ST. GEORGE HARBOR IMPROVEMENT FEASIBILITY STUDY

FEASIBILITY REPORT

ST. GEORGE, ALASKA

May 2020

U.S. Army Corps of Engineers
Alaska District

St. George Harbor Improvement

Feasibility Report

St. George, Alaska

Prepared By:

U.S. Army Corps of Engineers
Alaska District

May 2020

ERRATA SHEET
St. George Harbor Improvement
Feasibility Report

The intent of the errata sheet is to document a few revisions to the report resulting from the final review of the Feasibility Report. The edits are primarily taken to update the cost sharing and include additional language on the Fur Seal Act of 1983, climate change, forecasting in the future without project conditions and to discuss screening of the management measures. The revisions do not affect the selection of the recommended plan or other considerations contemplated by the Feasibility Report. Each edit is discussed further below.

Executive Summary

- **Removed the following language from paragraph 8:**

  "The project would be cost shared 90 percent Federal and 10 percent non-Federal for the cost of design and construction of the general navigation features attributable to dredging to a depth, not in excess of -20 feet MLLW, plus 75 percent Federal and 25 percent non-Federal for the cost of design and construction of the general navigation features attributable to dredging to a depth in excess of -20 feet MLLW but not in excess of - 50 feet MLLW. The non-Federal sponsor (NFS) would pay with interest, over a period not to exceed 30 years following completion of the period of construction of the project, up to an additional 10 percent of the total cost of construction of the general navigation features. The Recommended Plan is supported by the City of St. George, which is the NFS, and they have provided a Self-Certification of Financial Capability dated 24 April 2020 (Appendix E)."

- **Added new paragraph 9 :**

  "Section 101 of WRDA 1986, as amended, states that during construction, the project would be cost shared 90 percent Federal and 10 percent non-Federal for the cost of design and construction of the general navigation features attributable to dredging to a depth, not in excess of -20 feet MLLW. The entrance channel would be developed to -25 feet MLLW based on the wave climate in the Bering Sea to ensure safe transit into the interior channel. Although the entrance channel would be constructed to a depth of -25 feet MLLW, ER 1105-2-100, Appendix E, E-8, b. (6) states, "Increased depths provided in entrance channels for transit of vessels between protected interior channels and the wave action zone, e.g., across an outer bar, will be cost shared the same as the deepest protected interior channel. Breakwaters, jetties and channel width increases are cost shared in the same manner." Therefore, the entrance channel would be cost shared 90 percent Federal and 10 percent non-Federal for the cost of design and construction for the project. The non-Federal sponsor (NFS) would pay with interest, over a period not to exceed 30 years following completion of the period of construction of the project, up to an additional 10 percent of the total cost of construction of the general navigation features. The Recommended Plan is supported by the City of St. George, which is the NFS, and they have provided a Self-Certification of Financial Capability dated 24 April 2020 (Appendix E)."

Pertinent Data

- **Revised the Pertinent Data Economics Table:**

Economics	
Item	**Total ($)**
Total Average Annual Equivalent Cost	$7,698,000
Total Average Annual Equivalent Benefit	$1,066,000
Net Annual National Economic Development Benefits	($6,632,000)
Benefit-Cost Ratio	0.14
Note: October 2019 Price (FY20) level, 50-Year Period of Analysis, 2.750 Percent Discount rate. Costs and benefits in this table are based on the certified cost for the Recommended Plan and differ slightly from the costs and benefits used for plan evaluation and comparison.	

Pertinent Data and Section 7.11.1, Table 20

- **Revised the Pertinent Data Cost Share Table and Table 20 to reflect updated costs:**

Cost Share Table (October 1, 2019 Price Levels, Program Year (FY) 2020)[1]				
WBS Number	**General Navigation Features**	**Project Cost w/ Contingency**	**Federal Share**	**Non-Federal Share**
10	Breakwater	$109,605,000	$98,644,500	$10,960,500
12	Navigation Ports and Harbors[2]	$31,594,000	$28,434,600	$3,159,400
30	Preconstruction, Engineering & Design (PED)[4]	$7,246,000	$6,521,400	$724,600
31	Construction Management (S&I)[3]	$11,318,000	$10,186,200	$1,131,800
	Subtotal Construction of GNF	**$159,763,000**	**$143,786,700**	**$15,976,300**
1	Lands, Easements, Right-of-Ways, Relocations (LERR)[4]- Federal	$0	$0	$0
1	Lands, Easements, Right-of-Ways, Relocations (LERR)[4]- Non-Federal	$75,000	$0	$75,000
	Total Project First Costs	**$159,838,000**	**$143,786,700**	**$16,051,300**
12	Aids to Navigation[5]	$91,000	$91,000	$0
	Credit for Non-Federal LERR[6]		$75,000	($75,000)
8	Roads and Docks- LSF	$17,999,000		$17,999,000
12	Navigation Ports and Harbors- LSF	$2,994,000		$2,994,000
30	Preconstruction, Engineering & Design (PED)- LSF	$1,084,000		$1,084,000
31	Construction Management (S&I)- LSF	$1,690,000		$1,690,000
	10% GNF Non-Federal[7]		($15,976,300)	$15,976,300
	Total Cost Apportionment	**$183,696,000**	**$127,976,400**	**$55,719,600**

1. Cost is based on Project First Cost (constant dollar basis) on Total Project Cost Summary Spreadsheet, at an effective price level 1 Oct 2019 (Cost Appendix). Aids to Navigation broken out and shown as a separate cost.

2. ER 1105-2-100, Appendix E, E-8, b. (6) states, "Increased depths provided in entrance channels for transit of vessels between protected interior channels and the wave action zone, e.g., across an outer bar, will be cost shared the same as the deepest protected interior channel. Breakwaters, jetties and channel width increases are cost shared in the same manner." Federal and non-Federal breakdown of costs reflect 90% Federal/10% non-Federal.

3. PED and Construction cost sharing totals are reflected as 90% Federal/10% non-Federal.

4. These are Real Estate administrative costs. There are no actual lands and damages but per USACE regulations, Real Estate administrative costs will be placed in the 01 account. Additional Real Estate costs will be cost shared according to the GNF. Escalation from the TPCS accounts for some numerical differences.

5. Aids to Navigation are reflected as a Federal cost, but are coordinated and paid for by the U.S. Coast Guard.

6. Credit is given for the incidental costs borne by the non-Federal sponsor for lands, easements, rights of way and relocations (LERR) per Section 101 of WRDA 86, not to exceed 10% of the GNF

7. The non-Federal sponsor shall pay an additional 10% of the costs of GNF of the NED plan, pursuant to Section 101 of WRDA 86. The value of LERR shall be credited toward the additional 10% payment except in the case of LERR for GNF.

Section 1.2.1 Fur Seal Act, amended 1983, P.L. 98-129

- **Added new paragraph 6:**

"As evidenced from the language in the 1983 Act, the federal government had an interest in promoting the development of a self-sustaining economy for the community of St. George. That interest has yet to be realized. The construction of a functioning harbor on St. George Island would provide an opportunity for the community to develop that economy by facilitating access to the Bering Sea's rich fisheries, which brings institutional significance to this study."

Section 3.1.15 Resilience and Adaptation to Climate Change

- **Removed paragraph 2:**

"Resilience to overtopping was analyzed by adjusting SLC curves to the year 2020 and comparing the relative change between the curves over the period of investigation for the project. Curve adjustments were made by taking the curves projected from 1992 and setting the 2020 values to 0. This produces a set of curves with slopes projected from the 1992 tidal epoch but starting form the value of zero in 2020 (Figure 6)."

- **Revised first sentence of paragraph 3 (now paragraph 2) to reference Figure 6:**

"Under the high curve scenario, overtopping would begin to occur approximately 43 years after construction in 2066 (Figure 6)."

Section 4.5 Socio-Economic Resources

- **Removed the following paragraphs 1-2:**

"The future without-project conditions mirror those under the existing conditions. Dangerous wave and seiche conditions at the existing harbor at Zapadni Bay would continue without harbor improvements. Harbor inaccessibility and days when the safe moorage threshold is exceeded would remain the same as the existing condition for all vessel classes. Freight and fuel delivery costs are expected to continue to be expensive due to the limitations upon barge operations imposed by the dangerous conditions. Cargo intended for St. George would continue to be delivered to St. Paul and require additional arrangements and expenses to be transported to St. George. Cargo is often flown into the community at a higher cost than ocean-going vessels could deliver. Damages to vessels entering the existing harbor would continue at current rates. A conservative estimate of $383,000 annually in the Individual Fishing Quota (IFQ) and the (Community Development Quota) (CDQ) crab would continue to be transferred to St. Paul for processing.

All these conditions would continue to limit the community's ability to develop a stable and sustainable local marine resource economy sufficient to support their mixed, subsistence-cash economy."

- **Added the following paragraphs 1-4:**

"The economy of St George was historically heavily based on commercial fur seal harvesting until a severe decline in the fur seal population transitioned the focus from harvesting to conservation (as discussed in Section 1.2.1). In 1983, the Fur Seal Act was amended to provide provisions to assist St. George and St. Paul Islands in the transition from an economy based on harvesting fur seals to a self-sustaining economy. Through the 1983 Act, the community of St. Paul was able to construct a harbor and establish an economy based on the utilization of the Bering Sea fisheries. St. George also constructed a harbor at Zapadni Bay, in conjunction with the State of Alaska. Unfortunately, construction of the harbor has not enabled the St. George community to establish a viable fishery-based economy. The current conditions at Zapadni Bay are such that navigation to, from, and within the harbor are unsafe due to wave climate in the harbor entrance, seiche conditions within the inner basin, and degradation and overtopping of the existing breakwaters. These unsafe conditions limit the use of the harbor for all potential users.

Without a functioning harbor, St George has suffered from higher costs of goods and services coming into the community, limited economic opportunity, and negative impacts to subsistence harvesting. During this time the population at St George has declined and led to closure of the school (for additional information see Section 2.2).

Future without-project conditions for the 50 year period of analysis starting with the base year of 2030, would remain similar to the difficult conditions currently experienced by the community. Without improved transportation, the cost of essential goods coming into the community would remain high. Lacking the necessary access and moorage, the commercial crabbing fleet will continue to deliver harvest elsewhere. The high cost of goods, coupled with dwindling economic opportunities and impacts to the accessibility of subsistence resources, are forecasted to continue to limit the community's ability to develop a stable and sustainable local marine resource based economy sufficient to support their mixed, subsistence-cash economy. Implementation of a project would stabilize the conditions that have led to the current socioeconomic conditions at St George.

Infrastructure damages to the existing harbor at Zapadni Bay are forecasted to continue and require repairs at the same rate as has been occurring historically. Without the benefit of a stable economic base, the existing vessel usage trends (and the associated damages, delays, increased transportation costs, and foregone subsistence harvest) are forecasted to continue under FWOP conditions at their current rate. Delays for fuel and freight barges are expected to continue at their current rate. Additional information is provided in Sections 4.5.1 through 4.5.6 and AAEQ calculations are discussed in Appendix C, Section 6. Without implementation of a project, the community of St George will continue to experience these difficult conditions that could be improved by a functional harbor."

Section 4.5.1 Population and Demographics

- **Added the following text to the end of paragraph 1:**

"While continued population decline is expected, the impact to the community carries a high degree of risk and uncertainty and therefore it is discussed qualitatively. Given the existing small population size and the mixed subsistence-cash economy, the economic ramifications of one member leaving the community versus another can vary significantly. For example, the outmigration of a lead subsistence fisherman could have a large impact on the community. Additionally, the aging of a youth into adulthood can also change the community dynamic. Outmigration and vulnerability is further discussed in Appendix C, Section 7.6."

Section 4.5.3 Existing Infrastructure and Facilities

- **Removed "Existing" from Section title**

Section 4.6 Navigation

- **Removed "Under current conditions" from first sentence of paragraph 1:**

The sentence now reads "Adverse wave and seiche conditions limit vessel access to the existing harbor as well as safe moorage within the harbor."

Section 5.1 Plan Formulation Rationale

- **Added new paragraph 2 and Table 3 after paragraph 1 (Note: All existing table numbers starting at Table 3 will shift down by one) :**

"The screening criteria used to determine which measures and alternatives would be carried forward to determine the Recommended Plan can be found in Table 3. The table walks through each item of the plan formulation process and identifies the screening criteria and outcome associated with each iteration. The table also references each section where further information can be found."

Table 3. Plan Formulation Key for Screening Measures and Alternatives.

Item	Screening Criteria	Section(s)
Non-structural and Structural Measures	• Does it address the problem? • Does the measure meet one or both of the study objectives? OUTCOME: Fifteen non-structural measures were screened to two measures carried forward. Seventeen structural measures were screened to ten measures carried forward. The measures carried forward were combined to develop the initial array of alternatives.	• Sections 5.3, 5.3.1 and 5.3.2 and Tables 3 and 4
Initial Array of Alternatives Z-1 to Z-7 and N-1 to N-4	• H&H Analysis to determine mooring improvements by alternative OUTCOME: Alternatives Z-1 to Z-7 were removed from further consideration. None of these alternatives improved harbor accessibility. Those alternatives that did improve mooring conditions did so marginally and at ROM construction costs between $70 million (13 additional safe moorage days) and $400 million. • Study Objectives and National Evaluation Criteria OUTCOME: Alternatives N-1 to N-4 address both of the study objectives and meet all four of the national evaluation criteria of Acceptability, Completeness, Effectiveness and Efficiency on a varying degree of high-low. It was determined that Alternatives N-1 to N-4 along with the No Action alternative will be carried forward to screen for harbor accessability. • Harbor Accessibility Analysis OUTCOME: Alternatives N-1 to N-4 all resulted in increased harbor accessibility and were carried forward as the final array of alternatives along with the No Action alternative.	• Section 5.6 and Table 5 • Section 5.6 and Table 6 • Section 5.8 and Table 7

Item	Screening Criteria	Section(s)
Final Array of Alternatives N-1 to N-4	• NED Analysis OUTCOME: No NED plan was identified. Under the Section 2006 Authority, in the absence of an NED plan, a CE/ICA can be conducted to inform plan selection. • CE//ICA OUTCOME: Two Best Buy plans were identified, Alternatives N-3 and N-4. • Annual Access/Moorage Days Gained by Fleet Type for Best Buy Plans was evaluated. OUTCOME: While Alternative N-4 provides a gain of 127 days of access when compared to the No Action Alternative, none of these days are associated with the crabbing (CDQ and IDQ) fleet. In comparison, Alternative N-3 provides 179 days of access, which includes 17 days of safe access and 17.4 days of safe moorage for the crabbing fleet. Based on the CE/ICA and given that the CDQ/IFQ crabbing fleet is a driver of community viability, Alternative N-3 is identified as the Recommended Plan. • Summary of Accounts OUTCOME: Based on this analysis of the four accounts, each alternative has positive effects for the RED and OSE accounts and temporary negative effects for the EQ account. A safe and functioning harbor that improves access to St. George would provide opportunities for the development of a local economy based upon the marine resources of the region. Such economic opportunities are essential for supporting St. George's mixed, subsistence-cash economy, combating out-migration, and helping to strengthen the viability of the community on St. George.	• Sections 6.4 and 6.4.1 and Tables 9 and 10 • Sections 6.5, 6.5.1 and 6.5.2, Tables 11-14, Figures 26 and 27 • Section 6.5.2 and Table 15 • Sections 6.6 to 6.6.5 and Table 16

Section 5.3.1 Non-Structural Measures

- **Added new paragraphs which are now paragraphs 3 and 4:**

"Two non-structural measures, Real-Time Monitoring Features and marine navigational aids, would address both study objectives regarding safe maneuverability and protected moorage and increased time the harbor can be safely accessed. Safe maneuverability is a concern in the Bering Sea due to the extreme wave climate. Vessel operators could use Real-Time Monitoring Features to assist their navigation of the entrance channel, maneuvering basin and moorage area, especially during periods of high wind and rain which could impede visibility. Marine navigational aids would mark channels and shallow areas or other obstacles in the harbor to ensure vessels can safely navigate into the moorage area while reducing the risk of vessel delays and damages.

Although, it is a location and not a measure, the offshore anchorage area would address one study objective regarding safe maneuverability and protected moorage. The North Anchorage area located on the north side of St. George is naturally more protected with less wind and wave energy than the west side of the island where the existing Zapadni Bay harbor is located, thus is more suited for protected moorage. In the existing Zapadni Bay harbor, the seiche conditions cause moored vessels to strike the docks repeatedly, resulting in vessel damage. Less wave energy and wind at the North Anchorage site would decrease the risk of maneuvering in and out of the moorage area, basin and channel. Wind and subsequent wave energy is reduced on the north side of the island resulting in increased safety and harbor access and maneuverability during a larger duration of the year. A harbor environment with less wave activity would result in reduced damage to moored vessels, along with increased access days."

Section 5.3.2 Structural Measures

- **Added new paragraphs which are now paragraphs 3 and 4:**

"The new harbor measure is the only measure to address both of the study objectives. It is the only structural measure that would increase time that the harbor can be safely accessed due to the extreme wave conditions on the west side of the island, which affects the existing Zapadni Bay harbor. Constructing a new harbor in an area with reduced wave energy would offer protected moorage and safer maneuverability within the harbor basin. Vessels would be able to safely enter and exit the harbor during more days of the year. The risk of damages being incurred by moored vessels from seiche conditions in the basin would also be reduced. A new harbor would provide increased safety for harbor users through development of a maneuvering basin and entrance channel that allowed adequate space for maneuvering vessels during periods of high winds and wave energy.

Of the structural measures considered, nine of the measures would address safe maneuverability and access by dissipating wave energy and reconfiguring the harbor layout and depth to allow for more space to maneuver. These measures would also increase the range of vessels that can access the harbor. None of the other structural measures considered addressed the study objective for increased time that the harbor can be safely accessed. A new harbor could be a standalone measure carried forward as an alternative. However, additional structural measures including breakwaters, docks etc. would be considered as components of a new harbor."

Section 7.4 Dredging and Disposal

- **Removed three sentences at the end of paragraph 1:**

"The authorized dredge depth for the navigation channel will be -27 feet (-25 feet MLLW plus overdepth) MLLW, and the authorized depth of the maneuvering basin will be -22 feet MLLW (-20 feet MLLW plus overdepth). These depths will be used to ensure that the minimum required depths for under keel clearance are met. Including a 2 foot overdepth allowance below the minimum required depth also provides space for sedimentation to occur without the immediate need for maintenance dredging."

- **Added two revised sentences at the end of paragraph 1:**

"The authorized dredge depth for the navigation channel would be -25 feet MLLW (plus 2 foot of overdepth), and the authorized depth of the maneuvering basin would be -20 feet MLLW (plus 2 foot of overdepth). These depths would be used to ensure that the minimum required depths for under keel clearance are met."

Section 7.7 Operations and Maintenance

- **Revised the last sentence of paragraph 4:**

"The Operations, Maintenance, Repair, Replacement, and Rehabilitation (OMRR&R) cost based on these assumptions is $9.48 million with an AAEQ cost of $351,000 for the Recommended Plan, Alternative N-3 (Appendix C)."

Section 7.9.1 Land Acquisition

- **Removed paragraph 1:**

"LERR necessary to implement this project are lands owned by the City of St. George, and St. George TANAQ Corporation (**Error! Reference source not found.**). The overnment's dominant right of navigation servitude would be exercised for project tidelands below the MHW line for the general navigation features (GNF)."

- **Added new paragraph 1:**

"The lands necessary to implement this project are owned by the City of St. George and the St. George TANAQ Corporation (Table 18). The overnment's dominant right of navigational servitude would be exercised for project tidelands below the MHW line for the general navigation features (GNF)."

Section 7.11.1 Cost Apportionment

- **Removed paragraph 1:**

"Section 101 of WRDA 1986, as amended, states that during construction, the project would be cost shared 90 percent Federal and 10 percent non-Federal for the cost of design and construction of the general navigation features attributable to dredging to a depth, not in excess of -20 feet MLLW, plus 75 percent Federal and 25 percent non-Federal for the cost of design and construction of the general navigation features attributable to dredging to a depth in excess of -20 feet MLLW but not in excess of - 50 feet MLLW. The NFS would pay with interest, over a period not to exceed 30 years following completion of the period of construction of the project, up to an additional 10 percent of the total cost of construction of the general navigation features. While the NFS owes an additional 10 percent of the cost of the general navigation features, this amount may be reduced by LERRD which the NFS proves as necessary for the general navigation features. Local service facilities are a sole non- Federal funding and performance responsibility."

- **Added new paragraph 1:**

"Section 101 of WRDA 1986, as amended, states that during construction, the project would be cost shared 90 percent Federal and 10 percent non-Federal for the cost of design and construction of the general navigation features attributable to dredging to a depth, not in excess of -20 feet MLLW. The entrance channel would be developed to -25 feet MLLW based on the wave climate in the Bering Sea to ensure safe transit into the interior channel. Although the entrance channel would be constructed to a depth of -25 feet MLLW, ER 1105-2-100, Appendix E, E-8, b. (6) states, "Increased depths provided in entrance channels for transit of vessels between protected interior channels and the wave action zone, e.g., across an outer bar, will be cost shared the same as the deepest protected interior channel. Breakwaters, jetties and channel width increases are cost shared in the same manner." Therefore, the entrance channel would be cost shared 90 percent Federal and 10 percent non-Federal for the cost of design and construction for the project. The NFS would pay with interest, over a period not to exceed 30 years following completion of the period of construction of the project, up to an additional 10 percent of the total cost of construction of the general navigation features. While the NFS owes an additional 10 percent of the cost of the general navigation features, this amount may be reduced by LERRD which the NFS proves as necessary for the general navigation features. Local service facilities are a sole non- Federal funding and performance responsibility.”

- **Added a new sentence at end of paragraph 2:**

“The costs presented in this cost share table are based on certified costs, which differ slightly from the costs used to compare and screen alternatives in Appendix C: Economics and the plan formulation sections of this Feasibility Report."

EXECUTIVE SUMMARY

This General Investigations study is being conducted under authority granted by Section 4010 of the Water Resources Development Act (WRDA) of 2007. This study evaluates Federal interest and the feasibility of constructing navigation improvements at St. George. Due to the complexity of the environmental analysis, the decision was made to prepare a standalone Environmental Assessment. The Environmental Assessment and appendices will be located on the Alaska District (POA) website under Reports and Studies→ Documents Available for Review →Civil Works → St. George, along with this Feasibility Report and appendices. Key information to compare alternatives, inform the decision and determine a Recommended Plan has been included in this Feasibility Report. All correspondence for this study can be found in Appendix E. Appendices G, H, I, J, K and L include the 404(b)(1) Clean Water Act Evaluation, Essential Fish Habitat, Draft Biological Assessment, U.S. Fish and Wildlife Service (USFWS) Coordination Act Report, National Historic Preservation Act (NHPA) Section 106 Documentation, and the Draft Finding of No Significant Impact (FONSI), respectively. In addition, this study is currently on a 58-month timeline per the time waiver (3x3 exemption) approved on 07 February 2019.

The City of St. George is on the north shore of St. George Island, one of the five islands in the Pribilofs located in the Bering Sea. It lies 49 miles south of St. Paul Island, the only other inhabited island of the Pribilofs. St. George is a mixed, subsistence-cash economy. While the residents hunt and fish for much of their protein needs, there is a need for a cash economy to pay for power, heat, fuel, construction goods, utilities, transportation resources, as well as public use facilities.

In 1973, after 110 years of using Alaska Aleut Natives on St. George to harvest, cure, and skin fur seals and their pelts for profit, the Federal Government, acting through the Department of Commerce, National Marine Fisheries Service (NMFS), stopped commercial fur sealing on St. George. This left the indigenous peoples with no other means of economic activity. A usable harbor has been a long-term goal of the community to help develop a self-sustaining economy that can benefit from the abundant marine resources of the Bering Sea. Commitments of the Federal Government to assist St. George and St. Paul Islands in the transition from an economy based on harvesting fur seals to a self-sustaining economy were included in the Fur Seal Act Amendments of 1983, P.L. 98-129. Under the Fur Seal Act Amendments of 1983, the Department of Commerce established a $20 million trust (St. George $8 million and St. Paul $12 million) to promote the islands' economic development.

Design of a harbor in Zapadni Bay on the south shore of St. George was undertaken by the State of Alaska in the early 1980s. Construction of the harbor was completed by the City of St. George by 1988. The current conditions in the harbor are such that navigation to, from, and within the harbor are unsafe due to the wave climate in the entrance channel, seiche conditions within the inner basin, and degradation and overtopping of the existing breakwaters. The harbor and breakwaters are frequently damaged by storms in the Bering Sea such that the Federal Emergency Management Agency (FEMA) provided funds on multiple occasions for repairs. These unsafe conditions limit the use of the harbor for all potential users. Access for barges is most restricted, with unsafe conditions occurring 52% annually, or 190 days per year. The inability and inefficiencies related to delivering goods and fuel to the island directly impacts the cost of living at St. George. Due to vessel delays and the risk of damages consumables are flown into the community at a higher cost than ocean going vessels could deliver.

While initial efforts of this study focused on improving the existing harbor in Zapadni Bay, numerical modeling results for the Zapadni Bay alternatives showed limited improvements in moorage conditions for some alternatives, and none of these alternatives improved harbor accessibility. Due to high project costs and marginal increase in benefits, the Zapadni Bay alternatives were removed from further consideration. The project was then re-scoped to focus on the site at North Anchorage. This decision resulted in the project delivery team (PDT) having to overcome several data gaps and make the risk-informed decision to collect geotechnical information in pre-engineering and design (PED). This has prolonged the environmental coordination and contributed to the need for a waiver of USACE policy requiring completion of Marine Mammal Protection Act (MMPA)/Endangered Species Act (ESA) consultation during the feasibility phase of the planning process, since this data collection is needed to inform the development of a Letter of Authorization (LOA) and finalize environmental compliance. A USACE policy wavier, permitting POA to conduct MMPA/ESA consultation during the Preconstruction, Engineering and Design phase was approved on 03 March 2020 (Appendix E).

This study meets the criteria for economic justification under Section 2006, Remote and Subsistence Harbors, of 2007 WRDA, as modified by Section 2104 of the Water Resources Reform and Development Act of 2014 and further modified by Section 1105 of WRDA 2016. The authority specifically states that in conducting a study of harbor and navigation improvements, the Secretary may recommend a project without demonstrating that the improvements are justified solely by National Economic Development (NED) benefits.

The four alternatives at the North Anchorage site were compared against the No Action Alternative to determine the Recommended Plan. National Economic Development analysis yielded no positive net benefits for any of the four North Anchorage alternatives; therefore, no NED plan has been identified. Pursuant to Remote and Subsistence Harbors Implementation Guidance, a Cost Effectiveness/Incremental Cost Analysis (CE/ICA) was pursued. The CE/ICA metric is vessel opportunity days for safe access and moorage. This metric allows for vessel class specific evaluation of improved access for the final array of alternatives. The CE/ICA yielded two Best Buy plans, Alternative N-3 and Alternative N-4.The selection of a Recommended Plan was further refined through analysis of the type of access and moorage provided by these two Best Buy plans. While Alternative N-4 provides a gain of 127 days of access when compared to the No Action Alternative, none of these days are associated with the crabbing (Community Development Quota (CDQ) and Individual Development Quota (IDQ)) fleet. In comparison, Alternative N-3 provides 179 days of access, which includes 17 days of safe access and 17.4 days of safe moorage for the crabbing fleet. Based on the CE/ICA and given that the CDQ/IFQ crabbing fleet is a driver of community viability, Alternative N-3 is identified as the Recommended Plan.

The Recommended Plan, consists of a 450-foot wide by 550-foot-long mooring basin dredged to -20 feet mean lower low water (MLLW) protected by a 1,731-foot-long north breakwater and a 250-foot-long spur breakwater at the west edge of the basin. The basin connects to the Bering Sea with a 250-foot wide navigation channel dredged to -25 feet MLLW. Dredging the channel and basin for this alternative requires the removal of approximately 353,052 cubic yards (CY) of material. Inner harbor facilities would be created by filling an area to +10 feet MLLW, and adding a 300-foot-long pile-supported dock and a concrete boat launch ramp to -5 feet MLLW for full tide launching access. The Recommended Plan certified project first cost with contingency is $159.8 million. The project would be cost shared 90 percent Federal and 10 percent non-Federal for the cost of design and construction of the general navigation features attributable to dredging to a depth, not in excess of -20 feet MLLW, plus 75 percent Federal and 25 percent non-Federal for the cost of design and construction of the general navigation features attributable to dredging to a depth in excess of -20 feet MLLW but not in excess of - 50 feet MLLW. The non-Federal sponsor (NFS) would pay with interest, over a period not to exceed 30 years following completion of the period of construction of the project, up to an additional 10 percent of the total cost of construction of the general navigation features. The Recommended Plan is supported by the City of St. George, which is the NFS, and they have provided a Self-Certification of Financial Capability dated 24 April 2020 (Appendix E).

In view of the analysis presented above, it is recommended that Alternative N-3 be approved as the Recommended Plan. The Recommended Plan would provide for 179 additional vessel opportunity days for safe access and moorage to support the subsistence vessel fleet; the fuel barge fleet; lash vessels and other cargo-carrying vessels; as well as approximately 85 percent of the existing crabber fleet. These additional days would allow for the more efficient delivery of fuel and goods to the community, increase opportunities to harvest subsistence resources, and allow a portion of the crabbing fleet to utilize the harbor. The resulting reduction in the cost of essential goods coupled with expanded economic opportunities would afford the community the ability to develop a local sustainable economy based on marine resources, which is essential for supporting St. George’s mixed subsistence-cash economy, combating out-migration and helping to strengthen the viability of the community of St. George.

PERTINENT DATA

Recommended Plan	
Alternative N-3: All Vessels, 85% of Crabber Fleet	
GNF Dredge Volume	286,838 CY
LSF Dredge Volume	66,214 CY
Total Dredge Volume	353,052 CY

Economics	
Item	**Total ($)**
Total Average Annual Equivalent Cost	$7,322,000
Total Average Annual Equivalent Benefit	$1,066,000
Net Annual National Economic Development Benefits	($6,256,000)
Benefit-Cost Ratio	0.15
Note: October 2019 Price (FY20) level, 50-Year Period of Analysis, 2.750 Percent Discount rate. Costs and benefits in this table are based on the certified cost for the Recommended Plan and differ slightly from the costs and benefits used for plan evaluation and comparison.	

Cost Share Table (October 1, 2019 Price Levels, Program Year (FY) 2020)[1]						
WBS Number	**General Navigation Features**	**Project Cost**	**Contingency[2]**	**Project Cost w/ Contingency**	**Federal Share**	**Non-Federal Share**
10	Breakwater	$87,684,000	$21,921,000	$109,605,000	$98,644,500	$10,960,500
12	Navigation Ports and Harbors[3]	$25,275,000	$6,319,000	$31,594,000	$26,865,300	$4,728,700
30	Preconstruction, Engineering & Design (PED)[4]	$5,797,000	$1,449,000	$7,246,000	$6,448,900	$797,100
31	Construction Management (S&I)[4]	$9,054,000	$2,264,000	$11,318,000	$10,073,000	$1,245,000
	Subtotal Construction of GNF	**$127,810,000**	**$31,953,000**	**$159,763,000**	**$142,031,700**	**$17,731,300**
1	Lands, Easements, Right-of-Ways, Relocations (LERR)[5- Federal]	$0	$0	$0	$0	$0
1	Lands, Easements, Right-of-Ways, Relocations (LERR)[5- Non-Federal]	$60,000	$15,000	$75,000	$0	$75,000
	Total Project First Costs	**$127,870,000**	**$31,968,000**	**$159,838,000**	**$142,031,700**	**$17,806,300**
12	Aids to Navigation[6]	$73,000	$18,000	$91,000	$91,000	$0
	Credit for Non-Federal LERR[7]	$0			$0	-$75,000
	10% GNF Non-Federal[8]	$0			($15,976,300)	$15,976,300
	Total Cost Apportionment	**$127,943,000**	**$31,986,000**	**$159,929,000**	**$126,146,400**	**$33,707,600**

1. Cost is based on Project First Cost (constant dollar basis) on Total Project Cost Summary Spreadsheet, at an effective price level 1 Oct 2019 (Cost Appendix). Aids to Navigation broken out and shown as a separate cost.
2. A contingency of 25 percent has been applied to each cost item.
3. Federal and non-Federal breakdown of costs reflect the change in cost share responsibility from 90% Federal/10% non-Federal for the basin and channel up to -20ft MLLW, to 75% Federal/25% non-Federal for the channel for -20 ft to -25ft MLLW.
4. PED and Construction cost sharing totals account for the change in cost share responsibility from 90% Federal/10% non-Federal for the basin and channel up to -20ft MLLW, to 75% Federal/25% non-Federal for the channel for -20 ft to -25ft MLLW.
5. These are Real Estate administrative costs. There are no actual lands and damages but per USACE regulations, Real Estate administrative costs will be placed in the 01 account. Additional Real Estate costs will be cost shared according to the GNF. Escalation from the TPCS accounts for some numerical differences.
6. Aids to Navigation are reflected as a Federal cost, but are coordinated and paid for by the U.S. Coast Guard.
7. Credit is given for the incidental costs borne by the non-Federal sponsor for lands, easements, rights of way and relocations (LERR) per Section 101 of WRDA 86, not to exceed 10% of the GNF
8. The non-Federal sponsor shall pay an additional 10% of the costs of GNF of the NED plan, pursuant to Section 101 of WRDA 86. The value of LERR shall be credited toward the additional 10% payment except in the case of LERR for GNF.

LIST OF ACRONYMS AND ABBREVIATIONS

ADEC	Alaska Department of Environmental Conservation
ADM	Agency Decision Milestone
AEP	annual exceedance probability
AHRS	Alaska Heritage Resources Survey
AK	Alaska
AKDOT&PF	Alaska Department of Transportation and Public Facilities
AMNWR	Alaska Maritime National Wildlife Refuge
ANCSA	Alaska Native Claims Settlement Act
APE	Area of Potential Effect
APICDA	Aleutian Pribilof Islands Community Development
ASA (CW)	Assistant Secretary of the Army, Civil Works
ATR	Agency Technical Review
BMPs	best management practices
BOEM	Bureau of Ocean Energy Management
BSAI	Bering Sea Aleutian Islands
CAA	Clean Air Act
CDQ	Community Development Quota
CE/ICA	Cost Effectiveness/Incremental Cost Analysis
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CSRA	Cost Schedule Risk Analysis
CY	Cubic Yards
CZMA	Coastal Zone Management Act
DPR	Detailed Project Report
DPS	Distinct Population Segment
DQC	District Quality Control
EEZ	Exclusive Economic Zone
EFH	Essential Fish Habitat
EA	Environmental Assessment
ER	Engineer Regulation
ERDC	Engineer Research and Development Center
EQ	Environmental Quality
ESA	Endangered Species Act
FCSA	Feasibility Cost Share Agreement
FEMA	Federal Emergency Management Agency
FMP	Fishery Management Plan
FONSI	Finding of No Significant Impact
ft	feet
FWCA	Fish and Wildlife Coordination Act
FWCAR	Fish and Wildlife Coordination Act Report
FUNWAVE	fully nonlinear Boussinesq wave model
GMSL	global mean sea level
GNF	general navigation features

HABS	Historical American Building Survey
H&H	Hydraulics and Hydrology
HQ	Headquarters
IDC	Interest During Construction
IDQ	Individual Development Quota
IEPR	Independent External Peer Review
IFQ	Individual Fishing Quota
IHA	Incidental Harassment Authorization
IPCC	Intergovernmental Panel on Climate Change
IPR	In-progress review
IWR	Institute for Water Resources
LAT	Lowest Astronomical Tide
LERR	Lands, Easements, Rights-of-Way, and Relocations
LOA	Letter of Authorization
LRR	Limited Reevaluation Report
LSF	Local Service Facilities
MHHW	mean higher high water
MHW	mean high water
MLLW	mean lower low water
MLW	mean low water
MMPA	Marine Mammal Protection Act
MOA	Memorandum of Agreement
MPRSA	Marine Protection, Research, and Sanctuaries Act
MSL	mean sea level
MTL	mean tide level
NASA	National Aeronautics and Space Administration
NED	National Economic Development
NEPA	National Environmental Policy Act
NFS	Non-Federal Sponsor
NHL	National Historic Landmark
NMFS	National Marine Fisheries Service
NMS	National Marine Sanctuary
NMSA	National Marine Sanctuary Act
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service
NPS	National Park Service
NRC	National Research Council
NRHP	National Register of Historic Places
OMRR&R	Operations, Maintenance, Repair, Replacement, and Rehabilitation
OSE	Other Social Effects
PCX	Planning Center of Expertise
PDT	Project Delivery Team
PED	Preconstruction Engineering and Design
POA	Pacific Ocean Alaska (Alaska District)

POD	Pacific Ocean Division
R	Republican
RED	Regional Economic Development
ROM	rough order of magnitude
RSLC	relative sea level change
S&A	State and Agency
SAV	Submerged Aquatic Vegetation
SHPO	State Historic Preservation Officer
SLC	sea level change
TPCS	Total Project Cost Summary
TSP	Tentatively Selected Plan
U.S.	United States
USACE	United States Army Corps of Engineers
USEPA	Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
VLM	vertical land movement
WRDA	Water Resources Development Act
WRRDA	Water Resources Reform and Development Act

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDICES

1.0 INTRODUCTION

This General Investigations study is being conducted under authority granted by Section 4010 of the Water Resources Development Act (WRDA) of 2007, Public Law 110-114 which states:

The Secretary shall conduct a study to determine the feasibility of providing navigation improvements at St. George Harbor, Alaska.

Additionally, Section 1322 of WRDA of 2016, (b)(2) Expedited Completion of Feasibility Studies, authorizes the Secretary to move directly into preconstruction engineering and design (PED) if the project is justified. Implementation guidance was published on 12 February 2018. Section 1322 states:

> EXPEDITED COMPLETION OF FEASIBILITY STUDIES. The Secretary shall give priority funding and expedite completion of the reports for the following projects, and, if the Secretary determines that the project is justified in the completed report, proceed directly to project preconstruction, engineering, and design in accordance with section 910 of the Water Resources Development Act of 1986 (33 U.S.C.2287):
>
> (A) The project for navigation, St. George Harbor, Alaska

1.1 Project and Study Authority

The project is utilizing the authority of Section 2006 of WRDA, 2007, Remote and Subsistence Harbors, as modified by Section 2104 of the Water Resources Reform and Development Act of 2014 (WRRDA 2014) and further modified by Section 1105 of WRDA 2016. The authority specifically states that in conducting a study of harbor and navigation improvements, the Secretary may recommend a project without demonstrating that the improvements are justified solely by National Economic Development (NED) benefits if the Secretary determines that the improvements meet specific criteria detailed in the authority. Following are the criteria outlined in the authority along with a description of how this study satisfies them:

1. The community to be served by the improvements is at least 70 miles from the nearest surface accessible commercial port and has no direct rail or highway link to another community served by a surface accessible port or harbor; or the improvements would be located in the State of Hawaii or Alaska, the Commonwealth of Puerto Rico, Guam, the Commonwealth of the Northern Mariana Islands, the United States Virgin Islands; or American Samoa:

   The project is located in Alaska.

2. The harbor is economically critical such that over 80 percent of the goods transported through the harbor would be consumed within the region served by the harbor and navigation improvement as determined by the Secretary, including consideration of information provided by the non-Federal interest; and

   Based upon their weight, commodities transported in the future with-project condition were analyzed to determine that more than 80 percent of the goods transported through the harbor would be consumed within the region. The community served by the navigation improvements was determined to be the island of St. George and the immediately surrounding marine area (about a 25-mile radius).

   Consistent with the authority, alternatives supporting fish and crab product exports from the island are considered to provide economic opportunities for the community. However, these exports were projected to weigh less than 20% of the total weight going through the harbor when considering market and institutional factors such as Community Development Quotas (CDQ) and prices. Total imports minus total exports were used in the projection. Imports included the weight of fuel, the weight of freight and construction materials, and the weight of raw fish. Exports included the weight of processed fish products leaving the island. Exports are estimated to make up 14.1% of harbor throughput on average, with a high estimate of 18.7% and a low estimate of 11.3%.

3. The long-term viability of the community in which the project is located, or the long-term viability of a community that is located in the region that is served by the project and that will rely on the project, would be threatened without the harbor and navigation improvement.

   The cultural identity of Alaska Native Tribes is highly dependent upon subsistence activities tied to specific locations and deep historical knowledge of land and subsistence resources. Rural economies in Alaska, including that which exists on St. George, can be characterized as a mixed, subsistence-cash economy in which the subsistence and cash sectors are interdependent and mutually supportive. The ability to successfully participate in subsistence activities is highly dependent on the opportunity to earn some form of monetary income and access the resources needed to engage in subsistence activities. Without a safe and functioning harbor, economic opportunities in the community would continue to be hindered, and the costs of basic essential goods required to support a subsistence lifestyle would remain prohibitively high, contributing to continued out-migration from St. George. When subsistence communities are forced to disband due to high costs of essential goods, including fuel, tribal identities, and cultural communities, are endangered. Reductions in the costs of such basic essential goods are essential to community viability. In addition, a safe and functioning harbor would provide opportunities for the development of a local economy based upon the marine resources of the region. Such economic opportunities are essential for supporting the mixed, subsistence-cash *economies common throughout rural Alaska, combating out-migration, and helping to ensure the viability of the community of St. George.*

While determining whether to recommend a project under the criteria above, the Secretary will consider the benefits of the project to the following:

- Public health and safety of the local community and communities that are located in the region to be served by the project and that will rely on the project, including access to facilities designed to protect public health and safety;
- Access to natural resources for subsistence purposes;
- Local and regional economic opportunities;
- Welfare of the local population; and
- Social and cultural value to the local community and communities that are located in the region to be served by the project and that will rely on the project.

As indicated above, navigation improvements at St. George meet all the above criteria to recommend a project. Compliance with the criteria of the authority was confirmed by the United States Army Corps of Engineers (USACE) Vertical Team during an In-Progress Review conducted on 23 January 2018.

1.2 Scope of the Study

This study evaluates Federal interest in and the feasibility of providing navigation improvements at St. George, Alaska. Previous efforts considered modifications and/or realignments of the breakwaters, entrance channel, and inner harbor basin intended to reduce shoaling, wave overtopping, damage to the breakwaters, and adverse wave and seiche conditions in the harbor. Previous efforts also looked at removing the pinnacles in the entrance channel to achieve intended project depths. These approaches, as well as construction of additional features to the current harbor and construction of a new harbor facility, have been considered as part of this study.

This study was conducted, and the Feasibility Report prepared in accordance with the goals and procedures for water resource planning as contained in Engineer Regulation (ER) 1105-2-100, “Planning Guidance Notebook,” and Institute for Water Resources (IWR) Report 10-R-4, “Deep Draft Navigation” by the Alaska District or Pacific Ocean Alaska (POA) which are used interchangeably throughout this document.

This study was re-scoped after the Tentatively Selected Plan milestone. This decision received concurrence from the USACE Vertical Team during an In-Progress Review (IPR) conducted on January 23, 2018. While initial efforts of this study focused on improving the existing harbor in Zapadni Bay, numerical modeling results for the Zapadni Bay alternatives showed limited improvements in moorage conditions for some alternatives, and none of these alternatives improved harbor accessibility. Due to high project costs and the numerical modeling results, the Zapadni Bay alternatives were removed from further consideration and the North Anchorage alternatives were carried forward along with the future without-project condition as the final array. This decision resulted in the project delivery team (PDT) having to overcome several data gaps and make the risk-informed decision to collect Geotechnical information in PED. This has prolonged the environmental coordination and contributed to the need for a waiver of USACE policy requiring completion of Marine Mammal Protection Act (MMPA)/ Endangered Species Act (ESA) consultation during the feasibility phase of the planning process, since this data collection is needed to inform the development of a Letter of Authorization (LOA) and finalize environmental compliance. The re-scoping effort and difficulty in accessing St. George for data collection (i.e. several missed trips) resulted in the need for additional time and funds to complete the study. This study is currently on a 58-month timeline per the time waiver (3x3 exemption) approved on 07 February 2019. A USACE policy wavier, permitting POA to conduct MMPA/ESA consultation during the Preconstruction, Engineering and Design phase was approved on 03 March 2020 (Appendix E).

1.2.1 Fur Seal Act, amended 1983, P.L. 98-129

In their search for the breeding grounds of the North Pacific Fur seal (*Callorhinus ursinus*; fur seal) in 1786, Russian navigators discovered the Pribilof Islands. The Russians enslaved and relocated the Unangax̂ from the Aleutian Islands to the Pribilof Islands of St. Paul and St. George to harvest fur seals. In 1868, the Pribilofs were declared to be a special federal reserve for purposes of management and preservation of fur seals and other fur-bearing species. By 1890, the effects of over-harvest and pelagic sealing brought the fur seal population close to extinction. As a result of the decline in the fur seal population, Federal attention towards the Pribilofs increased. Although the government's focus remained primarily on management of the fur seal harvest, the Federal response in the Pribilofs ensured greater engagement by the United States (U.S.) with the lives of the Unangax̂.

Between 1910 and 1972, the U.S. government enacted or signed a suite of laws or conventions designed to protect fur seal populations. In 1973, the Fur Seal Commission adopted the government’s recommendation to establish a research program for fur seals by setting aside St. George as a research reserve and prohibiting commercial harvesting of fur seals on the island. However, the Unangax̂ subsistence harvest and commercial harvest on St. Paul continued as part of a study to determine the causes of the decline of fur seals. During this period, the government’s policy regarding fur seals in the Pribilofs continued to evolve toward conservation. This new policy towards the Unangax̂ began to convey interim title to the townships and other lands to the native corporations.

The attention of Congress in the early 1980s turned to the promotion of a self-sufficient and self-sustaining economy on the Pribilofs and a phase-out of federal support. In 1983, the Secretary of Commerce and the Governor of Alaska formed a working group composed of State, Island, and Federal representatives. It was recommended that the Unangax̂ construct harbors on both islands in order to transition their communities to a self-sustaining economy.

In 1983, the Fur Seal Act (1983 Act) was amended to provide provisions to assist St. George and St. Paul Islands in the transition from an economy based on harvesting fur seals to a self-sustaining economy, specifically stating:

> Sec. 205(d) "A Memorandum of Understanding shall be entered into by the Secretary [Commerce], a representative of the local governmental authority on each Island, the trustee or trustees, and the appropriate officer of the State of Alaska setting forth the respective responsibilities of the Federal Government, the Trust, and the state regarding—
> (1) […]
> (2) funding to be allocated by the State of Alaska for the construction of boat harbors on St. Paul and St. George Islands; […]
> (7) the cooperation of government agencies, rendered through existing programs, in assisting with an orderly transition from Federal management and the creation of a private enterprise economy on the Pribilof Islands as described in this Act; and […]"

Under the 1983 Act, "the Department of Commerce's responsibilities with regard to the Islands were limited to (1) Establishing the one-time trust ("the Trust") to be administered by a non-government trustee in order to promote the development of a stable, self-sufficient, enduring and diversified economy not dependent on sealing (section 1166);…"(NOAA 1997). The purpose of the $20 million Trust, of which $8 million was allotted to St. George, the remainder allotted to St. Paul, "was to try to provide some sort of independence for the islanders, to provide them with some capital to pay their current expenses and for future development."

Through the 1983 Act, the community of St. Paul was able to construct a harbor and establish an economy based on the utilization of the Bering Sea fisheries. St. George also constructed a harbor at Zapadni Bay, in conjunction with the State of Alaska. Unfortunately, construction of the harbor has not enabled the St. George community to establish a viable fishery-based economy. The current conditions in the harbor are such that navigation to, from, and within the harbor are unsafe due to wave climate in the harbor entrance, seiche conditions within the inner basin, and degradation and overtopping of the existing breakwaters. These unsafe conditions limit the use of the harbor for all potential users.

1.3 Study Location

The City of St. George is on the northeast shore of St. George Island, the southern-most of five islands in the Pribilofs located in the Bering Sea (Figure 1). It lies 49 miles south of St. Paul Island, 750 air miles southwest of Anchorage, and 250 miles northwest of Unalaska. The harbor sites investigated on St. George are located at Zapadni Bay, North Anchorage, and Garden Cove (Figure 1). The 2017 population of St. George is 72, according to the Alaska Department of Commerce, Community, and Economic Development. St. George is accessible only by water and air. St. George is also the name of the federally-recognized tribe on St. George. Subsistence activities are vital to this Alaska community and to many long-term non-Native residents, as well.

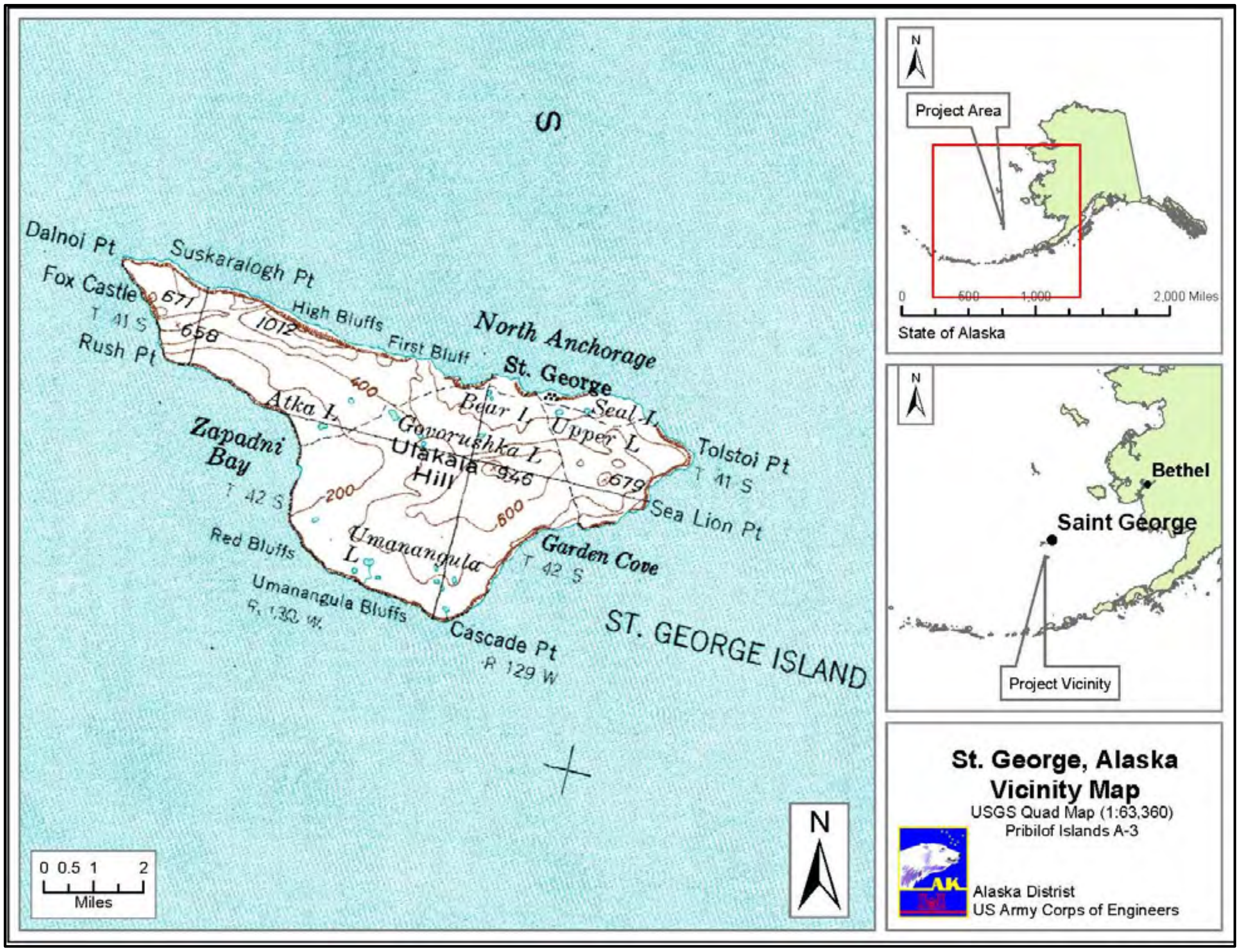

Figure 1. Vicinity Map, St. George, Alaska.

The Pribilof Islands are ecologically significant and are colloquially referred to as “the Galapagos of the north” due to their rich fisheries, abundance of colonial seabirds, and Steller sea lion and northern fur seal rookeries. The area around the Pribilof Islands supports some of the most important commercial fisheries in the U.S., including Pacific halibut, mackerel, cod, snow crab, red king crab, and the Alaska walleye pollock fishery, which is the nation’s largest by tonnage and value. According to a recent analysis by the Aleutian Pribilof Island Community Development Association (APICDA), St. George is located right in the middle of an area with an annual harvest quota for groundfish of two million metric tons (the equivalent of 4.4 billion pounds), in addition to shellfish or crab fisheries that harvest tens of millions of pounds.

1.4 Congressional District

The study area is in the Alaska Congressional District, which has the following representation:

- Senator Lisa Murkowski (R-AK)
- Senator Dan Sullivan (R-AK)

- Representative Don Young (R-AK)

1.5 Non-Federal Sponsor

The City of St. George is the non-Federal sponsor (NFS) and has stated its intention to cost-share in a federally-constructed navigation improvement project. The Federal Cost Sharing Agreement (FCSA) for this study was signed on 27 September 2017. This agreement creates a Federal and non-Federal partnership with the objective of serving both local and national interests effectively. The feasibility phase is conducted at a 50/50 cost-share under Section 105(a) of WRDA 1986.

1.6 Related Reports and Studies

Navigation Improvements Limited Reevaluation Report, Saint George, Alaska, July 2004. The USACE, Alaska District, found that there was no Federal interest in removing pinnacles in the entrance channel without addressing other issues with the existing harbor.

Section 905(b) (WRDA 86) Analysis Navigation Improvements, Saint George, Alaska, October 2002. The USACE, Alaska District report recommended further research into providing harbor improvements at St. George. The feasibility phase of the study has not been initiated due to the lack of matching funds from the NFS.

Limited Reevaluation Report St. George Harbor Entrance Channel, August 1993. The USACE, Alaska District Limited Reevaluation Report (LRR) updating the 1988 Final Detailed Project Report (DPR) and EA on the project. The report examined changes in economic conditions and described the cost and design features of the project.

Harbor Dredging Draft Detailed Project Report and Environmental Assessment, St. George, Alaska, May 1988. The USACE, Alaska District assessment was in response to a letter request from the City of St. George that provided cost-sharing funds to initiate this detailed study in November 1987.

Harbor Dredging Section 107 Reconnaissance Report, August, 1987, The USACE, Alaska District, reconnaissance report was in response to a letter from the City of St. George that requested assistance for navigation improvements pursuant to Section 107 of the 1960 River and Harbor Act, as amended.

St. George Harbor, Supplemental Dredging and Sedimentation Analysis, March 1985. The USACE, Alaska District, conducted a dredging and sedimentation analysis.

Review of St. George Breakwater Design, August 1984. The Waterways Experiment Station, Coastal Engineering Research Center (Dennis Markle, W.C. Seabergh, Paul Farrar) concluded that wave hindcasting appeared to be acceptable, but that advance techniques were not used to account for wave-wave interactions. The harbor layout design was found to appear satisfactory. Several concerns were documented regarding the berm breakwater design, which the USACE had no prior experience with. Scale effects may have been such that damage results from the physical model tests are questionable. Testing at various wave directions were not conclusive in demonstrating breakwater stability under the worst potential conditions. Wave heights were not appropriately measured as they included incident and refracted components.

St. George Island, Alaska, Section 107 Appraisal Report was prepared in 1979 under the authority of Section 107 of the River and Harbor Act of 1960, as amended.

