APPENDIX A

LAKE WORTH INLET

Palm Beach Harbor

NAVIGATION STUDY FOR
LAKE WORTH INLET, FLORIDA

DRAFT INTEGRATED FEASIBILITY REPORT
AND ENVIRONMENTAL IMPACT STATEMENT

APPENDIX A

ENGINEERING

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A. INTRODUCTION

1. General. This appendix presents the discussion of applicable design considerations and construction methods utilized to adequately address the project requirements and to establish a basis for the cost estimates. General requirements for real estate and operation and maintenance are also presented.

2. Tentatively Selected Plan. The Tentatively Selected plan incorporates National Economic Development (NED) improvements to the Federal navigation project at Lake Worth Inlet, Florida. These improvements would include the addition of a new channel flare on the south side of the Entrance Channel, a widening of the Entrance Channel by either 40' or 60' to the north, widening of the Inner Harbor Cuts 1 and 2 to provide for a minimum channel width of 450', a 150' expansion of the Southern (Main) Turning Basin to the south, and an expansion of the Southern (Main) Turning Basin on the north side to remove a notch currently encroaching into the basin. The channel would be deepened to a project depth of 39 feet Mean Lower Low Water (MLLW) for the Inner Harbor and 41 feet MLLW for the Entrance Channel plus applicable allowances and overdepths discussed in this Appendix. Refer to Plate 2 for a complete description of the NED project improvement features.

In addition to the navigation project improvements described above that are necessary to facilitate the safe and efficient navigation of the design vessel, there are other features needed to support the project. These features include North Jetty stabilization, reconfiguration of the Advance Maintenance Zones, reconfiguration of the Settling Basin, Seagrass Mitigation Area construction, and Hardbottom Mitigation Area construction as detailed in this Appendix and other areas of the Feasibility Study Report.

A discussion of the plan formulation involved in the selection of the Tentatively Selected plan is presented in the main portion of this report. All soundings presented in this report are at MLLW based on the latest tidal epoch available from NOAA and the project is located geospatially in the North American Datum of 1983 (NAD83).

B. HYDROLOGY AND HYDRAULICS

3. General. A project location and vicinity map showing the features described below is provided on Plate 1. The currents and water surface elevations in Palm Beach Harbor are subject to tide, the effects of winds, upland drainage, and variations in barometric pressure. These factors serve as boundary conditions for the hydraulic forces influencing the smaller scale limits of this study area. The hydrodynamic model investigations conducted for this feasibility study are presented in an Attachment to this Appendix. Attachment A (Hydrodynamic Modeling) includes two dimensional model descriptions and results that were conducted in support of alternative evaluations and an assessment of channel modification impacts on bay circulation (i.e., currents), channel shoaling and storm surge.

4. Tides. The astronomical tide is the most important factor driving the circulation of water within the Harbor and in the variation of water elevations. The tide is semi-diurnal where two high waters and two low waters generally occur in a tidal day. The mean tide range is 2.72 ft and the spring tide range is 3.26 ft.

5. Currents. Tidal currents in the Palm Beach Harbor entrance channel are strong. The maximum currents occur in the entrance channel where maximum flood currents of 6.0 feet per second (3.6 knots) are experienced and the maximum ebb velocity is 4.0 feet per second (2.4 knots). Average flood and ebb velocities in the entrance channel are 3 feet per second (1.75 knots) and 2 feet per second (1.25 knots) respectively. At the Inner channel the average flood and ebb velocities are 2.7 feet per second (1.6 knots) and 2.5 feet per second (1.5 knots). In the Intracoastal Waterway (IWW) at Peanut Island the average flood and ebb velocities are both 1.3 feet per second (0.75 knots).

6. Sea Level Rise. The geologic record of historical sea level variations indicates that both increases and decreases in global sea level have occurred. Both global cooling and warming contribute to sea level change. The National Ocean Service (NOS) has compiled long term records of measured water surface elevations along the Atlantic coast. This data is the basis for projecting future relative sea level rise at Palm Beach Harbor.

Relative sea level (RSL) refers to local elevation of the sea with respect to land, including the lowering or rising of land through geologic processes such as subsidence and glacial rebound. It is anticipated that sea level will rise within the next 100 years. To incorporate the direct and indirect physical effects of projected future sea-level change on design, construction, operation, and maintenance of coastal projects, the U.S. Army Corps of Engineers (USACE) has provided guidance in the form an Engineering Circular, EC 1165-2-212 (USACE, 2011).

EC 1165-2-212 provides both a methodology and a procedure for determining a range of sea level rise estimates based on the local historic sea level rise rate, the construction (base) year of the project, and the design life of the project. Three estimates are required by the guidance, a baseline estimate representing the minimum expected sea level change, an intermediate estimate, and a high estimate representing the maximum expected sea level change. Following procedures outlined in EC 1165-2-212, Appendix B, baseline, intermediate, and high sea level rise values were estimated over the life of the project. Based on historical sea level measurements taken from NOS gage 8723170 at Miami Beach, Florida, the historic sea level rise rate was determined to be 2.39 mm/year (0.0078 ft/year) (http://tidesandcurrents.noaa.gov/sltrends/index.shtml); the project base year was specified as 2017; and the project life was projected to be 50 years. Figure F-1 shows the three levels of projected future sea level rise for the life of the project. From these curves, the baseline, intermediate, and high sea level rise values at the end of the 50 year life of the project were projected to be 0.39, 0.89 ft, and 2.47 ft, respectively.

The total regional sea level rise predicted by the three scenarios (baseline, intermediate, and high) will not have a significant impact to the performance of the Palm Beach Harbor project. Potential impacts of rising sea level include overtopping of waterside structures, increased shoreline erosion, and flooding of low lying areas. A positive potential impact of sea level rise on the project is a reduction in required maintenance due to increased depth in the channel.

In general, regional sea level rise (baseline, intermediate, and high) will not affect the function of the project alternatives or the overall safety of the design vessel. While there is expected to be a small increase in tidal surge and penetration for all three scenarios, the structural aspects of the project will be either unaffected or can be easily adapted to accommodate the change.

7. Storm Surge. An analysis was conducted to determine if there would be an impact to storm surge water levels at the project site due to proposed deepening of the Palm Beach Harbor Federal Navigation Project. A two-dimensional hydrodynamic model was used to simulate a 100-year return interval total storm tide event on two different model bathymetries representing the existing condition bathymetry and a future bathymetry representing the Federal project with all proposed deepening and widening of the channels and Harbor. The results of these numerical simulations were analyzed to determine any potential changes to total storm tide that might result from the proposed modifications to Palm Beach Harbor. Differences between with and without project water-level elevations in the vicinity of the harbor were less than 0.1 m. Therefore no significant impact of project alternative to storm surge is anticipated.

8. Shoaling. In order to assess changes to shoaling patterns and volumes resulting from proposed channel modifications, a two-dimensional hydrodynamic model was developed that is capable of simulating complex coupled wave, current and sediment transport processes. The settling basin to the north of the entrance channel is an integral part of the sediment transport dynamics in the entrance channel area. The settling basin has been expanded several times to reduce shoaling in the entrance channel. Included in this investigation is an evaluation of the present and proposed settling basin as well as recommended modification for greater reduction of shoaling in the navigation channel.

Future maintenance requirements based on model results and historical shoaling volumes for the Inner Harbor, which include the Inner Channel and Turning Basins is estimated to be a 9.5% increase (1636 cy/yr) of the historical volume (17,224 cy/yr) (See Attachment A, Hydrodynamic Modeling, Table ST1) which corresponds to the increase in project footprint for the Southern (Main) Turning Basin. The Inner Channel (Cuts 1 and 2) does not currently require any maintenance due to tidal flushing and this condition is not anticipated to change based on hydrodynamic modeling results. Since the Turning Basins are not dredged as often as the Entrance Channel and Settling Basin, it should not affect the dredging frequency.

In order to accommodate shoaling that occurs in the selected project alternative channel depth, advanced maintenance zones were established. Future maintenance requirements based on model results for the Entrance Channel (including Adv. Maint.) predict a shoaling rate of 33,000 cy/yr and for the Settling Basins a rate of 68,000 cy/yr. That is similar to the current shoaling rate; however, a significant portion of the volume is trapped in the settling basin rather than the channel. The dredge cycle for the proposed project is once every 2 years (it is 1 year currently) as the new capacity of these optimized features prevents the project from shoaling significantly above the project depth. Therefore, the total maintenance volume estimate is 202,000 cy/2 yr. This is based on an average basis, depending upon storm activity or lack thereof, where there may be periods when dredging is required annually and others where dredging is not required until 3 years after the previous event. Based on experience from other construction deepening projects completed by the Jacksonville District, it is anticipated that the first maintenance event for the project will not be needed until the third year following initial construction. This is primarily due to the incorporation of required overdepth in the initial construction dredging. The overall estimate is 24 Maintenance Dredging events over the 50-year project life.

C. GEOTECHNICAL

9. General. The geotechnical investigations and the geologic conditions encountered within the scope of study are presented in an Attachment to this Appendix. Attachment C (Geotechnical) includes core boring locations and associated representative data. Additional Investigations will be required to enhance the existing data to bring it to Plans and Specification standards.

10. Existing Jetty Stability. A slope stability analysis was performed using SLOPE/W within the GeoStudio 2004 (Version 6.22) suite to determine the stability of the existing channel slopes in the vicinity of both the north and south jetty. Slope geometry was based on information provided by a survey performed in 2002. Since the exact foundation elevations for both the north and south jetties are unknown, as described in Attachment C, it was conservatively assumed that between elevation -23.5 NAVD88 and -30.0 NAVD88 the foundation material consists of high blow count sand and not jetty stone. Engineering Manual (EM) 1110-2-1902 "Slope Stability" (dated 2003) was the guidance used, with Table 3-1 requiring a long-term minimum factory of safety of 1.5. The worst-case (i.e., steepest) slope scenarios were analyzed. The results of the slope stability analysis indicated that between an isolated area, from STA 42+50 to STA 45+50, for which the 2002 survey showed existing side slopes steeper than one foot vertical to two feet horizontal (1V:2H), the south jetty (in its current state) has an inadequate factor of safety of 1.05. The same 2002 survey indicated no specific areas of concern for the north jetty, and analysis determined that this jetty has an adequate factor of safety of 1.87 in its current state. It should be noted that the final plans and specifications will be referenced in the project datum, MLLW. However, this geotechnical analysis was performed using NAVD88 as the datum since the 2002 survey data, for which the slope stability model geometries were based on, was referenced to NAVD88.

11. Jetty Stability with Tentatively Selected Plan. A slope stability analysis was performed to determine if the proposed dredge design template would impact the stability of the existing jetties located to the north and south of the proposed project.

South Jetty: Analysis was performed at locations where the design template intercepted the existing slope closest to the jetties. The stability of the south jetty remained unaffected, as shown in Figure 2 of Attachment C, since the design template terminates approximately 50 feet north (i.e. 50 foot buffer) of the toe of the existing slope. As stated above, the south jetty in its current state has an inadequate factor of safety based on conservative assumptions outlined in Attachment C. No jetty stabilization features will be implemented since the proposed dredge design template will not impact its stability in its current state, and would therefore be outside the scope of this project.
North Jetty: Due to several unknown factors detailed in Attachment C, a 15 foot horizontal bench (i.e., 15 foot buffer) was established in the design, beyond the channel side toe of the north jetty, as an added safety measure. At locations along the north jetty from STA 39+00 to 44+00, where the channel template encroached into the 15 foot buffer, the channel template was adjusted to negate the impact, or jetty stabilization measures were incorporated into design to stabilize the jetty. The template was adjusted by eliminating the advanced maintenance in the areas where the design template width extends beyond the existing template (i.e., closer to the jetty). However, an abbreviated area, from approximately STA 38+75 to 40+75, still required the advance maintenance area due to the vast amount of sand that has been shown to shoal around the north jetty head. The preliminary design of a jetty stabilization feature consists of sheet pile wall placed near the jetty toe in this area which still required advanced maintenance. Details of the preliminary analysis including existing conditions, with project conditions, the methods used, and results are presented in Attachment C. Based on this preliminary evaluation, a PZC-26 sheet, extending below the surveyed bottom to an elevation -60.0 NAVD88 is currently recommended to stabilize the existing jetty.

Horizontal extents of this feature are currently anticipated to extend parallel to the jetty toe from approximately STA 38+75 to 40+75. Design details such as exact location, width, depth (minimum tip elevation), and sheet pile type will need to be refined during the PED phase using data resulting from the upcoming geotechnical exploration, scour analysis, and other design factors.

12. Channel Side Slope Selection. The available Geotechnical data indicates that the subsurface conditions for the areas west of STA 45+00 are composed of either thinly bedded and moderately hard limestone and sandstone, or layers of sand, silty sand, limestone and sandstone; therefore, side slopes of 1 foot vertical to 1 foot horizontal (1V:1H) were preliminarily selected for these areas. As an exception in these areas, the southern expansion of the Main Turning Basin will have a tiered system, with 1 foot vertical to 3 feet horizontal (1V:3H) slopes above EL 30.0 MLLW, and 1 foot vertical to 1 foot horizontal (1V:1H) below EL 30.0 MLLW. East of STA 45+00, borings indicate sand and silty sand; therefore, all slopes shall be no steeper than 1 foot vertical to 3 feet horizontal (1V:3H). The side slopes were derived from historical project information, an analysis of the materials to be dredged and existing channel bathymetry. Additional information is provided in Section D below.

D. DESIGN AND CONSTRUCTION

13. General. A project location map is shown on Plate 1. The proposed project plan of improvements to the Federal navigation channel is shown on Plates 2 through 8, and typical sections of the channel are provided on Plates 13 through 18.

14. Side Slopes. For estimating purposes, the average side slope for the proposed excavation was determined to be 1 vertical on 3 horizontal (1V:3H) for the Entrance Channel Station 0+00 to Station 45+00 and 1 vertical on 1 horizontal (1V:1H) for the remainder of the project with the exception of the southern expansion of the Main Turning Basin which utilizes a combined slope of 1V:1H below elevation -30' MLLW and 1V:3H above -30' MLLW, refer to Plates 11 through 18 for details.

15. Overdepths. An additional 2-foot of required overdepth and 1-foot of allowable overdepth are included in the estimated excavation quantities. The required overdepth would be necessary to facilitate future maintenance of the channel due to the existence of consolidated material at project depth. The allowable overdepth would be included to provide for inaccuracies in the dredging process in accordance with ER-1130-2-520, Navigation and Dredging Operations and Maintenance Policies.

16. Advance Maintenance and Settling Basin Reconfiguration. The existing project incorporates both advance maintenance and settling basin features as shown on Plate 9. In order to optimize the performance of these features, hydrodynamic modeling was conducted and the resulting reconfiguration of the advance maintenance zones and settling basins are shown on Plate 10. The primary purpose of the reconfigured features is to trap sediment outside of the Federal navigation channel thus preventing shoaling of the channel and decreasing the frequency of maintenance dredging needed to keep the channel open and free from navigation restrictions.

17. North Jetty Stabilization. The preliminary slope stability analysis determined that the North Jetty will require stabilization features to ensure jetty stability once the proposed project has been constructed. The stability of a portion of the North Jetty is affected by the 40-foot widening of the Entrance Channel to the north coupled with the need to incorporate advance maintenance zone C (AMZ-C) at the tip of the jetty to capture the littoral sand transport. The stabilization feature, sheet

pile, was developed using engineering judgment based on the limited core boring data available and historical records for the jetty construction. Refer to Plates 4, 10, and 15 for details regarding the location and length of the proposed sheet pile. A complete and thorough analysis of the subsurface conditions, design of the stabilization feature, as well as any new information pertaining to the existing jetty itself will be required during the PED phase based on the results of the new geotechnical exploration program.

18. Disposal Areas. It is anticipated that all of the material to be excavated from the Entrance Channel from Station 18+00 (project beginning) up to Station 45+00 would be placed in the Nearshore Placement Area immediately offshore of the existing beach placement area located south of the inlet. Currently, some real estate easements are not available for beach placement; however, if they become available at the time of construction then beach quality material would be placed to capacity in the Beach Placement areas prior to placement in the Nearshore. All material from the remainder of the project (Entrance Channel Station 45+00 to end, Cut-1, Cut-2, Southern Turning Basin, and reconfigured Settling Basins) would either be placed in the Palm Beach Ocean Dredged Material Disposal Site (ODMDS) or in the required mitigation sites for seagrass or hardbottom habitat. If, based on additional geotechnical investigations, it is determined that beach quality material exists in sufficient quantity and can be feasibly recovered from these areas of the project, then this material could be placed in the Beach or Nearshore Placement Areas rather than the ODMDS. Refer to Plates 19 and 20 for the Beach and Nearshore Placement Areas plan and typical sections, Plate 23 for the Palm Beach ODMDS site plan, and Plates 21 and 22 for mitigation site locations and conceptual plan and typical sections.

Opportunities for additional beneficial use of dredged material exist in the project vicinity such as the filling of anoxic deepwater holes in the Lake Worth Inlet Lagoon, creation of hardbottom habitat, creation of habitat for submerged aquatic vegetation such as seagrasses and/or placement of beach quality material at the MidTown Beach Placement Area. It is not anticipated that the alternative forms of disposal of the dredged material from this project for purposes of beneficial use will result in any cost savings to the project; however, if cost increases are considered small or if there is local interest in paying for any cost difference, these alternatives could be further developed and incorporated into the project.

19. Construction Procedure. For cost estimating purposes, it is anticipated that a mechanical dredge (barge mounted backhoe) and scow barges would be used for construction of the Inner Harbor and Settling Basin and a hydraulic cutter-suction dredge would be utilized to dredge the Entrance Channel where beach quality material exists. Mechanical dredging would be utilized for the portions of the project that involve disposal at the ODMDS or mitigation sites and the hydraulic dredge is utilized where beach quality material exists and disposal occurs by pumping material directly onto the beach or into the nearshore placement area.

E. RELOCATIONS

20. General. The project sponsor would be required to assume the costs of all relocations and alterations. An investigation into possible utility relocations has been conducted and based on its results there are no relocations anticipated. There is an existing pipeline under the Entrance Channel to service the Sand Transfer Plant that is below the depth of the proposed project as shown on Plate 5.

F. OPERATION AND MAINTENANCE

21. General. The Federal Government currently maintains the existing project annually. The Federal Government would be responsible for operation and maintenance of the improvements to the Federal Navigation project proposed in this report upon completion of the construction contract. The local sponsor, Port of Palm Beach, would be responsible for the costs of the construction and maintenance dredging of the Port Slip 3. The Port of Palm Beach is also responsible for the costs of infrastructure improvement of the port facilities that are scheduled to be completed in advance of the authorization of the Federal navigation improvements.

22. Estimated Annual Cost. Based on the hydrodynamic model results it is shown that the proposed project improvements result in a relatively small increase in maintenance volumes in the Inner Channels and Entrance Channel. However, with the implementation of the reconfigured Settling Basin and Advance Maintenance features it is anticipated that the frequency of maintenance dredging events can be decreased from an annual basis to a biannual basis. For the project life of 50 years this optimization will result in an overall reduction of maintenance dredging costs by reducing the fixed costs of dredge mobilization and the administration of 24 rather 50 contracts. Refer to the Economic Appendix for further details regarding the estimated maintenance costs for the project.

23. Navigation Aids. The U.S. Coast Guard (USCG) would be responsible for providing and maintaining navigation aids. Since there will only be a slight realignment of the Entrance Channel centerline (20' northerly shift), the Palm Beach Harbor Pilots have requested that there be no relocation of the Range Markers from their current positions. The channel widening and turning basin expansion will necessitate the need to relocate certain buoys; however, this relocation is considered minor and incidental by the USCG and therefore there will be no cost to the project for their physical relocation. A relatively small amount of cost is identified in the MCACES estimate to cover miscellaneous administrative costs for coordination with the USCG during and post construction.

G. QUANTITIES AND COST ESTIMATES

24. Summary of Quantities. A summary of the major construction items are presented in Table T-1 and details of the areas to be dredged are provided in Tables T-2 and T-3 below.

25. Summary of Costs. The estimates of first cost for construction of the NED Plan were prepared using MCACES software and are presented in the Cost Appendix. The estimate includes a narrative, a summary cost, and a detailed cost showing quantity, unit cost, and the amount for contingencies for each cost item. The costs of the non-construction features of the project are also included in the cost estimate.

The costs have been prepared for an effective date of Fiscal Year 2013 (FY13).

H. SHIP SIMULATION STUDY

26. Discussion. The preliminary engineering design for improvements to deep draft navigation features at Lake Worth Inlet and Palm Beach Harbor was completed in May of 2011. Optimization and testing of the design was scheduled for the third quarter of that year. The Full-Bridge, 360 degree Simulator at STAR Center, in Dania, Florida was selected for the simulation work, and testing by the Professional Harbor Pilots from the Port of Palm Beach. STAR Center was the preferred site for the ship simulation study, based on the fact that they maintain a validated simulation model of Palm Beach Harbor, that could be modified to optimize and test the new engineering design, in conformance with engineering quality requirements mandated by the Corps. The model had been developed earlier, for a study conducted by the Port, of their planned cruise terminal expansion and associated deep draft facilities. A formal proposal to conduct the study at STAR Center was negotiated at the Corps of Engineers in Jacksonville, in July of 2011. Engineering oversight for the work at STAR Center was provided by Dennis W. Webb, PE, Group Leader, Deep Draft Navigation Group, US Army Corps of Engineers, Engineering Research and Development Center, Vicksburg, Mississippi, and, Philip T Sylvester, hydraulic engineer ship simulation technical expert from the Corps of Engineers, Jacksonville District.

Validation of the Lake Worth Inlet / Palm Beach Harbor simulation model was accomplished during the first day of simulations that were completed over the two week period, September 18 to October 2, 2011. Validation is a test of the water currents used in the model. It is a confirmation of the channel layout and navigation aid placement. Validation is a check of the maneuverability and ship handling characteristics, in real time, that each design vessel demonstrates, in the exact visual space displayed by the simulator, as the engineering design of the harbor, properly and correctly referenced and fixed, in the overall larger testing domain. The water currents examined and verified were provided through hydrodynamic modeling of the harbor, by the Corps Coastal Hydraulics group in Jacksonville. Validation is an essential component of the study, performed by the licensed professional harbor pilots from Palm Beach Harbor, that certifies the usefulness and correctness of the simulation model as an engineering tool properly conceived and developed to optimize and test the proposed engineering design.

STAR Center completed their Final Report of Lake Worth Feasibility Study in December of 2011. The report is a comprehensive discussion of the simulator facility, and the activities associated with ship simulation testing of the proposed engineering design for Lake Worth Inlet /Palm Beach Harbor. Simulation testing matrix, simulation scenario track plots, and harbor pilot post test run evaluations are included in it appendices. The report also includes observations and recommendations with regard to engineering design in the context of navigation usefulness, relevance, and safety. The Report is provided as Attachment B for review and reference. The track plots and comment sheets from the Report are considered to be proprietary intellectual information by the Port of Palm Beach Pilots. A copy of this information is held in confidence by ERDC and the District Office (Philip Sylvester 904-232-1142).

27. Optimization. The Professional Harbor Pilots from Palm Beach Harbor have been on the engineering study team from the very beginning of design development for their facility. The Corps of Engineers in Jacksonville always engages the local harbor pilot group and cultivates a close professional working partnership with them, to learn their site, to understand their problem, and formulate a possible solution that will improve their efficiency and safety. Palm Beach Harbor Pilots' Association has been an active, cooperative, and highly valued member of the engineering design team. Their group has provided many hours of work to develop and shape the engineering design for their facility. This work included direct visits of the Corps design team to the Pilots' office to

work hand in hand on refinements of the channel in order to ensure that no mistakes or misunderstandings could occur with the development of the final plan. They have provided a written statement of support for the design alternative selected during simulations, and worked with the Jacksonville engineering design team to iterate that tested concept into its current, "perfected", buildable form. Their letter of support is included in the Attachment B for review and reference.

28. Agency Technical Review. The control of quality is an essential component of the engineering mission at the Jacksonville District. The ship simulation study conducted at STAR Center – its concept, development, execution, oversight, and conclusions – has been successfully examined for quality and correctness, within the formal framework of Agency Technical Review. All comments have been evaluated, addressed, and back-checked to the satisfaction of the assigned review team. A copy of the ATR comment report has been added to Attachment B.

Figure F-1. Projected Future Sea Level Rise at Palm Beach Harbor

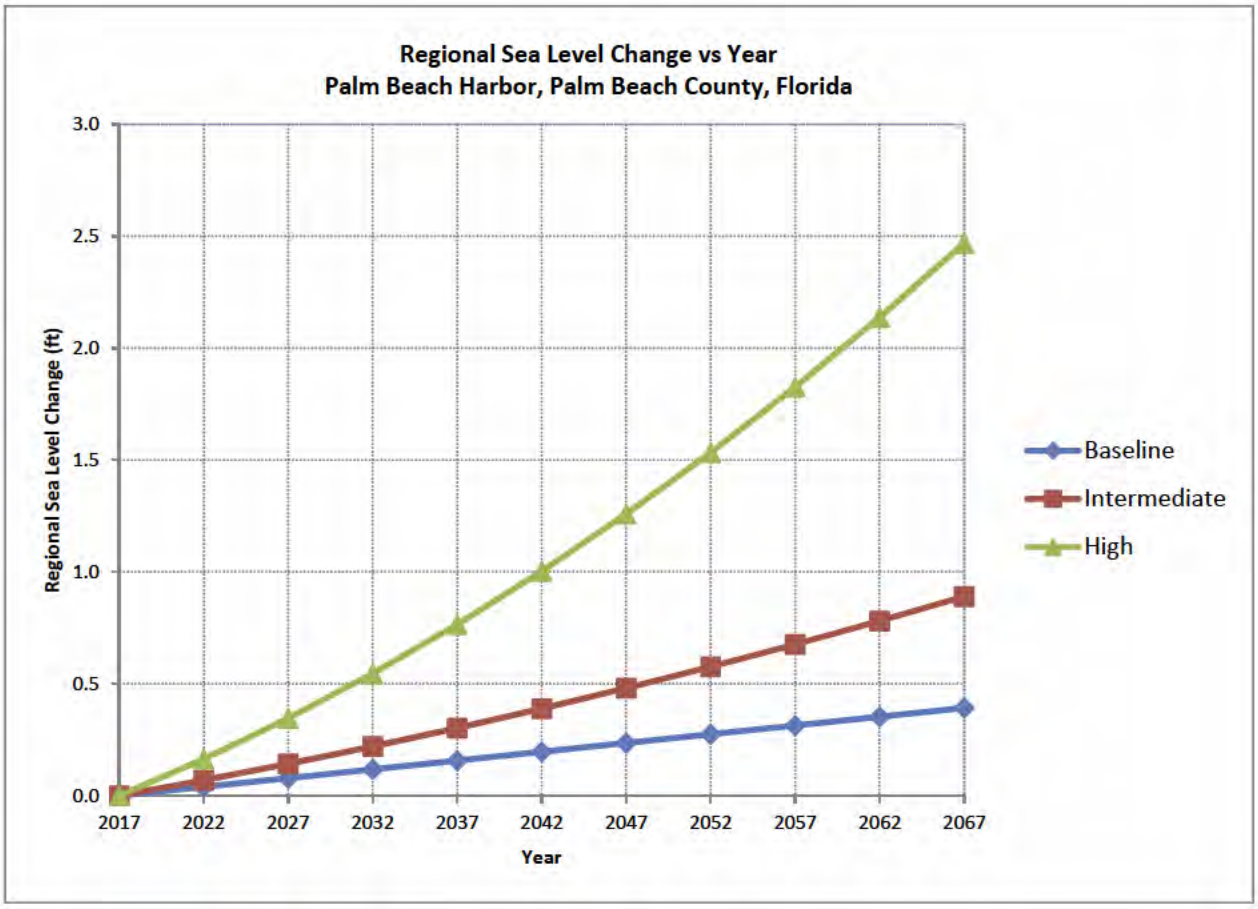


Table T-1 Summary of Construction Quantities for Tentatively Selected Plan

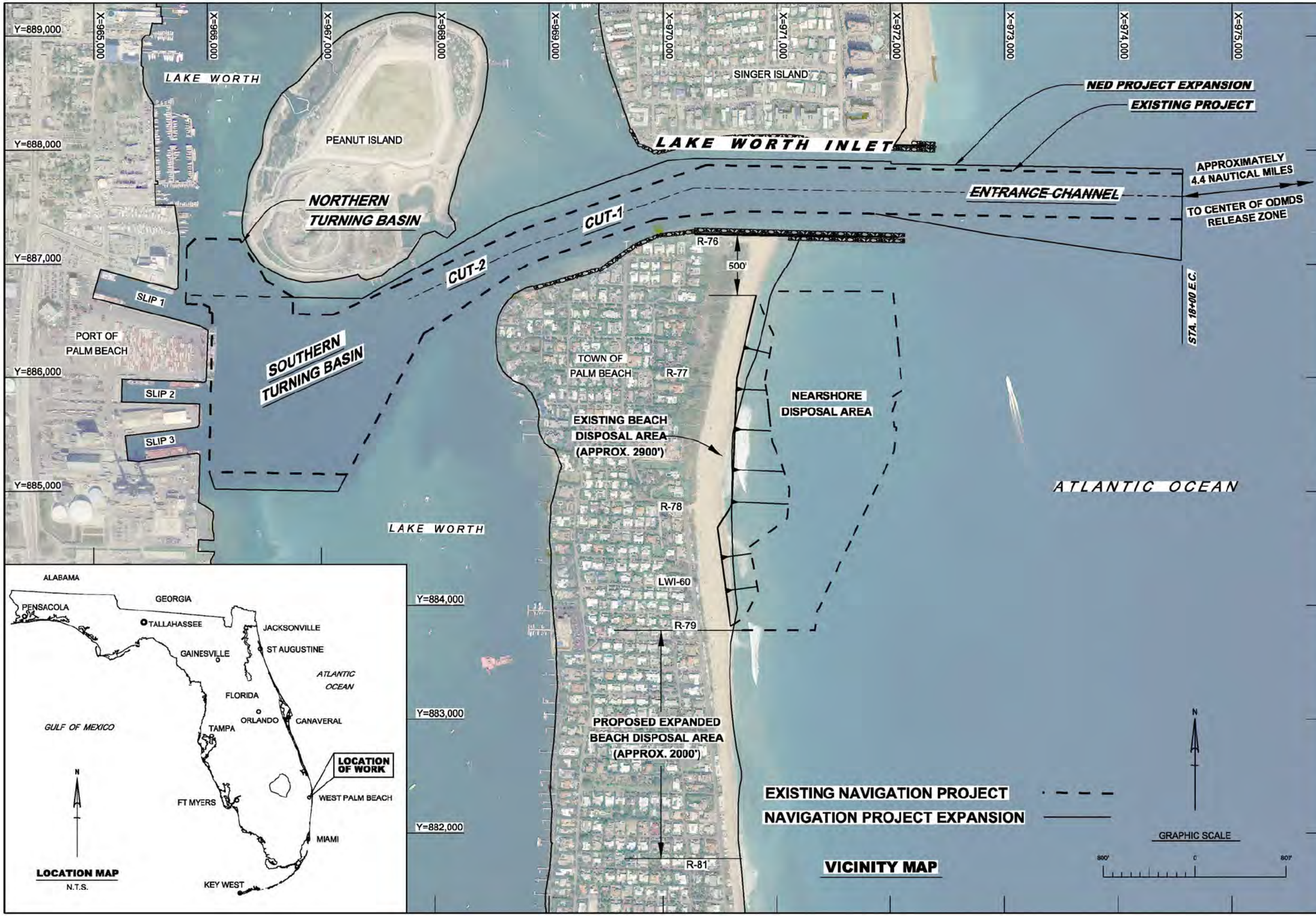
Item	Quantity	Notes
Dredging Volumes (Federal)		
Entrance Channel	285,404 cubic yards	Disposal in nearshore
Entrance Channel	145,767 cubic yards	Disposal in ODMDS
Inner Harbor	910,129 cubic yards	Disposal in ODMDS
Inner Harbor	112,950 cubic yards	Disposal in Seagrass Mitigation Area
Advance Maintenance	173,500 cubic yards	Disposal in nearshore
Advance Maintenance	12,000 cubic yards	Disposal in ODMDS
Settling Basin	258,000 cubic yards	Disposal in ODMDS
North Jetty Stabilization		
PZC26 Sheet Pile	200 LF, pile length = 63 feet	
Seagrass Mitigation Construction		
Dredge, Transport and Place Fill	75,825 cubic yards*	Place in Dredged Hole
Dredge, Transport and Place Select Fill	37,125 cubic yards*	Place in Dredged Hole
Hardbottom Mitigation Construction		
Provide and place limestone boulders	25,100 cubic yards	Place in Artificial Reef Site

*It is anticipated that approximately 112,950 cy of material from the Inner Harbor will be used in the construction of the Seagrass Mitigation Area rather than be disposed in the ODMDS.

*modified by stacey to palce border, background white, and remove specific assumed mitigation sites

Table T-2 Summary of Dredge Areas and Haul Distances			
Dredge Area	Surface Area (sqft)	Distance to Nearshore (ft)	Distance to ODMDS (ft)
1	48000	4285	27163
2	480000	4153	27189
3	346746	3950	27237
4	52000	3390	28405
5	520000	3222	28430
6	166900	3012	28465
7	10555	2979	29150
8	80000	2786	29174
9	3150	2597	29201
10	1200	2884	29350
11	80000	2693	29374
12	78000	2666	30096
13	524495	2461	30119
14	385806	N/A	32332
15	1048763	N/A	32176
16	75813	N/A	34288
17	2340508	N/A	34977
18	535596	N/A	35822
4AMA	36000	3390	28405
4AMC	6000	3390	28405
5AMA	360000	3222	28430
5AMC	18750	3222	28430
6AMA	142420	3012	28465
5/8AMB	221250	2786	29174
11AMB	80000	2693	29374
SB1	266000	3770	28330
SB2	38000	3770	28530
SB3	78750	3965	28650

Table T-3 Summary of Dredging Volumes for Tentatively Selected Plan				
Project Depth = 39 feet (Volumes include 2 feet required overdepth plus 1 foot allowable overdepth)				
Supports unrestricted vessel movement at draft = 36 feet (3 feet Underkeel Clearance for Inner Harbor and 5 feet Underkeel Clearance for Entrance Channel)				
Channel Area	Depth	Volume (cy)	Nearshore	ODMDS
1	44	6648	X	
2	44	65724	X	
3	44	69081	X	
4	44	40765	X	
4AMA	52	10700	X	
4AMC	52	1800	X	
5	44	45336	X	
5AMA	52	107000	X	
5AMC	52	5500	X	
6	44	43657	X	
6AMA	52	42500	X	
7	44	3281	X	
8	44	9577	X	
8AMB	48	6000	X	
9	44	1335	X	
10	44	5568		X
11	44	15663		X
11AMB	48	12000		X
12	44	40867		X
13	44	83669		X
14	42	228339		X
15	42	118469		X
16	42	66063		X
17	42	429989		X
18	42	180219		X
TOTALS		1639750	458904	1180846
Settling Basin Area				
SB1	52	167000		X
SB2	35	31000		X
SB3	27	60000		X
TOTALS		258000		258000



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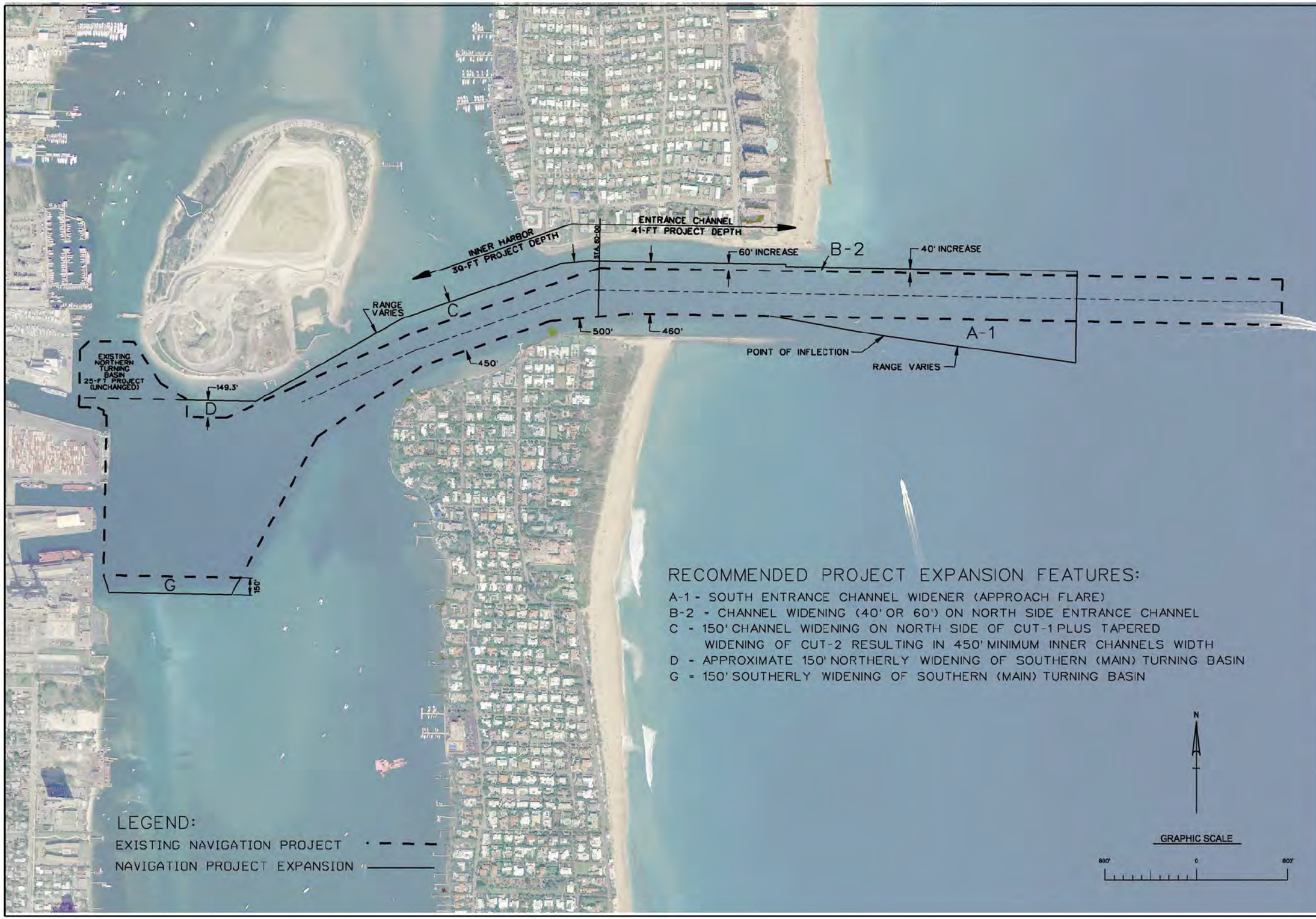
LAKE WORTH INLET NAVIGATION PROJECT
PALM BEACH HARBOR, FLORIDA

NED PLAN
LOCATION AND VICINITY MAPS

FEASIBILITY STUDY - ENGINEERING APPENDIX

PLATE
1



RECOMMENDED PROJECT EXPANSION FEATURES:

A-1 - SOUTH ENTRANCE CHANNEL WIDENER (APPROACH FLARE)
B-2 - CHANNEL WIDENING (40' OR 60') ON NORTH SIDE ENTRANCE CHANNEL
C - 150' CHANNEL WIDENING ON NORTH SIDE OF CUT-1 PLUS TAPERED WIDENING OF CUT-2 RESULTING IN 450' MINIMUM INNER CHANNELS WIDTH
D - APPROXIMATE 150' NORTHERLY WIDENING OF SOUTHERN (MAIN) TURNING BASIN
G - 150' SOUTHERLY WIDENING OF SOUTHERN (MAIN) TURNING BASIN

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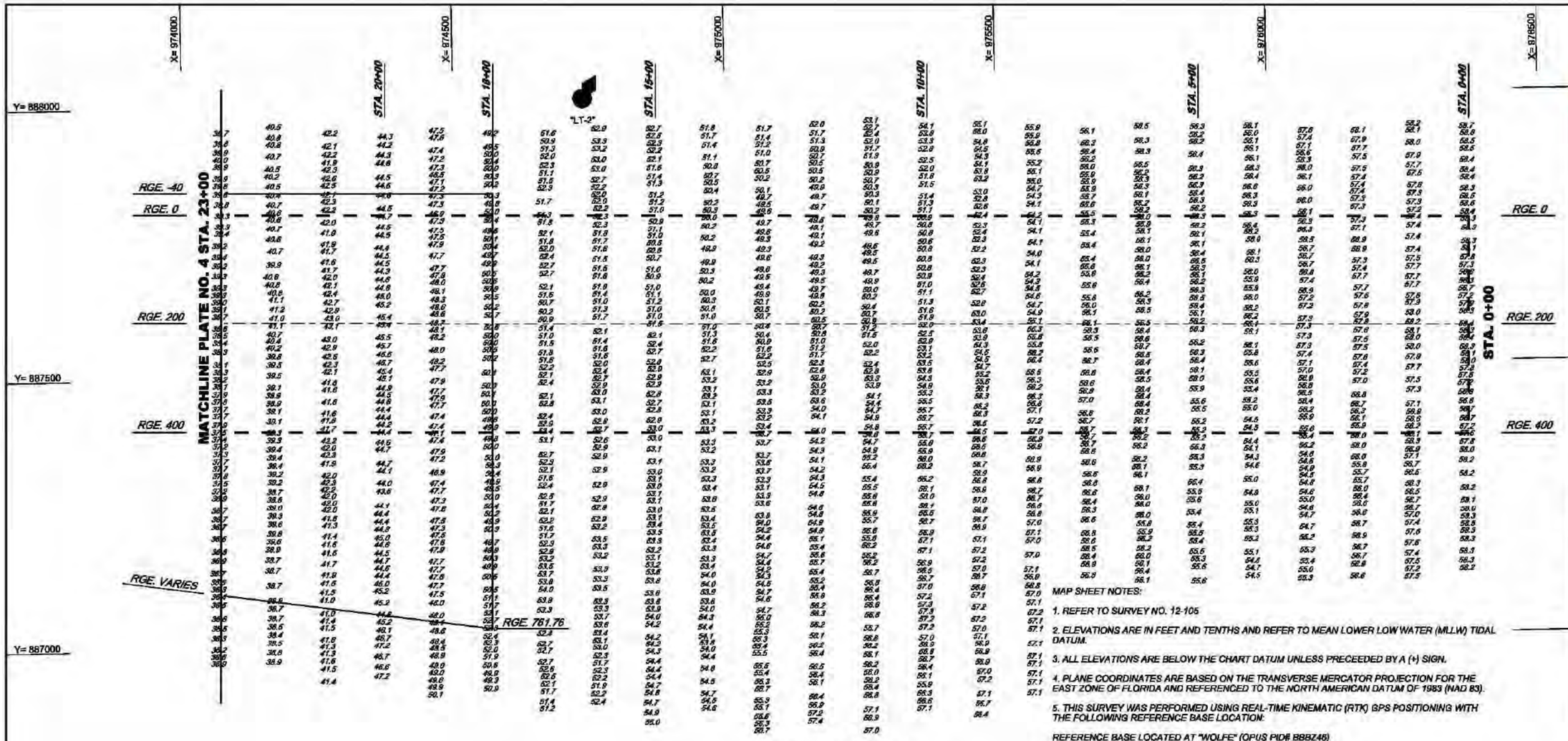
LAKE WORTH INLET NAVIGATION PROJECT
PALM BEACH HARBOR, FLORIDA
NED PLAN
IMPROVEMENTS OVERVIEW
FEASIBILITY STUDY - ENGINEERING APPENDIX

PLATE
2



AIDS TO NAVIGATION	PLANE COORDINATES	
	X	Y
LT. BUOY-2 (04/12)	974739.28	888007.95

EXISTING NAVIGATION PROJECT

NAVIGATION PROJECT EXPANSION

NOTE: STATION AND RANGE VALUES ARE RELATIVE TO THE EXISTING PROJECT CONTROL.

