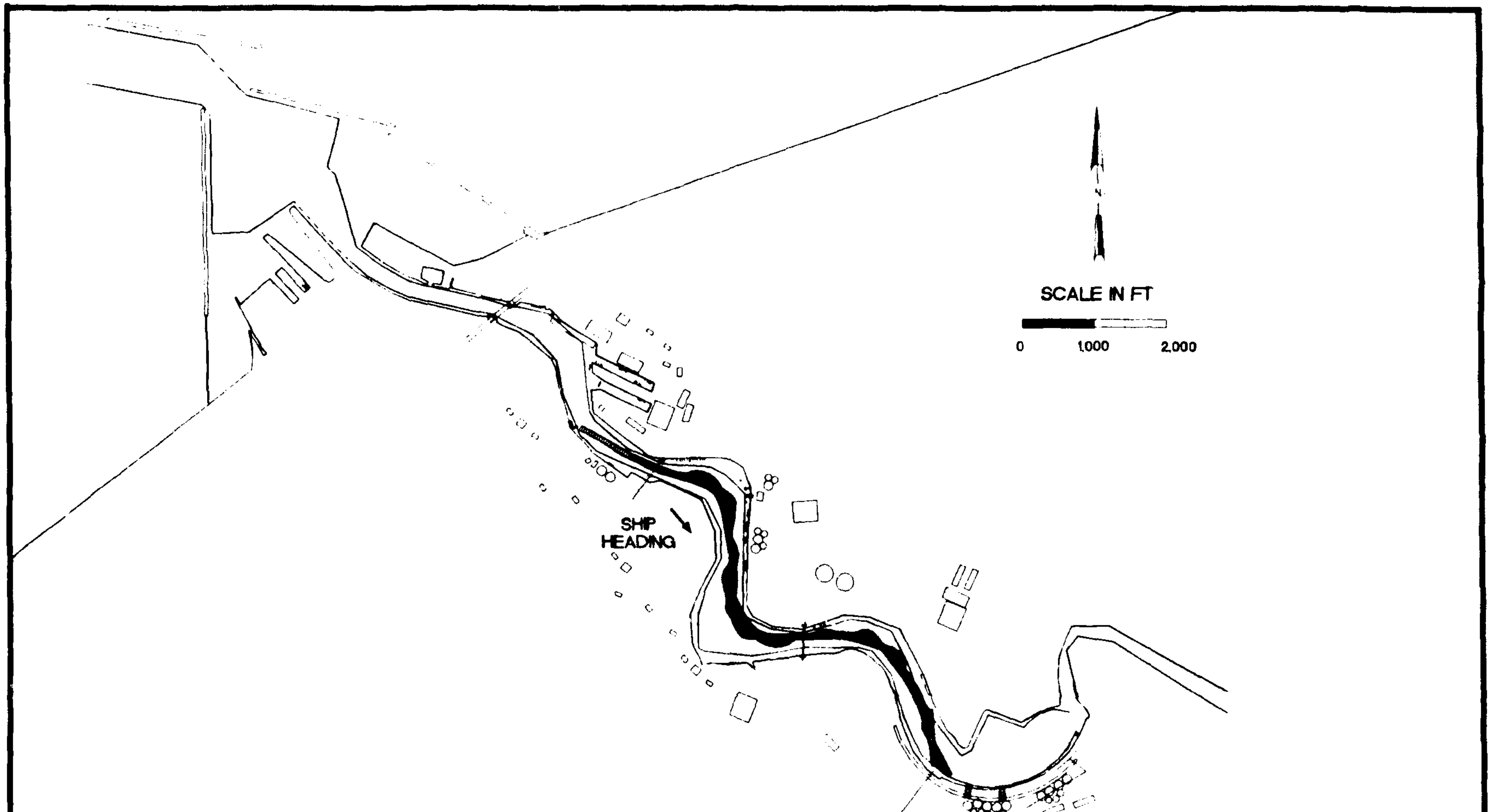
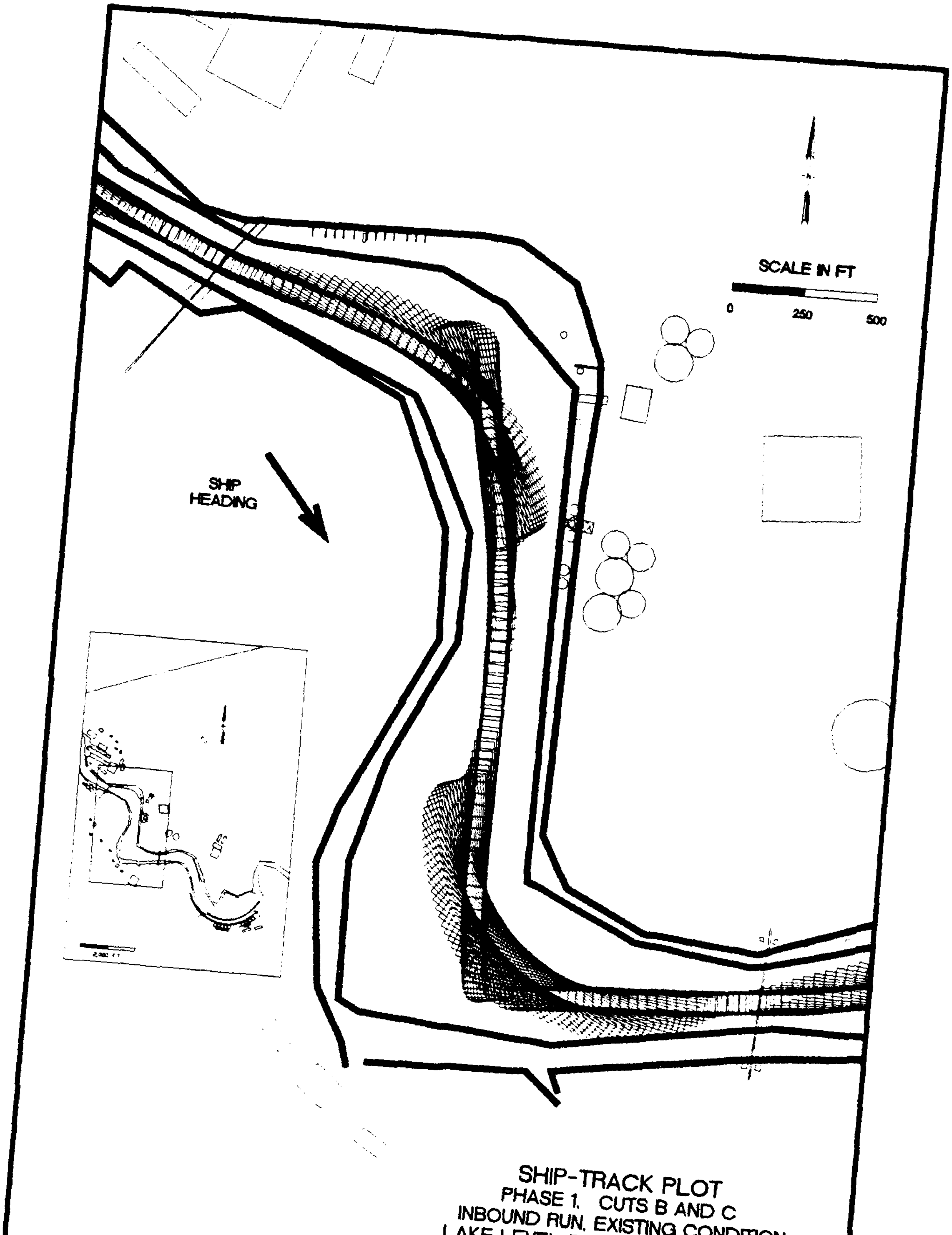
0
1,000
2,000
N
SHIP HEADING
SHIP-TRACK PLOT
PHASE 1
INBOUND RUN, EXISTING CONDITION
LAKE LEVEL 568.6 FT, 24.5-FT DRAFT
SHIPMASTER A, REPETITION 1

PLATE 6

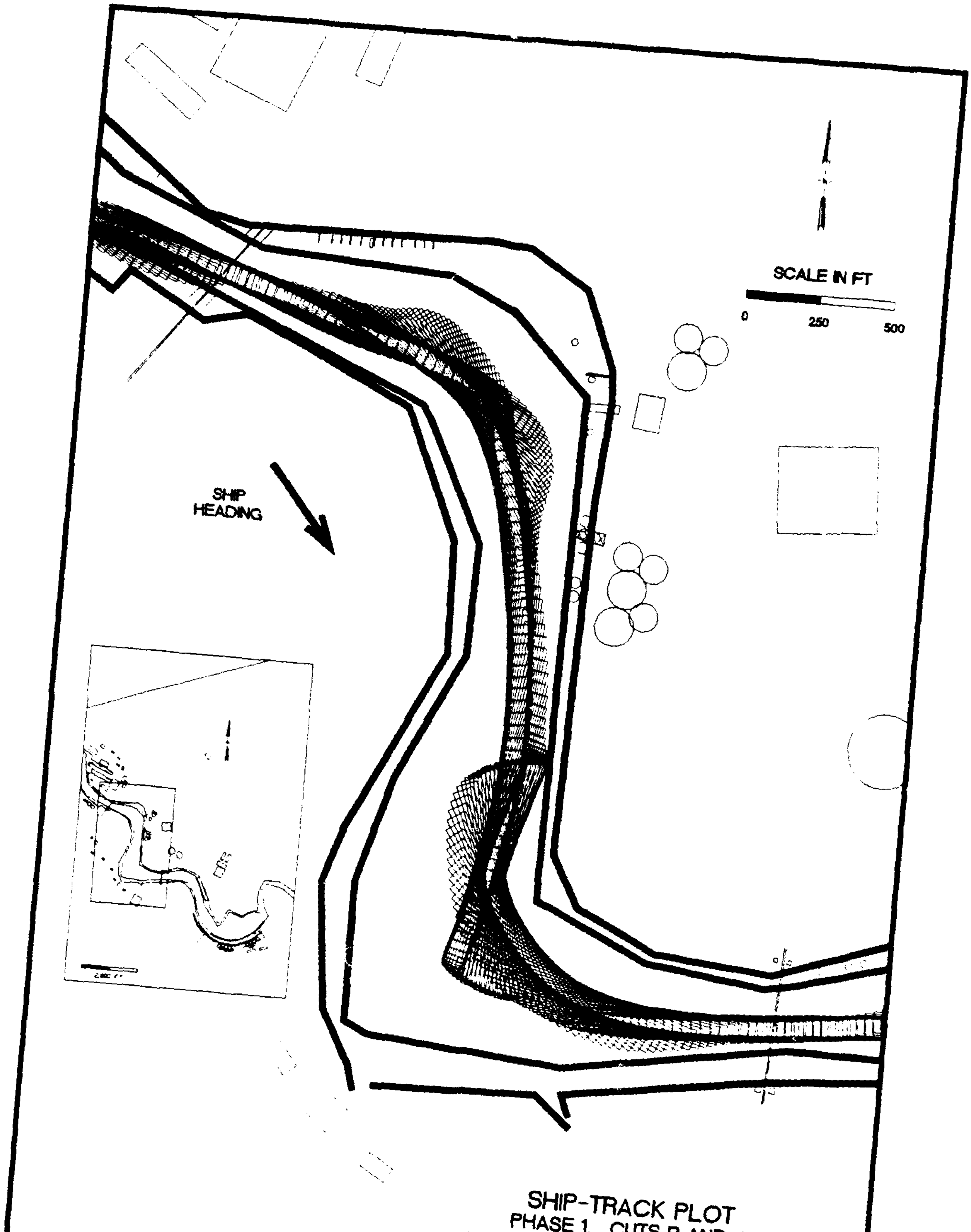


SHIP-TRACK PLOT
PHASE 1
INBOUND RUN, EXISTING CONDITION
LAKE LEVEL 568.6 FT, 24.5-FT DRAFT
SHIPMASTER B, REPETITION 2



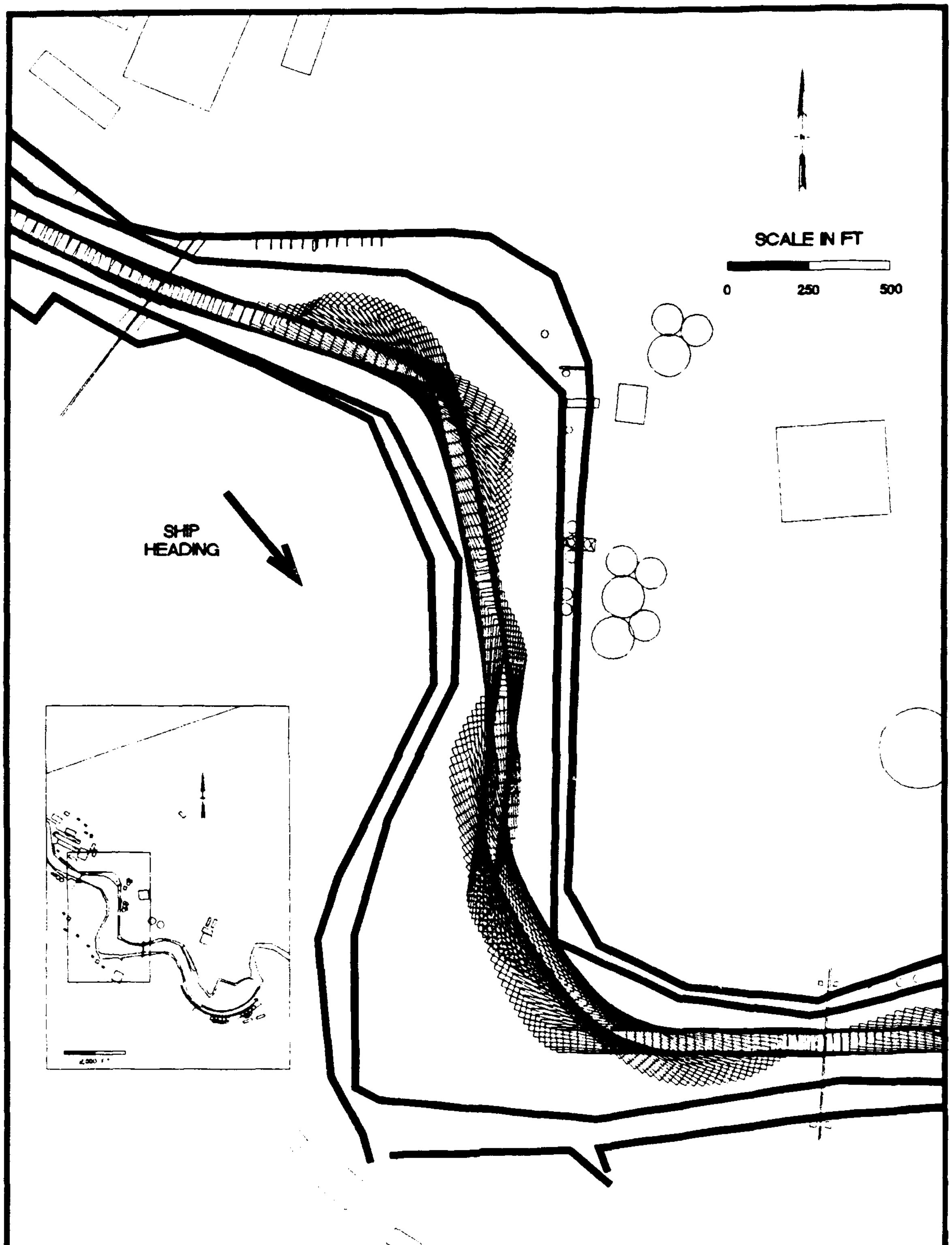
SHIP-TRACK PLOT
PHASE 1, CUTS B AND C
INBOUND RUN, EXISTING CONDITION
LAKE LEVEL 568.6 FT, 24.5-FT DRAFT
SHIPMASTER A, REPETITION 1

PLATE 8

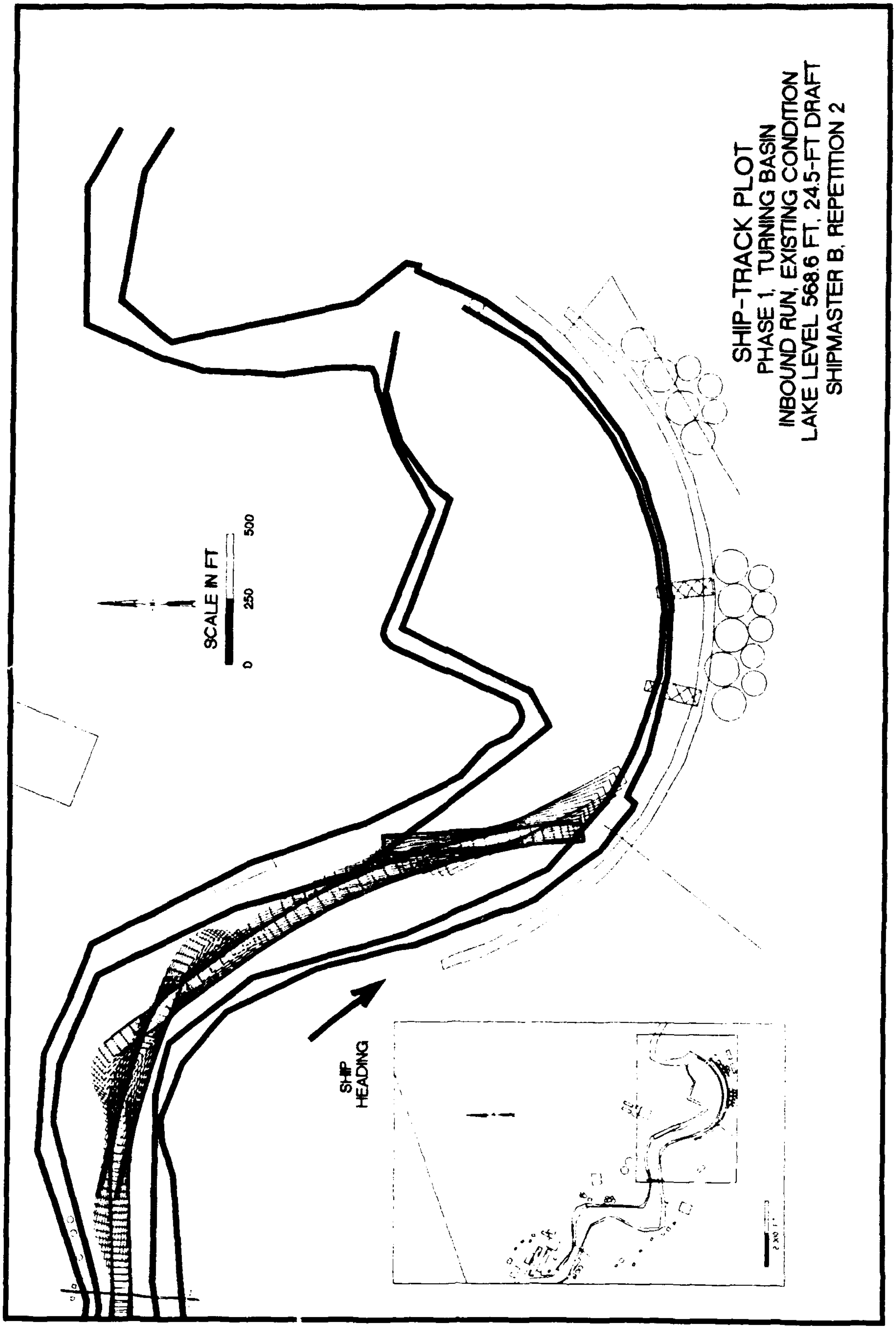


SHIP-TRACK PLOT
PHASE 1, CUTS B AND C
INBOUND RUN, EXISTING CONDITION
LAKE LEVEL 568.6 FT, 24.5-FT DRAFT
SHIPMASTER B, REPETITION 1

PLATE 9

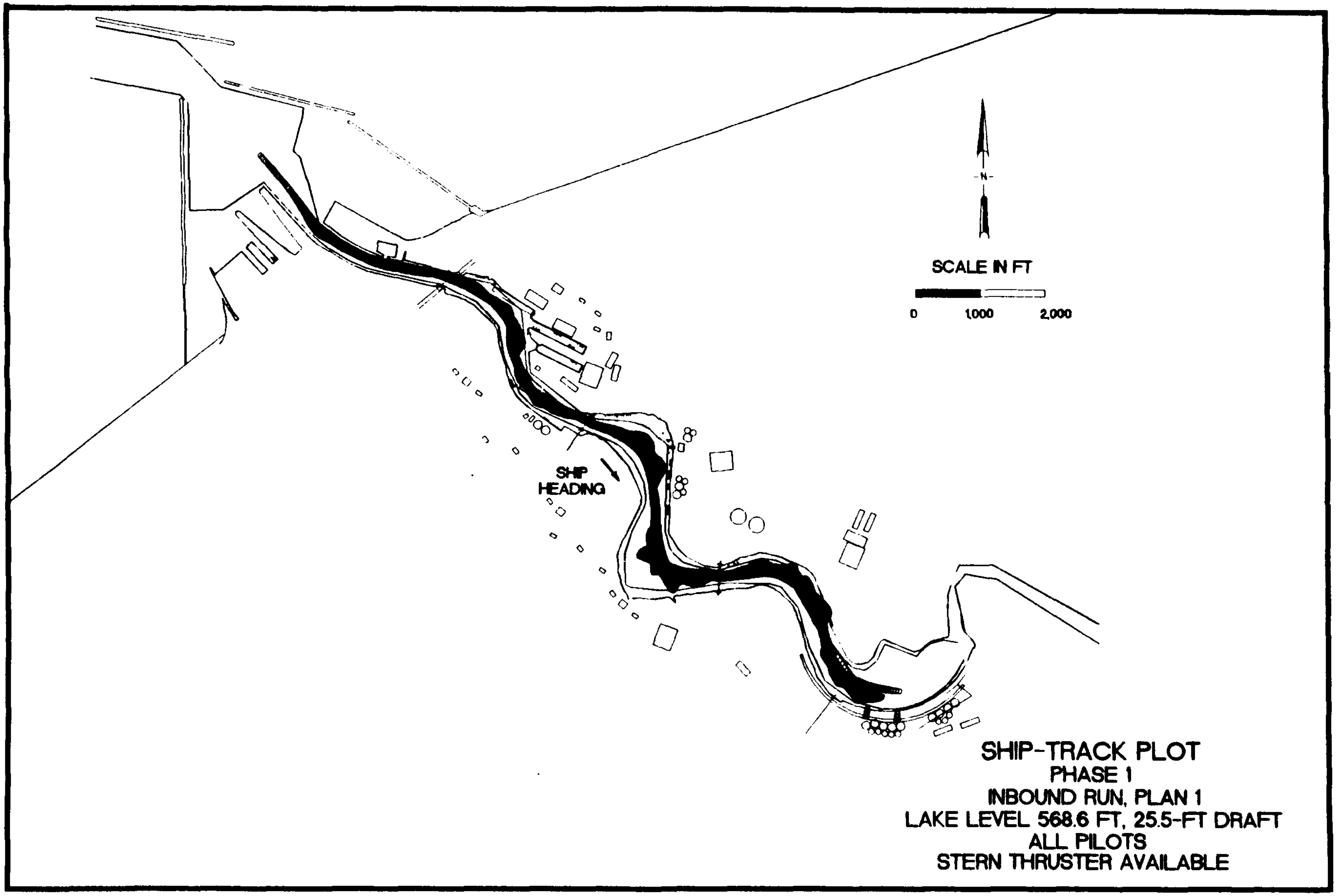


SHIP-TRACK PLOT
PHASE 1, CUTS B AND C
INBOUND RUN, EXISTING CONDITION
LAKE LEVEL 568.6 FT, 24.5-FT DRAFT
SHIPMASTER B, REPETITION 2

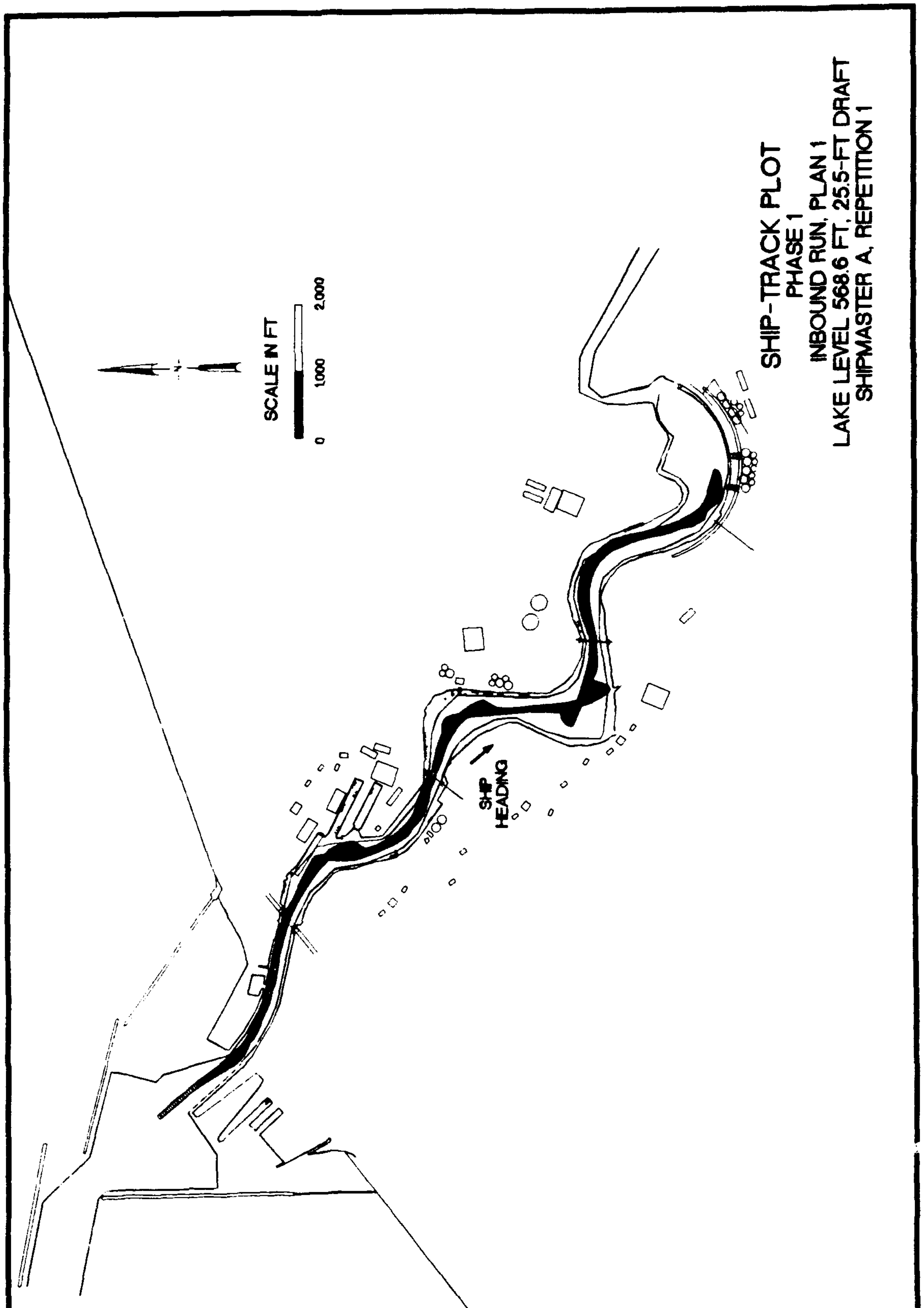


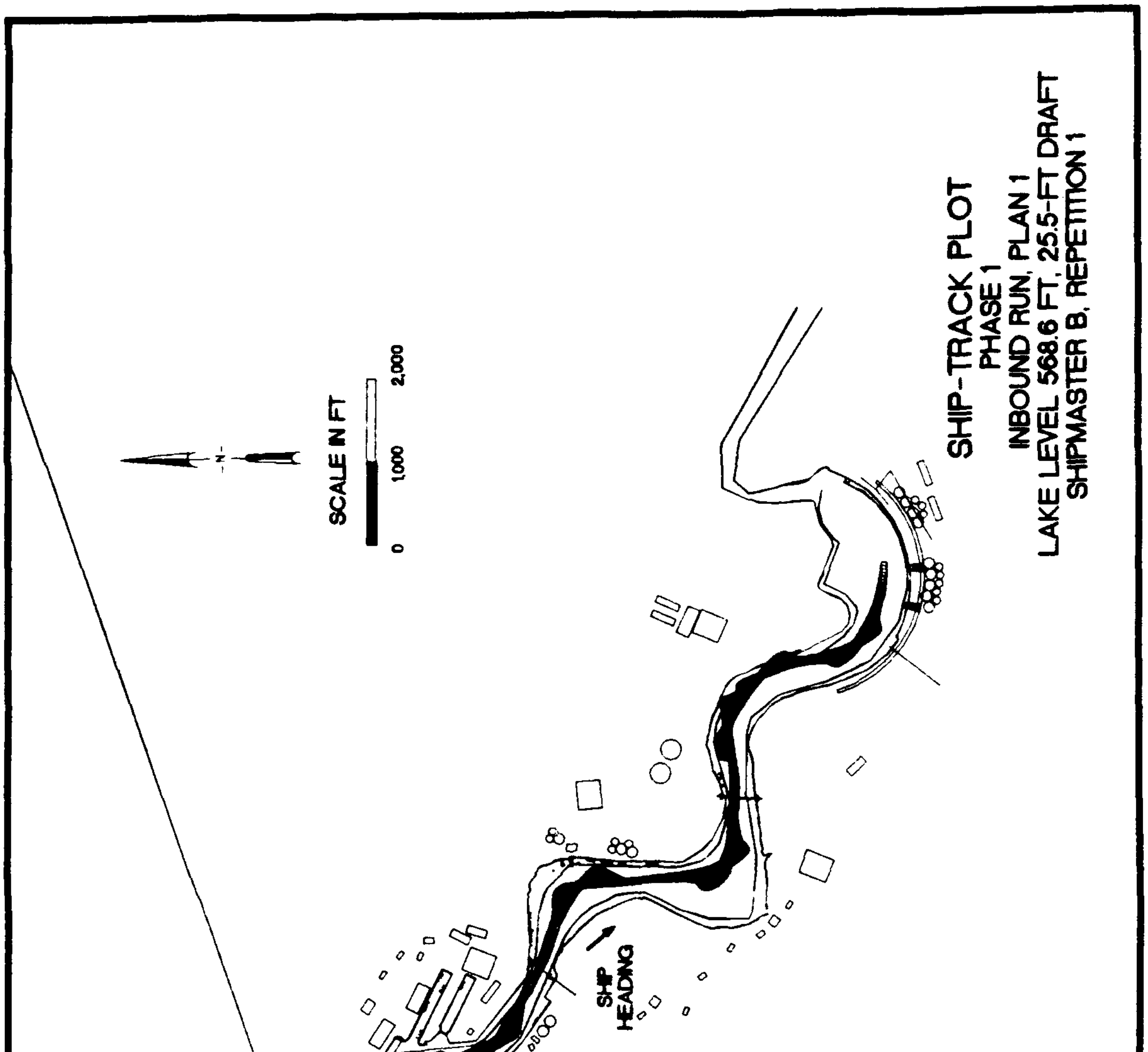
SHIP-TRACK PLOT
PHASE 1, TURNING BASIN
INBOUND RUN, EXISTING CONDITION
LAKE LEVEL 568.6 FT, 24.5-FT DRAFT
SHIPMASTER B, REPETITION 2
SCALE IN FT
0
250
500
SHIP
HEADING

PLATE 11

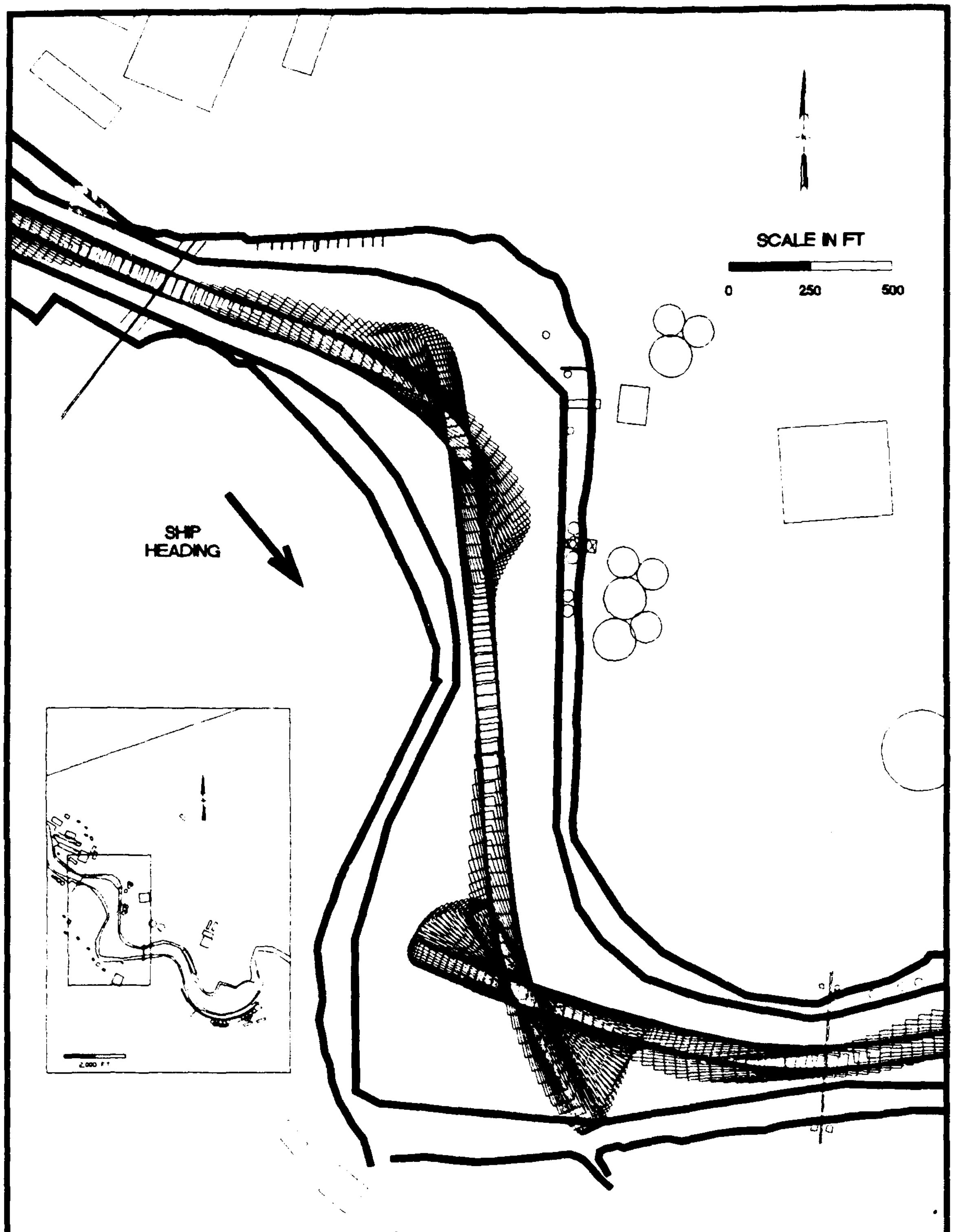


SHIP-TRACK PLOT
PHASE 1
INBOUND RUN, PLAN 1
LAKE LEVEL 568.6 FT, 25.5-FT DRAFT
ALL PILOTS
STERN THRUSTER AVAILABLE

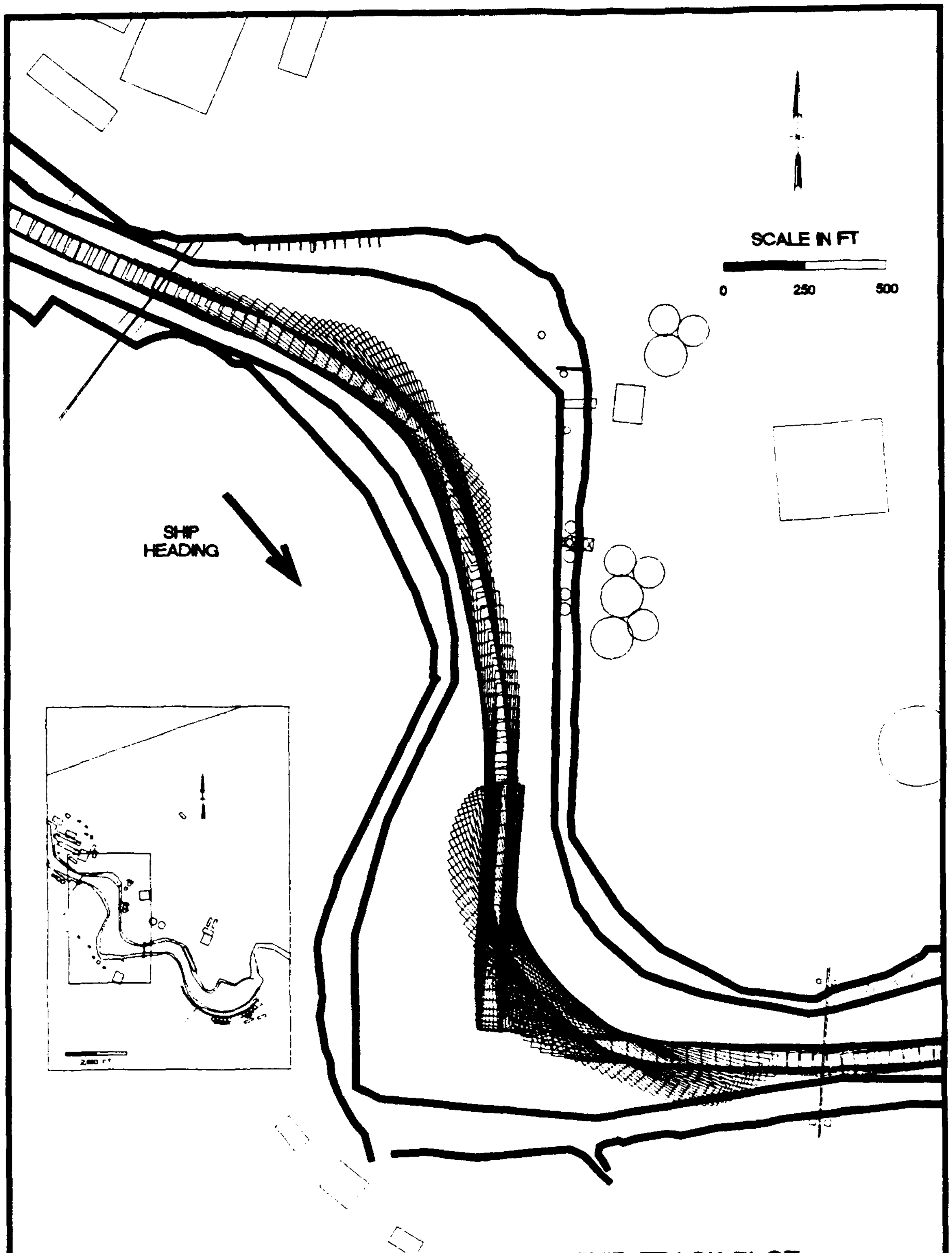

SCALE IN FT
0
1000
2,000
SHIP HEADING
SHIP-TRACK PLOT
PHASE 1
INBOUND RUN, PLAN 1
LAKE LEVEL 568.6 FT, 25.5-FT DRAFT
SHIPMASTER A, REPETITION 1