2.0 PLANNING CRITERIA, PURPOSE AND NEED FOR PROPOSED ACTION

2.1 Problem

In 1973, after 110 years of using Alaska Aleut Natives on St. George to harvest, cure, and skin fur seals and their pelts for profit, the Federal Government, acting through the Department of Commerce, National Marine Fisheries Service (NMFS), stopped commercial fur sealing on St. George Island. This was done as a matter of Federal wildlife conservation policy. In the early 1980s, the Department of Commerce proposed that Congress change the Fur Seal Act and permit NMFS to withdraw from property ownership and municipal management of St. George. Congress, the State of Alaska, and all concerned parties recognized that, without a boat harbor, this Federal phase-out would cause an effective “termination” of the Native community. Lacking harbor infrastructure to support commercial fishing, the residents would need to resume commercial fur sealing, contrary to Federal policy. Therefore, a goal of harbor construction has been to provide for the transition of the local economy from being dependent upon the government managed seal harvest to an economy that could benefit from the abundant marine resources of the Bering Sea. Commitments of the Federal Government to assist St. George and St. Paul Islands in the transition from an economy based on harvesting fur seals to a self-sustaining economy were included in the Fur Seal Act Amendments of 1983, P.L. 98-129. More than 30 years after the signing of P.L. 98-129, the residents of St. George have not attained a safe, accessible harbor to sustain a marine resource economy sufficient to support their mixed, subsistence-cash economy. The survival of the community is dependent upon a more accessible harbor as there can be no viable long-term economy on St. George without it.

The Zapadni Bay harbor was constructed with the intent to meet the goal of transforming the modest local economy to a marine-based economy (Figure 2). Section 4.6 explains the existing navigation conditions and challenges with the Zapadni Bay harbor.

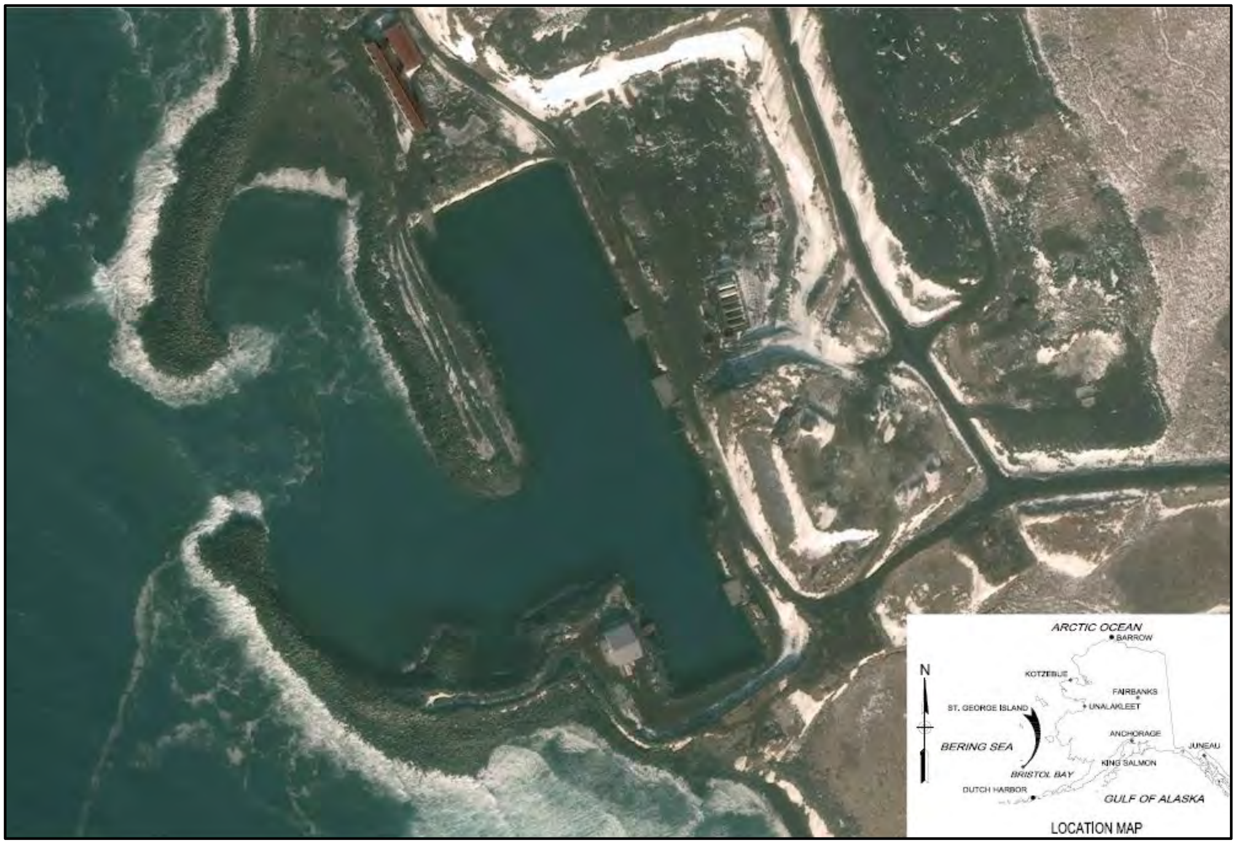

Figure 2. Aerial Image of Existing Harbor in Zapadni Bay.

2.1.1 Problem Statement

Conducting navigation improvements at St. George would reduce risk and better provide safe navigation of subsistence vessels, fuel barges, cargo vessels, and a limited commercial fleet.

2.2 Purpose and Need

The purpose of the project is to increase the safe accessibility of marine navigation to the community of St. George, Alaska. The need for the project is to reduce hazards to provide better safe navigation of subsistence vessels, fuel barges, cargo vessels, and a limited commercial fleet, all of which are critical to the long term viability of the mixed subsistence-cash economy at St. George.

Dangerous wave and seiche conditions at the existing harbor in Zapadni Bay limits opportunities for safe access and moorage to the current fleet. These conditions reduce subsistence opportunities and impacts the delivery of goods to the community and imperils the long-term viability of the community. Since crab rationalization established individual fishing and harvesting quotas (enacted circa 2000 with full implementation by the 2005/2006 season), commercial fishing vessels all but abandoned St. George as an option to deliver catch due to it being cost-prohibitive compared with the risk of damages and delays. The community is legally entitled to a percentage of the CDQ from APICDA for crab; however, without a safe harbor, St. George is unable to realize that revenue benefit and the crab is delivered to neighboring St. Paul. The cost of fuel is exorbitant (>$7/gallon on St. George vs. ~$3/gallon on St. Paul) because of the necessary inclusion of anticipated delays and operating costs associated with delivering to St. George. Due to vessel delays and the risk of damages, consumables are flown into the community at the cost of $1.58 more per pound than ocean-going vessels could deliver.

The cultural identity of Alaska Native Tribes is highly dependent upon subsistence activities tied to specific locations and deep historical knowledge of land and subsistence resources. Rural economies in Alaska, including that which exists on St. George, can be characterized as a mixed, subsistence-cash economy in which the subsistence and cash sectors are interdependent and mutually supportive. The ability to successfully participate in subsistence activities is highly dependent on the opportunity to earn some form of monetary income and access the resources needed to engage in subsistence activities. Without a safe and functioning harbor, economic opportunities in the community would continue to be hindered, and the costs of basic essential goods required to support a subsistence lifestyle would remain prohibitively high, contributing to continued out-migration from St. George. The result was closure of the school following the 2016/2017 school year when enrollment fell below minimum thresholds for State funding. St. George has taken steps to ensure that the school is in position to reopen if enrollment again surpasses that minimum threshold, such as happened formerly in the remote Alaskan communities of Adak, Rampart, and Clarks Point. The community has taken steps to position re-opening of the school, including implementing a distance learning program for children remaining on the island, assuming upkeep and maintenance of the school, and recruitment of families to the island. The one major component lacking, however, are the economic opportunities that a safe and functioning harbor could provide.

2.3 National Objectives

The Federal objective of water and land resources planning is to contribute to the NED in a manner consistent with protecting the nation’s environment. NED features increase the net value of goods and services provided to the economy of the nation as a whole.

2.4 Study Objectives

The overall objective of this study is to increase the safe accessibility of marine navigation to the community by meeting the following:

- Provide for the safe maneuverability and protected mooring of the existing and anticipated fleet
- Increase the percentage of time that harbor facilities can be safely accessed

2.5 Opportunities

Potential opportunities to be realized by improving navigation to/from St. George include the following:

- Promote community viability and survival
- Expand economic opportunities:
  - Establish a self-sustaining, marine-resource-based economy
  - Realize allocated CDQ for crab
  - Provide more affordable access to goods, services, and marine resources
- Improve access to subsistence resources resulting in improved food security
- Increase response capacity to environmental hazards (eg. oil spills)
- Provide functional Harbor of Refuge during storms in the central Bering Sea

2.6 Study Constraints

Study constraints that would be taken into account during Feasibility level analysis are the following:

- Minimize negative impacts to infrastructure, community, historical buildings, etc.
- Avoid or minimize negative impacts to subsistence activities

2.7 National Evaluation Criteria

Alternative plans should be formulated to address study objectives and adhere to study criteria. Federal Principles and Guidelines establish four criteria for evaluation of water resources projects. These criteria and their definitions are explained in Sections 2.7.1 through 2.7.4.

2.7.1 Acceptability

Acceptability is defined as "the viability and appropriateness of an alternative from the perspective of the Nation's general public and consistency with existing Federal laws, authorities, and public policies. It does not include local or regional preferences for particular solutions or political expediency."

2.7.2 Completeness

Completeness is defined as "the extent to which an alternative provides and accounts for all features, investments, and/or other actions necessary to realize the planned effects, including any necessary actions by others. It does not necessarily mean that alternative actions need to be large in scope or scale."

2.7.3 Effectiveness

Effectiveness is defined as "the extent to which an alternative alleviates the specified problems and achieves the specified opportunities."

2.7.4 Efficiency

Efficiency is defined as "the extent to which an alternative alleviates the specified problems and realizes the specified opportunities at the least cost."

2.8 Study Specific Evaluation Criteria

Study-specific screening criteria used to evaluate an alternative measures included constructability, avoidance of constraints, completeness, first costs, and maintenance costs.

Also, the study is utilizing the authority of Section 2006 of WRDA 2007, Remote and Subsistence Harbors, as modified by Section 2104 of the WRRDA of 2014 and further modified by Section 1105 of WRDA 2016. According to the USACE's Implementation Guidance for Section 1105 of WRDA 2016 issued on July 6, 2017, an NED analysis and identification of the NED Plan, if any, is required in conjunction with analyzing the criteria detailed in Section 1.2 as related to the navigation improvements project. If there is no NED Plan and/or selection of a plan other than the NED Plan is based in part or whole on non-monetary units. Then, the selection would be supported by a Cost-Effectiveness/Incremental Cost Analysis (CE/ICA) consistent with ecosystem restoration evaluation procedures.

3.0 BASELINE CONDITIONS

3.1 Physical Environment

St. George is the southernmost and second largest of a group of five historically volcanic islands that compose the Pribilof Archipelago, located approximately 750 miles west of Anchorage and 250 miles north by northwest of Unalaska Island in the southern Bering Sea. St. George's position at the western margin of Alaska's continental shelf puts it close to the much deeper waters of the Bering Sea's abyssal plain. The abrupt change in seafloor elevation occurring at the continental slope facilitates natural upwelling processes; as a result, surface waters in the region are some of the most productive on the planet.

While St. George and its slightly larger northern neighbor, St. Paul, are currently inhabited, Otter, Walrus, and Sea Lion Rock Islands are not. As a group, as well as singularly, the islands are ecologically significant and are colloquially referred to as "the Galapagos of the north" due to their rich fisheries, abundance of colonial seabirds, and Steller sea lion and northern fur seal rookeries.

St. George falls within the overarching boundary of the Alaska Maritime National Wildlife Refuge (AMNWR). Portions of its surface landmass are owned and managed by the U.S. Fish and Wildlife Service (USFWS) for conservation, protection, and the overall enhancement of fish, wildlife, plants, and their habitats for the continuing benefit of the

American people. St. George is difficult to access by airplane or boat due to the wave, wind, and fog climate of the central Bering Sea.

3.1.1 Climate

St. George falls within the southwest maritime climate zone, characterized by persistently overcast skies, high winds, and frequent cyclonic storms. The climate of St. George is controlled by the cold waters of the Bering Sea. The summers are cold and windy; the winters are long, freezing, and extremely windy; and it is overcast year-round. Throughout the year, the temperature typically varies from 24°F to 52°F and is rarely below 9°F or above 56°F.

3.1.2 Tides

The nearest tidal station is located at Village Cove on St. Paul, approximately 50 miles away. Due to the similarity of the sites, tidal data from St. Paul was used for this study (Table 1).

Table 1. Published tidal data for Village Cove, St. Paul, Alaska. Values in feet, Mean Lower Low Water (MLLW).

Published tidal data for St. Paul, Alaska (ft)

Highest Observed Water Level (12/08/06)…..	+5.26
Highest Astronomical Tide (HAT) …….........	+4.09
Mean Higher High Water (MHHW)…...........	+3.30
Mean High Water (MHW)............................	+3.08
Mean Tide Level (MTL)…….........................	+2.03
Mean Tide Level (MSL)…..............................	+1.96
Mean Low Water (MLW).............................	+0.97
Mean Lower Low Water (MLLW).................	0.00 (datum)
Lowest Astronomical Tide (LAT)….................	-1.50
Lowest Observed Water Level (12/06/10)…...	-2.10

Source: NOAA NOS, Tidal Epoch 1983-2001, published 12/12/11.

From the above data, the mean tide level (arithmetic average of the Mean High Water (MHW) and the Mean Low Water (MLW)) is +2.03 foot. The mean tide range (the difference between MHW and MLW) is 2.11 feet.

3.1.3 Sea Level Change

The USACE requires that planning studies and engineering designs consider alternatives that are formulated and evaluated for the entire range of possible future rates of sea level change (SLC). Guidance for addressing SLC is in ER 1100-2-8162 and detailed below. Three scenarios of "low," "intermediate," and "high" SLC are evaluated over the project life cycle. According to the ER, the SLC "low" rate is the historic SLC. The "intermediate" and "high" rates are computed using the following:

> "Estimate the "intermediate" rate of local mean SLC using the modified National Research Council (NRC) Curve I and the NRC equations. Add those to the local historical rate of vertical land movement.
>
> Estimate the "high" rate of local mean SLC using the modified NRC Curve III and NRC equations (see Appendix A). Add those to the local rate of vertical land movement (VLM). This "high" rate exceeds the upper bounds of Intergovernmental Panel on Climate Change (IPCC) estimates from both 2001 and 2007 to accommodate potential rapid loss of ice from Antarctica and Greenland."

The local St. Paul tide station does not have the recommended 40-year period of record for the relative sea level change (RSLC) value. The tide station has a 10-year water level records from 2006. Based on the tide data available, the RSLC would be +0.015mm/yr.

VLM was investigated at the St. Paul gage, reported as site AC58 by the Jet Propulsion Laboratory. VLM for St. Paul was estimated to be -0.542 mm ± 0.279 mm/year (National Aeronautics and Space Administration (NASA) Jet Propulsion Laboratory n.d.). Over 50 years, this vertical movement would increase sea level rise at St. Paul by 0.09 feet; over a 100-year span, it would increase by 0.18 feet.

Per the ER recommendation, a U.S. tide station with a 40-year period of record was investigated for use as the RSLC value. The nearest U.S. tide station with the required 40-year period of record is the Unalaska, Alaska station, roughly 225 miles from the site. It has a historic RSLC of -5.58 mm/yr.

As a result of the distance from St. George, the Unalaska gage was not further investigated. Due to the short period of record at St. Paul, the global mean sea level (GMSL) rate was used to model SLC at St. George (Figure 3, Table 2). A project construction year of 2023 with projected sea levels in 2073 for a 50-year project life and 2123 for a 100-year adaptation horizon is assumed in Table 2.

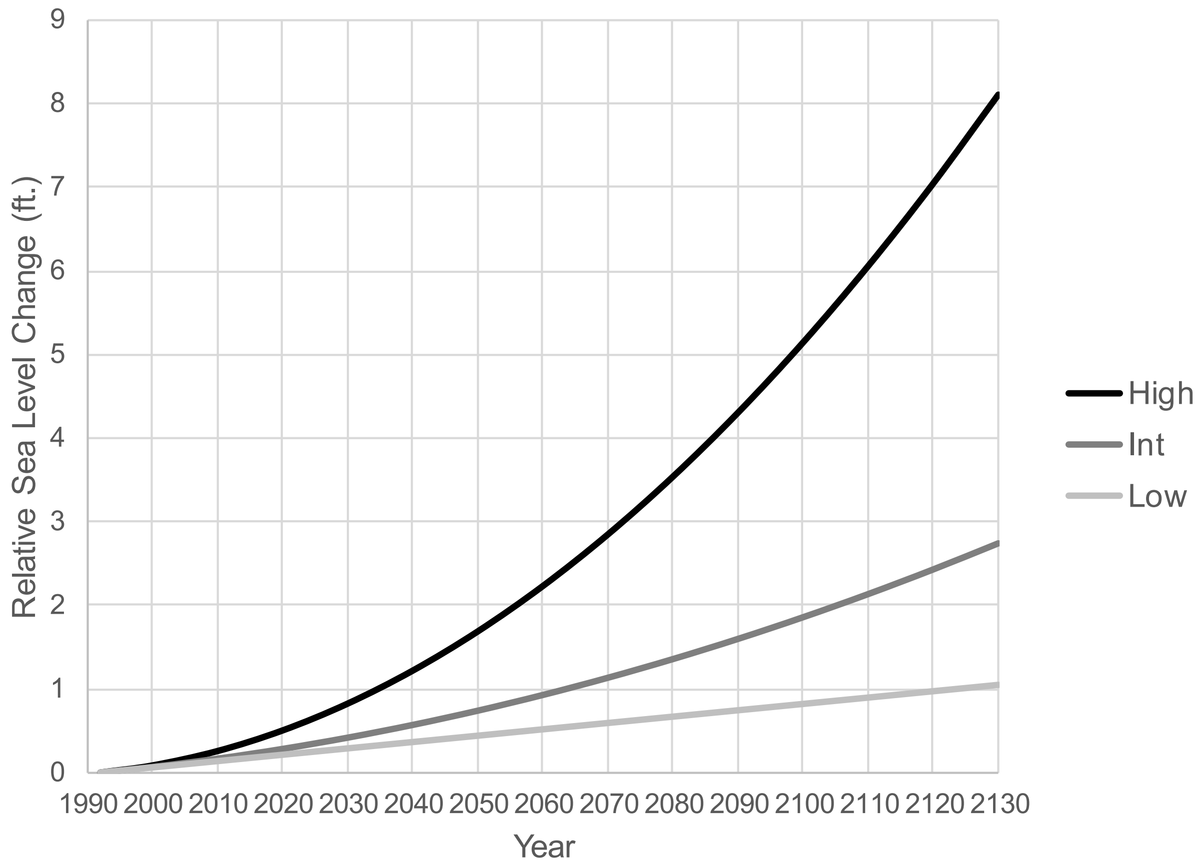

Figure 3. Global SLC evaluated at St. George using GMSL adjusted with VLM at St. Paul.

Table 2. SLC Prediction using GMSL and VLM.

Scenario	Low (Historic)	Intermediate (Curve I)	High (Curve III)
2073	+0.40 feet	+0.92 feet	+2.54 feet
2123	+0.78 feet	+2.24 feet	+6.85 feet

3.1.4 Water Levels

Shoreline geometry and bathymetry at St. Paul and St. George differ significantly in regards to the potential to produce storm surge. At St. Paul, the shoreline is bounded to the south by Reef Point and the west by Zapadni Point. Bathymetry between these features is fairly uniform with a gentle slope (Figure 4) creating potential for west and southwest wind and wave events to produce a storm surge at St. Paul. The event reported in 1966 was a result of wind and waves surging into the village at Zolotol Bay, to the south of Village Cove, where the harbor is located.

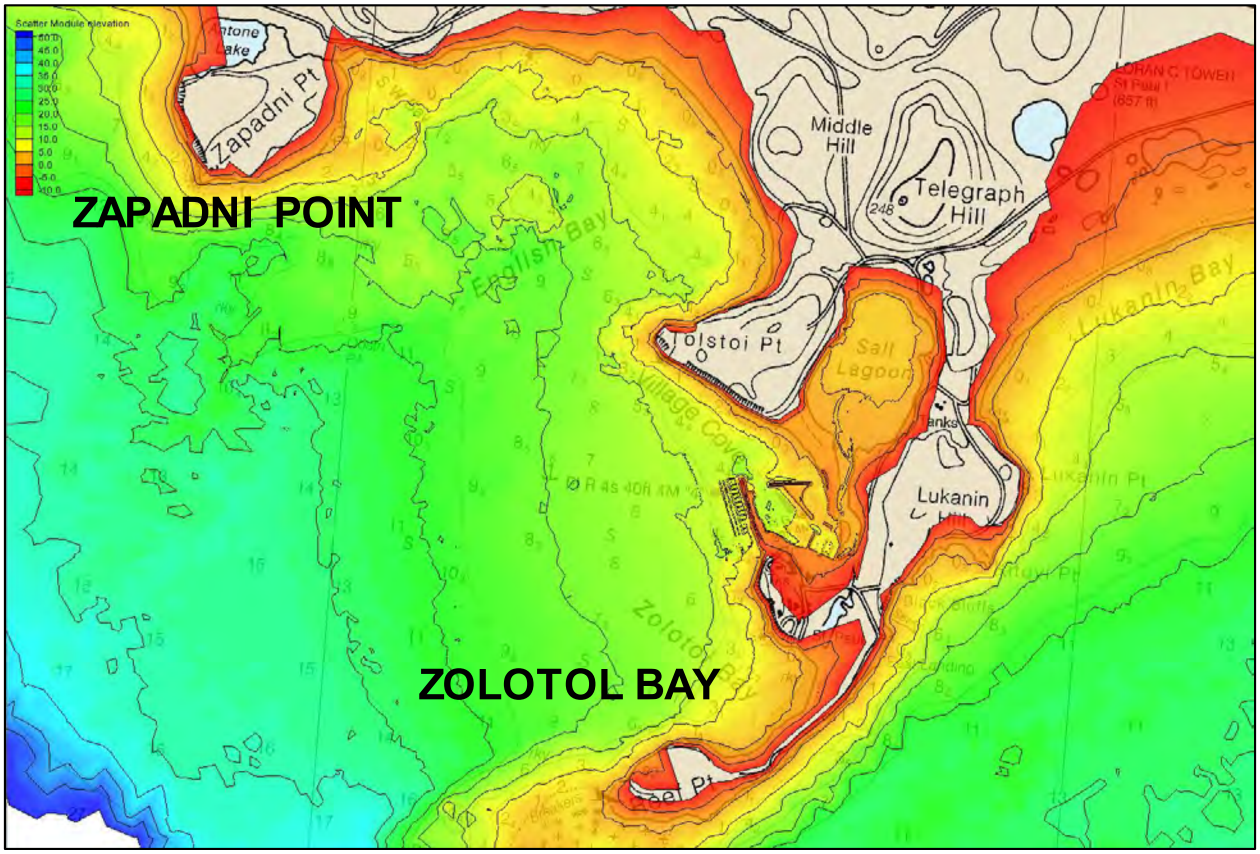

Figure 4. St. Paul shoreline and bathymetry. Detail from National Oceanic and Atmospheric Association (NOAA) chart 16382 with contour shading from National Ocean Service (NOS) digital bathymetry and 2009 project condition survey data. Color ramp and contours are in 5-meter intervals. Depth at the edge of the color ramp is -50 meters MLLW.

For design purposes, two water levels were used. For modeling wave propagation through the harbor and alternative designs, a water level of +5.9 feet MLLW (+1.8 m MLLW) was used for all simulation runs (Appendix A). This water level is above the highest measured data at St. Paul and is representative of the nominal sea surface elevation as storms approach the island. For breakwater design, a water level of +8.5 feet MLLW was used to account for historical surge events. This higher value was selected to ensure that breakwater structures not be overtopped during storm events.

For this study, it is assumed that the design water level of +5.9 feet MLLW is an extreme event and has a frequency of 0.02 annual exceedance probability (AEP). See Appendix A for further information on water level calculations.

3.1.5 Currents

Measured current data is not available for St. George. Barge operators related experiences navigating through beam-on currents when entering and exiting the harbor at St. George. The predominant current direction is to the north, though it was noted that it sometimes flows to the south. Fishing vessel captains contacted did not report having any concerns for currents at the harbor. Current velocities were not estimated.

3.1.6 Wave Climate

The wave climate at St. George is very similar to that of St. Paul and is controlled by the Bering Sea. Two storm mechanisms were identified, producing the most severe effects in the Bering Sea. Typically, winter storms in the Bering Sea are generated in the Sea of Okhotsk and travel east. These storm systems can occur multiple times throughout a season and sometimes follow one after another for multiple weeks at a time. The most severe wave conditions occur in the winter months as typhoon remnants from the south Pacific blow past the Aleutian chain and generate waves in the Bering Sea. Buoy data to the north of the Chain shows waves in excess of 30 feet on an annual basis. St. George is directly exposed to these waves, and energy is only dissipated from these events in the nearshore zone as bathymetry causes these waves to shoal and break before reaching the shore. The nearshore wave climate around the island is depth-limited, with wave breaking caused by bottom friction being the only mechanism to reduce wave energy from storms before it reaches the shore.

3.1.7 Geology/Topography

St. George is primarily composed of lava flows and sills of basaltic olivine (Barth 1956). Some pyroclastic tuffaceous and glacial materials are surficially evident. St. George's landmass consists of interspersed hills and valleys of varying steepness reaching a maximum elevation of 1,200 feet above sea level, relatively few planal areas, and is nearly circumscribed by steep oceanic cliffs. Areas of gradual, rocky beach-like shoreline to upland transition are uncommon.

3.1.8 Bathymetry

St George occurs at the western margin of Alaska's continental shelf, where maximum depths do not regularly exceed 70 fathoms. However, some 75 miles to the west-southwest, the water depth is greater than 3,000 fathoms. NOAA Chart 16380 describes the physical characteristics of St. George's nearshore areas as rocky, and gradually increasing in depth from the shoreline to 25 to 45 fathoms 3 miles from the shore.

3.1.9 Seismicity

Although they are not located along the Aleutian subduction zone, one of the most seismically active areas in the world, the Pribilof Islands are prone to regular seismic activity. St. George was struck by a 6.7 magnitude quake in 1991, and then again by a swarm of small <5.0 magnitude quakes in 2015.

3.1.10 Air Quality

Air quality on St. George is considered to be very good. Atmospheric convection is quite rigorous due to relative location and inherent topographical characteristics, while anthropogenic influence is negligible. Furthermore, the North Anchorage study area is not in or near a “non-attainment,” “maintenance,” or Class I area (as defined by the Clean Air Act (CAA)).

3.1.11 Noise

At the North Anchorage site, there is relatively little anthropogenically generated noise. During the nesting season, the cacophony of thousands of colonial nesting seabirds and breaking waves compete with the attenuating effect of the constant wind for dominance. However, after the birds have departed for the winter, wave action and wind are the prevailing and most attenuating sources of noise in the area.

3.1.12 Ice Conditions

St. George lies at the southern extent of sea ice in the Bering Sea. Typically, Zapadni Bay is ice-free. Historical sea ice concentrations have been cataloged and recorded in Alaskan waters from the 1850s to the present. Sea ice concentrations were investigated at 56.75°N, 169.5°W, which is to the south of St. George. The records show that St. George historically has open waters (ice concentrations of 30% or less) from June through February and greater concentrations of ice from March through May. The records also show that pack ice (concentrations over 90%) have never been recorded at St. George. The most recent recorded ice at St. George above 30% was in January of 2000 with the next previous event occurring before 1980.

Ice coverage analysis was performed to the north of St. George to determine the likelihood of ice sheet coverage near the North Anchorage site that would indicate the presence of marine mammals that use ice sheets as haul out habitat. For North Anchorage, sea ice concentrations were investigated at 57.0°N, 169.5°W. This would be a consideration for construction activities during the winter season. To account for the presence of ice sheets at St. George, a 60% ice coverage criteria was used. Two events were noted in March and April in 1970 and 1976, and eight May events were noted from 1859 to 1906. Over the 165 years of record, there were ten occurrences of ice concentration, which roughly corresponds to a 6% occurrence of pack ice at North Anchorage. Impacts of these occurrences are likely to represent delays to project construction of up to two months. See Appendix A for additional information on ice conditions at St. George.

3.1.13 Sediments

Sedimentation has been observed to occur in the existing harbor at Zapadni Bay. USACE maintained the navigation channel into the harbor at Zapadni Bay through 1996. Surveys from the time of construction to that date showed no change in bathymetric conditions in the harbor except for construction activities. No surveys were performed from 1995 when the Tanaq Corporation had the harbor surveyed until 2013 when the City of St. George began to investigate navigation improvements at their harbor. The 2013 survey showed significant shoaling in the channel with the formation of a bar across the outer breakwaters with a minimum elevation of about -14 feet MLLW. A subsequent survey in 2016 showed that this bar had migrated into the harbor at about the same depth. Several large storms occurred over this interval, including one that damaged the south breakwater in December 2015, requiring repairs to be performed in 2016 and 2017.

Marine sediments within the study footprint at the North Anchorage site are believed to be entirely rocky, presumably basaltic olivine bedrock overlain by sands, gravels, shell hash, cobbles, and boulders. Currently, no geotechnical information exists for the North Anchorage study area; however, these data would be scheduled for collection and analysis in PED. Additional information on sediments at St. George can be found in Appendix A.

3.1.14 Climate Change

NOAA began publishing an annual, peer-reviewed Arctic Report Card in 2006. The Report Card is a “source for clear, reliable, and concise environmental information on the current state of different components of the Arctic environmental system relative to historical records” (Osborne, Richter-Menge, & Jeffries, 2018). The 2018 Report Card states that the Arctic sea ice cover is continuing to decline in the summer maximum extent and winter minimum extent (Perovich, et al., 2018). The minimum sea ice extent usually occurs in late September. In 2018, the ice cover was 26% lower in late September than the average coverage between 1981 and 2010 and was tied for the 6th lowest ice cover since 1979 (Perovich, et al., 2018). With a decreased sea ice extent there is an increase in time that the sub-Arctic (i.e. the Bering Sea) is ice-free or has limited sea ice coverage.

According to the Fourth National Climate Assessment (Wuebbles, et al., 2019), a warming trend relative to average air temperatures recorded from 1925 through 1960. A trend of increasing temperatures starting in the 1970s has been identified and is projected to continue throughout the state of Alaska. The largest temperature increases have been found in winter months with average minimum temperature increases of around 2° F statewide. Carbon emission models project variable increases in statewide temperatures across the state; for the Pribilof Islands, forecast temperature increases appear to be in the 4 – 6°F range for an intermediate model (RCP4.5) and in the 8 – 10°F range for a high model (RCP8.5) (Figure 5).

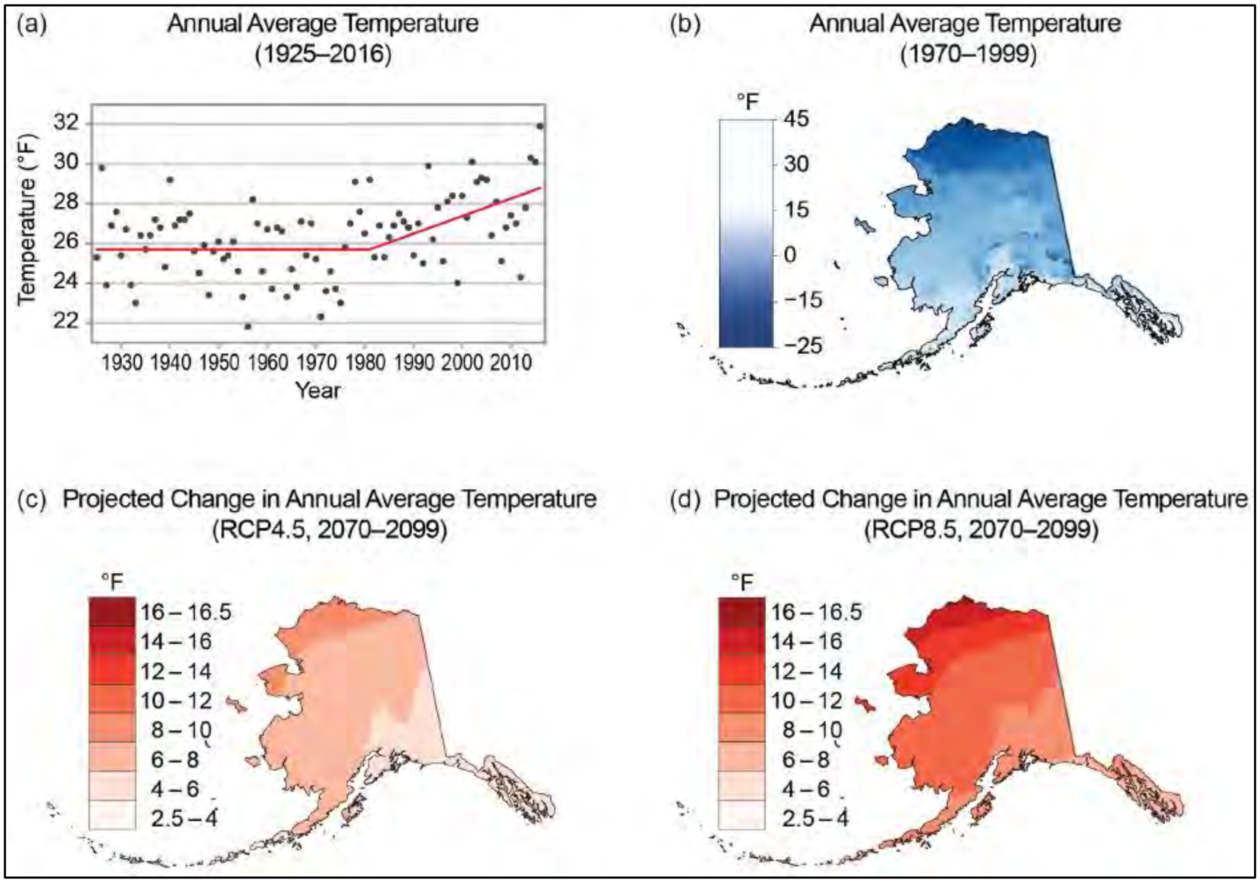

Figure 5. Average Annual Air Temperature- Figure 26.1 from (Wuebbles, et al., 2019).

Note: Annotation truncated from report): (a) Alaska statewide annual temperatures for 1925-2016. The record shows high variability from 1925 to 1976, but from 1976-2016 a clear trend of +0.7°F per decade is evident. (b) 1970-1999 annual average temperature. (c) Projected changes from climate models in annual average temperature for end of 21st century (compared to 1970-1999 average) under a lower scenario. (d) The map is the same as (c) but for a higher scenario. Sources: (a) NOAA and U.S. Geological Survey (USGS), (b-d) (USGS 1976).

An increase in winter temperatures in the region could decrease the period of sea ice formation in the Bering Sea south of the Bering Straits and the site could be impacted by waves and storm surge in later parts of the year than the season of analysis used for this study. Changing sea ice conditions and potential sea level rise at the project site could result in increased wave severity from storms originating from the north and potentially increased overtopping of the breakwaters during high water events. The change in sea ice conditions is not anticipated to affect the armor stone size since the largest storms that control breakwater design predominantly originate from the southwest and west and are not affected by the presence or extent of ice to the north of the islands.

3.1.15 Resilience and Adaptation to Climate Change

Construction constraints at St. George pose a significant barrier to adapt a project to relative increases in sea level over time. The challenges with the site, high mobilization costs, short construction seasons, limited local support for construction, make it preferable to plan for construction of a resilient structure that needs no intervention in future years. The primary cause for concern at the site is for increasing sea levels to increase the likelihood of overtopping causing damage to the breakwater and inner harbor facilities. Harbor design is generally based on a design water level of +5.9 feet MLLW to account for tides and storm surge at St. George. To provide resiliency to overtopping, a design water level of +8.5 feet MLLW was used to determine the crest height of the breakwaters for all alternatives considered in the study. This water level is 2.6 feet above the harbor design water level and accounts for potential SLC under a high curve scenario 50 years from the time of construction.

Resilience to overtopping was analyzed by adjusting SLC curves to the year 2020 and comparing the relative change between the curves over the period of investigation for the project. Curve adjustments were made by taking the curves projected from 1992 and setting the 2020 values to 0. This produces a set of curves with slopes projected from the 1992 tidal epoch but starting form the value of zero in 2020 (Figure 6).

Under the high curve scenario, overtopping would begin to occur approximately 43 years after construction in 2066. Overtopping does not occur under the low or intermediate scenarios within a 100 year adaptation horizon. While this analysis shows a conservative formulation for overtopping, it should be noted that the effects of receding ice packs over winter months and longer open water periods are not known. It is possible that these impacts may increase wave heights on the structure which could lead to an acceleration of the timeline to require intervention to prevent overtopping.

In the event that overtopping of the breakwater causes damages in the harbor, the crest elevation of the primary breakwater can be elevated by adding two rows of armor stone to the crest. At Zapadni Bay, using 30 ton armor stone, this would increase the crest height of the primary breakwater by 7 feet. At the North Site, using 10 ton armor stone, this would increase the height 5 feet.

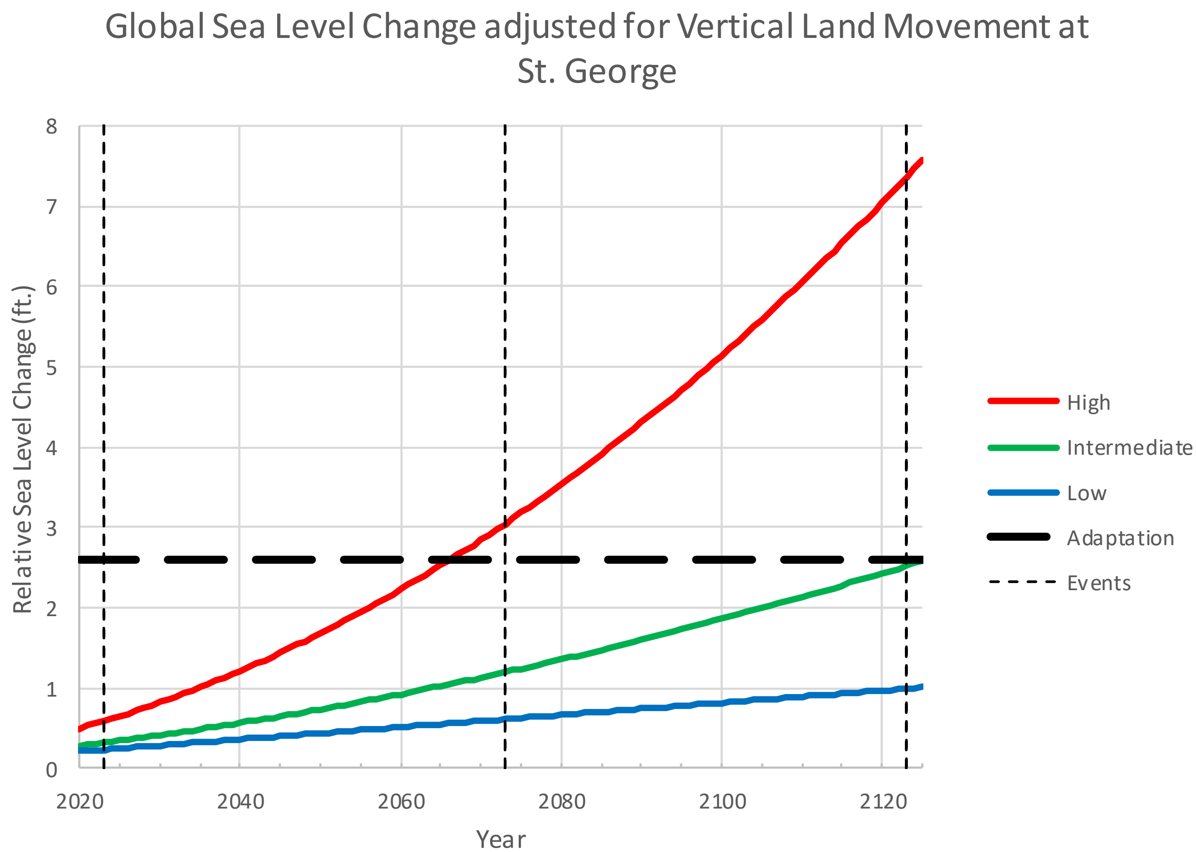

Figure 6. Resilience analysis for overtopping of St. George breakwater alternatives. Vertical lines show estimated start of construction, 50 year project economic period, 100 year adaptation period. The horizontal line shows the threshold at which overtopping is expected to begin to cause damages to harbor facilities requiring intervention.

3.2 Biological Resources

The following sections discuss the diverse biological resources located at St. George.

3.2.1 Fish and Essential Fish Habitat

Essential Fish Habitat (EFH) is defined by the Magnuson-Stevens Fishery Conservation and Management Act as those waters and substrates necessary to fish for spawning, breeding, feeding, or growth to maturity. St. George does not have any anadromous waters or streams that would traditionally be associated with salmonids and their allies, as defined under AS 16.05.871(a). However, the marine waters surrounding St. George, from the shoreline outward, are designated as EFH under the Groundfish of the Bering Sea Aleutian Islands (BSAI) Fishery Management Plan (FMP), the FMP for Bering Sea/Aleutian Islands King and Tanner Crabs, and the FMP for the Salmon Fisheries in the Exclusive Economic Zone (EEZ) off Alaska. A complete list of those fish species occurring within the various habitat types in marine waters near the Pribilof Islands has been derived from the NMFS EFH mapping tool. This information is included in Appendix H.

In June of 2019, USACE and NMFS biologists conducted a comprehensive assessment of the existing environment on St. George. Intertidal and subtidal vegetation observations and photographs were collected spanning from the derelict small boat landing to the small rocky cliff spur that demarks both lobes of the cove. Observations stopped at the spur area because the cliff face showed signs of instability and recent slides. The beach width at that point was also quite narrow and did not allow for observations from below. It was observed that the intertidal zone of the western lobe of Village Cove was not as densely colonized by intertidal and subtidal submerged aquatic vegetation (SAV), as was the eastern lobe despite the two rocky shorelines appearing to be similar.

Dragon kelp (*Alaria fistulosa*) is the predominant epiphyte in Village Cove. It occurs from medium to very high density from the lower intertidal to the shallow subtidal zones. Also common within the mid to low intertidal and shallow subtidal zone were intermittent bunches of sea fern fringe (*Hymenana ruthenica*). Interspersed amongst the mid to low intertidal zone were small clusters of sieve kelp (*Agarum clathratum*). The upper-most intertidal zone was primarily colonized intermittently by rockweed (*Fucus distichus subspecies evanenescens)* and Arctic sea moss (*Acrosiphona arcta*).

SAV, as observed from the shoreline, appeared to be restricted to the highest energy portion of the surf zone. It did not extend more than approximately 50 meters from the shoreline within the cove, and was predominantly comprised of dragon kelp. USACE biologists confirmed this observation with underwater videography taken at approximately the 30-foot depth contour of Village Cove. Large epiphytic species were absent at this depth. These species were replaced in low densities by what appeared to be a small calciferous epiphyte, not exceeding an estimated 15 centimeters in height. Additional EFH information can be found in Appendix H.

3.2.2 Invasive Species

St. George is relatively free from non-native species. Domestic reindeer were introduced as a food source and are now established on St. George. Non-native plants are also known to occur on the island. However, neither the reindeer nor the plants are known to be invasive. The USFWS works with the Tribe and the City to implement biosecurity measures to prevent the establishment of non-native rodents. No non-native marine species are known to occur in the St. George area. Non-native species have the potential to become established, and impact native and endemic island flora and fauna. It is critical to prevent introductions.

3.2.3 Marine Birds

The marine birds of St. George number 189 species, of which 26 are known to breed on the island (Guitart et al. 2018). According to USFWS's annual monitoring reports, ten species of seabirds and seaduck commonly occur in the study area. Of these ten, the red-faced cormorant, thick-billed murre, red-legged kittiwake, and least auklet were identified during the Fish and Wildlife Coordination Act (FWCA) process as important and warranting further evaluation because the proximity of their habitat to the study area. Of these four species, the cormorant, murre, and kittiwake perch and nest on the cliffs surrounding the study area. Each species normally lays its eggs on ledges with minimal to no actual nest built. Additional information on marine birds can be found in Appendix J.

3.2.4 Marine Invertebrates

During surveys conducted in June 2019, the most commonly encountered marine invertebrate was the Oregon hairy triton (*Fusitriton oregonensis*), followed by common Sunstar (*Crossaster papposus*), widehand hermit crab (*Elassochirus tenumanus*), and green urchin (*Strongylocentrotus droebachiensis*), respectively. No commercially relevant species of marine invertebrate were encountered. Marine invertebrates that are commercially relevant or that are extended habitat protections under the BSAI FMP include blue king crab (*Paralithoides platypus*), red king crab (*Paralithoides camtschaticus*), tanner crab (*Chionoecetes bairdi*), and octopus (*Enteroctopus dofleini*).

Benthic invertebrates were notably absent in areas that displayed rapidly moving currents and along the sand wave-type substratum. Invertebrate diversity increased once the substrate began to transition to shell hash and rocky reef. Various hermit crabs, sponges, scallops, brittle stars, common Sunstar, and chitons were observed in this transition zone. Additional information on marine invertebrates can be found in Appendix J.

3.2.5 Marine Mammals, Endangered Species and Critical Habitat

All marine mammals are protected under the MMPA, 1972. Based on NMFS's protected species mapping tool and available literature describing stocks of marine mammals in Alaska, 18 marine mammals have the potential to occur in the Pribilof region of the Bering Sea. These species include: harbor seal (*Phoca vitulina*), northern fur seal (*Callorhinus ursinus*), ribbon seal (*Histriophoca fasciata*), spotted seal (*P. largha*), beluga whale (*Delphinapterus leucas*), Dall's porpoise (*Phocoenoides dalli*), killer whale (*Orcinus orca*), minke whale (*Balaenoptera acutorostrata*), Stejneger's beaked whale (*Mesoplodon stejnegeri*), Steller sea lion (*Eumetopias jubatus*), fin whale (*B. physalus*), humpback whale (*Megaptera novaeangliae*), North Pacific right whale (*Eubalaena japonica*), sperm whale (*Physeter macrocephalus*), gray whale (*Eschrictius robustus*), bearded seal (*Erignathus barbatus nauticus*), ringed seal (*Pusa hispidia hispidia*), and Northern sea otter (*Enhydra lutris kenyoni*). The latter 9 of the above 18 species or Distinct Population Segments (DPS) are extended additional protections under the ESA, 1973. The take (e.g., to harass, harm, kill) of species listed under the MMPA or ESA is prohibited without a permit. Although stocks or individuals of the aforementioned species list are alleged to occur in the Pribilof region of the Bering Sea, some of these species are dismissed from further discussion in the existing environment and from consideration in the effects analysis because their likelihood of being in proximity to the study area is so remote as to be discounted.

Harbor seals inhabit the Pribilof Island region year-round at low densities, likely due to their high latitudes coinciding with the species' northern-most distribution. A 2010 stock abundance estimate of the Pribilof Islands harbor seal stock was 232 animals, which was also the number of individual animals observed during the July 2010 survey. Approximately 185 adults and 27 pups were observed on Otter Island plus an additional 20 other individuals on all the other islands combined (NOAA 2017).

Northern fur seals are regularly observed in great numbers in the nearshore waters of the Pribilof Islands, where it is estimated that greater than 70% of the global population aggregates around the summer breeding season, which occurs between June and August. On St. George, rookeries occur at beach areas where cliff faces do not preclude access to the gently sloping, grass-covered upland areas. One rookery, in particular, the North Rookery, exists approximately 1 kilometer to the west of USACE's proposed project area and produced approximately 6,200 of the Island's total 20,261 pups in 2016 (NOAA 2016).

Adult male fur seals arrive at rookery beaches in May and stay until mid-August to stake their claim to the best breeding areas. The majority of pregnant females begin arriving mid-June, and the peak of pupping season occurs in early July. From their rookery areas, females make frequent foraging trips, lasting 3-10 days, and suckle their pup for one to two days in between. Weaning is abrupt, and pups begin to depart by early November. By December, the entirety of the herd has departed the rookery grounds and surrounding waters (NOAA 2019). Most northern fur seals overwinter in the north Pacific away from St. George.

Killer Whales are regularly observed in the waters of the Pribilof Islands. Little is understood about the population dynamics of these animals inhabiting the Bering Sea; however, a portion of the transient population spends time in the waters surrounding the Pribilof Islands during the fur seal breeding months (2016b).

Minke whales are known to occur throughout the entirety of the Bering Sea and into the Chukchi Sea. NMFS currently estimates their abundance along the eastern Bering Shelf at 389 individuals. However, this estimate is approximately ten years old. Minke whales are typically observed in small groups of two to three, but larger aggregations are common when food resources are abundant. Minke whales in Alaskan waters are migratory, but animals found south of the Gulf of Alaska are considered resident animals. (NOAA 2018c).

Steller sea lions (western DPS) range throughout the entirety of the Bering Sea and have known rookery and haulout sites throughout the Pribilof Islands. Steller sea lions once came ashore at St. George to breed and whelp in the thousands, but were systematically eradicated from breeding grounds. Although no pups have been recorded on St. George since 1916 (NMFS 2008), locations of the historic rookeries are known. Steller sea lions are frequently observed transitioning through and foraging in the nearshore waters of Village Cove and the North fur seal rookery. Overall, populations of Steller sea lions declined precipitously in the decades between the 1950s and 1980 and began to stabilize and slightly increase by the 2000s.

Fin whales are seasonal migrants to the Bering and Chukchi Seas. There is limited data concerning North Pacific fin whale distribution; however, it is known that they are migratory, spending winter months in the warmer waters of the lower latitudes (NOAA 2018a). According to NMFS, there are no reliable estimates of the current and historical abundances for the entire Northeast Pacific fin whale stock. However, according to NMFS's stock report, relative densities of observed fin whales are greatest across the Bering Sea shelf break (200-meter isobaths) (NOAA 2018a).

Humpback whales in the Aleutian Islands, Bering, Chukchi, and Beaufort Seas are part of three recognized North Pacific DPSes: the Western North Pacific DPS, the Hawaii DPS, and the Mexico DPS. Humpback whales from the Western North Pacific DPS, listed as Federally endangered, are the least likely to be encountered in Alaskan waters with a probability of 4.4 percent. Humpback whales from the Mexico DPS, listed as federally threatened, have a similarly low encounter probability at 11.3 percent. Humpback whales from the Hawaii DPS are not listed under the ESA. They are the most likely to be encountered in Alaskan waters at 86.5 percent (NOAA 2016). It should be noted that among these DPSes, individual whales do not exhibit physical traits that would allow for visual confirmation of population lineage. Humpback whales are known to traverse the Bering shelf and likely come within visual observation range of the landmass of St. George. Humpback whales are gregarious and often travel together or congregate at areas where food density is relatively high.

Ringed Seals are the smallest and most common Arctic seal; they exhibit a circumpolar distribution and are divided into five subspecies. The Alaska stock is the only recognized stock of Arctic ringed seals in U.S. waters and contains over 300,000 individuals. They are pagophilic and spend the majority of their time with the ice, relying upon it for pupping, nursing, resting, and molting. During the sea ice maximum, ringed seals are commonly observed in the northern Bering Sea, Norton and Kotzebue Sounds, and the Chukchi and Beaufort Seas. They are not typically abundant south of Norton Sound, even in years of extensive ice coverage (NOAA 2016a).

Bearded Seals exhibit circumpolar distribution, and likely number over 500,000 worldwide. Bearded seals rely on the availability of suitable sea ice over relatively shallow waters for use as a haul-out platform for giving birth, nursing pups, molting, and resting. Bearded seals rarely haul-out on land. Similarly, bearded seals typically migrate in concert with the pack ice at the sea ice's edge along with those animals overwintering in the Bering Sea. They can be found migrating through the Bering Strait and over-summering in the waters of the Chukchi Sea until the sea ice reforms. Bearded Seals would then migrate south back into the Bering Sea. The Okhotsk and Beringia DPSes of the Pacific sector are listed as threatened under the ESA (NOAA 2018).

Northern sea otters in the St. George area are listed as a threatened DPS. Otters are not abundant, but are regularly cited in the area (Guitart et al. 2018; Michelle St. Martin, USFWS, Nov 2019 pers. comm.). They can use all coastal marine habitats within their range, but are most commonly observed within a few kilometers of shore. Their seaward distributional limit is defined by their diving ability and is approximated by the 100 meter depth contour. Sea otters may haulout on intertidal or supratidal shores. Additional endangered species information can be found in Appendix J.

3.3 Socio-Economic Resources

St. George is centrally located among commercial, subsistence, and shellfish fisheries, which could result in a successful marine resource-based economy. The following sections describe the socio-economic resources at St. George.

3.3.1 Population and Demographics

In 1880, the U.S. Census reported a human population of 92 on St. George. It reached a high of 264 in 1960. Since then, decadal assessments illustrate a consistent decline in population to the most recent estimate of 70 in 2018. There was an isolated instance of population increase from 138 in 1990 to 152 in 2000, which corresponds to when SnoPac Seafoods had a floating crab processor moored inside the existing harbor at Zapadni Bay.

The closure of the public school in 2017 further indicates the continued out-migration from St. George. St. George School held classes from pre-kindergarten to 12th grade on St. George. Only six students were enrolled in 2016/2017, declining from 10 students in the previous school year. As a result of the school closure, students must attend school on neighboring St. Paul, attend Mt. Edgecumbe High School in Sitka, or utilize the Pribilof School District Correspondence Program. More detailed population information is contained in Appendix C.

3.3.2 Employment and Income

The City of St. George is an employer for residents; however, the local tax base is not sufficient to sustain employee pay or the City's expenses. The St. George Tanaq Corporation (an Alaska Native Claims Settlement Act (ANCSA) village corporation), and St. George Tribal Council (Tribe) are other employers in the community. There were 14 halibut permit holders in 2016, but only six permit holders fished. That accounted for a little more than 50,000 lbs. of halibut caught. An estimated 11 residents live below the poverty line. This number has held steady while the overall population has declined. Thus, the percentage of residents below the poverty line has increased from 7.9 percent in 2000 to 17.2 percent in 2010. The Alaska Department of Commerce, Community, and Economic Development estimated that 24.2 percent were below the line in 2014. More detailed employment and income information is contained in Appendix C.

3.3.3 Existing Infrastructure and Facilities

The City constructed the existing harbor at Zapadni Bay (Figure 7). It is a 3-acre boat basin enclosed by two rubble mound breakwaters. A third inner breakwater protects the inner harbor. The entrance channel is 280 feet wide at the waterline. In its existing condition, the depth of the entrance channel varies from -26 to -18 feet MLLW with shallow areas consisting of rock pinnacles.