N

GRAPHIC SCALE

200' 0 200'

MAP SHEET NOTES:

1. REFER TO SURVEY NO. 12-105

2. ELEVATIONS ARE IN FEET AND TENTHS AND REFER TO MEAN LOWER LOW WATER (MLLW) TIDAL DATUM.

3. ALL ELEVATIONS ARE BELOW THE CHART DATUM UNLESS PRECEEDED BY A (+) SIGN.

4. PLANE COORDINATES ARE BASED ON THE TRANSVERSE MERCATOR PROJECTION FOR THE EAST ZONE OF FLORIDA AND REFERENCED TO THE NORTH AMERICAN DATUM OF 1983 (NAD 83).

5. THIS SURVEY WAS PERFORMED USING REAL-TIME KINEMATIC (RTK) GPS POSITIONING WITH THE FOLLOWING REFERENCE BASE LOCATION:

REFERENCE BASE LOCATED AT "WOLFE" (OPUS PID# BBBZ46)

TIDE STAFF LOCATED FROM "A 310" (PID# AD2870)

6. DEPTHS DEPICTED BY THIS SURVEY ARE REFERENCED TO MLLW, TIDAL EPOCH 1983-2001, AS REPORTED BY THE NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION (NOAA). NOAA'S VDATUM MODEL WAS USED AND CALIBRATED TO THE PUBLISHED MLLW HEIGHTS OF THE BEANCH MARKS ASSOCIATED WITH THE TIDE GAGE SITE SPECIFIED BELOW:

NOAA TIDAL STATION 872-2588, PORT OF W. PALM BEACH, LAKE WORTH

7. VERTICAL MEASUREMENTS WERE MADE USING A ROSS SMART SOUNDER MODEL 835 WITH A SINGLE BEAM TRANSDUCER OPERATING AT 28 AND 200 kHz. SOUNDINGS SHOWN ARE IN HIGH FREQUENCY.

SURVEY VESSEL	DATE OF SURVEY	CUT
SB-32	24-25 APR 2012	ENT CH, CUT-1, CUT-2, TURNING BASIN

8. THE INFORMATION DEPICTED ON THIS MAP REPRESENTS THE RESULTS OF SURVEYS MADE ON THE DATES INDICATED ABOVE AND CAN ONLY BE CONSIDERED AS INDICATING THE GENERAL CONDITIONS AT THAT TIME. THIS CHART IS SOLELY FOR THE DISTRIBUTION OF AVAILABLE DEPTHS AT THE TIME OF SURVEY.

9. SURVEY ACCURACY STANDARDS, QUALITY CONTROL, AND QUALITY ASSURANCE REQUIREMENTS WERE FOLLOWED DURING THIS SURVEY IN ACCORDANCE WITH USACE EM 1110-2-1003, HYDROGRAPHIC SURVEYING, 1 JAN 02.

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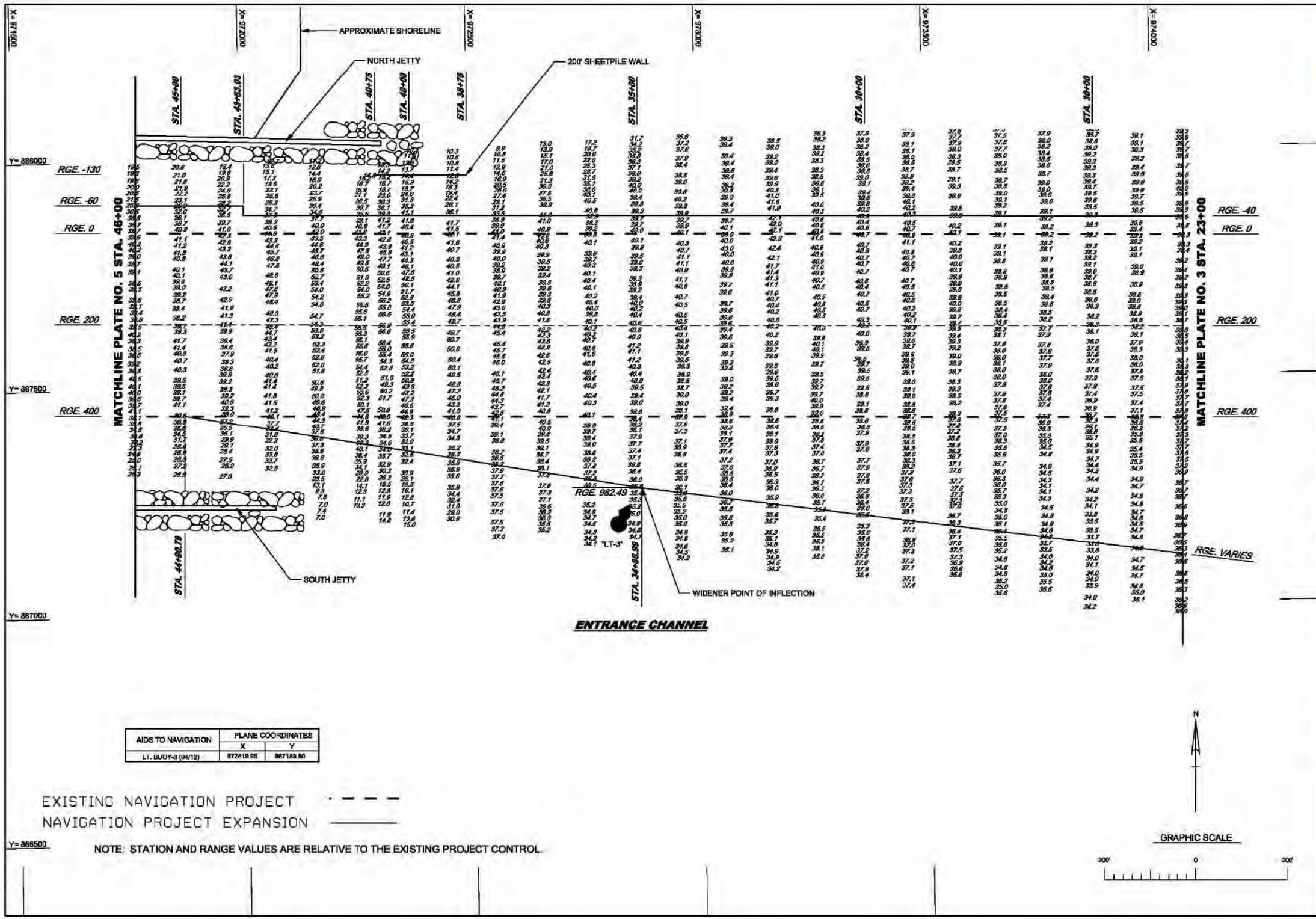
LAKE WORTH INLET NAVIGATION PROJECT
PALM BEACH HARBOR, FLORIDA
NED PLAN
STA. 0+00 TO STA. 23+00 ENTRANCE CHANNEL
FEASIBILITY STUDY - ENGINEERING APPENDIX

PLATE
3



AIDS TO NAVIGATION	PLANE COORDINATES	
	X	Y
LT. BUOY-3 (04/12)	972819.95	867189.80

EXISTING NAVIGATION PROJECT · — — —

NAVIGATION PROJECT EXPANSION ———

NOTE: STATION AND RANGE VALUES ARE RELATIVE TO THE EXISTING PROJECT CONTROL.

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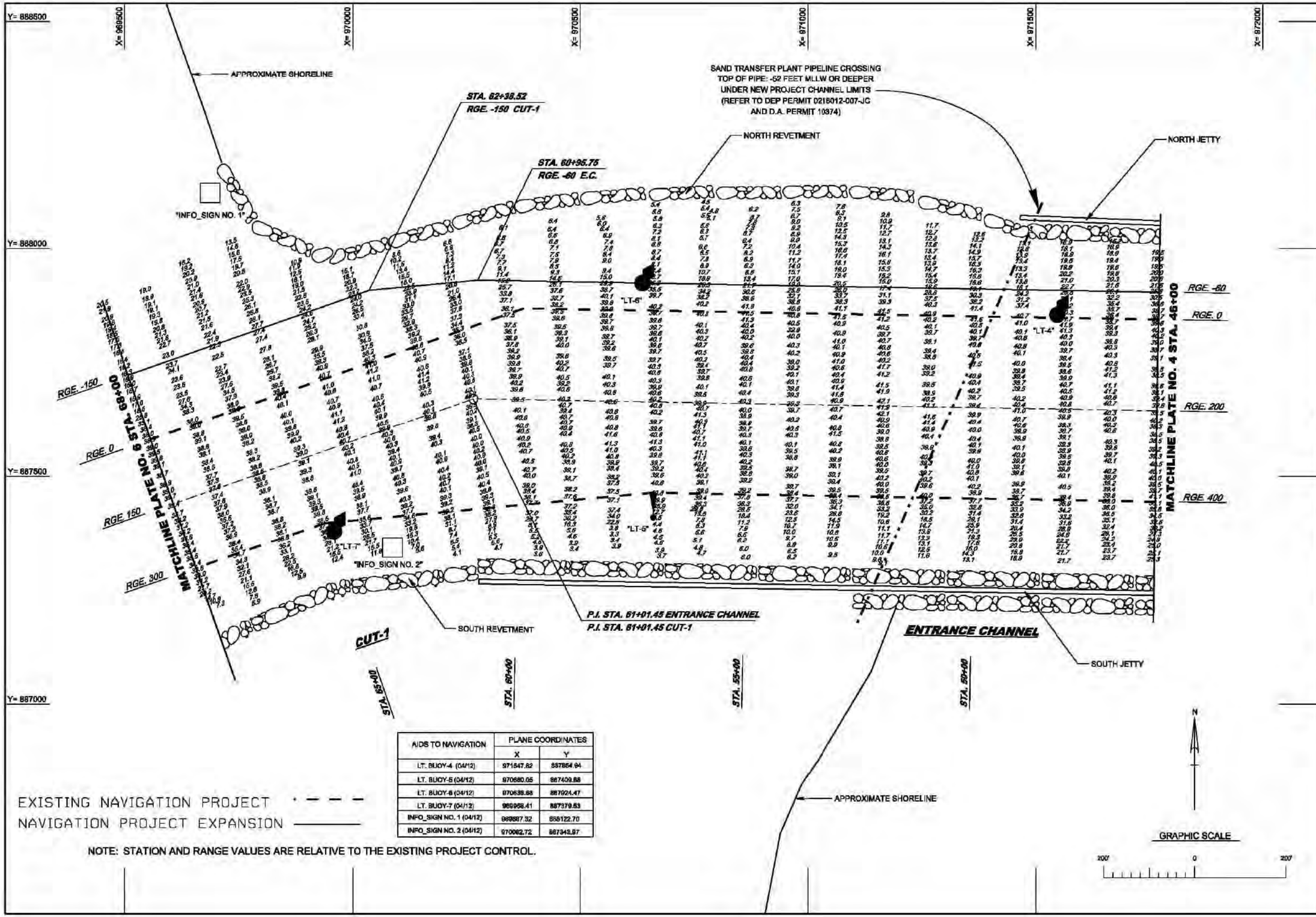
LAKE WORTH INLET NAVIGATION PROJECT
PALM BEACH HARBOR, FLORIDA
NED PLAN
STA. 23+00 TO STA. 46+00 ENTRANCE CHANNEL
FEASIBILITY STUDY - ENGINEERING APPENDIX

PLATE
4



AIDS TO NAVIGATION	PLANE COORDINATES	
	X	Y
LT. BUOY-4 (04/12)	971547.62	887854.94
LT. BUOY-5 (04/12)	970680.05	887409.88
LT. BUOY-6 (04/12)	970639.88	887924.47
LT. BUOY-7 (04/12)	969958.41	887379.53
INFO_SIGN NO. 1 (04/12)	969887.32	888122.70
INFO_SIGN NO. 2 (04/12)	970062.72	887343.97

EXISTING NAVIGATION PROJECT
NAVIGATION PROJECT EXPANSION

NOTE: STATION AND RANGE VALUES ARE RELATIVE TO THE EXISTING PROJECT CONTROL.

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Plot scale:
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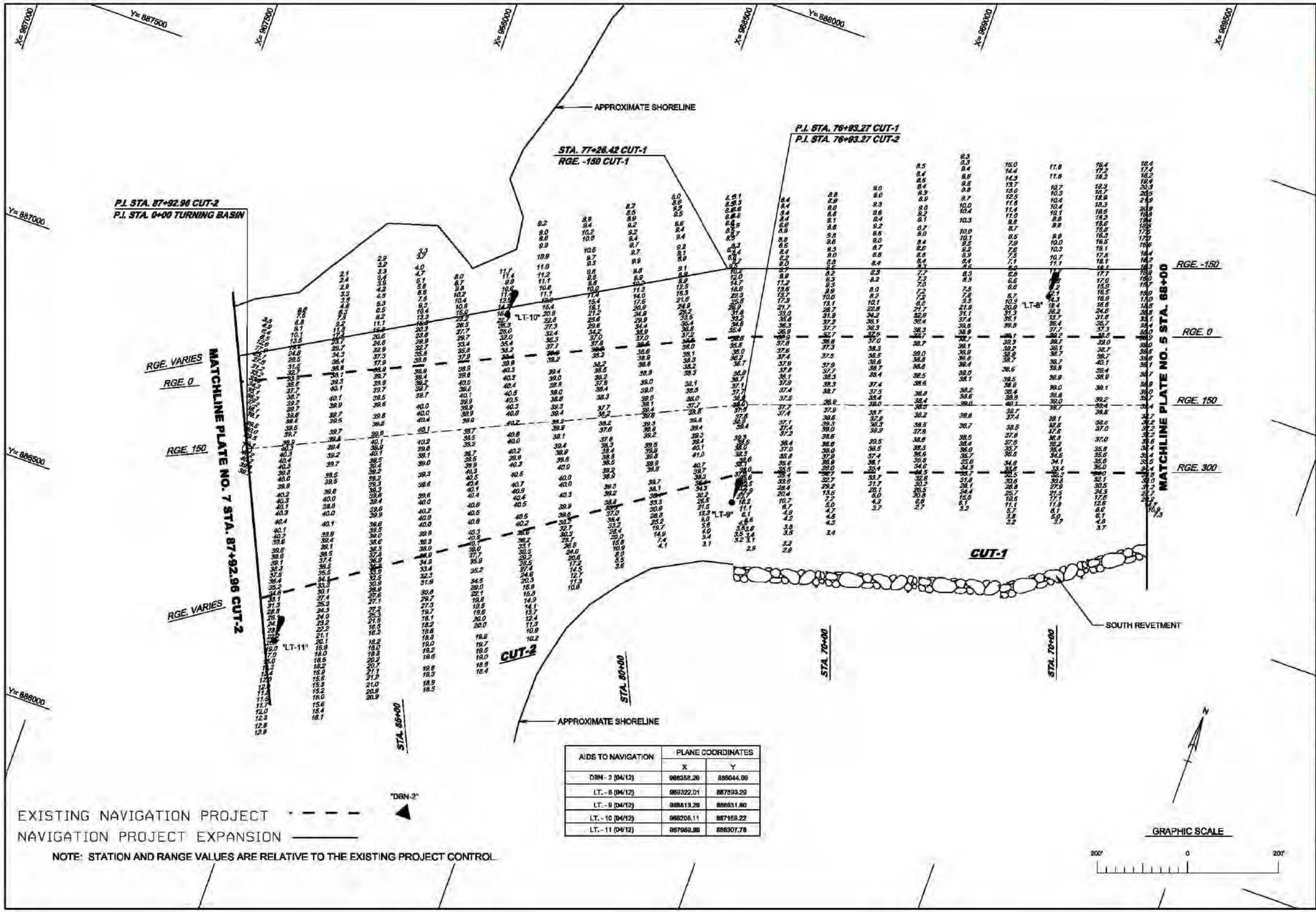
Reference files:

LAKE WORTH INLET NAVIGATION PROJECT
PALM BEACH HARBOR, FLORIDA
NED PLAN
STA. 46+00 ENTRANCE CHANNEL TO STA. 68+00 CUT-1
FEASIBILITY STUDY - ENGINEERING APPENDIX

PLATE
5



AIDS TO NAVIGATION	PLANE COORDINATES	
	X	Y
DBN - 2 (04/12)	868358.26	886044.66
LT. - 8 (04/12)	868322.01	887593.29
LT. - 9 (04/12)	868813.29	886831.80
LT. - 10 (04/12)	868208.11	887168.22
LT. - 11 (04/12)	867959.89	886307.78

NOTE: STATION AND RANGE VALUES ARE RELATIVE TO THE EXISTING PROJECT CONTROL

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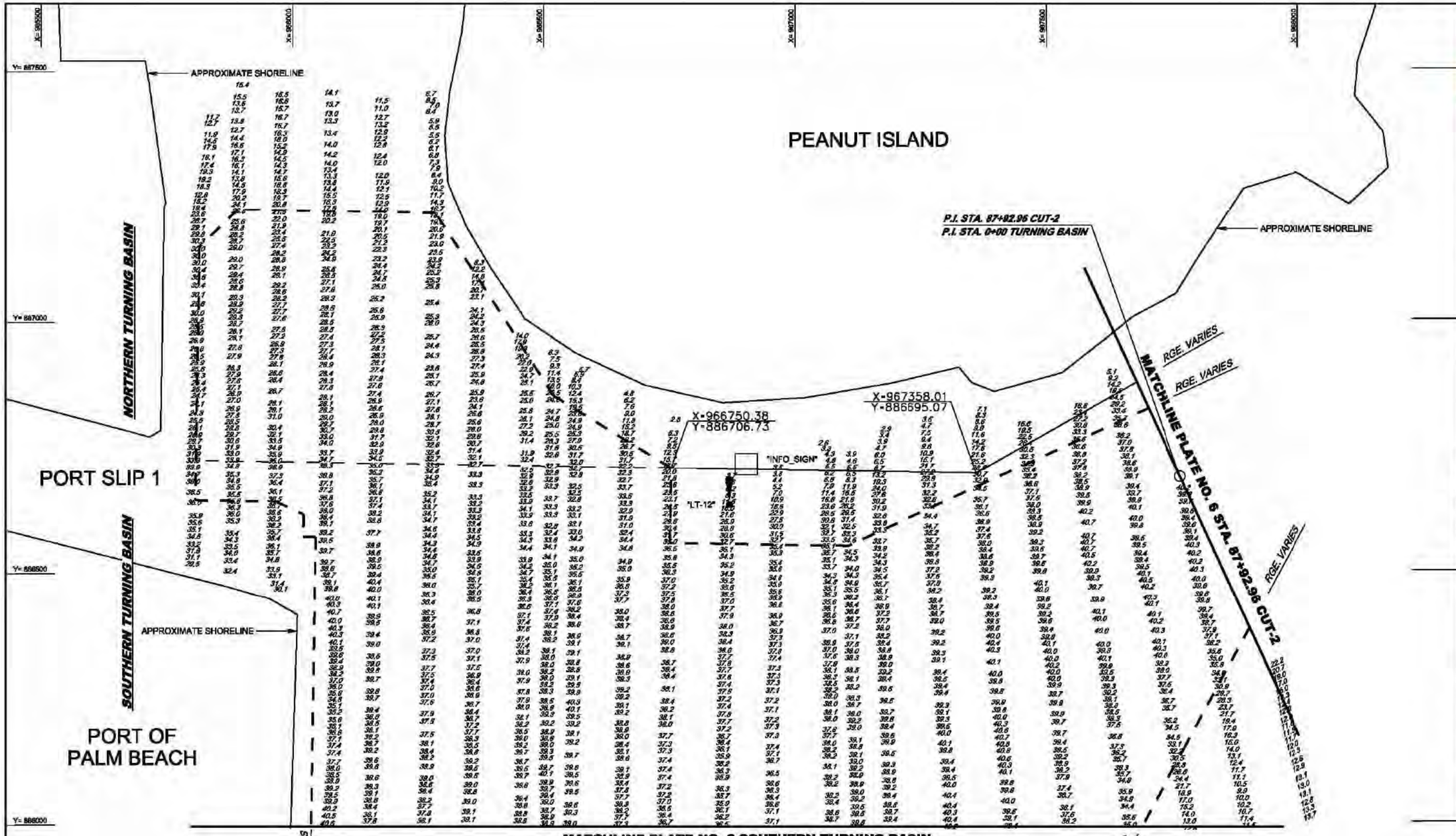
Reference files:

LAKE WORTH INLET NAVIGATION PROJECT
PALM BEACH HARBOR, FLORIDA
NED PLAN
STA. 68+00 CUT-1 TO STA. 87+92.96 CUT-2
FEASIBILITY STUDY - ENGINEERING APPENDIX

PLATE
6



AIDS TO NAVIGATION	PLANE COORDINATES	
	X	Y
LT. - 12 (04/12)	967959.99	886307.78
INFO SIGN (04/12)	968899.52	886714.27

EXISTING NAVIGATION PROJECT

NAVIGATION PROJECT EXPANSION

NOTE: STATION AND RANGE VALUES ARE RELATIVE TO THE EXISTING PROJECT CONTROL.

GRAPHIC SCALE

200' 0 200'

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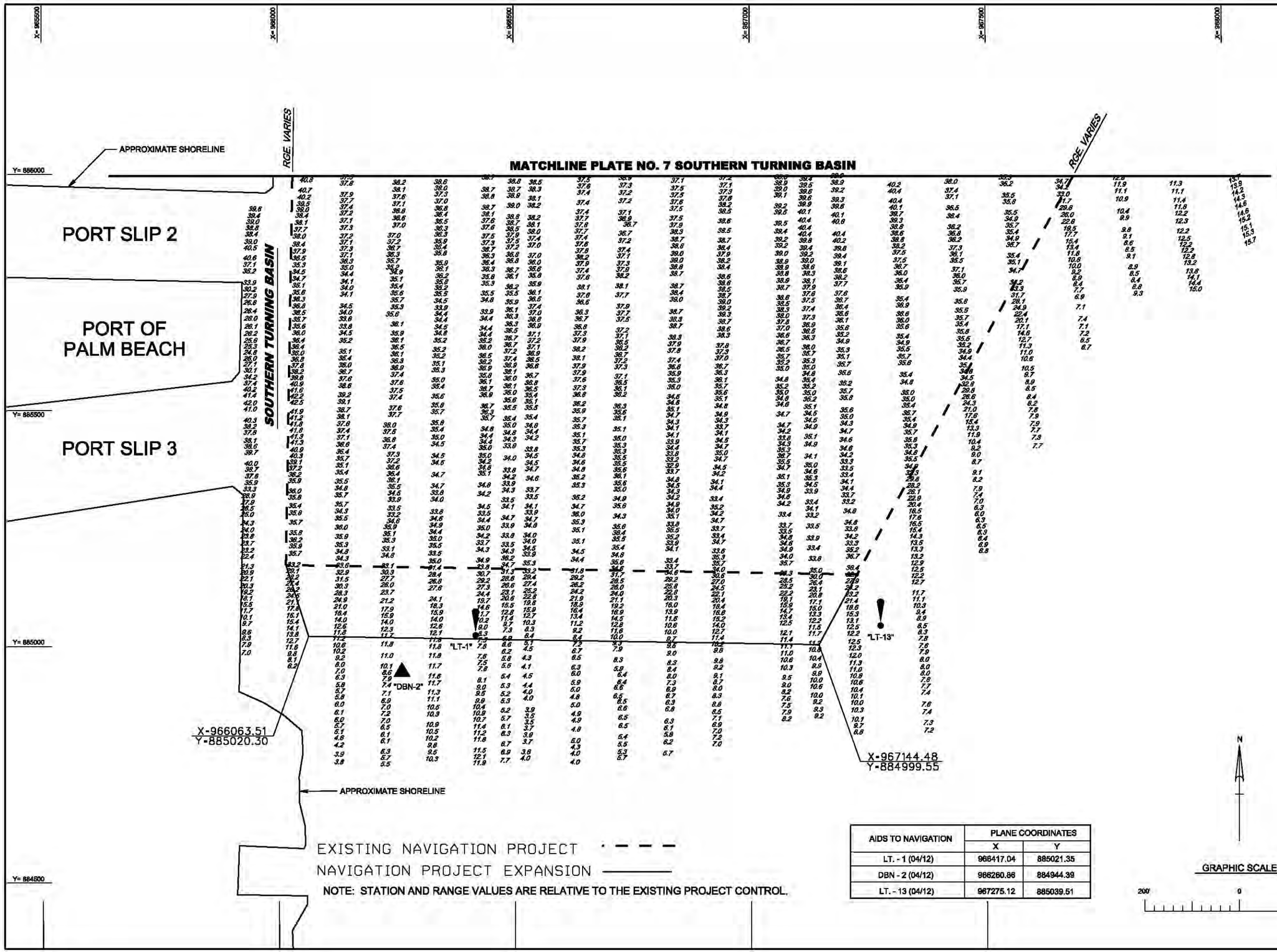
LAKE WORTH INLET NAVIGATION PROJECT
PALM BEACH HARBOR, FLORIDA
NED PLAN
NORTHERN AND SOUTHERN TURNING BASINS
FEASIBILITY STUDY - ENGINEERING APPENDIX

PLATE
7



AIDS TO NAVIGATION	PLANE COORDINATES	
	X	Y
LT. - 1 (04/12)	966417.04	885021.35
DBN - 2 (04/12)	966260.86	884944.39
LT. - 13 (04/12)	967275.12	885039.51

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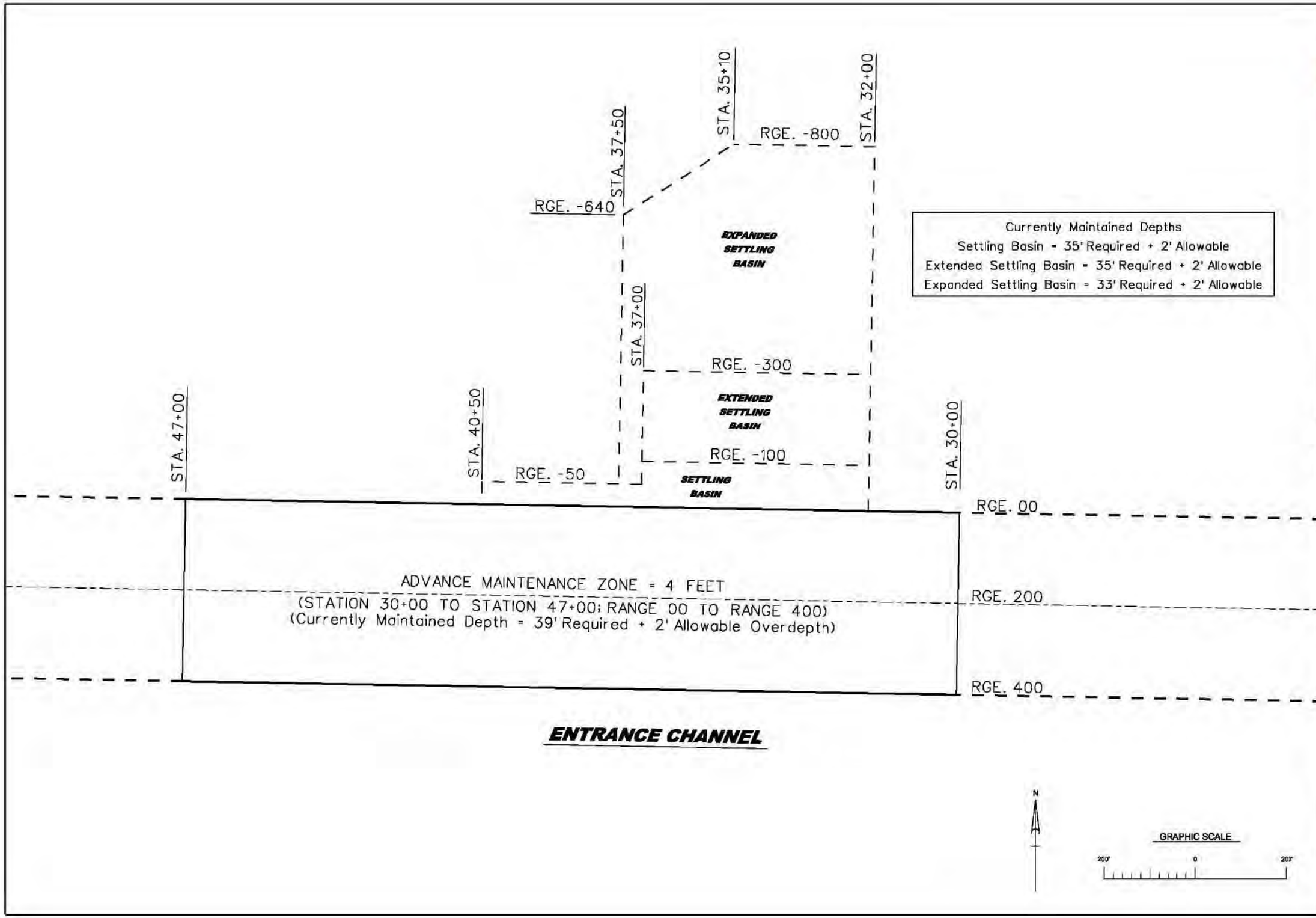
Reference files:

LAKE WORTH INLET NAVIGATION PROJECT
PALM BEACH HARBOR, FLORIDA
NED PLAN
SOUTHERN TURNING BASIN
FEASIBILITY STUDY - ENGINEERING APPENDIX

PLATE
8



Currently Maintained Depths
Settling Basin - 35' Required + 2' Allowable
Extended Settling Basin - 35' Required + 2' Allowable
Expanded Settling Basin - 33' Required + 2' Allowable

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Date: SEPTEMBER 2012
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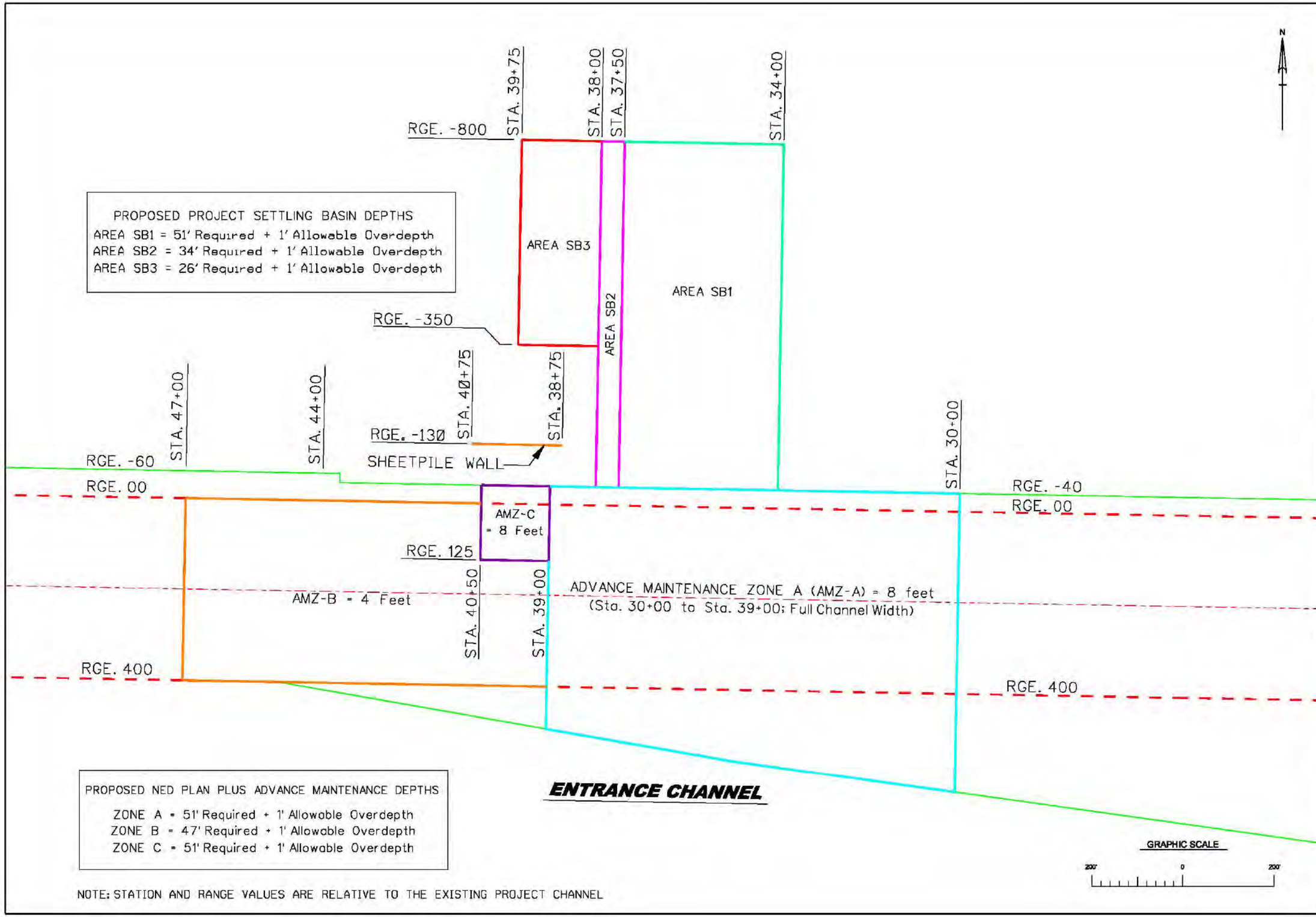
LAKE WORTH INLET NAVIGATION PROJECT
PALM BEACH HARBOR, FLORIDA
EXISTING PROJECT - ADVANCE MAINTENANCE AND SETTLING BASIN PLAN
FEASIBILITY STUDY - ENGINEERING APPENDIX

PLATE
9



NOTE: STATION AND RANGE VALUES ARE RELATIVE TO THE EXISTING PROJECT CHANNEL

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Plot scale:
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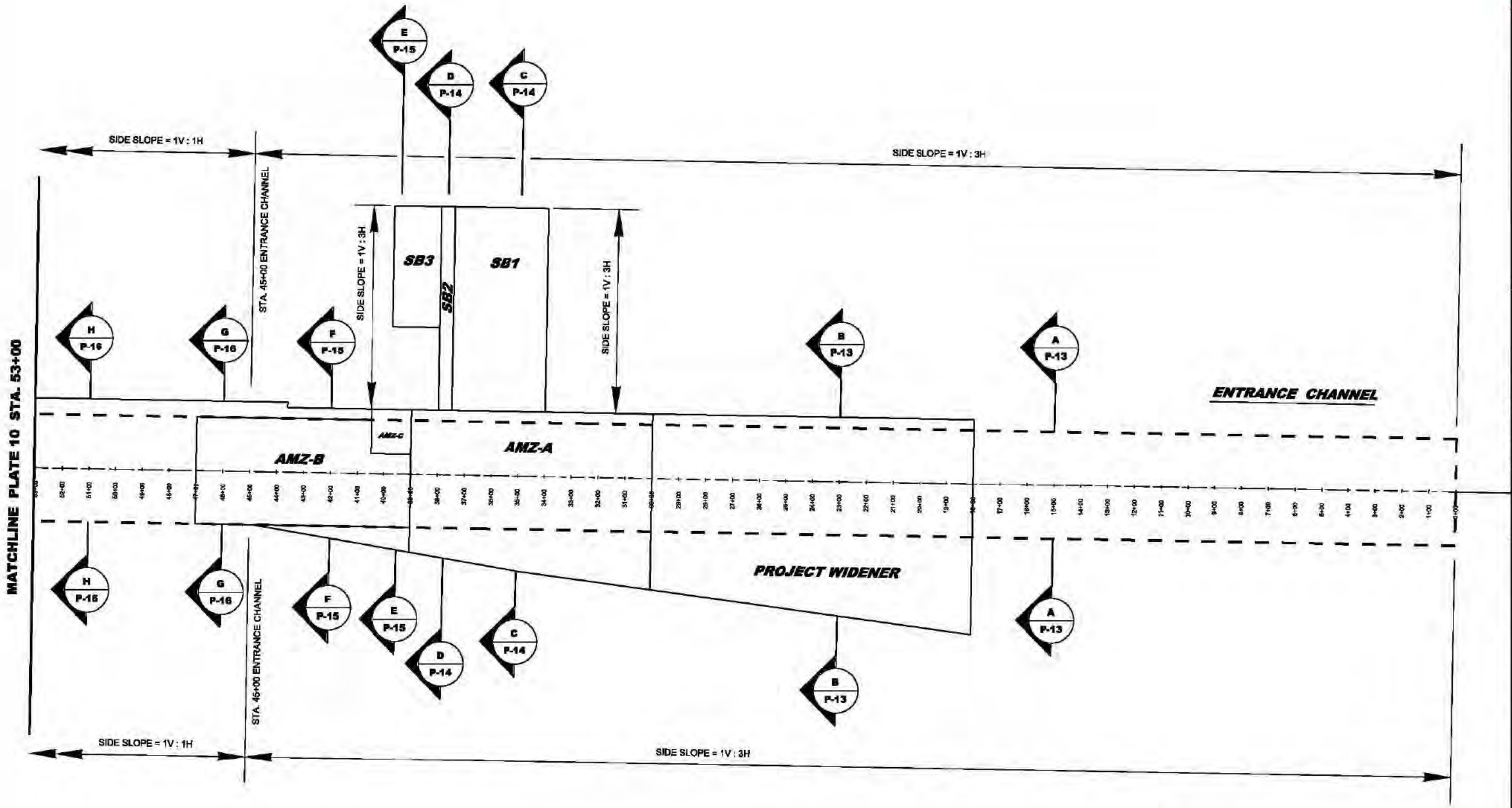
Reference files:

LAKE WORTH INLET NAVIGATION PROJECT
PALM BEACH HARBOR, FLORIDA
PROPOSED PROJECT - ADVANCE MAINTENANCE AND SETTLING BASIN PLAN
FEASIBILITY STUDY - ENGINEERING APPENDIX

PLATE
10



LEGEND:

EXISTING NAVIGATION PROJECT - - -

NAVIGATION PROJECT EXPANSION ———

NOTE: STATION AND RANGE VALUES ARE RELATIVE TO THE EXISTING PROJECT CONTROL.