SHIP-TRACK PLOT
PHASE 1
INBOUND RUN, PLAN 1
LAKE LEVEL 568.6 FT, 25.5-FT DRAFT
SHIPMASTER B, REPETITION 1

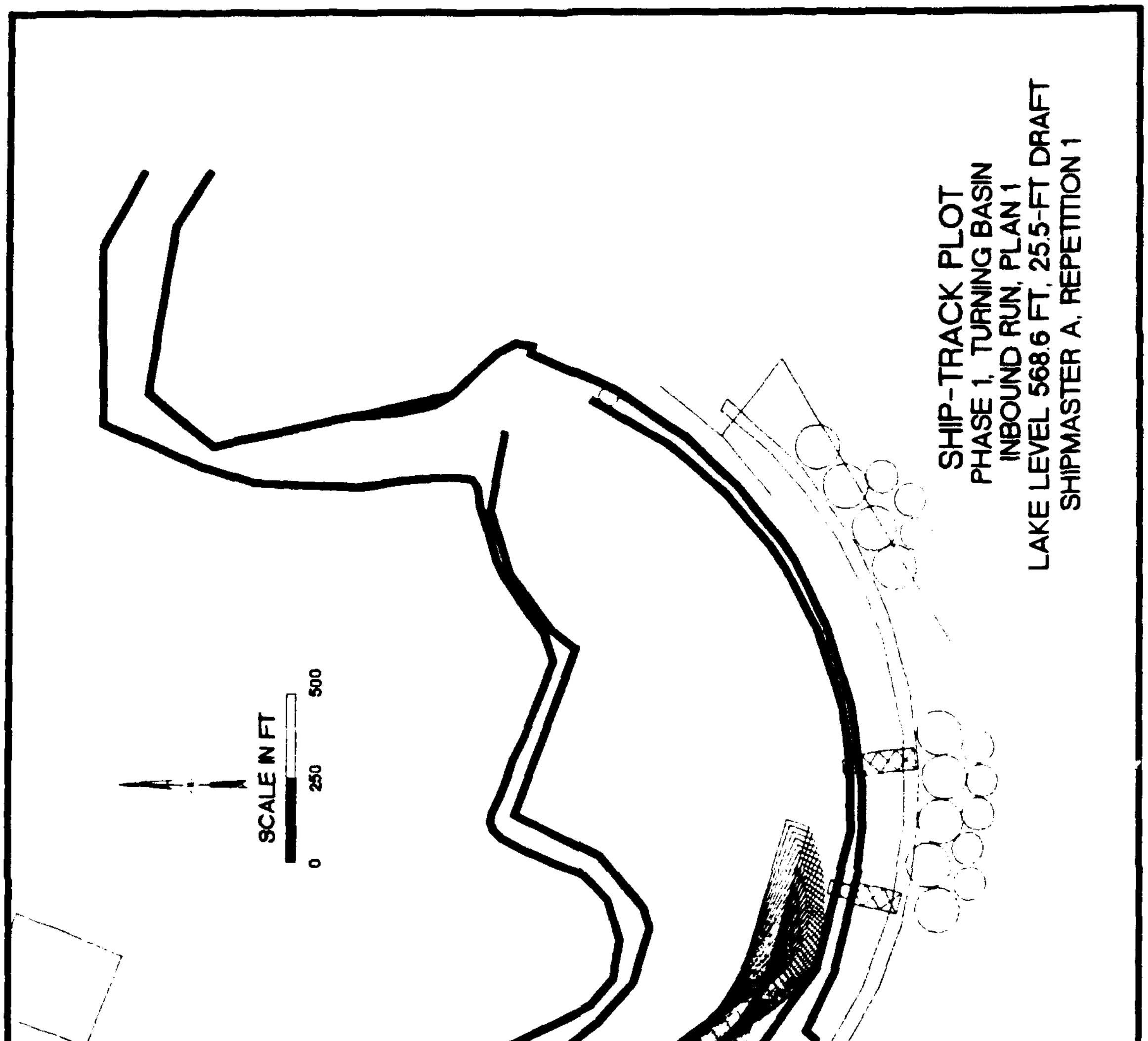


SHIP-TRACK PLOT
PHASE 1, CUTS B AND C
INBOUND RUN, PLAN 1
LAKE LEVEL 568.6 FT, 25.5-FT DRAFT
SHIPMASTER A, REPETITION 1



SHIP-TRACK PLOT
PHASE 1, CUTS B AND C
INBOUND RUN, PLAN 1
LAKE LEVEL 568.6 FT, 25.5-FT DRAFT
SHIPMASTER B, REPETITION 2

PLATE 16



SHIP-TRACK PLOT
PHASE 1, TURNING BASIN
INBOUND RUN, PLAN 1
LAKE LEVEL 568.6 FT, 25.5-FT DRAFT
SHIPMASTER A, REPETITION 1

PLATE 17

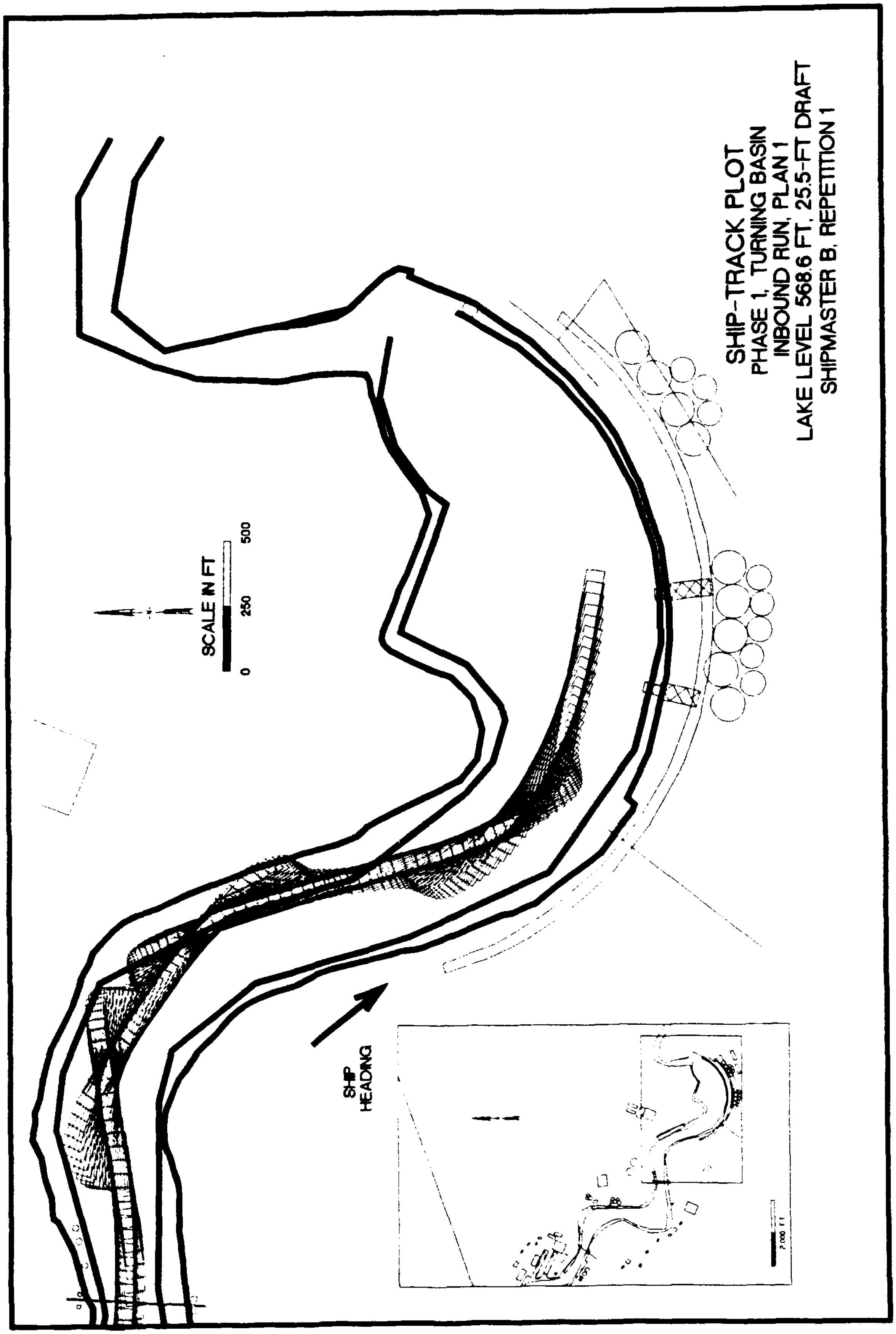
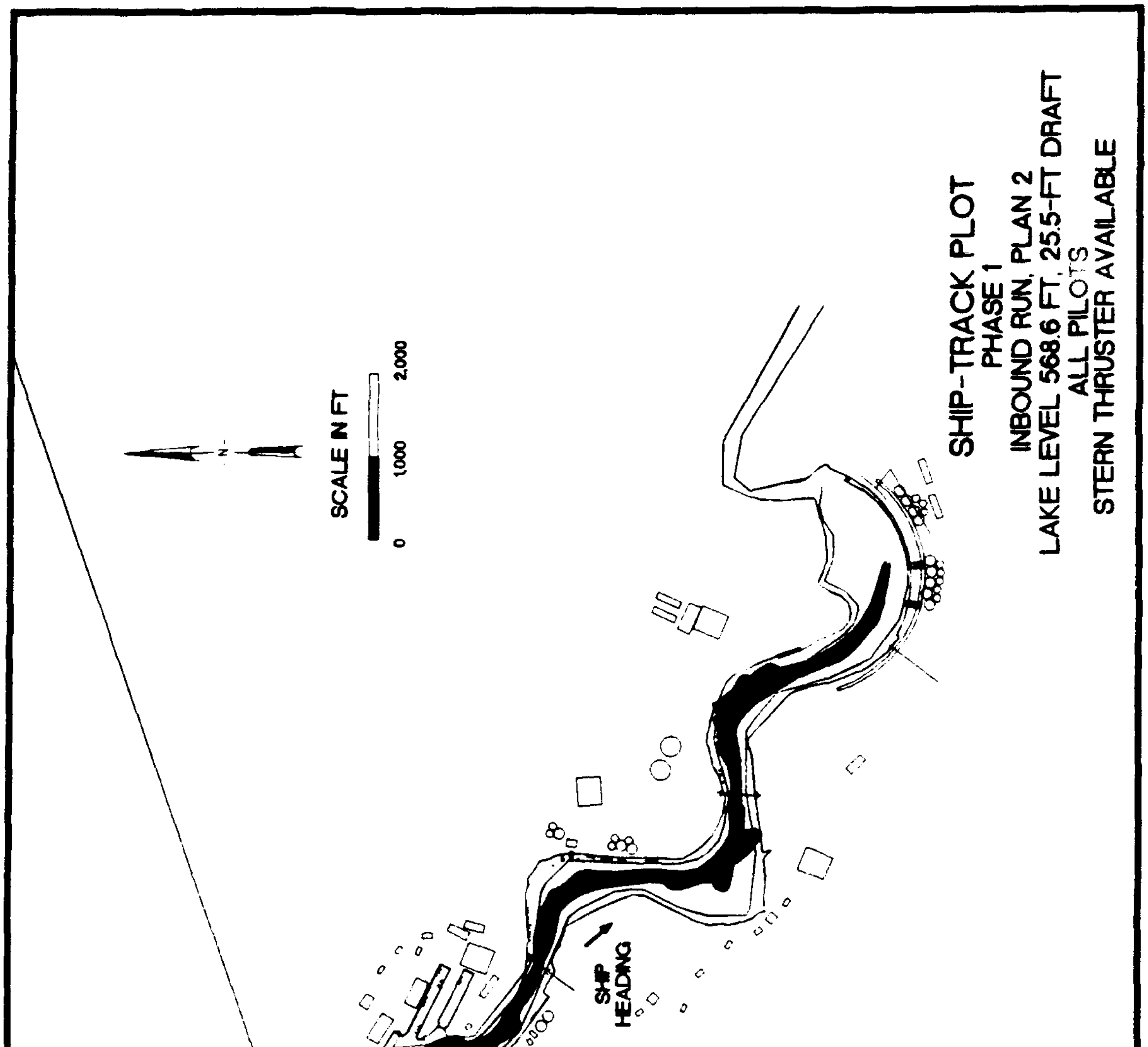
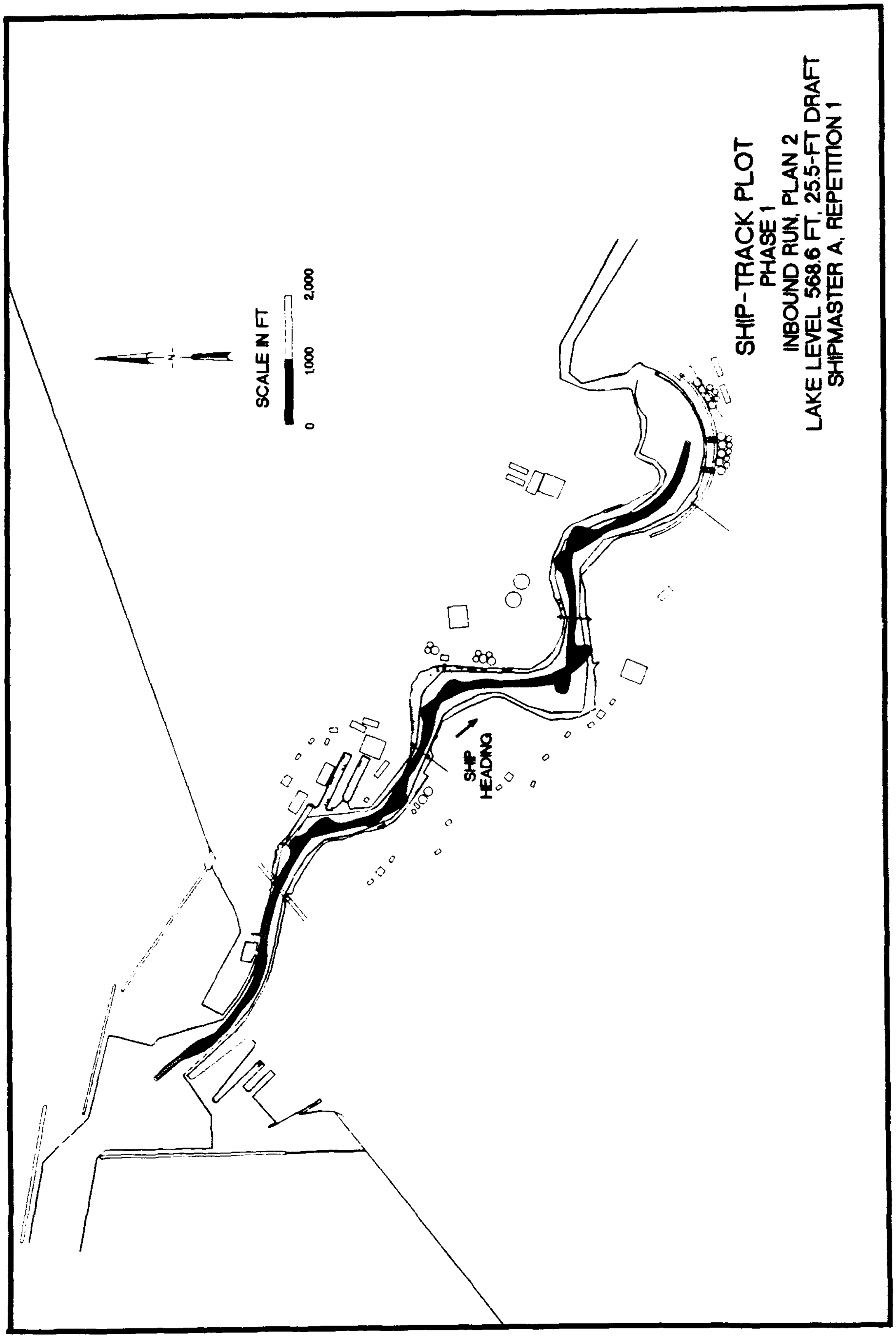
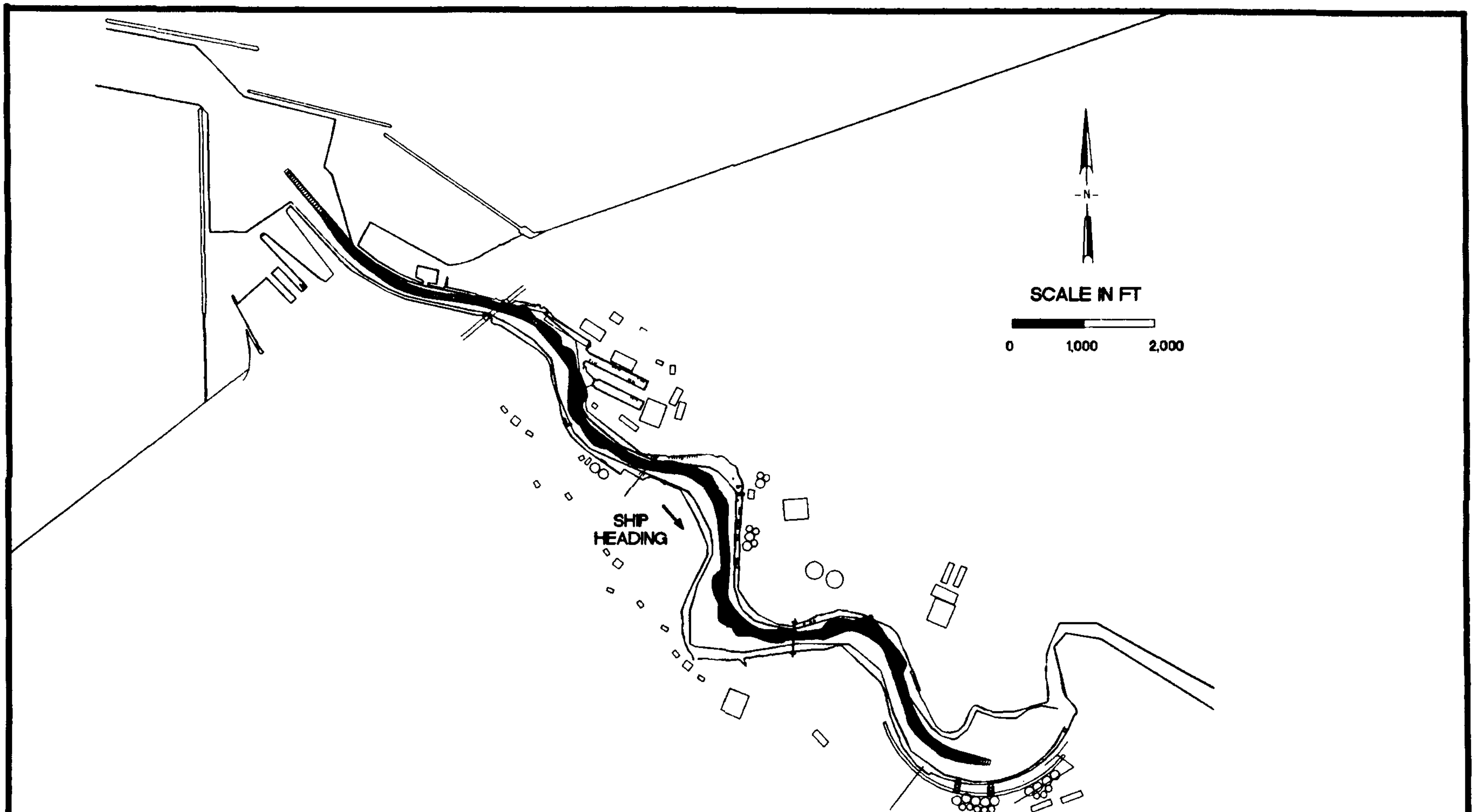

SHIP-TRACK PLOT
PHASE 1, TURNING BASIN
INBOUND RUN, PLAN 1
LAKE LEVEL 568.6 FT, 25.5-FT DRAFT
SHIPMASTER B, REPETITION 1
SCALE IN FT
0
250
500
SHIP
HEADING

PLATE 18

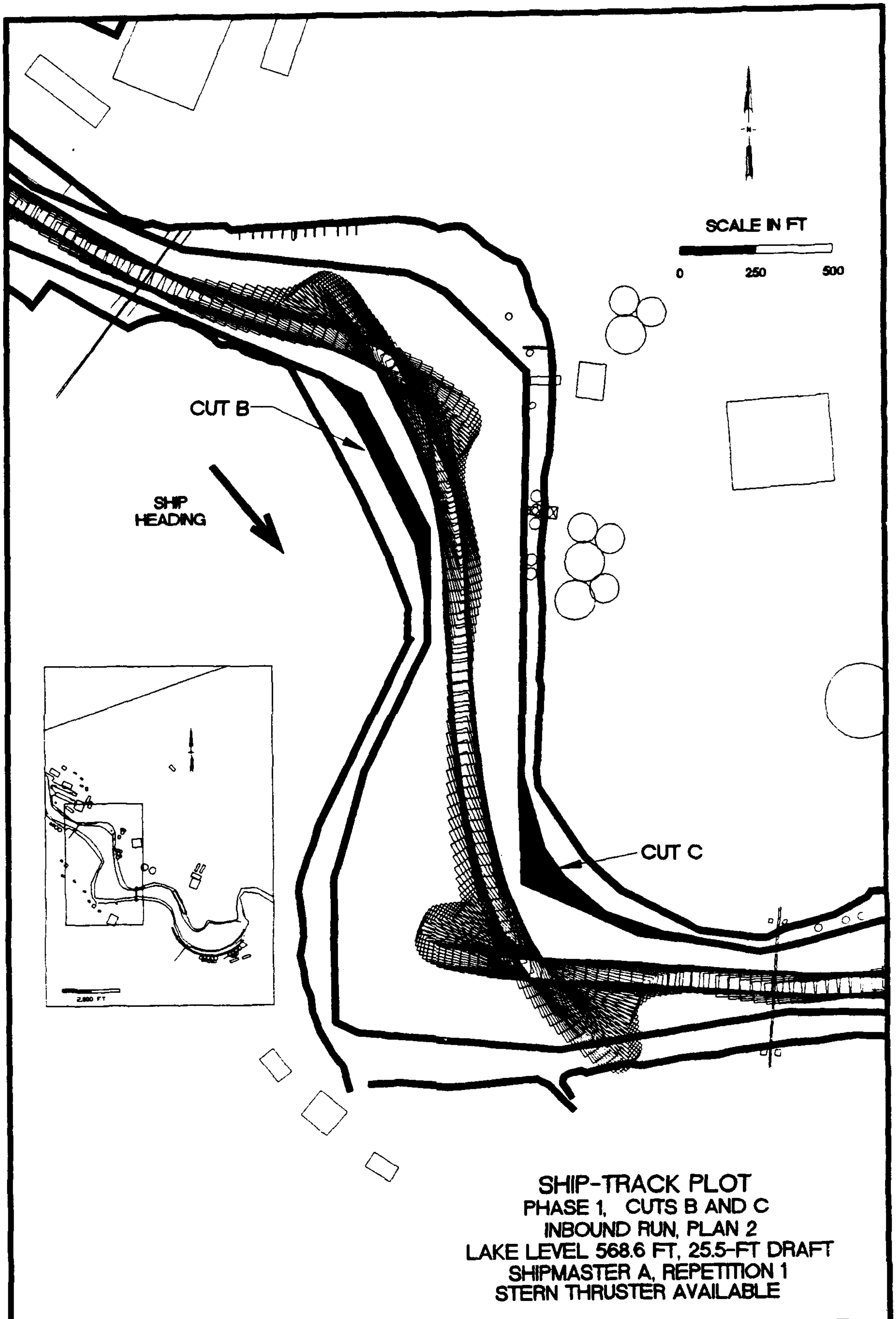

SCALE IN FT
0
1,000
2,000
N
SHIP HEADING
SHIP-TRACK PLOT
PHASE 1
INBOUND RUN, PLAN 2
LAKE LEVEL 568.6 FT, 25.5-FT DRAFT
ALL PILOTS
STERN THRUSTER AVAILABLE



SHIP-TRACK PLOT
PHASE 1
INBOUND RUN, PLAN 2
LAKE LEVEL 568.6 FT, 25.5-FT DRAFT
SHIPMASTER A, REPETITION 1

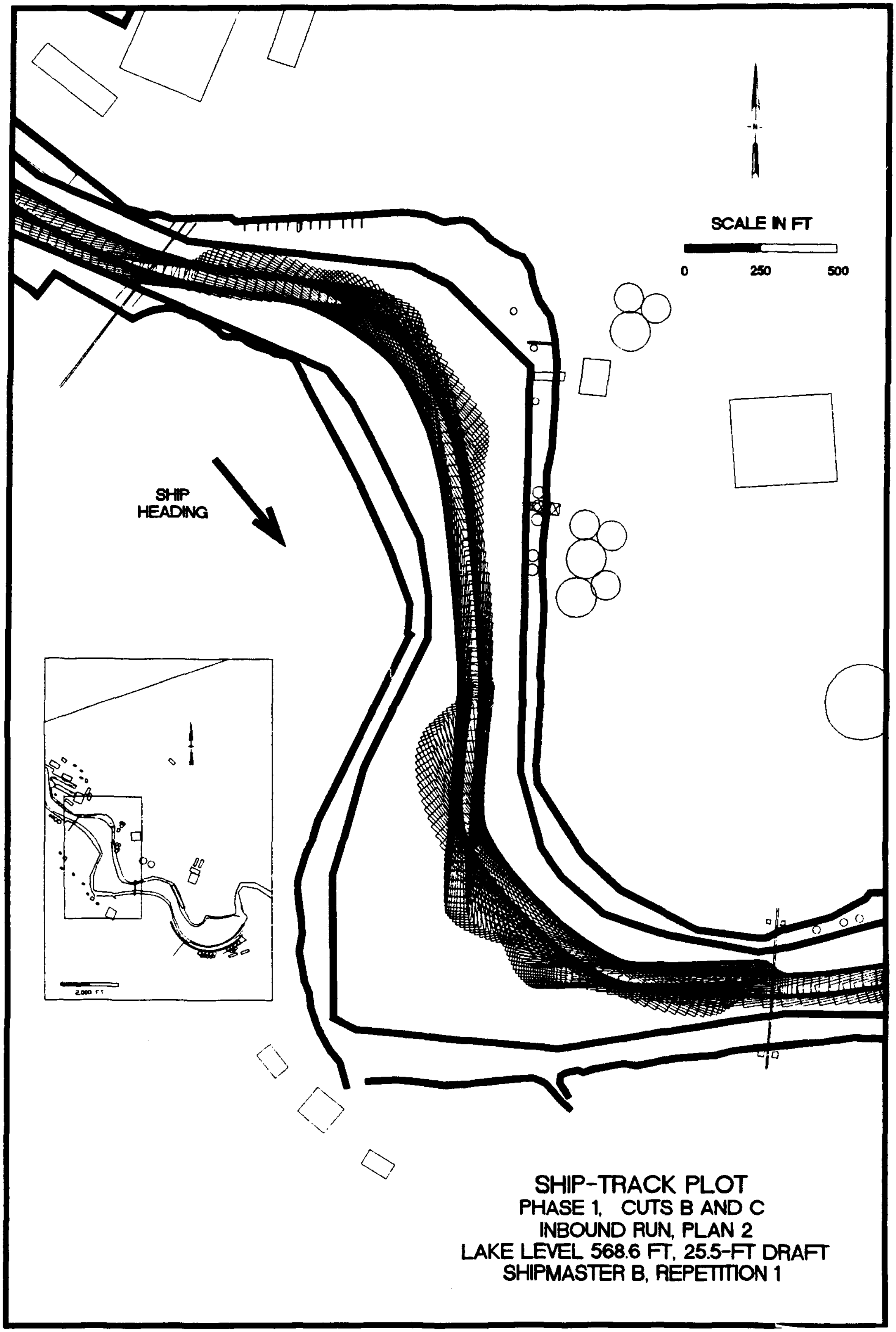


SHIP-TRACK PLOT
PHASE 1
INBOUND RUN, PLAN 2
LAKE LEVEL 568.6 FT, 25.5-FT DRAFT
SHIPMASTER B, REPETITION 1



SCALE IN FT
0
250
500
CUT B
SHIP HEADING
CUT C
2,800 FT
SHIP-TRACK PLOT
PHASE 1, CUTS B AND C
INBOUND RUN, PLAN 2
LAKE LEVEL 568.6 FT, 25.5-FT DRAFT
SHIPMASTER A, REPETITION 1
STERN THRUSTER AVAILABLE

PLATE 22



SHIP-TRACK PLOT
PHASE 1, CUTS B AND C
INBOUND RUN, PLAN 2
LAKE LEVEL 568.6 FT, 25.5-FT DRAFT
SHIPMASTER B, REPETITION 1

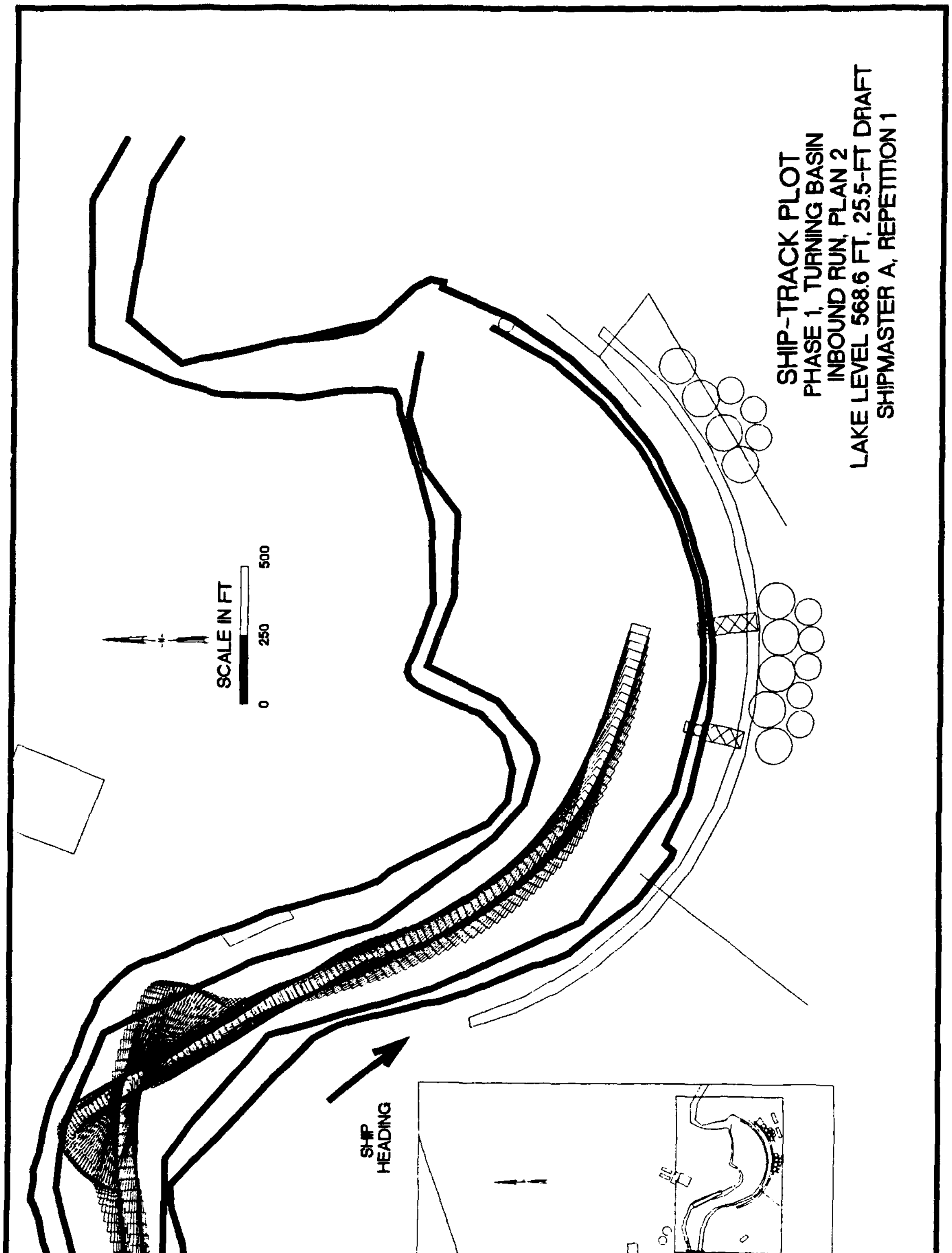
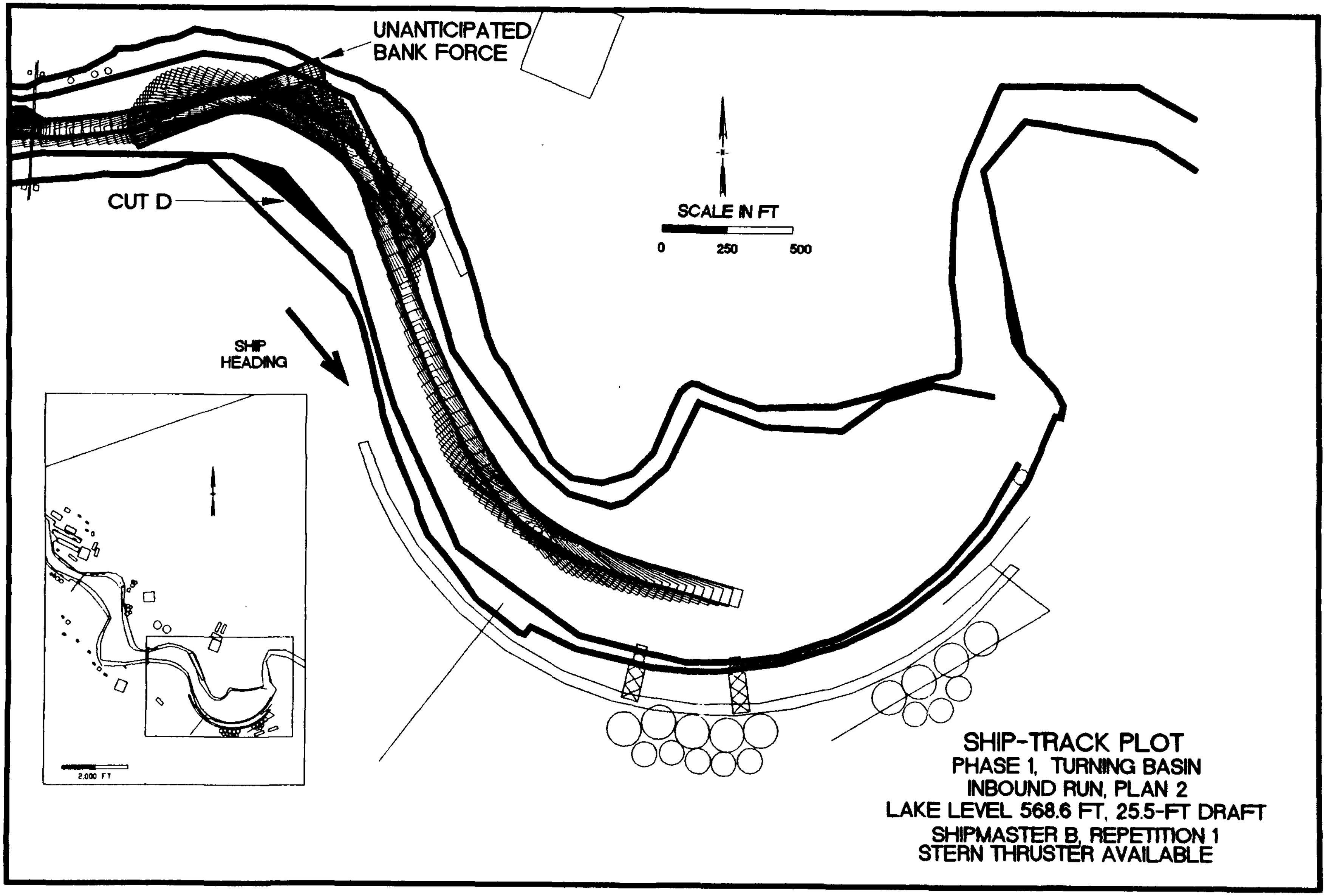
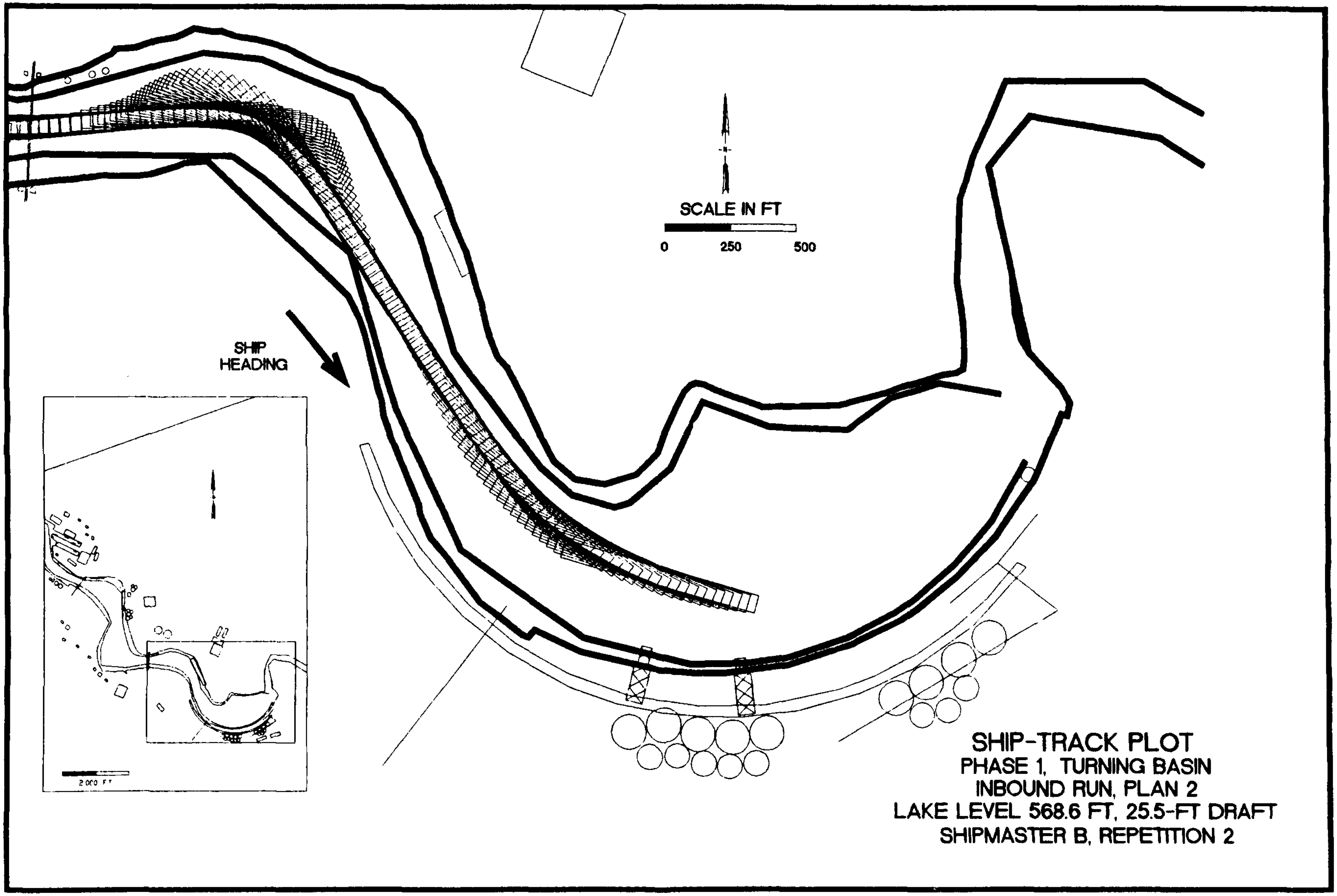

SHIP-TRACK PLOT
PHASE 1, TURNING BASIN
INBOUND RUN, PLAN 2
LAKE LEVEL 568.6 FT, 25.5-FT DRAFT
SHIPMASTER A, REPETITION 1
SCALE IN FT
0
250
500
SHIP HEADING
2,000 FT

PLATE 24

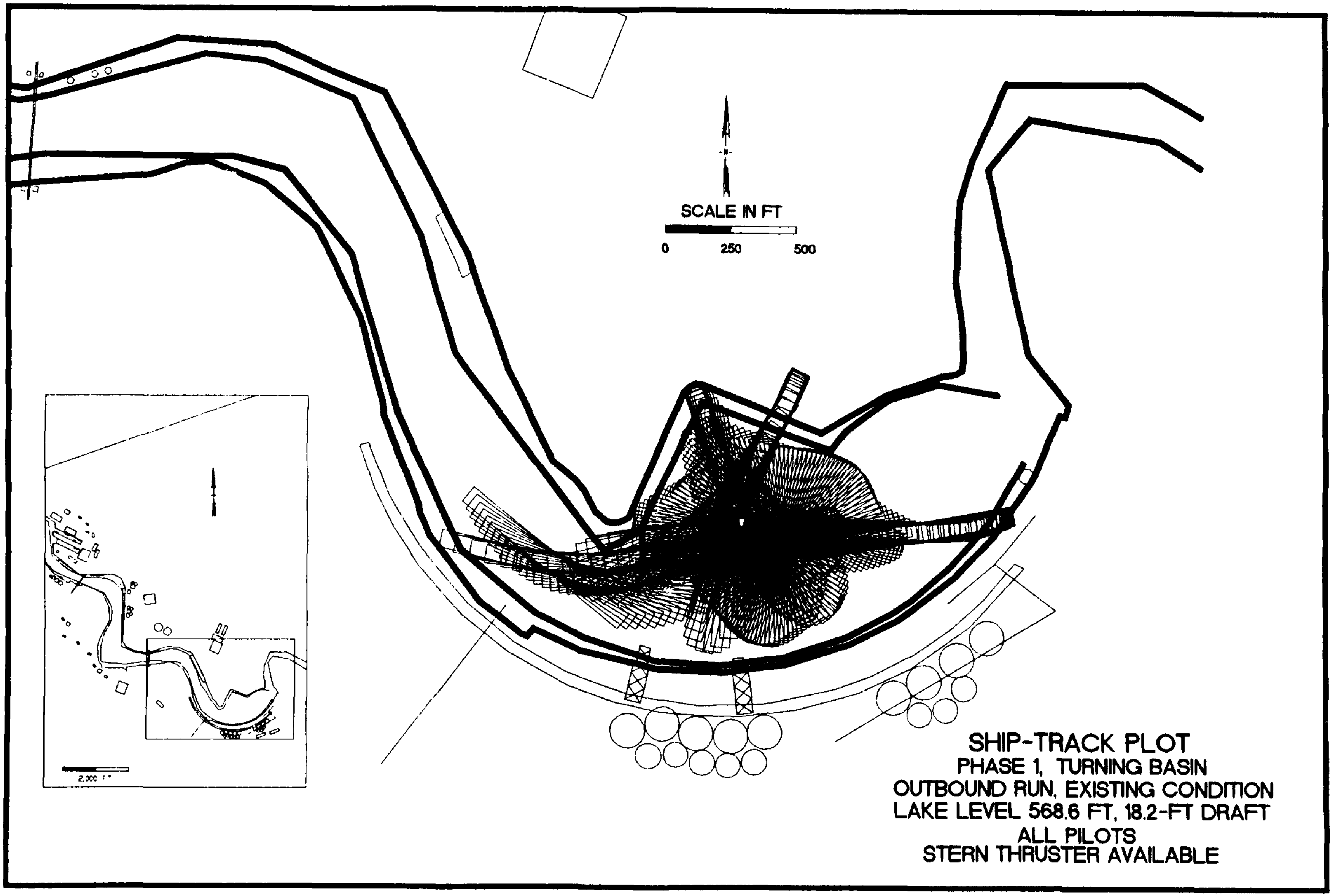


SHIP-TRACK PLOT
PHASE 1, TURNING BASIN
INBOUND RUN, PLAN 2
LAKE LEVEL 568.6 FT, 25.5-FT DRAFT
SHIPMASTER B, REPETITION 1
STERN THRUSTER AVAILABLE

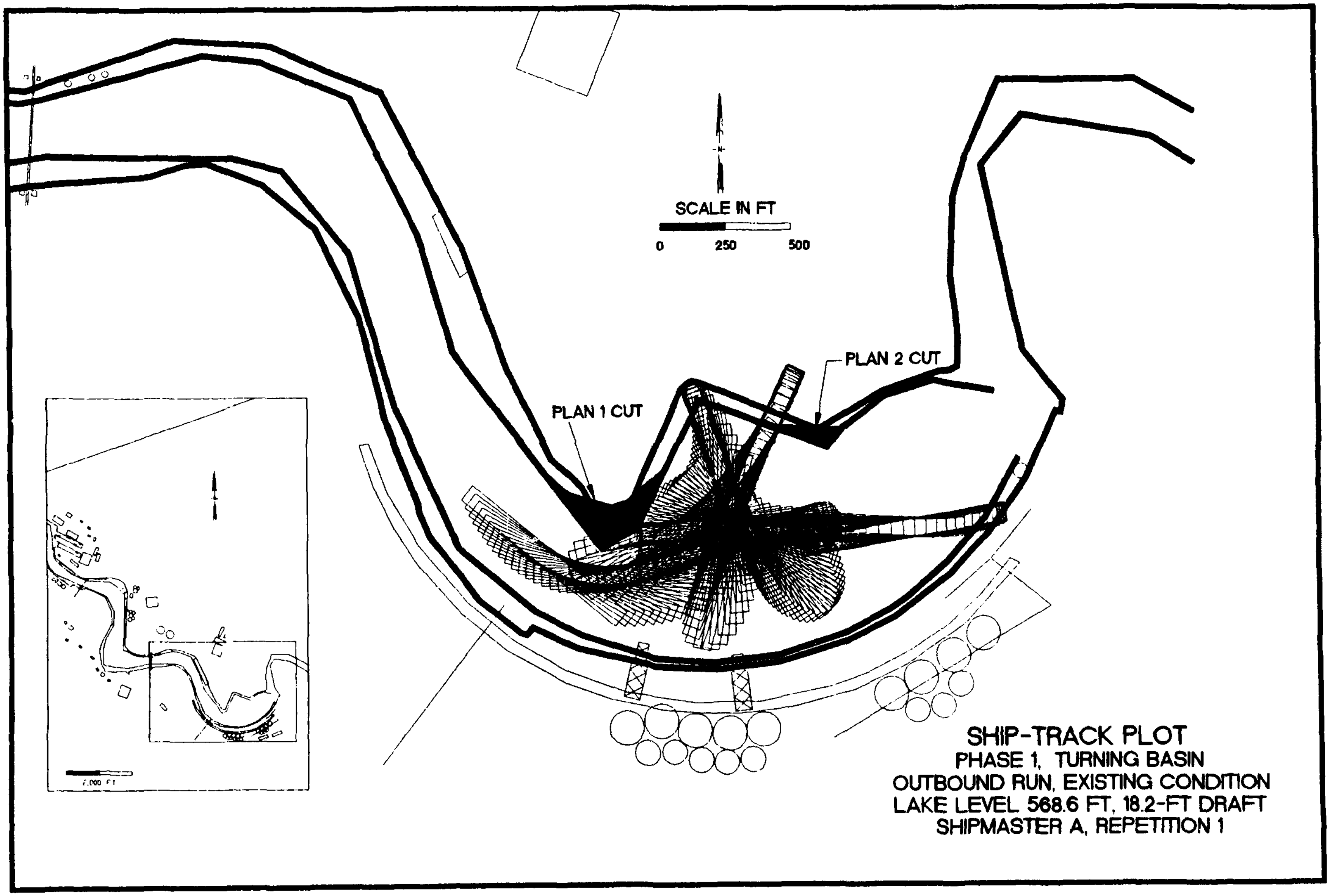


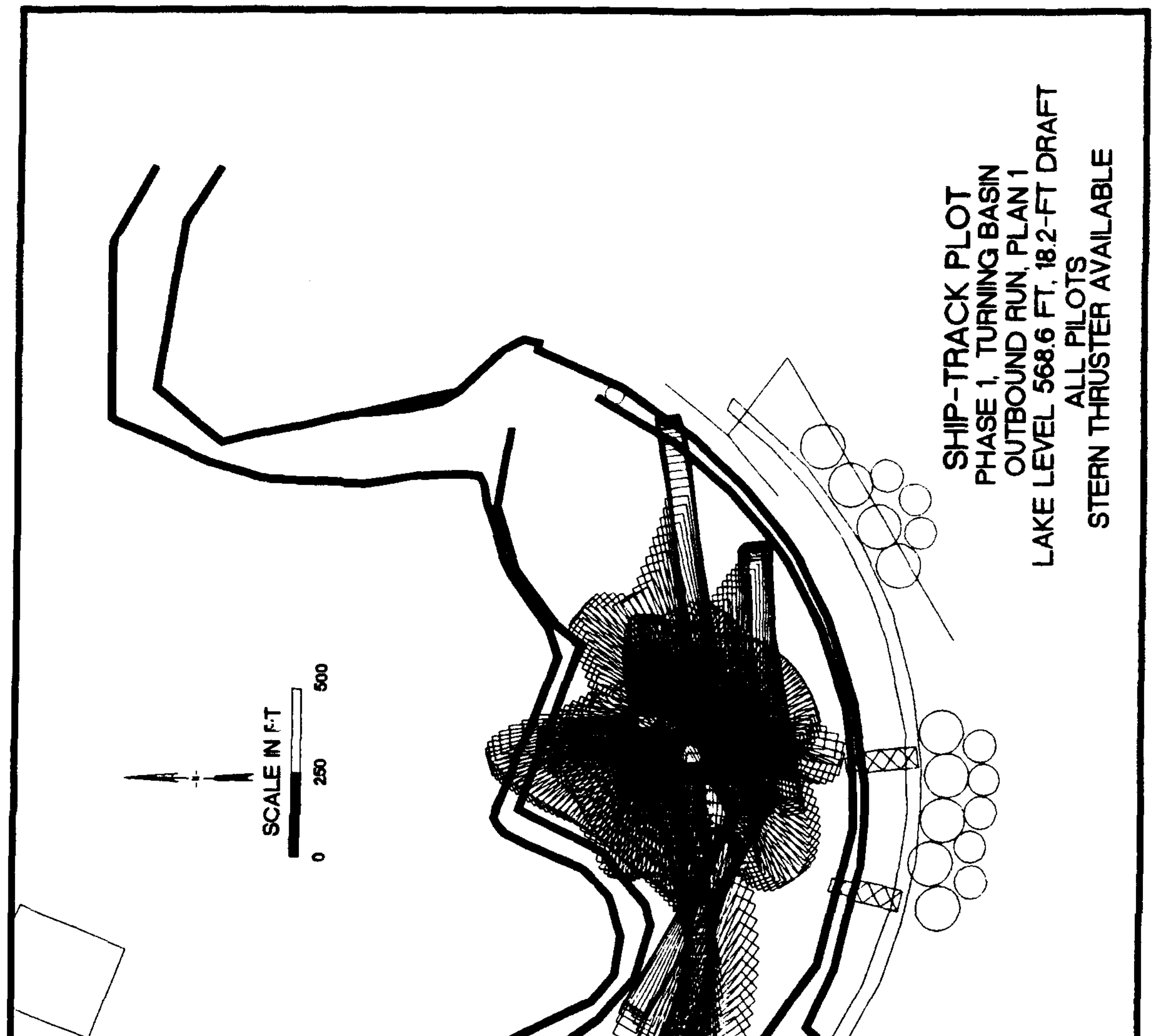
SHIP-TRACK PLOT
PHASE 1, TURNING BASIN
INBOUND RUN, PLAN 2
LAKE LEVEL 568.6 FT, 25.5-FT DRAFT
SHIPMASTER B, REPETITION 2

PLATE 26



SHIP-TRACK PLOT
PHASE 1, TURNING BASIN
OUTBOUND RUN, EXISTING CONDITION
LAKE LEVEL 568.6 FT, 18.2-FT DRAFT
ALL PILOTS
STERN THRUSTER AVAILABLE


SCALE IN FT
0
250
500
PLAN 1 CUT
PLAN 2 CUT
SHIP-TRACK PLOT
PHASE 1, TURNING BASIN
OUTBOUND RUN, EXISTING CONDITION
LAKE LEVEL 568.6 FT, 18.2-FT DRAFT
SHIPMASTER A, REPETITION 1


SHIP-TRACK PLOT
PHASE 1, TURNING BASIN
OUTBOUND RUN, PLAN 1
LAKE LEVEL 568.6 FT, 18.2-FT DRAFT
ALL PILOTS
STERN THRUSTER AVAILABLE
SCALE IN FT
0
250
500
2,000 FT

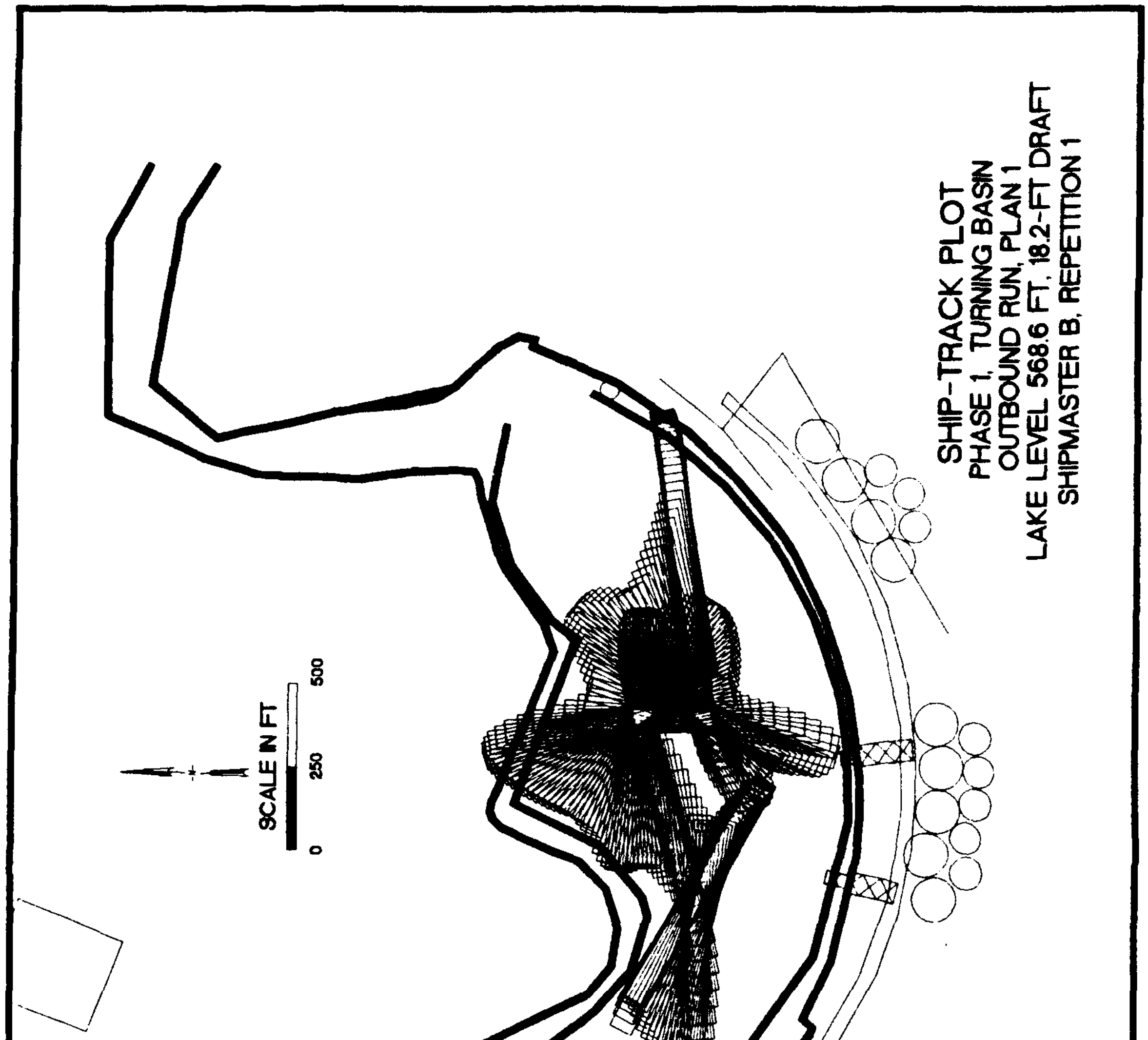
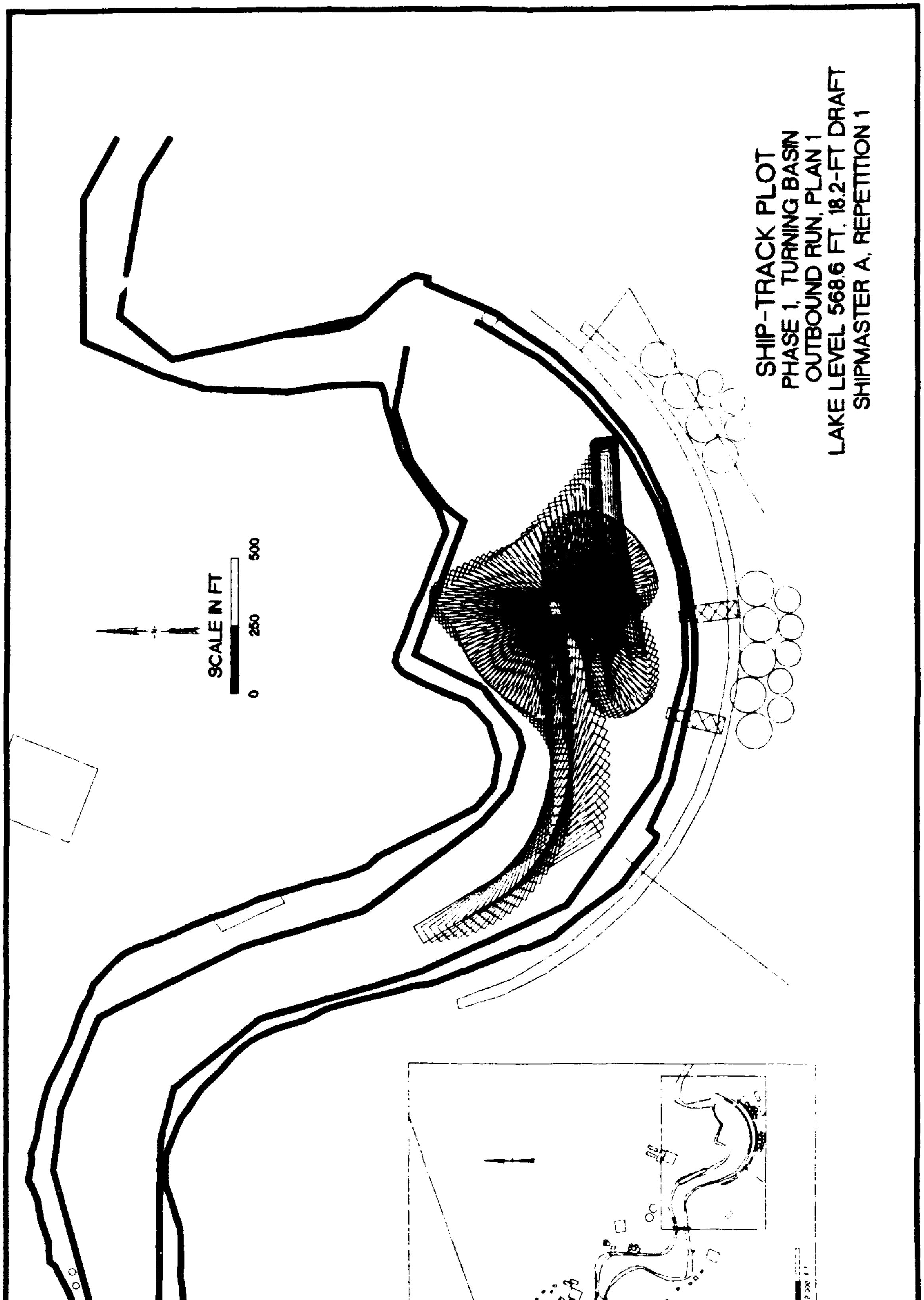
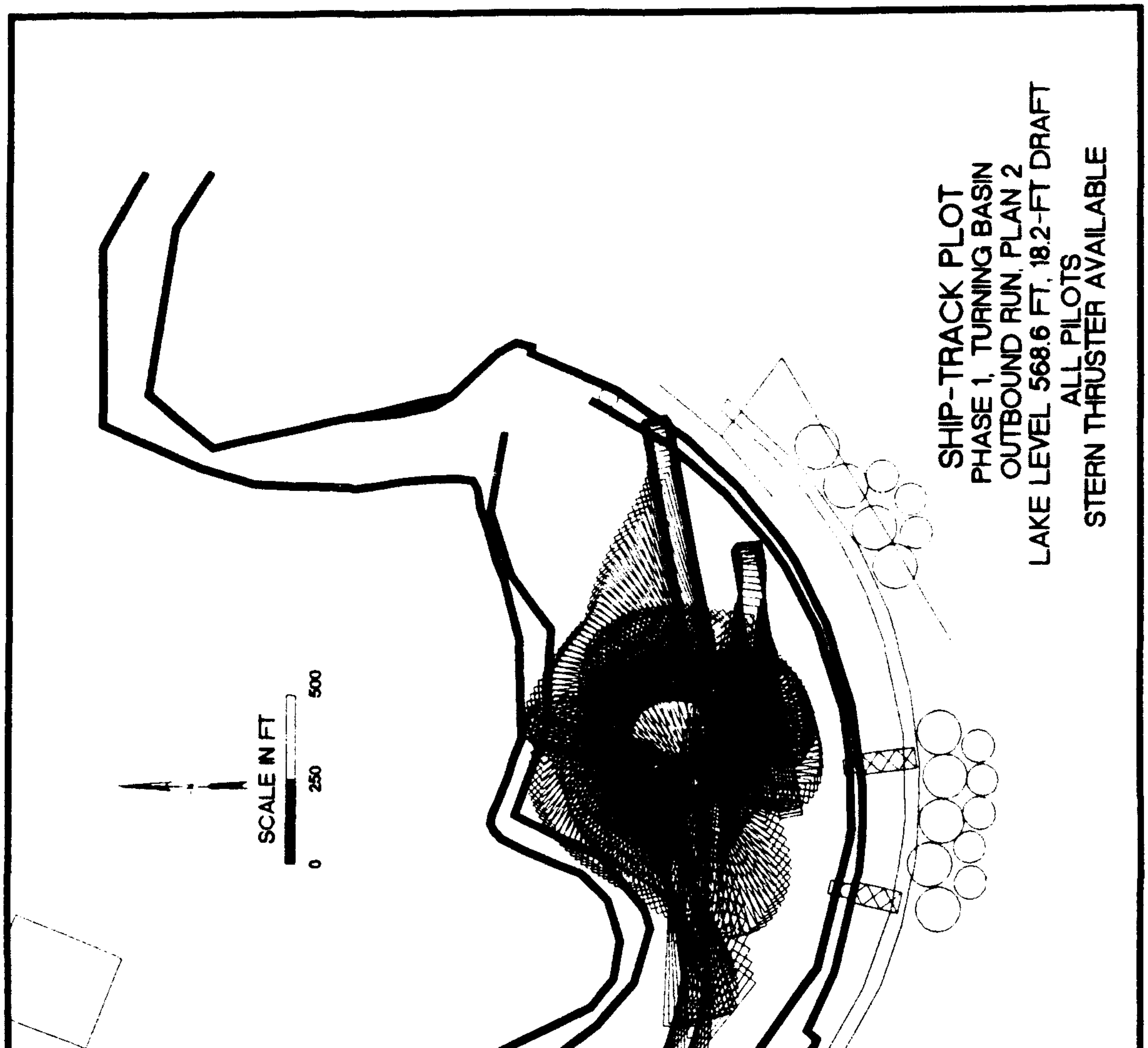
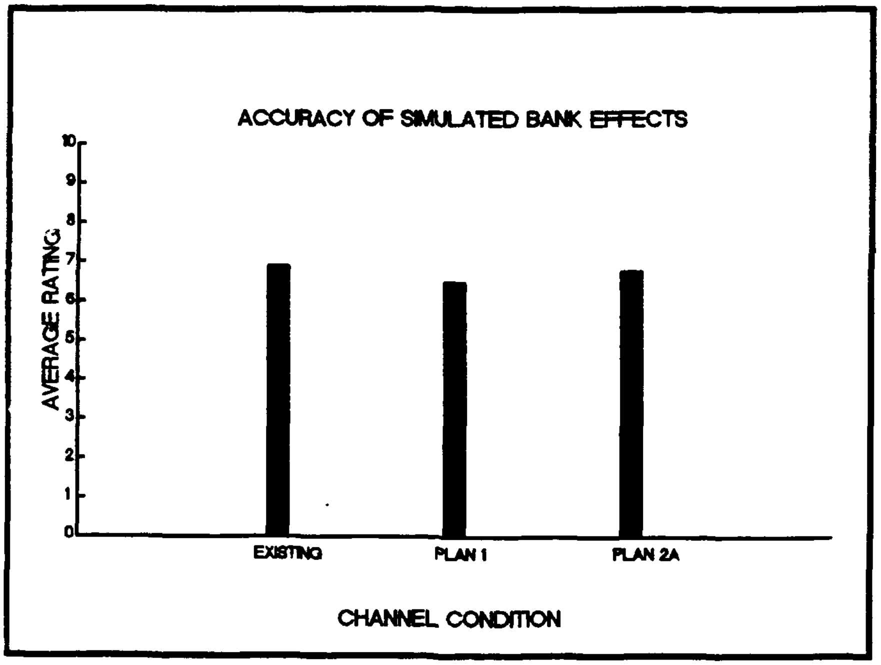
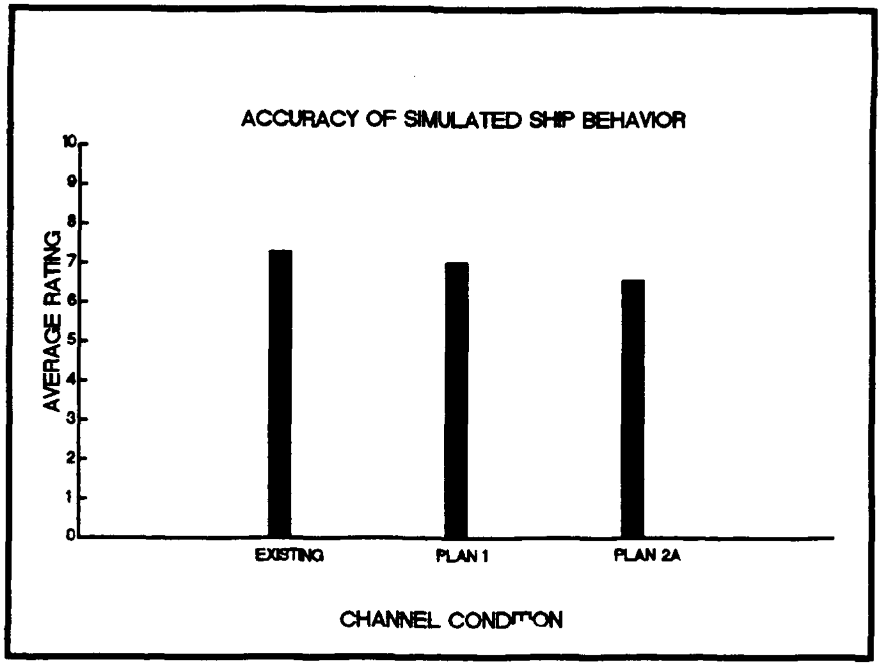