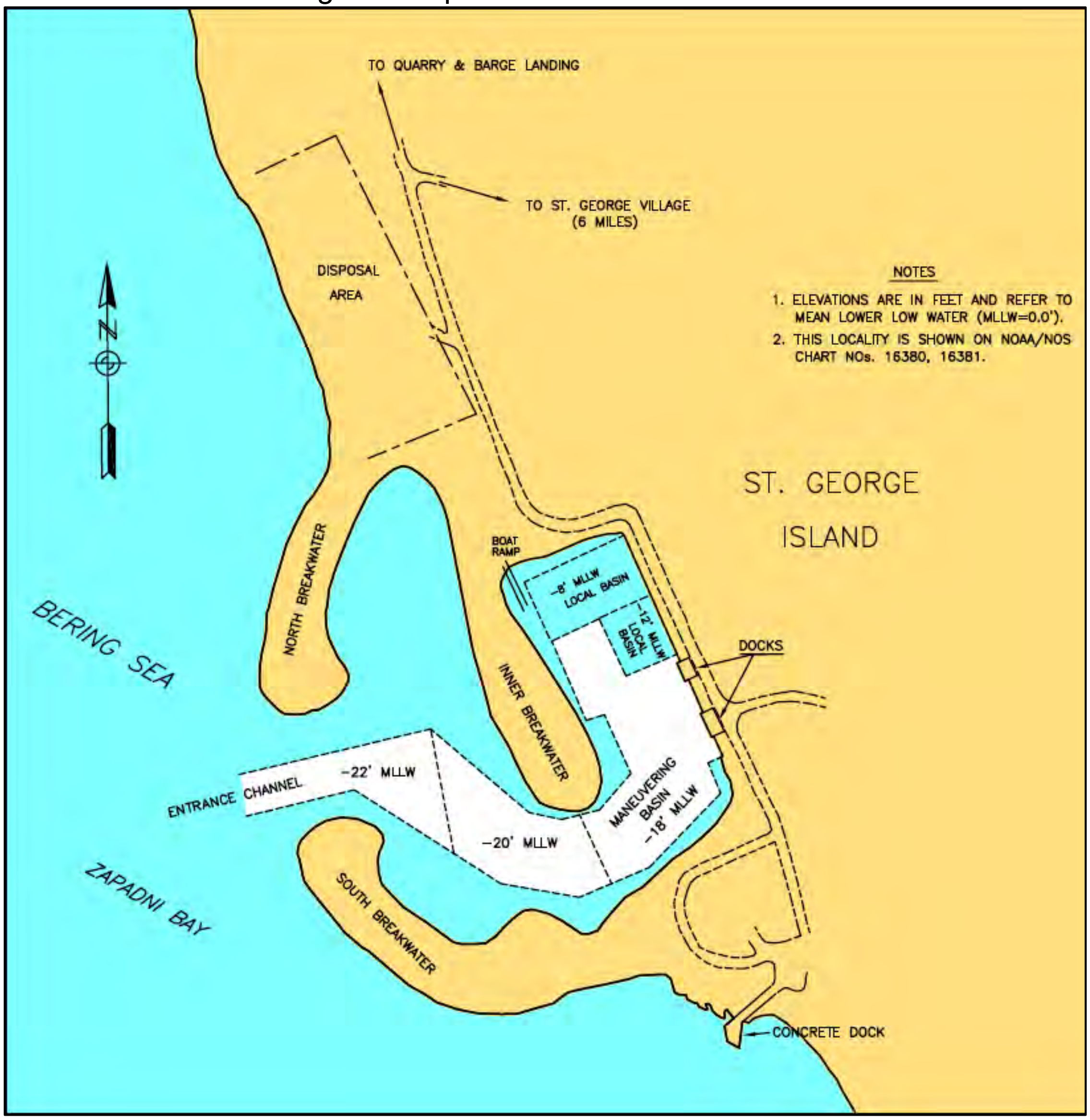

Figure 7. St. George Harbor Federally-maintained Portion in White (suspended). The locally-maintained portion is in blue.

3.3.4 Freight & Fuel Delivery

Freight delivery to St. George is currently carried out by air freight. Infrequent freight barges offload supplies, equipment, and material at St. George for construction activities. The vessels chosen to represent this operation were taken from Alaska Marine Lines' fleet data. They operate a 270 foot barge, Western Service, which is 270-feet long, 70 feet wide with a draft of 19 feet. The largest tug operated by the same group has dimensions of 94 feet long, 27 feet wide, and 14 feet draft. Another tug in their fleet had a beam of 30 feet, which creates a maximum vessel beam of 100 feet.

Recent construction activities to repair the Zapadni Bay South Breakwater was supported by an articulated tug and barge operated by Brice Marine with a length of 245 feet and a loaded draft of 9.1 feet. This vessel navigated to the inner harbor to offload rocks for the repairs.

Fuel deliveries to St. George are currently supplied by Delta Western, which uses vessels operated by Cook Inlet Tug and Barge. The barge used for this mission is 180 feet long and 54 feet wide. It is assumed that other shippers would use similar vessels should the service provider for the community change. The loaded draft of this vessel is approximately 10 feet. Crowley Marine uses a 180-foot barge with a width of 52 feet and a loaded draft of 12.25 feet in the region. Tugs for the Crowley fleet can be up to 32 feet in width, which would create a maximum vessel beam of 84 feet for a tug on hip. For all harbor alternatives considered in this study, tug and barge deliveries require the tug to make up alongside the barge outside the harbor. This maneuver requires relatively calm seas ranging from a few feet according to the barge operators to "dead calm," according to the harbormaster at St. Paul. For this study, a wave criteria of 0.5 meter was used to determine whether a tug and barge could make up on hip outside the harbor before navigating to the dock and mooring. For these vessels, the wave climate outside the harbor controls whether or not a delivery can be made.

3.3.5 Subsistence Activities

A subsistence lifestyle continues to be crucial to the residents of St. George for maintaining food security and an essential part of culture and traditions. Important food sources harvested include fur seal, stellar sea lion, bird eggs, berries, halibut, and other fish species; other important food resources include seagrass for vitamin C and mollusks for iron and other minerals. Recent subsistence reports from 2009-2011 indicate that approximately one seal is harvest per resident per year and that the harvesting of stellar sea lions is only a few per year in total. A reindeer population has been managed by the Tribe since the 1980s and is an important meat source. Halibut is desired for both subsistence and commercial purposes. By-products from the subsistence such as furs, pelts, skins, and bones are used in the manufacturing of artwork and other crafted objects. These subsistence resources are considered fundamental to the community and heritage.

3.3.6 Cultural Resources

St. George is part of the Pribilof Islands group located in the Bering Sea, approximately 250 miles north of the Islands of Four Mountains in the Aleutian archipelago and 300 miles west of the mainland of Alaska. Russian fur-hunting crews had actively sought these islands since at least 1768, as they knew that the northern fur seals (*Callorhinus ursinus*) they had observed and hunted in the passes of the eastern Aleutians must have breeding grounds somewhere to the north. On June 25, 1786, St. George was discovered by the crew of *Sv. Georgii Pobedonosets* (*St. George the Victorious*), commanded by Gavriil Loginovich Pribylov of the Lebedev-Lastochkin Company. Upon finding no safe harbor, Pribylov left a party of 40 men to winter there and returned to Unalaska Island for supplies. While the crew was on St. George, they spotted another island to the northwest. Once Pribylov returned the following summer, they sailed to this new island and named it St. Peter and St. Paul Island, for the Saints' day on which they landed. This island's name has since been shortened to St. Paul (Eldridge 2016).

Although the Pribilof Islands were uninhabited when the *St. George the Victorious* arrived, Unangax̂ oral history holds that they had known of these island for some time before their documentation by the Russians (Black 2004; Elliott 1882; Jochelson 2003; Osgood et al. 1915; Torrey 1980; Veniaminov 1984). In 1787, rival Russian fur-hunting companies quickly established seasonal sealing camps around the coasts of both St. George and St. Paul to harvest the valuable northern fur seal pelts. Unangax̂ from Unalaska, Umnak, and Atka Islands were brought to the islands to provide labor for the Russians (Eldridge 2016). They constructed traditional semi-subterranean barabaras on the southern shore and a permanent village on the north of St. George (Etnier 2004). After the Treaty of Cession in 1867, a transitional period followed during which the Alaska Commercial Company destroyed most of the Russian structures built on the island and replaced them with new wood-frame buildings (Faulkner *et al*. 1987).

After the Alaska Commercial Company razed the Russian buildings, they built several new buildings on the north side of the island. Buildings included the Great Martyr Orthodox Church, completed in 1936 (Historical American Building Survey (HABS) No. AK-50), as well as the old administrative core building with staff housing overlooking the old Russian-era dock. Six rows of houses spread out southeast of the church, including a community center. Down near the old dock is the commercial district comprised of fourteen buildings. Some of the commercial buildings were destroyed in a fire along the waterfront in 1950 (Faulkner 1986; Faulkner *et al*. 1987).

The Fur Seal Rookeries National Historic Landmark (NHL; XPI-002) is made up of three non-contiguous units located on both St. Paul and St. George: St. George Village, St. Paul Village, and Northeast Point on St. Paul. These units were found to be eligible for the National Register of Historic Places (NRHP) in 1962 and nominated for formal listing on the NRHP in 1986 (Faulkner 1986). On St. George, the NHL encompasses the village of St. George. Across both islands, the NHL includes 106 buildings, two structures, 12 rookeries, and nine archaeological sites [Alaska Heritage Resources Survey (AHRS 2018)]. Both Russian and American buildings and structures within the NHL continued to be associated with northern fur seal processing into the late 19th and early 20th centuries (Torrey 1980). Many of these buildings and structures are formally considered to be contributing features of the NHL; however, other buildings and structures within the NHL boundaries have not yet been formally evaluated (AHRS 2018; Figure 8). All contributing features to the NHL have specific historical significance for the period 1786–1959, with unique themes related to industry, conservation, and ethnic heritage (Faulkner 1986; Faulkner *et al.* 1987).

Figure 8. Overview of the NHL (pink polygon below) at St. George Village and Approximate Locations of Sites within the NHL (pink dots above) (AHRS 2018).

A search of the NOAA'S Wrecks and Obstructions Database shows no known shipwrecks in the vicinity of St. George (NOAA 2018). The Bureau of Ocean Energy Management's (BOEM) Shipwreck Database lists a single shipwreck, a steamer known as the *Laurada*, which sunk off Zapadni Point in 1899 (BOEM 2011). However, the BOEM database appears to be incorrect; Zapadni Point is on St. Paul, not St. George.

Likely, the *Laurada* is not located off of St. George. Any unknown shipwrecks that would be in the old harbor would be visible from shore; the bay is shallow, with the seabed comprising of bedrock with no sand to bury any materials.

A single known archaeological site is located on the southern shore of St. George in the vicinity of the current harbor at Zapadni Bay (Figure 9). The Zapadni Bay site (XPI-012) consists of at least three barabara house depressions and two large rectangular depressions. Since the site's identification, the area has been heavily disturbed; the site was reportedly destroyed during harbor construction in 1985 (AHRS 2018).

Figure 9. Approximate Location of XPI-012 (pink dot) Near the Current Harbor (AHRS 2018).

4.0 FUTURE WITHOUT-PROJECT CONDITIONS

4.1 Physical Environment

Under the future without-project condition, St. George would continue to be ecologically significant and contain abundant fisheries, abundance of colonial seabirds, and Steller sea lion and northern fur seal rookeries. Portions of its surface landmass would continue to be owned and managed by the USFWS for conservation, protection, and the overall enhancement of fish, wildlife, plants, and their habitats for the continuing benefit of the American people. St. George is difficult to access by airplane or boat due to the wave, wind, and fog climate of the central Bering Sea. The extreme wave climate at the existing harbor in Zapadni Bay would continue to cause delays and damages to vessels resulting in continued impacts on the island's economy. The City unconditionally believes that improved harbor conditions are essential to efforts to reopen the school and to ensure the economic and cultural survival of the community of St. George. The school was closed after the 2016/2017 school year when enrollment fell below minimum thresholds for State funding (Section 4.6). Sections 4.2 to 4.11 describe these conditions and how they would continue to limit the community's ability to develop a stable and sustainable local marine resource based economy sufficient to support their mixed, subsistence-cash economy.

4.2 Biological Environment

The central Bering Sea is a dynamic ecological region. While there is no way of knowing with certainty what the future condition of the ecological baseline at the North Anchorage location without the implementation of the project would be, the reasonable continuation of its existing processes helps guide these assumptions. Given the history of development on St. George, its population dynamics, the condition of its current harbor, and the logistical difficulty of completing large-scale construction projects in the Bering Sea, there would likely be no other major development projects proposed at the North Anchorage site in the foreseeable future. In the absence of this type of anthropogenic influence, the North Anchorage site is expected to maintain its current ecological function.

- Retrograding cliff faces would continue to provide nesting and rearing habitat for colonial sea birds.

- The north rookery would continue to maintain its function as a suitable rookery site for northern fur seals.

- Nearshore marine waters would continue to maintain their ecological function and support seasonal abundances of phyto- and zooplankton, fishes, birds, and marine mammals.

4.3 National Marine Sanctuary Designation

At the request of the City of St. George, NOAA is considering the marine areas around St. George for designation as a national marine sanctuary. The Secretary of Commerce (delegated to NOAA) is required under the National Marine Sanctuaries Act (NMSA) to consider various factors when deciding on whether or not to designate a new national marine sanctuary. NOAA may designate any discrete area of the marine environment as a national marine sanctuary and promulgate regulations implementing the designation if NOAA determines that the area meets national standards, including a determination that existing State and Federal authorities are inadequate or should be supplemented to ensure coordinated and comprehensive conservation and management. Furthermore, for purposes of determining if an area of the marine environment meets this standard, NOAA shall consider specific factors, including the present and potential uses of the area that depend on the maintenance of the area's resources; the present and potential activities that may adversely affect the present and potential uses; and the existing State and Federal regulatory and management authorities applicable to the area.

Collectively, the USACE would translate these mandated national marine sanctuary standards and factors into the current harbor designs in this Feasibility Report. These considerations include assessing the potential location, footprint below MHW and activities planned for a harbor improvement project, and comparing them to the compatibility of any proposed regulations put forth in a sanctuary designation proposal. NOAA has a history of successfully co-locating national marine sanctuaries adjacent to harbors, drawing sanctuary boundaries adjacent to harbors, supplementing current management, and crafting regulations that accommodate existing harbor activities. A recent example that highlights how NOAA considers the current and potential footprint of a harbor when drawing sanctuary boundaries occurred during the expansion of Greater Farallones National Marine Sanctuary (NMS). NOAA worked with harbor and county officials to place the boundary at Arena Cove, a small local fishing harbor in northern California, so as to ensure harbor facilities and operations would occur outside of the sanctuary. The boundary ultimately selected in 2016 excludes all of the current harbor pier and moorings from the sanctuary, as well as a buffer zone, allowing for future expansion of harbor facilities and operations.

An example highlighting how national marine sanctuaries consider the present uses of a harbor occurred during the 2002 management plan review process for Monterey Bay NMS. NOAA staff collaborated with harbors and partnered with federal agencies to ensure that historic dredge disposal sites adjacent to the Monterey and Santa Cruz harbors were effectively and clearly codified as 'approved sites.' Since that decision, sanctuary staff coordinates on an annual basis with local, state, and federal regulatory agencies to ensure dredge disposal materials are clean, while streamlining permitting and approvals of dredged disposal within the sanctuary. Roughly, more than 7,000,000 cubic yards of harbor dredged material has been discharged into that sanctuary since its designation in 1992. A negligible amount (less than 2 percent) of the proposed material was denied for discharge due to contamination levels, unsuitable grain size, or other environmental issues like turbidity or potential smothering of sensitive resources.

Numerous interactions between harbors and national marine sanctuaries occur annually, including NOAA staff participating in public education events such as harbor celebrations, whale festivals, and fishermen-sponsored outreach events. NOAA staff regularly assist with developing signage in and along harbors to educate the public about important resource conservation needs, or wildlife viewing opportunities. Sanctuary program staff also have worked closely to assist harbor officials in obtaining grant funding, for instance, to assist with the installation of oily bilge water pump-out facilities.

A national marine sanctuary designation process typically leads to the accommodation of existing harbor operations and facilities. If St. George harbor were expanded or relocated, the typical process would be to use regulatory tools to accommodate the expanded harbor (or the existing harbor). If a sanctuary designation were to precede St. George harbor expansion or relocation, ACOE would expect to work with NOAA during the designation process to ensure that the sanctuary regulations and management regime would properly accommodate a future harbor expansion or relocation. ACOE would also work with NOAA to ensure likely planned harbor activities would not adversely affect the sanctuary.

While it is unknown to USACE whether a national marine sanctuary would be designated around St. George, based upon the information provided here, there is minimal risk that such a designation would adversely impact construction or operations of any navigation improvements recommended as a result of this study.

4.4 Marine Resource Assessment

In the Pribilof Islands, there is a subsistence fishery, a commercial crab and fish industry, and potential for a small sport/tourism fishery. Fisheries are managed with subsistence needs prioritized, followed by commercial participation and sport fishing. Over the 50-year period of analysis considered for this study, the total biological stock available is expected to vary from year-to-year but is considered to be stable overall. The full marine resource assessment can be found in Appendix C.

4.5 Socio-Economic Resources

The future without-project conditions mirror those under the existing conditions. Dangerous wave and seiche conditions at the existing harbor at Zapadni Bay would continue without harbor improvements. Harbor inaccessibility and days when the safe moorage threshold is exceeded would remain the same as the existing condition for all vessel classes. Freight and fuel delivery costs are expected to continue to be expensive due to the limitations upon barge operations imposed by the dangerous conditions. Cargo intended for St. George would continue to be delivered to St. Paul and require additional arrangements and expenses to be transported to St. George. Cargo is often flown into the community at a higher cost than ocean-going vessels could deliver. Damages to vessels entering the existing harbor would continue at current rates. A conservative estimate of $383,000 annually in the Individual Fishing Quota (IFQ) and the (Community Development Quota) (CDQ) crab would continue to be transferred to St. Paul for processing.

All these conditions would continue to limit the community's ability to develop a stable and sustainable local marine resource economy sufficient to support their mixed, subsistence-cash economy.

4.5.1 Population and Demographics

Given the lack of a sustainable marine resource economy, under future without-project conditions the population decline of St. George is expected to continue at a rate similar to what has been witnessed historically.

St. George school is currently closed. While the community is in a position to reopen the school if enrollment surpasses the minimum threshold of 10 students, this is not expected to happen under future-without project conditions. The community has implemented a distance learning program for children remaining on the island.

4.5.2 Employment and Income

Due to the factors described in Section 4.5, under without-project conditions the cost of essential goods remains high, which is coupled with dwindling economic opportunities and impacts to the accessibility of subsistence resources.

Crabbing vessels no longer call on St. George due to the dangerous conditions within the existing harbor. Instead, all of the St. George CDQ catch of crab is delivered to and processed at St. Paul resulting in a loss of revenue to St. George.

All of these conditions would continue to limit the community's ability to develop a stable and sustainable local marine resource-based economy sufficient to support their mixed, subsistence-cash economy. Given these conditions, employment and income are expected to continue at their existing level under future without-project conditions.

4.5.3 Existing Infrastructure and Facilities

Wave overtopping and damage to the main breakwater would continue to limit the usability of the existing harbor at Zapadni Bay under future without-project conditions. Damage to the breakwaters, similar to what occurred in 2004 and December 2015, could be expected to occur throughout the remaining lifetime of the existing harbor periodically.

4.5.4 Freight & Fuel Delivery

Fuel barges deliver to St. George at a higher cost due to anticipated delays and increased operating costs associated with delivering to the community. Cargo vessels, which include those vessels delivering construction materials to the islands, often wait on the north side of the island until conditions in Zapadni Bay are safe to deliver cargo. On one occasion in June 2017, a Bryce barge delivering rock to repair the South Breakwater of the St. George Harbor was forced to sit off the north shore of the island for two weeks.

The fuel service barge would continue to experience delays at the same frequency as the existing condition. The fuel barge and tug currently call on St. George two to six times a year. There are 100 days in the winter (October to March) when sea conditions are too rough to enter the current harbor, and there are 90 days in the summer (April to September) when the harbor is inaccessible. Additionally, there are 36 days annually when the 1.5-foot threshold inside the harbor is exceeded. If a barge was moored at the dock during these conditions, extreme pressure on the docks, cables, and bollards pulling and beating against one another could cause lines to break and damages to the vessel and harbor infrastructure.

4.5.5 Subsistence Activities

The St. George subsistence fleet consisting mainly of small craft drafting approximately four feet is limited in the ability to launch from the existing boat ramp in the existing harbor. They are limited due to the location of the harbor on the opposite side of the island and additionally by the dangerous conditions often occurring within the harbor. Often the subsistence fleet opts to launch from an unimproved concrete boat launch by the village increasing risks of vessel damage.

4.5.6 Cultural Resources

The Fur Seal Rookeries National Historic Landmark will still be present if a project is not implemented. However, without the increase in population and increase in economy, it is likely structures and buildings that are part of the St. George portion of the NHL would see continued weathering from intense Bering Sea storms with limited resources. This would lead to a long-term abandonment and possible collapse of these historic structures. The docks and buildings closest to the shore may also be subject to further wave and storm damages from elevated sea levels and increasing strength of storms.

4.6 Existing Navigation Conditions

Under current conditions, adverse wave and seiche conditions limit vessel access to the existing harbor as well as safe moorage within the harbor. The current harbor configuration is portrayed through fully nonlinear Boussinesq wave model (FUNWAVE) numerical modeling, demonstrating conditions at the entrance, within the harbor channel, and within the inner basin (Figure 10). Offshore wave climate conditions from the ongoing Wave Information Study of Alaska, published by the Engineering Research and Development Center's Coastal Hydraulics Laboratory indicate that offshore waves producing unmoorable conditions at the fuel dock in the harbor occur or are exceeded 9.2 percent of the time over the crabbing season or 17 days out of 182 days. Waves producing unsafe entrance channel condition are slightly more common at 13 percent annually, or 49 days. Access for barges is most restricted, with unsafe conditions occurring 52 percent annually, or 190 days.

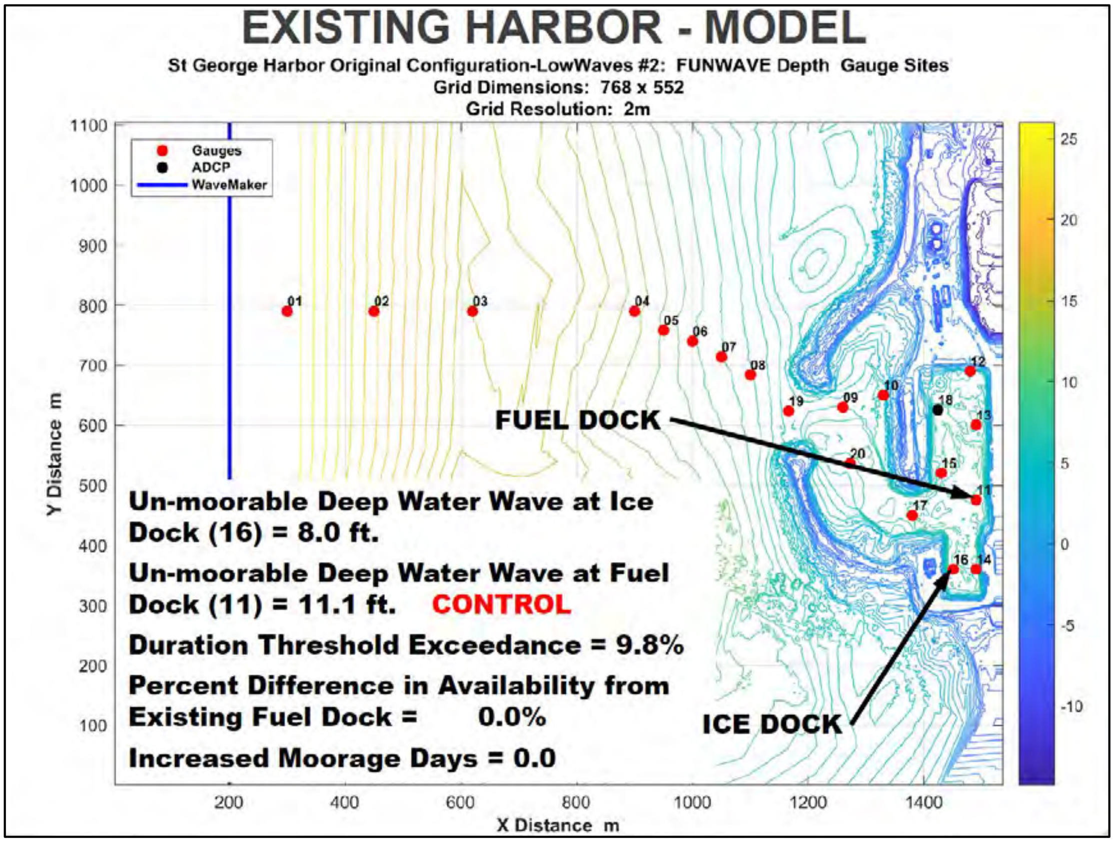

Figure 10. Existing Harbor Schematic and Modeling Results.

Under certain conditions, vessels within the harbor may not be able to safely moor or offload cargo due to the seiche effect inside the harbor basin. Vessels maneuvering through the harbor are further challenged due to shallow pinnacles. Further constraints include weather, such as times of high wind or heavy seas where southwesterly storms close both St. George Harbor and St. Paul Harbor to the north. Vessels are forced to seek refuge anchored off the north side of St. George. A picture taken on February 13, 2018, during a storm, shows wave conditions at the existing Zapadni Bay harbor (Figure 11). This resulted in vessels seeking refuge off the north side of the island (Figure 12).

Figure 11. St. George Harbor South Breakwater, February 13, 2018, Southwesterly Storm.

Figure 12.Three Crab Vessels Anchored at St. George North Anchorage, February 13, 2018.

4.7 Commercial Fleet

In the Bering Sea, the annual harvest quota for groundfish (consisting of pollock, Pacific cod, flatfish Atka mackerel, Pacific Ocean Perch, and other species) is two million metric tons. St. George is located right in the middle of these fisheries. In addition to groundfish, there are also shellfish or crab fisheries that harvest tens of millions of pounds of king, snow, and bairdi crab every year.

Most fisheries in the Bering Sea are rationalized, which means one of several management systems is in place to manage over-capitalization and eliminate the race to fish. These generally consist of an IFQ issued to an individual or a corporation usually coupled with an Individual Processing Quota (IPQ) issued to a processing company, or harvest and/or catch rights issued to a cooperative. Transfers of both IFQ and IPQ are allowed, meaning they can be sold from one harvester or processor to another or leased. Either system results in the same outcome: the harvester, whether an individual or a corporation, and the processor each have a defined amount of the species' quota they can harvest and/or process each year. When the programs were designed and implemented, each participant in a fishery about to be rationalized was given credit for their historical catching or processing history, which is then converted into a percentage of all future quota available for harvesting and processing. These are generically referred to as catch share systems. The three catch share systems most germane to St. George are the crab IFQ/IPQ program, the Pacific cod Freezer Longline Cooperative, and the halibut IFQ program.

In the crab IFQ/IPQ program, 100 percent of the quota available for harvest is issued to crab harvesters to catch, and 90 percent of the quota is issued to crab processors to purchase from the crab harvesters and process and market. The 10 percent difference allows the crab harvesters to sell that crab to any processing company they wish, thus encouraging competition. The prices paid to crab harvesters are determined ultimately by a formula agreed to by both the harvesters and the processors, with disputes settled by binding arbitration.

The crab fleet consists of large vessels, generally longer than 100 feet. The crab fisheries in the Bering Sea begin in October with red king crab, followed immediately by St. Matthew's blue king crab (when there is a season), and then by snow crab and bairdi generally beginning in January. The length of each season is primarily dependent upon the size of the quota, although weather and ice have resulted in lengthy delays in the past.

The Freezer Longline Cooperative is a different catch share system that the IFQ/IPQ program. Freezer longline vessels are large vessels (generally 100 to 160 feet long) that fish with longlines baited with hooks on the bottom. Some vessels are capable of fishing 60,000 or more hooks per day. The vessels are also equipped with factories on board, so they are also referred to as "catcher-processing vessels." They produce the finest quality of cod in the world. The amount of Pacific cod allocated to the Freezer Longline Coalition in 2018 was 89,000 metric tons.

About 28 vessels belong to the Freezer Longline Coalition, which manages the cooperative. Each company is allocated a percentage of the annual quota and a percentage of the prohibited species (halibut – which must be immediately returned to sea when taken as bycatch) allocated to the cooperative. The percentage is based upon each company's historical harvest during a defined number of years prior to the cooperative's creation. As with crab, cooperative percentages may be traded among companies.

The last of the catch share programs of importance to St. George is the halibut IFQ program. This program was the first IFQ program implemented in Alaska, going into effect in 1995. This IFQ plan is for harvesters who received an initial IFQ based upon their historical landings or subsequently bought into the program. There is no associated IPQ allocation; IFQ holders can deliver where they wish.

There are approximately 12,000 pounds of IFQ owned by residents of St. George. There is significantly more owned by residents of St. Paul, possibly over 200,000 pounds. The APICDA also owns halibut IFQ in the area around the Pribilof Islands – around 30,000 pounds. For many years, the halibut harvested by St. George fishermen were transported to St. Paul for processing at the Trident Seafoods processing plant.

Commercial fishing would be accomplished using ocean-going vessels of the same type found at St. Paul or Dutch Harbor. Vessel dimensions were obtained for 78 vessels operating with permits in the Bering Sea. This sample was assumed to be representative of the fishing fleet, and representative dimensions were taken from this data. Vessels sampled have length dimensions from 80 feet to 170 feet, beam from 24 feet to 41 feet, and draft from 8 feet to 17 feet. Since the vessel draft for this fleet is a controlling dimension for channel design, the distribution of vessel drafts was created to see what percentage of the vessels in the fleet exceed various draft thresholds
Figure 13).

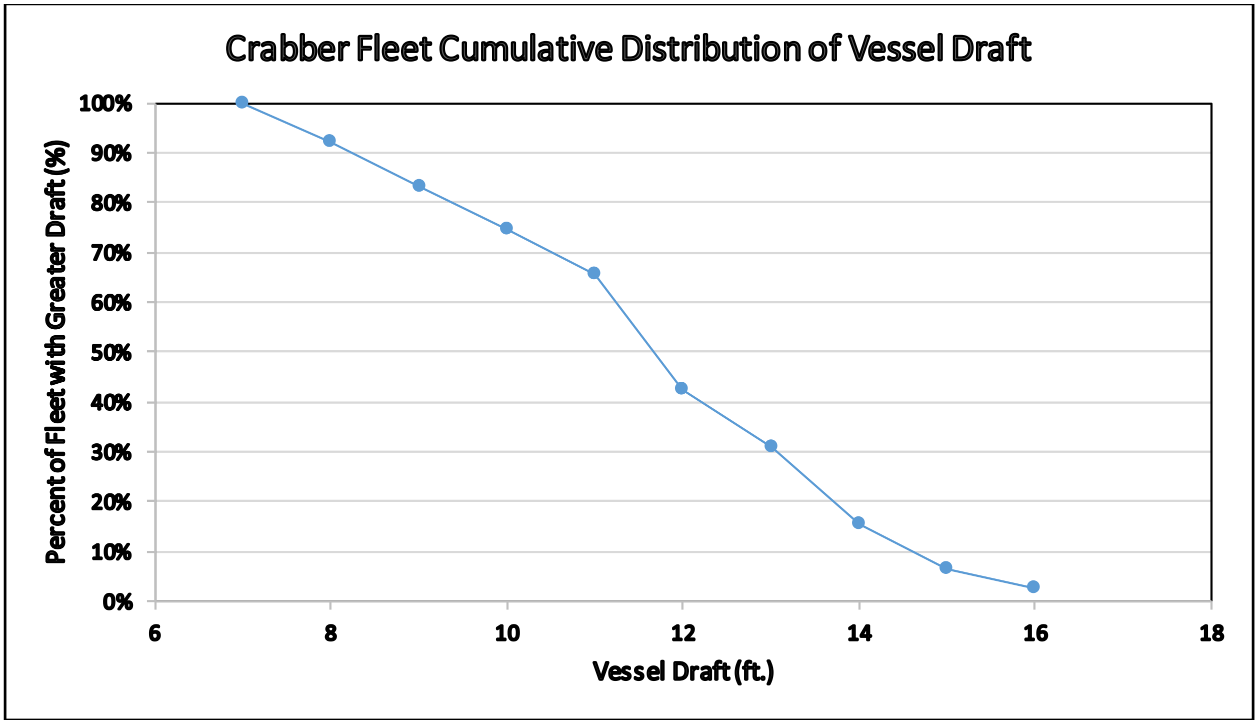

Figure 13. Distribution of vessel draft of crabber vessels operating in the Bering Sea.

Based on the draft distribution, a design vessel draft of 14 feet was selected for the fleet accessing St. George. This draft includes 85 percent of the vessels sampled. The deeper draft vessels generally have the longest length and beam dimensions and are less likely to call at St. George as they would not be able to offload their entire hold of product at facilities likely to be operated at St. George. A design vessel draft of 10 feet, which would be the minimum to accommodate the fuel barge, would include 25 percent of the vessels sampled.

For the purpose of this study, it was assumed that waves at the harbor entrance must be 10 feet or less in height for a crabber to enter the harbor. When analyzing the model output, the threshold value for crabbers to enter and exit the harbor is 3 meters. This is based on prescriptive guidance from St. Paul Harbor operations that the harbor is generally closed when waves at the main breakwater reach 10 feet. Some variation in acceptable harbor accessibility conditions are expected depending upon vessel characteristics and crew experience.

4.8 Subsistence Fleet

Residents of St. George operate boats to harvest marine resources for subsistence. The local fleet is generally comprised of welded trailer-able aluminum boats of beams of 8.5 feet or less. Trailer able boats usually have lengths up to 28 feet and drafts up to 4 feet. Wave criteria for these vessels were set at a 4 foot (1.2 meter) wave height. This criterion is based on discussions with vessel operators.

Fishing activities can be year-round under subsistence rights. For St. George, halibut, cod, sablefish, salmon, snails, and urchins are essential to community livelihood. These species, together with fur seal, provide about 40% of the dietary needs for the community. Other subsistence foods are also traded with other Aleutian communities. Local knowledge adds value to the subsistence harvest in many ways, such as understanding species diversification. The harvest, stock, and community demand of all of these species vary from year-to-year and from family-to-family. The supply of subsistence seafood resources generally exceeds demand; however, accessing marine resources is still costly, both in monetary terms and in terms of required effort. Since periods of safe access and moorage conditions in St. George Harbor is limited, there is additional demand for fishing activity that is not being met. Subsistence vessels need a wave 4 feet or less in the entrance channel and 1.5 feet at the boat launch to haul out.

4.9 Sport Fishing

St. George does not have any known charter or lodge businesses; however, the opportunity to sell Bering Sea experiences to tourists is possible and would be better served with a fully functioning harbor. While there is an abundant opportunity for sport fishing and crabbing, the expense of travel and the difficulty of access limits participation.

4.10 Community Development Quota Program

The CDQ program was designed to provide a means for economically distressed communities in the Bering Sea/Aleutian Islands to generate capital that would, in turn, allow them to invest in Alaska's seafood industry to generate jobs and financial resources to build local economies. There are 67 communities (some 27,000 residents) that participate in the program; those communities formed six CDQ groups, more or less along geographical lines. St. Paul is the only single-community CDQ group.

The APICDA receives a CDQ allocation of roughly 31,000 metric tons of groundfish and 315,000 pounds of crab to help support the communities of Akutan, Atka, False Pass, Nelson Lagoon, Nikolski, and St. George. These allocations generate over $12 million a year in royalties to the APICDA. By quantity, the largest allocation is of pollock (19,400 metric tons). The APICDA's pollock allocation is harvested 100% by trawl catcher processors.

The second most important species to APICDA is Pacific cod, for which they receive an allocation of slightly more than 3,000 metric tons. APICDA's Pacific cod allocation has nearly always been harvested by longline catcher processors. APICDA does retain the right to harvest Pacific cod using vessels other than longline catcher processors in order to meet community needs.

4.11 Summary of Without Project Condition

Under without-project conditions, the cost of essential goods would remain high. The high cost of goods, coupled with dwindling economic opportunities and impacts to the accessibility of subsistence resources, would continue to limit the community's ability to develop a stable and sustainable local marine resource based economy sufficient to support their mixed, subsistence-cash economy. This has already resulted in the closure of the school following the 2016/2017 school year when enrollment fell below minimum thresholds for State funding. The City unconditionally believes that improved harbor conditions are essential to efforts to reopen the school and to ensure the economic and cultural survival of the community of St. George. The likely outcome of the future without-project condition is that the health of the community would follow its historical trend and St. George residents would continue to out-migrate for better opportunities.

5.0 FORMULATION AND EVALUATION OF ALTERNATIVE PLANS

5.1 Plan Formation Rationale

Plan formulation is the process of building alternative plans that meet planning objectives and avoid planning constraints. Alternatives are a set of one or more management measures functioning together to address one or more planning objectives. A management measure is a feature or activity that can be implemented at a specific geographic location to address one or more planning objectives. A feature is a “structural” element that requires construction or assembly on-site, whereas activity is defined as a “nonstructural” action.

5.2 Plan Formulation Criteria

Alternative plans were formulated to address study objectives and adhere to study constraints. As part of Federal guidelines for water resources projects, there are general feasibility criteria that must be met. According to the USACE ER 1105-2-100 for planning, USACE projects must be analyzed with regard to the four criteria defined in Section 2.7.2.

In addition to these criteria used for all potential USACE water resource development projects, a study-specific CE/ICA metric of increased vessel opportunity days for safe access and moorage has been identified.

5.3 Management Measures

The following non-structural and structural management considerations were developed during the planning charette conducted in Anchorage, AK, January 13–15, 2016. For this analysis, a measure is considered non-structural if it is not intended to physically alleviate the adverse maritime access and moorage conditions experienced at St. George. All ideas from charette attendees are identified in Table 3 and Table 4. The PDT screened the considerations proposed at the charette and determined if they qualified as a measure that would address the problem in Section 2.1 and were screened on the basis of meeting the study objectives described in Section 2.4. Discussion is provided in Sections 5.3.1 and 5.3.2 to explain if each item was considered a measure to address the problem and why the measures were either carried forward or screened from further consideration. Considerations that did not qualify as a measure were not considered further.

5.3.1 Non-Structural Measures

Non-structural measures are those measures that reduce the consequences of vessel delays and utilize currently available resources. Fifteen non-structural measures were developed during the planning charette and compared to the study objectives (Table 3).

Table 3. Non-Structural Considerations Identified at the Charette.

	Study Objectives	
	Provide for safe maneuverability and protected moorage	Increase time that harbor can be safely accessed
Measure Name	Do the following non-structural considerations meet the study objectives? (Yes/No)	
Subsidies to reduce the cost of living	No	No
Improved emergency response for humans and the environment	No	No
Improved telemedicine	No	No
Rodent control	No	No
Relocation of community	No	No
Air freight operational change	No	No
Intermodal connectivity (road) between harbor and airport	No	No
Offshore Anchorage area	Yes	No
Real-Time Monitoring Features	Yes	Yes
Inter-island access	No	No
Marine navigational aids	Yes	Yes
Air navigation aids	No	No
Fuel storage	No	No
Improved utilities	No	No
Harbor lighting	No	No

After the charette, the PDT screened the non-structural considerations identified at the meeting and determined whether these were measures or opportunities that could be realized with implementation of a harbor improvement project. The next several paragraphs discuss the various non-structural considerations identified during the charette and how they were screened or carried forward for further consideration (Table 3).

Subsidies to reduce the cost of living would aim to address the economic hardships the community faces with the absence of a functional harbor but would not address any maritime activities regarding safe maneuverability, protected moorage, or increased access to the harbor. This is not considered a measure for a harbor project and was removed from further consideration.

Improved emergency response for humans and the environment does not address harbor improvements such as providing safe access and protected moorage. However, the creation of a functioning harbor at St. George or Harbor of Refuge in the Bering Sea, could improve emergency response times to distressed vessels. Although this item was removed from consideration as a measure, it could be an opportunity with the implementation of a project.

Improved telemedicine does not address harbor improvements and accessibility. However, this item could be an opportunity with the implementation of a project. Increased vessel access to a functional harbor could allow the delivery of goods on a more frequent basis, increasing the availability of telepharmacy orders. This is not a measure; therefore not further considered.

Rodent control is an important environmental consideration and the USFWS works with the City to implement biosecurity measures to prevent the establishment of non-native rodents. However, it is not a measure and was screened from further consideration.

Relocation of the community could address the socio-economic hardships the community is currently facing. However, the high cost of relocating an island community and the loss of their culture by absorbing the people into a nearby village was the basis for removing this measure from further consideration. The infrastructure is not being imminently threatened by physical factors which could require relocation. The viability of the community is currently threatened with the absence of a functional harbor negatively impacting the subsistence-cash economy.

The community already utilizes air freight and has recently changed their carrier. This is not a measure that would address safe access and moorage in a harbor and was removed from further consideration.

Intermodal connectivity (road) between harbor and airport would not address harbor improvements or the viability of the community. If a road was determined to be necessary after construction of harbor improvements, the cost of the road would be considered local service facilities (LSF) and 100 percent responsibility of the NFS.

The offshore Anchorage area was determined to meet the study objective addressing safe maneuverability and protected moorage, however this is a location, not a measure. This location was carried forward as a viable location for harbor improvements and is explained in Section 5.4.3.

Inter-island access is currently addressed by having an air carrier that travels through St. Paul to get to St. George. Having a marine option for inter-island access could be an opportunity realized by implementation of harbor improvements at St. George. Since this is an opportunity, it was removed from further consideration as a measure.

Air navigation aids are not a harbor improvement measure and does not address safe navigation or protected moorage. This item was removed from further consideration.

Fuel storage, improved utilities and harbor lighting would be considered local service facilities and 100 percent responsibility to the NFS. These do not directly address safe access and protected moorage, but would be considered as necessary for realizing benefits for a harbor improvement project and were carried into initial alternative development.

Real-Time Monitoring Features and marine navigational aids are not effective measures either standalone or combined because they do not address access to a harbor or protective moorage. They do meet both study objectives and were carried forward and combined with structural measures to create the initial array of alternatives.

5.3.2 Structural Measures

Structural measures are generally those measures that reduce the probability of vessel delays due to insufficient depths and improve access to the harbor system. Structural measures were developed during the planning charette and compared to the study objectives (Table 4).

Table 4. Structural Measures Identified at the Charette.

	Study Objectives	
	Provide for safe maneuverability and protected moorage	Increase time that harbor can be safely accessed
Measure Name	Do the following structural measures meet the study objectives? (Yes/No)	
Dredging	Yes	No
Breakwaters	Yes	No
Docks	No	No
Spending beach; energy dissipation features	Yes	No
Offshore reef	No	No
Boat launch	No	No
Vessel haul-out facility	No	No
Moorage basin	Yes	No
Modify geometry of inner basin	Yes	No
Maneuvering basin	Yes	No
Approach/entrance channel	Yes	No
Vessel dry dock	No	No
Jetties	Yes	No
Inner harbor facilities, staging, etc.	No	No
Barge landing	No	No
Sediment control structure	Yes	No
New harbor	Yes	Yes

Seventeen structural measures were identified during the charette. After the charette, the PDT screened the structural measures to determine which items should be carried forward into the initial array of alternatives (Table 4). The next several paragraphs discuss the structural measures and whether they meet the study objectives for the implementation of a project

Although a spending beach and modifying geometry of the inner basin do meet the objective of providing protected moorage and safe maneuverability, these are specific measures to address the conditions in the existing harbor at Zapadni Bay and were only carried forward and combined in the development of the Zapadni Bay alternatives. These measures were not included in the new harbor alternatives at the North Anchorage site.

An offshore reef does not address protected moorage and safe access and maneuverability. It could dissipate wave energy, but would be duplicative with the use of breakwaters to protect harbor facilities. This measure was removed from further consideration.

Docks, boat launch, vessel dry dock, barge landing and inner harbor facilities, staging, etc. do not meet either of the study objectives, but would all be evaluated as local service facilities to support harbor usage with implementation of the proposed project. These measures would be combined as appropriate depending on harbor configuration and vessel class access in the initial array of alternative to realize harbor benefits.

A vessel haul-out facility does not address protected moorage or safe access to the harbor, but could be an additional local service facility based on community need. This facility would be included if necessary to realize harbor benefits as a local service facility and a 100 percent responsibility of the NFS.

Jetties and a sediment control feature could trap sediment from long-shore transport or deposition creating a protective feature for protected moorage. These could be used in addition to the existing breakwaters at the harbor in Zapadni Bay to create an additional layer of protection for moorage facilities. However, a breakwater would also provide protected moorage and safe maneuverability to a mooring basin, docks and harbor facilities. The North Anchorage site is on a more naturally protected side of St. George. A breakwater would be sufficient to reduce wave action to the harbor and provide safe access. Breakwater was carried forward as a structural measure for consideration in the development of the initial array of alternatives. Jetties and a sediment control feature were carried forward into the initial development of the Zapadni Bay alternatives only.

A moorage basin, maneuvering basin and an entrance channel are harbor navigation components that would be evaluated to improve safe maneuverability and protected moorage. These measures were carried forward and would be combined as appropriate for the development of the initial array of alternatives.

Dredging to create navigation channels or deepen an existing channel or basin for safe maneuverability would be evaluated to reach the desired depth to realize benefits for the design vessel or vessel classes. Dredging was carried forward and would be combined as appropriate for the development of the initial array of alternatives.

New harbor is the only measure that addresses both study objectives for safe access and protected moorage and was carried forward into the initial alternative development.

5.4 Site Selection

Three sites were considered for the development of navigation improvements: Zapadni Bay, Garden Cove, and North Anchorage. As discussed in Section 5.4.2, Garden Cove was immediately screened from further consideration due to the site characteristics. Zapadni Bay and North Anchorage were carried through into plan formulation (Figure 14).

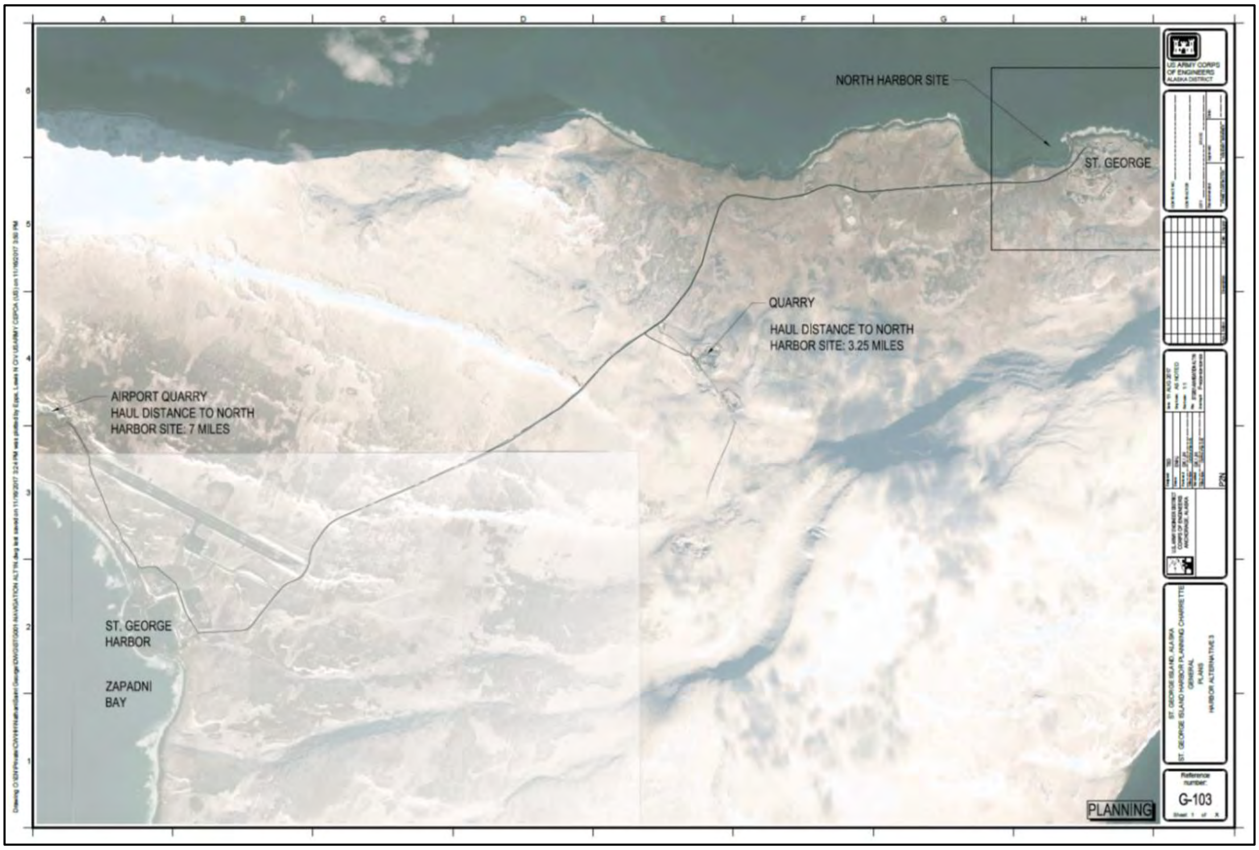

Figure 14. Site Locations.

5.4.1 Zapadni Bay

The City constructed the existing harbor at Zapadni Bay. It is a 3-acre boat basin enclosed by two rubble mound breakwaters. An inner breakwater arm protects the inner harbor. The entrance channel is 280 feet wide at the waterline. In its existing condition, the depth of the entrance channel varies from –26 to –18 feet MLLW with shallow areas consisting of rock pinnacles. Zapadni Bay was also attractive for the perceived magnitude of its potential environmental footprint; its previously disturbed footprint seemed appropriate for considering environmental enhancements.

Numerical modeling runs performed after the Alternatives Milestone indicated that there are minimal opportunities to improve conditions at the existing harbor. Physical modeling, which would provide more definite results, was delayed until the PED phase to meet the timeline of this study. Preliminary estimates indicate that harbor improvements costing approximately $100 million to $400 million would provide no additional safe access days, based upon hindcast conditions within the entrance channel, and limited additional safe moorage days based upon modeled conditions within the harbor. While safe moorage provides some opportunities for additional harbor activity, it alone does not meet the study objective of increased access.

5.4.2 Garden Cove

This location, located on the southeastern shore of the island, lacks road access, is composed of sea cliffs, with little to no accessible uplands, is adjacent to a maritime refuge, and is not well protected from waves. This did not appear to be a suitable location for the development of a harbor and was eliminated from further consideration.

5.4.3 North Anchorage

A harbor site located near the existing village on the north shore of St. George within a bay locally referred to as Village Cove would require the development of suitable access and any required support facilities, as none currently exists there. Additionally, access to this site may occasionally be limited due to sea ice.

The cost of constructing facilities to support the processing of the CDQ (fish plant, water supply, roads, wastewater treatment plant, etc.) were initially estimated to be in the magnitude of $50 million in addition to the cost of constructing the actual harbor. This site appeared to be infeasible due to these additional local costs and was initially eliminated from further consideration. Additional analysis of the support facilities required to realize benefits, including options such as a floating processor rather than a land-based plant, was later developed and is discussed in Section 6.

As stated above, the numerical modeling of Zapadni Bay indicated that there are minimal opportunities to improve conditions at the existing harbor. Based on the numerical modeling, the North Anchorage site was reconsidered and ultimately carried forward for consideration in the new harbor development. The St. George City Council agreed to the expansion of the study scope to include potential facilities at the North Anchorage site on December 5, 2017. A letter from the NFS expressing support of this decision is included in Appendix E.

5.5 Initial Alternative Plans

The structural and non-structural measures carried forward were combined to form an array of alternatives.

5.5.1 Alternative 1: No Action

Without navigation improvements at St. George, adverse wave and seiche conditions would continue within the existing harbor. Freight delivery costs would continue to be expensive, and a majority of cargo intended for St. George would continue to be delivered to St. Paul and require additional arrangements and expenses to be transported to St. George or be flown in via air freight service. Periodic damage to the breakwaters would continue. The existing conditions would limit the ability to safely operate an onshore fish processing facility at the harbor or a floating facility within the harbor. Without safe access to such facilities, fishing boats, fish processors, and other vessels would continue to avoid utilizing the existing harbor facilities at St. George.

Offshore wave climate conditions from the ongoing Wave Information Study of Alaska published by the Engineering Research and Development Center's Coastal Hydraulics Laboratory indicate that offshore waves producing unmoorable conditions in the harbor occur or are exceeded 9.2% of the time over the crabbing season or 17 days out of 182 days. Waves producing unsafe entrance channel condition are slightly more common at 13% annually, or 49 days. Access for barges is most restricted, with unsafe conditions occurring 52% annually, or 190 days.

Without a safe harbor to support a viable marine resource economy to support the local mixed, subsistence-cash economy, St. George residents would increasingly choose to relocate to other communities, threatening the very existence of the community. Improved harbor conditions are essential to ensure the economic and cultural survival of the community of St. George.

5.5.2 Alternative Z-1: Altered Navigation

Alternative Z-1 includes constructing an 800-foot long extension to the existing south breakwater with a crest elevation of +35 feet MLLW, a 500 foot jetty off the existing north breakwater with a crest elevation of +10 feet MLLW, three 1,000-foot long submerged reefs with crest elevations of -12 feet MLLW, a new inner breakwater with a crest elevation of +20 feet MLLW with a spending beach sloped at 10H:1V and a new navigation channel with a depth of -22 feet MLLW and a new turning basin with a depth of -20 feet MLLW (Figure 15). This alternative re-routes vessel traffic to the north end of the harbor in an attempt to reduce the occurrence of storm waves entering the harbor from the southwest direction. The Rough Order Magnitude (ROM) cost of this alternative is identified in Section 5.6 (Table 5).

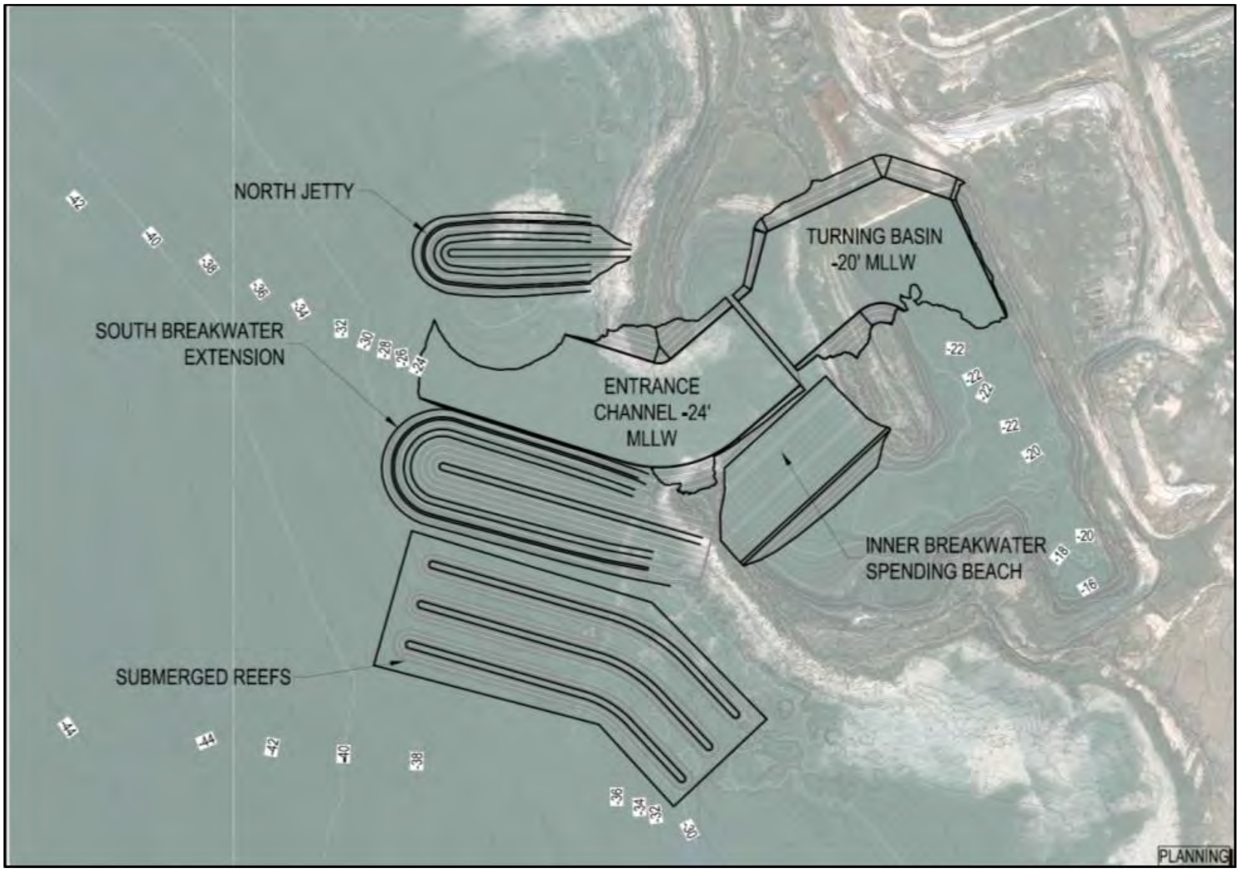

Figure 15. Alternative Z-1 Schematic and Modeling Results.

