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Coastal and Hydraulics Laboratory

US Army Corps of Engineers®
Engineer Research and Development Center

Port of Baltimore Navigation Simulation Study

Gary C. Lynch

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by Gary C. Lynch

Coastal and Hydraulics Laboratory
U.S. Army Engineer Research and Development Center
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Final report

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P.O. Box 1715
Baltimore, MD 21203-1715

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Preface

This navigation study was performed by the Coastal and Hydraulics Laboratory (CHL), U.S. Army Engineer and Development Center (ERDC), Vicksburg, MS, for the U.S. Army Engineer District, Baltimore (CENAB). The study was performed during the period September 1997 through mid 1998.

The investigation was conducted by Mr. Gary C. Lynch, with the assistance of Ms. Donna C. Derrick and Ms. Sally F. Harrison, Navigation Branch, CHL, under the direct supervision of Dr. Sandra K. Knight, Chief, Navigation Branch, CHL.

Acknowledgment is made to Messrs. Jeff McKee and Kevin Mainquist, CENAB, for cooperation and assistance. Special thanks is extended to the Maryland Pilots for their participation in the study and their hospitality and assistance during the reconnaissance trip.

At the time of publication of this report, the Director of ERDC was Dr. James R. Houston. The Commander of ERDC was COL James S. Weller, EN.

Conversion Factors, Non-SI to SI 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	4.046	square meters
degrees	0.0175	radians
feet	0.3048	meters
miles	1.609	kilometers
nautical miles	1.852	kilometers
square miles	2.589	square kilometers

1 Introduction

Background

The Port of Baltimore was established in 1706. It is one of America's busiest deep-water ports. It is situated in a sheltered harbor and is easily accessed by major American and foreign ports. Its 72-km (45-mile) shoreline supports many terminals for commercial trade, as well as public and private cargo terminals. It is located approximately 19 km (12 miles) northwest of the Chesapeake Bay on an 83-sq-km (32-square-mile) area of the Patapsco River, Figure 1. The Patapsco River originates near Westminster, Maryland, and flows southeasterly for 105 km (65 miles) to enter the Chesapeake Bay 15 km (9 miles) south of Fort McHenry.

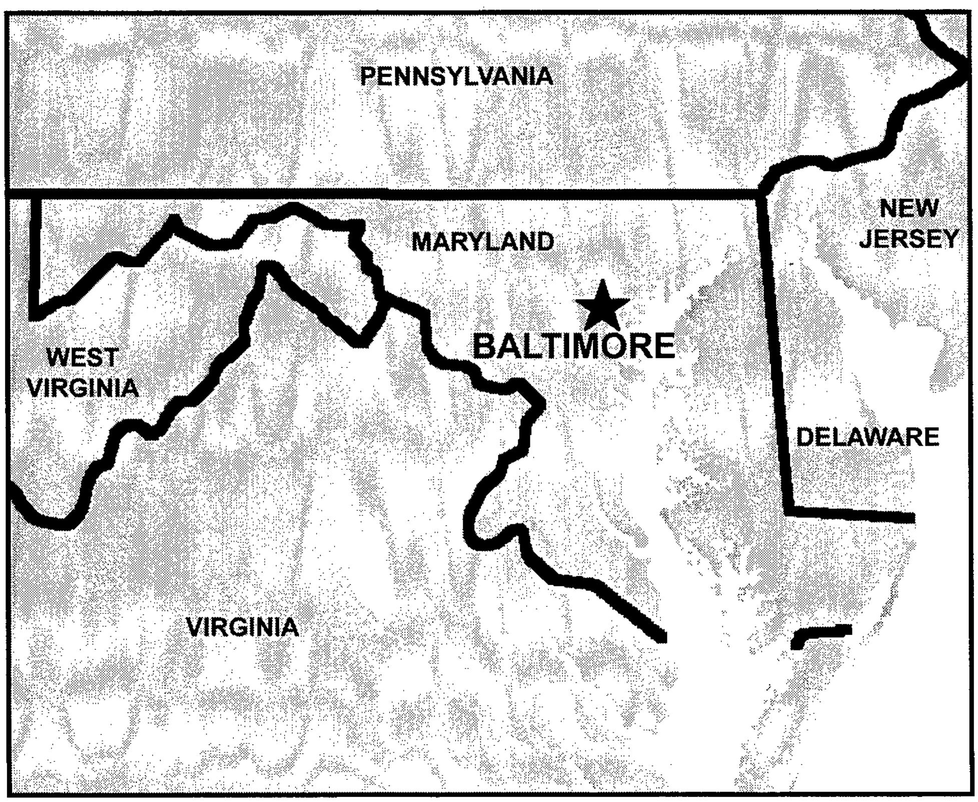


Figure 1. Project location map

The port may be reached from the Atlantic Ocean by traveling 209 km (113 nautical miles) west through the Delaware Bay, Chesapeake and Delaware (C&D) Canal, and the Chesapeake Bay or by traveling 276 km (150 nautical miles) north through the Virginia Capes and the Chesapeake Bay. The harbor area includes almost 6,474 sq km (1,600 acres) of sheltered waters. Figure 2 shows the Port of Baltimore.

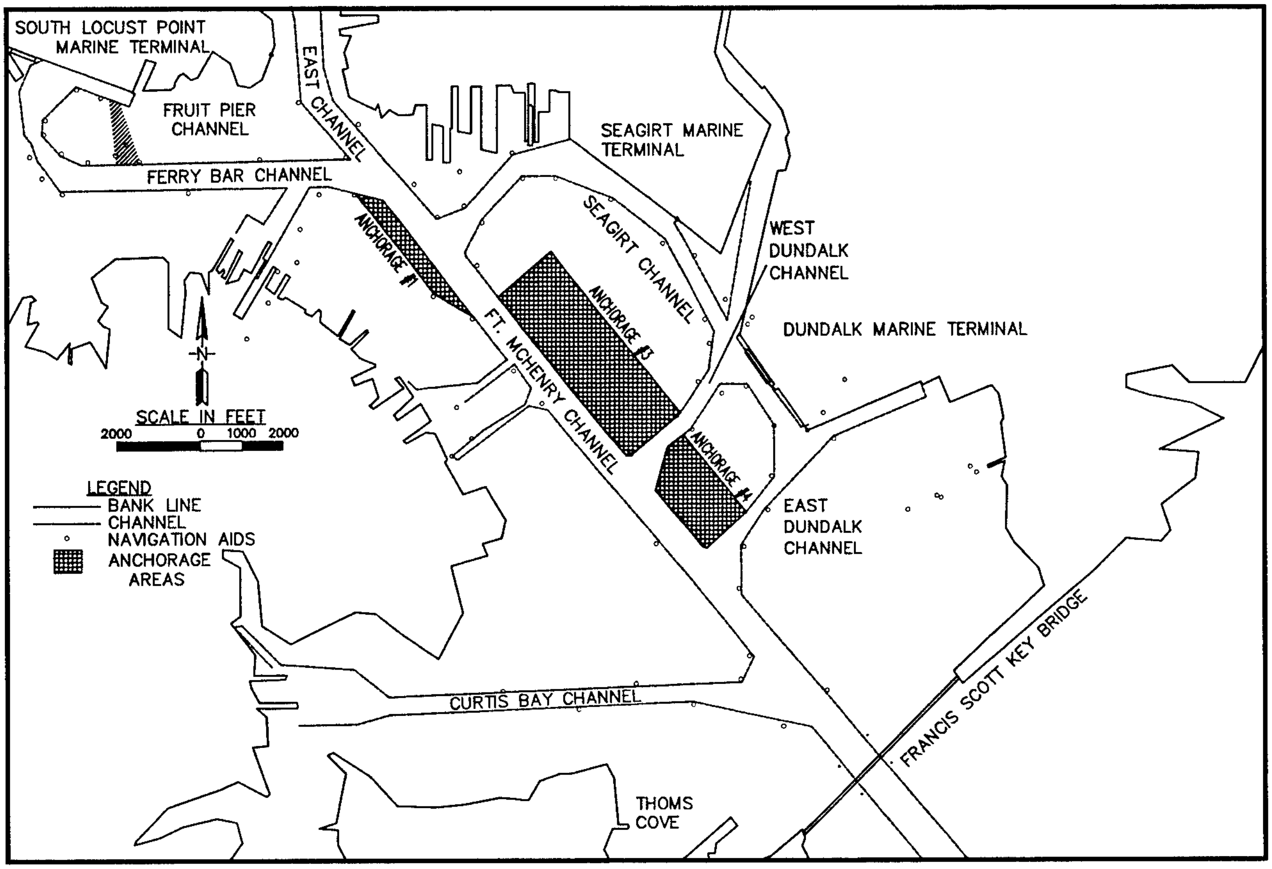


Figure 2. Port of Baltimore. (A table for converting non-SI units of measurement to SI (metric) can be found on page vi)

Vessels arrive and depart the Port of Baltimore via the southern Chesapeake Bay (Cape Henry) route or the northern Chesapeake Bay route through the C&D Canal. In October 1990, the main shipping channel from Cape Henry to Fort McHenry was dredged to a depth of 15 m (50 ft) as part of the Baltimore Harbor and Channels (15-m (50-ft)) project, which gave vessels with drafts up to 14 to 15 m (47 to 48 ft) access to the harbor. Ships using the C&D Canal must have a draft no greater than 10 m (33 ft).

Ships calling on the Port of Baltimore include containers, bulk carriers, car carriers, tankers, general cargo ships, ro-ro (roll on-roll off) ships, tugs, tug/barge combinations, and naval ships. Container business dominates the port, making it the third largest handler of containerized cargo on the Eastern seaboard.

Navigation Concerns

Increasing growth of the commercial trade in the Port of Baltimore has led to enlargement and improvement of the area. In 1990, the main shipping channel was deepened to 15 m (50 ft), allowing deeper-draft vessels to enter the port. In addition, new terminals were constructed, and public and private marine terminals were expanded.

U.S. Army Engineer District, Baltimore (CENAB), proposed a channel improvement project for Baltimore Harbor anchorage and channels in 1997. The proposed improvements involved widening of the East and West Dundalk Channels and the connecting channel, which joins the Seagirt and West Dundalk Channels. The South Locust Point Channel improvements would involve deepening and widening the Fruit Pier Channel. In addition, a proposed improvement involved construction of a 366-m-sq (1,200-ft-square) Turning Basin at the head of the Fort McHenry Channel to a depth of 15 m (50 ft). The improvements also include deepening and widening portions of Anchorages #3 and #4.

The problems facing pilots in the Dundalk/Seagirt terminal areas result from the narrowness of channel widths in the area. The west branch channel to the Seagirt Marine Terminal is 152 m (500 ft) wide by 13 m (42 ft) deep. The west branch channel to the Dundalk Marine Terminal and the connecting channel between Seagirt and Dundalk are 107 m (350 ft) wide by 13 m (42 ft) deep. The narrowness of the west branch channel to Dundalk and the connecting channel presents maneuvering problems to vessels, with potential hazards and increased maneuvering times. It was proposed that the west branch channel of Dundalk and the connecting channel be widened to 152 m (500 ft). This modification would allow for safe one-way movement of vessels by creating a consistent loop channel with efficient access to Seagirt and Dundalk terminals. The east branch channel to Dundalk is 91 m (300 ft) wide and 13 m (42 ft) deep. Navigational difficulties exist in this area as a result of the narrowness of the channel. It was proposed that the east branch channel to Dundalk be widened to 122 m (400 ft) to improve maneuverability.

The existing channel configuration in the South Locust Point Terminal area presents problems to larger ships. To exit the terminal, large vessels must be maneuvered by tugs in the turning basin and depart through the maintained channel section. These conditions are not time or cost efficient. At present, shallow-draft vessels exit the terminal via the Fruit Pier Channel, requiring no turning or assistance from tugs. It was proposed that this existing old channel be widened to 122 m (400 ft) with extra widening at the bends and entrances and deepened to a uniform depth of 11 m (36 ft). This modification would result in a usable, loop channel, 11 m (36 ft) deep, for all vessels coming to port and eliminate the need for turning exiting larger ships.

The Anchorage #1 (Fort McHenry Anchorage) area at the intersection of the Fort McHenry Channel and the Ferry Bar Channel is often used to turn vessels backing out of the berth at Consolidation Coal Sales Company pier. With a depth of 11 m (35 ft), the anchorage is too shallow for large ships; therefore, deep-draft ships are required to negotiate turns in the main channel outside the anchorage.

Because of the restricted area, turning a large vessel requires full tug assistance and takes a significant amount of time. In addition, pilots have reported potentially dangerous conditions during these maneuvers, and deep-draft vessels have been damaged by backing into the Anchorage. It was proposed that a 366-m- (1,200-ft-) wide, 15-m- (50-ft-) deep turning basin be constructed at the head of the Fort McHenry Channel. The turning basin would include the north section of Anchorage #1. This modification would require deepening of the anchorage area included in the turning basin design. The increased depth within the anchorage would improve the efficiency and safety of turning operations at this location.

2 Simulation

Simulation Database Generation

Required data

Data required for a simulation study includes channel layout, bottom topography (bathymetry), channel currents, design ships, and the visual database for each of the Base and Plan Conditions. The method for developing each of these is described below.

Visual scene

The creation of the visual scene database for Baltimore Harbor was mainly derived from navigation charts and from aerial photographs supplied by the CENAB. Modification to these main sources of information was aided by using video and still photos taken during a ship transit and harbor tour with the Association of Maryland Pilots. Employees of the U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL), participated in this reconnaissance trip. The reconnaissance trip was also used to document pilot comments on different areas of the channel while in transit. During this trip, a general understanding of the study area was obtained and used along with the data to prepare the simulation prior to validation by the pilots. Revisions were also made based on the pilots' comments during the validation. Bank line configuration, buildings, docks, and other landside features were defined in X, Y, and Z coordinates. These features were then preprocessed for input into the Silicon Graphics Onyx, which generated the visual scene for the harbor. The visual scene was displayed on three large screens per simulator with one-way traffic runs. The simulator setup at the time of this project is shown in Figure 3. Although two-way traffic was not employed for this simulation, both simulators were used for concurrent experimentation.

Radar scene and tugboats

The radar file was created from the digitized bank line of Baltimore Harbor created for the visual scene database. The radar database contains information available from the true radar readout of a ship, but the database image, Figure 4, is much clearer than the radar display of a typical ship to counteract the loss of depth

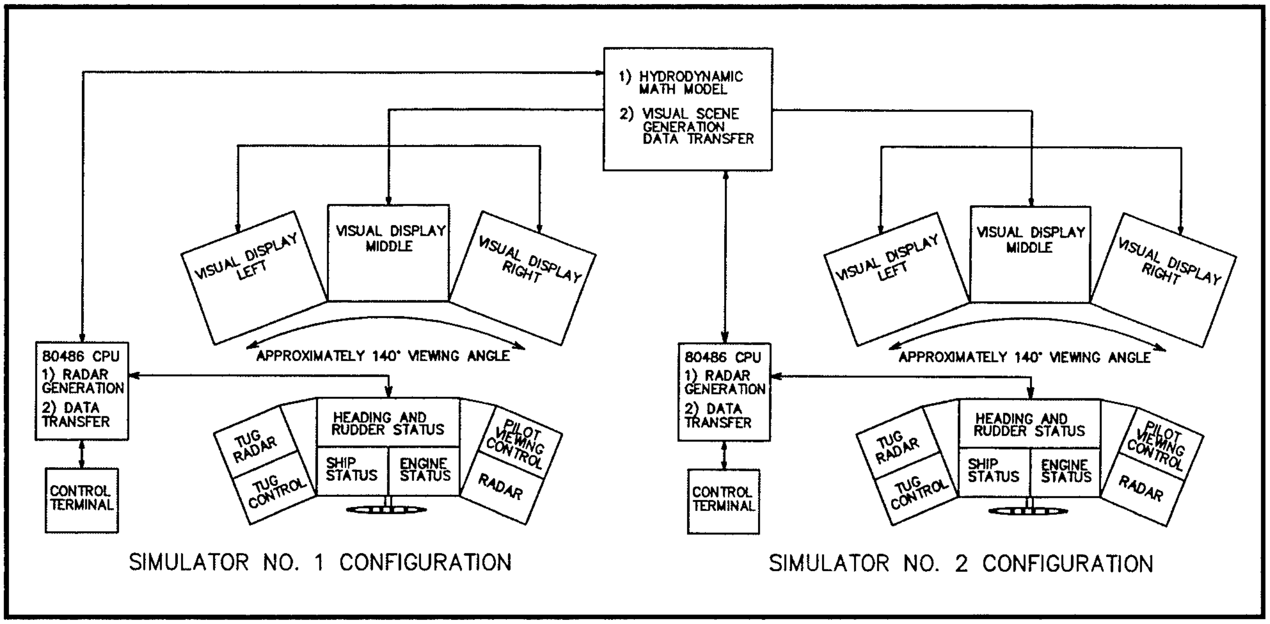


Figure 3. Ship/Tow simulator configuration

perception from the use of two-dimensional visuals. For this study, four radar ranges were available. A one-quarter-mile-range screen was visible at all times. The other radar screen used was adjustable between 1.2-, 2.4-, and 4.8-km (0.75-, 1.50-, and 3.00-mile) ranges.

The 0.40-km (0.25-mile) radar range screen also displayed data about the use of tugboats for maneuvering. A vector on the screen, Figure 5, showed tug placement, heading, and engine setting. The pilots were asked to use tugs as they would in the harbor. Tugboat settings were verified to act as a typical tugboat available in Baltimore Harbor (a horsepower rating of 3,000). Most pilots used no more than two tugs during an experiment and were allowed to reposition the tug during the run. The time used for repositioning the tug and getting it set up again was based upon the pilot's experience and what type of maneuvering was required by the tug.

Channel database

The channel database was generated from a TABS-MD hydrodynamic study that had been completed at ERDC for the Brewerton Channel Eastern Extension and Tolchester Channels Study in 1996. Currents for an entire Spring Tidal Cycle were calculated. Preliminary analysis showed current magnitudes less than 0.15 m (0.5 ft/sec), so postproject conditions were not calculated separately. The channel database contains the channel bathymetry, current magnitude and direction, and any pertinent environmental data such as wind or waves.

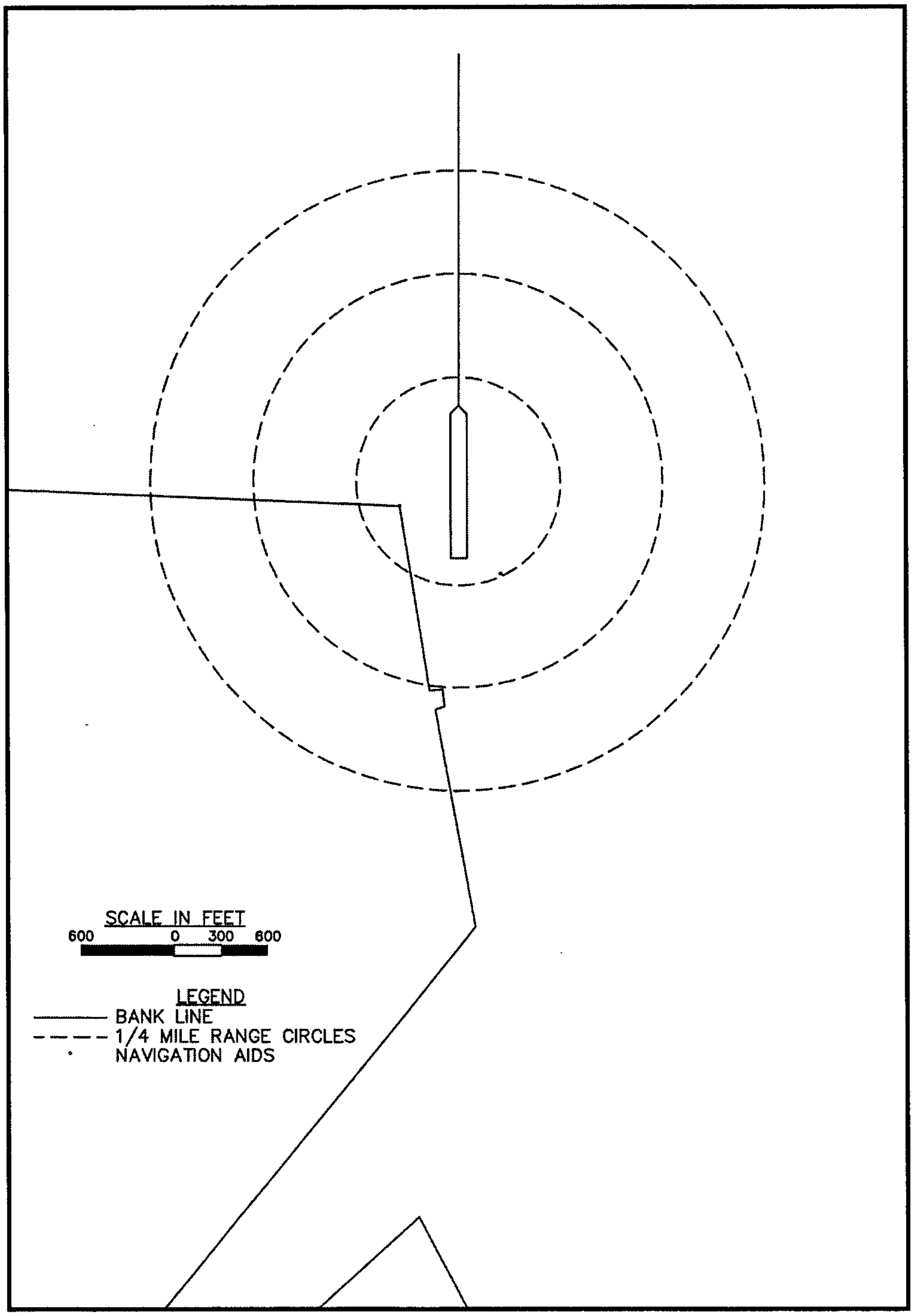


Figure 4. Variable range radar image

Ship files

The following two ships were used for the simulation exercise:

a. A bulk carrier, 302-m (990-ft) length overall (LOA) × 48-m (156-ft) beam (B) × 13-m (44-ft) draft.