SHIP-TRACK PLOT
PHASE 1, TURNING BASIN
OUTBOUND RUN, PLAN 1
LAKE LEVEL 568.6 FT, 18.2-FT DRAFT
SHIPMASTER B, REPETITION 1
SCALE IN FT
0
250
500
2000 FT

PLATE 30

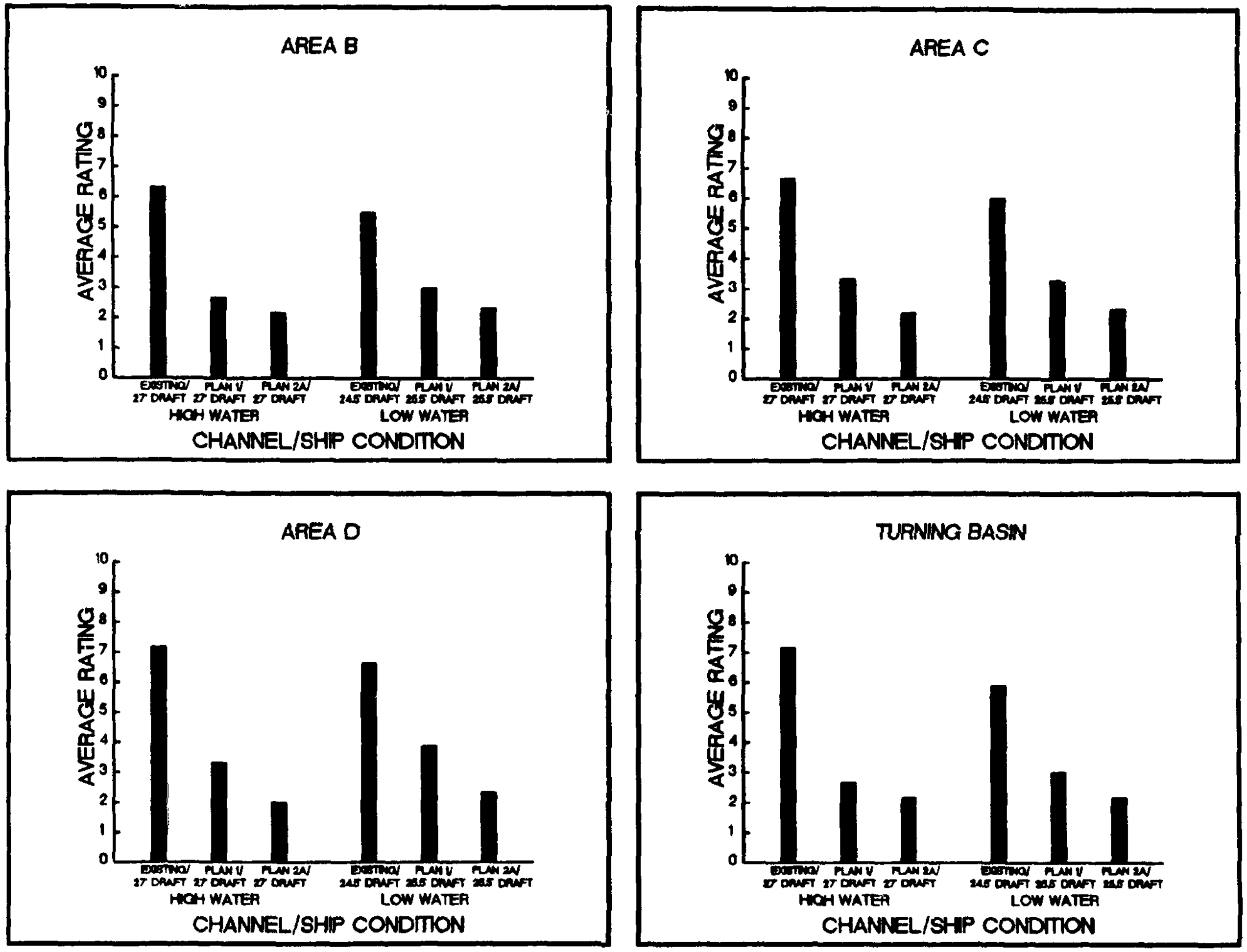

SHIP-TRACK PLOT
PHASE 1, TURNING BASIN
OUTBOUND RUN, PLAN 1
LAKE LEVEL 568.6 FT, 18.2-FT DRAFT
SHIPMASTER A, REPETITION 1
SCALE IN FT
0
250
500


SHIP-TRACK PLOT
PHASE 1, TURNING BASIN
OUTBOUND RUN, PLAN 2
LAKE LEVEL 568.6 FT, 18.2-FT DRAFT
ALL PILOTS
STERN THRUSTER AVAILABLE
SCALE IN FT
0
250
500

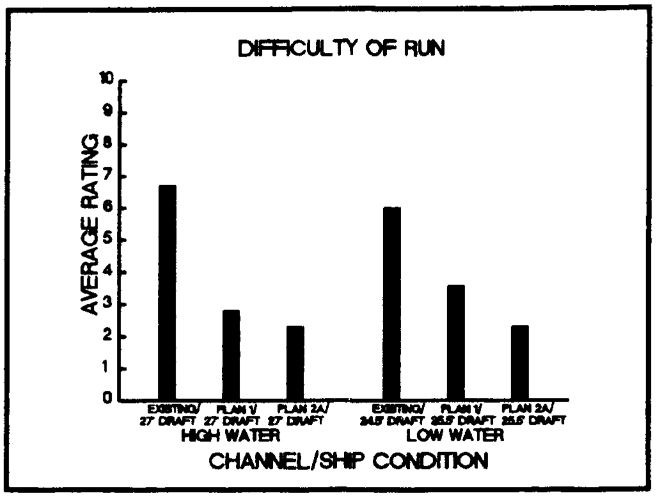


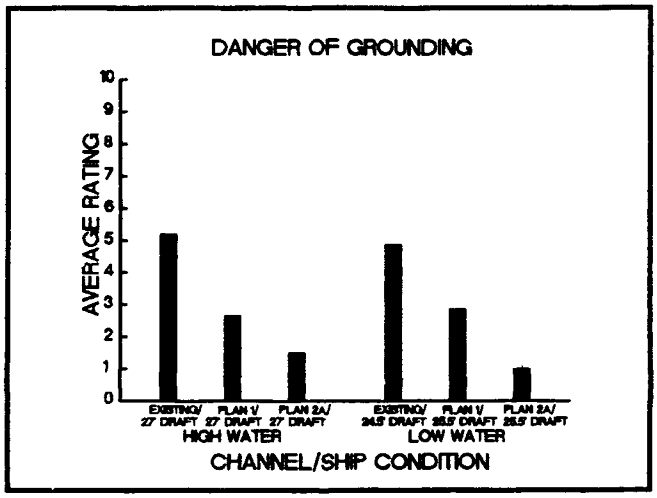


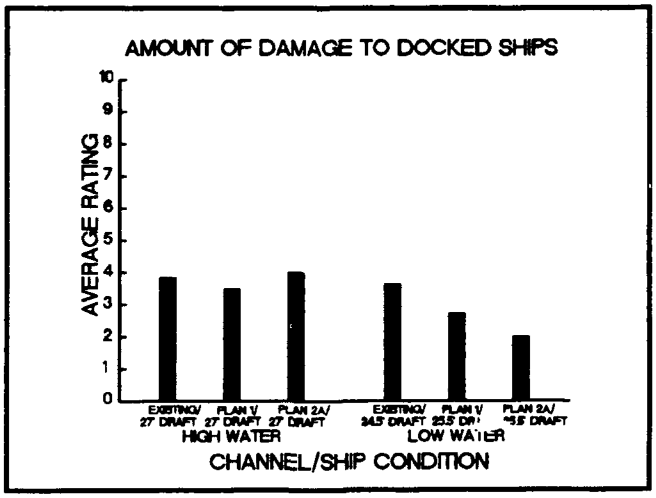
SHIPMASTER EVALUATION, PHASE 2



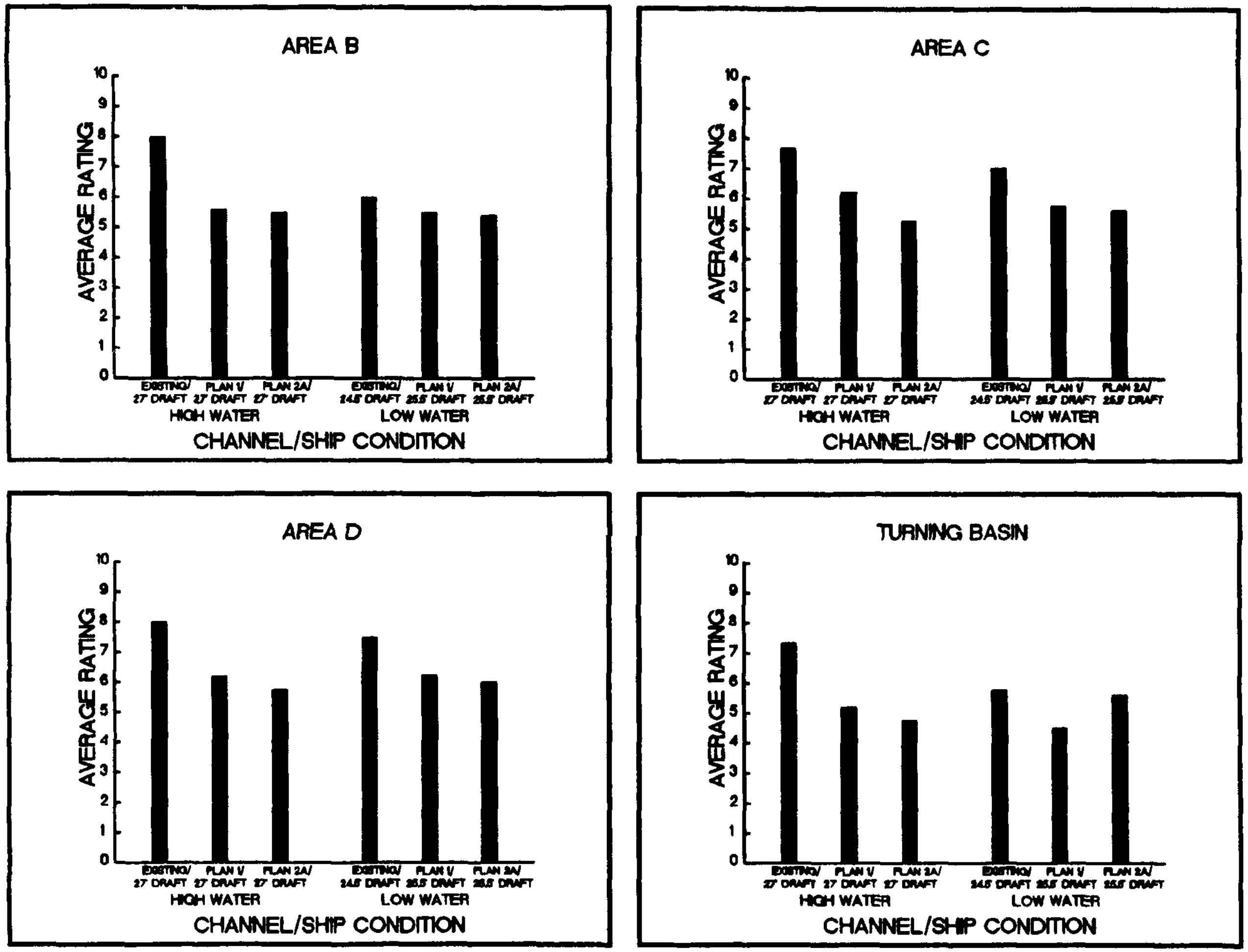
SHIPMASTER EVALUATION, PHASE 2
INBOUND WITH STERN THRUSTERS
CONTROLLABILITY OF SHIP PER AREA



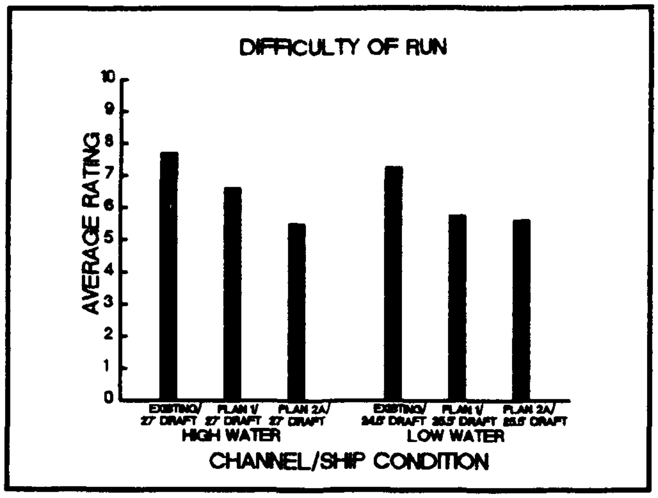


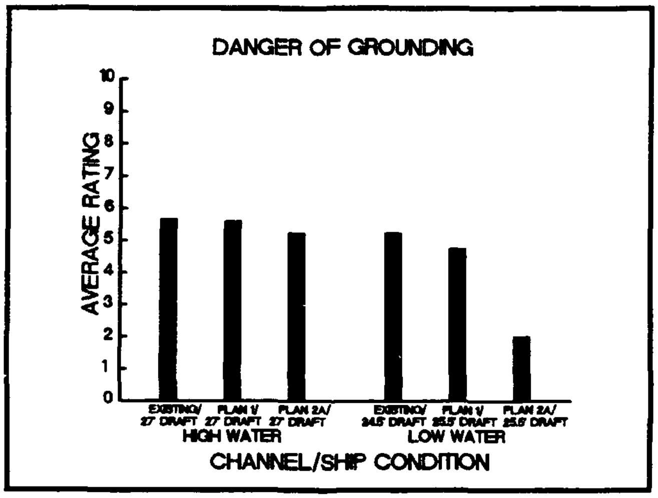


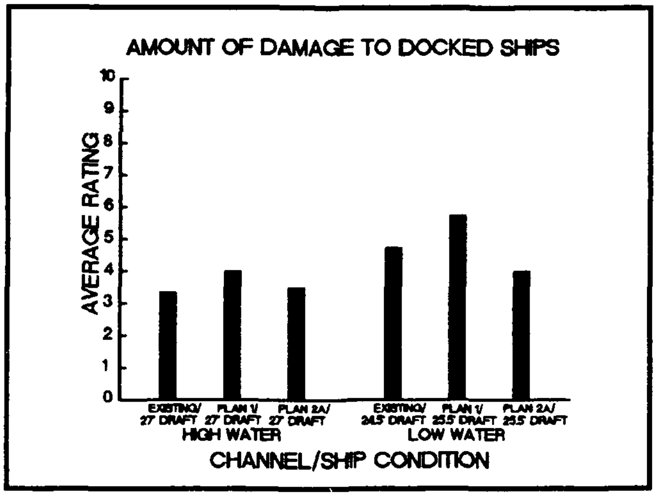
SHIPMASTER EVALUATION, PHASE 2
INBOUND WITH STERN THRUSTERS
ALL AREAS



SHIPMASTER EVALUATION, PHASE 2
INBOUND WITHOUT STERN THRUSTERS
CONTROLLABILITY OF SHIP PER AREA







SHIPMASTER EVALUATION, PHASE 2
INBOUND WITHOUT STERN THRUSTERS
ALL AREAS

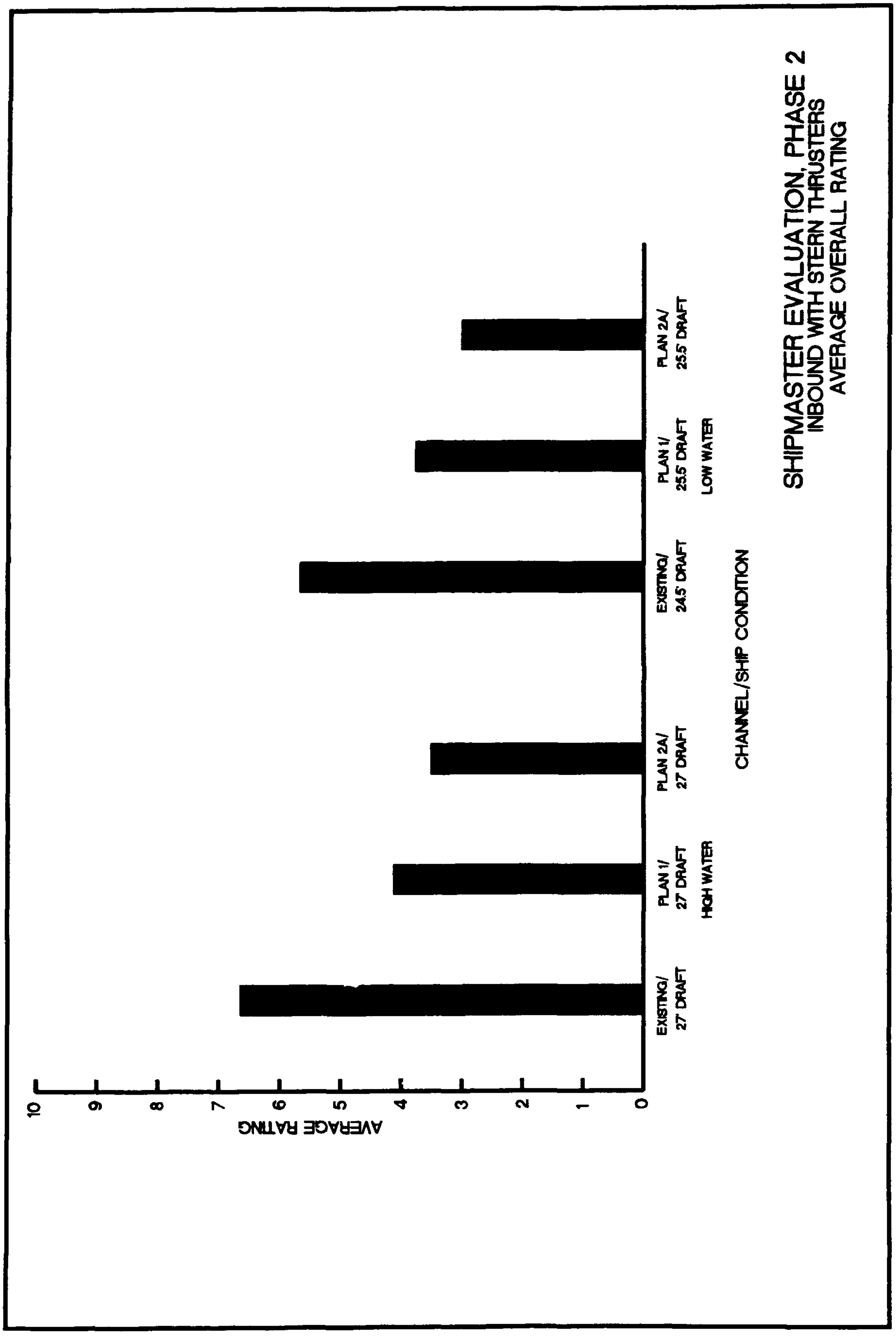
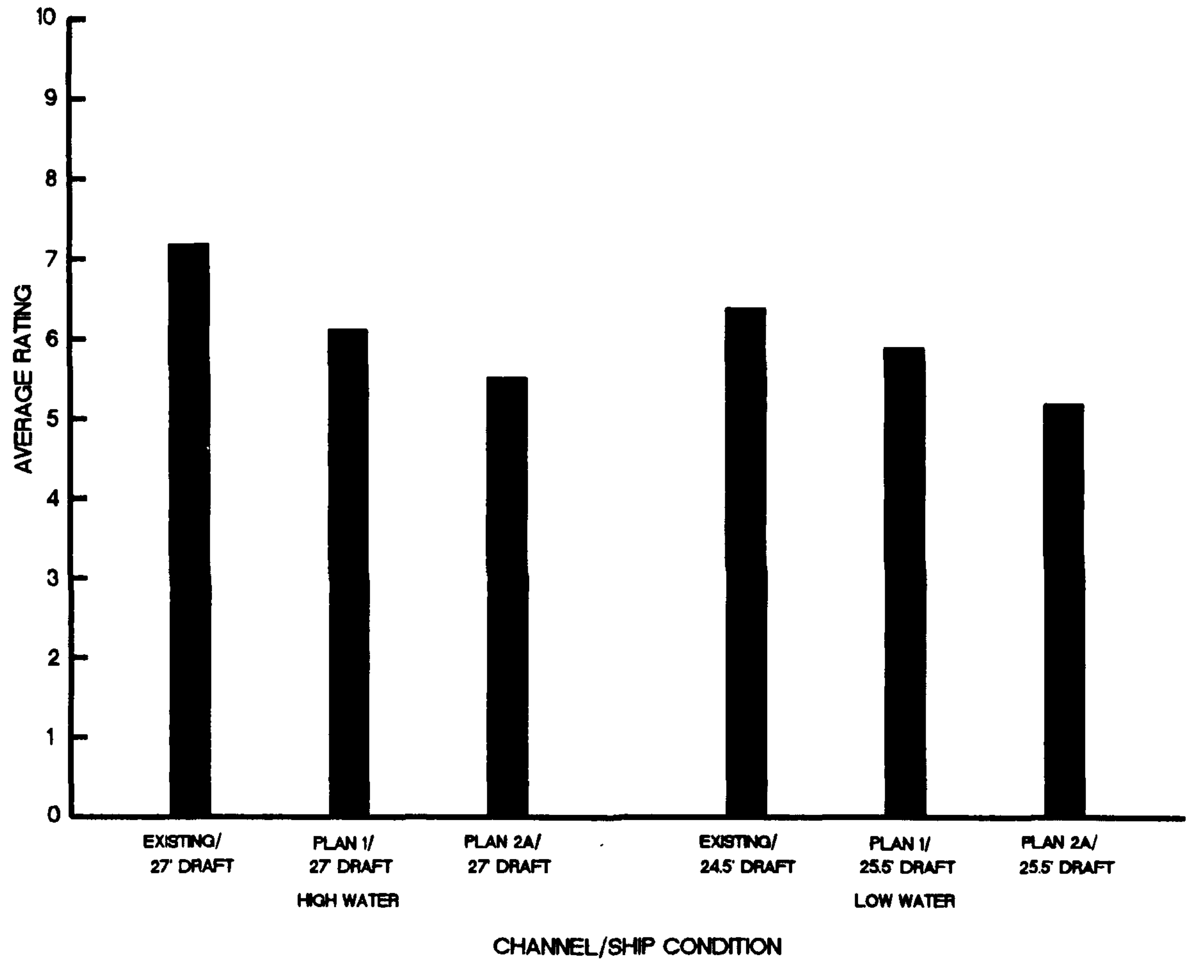
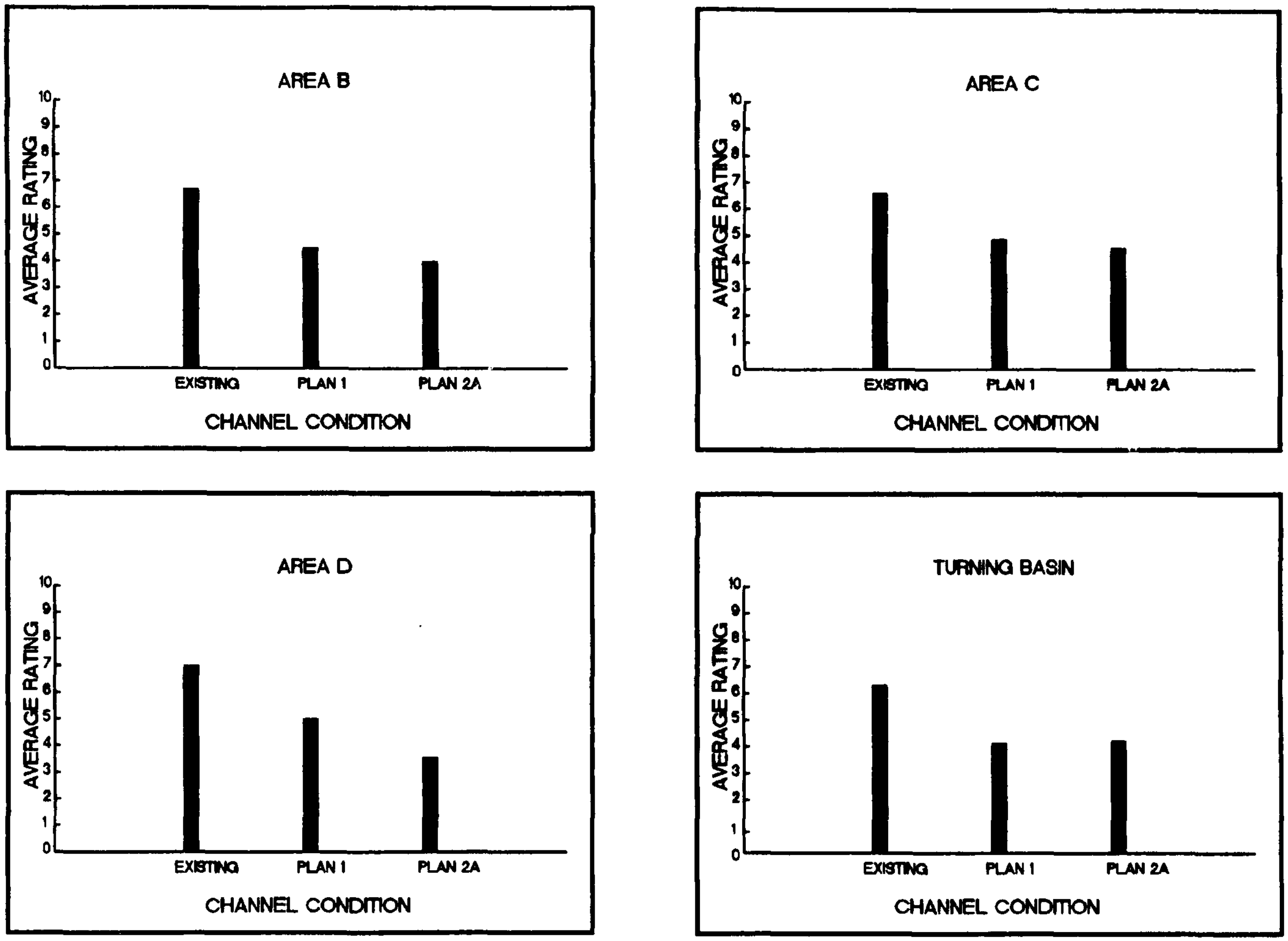

SHIPMASTER EVALUATION, PHASE 2
INBOUND WITH STERN THRUSTERS
AVERAGE OVERALL RATING
AVERAGE RATING
0
1
2
3
4
5
6
7
8
9
10
EXISTING/
27' DRAFT
PLAN 1/
27' DRAFT
PLAN 2A/
27' DRAFT
HIGH WATER
EXISTING/
24.5' DRAFT
PLAN 1/
25.5' DRAFT
PLAN 2A/
25.5' DRAFT
LOW WATER
CHANNEL/SHIP CONDITION

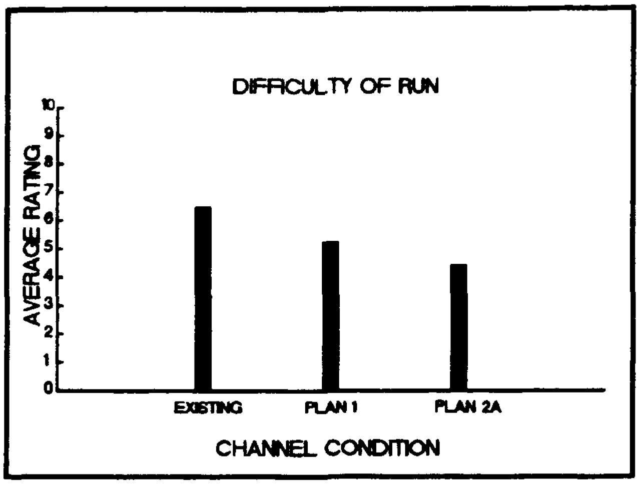
PLATE 38

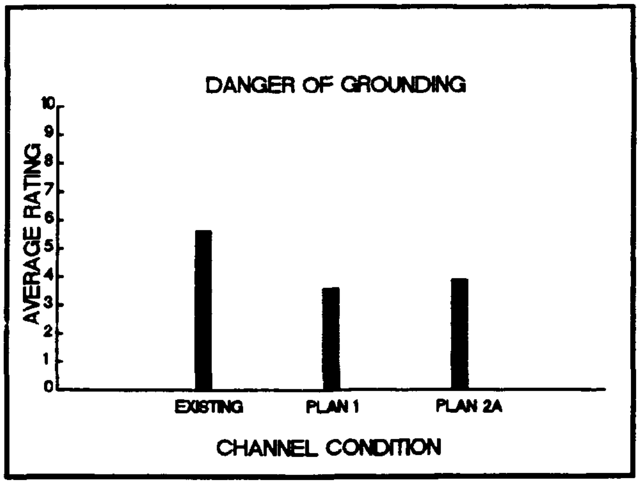


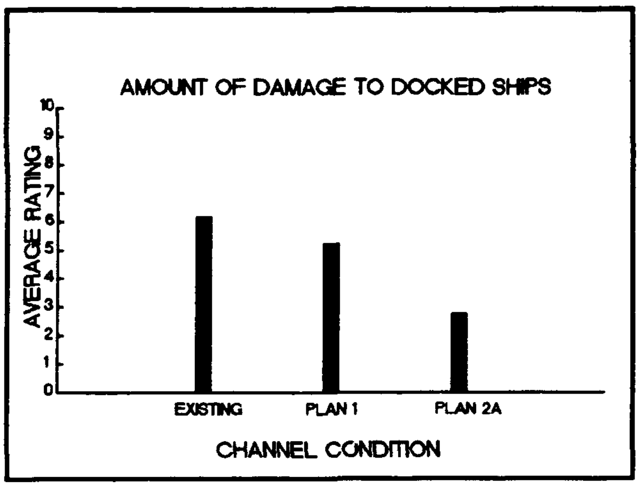
SHIPMASTER EVALUATION, PHASE 2
INBOUND WITHOUT STERN THRUSTERS
AVERAGE OVERALL RATING



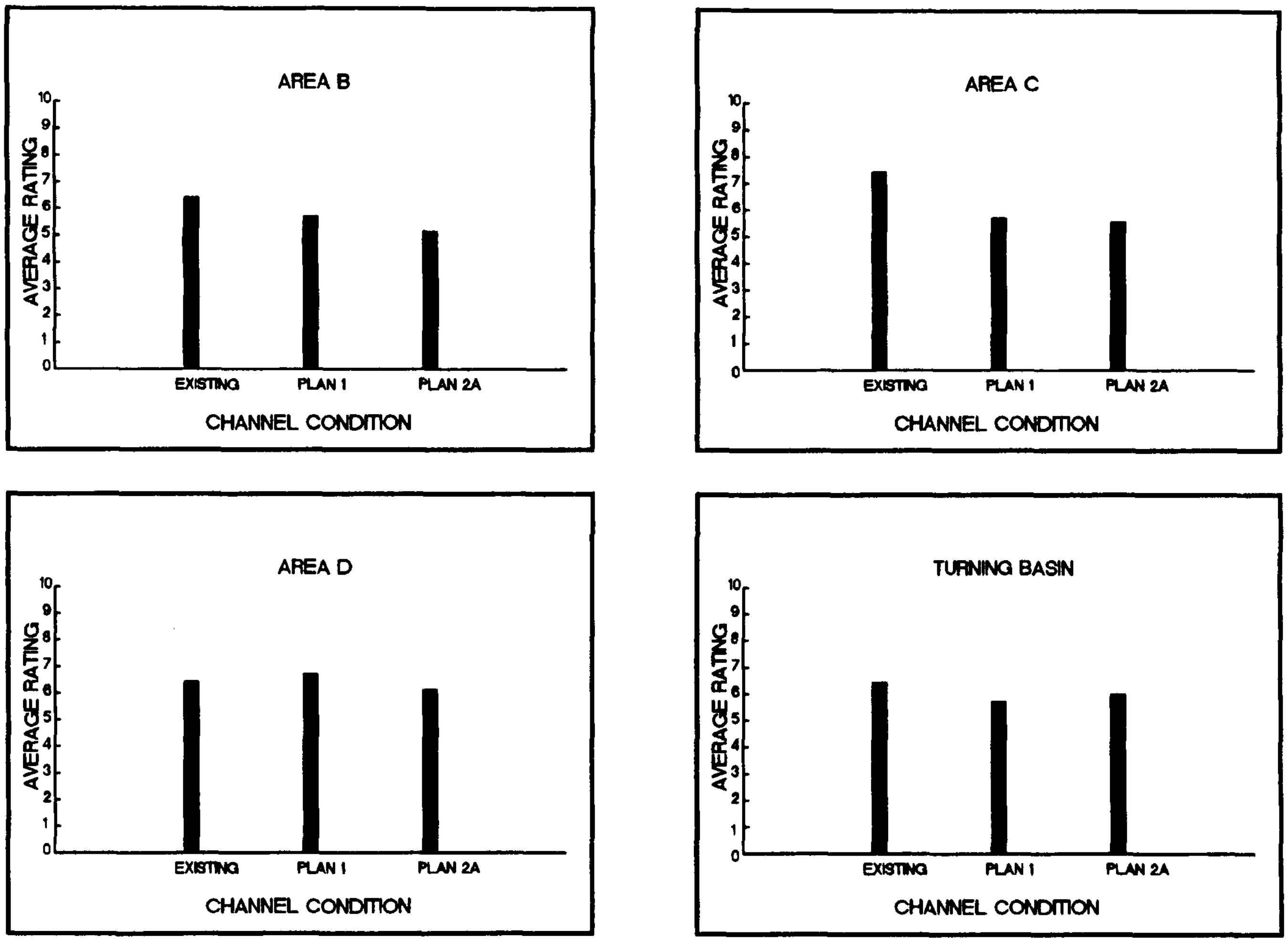
SHIPMASTER EVALUATION, PHASE 2
OUTBOUND WITH STERN THRUSTERS
CONTROLLABILITY OF SHIP PER AREA



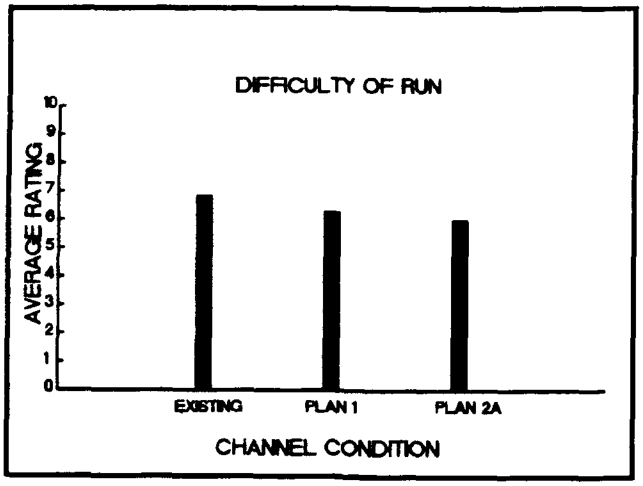


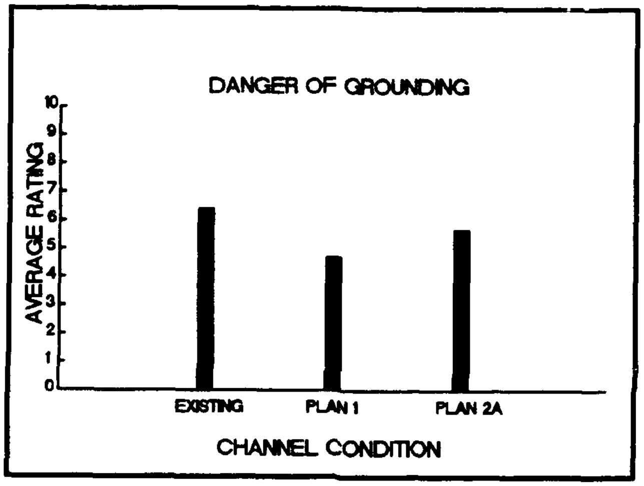


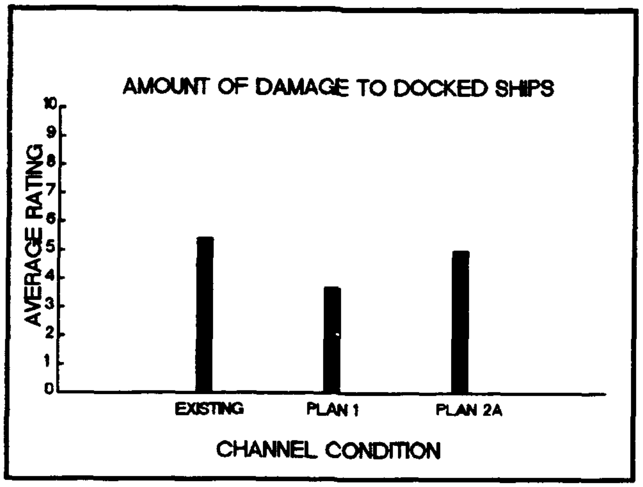
SHIPMASTER EVALUATION, PHASE 2
OUTBOUND WITH STERN THRUSTERS
ALL AREAS



SHIPMASTER EVALUATION, PHASE 2
OUTBOUND WITHOUT STERN THRUSTERS
CONTROLLABILITY OF SHIP PER AREA







SHIPMASTER EVALUATION, PHASE 2
OUTBOUND WITHOUT STERN THRUSTERS
ALL AREAS

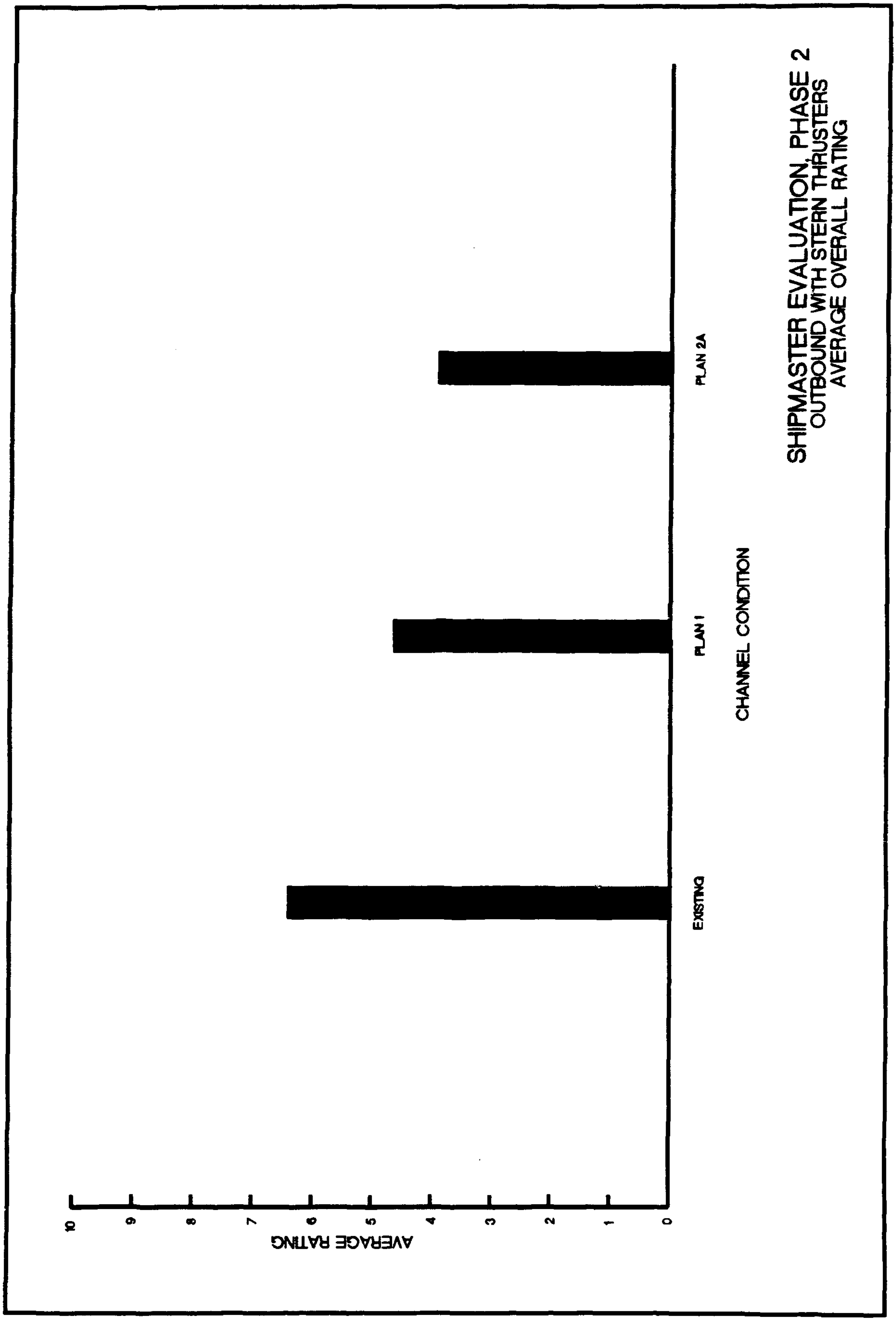
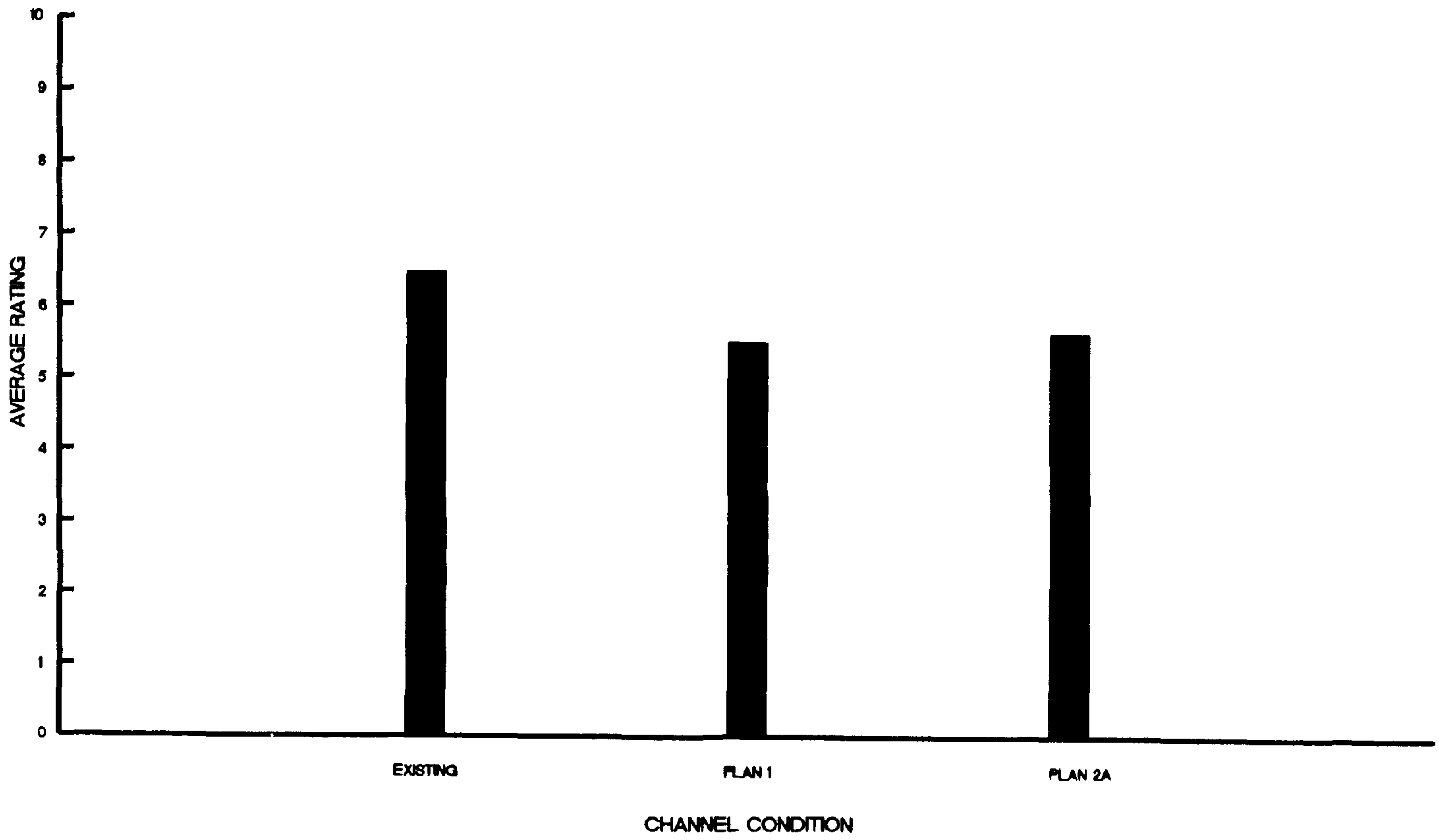