N

GRAPHIC SCALE

400' 0 400'

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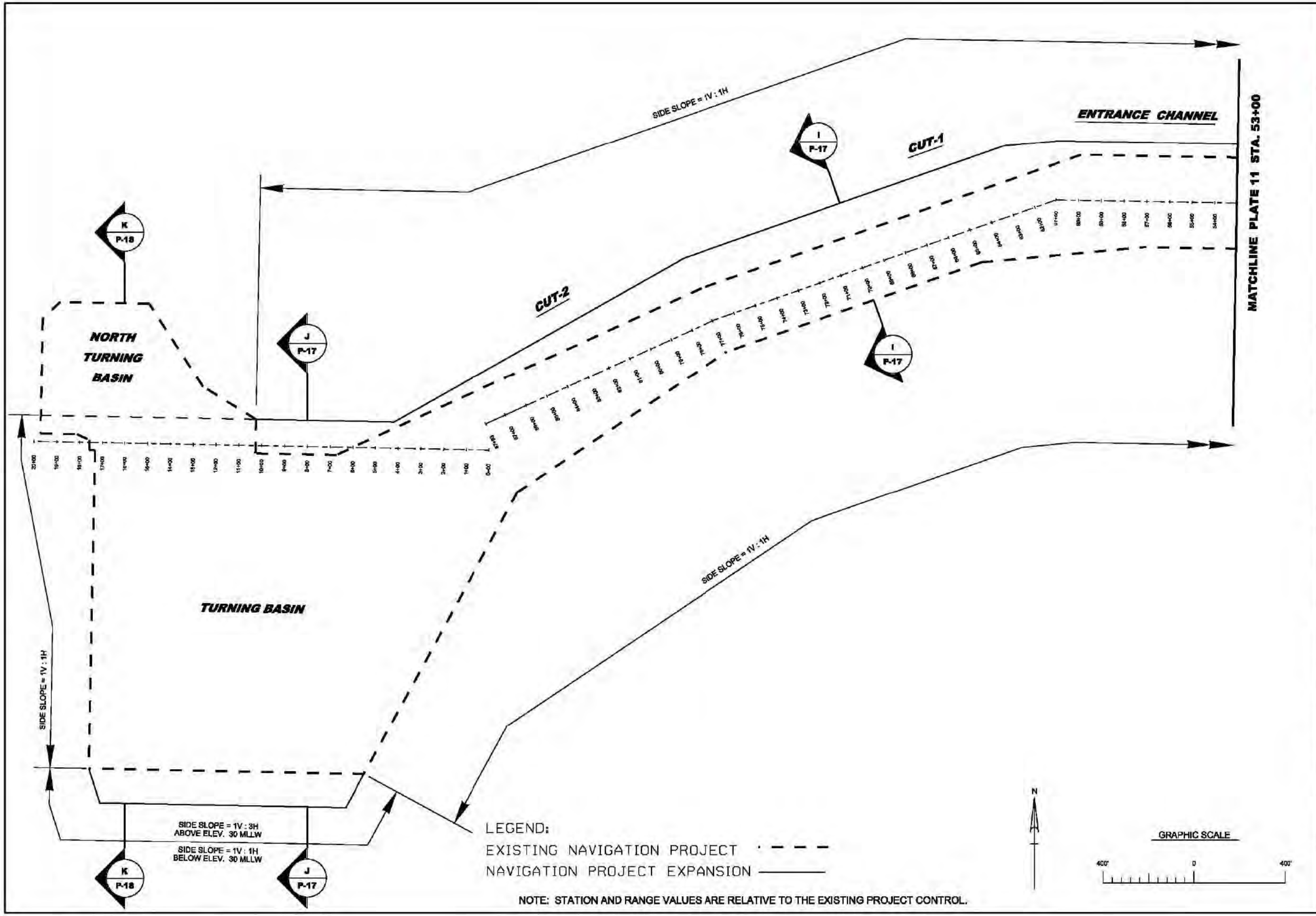
LAKE WORTH INLET NAVIGATION PROJECT
PALM BEACH HARBOR, FLORIDA
SIDE SLOPE PLAN
AND TYPICAL DREDGING SECTIONS
FEASIBILITY STUDY - ENGINEERING APPENDIX

PLATE
11



NOTE: STATION AND RANGE VALUES ARE RELATIVE TO THE EXISTING PROJECT CONTROL.

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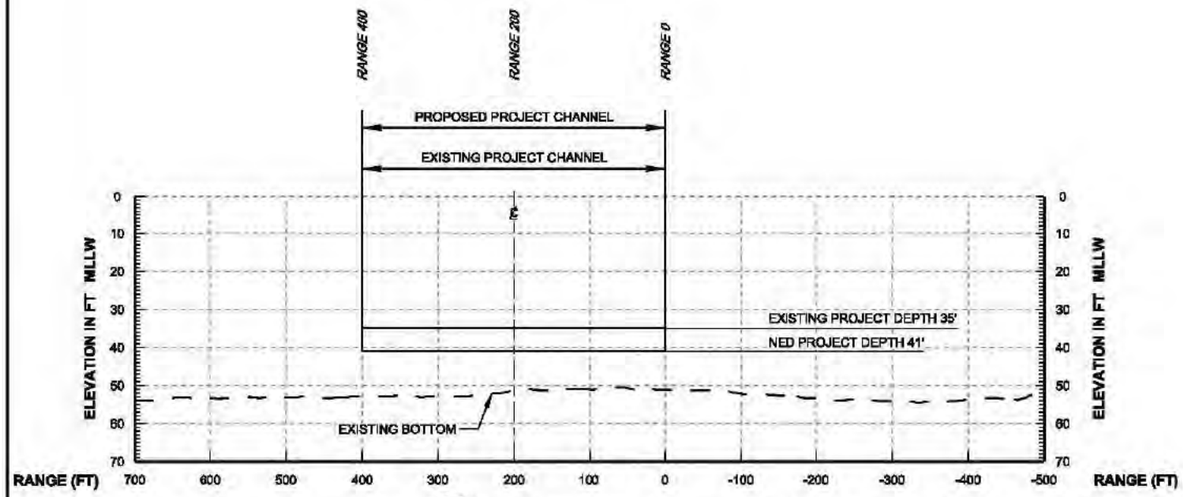
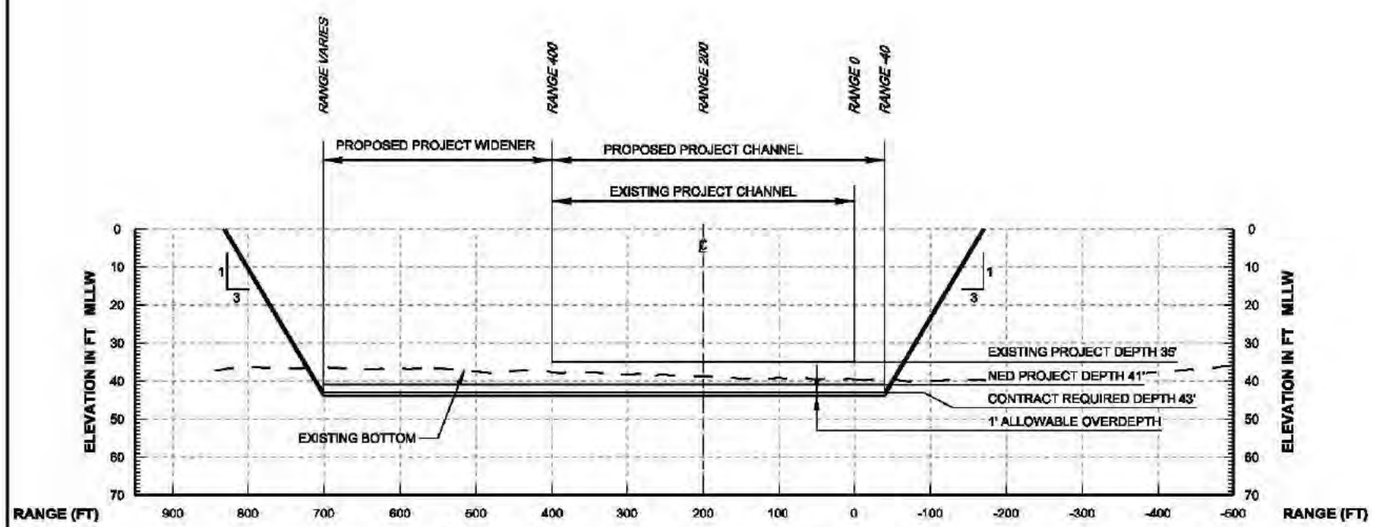
LAKE WORTH INLET NAVIGATION PROJECT
PALM BEACH HARBOR, FLORIDA
SIDE SLOPE PLAN
AND TYPICAL DREDGING SECTIONS
FEASIBILITY STUDY - ENGINEERING APPENDIX

PLATE
12



A / P-11 **CROSS SECTION** **STA. 15+00** **NO DREDGING REQUIRED**

HORZ = SCALE: A
VERT = SCALE: B



B / P-11 **CROSS SECTION** **STA. 23+00**

HORZ = SCALE: A
VERT = SCALE: B

GRAPHIC SCALES

"A" 200' 0 200'

"B" 40' 0 40'

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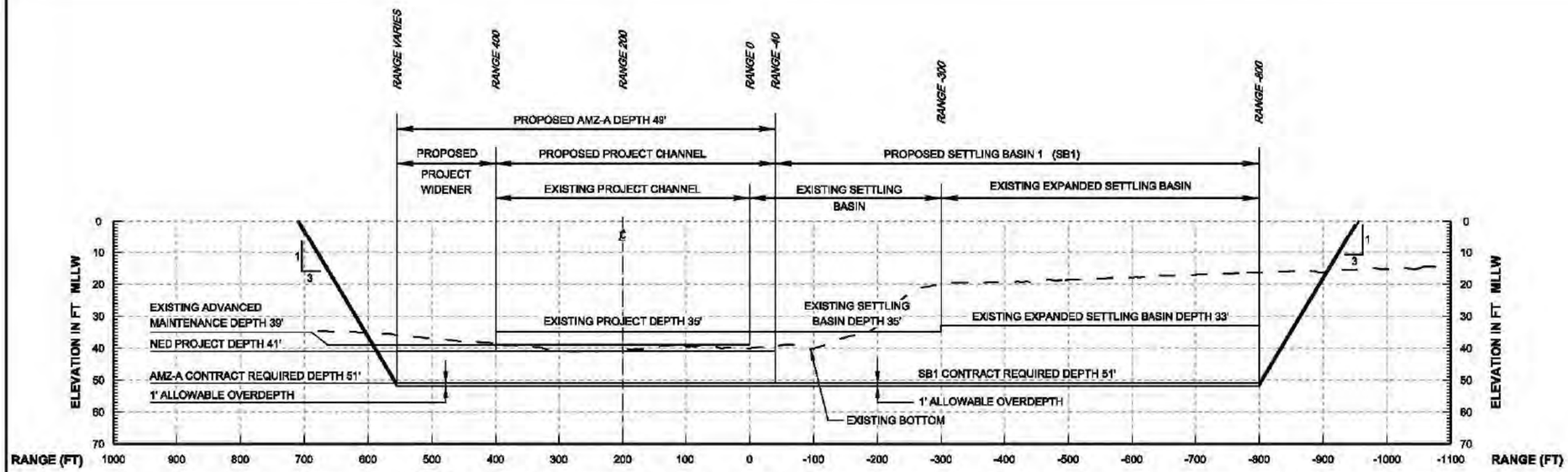
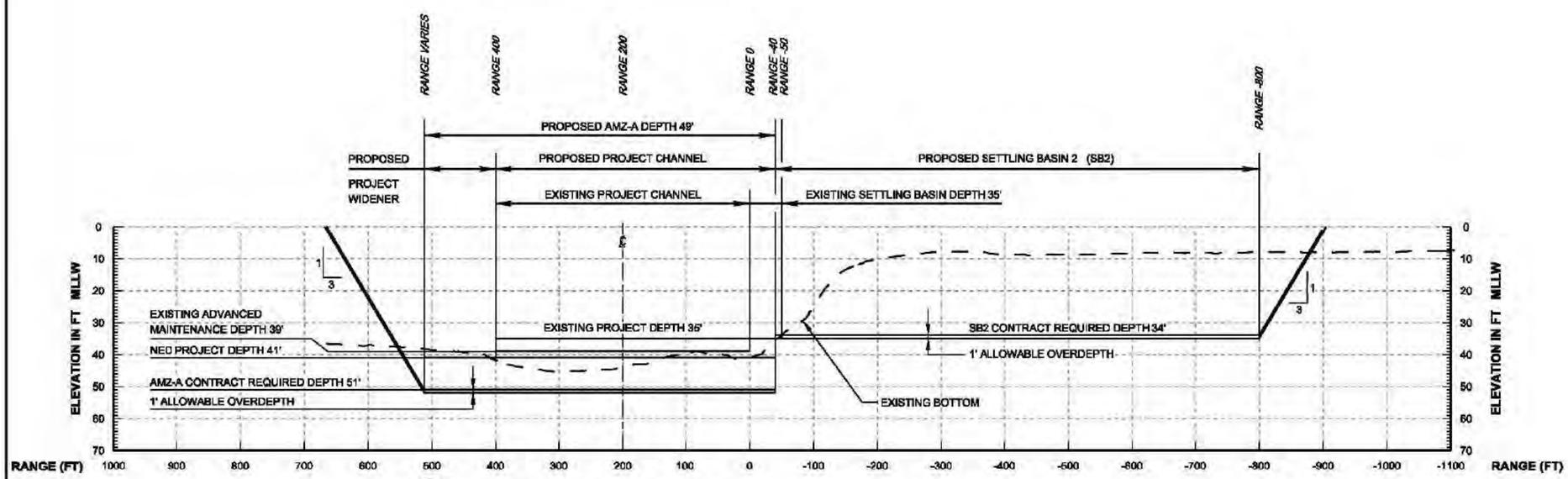
LAKE WORTH INLET NAVIGATION PROJECT
PALM BEACH HARBOR, FLORIDA
TYPICAL DREDGING SECTIONS
FEASIBILITY STUDY - ENGINEERING APPENDIX

PLATE
13



C / F-11 **CROSS SECTION** **STA. 35+00**

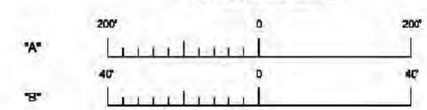
HORZ = SCALE: A
VERT = SCALE: B



D / F-11 **CROSS SECTION** **STA. 37+75**

HORZ = SCALE: A
VERT = SCALE: B

GRAPHIC SCALES



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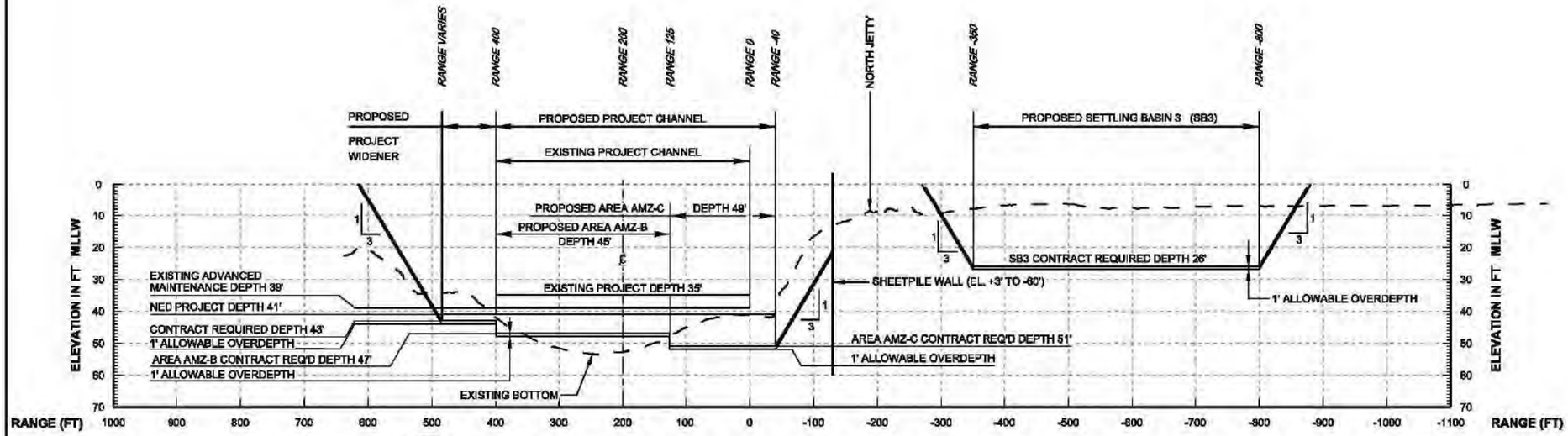
LAKE WORTH INLET NAVIGATION PROJECT
PALM BEACH HARBOR, FLORIDA
TYPICAL DREDGING SECTIONS
FEASIBILITY STUDY - ENGINEERING APPENDIX

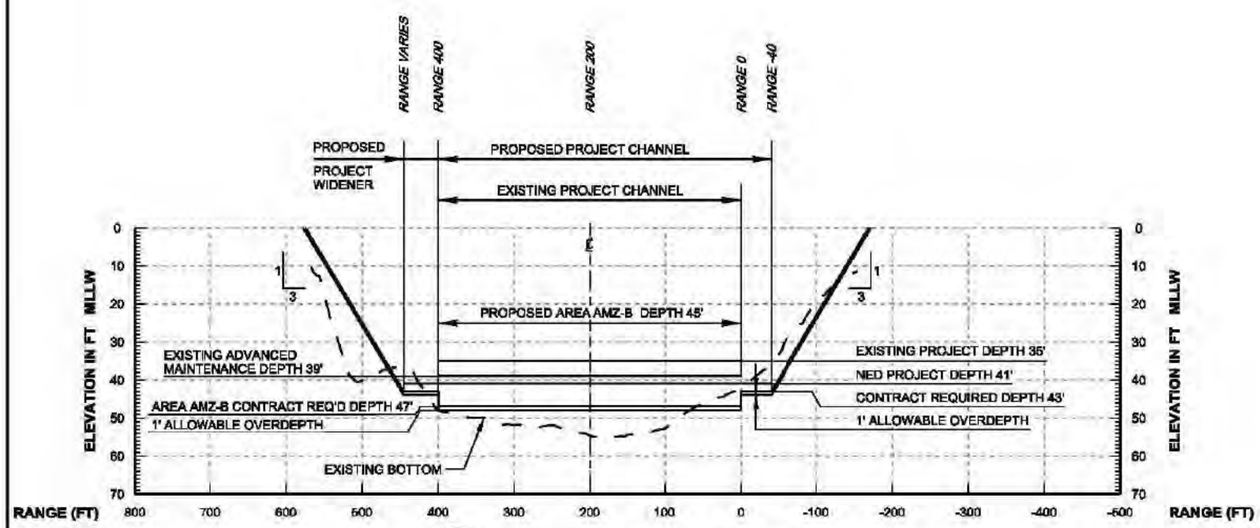
PLATE
14



E
P-11

CROSS SECTION **STA. 39+50**

HORZ = SCALE: A
VERT = SCALE: B

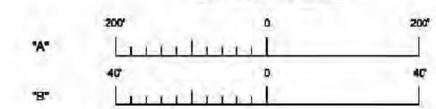


F
P-11

CROSS SECTION **STA. 42+00**

HORZ = SCALE: A
VERT = SCALE: B

GRAPHIC SCALES



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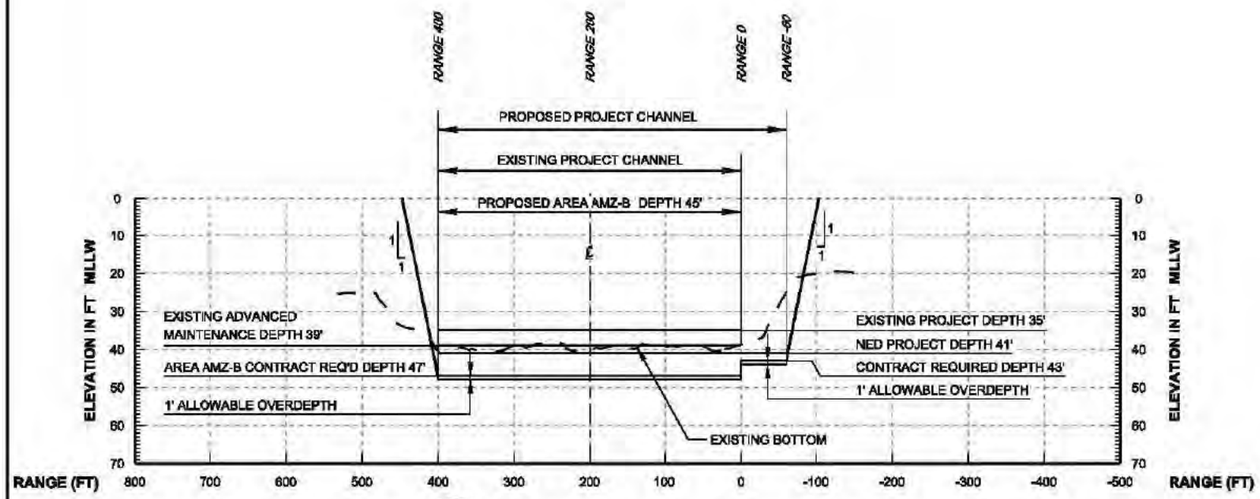
Reference files:

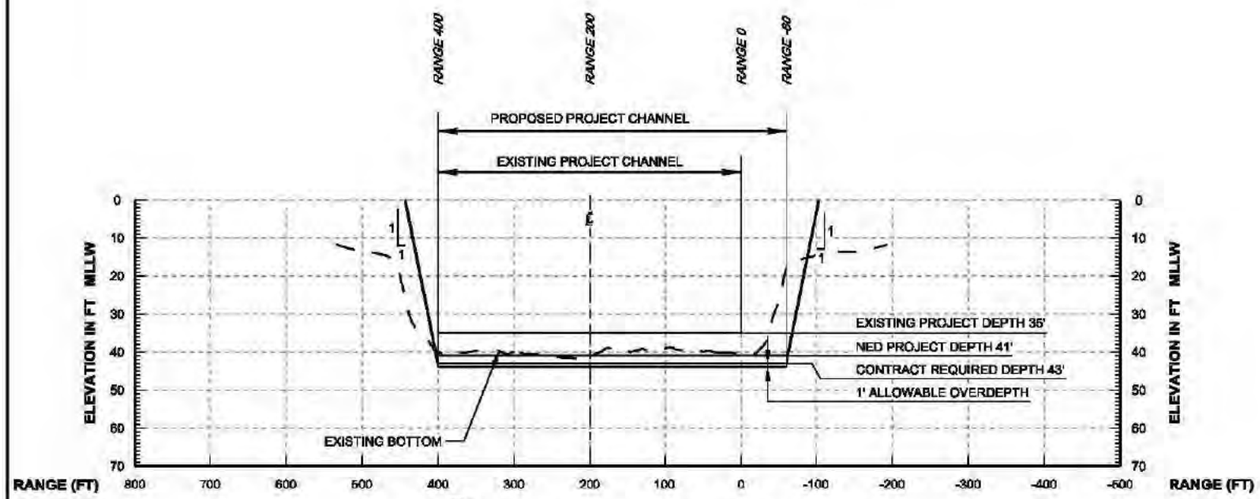
LAKE WORTH INLET NAVIGATION PROJECT
PALM BEACH HARBOR, FLORIDA
TYPICAL DREDGING SECTIONS
FEASIBILITY STUDY - ENGINEERING APPENDIX

PLATE
15



G / P-11 **CROSS SECTION** **STA. 46+00**

HORZ = SCALE: A
VERT = SCALE: B



H / P-11 **CROSS SECTION** **STA. 51+00**

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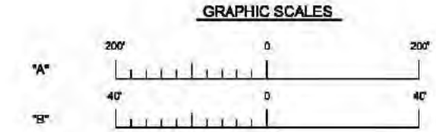

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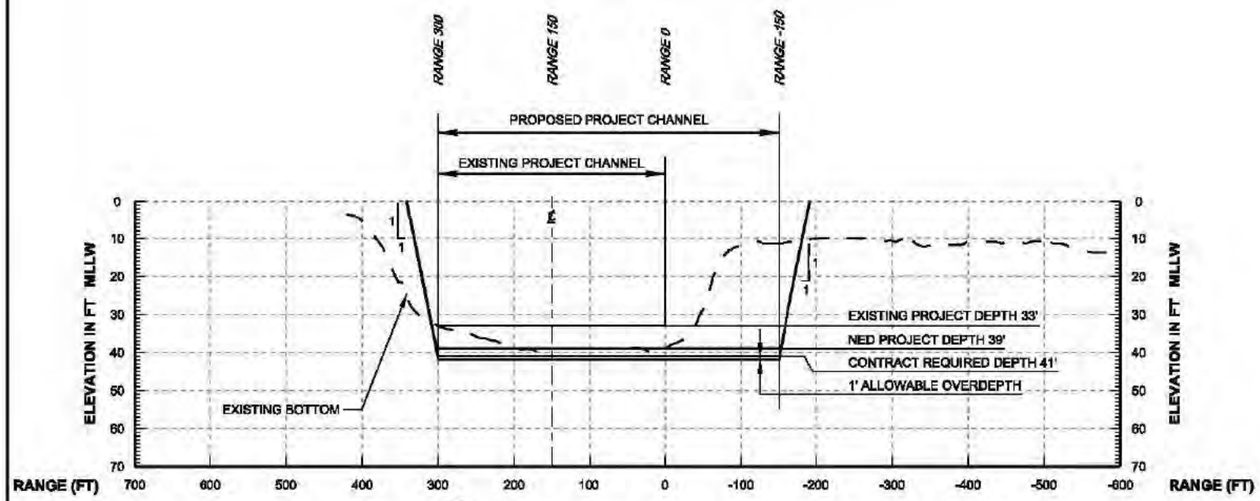
LAKE WORTH INLET NAVIGATION PROJECT
PALM BEACH HARBOR, FLORIDA
TYPICAL DREDGING SECTIONS
FEASIBILITY STUDY - ENGINEERING APPENDIX

PLATE
16



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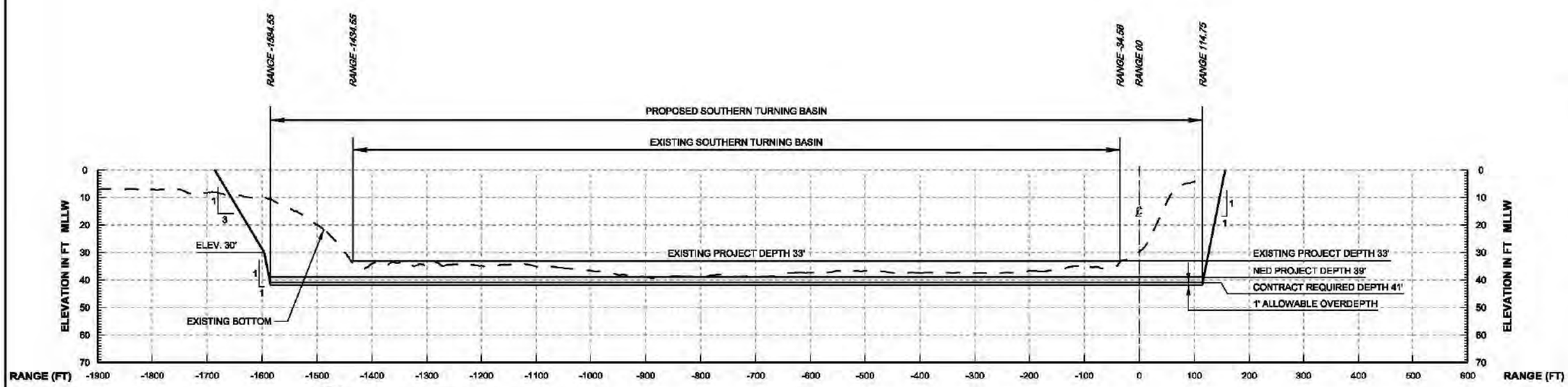

J / P-12 **CROSS SECTION** **STA. 8+00**

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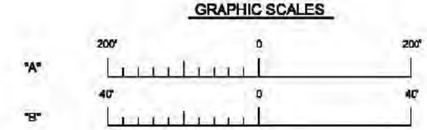
GRAPHIC SCALES



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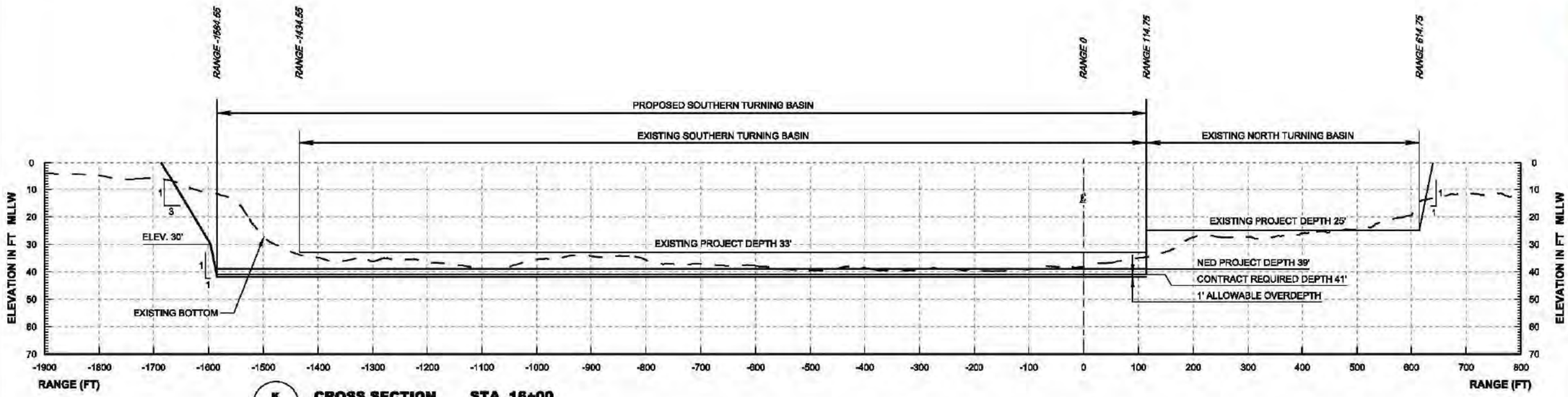
LAKE WORTH INLET NAVIGATION PROJECT
PALM BEACH HARBOR, FLORIDA
TYPICAL DREDGING SECTIONS
FEASIBILITY STUDY - ENGINEERING APPENDIX

PLATE
17



K / F-12 **CROSS SECTION** **STA. 16+00**

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VERT = SCALE: B

GRAPHIC SCALES

"A" 200' 0 200'

"B" 40' 0 40'

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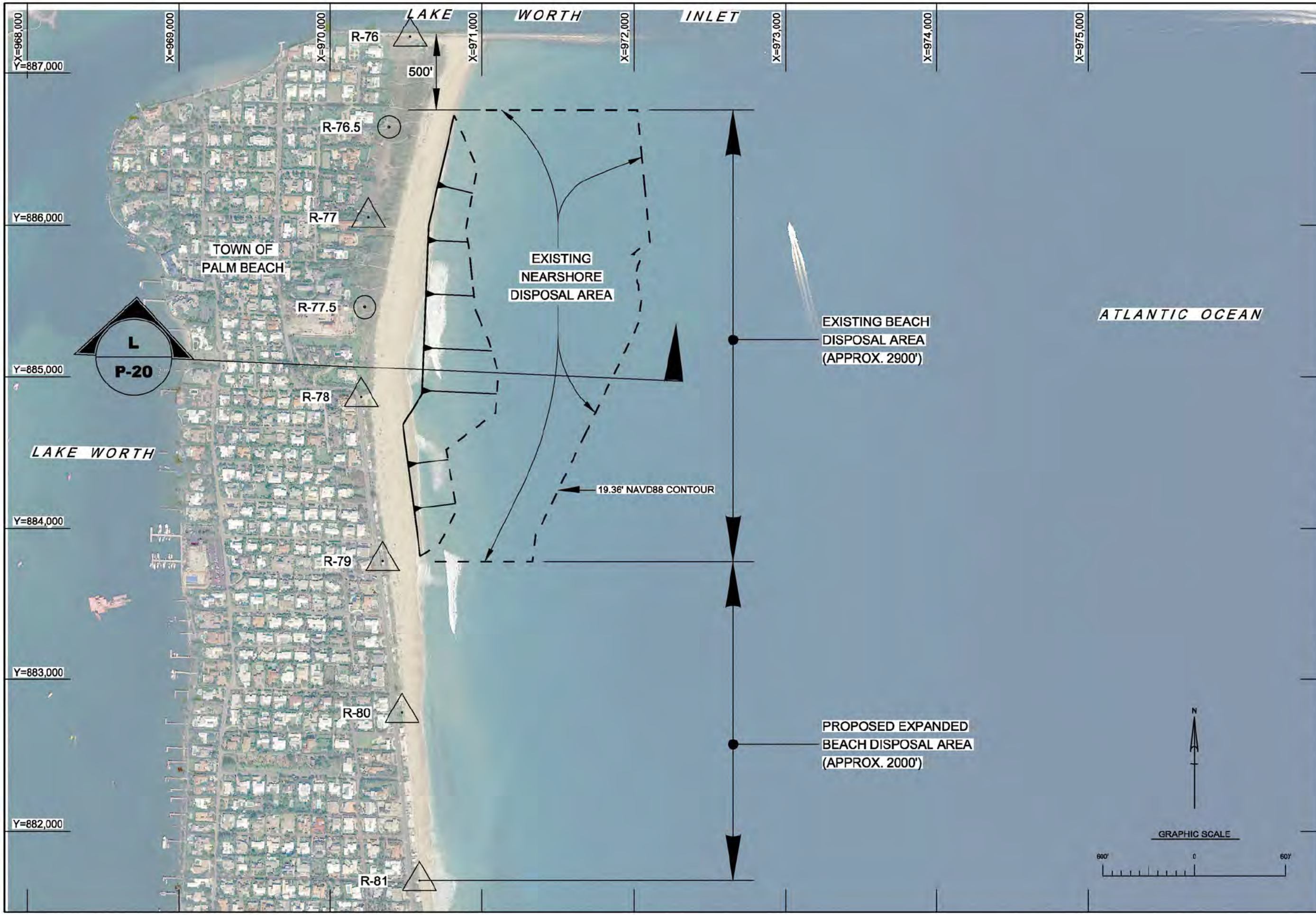
LAKE WORTH INLET NAVIGATION PROJECT
PALM BEACH HARBOR, FLORIDA

TYPICAL DREDGING SECTIONS

FEASIBILITY STUDY - ENGINEERING APPENDIX

PLATE 18



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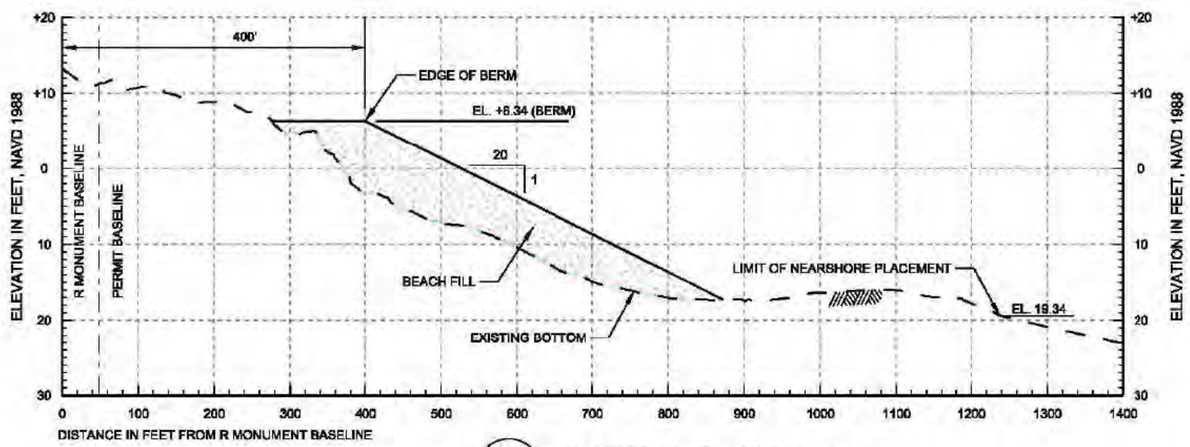
LAKE WORTH INLET NAVIGATION PROJECT
PALM BEACH HARBOR, FLORIDA
BEACH/NEARSHORE DISPOSAL PLAN
FEASIBILITY STUDY - ENGINEERING APPENDIX

PLATE
19



L
P-19

TYPICAL BEACH PROFILE

SCALE: A (HORZ)
SCALE: B (VERT)

GRAPHIC SCALES

"A" 200' 0 200'

"B" 20' 0 20'

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LAKE WORTH INLET NAVIGATION PROJECT
PALM BEACH HARBOR, FLORIDA
TYPICAL BEACH DISPOSAL SECTION
FEASIBILITY STUDY - ENGINEERING APPENDIX

PLATE
20

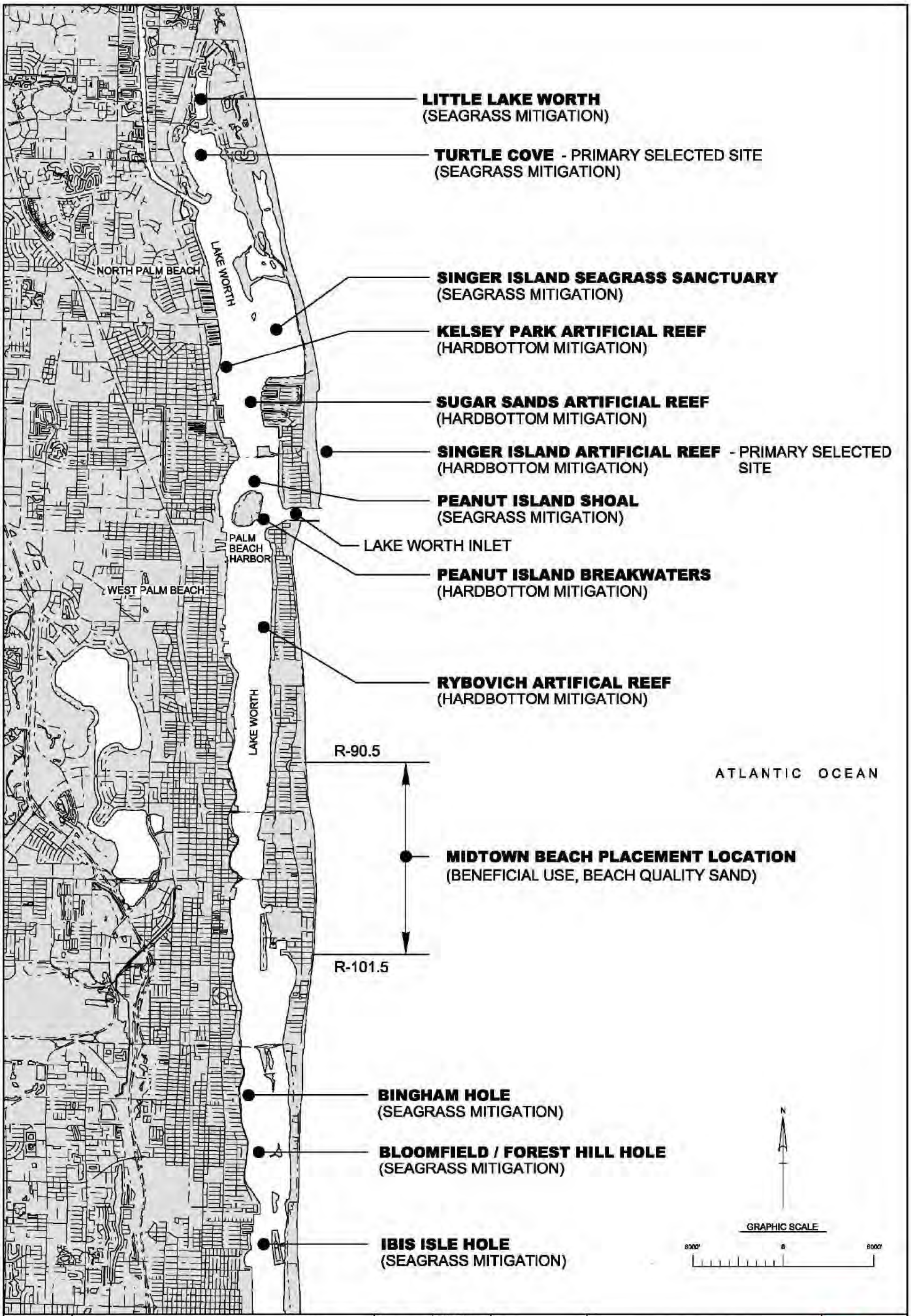

PLATE 21

LAKE WORTH INLET NAVIGATION PROJECT
PALM BEACH HARBOR, FLORIDA

PROPOSED POTENTIAL MITIGATION / BENEFICIAL USE SITES

FEASIBILITY STUDY - ENGINEERING APPENDIX

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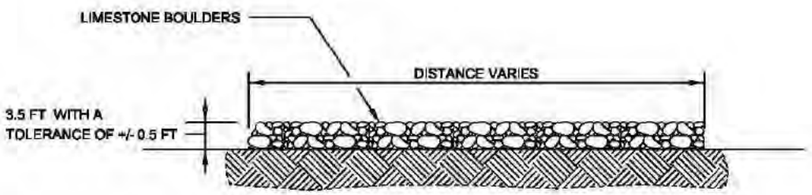