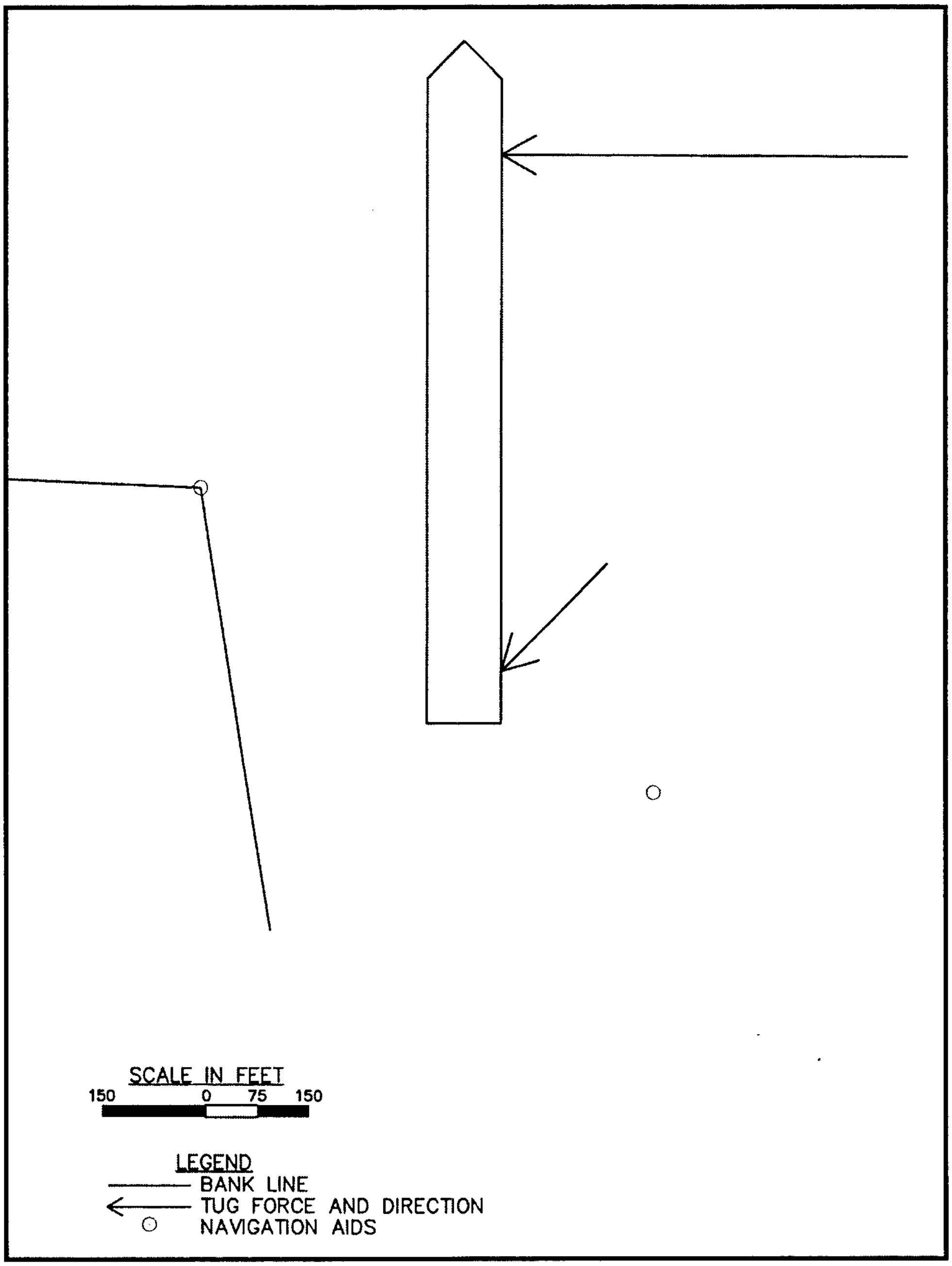


Figure 5. One-quarter-mile radar screen with tug visual

b. A containership, 294-m (965-ft) LOA × 32-m (106-ft) B × 12-m (39-ft) draft.

Each of these ships had been previously verified on several other projects performed by the CHL Ship/Tow Simulator, but some changes were made for this study. The most notable changes were the handling characteristics of the ships at slow speeds (less than 1 knot). The maneuvering performed during this study used assist tugs and slow speeds because of the docking procedures.

Though a helmsman would normally perform the commands given by the pilot during a transit in the harbor, ship handling was accomplished by the pilot during simulation. This is typically the case in the simulation experiments performed at CHL. The demands placed upon the pilot are considerable, adapting to new and existing channel configurations, rapidly changing ships, and long hours of intense concentration. Having the pilot perform the ship handling eliminates the possibility of the helmsman's confusing instructions during the experiment.

Simulation Program

The existing channel and the District supplied the plans that are shown in Figures 6 through 15.

The simulation program consisted of three stages: a) validation, b) testing, and c) presentation of results. During validation, two pilots licensed for Baltimore Harbor came to the CHL Ship/Tow Simulator and simulated transits in the existing harbor for 1 week. During this stage, any problems are worked out with the simulation of the project, such as missing objects in the visual scene, problems with ship handling that would not be experienced in the prototype harbor, bank effects, wind, currents, etc. After any discrepancies were addressed and/or corrected, the simulated harbor was considered as close to the prototype as CHL, the District, and the pilots felt was possible.

Stage 2 for this project involved six licensed pilots, sent in groups of two for 1 week at a time. During the testing, the existing channel conditions and proposed design considerations were run in random order (see Table 1 for a full list of runs tested). The existing channel was used as the base to compare with the results of the proposed design runs.

Both existing and design runs were tested using the spring maximum flood and ebb tides during the first week of testing. However, it was determined with the pilots and the District office that the current magnitude and direction change between the two tidal conditions were insignificant. All remaining experiments were conducted with a flood tide only. Where applicable, inbound and outbound maneuvers were tested.

During the third week of testing, it became apparent that the planned channel at South Locust Point shown in Figure 12, currently known as the Fruit Pier Channel, did not allow ample room for the ship to maneuver into the dock. With input from the pilots and the District office, a modified, slightly widened configuration was designed to be studied (Figure 13).

Stage 3, the results, are presented as track plots in Plates 1 through 22. Output from each simulation run (taken at 5-sec intervals) was collected over the entire schedule of experiments and included the ship's speed, heading, rpm, rudder angle, rate-of-turn, tug usage, and port and starboard clearance to the toe of the channel. The track plots shown in the plates are a representation of the ship's path during the test. Each ship icon indicates the ship's location and heading at approximately 1-min intervals. The rudder displayed on each ship icon is correct

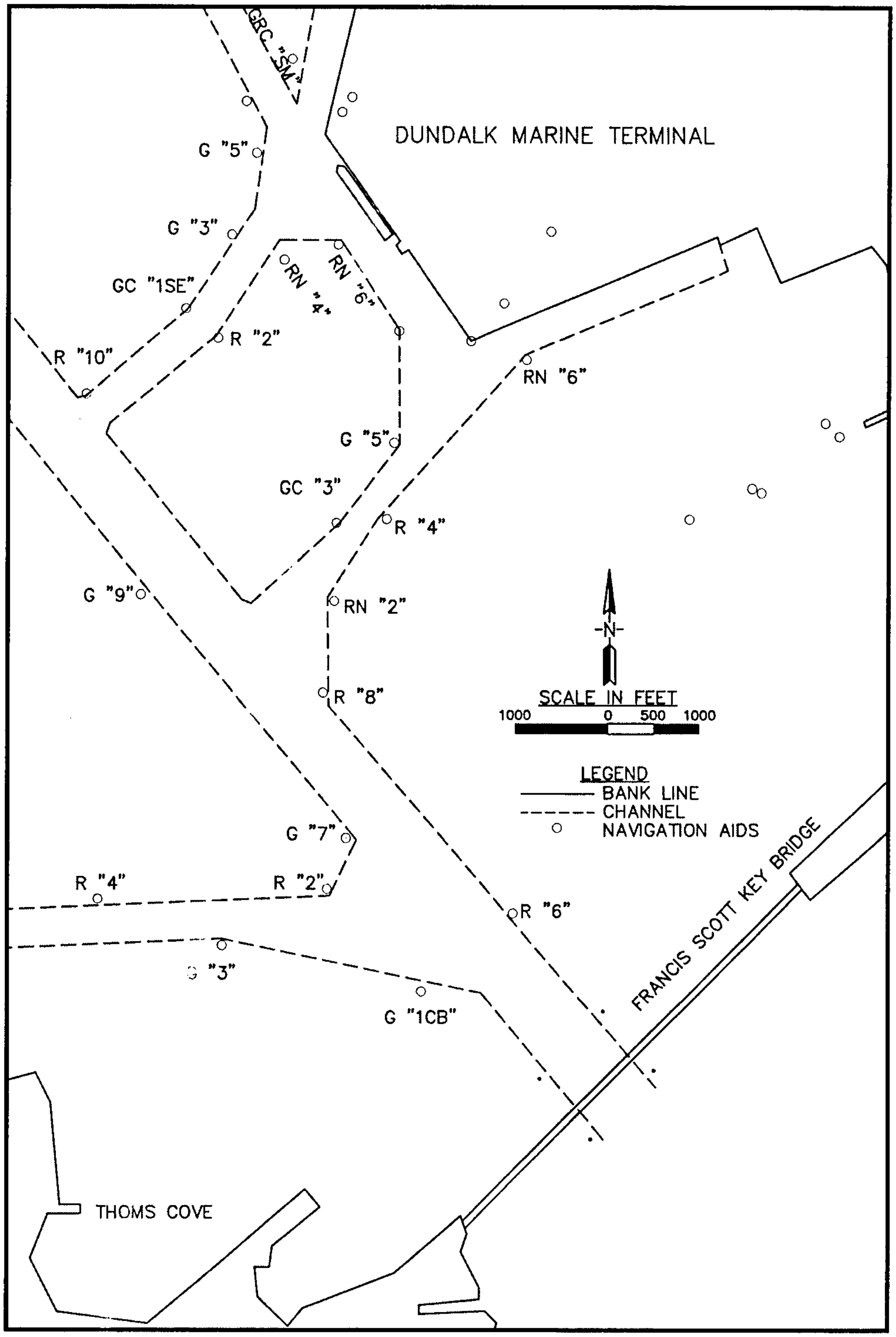


Figure 6. Dundalk Terminal existing conditions

for that point in time for the transit; however, it quickly becomes difficult to distinguish between the rudder and the ensuing ship icons. Because of the slow speeds and the tug usage, the rudder angle is not as important for these results as it might be for other projects. Transit time is always a factor for the ships; the difference in time that the plan changes make are also shown in the results.

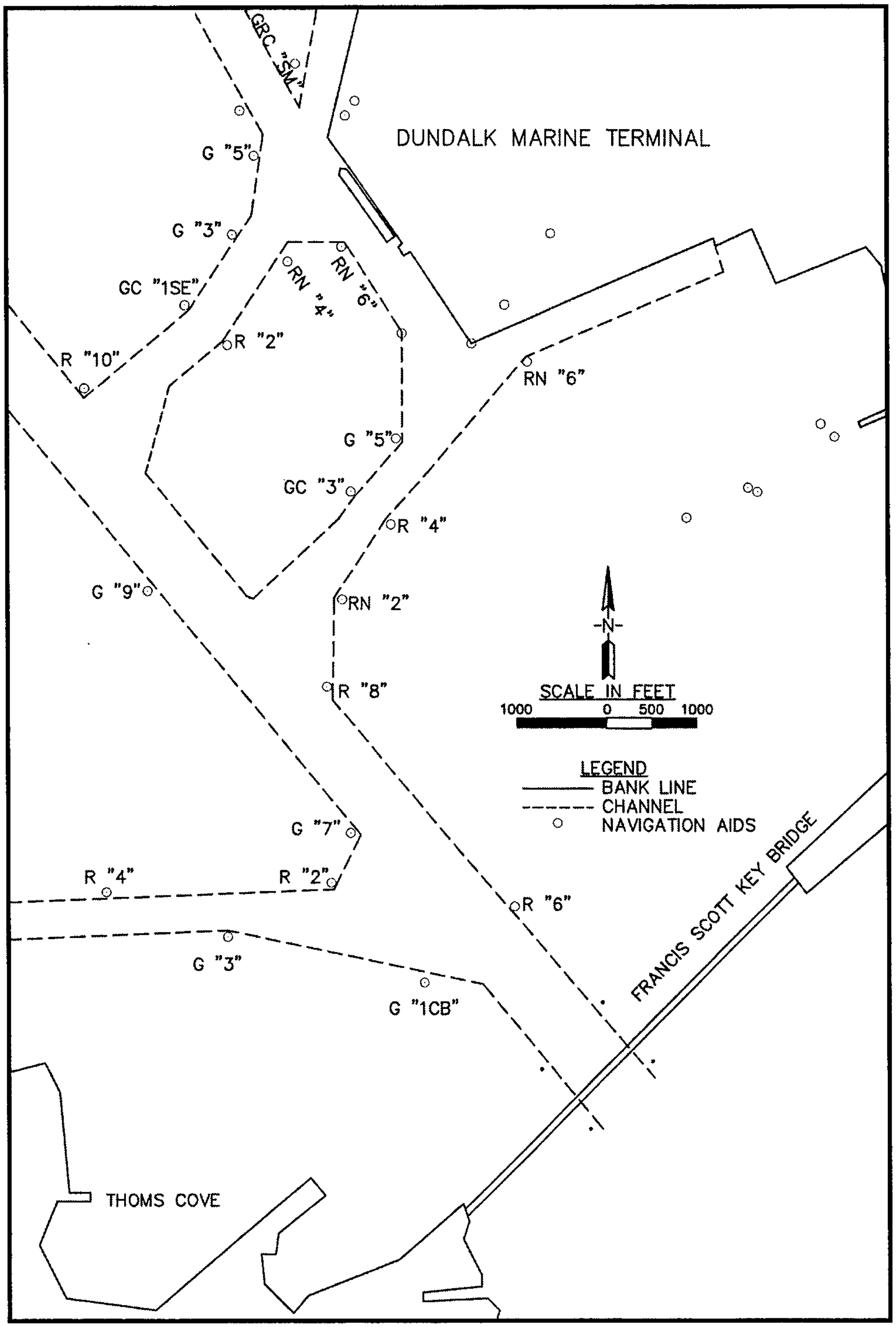


Figure 7. Dundalk Terminal plan conditions

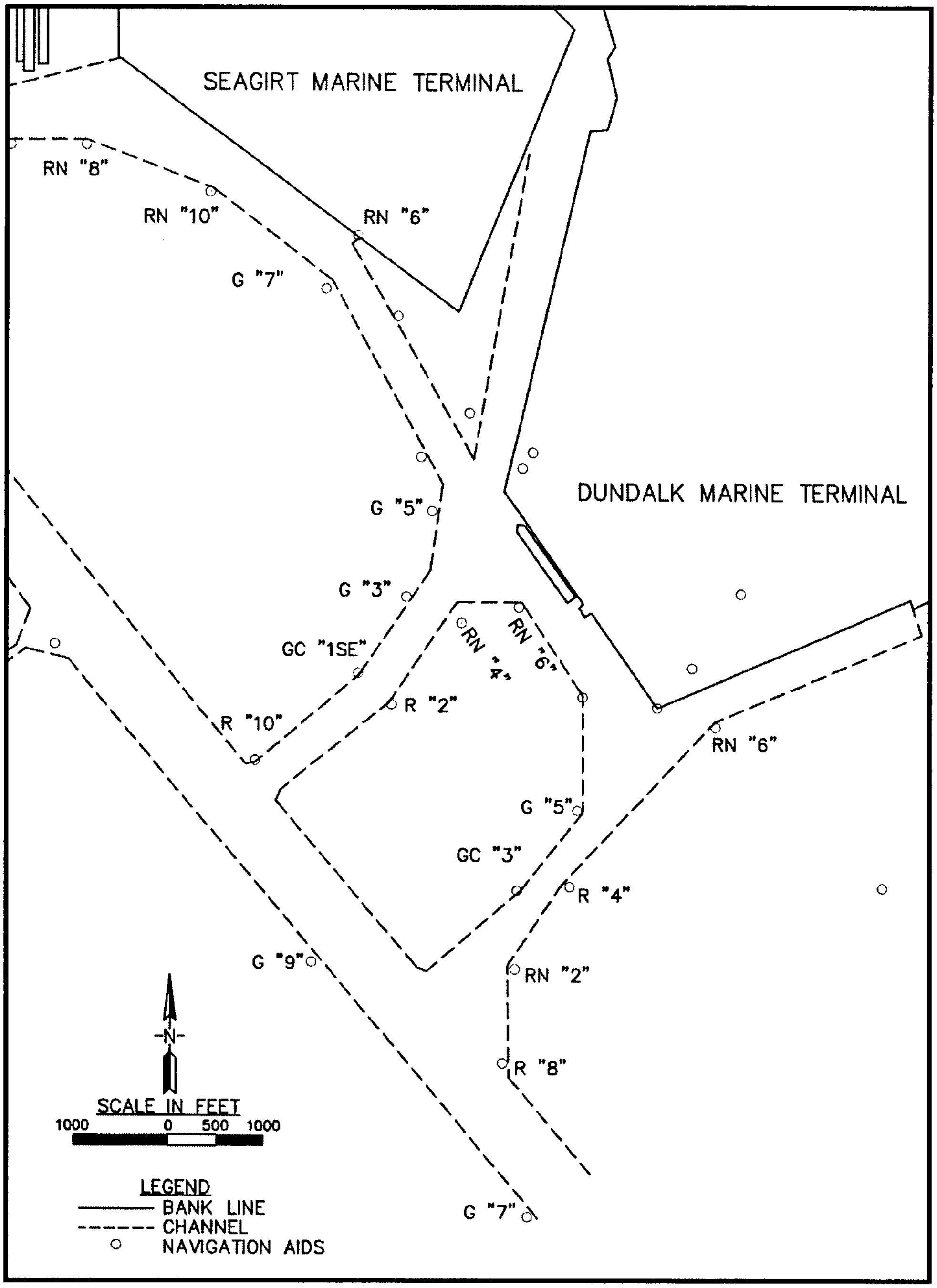


Figure 8. Seagirt Terminal existing conditions

Simulation Results

The results of the navigation study will be shown by the areas of interest within the Port of Baltimore. These areas are: a) Dundalk Channel, b) Seagirt Channel, c) South Locust Point, and d) Fort McHenry Turning Basin. Plates representing the existing channel and suggested plan channels will be discussed for each area, respectively. Since the ebb tide condition was discontinued, those

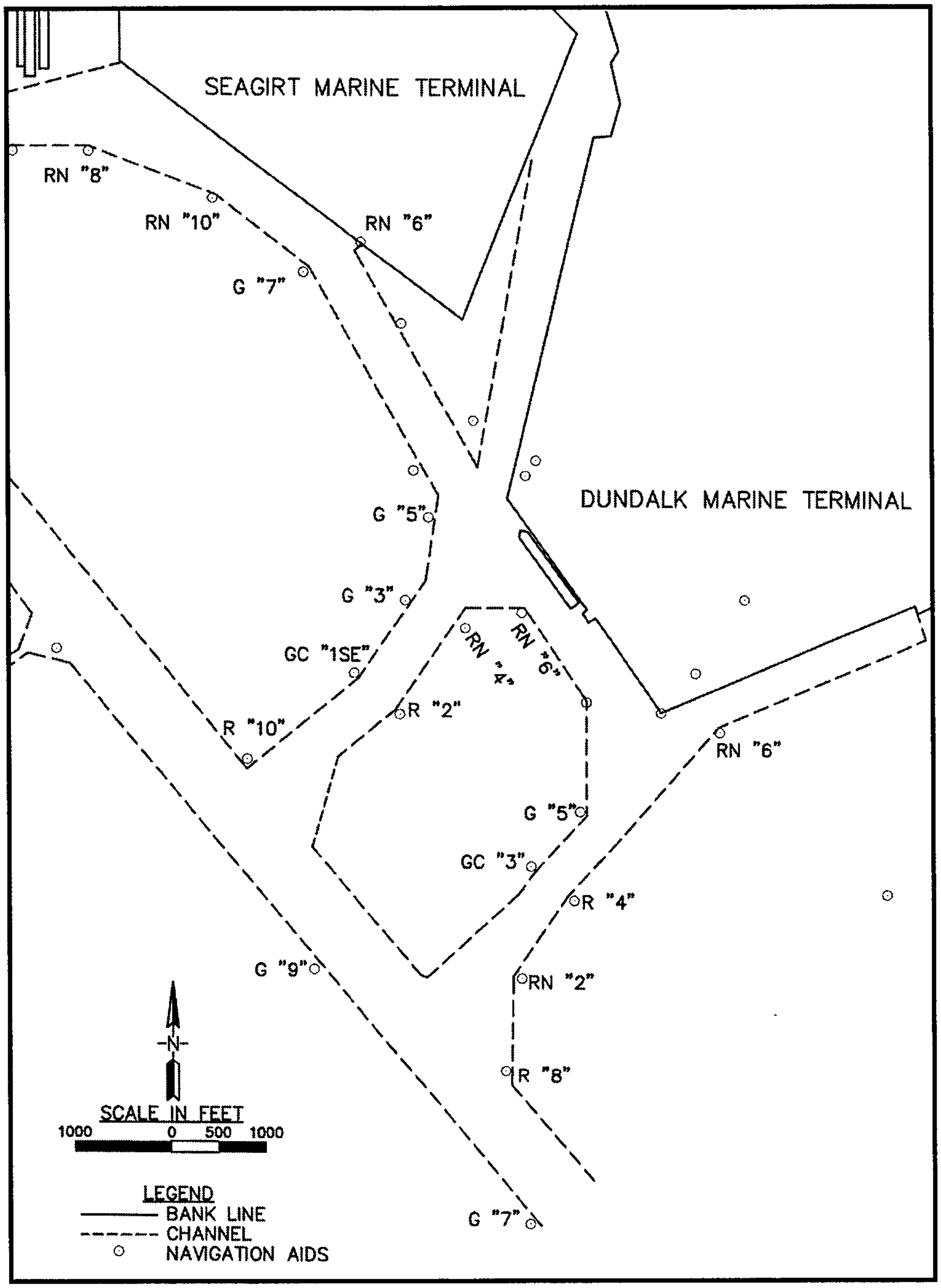


Figure 9. Seagirt Terminal plan conditions (Scenario 1)

results will be incorporated into the flood tide results, and the two will be discussed as one condition.

Dundalk - Scenario 1

Dundalk Scenario 1 inbound existing and plan tests, Plates 1 and 2, began just inside the Francis Scott Key Bridge, continued up the East Dundalk Channel, and

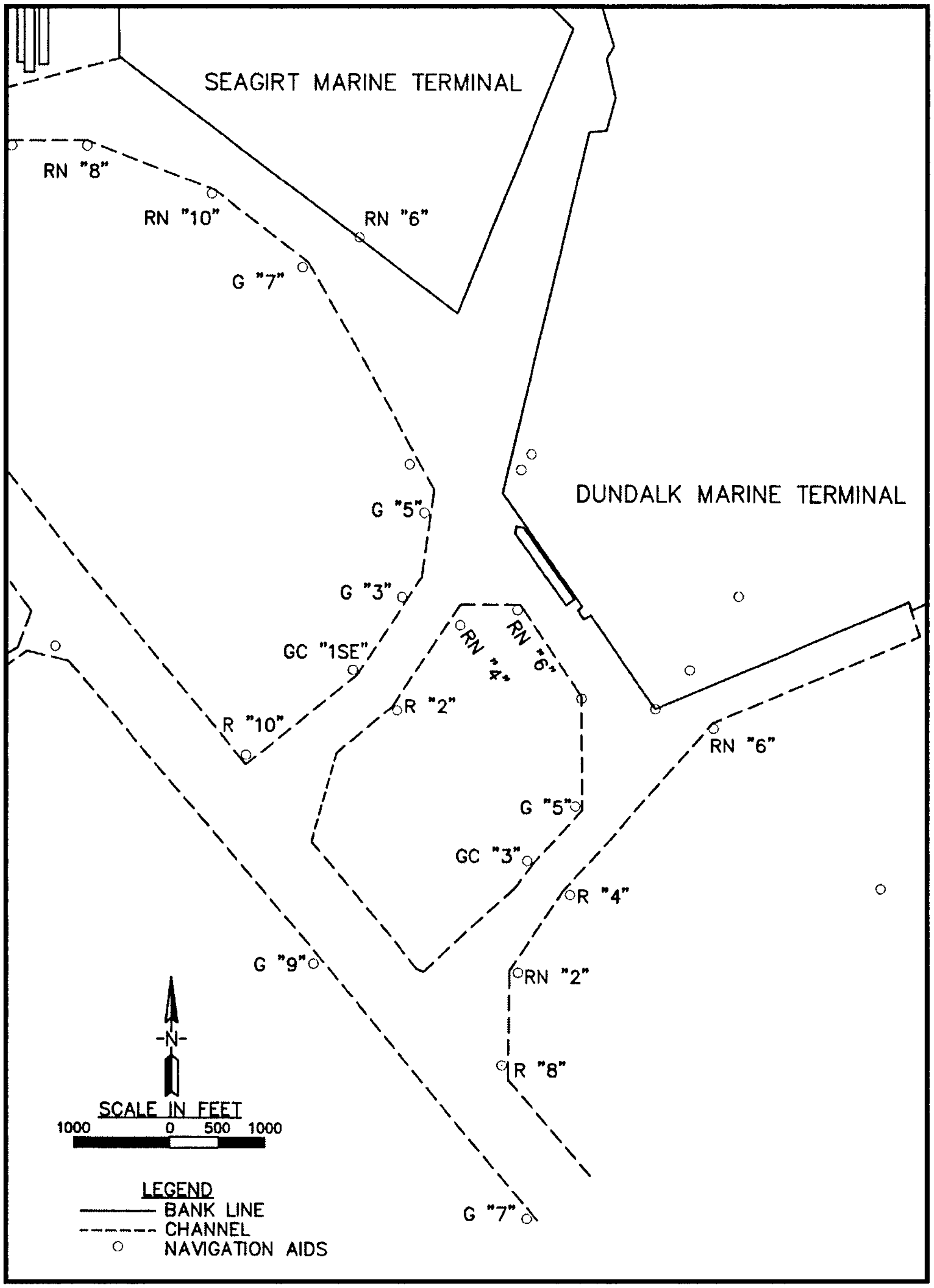


Figure 10. Seagirt Terminal plan conditions (Scenario 2)

ended at the Dundalk slip. Note the encroachment of the vessel on the channel up from "R 4" in the existing conditions, Plate 1. The vessels went outside of the channel by about 41 m (135 ft). As seen in Plate 2, the widening in the plan design alleviated this problem.