SHIPMASTER EVALUATION, PHASE 2
OUTBOUND WITH STERN THRUSTERS
AVERAGE OVERALL RATING
AVERAGE RATING
0
1
2
3
4
5
6
7
8
9
10
EXISTING
PLAN 1
PLAN 2A
CHANNEL CONDITION

PLATE 44



SHIPMASTER EVALUATION, PHASE 2
OUTBOUND WITHOUT STERN THRUSTERS
AVERAGE OVERALL RATING

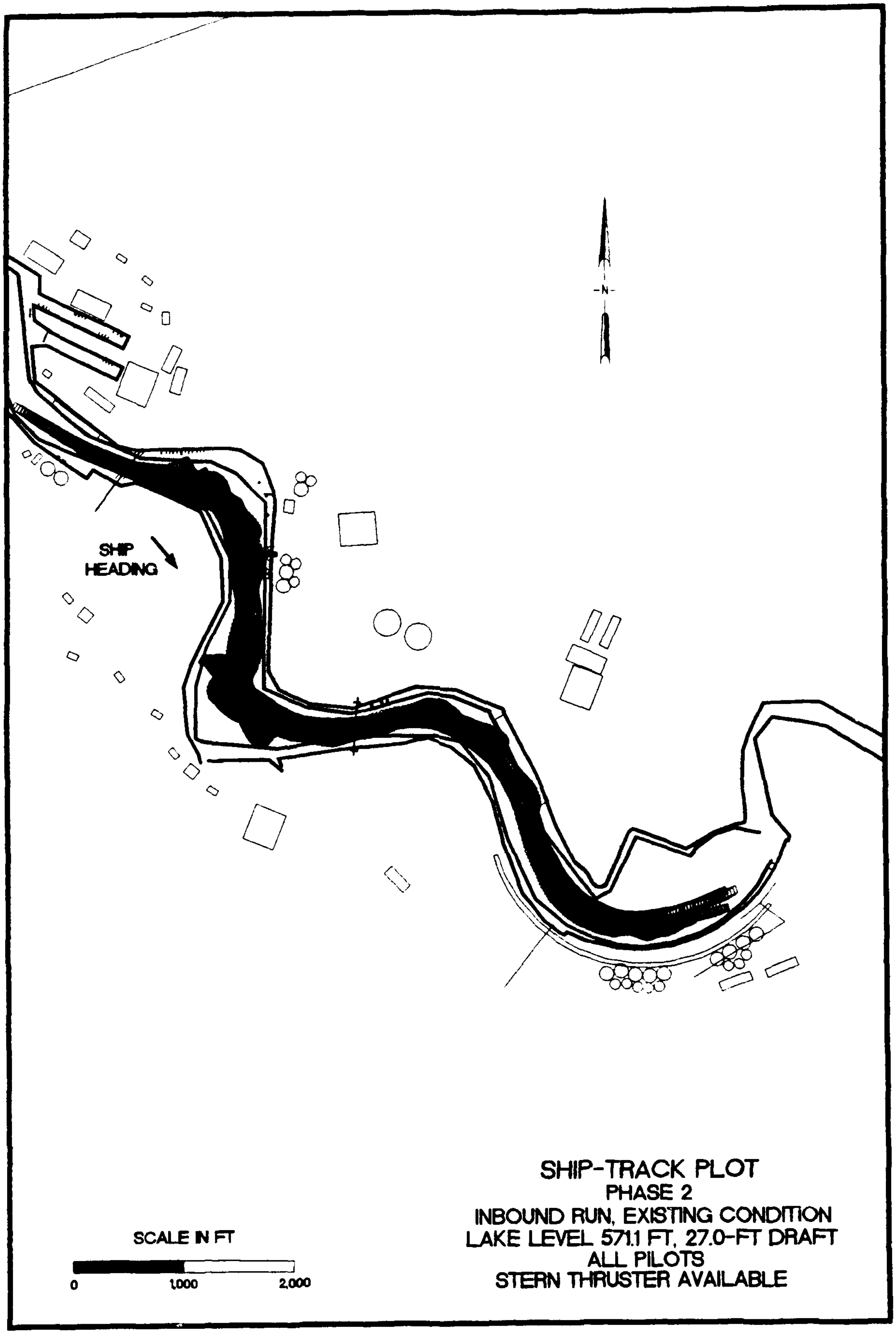
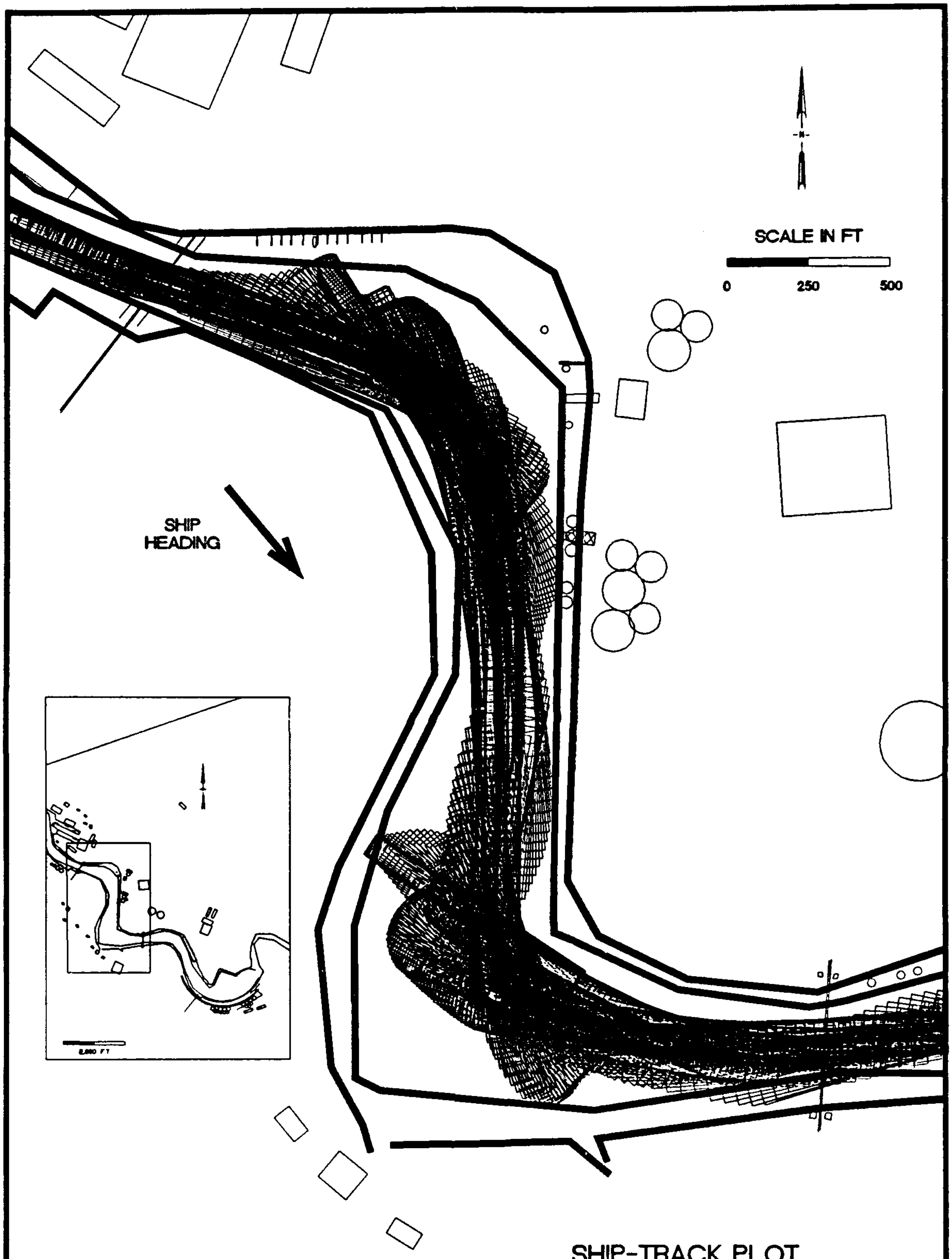

N
SHIP HEADING
SHIP-TRACK PLOT
PHASE 2
INBOUND RUN, EXISTING CONDITION
LAKE LEVEL 571.1 FT, 27.0-FT DRAFT
ALL PILOTS
STERN THRUSTER AVAILABLE
SCALE IN FT
0
1,000
2,000

PLATE 46



SHIP-TRACK PLOT
PHASE 2, CUTS B AND C
INBOUND RUN, EXISTING CONDITION
LAKE LEVEL 571.1 FT, 27.0-FT DRAFT
ALL PILOTS
STERN THRUSTER AVAILABLE

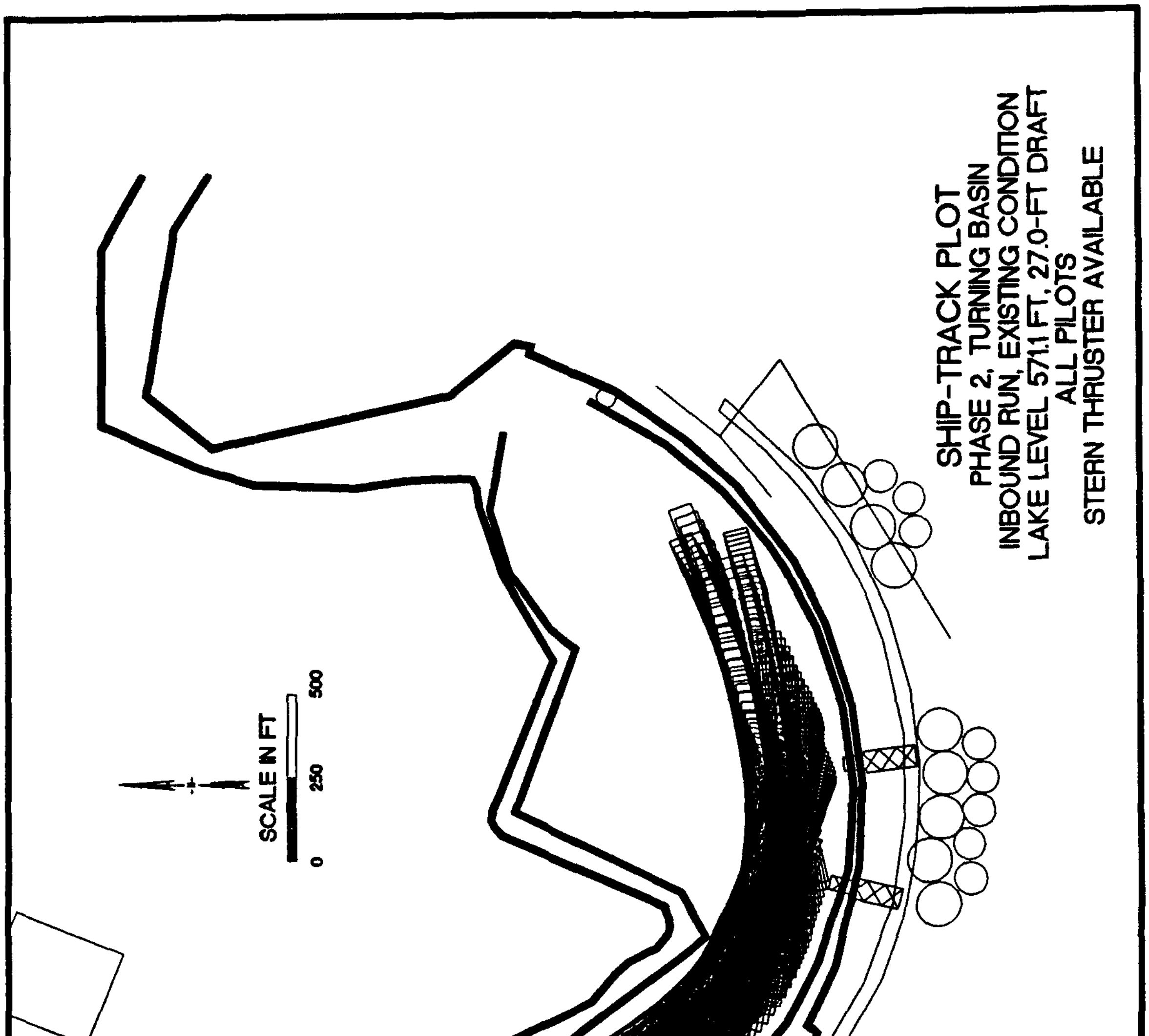
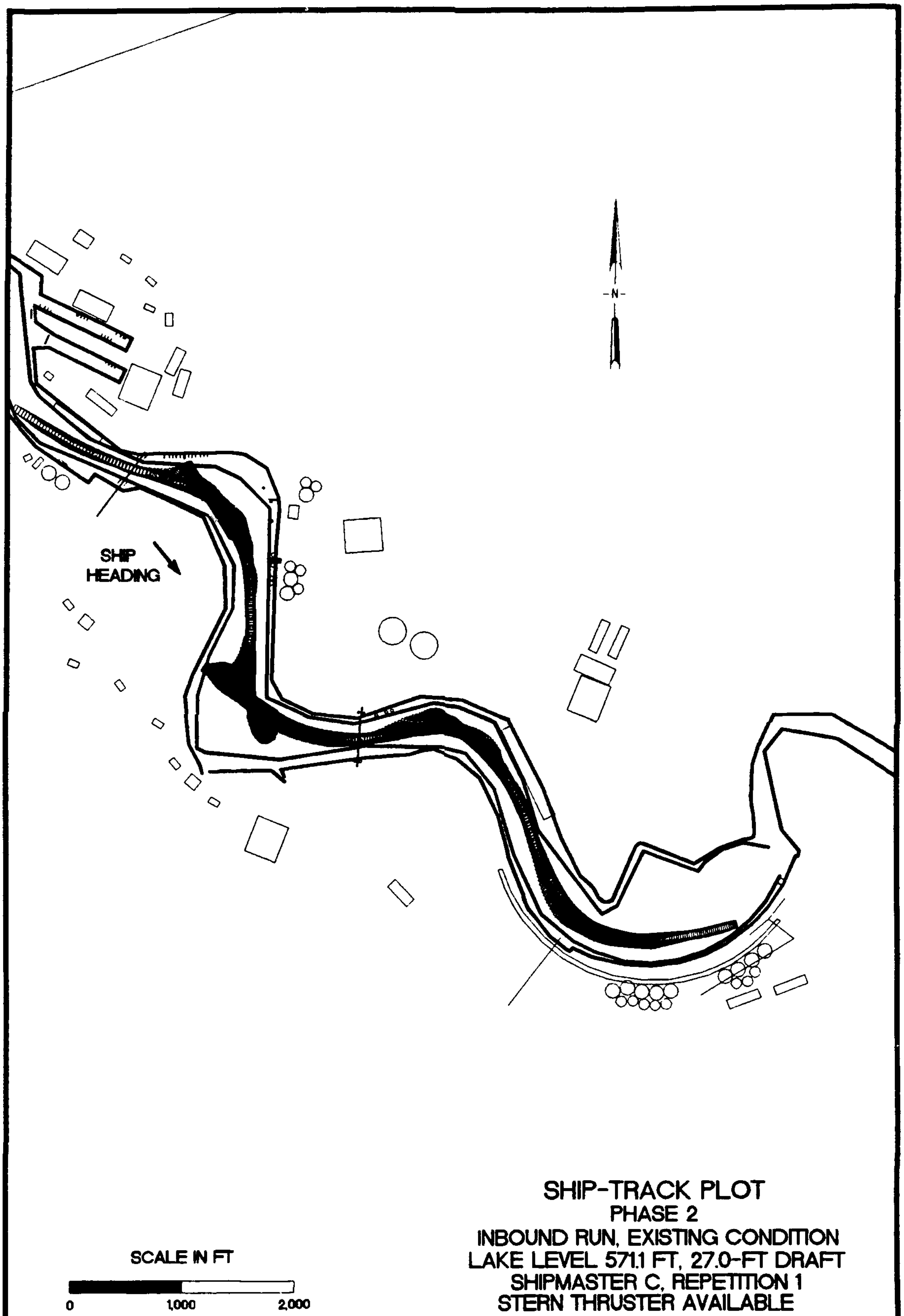
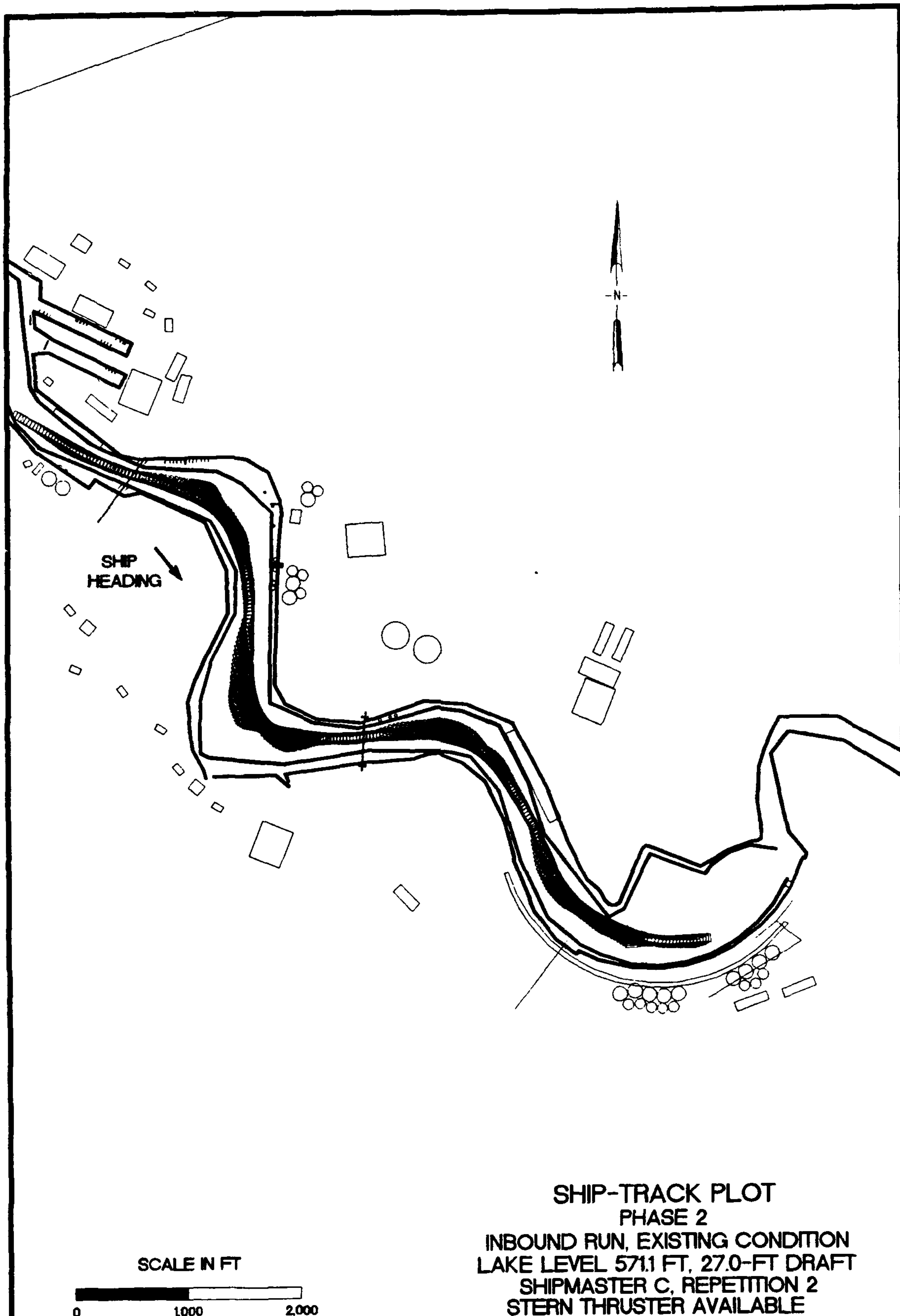

SHIP-TRACK PLOT
PHASE 2, TURNING BASIN
INBOUND RUN, EXISTING CONDITION
LAKE LEVEL 571.1 FT, 27.0-FT DRAFT
ALL PILOTS
STERN THRUSTER AVAILABLE
SCALE IN FT
0
250
500
SHIP
HEADING
2,000 FT

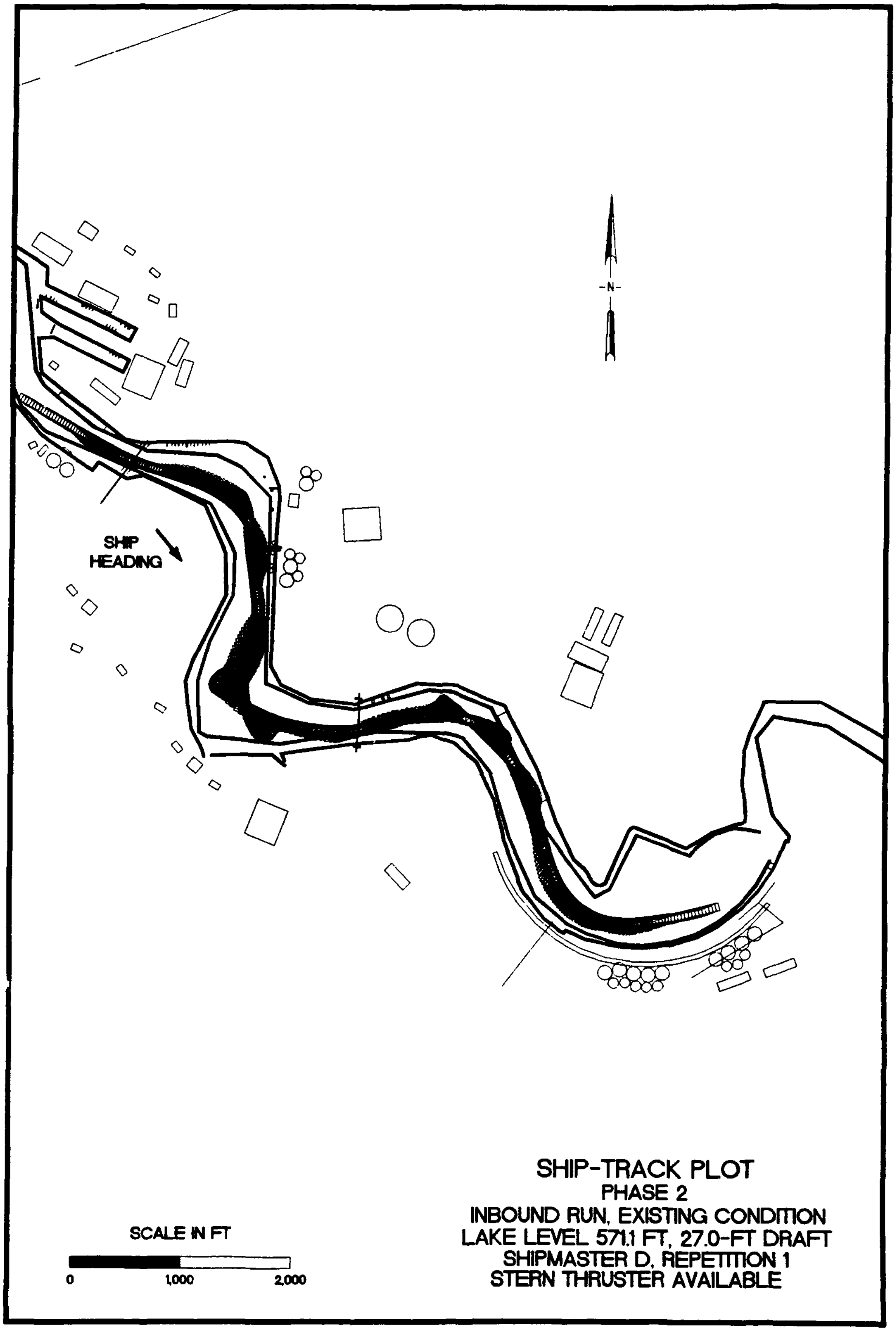
PLATE 48



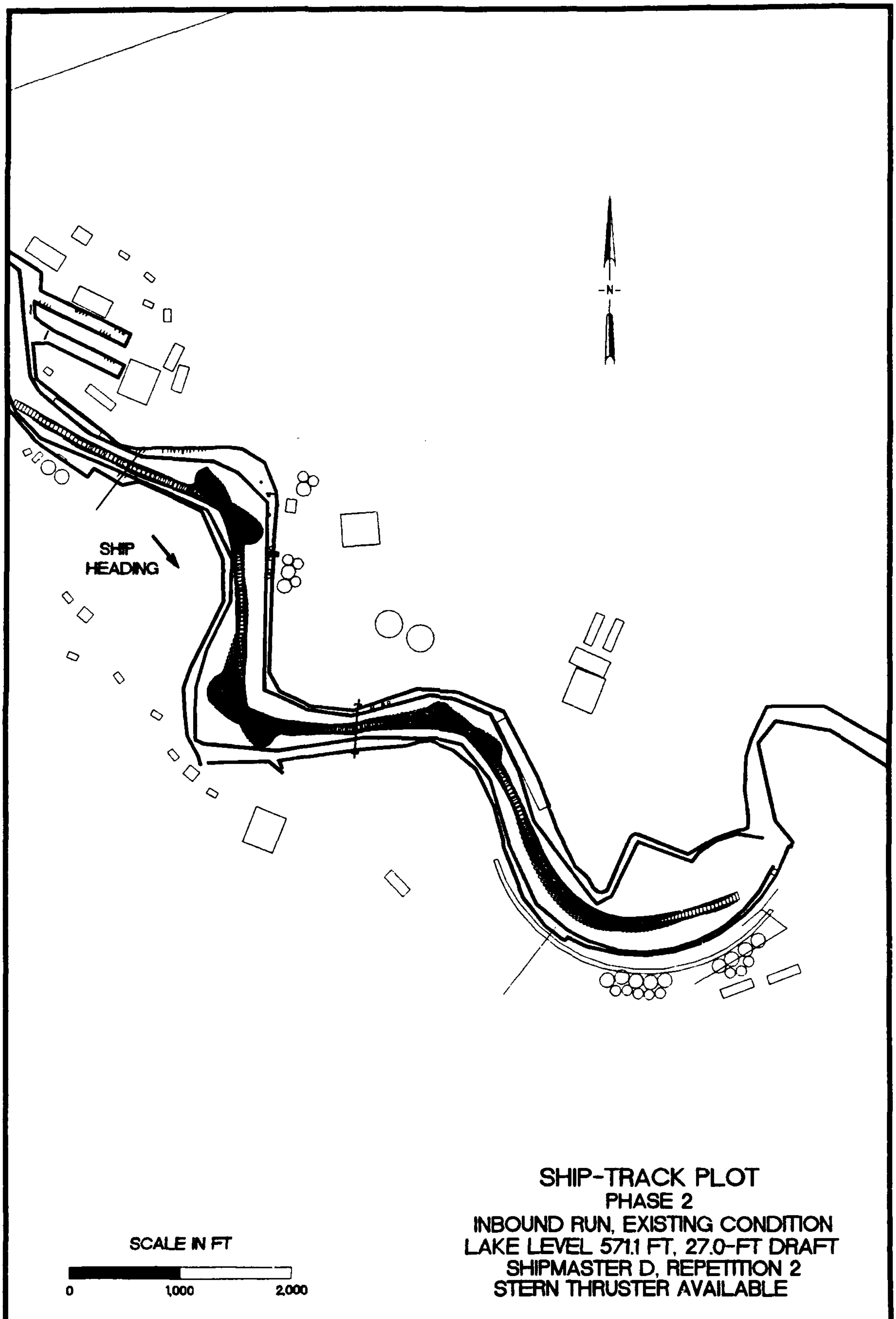
SHIP-TRACK PLOT
PHASE 2
INBOUND RUN, EXISTING CONDITION
LAKE LEVEL 571.1 FT, 27.0-FT DRAFT
SHIPMASTER C, REPETITION 1
STERN THRUSTER AVAILABLE



SHIP-TRACK PLOT
PHASE 2
INBOUND RUN, EXISTING CONDITION
LAKE LEVEL 571.1 FT, 27.0-FT DRAFT
SHIPMASTER C, REPETITION 2
STERN THRUSTER AVAILABLE

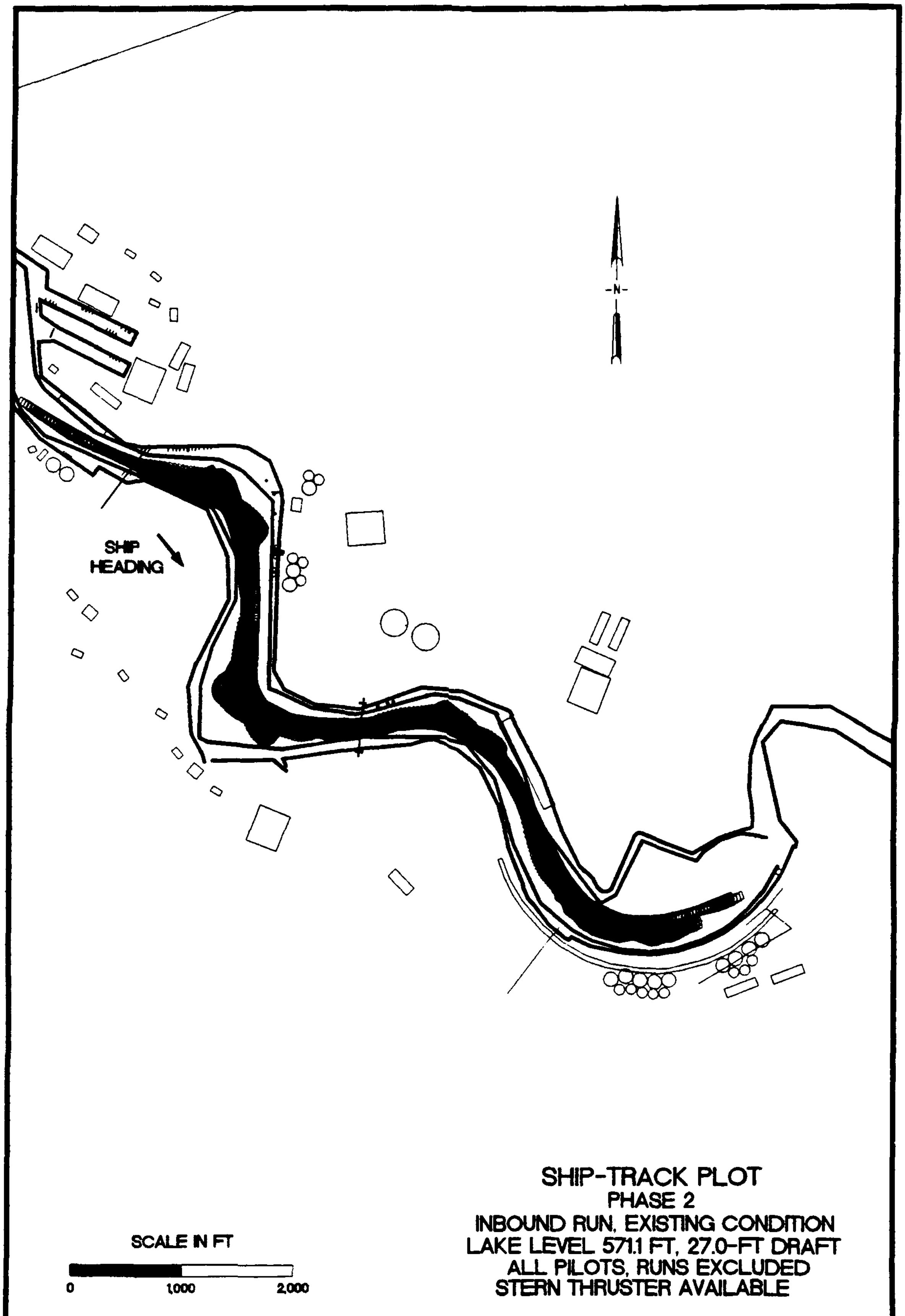


SHIP-TRACK PLOT
PHASE 2
INBOUND RUN, EXISTING CONDITION
LAKE LEVEL 571.1 FT, 27.0-FT DRAFT
SHIPMASTER D, REPETITION 1
STERN THRUSTER AVAILABLE

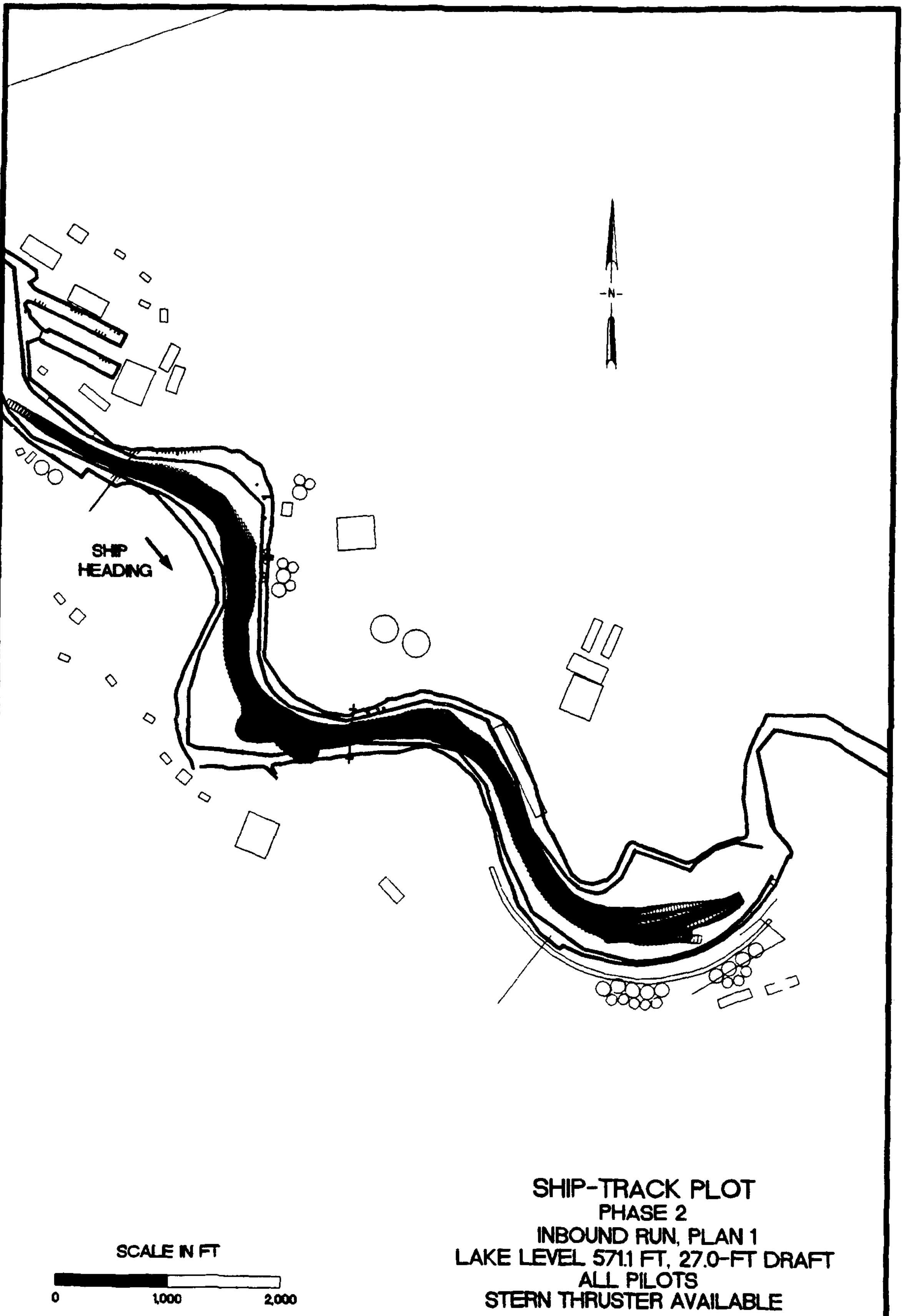


SHIP-TRACK PLOT
PHASE 2
INBOUND RUN, EXISTING CONDITION
LAKE LEVEL 571.1 FT, 27.0-FT DRAFT
SHIPMASTER D, REPETITION 2
STERN THRUSTER AVAILABLE

PLATE 52

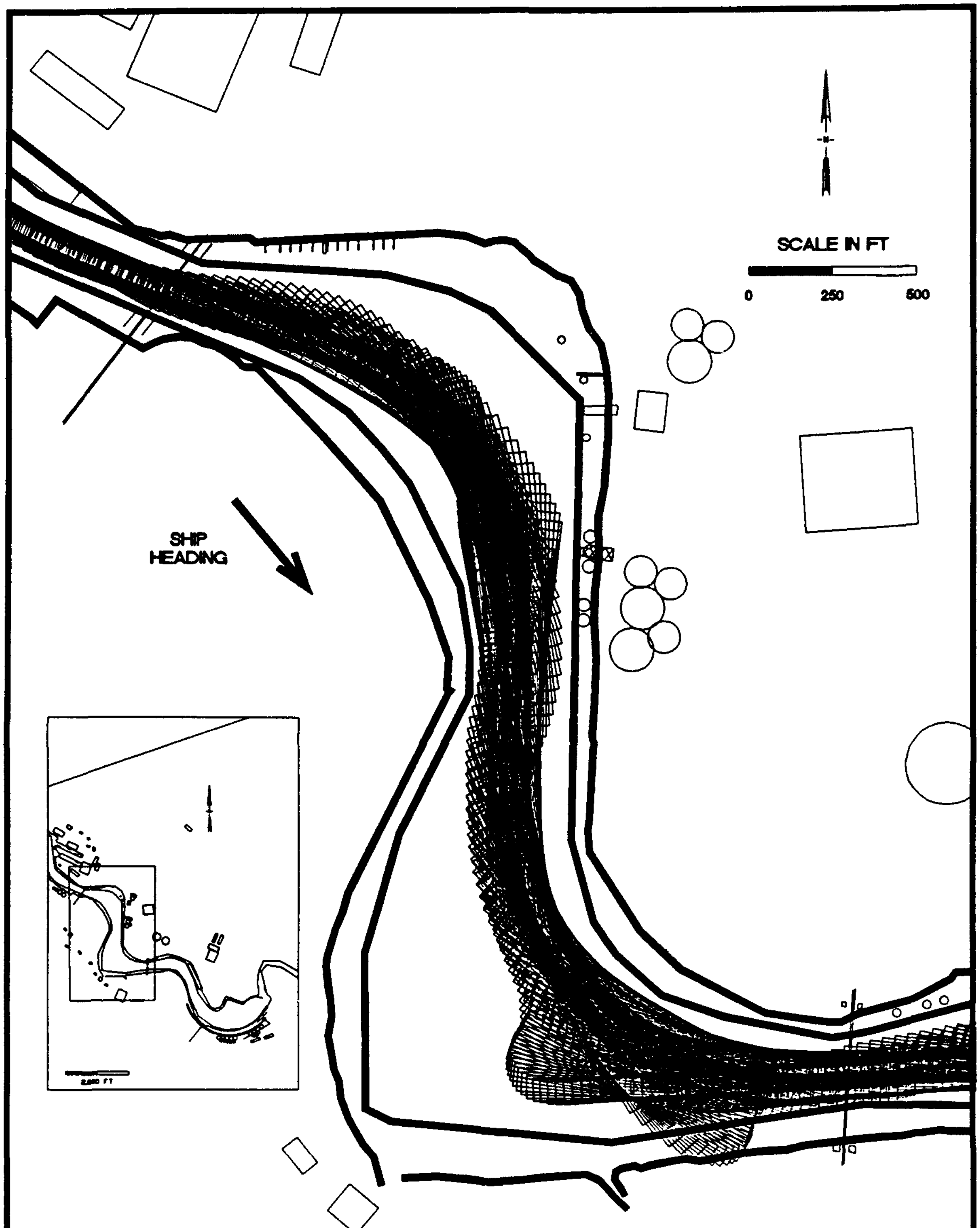


SHIP-TRACK PLOT
PHASE 2
INBOUND RUN, EXISTING CONDITION
LAKE LEVEL 571.1 FT, 27.0-FT DRAFT
ALL PILOTS, RUNS EXCLUDED
STERN THRUSTER AVAILABLE



SHIP-TRACK PLOT
PHASE 2
INBOUND RUN, PLAN 1
LAKE LEVEL 571.1 FT, 27.0-FT DRAFT
ALL PILOTS
STERN THRUSTER AVAILABLE

PLATE 54



SHIP-TRACK PLOT
PHASE 2, CUTS B AND C
INBOUND RUN, PLAN 1
LAKE LEVEL 571.1 FT, 27.0-FT DRAFT
ALL PILOTS
STERN THRUSTER AVAILABLE

PLATE 55

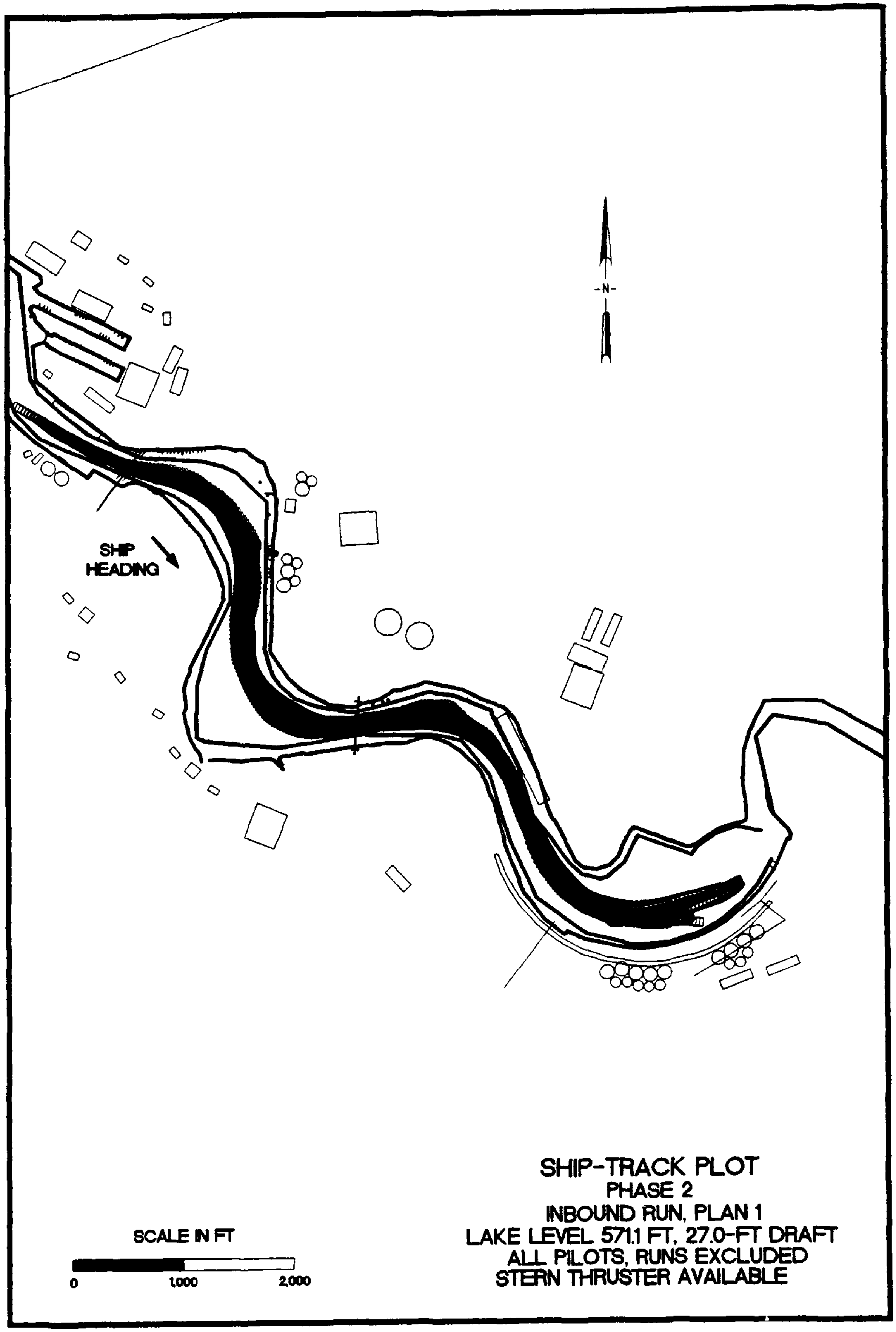
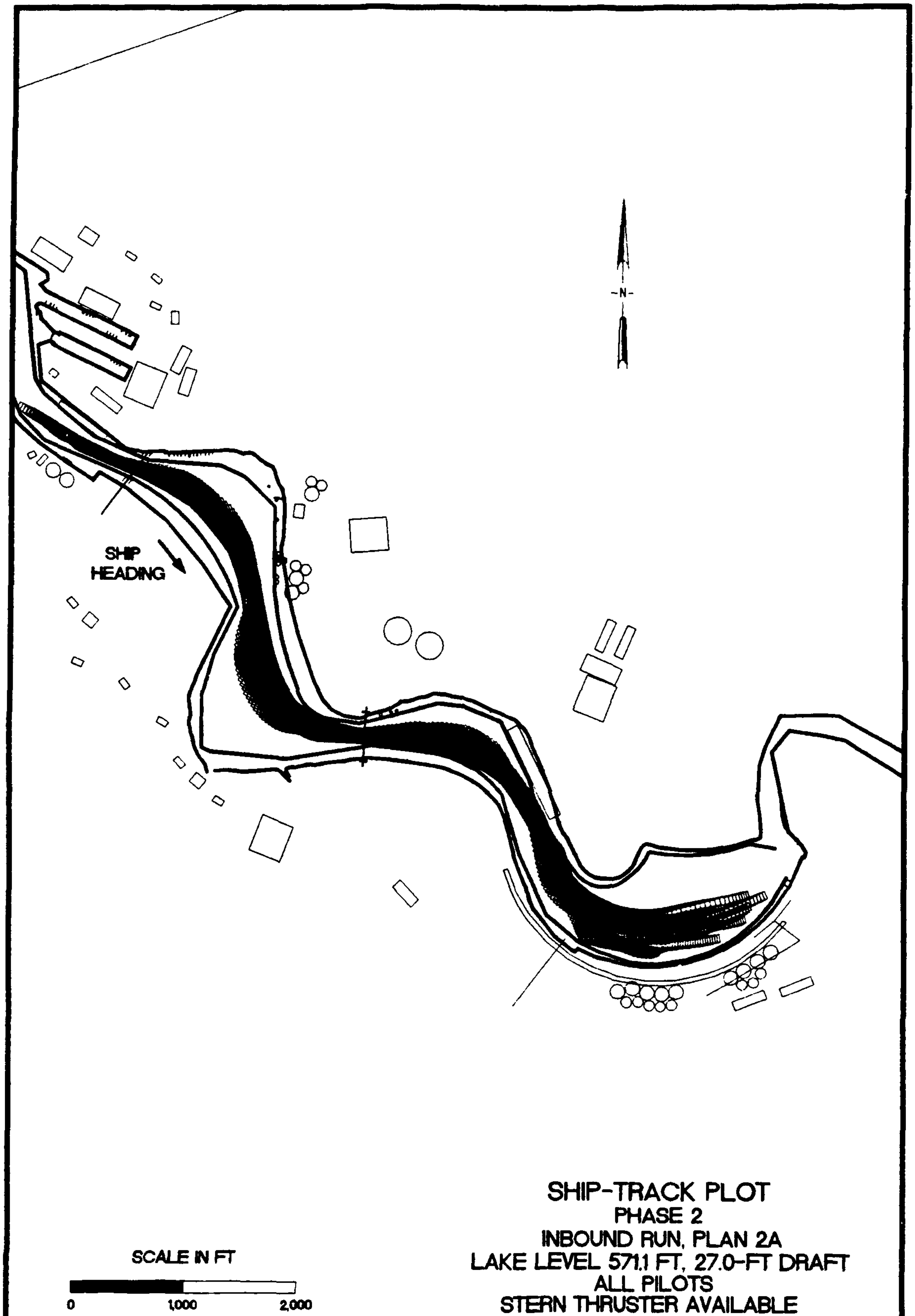

SHIP HEADING
-N-
SHIP-TRACK PLOT
PHASE 2
INBOUND RUN, PLAN 1
LAKE LEVEL 571.1 FT, 27.0-FT DRAFT
ALL PILOTS, RUNS EXCLUDED
STERN THRUSTER AVAILABLE
SCALE IN FT
0
1,000
2,000