5.5.3 Alternative Z-2: North Overlap

Alternative Z-2 includes constructing a 1,050-foot long cap and extension to the existing south breakwater with a crest elevation of +35 feet MLLW, a 400-foot jetty north of the new breakwater with a crest elevation of +10 feet MLLW and a new navigation channel with a depth of -22 feet MLLW and a new turning basin with a depth of -20 feet MLLW (Figure 16). The existing north breakwater would be demolished to allow vessels to pass through this area. The construction provides a breakwater overlap of the inner harbor facilities in an attempt to provide improved protection for the existing docks. The ROM cost of this alternative is identified in Section 5.6 (Table 5).

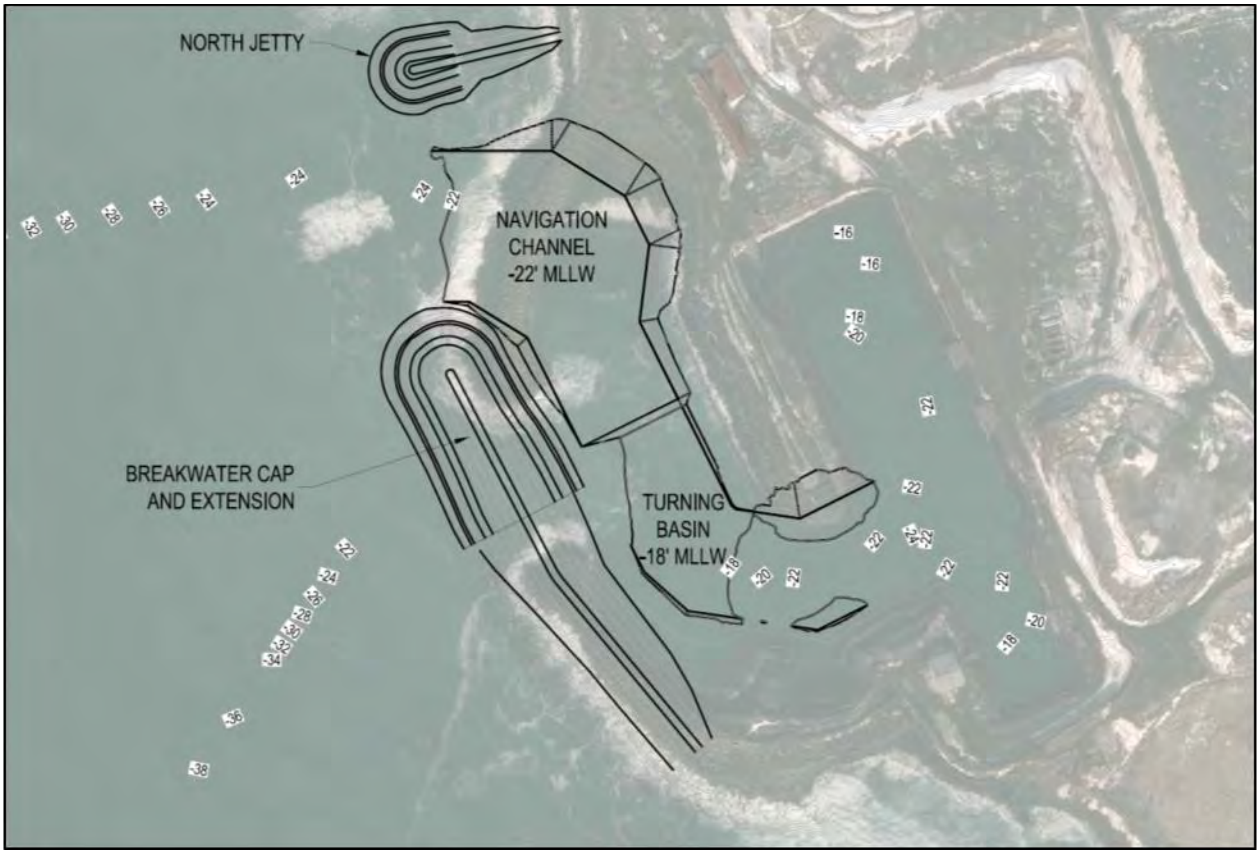

Figure 16. Alternative Z-2 Schematic and Modeling Results.

5.5.4 Alternative Z-3: Inland Basin

Alternative Z-3 includes constructing a new 700-foot long by 500-foot wide mooring basin to the northeast of the existing harbor (Figure 17). The new basin would be connected to the existing harbor by a 200-foot wide navigation channel. Excavation of the new mooring basin included excavation to construct a road around its perimeter to allow vehicles to traverse the perimeter of the harbor. The north end of the existing inner basin and the new inner basin would be sloped at 5H:1V to reduce wave reflection within the mooring basins. Excavation quantities for this alternative are approximately 2 million cubic yards of material. The existing harbor breakwaters would remain in their existing condition, and the existing channel would be widened to a minimum of 200 feet at the head of the inner breakwater and dredged to a depth of -22 feet MLLW. The ROM cost of this alternative is identified in Section 5.6 (Table 5).

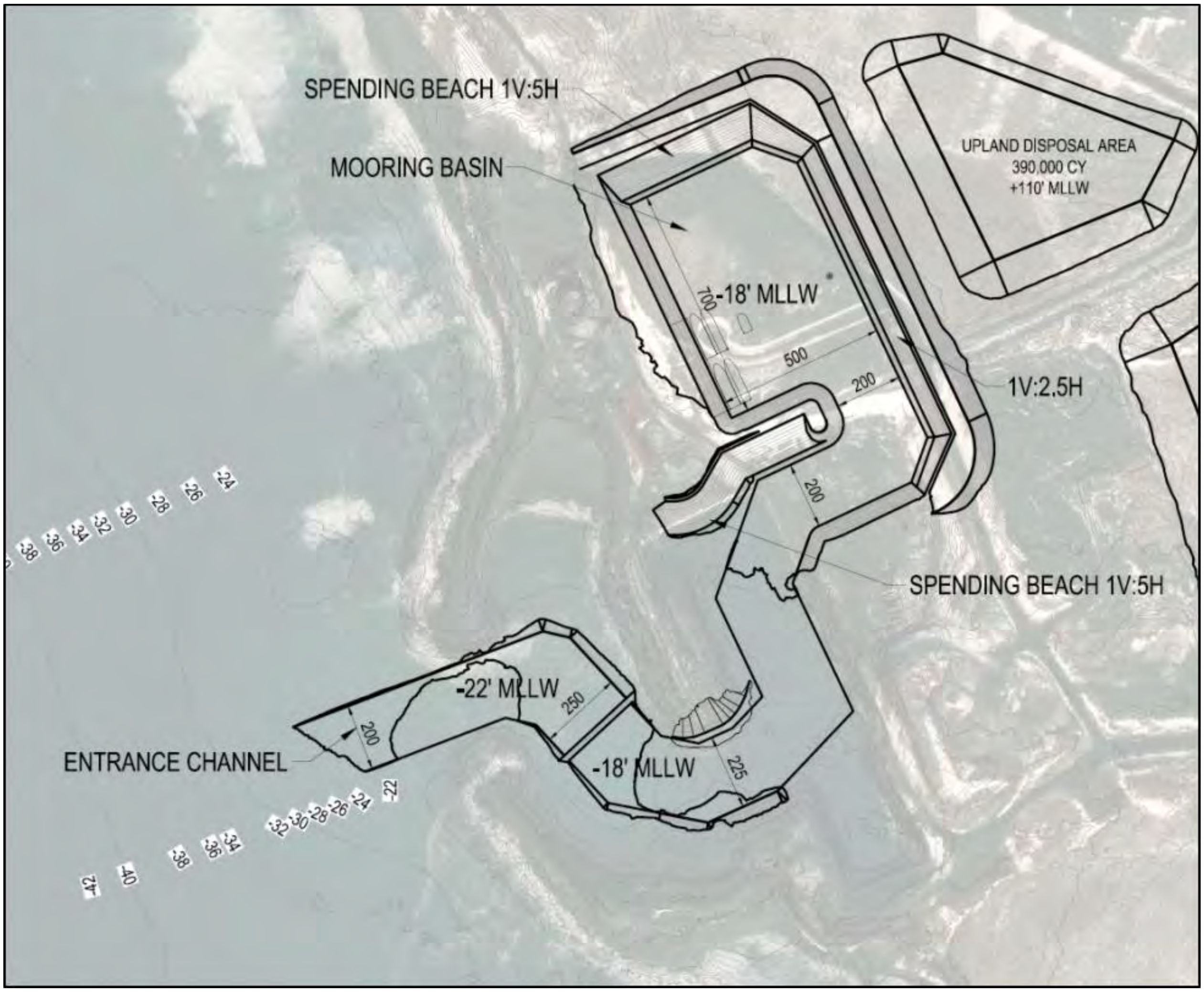

Figure 17. Alternative Z-3 Schematic and Modeling Results.

5.5.5 Alternative Z-4: Overall Harbor Concept (OHC)

Alternative Z-4 was adapted from an Overall Harbor Concept plan developed by the Alaska Department of Transportation and Public Facilities (AKDOT&PF) and HDR Inc. prior to initiation of the USACE feasibility study effort (Figure 18). The AKDOT&PF plan was modified to meet navigation requirements for the fuel barge to enter the harbor; however, the parallel jetties would still pose an impediment for the barge to clear the outer breakwaters. This alternative includes constructing a 400-foot long jetties at the ends of the north and south breakwaters with a crest elevation of +35 feet MLLW, a 500-foot inner north breakwater with a crest elevation of +20 feet MLLW and a north mooring basin with a depth of -10 feet MLLW. The ROM cost of this alternative is identified in Section 5.6 (Table 5).

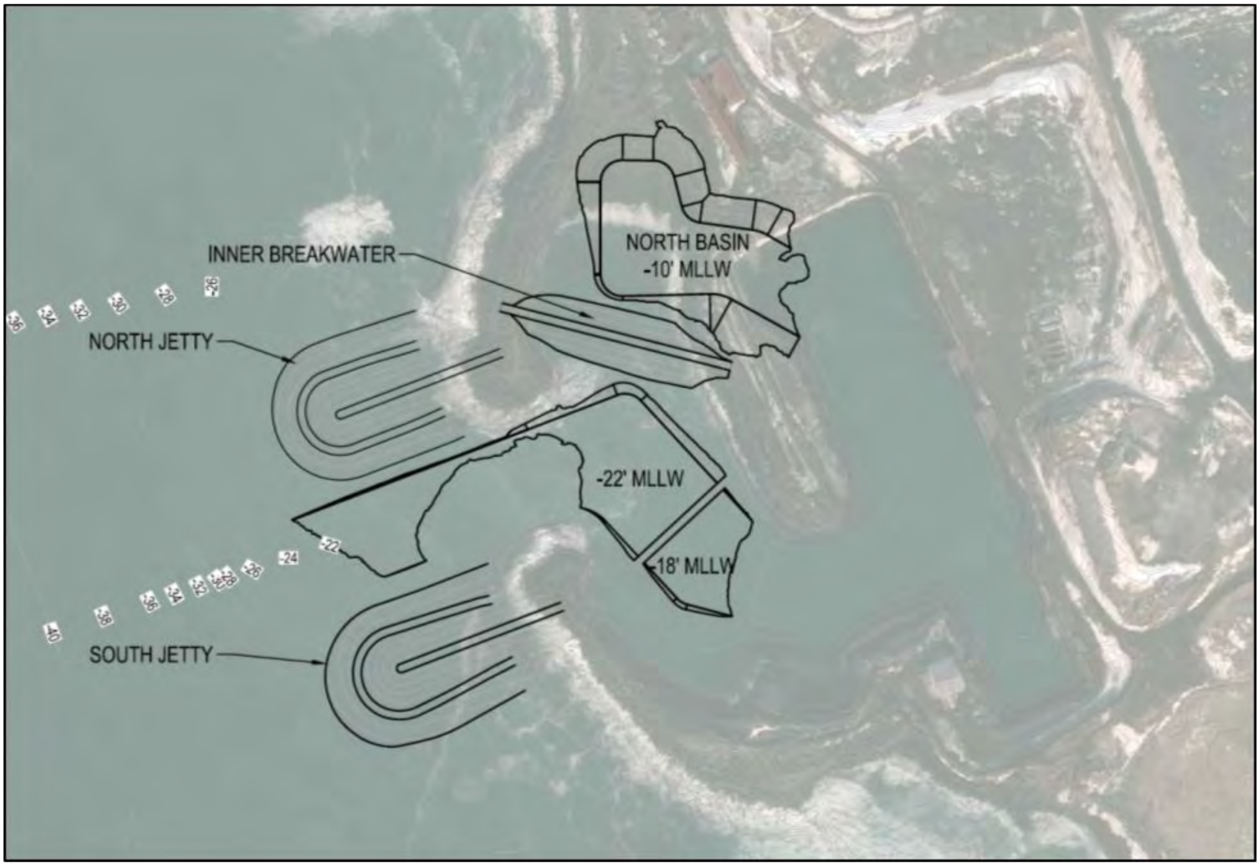

Figure 18. Alternative Z-4 Schematic and Modeling Results.

5.5.6 Alternative Z-5: Outer Breakwater

Alternative Z-5 includes demolishing the existing south breakwater and constructing a 3,000-foot long breakwater from the ice plant to an overlap position seaward of the existing north breakwater with a crest elevation of +35 feet MLLW (Figure 19). A 300-foot long extension of the north breakwater would be constructed with a crest elevation of +20 feet MLLW perpendicular to the new breakwater to define the mooring basin behind the new breakwater. New docks would be constructed on the inside of the new main breakwater with the entire basin enclosed by the new breakwaters being dredged to -22 feet MLLW. The back slope of the existing inner harbor would be filled at a 10H:1V slope to provide a spending beach in the new mooring basin. The ROM cost of this alternative is identified in Section 5.6 (Table 5).

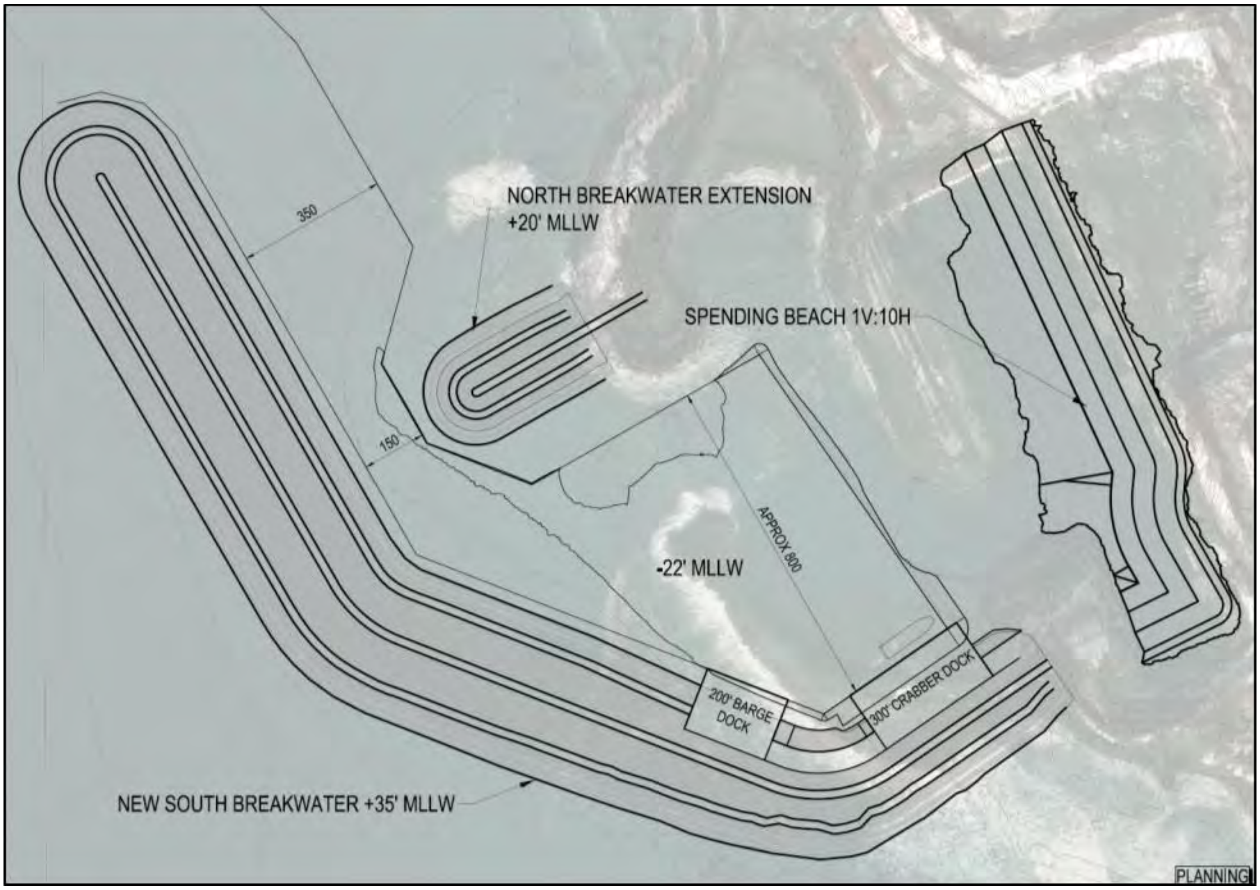

Figure 19. Alternative Z-5 Schematic and Modeling Results. Note: There are 30.4 increased moorage days at the inner dock and 19.1 at the outer dock.

5.5.7 Alternative Z-6: Berm Breakwater

Alternative Z-6 adapts the original berm breakwater design of St. George Harbor to the current shoreline (Figure 20). The design includes the original design locations for the breakwater utilizing a berm cross-section with a crest elevation of +26 feet MLLW. This would entail complete removal of both existing North and South breakwaters to allow for the new construction. The existing harbor geometry was modified by adding spending beaches at a 1V:10H slope to both ends of the inner harbor basin. Dredge areas for entrance and outer basin maneuvering are designed to -22 feet MLLW and -18 feet MLLW, respectively. The ROM cost of this alternative is identified in Section 5.6 (Table 5).

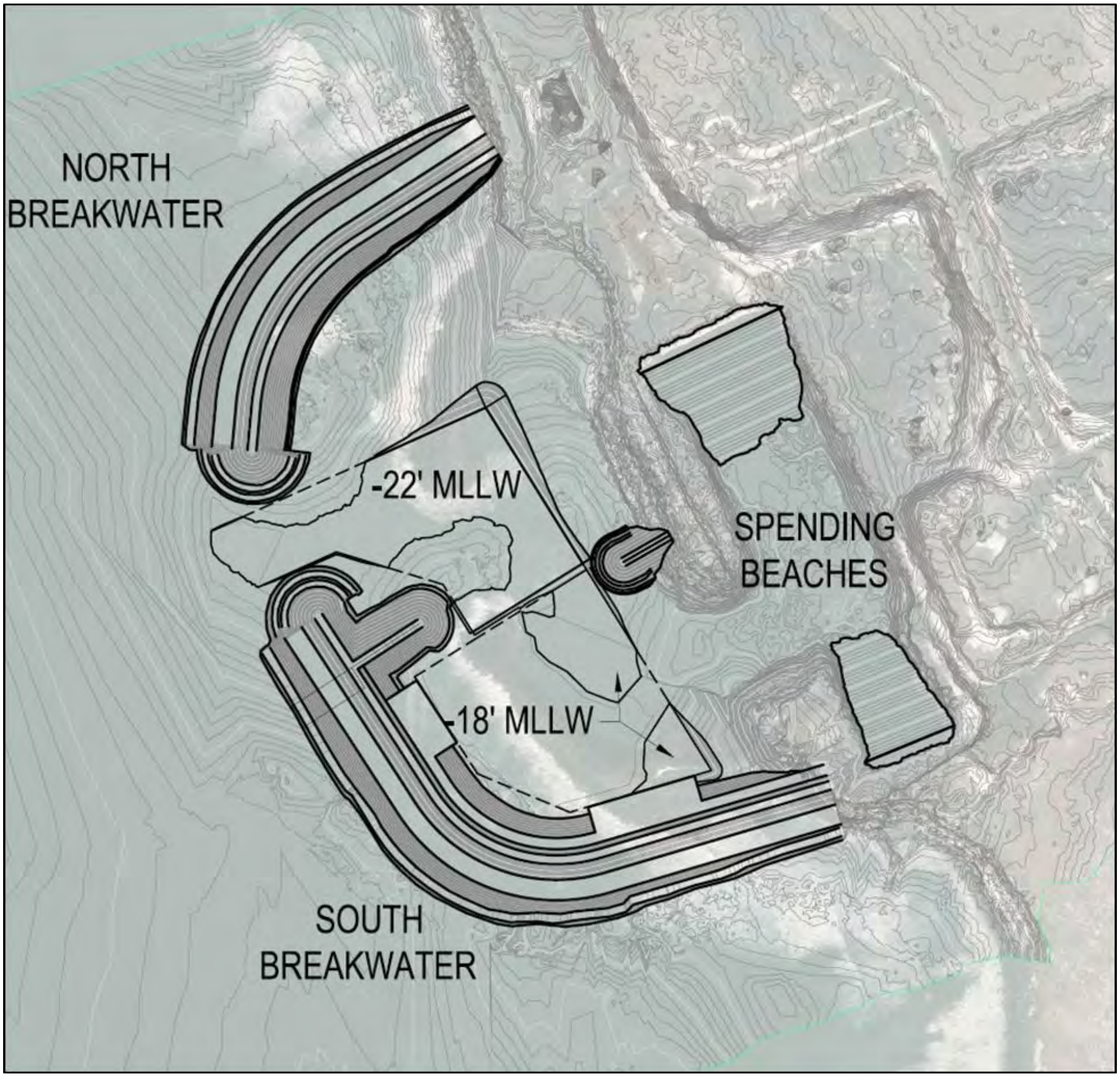

Figure 20. Alternative Z-6 Schematic and Modeling Results.

5.5.8 Alternative Z-7: Half Moon Harbor

Alternative Z-7 includes constructing a new 900-foot radius semi-circular mooring basin into the eastern edge of the existing inner harbor (Figure 21). The side slope of the new basin would be 10H:1V to reduce reflection in the mooring area. Excavation of the new mooring basin included excavation to construct a road around its perimeter to allow vehicles to traverse the perimeter of the harbor. Excavation quantities for this alternative are approximately 6 million CYs of material. The existing harbor breakwaters would remain in their existing condition, and the existing channel would be widened to a minimum of 200 feet at the head of the inner breakwater and dredged to a depth of -22 feet MLLW. The ROM cost of this alternative is identified in Section 5.6 (Table 5).

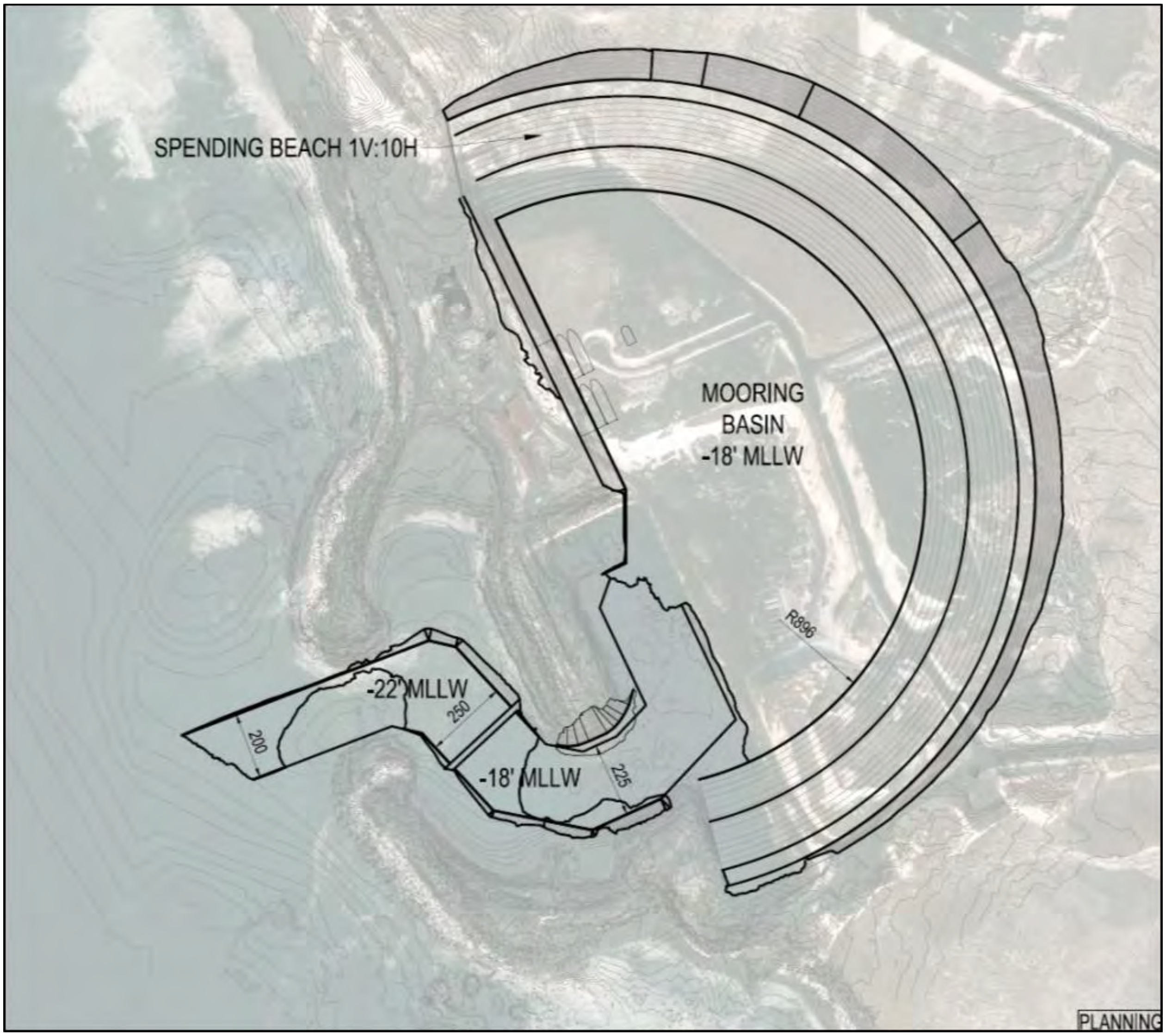

Figure 21. Alternative Z-7 Schematic and Modeling Results.

5.5.9 Alternative N-1: Subsistence Fleet

Alternative N-1 is a subsistence vessel launch harbor with a 775-foot long breakwater, and a 700-foot long entrance channel dredged to -10 feet MLLW, with a launch zone dredged to -8 feet MLLW (Figure 22). Dredging the channel for this alternative requires the removal of approximately 10,000 cubic yards of material. Subsistence vessels access the harbor through concrete launch ramp to -5 feet MLLW providing full tide access for launching. An inner harbor facilities area to support vessel preparation and launching operations would be created by filling to +10 feet MLLW. Under this alternative, safe access and moorage days increased by 38 days. The ROM cost of this alternative is identified in Section 5.6 (Table 5).

Figure 22. Alternative N-1 Schematic.

5.5.10 Alternative N-2: Subsistence Fleet, Fuel Barge, Freight, 25% Crabber Fleet

Alternative N-2 consists of a 450-foot wide by 550-foot-long mooring basin dredged to -16 feet MLLW protected by a 1,731-foot-long north breakwater and a 250-foot-long spur breakwater at the west edge of the basin (Figure 23). The basin connects to the Bering Sea with a 250-foot wide navigation channel dredged to -18 feet MLLW. Dredging the channel and basin for this alternative requires the removal of approximately 230,000 cubic yards of material. Inner harbor facilities would be created by filling an area to +10 feet MLLW, with a 300-foot-long pile-supported dock and a concrete boat launch ramp to -5 feet MLLW for full tide launching access. This alternative provides access for the subsistence fleet, the fuel barge, and approximately 25 percent of the commercial fishing fleet. Under this alternative, safe access and moorage days increased by 149 days. The ROM cost of this alternative is identified in Section 5.6 (Table 5).

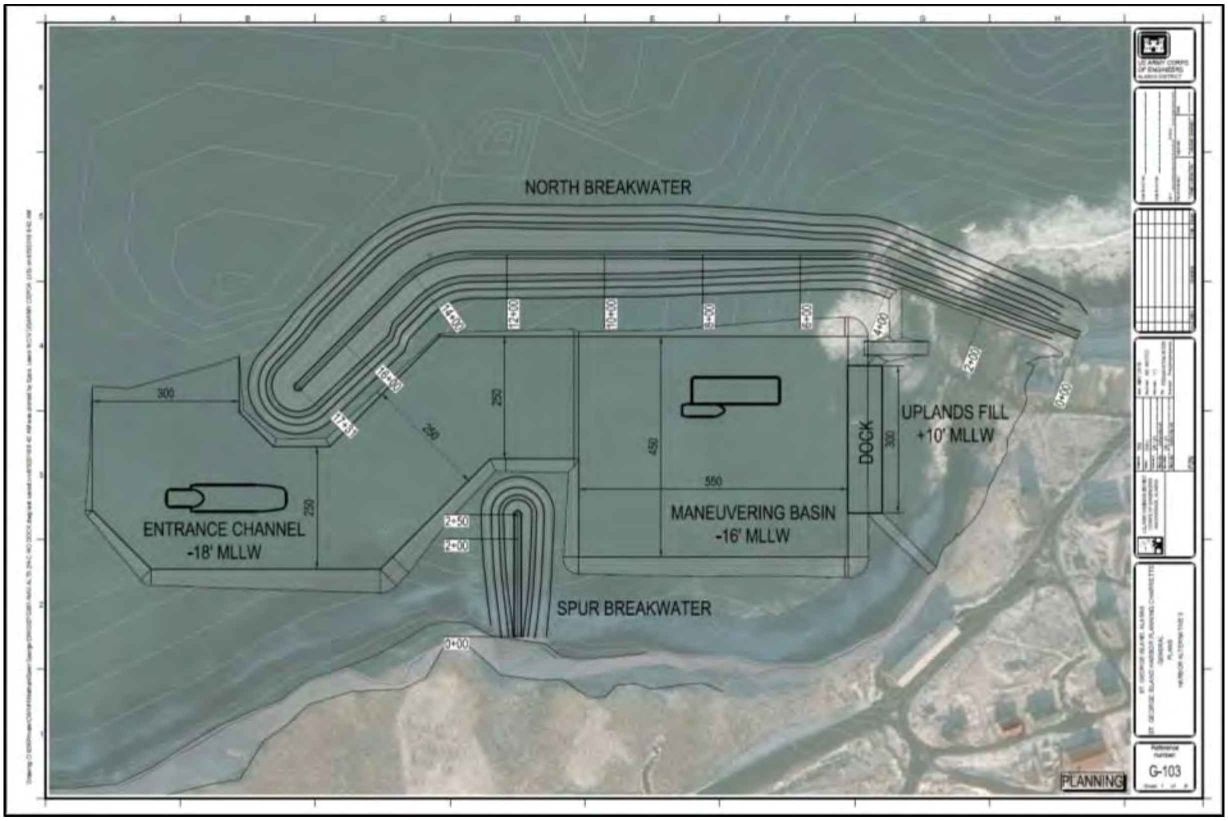

Figure 23. Alternative N-2 Schematic.

5.5.11 Alternative N-3: Subsistence Fleet, Fuel Barge, Freight, 85% Crabber Fleet

Alternative N-3 consists of a 450-foot wide by 550-foot-long mooring basin dredged to -20 feet MLLW protected by a 1,731-foot-long north breakwater and a 250-foot-long spur breakwater at the west edge of the basin (Figure 24). The basin connects to the Bering Sea with a 250-foot wide navigation channel dredged to -25 feet MLLW. Dredging the channel and basin for this alternative requires the removal of 353,052 cubic yards of material. Inner harbor facilities would be created by filling an area to +10 feet MLLW, with a 300-foot-long pile-supported dock and a concrete boat launch ramp to -5 feet MLLW for full tide launching access. This alternative provides access for the subsistence fleet, the fuel barge, and approximately 85 percent of the commercial fishing fleet. Under this alternative, safe access and moorage days increased by 179 days. The ROM cost of this alternative is identified in Section 5.6 (Table 5).

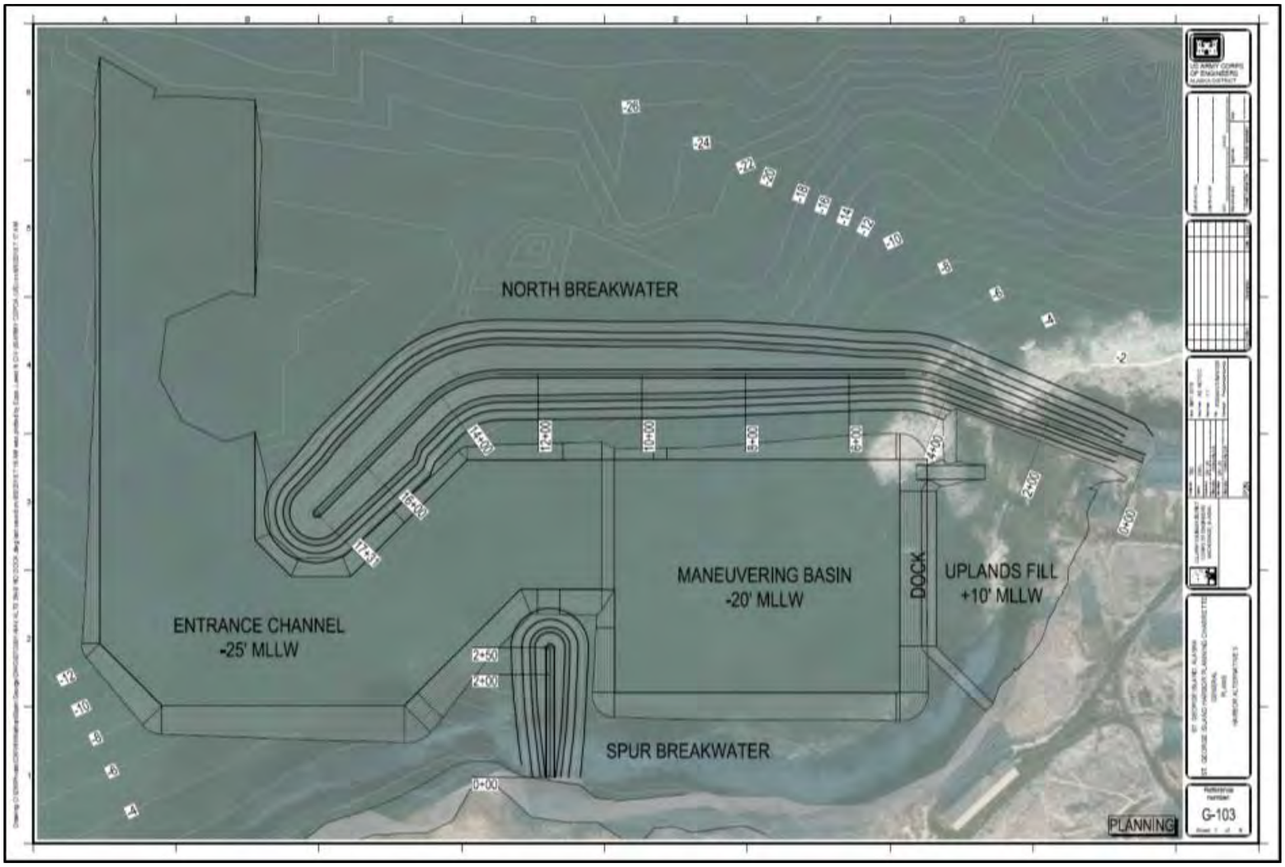

Figure 24. Alternative N-3 Schematic.

5.5.12 Alternative N-4: Subsistence Fleet, Fuel Barge

Alternative N-4 is a subsistence vessel launch harbor with a 1,100-foot long breakwater; the entrance channel dredged to -18 feet MLLW, with a maneuvering basin dredged -16 feet MLLW (Figure 25). Dredging the channel and basin for this alternative would require the removal of approximately 150,000 cubic yards of material. Inner harbor facilities would be created by filling an area to +10 feet MLLW. Under this alternative, safe access and moorage days increased by 127 days. Although this alternative provides 127 added days, it does not address the crabber fleet which is a driver of community viability and the purpose of this study. The ROM cost of this alternative is identified in Section 5.6 (Table 5).

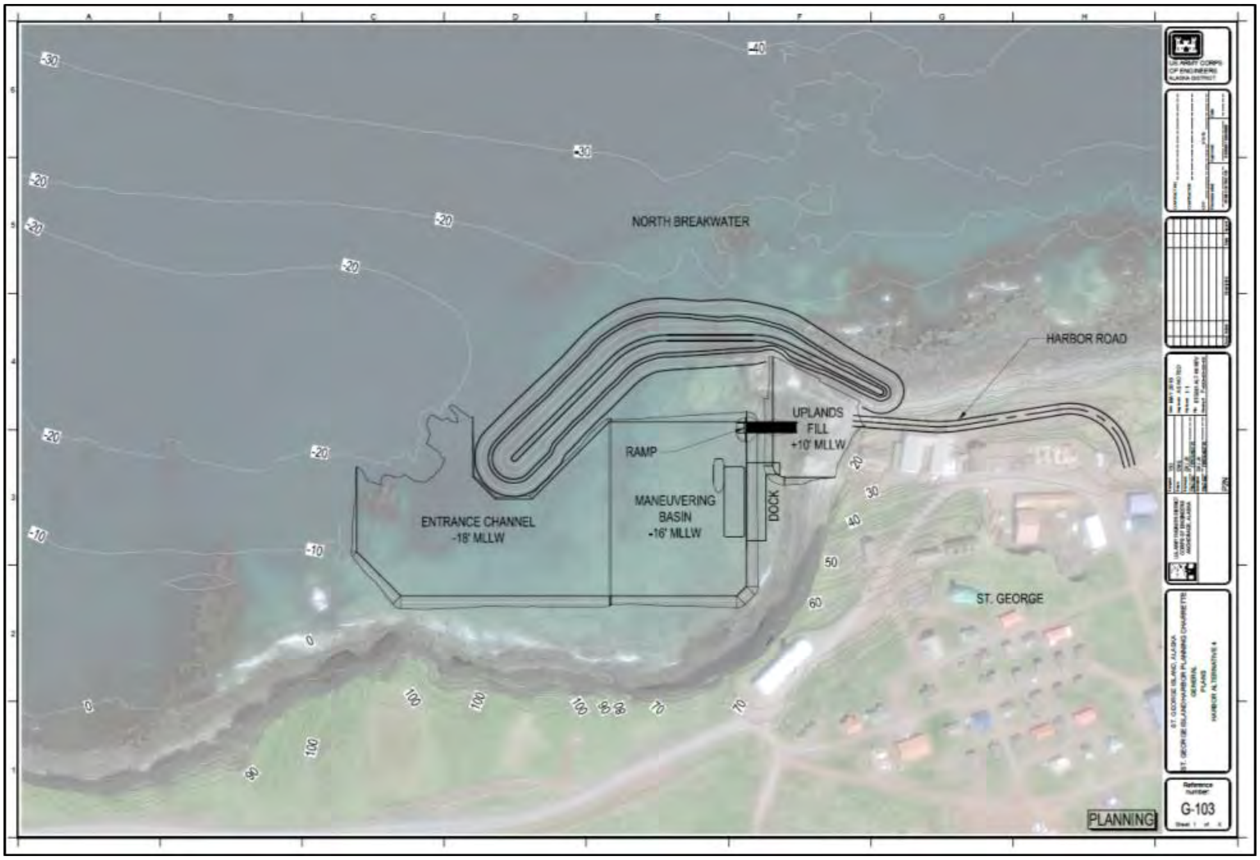

Figure 25. Alternative N-4 Schematic.

5.6 Screening of Alternatives and Detailed Analysis

For moorage analysis, wave modeling results were used to find the duration of wave height threshold exceedance for each site and compared to the existing condition. Moorage analysis was based on the availability of dock space based on wave conditions in the harbor (Table 5). This table shows the wave height outside the harbor that caused unmoorable conditions at the dock. This wave height was compared to the offshore wave conditions and the duration of time this wave height was exceeded was found and expressed as a percentage of total time. All docks were compared to conditions at the existing fuel dock at Zapadni Bay, which has be best mooring conditions, and both the difference in available moorage duration and annual moorable days are shown. ROM cost estimates are representative of the construction cost for each alternative (Table 5).

Table 5. Numerical Modeling Results Comparison – Mooring Improvements by Alternative.

Location	Wavemaker Wave To Induce Threshold (m)	Duration Threshold Exceeded	Percent Duration Difference from Existing Fuel Dock	Number of Increased Moorable Days
Original Harbor				
Ice Dock	2.44	17.77%	-7.96%	-29.1
Fuel Dock	3.37	9.81%	0.00%	0.0
Alternative Z-1 - Altered Navigation - $160 M				
Ice Dock	Less than 2 m	Greater than 27.32%	< -17.5%	< - 63.9
Fuel Dock	Less than 2 m	Greater than 27.32%	< -17.5%	< - 63.9
Alternative Z-2 - North Overlap - $100 M				
Ice Dock	2.39	18.37%	-8.56%	-31.2
Fuel Dock	Less than 2 m	Greater than 27.32%	< -17.5%	< - 63.9
Alternative Z-3 - Inland Basin - $70 M				
Ice Dock	2.71	14.54%	-4.73%	-17.3
Fuel Dock	3.28	10.38%	-0.57%	-2.1
Fishery Dock	4.14	6.26%	3.55%	13.0
Alternative Z-4 - OHC - $85 M				
Ice Dock	2.44	17.77%	-7.96%	-29.1
Fuel Dock	3.14	11.28%	-1.47%	-5.4
Alternative Z-5 - Outer Breakwater - $400 M				
Outer Dock	4.59	4.57%	5.24%	19.1
Inner Dock	6.90	1.49%	8.32%	30.4
Alternative Z-6 – Berm Breakwater - $180 M				
Outer Dock	Less than 2 m	Greater than 27.32%	< -17.5%	< - 63.9
Inner Dock	Less than 2 m	Greater than 27.32%	< -17.5%	< - 63.9
Alternative Z-7 - Half Moon Harbor - $170 M				
Fishery Dock	5.49	2.63%	7.18%	26.2
Alternative N-1 Subsistence Fleet Launch - $25M				
Launch (NEW)	NO MODEL RESULTS			
Alternative N-2 North Barge Access - $85M				
Dock (NEW)	3.41	7.43%	2.38%	8.7
Alternative N-3 North Fishing Fleet Access - $95M				
Dock (NEW)	3.41			
Alternative N-4 Subsistence Fleet Launch -				
Launch (NEW)	NO MODEL RESULTS			

The modeling results for the Zapadni Bay alternatives showed limited improvements in moorage conditions for some alternatives (Table 5). None of these alternatives improved harbor accessibility. Those alternatives that did improve mooring conditions did so marginally and at ROM construction costs between $70 million (13 additional safe moorage days) and $400 million (49 additional safe moorage days). Although Alternative Z-5 increased safe moorage by 49 days, harbor accessibility did not increase. Due to the high cost and no increase in harbor access days, Alternative Z-5 was screened from further consideration. Following this analysis, Alternatives Z-1, Z-2, Z-3, Z-4, Z-6, and Z-7 were also screened from further consideration.

Alternatives N-1 through N-4 in addition to the No Action (labeled NA in the table) were screened using the national evaluation criteria of acceptability, completeness, effectiveness, and efficiency against the study objectives (Table 6). The table screens the alternatives based on a metric of high (H), medium (M), and low (L) for meeting each of the four national evaluation criteria.

Table 6. Alternatives Screening for Study Objectives and National Evaluation Criteria.

Alts	**Study Objectives**																							
	Provide for safe maneuverability and protected moorage												Increase time that harbor can be safely accessed											
	National Evaluation Criteria																							
	Accept.			Complete.			Effective.			Efficien.			Accept.			Complete.			Effective.			Efficien.		
	H	M	L	H	M	L	H	M	L	H	M	L	H	M	L	H	M	L	H	M	L	H	M	L
NA			X			X			X			X			X			X			X			X
N-1			X			X			X		X			X			X			X		X		
N-2		X		X			X			X			X			X				X			X	
N-3	X			X			X					X	X			X			X					X
N-4			X			X		X			X			X			X			X			X	

All of the remaining alternatives (N-1 to N-4 and the No Action) meet the national evaluation criteria and will be carried forward as the final array of alternatives (Table 6). The following paragraphs further explain the comparison of the alternatives against these criteria and why they were ranked high, medium or low for each item.

The No Action alternative would not provide the community with a project and therefore does not address the two study objectives. Although it ranked low among the four evaluation criteria, the No Action alternative gives us a basis for comparison and will be carried forward into the final array of alternatives.

Alternative N-1 allows for subsistence fleet launching and would provide increased access and safe maneuverability for these vessels only. It is also a cost effective option for providing increased harbor access for the subsistence fleet. This alternative would not provide increased moorage and was ranked low for this study objective when evaluating acceptability, completeness and effectiveness. It was ranked medium for efficiency because it would address some of the issues for the community in regards to the subsistence fleet and is more cost effective then some of the larger plans.

Alternative N-2 aims to address the subsistence fleet, barge access and about 25 percent of the crabber fleet, which ranked it high for completeness, effectiveness and efficiency for addressing safe maneuverability and protected moorage. This alternative would provide economic opportunities to the community with the added harbor depth and moorage to account for 25 percent of the crabber fleet, but more opportunity would come from N-3 with 85 percent of the crabber fleet so this alternative was ranked medium for acceptability based on protected moorage. Alternative N-2 increases access and moorage by 149 days and ranked high for completeness and acceptability based on increased harbor access. This alternative ranked medium for effectiveness and efficiency because it does alleviate part of the problem St. George faces, but more access for the crabber fleet would add additional economic opportunity. In addition, the increase in harbor depth, the need for blasting and the additional rock needed for a larger breakwater resulted in a high project cost and contingency.

Alternative N-3 addresses safe maneuverability, protect moorage and increased access for the subsistence fleet, fuel barge and 85 percent of the crabber fleet. The economic opportunity of having 179 increased access and moorage days for these vessel classes is highly acceptable to the community and general public, and presents a complete and effective plan to meet the study objectives and support a cash-subsistence based economy and address community viability. However, this is the most costly plan due to the additional blasting and dredging required to accomplish the required harbor depth needed for 85 percent of the crabber fleet. Therefore, Alternative N-3 was ranked low for efficiency for both of the study objectives.

Alternative N-4 moderately addresses increased harbor access by providing the subsistence fleet and the fuel barge 127 increased moorage and access days. This alternative was ranked medium for all of the national evaluation criteria under the increased access study objective. It does allow for increased access and is cost effective for what it would provide the community, but it does not support a cash-subsistence base economy with the lack of crabber fleet access. Regarding increased moorage and safe maneuverability, Alternative N-4 was ranked medium for effectiveness and efficiency because the benefits of allowing the fuel barge to access the community on a more frequent basis would reduce delays and the resulting monetary impacts of time savings. However, this alternative does not address any percentage of the crabber fleet for safe maneuverability and moorage and therefore does not provide economic opportunity and community viability. Alternative N-4 was ranked low for acceptability and completeness because it does not address the problem of community viability.

Additional comparison of plans using the four accounts can be found in Section 6.6.5 of this Feasibility Report.

5.7 Alternatives Carried Forward

Alternatives N-1, N-2, N-3, N-4 and the No-Action were carried forward for comparison and selection of the Recommended Plan.

5.8 Alternative Comparison

The effectiveness of the alternatives were analyzed by comparing improvements in vessel access and opportunities to moor at the docks in each proposed harbor. Harbor access and moorage was determined by comparing the occurrence of wave heights exceeding the threshold for vessels in the fleet spectrum to operate. For access considerations, the offshore condition was analyzed to determine how often vessels in the fleet spectrum would be able to navigate to and into the harbor (Table 7).

Table 7. Harbor Accessibility Analysis

		Annual Harbor Accessibility Duration (%)			Annual Harbor Accessibility Duration (days)		
Vessel	Wave Criteria (m)	South	North	Δ_{North}	South	North	Δ_{North}
Fuel Barge	1	48%	58%	10%	175	211	36
Subsistence Vessel	1.2	54%	62%	8%	197	226	29
Crabber	3	87%	89%	2%	316	324	9

Further development of harbor accessibility criteria can be found in the Appendix C. A more detailed cost summary of the North Anchorage alternatives is shown in Table 8.

6.0 COMPARISON AND SELECTION OF PLANS

6.1 With-Project Conditions

Several critical assumptions were made when conducting the future with-project economic analysis. The existing fisheries in the region would continue to support the fleet. This is a critical assumption supported by fisheries present in the St. George area are highly regulated to assure the future viability of the resource.

It is assumed that a quota portion of the Bering Sea commercial crab and fish catch would be transferred back to St. George (currently this quota is processed in St. Paul). There would also be transportation cost savings and improved efficiencies by having a floating processor in St. George, but these efficiency gains are not significant enough to affect regional ex-vessel profits.

The value of CDQ and IFQ crab allocated to APICDA and intended for St. George is estimated at approximately $383,000 annually. Without a project, it is expected that this catch would continue to be delivered to St. Paul. Given the remote and mixed subsistence-cash economy of St. George, this unrealized profit would continue to hamper the community’s long term viability.

The future fleet at St. George is expected to be similar in size to the current fleet calling on St. George and St. Paul, the neighboring island about 50 miles north of St. George. The proposed harbor is designed to accommodate vessels up to the size of the design vessel that may seek refuge during storms. Also, by constructing a harbor on the north side of St. George, conditions would exist where storms would cause waves outside of St. Paul Harbor to be too high for vessels to enter, but at St. George, the island would shelter the harbor from the storm waves and vessels would still be able to navigate to the dock. Ice conditions at the North Anchorage site would also impact winter construction activities for blasting and dredging.

The Coast Guard provided information in an email to the USACE on how their presence at St. George would change with implementation of a new harbor (Appendix E). The Coast Guard presence would scale up if the new St. George Harbor drew additional fishing activity. If the harbor winds up boosting onshore processing and commercial fishing vessels come in increasing numbers, the Coast Guard would wind up conducting more operations in that area as there are at-sea boarding goals to reach a certain percentage for each fishing fleet.

6.1.1 Planned Development

With the construction of a safe and functioning harbor at St. George, the APICDA has expressed their intended support for the following additional development:

1. Construction of a lodge concurrent with harbor construction ($4 million APICDA investment – estimated ten new jobs)

2. Expansion of seafood processing to process cod, halibut, and sea urchins concurrent with harbor construction (additional $10 million APICDA investment to the $4 million already invested – estimated 100 new jobs)

3. Private/public sector seasonal ferry between St. George and St. Paul ($1 million APICDA investment – estimated four new jobs)

4. New small businesses to serve fishing and tourism develop (estimated 20 new jobs)

6.2 Biological Condition

Sections 6.2.1 to 6.2.5 discuss the comparison and selection of a plans under the with-project condition based on the biological resources at St. George.

6.2.1 Fish and Essential Fish Habitat (EFH)

Under the No-Action Alternative, no harbor would be constructed. Fish would be likely continue to be harvested at low levels by subsistence fishermen. EFH would likely continue to be affected at a very low level from subsistence activities.

Alternative N-3 would have the largest impact on fish and EFH of the four alternatives. In the short-term, all of the benthic habitat in the mooring basin and entrance channel would be lost due to blasting and dredging. The area underlying the two breakwaters would be permanently lost. It is likely that the habitat re-colonization process would begin relatively rapidly once construction-related activities ceased. Because the benthic habitat would be transformed from one varying in depth (-5 to -25 feet MLLW) to a relatively uniform -25 feet, it is likely that the benthic community inhabiting the area would differ from the original community. Some of this alteration of benthic community is likely to be compensated for with the habitat created by the breakwaters. These structures would provide substrate at varying depths for colonization by benthic species. Fish occupying the area during blasting would likely be killed. During other construction-related activities, fish would likely be displaced. Return and re-colonization of fish, respectively, would likely occur rapidly considering the small footprint of the project relative to the quantity of high quality habitat surrounding St. George. Alternative N-2 would have very similar impacts to Alternative N-3 since the areal footprints are identical and the dredge areas are similar, although the depths for Alternative N-2 are shallower. The impacts to fish and EFH from Alternatives N-1 and N-4, would likely be less than Alternative N-2 due to their smaller footprints and reduced dredging requirements.

6.2.2 Invasive Species

Under the No-Action Alternative, no harbor would be constructed, and the probability of inadvertent introduction of invasive species would likely not increase from the existing conditions.

Alternative N-3 would have the greatest likelihood of inadvertently introducing species to St. George. This alternative would require more materials to be delivered to the island, which carries an inherent risk of introducing species. Similarly, because Alternative N-3 is of the greatest scale (areal footprint and dredge depths), it would likely require the most time to complete, which would translate into more personnel and equipment transition to and from the island with the associated risk of introducing species. Alternative N-2 would likely carry a slightly reduced risk relative to Alternative N-3, because of its reduced dredge depths, which would translate into a shorter duration project. Alternatives N-1 and N-2, would have considerably lower risks of introducing species to St. George than Alternative N-1 because less material would be required to be shipped and the duration of the project would likely be reduced.

6.2.3 Marine Birds

Under the No-Action Alternative, no harbor would be constructed, and marine birds would likely not be impacted.

Under Alternative N-3, impacts to marine birds would likely be minor and would primarily consist of disturbance from construction-related activities. Noise sources would range from activities such as underwater blasting and pile driving (high decibel (db) and short-duration) to construction- and harbor-related vessel traffic (lower db and longer duration). In addition to impacts associated with noise, increased artificial lighting for construction and the temporary presence of tall structures (e.g., construction equipment) would likely have minor impacts to marine birds. However, impacts from high db activities, lighting, and structures height would be reduced because of mitigation measures (see Section 8.11). The long-term impacts from harbor operations would be minor and those birds occupying the area adjacent to the harbor would be expected to acclimatize to the increase noise and activity. The impacts to marine birds from Alternative N-2 would be the same as Alternative N-3. Although both Alternatives N-1 and N-4, comprise smaller areal footprints and require less dredge-related activity, the impacts to marine birds would likely be comparable to Alternative N-3 because the anticipated effectiveness of mitigation measures. The long-term impacts of Alternatives N-1 and N-4 from harbor operations would likely be less than Alternative N-3 because the smaller fleet would directly translate to less overall activity.