TYPICAL CROSS SECTION

HIGH-RELIEF, HIGH COMPLEXITY HARDBOTTOM MITIGATION SECTION

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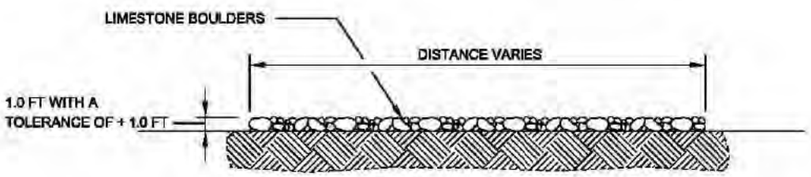

TYPICAL CROSS SECTION

LOW-RELIEF, LOW COMPLEXITY HARDBOTTOM MITIGATION SECTION

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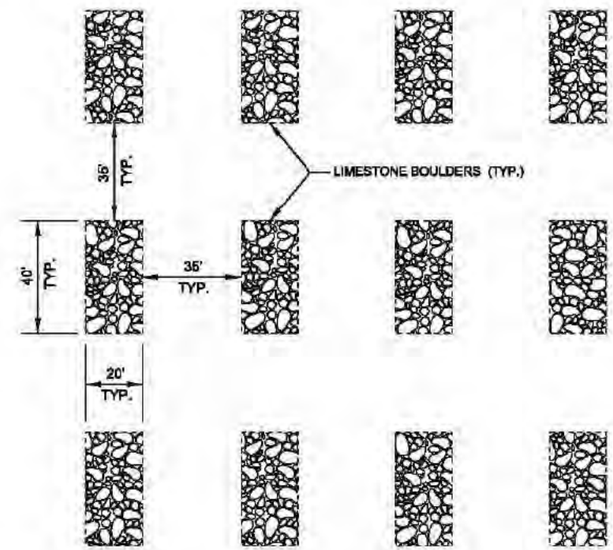

HIGH-RELIEF, HIGH COMPLEXITY HARDBOTTOM MITIGATION PLAN

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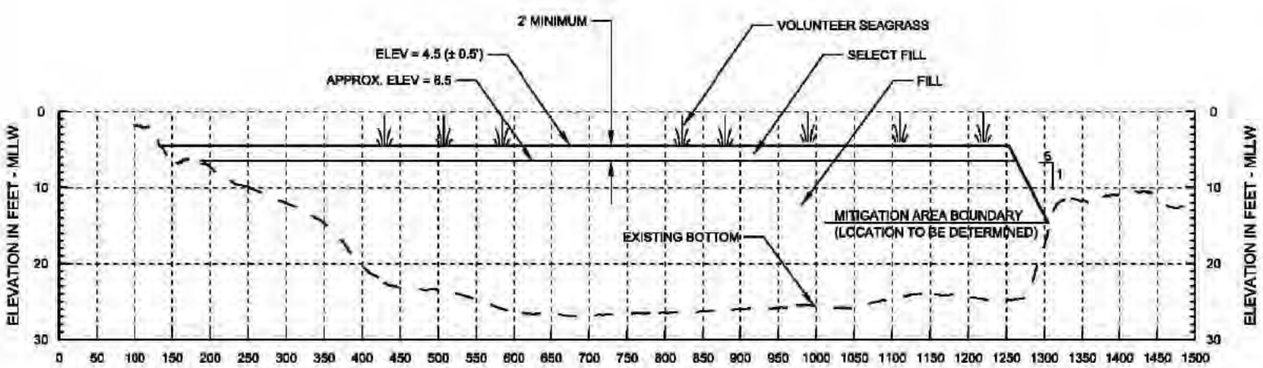
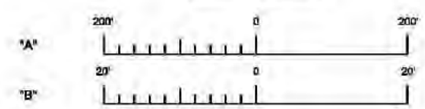


TYPICAL CROSS SECTION SEAGRASS MITIGATION AREA

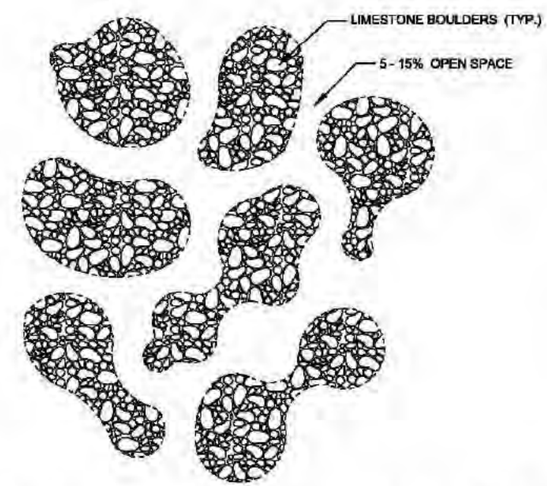
HORZ = SCALE: A
VERT = SCALE: B

GRAPHIC SCALES



NOTE:

DESIGN IS CONCEPTUAL, ELEVATIONS AND OTHER PARAMETERS ARE SUBJECT TO MODIFICATION.



LOW-RELIEF, LOW COMPLEXITY HARDBOTTOM MITIGATION PLAN

N.T.S.

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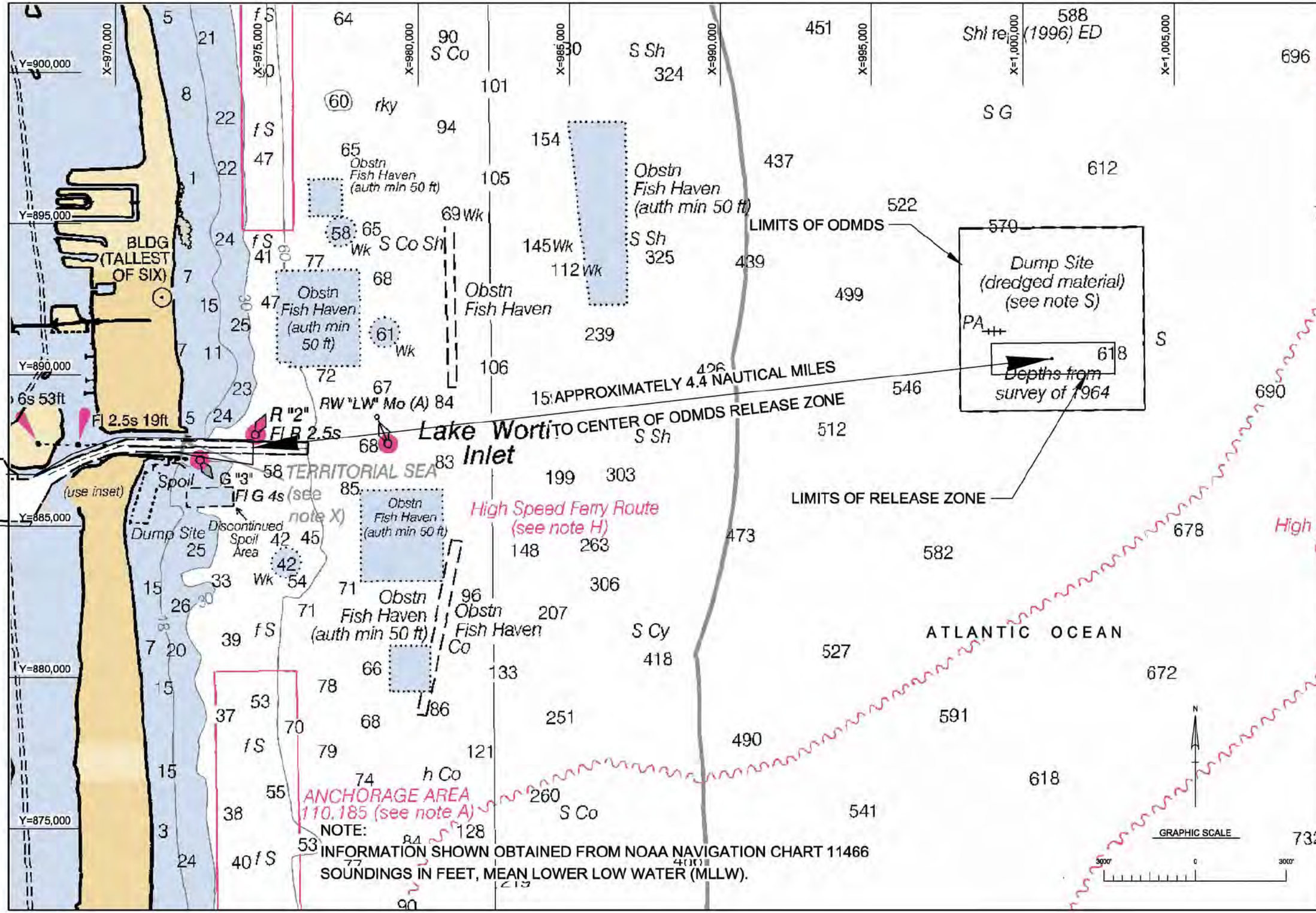
LAKE WORTH INLET NAVIGATION PROJECT
PALM BEACH HARBOR, FLORIDA
TYPICAL CROSS SECTIONS - SEAGRASS AND HARDBOTTOM MITIGATION AND HARDBOTTOM MITIGATION PLAN
FEASIBILITY STUDY - ENGINEERING APPENDIX

PLATE
22



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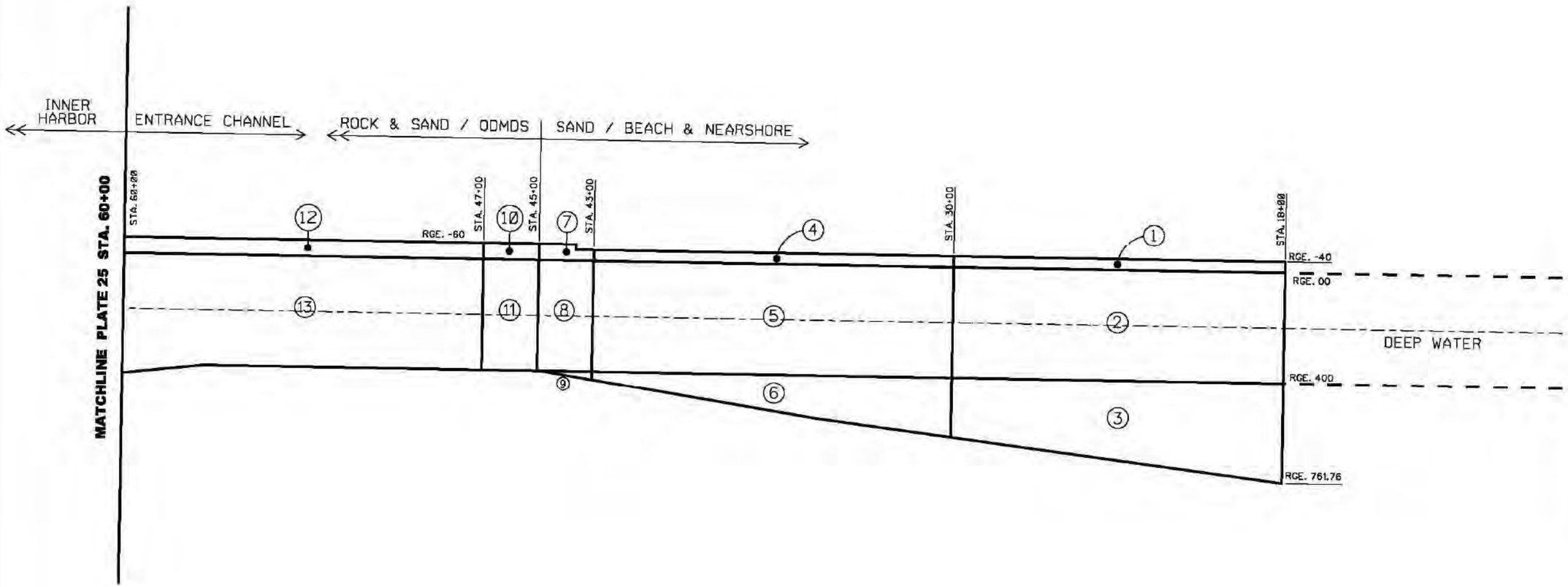
LAKE WORTH INLET NAVIGATION PROJECT
PALM BEACH HARBOR, FLORIDA
ODMDS PLAN
FEASIBILITY STUDY - ENGINEERING APPENDIX

PLATE
23



N

GRAPHIC SCALE

400' 0 400'

NOTE: STATION AND RANGE VALUES ARE RELATIVE TO THE EXISTING PROJECT CONTROL.

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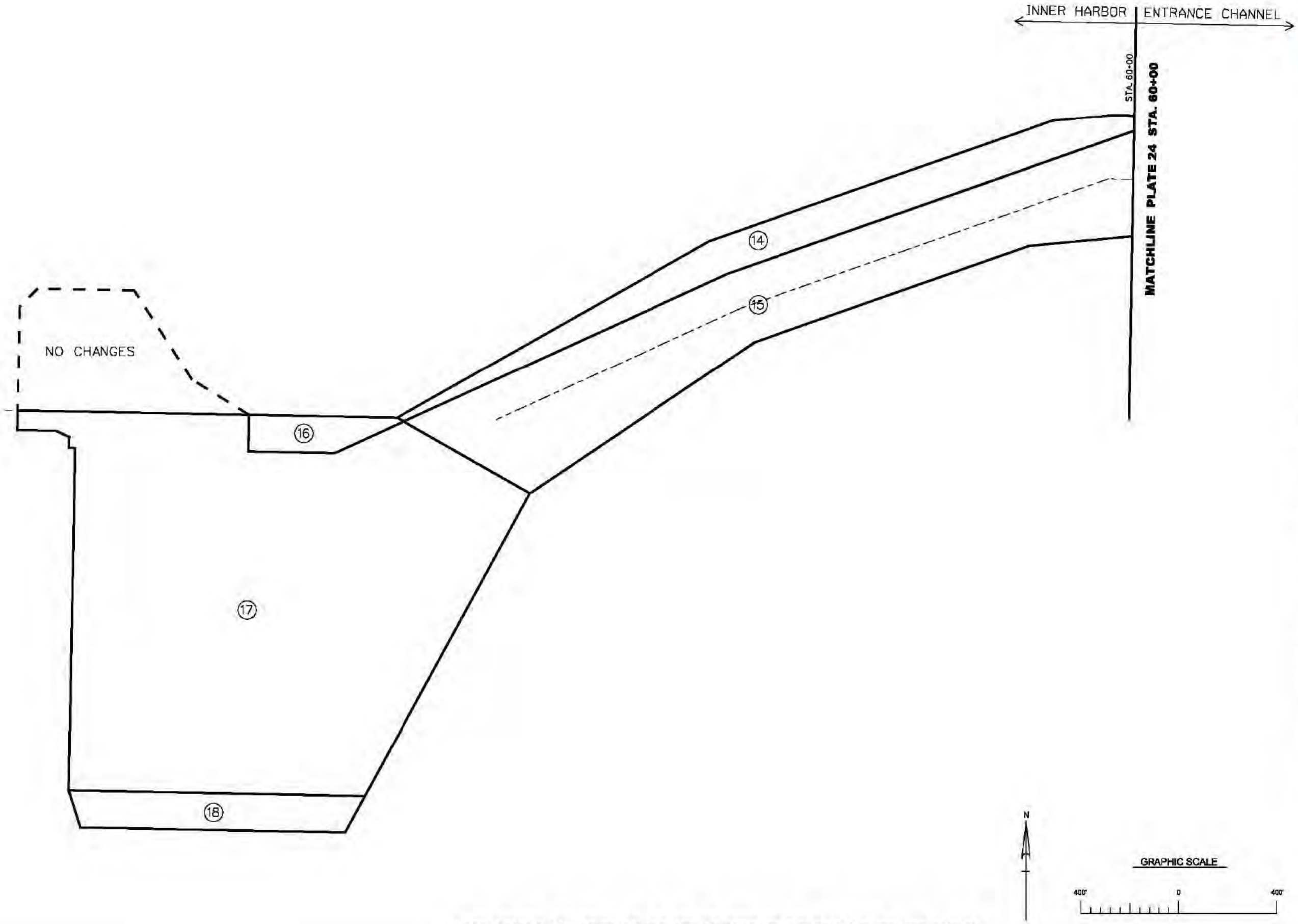
LAKE WORTH INLET NAVIGATION PROJECT
PALM BEACH HARBOR, FLORIDA
NED PLAN
AREA BREAKDOWN FOR VOLUMETRIC AND COST ANALYSIS
FEASIBILITY STUDY - ENGINEERING APPENDIX

PLATE
24



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LAKE WORTH INLET NAVIGATION PROJECT
PALM BEACH HARBOR, FLORIDA
NED PLAN
AREA BREAKDOWN FOR VOLUMETRIC AND COST ANALYSIS
FEASIBILITY STUDY - ENGINEERING APPENDIX

PLATE
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DRAFT

LAKE WORTH INLET, FLORIDA
FEASIBILITY STUDY REPORT

ENGINEERING APPENDIX - ATTACHMENT A

Hydrodynamic Modeling

-

DRAFT

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HYDRODYNAMIC MODELING ATTACHMENT
PALM BEACH HARBOR GRR, WEST PALM BEACH, FLORIDA

INTRODUCTION

Background

Lake Worth Inlet and Palm Beach Harbor are located on the east coast of Florida in Palm Beach County. Lake Worth Inlet is the entrance to the Port of Palm Beach and is the northern most of two inlets that connect Lake Worth to the Atlantic Ocean.

Lake Worth Inlet is a man-made inlet. The USACE has maintained the Palm Beach Harbor Navigation Project since 1934, which includes the jetties, channel, turning basin, inlet revetments, and settling basin to the north of the entrance channel (See Figure 1). Palm Beach Harbor consists of an entrance channel 35 feet deep, 400 feet wide, merging with an inner channel (Cuts 1 & 2) 33 feet deep, 300 feet wide, then flaring into a turning basin with a 1,200 foot turning diameter and jetties on the north and south of the inlet. This project currently requires annual maintenance dredging. The Palm Beach Harbor navigation project also includes a settling basin on the north side of the entrance channel. The settling basin was designed to catch sediment moving from the north around the north jetty and into the channel. The dimensions of the settling basin are 200 feet (north-south) by 500 feet (east-west) with a depth of 35 feet.

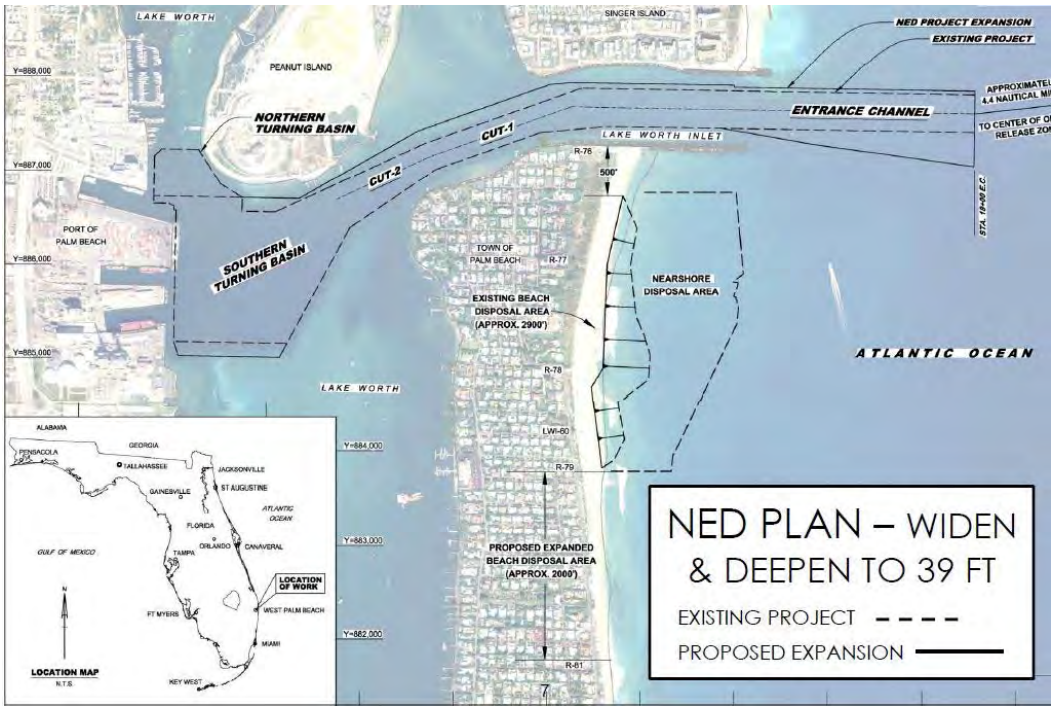

Figure 1. Lake Worth Inlet/ Palm Beach Harbor Navigation Study Area.

Objectives

The Palm Beach Harbor Navigation Project Management Plan (PMP) outlines a plan for identifying solutions for improving the navigation in federally maintained channels in the northern area of Lake Worth. Two critical elements, identified in the plan, for reaching that goal are the currents within the channels associated with each alternative and estimating project induced channel shoaling rates.

The objectives of the hydrodynamic modeling were as follows:

1) To provide the hydrodynamic inputs for use in the Ship Simulation Model. In order to meet this objective, a two-dimensional hydrodynamic model was developed that is capable of simulating complex flows in a large model domain. A two-dimensional hydrodynamic model was considered appropriate for comparison of current magnitude and direction between alternatives since the Lake Worth Lagoon is a well mixed estuary and the currents are primarily driven by tidal forcing. Also the Ship Simulator Model requires two-dimensional, depth averaged, currents and can not utilize three-dimensional currents.

2) To assess changes to circulation and shoaling patterns resulting from proposed channel geometry deepening modifications. The settling basin to the north of the entrance channel is an integral part of the sediment transport dynamics in the entrance channel area. The settling basin has been expanded several times to reduce shoaling in the entrance channel. Included in this investigation is an evaluation of the present and proposed settling basin as well as recommended modification for greater reduction of shoaling in the navigation channel. Evaluation of scour and hydrodynamic forces of the north jetty stabilization sheetpile wall would require a finer scale hydrodynamic model are not included in this modeling effort.

Technical Approach - Hydrodynamic Modeling

The technical criteria for selecting an appropriate hydrodynamic model are based primarily on the objectives of the navigation study, which are to optimize channel modifications and to assess impacts to channel shoaling.

The existing main channel is 400 ft wide and the alternatives under consideration include widening the channel to 500 ft. In order to represent these modifications in a hydrodynamic model, the horizontal grid resolution must be on the order of 50 ft. The Lake Worth Inlet/ Palm Beach Harbor Navigation Channel is about 1.7 nmi in length from the seaward limit to the port. Given the relatively small project area, it is feasible to represent the Palm Beach Harbor navigation and vicinity with a structured grid model.

To represent the Lake Worth Inlet/ Palm Beach Harbor Navigation Channel and vicinity hydrodynamics and the inlet system sediment transport and its response to wave action,

circulation, and engineering alternatives, the Coastal Inlets Research Program (CIRP) Coastal Modeling System (CMS) (Sanchez, et.al. 2011) models were applied.

CMS is an integrated two-dimensional (2-D) numerical modeling package for simulating waves, current, water level, sediment transport, and morphology change at coastal inlets and entrances. The emphasis of the CMS is on navigation channel performance and sediment exchange between the inlet and adjacent settling basin area. The numerical wave and circulation models, CMS-WAVE and CMS-FLOW, were run in a coupled mode with information passed between the models at specified intervals.

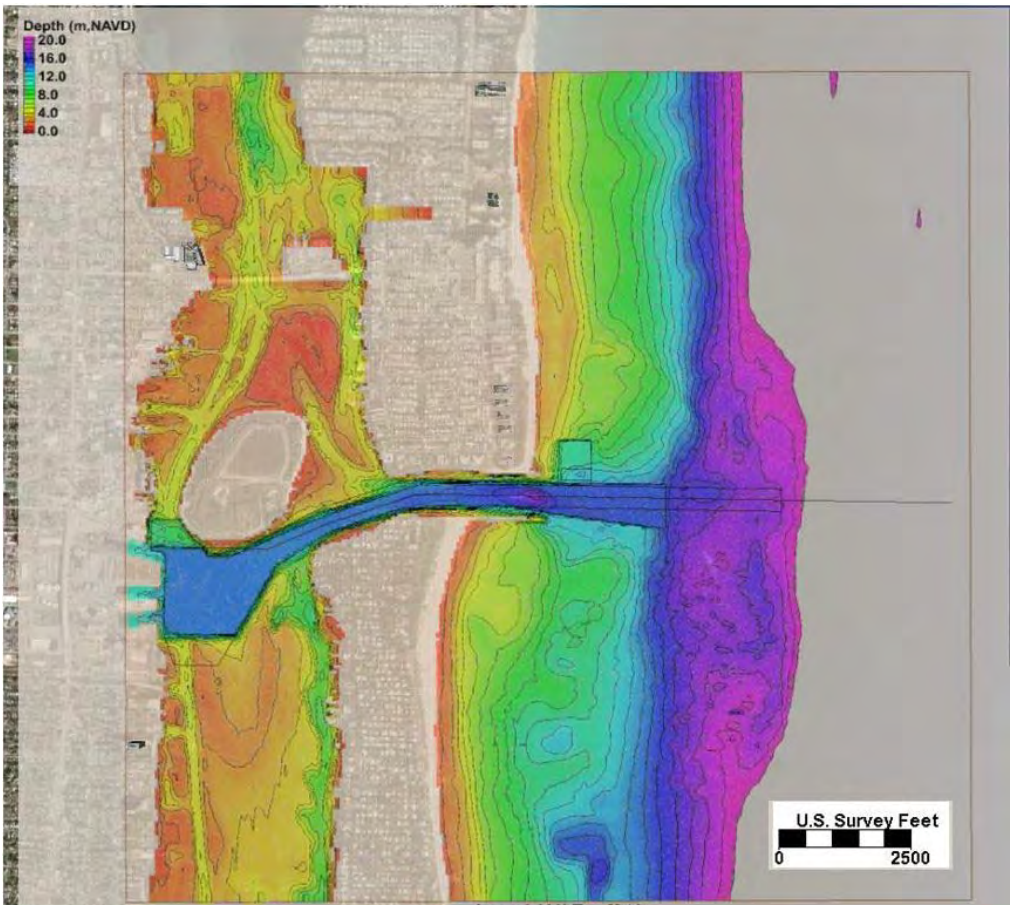

Figure 2. **Lake Worth Inlet/ Palm Beach Harbor hydrodynamic model grid domain and bathymetry. Model grid cells are 49.2 ft (15 m) on each side.**

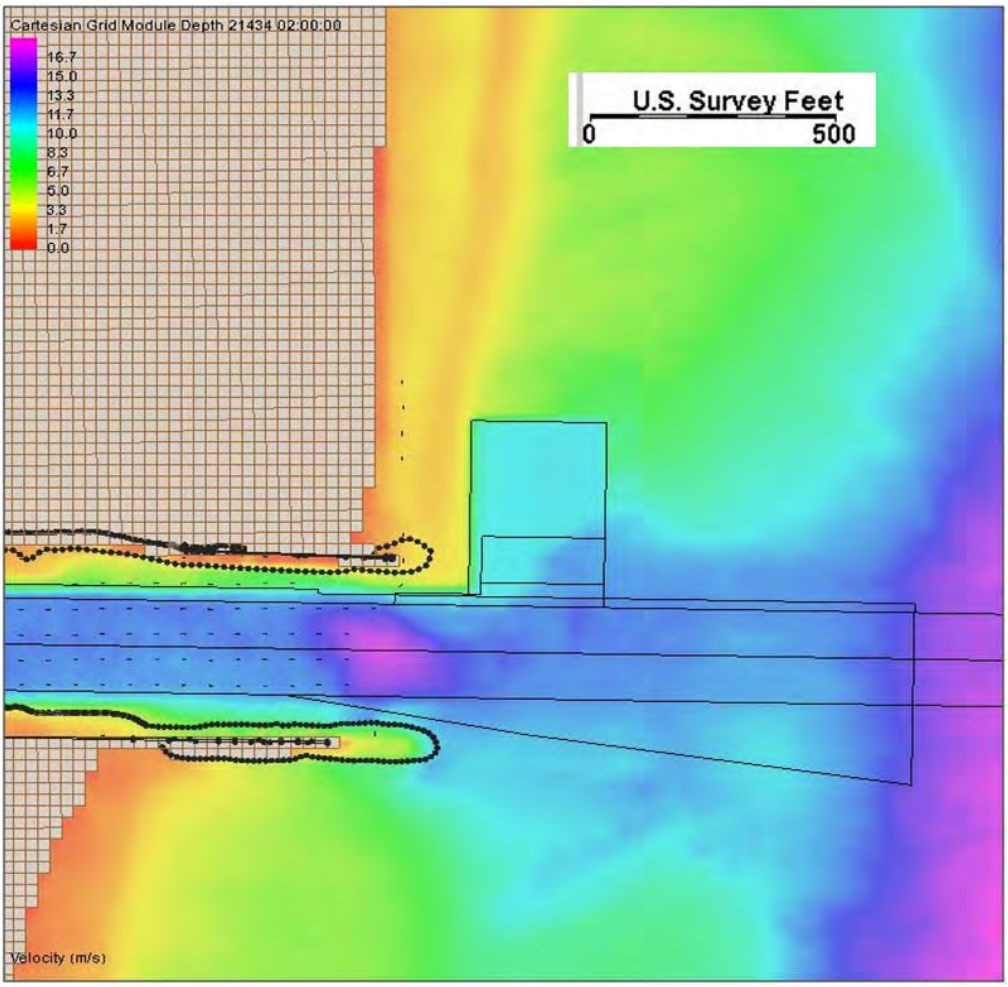

Figure 3. **Lake Worth Inlet/ Palm Beach Harbor hydrodynamic model grid cell resolution. Model grid cells are 49.2 ft (15 m) on each side.**

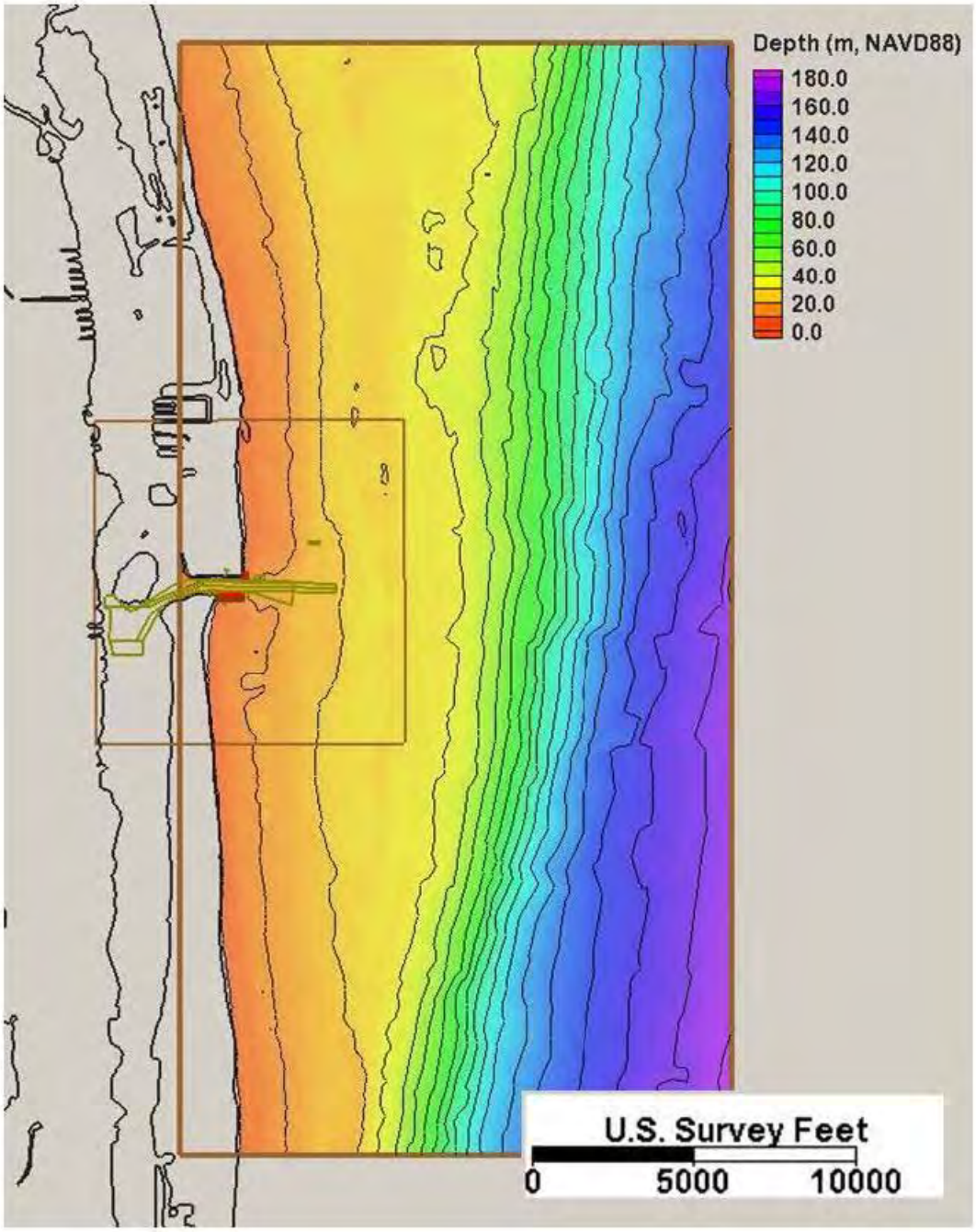

Figure 4. Lake Worth Inlet/ Palm Beach Harbor wave model grid domain. Model grid cells are 164 ft (50 m) on each side.

HYDRODYNAMIC MODEL APPLICATION

Hydrodynamic Model Setup

Numerical Grid Development

A variable rectilinear grid was used to accurately and efficiently represent the hydrodynamics of the Palm Beach Harbor Navigation Channel and Lake Worth area including the details of the navigation channel alternatives. Figure 2 shows the hydrodynamic model grid domain. Figure 3 shows the Palm Beach Harbor entrance channel model area.

The existing entrance channel is 400 ft wide and the proposed alternative width is 500 ft. The CMS-FLOW model consists of a variable rectilinear grid with 40,077 cells. Cell size ranges from 50 ft (15m) on a side within the navigation channel area to 240 ft (73 m) at the north and south limits of the grid. This resolution results in eight grid cells across the width of the existing entrance channel. This approach allows the model to represent the channel widening alternative of 500 ft.

The CMS-WAVE grid, shown in Figure 4, extends 8.4 nmi along the coast and 4.3 nmi in the cross shore direction and was specified to have 164 ft (50 m) spacing over its domain. This spacing provides adequate resolution for sediment transport and shoal rate estimates. The wave model grid includes the entrance channels and surrounding coastal area.

Bathymetry

Bathymetry for the hydrodynamic model is based on USACE surveys of the navigation channel and the National Oceanic and Atmospheric Administration's (NOAA) LIDAR data in the project area. Figure 5 shows the base condition bathymetry used in the hydrodynamic model.

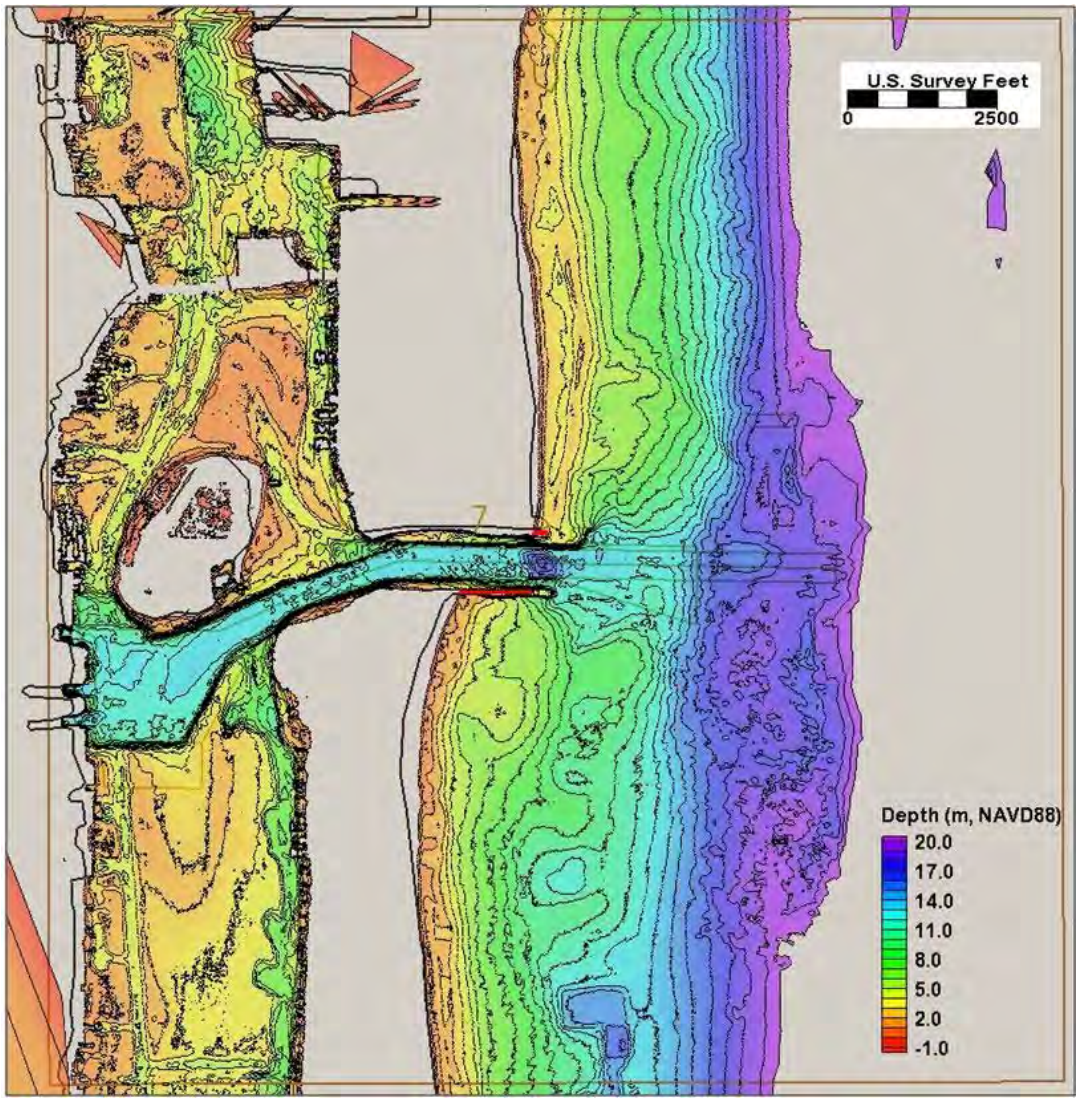

Figure 5. Palm Beach Harbor hydrodynamic model bathymetry (depth in meters). .