PLATE 56



SHIP-TRACK PLOT
PHASE 2
INBOUND RUN, PLAN 2A
LAKE LEVEL 571.1 FT, 27.0-FT DRAFT
ALL PILOTS
STERN THRUSTER AVAILABLE

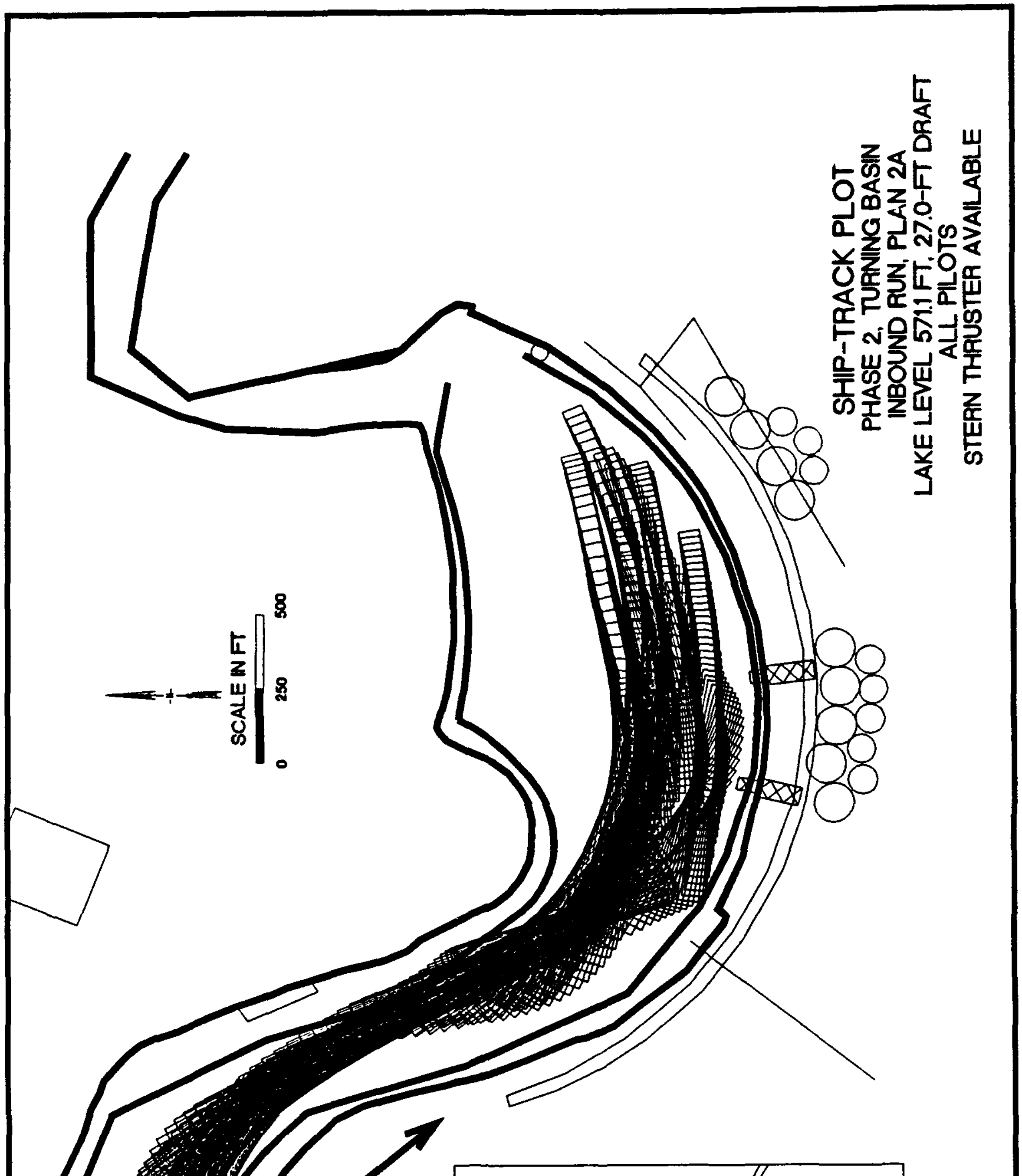
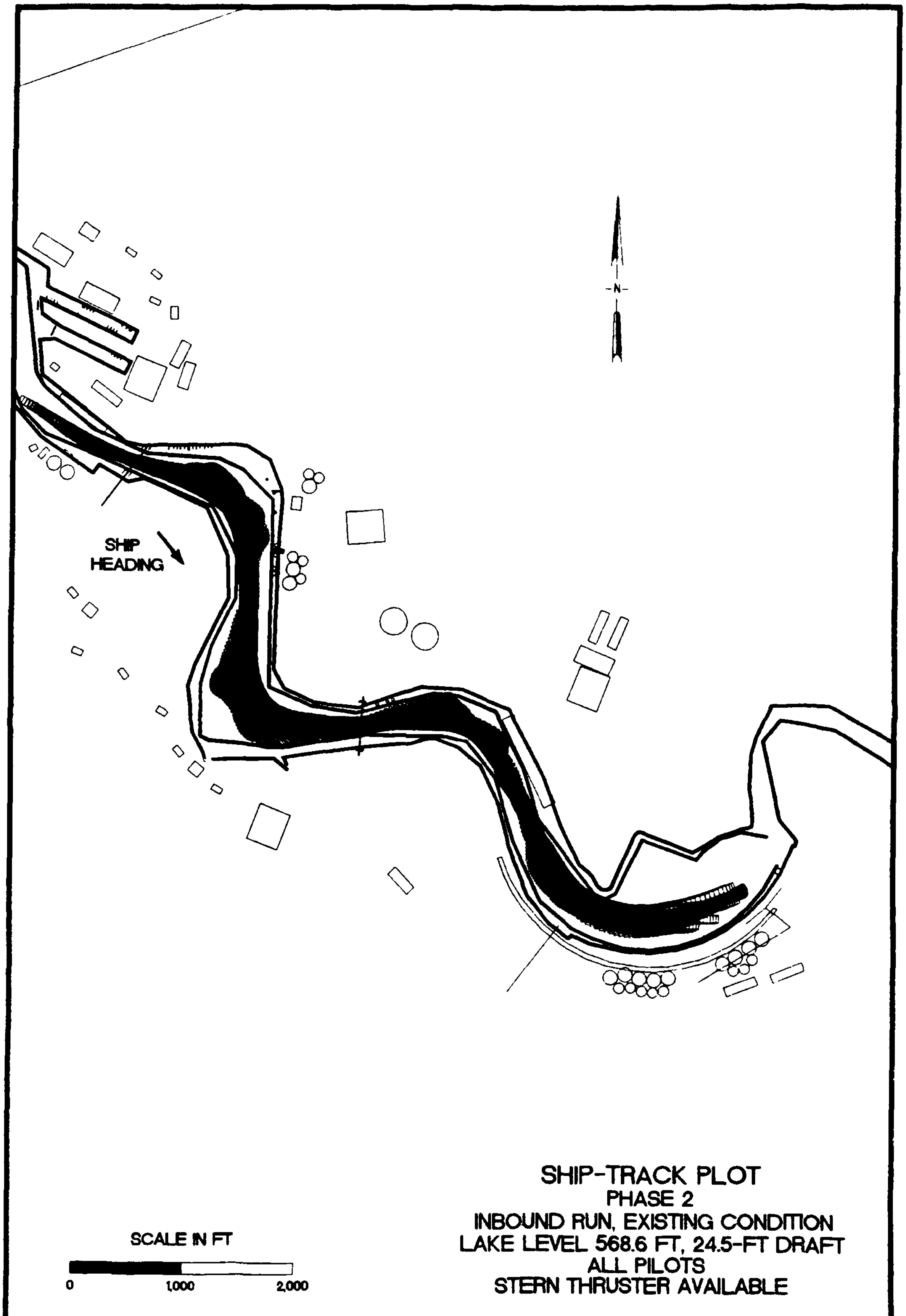

SHIP-TRACK PLOT
PHASE 2, TURNING BASIN
INBOUND RUN, PLAN 2A
LAKE LEVEL 571.1 FT, 27.0-FT DRAFT
ALL PILOTS
STERN THRUSTER AVAILABLE
SCALE IN FT
0
250
500
SHIP HEADING
2,000 FT

PLATE 58



SHIP-TRACK PLOT
PHASE 2
INBOUND RUN, EXISTING CONDITION
LAKE LEVEL 568.6 FT, 24.5-FT DRAFT
ALL PILOTS
STERN THRUSTER AVAILABLE

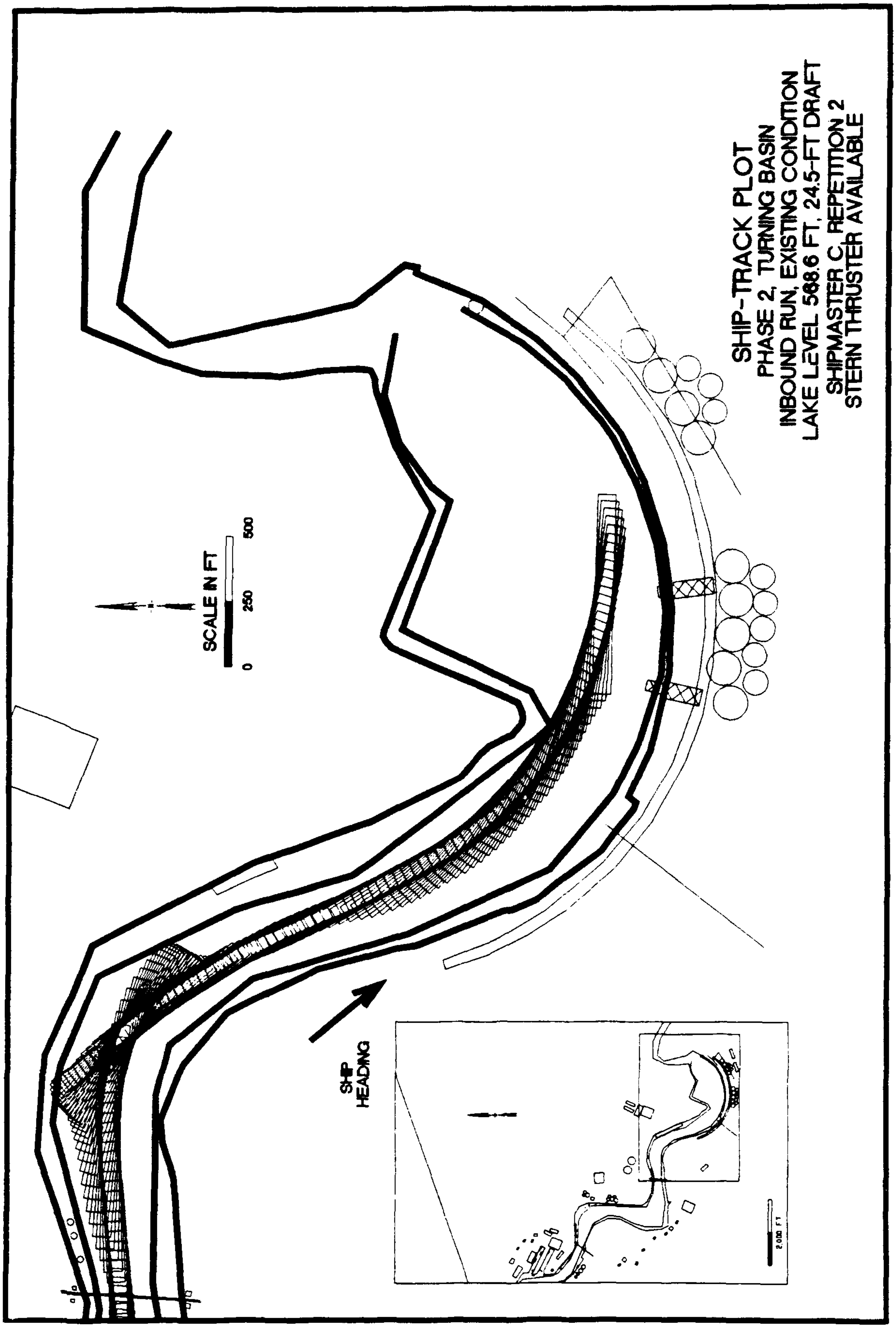
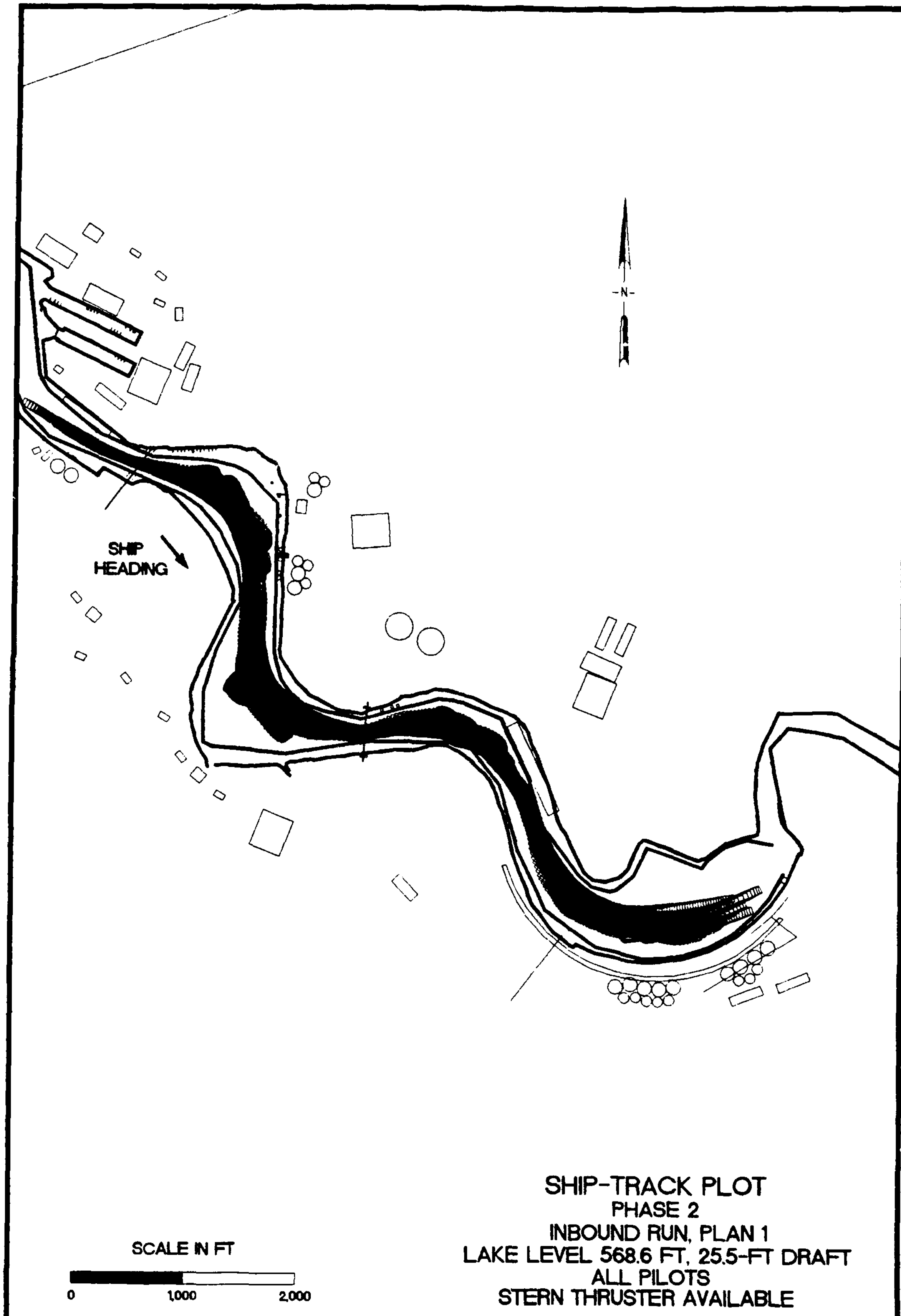
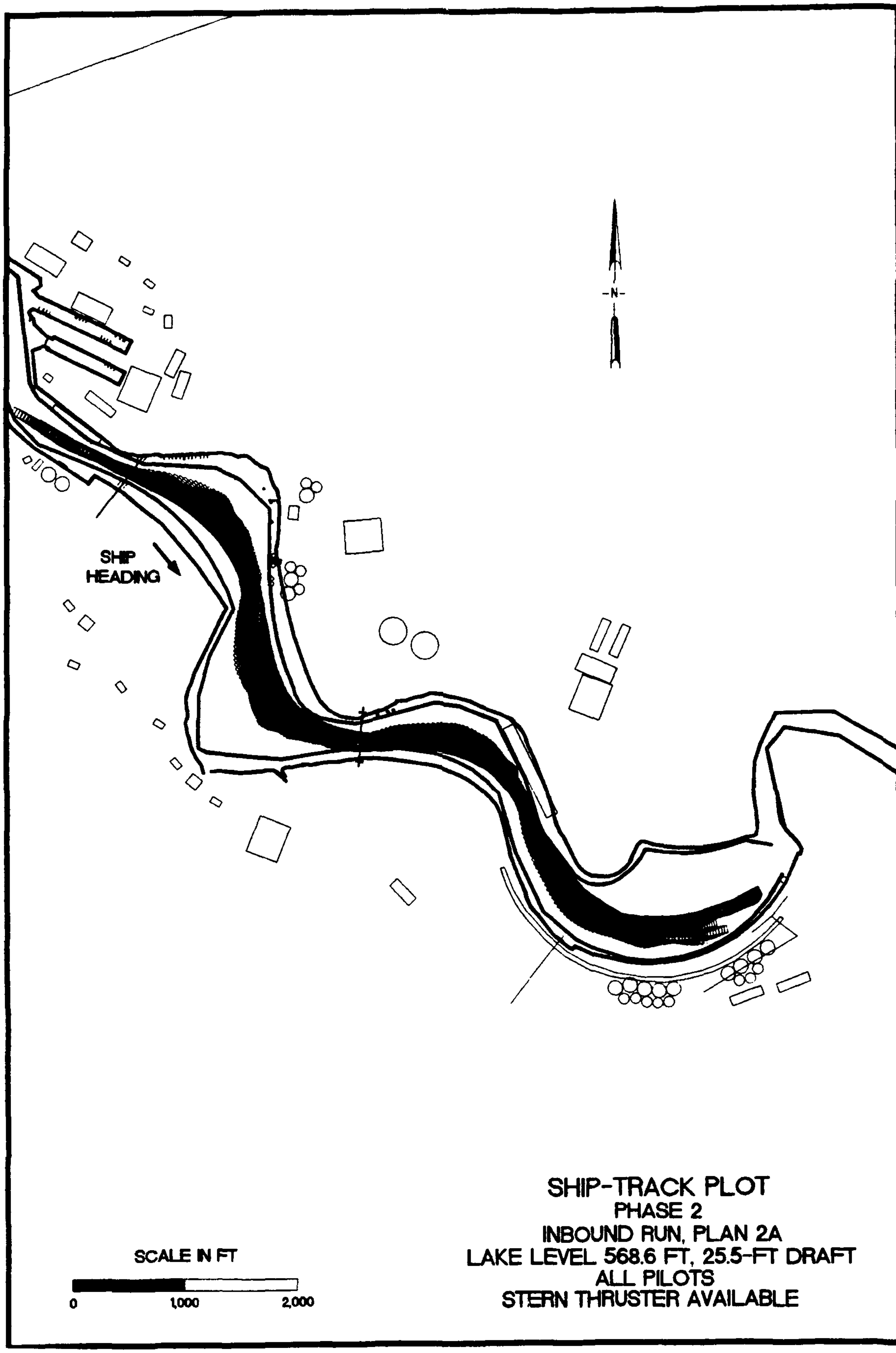

SHIP-TRACK PLOT
PHASE 2, TURNING BASIN
INBOUND RUN, EXISTING CONDITION
LAKE LEVEL 568.6 FT, 24.5-FT DRAFT
SHIPMASTER C, REPETITION 2
STERN THRUSTER AVAILABLE
SCALE IN FT
0
250
500
SHIP
HEADING

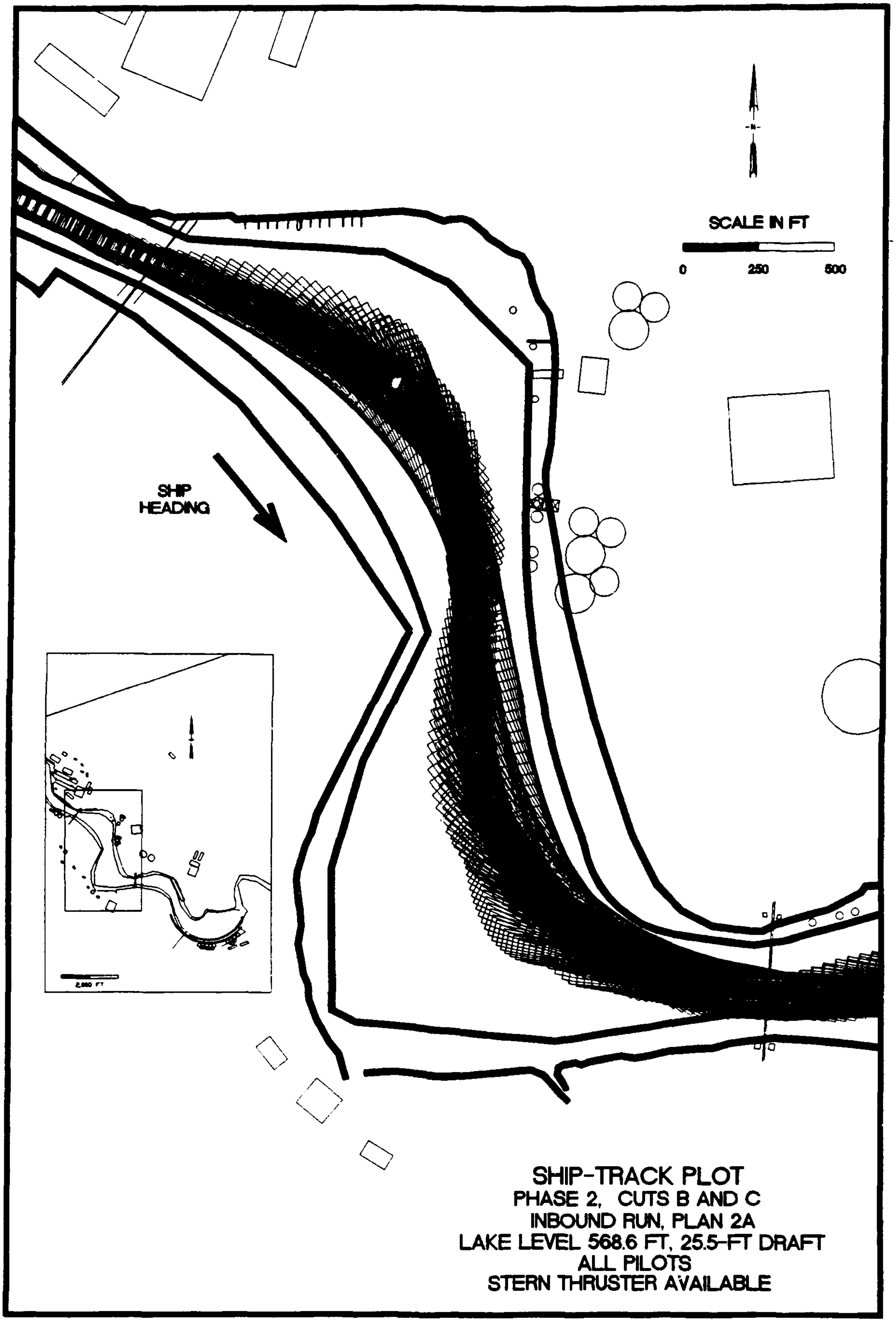
PLATE 60



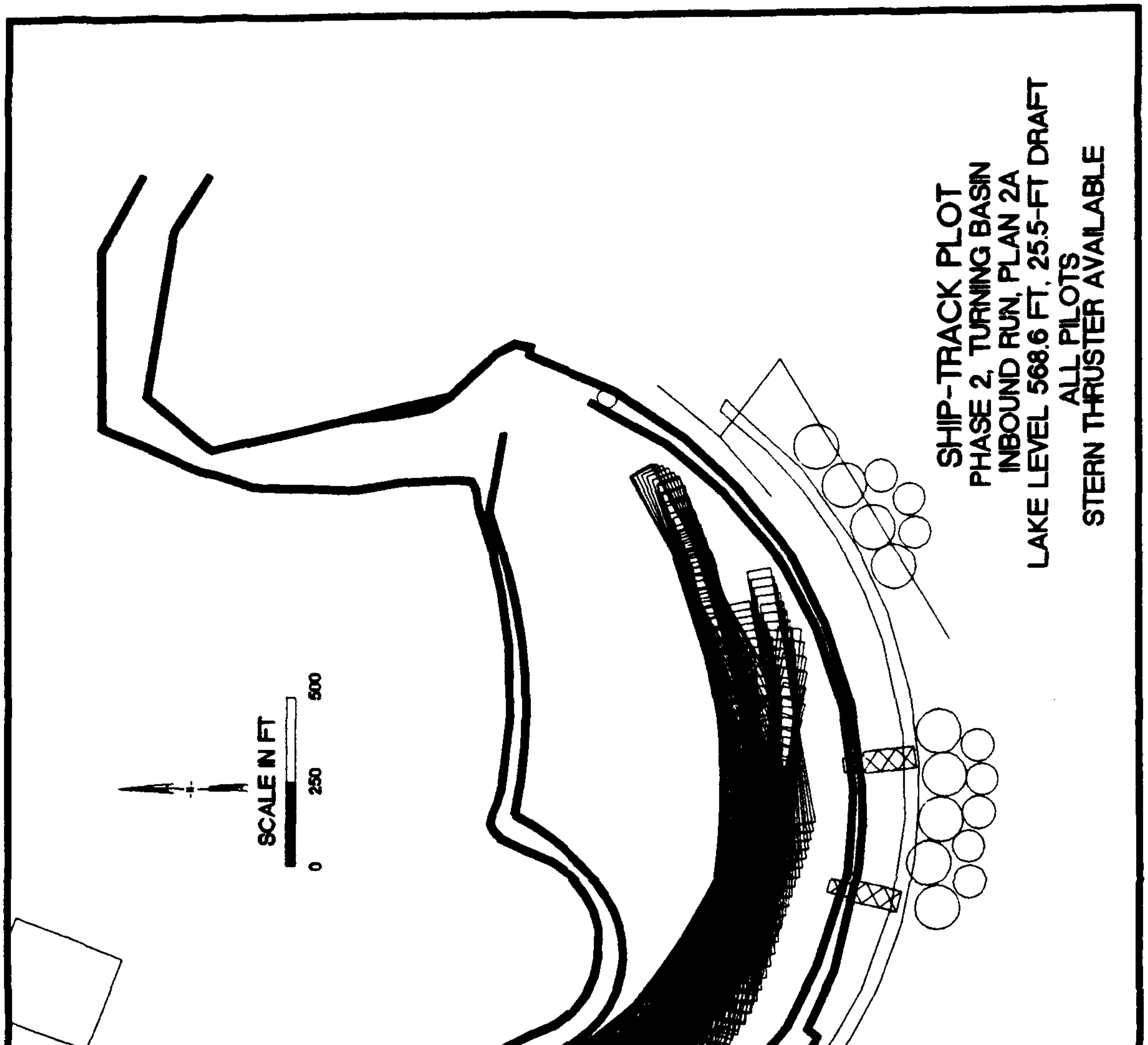
SHIP-TRACK PLOT
PHASE 2
INBOUND RUN, PLAN 1
LAKE LEVEL 568.6 FT, 25.5-FT DRAFT
ALL PILOTS
STERN THRUSTER AVAILABLE

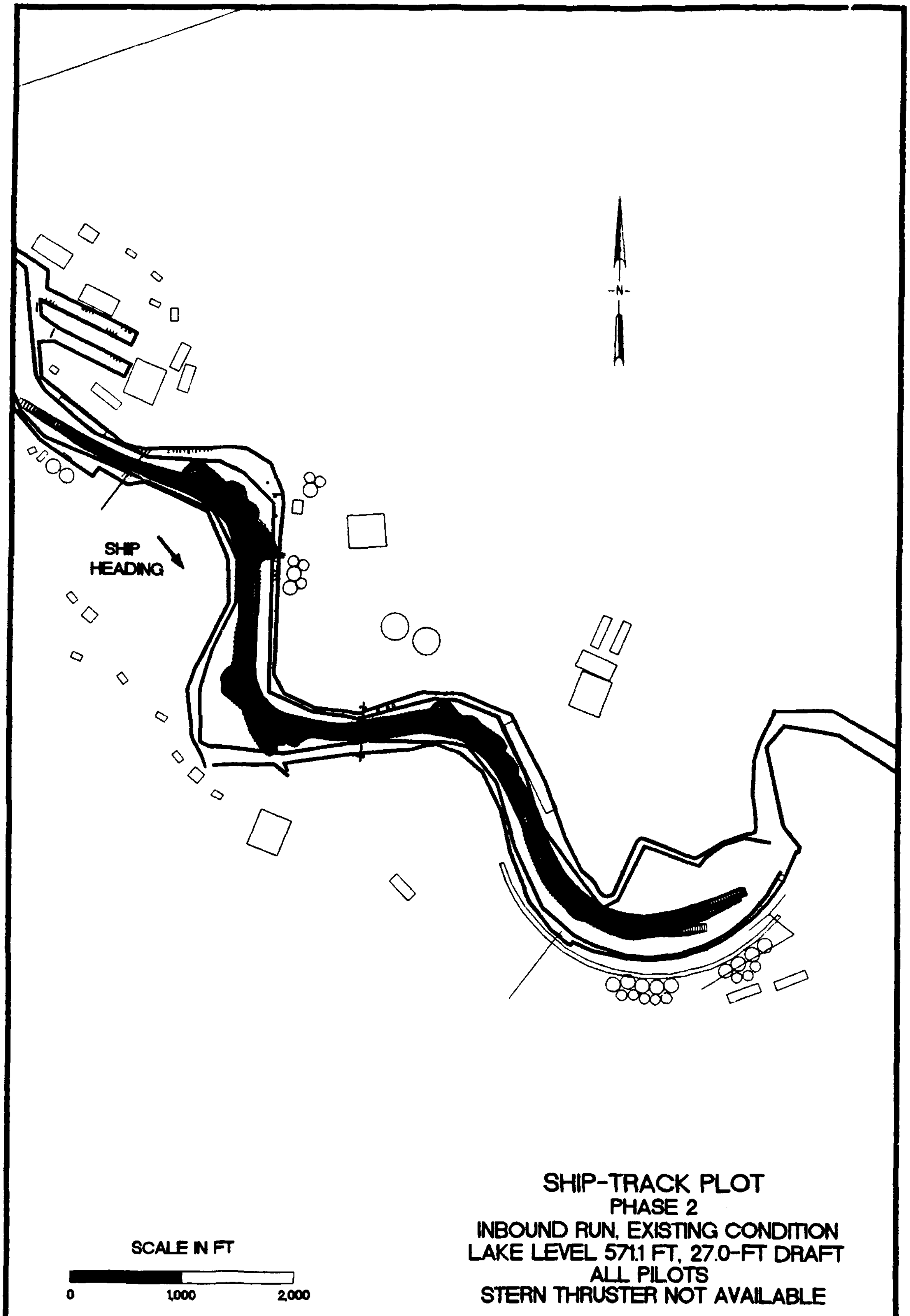


SHIP-TRACK PLOT
PHASE 2
INBOUND RUN, PLAN 2A
LAKE LEVEL 568.6 FT, 25.5-FT DRAFT
ALL PILOTS
STERN THRUSTER AVAILABLE



SHIP-TRACK PLOT
PHASE 2, CUTS B AND C
INBOUND RUN, PLAN 2A
LAKE LEVEL 568.6 FT, 25.5-FT DRAFT
ALL PILOTS
STERN THRUSTER AVAILABLE


SHIP-TRACK PLOT
PHASE 2, TURNING BASIN
INBOUND RUN, PLAN 2A
LAKE LEVEL 568.6 FT, 25.5-FT DRAFT
ALL PILOTS
STERN THRUSTER AVAILABLE
SCALE IN FT
0
250
500
SHIP HEADING
2,000 FT



SHIP-TRACK PLOT
PHASE 2
INBOUND RUN, EXISTING CONDITION
LAKE LEVEL 571.1 FT, 27.0-FT DRAFT
ALL PILOTS
STERN THRUSTER NOT AVAILABLE

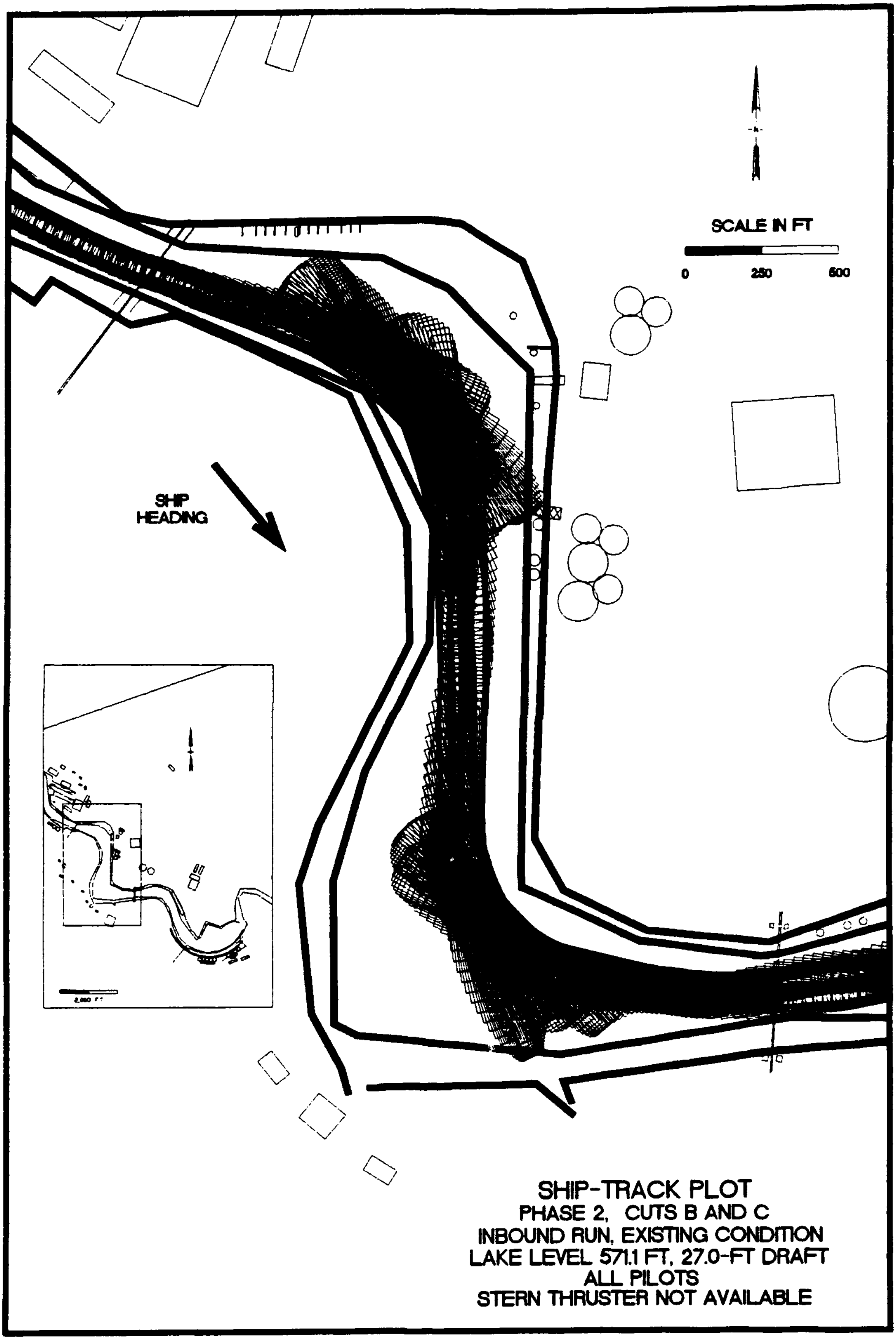
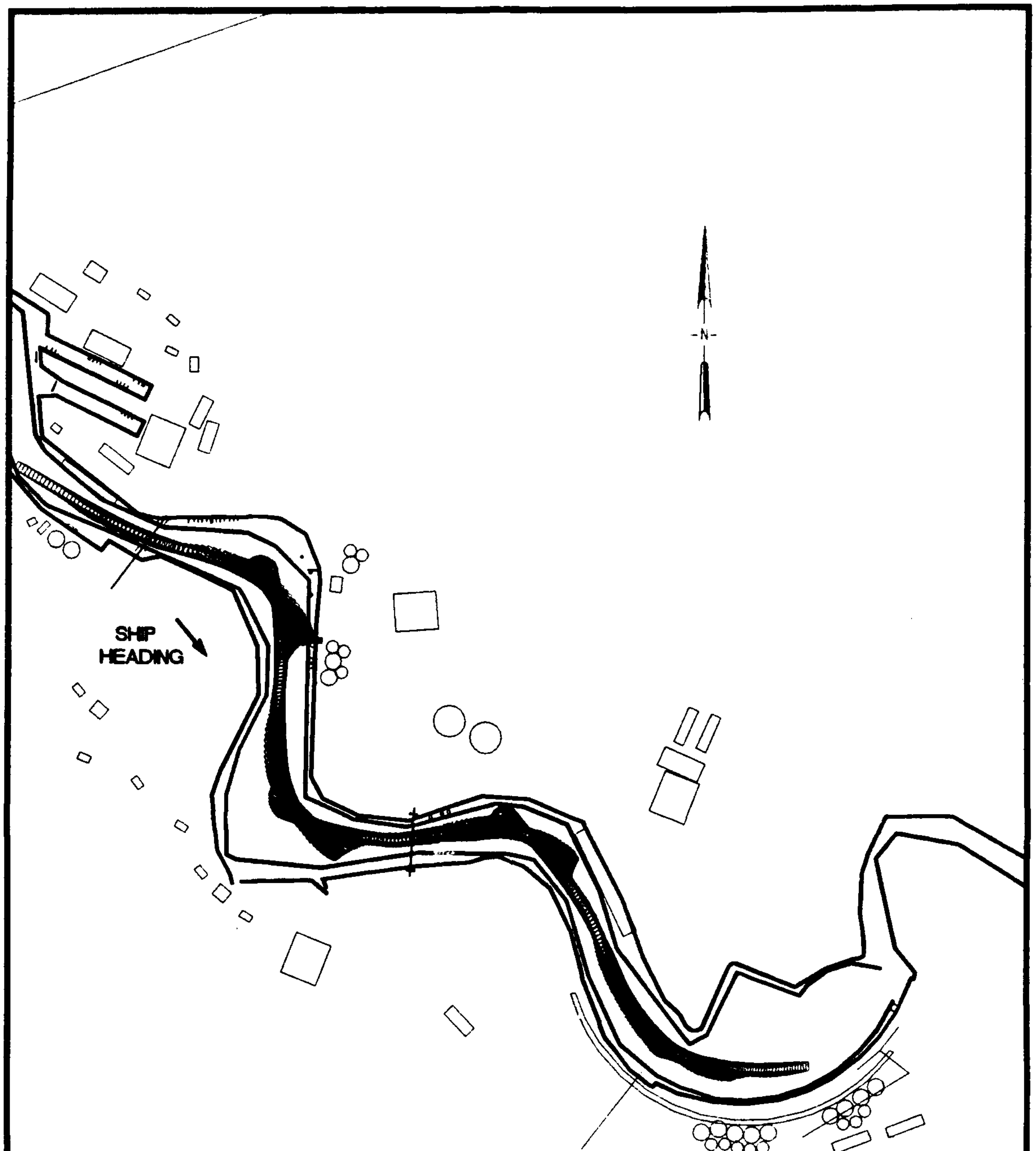

SCALE IN FT
0
250
500
SHIP
HEADING
SHIP-TRACK PLOT
PHASE 2, CUTS B AND C
INBOUND RUN, EXISTING CONDITION
LAKE LEVEL 571.1 FT, 27.0-FT DRAFT
ALL PILOTS
STERN THRUSTER NOT AVAILABLE

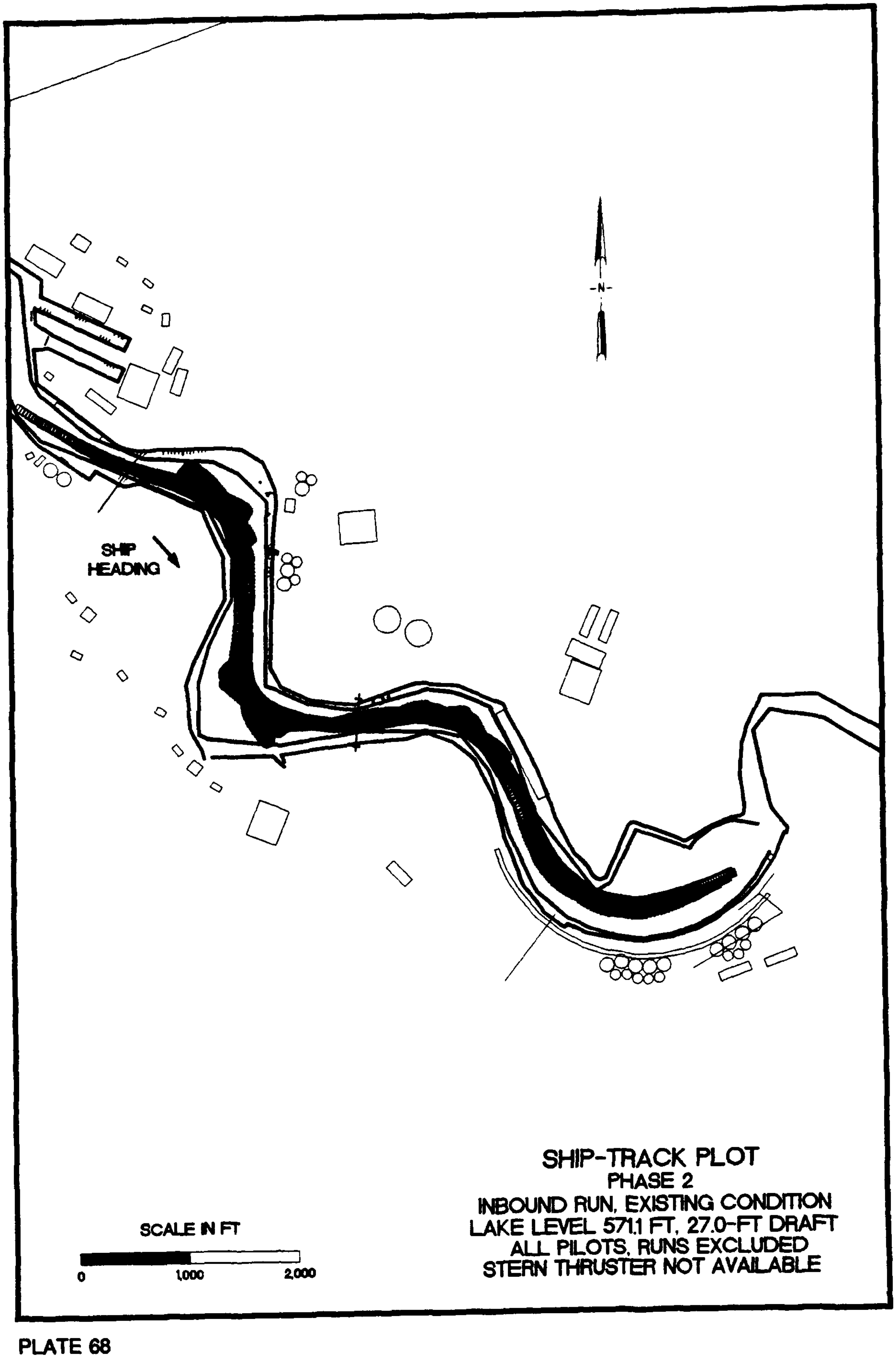
PLATE 66



SCALE IN FT

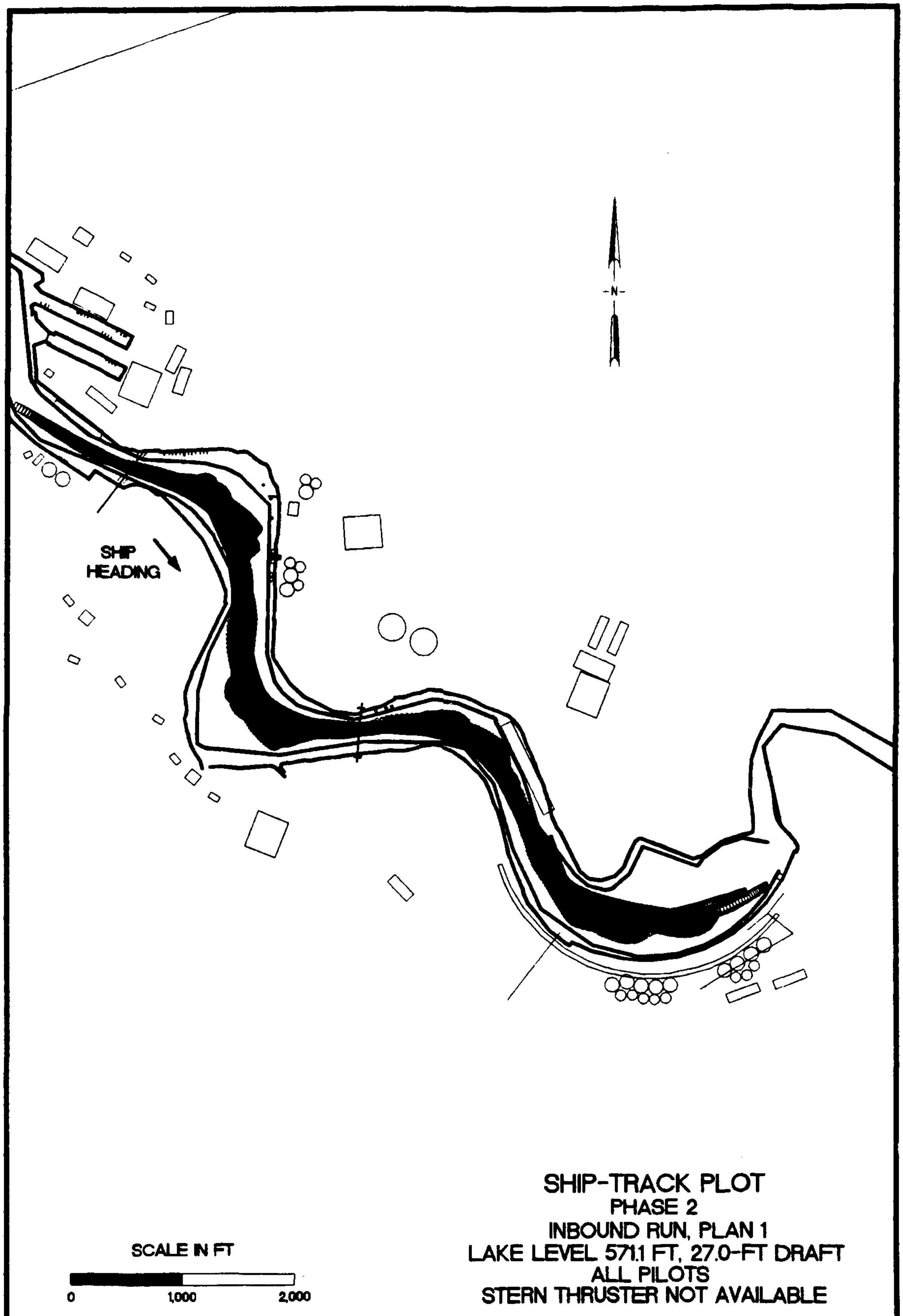
0 1,000 2,000

SHIP-TRACK PLOT
PHASE 2
INBOUND RUN, EXISTING CONDITION
LAKE LEVEL 571.1 FT, 27.0-FT DRAFT
SHIPMASTER C, REPETITION 1
STERN THRUSTER NOT AVAILABLE

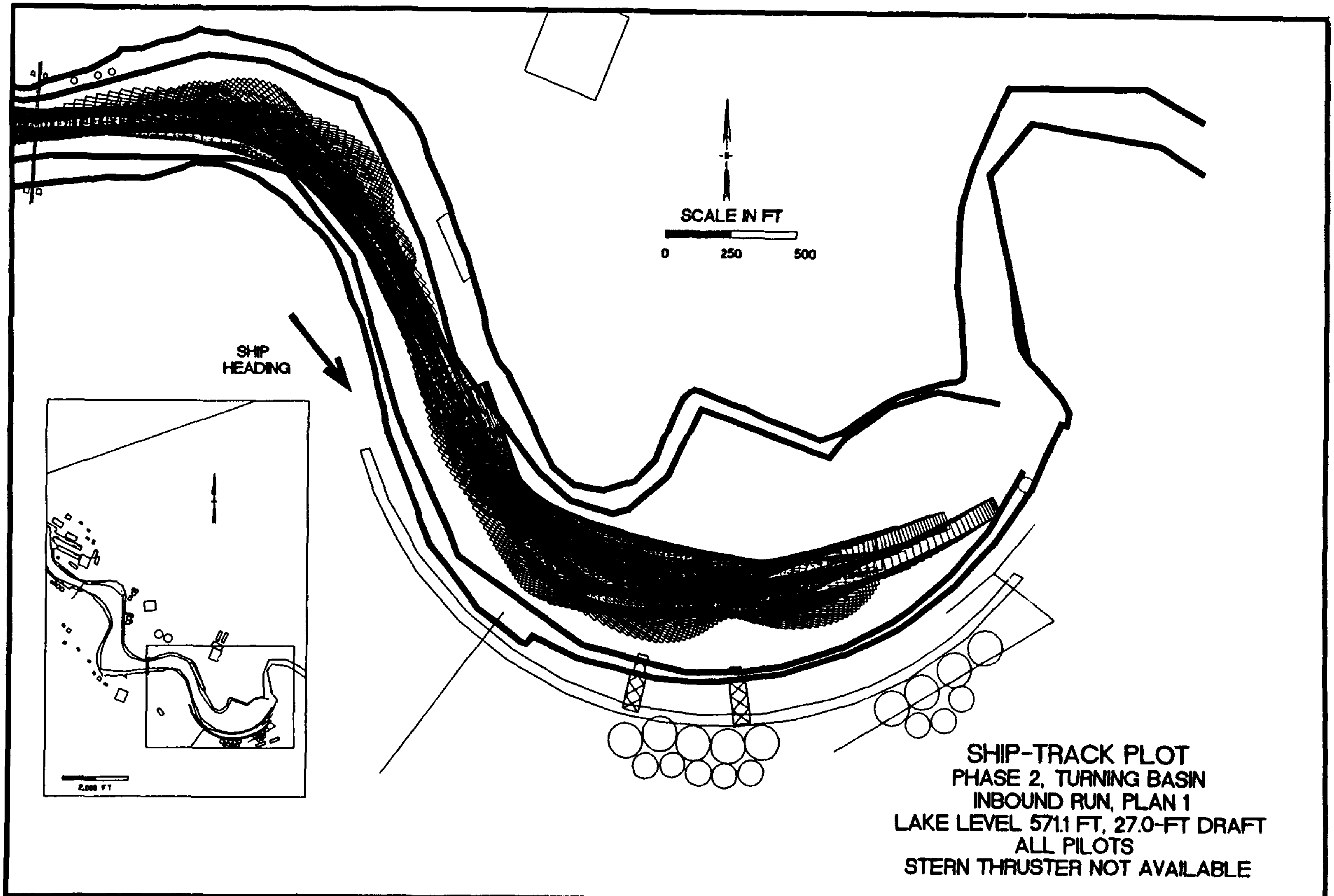


SHIP-TRACK PLOT
PHASE 2
INBOUND RUN, EXISTING CONDITION
LAKE LEVEL 571.1 FT, 27.0-FT DRAFT
ALL PILOTS, RUNS EXCLUDED
STERN THRUSTER NOT AVAILABLE