The outbound experiments, Plates 3 and 4, reverse the above transit. The vessels start out by backing from the dock and then turning at the head of East Dundalk Channel before continuing outbound to the bridge. Although the

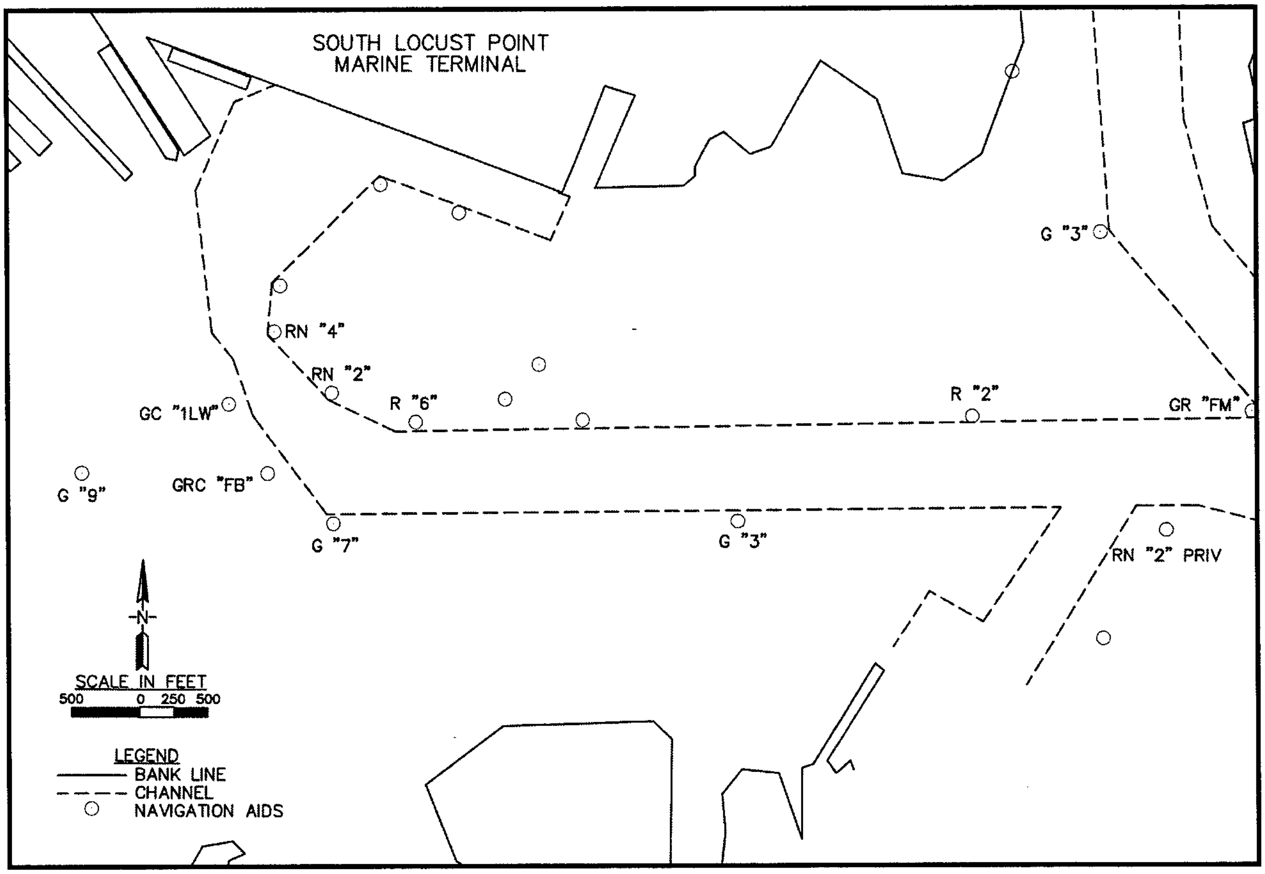


Figure 11. South Locust Point existing conditions

existing track lines in Plate 3 did come closer to the eastern-most channel line than the plan track lines, there were no significant problems with this outbound scenario.

Figure 16 shows the ending point of the average distance traveled by the vessels during testing for the East Dundalk Channel before docking maneuvers begin. This reference point was selected by picking an area a short distance away from the initiation of docking maneuvers and examining the output file to see which condition, existing or plan, had an elapsed time shorter than the other. It was important to select an area outside of docking, because each pilot handles docking differently, and no time constraints are placed upon the pilot that would make the total transit time for each experiment comparable. Once the reference point and the shortest elapsed time were found, (in this case the plan condition), one pilot was chosen to find the corresponding points in the other condition (in this case, the existing condition). Only one pilot's trackplot was chosen to minimize the error induced because of the pilot's different approaches to the channel. The figure shows the two transit positions for the vessels. For Figure 16, the distance between the existing and plan vessel is approximately 488 m (1,600 ft). This translates into a time reduction of about 14 min if a comparison speed of 1.5 knots is assumed.

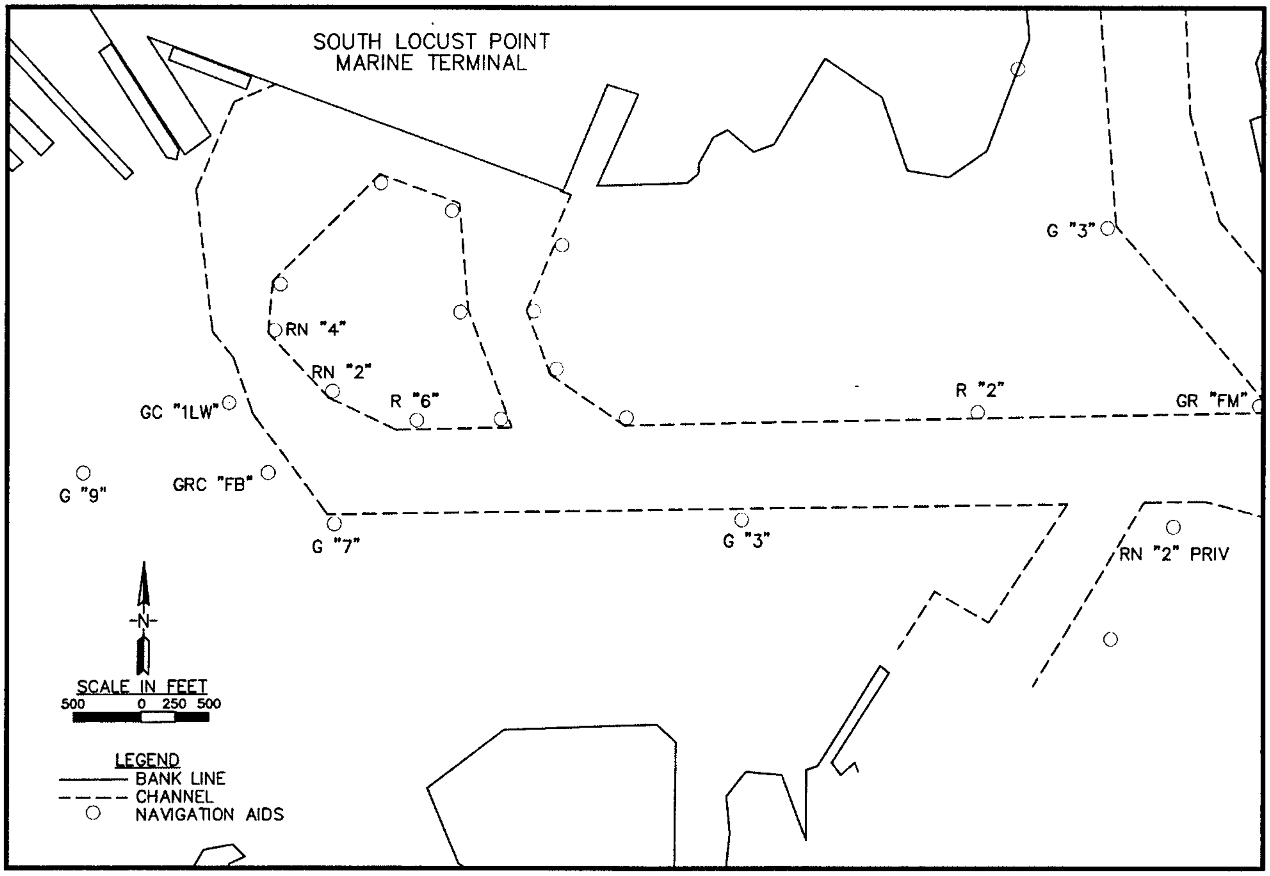


Figure 12. South Locust Point plan conditions

Dundalk - Scenario 2

Dundalk Scenario 2 inbound experiments, Plates 5 and 6, also began just inside the Francis Scott Key Bridge, continued up the East Dundalk Channel, but ended at the western Dundalk slip.

The outbound experiments, Plates 7 and 8, started at the western Dundalk slip, and turned down the West Dundalk Channel. No major problems existed in either of these sets of track plots; however, once again there was a slight decrease in the maneuvering required in the planned channel that created a reduction in transit time, shown in Figure 17, of about 14 min (about the same as Scenario 1).

Seagirt - Scenario 1

Plates 9 through 12 show the inbound and outbound transits for Scenario 1, which started at the Francis Scott Key Bridge and ended alongside Seagirt Marine Terminal. None of these experiments showed any significant navigation problems. Although the ships do cut across part of the anchorage just before "R 2," this area is already deep and therefore not a problem. Figure 18 shows a slight advantage in transit time for the inbound transits in the planned channel, about 6 min.

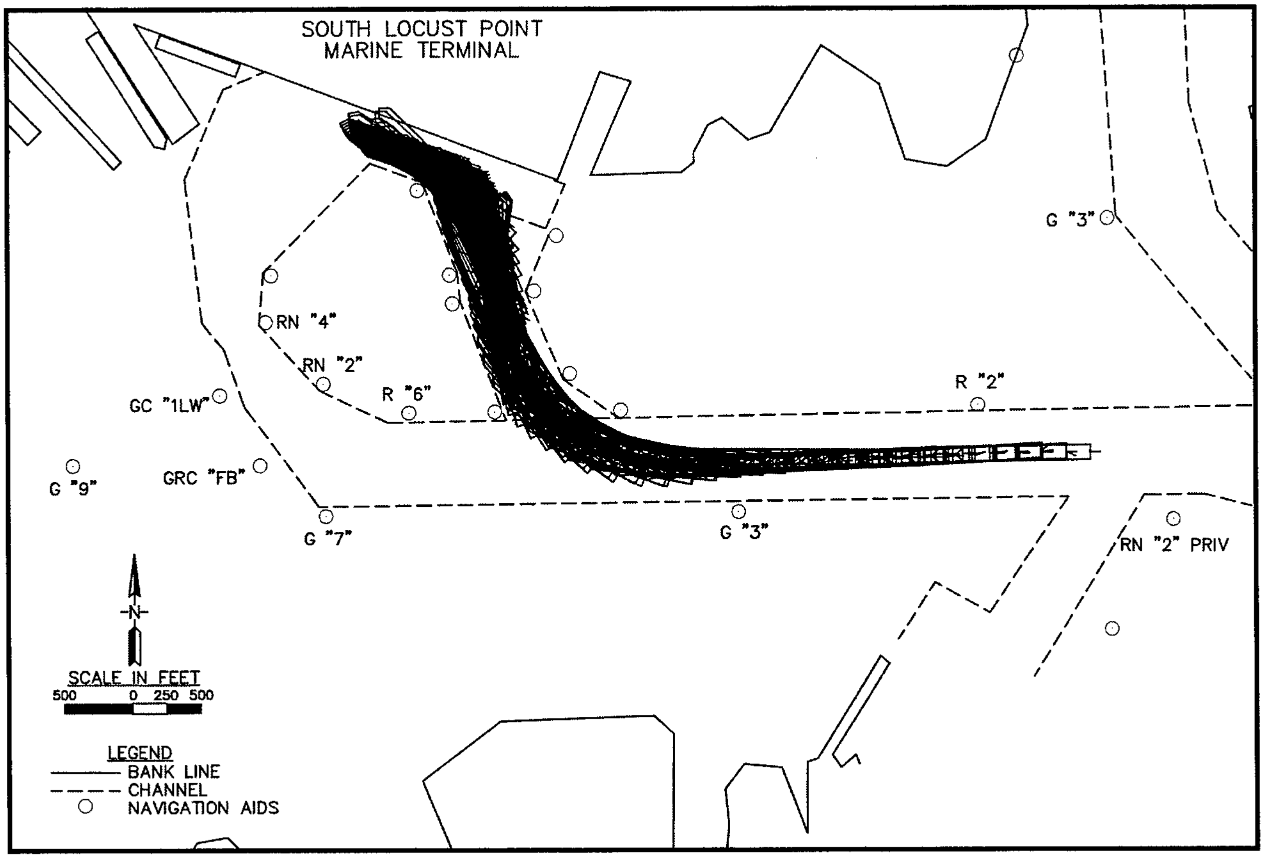


Figure 13. South Locust Point modified plan conditions

Seagirt - Scenario 2

Plate 13 shows the inbound transits for Scenario 2. There is no existing condition plate, because this widened area does not exist currently. There were no problems encountered in these sets of experiments. No outbound runs were performed for this condition because it so closely resembles the outbound Seagirt – Scenario 1.

South Locust Point

Transits into South Locust Point using existing conditions are shown in Plate 14. Normal operation for this terminal involves turning the ship to port and backing to the dock. This maneuver is time consuming but will allow the vessel to exit the dock more smoothly (Plate 15). Plates 16 and 17 show the inbound transits for the South Locust plan conditions. With the Fruit Pier Channel deepened and marked, the vessel can simply pull into the terminal port side to Plate 16 or starboard side to Plate 17.

Plate 18 shows outbound plan condition transits. These track plots exhibit some difficulty in maneuvering the Fruit Pier Channel. After discussions with the pilots and the District office, a modified South Locust Point Channel (Figure 13) was developed. Plates 19 and 20 show the inbound and outbound experiments

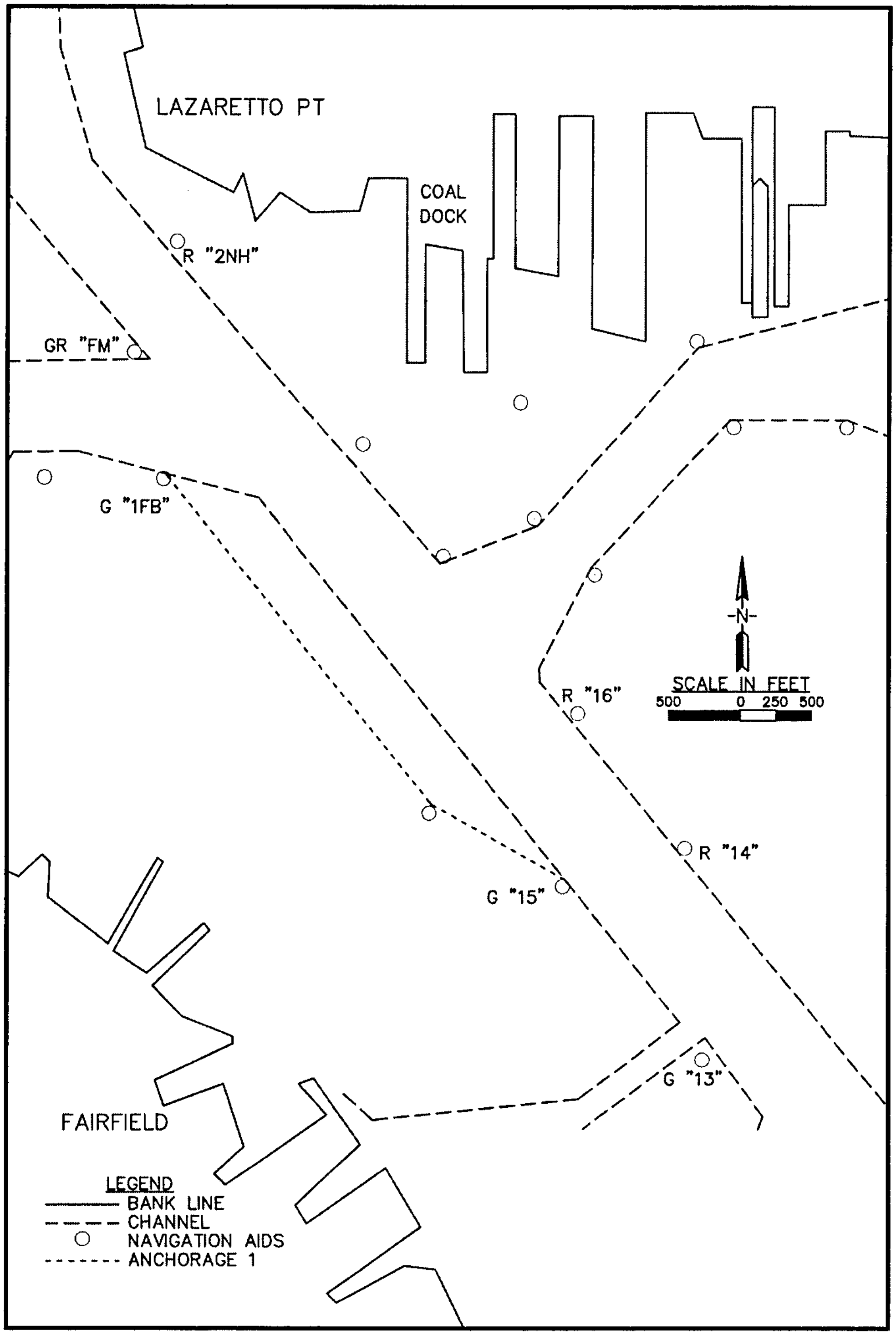


Figure 14. Ft. McHenry Channel and Anchorage #1 existing conditions

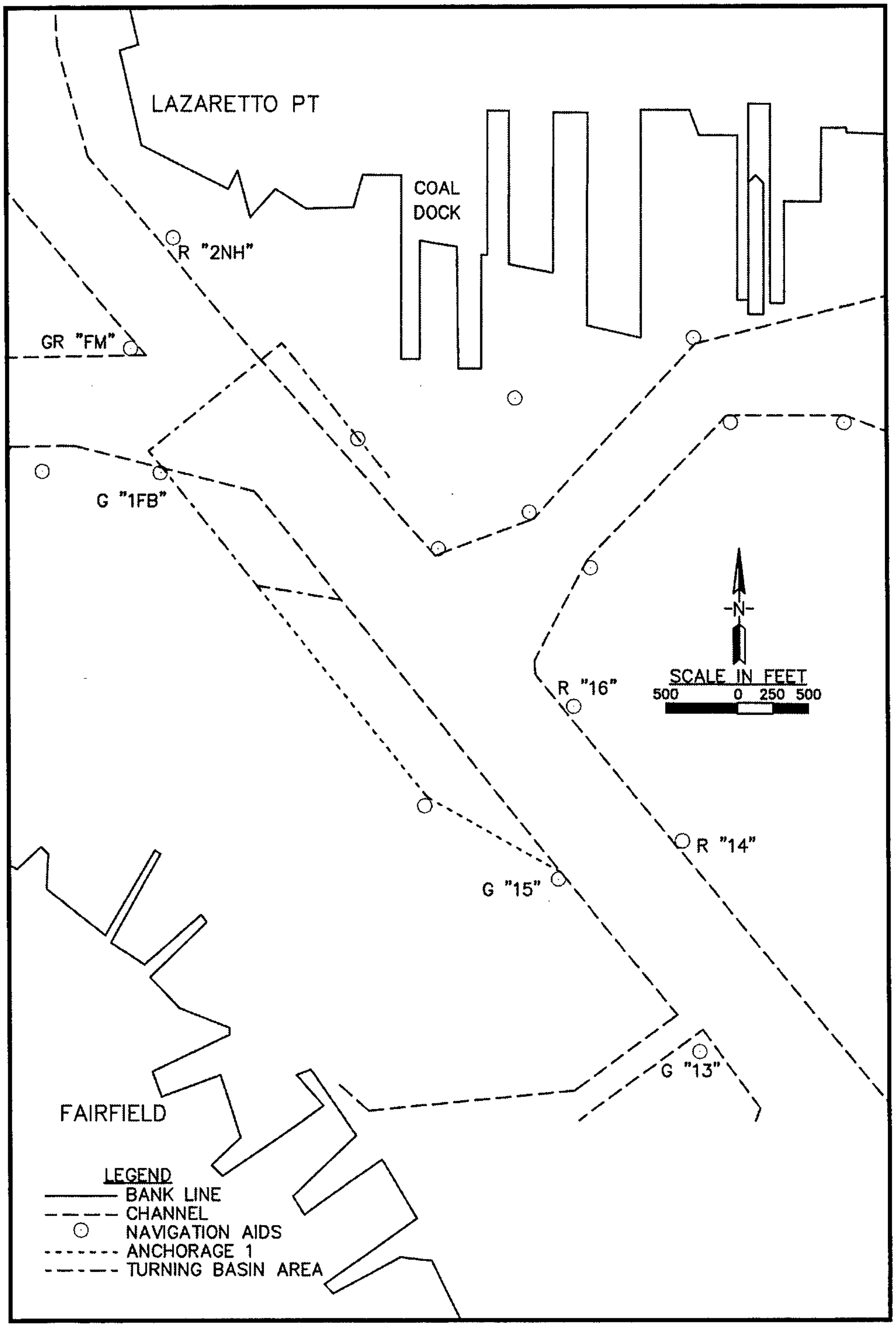


Figure 15. Ft. McHenry Turning Basin plan conditions

Table 1 Simulation Scenarios for Baltimore Harbor Navigation Study			
Run	Scenario	Channel	Heading
1	Dundalk 1	Existing	Inbound
2	Dundalk 1	Existing	Outbound
3	Dundalk 1	Proposed	Inbound
4	Dundalk 1	Proposed	Outbound
5	Dundalk 2	Existing	Inbound
6	Dundalk 2	Existing	Outbound
7	Dundalk 2	Proposed	Inbound
8	Dundalk 2	Proposed	Outbound
9	Seagirt 1	Existing	Inbound
10	Seagirt 1	Proposed	Inbound
11	Seagirt 2	Proposed	Inbound
12	South Locust Point	Existing	Inbound
13	South Locust Point	Existing	Outbound
14	South Locust Point	Proposed	Inbound
15	South Locust Point	Proposed	Inbound
16	South Locust Point	Proposed	Outbound
17	South Locust Point	Modified	Outbound
18	Turn in Anchorage	Existing	Outbound
19	Turning Basin	Proposed	Outbound

done with this modified Fruit Pier Channel Plan. One pilot (Plate 20 - bow outside of the channel line) had one incident caused by unfamiliarity with the plan. After that, there were no further problems.