Boundary Conditions

The water level boundary condition is based on National Ocean Service (NOS) measured water level data in the Lake Worth inlet area. NOS stations used to construct the water level boundary condition include the Port of Palm Beach Harbor, Lake Worth Pier and PGA Blvd. Water level boundary conditions for the calibration of the CMS-FLOW model used for alternative optimization were constructed for the period 17 Dec 2008 to 22 Dec 2008. Alternative sediment transport simulations were based on the period 1 Sep to 30 Nov 2011.

Wave data for the sediment transport modeling was transformed in the CMS-WAVE from National Buoy Data Center (NDBC) Canaveral and Ft Pierce stations.

-

Hydrodynamic Model Calibration and Verification

Calibration and verification time periods were selected in order to make use of the physical oceanographic data collected in the Lake Worth Inlet area by NOS and the USACE, shown in Table 1. NOS data includes water-levels collected at the Port of Palm Beach Harbor station and ADCP currents collected at the inlet throat, Pier 3, and north of the turning basin from November 2008 to January 2009 (See Figure 7a & 7b). USACE data includes water-levels collected at stations north and south of the harbor area and offshore north of the inlet and ADCP currents collected at the inlet throat, Cut-2 from August 2008 to October 2008 (See Figure 6a & 6b).

An existing conditions CMS-FLOW model was developed and calibrated to match field-measured parameters such as velocities and water levels for the periods August 2008 to October 2008 and 9 to 23 December 2008.

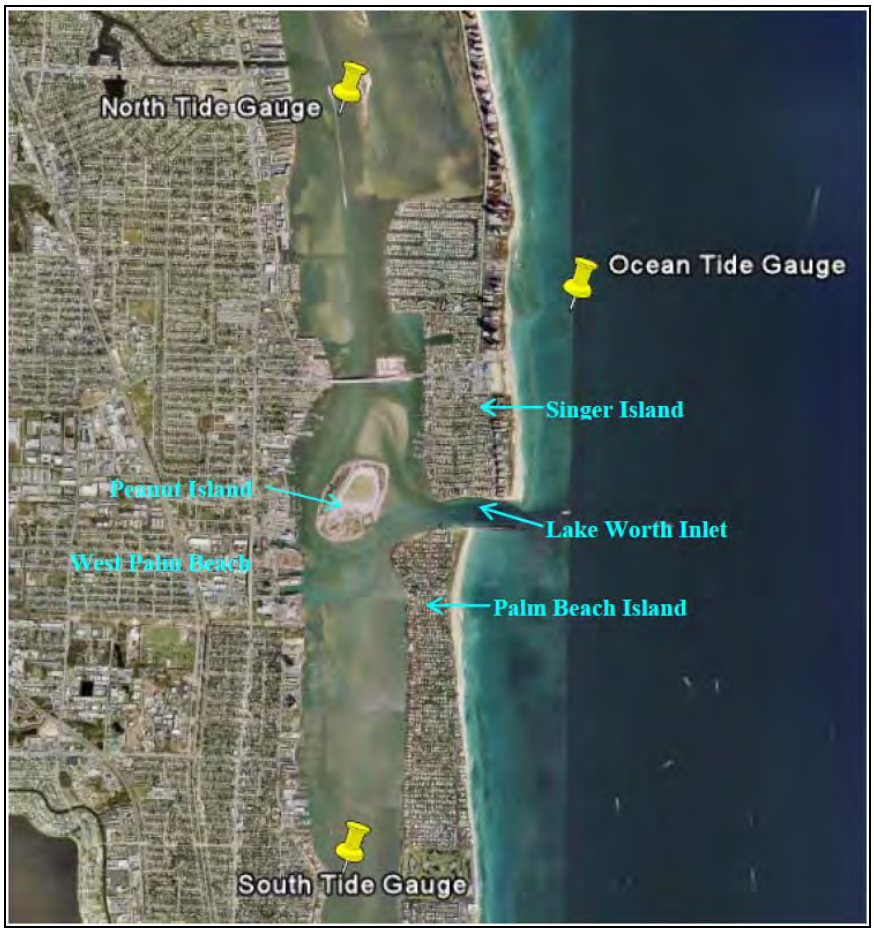

Figure 6a. USACE water-level data locations.

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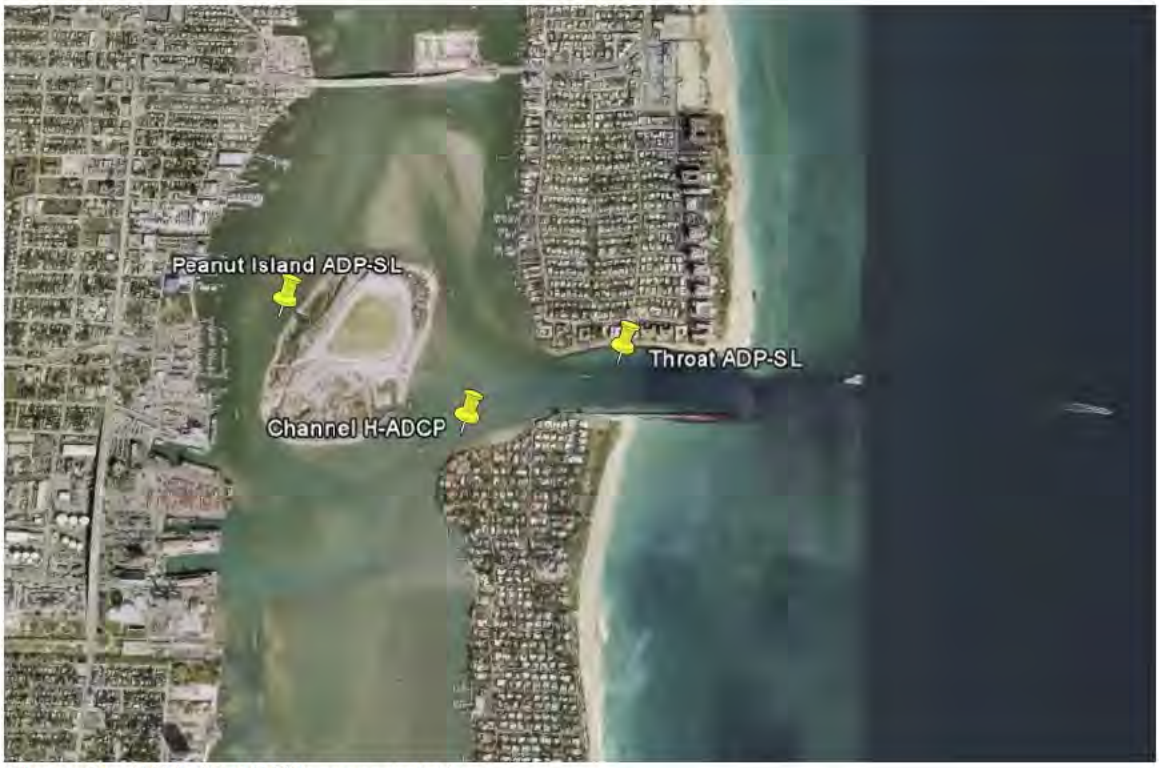

Figure 6b. USACE ADCP current stations.

Table 1. Observed Water Level and Current Gages

INSTRUMENT	Station No.	Latitude	Longitude	Observation Period
North Tide Gage		26° 48.266'	80° 02.839'	8/28 to 10/8/2008
South Tide Gage		26° 44.616'	80° 02.822'	8/28 to 10/8/2008
Ocean Tide Gage		26° 47.325'	80° 01.601'	8/28 to 10/8/2008
Throat ADP-SL		26° 46.296'	80° 02.084'	Aug 29-31 & Sep 22-24, 2008
Channel H-ADCP		26° 46.245'	80° 02.512'	Aug 29-31 & Sep 22-24, 2008
Peanut Is. ADP-SL		26° 46.484'	80° 02.933'	Aug 29-31 & Sep 22-24, 2008
NOS				
Port of West Palm Beach –Tide Gage	8722588	26° 46.2	80° 3.100	Jan 25, 2008 to Oct 20, 2010
Lake Worth ICW – Tide Gage	8722669	26° 36.8'	80° 2.8'	Jan 25, 2008 to Oct 18 2010
Lake Worth Pier – Tide Gage	8722670	26° 36.7'	80° 2.0'	Oct 27,2001 to Present
Lake Worth Inlet - ADCP	LWI0901	26° 46.379'	80° 2.172'	Dec17, 2008 to Jan 19, 2009
Pier 13 -ADCP	LWI0903	26° 46.022'	80° 3.008'	Nov14, 2008 to Jan 19, 2009
N. Turning Basin - ADCP	LWI0904	26° 46.276'	80° 3.024'	Nov14, 2008 to Jan 19, 2009

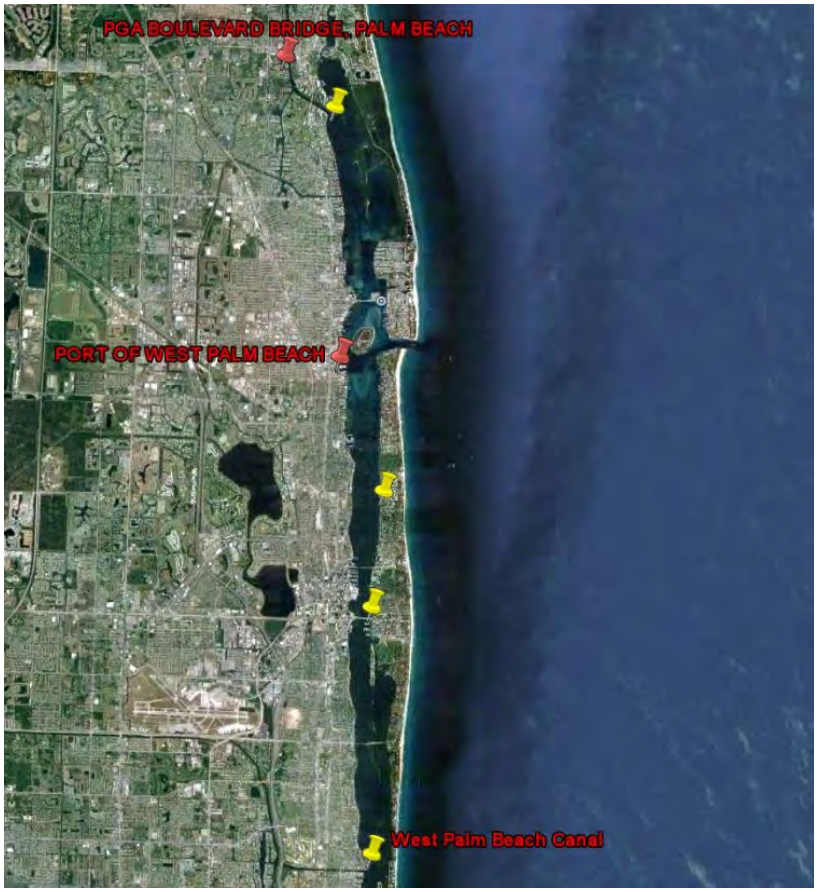

Figure 7a. NOS water-level stations.

Figure 7b. NOS ADCP current stations.

Waterlevels

CMS-FLOW waterlevels were calibrated at the 3 USACE stations (North, South , & OceanTide Gauges) and the NOS station number 8722588, Port of West Beach.
Figure 8 shows the comparison between CMS-FLOW and NOS 8722588 water levels for the period December 9th to 23nd, 2008. Agreement between model and measured values are good, with an RMS error of 0.07 m.

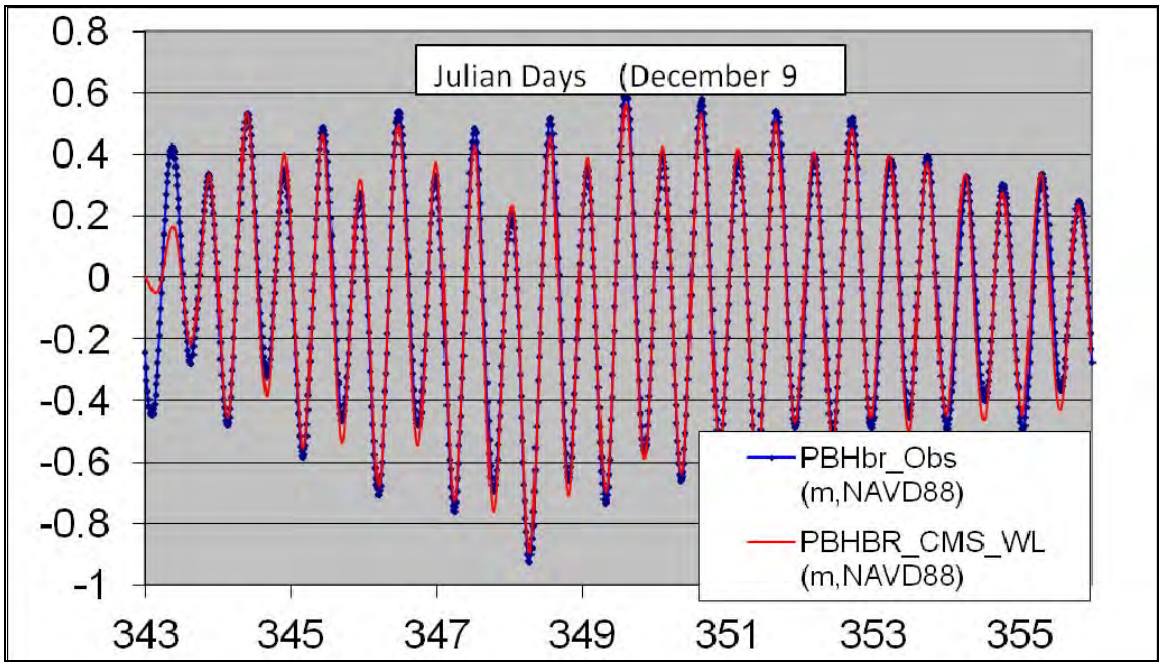

Figure 8. CMS-FLOW Port of West Palm Beach vs Measured Waterlevel (draft)

Currents

CMS-FLOW currents were calibrated at the NOS station LWI0901, in the inlet throat. Figure 9 shows the comparison between CMS-FLOW and NOS LWI0901 currents for the period December 17th to 22nd, 2008. Agreement between model and measured values are good, with an RMS error of 0.09 m.

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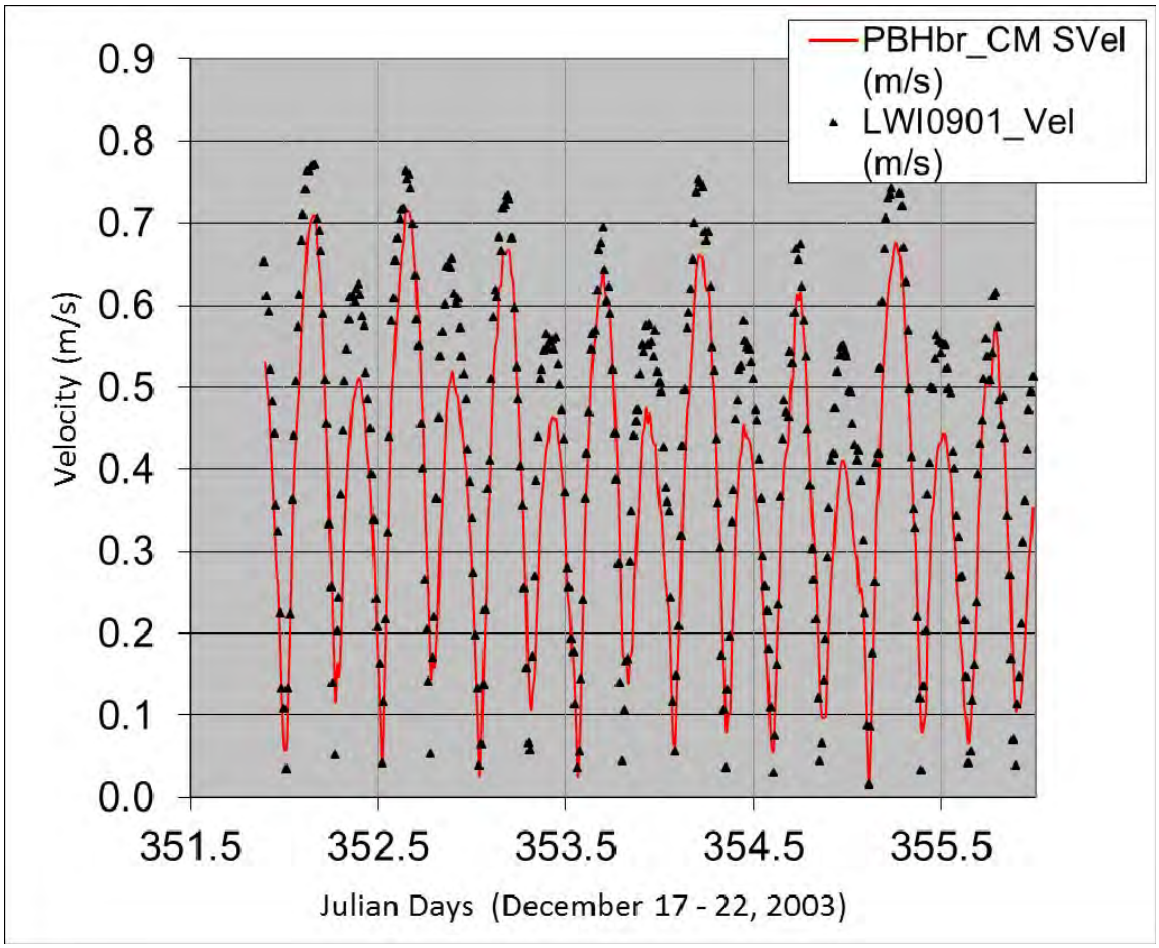

Figure 9. CMS-FLOW inlet throat vs Measured Depth averaged current velocities (m/s).

Hydrodynamic Modeling for Ship Simulation

Currents for Ship Simulation Validation

In order to provide currents for the validation of the Ship simulation model, the existing Palm Beach Harbor Navigation Channel configuration consisting of a 400 ft wide, 35 ft entrance channel project depth, a 33 feet deep, 300 feet wide inner channel and a 1,200 foot turning diameter turning basin as well as the 200 feet (north-south) by 500 feet (east-west), 35 ft existing settling basin was simulated.

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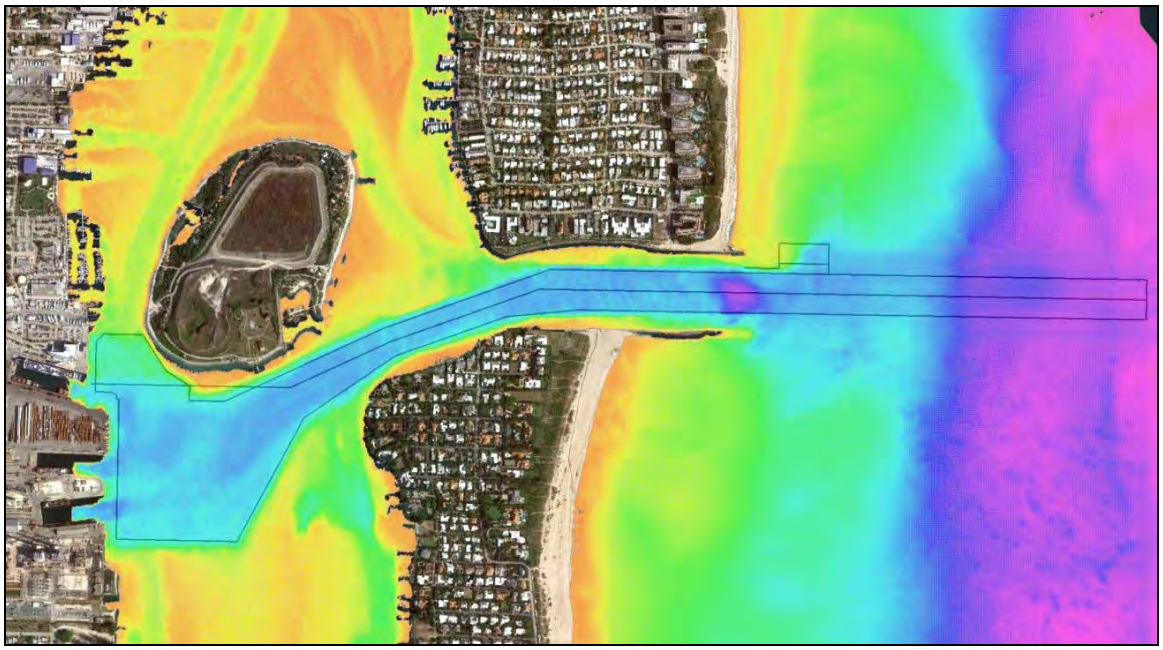

Figure 10. Existing Condition- Palm Beach Harbor

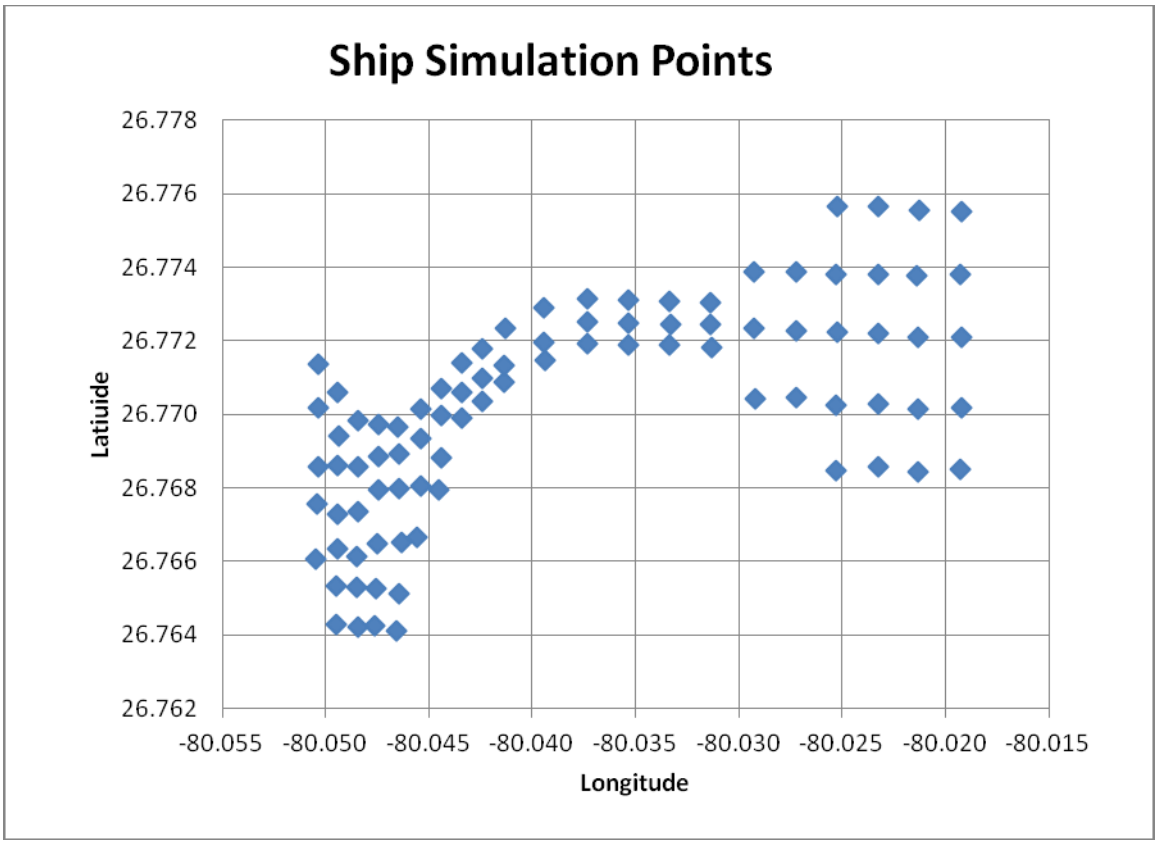

Figure 11. Ship Simulation Current Point Locations.

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Plan1 Currents

CMS-FLOW hydrodynamic simulations provided currents for simulations of Alternative Plan 1 Ship Simulations. Alternative Plan 1 consists of an entrance channel flare (A-1), entrance channel widening (B-1, B-2), an inner channel widener (C), and expansion of the turning basin (D, F, & G).

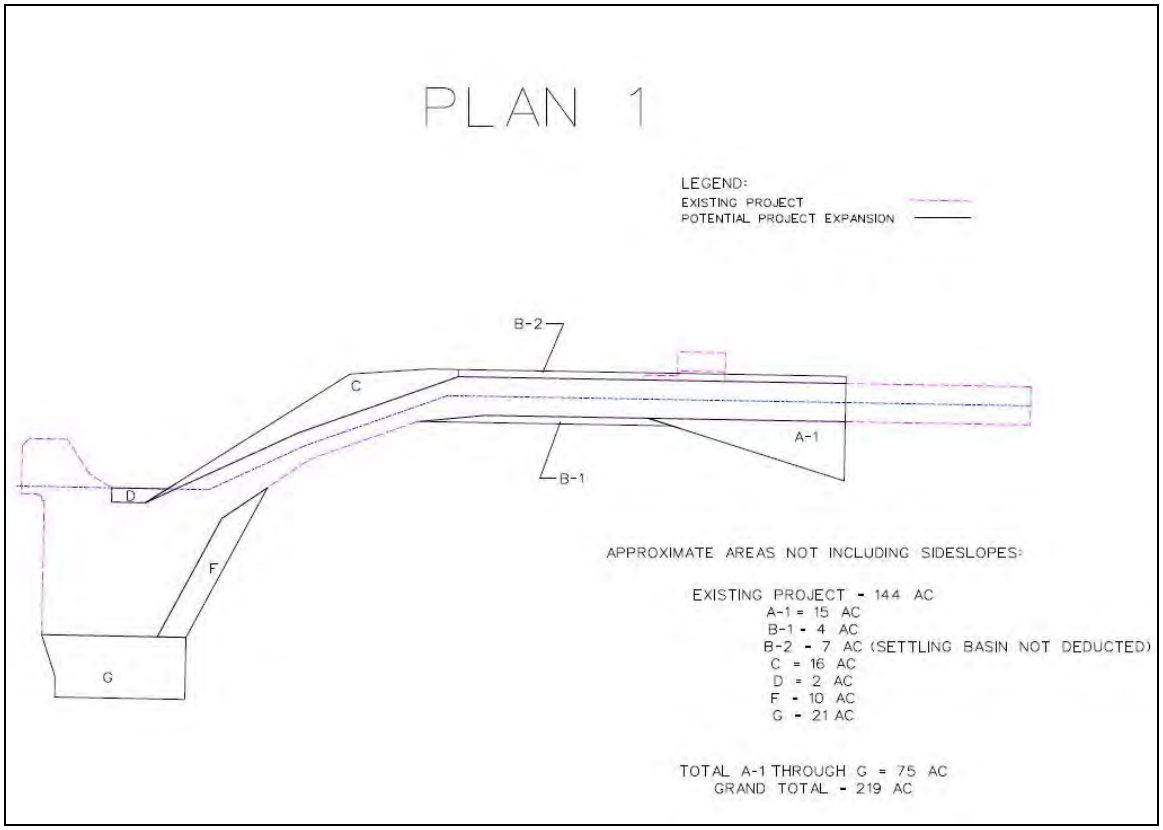

Figure 11. Ship Simulation- Alternative Plan1

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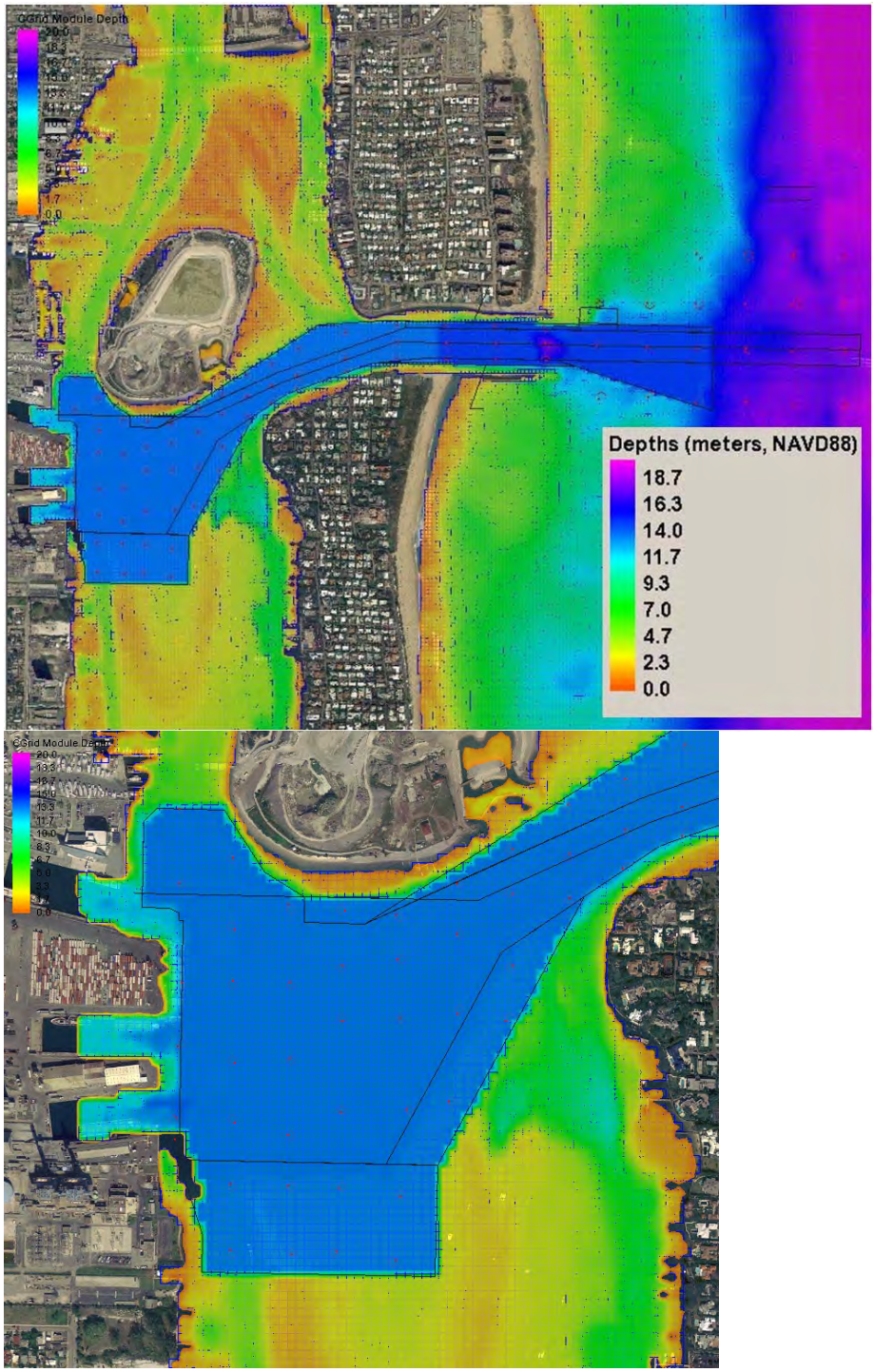

Figure 13. Ship Simulation – Plan 1 CMS-FLOW bathymetry and detail of Turning Basin.

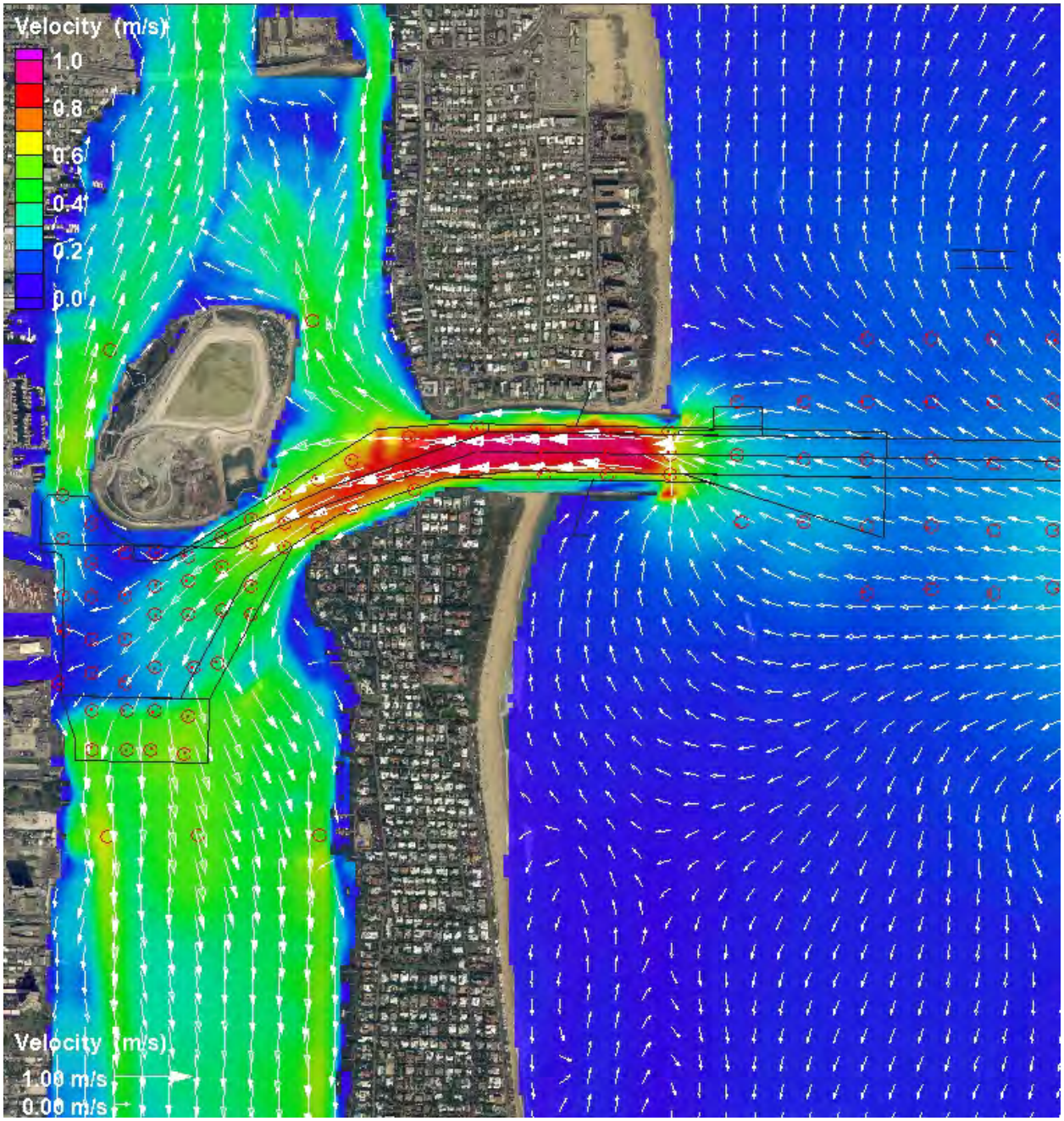

Figure 14. Existing Flow vectors for maximum spring flood tide.

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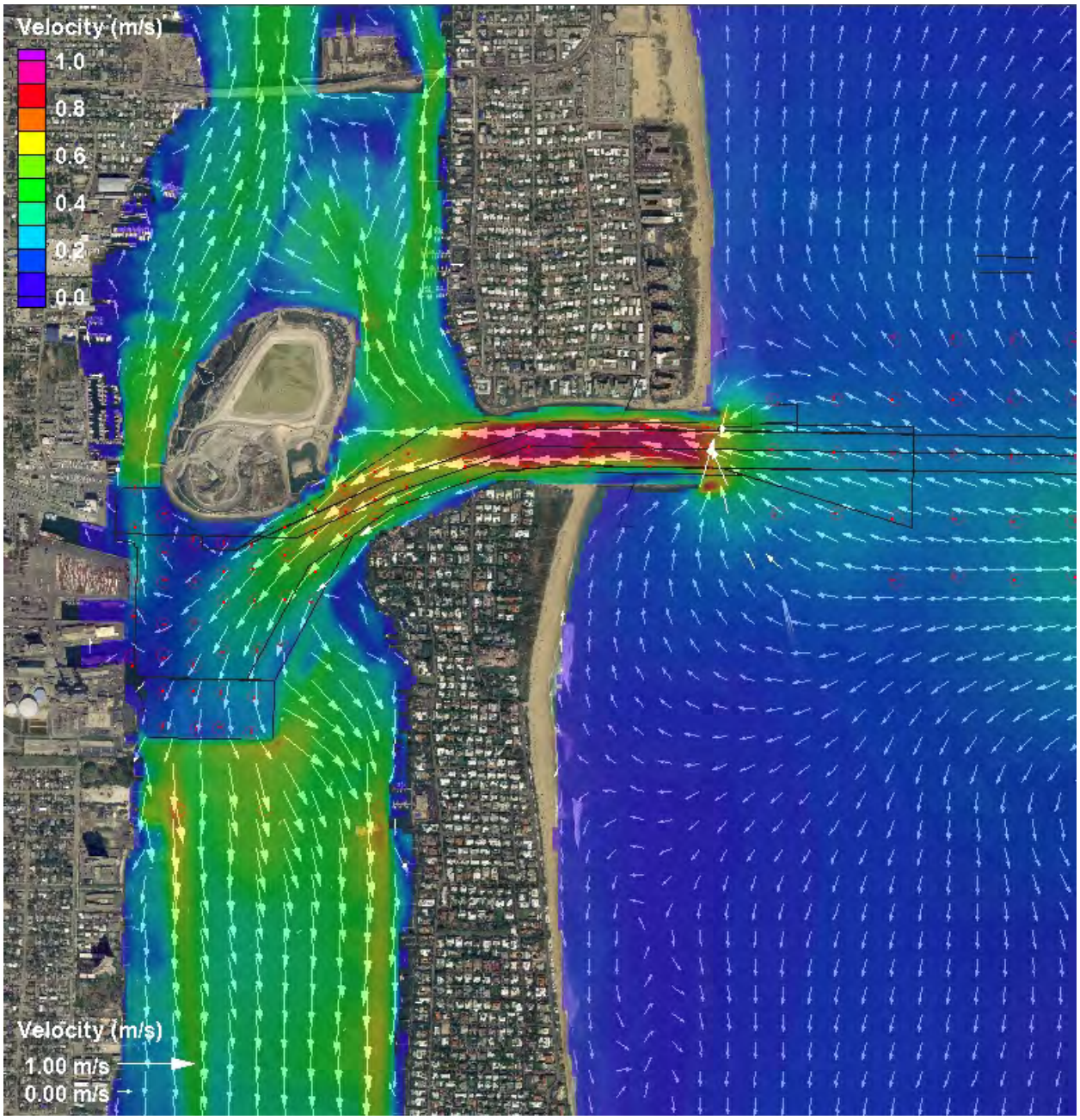

Figure 15. Plan1 Flow vectors for maximum spring flood tide.