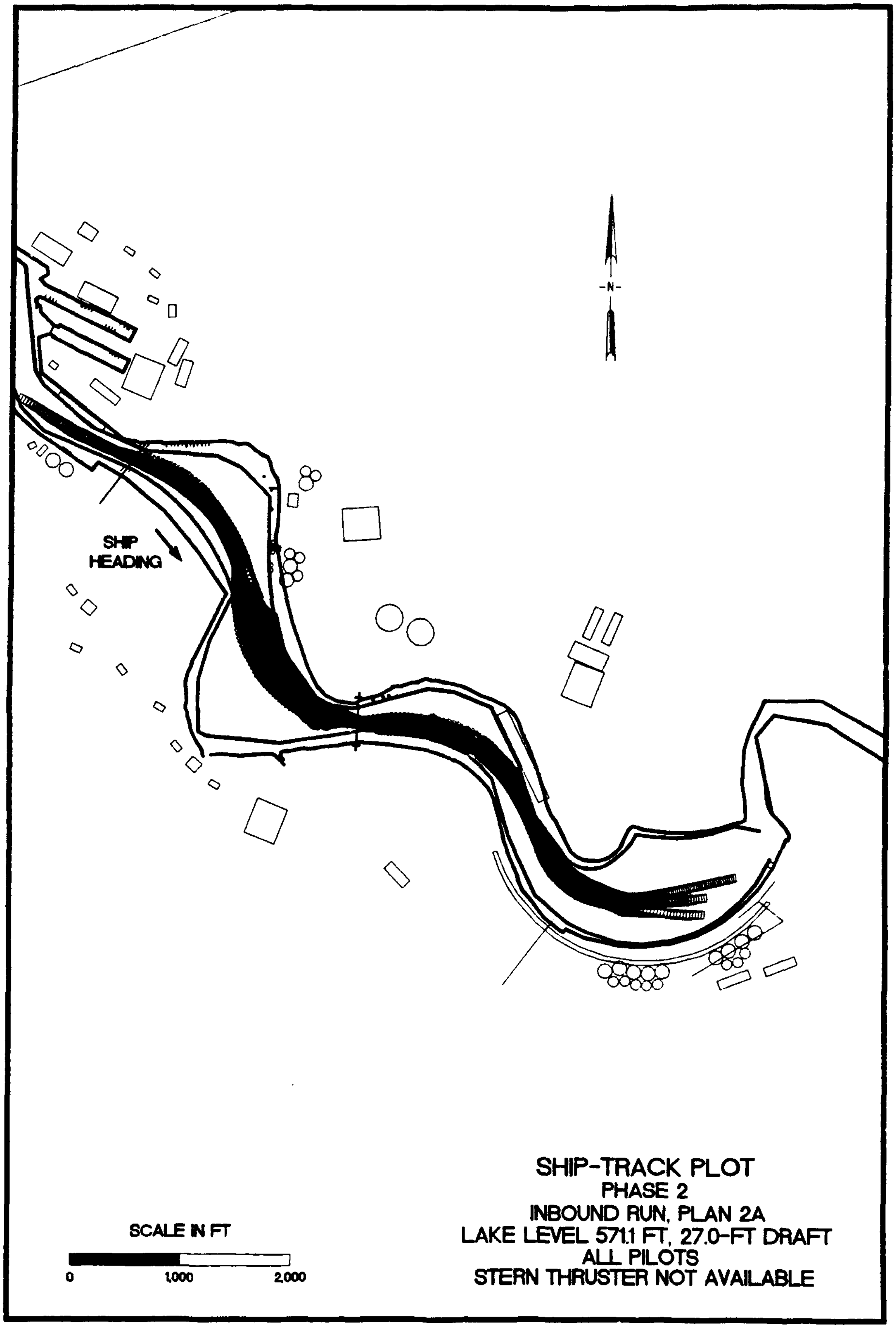
PLATE 68



SHIP-TRACK PLOT
PHASE 2
INBOUND RUN, PLAN 1
LAKE LEVEL 571.1 FT, 27.0-FT DRAFT
ALL PILOTS
STERN THRUSTER NOT AVAILABLE

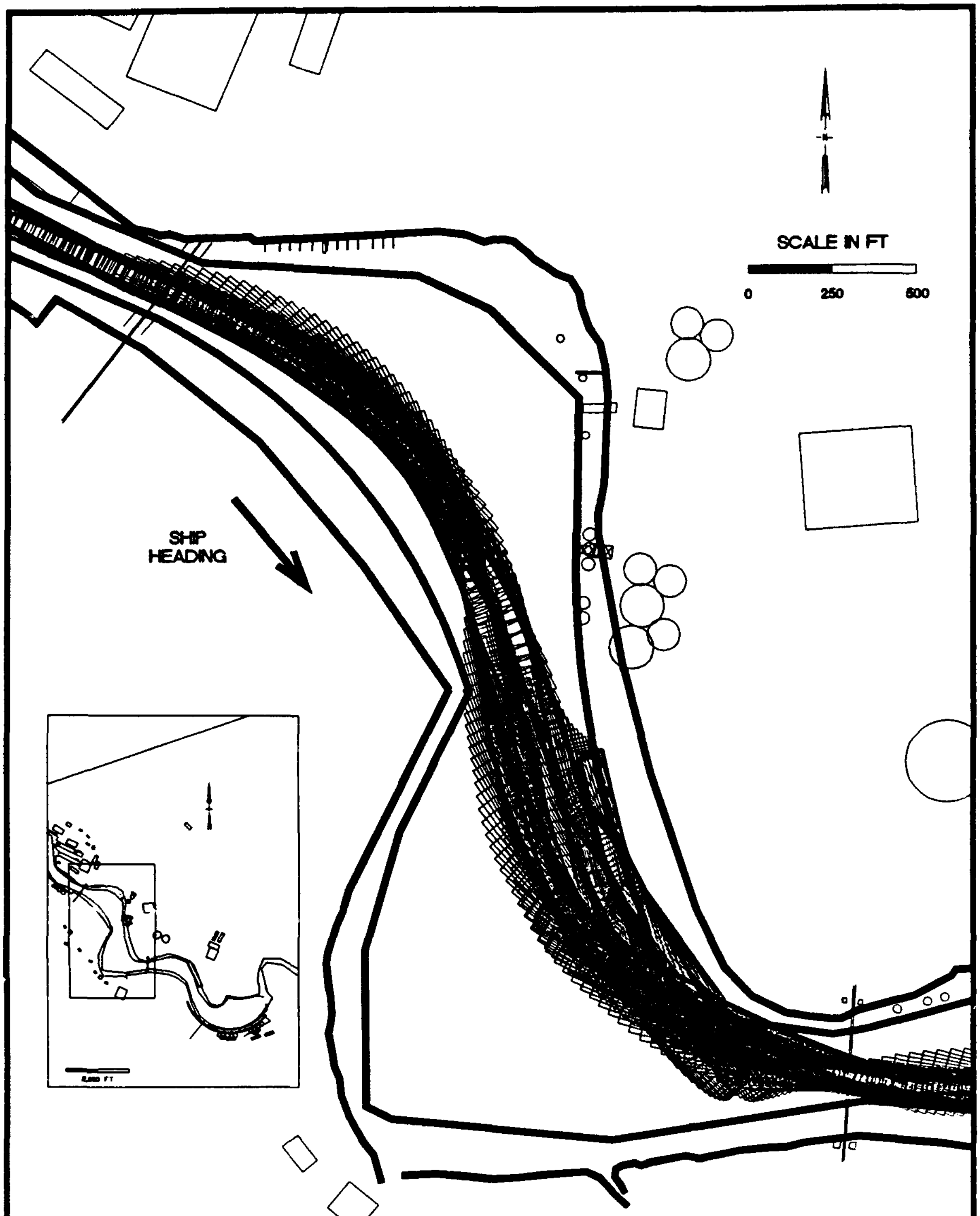


SHIP-TRACK PLOT
PHASE 2, TURNING BASIN
INBOUND RUN, PLAN 1
LAKE LEVEL 571.1 FT, 27.0-FT DRAFT
ALL PILOTS
STERN THRUSTER NOT AVAILABLE

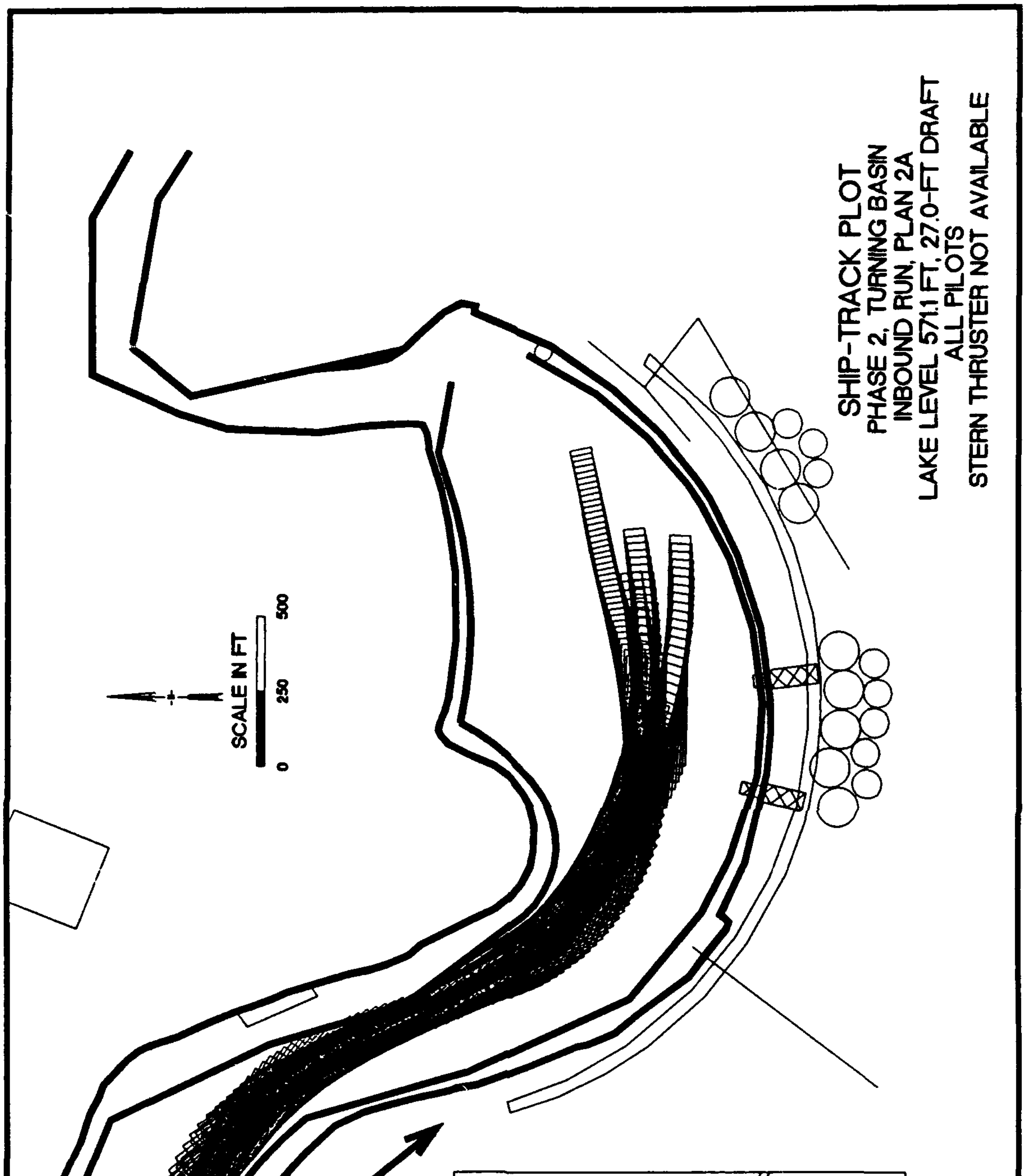


N
SHIP
HEADING
SHIP-TRACK PLOT
PHASE 2
INBOUND RUN, PLAN 2A
LAKE LEVEL 571.1 FT, 27.0-FT DRAFT
ALL PILOTS
STERN THRUSTER NOT AVAILABLE
SCALE IN FT
0
1,000
2,000

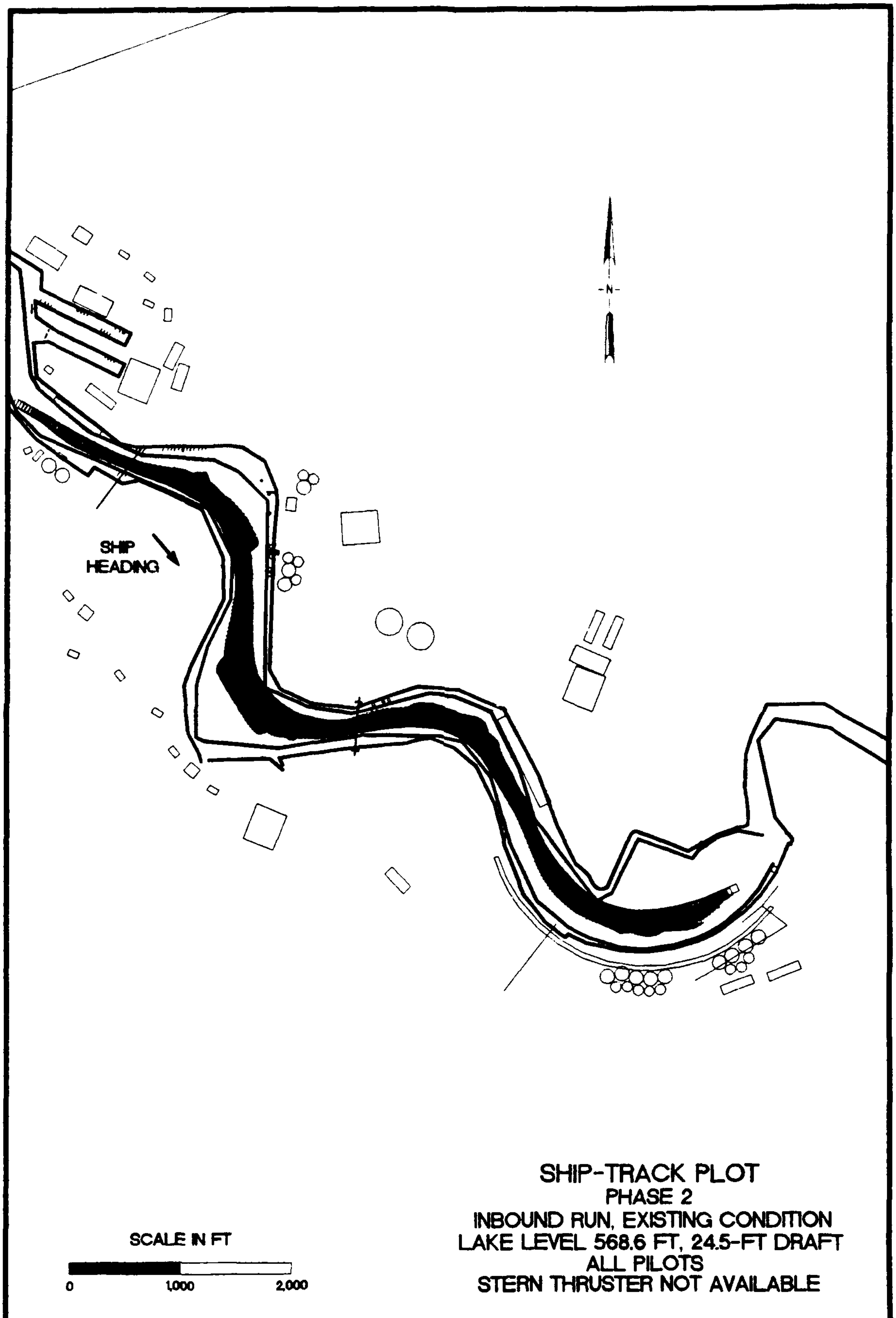
PLATE 71



SHIP-TRACK PLOT
PHASE 2, CUTS B AND C
INBOUND RUN, PLAN 2A
LAKE LEVEL 571.1 FT, 27.0-FT DRAFT
ALL PILOTS
STERN THRUSTER NOT AVAILABLE



SHIP-TRACK PLOT
PHASE 2, TURNING BASIN
INBOUND RUN, PLAN 2A
LAKE LEVEL 571.1 FT, 27.0-FT DRAFT
ALL PILOTS
STERN THRUSTER NOT AVAILABLE
SCALE IN FT
0
250
500
SHIP HEADING


N
SHIP
HEADING
SHIP-TRACK PLOT
PHASE 2
INBOUND RUN, EXISTING CONDITION
LAKE LEVEL 568.6 FT, 24.5-FT DRAFT
ALL PILOTS
STERN THRUSTER NOT AVAILABLE
SCALE IN FT
0
1,000
2,000

SCALE IN FT

0 1,000 2,000

SHIP-TRACK PLOT
PHASE 2
INBOUND RUN, PLAN 1
LAKE LEVEL 568.6 FT, 25.5-FT DRAFT
ALL PILOTS
STERN THRUSTER NOT AVAILABLE

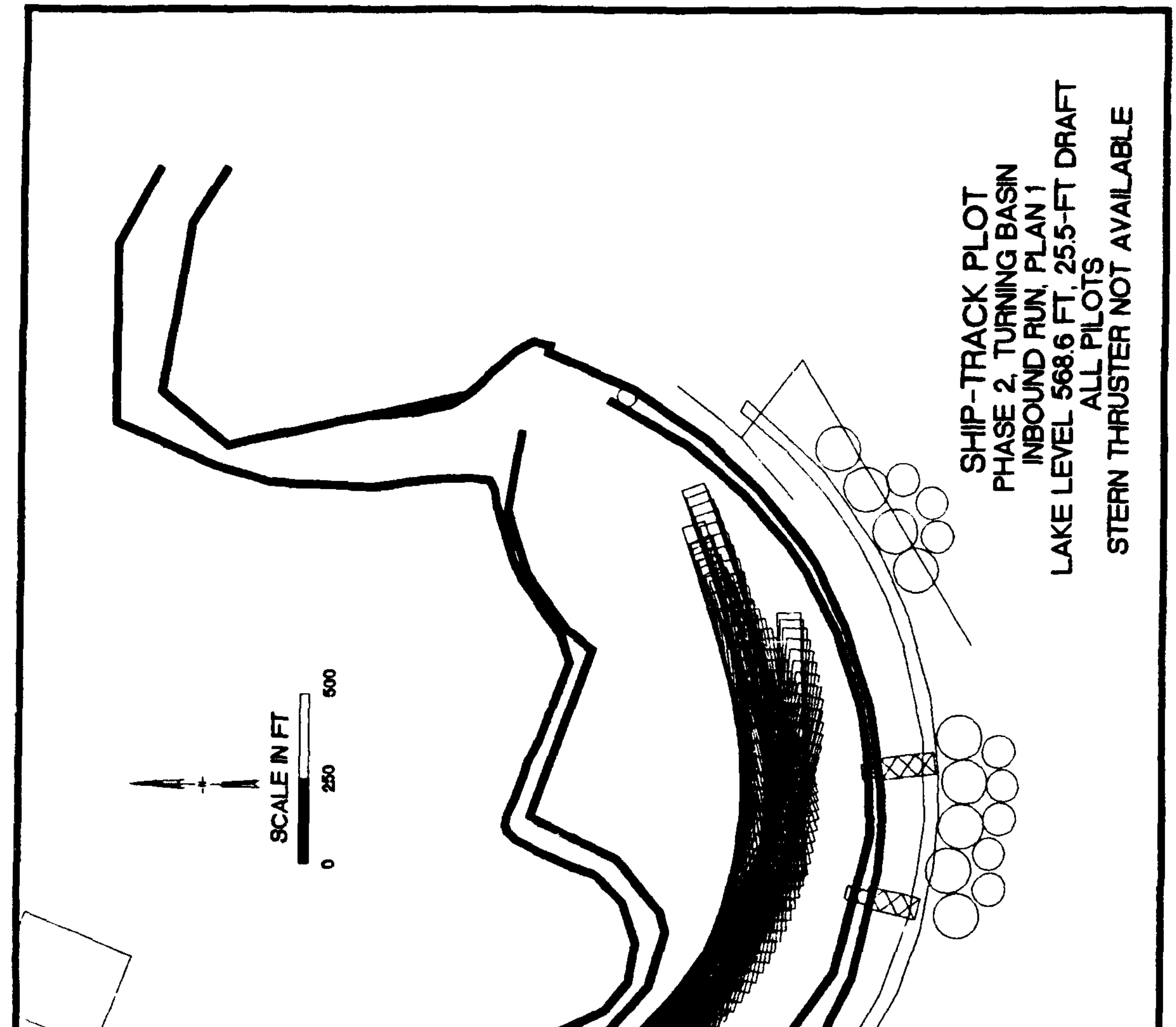
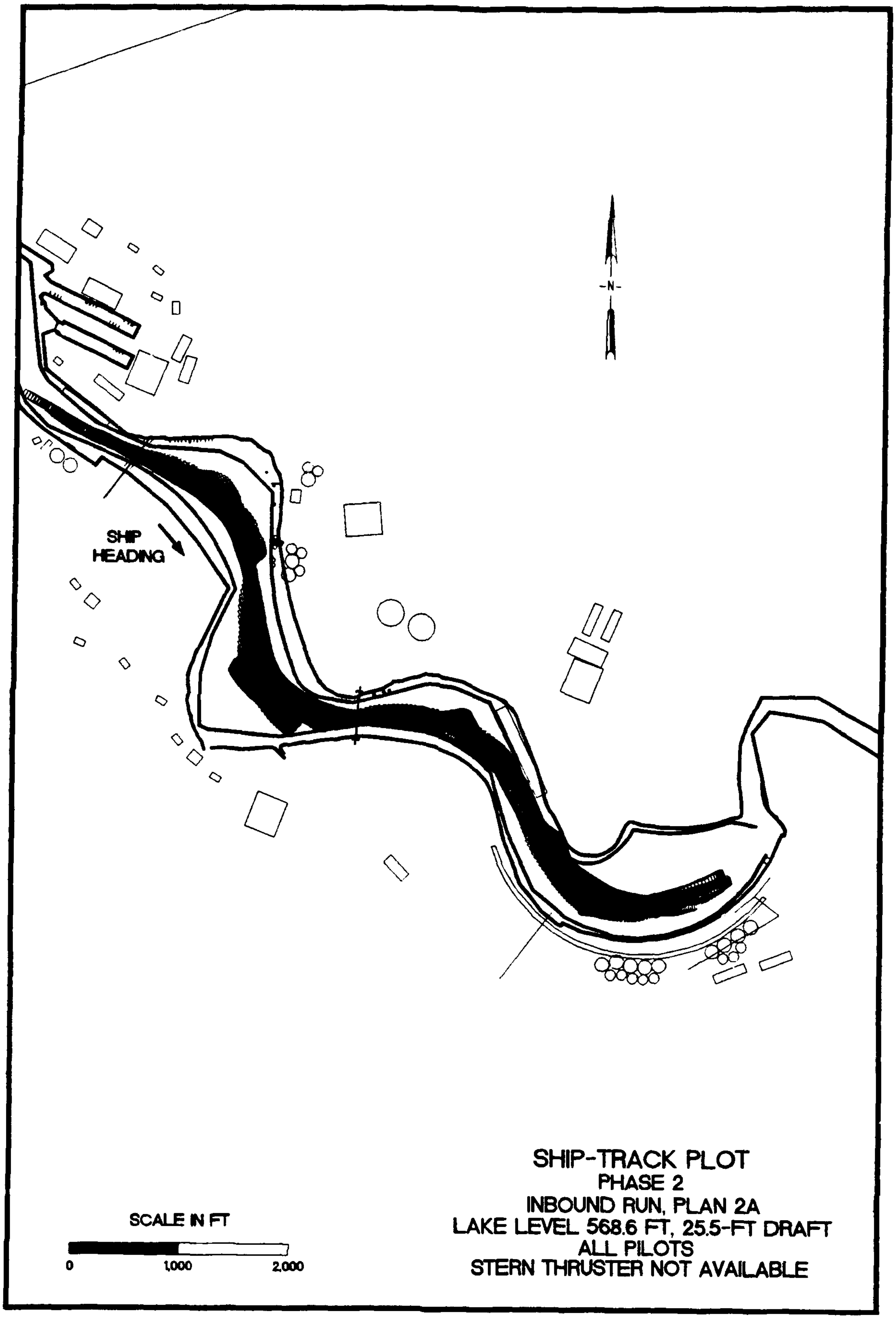
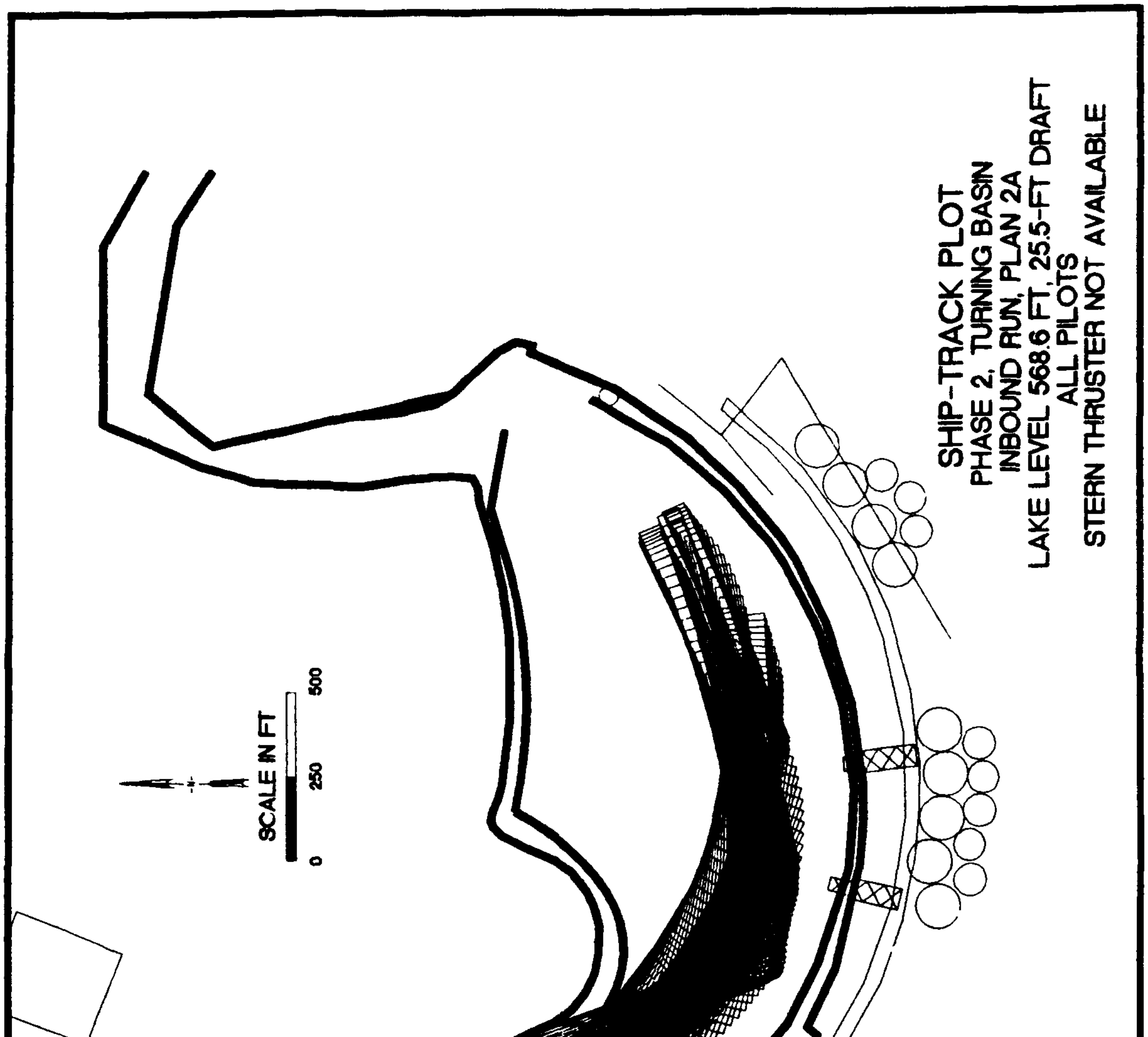
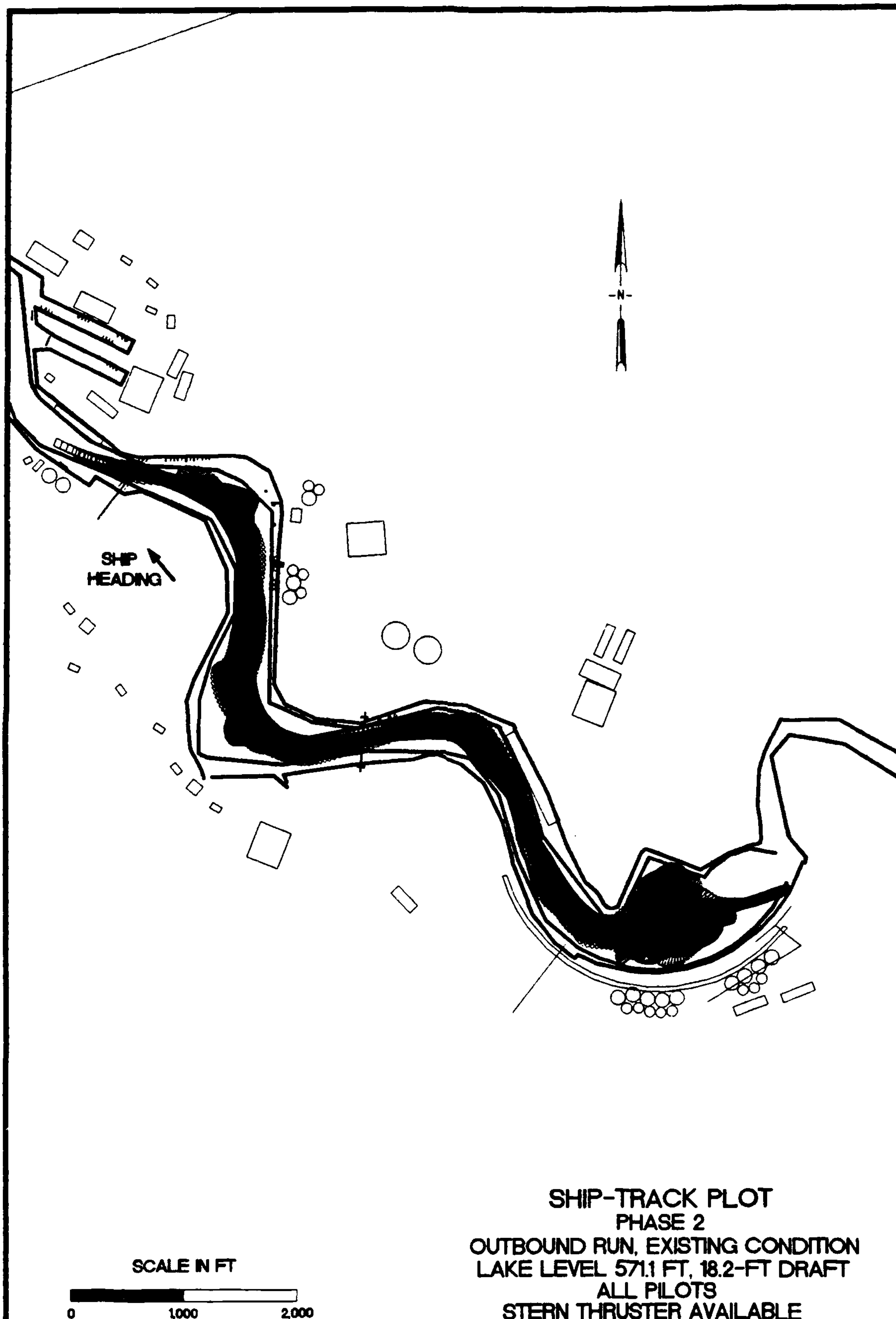

SHIP-TRACK PLOT
PHASE 2, TURNING BASIN
INBOUND RUN, PLAN 1
LAKE LEVEL 568.6 FT, 25.5-FT DRAFT
ALL PILOTS
STERN THRUSTER NOT AVAILABLE
SCALE IN FT
0
250
500
SHIP HEADING

PLATE 76



SHIP-TRACK PLOT
PHASE 2
INBOUND RUN, PLAN 2A
LAKE LEVEL 568.6 FT, 25.5-FT DRAFT
ALL PILOTS
STERN THRUSTER NOT AVAILABLE


SHIP-TRACK PLOT
PHASE 2, TURNING BASIN
INBOUND RUN, PLAN 2A
LAKE LEVEL 568.6 FT, 25.5-FT DRAFT
ALL PILOTS
STERN THRUSTER NOT AVAILABLE
SCALE IN FT
0 250 500
SHIP HEADING
2,000 FT



SHIP-TRACK PLOT
PHASE 2
OUTBOUND RUN, EXISTING CONDITION
LAKE LEVEL 571.1 FT, 18.2-FT DRAFT
ALL PILOTS
STERN THRUSTER AVAILABLE

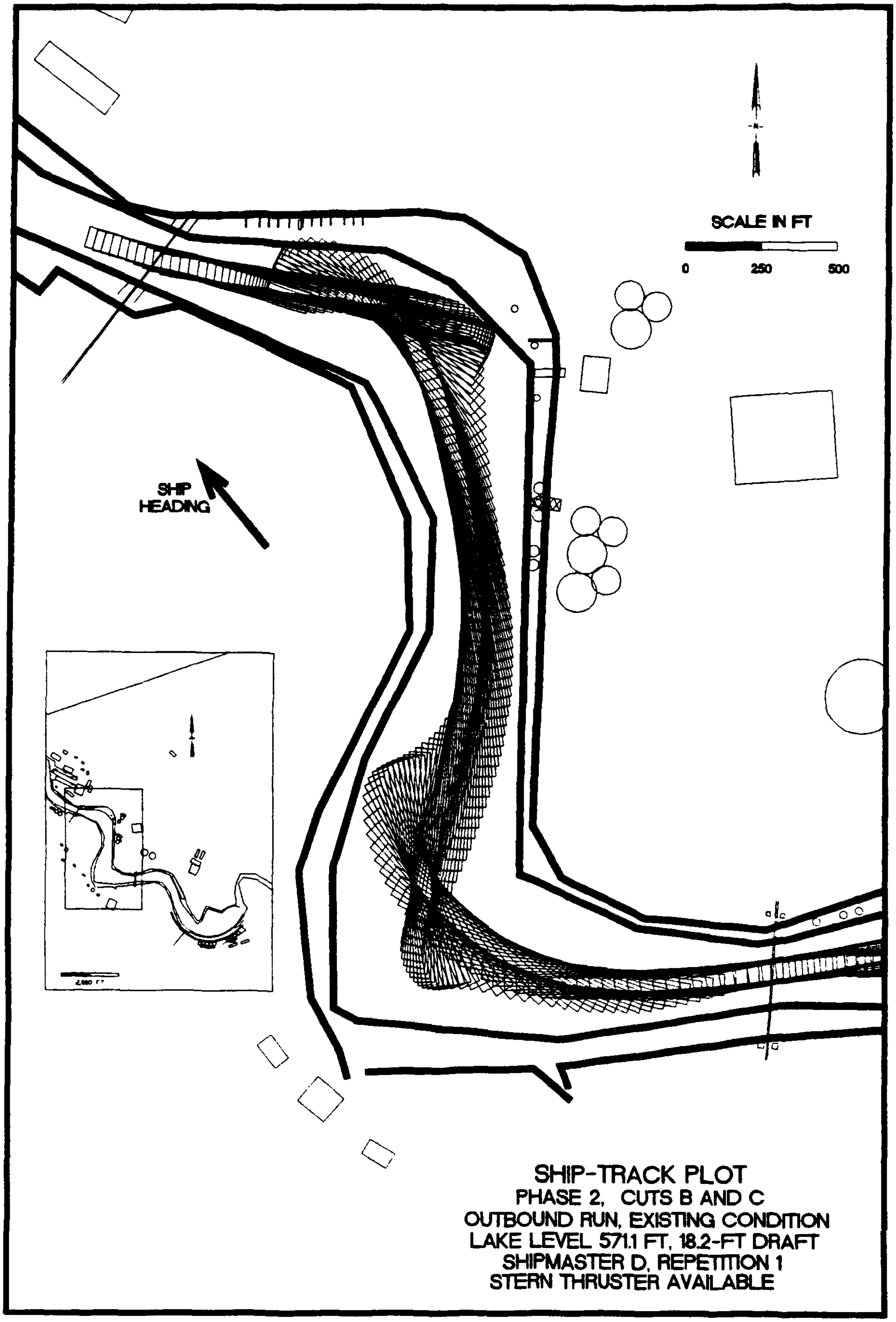
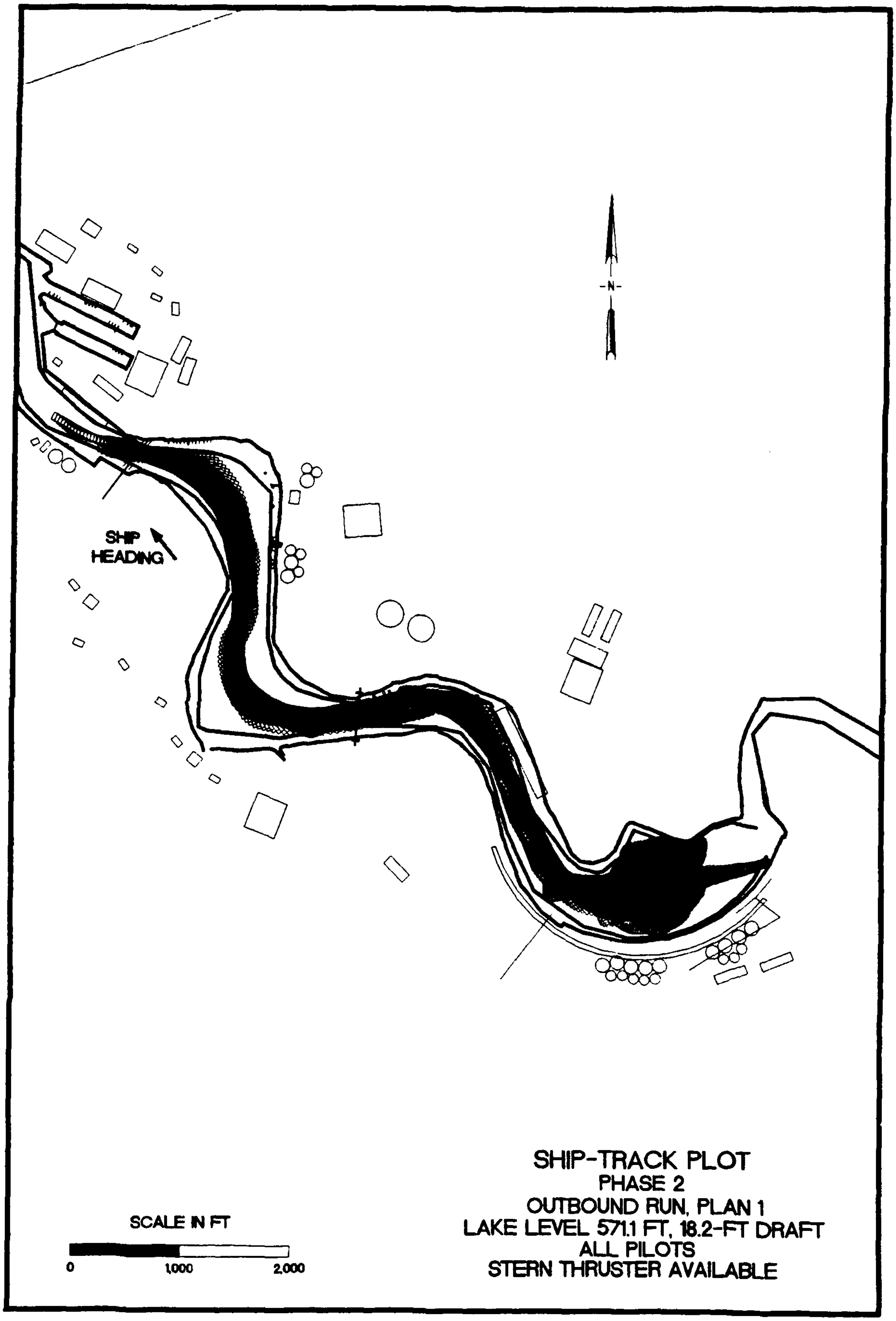

SCALE IN FT
0
250
500
SHIP
HEADING
SHIP-TRACK PLOT
PHASE 2, CUTS B AND C
OUTBOUND RUN, EXISTING CONDITION
LAKE LEVEL 571.1 FT, 18.2-FT DRAFT
SHIPMASTER D, REPETITION 1
STERN THRUSTER AVAILABLE

PLATE 80



SHIP-TRACK PLOT
PHASE 2
OUTBOUND RUN, PLAN 1
LAKE LEVEL 571.1 FT, 18.2-FT DRAFT
ALL PILOTS
STERN THRUSTER AVAILABLE

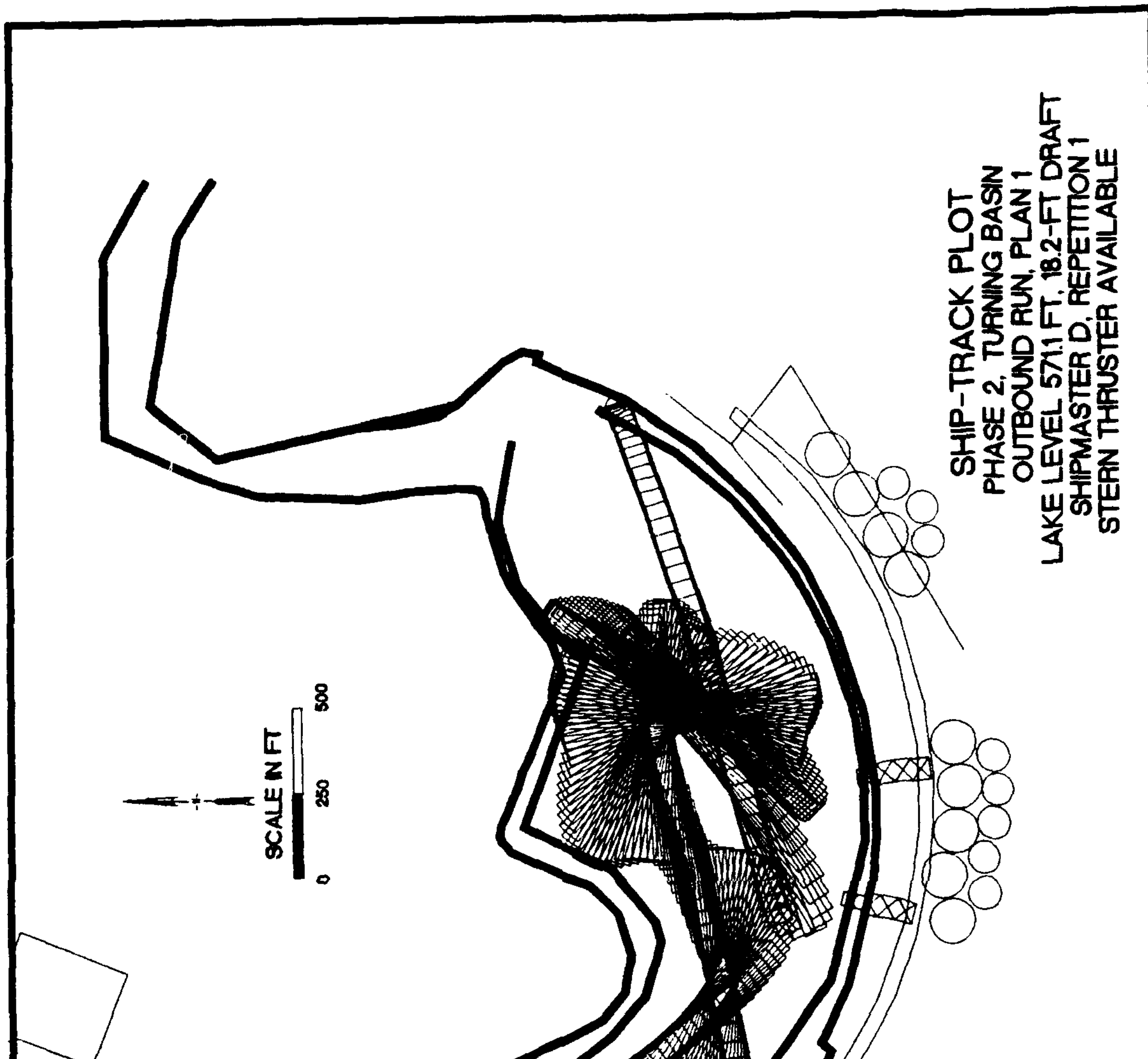
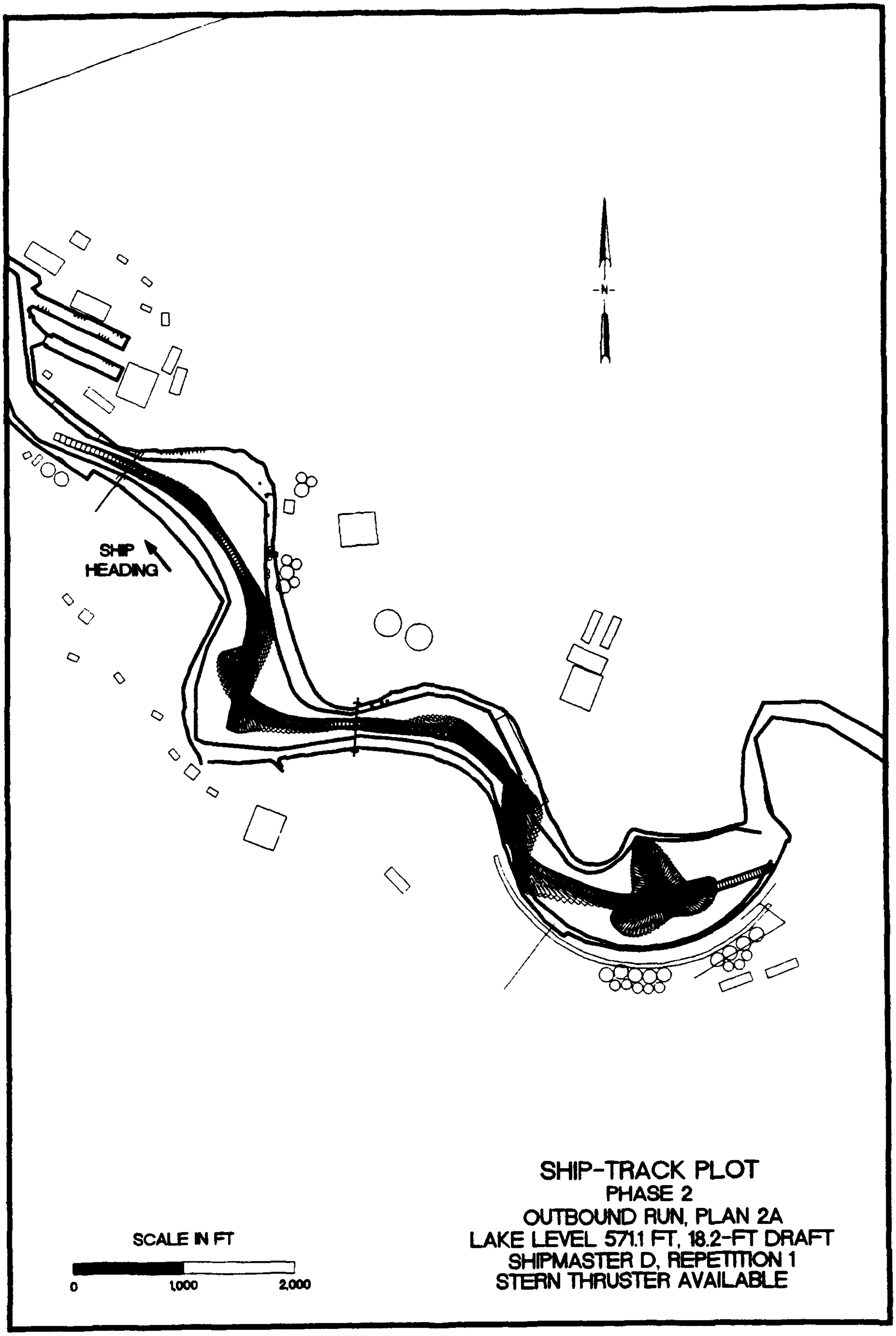
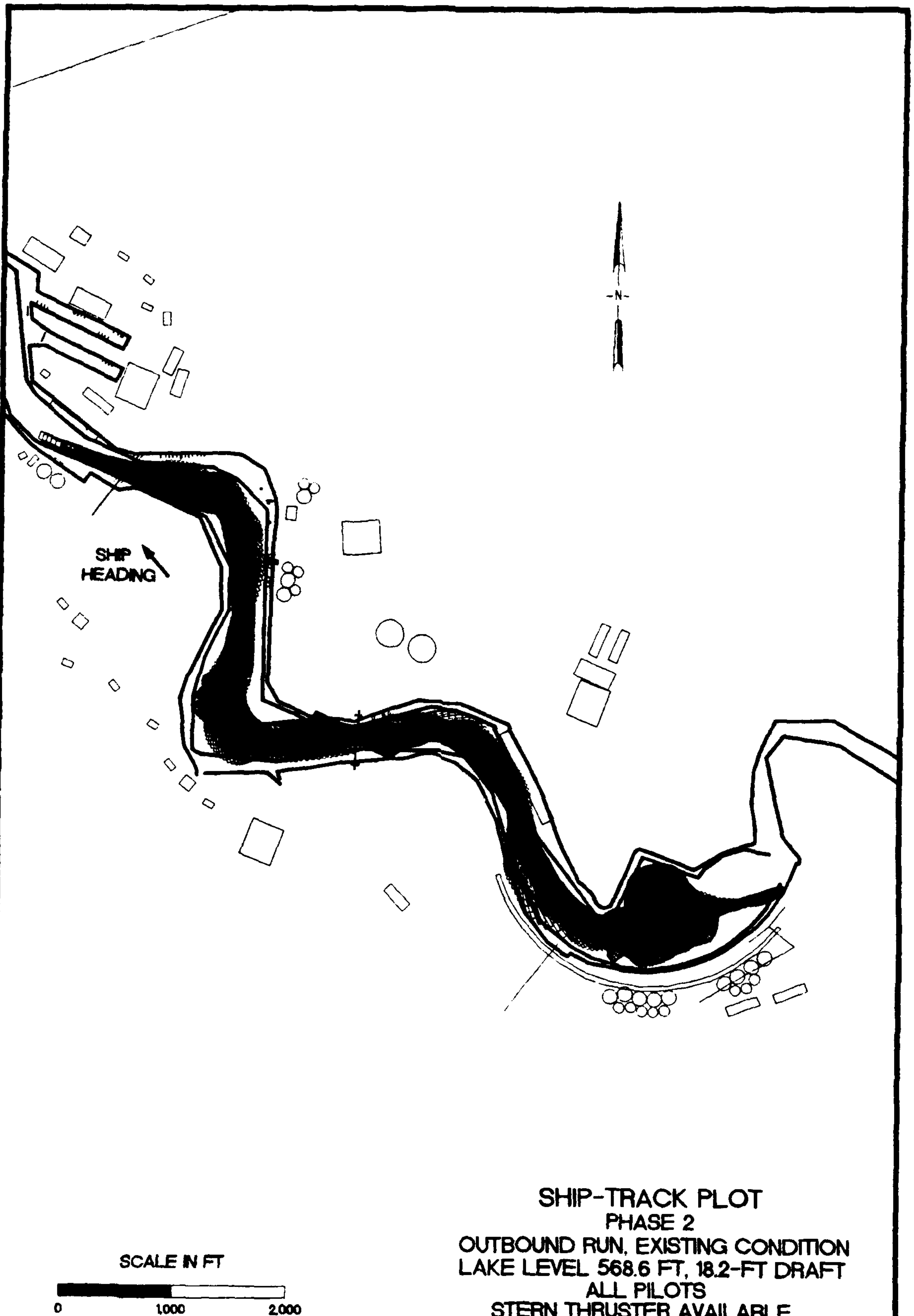