6.2.4 Marine Invertebrates

Under the No-Action Alternative, no harbor would be constructed. Marine invertebrates would be likely continue to be harvested at low level by subsistence fishermen.

Alternative N-3 would have the largest impact on marine invertebrates of the four alternatives. In the short-term, all of the benthic habitat in the mooring basin and entrance channel would be lost due to blasting and dredging. The area underlying the two breakwaters would be permanently lost. It is likely that the habitat re-colonization process by marine invertebrates would begin relatively rapidly once construction-related activities ceased. Because the benthic habitat would be transformed from one varying in depth (-5 to -25 feet MLLW) to a relatively uniform -25 feet, it is likely that the invertebrate community inhabiting the area would differ from the original community. Some of this alteration of invertebrate community is likely to be compensated for with the habitat created by the breakwaters. These structures would provide substrate and interstitial spaces at varying depths for colonization by a suite of marine invertebrates. Invertebrate species occupying the area during blasting would likely be killed and some may be displaced during other construction-related activities. Return and re-colonization of marine invertebrates, respectively, would likely occur rapidly considering the small footprint of the project relative to the quantity of high quality habitat surrounding St. George. Alternative N-2 would have very similar impacts to N-3 since the areal footprints are identical and the dredge areas are similar, although the depths for N-2 are shallower. The impacts to marine invertebrates from Alternatives N-1 and N-4, would likely be less than N-1 due to their smaller footprints and reduced dredging requirements.

6.2.5 Marine Mammals, Endangered Species, and Critical Habitat

Under the No-Action Alternative, no harbor would be constructed, and there would likely be no impact to marine mammals, endangered species, or their respective designated critical habitats.

Under Alternative N-3, short-term, direct impacts to marine mammals from underwater blasting and other in-water activities would be moderate and would likely result in temporary exposure to sounds or equipment that may causes them to alter their natural behavior; however, mitigation measures would eliminate the likelihood of mortality or permanent injury (see Section 8.2.4 for a detailed impact analysis). Long-term, direct impacts to marine mammals or their stocks would not be likely. Indirect impacts to marine mammals would likely arise from the emplacement of the breakwater structures. Some marine mammals would likely use the habitat created by the proposed harbor, making them more susceptible to habituation, exposure to chemicals, or vessel strikes. Although, mitigation measures would minimize the risk of the latter two. Adverse modification of Steller sea lion critical habitat would not be expected to occur from project actions. Alternative N-2 would likely have very similar impacts to Alternative N-3. Alternatives N-1 and N-4 would likely have considerably less impact on marine mammals compared to Alternative N-3. The smaller footprints of Alternatives N-1 and N-4 would likely translate into reduced volume and duration of noise. The smaller footprints would also create less habitat, thus reducing the number of animals likely to be habituated or exposed to chemicals or vessel strikes.

6.3 Alternative Plan Costs

Interest during construction (IDC) assumes a 3-year construction window. Initial estimates of operations and maintenance assume dredging would occur every 10 years, and 2.5 percent of breakwater armor rock would be replaced in 25 years. Project costs were developed without escalation and are in 2020 dollars (Table 8).

Table 8. Project Costs by Alternative.

Cost Description	Alt. N-1	Alt. N-2	Alt. N-3	Alt. N-4
Project First Cost (compounded to base year)*	$44,553,000	$166,476,000	$175,713,000	$97,309, 000
Interest During Construction	$1,231,000	$4,599,000	$4,854,000	$2,688,000
Operations, Maintenance, Repair, Replacement, and Rehabilitation (OMRR&R)	$7,073,000	$7,073,000	$7,073,000	$7,073,000
Total PV Cost	$52,856,000	$178,148,000	$187,639,000	$107,070,000
Annual Cost	$1,958,000	$6,599,000	$6,950,000	$3,966,000

*For economic analysis, costs and benefits are compared at the same price level. The Project First Cost referenced here is compounded to the base year and would differ from the Project First Cost referenced elsewhere in this Feasibility Report.

6.4 National Economic Development (NED) Analysis

Benefit categories for the NED analysis are described below. These categories were evaluated for each alternative and the results were summarized (Table 9 and Table 10).

Infrastructure Damages. Infrastructure damages to the existing harbor at Zapadni Bay are expected to continue to occur from storms in the frequency and severity of the existing condition. Repairs by the Federal Emergency Management Agency (FEMA) are also expected to continue. The existing harbor at Zapadni Bay will continue to be severely underutilized, inaccessible with limited safe moorage days as described in the existing conditions for all vessel classes.

Vessel Damages. Damages to vessels calling on St. George are expected to continue without harbor improvements. Under future without-project conditions, average annual damages experienced by the barge fleet are estimated at $4,400, but could be as high as the historical maximum of $64,000.

Vessel Delays. Delays to fuel and freight vessels will continue at the rate they have been seen historically, with costs of fuel and supplies remaining prohibitively high.

Unrealized Revenues. The value of CDQ crab allocated to APICDA and intended for St George is estimated at approximately $384,000 annually. Without a project, this will continue to be delivered to St. Paul for processing, leading to not only an unrealized economic opportunity for St. George but also higher transportation costs for crabbers that must deliver their catch to St. Paul. Given the remote and mixed subsistence-cash economy of St. George, this unrealized profit would continue to hamper the community's economy. Lack of economic opportunity in the community due to lack of a functioning harbor will continue to result in out-migration, leading to increased concerns about the long-term viability.

Subsistence Harvests. The opportunity to subsist will continue to be impacted under future without-project conditions. Following the historical trend, access the subsistence fleet has to resources will continue to be impacted. Given the high dependence of the community on subsistence resources, both culturally and economically, this will continue to be a major factor in long-term community viability.

6.4.1 With-Project Benefits

Net benefits and the benefit-cost ratio are determined using the average annual benefits and average annual costs for each alternative. Net benefits are determined by subtracting the average annual equivalent costs from the average annual benefits for each alternative; the benefit-cost ratio is determined by dividing average annual benefits by average annual costs. Project costs, benefits, and the benefit-cost ratio were summarized by alternative (Table 9). Benefits by category were calculated for each alternative (Table 10).

Table 9. NED Summary.

	No Action	N-1	N-2	N-3	N-4
Present Value Benefits	N/A	$3,138,000	$29,344,000	$29,560,000	$29,266,000
Average Annual Benefits	N/A	$116,000	$1,087,000	$1,095,000	$1,084,000
Present Value Costs	N/A	$52,856,000	$178,148,000	$187,639,000	$107,070,000
Average Annual Costs	N/A	$1,958,000	$6,599,000	$6,950,000	$3,966,000
Net Annual Benefits	N/A	($1,842,000)	($5,512,000)	($5,855,000)	($2,882,000)
Benefit-Cost Ratio	N/A	0.06	0.16	0.16	0.27

1) Alternative N-1 has the least negative net benefits, however there is no plan with positive net benefits so plan selection is determined through CE/ICA.
2) These numbers are based on the final iteration of costs for plan formulation and may not match the pertinent data table since the pertinent data table is based on the certified cost for Alternative N-3.

Table 10. Average Annual NED Benefits by Category.

	No Action	N-1	N-2	N-3	N-4
Expected Infrastructure Damages Prevented	N/A	$0	$964,000	$964,000	$964,000
Vessel Damages Prevented	N/A	$1,000	$1,000	$1,000	$1,000
Fuel and Freight Vessel Delays Prevented	N/A	$0	$4,000	$4,000	$4,000
Crabber Transportation Costs Savings	N/A	$0	$3,000	$11,000	$0
Subsistence Opportunity Cost Savings	N/A	$70,000	$70,000	$70,000	$70,000
Increased Subsistence Foods Harvested Value	N/A	$45,000	$45,000	$45,000	$45,000
Total	**N/A**	**$116,000**	**$1,087,000**	**$1,095,000**	**$1,084,000**

No NED plan was identified. Since no alternative has positive net benefits, plan selection is based on CE/ICA. While these values represent NED benefits resulting from navigation improvements at St. George, they do not represent the full scale of benefits that could be realized with implementation of a project. The next section discusses the CE/ICA summarizes results.

6.5 Cost Effectiveness/Incremental Cost Analysis

The Section 2006 Remote and Subsistence authority notes that when conducting a study of harbor and navigation improvements, the Secretary may recommend a project without the need to demonstrate that the improvements are justified solely by NED benefits. Therefore, after it was determined that there was no NED plan, other benefits from the Other Social Effects category were considered. Further, following implementation guidance, if there is no NED Plan and/or the selection of a plan other than the NED Plan is based in part or whole on non-monetary units (Environmental Quality (EQ) and Other Social Effects (OSE) accounts), then the selection will be supported by a cost effectiveness/incremental cost analysis.

A plan justified solely by NED benefits could not be identified for St. George, therefore the plan selection is supported by a CE/ICA. The CE/ICA metric for this study is increased safe access and moorage days. Increased vessel opportunity days for safe access and moorage allows for vessel-class specific evaluation of improved wave and seiche conditions in comparison to the existing entrance channel and the inner harbor. It also allows for the evaluation of vessel-class specific safe maneuverability and mooring of the anticipated fleet and the percentage of time (in days) that harbor facilities can be safely accessed. Therefore, this metric directly addresses the study's objectives. In addition, Section 2006 provides an opportunity to consider the additional benefits in the RED, OSE, and EQ accounts through a CE/ICA. These were developed so that there was no double-counting of benefits between the four accounts. The benefits for consideration under Section 2006 include:

- Public health and safety of the local community and communities that are located in the region to be served by the project and that will rely on the project, including access to facilities designed to protect public health and safety;
- Access to natural resources for subsistence purposes;
- Local and regional economic opportunities;
- Welfare of the local population; and
- Social and cultural value to the local community and communities that are located in the region to be served by the project and that will rely on the project.

As the output of the CE/ICA, increased vessel opportunity days for safe access and moorage are also significant for non-monetary benefits in terms of the output's institutional, public, and technical significance, as defined in ER 1105-2-100 (Table 11).

Table 11. Significance for Future With-Project Condition.

Significance	Future With-Project Condition
Institutional	• Addresses crab quota system where regulations intended for St. George community development
Public	• Provides opportunities for additional subsistence resource use, increasing the continuity of cultural heritage and customs that are significant to the community of St. George • Promotes life, health, and safety
Technical	• Addresses negative impacts to social well-being that have been documented in association with outmigration from St. George

By analyzing harbor designs that crabbers and fishing vessels can access as part of the anticipated fleet, the metric brings institutional significance to this study—specifically, crab quota regulations intended to support community development, and life, health, and safety laws that help protect mariners.

Increased vessel opportunity days for safe access and moorage is publically significant in that it specifies the amount of additional local subsistence use and procurement of resources expected to occur, while also increasing the continuity of cultural heritage customs associated with subsistence harvests.

Last, the metric is technically significant in that without increased vessel opportunities for safe access and moorage, out-migration from St. George is likely to continue. This has consequences that include sociological, psychological, health, and anthropological effects that are tied to the cultural identity associated with a narrow geographic range (i.e., St. George).

6.5.1 CE/ICA Metric Calculation

The draft characteristics of the anticipated vessel fleet was used to develop the wave criteria for accessibility and moorage at St George. The wave criteria for safe access and moorage differ. The wave criteria for safe access ranged from 3 to 10 feet at the harbor entrance for the anticipated fleet (fuel and freight barge, subsistence, crabbing and water taxis). A separate wave criteria of 1.6 feet at the dock dictates safe moorage inside the harbor for all vessel classes. As such, access and moorage days are calculated separately and then combined into a single metric.

To calculate access days, the Alaska District Hydraulics & Hydrology (H&H) engineers modeled the annual accessibility of a harbor on the south side of the island at Zapadni Bay and on the north side of the island at the North Anchorage site. A comparison of access conditions between the two sites showed a higher percentage of accessibility at the North Anchorage site (Table 12). To determine annual access days, the percentage of accessibility is multiplied by 365 opportunity days.

Table 12. Accessibility Wave Criteria

Vessel Class	Wave Criteria (feet)	South Site	North Site	ΔNorth	Annual Opportunity Days	Access Days Gained at North Site
Fuel Barge	3.2	48%	58%	10%	365	36.0
Subsistence Vessel	4	54%	62%	8%	365	29.0
Crabber	10	87%	89%	2%	365	8.6
Water Taxi	10	87%	89%	2%	365	8.6

To calculate moorage days, H&H modeling determined conditions at the existing dock in Zapadni Bay would exceed the moorage threshold for the vessel fleet 27.3 days annually. The maximum access days gained (36 days) is assumed as the maximum opportunity days for moorage. Moorage days gained by each alternative is calculated as the difference between maximum opportunity moorage days and the days in which the moorage threshold is exceeded.

These access and moorage days are applied to each vessel class by alternative and range between a low of 38 days (Alternative N-1) to a high of 179 days (Alternative N-3). The analysis of safe access and moorage by alternative is then further refined by conducting the CE/ICA and comparing the vessel classes that are served as described in Section 6.5.2.

6.5.2 CE/ICA Results

The CE/ICA was performed in IWR Planning Suite. This analysis yielded four cost-effective plans, two of which are the best buy plans (Alternatives N-3 and N-4). Neither Alternative N-1 nor N-4 provide access for the crabbing fleet, which is a critical factor for community viability. While N-3 and N-4 are both best buy plans, N-3 increases access for 85% of the crabbing fleet, compared to 25% of the crabber fleet with N-2. The CE/ICA results for Alternatives N-1 to N-4 determined two best buy plans (Table 13 and Figure 26)

Table 13. CE/ICA Summary.

Alternative	Average Annual Cost	Days Gained	Cost Effective	Best Buy
N-1	$1,958,000	38	Yes	No
N-4	$3,966,000	127	Yes	Yes
N-2	$6,599,000	149	Yes	No
N-3	$6,950,000	179	Yes	Yes

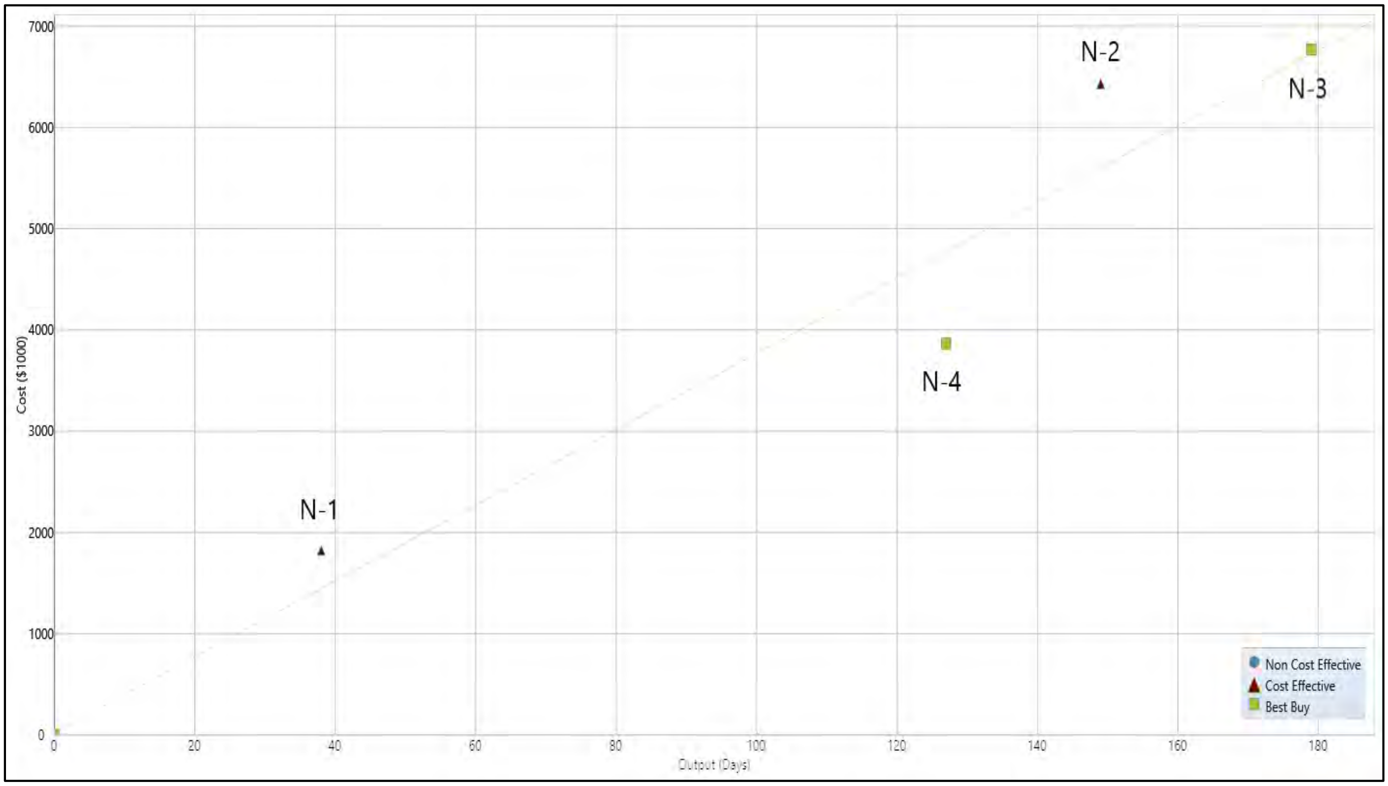

Figure 26. Cost Effectiveness Analysis: Increased Vessel Opportunity Days for Safe Access and Moorage

The best buy plans were compared by incremental cost per unit of output (vessel opportunity days for safe access and moorage) for Alternatives N-3 and N-4 (Table 14, Figure 27).

Table 14. Annual Incremental Cost vs. Output for Best Buy Alternatives.

Alternative	Incremental Days Gained	Incremental Cost	Incremental Cost Per Day Gained
N-4	127	$3,966,000	$31,200
N-3	52	$2,984,000	$57,300

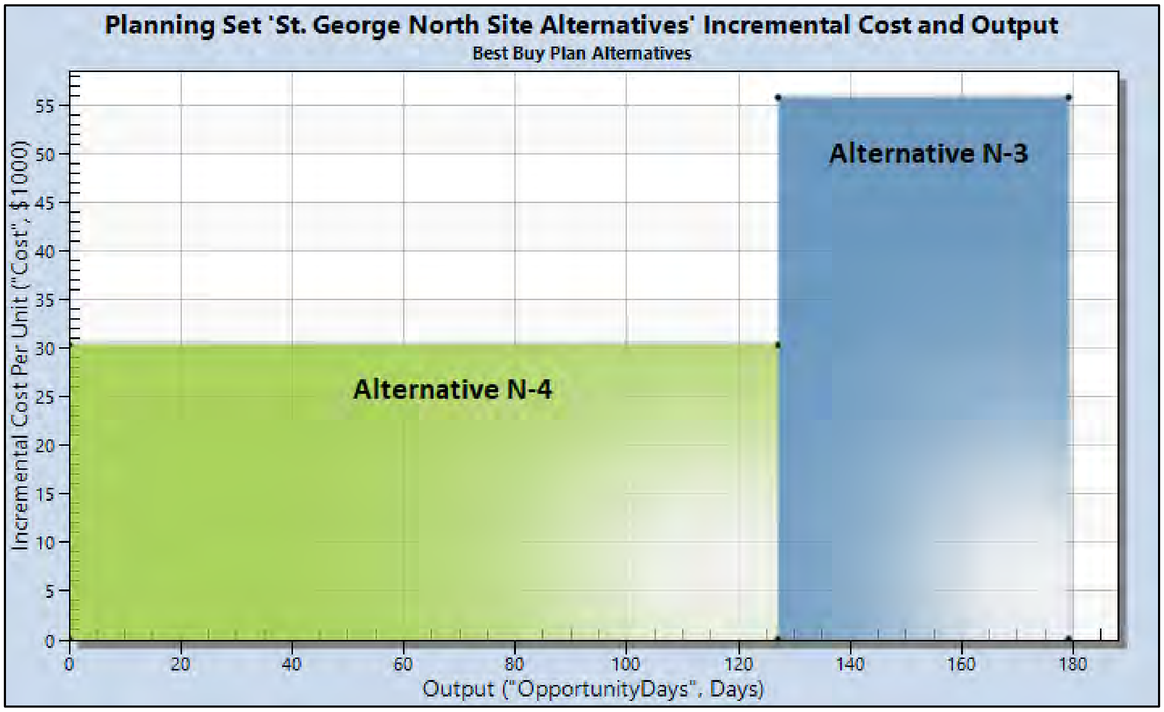

Figure 27. Incremental Cost Analysis: Increased Vessel Opportunity Days for Safe Access and Moorage

The selection of a Recommended Plan was further refined through analysis of the type of access and moorage provided by the two Best Buy plans. While Alternative N-4 provides a gain of 127 days of access when compared to the No Action Alternative, none of these days are associated with the crabbing (CDQ and IDQ) fleet. In comparison, Alternative N-3 provides 179 days of access, which includes 17 days of safe access and 17.4 days of safe moorage for the crabbing fleet (Table 15).

Table 15. Annual Access/Moorage Days Gained by Fleet Type for Best Buy Plans.

	Alternative N-4	Alternative N-3
Access Days Gained		
Fuel Barge	36.0	36.0
Freight	36.0	36.0
Subsistence Vessel	29.0	29.0
Crabber x2	0.0	17.0
Taxi	0.0	9.0
Moorage Days Gained		
Fuel Barge	8.7	8.7
Freight	8.7	8.7
Subsistence Vessel	8.7	8.7
Crabber x2	0.0	17.4
Taxi	0.0	8.7
Total Days Gained	**127.1**	**179.2**

Based on the CE/ICA and given that the CDQ/IFQ crabbing fleet is a driver of community viability, Alternative N-3 is identified as the Recommended Plan.

6.6 Summary of Accounts

USACE planning guidance establishes four accounts to facilitate and display the effects of alternative plans.

6.6.1 National Economic Development

Plan formulation was performed for this study with a focus on contributing to NED with consideration of all effects, beneficial or adverse, to each of the four evaluation accounts identified in the Principal and Guidelines. A NED analysis has concluded that there is not a plan justified solely on NED benefits (Reference Appendix C, Economics for more detailed information). The study team received the USACE Vertical Team agreement and subsequent concurrence from the Technical Director of the Deep Draft Navigation Planning Center of Expertise that no NED Plan is attainable during an In-Progress Review conducted on September 22, 2017, and again during subsequent meetings with the Technical Director. Therefore, the analysis described in this Feasibility Report follows implementation guidance for Section 2006 authorized projects, which allows for plan selection based on CE/ICA.

6.6.2 Regional Economic Development (RED)

Economic benefits that accrue to the region, but not necessarily the nation, include increased income and employment associated with the implementation of a project, as well as realization of local and regional economic opportunities through the delivery of commercial fishing harvests to St. George.

6.6.3 Environmental Quality (EQ)

Environmental Quality displays the non-monetary effects of the alternatives on natural resources and is described in the environmental sections of this Feasibility Report. Qualitative enhancements to the environment include a reduction in fossil fuel usage and emissions due to decreased delays for vessels along with reduced transportation distances for vessels to access fishing grounds. Those benefits would be overshadowed by negative impacts to the environment from harbor construction, increased vessel traffic, increased risks associated with inadvertent release of environmentally persistent pollutants (i.e., fuel spill, oil spill), etc. Additional information is available in Section 8.

6.6.4 Other Social Effects (OSE)

The OSE of each alternative are generally positive and beneficial, with the exception being the No-Action Alternative. St. George, like many rural economies throughout Alaska, is a mixed, subsistence-cash economy in which the subsistence and cash sectors are interdependent and mutually supportive. The ability to successfully participate in subsistence activities is highly dependent on the opportunity to earn some form of monetary income and access the resources need to engage in these activities. Without a safe and functioning harbor that provides access for subsistence vessels, fuel, and freight delivery, and a portion of the commercial fishing fleet, economic opportunities in the community would continue to be hindered. The costs of basic essential goods required to support a subsistence lifestyle would remain prohibitively high, contributing to continued out-migration from St. George. When community viability is threatened by high costs of essential goods (including fuel), tribal identities, and cultural communities, can be lost.

A safe and functioning harbor that improves access to St. George would provide opportunities for the development of a local economy based upon the marine resources of the region. Such economic opportunities are essential for supporting St. George's mixed, subsistence-cash economy, combating out-migration, and helping to strengthen the viability of the community on St. George.

6.6.5 Four Accounts Evaluation Summary

Based on this analysis of the four accounts, each alternative has positive effects for the RED and OSE accounts and temporary negative effects for the EQ account. The four accounts were summarized for all of the alternatives and the Recommended Plan was highlighted in yellow (Table 16).

Table 16. Four Accounts Summary.

Alternative	Benefit-Cost Ratio	Average Annual Cost	RED	EQ	OSE (increased access and moorage
No Action	N/A	$0	Neutral	Neutral	0
N-1	0.06	$1,958,000	Increased employment and income for the region and state	Negative	38
N-2	0.16	$6,599,000	Increased employment and income for the region and state	Negative	149
N-3	0.16	$6,950,000	Increased employment and income for the region and state	Negative	179
N-4	0.27	$3,966,000	Increased employment and income for the region and state	Negative	127

7.0 RECOMMENDED PLAN

7.1 Description of Recommended Plan

In consideration of the CE/ICA presented previously, the Recommended Plan is Alternative N-3 (Figure 24). This alternative includes constructing protected boat launch and recovery area for the local subsistence fleet. A new 1,731 foot long North Breakwater with 10 ton armor stone and a crest elevation of +25 feet MLLW would protect a new 550 foot by 450 foot maneuvering basin, a 300 foot dock and concrete launch ramp. A Spur Breakwater with 10 ton armor stone and a crest height of +20 feet would be constructed inside the North Breakwater from the base of the cliffs along the south edge of the harbor to filter waves diffracted around the nose of the North Breakwater. These waves reached a maximum height of 2.1 meters in model simulation and overtopping is not expected to occur. The maneuvering basin would be dredged to -20 feet MLLW with a transition zone and an entrance channel dredged to -25 feet MLLW. This channel depth would allow 85 percent of the crabber fleet to access this harbor. The entrance channel maintains a 300 foot width from deep water to the end of the breakwater and includes widened turning section outside the breakwater nose. The channel narrows to 250 feet wide at the breakwater nose. The wind and wave climate as well as the wider entrance channel are expected to improve barge access to St. George.

The north breakwater would be incorporate three layers of consecutively smaller boulders to efficiently dissipate wave energy (Figure 28). The outer layer, A rock, would consist of multi-ton armorstone that would be subject to the majority of the wave energies. The second layer, B rock, would be comprised of slightly smaller boulders, adding a redundant layer of protection. The core of the breakwater would consist of C rock. The north breakwater requires approximately 100,423 CY of armor stone, A rock, 63,068 CY of B rock, and 119,782 CY of core rock, C rock. The spur breakwater requires approximately 7,445 CY of armor stone, 5,007 CY of B rock, and 3,734 CY of core rock. The basin and navigation channel require removal of approximately 353,052 CY of material to reach the proposed maximum pay depths for the Recommended Plan. Construction of the area for inner harbor facilities would require approximately 51,116 CY of fill.

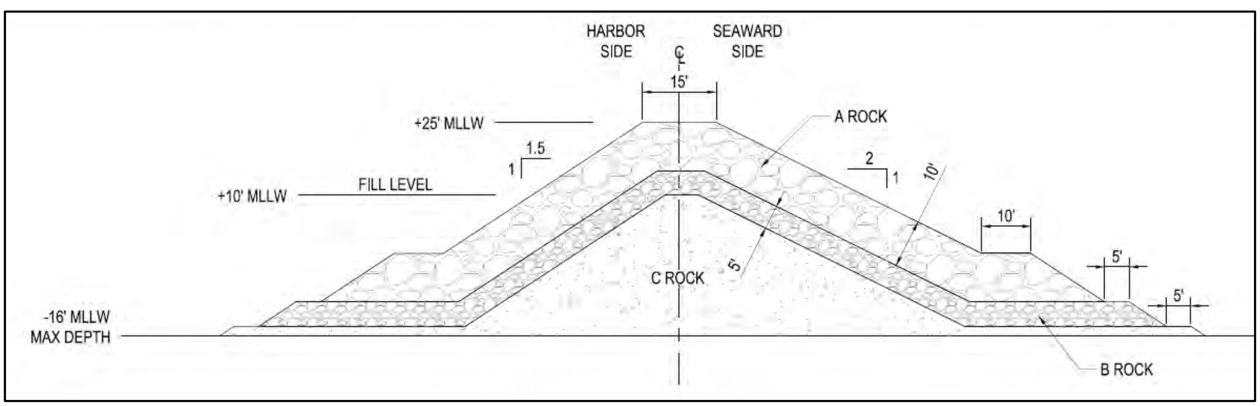

Figure 28. Typical breakwater cross-section.

7.2 Plan Components

Major construction features for the Recommended Plan include rubblemound north and spur breakwaters, dredging, pile-supported docks, and fill areas for inner harbor facilities. The material source for breakwater construction would be offsite from an established quarry such as Cape Nome or Granite Cove on Kodiak Island. The material source would most likely be far enough away from the site that rock production would need to significantly lead placement operations to ensure that the construction crew on-site has enough material delivered to the site for a full season of work. Stone production in the quarry and delivery to the site would likely be the first project tasks undertaken.

Construction of the North Breakwater is most likely to be performed with land-based equipment. The breakwater core would be constructed to above the tide range to allow the placing equipment to drive the breakwater core and place B and A rock layers to protect the work in progress. Core rock would likely be transported and staged on the breakwater with off-road dump trucks, then shaped to the design prism by an excavator. Near the west end of the breakwater, an excavator on a barge may be required to shape the toe and benches of the breakwater where the seabed is deeper. The area for inner harbor facilities would be constructed concurrently with the breakwater to build a staging area for breakwater material.

7.2.1 Required Further Design Studies

Due to the lack of site data, numerical models cannot be calibrated to local conditions and further investigations would be necessary to design harbor structures. The following items require further study in the PED phase of the project before plans for construction can be published:

1) Geotechnical investigation and analysis of subsurface materials at the North Site would be collected to determine the physical characteristics and chemical composition, dredging methods and equipment requirements, and suitability as foundation materials for the proposed causeways, breakwaters, docks, and upland facilities.

2) A detailed physical model study would be conducted in a facility that is capable of simulating wave spectra originating from multiple directions of approach. This step is necessary to validate numerical model results and to identify harbor-specific hydrodynamic issues that the numerical models are not capable of replicating. This study needs to be performed in a facility dedicated to wave modeling run by full time research engineering staff. The USACE owns and operates the necessary facilities at the Engineer Research and Development Center (ERDC) Coastal Hydraulics Laboratory in Vicksburg, MS. This work is an essential step in the design process and needs to be completed before plans and specifications for construction can be created. The physical model study will also incorporate additional numerical wave modeling to refine input wave conditions at the offshore boundary of the physical model domain.

7.3 Design Vessel and Fleet

A fleet spectrum was developed for the arctic region and is outlined in the Economics Appendix for this study. Expected fleet missions are commercial fishing, subsistence fishing, and freight and fuel delivery. Characteristic vessels have been identified to provide the minimum design requirements for port facilities. Design vessel dimensions for the fleet expected to utilize the harbor at St. George were developed for subsistence, crabber, and fuel tug and barge (Table 17).

Table 17. Design Vessel Dimensions.

Design Vessel	Length (ft.)	Beam (ft.)	Draft (ft.)
Subsistence Vessel	28	8.5	4
Crabber	150	36	14
Fuel Tug and Barge	180	84	10

7.4 Dredging and Disposal

The material at all sites is assumed to require blasting and mechanical dredging equipment to reach design depths. Dredging features typically include a 2-foot overdepth allowance to ensure that the minimum required depth is met. Blasting also requires a minimum 2-foot depth allowance to ensure that minimum depth is achieved, so blasting patterns would need to be established to loosen material to 4 feet below the minimum required depths designed for the Recommended Plan. The dredging machinery would load a scow, which would deliver the dredged material to an offshore disposal site. Multiple scows may be used to provide for continuous dredging operations. The authorized dredge depth for the navigation channel will be -27 feet (-25 feet MLLW plus overdepth) MLLW, and the authorized depth of the maneuvering basin will be -22 feet MLLW (-20 feet MLLW plus overdepth). These depths will be used to ensure that the minimum required depths for under keel clearance are met. Including a 2 foot overdepth allowance below the minimum required depth also provides space for sedimentation to occur without the immediate need for maintenance dredging.

The beneficial use of dredged material to create a crab habitat is being analyzed. Beneficial impacts from the placement of the dredged material are likely to increase over time as the material colonizes with fish and invertebrates. The project area is within the extent of the 20 nautical mile distance from major haulouts, and that is considered critical habitat, but the two haulouts are between eight and ten nautical miles away from the project site and are on the opposite side of the island. Changes in the habitat at the project site and potential impacts during construction would have minimal effects on designated critical habitat.

7.5 Aids to Navigation

As part of the construction of the project, concrete navigation marker bases would be constructed at the heads of the new causeways and/or breakwaters. Coordination with the U.S. Coast Guard Aids to Navigation Office will be conducted in PED to ensure that necessary marking of the new entrance channels are considered.

7.6 Construction Timeline

Dredging could occur concurrently with stone production. Initial observations of the site indicate that confined underwater blasting is the preferred substrate pretreatment to facilitate dredging. This will require special scheduling considerations due to the proximity of the fur seal rookery, and schedule delays could be incurred due to the presence of marine mammals near the blasting zone during dredging operations. With the anticipated approval of Incidental Harassment Authorizations, dredging actions could be authorized to occur throughout the majority of a calendar year. Some dredging prior to constructing the breakwaters would provide access for construction barges to the breakwater sites. The total estimated construction time of the project is a minimum of 3 years, but could take up to 5 years.

7.7 Operations and Maintenance

The non-Federal operator of the Port would be responsible for the operation and maintenance of the completed mooring areas and local service facilities portion of the project. The Federal Government would be responsible for the maintenance of the causeway extension and breakwaters (except for docks and other local service facilities) and the entrance channel portions of the project. The Alaska District, USACE, would visit the site periodically to inspect the breakwaters and perform hydrographic surveys at 3- to 5-year intervals for the dredged areas. The hydrographic surveys would be used to verify whether the predicted minimal maintenance dredging was warranted for the entrance channel and maneuvering areas. Maintenance requirements for breakwaters would be determined from the surveys and inspections. Local and Federal dredging requirements, if necessary, would probably be combined, so there would be only a single mobilization and demobilization cost.

The breakwaters were designed to be stable for the 50-year predicted wave conditions. Therefore, no significant loss of stone from the rubblemound structures is expected over the life of the project. It is estimated that in the worst case, 2.5 percent of the armor stone would need to be replaced every 25 years. Because stone quality would be strictly specified in the project construction contracts, little to no armor stone degradation would be anticipated. For the Recommended Plan, Alternative N-3, a quantity of 2,100 cubic yards of A-Rock would be required for replacement on the North and Spur Breakwaters at year 25.

Maintenance dredging would be conducted on an estimated 10-year cycle. The entrance channel and maneuvering area would require dredging of approximately 10,000 cubic yards. A dredged material management plan would be developed for the project in which a long-term disposal option would be identified. For purposes of this study, it is assumed that the entrance channel and maneuvering area material would be disposed of in the offshore disposal area east of the harbor. Clamshell bucket dredging equipment with a scow barge would likely be used for maintenance dredging. Dredged material characteristics should be easier to remove than construction dredging of the area, and no blasting would be required for maintenance.

Based upon preliminary operation and maintenance estimates, dredging would likely be performed at 10-year intervals. Sedimentation is expected at a rate of 1,000 CY per year. The dredging cost, approximately $30 per CY, would be less than the construction dredging unit price since this will be the removal of sand and gravel with no blasting requirements. Approximately 2.5% of the armor stone will need to be replaced every 25 years. The Operations, Maintenance, Repair, Replacement, and Rehabilitation (OMRR&R) cost based on these assumptions is $7.1 million for the Recommended Plan, Alternative N-3 (Appendix C).

7.8 Integration of Environmental Operating Principles

The following environmental operating principles have been integrated into the planning process:

Foster sustainability as a way of life throughout the organization: This project would increase access and moorage days, fostering a sustainable subsistence-cash economy utilizing marine resources in the Bering Sea. The future without-project condition sees continued vessel delays and damages with the dangerous physical conditions in the existing harbor at Zapadni Bay. By constructing the Recommended Plan, these negative impacts on the fishing fleet and St. George’s economy could be reduced.

Proactively consider environmental consequences of all Corps activities and act accordingly: Environmental consequences were considered throughout the planning process, and every effort has been made to avoid, minimize, or mitigate all anticipated impacts. These mitigation actions were coordinated with USFWS and are described in the Fish and Wildlife Coordination Act Report (FWCAR) dated 1 Oct 2019 (Appendix J).

Create mutually supporting economic and environmentally sustainable solutions: No NED plan was identified for this project, but the Section 2006 authority affords the PDT the flexibility to use CE/ICA in the absence of a NED plan. The Recommended Plan, Alternative N-3, is a best buy plan based on the CE/ICA. This project was formulated in a way that makes it lasting, requiring limited maintenance and avoiding long term environmental impacts wherever possible. The sediments removed from the mooring basin and navigation channel would be placed in ocean waters north of the project area. The placement would be designed to create habitat for blue king crab. The District has identified a suitable dredged material placement location approximately one mile offshore.

Continue to meet our corporate responsibility and accountability under the law for activities undertaken by the Corps, which may impact human and natural environments: A full environmental assessment (EA) has been conducted as required by the National Environmental Policy Act (NEPA). In addition, a draft Finding of No Significant Impact (FONSI) was prepared. The principles of avoidance, minimization, and mitigation would be enacted to the extent possible.

Consider the environment in employing a risk management and systems approach throughout the life cycles of projects and programs: For this study, extensive coordination has taken place to determine the impacts and subsequent mitigations actions regarding environmental impacts.

Leverage scientific, economic, and social knowledge to understand the environmental context and effects of Corps actions in a collaborative manner: USACE worked closely with the City of St. George throughout this study. The City and other agencies that work on St. George are very knowledgeable about the environment surrounding the North Anchorage site. Coordination with agencies is on-going and may be completed in PED, per the Corps policy waiver regarding MMPA/ESA consultation during feasibility, which was approved on 03 March 2020.

Employ an open, transparent process that respects the views of individuals and groups interested in Corps activities: USACE made every effort to be responsive to stakeholder concerns. Public input was solicited and used for both environmental and economic analysis purposes. A meeting was held before this study started to gain feedback from commercial fishermen, the City, and stakeholders on what problems the community faces and the impacts on marine activities with the existing harbor at Zapadni Bay. The group defined objectives, opportunities, and constraints for this study and discussed alternative ideas. After a re-scoping effort and the removal of Zapadni Bay as a viable harbor improvement location, the team analyzed four North Anchorage alternatives and used these as the final array to determine the Recommended Plan (Sections 5.5.9 to 5.5.12). The draft EA was released for a 30-day public comment period on 12 December 2020. No public comments were received. The NMFS reviewed the EA and had no additional comments. Five USFWS comments were received and are stated in Section 9.1.

7.9 Real Estate Considerations

There are no other existing federal projects that lie fully or partially within the lands, easements, rights-of-way, and relocations (LERR) required for this project.

Per 33 Code of Federal Regulations (CFR) § 329.4, navigable waters of the U.S. are those waters that are subject to the ebb and flow of the tide and/or are presently used, or have been used in the past, or maybe susceptible for use to transport interstate or foreign commerce.

Navigation Servitude will apply laterally over the entire surface of the water-body and is not extinguished by later actions or events that impede or destroy navigable capacity. The Government's dominant right of navigation servitude will be exercised for project tidelands below the MHW line.

7.9.1 Land Acquisition

LERR necessary to implement this project are lands owned by the City of St. George, and St. George TANAQ Corporation (**Error! Reference source not found.**). The overnment's dominant right of navigation servitude would be exercised for project tidelands below the MHW line for the general navigation features (GNF).

Table 18. LERR Required for Recommended Plan.

Project Tract ID	Features	Owners	Acres	Standard Estate
15	-20"" MLLW Maneuvering Basin	State of Alaska	8.	Navigation Servitude
13	-25"" MLLW Entrance Channel	State of Alaska	15	Navigation Servitude
10	Construction Area	NFS	0.27	Temporary Easement Estate #15
11	Construction Area	Private	0.058	Temporary Easement Estate #15
17	Material Disposal Site – Water (Bering Sea)	State of Alaska	650	Navigation Servitude
09	North Breakw ater	NFS	0.48	Permanent Easement Estate #8
08	North Breakw ater	Private	0.41	Permanent Easement Estate #8
12	North Breakw ater	State of Alaska	7.69	Navigation Servitude
14	Spur Breakw ater	State of Alaska	0.81	Navigation Servitude
16	Staging Area	Private	3	Temporary Easement Estate #15
18	Zapadni Bay Staging Area	Private/ Leased to NFS	4.8	Temporary Easement Estate #15
01	Access Road	Private	0.061	Temporary Road Easement Estate #11
02	Access Road	Private	0.19	Temporary Road Easement Estate #11
03	Access Road	NFS	0.075	Temporary Road Easement Estate #11
04	Access Road	NFS	0.075	Public Road
05	Access Road	NFS	0.0013	Temporary Road Easement Estate #11
06	Access Road	Federal Gov.	0.054	Temporary Road Easement Estate #11
07	Access Road	NFS	0.00095	Public Road
Project Boundary	**North Harbor Site** **Staging Area** **Zapadni Bay Staging Area** **Beneficial Use Dredge Material Placement Area**			**62.48 AC** **3.00 AC** **4.80 AC** **650.00 AC**

7.10 Risk and Uncertainty

There are three remaining risks and uncertainties for this study, two moderate and one high risk (Table 19). The high risk is based on the uncertainties of blasting during construction and impacts to the schedule based on environmental construction windows. In addition, the OMRR&R requirements of the Recommended Plan are unknown due to the lack of sedimentation data currently available for the North Anchorage site.

The dredging characteristics of the bottom material at the North Anchorage site are not well known. Large boulders on the shoreline could be representative of bottom conditions, but it is not known whether material within the dredge prisms under consideration are sands and gravel, cobbles and boulders, or bedrock. The characteristic of this material greatly affects the requirements for dredging, and it is currently assumed that confined underwater blasting and mechanical removal is required. Blasting restrictions due to the presence of marine mammals also presents a construction schedule risk. The proposed construction methods essentially assume worst case conditions and costs are based on a requirement to blast 100% of the material to be dredged. It is possible that other methods of removal, ripper tooth or heavy clamshell would work so the current assumption is conservative.

A subsurface investigation was not performed during feasibility. The stability and settlement of the breakwater was analyzed based on bedrock being encountered approximately 10 feet below mean low water. If the average depth of bedrock is deeper than 10 feet below mean low water, a larger structural section will be needed to extend the breakwater to bedrock. The depth of bedrock is an unknown and could increase the cost of materials and construction of the proposed breakwater. Should sort material be found at the site during subsequent geotechnical investigations, the breakwater design would need to be altered to include different filtering criteria and potential design for settlement. These changes would increase project cost but are considered unlikely.

The rate of sediment movement at the North Anchorage site is not well known. There is insufficient data at this site to make a direct analysis of sediment transport. Future maintenance needs could be substantially different from those estimated in this study.

Mitigation concepts such as those that define the timing window for confined underwater blasting, the development of a spill response plan, placing limitations upon vessel speeds and maneuvering, and the development and implementation of a biosecurity plan prior to construction activities have been included in the avoidance and minimization strategy of more than one interagency coordination process are listed in Section 8.9.2 (Table 22). This table also identifies which measures will be undertaken by the NFS.

Despite the relatively conservative avoidance measures, USACE has in the Draft Biological Assessment that the proposed action "may affect and is likely to adversely affect" ESA-listed marine mammals, and the formal ESA consultation procedures established by 50 CFR 402 et seq. are triggered, which would lead to the development of a Biological Opinion by NMFS. USACE intends to collect the data required to apply for an LOA during the project’s PED phase, which would provide more detail regarding the specific impacts to marine mammals, including ESA-listed marine mammals. Avoidance, minimization, and mitigation measures to reduce these impacts would also be developed, in consultation with NMFS, along with the predicted number of marine mammals that could be taken by harassment. The final mitigation measures for the Recommended Plan cannot be presented prior to the development of the LOA in PED. The Alaska District requested a waiver of USACE policy requiring the District to complete the consultation in feasibility, based on the need for additional time to finish environmental compliance beyond the timeline of the feasibility phase. The waiver was approved on 03 March 2020. Due to the work that would be continuing in PED for environmental compliance and the final determination of the blasting/construction window as a minimization measure, the PDT has made a risk-informed decision to carry forward this high risk item and address it by capturing the unknown with a project cost contingency of 25 percent. The Cost Schedule Risk Analysis (CSRA) developed with input from the PDT was used to develop the contingency for this high risk item (Appendix D). This contingency has been reduced from the 39 percent presented at the TSP Milestone with input from the PDT based on the additional information collected for H&H (FUNWAVE and BOUSS2D) and the Environmental surveys conducted in June 2019.

Table 19. Risks and Uncertainties.

Risk	Work to Date	Future Work	Timing
Delays to the schedule: – 13 May 20 transmittal gives HQ 3 months to Chief's Report (less time to complete State & Agency (S&A), etc)	– Re-scoped schedule	– S&A Review	Feasibility
Not completing Environmental compliance in feasibility.	– Coordinating with Agencies – Received USACE policy waiver permitting POA to conduct MMPA/ESA consultation during PED, 03 March 2020	– Complete Biological Opinion – Seek LOA	PED
Aligning blasting/construction schedules and biological windows of sensitive species	– District is coordinating with Agencies for FWCA and discussed avoidance and minimization measures	– Determine cost impacts to the project – Continue coordination with Agencies and the Vertical Team – Implement mitigation measures	PED/ Construction

7.11 Project Cost

Cost analyses indicate that the Recommended Plan would have an average annual equivalent cost of approximately $7 million. Maximum annual benefits for the Recommended Plan are estimated at $1.1 million. Total certified project first cost with contingency is $159.8 million.

7.11.1 Cost Apportionment

Section 101 of WRDA 1986, as amended, states that during construction, the project would be cost shared 90 percent Federal and 10 percent non-Federal for the cost of design and construction of the general navigation features attributable to dredging to a depth, not in excess of -20 feet MLLW, plus 75 percent Federal and 25 percent non-Federal for the cost of design and construction of the general navigation features attributable to dredging to a depth in excess of -20 feet MLLW but not in excess of - 50 feet MLLW. The NFS would pay with interest, over a period not to exceed 30 years following completion of the period of construction of the project, up to an additional 10 percent of the total cost of construction of the general navigation features. While the NFS owes an additional 10 percent of the cost of the general navigation features, this amount may be reduced by LERRD which the NFS proves as necessary for the general navigation features. Local service facilities are a sole non- Federal funding and performance responsibility.

The Total Project Cost Summary (TPCS) is included in Appendix D. Project cost contingency was calculated from the CSRA (Appendix D). The Federal and Non-Federal cost apportionment was broken out by line items from the TPCS to calculate estimated total contributions by entity (Table 20).

Table 20. Cost Share Breakdown.

(October 1, 2019 Price Levels, Program Year (FY) 2020)[1]						
WBS Number	General Navigation Features	Project Cost	Contingency[2]	Project Cost w/ Contingency	Federal Share	Non-Federal Share
10	Breakwater	$87,684,000	$21,921,000	$109,605,000	$98,644,500	$10,960,500
12	Navigation Ports and Harbors[3]	$25,275,000	$6,319,000	$31,594,000	$26,865,300	$4,728,700
30	Preconstruction, Engineering & Design (PED)[4]	$5,797,000	$1,449,000	$7,246,000	$6,448,900	$797,100
31	Construction Management (S&I)[4]	$9,054,000	$2,264,000	$11,318,000	$10,073,000	$1,245,000
	Subtotal Construction of GNF	**$127,810,000**	**$31,953,000**	**$159,763,000**	**$142,031,700**	**$17,731,300**
1	Lands, Easements, Right-of-Ways, Relocations (LERR)[5- Federal]	$0	$0	$0	$0	$0
1	Lands, Easements, Right-of-Ways, Relocations (LERR)[5- Non-Federal]	$60,000	$15,000	$75,000	$0	$75,000
	Total Project First Costs	**$127,870,000**	**$31,968,000**	**$159,838,000**	**$142,031,700**	**$17,806,300**
12	Aids to Navigation[6]	$73,000	$18,000	$91,000	$91,000	$0
	Credit for Non-Federal LERR[7]	$0			$0	-$75,000
	10% GNF Non-Federal[8]	$0			($15,976,300)	$15,976,300
	Total Cost Apportionment	**$127,943,000**	**$31,986,000**	**$159,929,000**	**$126,146,400**	**$33,707,600**

1. Cost is based on Project First Cost (constant dollar basis) on Total Project Cost Summary Spreadsheet, at an effective price level 1 Oct 2019 (FY20) (Cost Appendix). Aids to Navigation broken out and shown as a separate cost.
2. A contingency of 25 percent has been applied to each cost item.
3. Federal and non-Federal breakdown of costs reflect the change in cost share responsibility from 90% Federal/10% non-Federal for the basin and channel up to -20ft MLLW, to 75% Federal/25% non-Federal for the channel for -20 ft to -25ft MLLW.
4. PED and Construction cost sharing totals account for the change in cost share responsibility from 90% Federal/10% non-Federal for the basin and channel up to -20ft MLLW, to 75% Federal/25% non-Federal for the channel for -20 ft to -25ft MLLW.
5. These are Real Estate administrative costs. There are no actual lands and damages but per USACE regulations, Real Estate administrative costs will be placed in the 01 account. Additional Real Estate costs will be cost shared according to the GNF. Escalation from the TPCS accounts for some numerical differences.
6. Aids to Navigation are reflected as a Federal cost, but are coordinated and paid for by the U.S. Coast Guard.
7. Credit is given for the incidental costs borne by the NFS for lands, easements, rights of way and relocations (LERR) per Section 101 of WRDA 86, not to exceed 10% of the GNF
8. The NFS shall pay an additional 10% of the costs of GNF of the NED plan, pursuant to Section 101 of WRDA 86. The value of LERR shall be credited toward the additional 10% payment except in the case of LERR for GNF.

7.11.2 Schedule

The study schedule for the feasibility phase is based on a 58-month timeline per the time waiver (3x3 exemption) approved by the ASA(CW) on 07 February 2019 (Table 21). A USACE policy wavier, permitting POA to conduct MMPA/ESA consultation during the Preconstruction, Engineering and Design phase was approved on 03 March 2020 (Appendix E).

Table 21. Study Schedule.

Title	Date
Execute FCSA	15-Oct-15
Planning Charette	12-13 Jan 2016
Alternatives Milestone	29-Sep-16
TSP Milestone	18-Apr-18
Draft EA released for public and agency comment	12-Dec-19
Start DQC	6-17 Jan 20
Evaluate DQC comments in DrChecks	21-31 Jan 20
ADM	31-Jan-20
Back-check DQC and close comments *	3-7 Feb 20
ADM MFR	7-Feb-20
ATR kick-off meeting	11-Feb-20
Start Final ATR and ATR team submits comments	12-26 Feb 20
PDT evaluates ATR comments	27 Feb -10 Mar-20
ATR team back-checks and close out comments	9-17 Apr-20
ATR Lead develops ATR Cert	17-24 Apr-20
Cost Certification	21-Apr-20
Final ATR Certification	01-May-20
POA Legal Review (and PDT respond to comments) for Final package	27 Apr -8 May 2020
MOA signed	06-May-20
Final Submittal	13-May-20
Senior Leader Brief	TBD June 2020
Signed Chief's Report to Congress	15-Aug-20

8.0 CONSEQUENCES OF THE RECOMMENDED PLAN

8.1 Physical Environment

The following sections describe the Recommended Plan's impacts on the physical environment.

8.1.1 Water Quality

Under Alternative N-3, impacts to water quality would be moderate and temporary. Impacts would likely come from increased turbidity in the area of disturbance as a function of construction and other project-related activities such as drilling, blasting, dredging, and placement of dredged material. Impacts on water quality could also be caused by project runoff and an increased probability of inadvertent release of environmentally persistent compounds over time.

Water quality at North Anchorage would be impacted by increased turbidity levels associated with drilling, blasting, and dredging. These impacts would be most apparent during or immediately after each of these iterations before wave action, and sediment fallout would return water turbidity levels to ambient conditions. Sediment characteristics at the site suggest that due to its high energy and likely high percentage of bedrock, sediment fallout would be rapid. Despite multiple iterations of drilling, blasting, and dredging required to implement the proposed project, impacts to water quality as a result of turbidity would not be long-lived.

Water quality at the dredged material placement site would be impacted by increased turbidity. Each placement would release approximately 2,500 CY of material from the dredge scow into the water column at the designated site. The mechanical action of sediments sinking through the water column would liberate finer particulate materials and set them adrift in the prevailing current, while those heavier sediments would impact the ocean floor and dislodge and expose finer sediments to the deep water current. Approximately 150-170 individual scow trips would be required to transport the entire dredge prism to the placement site. Water quality would be expected to be temporarily impacted in each case; however, turbidity values would decrease rapidly, the impact would be highly localized, and the interval between placements longer than the time required for turbidity to return to ambient levels. The impact on water quality of the Bering Sea or even the span of such that separates St. George and St. Paul would be negligible.

Runoff from the disturbed and exposed ground in proximity to or associated with the proposed project site represents a more likely source of fine particulate material that could impact water quality due to turbidity. St. George's coastal wave climate and currents would effectively dilute impacts from this source of turbidity, but would not be necessary if an appropriate stormwater pollution prevention plan were implemented to reduce such impacts. Impacts from project-related runoff would be minor with the implementation of a comprehensive stormwater pollution prevention plan.

Indirectly, in-water construction actions; short- and long-term petroleum, oil, and lubricant utilization and storage; increased vessel activity; and increased anthropogenic activity would increase the probability of an inadvertent release of compounds that could negatively affect water quality. Impacts on water quality as a result of such a release would be lessened by an appropriate spill response plan (both on land and at sea), a hazardous materials management plan, and the enforcement of safe navigational procedures into and away from the project site. Through appropriate planning and procedure, potential impacts to water quality through the inadvertent release of environmentally persistent compounds would be negligible.

Long-term impacts on water quality as a result of implementation of Alternative N-3, specifically the placement of the breakwater structure, would be negligible. St. George is quite isolated within the Bering Sea and exposed to hundreds of miles of fetch in all directions, resulting in a rigorous nearshore wave climate. Sea surface temperatures in the central Bering Sea are relatively cold year-round (approximately 29 degrees Fahrenheit during the winter and less than 55 degrees Fahrenheit during the summertime). When considered in conjunction with the vigorous ambient wave and wind action, the cold nearshore waters are likely near saturation for dissolved oxygen at all times, particularly in the intertidal zone. Dissolved oxygen saturated seawater is expected to diffuse through the porous breakwater structure into the mooring basin via continuous wave action. In a similar fashion, nearshore surface and sub-surface currents and St. George's diurnal tidal cycle would facilitate seawater circulation within the inner basin. Frequent storm activity, as generally occurs in the central Bering Sea would also influence the dissolved oxygen and rate of seawater exchange in the inner Basin. Short-term temporary impacts to water quality in the form of localized increased turbidity levels would be expected to occur as a result of the implementation of Alternative N-3. Implementation of best management practices regarding stormwater pollution prevention, safe material storage, and safe navigation practices would ensure that the potential impact on water quality would be reduced as much as practicable.

8.1.2 Sediments

Under Alternative N-3, impacts to sediments would be short in duration but, in some cases, disruptive. Approximately 353,052 CY of marine sediments within the project footprint would be subject to drilling, blasting, dredging, compression, and hydraulic and atmospheric processes. Approximately 45,000 CY of these sediments could be incorporated as fill into the project's inner harbor facilities, while the remaining would be placed between the 20 and 30-fathom contours, approximately one mile offshore to the north. A proposed in-water disposal site has been identified north of the harbor location (Figure 29).