Fort McHenry Turning Basin

Plate 21 shows the experiments conducted for Fort McHenry Channel/ Anchorage #1 existing conditions. As shown in the plate, the vessels did not back fully into the anchorage area, since the anchorage is shallow (authorized to 11 m (35 ft) deep), and the pilots do not depend upon that extra space. The position of the unnamed buoy directly down from "R - 2NH" (shown in Figure 14 but not shown in Plate 21) forces the pilot to wait as long as he thinks possible before starting his turn. The combination of the shallow area and the buoy severely limit the margin of error for this departure. The buoy was encroached upon several times during experimentation.

Although the location of the unnamed buoy does not change in the plan condition (Plate 22), the assurance of the deepened anchorage allowed the pilots to postpone the start of the turn until the ship cleared this buoy.

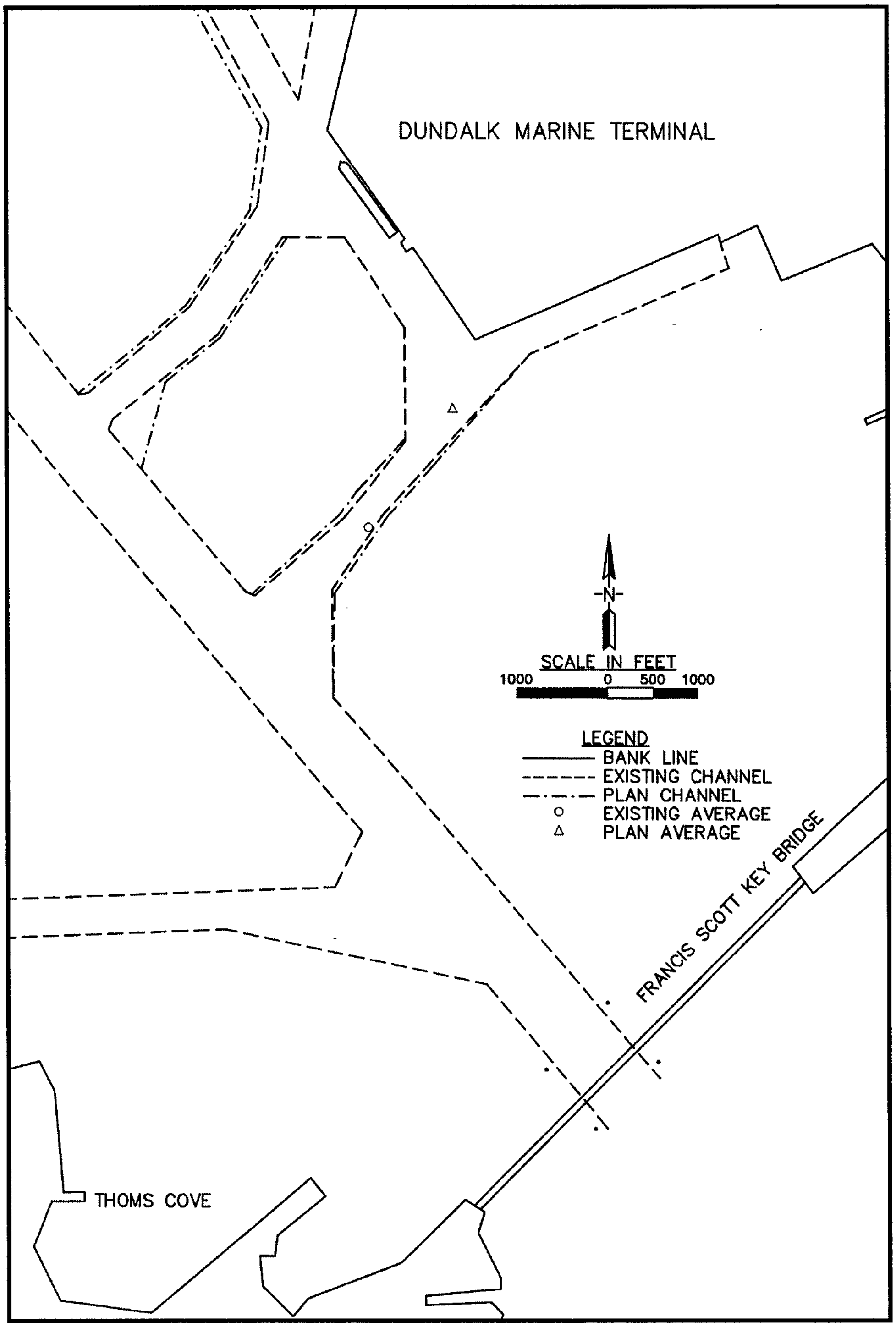


Figure 16. Average traveled distance, Dundalk Scenario 1

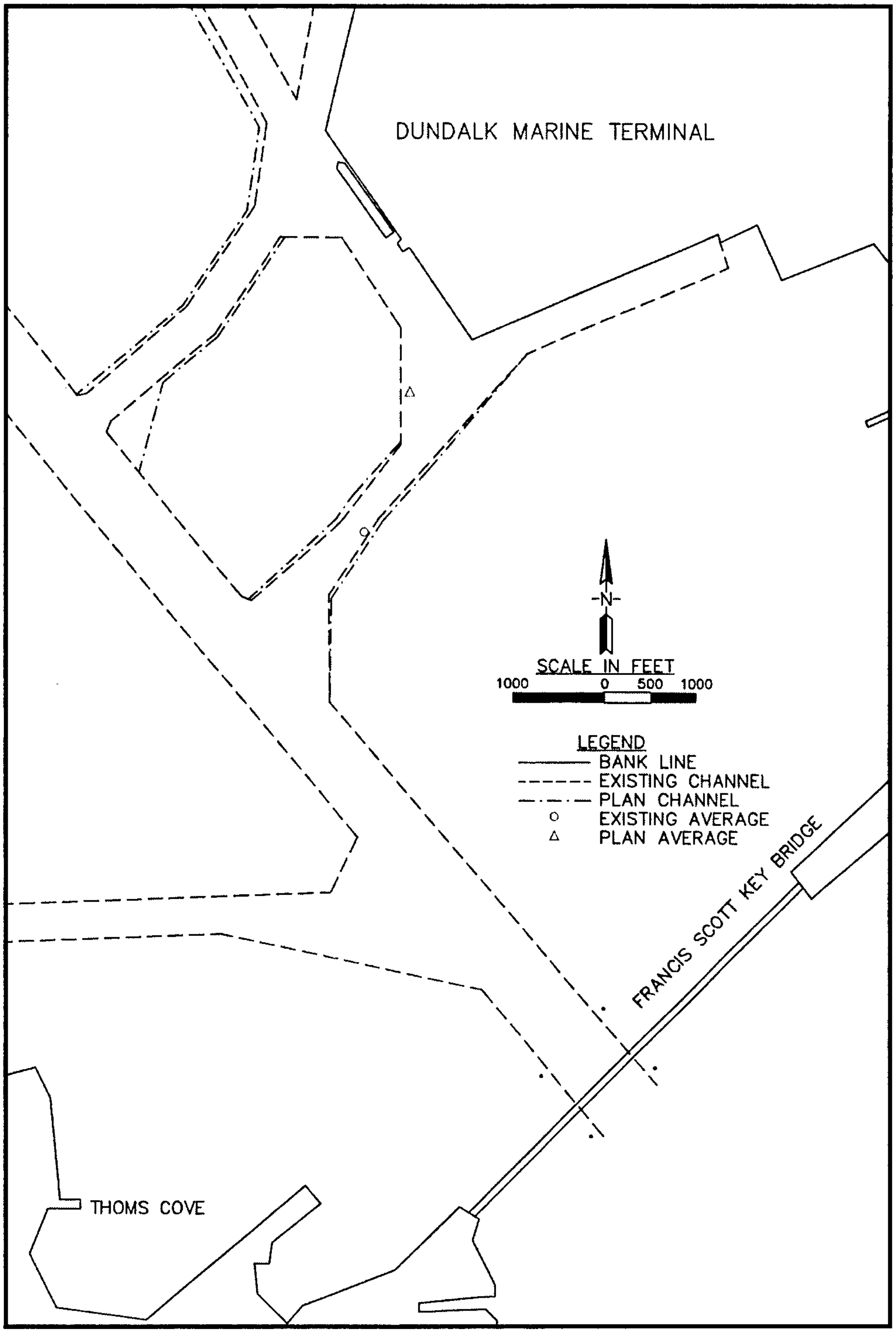


Figure 17. Average traveled distance, Dundalk Scenario 2

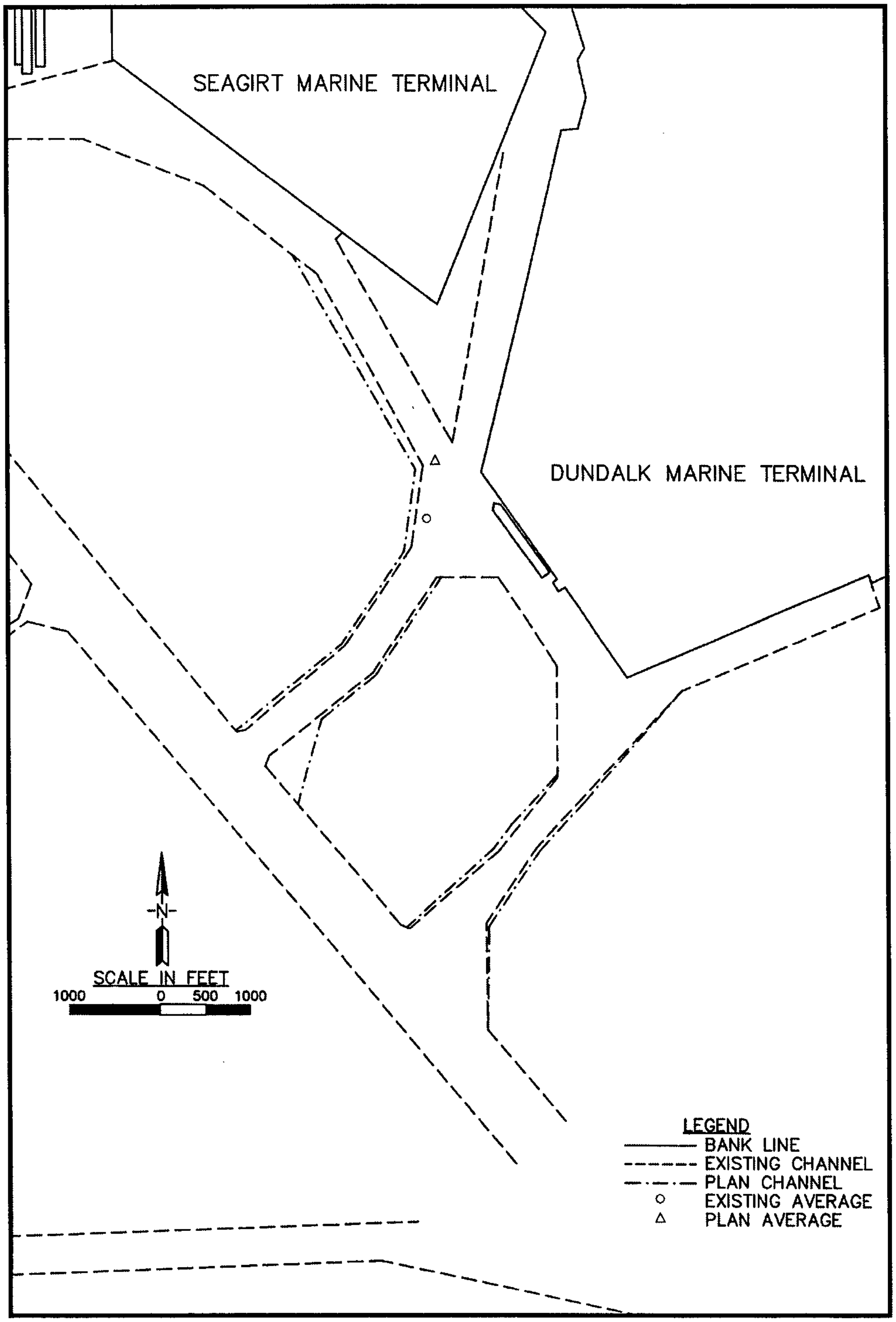


Figure 18. Average traveled distance, Seagirt Scenario 1

3 Recommendations and Conclusions

Dundalk and Seagirt

In Dundalk Scenarios 1 and 2 and Seagirt Scenario 1, the widening of the channel improved the maneuverability of the transit. The degree of improvement is not readily apparent in the track plot plates. It must be remembered that the ships are under tug assistance. Most of the improvement was seen in the shortened transit time shown in Figures 16 through 18. For a vessel speed of approximately 1.5 knots, these figures show a 6- to 14-min reduction in transit time when going from the existing channel configuration to the plan channel. These time reductions are only for comparison. The total time savings may or may not be economically significant. Even though each pilot approaches the channel and utilizes tug assistance differently, the time reduction tends to indicate an easier and safer transit. Since this study was completed, a larger design vessel has been considered for the port, thus increasing the economic benefit of this time reduction. The degree of benefit from this improvement must be assessed by the District.

Seagirt Scenario 2 opens a new slip at Seagirt Termial. The design for this widening demonstrated no problems during testing.

South Locust Point

The addition of the Fruit Pier Channel as a navigable channel reduces the transit time by more than half from buoy “R-2” at South Locust, when the vessel needs to be starboard side to the terminal. This reduction is simply because the vessel no longer has to turn 180 deg before beginning docking maneuvering. This translates into about a 1-hr difference once the vessel gets to this point in the channel. The only problems with this plan were addressed in the modified plan (Figure 13). Once this modification to the Fruit Pier Channel at South Locust Point was put in place, the full potential of this improvement was realized.

Fort McHenry Turning Basin

Ship maneuverability improved with the provision of a 15-m- (50-ft-) deep and 366-m- (1,200-ft-) wide turning basin at the head of the Fort McHenry Channel. However, the pilots were able to utilize very little of the deepened and widened turning basin, because the vessel was so constricted backing out of the coal dock. Therefore, the Turning Basin improvement must be reconsidered. Figure 19 shows a section marked "Area most used for turning." A widening and deepening in this area would better help the vessels turning out of the coal dock and give them some amount of flexibility that they do not now have with the shoaling in that area. A design for widening in that area should be further looked at by the District.

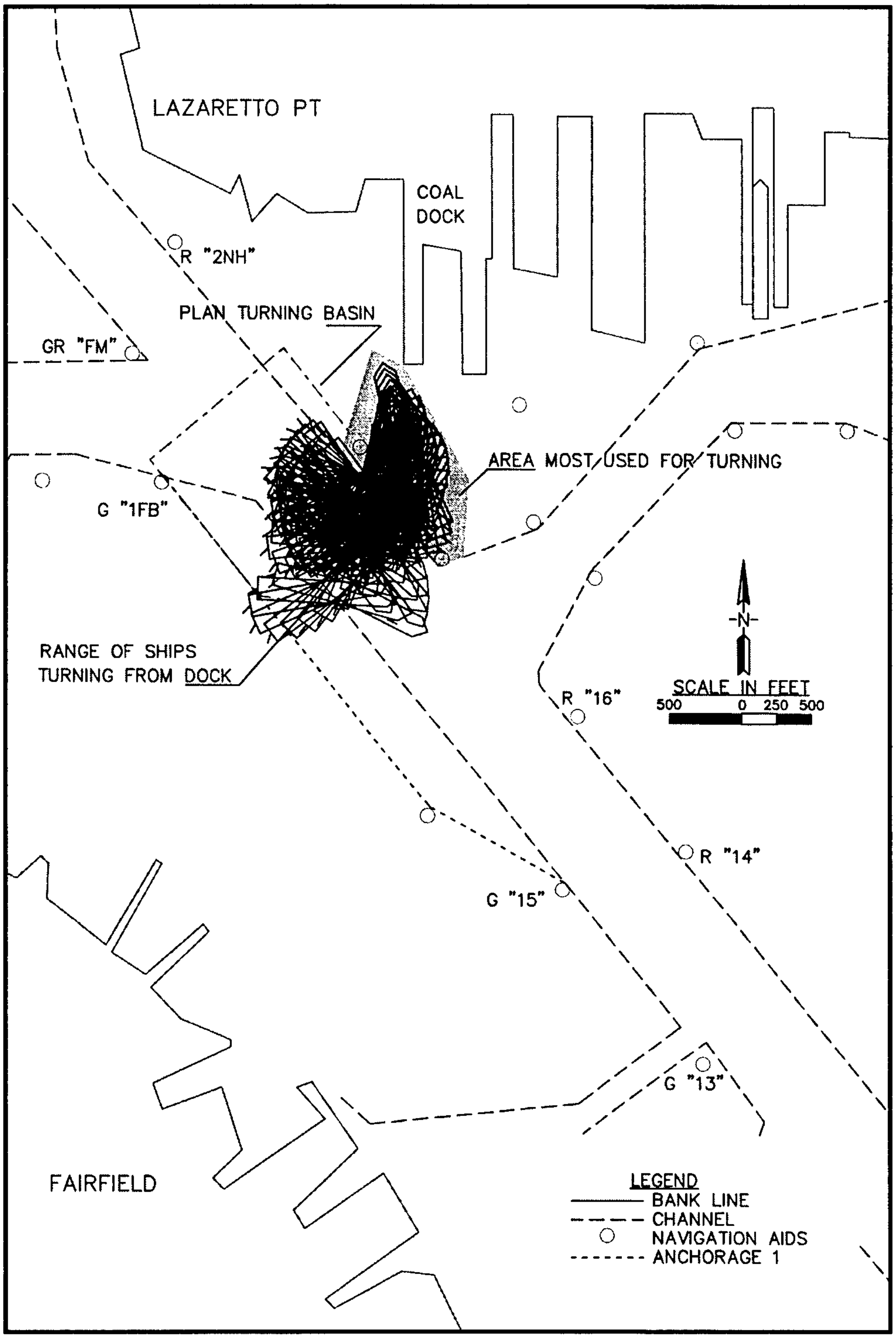
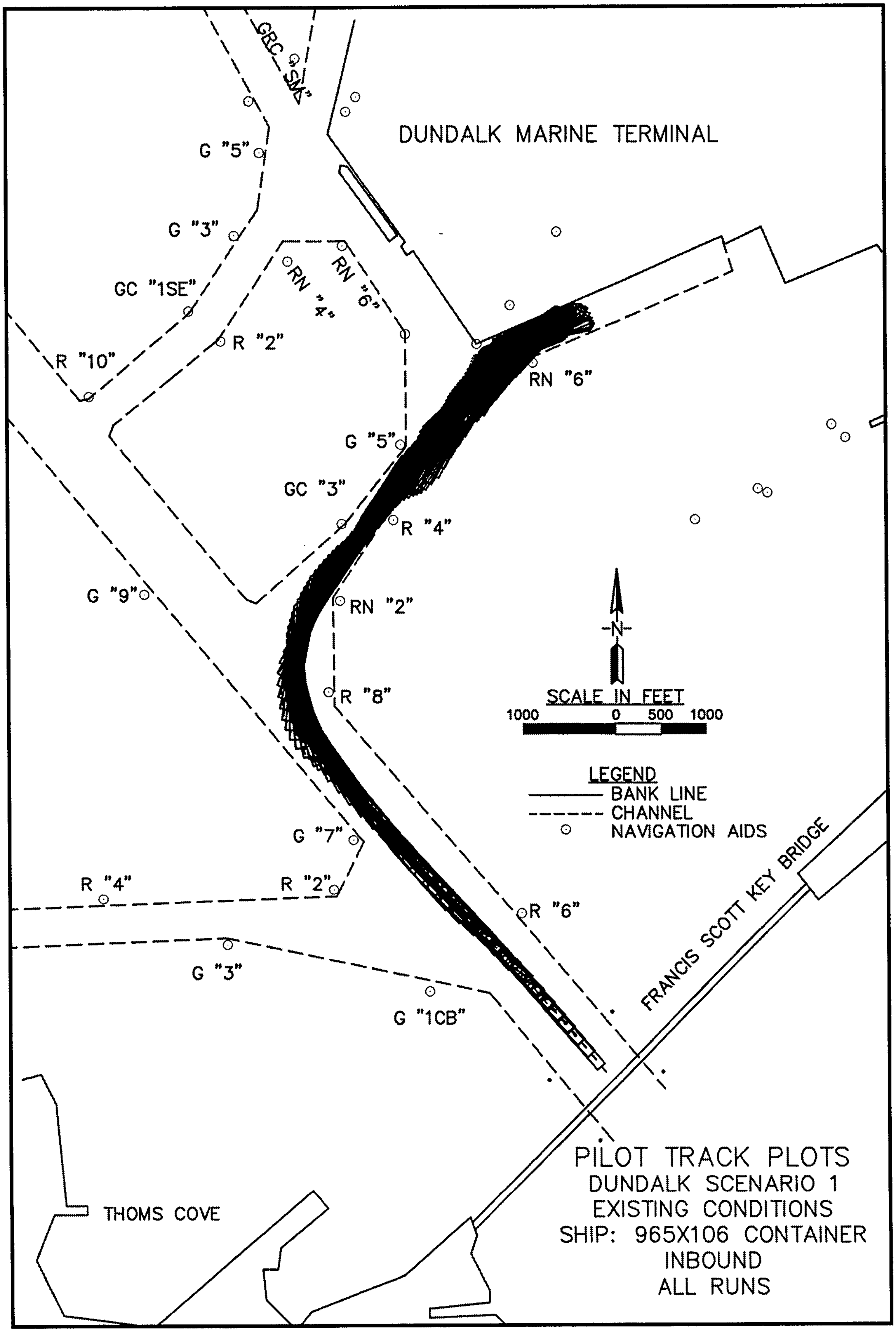
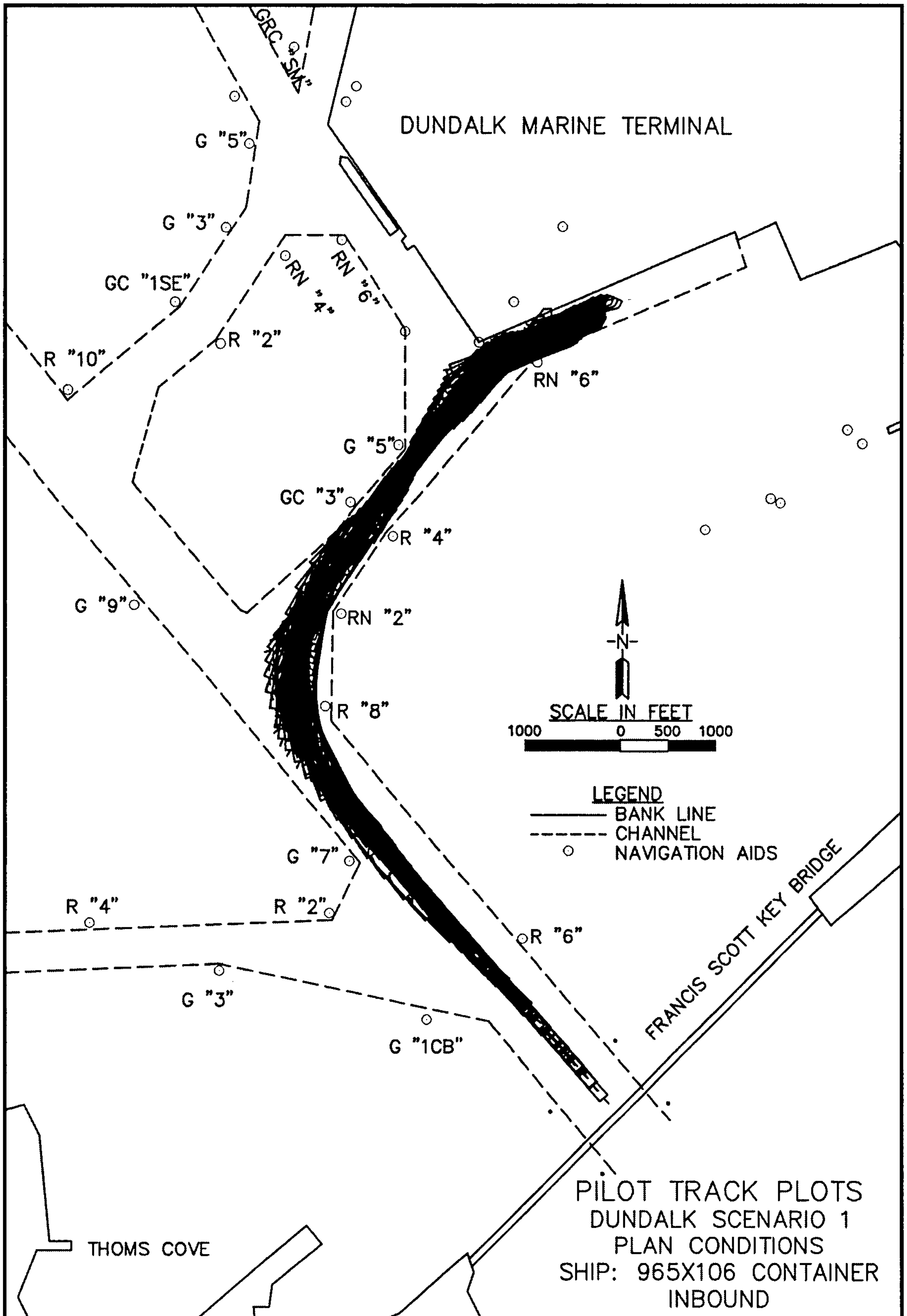