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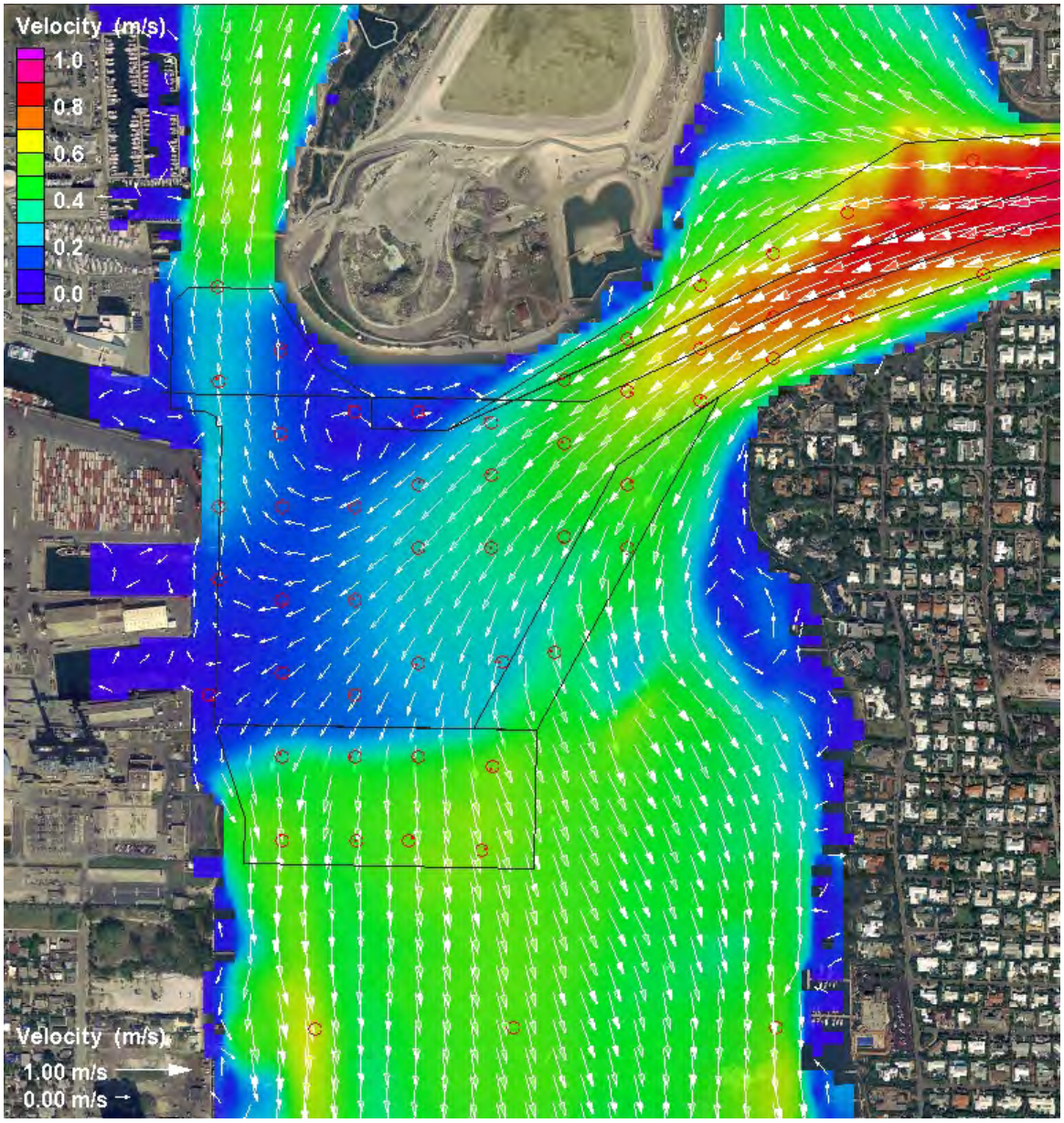

Figure 15. Existing Flow vectors for maximum spring flood tide.

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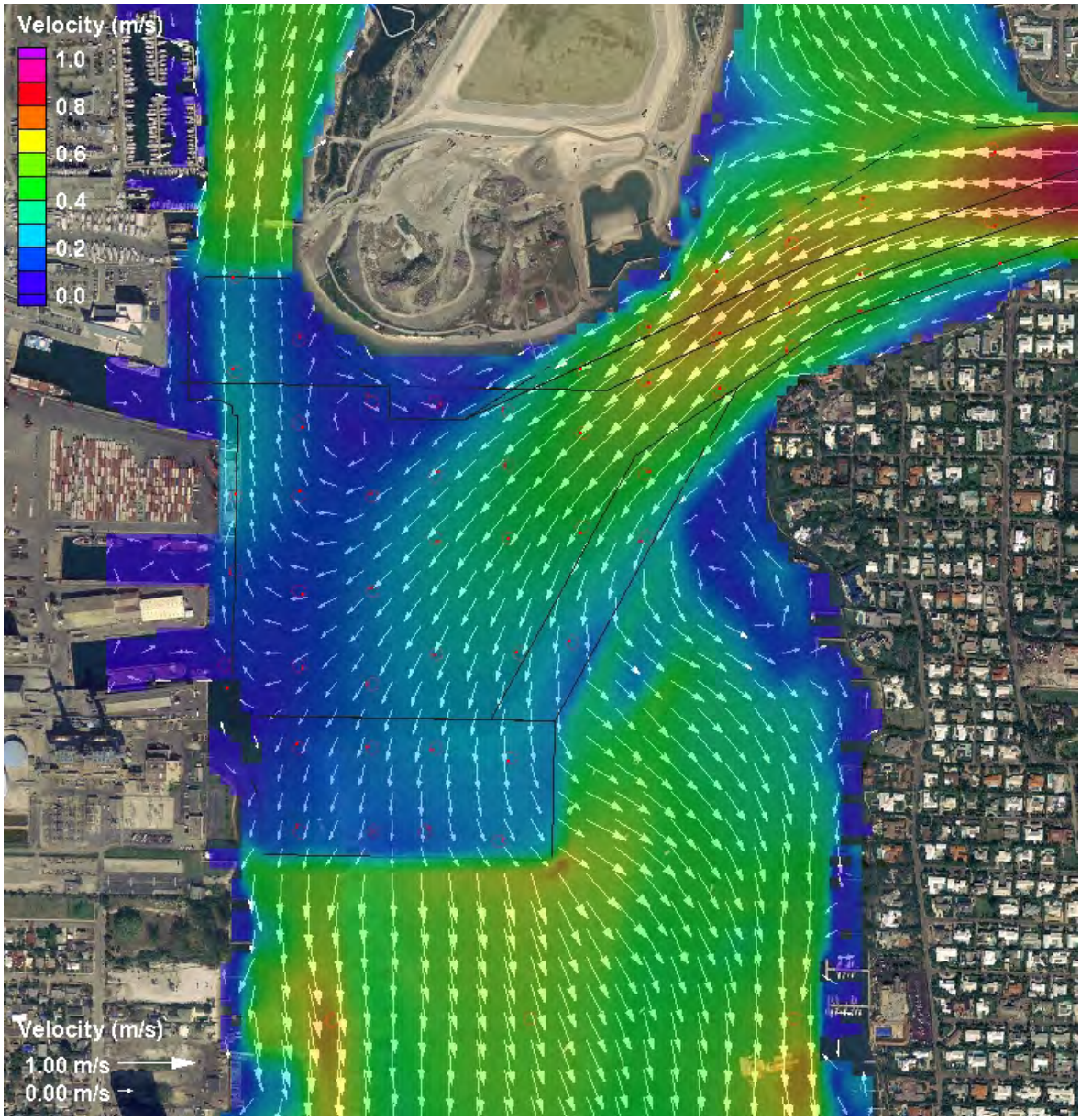

Figure 17. Plan1 Flow vectors for maximum spring flood tide.

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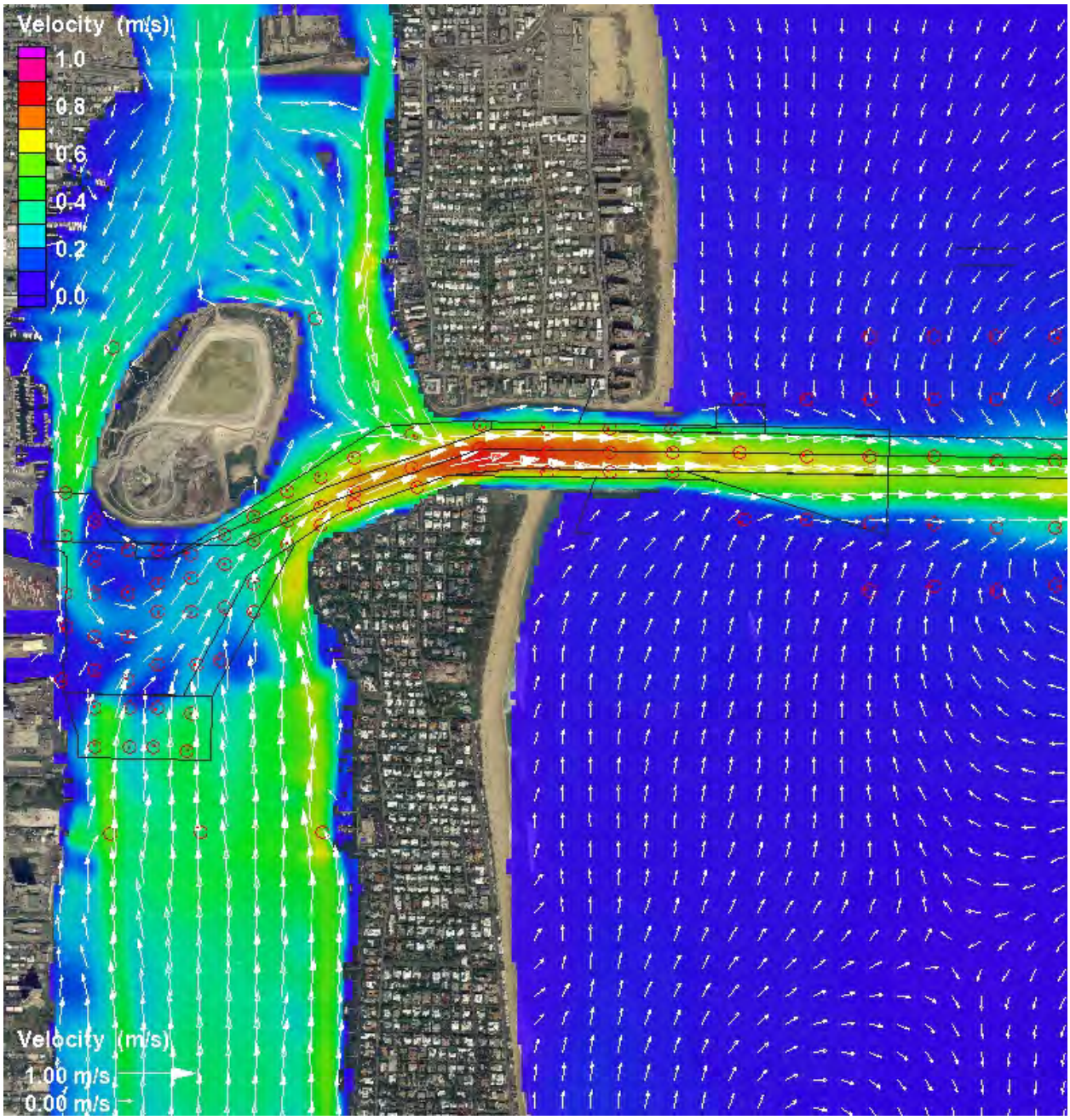

Figure 18. Existing Flow vectors for maximum spring ebb tide.

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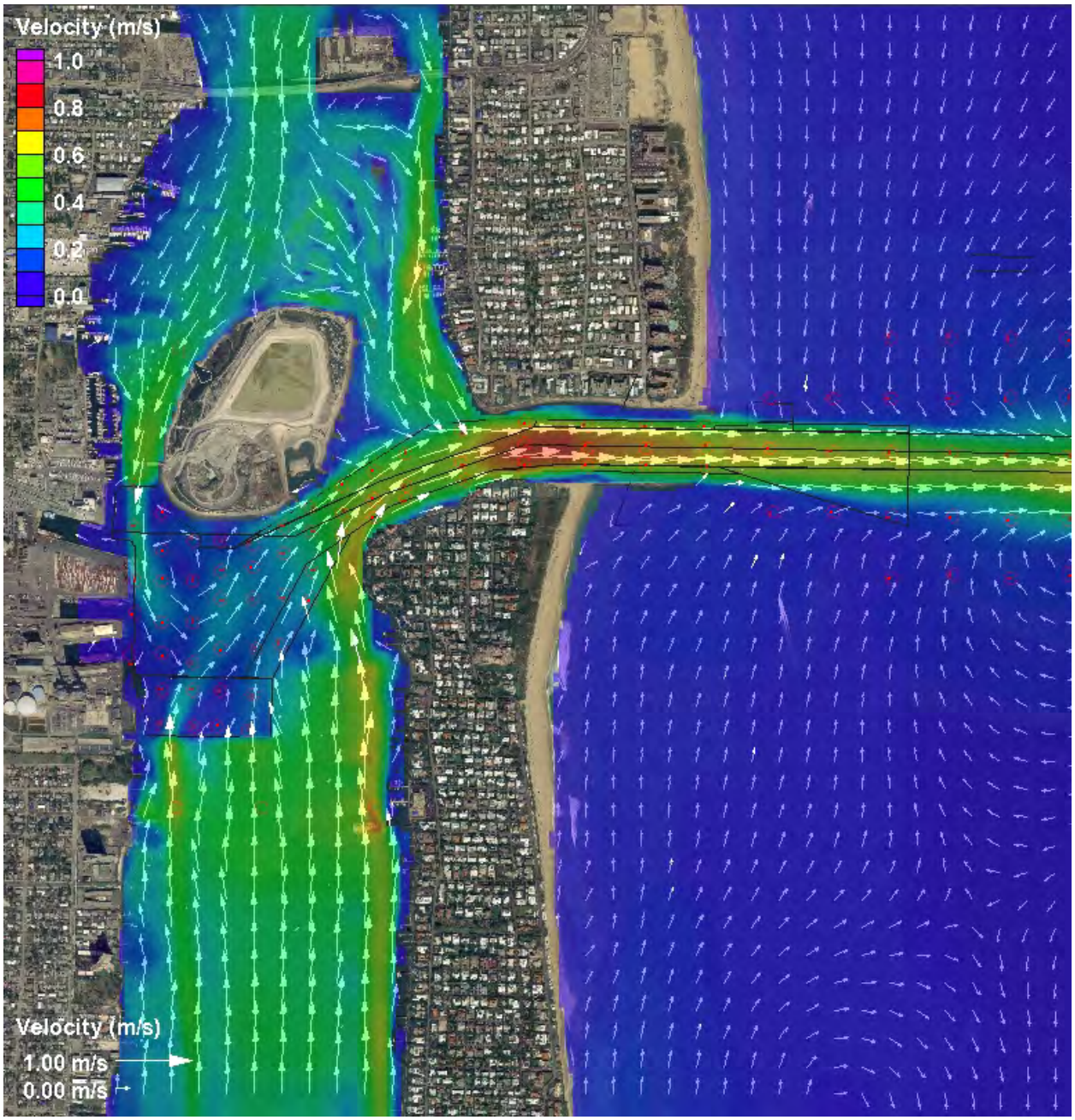

Figure 19. Plan1 Flow vectors for maximum spring ebb tide.

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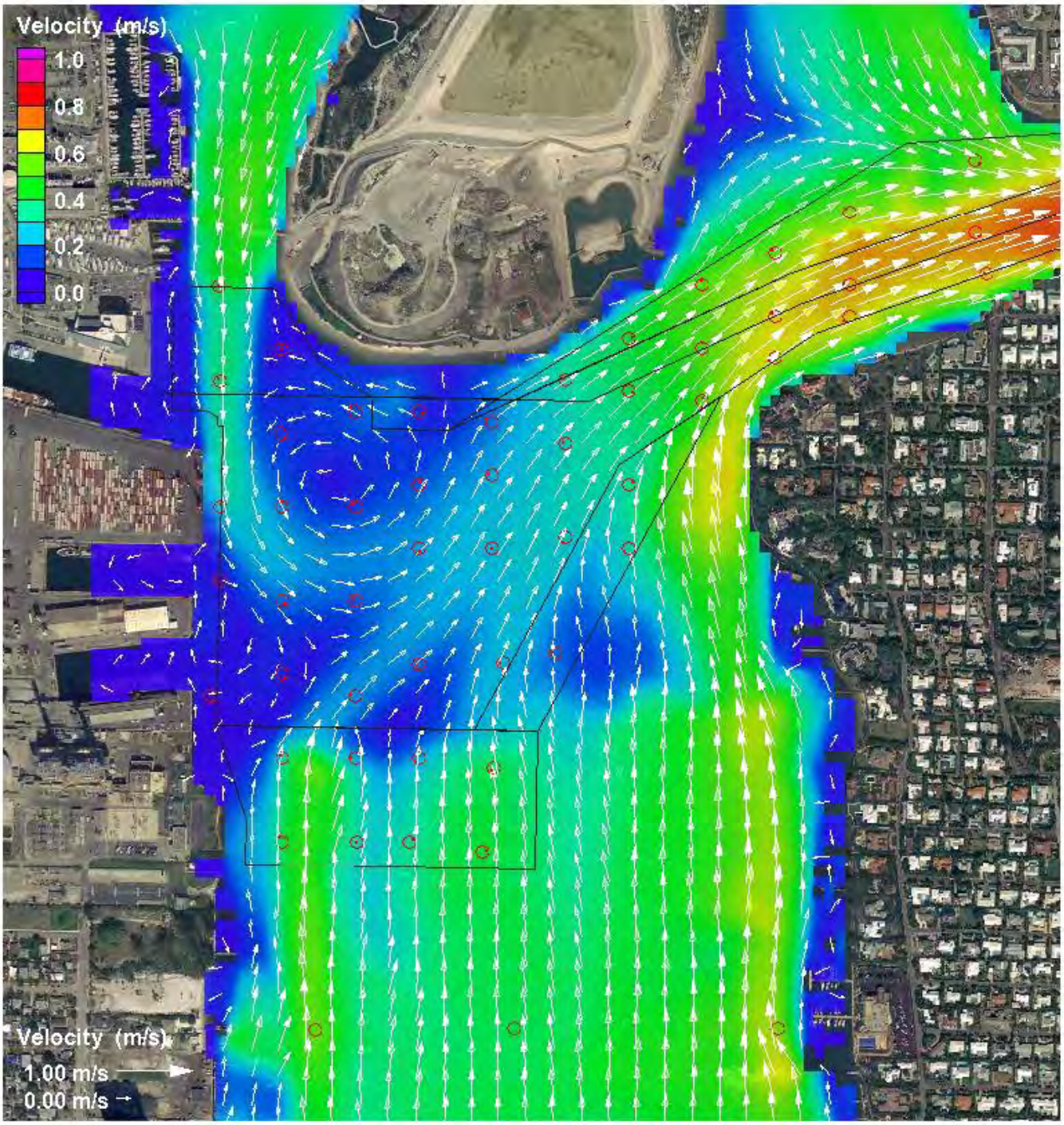

Figure 20. Existing Flow vectors for maximum spring ebb tide.

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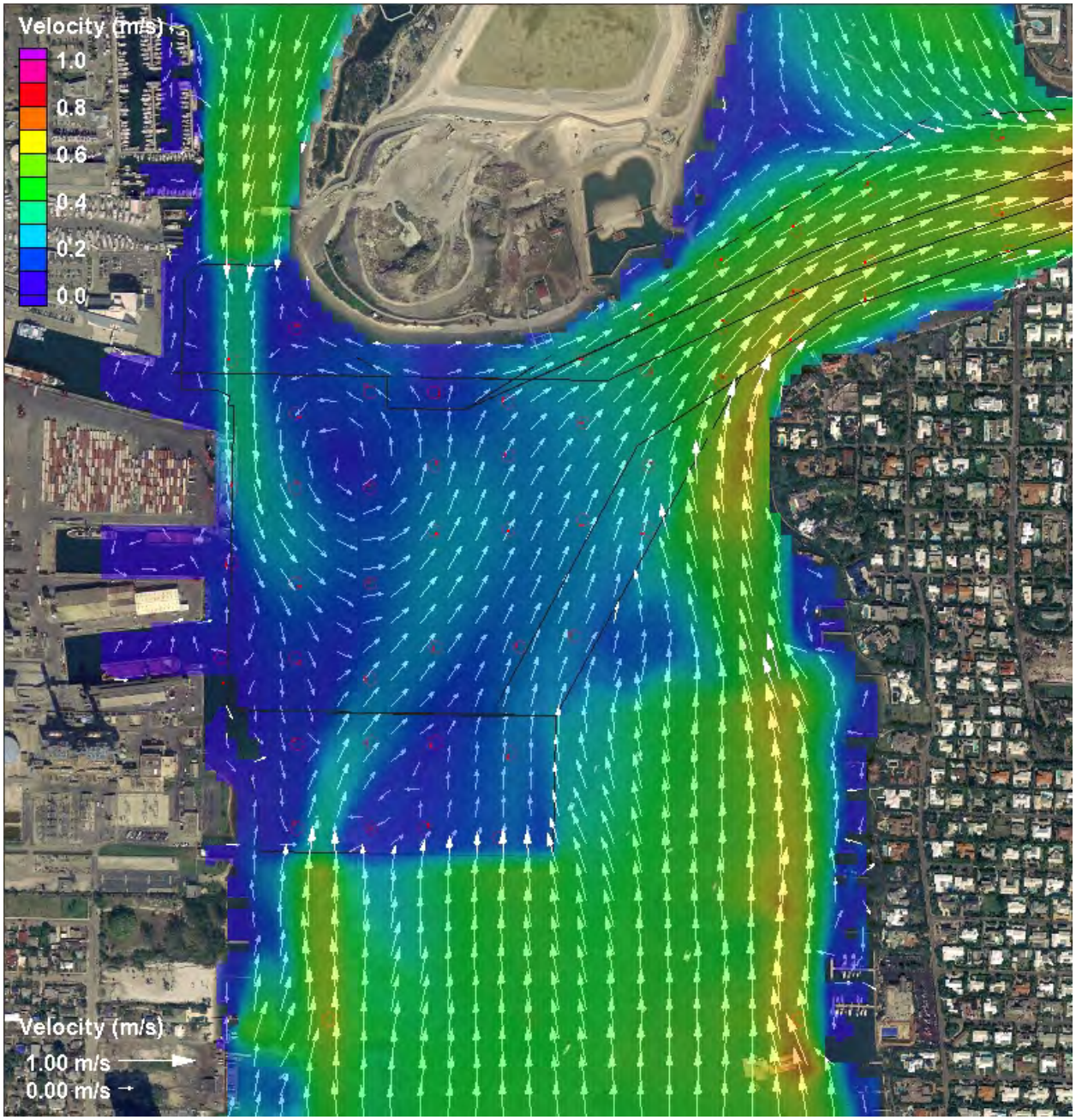

Figure 21. Plan 1 Flow vectors for maximum spring ebb tide.

Plan 2 Currents

CMS-FLOW hydrodynamic simulations provided currents for simulations of Alternative Plan 2 Ship Simulations. Alternative Plan 2 consists of a reduced entrance channel flare (A-1), entrance channel widening (B-1, B-2), a reduced inner channel widener (C), and reductions of areas F and G.

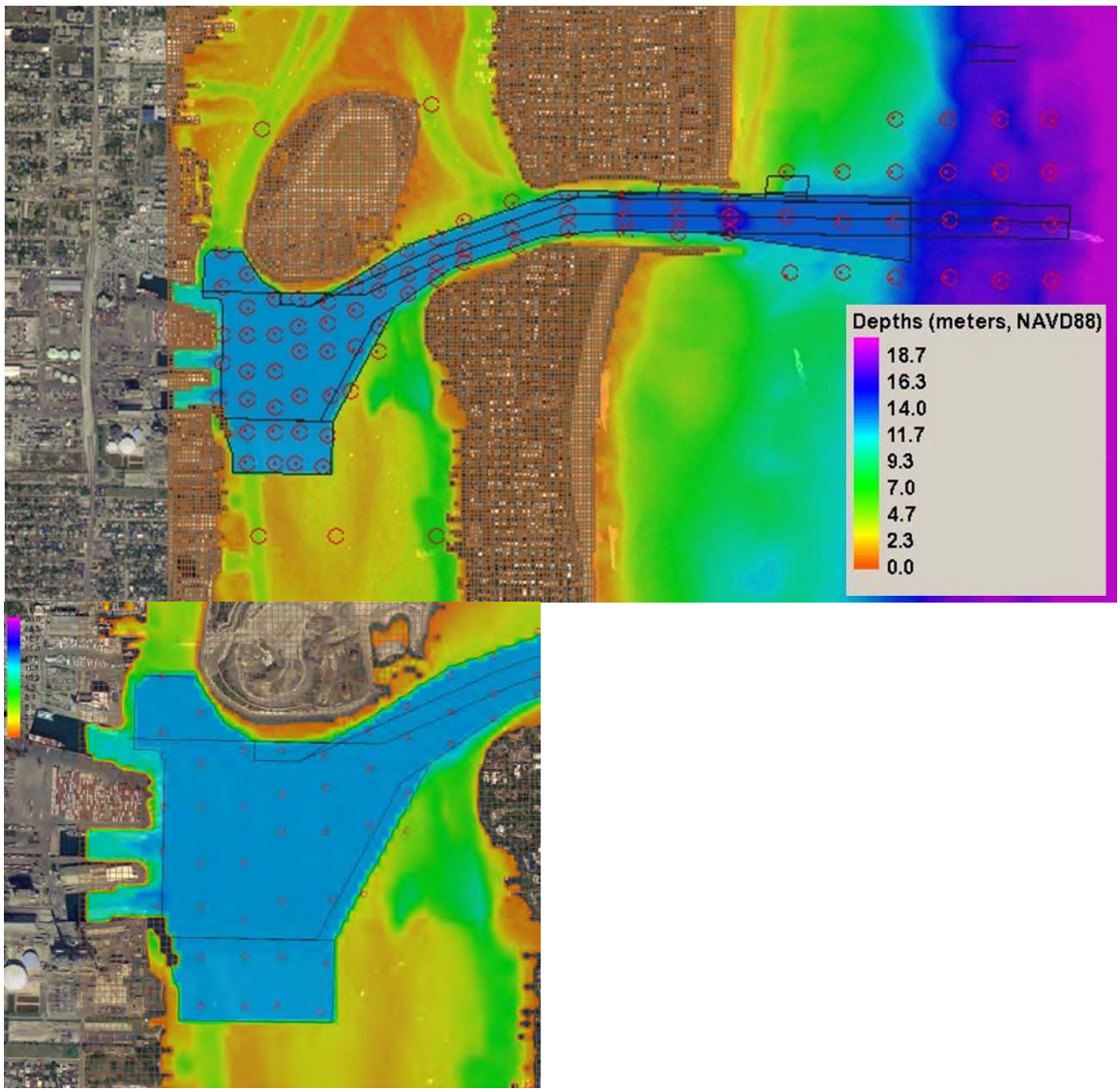

Figure 22. Alternative Plan 2 and detail of Turning Basin.

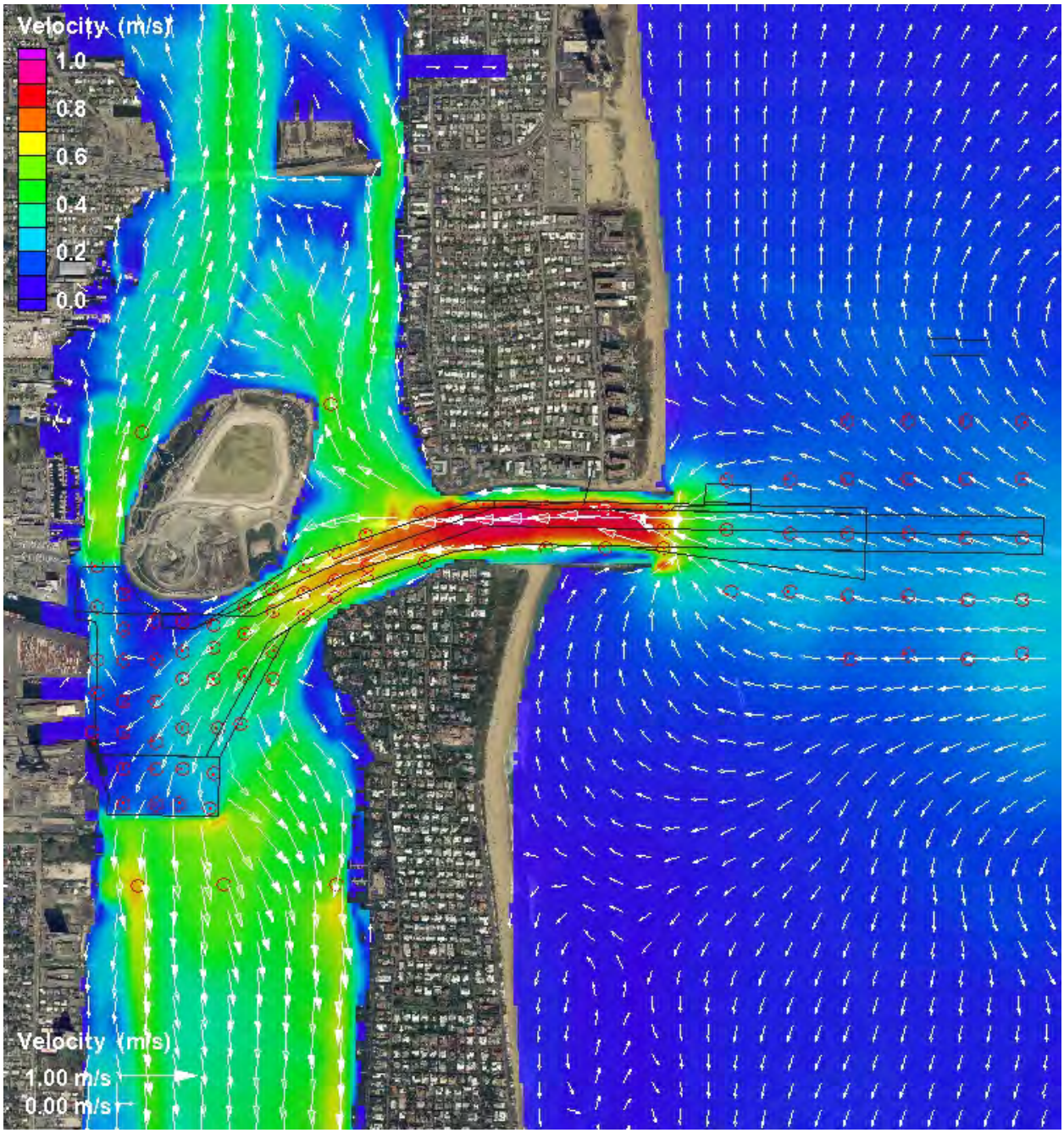

Figure 23. Plan 2 Flow vectors for maximum spring flood tide.

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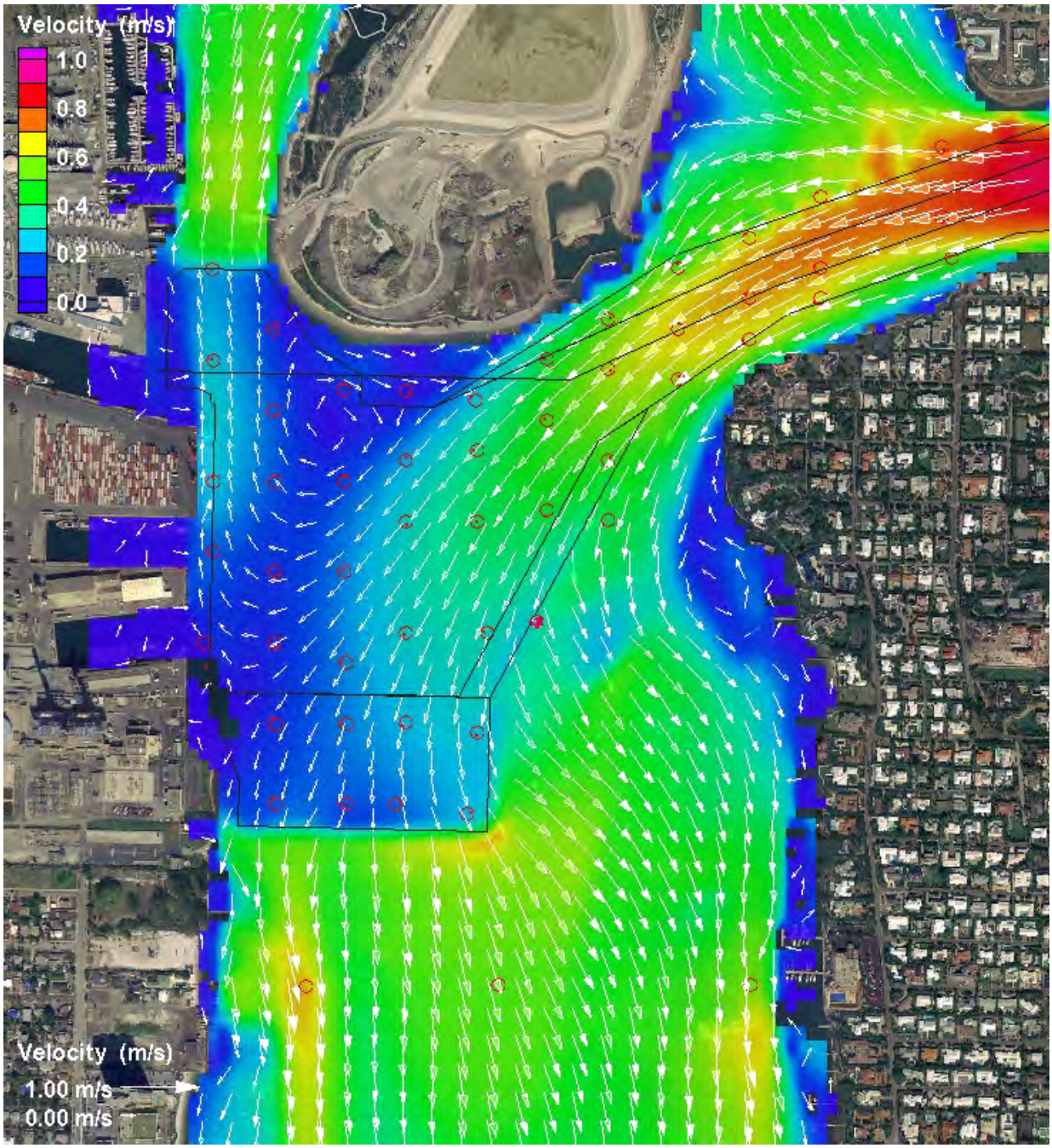

Figure 24. Plan2 Flow vectors for maximum spring flood tide.

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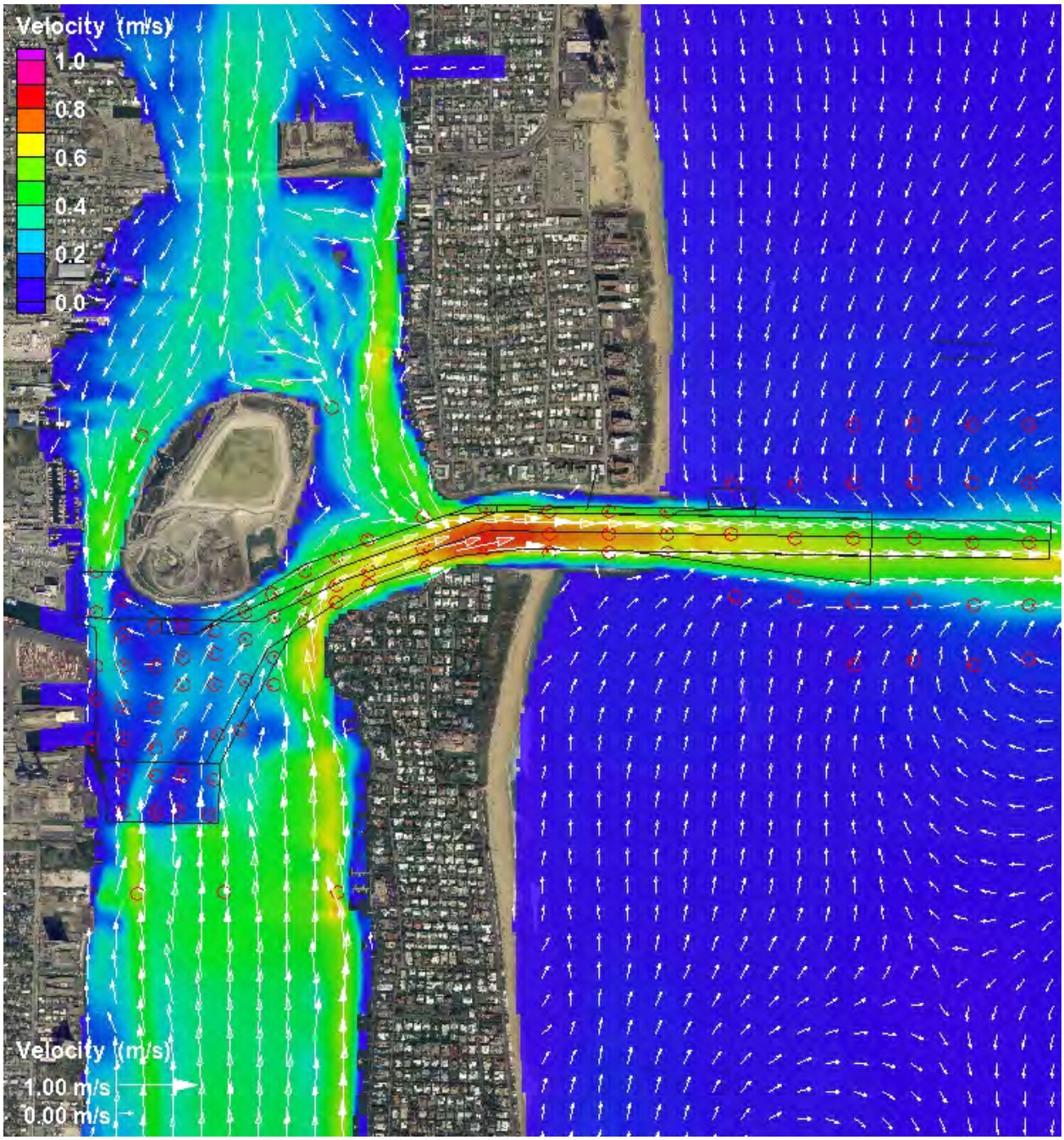

Figure 25. Plan 2 Flow vectors for maximum spring ebb tide.

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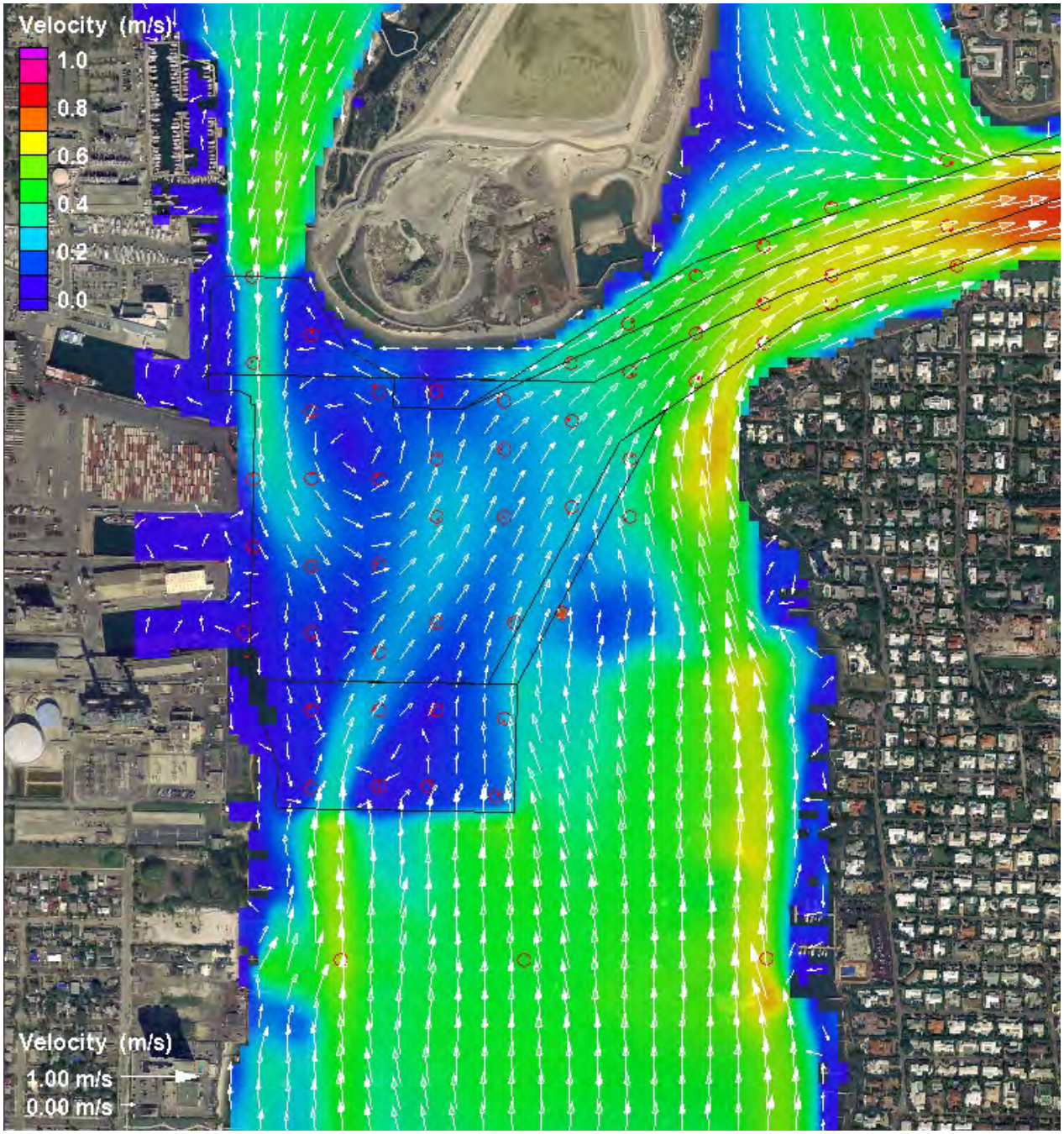

Figure 26. Plan 2 Flow vectors for maximum spring ebb tide.