Initially, sediments would be fractured and pulverized during drilling and blasting; these forces would also expose sediments to wave and current action, which may mobilize some sediments or cause others to fall out of suspension. Sediments would be compressed and compacted during dredging operations, creation of the area for inner harbor facilities, and placement of dredged materials at the beneficial use site.

Sediments placed at the dredged material placement site would be subject to the prevailing currents in the water column as they descend towards the bottom. Similarly, disturbance of those bottom sediments would occur as each iteration of placement occurs. Some sediments in these areas would be mobilized by such disturbance and later redistributed by the prevailing current.

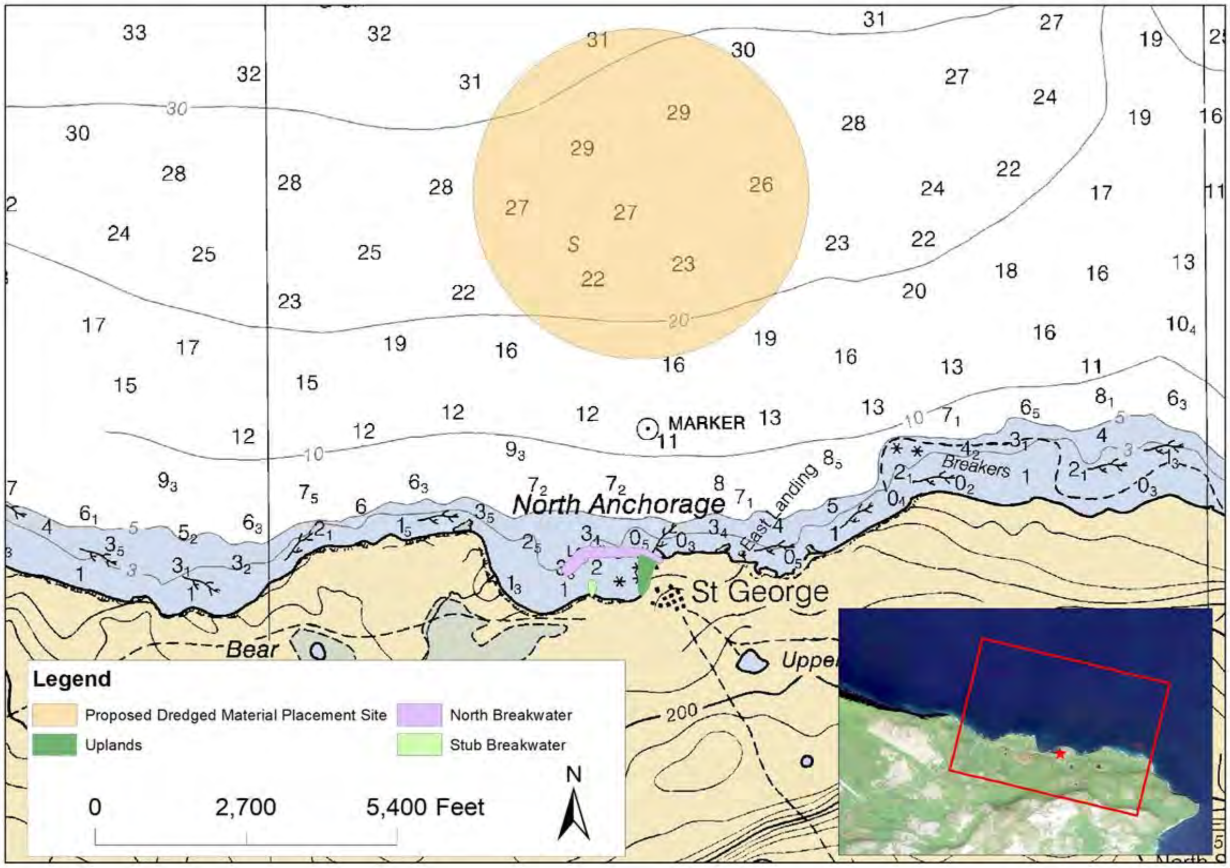

Figure 29. Dredge Material Placement Site.

Sediments used to create the area for inner harbor facilities may be subject to atmospheric weathering processes that cause them to degrade further or cause smaller particulate sediments to mobilize back into the marine environment where they may generate a short-lived and localized plume of suspended sediments. Wave action is rigorous enough at the project site that suspended sediments would be dispersed effectively, or they would fall out of suspension and be incorporated into the littoral sediment budget. These processes would be expected to subside over time.

Newly exposed shoreline sediments may be indirectly affected over the long-term by the implementation of the project and may experience reduced capacity for mobilization as the project's two breakwaters would likely reduce the wave energy allowed to come into contact with those sediments behind it. Similarly, those areas of protected waters behind the breakwater would likely facilitate suspended sediments to fall out and accumulate.

Implementation of Alternative N-3 would likely have a disruptive impact on sediments in the short-term. However, these impacts would be expected to dissipate and ultimately result in a minimal long-term impact on sediments.

8.1.3 Noise

Under Alternative N-3, impacts from project-related noise would be moderate, and are best categorized as in-water and atmospheric. Certain point source entities would be capable of generating noises or sound pressure levels that would impact both media at the same time, especially if they are operating at or near the atmospheric / in-water interface.

Short-term direct impacts on ambient atmospheric noise levels would occur at their highest intensity during the construction phase of the project, which could occur at least seasonally for approximately 3- 5 years. The operation of heavy equipment such as loaders, excavators, cranes, dump trucks, and impact pile drivers during construction could occur at times in 24-hour shifts to take advantage of seasonal daylight periods. Concurrently, the operation of drilling and dredging barges, confined underwater blasting, active dredging, keying in armor stone (placement), and impact pile driving would contribute to the overall impact on the ambient atmospheric noise. Impacts to ambient atmospheric noise levels would also occur at the existing Zapadni Bay harbor and along the roadway that connects that harbor and the town of St. George. Increased barge traffic ferrying equipment and raw construction materials would likewise require additional over-ground transport via heavy equipment to the proposed project site that would periodically impact ambient noise levels.

Similar short-term direct impacts to ambient in-water noise levels would occur at their greatest intensity during the drilling and blasting of the maneuvering basin and entrance channel, and presumably less so during dredging, barge operation, pile driving, and breakwater construction activities. Impacts would likely be seasonal, but would not necessarily occur at the same time as the creation of the area for inner harbor facilities; project elements that generate in-water noise would be subject to specific windows of time or restrictions due to their propensity to potentially harass marine mammals.

Long-term impacts on atmospheric and in-water ambient noise levels as a result of the implementation of Alternative N-3 would likely be in the form of those noises produced as a result of increased vessel traffic and operation of attendant dock-side support equipment. If implemented commercial and subsistence vessel traffic would be reasonably expected to increase as well, which would moderately affect the ambient baseline of the in-water and atmospheric noise profile at Village Cove.

Impacts on both atmospheric and in-water ambient noise levels would be most severe in the short-term; however, it would decrease over time as the largest construction features were completed. In the longer term, however, the acoustic baseline would come to resemble that of a small boat harbor. Conservation measures directing the specific timing of major construction elements would likely reduce potential impacts to in-water ambient noise levels. Overall impacts on ambient noise at St. George would be moderate.

8.2 Biological Resources

The following sections describe the Recommended Plan's impacts on biological resources.

8.2.1 Marine Birds

Under Alternative N-3, marine birds that nest along the ledges of the cliff face that comprises Village Cove's southern margin would likely be impacted by disturbances associated with the timing and intensity of construction activities, and again by the long-term operation of the proposed harbor.

Cliff-nesting marine birds would be present in, and in close proximity to the proposed project area in high densities beginning in the months of April and May, and lasting until October and possibly November. During this period, cliff-nesting marine birds socialize, select nesting sites, make foraging trips out to sea, stage in large numbers in the nearshore areas, engage in courtship rituals, lay and incubate eggs, and care for and fledge their young. Marine birds linger here until seasonal weather and food abundance patterns change, triggering migration to the open ocean. Cliff-nesting marine birds are sensitive to anthropogenic disturbance, such as the intensive construction actions required by Alternative N-3. Impacts associated with such disturbance would likely cause birds to startle off of their nest ledges, cause loss or abandonment of eggs or chicks, result in failure to establishing nests, and relocate to sub-optimal nesting habitat. Therefore, impacts associated with drilling, confined underwater blasting, proximal dredging and material placement, and construction of the spur breakwater during the birds' high nesting period would be avoided to the greatest extent practicable. Alternative N-3 is estimated to require three to five years to implement. The duration of implementation is a function of seasonal work windows and would most likely be applied to specific activities. This would conflict with the conservation of marine mammals and cliff-nesting marine birds.

Long-term impacts to marine birds that nested at the Village Cove cliff site would be unavoidable once the harbor becomes operational. However, the intensity of the impact would be reduced from those impacts expected during the construction phase of the project. Intermittent vessel traffic, artificial lighting, tall structures, the sights and sounds of a functioning harbor, and an increased anthropogenic presence could make some birds abandon nest sites at Village Cove or could impact birds through direct interaction (i.e. disruption of nearshore staging behavior, collisions with equipment, and ingestion of refuse). However, these impacts would likely be reduced through the implementation of a harbor management plan that would make provisions for trash management, emergency spill response, and lighting discipline. Development and implementation of a harbor management plan would be the responsibility of the non-Federal Sponsor. The harbor management plan would include the responsibility to implement the biosecurity plan after harbor construction is completed. Some birds could acclimate to the disturbance over time and could be less affected by harbor operations.

Indirect impacts to cliff-nesting marine birds as a result of construction and eventual harbor operation include the inadvertent release of invasive species, increased presence of plastic debris and trash, and a likely increase in the inadvertent release of environmentally persistent compounds. However, these and some direct impacts to cliff nesting birds would be reduced through the application of avoidance and minimization actions that USACE coordinated with USFWS during the Fish and Wildlife Coordination Act process such as the development and pre-construction implementation of a biosecurity plan, no destruction of cliffside nesting habitat, and the observance of a 330' construction buffer. The cliffs at Village Cove represent less than 1% of available suitable nesting habitat on St. George Island. Mitigation measures that would offset the timing of major construction actions with the majority presence of marine birds would result in only minor impacts to marine birds.

8.2.2 Fish and Essential Fish Habitat

Under Alternative N-3, fish and their corresponding EFH would be moderately impacted by in-water construction-related activities: drilling, blasting, dredging of sediments, and the placement of dredge sediments and breakwater structures. To achieve project depths, 353,052CY of material would be removed, these sediments would be placed approximately one mile to the north of the project in 120-180 feet of water and the placement would create rocky reef type habitat for blue king crab (Figure 29). Placement of the North breakwater rock would represent the loss of about 8.3-acres of poorly characterized subtidal habitat, replacing it with relatively steep, rocky subtidal, intertidal, and supratidal habitat. The spur breakwater would convert about 0.8-acres of rocky intertidal and sub-tidal habitat to a more vertically structured habitat similar to the North Breakwater. The area for the inner harbor facilities would convert about 4.0-acres. Overall, the conversion of these habitats represents a permanent increase in the complexity of the habitat.

Drilling the bedrock in preparation for blasting would be a temporary mechanical and audible disturbance to fishes in the waters of Village Cove. Some fish may refuse to tolerate such disturbance and move to similar habitat within St. George's nearshore areas. However, some fishes may not be able to move to unaffected habitat due to size, habitat preference, lack of motility, or risk of predation, and would be subject to temporary audible and mechanical disturbance. Fishes unable to avoid exposure to drilling and blasting may suffer decreased fitness.

Confined underwater blasting would be a temporary, yet pervasive impact to fishes, likely resulting in the immediate death or mortal injury of those fishes within the highest energy blast radius. Similarly, fishes exposed to non-lethal blasting energy may alter their inherent behaviors associated with feeding predator evasion and communication, or they may seek to avoid the waters of Village Cove entirely. Conversely, the effects of blasting, the mortality of some fishes, could serve as a nuisance attractant for other fishes. Physical characteristics of the submerged habitat at Village Cove would be permanently impacted as successive blasting iterations deepened and shaped the navigation features of Alternative N-3.

Village Cove's depth contours and epibenthic habitat features would be permanently impacted by dredging activities. Fishes that are in and amongst the substrate during dredge operations would be at risk of injury or mortality. However, some fishes may not tolerate acoustic and mechanical disturbance generated by the dredging actions and would move from the area to suitable adjacent habitat. Dredging would be temporary in nature, yet its effects upon the depth at Village Cove would be permanent.

Dredge material placement represents a temporary disruptive impact to fish and their habitat along the seafloor at the proposed placement area. Some fishes may be crushed by successive barge scow-loads of dredged material from the Village Cove area. Rocky and similar sediments would be expected to disturb some fish as they impacted the seafloor and liberated sediments into the water column. Some fishes may be displaced by the creation of the dredge material placement site because soft-bottom habitat would be replaced by rocky reef-type habitat. However, the creation of rocky reef-type habitat where none previously existed would be expected to be beneficial to juvenile blue king crab and other species that utilize interstitial spaces during their life history. Rocky substrate similarly facilitates colonization by invertebrates and marine algae.

Placement of the breakwater structures would have a permanent impact on fish and their habitat because it would reduce wave energy to the waters behind it. Some fishes may find advantages in such reduced energies, while others may migrate to more suitable habitat conditions nearby. The breakwater structures would also act as rocky reef habitat and provide an appropriate substrate for invertebrates and marine algae colonization. Similarly, interstitial spaces created by boulder-upon-boulder placement would be beneficial for fish species that utilize such habitat during any portion of their life history. Placement of the breakwater structures would be a temporary disruptive impact to fishes throughout the nearshore water column of Village Cove. Fishes may choose to abandon the area influenced by the disturbance for similar, undisturbed habitat nearby.

Potential impacts to EFH and EFH-managed species/species complexes are likely to be highly localized, temporary, and minimal, and would not reduce the overall value of EFH in the Bering Sea. Mitigation measures have been developed as a function of the USACE's EFH assessment and subsequent coordination with NMFS Alaska Region Habitat Division subject matter experts (Appendix H). These would be implemented to reduce or offset the potential unavoidable impacts of USACE activity. The construction of a reef intended to provide habitat for blue king crab would represent a substantial beneficial impact of the project. Therefore, the USACE concludes that its Federal action may affect, but is not likely to adversely affect EFH and EFH-managed species/species complexes for BSAI groundfish, crab, and Alaska stocks of Pacific salmon. Potential indirect effects to fish and EFH have not been identified; furthermore, a significant reduction of their habitat would likely not be expected to occur as the remaining 98% of St. George's nearshore habitat is unaffected by anthropogenic development.

8.2.3 Marine Invertebrates

Under Alternative N-3, long-term impacts on marine invertebrates would range from negligible to beneficial. Approximately 353,052CY of material will be removed to achieve targeted project depths, these sediments would be placed approximately one mile to the north of the project in 120-180 feet of water and the placement would be designed in such a way as to create rocky reef type habitat for blue king crab (Figure 29). Placement of the North breakwater would represent the loss of about 8.3-acres of poorly characterized subtidal habitat, replacing it with relatively steep, rocky subtidal, intertidal, and supratidal habitat. The spur breakwater would convert about 0.8-acres of rocky intertidal and sub-tidal habitat to a more vertically structured habitat similar to the North Breakwater. The area for the inner harbor facilities would convert about 4.0-acres. Overall, the conversion of these habitats represent a permanent increase in the complexity of the habitat. Overall, implementation of Alternative N-3 would be expected to last approximately 3 to 5 years. Marine invertebrates would be temporarily impacted by in-water project-related actions that alter the geometry of, fracture, dislodge, crush-together, cover, and/or bury the sediments and substrates that they use for attachment, cover, feeding, egg-laying, and breeding.

Impacts to marine invertebrates would occur during all phases of in-water construction: drilling, confined underwater blasting, dredging, dredged material placement, construction of the breakwater structures, and inner harbor facilities. Many invertebrates, with the exception of some cephalopods, lack the innate motility to extract themselves from acute disturbance quickly. As such, impacts from project-related in-water construction activities would pulverize, crush, dislodge, increase susceptibility to predation, and injure or kill invertebrates within the proposed project area. Construction-related impacts would be temporary, likely occurring seasonally over an approximately 3 to 5 year period. Indirect impacts to marine invertebrates include those associated with the long-term operation of the harbor and the increased probability of the inadvertent release of environmentally persistent compounds.

Permanent impacts on marine invertebrates resulting from the implementation of Alternative N-3 include decreased wave energy and increased depth in the harbor entrance channel and mooring basin behind the breakwater structure and an overall increase in the quantity of rocky reef-type substrate at the breakwater and dredged material placement areas. Despite being permanent, over time, these impacts would likely be beneficial to some marine invertebrate communities by providing suitable substrate and structure for colonization. Similarly, over time, and despite alterations to the existing habitat, invertebrate communities would recover to some degree of equilibrium in the inner basin and at the dredged material placement site. Organisms generally precluded from the surf and intertidal zones may find the deeper, calmer waters of the inner basin suitable for settlement, while at the material placement area, those species whose life history is dependent upon rocky reef type habitat would be expected to colonize the habitat and eventually reach some degree of equilibrium. In total, USACE would expect invertebrate community compositions at the affected habitats to change over time following the implementation of the project. However, USACE acknowledges that its data concerning the intertidal and subtidal marine invertebrate community at the Village Cove site is limited and that the exact scenario and rate at which the affected habitats might become recolonized is unknown.

8.2.4 Marine Mammals, Endangered Species, and Critical Habitat

Under alternative N-3, impacts to marine mammals would be moderate and would likely result in temporary exposure to sounds or equipment that may cause them to alter their natural behavior. Marine mammals, and threatened or endangered species would be impacted by construction activities, shipping, and logistical activities, and the long-term operational activities of the harbor itself. Marine mammals are seasonally abundant in the waters of St. George, but it is important to note that this abundance is largely due to the presence of northern fur seals near rookeries during late spring, summer and fall. Accordingly, most of the overall abundance around St. George is represented by a single species (fur seals) that primarily occur in localized areas (most near rookeries) and are present during only a portion of the year. Other marine mammals, such as humpback or minke whales, occur in far lower numbers within a much larger area and are most abundant during the summer. Ice seal (ringed, ribbon, spotted, and bearded seals) abundance and distribution near St. George is poorly understood, but is generally influenced by the seasonal extent of the ice edge and thus their potential exposure is influenced by the time of year, weather, and variable prey distribution patterns. While these seals are ice-associated, it is not uncommon for many of them to be found well south of the sea ice edge and thus be present, in small numbers, near the project site during some portion of winter construction. Adverse modification of Steller sea lion critical habitat would not be expected to occur from project actions.

Under the MMPA, the harassment of marine mammals is both prohibited and plainly defined. “Harassment” means the act of pursuit, torment, or annoyance which (A), has the potential to injure a marine mammal or marine mammal stock in the wild; or, (B), has the potential to disturb a marine mammal or marine mammal stock in the wild by causing disruption of behavioral patterns, including, but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering. These definitions (A), and (B), are commonly referred to Level A and Level B harassment parameters, respectively, and are utilized by NMFS and USFWS as defining parameters for determining the severity of an impact to marine mammals or their stocks in the wild. NMFS has published guidance concerning the sensitivity of marine mammals to explosive underwater sound pressure level exposure. NMFS utilizes known functional hearing groups among marine mammal species as its baseline for determining the severity of an exposure to specific sound pressure levels. Similar to humans, marine mammals may lose auditory sensitivity when exposed to intense sounds, which can be independent of exposure duration. The loss of such auditory threshold sensitivity can be temporary or permanent depending upon the level of exposure.

Confined underwater blasting, followed closely by pile driving, has been determined to be the project elements that could have the greatest potential in-water sound pressure impact upon all marine mammals in the area (regardless of ESA status), followed by dredging, dredge material placement, and vessel/harbor operation. USACE has determined that due to the extensive presence of northern fur seals in the proposed project's action area during the late spring to late fall timeframe, it would seek to avoid impacts through a conservative work window for its confined underwater blasting. Confined underwater blasting would be limited to the period from 1 November through 30 April. Although primarily concerned with reducing impacts on northern fur seals, conducting confined underwater blasting during winter months likely increases the probability of impacts to ice seals. Overall, due to habitat preference and close association with the sea ice, the potential impact to ice seals during the proposed work window would likely be far less than the impact on fur seals during the summer breeding season.

Because of the very low frequency of occurrence of Northern sea otters, USACE has determined that there would be no effect on this species from project-related activities. Short-term direct impacts to marine mammals from construction-related noise or equipment presence could cause them to temporarily alter their natural behavior (foraging, surfacing for breath, diving, feeding of young, socializing, and transiting through an area). These types of effects are consistent with Level B harassment and approval for this level of harassment would be sought in the form of an LOA from NMFS. However, long-term direct impacts to marine mammals or their stocks, i.e., Level A harassment such as changes in seasonal distributions over a long period of time, or reduction of critical food resources, or barriers to migration or haul-out or rookery areas would not be likely as a result of the project because of its relatively small footprint within the greater region of the central Bering Sea and because of the proposed mitigation measures.

Indirect impacts to marine mammals may include those that occur as a result of placement of the breakwater structures. Some marine mammals would likely choose to haul-out on such structures. Reduced wave energies in the maneuvering basin could serve as an attractant for some marine mammals, particularly juvenile fur seals; this would expose or habituate these animals to the increased anthropogenic presence in the harbor itself leading to the possibility of acute impact if there were an inadvertent release of environmentally persistent compounds. Increased vessel traffic would also likely increase the probability of a vessel strike. Implementation of a spill response plan and guidelines for human/marine mammal interaction would reduce the severity of these potential impacts.

In summary, USACE expects to continue its coordination with NMFS throughout the LOA application process and formal ESA consultation process and expects that opportunities for creative implementation of avoidance and minimization measures would further lessen impacts to marine mammals resulting from the implementation of Alternative N-3. USACE further expects that through its collaborative coordination process with NMFS and USFWS, that through the implementation of avoidance and minimization measures and best management practices (BMPs) already identified, overall impacts to marine mammals would be moderate.

8.2.5 Invasive Species

Under Alternative N-3, a harbor and attendant facilities would be constructed. This would result in a short-term increase in air and sea traffic to the island during the construction process. During construction, heavy equipment, including barges, cranes, generators, loaders, etc., would be transported to St. George from elsewhere in Alaska. Similarly, material for the breakwater would be sourced off-island from sites in Alaska. Material and equipment sourced from off-island would have the potential to harbor and introduce species to St. George that are not native to St. George or the Pribilof Islands. During construction, a greater number of personnel on work crews would be transiting from mainland Alaska on a regular basis and increase the potential for transporting non-native species in supplies and clothing. Post-construction, there would be a long-term increase in air and sea traffic, which would carry the same risks described for the construction phase. Implementation of best management practices regarding the preclusion of invasive species would be expected to greatly reduce the likelihood of non-native species being introduced to St. George. Indirect effects related to invasive species would be unlikely.

8.3 Socio-Economic Resources

Under Alternative N-3, the socioeconomic paradigm within the community of St. George would be positively impacted. As such, impacts to the community's population and demographics, and employment and income would be likely to occur at some level in both the short- and long-term.

8.3.1 Population and Demographics

Facets of the community's population and demographics would be impacted by all aspects of the proposed project. Increased economic opportunity at St. George would likely impact the existing immigration to emigration ratio.

St. George has taken steps to ensure that the school is in a position to reopen if enrollment surpasses the minimum threshold of 10 students, such as has happened formerly in the remote Alaskan communities of Adak, Rampart, and Clarks Point. Steps the community has taken include continued upkeep and maintenance of the school and recruitment of families to the island.

8.3.2 Employment and Income

Significant portions of the construction work are likely to require heavy equipment operators, engineers, logistical specialists, and other well-paying positions. The project, as proposed, could take as long as 5 years or more to complete. Long-term operation of the harbor and efforts that support maintenance and oversight of those facilities would also likely generate employment opportunities.

An increase in transient laborers during construction and then more permanent-type positions during long-term harbor operations would beget requirements for support services. All of which would generate employment opportunities that may attract potential residents to St. George.

Indirect impacts could vary in scale or scope but could include the establishment of ecotourism, fish processing, marine repair, or similar type of business based at St. George.

8.3.3 Public Infrastructure

Under Alternative N-3, St. George's public infrastructure would be impacted by an increase in the number of personnel and type of equipment that would be utilizing it in order to implement the project. However, in its current state, the majority of St. George's existing public infrastructure is capable of handling an increase in utilization with only minor, temporary impact, including the existing harbor and facilities, road system, airfield, and St. George's solid waste management facilities.

St. George's existing harbor would be impacted by an increase in barge traffic, bringing construction-related equipment and raw materials to the island. However, these impacts would be temporary in nature and likely discountable because of its current state of underutilization.

St. George's main road from the existing harbor to the Village site, which is improved, but not paved, would be impacted by episodic increases in heavy equipment traffic, specifically when equipment and rock barges started arriving at the existing harbor and debarking their cargo for transference to the north side of the island. Some minor, yet temporary road repairs may be necessary as a result of the increased traffic, but they may not have as much impact on overall road quality as the annual weather regime does. These impacts would be temporary, but the added traffic could pose a collision hazard to local residents who frequently rely upon 4-wheelers as their preferred method of transportation around the local roads. Safe vehicle operation procedures such as the observation of speed limits and operating with hazard lights on would reduce the potential collision hazard of heavy equipment sharing the roadway with 4-wheelers.

St. George's existing airfield is currently underutilized, receiving few commercial and private aircraft per week. An increase in air traffic as a result of project construction or full project implementation would be easily supported, and represent only a temporary impact, In the long-term, the erosive forces of the Bering Sea's climate would have a more pronounced physical impact upon the airfield than a slight-to-moderate increase in air traffic.

St. George's solid waste management facilities are currently underutilized and would be only temporarily impacted by an increase in the solid waste stream generated by the project's construction activities. Full implementation of the proposed project would require dedicated long-term solid waste management support, but this is not expected to impact the existing condition of solid waste management on St. George.

Existing electrical and water distribution systems may require supplemental capacity or expansion of infrastructure to support project-related functions at either the existing harbor, which currently has no running water, or at the Village Cove project site, which has neither water nor power. BMPs would be incorporated into the construction plan to ensure appropriate fueling and fuel storage procedures. Currently, there is no supporting data to suggest that existing water and electrical delivery systems would be overtaxed by project-related activities that they could be reasonably expected to support.

Long-term impacts on St. George's public infrastructure are most likely to be those associated with the requirements of the harbor itself, the water and electricity that it would draw, and the solid waste management support that it would require. The harbor would essentially become its own public infrastructure asset and would have to be addressed as such with maintenance and upkeep, incremental modernization, and constant monitoring.

After project implementation, impacts to the public infrastructure would not be expected to attain the same level of intensity compared to when construction was actively occurring. The most recognizable direct effect to the existing public infrastructure would be the long-term demands and management of the new harbor. Indirect effects to public infrastructure could include increased air traffic, and an increase in overall traffic compared to the existing baseline. However, such increases would reasonably be expected to occur over an extended period of time. The weather and wave climate of the Bering Sea have traditionally stemmed travel and immigration to the Pribilof Islands and the implementation of Alternative N-3 would provide the community of St. George a reliable method of addressing increased demands upon their public infrastructure in an incremental and practical manner. Overall, impacts to St. George's public infrastructure are likely to be minor as a result of the implementation of Alternative N-3.

8.3.4 Fuel & Freight Delivery

Reliable, long-term operation of the harbor would be expected to reduce associated transportation costs applied to the fuel and durable goods that borne by the community.

Long-term effects stemming from the implementation of Alternative N-3 may also include the stability that the harbor offers the community of St. George, fuel and durable goods could be reliably delivered, where in the past, this was not guaranteed.

8.3.5 Subsistence Activities

St. George, like many rural economies throughout Alaska, is a mixed, subsistence-cash economy in which the subsistence and cash sectors are interdependent and mutually supportive. The ability to successfully participate in subsistence activities is highly dependent on the opportunity to earn some form of monetary income and access the resources need to engage in these activities.

A safe and functioning harbor that improves access to St. George would provide opportunities for the development of a local economy based upon the marine resources of the region. Such economic opportunities are essential for supporting St. George's mixed, subsistence-cash economy, combating out-migration, and helping to strengthen the viability of the community on St. George.

8.3.6 Cultural Resources

The construction of Alternative N-3 (Proposed) would have an adverse effect on The Seal Islands Historic District National Historic Landmark (XPI-00002) by permanently altering the viewshed. There would also be an adverse effect on two of the NHL's contributing structures, the St. George Inside Landing (XPI-00195) and the St. George Outside Landing (XPI-00194); these two structures would be removed or buried within the project area. No other historic property or cultural resource would be impacted by this alternative. The State Historic Preservation Office (SHPO) has concurred that any of the structural alternatives would have an adverse effect on historic properties; this information is explained in detail in the Section 106 consultation documents between the USACE and the SHPO (Appendix K). Per 36 CFR § 800.6, this adverse effect would be resolved through the implementation of mitigation identified in a *Memorandum of Agreement among the USACE, SHPO, and the City of St. George Regarding the St. George Navigation Improvements*. The National Park Service (NPS) was also notified of the study through the SHPO coordination process, and was invited to participate in the memorandum of agreement (MOA). The NPS agreed to participate as a consulting party.

The NFS, USACE, and the SHPO are the signatories to the MOA. The Advisory Council on Historic Preservation was invited to participate for the MOA, and has declined. The NPS was also invited to participate in the MOA, and has accepted to consult on the MOA instead. Mitigation would not minimize the impact to the resource but instead would compensate for the adverse effect on historic properties. Mitigation is likely to include the creation of an artistic recreations of the landscape at the St. George North Anchorage viewshed during three periods of history: prior to the settlement of the community, the Russian Period, and the U.S. Territorial period. These depictions would likely be displayed from the vantage of the same North Anchorage viewshed, on a hill west of the community where a monument to the historic fur seal industry is already emplaced. The mitigation will address the adverse effects to both the viewshed of the NHL, as well as the destruction of the Inside and Outside Landings that are within the area of potential effect (APE). The signed MOA is included in Appendix K.

8.4 Navigation

Under Alternative N-3, the cumulative effects of the proposed project would be beneficial to navigation in the region. The 8 to 12 local subsistence vessels currently using Zapadni Bay would be expected to transition their activity to the proposed harbor.

Additionally, neighboring St. Paul registers 17 subsistence-class vessels. It is anticipated that 5 to 8 of these vessels would operate out of St. George periodically based on fish season openings. These 13 to 20, subsistence vessels would be anticipated to transit in and out of the harbor up to 37 days per year, and these transit days would occur primarily during the fishing openings. The number of vessels in St. George's crabber fleet would be expected to increase from 0 to 2 vessels; however, 84 commercial crabbing vessels operate in the region, and approximately 70 these would be expected to use the harbor. Crabbing vessels would be anticipated to transit in and out of the harbor 8 to 17 days per year during the crabbing season. It is also anticipated that an approximately 300-foot-floating processor would operate inside the harbor and that additional vessels would transit to and from the harbor to deliver product. Freight and fuel barges currently using Zapadni Bay would be expected to transition delivery to the new harbor. The fuel barge would be expected to make deliveries 2 to 6 times per year at the new harbor; whereas, 1 freight delivery would be expected annually. Because there is little to no navigational traffic in the proposed project area, this increase in boat traffic would not likely affect existing navigation. Placement of dredged material between the 20 and 30-fathom isobath would not raise the elevation of the seafloor enough to impact navigation.

8.5 Aesthetics

Under Alternative N-3, impacts on the aesthetics of St George would be unavoidable and permanent. Views of the high cliffs supporting active bird communities, and the shorelines providing areas for seal rookeries where no anthropogenic structures currently exist would be marred by the sight of a breakwater protected harbor. Mitigation, as explained in a forthcoming cultural resources MOA, would be implemented, but these measures would not minimize the impact on the resource.

8.6 Mitigation Measures

The following sections discuss the cultural and biological mitigation actions that would be proposed with implementation of the Recommended Plan, Alternative N-3. The USACE would implement a suite of mitigation measures designed to minimize the impact of the project on the area's biological and cultural resources. While these measures would reduce the potential impacts on resources, they would not eliminate them entirely and it is anticipated that direct and indirect impacts would result from project activities (e.g. Level B harassment of marine mammals, see Section 8.2.4). Mitigation measures have been identified and would be implemented by both the USACE and NFS (Table 22).

8.6.1 Cultural Resources

Per 36 CFR § 800.6, the adverse effect on historic properties would be resolved through the implementation of mitigation identified in a *Memorandum of Agreement among the USACE, SHPO, and the City of St. George Regarding the St. George Navigation Improvements*. This mitigation would include the creation of an artistic rendering of the St. George North Anchorage viewshed during three periods of its history: prior to the settlement of the community, the Russian Period, and the U.S. Territorial period. These depictions would likely be displayed from the vantage of the same North Anchorage viewshed, on a hill west of the community where a monument to the historic Fur Seal Industry is already located.

8.6.2 Biological Resources

Mitigation actions include those measures that would avoid, minimize, and implement best management practices that have been identified and refined as a function of the resource agency coordination processes for the purpose of conserving relevant resources. Mitigation concepts such as those that define the timing window for confined underwater blasting, the development of a spill response plan, placing limitations upon vessel speeds and maneuvering, and the development and implementation of a biosecurity plan prior to construction activities were included in the avoidance and minimization strategy of more than one interagency coordination process (Table 22).

Table 22. Mitigation Measures.

MITIGATION, AVOIDANCE, MINIMIZATION, AND BMPS						
Specific Measure and Source	**Draft BA**	**USFWS CAR**	**EFH Analysis**	**404 (b)(1)**	**USACE Would Implement**	**NFS would Implement**
Drilling and Confined Underwater Blasting Window 01 Nov - 30 April	X		X	X	X	
Biosecurity Plan *		X			X	X*
Cliff Nesting Marine Bird Monitors During Construction		X			X	
Establish a 330' Cliff Nesting Bird Buffer		X			X	
Marine Mammal / Protected Species Observers	X			X	X	
Vessel Speed Limits	X		X		X	
Project Related Vessels Not Permitted to Ground Unless for Emergency			X		X	
Spill Prevention Plan			X		X	
Vessels Must Avoid Steller's Sea Lion Haulout or Rookery			X		X	
Barge Safe Loading Practices			X		X	
Post-Dredge Bathymetry Survey			X		X	
Establishment of Exclusion and Shut-Down Radii	X			X	X	
Vessel Safe Operational Procedures	X			X	X	
Fuel Handling and Storage Procedures	X				X	
Establish BMPs to counter Sediment Escapement	X				X	
Ramp-up Procedures for Pile Driving	X				X	
Periodic Monitoring Reports	X				X	
Stemmed and Delayed Charges	X				X	
Develop and Implement a Harbor Operations Plan		X				X
Avoid Removal of Cliffside Habitat		X			X	
Lower Vertical Equipment at Night		X			X	
Maintain Good Light Discipline		X			X	

* After completion of the construction phase, responsibility transfers to the NFS.

8.6.2.1 Marine Mammals and Endangered Species

Measures derived from the Draft Biological Assessment and FWCAR primarily seek to avoid impacts to marine mammals and endangered species though avoidance (Appendices I and J). The timing of drilling and confined underwater blasting activities would be restricted so that they wouldn't coincide with peak densities of marine mammals. Similarly, shut-down radii would be observed and known haul-outs of endangered species would be avoided entirely.

Despite relatively conservative avoidance measures, USACE has determined in its Draft Biological Assessment that the proposed action "may affect and is likely to adversely affect" ESA-listed marine mammals, and the formal ESA consultation procedures established by 50 CFR 402 et seq. are triggered, which would lead to the development of a Biological Opinion by NMFS. Section 7(b)(4)(C) of the ESA provides that if an endangered or threatened marine mammal is involved, the incidental taking (in this case, through harassment) must first be authorized by Section 101(a)(5) of the MMPA through an LOA or incidental harassment authorization (IHA) prior to the issuance of a Biological Opinion.

USACE intends to collect the data required to apply for an LOA during the project's PED phase, which would provide more detail regarding the specific impacts to marine mammals, including ESA-listed marine mammals. Well-reasoned and effective avoidance, minimization, and mitigation measures to reduce those impacts would also be developed, in consultation with NMFS, along with the predicted number of marine mammals that could be taken by harassment. The final mitigation measures for the proposed project cannot be presented prior to the development of the LOA.

8.6.2.2 Essential Fish Habitat and Water Quality

During the 404(b)(1) evaluation and the EFH Assessment consultation processes, avoidance and minimization measures for water quality and EFH were developed and adopted (Appendices G and H) (Table 22).

8.6.2.3 Cliff Nesting Seabirds

The development of avoidance and minimization measures to protect cliff nesting seabirds was a collaborative effort between the Anchorage Office of the USFWS's Ecological Services Division, Alaska Maritime National Wildlife Refuge staff, and USACE biologists and project manager. Avoidance and minimization measures are presented above (Table 22). Also presented within the FWCAR are compensatory mitigation recommendations for out-of-kind mitigation for unavoidable impacts to fish and wildlife resources by the proposed project. USFWS acknowledges that in order to implement these compensatory mitigation recommendations, entities other than USACE would be required to make commitments in order to facilitate their execution. As such, USACE would not commit to compensatory mitigation recommendations other than the development and implementation of a biosecurity plan that included a funding mechanism and maintenance and monitoring plans that would ensure ongoing rat prevention and control. However, USACE would only commit to this measure if cliff nesting habitat were destroyed as function of the project's construction process. Similarly, the NFS would have to willingly agree to USFWS' compensatory mitigation recommendations, which has not been coordinated to date.

- To increase habitat value and minimize hazards and potential sources of contaminants, remove old structures, heavy equipment, and buildings from around the existing harbor and the proposed new harbor site.

- To decrease the risk of deterioration and possible contamination of habitat, repurpose vacant buildings such as the Tanaq construction housing, possibly for seasonal work, so that buildings are maintained and the risk of deterioration and potential pollution is reduced.

- To decrease the risk of deterioration and possible contamination of habitat, explore uses for the currently closed buildings such as the school that belongs to the City, possibly as an extension location for marine studies in order to keep the building maintained.

9.0 PUBLIC AND AGENCY INVOLVEMENT

9.1 Public/Scoping Meetings

Planning Charette - January 2016
While this planning meeting was not open for participation to the general public, it served as an appropriate scoping exercise that helped USACE define its overall project objectives. It was decided over the course of the charette to study the feasibility of implementing navigational improvements at the St. George Harbor at Zapadni Bay.

Community Meeting at St. George – June 2017
A USACE sponsored public meeting was held in the St. George school gymnasium and attended by approximately 11 community members and 2 US Fish and Wildlife personnel. USACE subject matter experts presented to the community about the progress of data collection efforts and regulatory coordination updates. Upon conclusion of the interdisciplinary presentation, local community members presented their concerns to USACE staff and these have been addressed in this Feasibility Report.

- Concern was expressed regarding a separate City initiative seeking designation of a marine sanctuary in the vicinity of St. George. Concern was expressed that this action could be the gateway to a more restrictive monument designation and could have an impact on the implementation of harbor improvements. Pat Pletnikoff, Mayor of St. George, responded that the harbor site would be precluded from the sanctuary designation and pointed out that 14 other sanctuaries have harbors. Further, the designation of a marine sanctuary is a 5-

year process and still requires additional efforts to be completed by the City of St. George.

USACE attempted to hold a February 2018 Scoping Meeting after the project site selection had changed, but inclement weather prohibited flights to and from St. George Island. This meeting was conducted in August 2018. Members of the City Council expressed their support for the Recommended Plan.

Public and Agency Review- December 2019
The draft EA was released for a 30-day public comment period on 12 December 2020. No public comments were received. The NMFS reviewed the EA and had no additional comments. Five USFWS comments were received and are stated below:

1. Provide more thorough analysis on marine birds
2. Impacts on least auklet should be discussed further
3. Table 4 needs updating on dates of occurrence and breeding habitat
4. Further analysis and mitigation measures should be included on the impacts and methods to reduce impacts from invasive species
5. Mitigation measures should be discussed in more detail

Agency comments were addressed in the Environmental Assessment.

9.2 Federal and State Agency Coordination

Agency Coordination was undertaken with ADEC, USEPA, NMFS and USFWS (Table 23).

Table 23. Agency Coordination.

Agency	Date	Coordination type
ADEC	Dec-15	Participated in charette
ADEC	Oct-19	Coordinated review of 404(b)(1) Analysis
ADEC	Jan-20	Receipt of Water Quality Certificate
USEPA	Apr-19	Dredge material disposal methodology planning coordination
NMFS	Dec-15	Participated in charette
NMFS	Jun-17	Coordination for on-island contacts for USACE site visit.
NMFS	May-18	Presented TSP to Protected Marine Resources and Habitat Division personnel
NMFS	Jun-19	Formal request and response of protected resources species list.
NMFS	Apr-19 - Sep-19	Development of the FWCAR. Site visit (Jun-19) to St. George with USFWS and NMFS Habitat Division.
NMFS	Sep-19 - Present	EFH analysis and dredge material placement strategy development
NMFS	Dec-19	Receipt of EFH coordination letter

USFWS	Dec-15	Participated in charette
USFWS	Jun-17	Coordinated with Alaska Maritime National Wildlife Refuge personnel concerning cliff-nesting bird monitoring. Conducted site familiarization with USFWS monitors during June 2017 site visit.
USFWS	Feb-18	USACE formally requested FWCAR
USFWS	July-19	FWCAR Scope of Work finalized
USFWS	May-19 - Sep-19	Development of the FWCAR Site visit (Jun-19) to St. George with USFWS and NMFS Habitat Division.
USFWS	Oct-19	FWCAR received

9.3 Status of Environmental Compliance

Environmental compliance is on-going and will not be completed in the Feasibility phase (Table 24). Items in green are fully completed (FC) or not applicable (N/A) and items in yellow are partially completed (PC). A USACE policy wavier, permitting POA to conduct MMPA/ESA consultation during the Preconstruction, Engineering and Design phase was approved on 03 March 2020 (Appendix E).

Table 24. Environmental Compliance Table.

Federal Statutory Authority	Compliance Status	Compliance Date/Comment
Clean Air Act	FC	This project is not reasonably expected to impact air quality negatively, nor is it in a non-attainment area.
Clean Water Act	FC	The USACE authorizes its own discharges under Section 404 of the CWA, applying all applicable substantive legal requirements. In compliance with Section 401 of the CWA, USACE has received a Certificate of Reasonable Assurance from the ADEC Water Quality Division dated 15 January 2020.
Coastal Zone Management Act	N/A	CZMA Federal consistency provision, Section 307, no longer applies in Alaska
Endangered Species Act	PC	Draft Biological Assessment was developed. Full compliance requires completion of MMPA consultation
Marine Mammal Protection Act	PC	USACE will complete the harassment analysis and apply for an LOA during PED – requires geotechnical and preliminary blast plan.
Magnuson-Stevens Fishery Conservation and Management Act	FC	NMFS EFH Response letter received December 2019.
Fish and Wildlife Coordination Act	FC	Final FWCAR received in October 2019.
Marine Protection, Research, and Sanctuaries Act	N/A	MPRSA is not triggered by this project.
Migratory Bird Treaty Act	FC	Conservation Measures provided by USFWS in FWCAR would be applied.
National Historic Preservation Act	FC	USACE and SHPO have concurred on adverse effects to cultural resources. The signed MOA is included in Appendix K of this Feasibility Report.
National Environmental Policy Act	PC	Pending completion of the Environmental Assessment and FONSI.

Executive Order 11990: Protection of Wetlands	FC	No wetlands are expected to be impacted by this project
Executive Order 12898: Environmental Justice	FC	Project does not disproportionately negatively affect underserved communities
Executive Order 13045: Protection of Children from Environmental Health Risks and Safety Risks	FC	Does not disproportionately affect the health or well-being of children
Executive Order 13112: Invasive Species	FC	Conservation measures would include anti-rodent provisions
Executive Order 13186 Protection of Migratory Birds	FC	Conservation Measures provided by USFWS in the FWCAR would be applied.

9.4 Views of the Sponsor

The City unconditionally believes that the economic and cultural survival of the community is dependent upon a more accessible harbor as there can be no viable long-term economy on St. George without it.

In Mayor Pat Pletnikoff's words, stated at the ADM:

"Since 1983 our community has thought to replace the lost economy of fur sealing. At that time the US government and Congress terminated the fur seal harvest and in the Fur Seal Act amendments of 1983 stated that an economy not depended [sic] on the fur sealing must be developed. Without a [functioning] harbor St. George will not be able to develop an economy not dependent on fur sealing. Given this our community will fail to exist… Our people, as well as our government, must fulfill its promise and obligation in a suitable harbor development. I cannot state enough how critical this project is. After review of Alternative 2 and Alternative 3, we feel Alternative 3 will best address the needs of our community. While we recognize the high costs in this development, we recognize our island's location as well as environment adds to this high costs. We also recognize how distant our island is from the road system in our state. We need to protect our community and environment. We must do all that is necessary to protect the protectors."

A letter of support from the City of St. George and the Self-Certification of Financial Capability with supporting letters dated 24 April 2020 can be found in Appendix E.

10.0 CONCLUSIONS AND RECOMMENDATIONS

10.1 Conclusions

In view of the analysis presented, it is recommended that Alternative N-3 be approved as the Recommended Plan. The Recommended Plan would provide for 179 additional vessel opportunity days for safe access and moorage to support the subsistence vessel fleet; the fuel barge fleet; lash vessels and other cargo-carrying vessels; as well as approximately 85 percent of the existing crabber fleet. These additional days would allow for the more efficient delivery of fuel and goods to the community, increase opportunities to harvest subsistence resources, and allow a portion of the crabbing fleet to utilize the harbor. The resulting reduction in the cost of essential goods coupled with expanded economic opportunities would contribute to the long-term viability of the mixed, subsistence-cash local economy of St. George. The Recommended Plan would provide an additional regional benefit by providing safe moorage during storms that have the potential to shut both the nearby St. Paul and existing St. George harbors due to unsafe conditions. The Recommended Plan is supported by the City of St. George, which is the NFS.

10.2 Recommendations

The Alaska District recommends that the selected navigation improvements plan at St. George, Alaska be constructed generally in accordance with the selected plan herein, and with such modifications thereof as in the discretion of the Director of Civil Works may be advisable at a certified project first cost with contingency of $159.8 million, provided that prior to construction the NFS agrees to the following:

a. Provide, during the periods of design and construction, funds necessary to make its total contribution for commercial navigation equal to:

   (1) 10% of the cost of design and construction of the general navigation features attributable to dredging to a depth, not in excess of -20 ft mean lower low water (MLLW), plus

   (2) 25% of the cost of design and construction of the general navigation features attributable to dredging to a depth in excess of -20 ft MLLW but not in excess of -50 ft MLLW, plus

   (3) 50% of the cost of design and construction of the general navigation features attributable to dredging to a depth in excess of -50 ft MLLW.

b. Provide all lands, easements, rights-of-way, and relocations, including those necessary for the borrowing of material and placement of dredged or excavated material, and perform or assure performance of all relocations, including utility relocations, as determined by the Federal government to be necessary for the construction or operation and maintenance of the general navigation features;

c. Pay with interest, over a period not to exceed 30 years following completion of the period of construction of the general navigation features, an additional amount equal to 10% of the total cost of construction of the National Economic Development Plan general navigation features less the amount of credit afforded by the Federal government for the value of the lands, easements, rights-of-way, and relocations, including utility relocations, provided by the NFS for the general navigation features. If the amount of credit afforded by the Federal government for the value of lands, easements, rights-of-way, and relocations, including utility relocations, provided by the NFS equals or exceeds 10% of the total cost of construction of the general navigation features, the NFS shall not be required to make any contribution under this paragraph, nor shall it be entitled to any refund for the value of lands, easements, rights-of-way, and relocations, including utility relocations, in excess of 10% of the total costs of construction of the general navigation features;

d. Provide 50% of the excess cost of operation and maintenance of the project over that cost which the Secretary determines would be incurred for operation and maintenance if the project had a depth of 50 ft;

e. Prevent obstructions or encroachments on the project (including prescribing and enforcing regulations to prevent such obstructions or encroachments) such as any new developments on project lands, easements, and rights-of-way or the addition of facilities which might reduce the outputs produced by the project, hinder operation and maintenance of the project, or interfere with the project's proper function;

f. Provide, operate, and maintain, at no cost to the Federal government, the local service facilities in a manner compatible with the project's authorized purposes and in accordance with applicable Federal and state laws and regulations and any specific directions prescribed by the Federal government;

g. Give the Federal government a right to enter, at reasonable times and in a reasonable manner, upon property that the NFS owns or controls for access to the project for the purpose of completing, inspecting, operating, maintaining, repairing, rehabilitating, or replacing the project.

h. Hold and save the United States free from all damages arising from the construction or operation and maintenance of the project, any betterments, and the local service facilities, except for damages due to the fault or negligence of the United States or its contractors;

i. Keep, and maintain books, records, documents, and other evidence pertaining to costs and expenses incurred pursuant to the project, for a minimum of 3 years after completion of the accounting for which such books, records, documents, and other evidence are required, to the extent and in such detail as will properly reflect total cost of the project, and in accordance with the standards for financial management systems set forth in the Uniform Administrative Requirements for Grants and Cooperative Agreements to State and local governments at 32 CFR, Section 33.20;

j. Perform, or ensure performance of, any investigations for hazardous substances that are determined necessary to identify the existence and extent of any hazardous substances regulated under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), 42 USC 9601-9675, that may exist in, on, or under lands, easements, rights-of-way, relocations, and disposal areas that the Federal government determines to be necessary for the construction or operation and maintenance of the general navigation features. However, for lands, easements, or rights-of-way that the Federal government determines to be subject to the navigation servitude, only the Federal government shall perform such investigation unless the Federal government provides the NFS with prior specific written direction, in which case the NFS shall perform such investigations in accordance with such written direction;

k. Assume complete financial responsibility, as between the Federal government and the non-Federal sponsor, for all necessary cleanup and response costs of any hazardous substances regulated under CERCLA that are located in, on, or under lands, easements, rights-of-way, relocations, and disposal areas required for the construction or operation and maintenance of the project;

l. Agree, as between the Federal government and the non-Federal sponsor, that the NFS shall be considered the operator of the local service facilities for the purpose of CERCLA liability, and, to the maximum extent practicable, perform its obligations related to the project in a manner that will not cause liability to arise under CERCLA;

m. Comply with Section 221 of Public Law 91-611, Flood Control Act of 1970, as amended, (42 U.S.C. 1962d-5b) and Section 101(e) of the WRDA 86, Public Law 99-662, as amended, (33 U.S.C. 2211(e)) which provide that the Secretary of the Army shall not commence the construction of any water resources project or separable element thereof, until the NFS has entered into a written agreement to furnish its required cooperation for the project or separable element;

n. Comply with the applicable provisions of the Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1970, Public Law 91-646, as amended, (42 U.S.C. 4601-4655) and the Uniform Regulations contained in 49 CFR Part 24, in acquiring lands, easements, and rights-of-way necessary for construction, operation, and maintenance of the project including those necessary for relocations, the borrowing of material, or the disposal of dredged or excavated material; and inform all affected persons of applicable benefits, policies, and procedures in connection with said act;

o. Comply with all applicable Federal and state laws and regulations, including, but not limited to: Section 601 of the Civil Rights Act of 1964, Public Law 88-352 (42 U.S.C. 2000d), and Department of Defense Directive 5500.11 issued pursuant thereto; Army Regulation 600-7, entitled "Nondiscrimination on the Basis of Handicap in Programs and Activities Assisted or Conducted by the Department of the Army"; and all applicable Federal labor standards requirements including, but not limited to, 40 U.S.C. 3141-3148 and 40 U.S.C. 3701-3708 (revising, codifying and enacting without substantive change the provisions of the Davis-Bacon Act (formerly 40 U.S.C. 276a et seq.), the Contract Work Hours and Safety Standards Act (formerly 40 U.S.C. 327 et seq.), and the Copeland Anti-Kickback Act (formerly 40 U.S.C. 276c)); and

p. Not use funds from other Federal programs, including any non-federal contribution required as a matching share, therefore, to meet any of the non-Federal sponsor's obligations for the project unless the Federal agency providing the funds verifies in writing that such funds are authorized to be used to carry out the project.

q. Accomplish all removals determined necessary by the Federal government other than those removals specifically assigned to the Federal government.

DAVID R. HIBNER
COL, EN
Commanding

MAY 13 2020
Date

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ST. GEORGE HARBOR IMPROVEMENT FEASIBILITY STUDY

APPENDIX A: HYDRAULIC DESIGN

ST. GEORGE, ALASKA

U.S. Army Corps of Engineers

Alaska District

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

1.1. Appendix Purpose

This appendix describes the technical aspects of proposed navigation improvements to support a harbor on Saint George Island, Alaska. It provides the engineering background information for determining the Federal interest in the major construction features including causeways, breakwaters, channel improvements, and support facilities. Existing data was gathered and analyzed to determine site characteristics, and numerical modeling was performed to determine the physical impacts of the wave climate for design of the proposed navigation improvements.

1.2. Current Stage of Work

This appendix describes the engineering that has been performed to arrive at the Agency Decision Milestone (ADM) for this study. The Tentatively Selected Plan (TSP) for this study is Alternative N-3 as described in this appendix, which is a small boat harbor on the north side of St. George Island near the Village of St. George which accommodates the local subsistence fleet, fuel delivery barges and fishing vessels to 14 foot draft. The TSP was selected with the analysis available to the team at the time. During the progression of this study, limitations in the numerical model being used to analyze harbor responses were revealed. Alterations to the numerical model to compensate for these deficiencies were pursued, but did not alter the decision for the selected plan. Due to limitations in the ability of numerical models to simulate harbor conditions during the design events, a physical model will need to be constructed and analyzed during the Preconstruction Engineering Design phase of the project to finalize the harbor configuration and to demonstrate the conditions under which the selected plan will support projected operations at St. George.

1.3. Project Purpose and Needs Assessment

The following objectives were identified for navigation improvements at Saint George Harbor.

- Provide safe and more efficient improvements for the various design fleets.
- Provide facilities for fuel barges, fishing vessels and freight logistics vessels for which current depths and facilities are not available.
- Reduce harbor access and moorage delays and increase port operation efficiencies.

The project purpose is to provide a safe and efficient harbor in an environmentally sound manner that satisfies the above objectives.

1.4. Study Location

Saint George Island is one of the Pribilof Islands which are located in the Bering Sea approximately 225 miles north of Dutch Harbor and 750 miles west of Anchorage (

Figure **1**). Two of the islands, St. Paul and St. George, are inhabited (

Figure **2**). St. Paul Island has a harbor constructed by the Corps of Engineers at Village Cove which supports crabbing vessels operating in the Bering Sea. St. George Island has a harbor at Zapadni Bay constructed by the City of Saint George with initial dredging performed by the Corps of Engineers. This harbor was also designed to serve crabbers.