Figure 19. New turning basin considerations



PILOT TRACK PLOTS
DUNDALK SCENARIO 1
EXISTING CONDITIONS
SHIP: 965X106 CONTAINER
INBOUND
ALL RUNS


DUNDALK MARINE TERMINAL
GRC "SM"
G "5"
G "3"
GC "1SE"
RN "4"
RN "6"
R "2"
R "10"
RN "6"
G "5"
GC "3"
R "4"
G "9"
RN "2"
R "8"
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SCALE IN FEET
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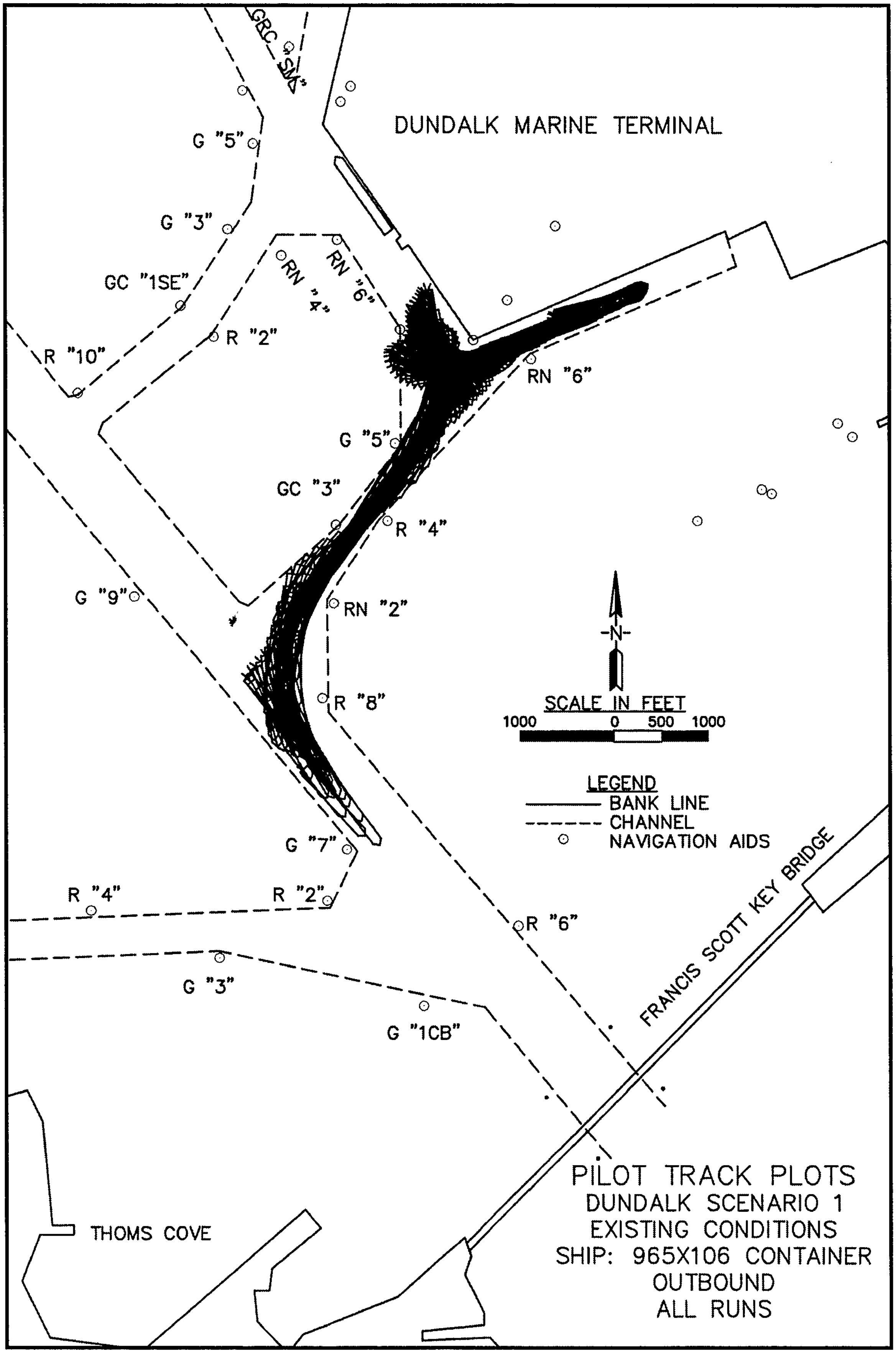
LEGEND
BANK LINE
CHANNEL
NAVIGATION AIDS
FRANCIS SCOTT KEY BRIDGE
G "7"
R "4"
R "2"
R "6"
G "3"
G "1CB"
THOMS COVE
PILOT TRACK PLOTS
DUNDALK SCENARIO 1
PLAN CONDITIONS
SHIP: 965X106 CONTAINER
INBOUND
ALL RUNS

Plate 2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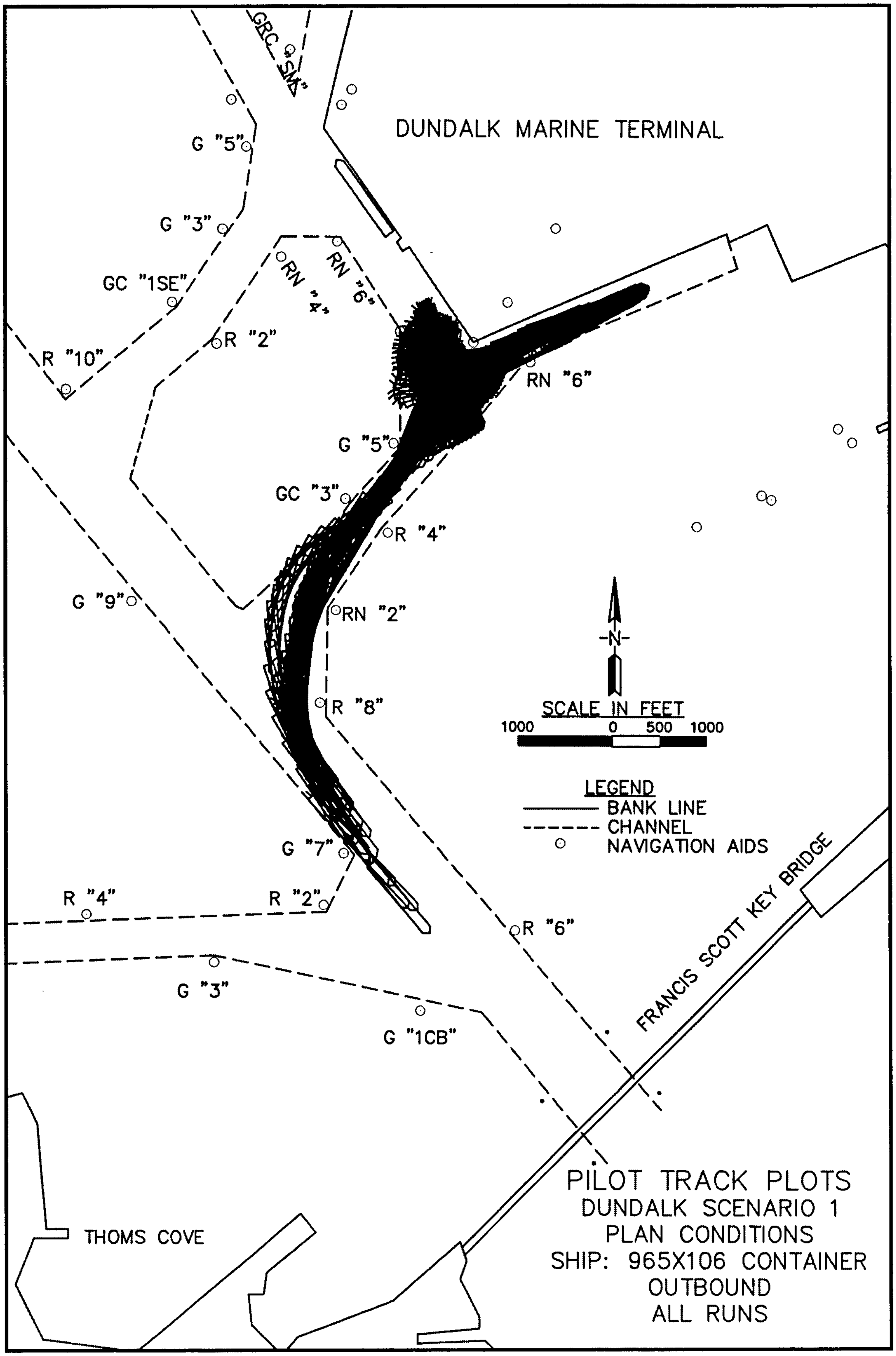
G "5"
G "3"
GC "1SE"
R "10"
R "2"
RN "4"
RN "6"
RN "6"
G "5"
GC "3"
R "4"
G "9"
RN "2"
R "8"
G "7"
R "4"
R "2"
R "6"
G "3"
G "1CB"
FRANCIS SCOTT KEY BRIDGE
THOMS COVE
N
SCALE IN FEET
1000 0 500 1000
LEGEND
BANK LINE
CHANNEL
NAVIGATION AIDS
PILOT TRACK PLOTS
DUNDALK SCENARIO 1
EXISTING CONDITIONS
SHIP: 965X106 CONTAINER
OUTBOUND
ALL RUNS



DUNDALK MARINE TERMINAL
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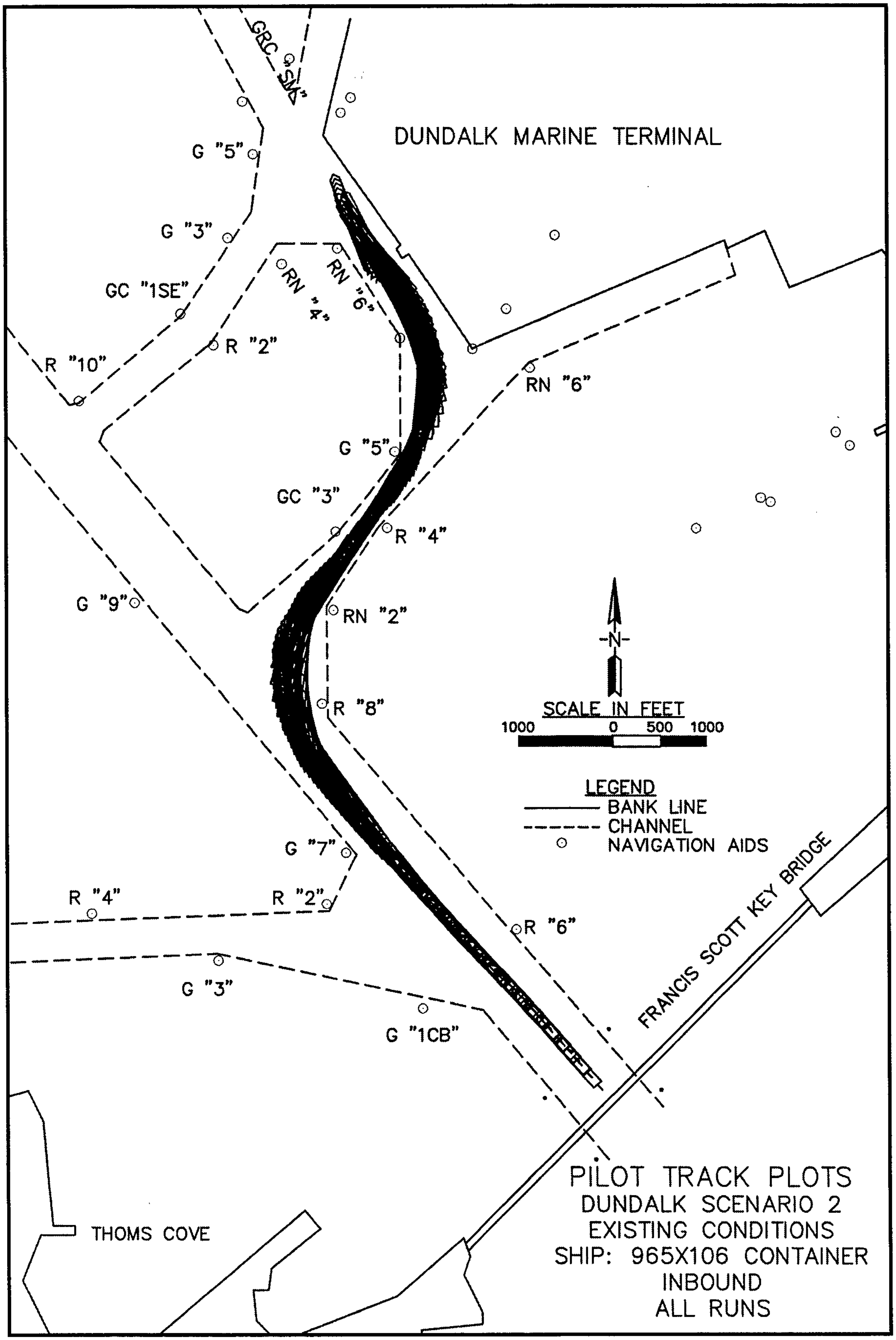
G "5"
G "3"
GC "1SE"
R "10"
R "2"
RN "4"
RN "6"
RN "6"
G "5"
GC "3"
R "4"
G "9"
RN "2"
R "8"
SCALE IN FEET
1000 0 500 1000
LEGEND
BANK LINE
CHANNEL
NAVIGATION AIDS
G "7"
R "4"
R "2"
R "6"
FRANCIS SCOTT KEY BRIDGE
G "3"
G "1CB"
THOMS COVE
PILOT TRACK PLOTS
DUNDALK SCENARIO 1
PLAN CONDITIONS
SHIP: 965X106 CONTAINER
OUTBOUND
ALL RUNS

Plate 4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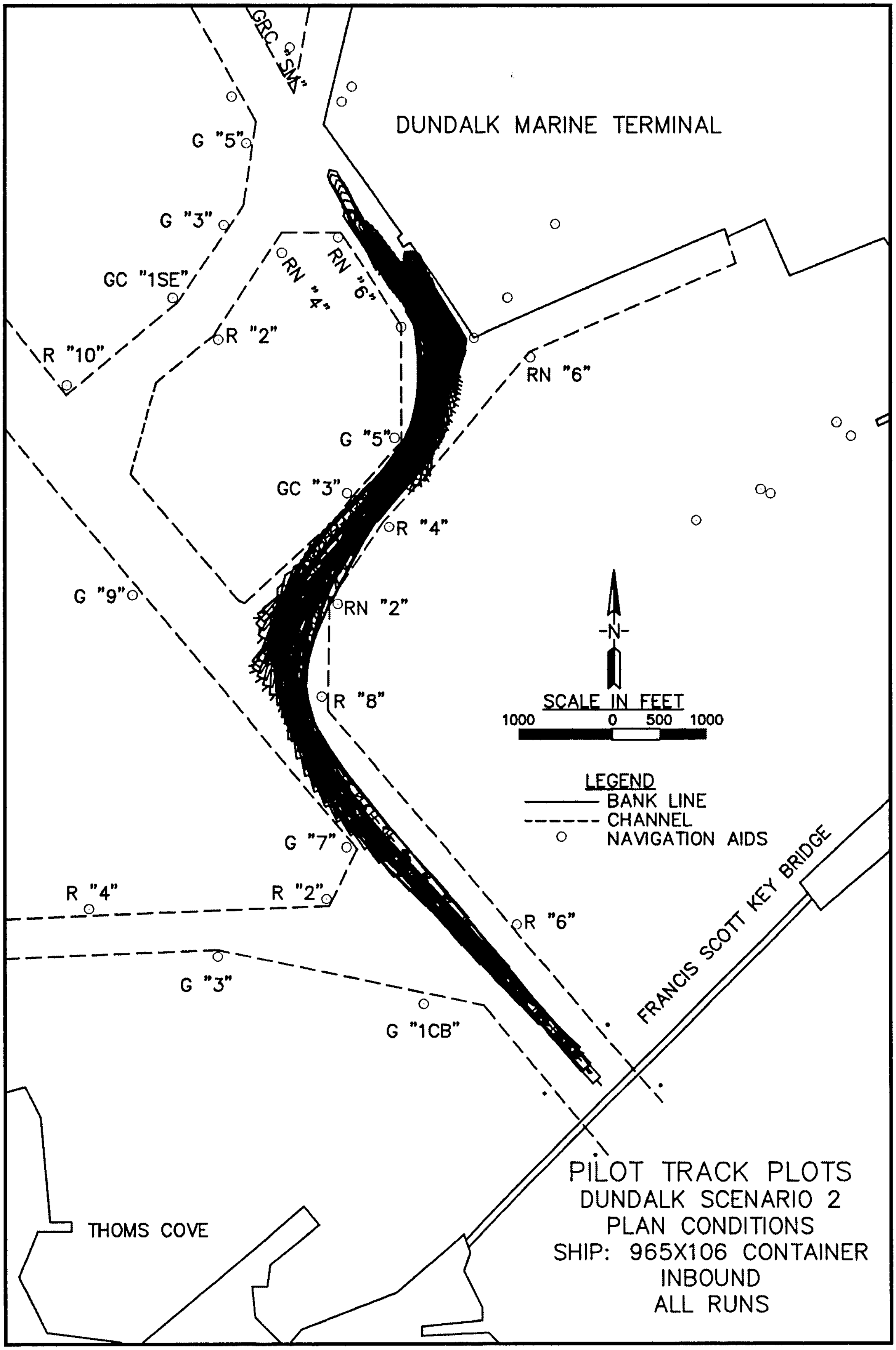
G "5"
G "3"
GC "1SE"
R "10"
R "2"
RN "4"
RN "6"
RN "6"
G "5"
GC "3"
R "4"
G "9"
RN "2"
R "8"
N
SCALE IN FEET
1000 0 500 1000
LEGEND
BANK LINE
CHANNEL
NAVIGATION AIDS
G "7"
R "4"
R "2"
R "6"
FRANCIS SCOTT KEY BRIDGE
G "3"
G "1CB"
THOMS COVE
PILOT TRACK PLOTS
DUNDALK SCENARIO 2
EXISTING CONDITIONS
SHIP: 965X106 CONTAINER
INBOUND
ALL RUNS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DUNDALK MARINE TERMINAL
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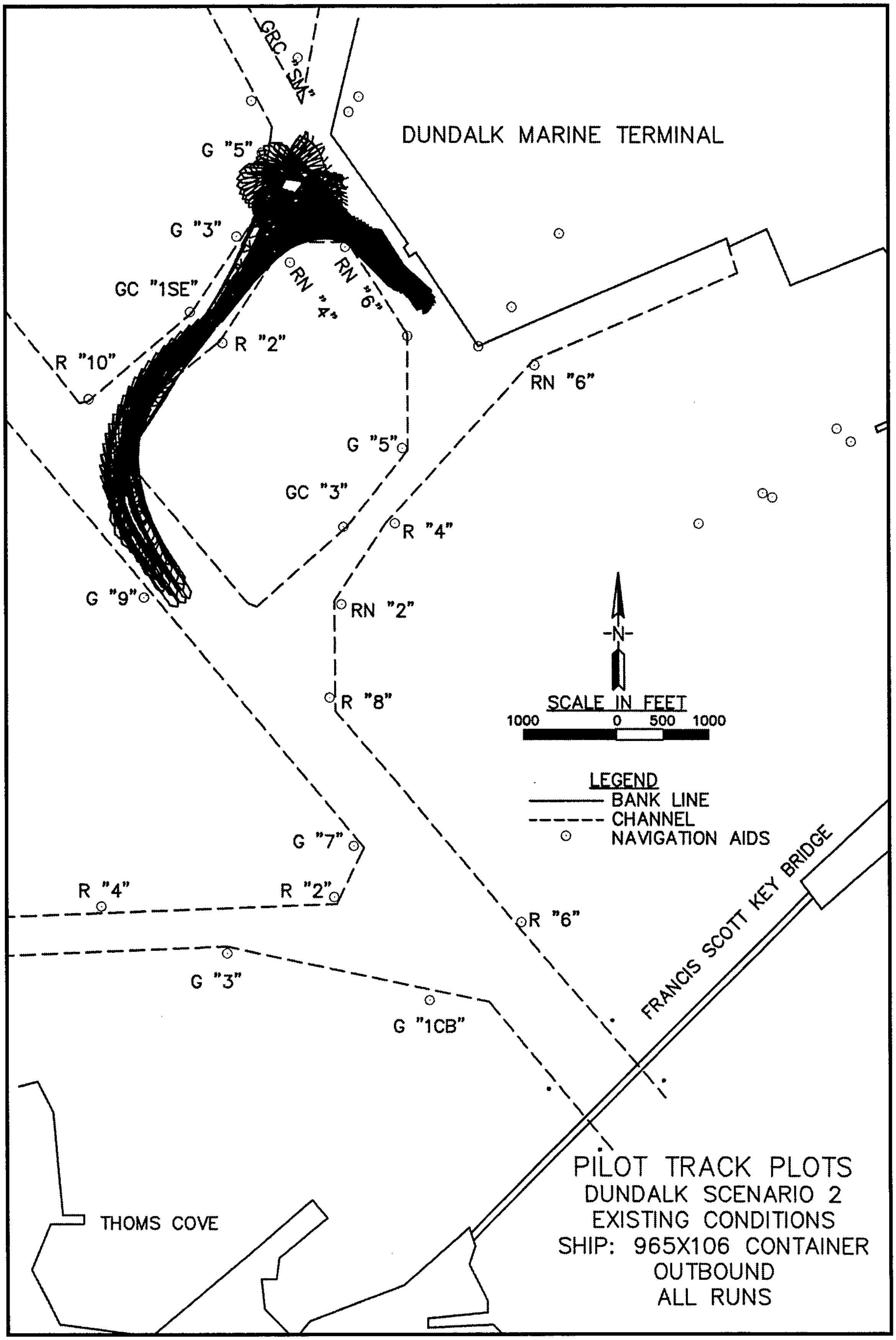
G "3"
GC "1SE"
RN "4"
RN "6"
R "2"
R "10"
RN "6"
G "5"
GC "3"
R "4"
G "9"
RN "2"
R "8"
-N-
SCALE IN FEET
1000 0 500 1000
LEGEND
BANK LINE
CHANNEL
NAVIGATION AIDS
FRANCIS SCOTT KEY BRIDGE
G "7"
R "4"
R "2"
R "6"
G "3"
G "1CB"
THOMS COVE
PILOT TRACK PLOTS
DUNDALK SCENARIO 2
PLAN CONDITIONS
SHIP: 965X106 CONTAINER
INBOUND
ALL RUNS