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Sediment Transport Modeling for Shoaling

CMS simulations conducted for this study included coupled CMS-FLOW and CMS-WAVE simulations of bed changes to estimate the shoaling rate for the project alternative as well as to optimize the settling basin design.

Sediment Transport Calibration

The simulation periods selected for this analysis span USACE bathymetry surveys conducted in September 2011, November 2011 and March 2012. The existing condition channel bathymetry in September 2011 was used as the initial condition for a 3 month calibration simulation which ends at the USACE November 2011 bathymetry survey (Figure ST1). The simulation period used for calibration from September 1st to November 30th, 2011 represents an energetic wave climate with the mean Hs= 1.24 m during this period and four (4) storm events with two (2) exceeding Hs =3.0m. The calibration period mean Hs is similar to the Wave Information Study (WIS) mean Hs = 1.3 m for station 63459. Figure ST2 shows the model results for existing condition channel shoaling and bed elevation change for the September to November 2011 time period. The shoaling volumes from the model were compared to the measured shoal volume based on the September to November 2011 surveys.

Sediment Transport Alternative Channel Depth and Settling Basin Optimization

Existing channel depths with the existing settling basin and the scheduled expanded settling basin were simulated and evaluated for channel shoaling volumes. Neither of these configurations results in channel shoaling volumes that would obviate the need for unscheduled maintenance dredging. Based on these results, simulations were conducted to optimize the expanded settling basin for both the existing channel depth (35/37 ft, MLLW) and the selected project alternative depth (47/ 50 ft, MLLW). Existing project feature constraints including the north and south jetties and beach area adjacent to the expanded settling basin limit both the alternative channel width and depth and the western extent of the settling basin. Figure ST3 shows these features including the location of the jetty toe. Both the channel and settling basin are constrained by a minimum distance from the jetty toe due to potential jetty instability caused by foundation failure from channel or settling basin encroachment (See Geotechnical Attachment C).

After a number of iterative simulations an optimum settling basin configuration was determined that would trap enough sediment during storm events to reduce channel shoaling to allow for longer scheduled maintenance dredging cycles. Figure ST4 shows the Existing Channel and Optimized Settling Basin shoaling. This combination reduces

channel shoaling but not to the extent which would lengthen the dredging cycle. Figure ST5 shows the Selected Project Channel Depth and Optimized Settling Basin Shoaling. This configuration reduces the channel shoaling enough to lengthen the dredging cycle to 2 years when combined with advanced maintenance. This configuration doesn't reduce the volume required to be dredged but does trap more of the volume in the settling basin rather than the channel and saves cost by reducing the number of required maintenance dredging events, on average, over the life of the project. Note that no significant shoaling was observed in the Inner Channel or Turning Basin. Therefore shoaling volumes estimates in these areas are based on historical rates and the increased area of the project features in these areas.

Advance Maintenance Zones and Annual Shoaling Volumes

In order to accommodate shoaling that occurs in the selected project alternative channel depth, advanced maintenance zones were established. Figure ST6 and Table ST2 shows the Advance Maintenance Zones and the corresponding annual shoal volumes and elevations. Future maintenance requirements based on model results and historical shoaling volumes for the Inner Harbor, which include the Inner Channel and Turning Basin is estimated to be a 17% increase of the historical volume of 17,224 cy, as shown in the historical dredging records in Table ST1, which corresponds to the increase in project footprint. Since this area is not dredged as often as the Entrance Channel and Settling Basin, it should not affect the dredging frequency.

Future maintenance requirements based on model results for the Entrance Channel (including Adv. Maint.) predict a shoaling rate of 30,000 cy/yr and for the Settling Basins a rate of 70,000 cy/yr. That is similar to the current shoaling rate, however, a significant portion of the volume is trapped in the settling basin rather than the channel. The dredge cycle for the project is once every 2 years (it is 1 year currently) as the new capacity of these optimized features prevents the project from shoaling significantly above the project depth. Therefore, the total maintenance volume estimate is 200,000 cy/2 yr. This is based on an average basis, depending upon storm activity or lack thereof, where there may be periods when dredging is required dredge and others where dredging is not required until 3 years. The overall estimate is 24 Maintenance Dredging events over the 50-year project life.

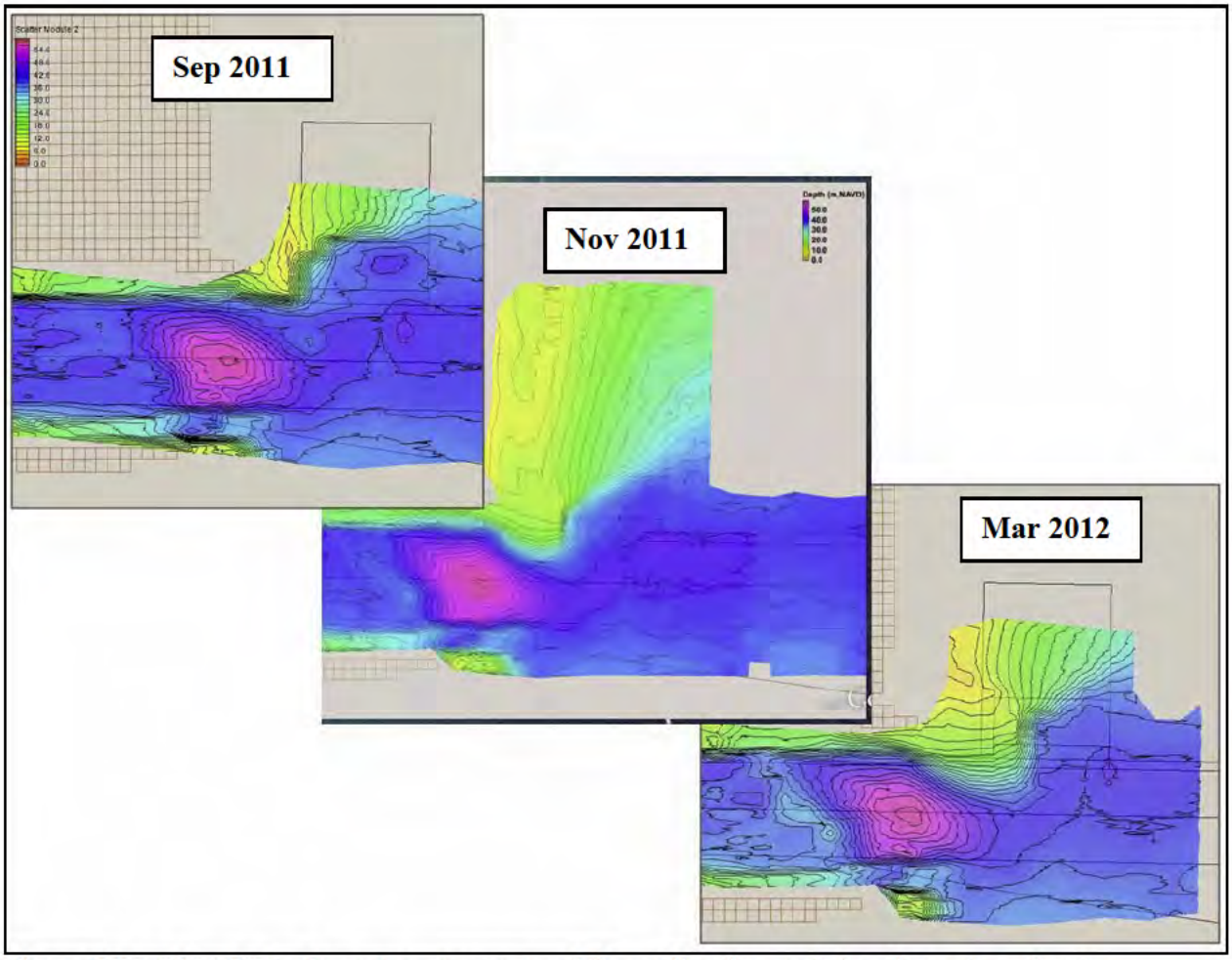

Figure ST1. USACE bathymetry surveys used for calibration and shoaling rate estimates.

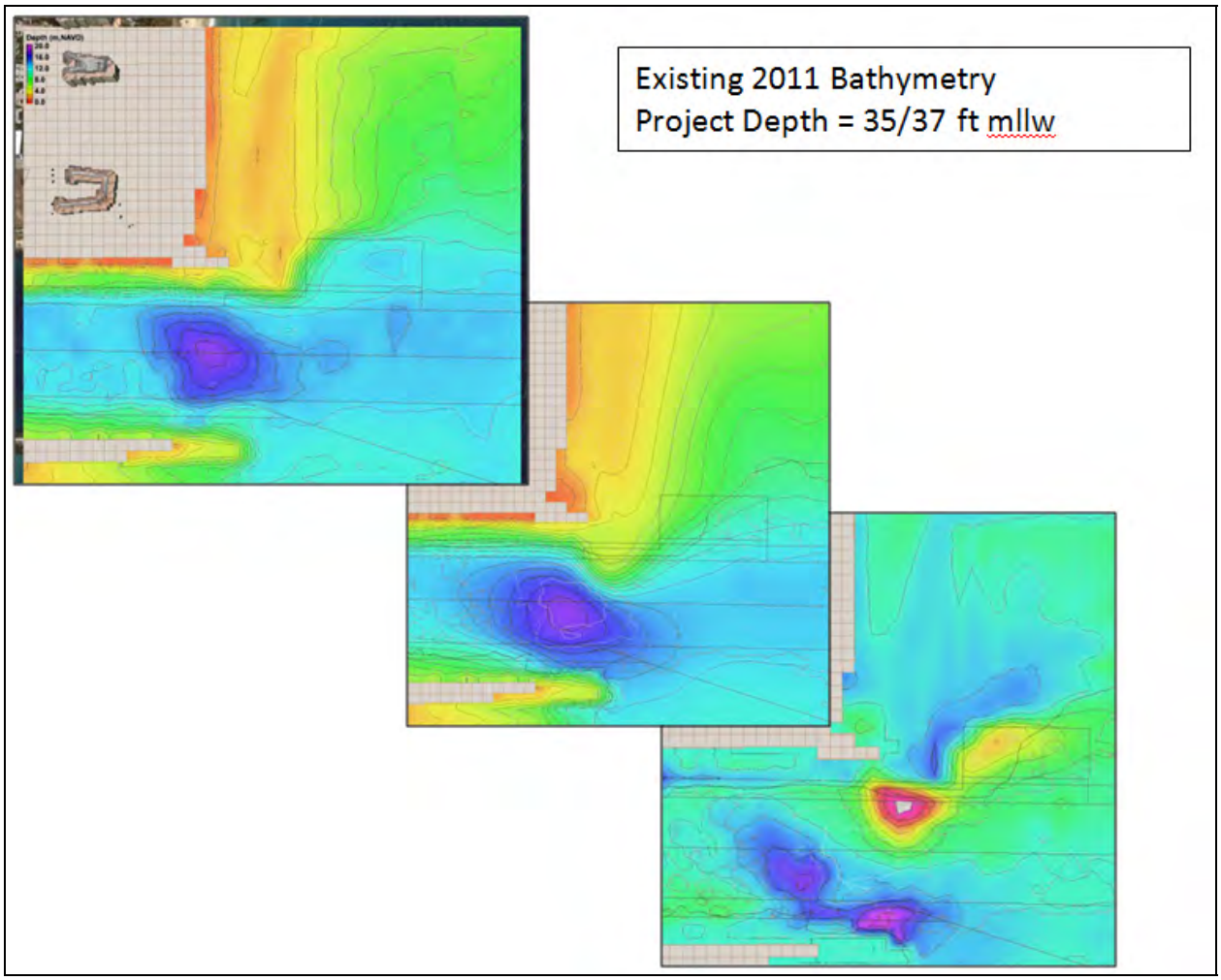

Figure ST2. Existing Channel and Settling Basin Shoaling

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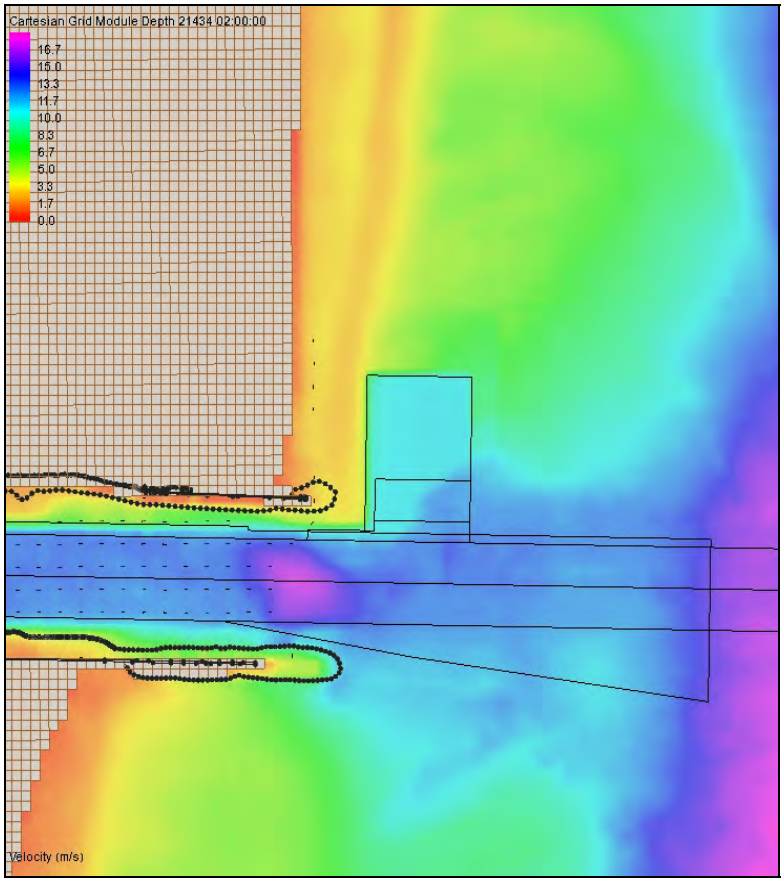

Figure ST3.Project features- Existing Channel, Alternative channel geometry, Planned Expanded Settling Basin, and toe of jetty (black dotted line).

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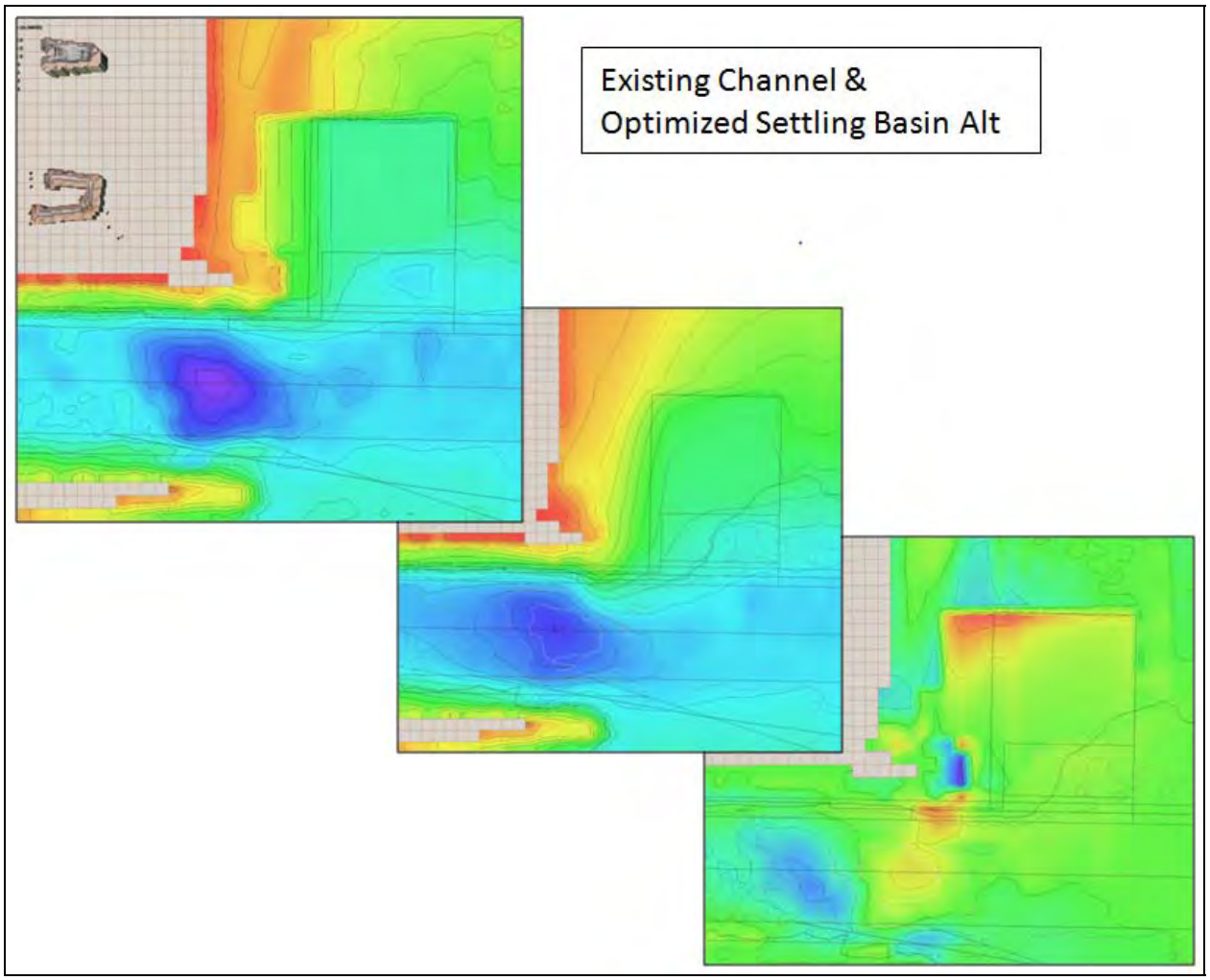

Figure ST4. Existing Channel and Optimized Settling Basin Shoaling.

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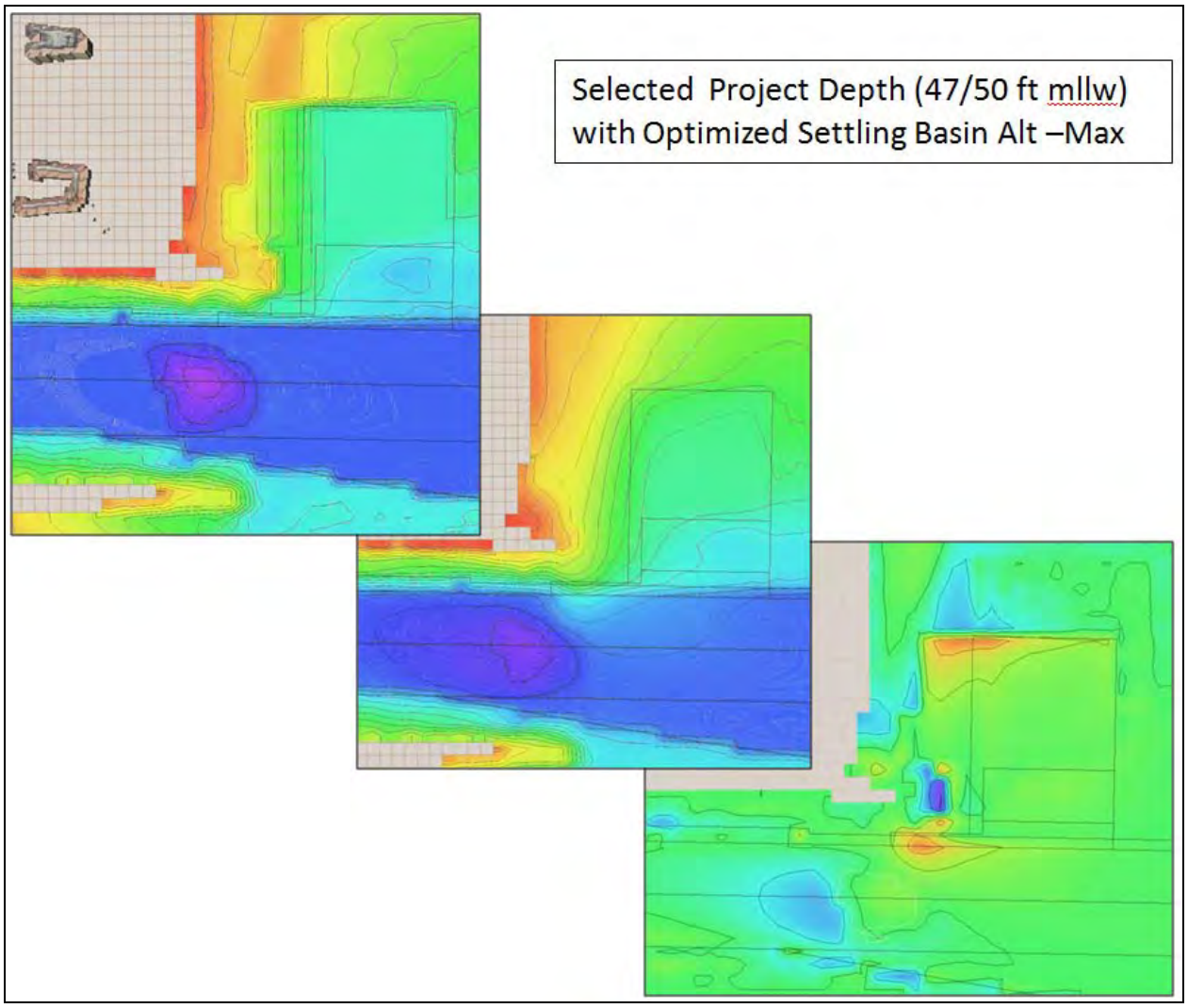

Figure ST5. Selected Project Channel Depth and Optimized Settling Basin Shoaling.

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Table ST1. Historic Dredging Records

JOB KEY	JOB NAME	END DATE	VOLUME DREDGED (CY)	Volume (%)
00SAJ065	PALM BEACH HBR, '00	3/27/2000	124,000	
01SAJ160	Palm Beach Hbr, MD	1/11/2001	57,332	
02SAJ003	Palm Beach Hbr, MD	3/25/2002	118,450	
03SAJ002	Palm Beach Hbr-03, MD	4/29/2003	76,624	
04SAJ050	Palm Beach Harbor	5/7/2004	71,285	
04SAJ141	Palm Beach Hurricane Emer MD	10/2/2004	504	
05SAJ292	Palm Beach Harbor	7/28/2005	305,467	
06SAJ005	Palm Beach Harbor	12/9/2005	70,689	
06SAJ017	Palm Beach Harbor Emergency	10/3/2006	2,312	
07SAJ003	Palm Beach Harbor (FY 07)	4/20/2007	185,000	
08SAJ005	PALM BEACH HARBOR	5/20/2008	157,828	
09SAJ009	Palm Beach Harbor	12/30/2009	64,068	
10SAJ007	PALM BEACH HBR O&M	5/11/2011	144,340	
		Total CY =	1,377,899	
		Annual Average Dredged Volume (CY) =	114,825	
		Entrance Channel & Sediment Basins =	97,601	85%
		Turning Basins =	17,224	15%

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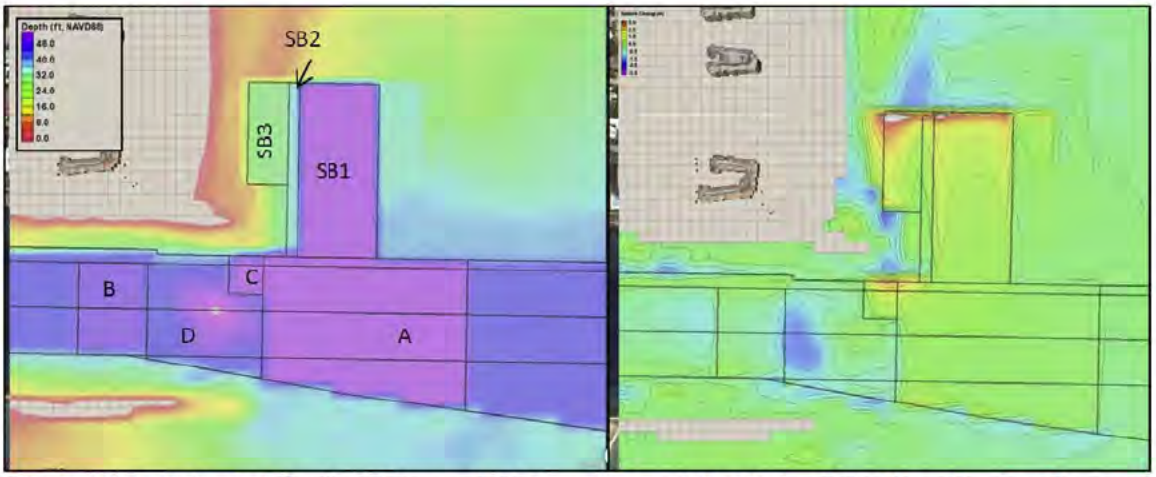

Figure ST6. Selected Project Channel Alternative and Optimized Settling Basin advanced maintenance zones and shoaling elevations.

Table ST2. Advance Maintenance Area Shoaling Volumes

Advance Maint. Areas	Max Shoal Height	Shoal Volume
	ft	cy
Inner Channel & Turning Basin	-	20,000
A	6.0	27,000
B	1.5	1,000
C	6.0	3,000
D	7.0	2,000
Entrance Channel Total		33,000
SB1	15.0	46,000
SB2	11.0	4,000
SB3	14.5	18,000
Settling Basin Total		68,000

Storm Surge Modeling

Introduction

An analysis was conducted to determine if there would be an impact to storm surge water levels at the project site due to proposed deepening of the Palm Beach Harbor Federal Navigation Project (Figure 1). The Coastal Modeling System (CMS) (Sanchez, et.al. 2011) was used to simulate a 100-year return interval total storm tide event on two different model grids representing the existing condition bathymetry and a future bathymetry representing the Federal project with all proposed deepening and widening of the channels and Harbor. The results of these numerical simulations are analyzed to determine any potential changes to total storm tide that might result from the proposed modifications to Palm Beach Harbor.

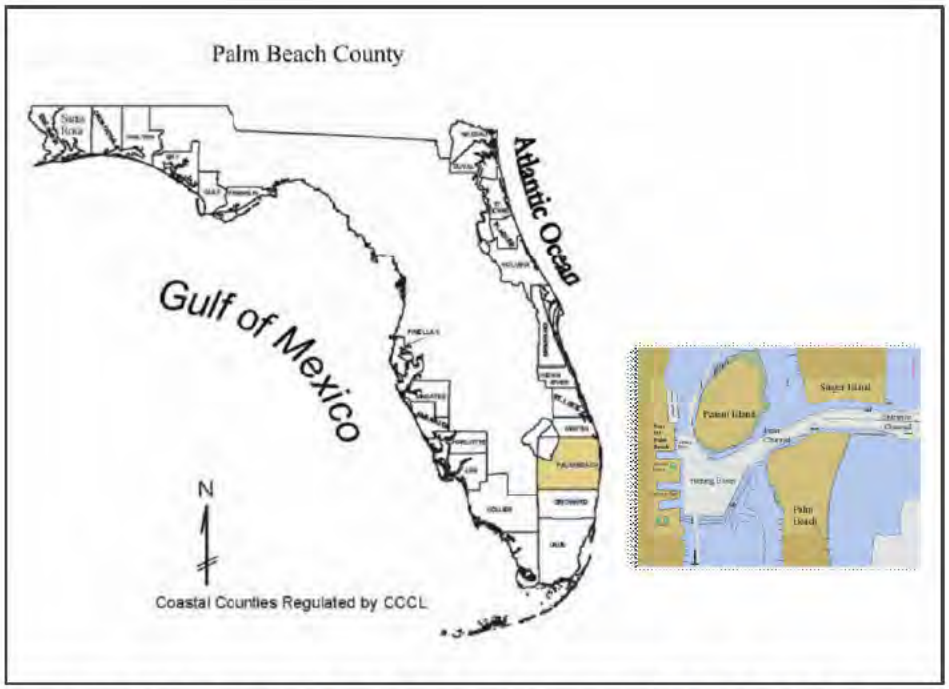

Figure 1: Study Location Map. Palm Beach County and Palm Beach Harbor

Modeled Storm

The 100-yr Storm was modeled using results from the published report, "Combined Total Storm Tide Frequency Analysis for Palm Beach County, Florida (Dean

et al., 1992). The 100-yr Storm modeled was the Combined Total Storm Tide, which is the storm surge due to the astronomical tide, wind stress and barometric pressure effects combined with the dynamic wave set-up. All meteorological forcing and wave climate forcing are included in the calculation for the Combined Total Storm Tide. Available historical hurricane statistics were combined with a set of numerical models to simulate the storm tides at Palm Beach County. Available statistics included tidal recordings during the hurricanes of 1926, 1945, 1947 and September 1979 (Hurricane David). Values in the report were converted from NGVD to NAVD88 by subtracting -1.52 feet using the NOAA NOS gauge at Palm Beach, FL, Station ID: 8722607 (Figure 2). The Combined Total Storm Tide (Figure 3) was used for the storm surge model.

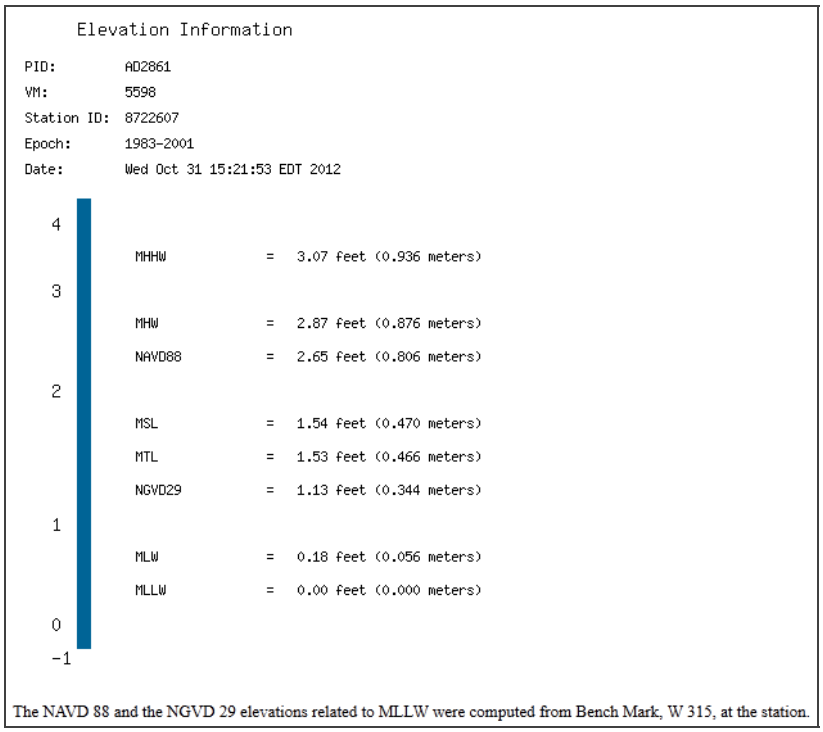

Figure 2: Datum Station 8722607 Palm Beach

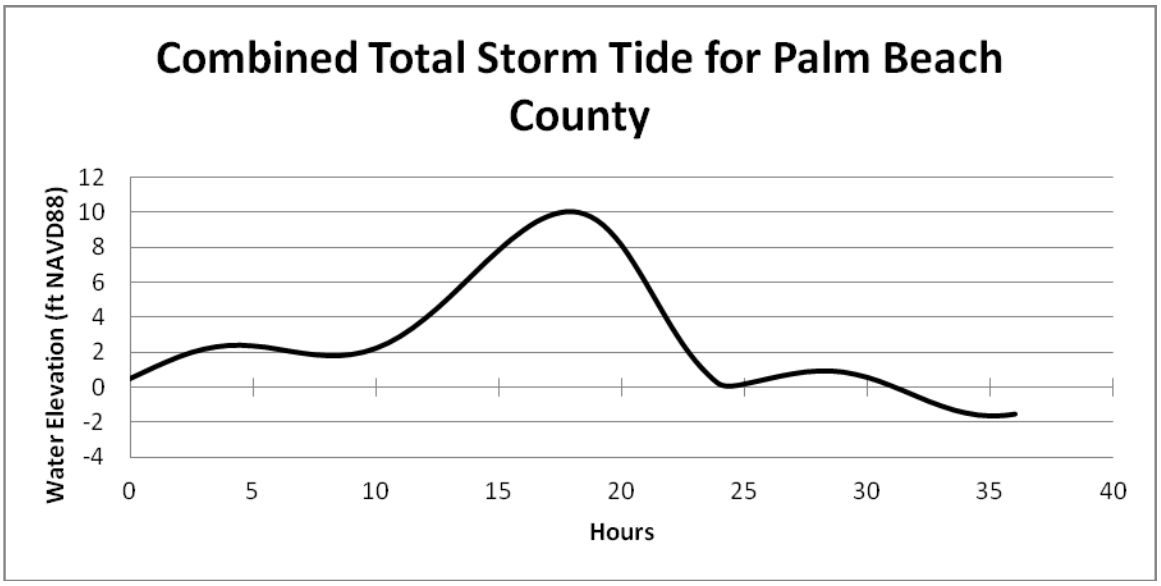

Figure 3: Total Storm Tide for Palm Beach County; 100-yr Storm

Bathymetry Data

The model grid was populated with LIDAR elevation data collected in 2006 and 2007 for the region. These data were also combined with NOS soundings for the regions including the entire navigation channel and inlet system, a 1-mile reach in the intracoastal waterway both north and south of the turning basin at the Harbor, and in the nearshore and offshore to deep water well beyond 100m depth. Areas where no LIDAR or NOS soundings exist were populated using the Coastal Relief Model, developed by and available from the NOAA National Geophysical Data Center (NGDC) (Figure 4).

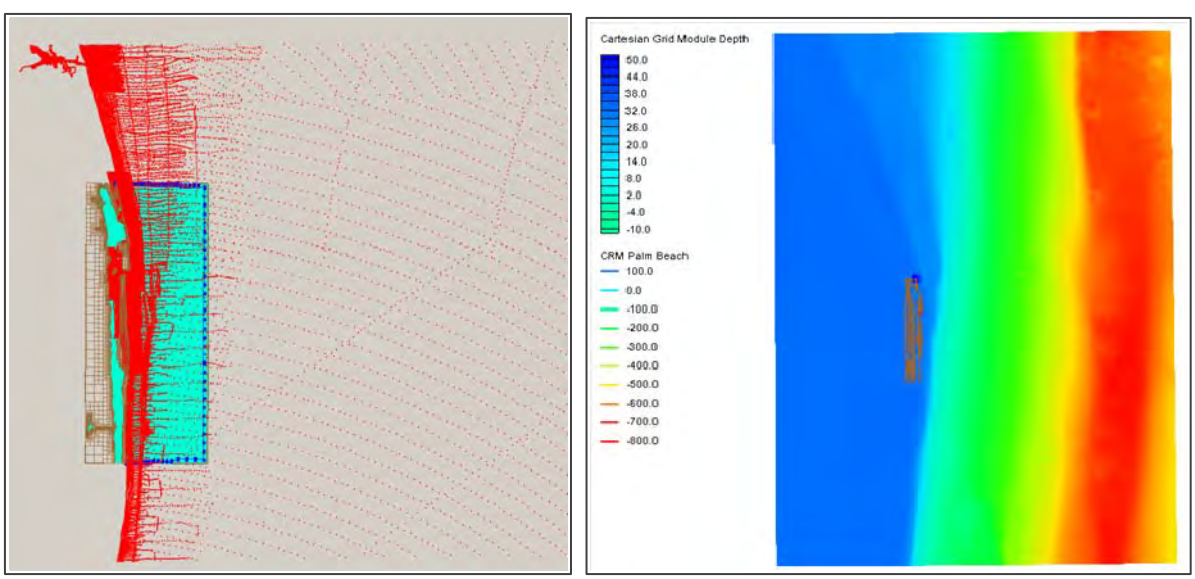

Figure 4: LIDAR and NOS data coverage (red dots) and NOAA CRM raster depths

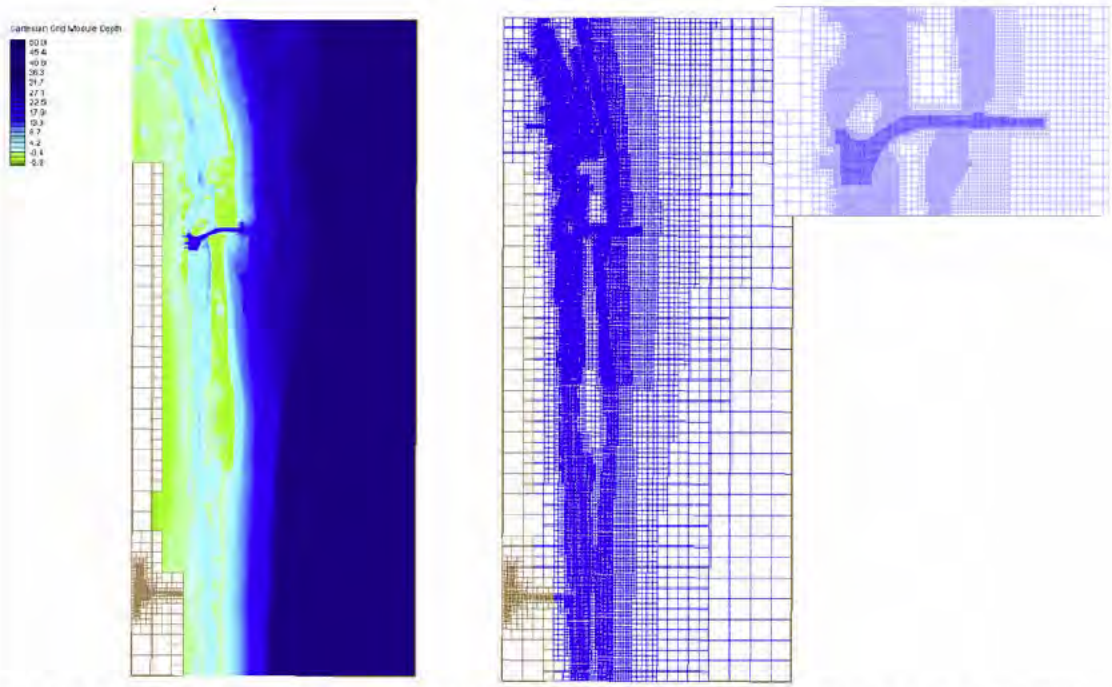

Figure 5: Model grid bathymetry mosaic of LIDAR, soundings and CRM model, the Combined Total Storm Tide was input as a boundary condition at the offshore boundary; model grid cells and detail of navigation channel and turning basin at Palm Beach Harbor (inset).

CMS Storm Surge Modeling

The CMS model was used to simulate the total storm tide at Palm Beach Harbor. This application included the implicit version of the depth-averaged hydrodynamic model, CMS (Sanchez, et.al. 2011).

Water Elevation Boundary Condition: The Combined Total Storm Tide (Figure 3) was used as the Surface Water Boundary Condition at the offshore boundary of the model (Figure 5).

Model Grid: The CMS model had 60081 cells, of which 59445 were ocean cells and 646 were land cells. The minimum cell size was 12.5m in the channel and turning basin for the Harbor. The maximum cell size was 800m on the offshore boundary. The maximum depth was 186m. The alongshore length of the model was 16 miles and the cross-shore length was 7 miles.

CMS Storm Surge Model Run

Current Velocities: The maximum flood and ebb currents for the with-project alternative are shown in Figure 6. Differences in the current structure between the with-project and the without-project alternatives were less than 0.3 m/s.