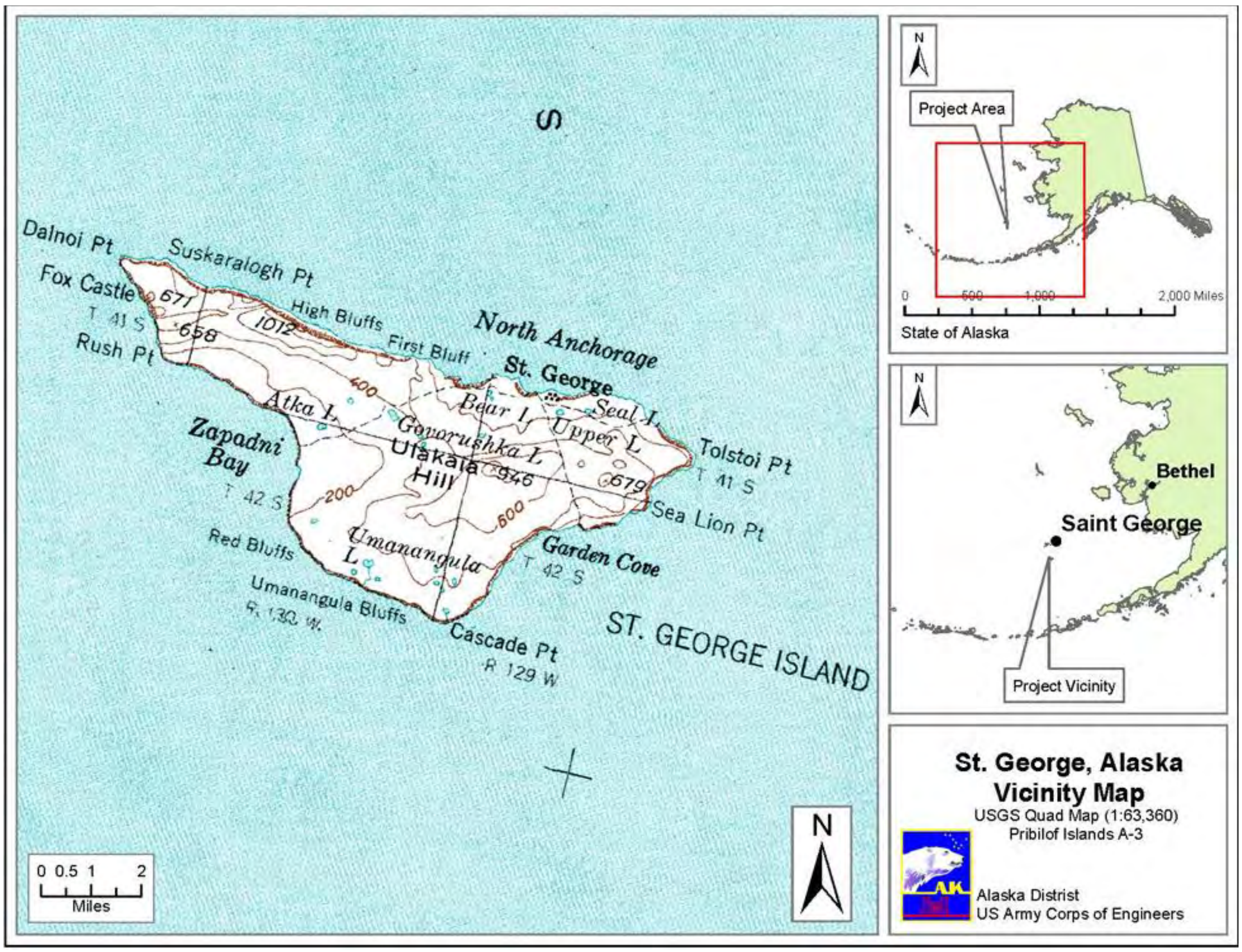

Figure 1. Location of St. George Island

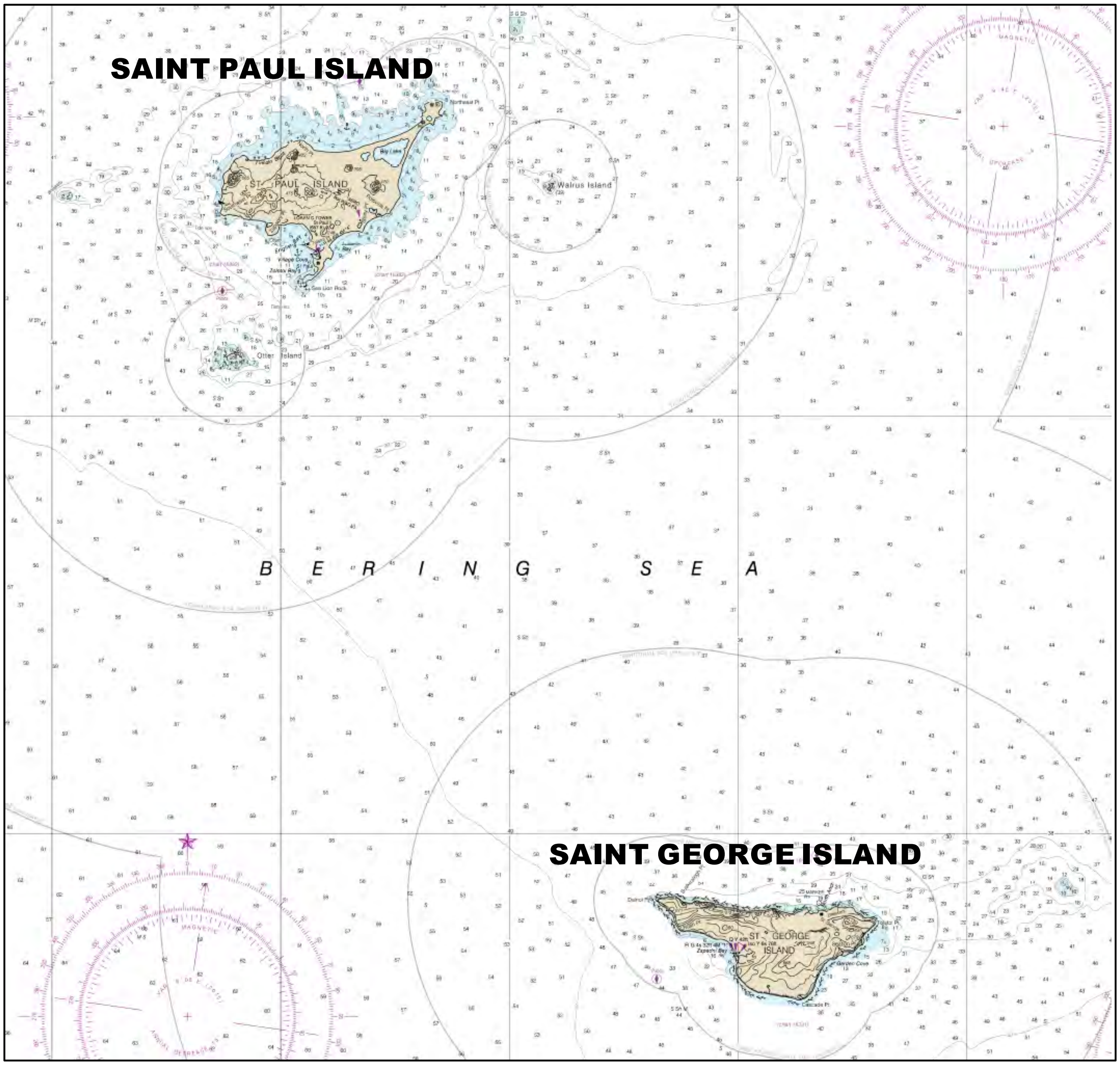

Figure 2. Pribilof Islands vicinity. Detail from NOAA Chart 16380, Pribilof Islands. Annotation Added. St George Island is approximately 49 miles to the southeast of St. Paul Island.

2.0 SITE SELECTION

This study encompasses two sites on Saint George Island; Zapadni Bay and the North Site, as shown in

Figure **3**. Initially, Zapadni Bay was selected through a charrette process that included stakeholders at the Federal, State and local levels. Zapadni Bay is the location of the existing harbor and upland infrastructure to support harbor operations. As the study progressed, the team investigated a location on the north shore of the island as a potential new harbor site with more favorable wave conditions than Zapadni Bay. The north site is located at the west end of the community of Saint George.

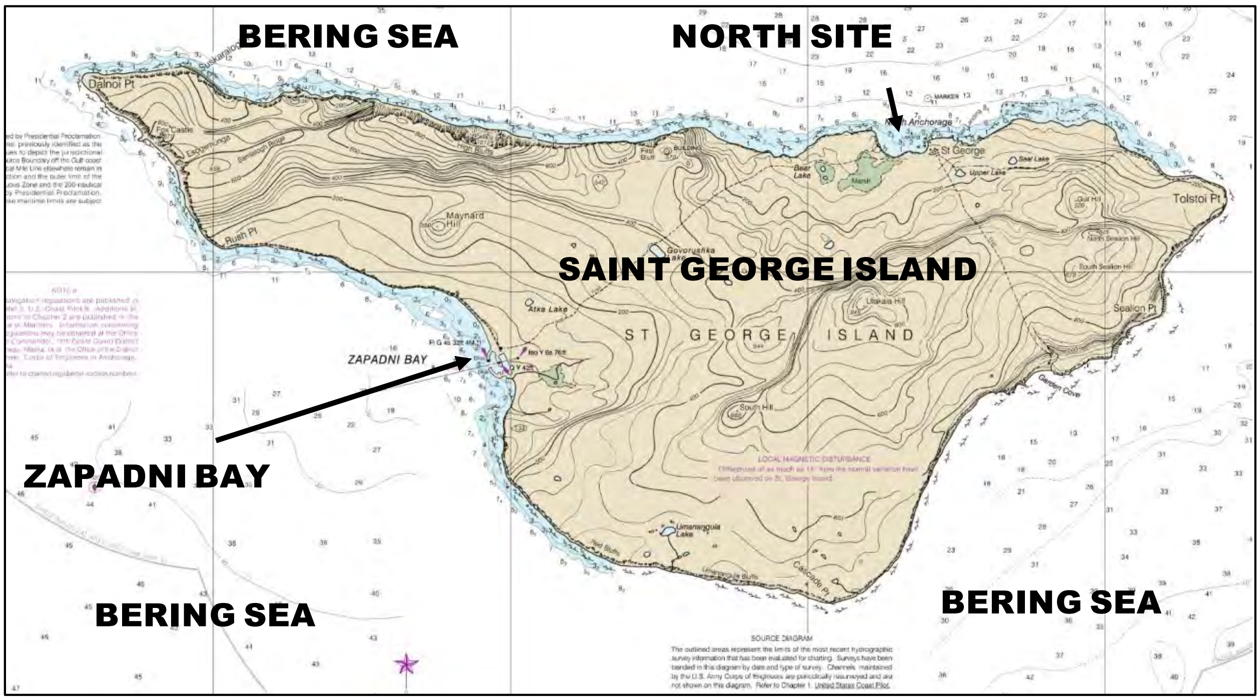

Figure 3. Site locations. Detail from NOAA Chart 16381, Saint George. Annotation Added.

2.1. St. George Harbor - Zapadni Bay

Zapadni Bay is the site of the existing harbor on Saint George Island. The harbor includes a navigation channel dredged by the Corps of Engineers and turning basin protected by three rubble mound berm breakwaters constructed by the City of Saint George. Federal maintenance of the navigation project was suspended in 1996 when the local sponsor was unable to enter a cost sharing agreement to complete construction dredging to reach the authorized depth.

2.2. Existing Facilities

The existing harbor breakwaters were constructed from 1984 to 1987 by the City of St. George with funding from the State of Alaska. The breakwaters were designed as berm structures with 8 ton armor stones produced from a local quarry. The original design called for the berm breakwaters to be built in depths of -30 feet MLLW with an inner stub breakwater connected to the south breakwater that would have protected a small basin in deep water. The shoreline inside the breakwater would act as a spending beach to dissipate wave energy and minimize reflection inside the harbor. During construction, the design was changed by moving the breakwaters into shallower water at about -20 feet MLLW and using the rock quarry as an inner harbor basin. The current configuration of the harbor is shown in Figure 4.

After the breakwaters were constructed, a federal navigation project was constructed to provide navigation depths required for vessels to use the harbor. The St. George Harbor navigation project was authorized on November 17, 1986 by Public Law 86-645 under Section 107 of the Rivers and Harbor Act of 1960. The authorization was to dredge a maneuvering area to -18 feet MLLW and an entrance channel to -20 feet MLLW which was estimated to require removal of approximately 176,000 cubic yards of material. Construction of St. George Harbor and related facilities progressed as follows:

1984 - The City of St. George undertakes construction of three rubble mound breakwaters funded by the State of Alaska.

1987 – Breakwater construction is completed.

1988 – A contract is awarded for dredging the federal project, including a 3 acre boat basin and 2 feet of advance maintenance in the entrance channel to be funded by the City of St. George and the State of Alaska.

1989 – Dredging begins in April and continues through the season until October with 54% of the project reported complete.

1990 – The contractor re-mobilizes in the spring and dredges into August.

1993 – The last project condition survey is completed.

1994 – Insufficient depth in the entrance channel necessitates further construction dredging.

1995 – Under the new local cooperation agreement, the City proceeds with improvements to the project, however project design depth is still not achieved.

1996 – The City of St. George is unable to enter into a new project cost sharing agreement with the Government to complete the project. The federal maintenance obligation is suspended.

2004 – Contract awarded by others to repair damage to the south breakwater.

2016 – Contract awarded by others to repair to the south breakwater caused by a December 2015 storm. New 8 ton armor stone is placed on the south breakwater.

2017 – Contract awarded by others to place a 10 foot seaward berm of 8 ton armor rock on the repaired extents of the south breakwater.

Figure 4. St. George Harbor aerial image.

2.2.1. North and South Breakwaters

The North and South Breakwaters were designed as berm breakwater structures which are intended to change shape over time in response to wave energy. The original breakwater design was performed by Peratrovich, Nottingham & Drage, Inc. (PN&D) in 1984. The typical design section consisted of primary armor stone weighing between 1.7 and 10 tons. The section included a 55 foot berm on the seaward face of the breakwater to be constructed to an elevation of +12 feet MLLW and a crest elevation of +26 feet MLLW (

Figure 5). Changes were made to the design during construction of the harbor and it is not known if the breakwater was originally constructed to this section. The concept for this section was to allow waves to move the rock in the berm to form a shallower seaward slope over time and function as a beach. Use of this concept has proven that the rock berm formed through this process has required emergency repairs in 2004 and 2016 and has not reduced the harbor wave climate to acceptable levels.

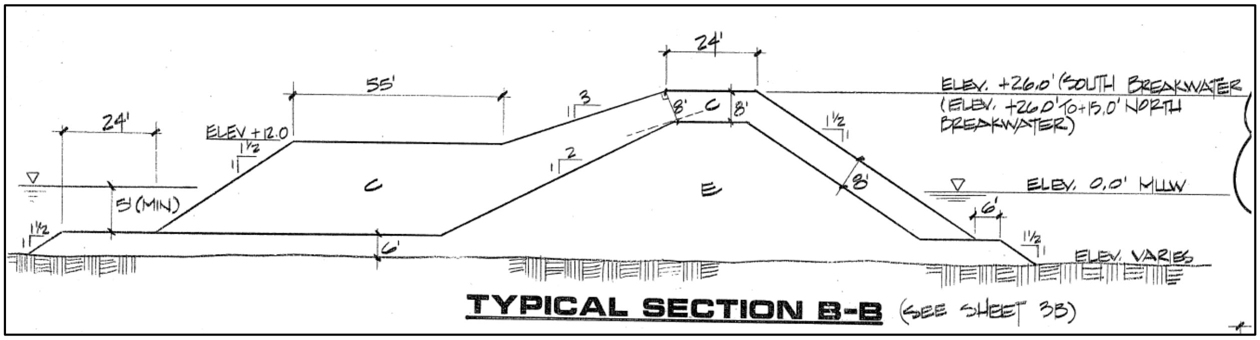

Figure 5. Typical berm breakwater section as designed by PN&D (1984).

2.2.2. Inner Breakwater

The inner breakwater was formed by the boundary of the quarry pit and the shoreline. The core material of this structure is solid rock. Additional rock was placed to increase the crest elevation to protect the inner harbor.

2.2.3. Entrance Channel and Maneuvering Area

The entrance channel and maneuvering area are currently the only federally constructed features at St. George Harbor. The entrance channel was dredged to depths of -20 and -22 feet MLLW and the Maneuvering basin was dredged to -18 feet MLLW. The north end of the inner harbor was not dredged, but the quarried depths of the basin are -12 feet and -8 feet MLLW. Construction dredging of the entrance channel was never completed; rock pinnacles and shallow areas limit navigable depth at the harbor entrance and at the south breakwater near the inner harbor entrance.

2.3. Climatology

Saint George falls within the southwest maritime climate zone, characterized by persistently overcast skies, high winds, and frequent cyclonic storms. The climate of St. George is controlled by the cold waters of the Bering Sea. The summers are cold and windy; the winters are long, freezing, and extremely windy; and it is overcast year round. Over the course of the year, the temperature typically varies from 24°F to 52°F and is rarely below 9°F or above 56°F.

2.4. Water Levels, Currents, and Waves

2.4.1. Tides

Water level data is not recorded at Saint George Island. The nearest tidal station is located at Village Cove on Saint Paul island, approximately 50 miles away. Due to the similarity of the sites, tidal data from Saint Paul was used for this study (Table 1).

Table 1. Published tidal data for Village Cove, Saint Paul Island, Alaska (Values in feet, Mean Lower Low Water).

Published tidal data for St. Paul, Alaska (ft)

Highest Observed Water Level (12/08/06)…..	+5.26
Highest Astronomical Tide (HAT)	+4.09
Mean Higher High Water (MHHW).............	+3.30
Mean High Water (MHW)..............................	+3.08
Mean Tide Level (MTL)................................	+2.03
Mean Tide Level (MSL)................................	+1.96
Mean Low Water (MLW)..............................	+0.97
Mean Lower Low Water (MLLW)..................	0.00 (datum)
Lowest Astronomical Tide (LAT)....................	-1.50
Lowest Observed Water Level (12/06/10)......	-2.10

Source: NOAA NOS, Tidal Epoch 1983-2001, published 12/12/11.

From the above data, the mean tide level (arithmetic average of the Mean High Water and the Mean Low Water) is +2.03 foot. The mean tide range (the difference between Mean High Water and Mean Low Water) is 2.11 feet.

2.4.2. Sea Level Change

The Corps of Engineers requires that planning studies and engineering designs consider alternatives that are formulated and evaluated for the entire range of possible future rates of sea level change (SLC). Guidance for addressing SLC is in Engineer Regulation ER 1100-2-8162 and detailed below. Three scenarios of "low," "intermediate," and "high" SLC are evaluated over the project life cycle. According to the ER, the SLC "low" rate is the historic SLC. The "intermediate" and "high" rates are computed using the following:

Estimate the "intermediate" rate of local mean sea-level change using the modified NRC Curve I and the NRC equations. Add those to the local historic rate of vertical land movement.

Estimate the "high" rate of local mean SLC using the modified NRC Curve III and NRC equations. Add those to the local rate of vertical land movement. This "high" rate exceeds the upper bounds of Intergovernmental Panel on Climate Change (IPCC) estimates from both 2001 and 2007 to accommodate potential rapid loss of ice from Antarctica and Greenland.

NRC Equations

The 1987 NRC described these three scenarios using the following equation:

$$E(t) = 0.0012t + bt^2$$

in which t represents years, starting in 1986, b is a constant, and $E(t)$ is the eustatic sea level change, in meters, as a function of t. The NRC committee recommended "projections be updated approximately every decade to incorporate additional data." At the time the NRC report was prepared, the estimate of global mean sea level change was approximately 1.2 mm/year. Using the current estimate of 1.7 mm/year for GMSL change, as presented by the IPCC (IPCC 2007), results in this equation being modified to be:

$E(t) = 0.0017t + bt^2$

The three scenarios proposed by the NRC result in global eustatic sea level rise values, by the year 2100, of 0.5 meter, 1.0 meter, and 1.5 meters. Adjusting the equation to include the historic GMSL change rate of 1.7 mm/year and the start date of 1992 (which corresponds to the midpoint of the current National Tidal Datum Epoch of 1983-2001), results in updated values for the variable b being equal to 2.71E-5 for modified NRC Curve I, 7.00E-5 for modified NRC Curve II, and 1.13E-4 for modified NRC Curve III.

Manipulating the equation to account for the fact that it was developed for eustatic sea level rise starting in 1992, while projects will actually be constructed at some date after 1992, results in the following equation:

$E(t_2) - E(t_1) = 0.0017(t_2 - t_1) + b(t_2^2 - t_1^2)$

where t_1 is the time between the project's construction date and 1992 and t_2 is the time between a future date at which one wants an estimate for sea level change and 1992 (or $t_2 = t_1 +$ number of years after construction) . For the three scenarios proposed by the NRC, b is equal to 2.71E-5 for Curve 1, 7.00E-5 for Curve 2, and 1.13E-4 for Curve 3.

The local St. Paul tide station does not have the recommended 40-year period of record for the relative sea level change (RSLC) value. The tide station has a 10-year water level records from 2006. Based on the tide data available, the RSLC would be +0.015mm/yr.

Vertical land movement (VLM) was investigated at the St. Paul gage, reported as site AC58 by the Jet Propulsion Laboratory. VLM for St. Paul was estimated to be -0.542 mm ± 0.279 mm/year (NASA Jet Propulsion Laboratory). Over a 50 year span, this vertical movement would increase sea level rise at St. Paul by 0.09 feet; over a 100 year span it would increase by 0.18 feet.

Per the guidance recommendation, a U.S. tide station with a 40-year period of record was investigated for use as the RSLC value. The nearest U.S. tide station with the required 40-year period of record is the Unalaska, Alaska station, roughly 225 miles from the site. It has a historic relative sea level change (RSLC) of -5.58 mm/yr.

Due to the distance from St. George, the Unalaska gage was not further investigated. Due to the short period of record at St. Paul, the GMSL rate was used to model sea level change at St. George (Figure 6). Table 2 shows the relative sea level change values along these curves assuming a project construction year of 2023 with projected sea levels in 2073 for a 50 year project life and 2123 for a 100 year adaptation horizon.

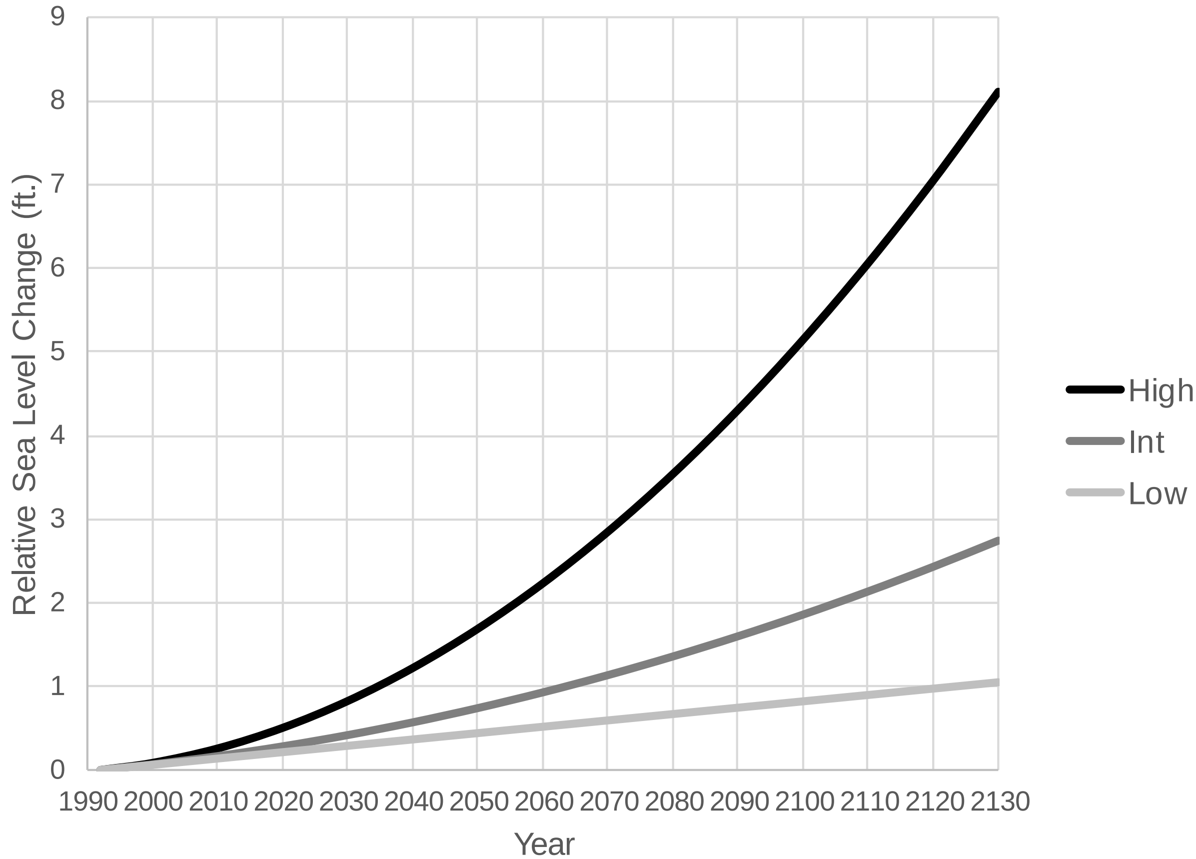

Figure 6: Global Sea Level Change evaluated at St. George using Global Mean Sea Level adjusted with Vertical Land Movement at St. Paul.

Table 2. Sea Level Rise Prediction using GMSL and VLM.

Scenario	Low (Historic)	Intermediate (Curve I)	High (Curve III)
2073	+0.40 feet	+0.92 feet	+2.54 feet
2123	+0.78 feet	+2.24 feet	+6.85 feet

2.4.3. Water Levels

Water levels at St. Paul are primarily affected by astronomical tides. The difference between predicted astronomical tides and observed water levels are attributable to storm surge and atmospheric pressures. The water level record at St. Paul includes predicted and observed values. The highest recorded water level in the record was +5.22 feet MLLW. The non-tidal residuals were analyzed to determine the range of positive and negative residuals. The highest positive residual in the record occurred on April 7, 2011 where the observed water level was 2.58 feet above the predicted tide. The lowest recorded water level at St. Paul was -2.10 feet MLLW.

The maximum non-tidal residuals did not coincide with the maximum high water levels for most events.

The water level record at St. Paul was then used to identify extreme high water events and extreme non-tidal residual events over the 10 year period of record. Extreme events of high water levels and non-tidal residuals were then analyzed with an Extreamal Type I, or Weibull distribution to estimate probabilistic water levels and residuals. The results estimate a total water level of 5.6 feet MLLW with an annual exceedance probability (AEP) of 0.02, which corresponds to a 50 year recurrence interval. This compares to a non-tidal residual of 3.0 feet at the same AEP of 0.02. The non-tidal residuals were added to the Mean Higher High Water level of +3.3 feet MLLW to compare to total water level measurements. Water levels calculated using MHHW and non-tidal residuals were 0.5 to 0.7 feet higher than total water levels (Table 3).

Table 3. Probabilistic Total Water Level and Non-Tidal Residuals

Annual Exceedance Probability	MHHW (ft., MLLW)	Non-Tidal Residual (ft.)	MHHW + Non-Tidal Residual (ft., MLLW)	Total Water Level (ft., MLLW)	Delta (ft.)
0.10	3.3	2.5	5.8	5.3	-0.5
0.05	3.3	2.7	6.0	5.4	-0.6
0.02	3.3	3.0	6.3	5.6	-0.7

Historic records of storm surge at St Paul are few. A single event was noted in the US Army Corps of Engineers Alaska District Flood Plain Management Files recording a storm surge of 5 feet at St. Paul on December 25, 1966 that flooded a house in the community. Flooding was attributable to wind driven waves and high water. The frequency of a 5 foot non-tidal residual is well beyond reasonable extrapolation of the period of record available at the site and was not used in this study.

Shoreline geometry and bathymetry at St. Paul and St. George differ significantly in regards to the potential to produce storm surge. At St. Paul, the shoreline is bounded to the south by Reef Point and to the west by Zapadni Point. Bathymetry between these features is fairly uniform with a gentle slope (Figure 7). This creates a potential for west and southwest wind and wave events to produce a storm surge at St. Paul. The event reported in 1966 was a result of wind and waves surging into the village at Zolotol Bay, to the south of Village Cove where the harbor is located.

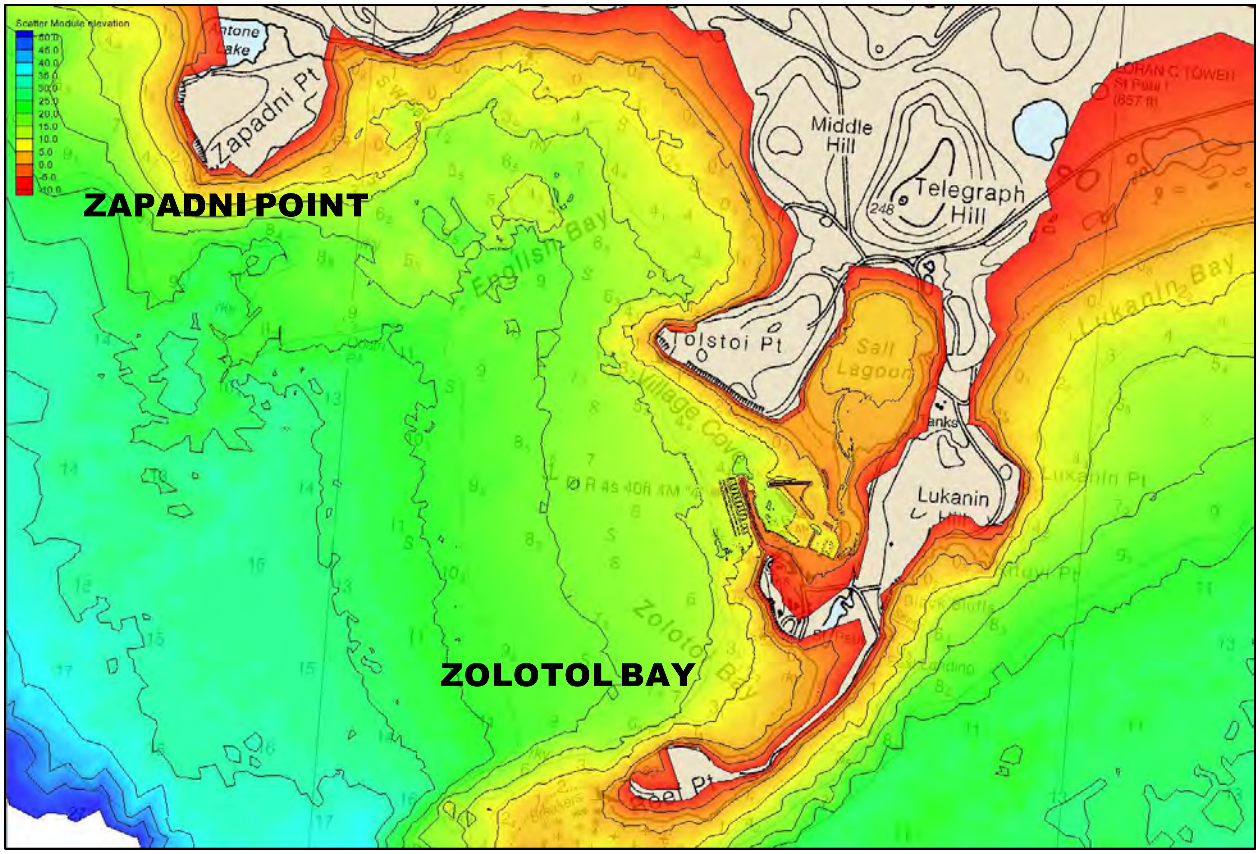

Figure 7. St. Paul shoreline and bathymetry, detail from NOAA chart 16382 with contour shading from NOS digital bathymetry and 2009 project condition survey data. Color ramp and contours are in 5 meter intervals. Depth at the edge of the color ramp is -50 meters MLLW.

At St. George, the shoreline is less confining for west and southwest events. Rush Point to the west and the Red Bluffs to the south do not extend as far beyond the harbor site as at the shoreline at St. Paul and nearshore bathymetry is deeper with a steeper slope to the shoreline (Figure 8). This shoreline geometry and deeper bathymetry allow for a more efficient flow of water around the island which results in a lower potential for storm surge.

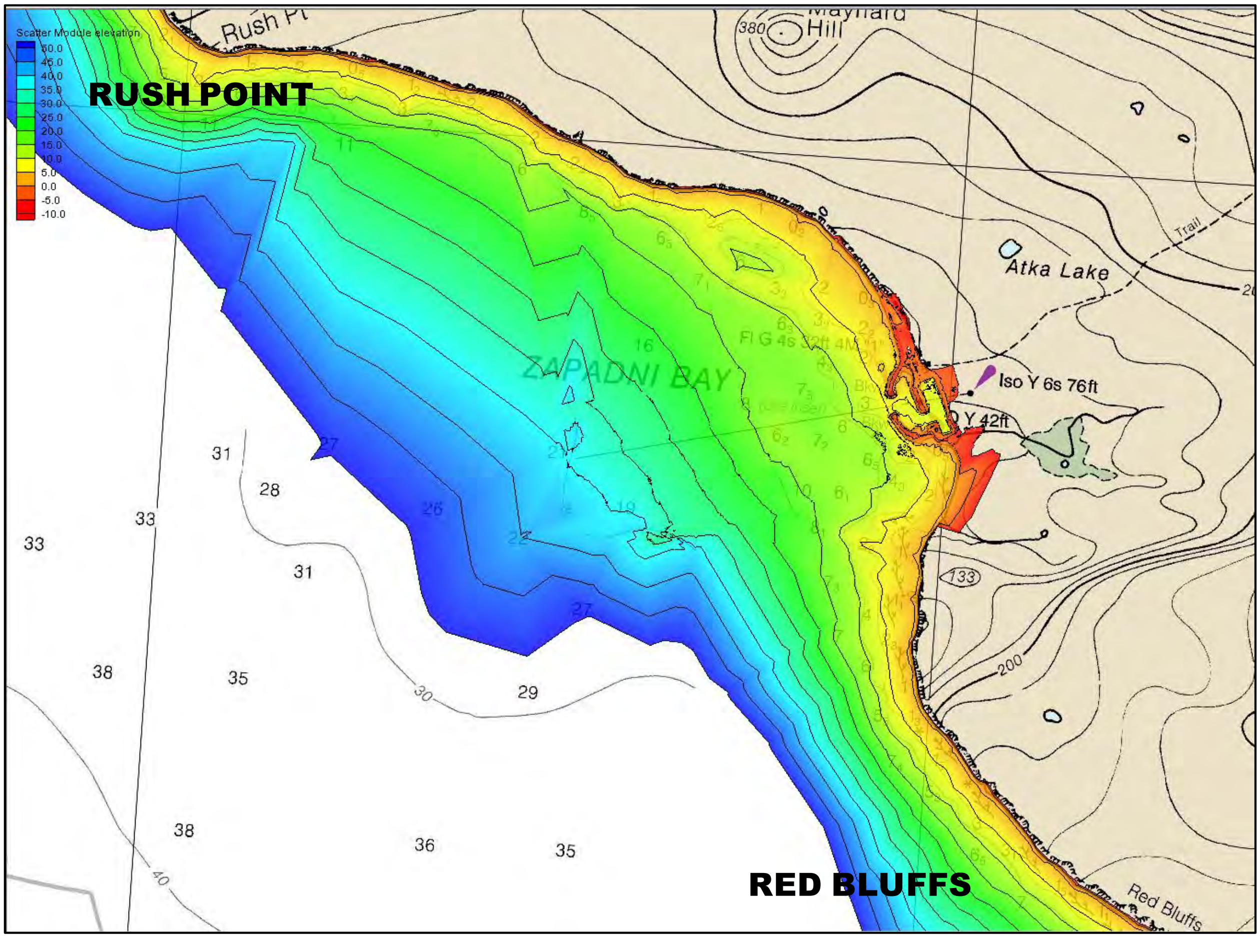

Figure 8. St. George shoreline and bathymetry, detail from NOAA chart 16381 with contour shading from NOS digital bathymetry and 2013 multibeam survey data. Color ramp and contours are in 5 meter intervals. Depth at the edge of the color ramp is -50 meters MLLW.

For design purposes, two water levels were used. For modeling wave propagation through the harbor and alternative designs, a water level of +5.9 feet MLLW (+1.8 m MLLW) was used for all simulation runs. This water level is above the highest measured data at St. Paul and is representative of the nominal sea surface elevation as storms approach the island. To determine the elevation of the breakwater crest, a water level of +8.5 feet MLLW was used to account for surge events. This water level was extrapolated from the water level frequency curve to represent a very infrequent event. This higher value was selected to ensure that breakwater structures would not be overtopped during storm events. Experience at St. Paul harbor has shown that overtopping wave energy can cause damage to the protected area of the harbor with adverse effects on facilities and moored vessels. The crest elevation of the breakwaters will be further refined in the PED phase of the project.

The total water method more directly represents the data. The non-tidal residual method predicts higher water levels and adds an offset to the record by assuming all events occur at MHHW. For the purpose of this study, it is assumed that the design water level of +5.9 feet MLLW is an extreme event and has a frequency of 0.02 AEP.

2.4.4. Currents

Measured current data is not available for St. George. Barge operators related experiences navigating through beam-on currents when entering and exiting the harbor at St. George. The predominant current direction is to the north, though it was noted that it sometimes flows to the south. Fishing vessel captains contacted did not report having any concerns for currents at the harbor. Current velocities were not estimated.

2.4.5. Wave Climate

The wave climate at St George is very similar to that of St. Paul and is controlled by the Bering Sea. Two storm mechanisms were identified producing the most severe effects in the Bering Sea. Typically, winter storms in the Bering Sea are generated in the Sea of Okhtosk and travel east. These storm systems can occur multiple times over the course of a season and sometimes follow one after another for multiple weeks at a time. The most severe wave conditions occur in the winter months as typhoon remnants from the south Pacific blow past the Aleutian chain and generate waves in the Bering Sea. Buoy data to the north of the Aleutian chain shows waves in excess of 30 feet on an annual basis. St. George is directly exposed to these waves and energy is only dissipated from these events in the nearshore zone as bathymetry causes these waves to shoal and break before reaching the shore. The nearshore wave climate around the island is depth-limited with wave breaking caused by bottom friction being the only mechanism to reduce wave energy from storms before it reaches the shore.

2.5. Ice Conditions

St George Island lies at the southern extent of sea ice in the Bering Sea. Typically, Zapadni Bay is ice free. Historical sea ice concentrations have been cataloged and recorded in Alaskan waters from the 1850s to the present. These records were compiled into a Sea Ice Atlas database which maps the Bering Sea in quarter degree increments. This work was done by the International Arctic Reasearch Committee and the University of Alaska Fairbanks. The atlas was accessed at http://seaiceatlas.snap.uaf.edu/ and sea ice concentrations were investigated at 56.75°N, 169.5°W which is to the south of St. George Island. The records show that St. George historically has open waters (ice concentrations of 30% or less) from June through February and greater concentrations of ice from March through May (Figure 9). The records also show that pack ice (concentrations over 90%) have never been recorded at St. George. The most recent recorded ice at St. George above 30% was in January of 2000 with the next previous event occurring prior to 1980.

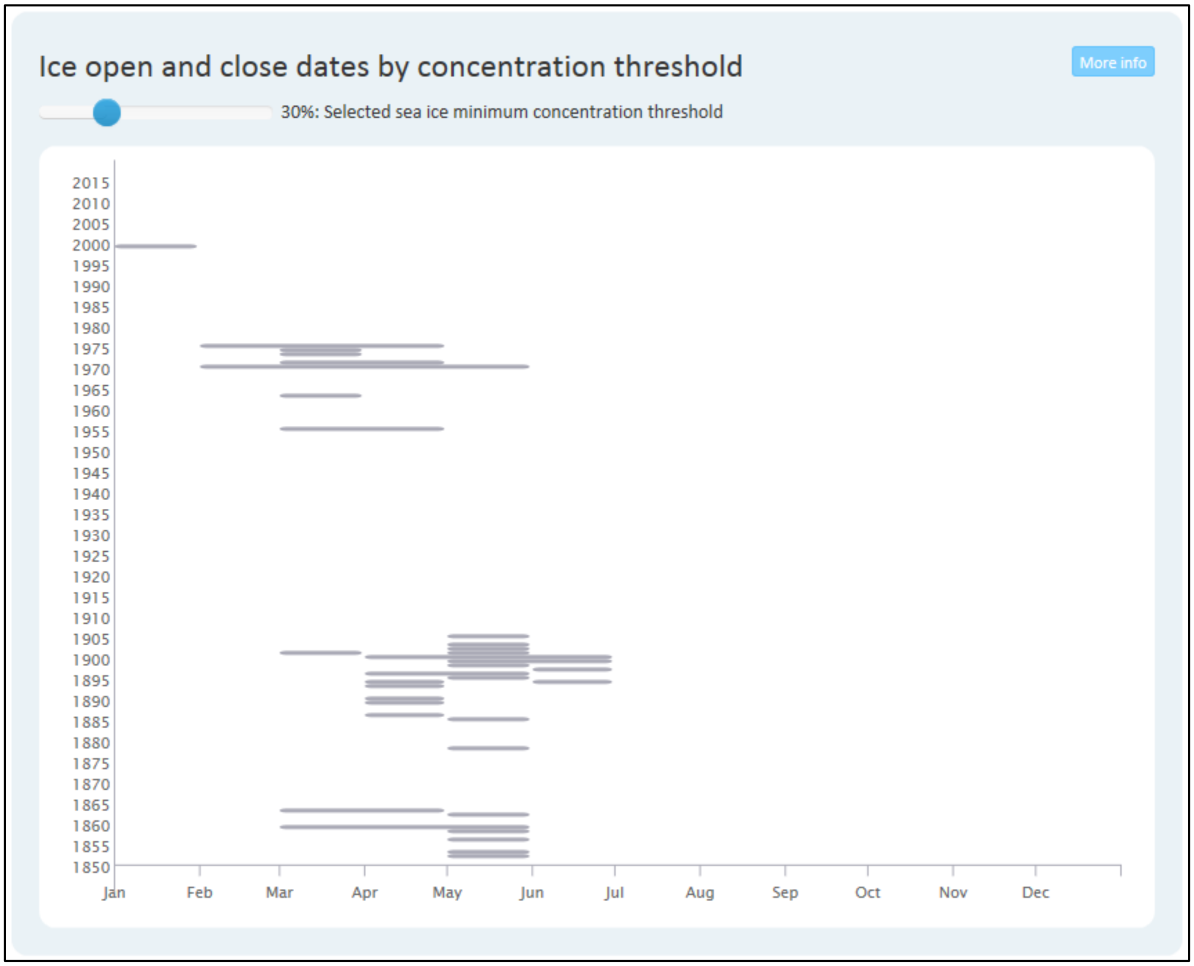

Figure 9. Historical concentrations of sea ice exceeding 30% at 56.75°N, 169.5°W, near Zapadni Bay, St. George.

Due to the orientation of the harbor and typical ice concentrations in the area, sheet ice is not expected to form and produce ice forces against harbor structures.

For comparison purposes, the historical sea ice concentrations at St. Paul were also investigated. More frequent ice coverage was noted in the records as shown in Figure 10. The most noticeable difference in ice coverage is from 2000 to 2010 where the St. George data shows no incidents of ice concentrations above 30% and St. Paul shows several events in the January through April timeframe. While this data indicates St George experiences less ice than St. Paul, there is insufficient detail in the records to determine what impacts this would have on vessels attempting to use a harbor in the Pribilof Islands during this season.

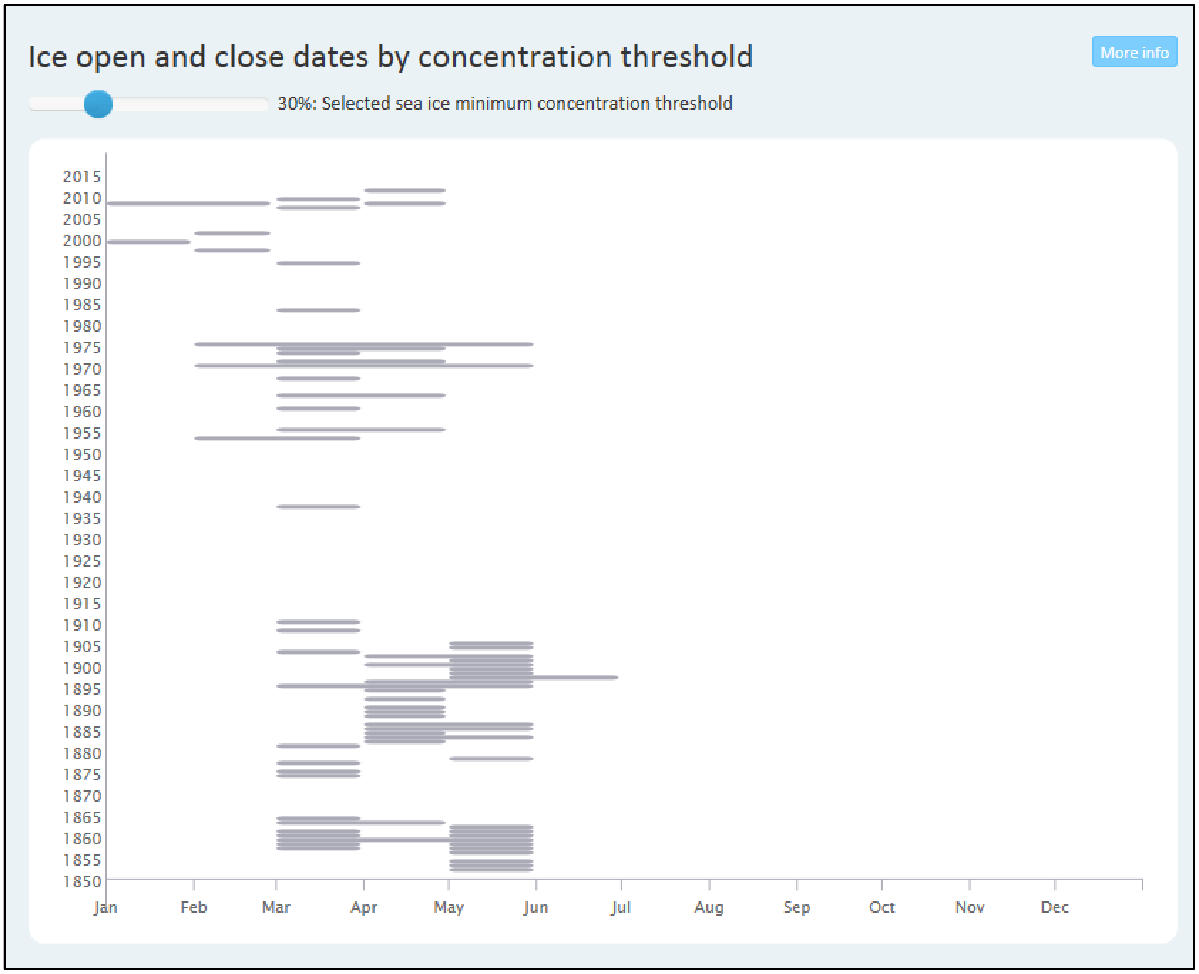

Figure 10. Historical concentrations of sea ice exceeding 30% at 57.25°N, 170.5°W near Village Cove, St. Paul.

Additional ice coverage analysis was performed to determine the likelihood of ice sheet coverage near the north site of St. George that would indicate the presence of marine mammals that use ice sheets as haul out habitat. For the north site, sea ice concentrations were investigated at 57.0°N, 169.5°W. This would impact winter construction activities at the north site for blasting and dredging, discussed later in this appendix. To account for the presence of ice sheets at St. George, a 60% ice coverage criteria was used. Two events were noted in March and April in 1970 and 1976 and eight May events were noted from 1859 to 1906. Over the 165 year period of record, there were ten occurrences of ice concentration which roughly corresponds to a 6% occurrence of pack ice at the north site. Impacts of these occurrences are likely to represent delays to project construction of up to two months.

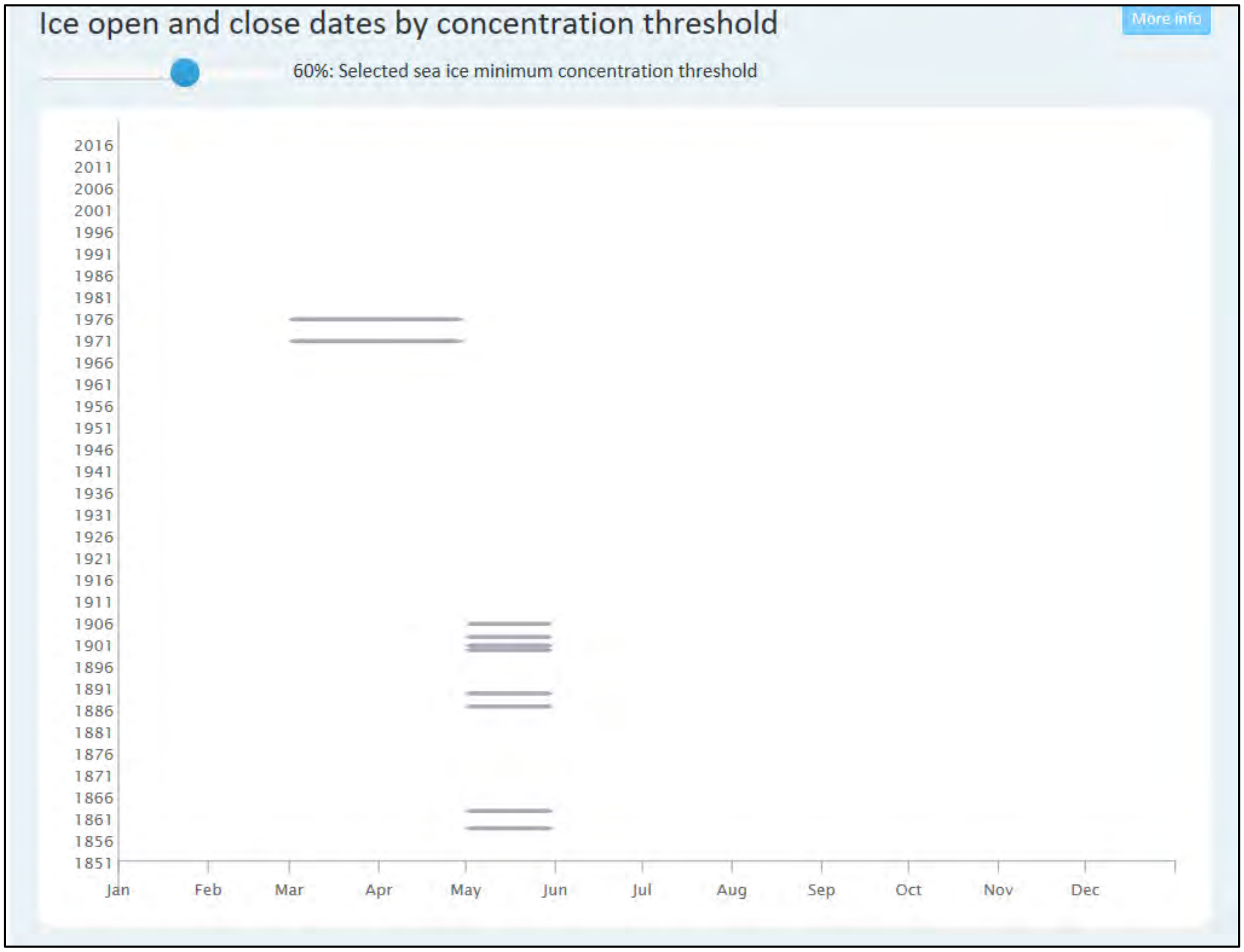

Figure 11. Historical concentrations of sea ice exceeding 60% at 57.0°N, 169.5°W near the north site, St. George.

2.6. Sedimentation

Sedimentation has been observed to occur in the harbor at Zapadni Bay. USACE maintained the navigation channel into the harbor at Zapadni Bay through 1996. Surveys from the time of construction to that date showed no change in bathymetric conditions in the harbor except for construction activities. Channel depths through this period remained at or below the authorized depth of -22 feet MLLW. Maintenance of the channel was suspended in 1996. No surveys were performed from 1995 when the Tanaq Corporation had the harbor surveyed until 2013 when the City of St. George began to investigate navigation improvements at their harbor. The 2013 survey showed significant shoaling in the channel with the formation of a bar across the outer breakwaters with a minimum elevation of about -14 feet MLLW. A subsequent survey in 2016 showed that this bar had migrated into the harbor at about the same depth. Several large storms occurred over this interval, including one that damaged the south breakwater in December 2015 requiring repairs to be performed in 2016 and 2017.

2.6.1. Sources and Sinks

St. George Island is an isolated sediment transport system and all sediment occurring along its shoreline is likely to have been generated by weathering of the stone cliffs that comprise the island's shoreline. Mariners noted that there is a dominant current at Zapadni Bay from the south to the north, though this current can reverse direction. Given the fact that the island poses only a minor obstruction to the circulation of water in the Bering Sea, it is likely that cross-shore transport of sediment during storm events is a greater contributor to sediment transport than longshore transport movements.

During the data collection phase at Zapadni Bay, one of the ADCP sensors was lost inside the harbor. During attempts to recover it, the surveyors noted that the bottom material of the harbor was fine material up to 5 feet deep. This material could be left over from quarry operations during the original harbor construction. Also, there is a potential that fine material is generated as the berm breakwater sized stones shift under storm conditions and as the rock walls of the inner harbor erode.

2.6.2. Sediment Transport Rate

The Limited Reevaluation Report for St. George published in 1993 estimated that to maintain the harbor at Zapadni Bay, 10,000 cubic yards would need to be dredged from the outer harbor every 2 years. A cursory evaluation of sedimentation was made by quantifying the volumetric change in conditions within the outer harbor between the 1995 and 2013 surveys and between the 2013 and 2016 surveys. Only the outer harbor areas were compared since an extension of the inner harbor was constructed between 1995 and 2013 which would skew results. The volume of bathymetric change was divided by width of the harbor opening measured at 0 feet MLLW between the outer breakwaters to give a unit rate of transport per harbor opening width. The harbor opening at Zapadni Bay by this definition is 300 feet.

2.6.2.1. Volumetric Change 1995 - 2013

Volumetric net change within the outer harbor between 1995 and 2013 was +3,000 cubic yards. Movement of material was greatest between the outer breakwaters with a maximum increase in elevation of +8 feet along the channel bottom. Change in volume rapidly decreased to below +3 feet within 100 feet of the harbor entrance, then tapered off to less than +1 foot within 250 feet of the opening. The average rate of sedimentation in the harbor over this period is approximately +170 cubic yards per year.

2.6.2.2. Volumetric Change 2013 - 2016

Volumetric net change within the outer harbor between 2013 and 2016 was +13,300 cubic yards. Movement of material near the outer breakwaters ranged from -7 feet to + 7 feet as the shoal migrated from across the harbor entrance to about 400 feet inside the harbor. This movement of material accounts for most of the net sediment transport within the harbor during this period. Volume change in the inner harbor was negligible. The average rate of sedimentation in the harbor over this period is approximately 4,400 cubic yards per year which is consistent with the estimate in the 1993 LRR report.

2.6.2.3. Design Sedimentation Rate for Zapadni Bay

The likely reason for the large difference in sedimentation rates between the two periods analyzed is the time required to form a sediment wedge around the toe of the breakwater. When the harbor was completed in 1990, sediment would have begun to accumulate at the toe of the breakwater. During this period of time, the only material to move in and out of the harbor would have been located directly at the harbor entrance. As the sediment wedge built over time, a new source of material became available to move into the harbor during storm events. It is possible that the majority of the sediment movement found in the period from 1995 to 2013 occurred near the end of this period once the sediment wedges had been formed. Since this source of material is currently the condition of the harbor, it is assumed that future sedimentation will follow the pattern observed from 2013 to 2016 and the maintenance dredging requirement at Zapadni Bay will be 4,400 cubic yards per year, or 15 cubic yards per linear foot of harbor opening.