SHIP-TRACK PLOT
PHASE 2, TURNING BASIN
OUTBOUND RUN, PLAN 1
LAKE LEVEL 571.1 FT, 18.2-FT DRAFT
SHIPMASTER D, REPETITION 1
STERN THRUSTER AVAILABLE
SCALE IN FT
0
250
500
SHIP HEADING
2000 FT

PLATE 82

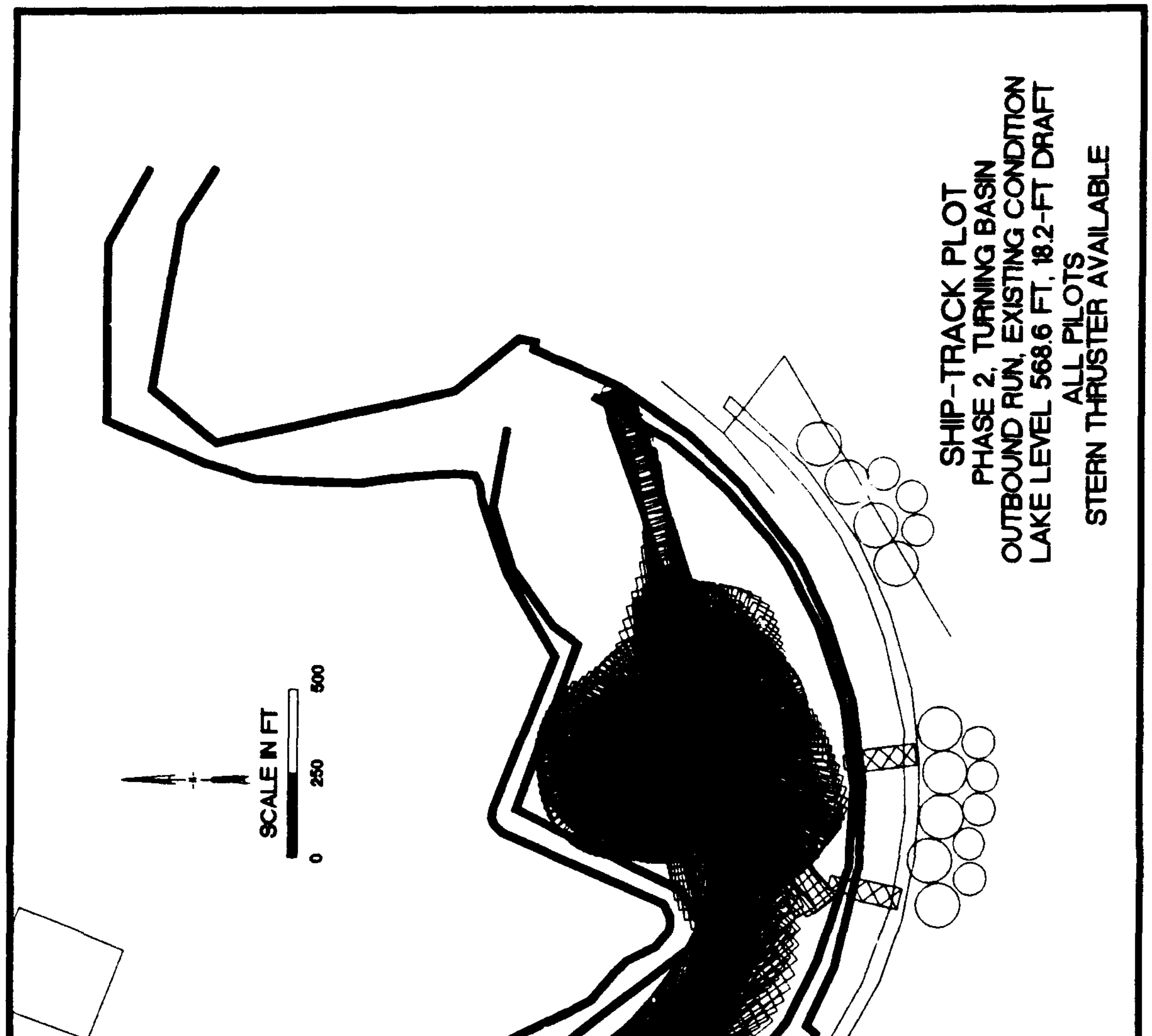
SHIP-TRACK PLOT
PHASE 2
OUTBOUND RUN, PLAN 2A
LAKE LEVEL 571.1 FT, 18.2-FT DRAFT
ALL PILOTS
STERN THRUSTER AVAILABLE

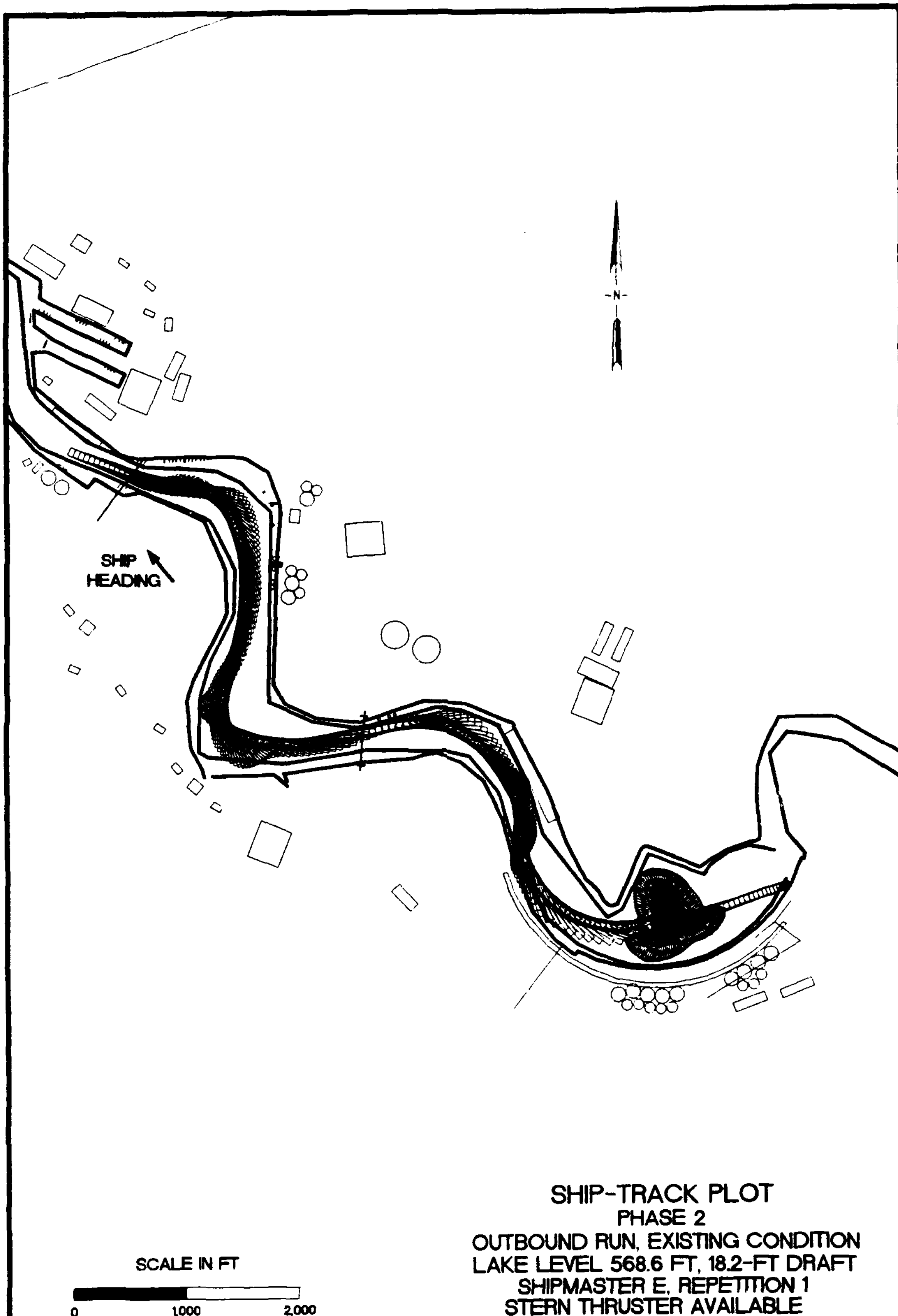

N
SHIP HEADING
SHIP-TRACK PLOT
PHASE 2
OUTBOUND RUN, PLAN 2A
LAKE LEVEL 571.1 FT, 18.2-FT DRAFT
SHIPMASTER D, REPETITION 1
STERN THRUSTER AVAILABLE
SCALE IN FT
0
1,000
2,000

SHIP-TRACK PLOT
PHASE 2
OUTBOUND RUN, PLAN 2A
LAKE LEVEL 571.1 FT, 18.2-FT DRAFT
ALL PILOTS, RUNS EXCLUDED
STERN THRUSTER AVAILABLE



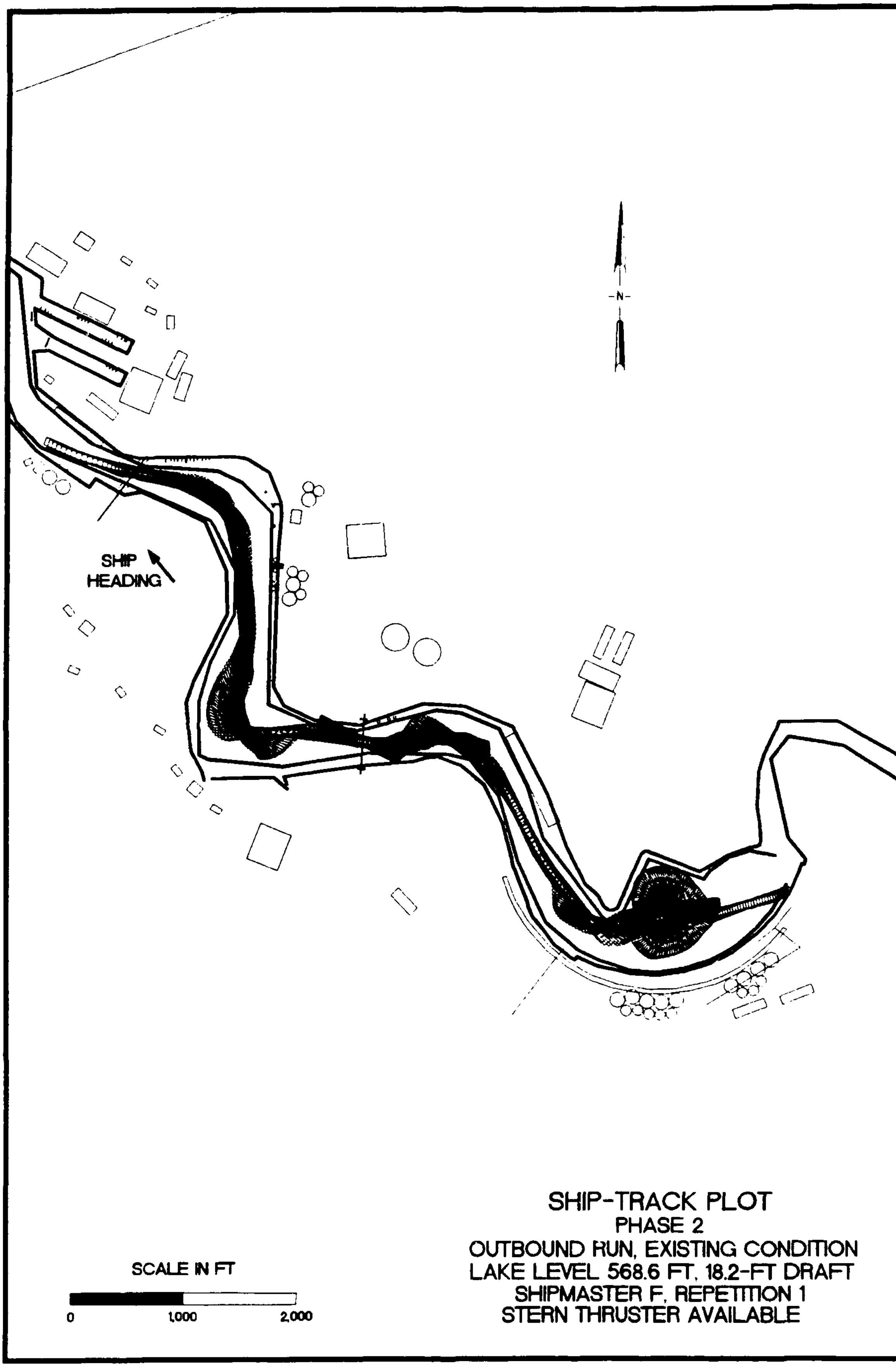
SHIP-TRACK PLOT
PHASE 2
OUTBOUND RUN, EXISTING CONDITION
LAKE LEVEL 568.6 FT, 18.2-FT DRAFT
ALL PILOTS
STERN THRUSTER AVAILABLE


SHIP-TRACK PLOT
PHASE 2, TURNING BASIN
OUTBOUND RUN, EXISTING CONDITION
LAKE LEVEL 568.6 FT, 18.2-FT DRAFT
ALL PILOTS
STERN THRUSTER AVAILABLE
SCALE IN FT
0
250
500
SHIP
HEADING

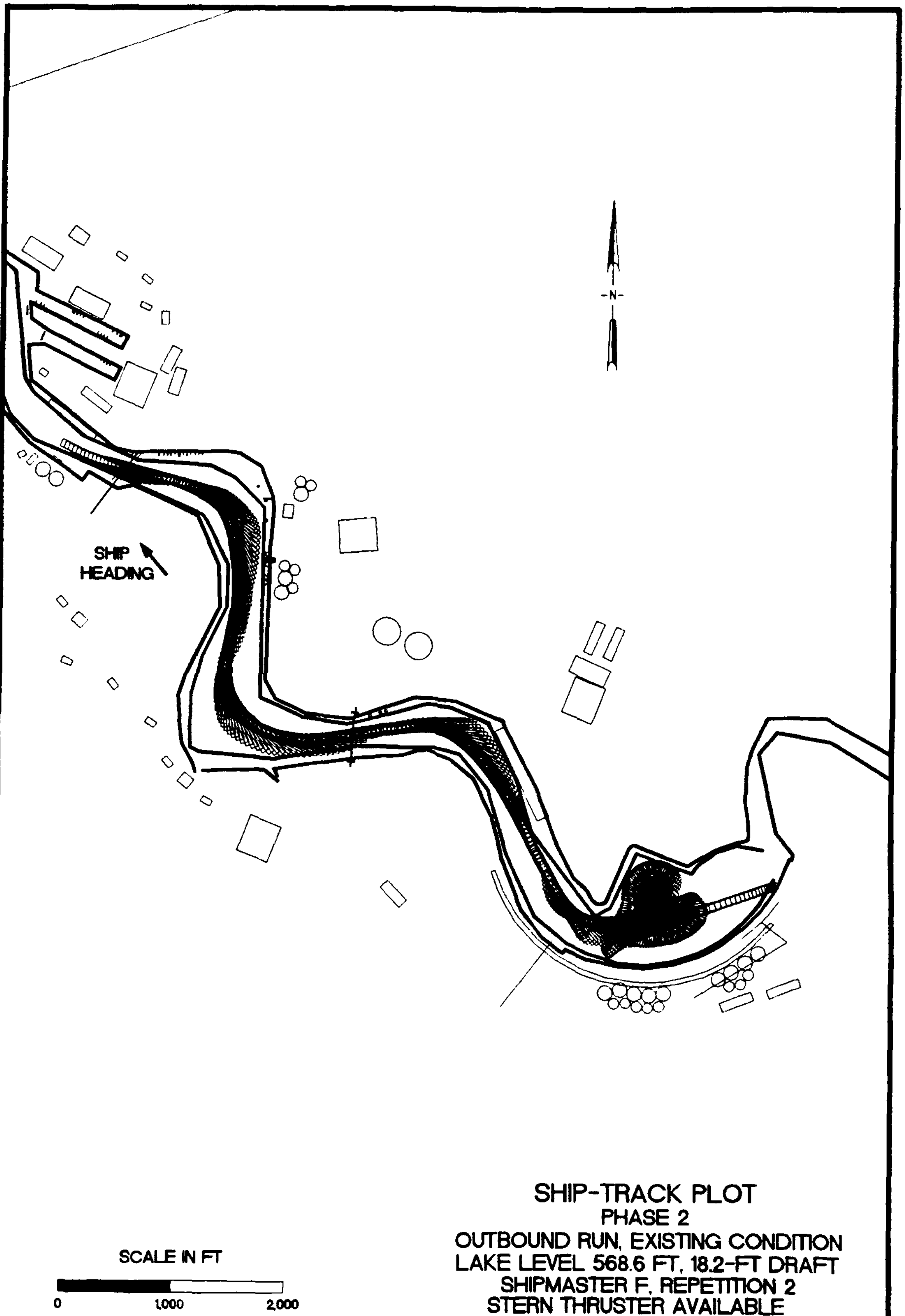


SHIP-TRACK PLOT
PHASE 2
OUTBOUND RUN, EXISTING CONDITION
LAKE LEVEL 568.6 FT, 18.2-FT DRAFT
SHIPMASTER E, REPETITION 1
STERN THRUSTER AVAILABLE

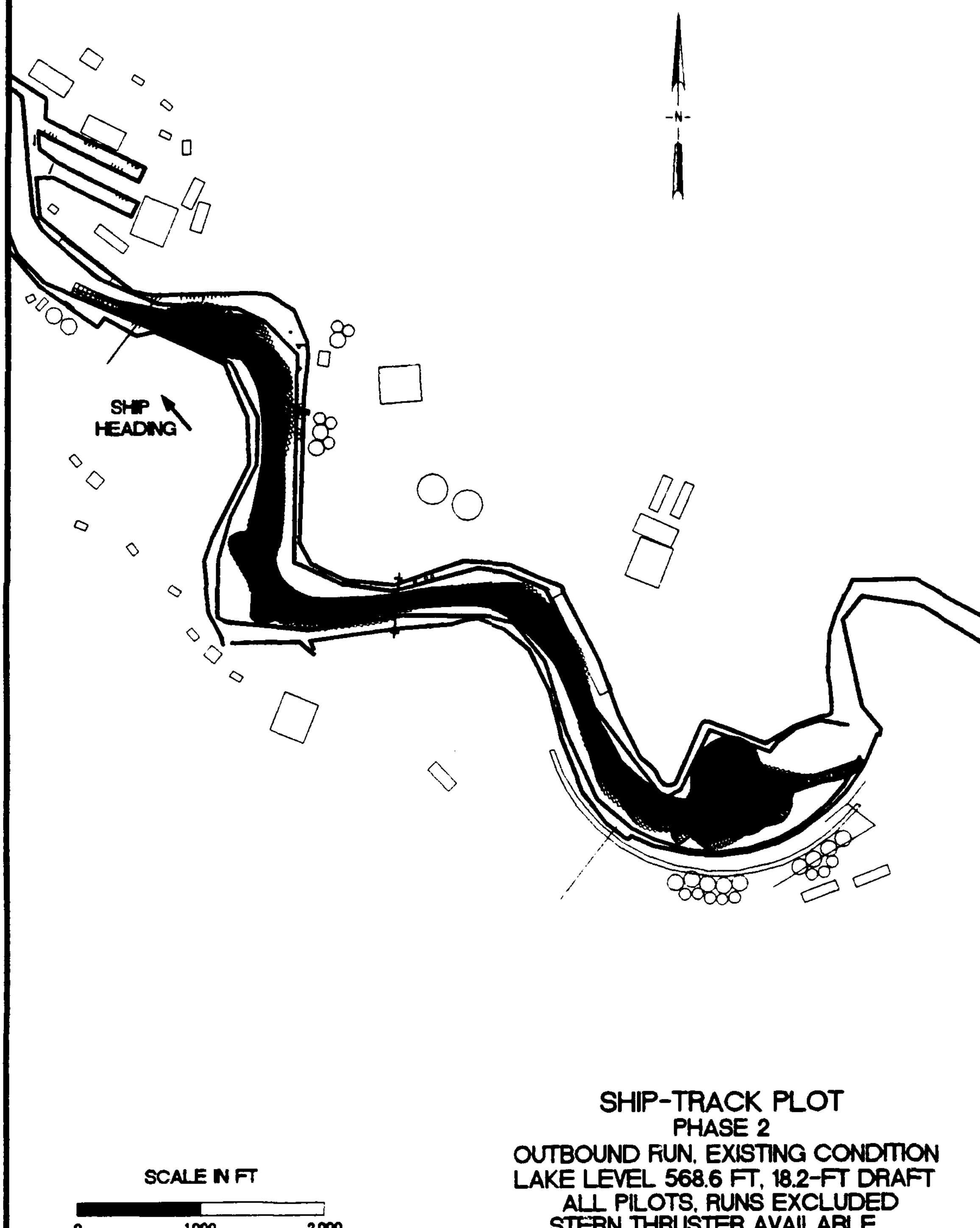
PLATE 88



SHIP-TRACK PLOT
PHASE 2
OUTBOUND RUN, EXISTING CONDITION
LAKE LEVEL 568.6 FT, 18.2-FT DRAFT
SHIPMASTER F, REPETITION 1
STERN THRUSTER AVAILABLE



SHIP-TRACK PLOT
PHASE 2
OUTBOUND RUN, EXISTING CONDITION
LAKE LEVEL 568.6 FT, 18.2-FT DRAFT
SHIPMASTER F, REPETITION 2
STERN THRUSTER AVAILABLE



SHIP-TRACK PLOT
PHASE 2
OUTBOUND RUN, EXISTING CONDITION
LAKE LEVEL 568.6 FT, 18.2-FT DRAFT
ALL PILOTS, RUNS EXCLUDED
STERN THRUSTER AVAILABLE

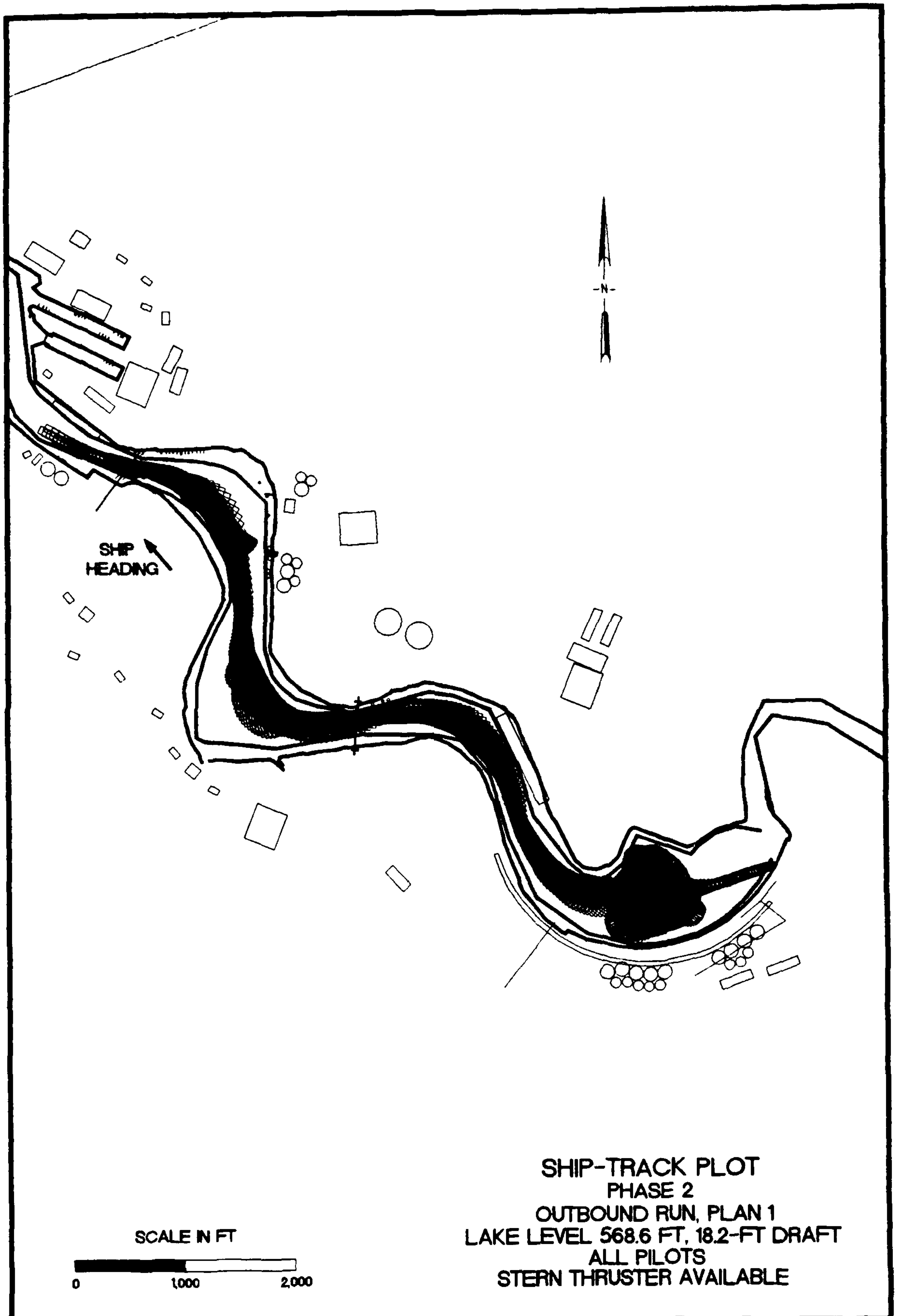
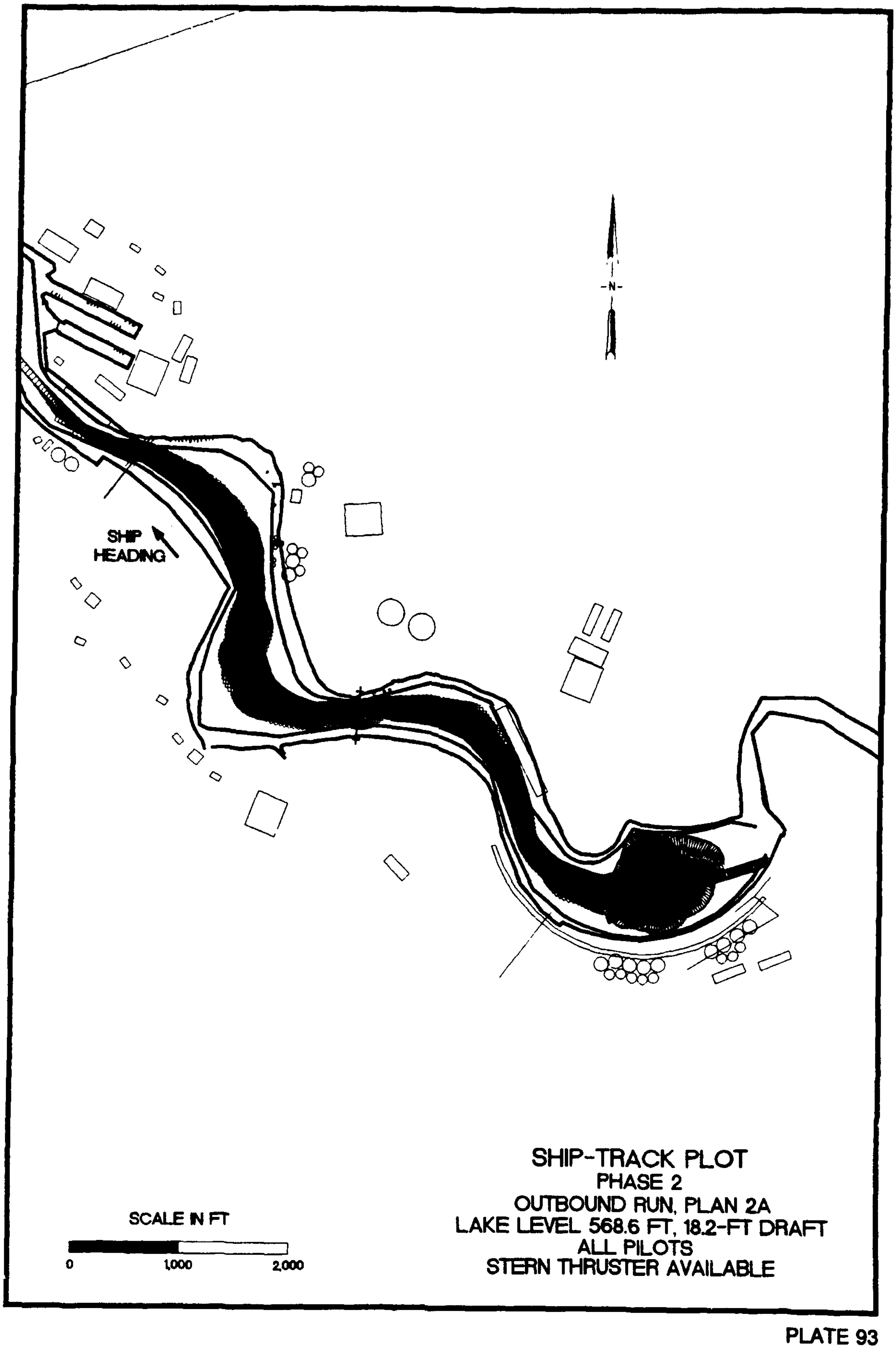
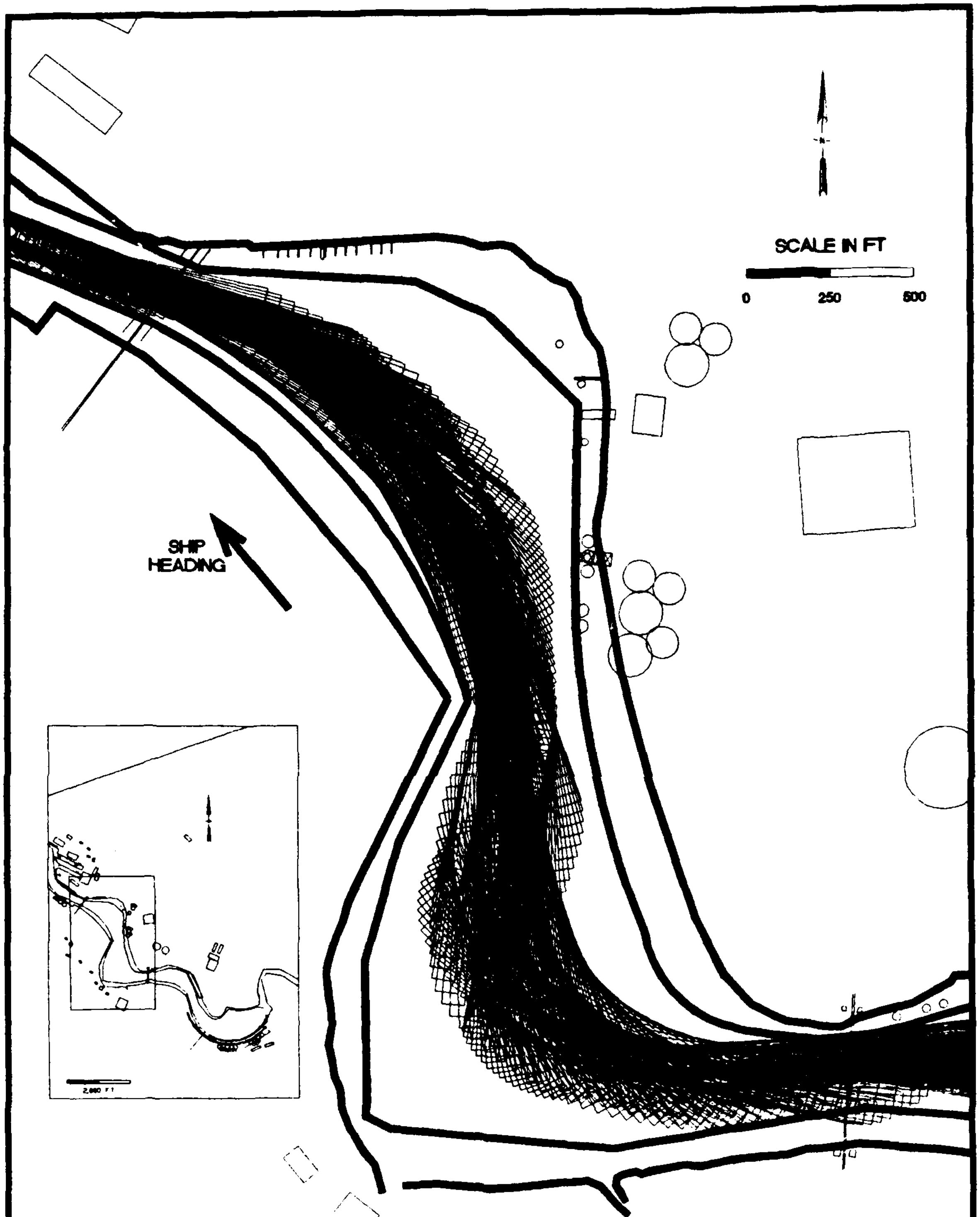

SHIP HEADING
N
SHIP-TRACK PLOT
PHASE 2
OUTBOUND RUN, PLAN 1
LAKE LEVEL 568.6 FT, 18.2-FT DRAFT
ALL PILOTS
STERN THRUSTER AVAILABLE
SCALE IN FT
0
1,000
2,000

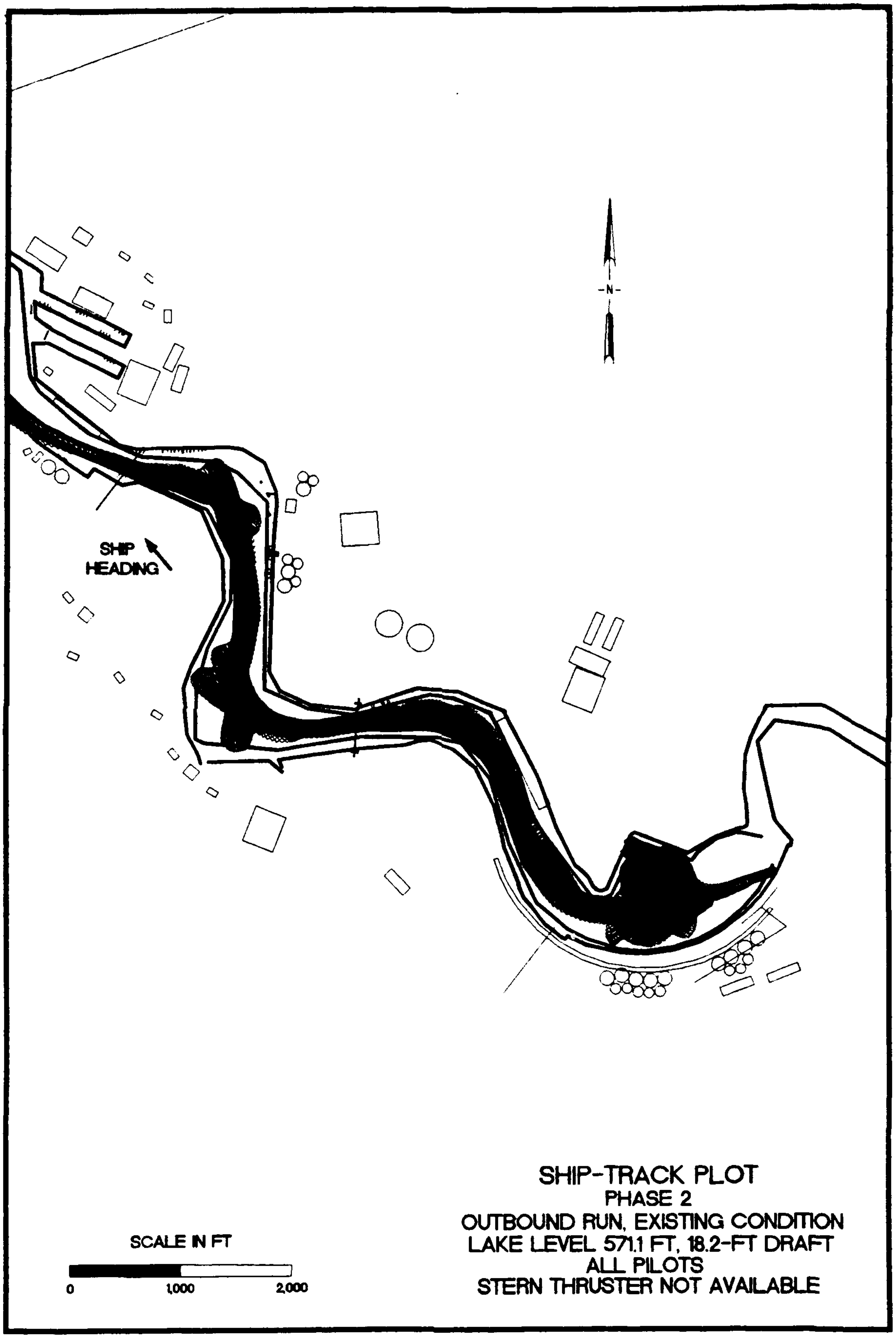
PLATE 92



SHIP-TRACK PLOT
PHASE 2
OUTBOUND RUN, PLAN 2A
LAKE LEVEL 568.6 FT, 18.2-FT DRAFT
ALL PILOTS
STERN THRUSTER AVAILABLE

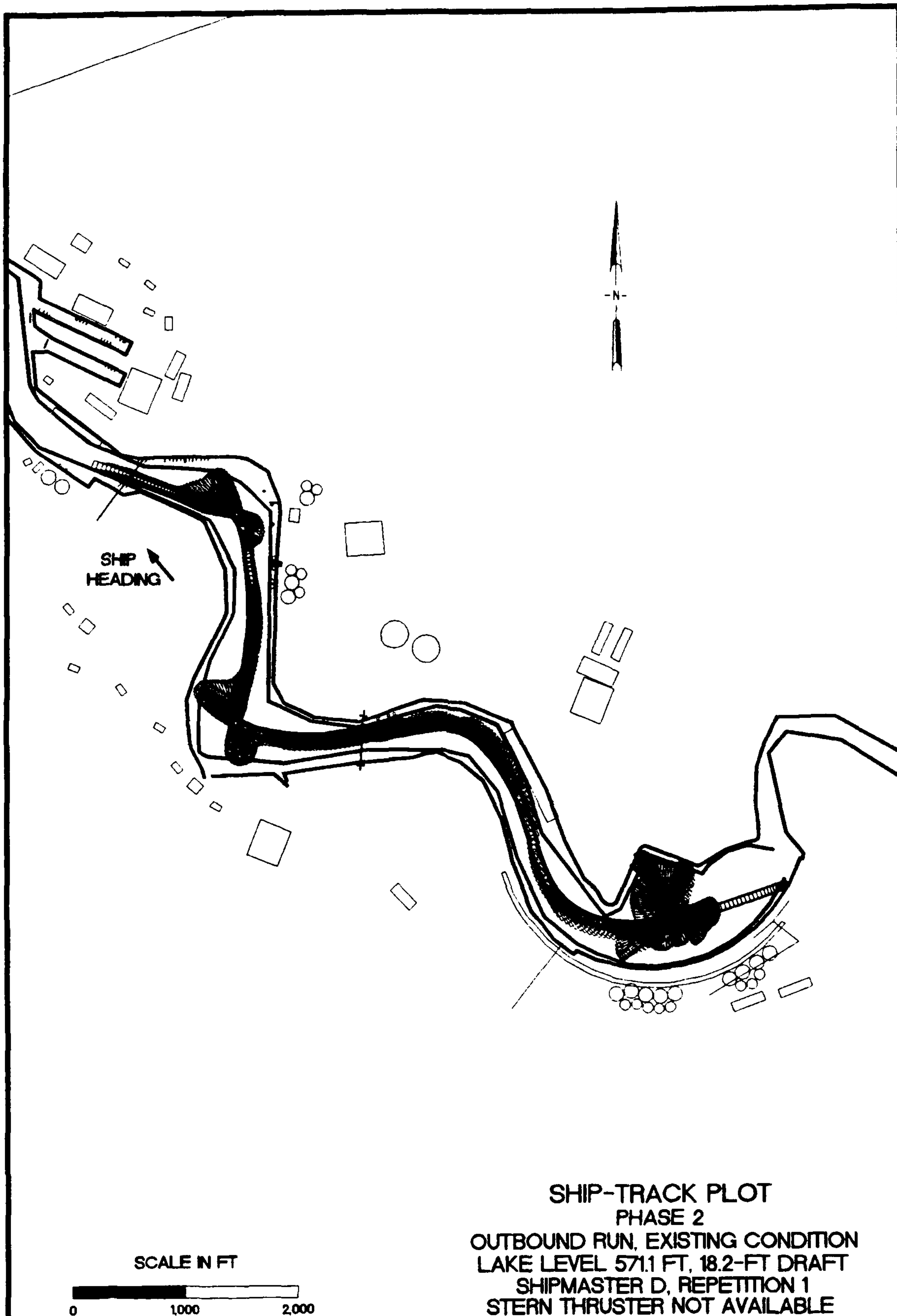


SHIP-TRACK PLOT
PHASE 2, CUTS B AND C
OUTBOUND RUN, PLAN 2A
LAKE LEVEL 568.6 FT, 18.2-FT DRAFT
ALL PILOTS
STERN THRUSTER AVAILABLE

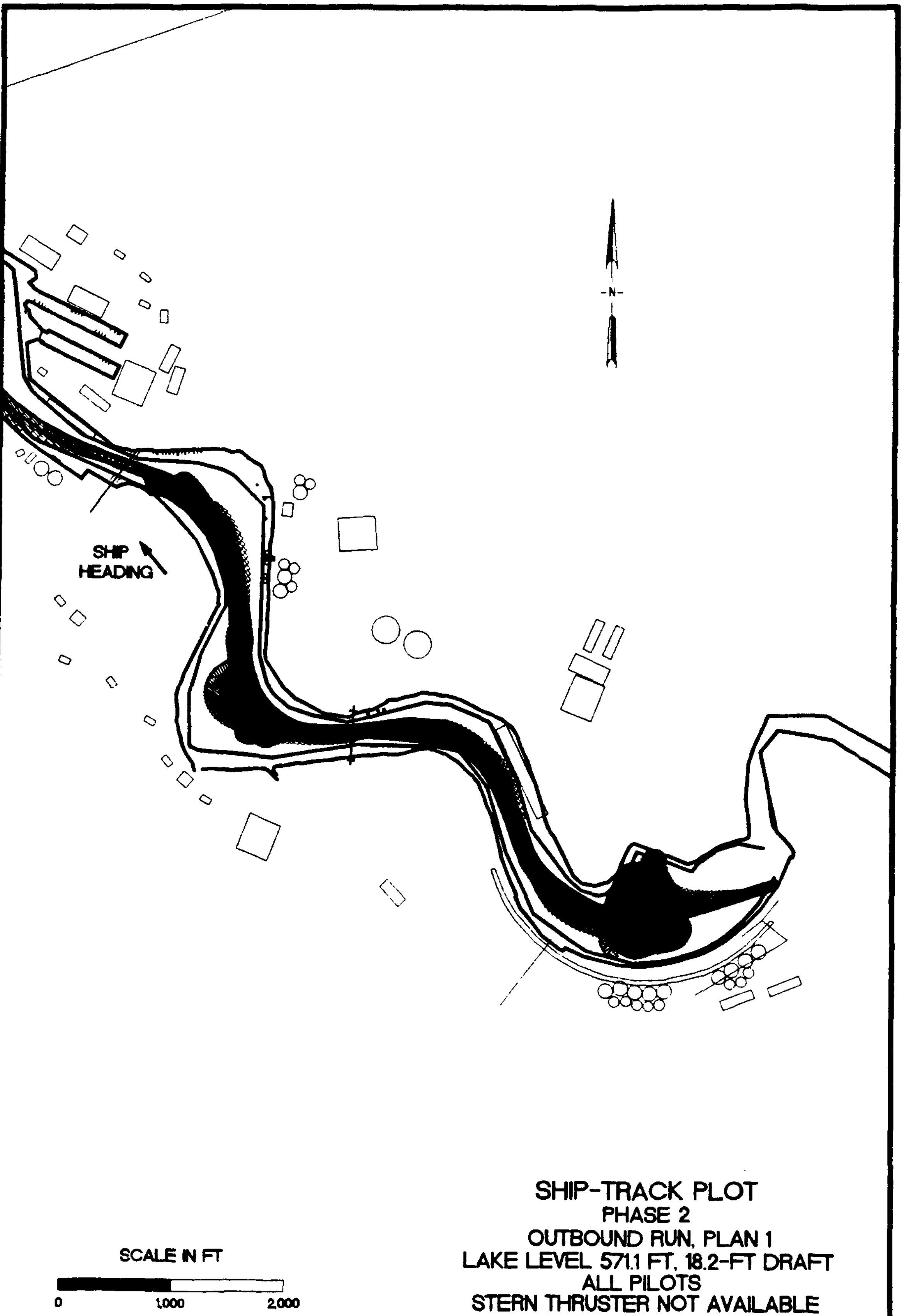


SHIP HEADING
-N-
SHIP-TRACK PLOT
PHASE 2
OUTBOUND RUN, EXISTING CONDITION
LAKE LEVEL 571.1 FT, 18.2-FT DRAFT
ALL PILOTS
STERN THRUSTER NOT AVAILABLE
SCALE IN FT
0
1,000
2,000