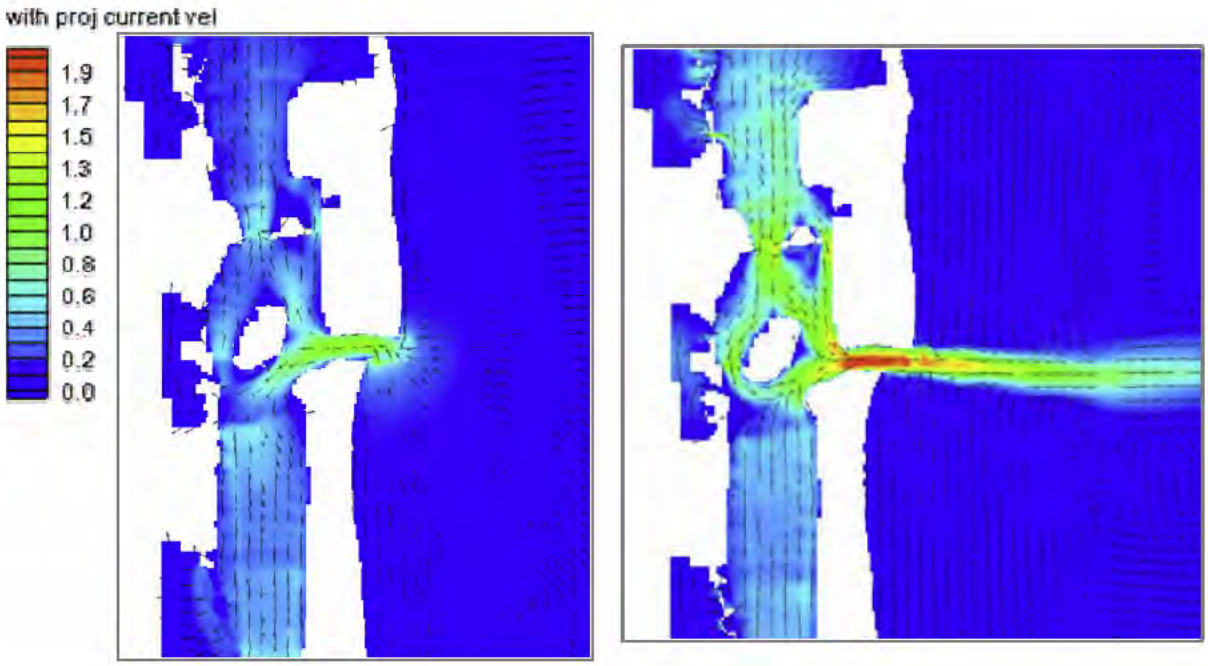

Figure 6: Maximum flood (left) and ebb (right) currents

Water Elevations: Water elevations were sampled within the model domain at four locations (Figure 7) in the Turning Basin (PT 1), the Navigation Channel (PT 2), in the ICW to the north of Peanut Island (PT 3) and in the ICW to the south of the Turning Basin (PT 4).

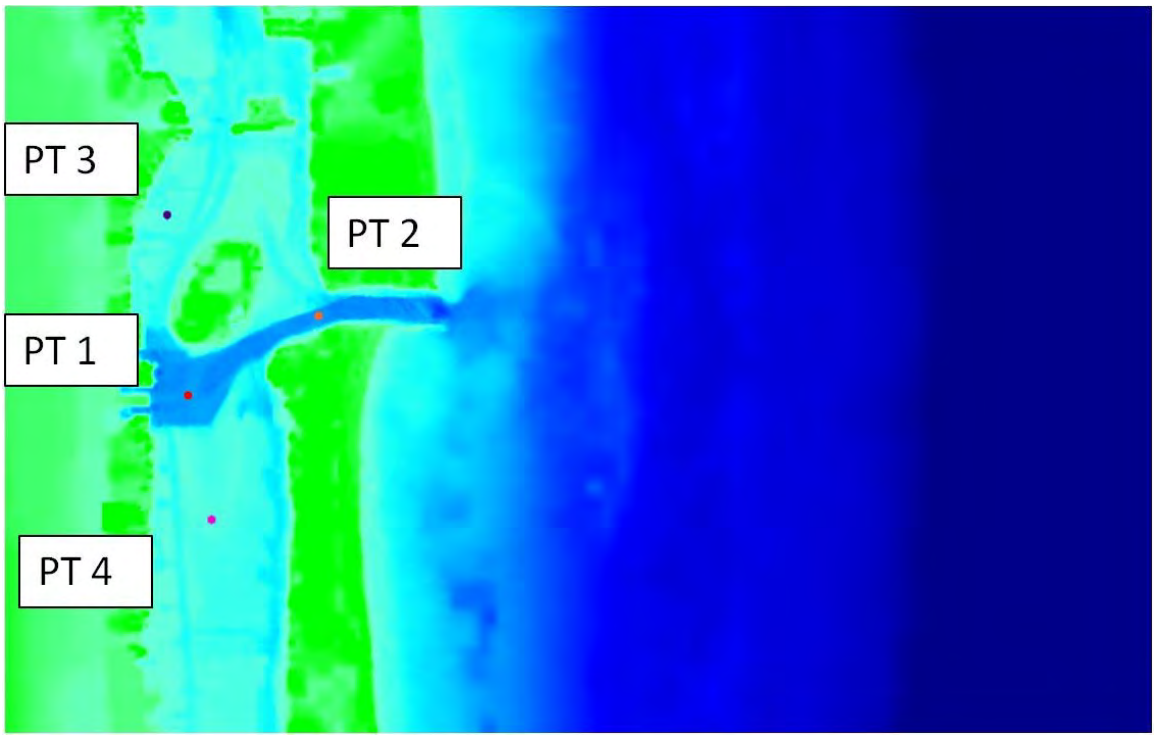

Figure 7: Sample locations for time-series analysis of water surface elevation

At the peak phase of the tide, when water levels offshore were maximum, the water level at the project site was the same for both alternatives, with and without the project (Figure 8; a,b,c&d). What was different between the scenarios was the phase of the water elevation; the phase for the with project alternative consistently lead the without project alternative both on the flood and ebb tides. This is due to the reduction in friction for the with-project scenario due to harbor deepening. Because the friction was reduced, the navigation channel, the turning basin and the ICW both filled with water sooner on the flood tide, and were emptied of water on the ebb tide sooner than the without-project scenario (Figure 8; a,b,c&d).

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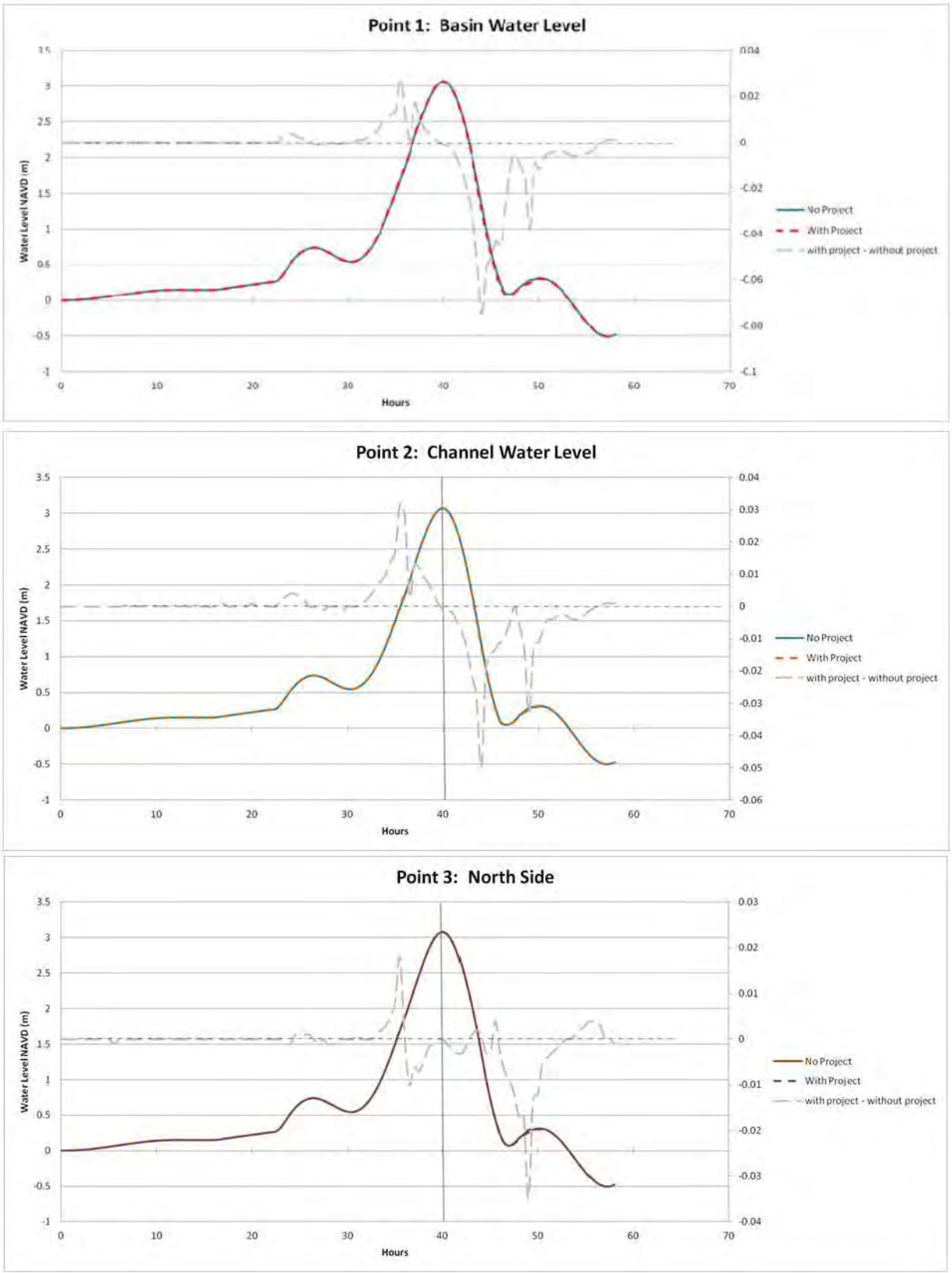

Figure 8 (a b & c): Water levels for the with and without project scenario. With project - without project water levels were subtracted (grey dashed line). Note the positive spike before hour 40 denoting the faster rate of flooding for the with project scenario and the negative spike after hour 40 denoting the faster rate of ebbing for the with project scenario.

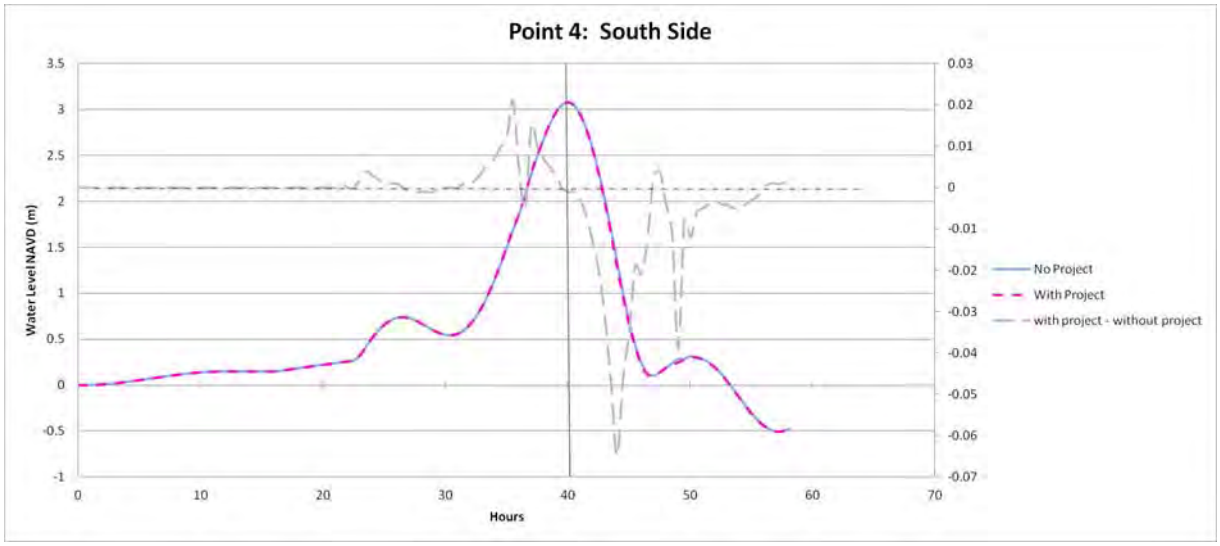

Figure 8d: Water levels for the with and without project scenario

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LAKE WORTH FEASIBILITY STUDY

OVERVIEW

The U. S. Army Corp of Engineers (USACE) is considering port expansion in the port of Palm Beach, Florida. This expansion involves widening and deepening of the entrance channel, inner channel, and turning basin. Some modification of the vessels berthing areas may also be indicated, however, the pier areas were not part of our examination.

Two channel plans were submitted for consideration. In order to test the boundaries of these proposed plans, two bulk carrier vessels were selected as the design vessels, in addition to a cruise vessel. The goal of these plans is to enable safe transits, and ample maneuver room for these vessels, especially the bulk carrier vessels when in a fully loaded condition. Selecting the plan that best provides this access during wind and tidal current conditions normally experienced at the port is the focus of the study. STAR Center, located in Dania Beach, Florida, was tasked with accomplishing this evaluation. An existing geographic database of the Port of Palm Beach, already available in STAR Center's database library, was updated using USACE provided depth and tidal current information. This existing database was modified to represent the two proposed harbor expansion plans. These prospective plans are identified as Plan 1 and Plan 2, and along with the existing harbor configuration, provided the basis for our testing.

The project was conducted using STAR Center's 360 degree field of view, full mission simulator during the period 18 September through 2 October 2011. This report summarizes the methodology, results, and conclusions of that project.

PARTICIPANTS

Four experienced pilots from the Port of Palm Beach actively participated in the project and operated the bulk carriers and cruise vessel during all simulation exercises. In addition to the pilots, representatives from the U.S. Army Corp of Engineers (USACE), the client, observed simulation runs and provided valuable insight into design strategies and background information. The run matrix, which provided the general scope and details of the project, was provided by USACE, which also selected the design vessels used in simulations.

STAR provided a Senior Researcher to manage the project, a simulator operator to operate the equipment, and also monitor and record data, and a technician to ensure

proper operation of the simulator. A bridge officer was provided to assist the pilot, carry out his steering and engine orders, and relay orders to assisting tug boats as necessary. A project facilitator observed and monitored simulations, noted conditions and results, briefed and debriefed the participating shiphandlers between simulation exercises.

GEOGRAPHIC DATABASE

The geographic database used in simulations was constructed from information based on C-Map electronic charts, NOAA Charts 11472 and 11466, up-to-date nautical publications, and tide and current tables. Digital photographs of the immediate area were included to provide an accurate and realistic visual reference for the shiphandlers. Details in these photographs included the pier area, shore installations, navigational aids, breakwaters, and shorelines.

Bathymetric information of area depths and currents was provided by USACE, and included in the database.

The Port of Palm Beach is accessed through Lake Worth Inlet using a 401.246 feet wide entrance channel. Charted depth in this channel, through the breakwaters is 39.370 feet, and continues at 36.089 feet in the inner channel and turning basin. These dimensions are represented in our existing channel database. The existing database is presented in **Figure 1 – Existing Channel** below.

FIGURE 1 – EXISTING CHANNEL

The existing database plan of the Port was modified to incorporate changes and modifications in depth and channel widths provided in design Plan 1.

While both proposed design plans offer the same entrance channel (46.259 ft.), inner channel and turning basin depths (42.979 ft.), Plan 1 offers the widest channel and turning basin options of either plan. The Plan 1 database is presented in **Figure 2 – Plan 1 Design** below.

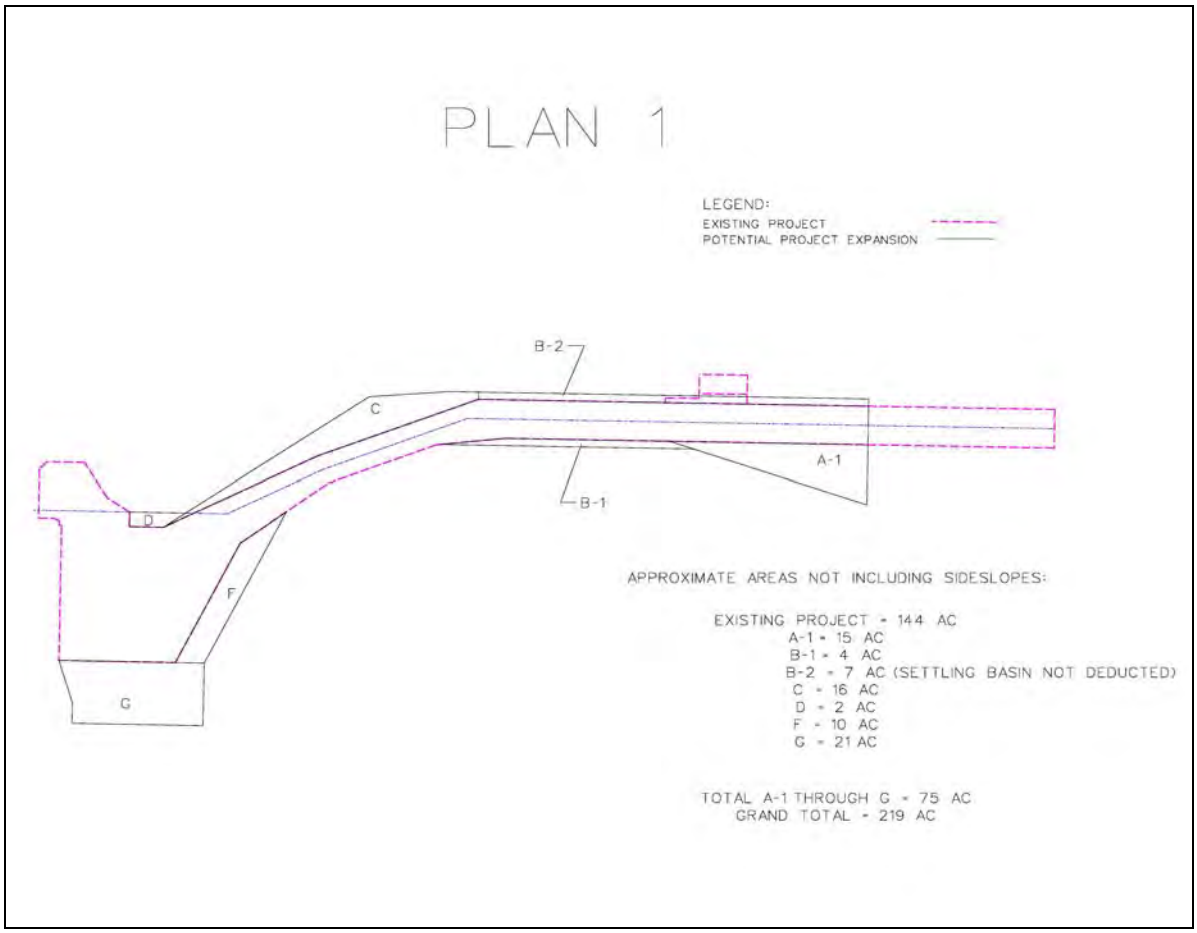

FIGURE 2 – Plan 1 Design

The existing database plan of the Port was also modified to incorporate changes and modifications in channel and turning basin design provided in design Plan 2. Channel and turning basin depths are the same as Plan 1; however, widening of those areas is less. The Plan 2 database is presented in **Figure 3 – Plan 2 Design** below.

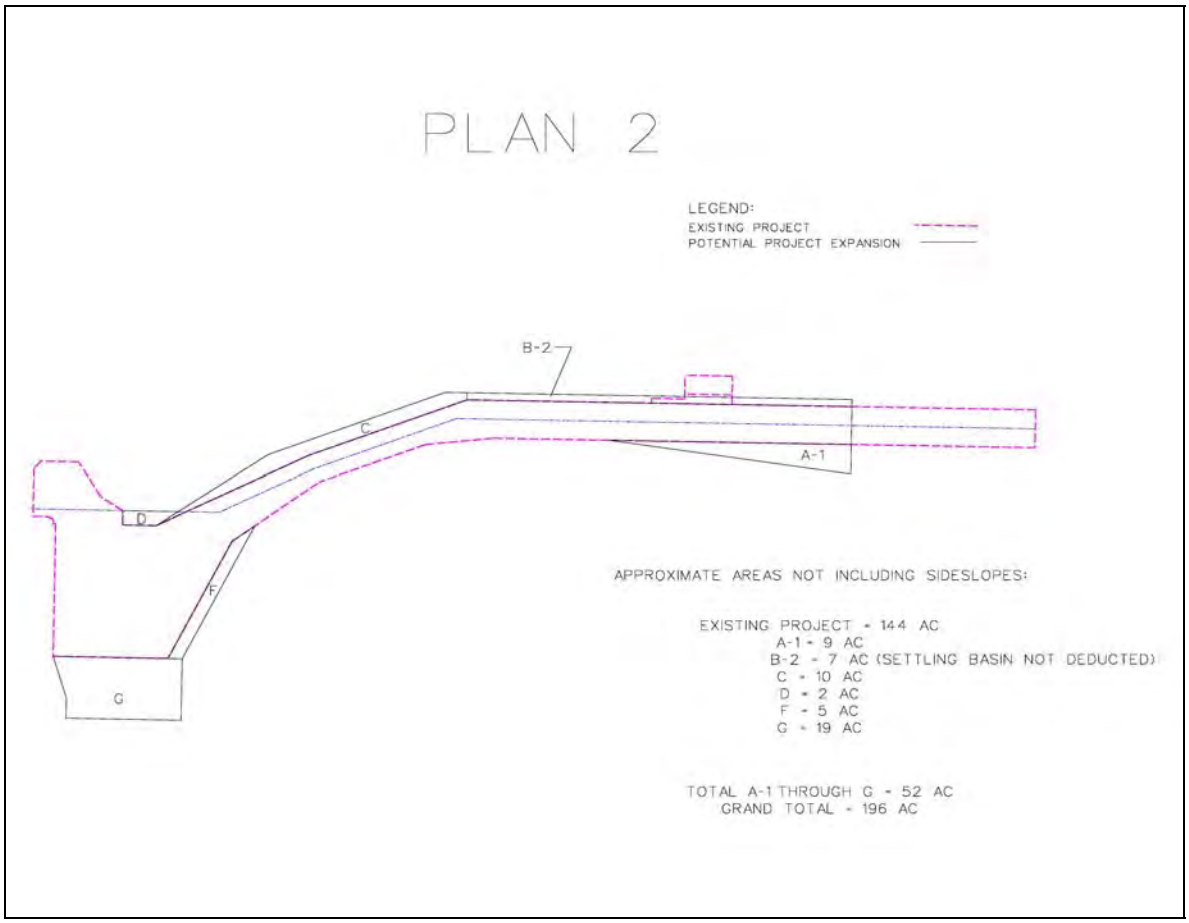

FIGURE 3 – Plan 2 Design

SHIP RESPONSE MODEL

The ship response hydrodynamic models provided for the study came from STAR's library of vessel models, or in the case of the "Palm Beach Brewer" were specifically constructed for this project. The bulk carrier vessels were selected as the design vessels as they represent vessels that may access the Port of Palm Beach in the future. The cruise vessel represents the same approximate size of a vessel now in use at the port, but would also benefit from an expanded channel and turning basin. Particulars for each vessel are presented in **Table 1 – Ship Particulars** below.

Table 1 – SHIP PARTICULARS

Ship Name	Palm Beach Brewer	Black Rose	Norwegian Sea	Black Rose
Condition	Loaded	Loaded	Design	Ballasted
Tonnage	62,820	65,085	19,810	33,140
LOA (ft)	656	707	710	707
Beam (ft)	106	105	93.2	105
Draft Fwd (ft)	40.02	40.02	22.3	18.4
Draft Aft (ft)	40.02	40.02	22.3	25
Propulsion	Diesel	Diesel	Diesel	Diesel
Bow Thruster hp	none	none	2,682	none
Stern Thruster hp	none	none	2,682	none
Shaft HP	13,357	13,512	14,161	13,512
Propeller	1 Fixed	1 Fixed	2 Variable	1 Fixed
Propeller Direction	CW	CW	Inward	CW
Max Rudder	35	35	35	35

SHIP ASSIST TUGBOATS

The Port of Palm Beach has at its disposal two conventional, twin propeller tug boats. The horsepower of these tugs is 2,000 and 900 respectively. The participating shiphandlers indicate that current practice is to augment these tugs when necessary, with the more powerful tugs available at nearby Port Everglades.

Bulk Carriers, with their deep draft, and minimum horsepower propulsion, are probably the least maneuverable vessels to visit the port. Their lack of maneuverability and sluggish steering capabilities at low channel transit speeds is amplified when the vessel is in a fully loaded condition. This fact dictates the use of reliable and powerful ship assist tug boats when in the entrance channel, the turning basin, and during docking and undocking maneuvers. Discussions conducted with the participating shiphandlers, prior to commencement of simulation exercises, stressed the need for more powerful tugs for use when maneuvering the bulk carriers. A 2,000 and a 3,000 horsepower tug boat configuration was tested. This 2,000/3,000 horsepower tug boat combination proved, in the opinion of the shiphandlers, to be inadequate in the conditions tested (runs 1 thru 9). It was decided, and was demonstrated in simulations, that the current 2,000hp tug when supplemented by a 5,000hp tug boat from Port Everglades, was adequate for all required transits and maneuvers. This 2,000/5,000 horsepower tug boat combination was used for all remaining simulations utilizing the bulk carriers.

Tug boat assistance is not normally required for arriving or departing cruise vessels due to their exceptional maneuverability, therefore, assist tugs were not used for the "Norwegian Sea".

ENVIRONMENTAL CONDITIONS

Wind

Wind direction and velocity used in simulations are those winds normally experienced in the area. Average light wind situations, generally Easterly, were incorporated in exercises involving both the "Palm Beach Brewer", and the "Black Rose". Wind effects are normally minimal for a loaded Bulk Carrier. Wind velocities were slightly higher when "Norwegian Sea" was used in simulations, because Cruise vessel susceptibility to wind effects is more pronounced. Winds from the North, Northeast, East, Southeast, and South were used.

Tidal Currents

The effects of tidal currents within the entrance channel, inner channel, and turning basin play an important roll in vessel performance. Current velocities up to or exceeding 1 knot in these areas, can be challenging, especially at the minimum transit speeds dictated for a laden bulk carrier. Current direction and velocities were supplied by USACE for inclusion in simulation exercises. They are generally described as Ebb or Flood currents, and the direction and velocity of their set adjusted accordingly. Slack water (no current) conditions were also used in simulations.

Prior to the start of our 14 day examination of the Port of Palm Beach, one additional day was devoted to adjustment of these currents. An experienced Palm Beach Pilot participated in this current validation effort by operating a "Black Rose" into and out of, the port during both ebb and flood conditions. His assessment as to the effects of the current on that vessel, were the basis of our validation. Slight current modifications dictated by that effort were accomplished during that one-day session, and were used throughout the project. Currents and their perceived effect on various vessels are subjective with each shiphandler. With this in mind, currents used were made to represent average conditions, accurate in direction of set, and based on USACE provided current data in their effect on vessels.

In addition to ebb and flood current, a slack current was also used within the confines of the harbor.

Gulf Stream Currents

Immediately outside the breakwater at the Lake Worth Inlet, the entrance channel is swept by the Gulf Stream Current. This current runs from South to North at varying velocities. Participating shiphandlers report that this Northerly current can be expected to run at between 1.0 and 2.5 knots immediately adjacent to the breakwaters. The challenge for the shiphandler when entering the channel is to maintain enough vessel speed, and enough course angle to overcome the effects of this current, and at the same time, immediately slow to safe channel transit speeds.

Tidal currents of ebb and flood within the channel blend with the Gulf Stream currents immediately outside, and duplicating these effects to the satisfaction of each shiphandler proved challenging. The effective simulated resultant current produced in simulations elicited shiphandler comments ranging from too strong, to too weak. In order to overcome this difficulty, it was decided to maintain the directionality, but decrease the Gulf Stream Current to 1.5 knots at the sea buoy and taper velocity to approximately 1 knot or less at the breakwater. This adjustment enabled the shiphandlers to continue their vessel course and speed strategies, with somewhat reduced effects.

In order that the full effect of this Gulf Stream current not be overlooked however, a brief series of exercises were included in simulations, and are identified as Gulf Stream currents.

Wind and Current conditions for each exercise are identified in **Table 2 – Run Matrix** see **Appendix B**.

TEST PROCEDURES

The shiphandler operated the vessel from the simulator pilot house, which is a replica of a vessel bridge. The bridge contains all the navigation and control equipment available to the shiphandler in actual practice. An additional display was made available to the shiphandler as part of this equipment. This display provided a bird's eye view of the vessel and its position in the channel/harbor. Its' inclusion was necessitated by the fact that the Electronic Chart Display (ECDIS) did not reflect changes made by dredge plans 1 and 2. Each shiphandler was assisted by a STAR Center provided mate to carry out his steering and engine orders, and relay verbal orders to the tugboats operated by the simulator operator, via VHF radio.

The general practice, followed throughout the simulation exercises, was to brief the shiphandler, identifying wind and current conditions used in each upcoming run. Also agreed upon, were the run start position and end point prior to the commencement of each run. The shiphandler selected the vessel's starting course, speed, and tug boat placement (if used) at that time.

At the completion of each exercise run, debriefing the just completed run included the completion of a "*Run Evaluation Form*". This form solicited his opinions and comments regarding the just completed exercise. It included questions relating to: adherence to intended track line, vessel controllability, adequacy of bow thrusters (if available), effectiveness of tug boats, and overall safety and task difficulty. Following completion of all exercises, participating shiphandlers were provided a "*Pilot's Final Evaluation*" form. This form solicited specific project related questions, and provided a forum for any additional comments or remarks participating shiphandlers wished to express.

Completed copies of both these forms are attached to this report.

All inbound exercises, for the bulk carriers and "Norwegian Sea", commenced outside the inlet breakwater, just south of the PB buoy (sea buoy), or just south of channel buoy number "2". Participants stated that the shortened starting point, South of buoy "2", was more practical, and in keeping with their strategy of entering the channel at, or just west of that point.

Bulk Carrier Inbound/Outbound Exercises

Inbound transits for "Palm Beach Brewer" and "Black Rose" ended when the vessel was parallel to Slip 3, slowed, and under comfortable control of the shiphandler. Both bow in and bow out approaches were examined. Shortened inbound runs concluded when the vessels cleared the inner channel turn at dredge Area C.

All outbound runs commenced in Slip 3 with mooring lines released, and ended at the entrance breakwaters. Both bow in and bow out departures were examined.**

Cruise Ship Inbound/Outbound Exercises

Inbound transits for "Norwegian Sea" ended when the vessel was parallel to Slip 1, slowed, and under comfortable control of the shiphandler. Both bow in and bow out approaches were examined. A number of shortened inbound runs were also conducted with "Norwegian Sea", and ended when the vessel cleared the Inner Channel turn at dredge Area C.

All outbound runs commenced in Slip 1 with mooring lines released, and ended at the entrance breakwaters. Both bow in and bow out departures were examined.

DATA COLLECTION

Track plots are a visual representation of vessel position, trajectory, and track history. After each simulation run a track plot was recorded. Also recorded and archived, was a parameter log, a numerical dataset listing items such as vessel heading, course and speed, information relating to control settings, and the resultant forces acting on the vessel.

STAR Center's staff maintained observation notes and discussed results with the participating shiphandlers after each test run. Simulator specific factors that might influence the interpretation of results were noted and taken into account when evaluating results.

These track plots and numerical dataset were used in post-project analysis, in conjunction with "Run Evaluation Forms", "Pilot Final Evaluations" and observation notes.

Copies of theses track plots, "Parameter Logs", "Run Evaluation Forms", and "Pilot Final Evaluations" are attached to this report.

**Note: One inbound and one outbound "special run" were conducted in the Existing Channel using "Black Rose" in a ballasted condition. With a maximum draft (aft) of 25.6 feet, these runs were completed successfully. These runs are identified as 55B and 56B in the Matrix table (see Appendix B). Their successful completion briefly demonstrates the fact that vessel draft, not vessel length, is the major limiting factor in safe access to the port.

FINDINGS

Dredge Depth

The fact that channel and harbor dredging would be required to provide safe access for "Palm Beach Brewer", and "Black Rose", each with a loaded draft of 40.02 feet, was apparent from the start of our examination given that the controlling depth of the channel is less than the deep draft of these ships. The depth of dredging would be dictated by the fact that approximately 3.28 feet of under-keel-clearance is normally accepted as the minimum clearance required for safe maneuvering when operating slower than approximately 5 knots of vessel speed. Common practice dictates that dredge depths should therefore be at least 43.3 feet, as per standard guidelines. Simulations indicate that a 43.3 feet depth proved to provide adequate and safe under-keel-clearance for vessel operations when in the turning basin and in the inner channel where slow speeds were maintained.

In the entrance channel however, shiphandlers use speed and drift angle[1] to overcome the North setting effects of the Gulf Stream current. Speeds of approximately 7 to 8 knots were used in simulations, and are considered conservative speeds to overcome these effects. These higher vessel transit speeds, with resultant squat[2], increase depth requirements. "Palm Beach Brewer", for instance, at a 7 knot speed would increase its draft by approximately 1.31 feet. "Black Rose" is in the same range. Depth in the entrance channel during simulations was 46.26 feet for this reason, and provided ample under-keel-clearance in all conditions tested.

Simulations involving the operation of "Norwegian Sea" contributed little to the determination of channel and turning basin depths. Its 22.31 feet draft easily maneuvered in the tested channel depths of 43 and 46 feet.

Channel and Turning Basin Widths

The limits of channel widening are determined by observation of usage of these areas, and the comments of the participating, experienced mariners.

Both **Plan 1** and, to a lesser extent, **Plan 2** provide widening in areas critical to vessel operations, as identified by planning engineers in consultation with participating shiphandlers.

The use of those areas in ebb, flood and slack water conditions, and the extent of that use, were examined here. Both of the bulk carrier vessels and the cruise vessel are affected by channel and turning basin widening and each contributed to our findings.

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[1] Drift Angle – or crab angle, the angular difference between course steered and the course made good.
[2] Squat– is the increase of a vessels draft due to the effects of its speed through the water.

"Norwegian Sea" results demonstrated maneuvers unassisted by tug boats, but it cannot be stressed enough that both "Palm Beach Brewer" and "Black Rose" results depend heavily on maneuver assistance provided by the 2,000hp and the 5,000hp tug boats used in simulations. These tug boats are called into service, during average weather conditions, when an arriving vessel is inside the breakwaters. In the case of both bulk carriers, their first, and primary use, involves slowing the vessels speed prior to entering the turn at the inner channel.

The turning basin, after run 18, included the addition of moored vessels along the pier faces just south of slips 1 and 3. This was done in order to evaluate available maneuver room when these berths may be occupied, and as a worse-case scenario for shiphandlers.

RESULTS

Expansion Areas

Area A1 – Used in almost all simulation runs for all three vessels. Its' recommended dredging is based on the shiphandlers' preferred strategy for approaching the entrance channel at that point, as opposed to entering at or near the sea buoy. This area is subject to greater drift angle to overcome effects of the Gulf Stream Current. A 10 degree drift angle, seen in some simulations, can produce an increased swept path of as much as 230 feet wide for the bulk carriers.
Advantage: provides a much wider channel entrance. It adds maneuver room. It is consistent with shiphandlers entrance strategies.
Comment: Would remain unmarked as part of the channel. No visible navigation aid to identify this area.

Area B1 – Expands and widens the entrance channel areas Southern boundary adjacent to the south breakwater.
Advantage: Wider channel.
Comments: Rarely used for transits.

Area B2 – Widens the usable entrance channel area, especially in an area where Gulf Stream currents may set a vessel North of the intended center channel approach.
Advantage: Gives shiphandlers additional maneuver room for safety. Increased channel width (especially North side) provides additional maneuver room at a time when course angle, used to compensate for Gulf Stream set effects is most likely.
Comments: Any channel width increase in this area will improve the margin of safety.

Area C – Widens and provides needed maneuver room at a critical point in the inner channel to slow and turn the vessel. Provides maneuver room for attending tug boats to assist in this maneuver.

Advantage: Adds to overall safety. It is a necessity for inbound and outbound Bulk Carriers.
Comments: Most used area of the Plans. It is critical for vessel and tug boat maneuverability. Of the 38 inbound runs conducted with "Palm Beach Brewer", 32 required the use of Area C.
Inbound and Outbound runs by "Black Rose" demonstrated similar run to area usage ratios.

Area D – Increases the approach and turning room for "Norwegian Sea" when using Slip 1 while docking or undocking.
Advantage: Added safety, especially when turning.
Comments: Of the 24 inbound and outbound runs conducted in plans 1 and 2, Area D was entered or brushed 19 times.

Area F – Increases the width of the turning basin by expanding the Eastern boundary.
Advantage: Added turning area maneuvering room.
Comments: This area was rarely used, even with the inclusion of moored vessels at the pier causing a further restriction of usable turning and maneuver space.

Area G – Used sparingly by inbound vessels to Slip 3 when arriving bow in. When backing from the slip in the bow in configuration, however, use of this area was most critical.
Advantage: Increased room to turn and increased tug boat maneuver room to assist, especially when backing from slip.
Comments: Backing from the slip in bow in configuration demonstrated a need for this area. Area G was used 5 of the 6 runs requiring backing out and turning. Representations of Area G usage are presented in **Figure 4 – Area G Usage** below.

Image 1- Run 22

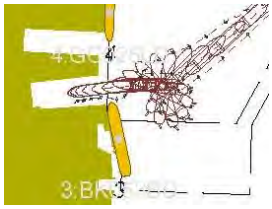
Image 2- Run 26

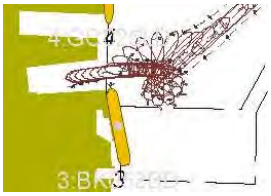
Image 3- Run 24

FIGURE 4 – Area G Usage

Image 1 depicts entry into G in run 22. Image 2 depicts slight entry in run 26, and finally, Image 3 depicts results of run 24, when the shiphandler was asked to avoid the area if possible.

The above areas are identified in Plan 1. Plan 2, however, presented a slightly less extensive scope to dredging in these areas, and eliminated completely Area B1 expansion. The advantages and brief comments presented with each area are the result of simulation observation and discussions with the participants.

Use of the expanded areas in Plans 1 and 2 was about the same. As can be expected, shiphandlers utilized the expanded area presented by Plan 1 when it was available, but their comments and simulator performance indicate that Plan 2 areas are adequate for all maneuvers, in the conditions tested. Evidenced in simulation, was the fact that no groundings, or unsuccessful transits were directly, or solely attributed to the reduced areas offered by Plan 2.

CONCLUSIONS

In this study we examined and evaluated the safe access of two bulk carrier vessels, and one cruise vessel to the Port of Palm Beach, via the Lake Worth Inlet channel modified by one of two prospective plans. The participation, cooperation, and patience of the Palm Beach pilots during the many simulation runs conducted during this project, ensured a practical look at plan impact on the mariner. Their comments and simulation results are the basis for the conclusions and recommendations expressed in this report.

Bulk Carriers

The modifications offered by both Plans 1 and 2 each provide the required elements of increased channel width to support "Palm Beach Brewer", and "Black Rose" safe access, during all conditions of wind and tidal currents tested. Both Plans were based on a dredged depth of 46 feet in the entrance channel, and 43 feet in the inner channel and turning basin. Simulations indicate that these depths do provide ample under-keel-clearance for safe transit and maneuvers of both vessels.

The locations selected as channel and turning basin widening points were obviously the result of thoughtful and appropriate pre-planning recommendations. As can be expected however, some areas were more important to the shiphandlers than others. Only two areas, identified in the plans as Areas B1 (Plan 1) and F (both Plans), were under-used and less critical for the participants in the exercise runs conducted.

Inbound transits, when transitioning from the Gulf Stream current to the entrance channel, are challenging for the shiphandler due to their pronounced effect on these vessels, but the assistance of powerful tug boats can ameliorate this situation.
There was little evidence in simulations that vessel transits and maneuvers were limited or adversely impacted by ebb, flood, or slack water conditions in either plan.

Cruise Vessel

"Norwegian Sea" took little advantage of plan designs, except in the area in both Plans 1 and 2, identified as Area D. The expansion of dredging at Area D would provide some

measure of safety for this vessel. The shoal area represented by Area D, if eliminated, would allow maneuver room should a Northerly set of the current effect the docking and undocking vessel. Any widening of the entrance and inner channel, designed to accommodate the bulk carrier vessels, would benefit this vessel, but is not necessarily delineated by it.

RECOMMENDATIONS

Expanded dredge areas presented in Plan 2 are adequate to support safe access by "Palm Beach Brewer", "Black Rose", and "Norwegian Sea", in all conditions tested.

A depth of 46 feet in the entrance channel does support safe vessel maneuvers.
The 43 feet in the inner channel and turning basin did support adequate maneuvers for all three vessels, in the case of the bulk carriers however, 3 feet under-keel-clearance provided no margin for safety. It is noted that participating shiphandlers assert that 10% (4 ft.) under-keel-clearance is necessary for safe operations in the harbor. This is not an uncommon practice, or rule of thumb at many ports. We concur with an inner channel and turning basin depth of 44 feet.

Simulations indicate that Area F expansion, even with the presence in simulation of moored vessels (further restricting maneuver and turning room) be eliminated as unnecessary.

##

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