Plate 6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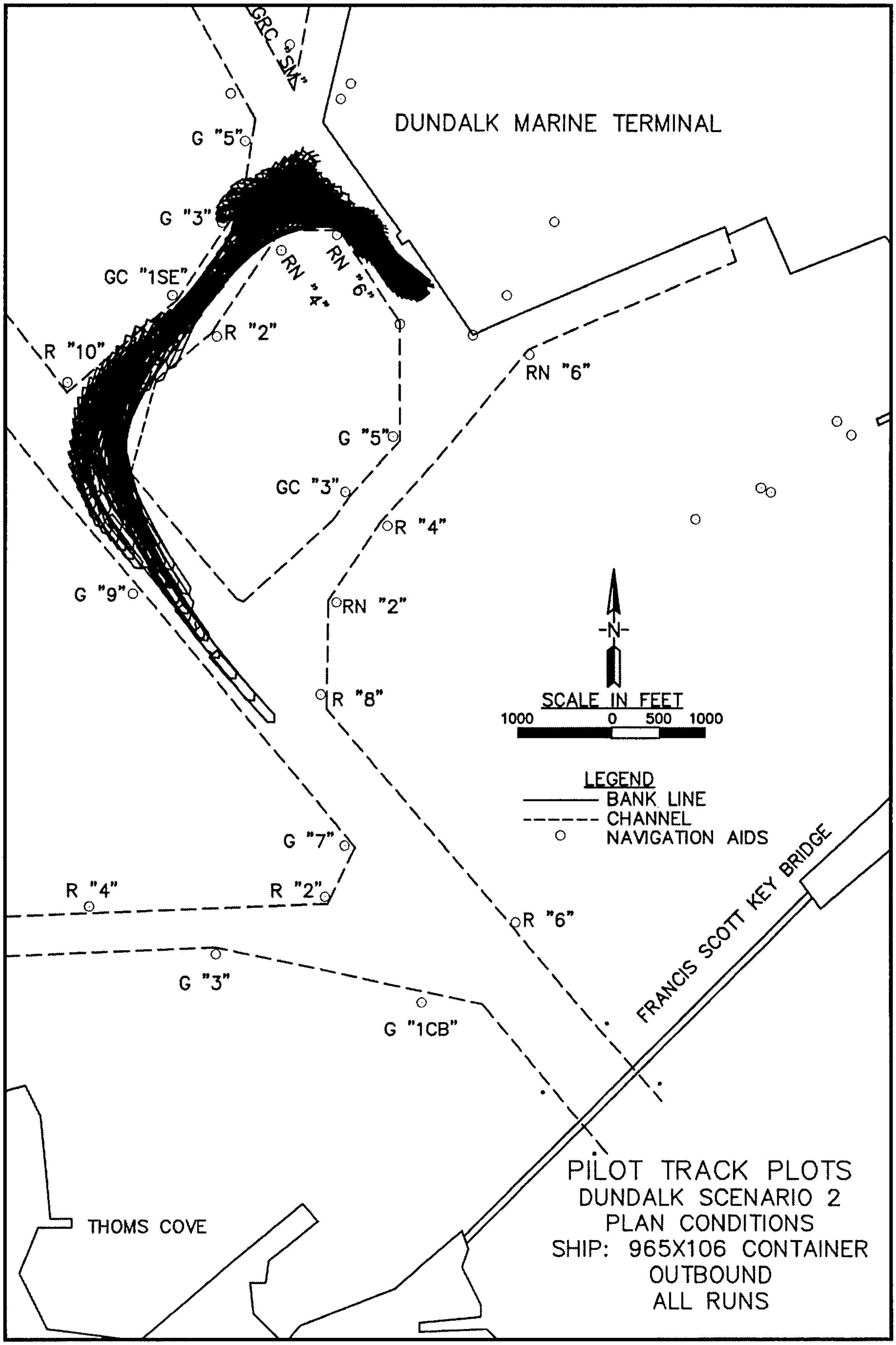
G "3"
GC "1SE"
R "10"
R "2"
RN "4"
RN "6"
RN "6"
G "5"
GC "3"
R "4"
G "9"
RN "2"
R "8"
SCALE IN FEET
1000 0 500 1000
N
LEGEND
BANK LINE
CHANNEL
NAVIGATION AIDS
G "7"
R "4"
R "2"
R "6"
G "3"
G "1CB"
FRANCIS SCOTT KEY BRIDGE
THOMS COVE
PILOT TRACK PLOTS
DUNDALK SCENARIO 2
EXISTING CONDITIONS
SHIP: 965X106 CONTAINER
OUTBOUND
ALL RUNS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G "3"
GC "1SE"
RN "4"
RN "6"
R "2"
R "10"
G "5"
GC "3"
RN "6"
R "4"
G "9"
RN "2"
R "8"
SCALE IN FEET
1000 0 500 1000
N
LEGEND
BANK LINE
CHANNEL
NAVIGATION AIDS
G "7"
R "4"
R "2"
R "6"
G "3"
G "1CB"
FRANCIS SCOTT KEY BRIDGE
THOMS COVE
PILOT TRACK PLOTS
DUNDALK SCENARIO 2
PLAN CONDITIONS
SHIP: 965X106 CONTAINER
OUTBOUND
ALL RUNS

Plate 8

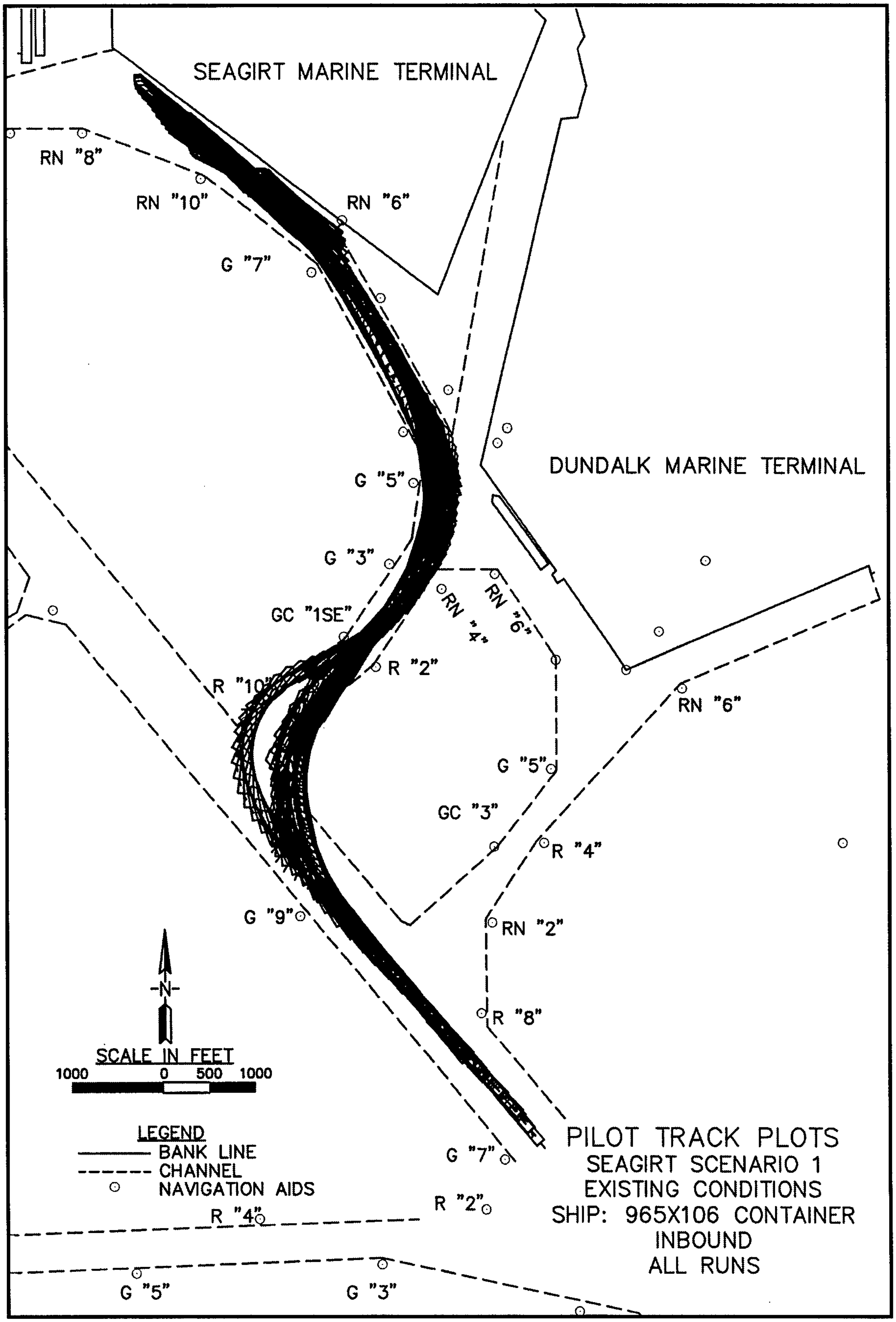

SEAGIRT MARINE TERMINAL
RN "8"
RN "10"
RN "6"
G "7"
DUNDALK MARINE TERMINAL
G "5"
G "3"
GC "1SE"
RN "4"
RN "6"
R "2"
R "10"
RN "6"
G "5"
GC "3"
R "4"
G "9"
RN "2"
R "8"
-N-
SCALE IN FEET
1000 0 500 1000
LEGEND
BANK LINE
CHANNEL
NAVIGATION AIDS
G "7"
R "2"
R "4"
G "5"
G "3"
PILOT TRACK PLOTS
SEAGIRT SCENARIO 1
EXISTING CONDITIONS
SHIP: 965X106 CONTAINER
INBOUND
ALL RUNS

Plate 9

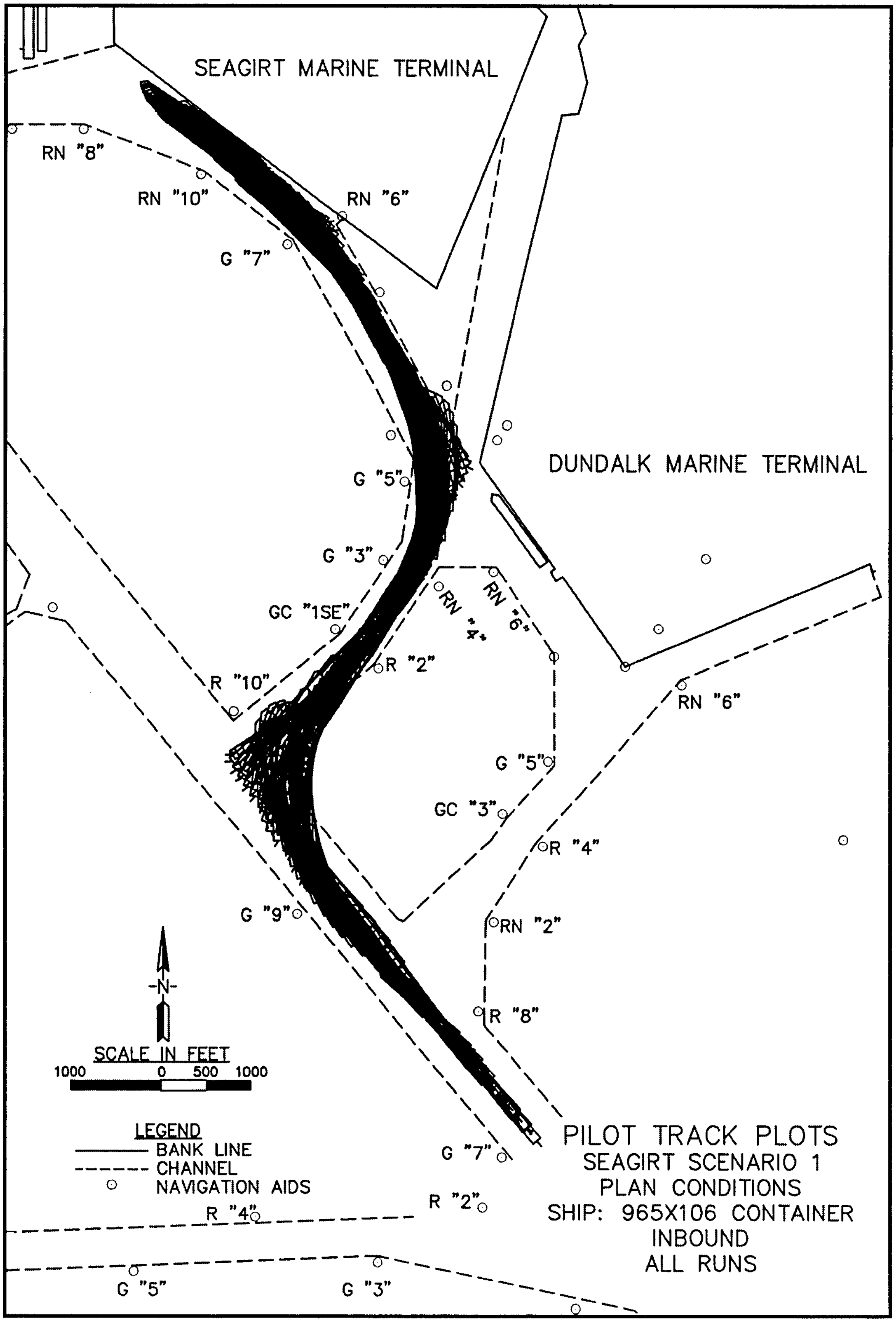
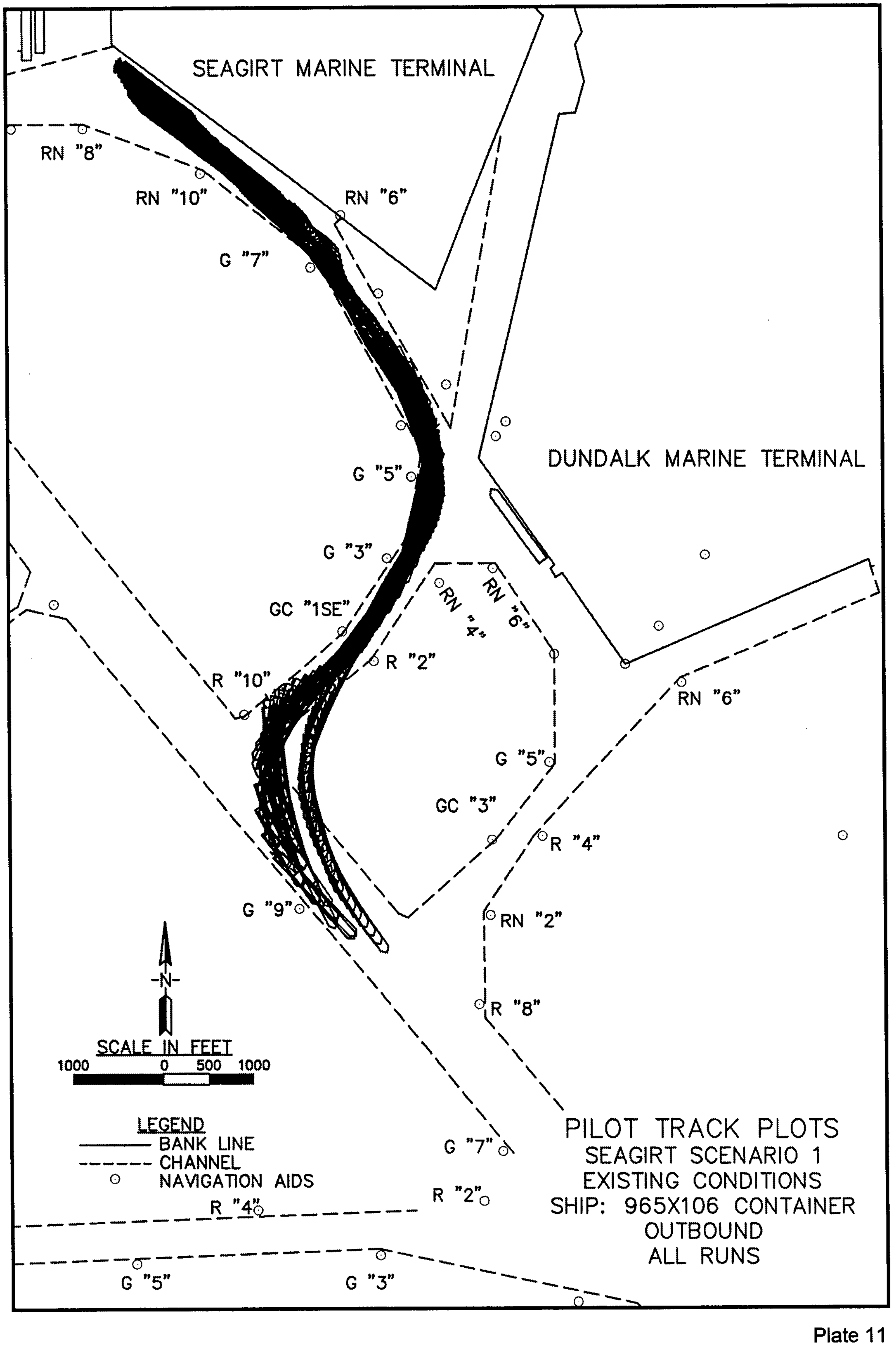
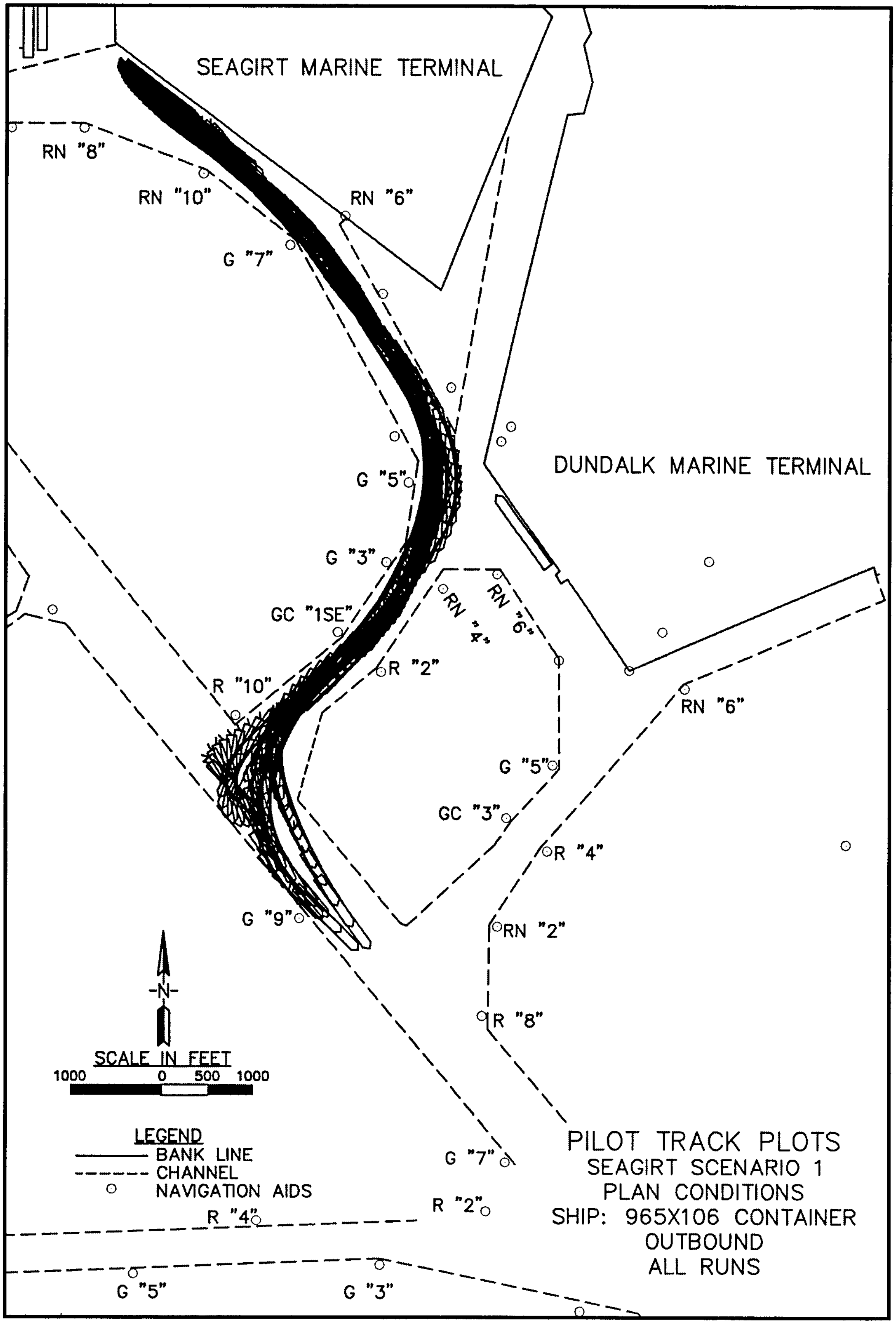