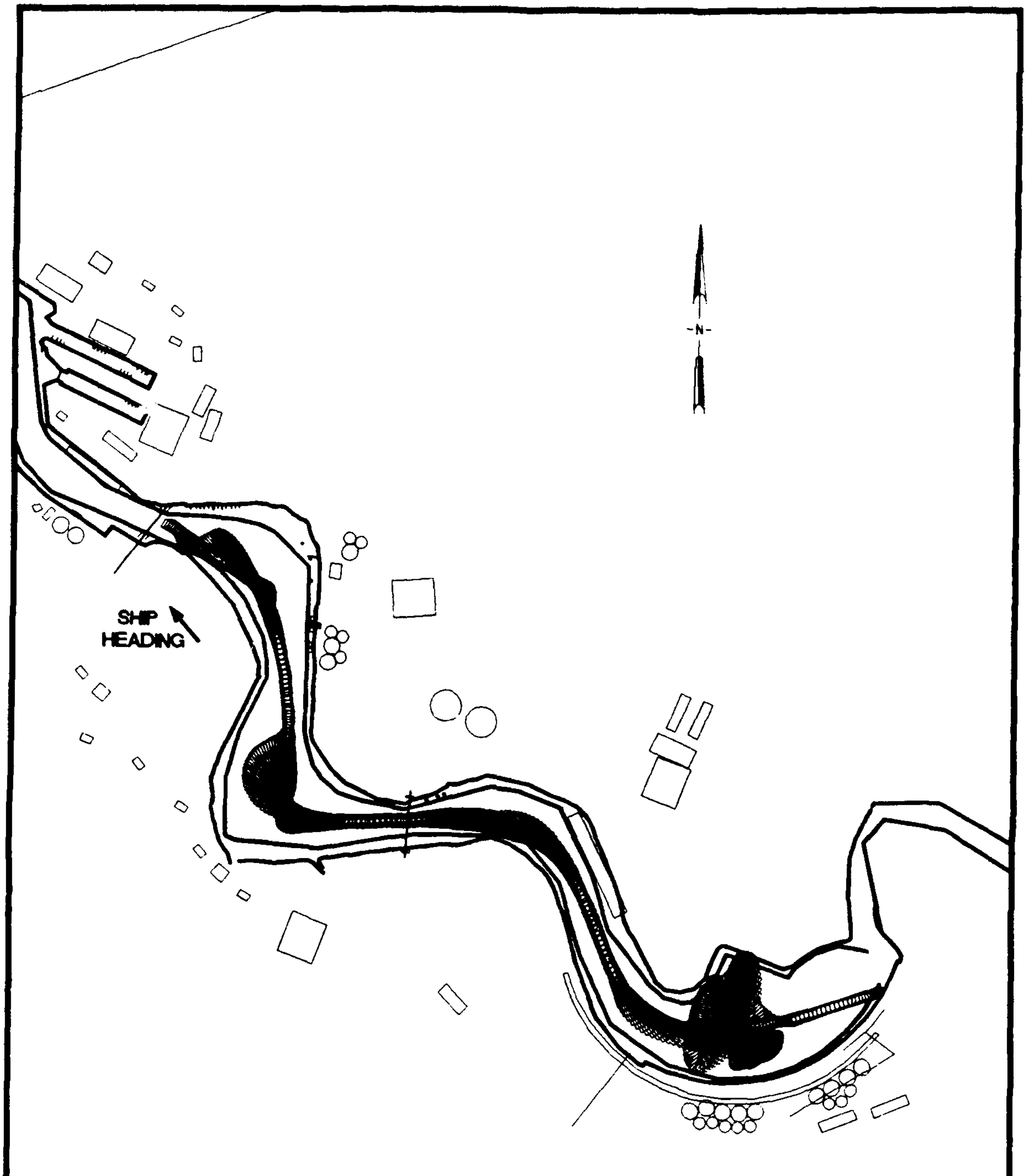
PLATE 95



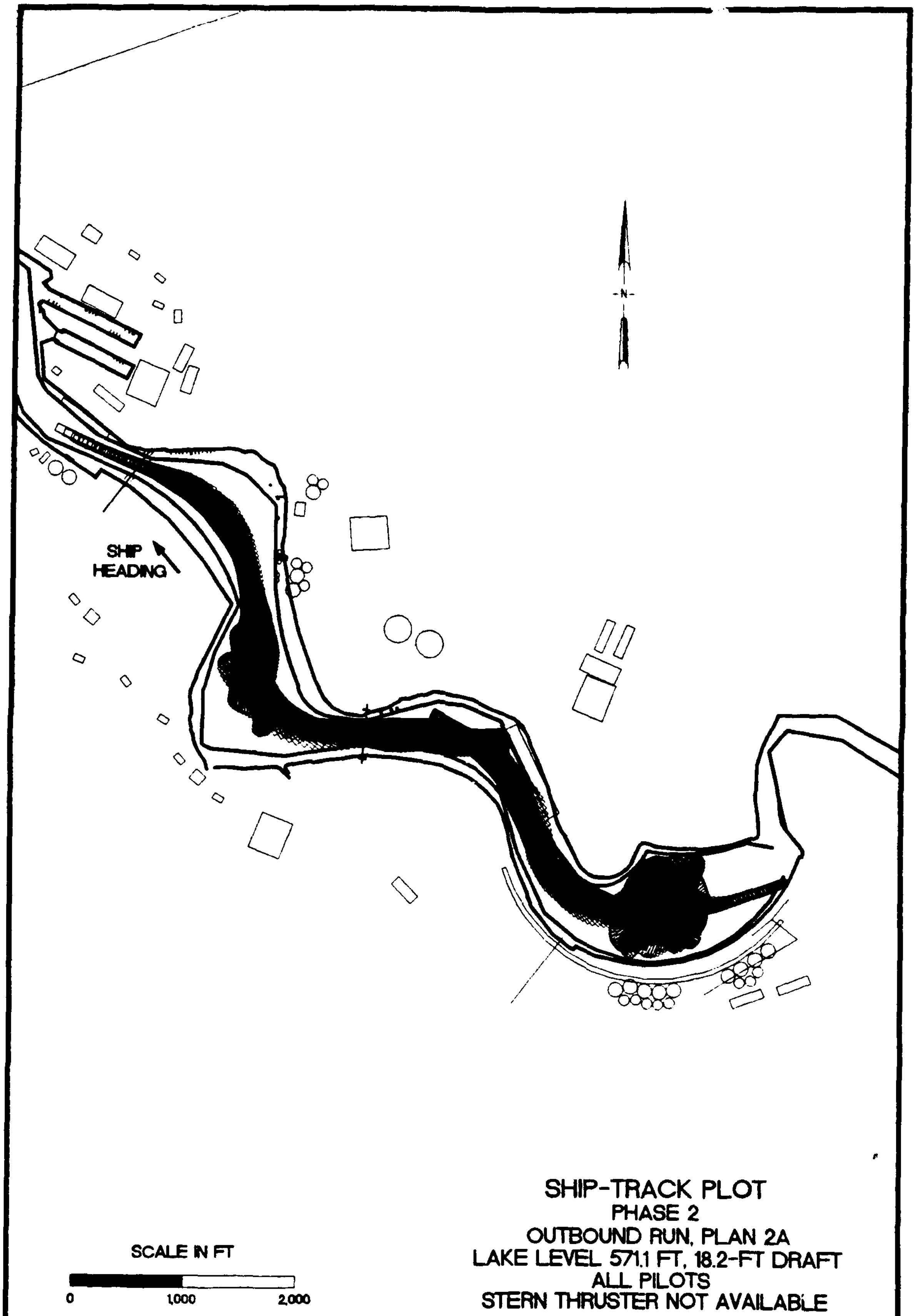
SHIP-TRACK PLOT
PHASE 2
OUTBOUND RUN, EXISTING CONDITION
LAKE LEVEL 571.1 FT, 18.2-FT DRAFT
SHIPMASTER D, REPETITION 1
STERN THRUSTER NOT AVAILABLE



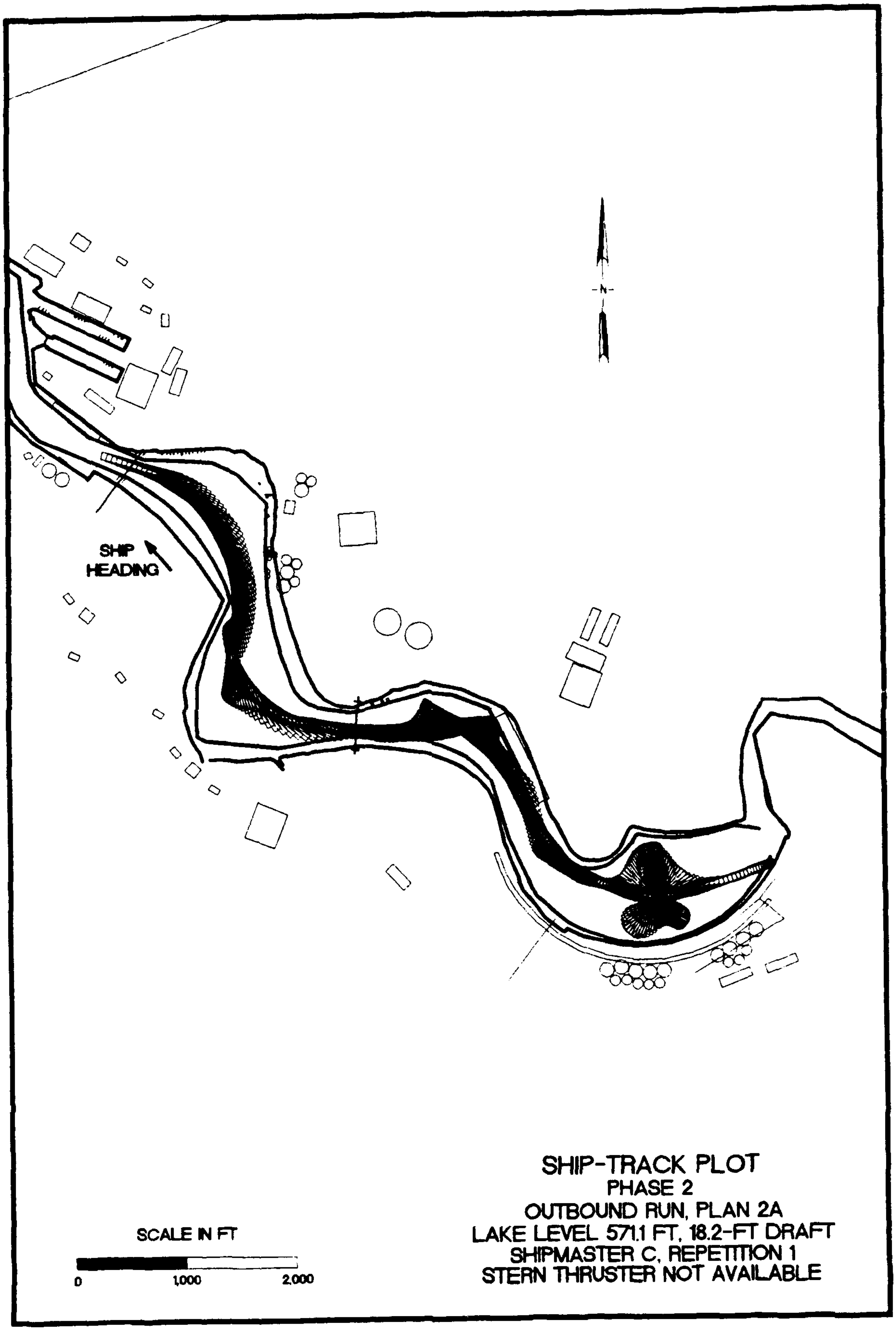
SHIP-TRACK PLOT
PHASE 2
OUTBOUND RUN, PLAN 1
LAKE LEVEL 571.1 FT, 18.2-FT DRAFT
ALL PILOTS
STERN THRUSTER NOT AVAILABLE



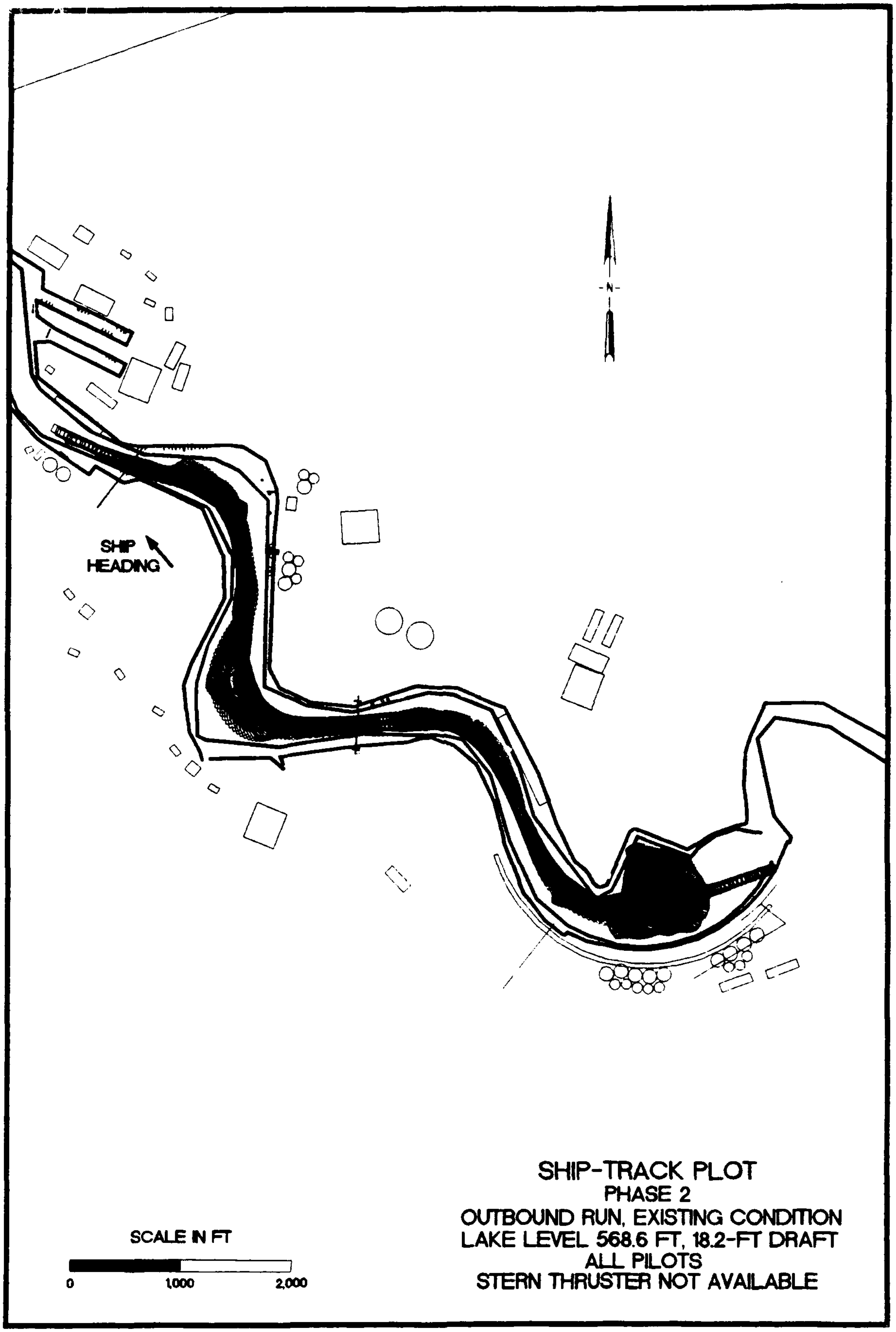
SHIP-TRACK PLOT
PHASE 2
OUTBOUND RUN, PLAN 1
LAKE LEVEL 571.1 FT, 18.2-FT DRAFT
SHIPMASTER D, REPETITION 1
STERN THRUSTER NOT AVAILABLE



SHIP-TRACK PLOT
PHASE 2
OUTBOUND RUN, PLAN 2A
LAKE LEVEL 571.1 FT, 18.2-FT DRAFT
ALL PILOTS
STERN THRUSTER NOT AVAILABLE



SHIP-TRACK PLOT
PHASE 2
OUTBOUND RUN, PLAN 2A
LAKE LEVEL 571.1 FT, 18.2-FT DRAFT
SHIPMASTER C, REPETITION 1
STERN THRUSTER NOT AVAILABLE



SHIP-TRACK PLOT
PHASE 2
OUTBOUND RUN, EXISTING CONDITION
LAKE LEVEL 568.6 FT, 18.2-FT DRAFT
ALL PILOTS
STERN THRUSTER NOT AVAILABLE

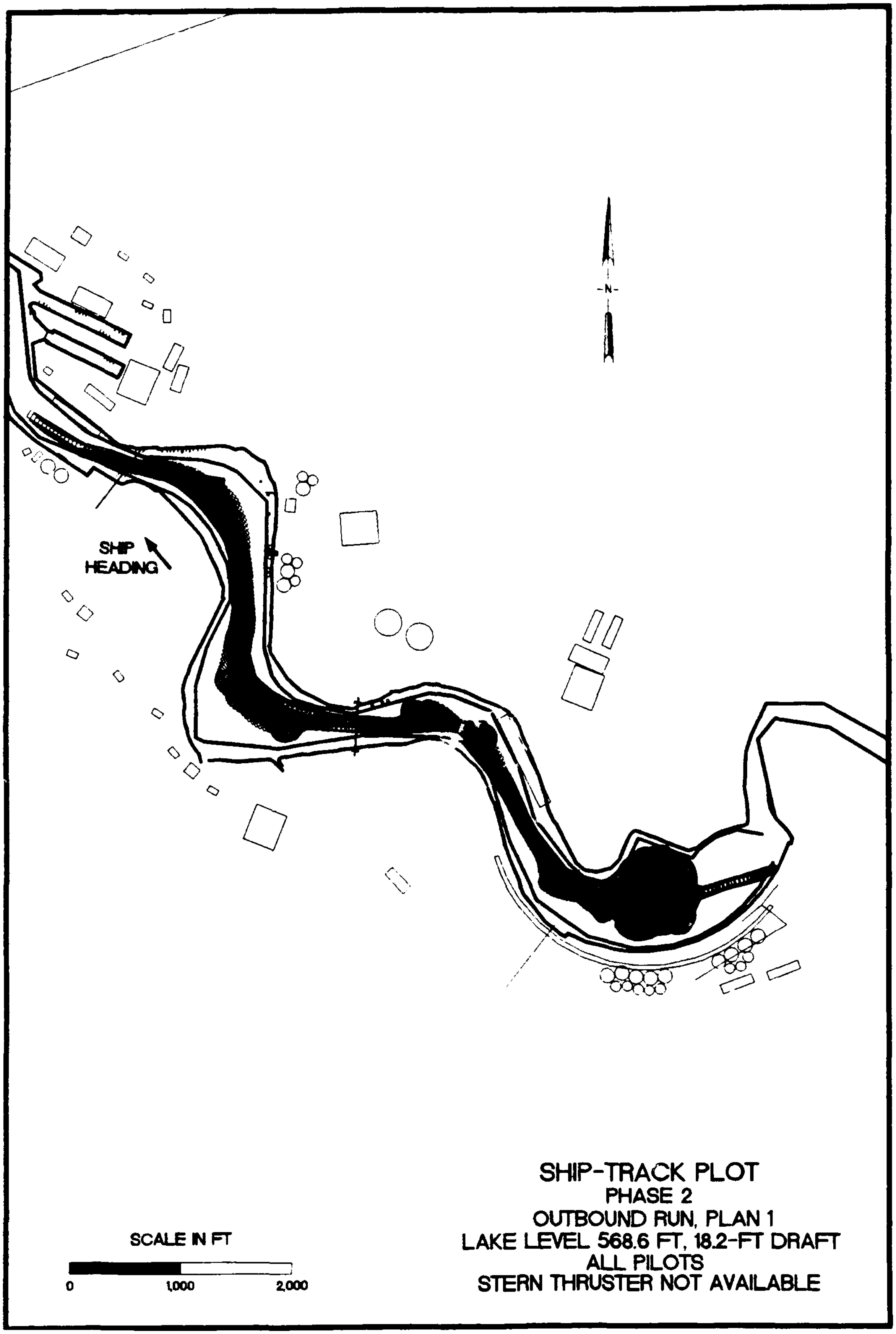
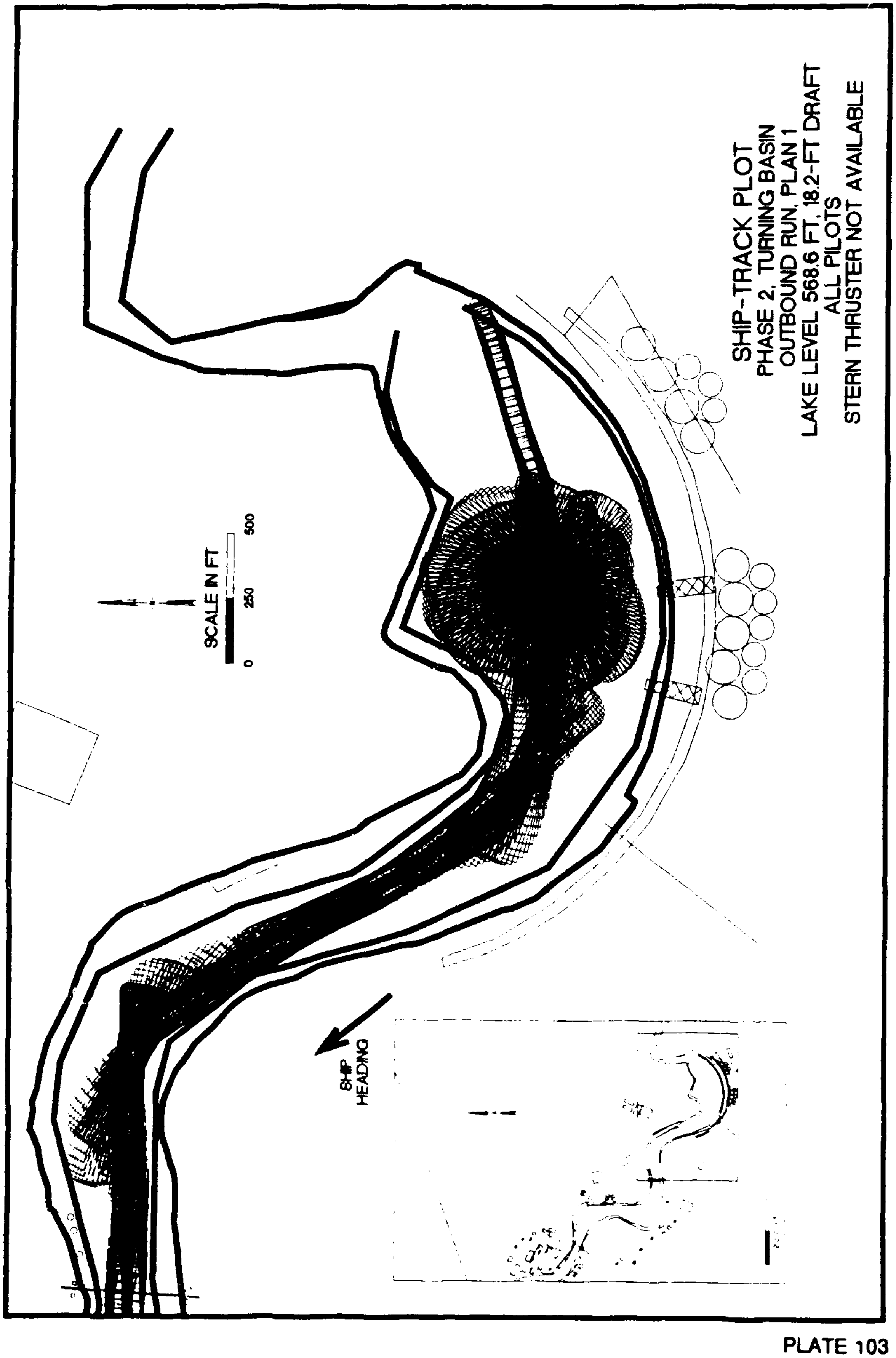
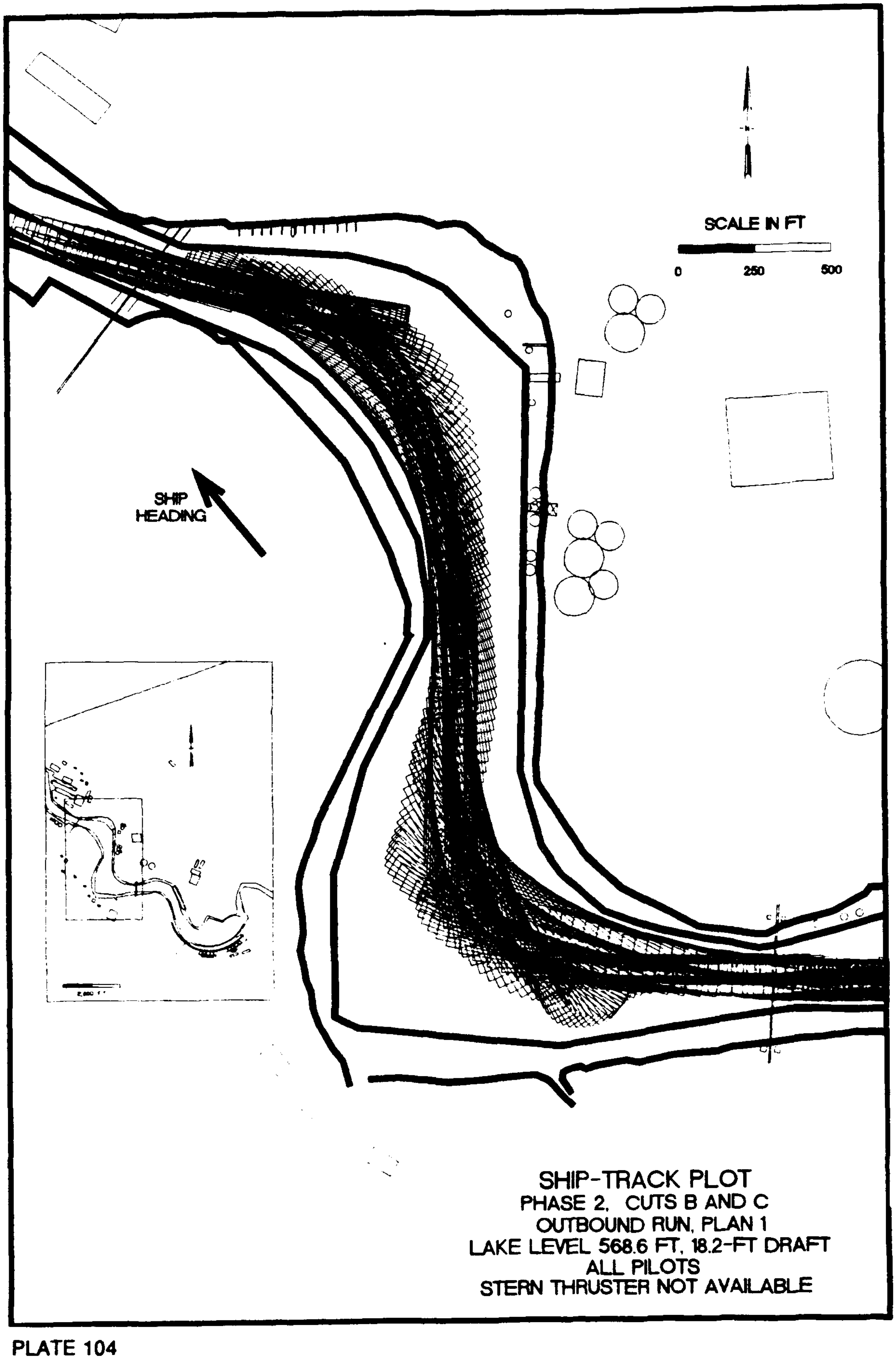

N
SHIP
HEADING
SHIP-TRACK PLOT
PHASE 2
OUTBOUND RUN, PLAN 1
LAKE LEVEL 568.6 FT, 18.2-FT DRAFT
ALL PILOTS
STERN THRUSTER NOT AVAILABLE
SCALE IN FT
0
1,000
2,000

PLATE 102

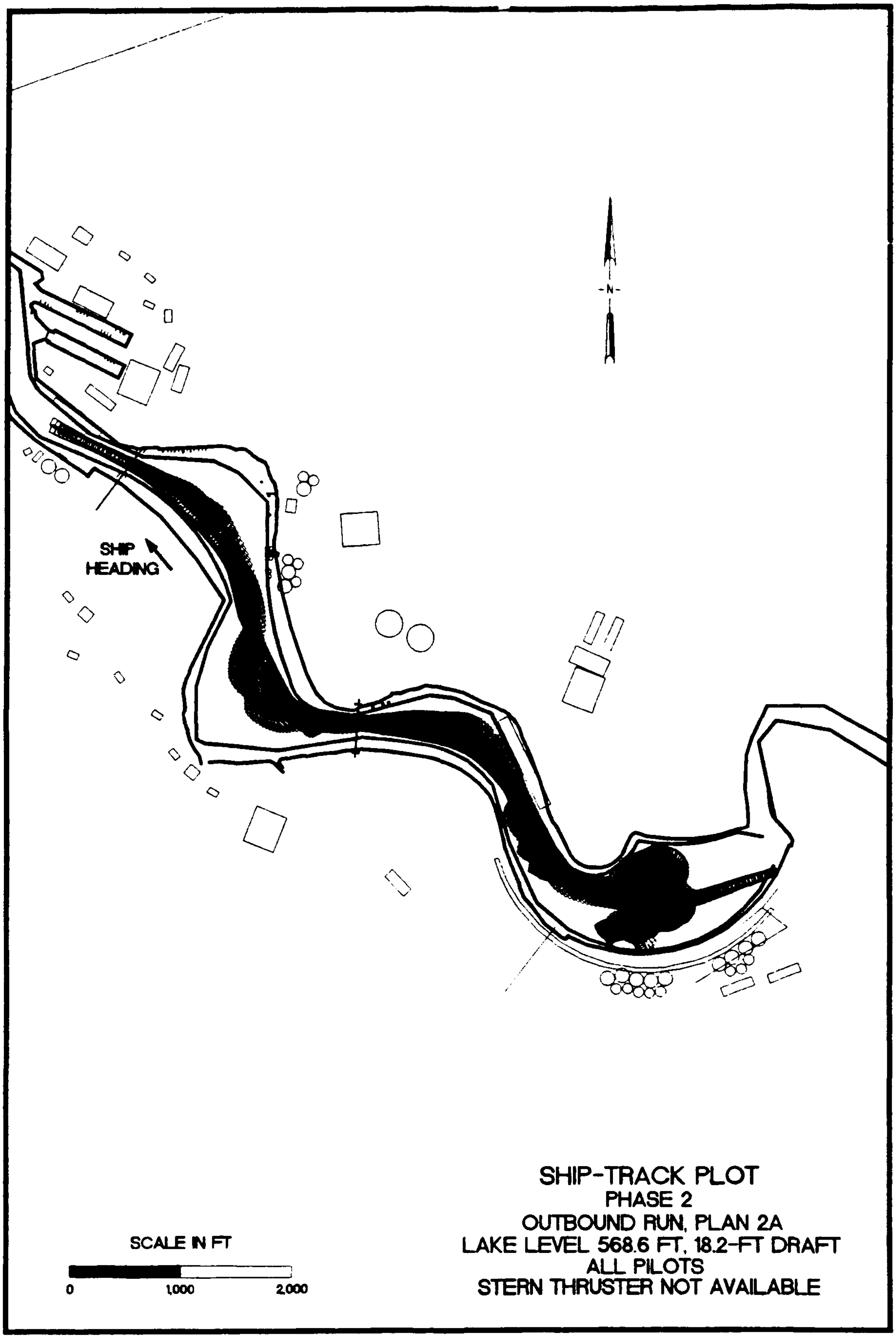


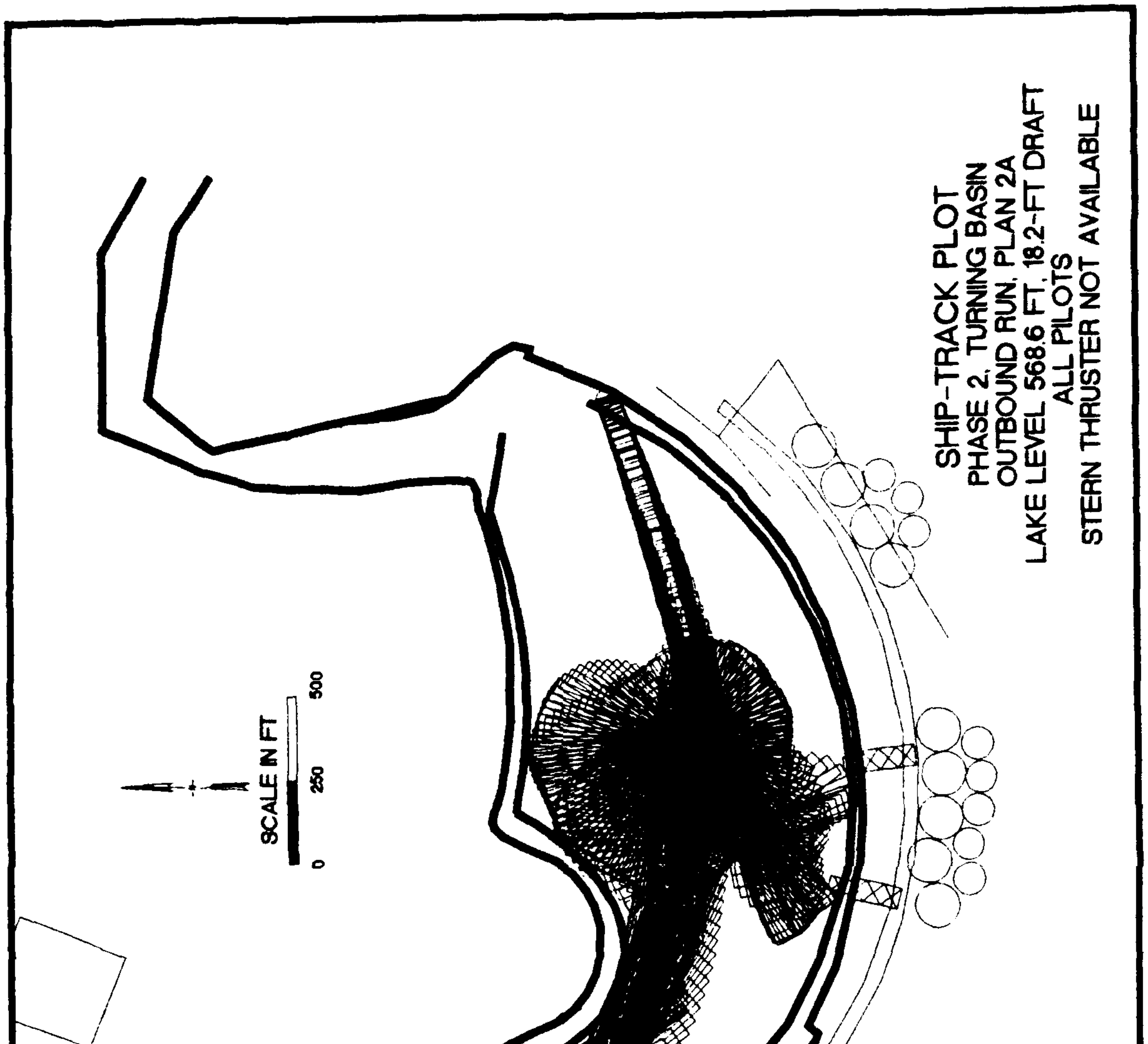
SHIP-TRACK PLOT
PHASE 2, TURNING BASIN
OUTBOUND RUN, PLAN 1
LAKE LEVEL 568.6 FT, 18.2-FT DRAFT
ALL PILOTS
STERN THRUSTER NOT AVAILABLE
SCALE IN FT
0 250 500
SHIP HEADING



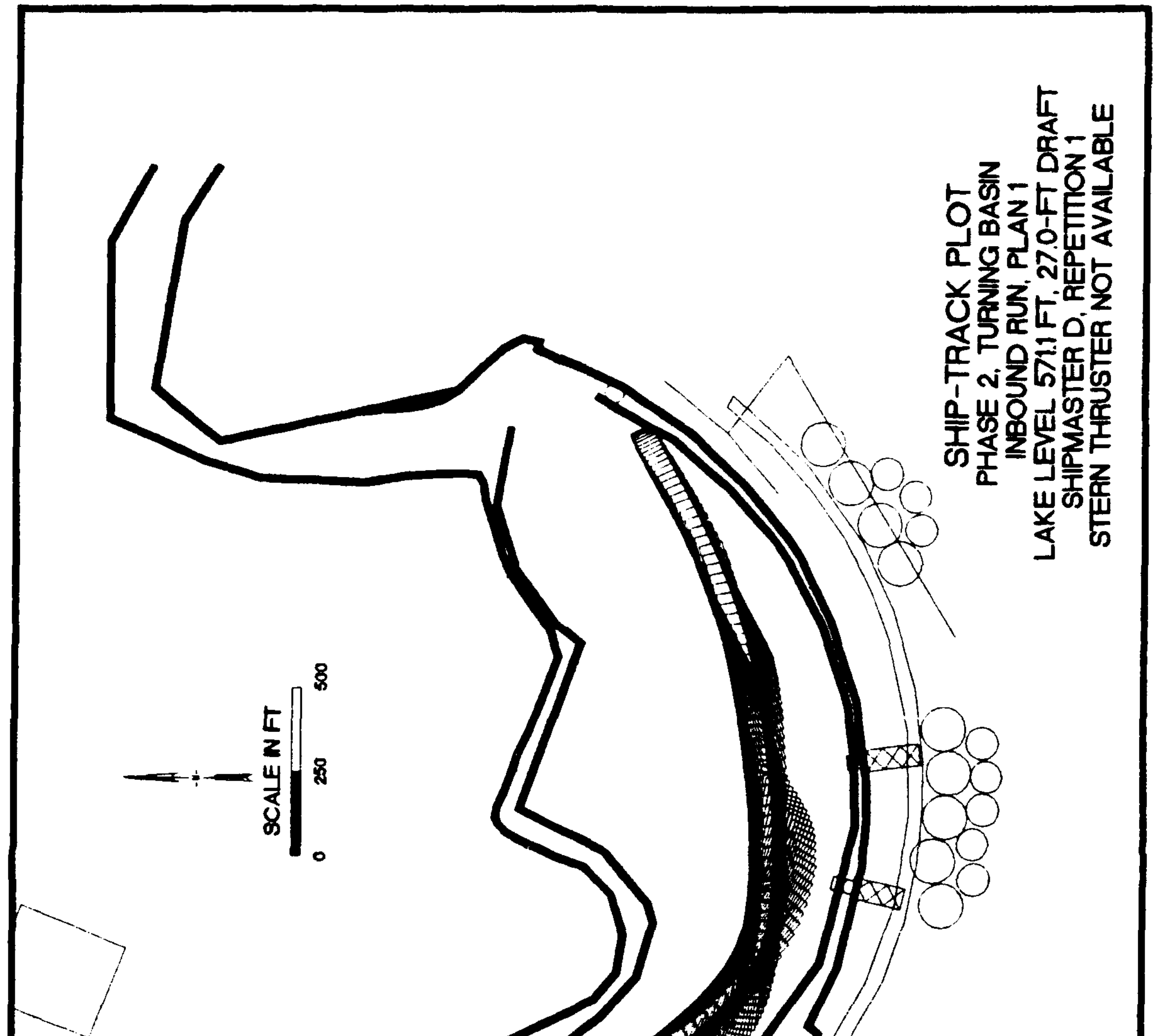
SHIP-TRACK PLOT
PHASE 2, CUTS B AND C
OUTBOUND RUN, PLAN 1
LAKE LEVEL 568.6 FT, 18.2-FT DRAFT
ALL PILOTS
STERN THRUSTER NOT AVAILABLE

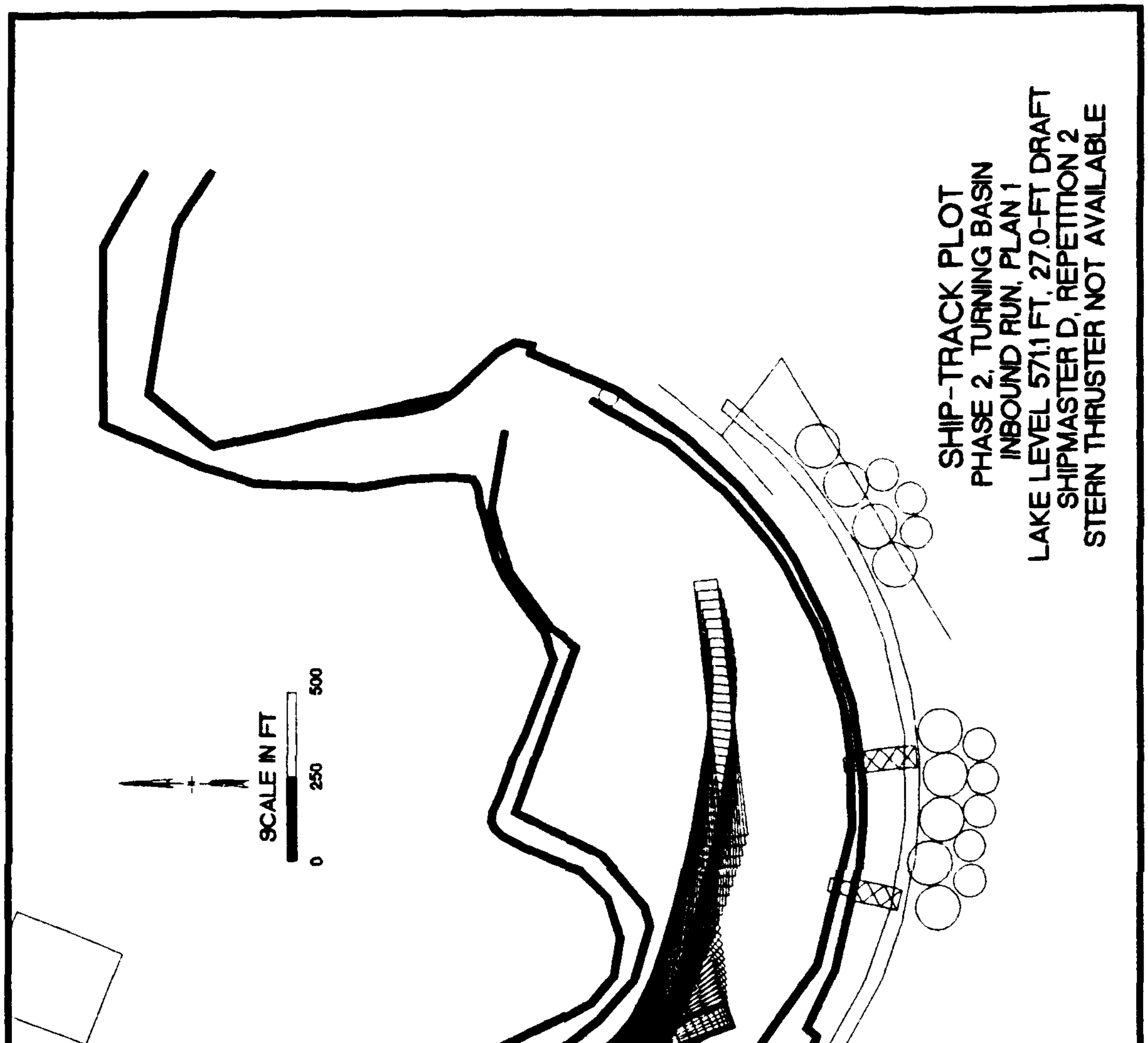
PLATE 104


SHIP HEADING
N
SHIP-TRACK PLOT
PHASE 2
OUTBOUND RUN, PLAN 2A
LAKE LEVEL 568.6 FT, 18.2-FT DRAFT
ALL PILOTS
STERN THRUSTER NOT AVAILABLE
SCALE IN FT
0
1,000
2,000

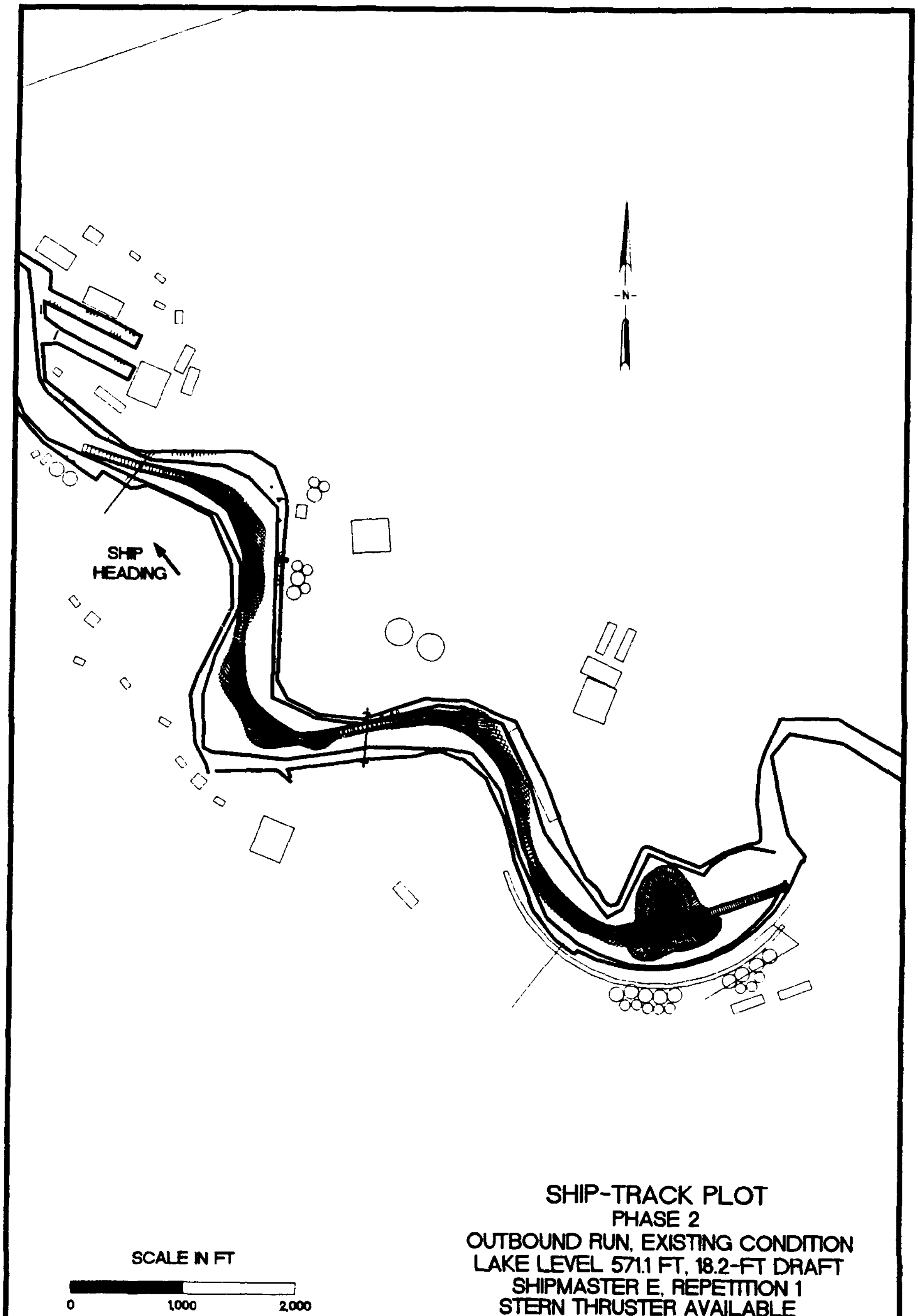


SHIP-TRACK PLOT
PHASE 2, TURNING BASIN
OUTBOUND RUN, PLAN 2A
LAKE LEVEL 568.6 FT, 18.2-FT DRAFT
ALL PILOTS
STERN THRUSTER NOT AVAILABLE


SHIP-TRACK PLOT
PHASE 2, TURNING BASIN
INBOUND RUN, PLAN 1
LAKE LEVEL 571.1 FT, 27.0-FT DRAFT
SHIPMASTER D, REPETITION 1
STERN THRUSTER NOT AVAILABLE
SCALE IN FT
0
250
500
SHIP HEADING
2,000 FT



SHIP-TRACK PLOT
PHASE 2, TURNING BASIN
INBOUND RUN, PLAN 1
LAKE LEVEL 571.1 FT, 27.0-FT DRAFT
SHIPMASTER D, REPETITION 2
STERN THRUSTER NOT AVAILABLE
SCALE IN FT
0
250
500
SHIP HEADING



SHIP-TRACK PLOT
PHASE 2
OUTBOUND RUN, EXISTING CONDITION
LAKE LEVEL 571.1 FT, 18.2-FT DRAFT
SHIPMASTER E, REPETITION 1
STERN THRUSTER AVAILABLE

REPORT DOCUMENTATION PAGE

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OMB No. 0704-0188

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	October 1993	Final report

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12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

A navigation investigation of the proposed channel improvements to Lorain Harbor, Lorain, OH, was conducted. The authorized project called for three bank cuts. The research consisted of a two-phase ship simulation study. The purpose of the ship simulation study was to test the proposed bank cuts and recommend design modifications that would allow safe and efficient use of the channel by the 767-ft vessels currently used in Lorain Harbor.

Two retired shipmasters from the USS Great Lakes Fleet (GLF) participated in Phase 1, which was designed as a low-cost study providing a rapid assessment of the proposed design changes and potential project benefits. The Phase 1 testing was conducted with three different channel designs: the existing channel, the authorized project, and a design suggested by a shipmaster who navigates the river. Each numerical model began at the lake approach channel and continued to the upper turning basin. Phase 1 raised questions about the transit time benefits of the study. Therefore, the testing was continued.

(Continued)

14. SUBJECT TERMS			15. NUMBER OF PAGES
Bank cut	Ship	Track plot	189
Channel	Shipmaster		16. PRICE CODE
Navigation	Simulation		

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED		

13. (CONCLUDED).

During Phase 2, the existing channel and the authorized project were tested. However, the channel design recommended by a shipmaster was changed to reflect the channel requirements based on Phase 1 results, referred to as Plan 2a. Since no benefits were demonstrated by bank cuts downstream of the Norfolk and Western Railroad Bridge, the Phase 2 tests began at this bridge instead of the outer harbor. During Phase 2, the existing channel model was verified by two shipmasters from USS GLF. Tests were run on the ship simulator in which four shipmasters from the Great Lakes conned the simulated ship through the three simulated channel conditions.

These tests showed that Plan 2a can be transited using a smooth and continuous motion in any of the conditions if the stern thruster is used. Maintaining a constant forward motion is safer than backing and filling as required in the existing condition. Backing decreases the control of the ship and increases risk to the propeller, rudder, and engine. Backing and filling also creates more chance of error due to the increase in number of operations. In addition, Plan 2a transit times remained within 3 minutes of the minimum transit time set by the maximum speed to navigate this channel. The other plans fluctuated two to three times as much.

Plan 2a was recommended.

Appendix A presents the shipmaster questionnaire and comments. Appendix B shows the track plot of each pilot's run.