SEAGIRT MARINE TERMINAL
DUNDALK MARINE TERMINAL
RN "8"
RN "10"
RN "6"
G "7"
G "5"
G "3"
GC "1SE"
RN "4"
RN "6"
R "2"
R "10"
RN "6"
G "5"
GC "3"
R "4"
RN "2"
G "9"
R "8"
-N-
SCALE IN FEET
1000 0 500 1000
LEGEND
BANK LINE
CHANNEL
NAVIGATION AIDS
G "7"
R "2"
R "4"
G "5"
G "3"
PILOT TRACK PLOTS
SEAGIRT SCENARIO 1
PLAN CONDITIONS
SHIP: 965X106 CONTAINER
INBOUND
ALL RUNS

Plate 10


SEAGIRT MARINE TERMINAL
DUNDALK MARINE TERMINAL
RN "8"
RN "10"
RN "6"
G "7"
G "5"
G "3"
GC "1SE"
R "10"
R "2"
RN "4"
RN "6"
RN "6"
G "5"
GC "3"
R "4"
RN "2"
R "8"
G "9"
G "7"
R "2"
R "4"
G "5"
G "3"
N
SCALE IN FEET
1000 0 500 1000
LEGEND
BANK LINE
CHANNEL
NAVIGATION AIDS
PILOT TRACK PLOTS
SEAGIRT SCENARIO 1
EXISTING CONDITIONS
SHIP: 965X106 CONTAINER
OUTBOUND
ALL RUNS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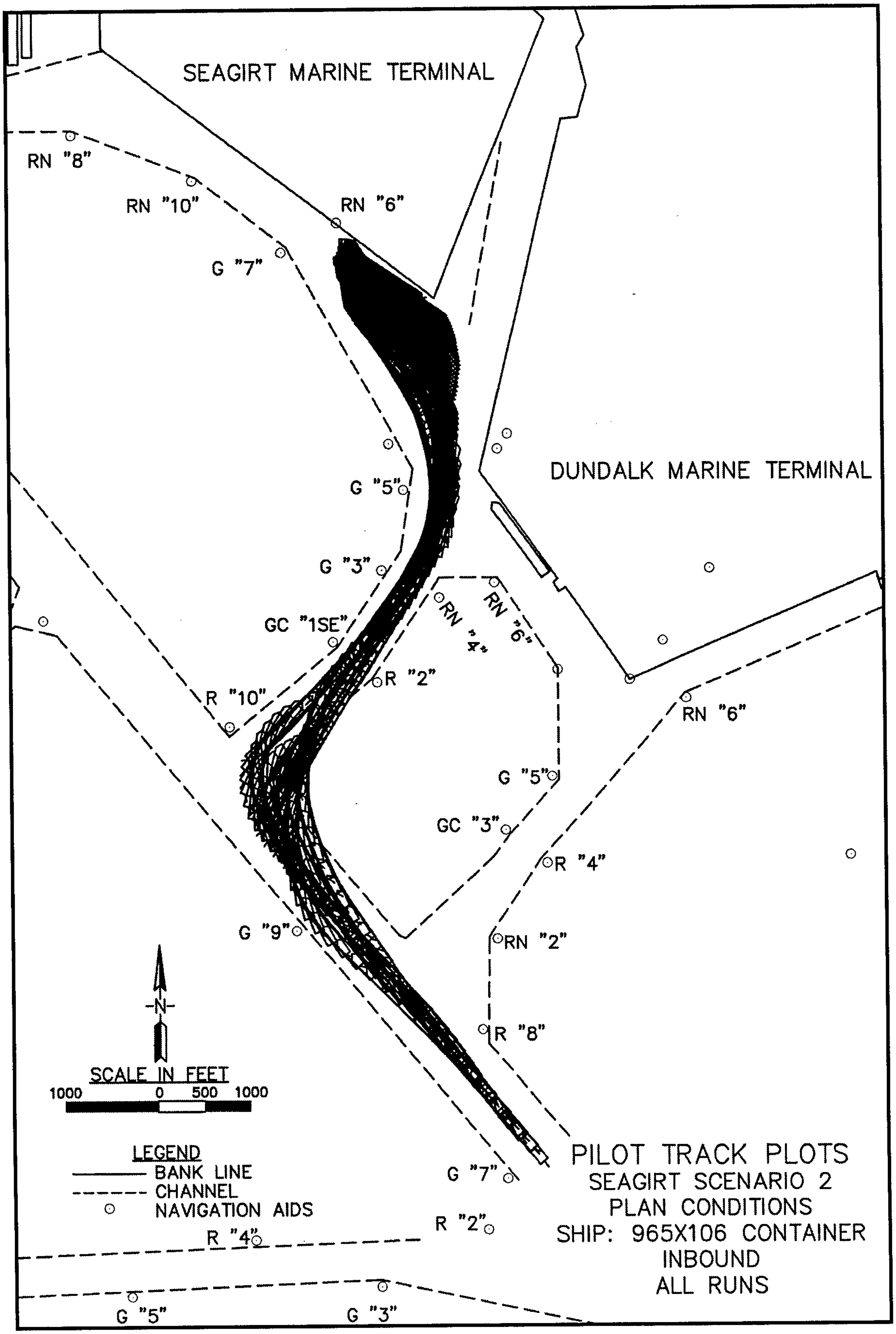
RN "8"
RN "10"
RN "6"
G "7"
DUNDALK MARINE TERMINAL
G "5"
G "3"
GC "1SE"
RN "4"
RN "6"
R "2"
R "10"
RN "6"
G "5"
GC "3"
R "4"
G "9"
RN "2"
R "8"
-N-
SCALE IN FEET
1000 0 500 1000
LEGEND
BANK LINE
CHANNEL
NAVIGATION AIDS
G "7"
R "2"
R "4"
G "5"
G "3"
PILOT TRACK PLOTS
SEAGIRT SCENARIO 1
PLAN CONDITIONS
SHIP: 965X106 CONTAINER
OUTBOUND
ALL RUNS

Plate 12


SEAGIRT MARINE TERMINAL
DUNDALK MARINE TERMINAL
RN "8"
RN "10"
RN "6"
G "7"
G "5"
G "3"
GC "1SE"
R "10"
R "2"
RN "4"
RN "6"
RN "6"
G "5"
GC "3"
R "4"
G "9"
RN "2"
R "8"
G "7"
R "2"
R "4"
G "5"
G "3"
-N-
SCALE IN FEET
1000 0 500 1000
LEGEND
BANK LINE
CHANNEL
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PILOT TRACK PLOTS
SEAGIRT SCENARIO 2
PLAN CONDITIONS
SHIP: 965X106 CONTAINER
INBOUND
ALL RUNS

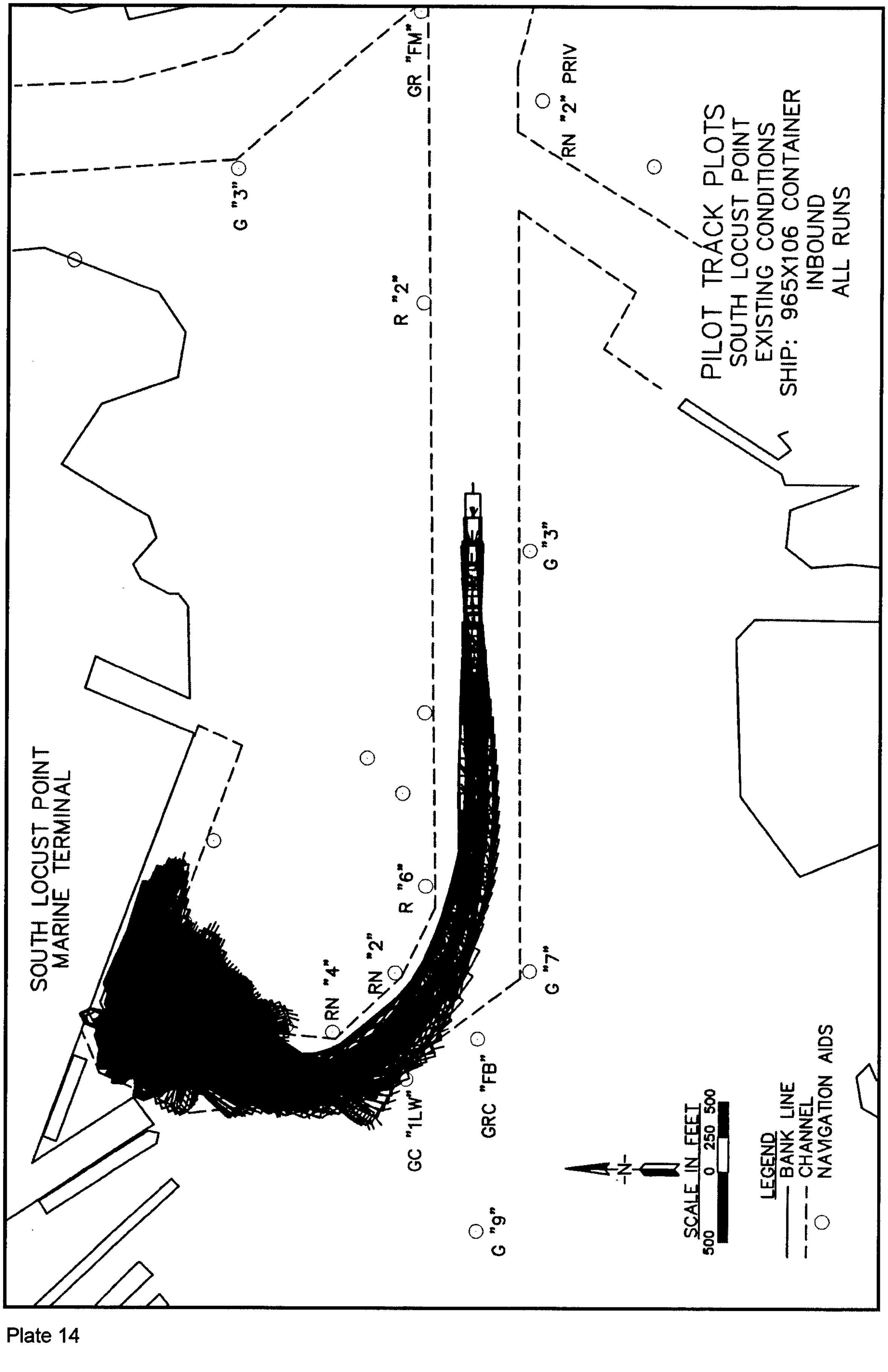

PILOT TRACK PLOTS
SOUTH LOCUST POINT
EXISTING CONDITIONS
SHIP: 965X106 CONTAINER
INBOUND
ALL RUNS
SOUTH LOCUST POINT
MARINE TERMINAL
G "3"
GR "FM"
RN "2" PRIV
R "2"
G "3"
R "6"
RN "2"
RN "4"
G "7"
GC "1LW"
GRC "FB"
G "9"
SCALE IN FEET
500 0 250 500
LEGEND
BANK LINE
CHANNEL
NAVIGATION AIDS
N

Plate 14

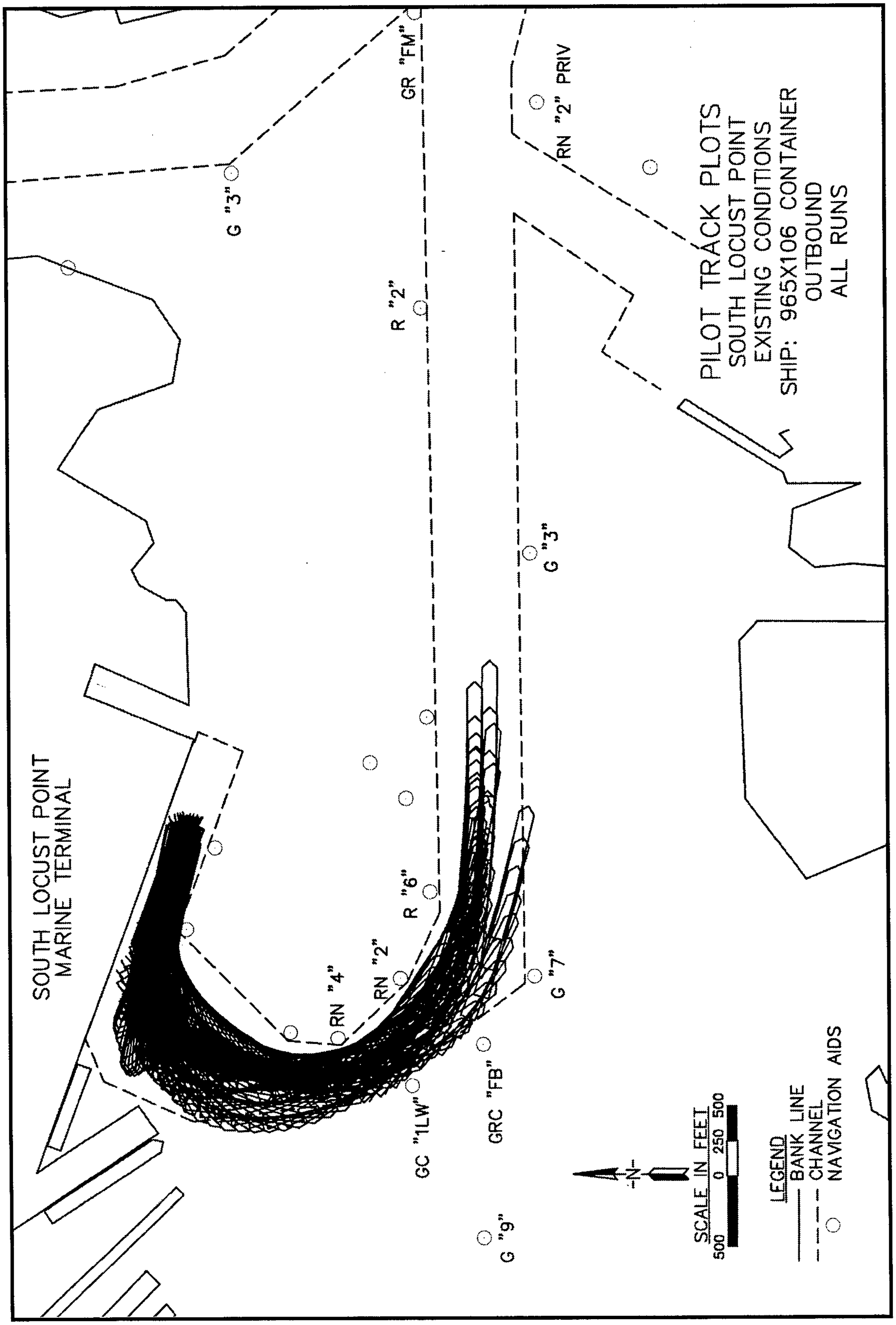

PILOT TRACK PLOTS
SOUTH LOCUST POINT
EXISTING CONDITIONS
SHIP: 965X106 CONTAINER
OUTBOUND
ALL RUNS
SOUTH LOCUST POINT
MARINE TERMINAL
G "3"
GR "FM"
RN "2" PRIV
R "2"
G "3"
R "6"
RN "2"
RN "4"
G "7"
GC "1LW"
GRC "FB"
G "9"
N
SCALE IN FEET
500 0 250 500
LEGEND
BANK LINE
CHANNEL
NAVIGATION AIDS

Plate 15

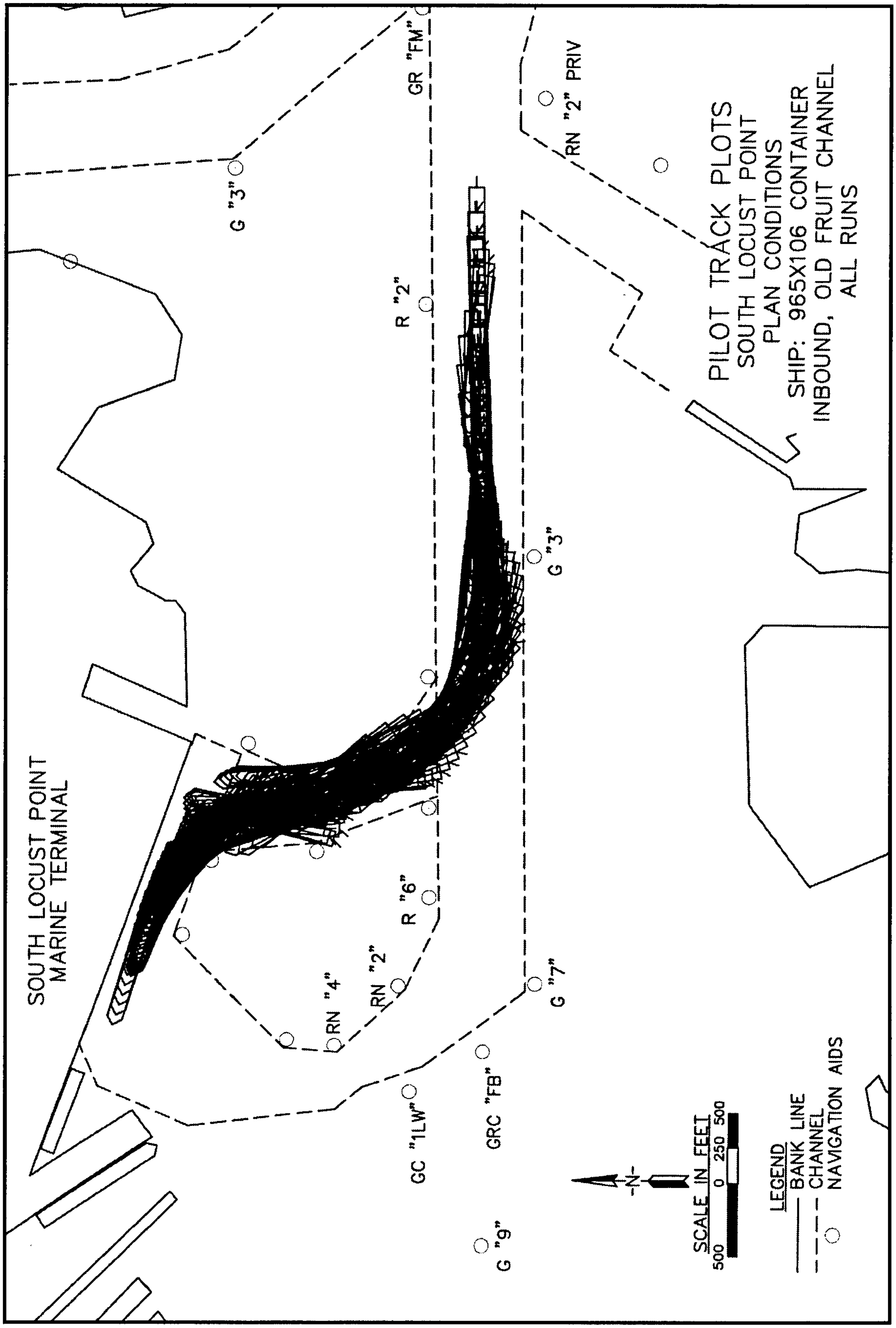
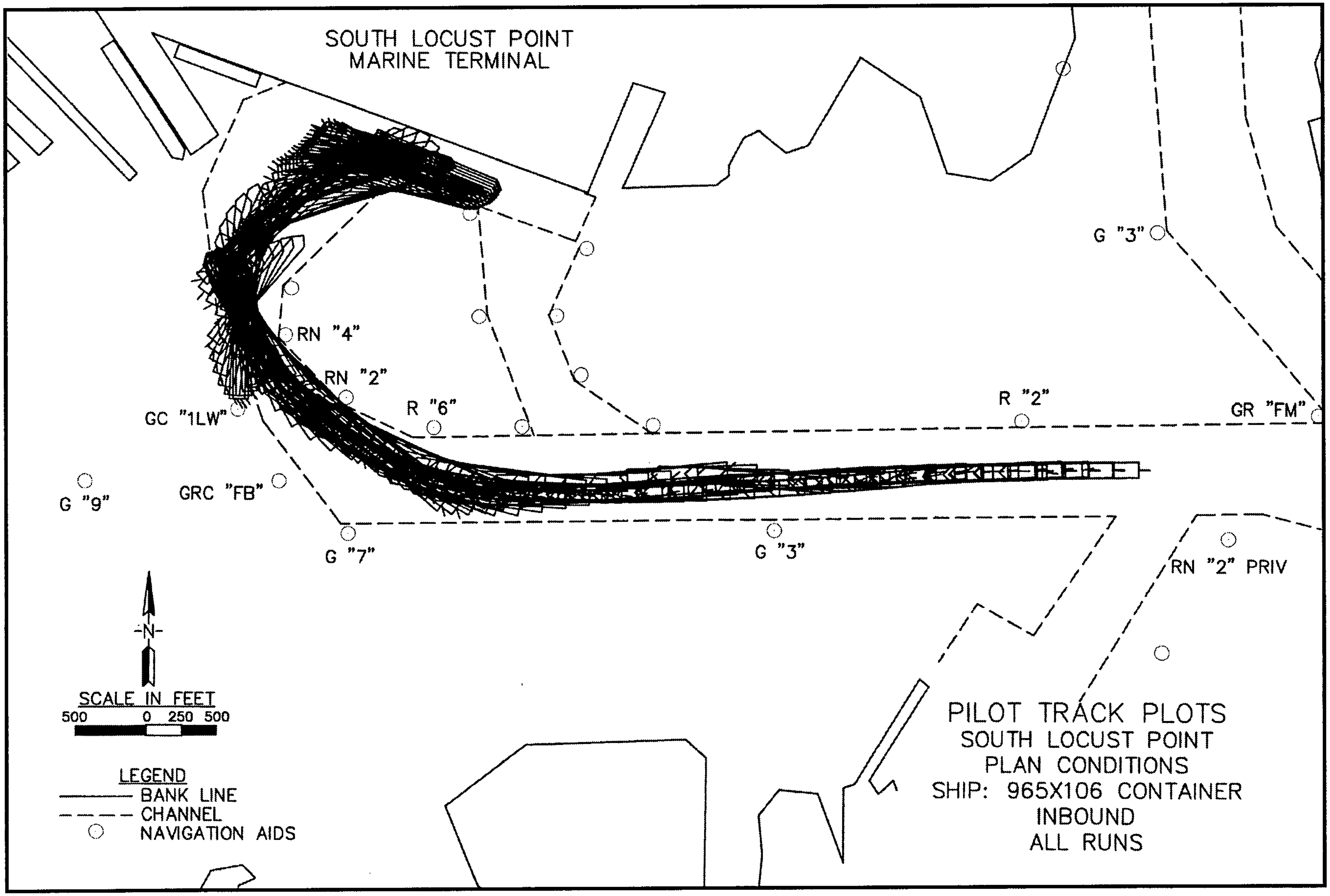

PILOT TRACK PLOTS
SOUTH LOCUST POINT
PLAN CONDITIONS
SHIP: 965X106 CONTAINER
INBOUND, OLD FRUIT CHANNEL
ALL RUNS
SOUTH LOCUST POINT
MARINE TERMINAL
G "3"
GR "FM"
RN "2" PRIV
R "2"
G "3"
R "6"
RN "4"
RN "2"
G "7"
GRC "FB"
GC "1LW"
G "9"
N
SCALE IN FEET
500 0 250 500
LEGEND
BANK LINE
CHANNEL
NAVIGATION AIDS

Plate 16


SOUTH LOCUST POINT
MARINE TERMINAL
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RN "4"
RN "2"
R "6"
R "2"
GR "FM"
GC "1LW"
G "9"
GRC "FB"
G "7"
G "3"
RN "2" PRIV
N
SCALE IN FEET
500 0 250 500
LEGEND
BANK LINE
CHANNEL
NAVIGATION AIDS
PILOT TRACK PLOTS
SOUTH LOCUST POINT
PLAN CONDITIONS
SHIP: 965X106 CONTAINER
INBOUND
ALL RUNS

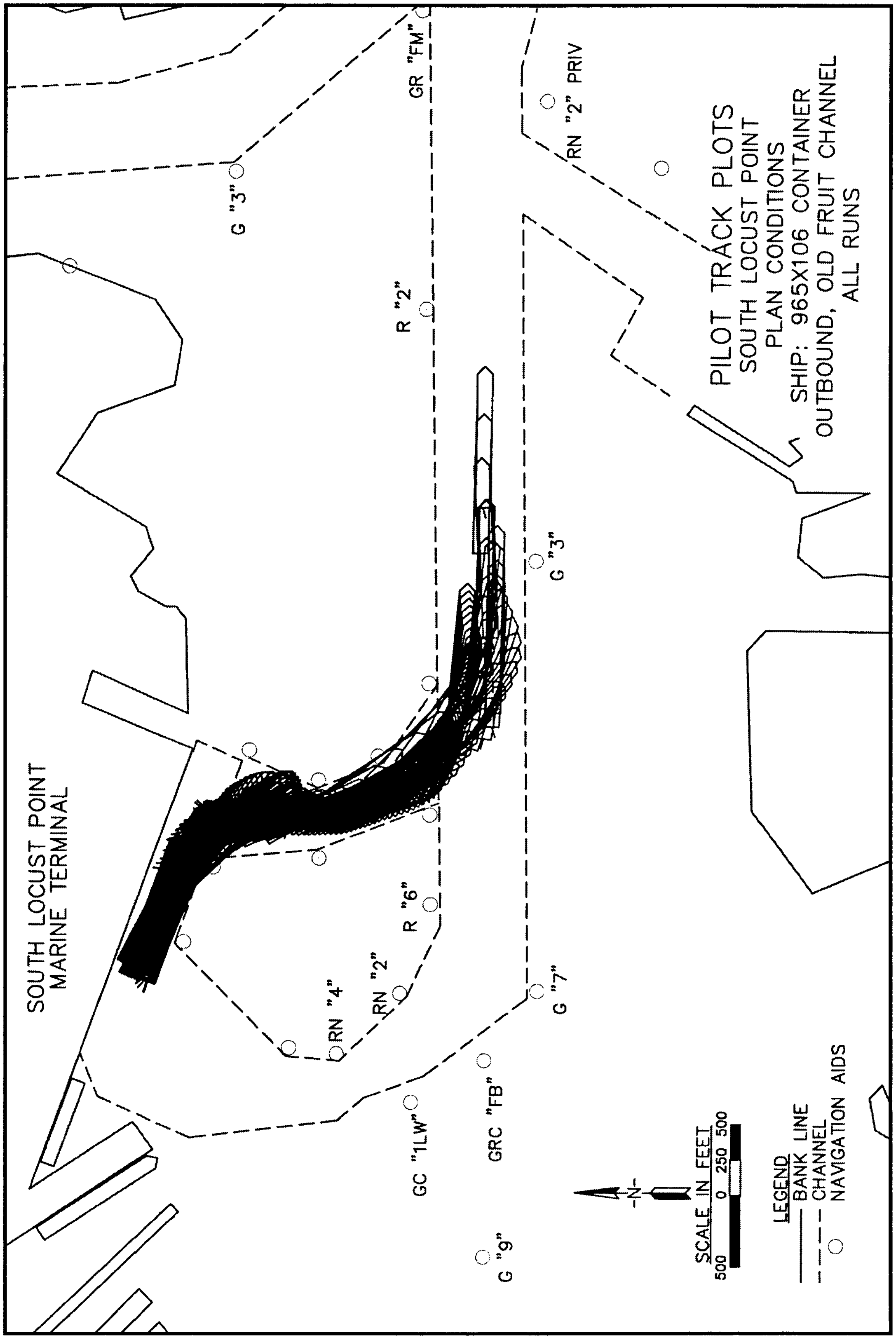
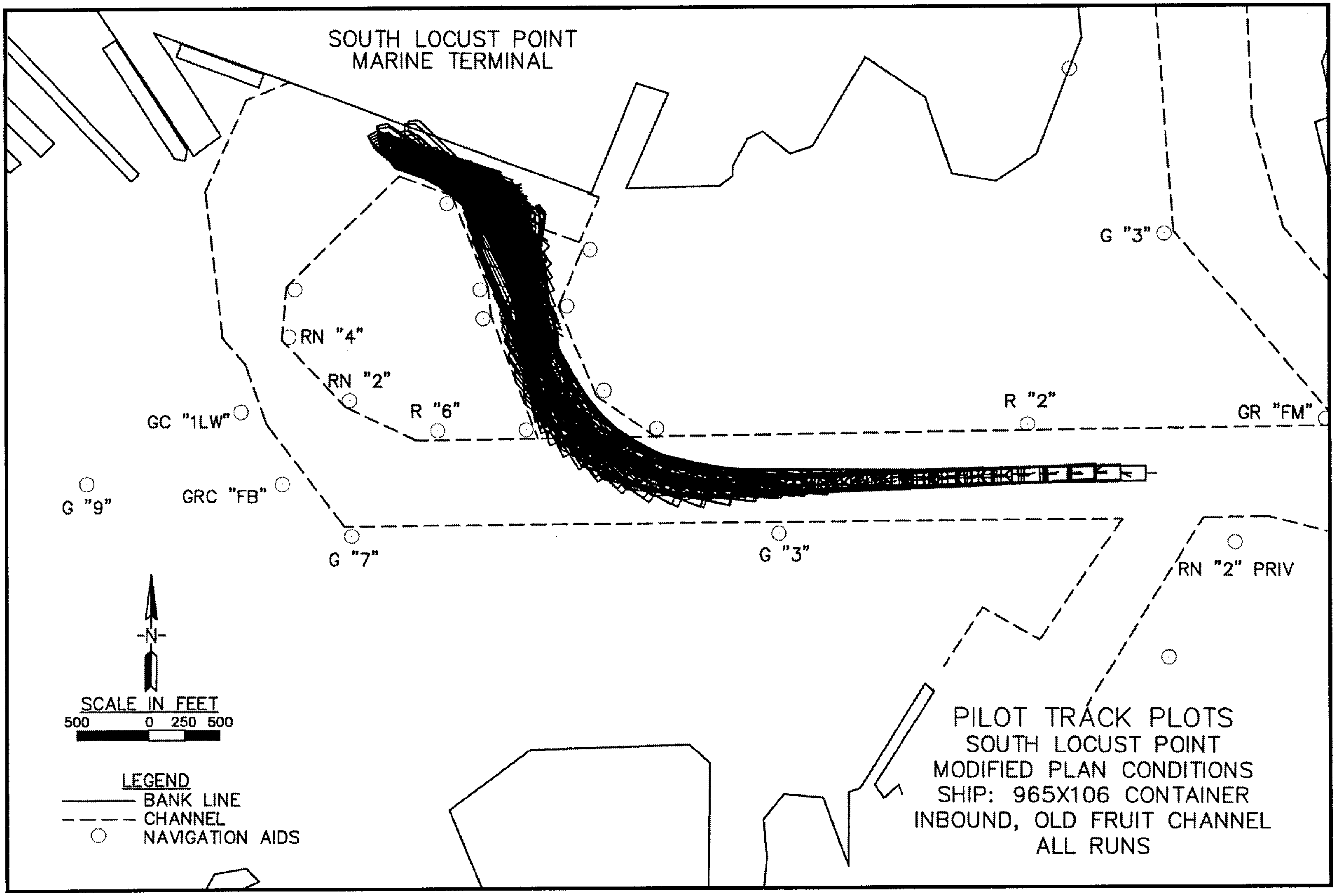

PILOT TRACK PLOTS
SOUTH LOCUST POINT
PLAN CONDITIONS
SHIP: 965X106 CONTAINER
OUTBOUND, OLD FRUIT CHANNEL
ALL RUNS
SOUTH LOCUST POINT
MARINE TERMINAL
GR "FM"
RN "2" PRIV
G "3"
R "2"
G "3"
R "6"
RN "4"
RN "2"
G "7"
GC "1LW"
GRC "FB"
G "9"
N
SCALE IN FEET
500 0 250 500
LEGEND
BANK LINE
CHANNEL
NAVIGATION AIDS

Plate 18


SOUTH LOCUST POINT
MARINE TERMINAL
G "3"
RN "4"
RN "2"
R "6"
GC "1LW"
R "2"
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G "9"
GRC "FB"
G "7"
G "3"
RN "2" PRIV
N
SCALE IN FEET
500 0 250 500
LEGEND
BANK LINE
CHANNEL
NAVIGATION AIDS
PILOT TRACK PLOTS
SOUTH LOCUST POINT
MODIFIED PLAN CONDITIONS
SHIP: 965X106 CONTAINER
INBOUND, OLD FRUIT CHANNEL
ALL RUNS

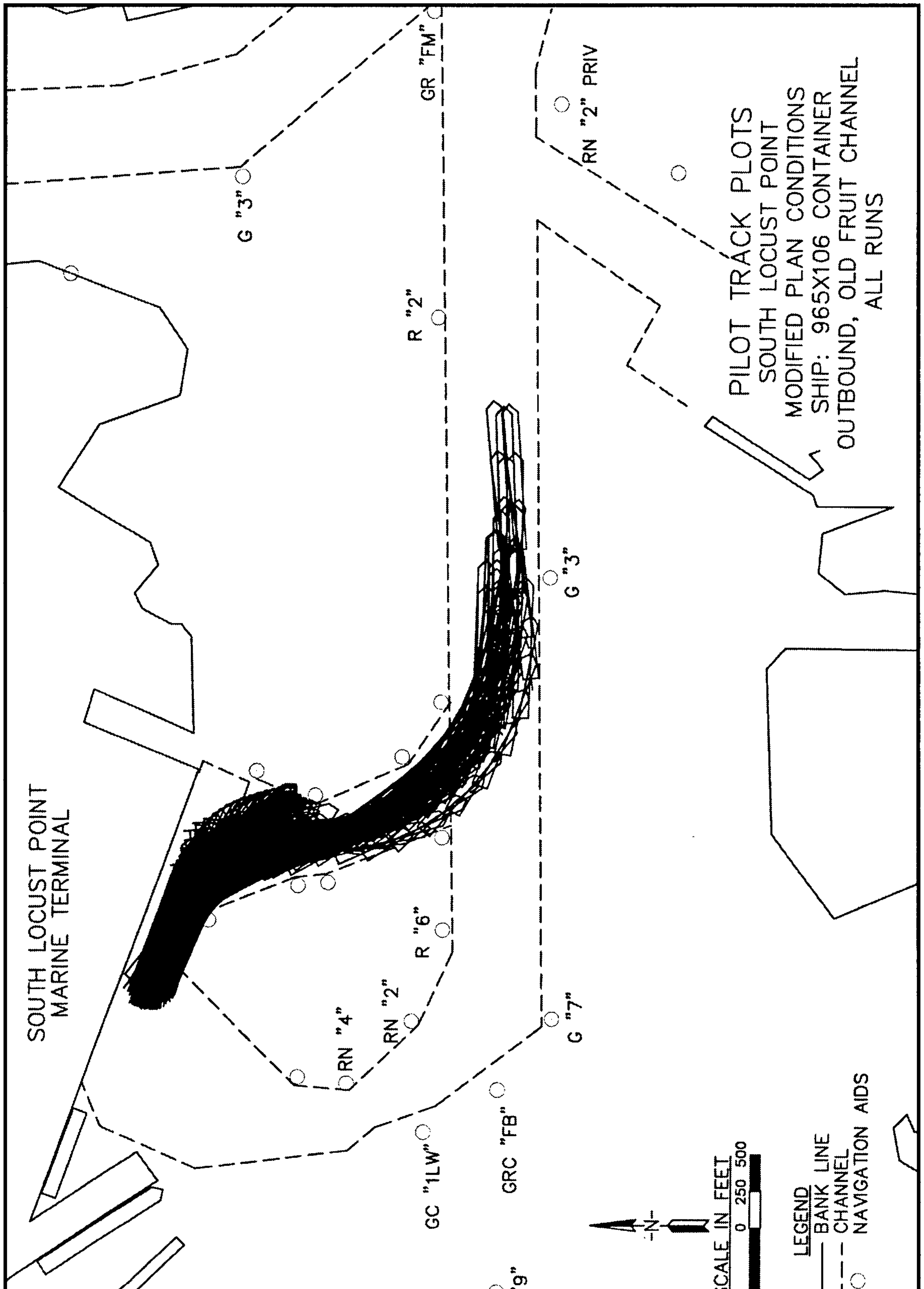
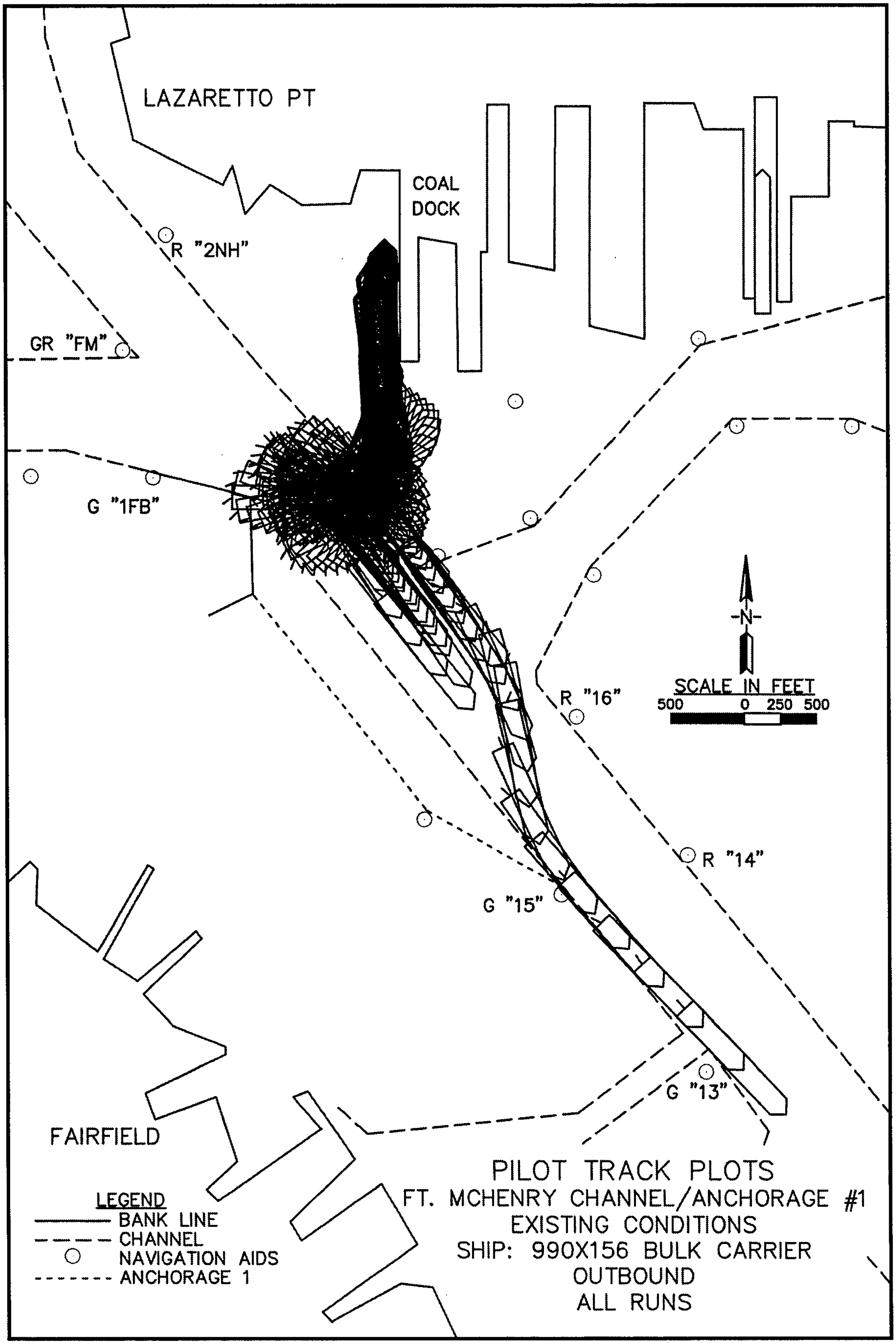

PILOT TRACK PLOTS
SOUTH LOCUST POINT
MODIFIED PLAN CONDITIONS
SHIP: 965X106 CONTAINER
OUTBOUND, OLD FRUIT CHANNEL
ALL RUNS
SOUTH LOCUST POINT
MARINE TERMINAL
G "3"
GR "FM"
RN "2" PRIV
R "2"
G "3"
R "6"
RN "4"
RN "2"
G "7"
GC "1LW"
GRC "FB"
G "9"
-N-
SCALE IN FEET
500 0 250 500
LEGEND
BANK LINE
CHANNEL
NAVIGATION AIDS

Plate 20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COAL
DOCK
R "2NH"
GR "FM"
G "1FB"
R "16"
R "14"
G "15"
G "13"
SCALE IN FEET
500 0 250 500
N
FAIRFIELD
LEGEND
BANK LINE
CHANNEL
NAVIGATION AIDS
ANCHORAGE 1
PILOT TRACK PLOTS
FT. MCHENRY CHANNEL/ANCHORAGE #1
EXISTING CONDITIONS
SHIP: 990X156 BULK CARRIER
OUTBOUND
ALL RUNS

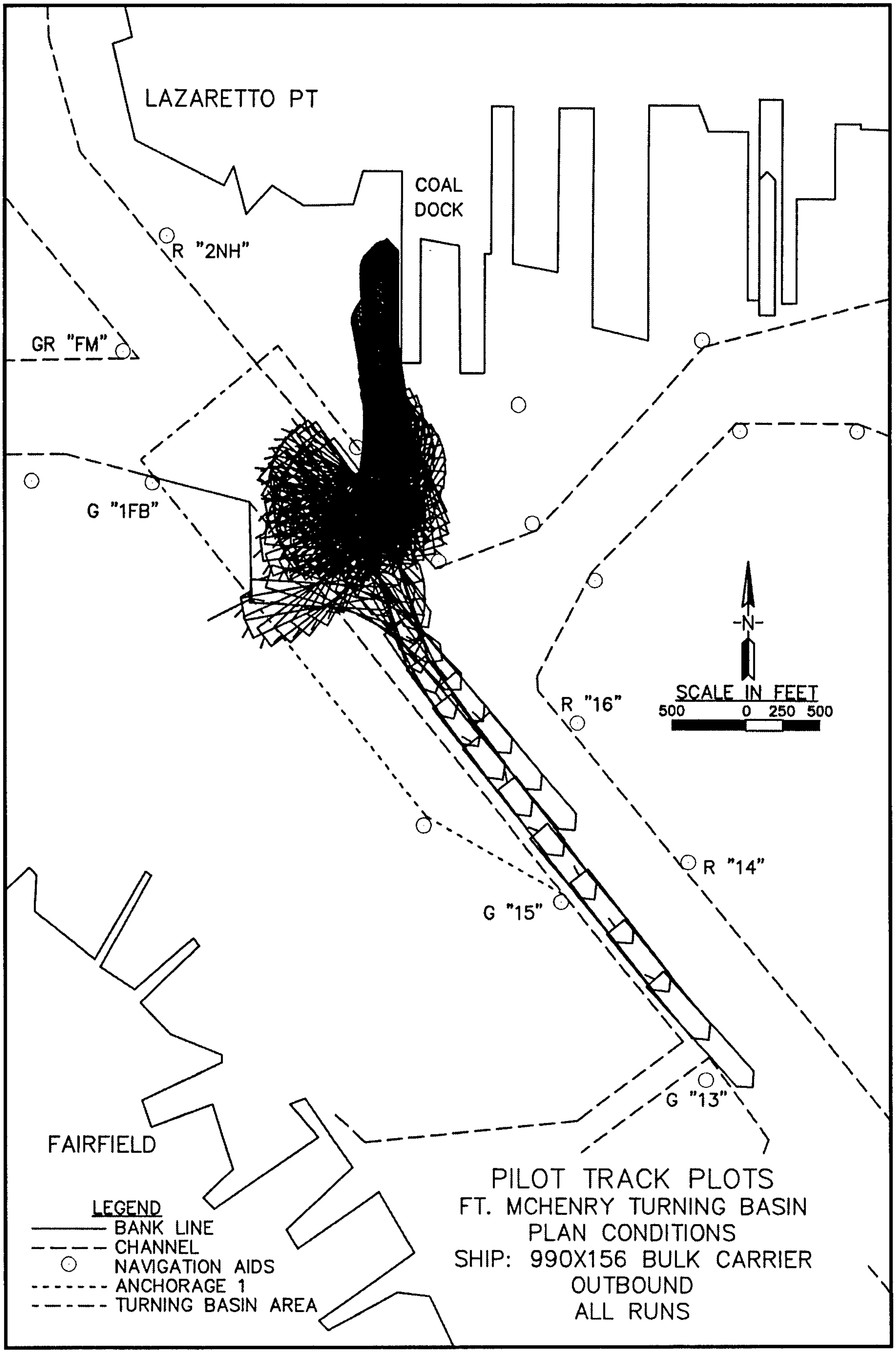
LAZARETTO PT
COAL DOCK
R "2NH"
GR "FM"
G "1FB"
R "16"
R "14"
G "15"
G "13"
N
SCALE IN FEET
500 0 250 500
FAIRFIELD
LEGEND
BANK LINE
CHANNEL
NAVIGATION AIDS
ANCHORAGE 1
TURNING BASIN AREA
PILOT TRACK PLOTS
FT. MCHENRY TURNING BASIN
PLAN CONDITIONS
SHIP: 990X156 BULK CARRIER
OUTBOUND
ALL RUNS

Plate 22

REPORT DOCUMENTATION PAGE

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5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Gary C. Lynch

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

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U.S. Army Engineer Research and Development Center
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Vicksburg, MS 39180-6199

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13. SUPPLEMENTARY NOTES

14. ABSTRACT

The Port of Baltimore was established in 1706 and is one of America's busiest deep-water ports. It is situated in a sheltered harbor and is easily accessed by major American and foreign ports. Its 45-mile shoreline supports many terminals for commercial trade, as well as public and private cargo terminals. In 1990, the main shipping channel from Cape Henry to Fort McHenry was dredged to a depth of 15 m (50 ft), allowing deeper-draft vessels to entry the port. In addition, new terminals were constructed, and public and private marine terminals were expanded. In 1997, the U.S. Army Engineer District, Baltimore, proposed a channel improvement project to widen the East and West Dundalk Channels and the connecting channel, which joins the Seagirt and West Dundalk Channels. The south Locust Point improvements would include widening the Fruit Pier Channel. In addition, the construction of a 15-m- (50-ft-) deep, 366-m- (1,200-ft-) square turning basin at the head of the Fort McHenry Channel was proposed. The improvements also included deepening and widening portions of Anchorages #3 and #4. The purpose of this simulation study was to evaluate the widening and realignment proposed by the District Office.

15. SUBJECT TERMS

Anchorage
Baltimore
Channel widening
Fort McHenry
Francis Scott Key Bridge
Navigation
Simulation
Turning basin

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON / 19b. TELEPHONE NUMBER *(include area code)*
UNCLASSIFEID	UNCLASSIFIED	UNCLASSIFIED		54	