2.6.3. North Site Sedimentation

No time series of surveys of the north site have been performed which would provide a basis for quantifying volumes of sediment transport. Wave analysis around the island indicates that there is greater wave energy and potential for cliff erosion and sediment transport on the southwest side of the island when compared to the north side of the island. Peak spectral energy on the north side during storms is in the 12 to 14 second range while on the southwest side, it is in the 18 to 22 second range. Using the log relationships between the WIS Stations representative of these coastlines, representative wave energy flux values were calculated based on the design wave height for breakwaters with peak periods in the range of the top ten storm events from each site.

Wave power is calculated by the formula: $P = {}^{1}\!/_{2}\, E_0 C_0$ where $E_0 = \frac{\rho g H^2}{8}$ and $C_0 = \frac{gT}{2\pi}$. The value of the constants in these equations were taken as ρ=1029 kg/m^3 (density of sea water) and g = 9.81 m/s^2 (gravity). The characteristic wave heights and periods used for Zapadni Bay and the north site were 7.1 meters, 20 seconds and 4.5 meters and 13 seconds respectively.

The wave power at the Zapadni Bay site was found to be approximately four times the value of the wave power at the north site. For the purpose of analyzing sediment movement at the north site, it is assumed that the rate of movement is one quarter the rate estimated at Zapadni Bay. The unitized rate of sediment transport into the harbor is assumed to be 4 cubic yards per linear foot of harbor opening, or approximately 1,000 cubic yards per year for a 300 foot opening similar to the existing harbor.

It should be noted that this is a high level assumption and does not take into account differences in the availability of sediment, differences in sediment gradation, and degradation rates of the coastline and rock structures or sheltering effects of shoreline geometry. To account for these effects, a time series of surveys of the north site, representative sampling of sediment from both sites and laboratory analysis would need to be performed, which is beyond the scope of this study. The site was surveyed in 2018. A cursory analysis of sediment movement would require an additional survey to be made to measure bathymetric changes at the site. No additional surveys are currently planned in the PED phase of the project and refinement of estimated sedimentation rates is not anticipated in the future.

2.7. Climate Change

2.7.1. Climate Change Impacts to St. George

The NOAA began publishing an annual, peer-reviewed Arctic Report Card in 2006. The Report Card is a "source for clear, reliable, and concise environmental information on the current state of different components of the Arctic environmental system relative to historical records" (Osborne, Richter-Menge, & Jeffries, 2018). The 2018 Report Card states that the Arctic sea ice cover is continuing to decline in the summer maximum extent and winter minimum extent (Perovich, et al., 2018). The minimum sea ice extent usually occurs in late September. In 2018, the ice cover was 26% lower in late September than the average coverage between 1981 and 2010 and was tied for the 6th lowest ice cover since 1979 (Perovich, et al., 2018). With a decreased sea ice extent there is an increase in time that the sub-Arctic (i.e. the Bering Sea) is ice-free or has limited sea ice coverage.

According to the Fourth National Climate Assessment (Wuebbles, et al., 2019), a warming trend relative to average air temperatures recorded from 1925 through 1960. A trend of increasing temperatures starting in the 1970s has been identified and is projected to continue throughout the state of Alaska. The largest temperature increases have been found in winter months with average minimum temperature increases of around 2° F statewide. Carbon emission models project variable increases in statewide temperatures across the state; for the Pribilof Islands, forecast temperature increases appear to be in the 4 – 6°F range for an intermediate model (RCP4.5) and in the 8 – 10°F range for a high model (RCP8.5) (Figure 12).

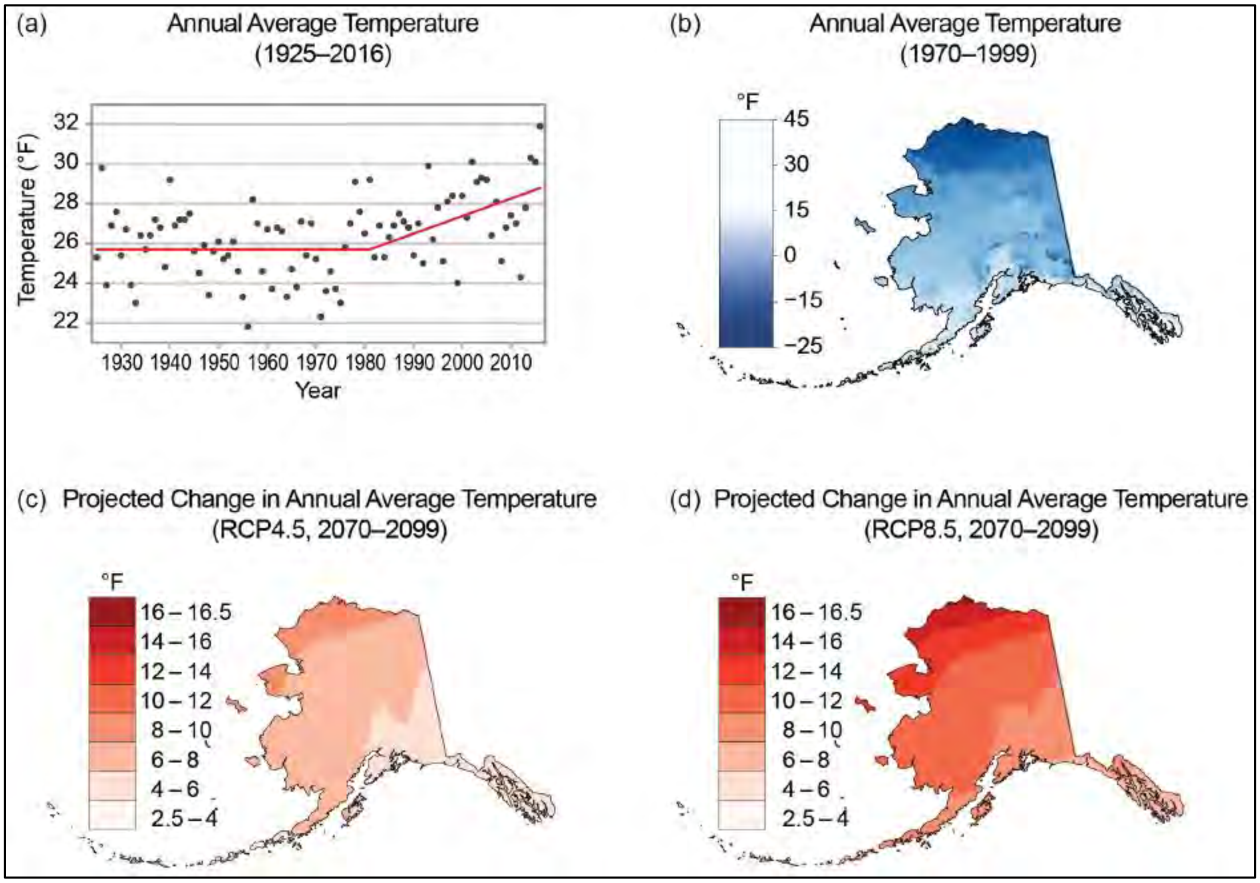

Figure 12. Figure 26.1 from (Wuebbles, et al., 2019)

Note: Annotation truncated from report): (a) Alaska statewide annual temperatures for 1925-2016. The record shows high variability from 1925 to 1976, but from 1976-2016 a clear trend of +0.7°F per decade is evident. (b) 1970-1999 annual average temperature. (c) Projected changes from climate models in annual average temperature for end of 21st century (compared to 1970-1999 average) under a lower scenario. (d) The map is the same as (c) but for a higher scenario. Sources: (a) NOAA and USGS, (b-d) USGS.

An increase in winter temperatures in the region could decrease the period of sea ice formation in the Bering Sea south of the Bering Straits and the site could be impacted by waves and storm surge in later parts of the year than the season of analysis used for this study. Changing sea ice conditions and potential sea level rise at the project site could result in increased wave severity from storms originating from the north and potentially increased overtopping of the breakwaters during high water events. The change in sea ice conditions is not anticipated to affect the armor stone size since the largest storms that control breakwater design predominantly originate from the southwest and west and are not affected by the presence or extent of ice to the north of the islands.

2.7.2. Resilience and Adaptation to Climate Change

Construction constraints at St. George pose a significant barrier to adapt a project to relative increases in sea level over time. The challenges with the site, high mobilization costs, short construction seasons, limited local support for construction, make it preferable to plan for construction of a resilient structure that needs no intervention in future years. The primary cause for concern at the site is for increasing sea levels to increase the likelihood of overtopping causing damage to the breakwater and inner harbor facilities. Harbor design is generally based on a design water level of +5.9 feet MLLW to account for tides and storm surge at St. George. To provide resiliency to overtopping, a design water level of +8.5 feet MLLW was used to determine the crest height of the breakwaters for all alternatives considered in the study. This water level is 2.6 feet above the harbor design water level and accounts for potential sea level change under a high curve scenario 50 years from the time of construction.

Resilience to overtopping was analyzed by adjusting sea level change curves to the year 2020 and comparing the relative change between the curves over the period of investigation for the project. Curve adjustments were made by taking the curves projected from 1992 and setting the 2020 values to 0. This produces a set of curves with slopes projected from the 1992 tidal epoch but starting form the value of zero in 2020 (Figure 13).

Under the high curve scenario, overtopping would begin to occur approximately 43 years after construction in 2066. Overtopping does not occur under the low or intermediate scenarios within a 100 year adaptation horizon. While this analysis shows a conservative formulation for overtopping, it should be noted that the effects of receding ice packs over winter months and longer open water periods are not known. It is possible that these impacts may increase wave heights on the structure which could lead to an acceleration of the timeline to require intervention to prevent overtopping.

In the event that overtopping of the breakwater causes damages in the harbor, the crest elevation of the primary breakwater can be elevated by adding two rows of armor stone to the crest. At Zapadni Bay, using 30 ton armor stone, this would increase the crest height of the primary breakwater by 7 feet. At the North Site, using 10 ton armor stone, this would increase the height 5 feet.

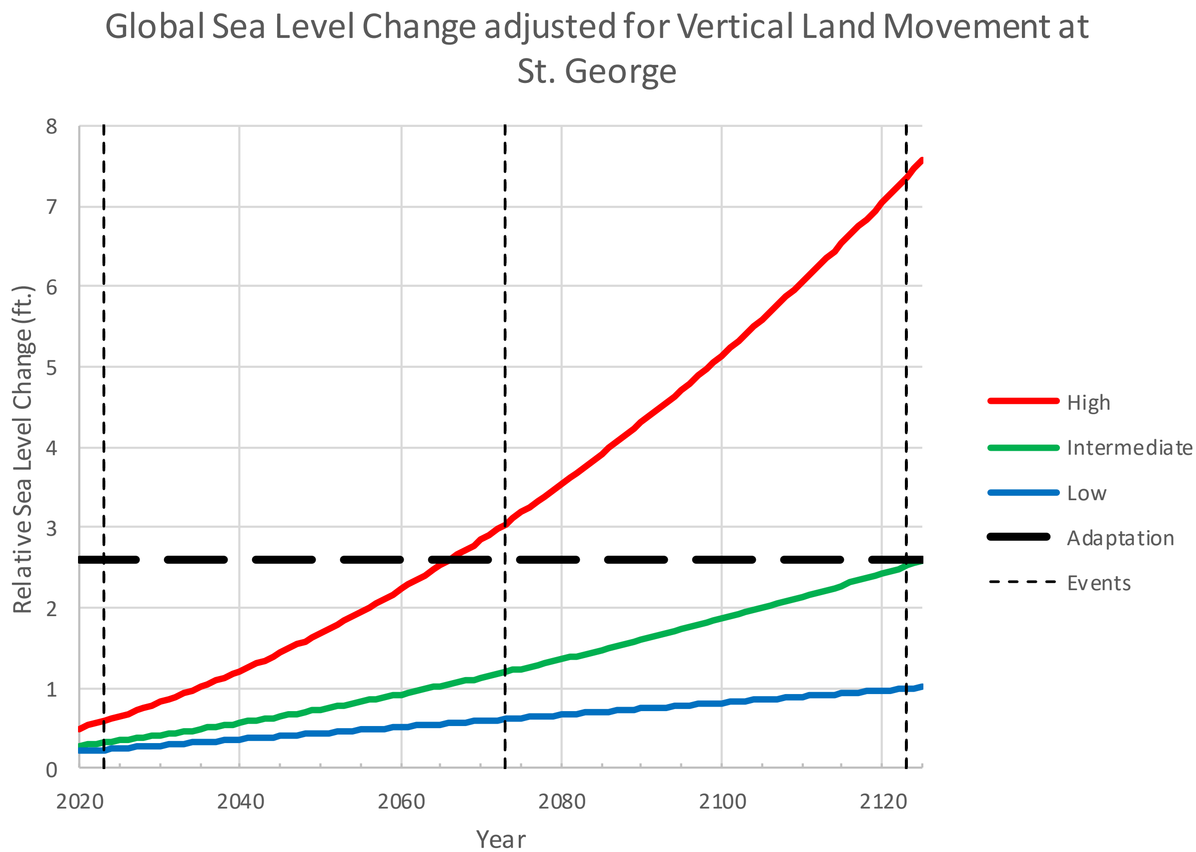

Figure 13. Resilience analysis for overtopping of St. George breakwater alternatives. Vertical lines show estimated start of construction, 50 year project economic period, 100 year adaptation period. The horizontal line shows the threshold at which overtopping is expected to begin to cause damages to harbor facilities requiring intervention.

3.0 DESIGN CRITERIA

3.1. Design Vessel and Fleet

A fleet spectrum was developed for the arctic region and is outlined in the Economics Appendix for this study. Expected fleet missions are commercial fishing, subsistence fishing and freight and fuel delivery. Characteristic vessels have been identified to provide the minimum design requirements for port facilities. General design vessel dimensions for the fleet expected to utilize the harbor at St. George is shown in Table 4.

Table 4. Design Vessel Dimensions

Design Vessel	Length (ft.)	Beam (ft.)	Draft (ft.)
Subsistence Vessel	28	8.5	4
Crabber	150	36	14
Fuel Tug and Barge	180	84	10

3.1.1. Commercial Fishing

Commercial fishing would be accomplished using ocean going vessels of the same type found at St. Paul or Dutch Harbor. Vessel dimensions were obtained for 78 vessels operating with permits in the Bering Sea. This sample was assumed to be representative of the fishing fleet and representative dimensions were taken from this data. Vessels sampled have length dimensions from 80 feet to 170 feet, beam from 24 feet to 41 feet and draft from 8 feet to 17 feet. Since vessel draft for this fleet is a controlling dimension for channel design, a distribution of vessel drafts was created to see what percentage of the vessels in the fleet exceed various draft thresholds (Figure 14).

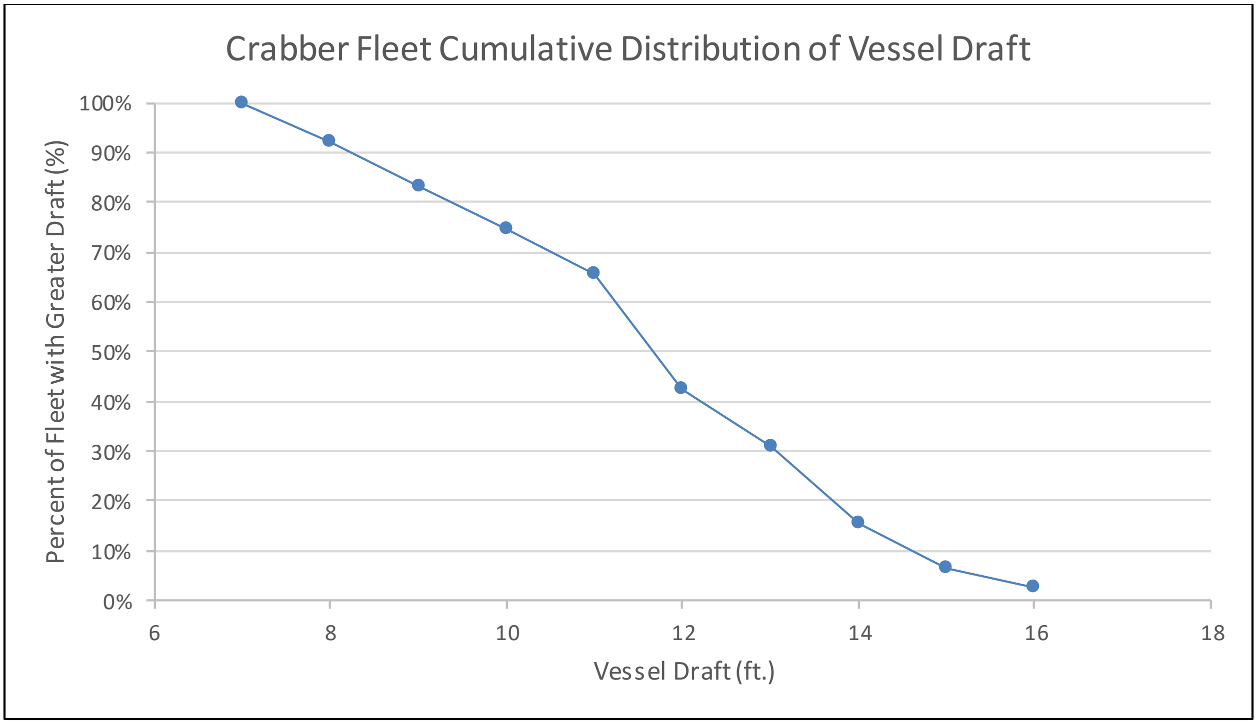

Figure 14. Distribution of vessel draft of crabber vessels operating in the Bering Sea.

Based on the draft distribution, a design vessel draft of 14 feet was selected for the fleet accessing St. George. This draft includes 85% of the vessels sampled. The deeper draft vessels generally have the longest length and beam dimensions and are less likely to call at St. George as they would not be able to offload their entire hold of product at facilities likely to be operated at St. George. A design vessel draft of 10 feet, which would be the minimum to accommodate the fuel barge, would include 25% of the vessels sampled.

For the purpose of this study, it was assumed that waves at the harbor entrance must be 10 feet or less in height for a crabber to enter the harbor. When analyzing model output, the threshold value for crabbers to enter and exit the harbor is 9.8 feet (3 meters). This is based on prescriptive guidance from St. Paul Harbor operations that the harbor is generally closed when waves at the main breakwater reach 10 feet. Some variation in acceptable harbor accessibility conditions are expected depending upon vessel characteristics and crew experience.

3.1.2. Freight Delivery

Freight delivery to St. George is currently carried out by air freight. Infrequent freight barges offload supplies, equipment and material at St. George for construction activities. The vessels chosen to represent this operation were taken from Alaska Marine Lines' fleet data. They operate a 270 foot barge, Western Service which is 270 feet long, 70 feet wide with a draft of 19 feet. The largest tug operated by the same group which has dimensions of 94 feet long, 27 feet wide and 14 feet draft. Another tug in their fleet had a beam of 30 feet, which creates a maximum vessel beam of 100 feet. Recent construction activities to repair the Zapadni Bay South Breakwater was supported by an articulated tug and barge operated by Brice Marine with a length of 245 feet and a loaded draft of 9.1 feet. This vessel navigated to the inner harbor to offload rocks for the repairs.

3.1.3. Fuel Delivery

Fuel deliveries to St. George are currently supplied by Delta Western which uses vessels operated by Cook Inlet Tug and Barge. The barge used for this mission is 180 feet long and 54 feet wide. It is assumed that other shippers would use similar vessels should the service provider for the community change. The loaded draft of this vessel is approximately 10 feet. Crowley Marine uses a 180 foot barge with a width of 52 feet and a loaded draft of 12.25 feet in the region. Tugs for the Crowley fleet can be up to 32 feet in width which would create a maximum vessel beam of 84 feet for a tug on hip.

For all harbor alternatives considered in this study, tug and barge deliveries require the tug to make up alongside the barge outside the harbor. This maneuver requires relatively calm seas ranging from a few feet according to the barge operators to “dead calm” according to the harbormaster at St. Paul. For the purpose of this study, a wave criteria of 3.3 feet (1 meter) was used to determine whether a tug and barge could make up on hip outside the harbor before navigating to the dock and mooring. For these vessels, the wave climate outside the harbor controls whether or not a delivery can be made.

3.1.4. Subsistence Fleet

Residents of St. George operate boats to harvest sea resources for subsistence. The local fleet is generally comprised of welded trailer able aluminum boats of beams of 8.5 feet or less. Trailer able boats usually have lengths up to 28 feet and drafts up to 4 feet. Wave criteria for these vessels was set at a 4 foot (1.2 meter) wave height. This criteria is based on discussions with vessel operations.

3.2. Vessel Navigation

The ability of the design fleet to navigate the harbor was a key design consideration. The small vessels of the local fleet and the commercial fishing vessels are maneuverable and can handle fairly tight turning scenarios. These vessels have hull designs with a deep vee to help them track a line through waves and have control surfaces that allow them to make these maneuvers. The fuel barge, on the other hand, is a flat bottomed vessel with no control surfaces and is maneuvered by tug thrust. Interviews with the tug and barge operations revealed specific concerns for the existing harbor at Zapadni Bay.

Fuel deliveries to St. George are about 85,000 gallons of fuel per delivery. While this is not a full load for the fuel hold, it is typically the heaviest delivery made to St. George and is in the least maneuverable vessel. The vessel must reconfigure outside the harbor from a tow line configuration to an on-hip configuration to allow the tug to vector thrust against the barge for maneuvering. Sea conditions outside the harbor control whether or not this can be done. The operators stated that a four foot swell creates unusable conditions at the existing harbor. Wind is a key factor for this vessel due to the low steerage experienced at slow speeds. Barge freeboard, indicative of the sail area of the vessel varies from 2 feet fully loaded to 10 feet empty.

To accomplish the turns described in this section, the vessel must reduce its velocity to nearly dead slow. This affects steerage by reducing flow past the tug's rudder and makes turns slow to accomplish. The low speed also allows wind on the superstructure and the portion of the hull above water to significantly affect the course of the vessel. During these maneuvers, there is a concern that wind gusts will overpower the available thrust and steerage and blow the vessel aground.

To improve navigation safety of the existing harbor, it was suggested by the fuel barge operators that widening the opening at the inner breakwater by a minimum of 15 feet would significantly improve navigation into the harbor and reduce the risk of vessel casualty during this maneuver. In general, reducing the turning requirements on the fuel vessel will improve navigation safety. To maintain fuel supply access at St. George, alternatives were planned to either maintain the current navigation maneuvers, since they currently support fuel deliveries to St. George, or reduce the turning requirements for the fuel vessel.

Entrance navigation into the existing St. George Harbor is shown in Figure 15. The fuel vessel transits the Bering Sea with the fuel barge on a tow line (1). To navigate the harbor, the tug makes up on hip, on the port side stern of the barge to assist in making the initial turn out of the sea past the outer breakwaters (2). While navigating the outer harbor, the vessel tries to approach the breakwater opening from the northwest to create as straight of a path as possible from the outer breakwaters to the nose of the inner breakwater (3). At the nose of the inner breakwater, the vessel slowly arcs around the breakwater at dead slow speed. The operators note that this is the most difficult stage of navigating to the docks since the distance between the nose of the inner breakwater and the opposite side of the inner harbor opening is very narrow, about 185 feet. Once the barge clears the inner breakwater, it moors across docks 2 and 3 on the back side of the inner harbor to deliver fuel (5).

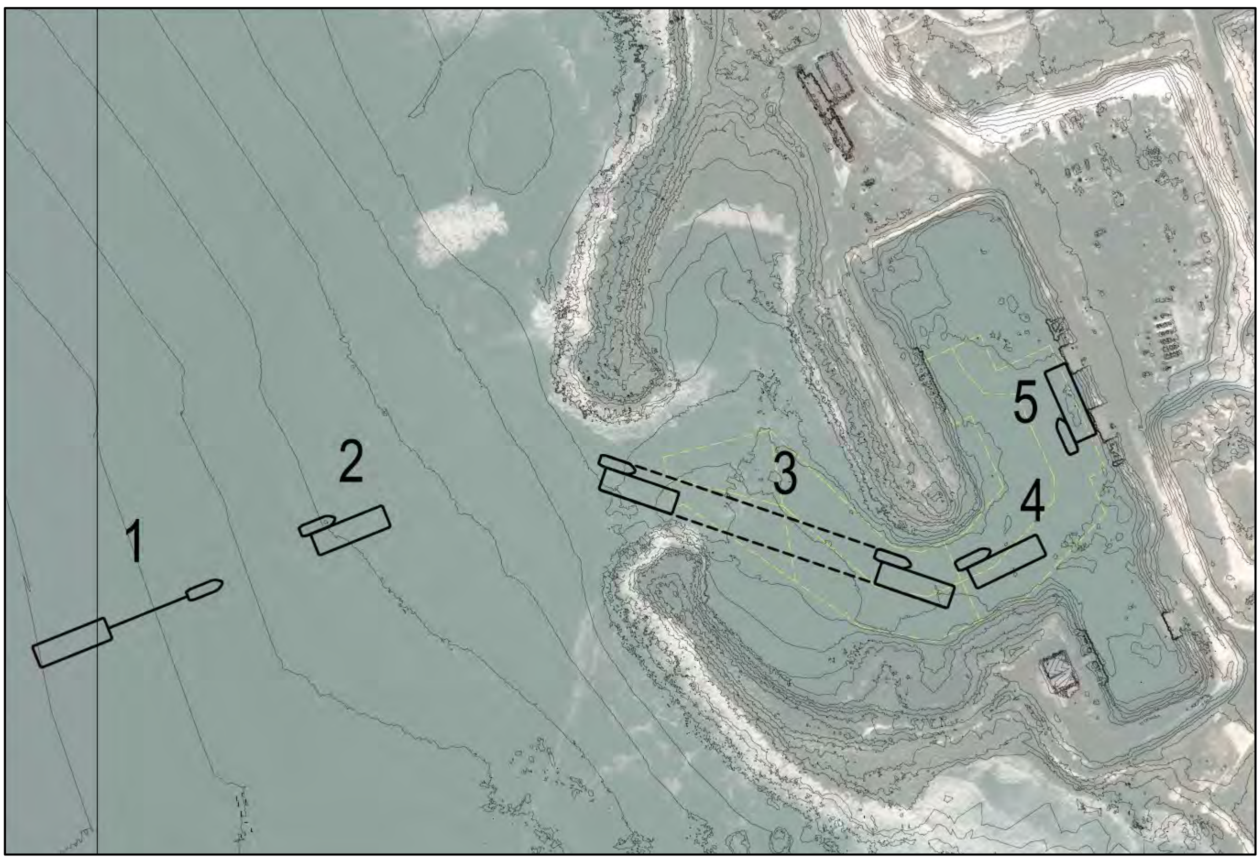

Figure 15. Fuel Barge Entrance Navigation Diagram

Departure navigation out of the existing St. George Harbor is shown in Figure 16. After making fuel deliveries at St. George, the fuel barge is nearly empty and rides near maximum freeboard, which is about 10 feet above the water surface. Exiting the harbor, the fuel vessel leaves the docks (1) backs up into the notch near the ice plant building (2) to begin its turn towards the outer harbor. At this point, the vessel is required to turn at a very slow speed to orient itself past the inner breakwater (3). The vessel then makes a slow path through the outer harbor and turns westward towards the outer breakwater opening (4). At this location, the vessel has minimal steerage and becomes most exposed to open ocean winds. Since fuel has been offloaded, the vessel also has maximum freeboard. The concern here for the operators is that a strong wind could overpower thrust and steerage causing the vessel to be blown into the shallows to the north of the harbor entrance. The operators cited this scenario as the cause of ships that have historically run aground at St. George. Once clear of the harbor, the vessel reconfigures back on the tow line for its return transit across the Bering Sea.

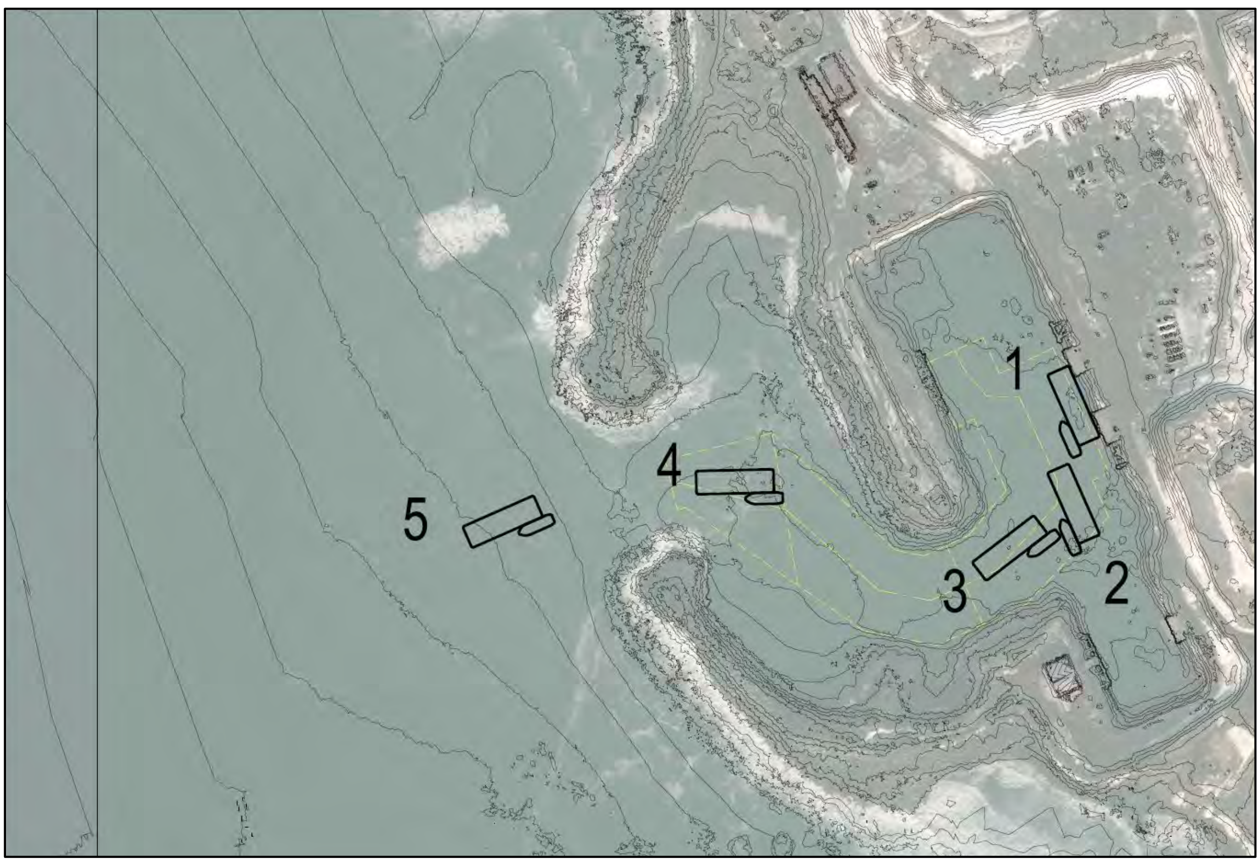

Figure 16. Fuel Barge Departure Navigation Diagram

3.3. Allowable Wave Heights

3.3.1. Sea Conditions

Since the harbor site has open exposure to Bering Sea waves, there are times when the wave climate outside the harbor is too severe to allow vessels to operate. At St. Paul Harbor, the harbormaster typically closes navigation to and from the harbor when waves outside the harbor exceed 10 feet. Many vessel captains choose to use a lower threshold to decide when to attempt to enter or exit the harbor. The sea outside the harbor at St. George has more directional exposure to the Bering Sea than St. Paul and similar operating constraints are expected.

3.3.2. Outer Harbor

The outer harbor of St. George is used for navigation only and does not require the level of protection needed for a vessel to moor at a dock or raft with other vessels. No target wave conditions were designed for this portion of the harbor; when sea conditions allow for vessels to enter or exit the harbor, the breakwaters provide sufficient protection to allow vessels to navigate to the entrance. When wave conditions outside exceed these thresholds, vessels will not be in this area.

3.3.3. Inner Harbor

The inner harbor is designed to support fuel deliveries and commercial fishing activities. Due to the size of the vessels in the fishing fleet that would use the harbor, wave height criteria have been established accordingly. Wave heights of less than 2.5 feet, (0.75 meters) are assumed to be acceptable for the use of this fleet. This criteria was established in the design of St. Paul harbor where it was recognized that some wave action would transmit through the breakwater and affect vessels inside the harbor. When wave conditions exceed 2.5 feet at the dock, it is assumed that vessels will wait at anchor in the harbor to minimize damage from impacts with the dock. All model output for the alternatives studied at St. George are spectral peak waves. This means that waves larger than those reported by the model are expected to occur. The distribution of these waves in the harbor is not well defined. To account for these higher waves, the model output threshold for mooring was reduced to 1.6 feet, or 0.5 meters.

3.4. Channel and Basin Widths and Depths

The channel design parameters discussed in this section apply to harbor development at both sites considered in this study.

3.4.1. Entrance Channel and Outer Harbor

The vessels making fuel deliveries to St. George also serve the community of St. Paul. The harbor configuration at St. Paul is a 250 foot wide channel dredged to -30 feet MLLW. The channel is perpendicular to the shore and makes a 90 degree turn to the south around the nose of the main breakwater. Through the turning section, the channel is 355 feet wide. Beyond the head of the breakwater, vessels pass between the main breakwater and the detached breakwater through a channel with a bottom width of 150 feet. Vessels enter and exit the harbor when waves outside of the harbor are 10 feet or less. Channel design for St. George follows similar criteria to St. Paul to accommodate the same vessels. Channel criteria discussed are applicable to harbor development at all sites on St. George Island.

Channel width is controlled by the tug and barge vessel. Per ER 1110-2-1613, the channels considered for this study are classified as a trench. For one way ship traffic under good conditions, the design channel width for the vessel is 231 feet.

The channel depths were determined based on economic evaluations, design vessel draft, vessel motion in waves, squat, tide, safety clearance, advanced maintenance, and dredging tolerance. Pitch, roll and heave requirements are based on the most severe wave conditions in which vessels calling at St. George are expected to operate.

Tidal accessibility of the proposed outer entrance channel depths was based on the information shown in Table 4, which lists a range of design water levels and the percentage of time the channel would be accessible based on an analysis of observed water levels at St. Paul (Figure 17). Based on this analysis, 0' MLLW was selected as the design water level for channel design which provides 94.3% accessibility to the harbor for vessels at the design draft for each class. Vessels drafting less than the design draft would have greater accessibility to the harbor, while vessels drafting more than the design drafts would have greater restrictions to navigation. Channel and basin depth requirements considering vessel motions and safety clearances for the vessel classes considered are shown in Tables 7, 8, and 9. Costs for construction and economic benefits for the various channel depths were evaluated in the Economic Appendix.

Table 5. Tidal Accessibility at St. George

Design Water Level (ft. MLLW)	-2	-1	0	1	2
% Time Water Level above Design Water Level	100	99.5	94.3	80.1	56.9

Channel depth optimization procedures are outlined in ER 1105-2-100. The procedure includes evaluation of economic benefits, estimated costs, safety, efficiency, and environmental impacts. Refer the Economics Appendix for discussion of channel depth optimization.

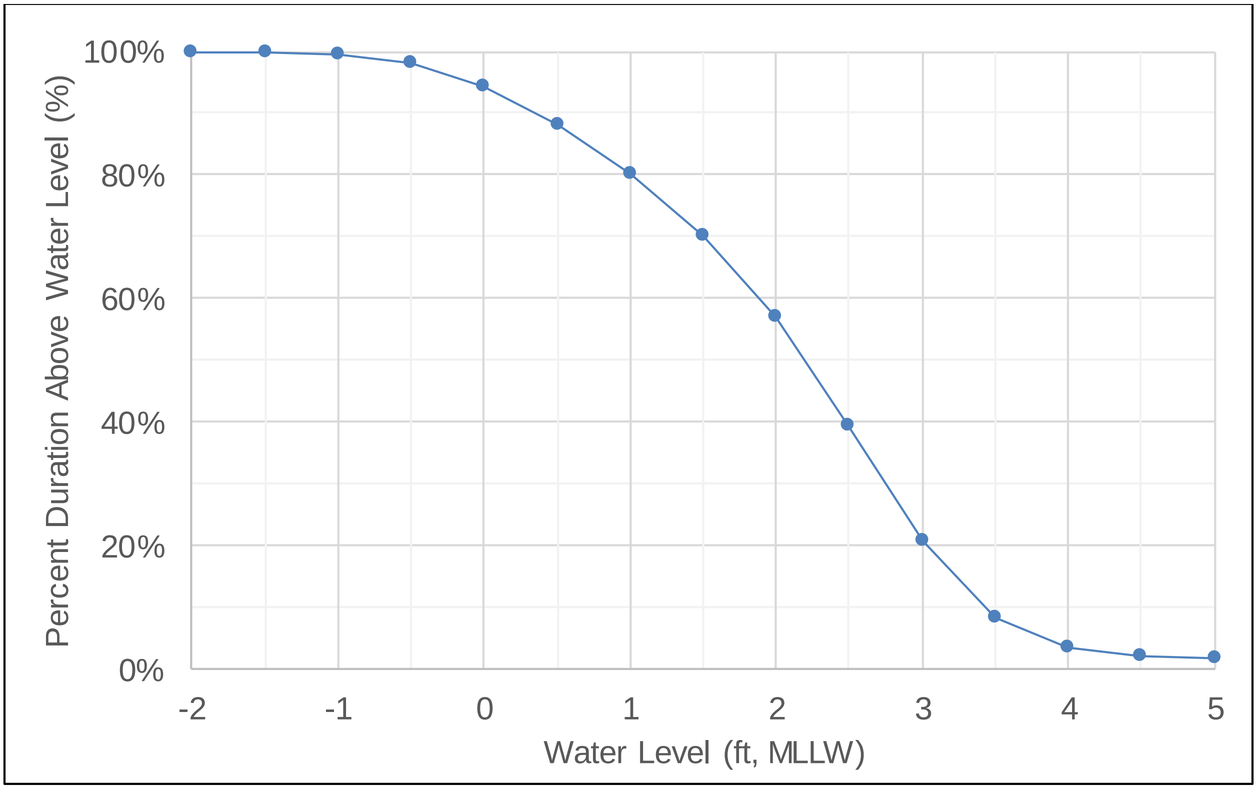

Figure 17. Frequency of water levels at St. Paul, Alaska based on recorded water levels at St. Paul from October 2006 to October 2016.

Table 6. Minimum Channel Depth Determination for Crabber Access

	Entrance Channel		Mooring Basin	
Crabber Channel Depth Criteria	Value (ft)		Value (ft)	
Water Level	0.0	ft. MLLW	0.0	ft. MLLW
Vessel Draft	14.0	ft.	14.0	ft.
Pitch, Roll, and Heave (2/3 of allowable wave height)	6.7	ft.	1.7	ft.
Squat	1.0	ft.	1.0	ft.
Safety clearance (based on rocky bottom)	3.0	ft.	3.0	ft.
Minimum Channel Depth	-24.7	ft. MLLW	-19.7	ft. MLLW

Table 7. Minimum Channel Depth Determination for Barge Access

	Entrance Channel		Mooring Basin	
Fuel Barge Channel Depth Criteria	Value (ft)		Value (ft)	
Water Level	0.0	ft. MLLW	0.0	ft. MLLW
Vessel Draft	10.0	ft.	10.0	ft.
Pitch, Roll, and Heave (2/3 of allowable wave height)	4.0	ft.	1.7	ft.
Squat	1.0	ft.	1.0	ft.
Safety clearance (based on rocky bottom)	3.0	ft.	3.0	ft.
Minimum Channel Depth	-18.0	ft. MLLW	-15.7	ft. MLLW

Table 8: Minimum Channel Depth Determination for Subsistence Fleet Access

	Entrance Channel		Mooring Basin	
Subsistence Fleet Channel Depth Criteria	Value (ft)		Value (ft)	
Water Level	0.0	ft. MLLW	0.0	ft. MLLW
Vessel Draft	4.0	ft.	4.0	ft.
Pitch, Roll, and Heave (2/3 of allowable wave height)	2.7	ft.	0.7	ft.
Squat	0.3	ft.	0.3	ft.
Safety clearance (based on rocky bottom)	3.0	ft.	3.0	ft.
Minimum Channel Depth	-10.0	ft. MLLW	-8.0	ft. MLLW

Dredging tolerance of 2 feet was assumed for a depth of -20 feet MLLW; therefore, it is anticipated that the construction contract for the deep draft navigation project would specify a required depth of -20 feet MLLW with a maximum pay line of -22 feet MLLW. Additional depth to account for advanced maintenance is not proposed.

3.5. Site Accessibility

To determine access availability for the harbor sites at St. George, hourly hindcast data from Wave Information Studies (WIS) stations were analyzed for exceedance of vessel operating thresholds. Hourly wave data was simulated for the period from 1985 through 2014. This wave data approximates sea conditions outside proposed harbors at Zapadni Bay and the North Site. WIS Station 82265 was used to represent Zapadni Bay conditions and WIS Station 82255 was used to represent North Site conditions. Applicability of these stations to their associated sites are discussed in paragraphs 5.3.1 and 5.3.2. Directional wave data was filtered to represent the sheltering effect the island has on conditions just outside the harbor sites. For the North Site, WIS Station 82255 was filtered to include waves originating from the north between 270 degrees and 090 degrees. For Zapadni Bay, WIS Station 82265 was filtered to include waves originating from the southwest between 120 degrees and 300 degrees (Figure 18). Waves originating outside these arcs were assigned a null value resulting in the 0 foot (0 meter) wave exceedance not equaling 100%. The portion of the exceedance graph beyond the range of the 0 foot (0 meter) wave height represents the occurrence of incident waves outside the arc of consideration for each station. For these conditions, the respective sites are assumed to be shielded by the island allowing vessel access. The hourly wave data was filtered against access criteria for different classes of vessels in the design fleet to determine what percentage of time the harbor sites would be available for a vessel to enter the harbor. The duration exceedance analysis compares the number of hours in the record that wave heights exceed the vessel threshold criteria to the total number hours in the record (Figure 19). The analysis generally shows that WIS Station 82255 has a shorter duration of wave heights exceeding any given threshold, though this is most pronounced at lower wave heights.

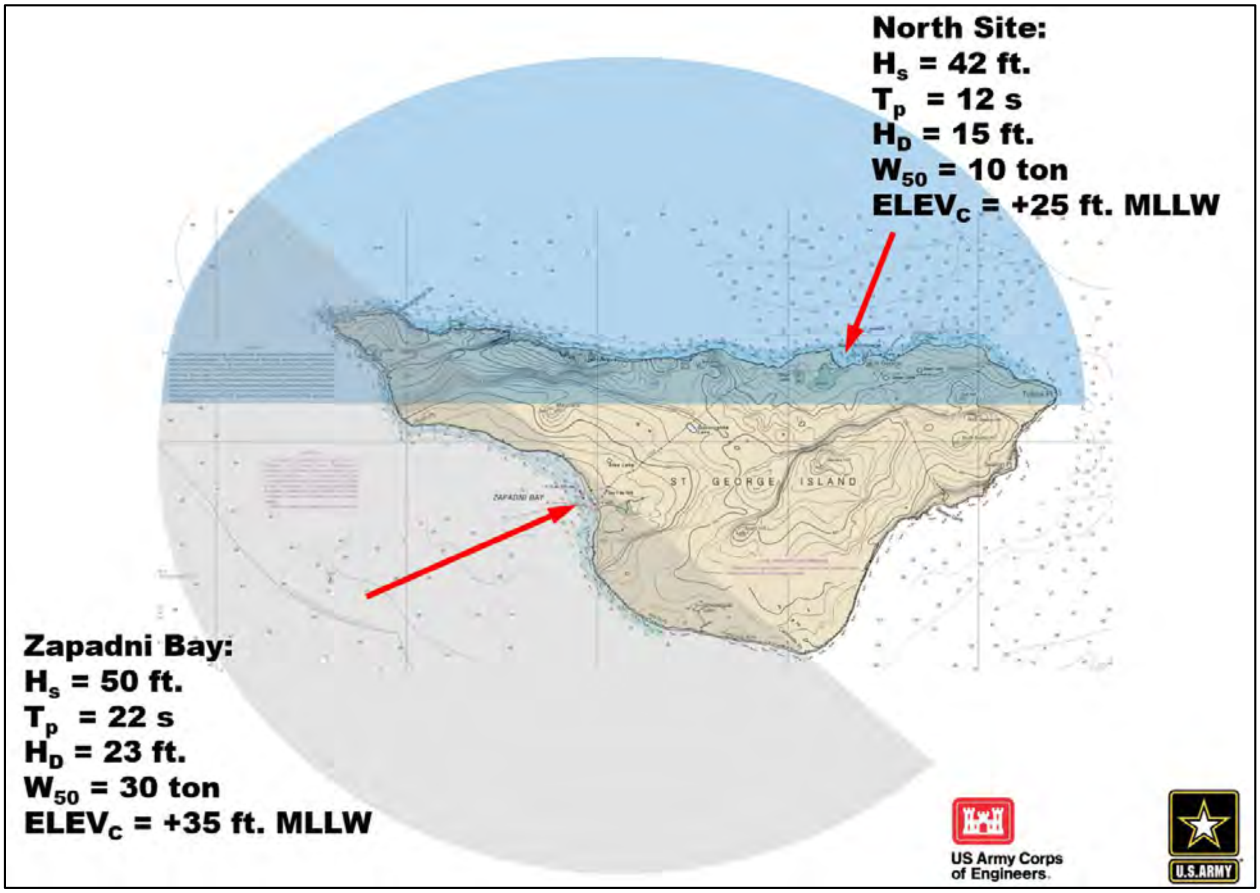

Figure 18. Site comparison between Zapadni Bay and the North Site. H_s is the design deep water wave, T_p is the design spectral peak period, H_D is the design wave height at the outermost breakwater, W_{50} is the median armor stone weight of the primary breakwater and $ELEV_C$ is the design crest elevation of the outer breakwater.

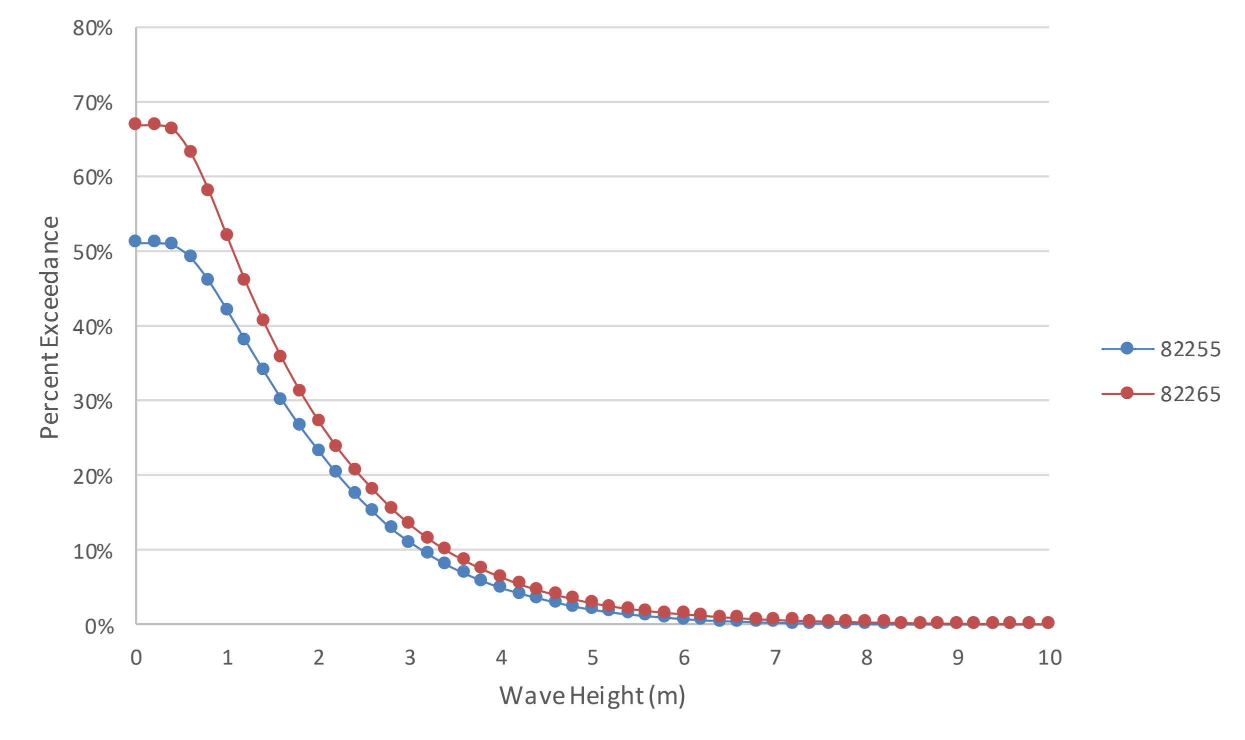

Figure 19. Wave Height Duration Exceedance at WIS Stations 82255 and 82265. 82265 (red curve) represents offshore conditions at Zapadni Bay. 82255 (blue curve) represents offshore conditions at the North Site.

The availability of harbor sites for vessels in the fleet as a percentage of time and as number of days per year are shown in Table 9. Wave criteria for the fleet and wave exceedance durations for both sites are shown in Table 9. In general, this analysis shows that wave conditions on the north shore of the island are more favorable than on the southwest shore.

Table 9. Vessel Operating Wave Threshold Exceedance at Study Sites

		Annual Harbor Accessibility Duration (%)			Annual Harbor Accessibility Duration (days)		
Vessel	Wave Criteria (m)	Zapadni Bay	North Site	Δ_{North}	Zapadni Bay	North Site	Δ_{North}
Fuel Barge	1	48%	58%	10%	175	211	36
Subsistence Vessel	1.2	54%	62%	8%	197	226	29
Crabber	3	87%	89%	2%	316	324	9

3.6. Circulation

The circulation aspects of the proposed harbors at St. George were evaluated based on guidance given in EM 1110-2-1202 (USACE 1987). Tidal variation, storm surge, wave driven currents, ice effects, and wind stresses are factors that affect water circulation. It is estimated that the predominant mechanism that would drive water circulation would be wave and wind stress induced currents within the maneuvering areas and entrance channel. Tidal variation at St. George is approximately 3.3 feet.

The aspect ratio (length divided by width) guidance for harbor improvements at Zapadni Bay is difficult to determine. The outer basin is an irregular shape and open to westerly waves. This portion of the harbor can readily exchange water with the open ocean. Wave activity within the existing inner basin location of all alternatives remains significant during storm events. Length to width ratios can be taken of the inner basins of harbor configurations. The guidance for harbor circulation can be applied in a general sense for this study to show the relative differences in potential circulation between alternatives. Aspect ratios of less than 3:1 reduce the potential for multiple circulation gyres to decrease the gross water exchange between the basin and ambient water. Another parameter used to evaluate harbor circulation is the ratio of the basin planform area (A) to the entrance cross-sectional area (a). Guideline values of A/a and $A/a^{1/2}w$ are given in Nece 1979. Typical values recommended are $A/a < 400$ and $A/a^{1/2}w < 100$ to ensure optimal basin configuration for flushing. Area ratios for selected alternatives are shown in Table 10.

Table 10. Indicator aspect ratios for circulation analysis

Basin Element	Aspect Ratio	A/a	$A/a^{1/2}w$
Without Project Condition	4.0:1	95	19
Alternative 1	4.3:1	85	23
Alternative 2	5.7:1	114	27
Alternative 3	7.8:1	210	44
Alternative 4	5.3:1	129	26
Alternative 5	1.4:1	204	15
Alternative 6	1.8:1	237	21
Alternative 7	2.0:1	383	29
Alternative N1	1.9:1	87	15
Alternative N2	1.5:1	93	13
Alternative N3	2.1:1	137	18

Rounding of basin corners may have some slight benefits in reducing local exchange in the "hot spots." Also, the orientation and location of a single, central entrance channel is generally favorable in driving harbor circulation.

Typically for deep draft navigation projects, physical and numerical modeling studies are recommended in order to analyze the hydrodynamics of proposed channel improvements. For this study, circulation was evaluated using the best available guidance and analytical techniques. Detention time, volume of water exchange, mixing, dilution, and stratification would not be expected to change significantly any of the harbor alternatives studied.

3.7. Life-Cycle Breakwater Design

Armor stone for the proposed breakwaters at St. George was sized using the 50-year design wave forces expected to impact the structure. This was determined to be the most cost-effective means of protection for port alternatives considered. The average sea side armor stone size for a 50-year design at Zapadni Bay is 30 tons. There is a 2 percent chance of a 50-year design event happening in any given year throughout the 50-year design life. The chance goes up to 4 percent for a 25-year design. The percentage goes down to 1.3 percent for a 75-year design level and to 1 percent if a 100-year design level is used. Due to the depth-limited nature of the coastline at St. George, there is minimal difference in cost between armor stone sized for a 25-year event versus a 50-year event. Rock for the project would likely either be barged from the quarry at Cape Nome to the project location. The Cape Nome quarry is the closest likely source to the project and has the capacity to produce 30 ton armor stone. Replacement costs are estimated to be relatively high because the project location is very remote and mobilization costs are substantial. A 75 or 100-year design would reduce the frequency and magnitude of needed maintenance, however design conditions for these events are not well known due to the period of record of data available at the site and there is less certainty that basing the design on a lower frequency event would produce a structure that would be capable of withstanding events of greater severity than those observed and studied. A 50-year design provides the optimum balance between minimizing maintenance requirements and the cost of procuring the stone for repairs. The loss or damage to a relatively small amount of armor stone over time would have little to no effect on the operation and use of the port; therefore, there was not sufficient justification for basing the design on a life-cycle horizon beyond the 50-year level.

3.8. Dredging

Dredging limits were determined based on vessel maneuvering characteristics as a function of length, beam, whether or not tug assist would be provided, turning radii, traffic, and wind conditions. Side slopes of 3H:1V were assumed based on the character of dredged material anticipated (sands, gravel, cobbles, and glacial till). Such side slopes would be stable and rock slope protection would not be necessary for placement on the side slopes.

A minimum offset bench width distance of 15 feet horizontal between the top of the dredge cut slope and the toe of any causeway or breakwater structure is recommended. For purposes of dredging adjacent to the proposed dock faces, the required depth can abut to the dock faces.

The maximum dredging depth determined for the site was to -25 feet MLLW. Previous studies have indicated a need to drill and blast 2 feet below the design depth to produce an efficient pattern to loosen the material for excavation. Dredging tolerances were assumed to be 2 feet due to the coarse nature of the material around the island and the potential need for blasting to remove it.

4.0 PHYSICAL MODEL STUDIES

For purposes of this study, physical modeling for wave analysis was beyond the scope, budget, and schedule. Due to the extreme wave climate and harbor resonance problems known to exist at St. George, physical modeling will be required prior to publishing of plans and specifications for harbor construction. This step is necessary to validate numerical model results and to identify harbor-specific hydrodynamic issues that the numerical models are not capable of replicating. This study needs to be performed in a facility dedicated to wave modeling run by full time research engineering staff. The Corps of Engineers owns and operates the necessary facilities at the ERDC Coastal Hydraulics Laboratory in Vicksburg, MS.

Physical modeling studies for design of the Port of Nome were used to validate the breakwater structures' capability to resist ice forces. For the Port of Nome, scale model testing showed that a minimum armor stone size of 8 tons was required on a 2H:1V slope to be stable for ice sheet impact. The design waves found around St. George require larger stones to survive wave attack. For the purposes of this study, design wave height controls armor stone size.

5.0 NUMERICAL MODEL STUDIES

Numerical modeling of wave conditions at St. George used a three tiered method that employed three separate models. Deep water wave conditions were analyzed from the Wave Information Study (WIS) results published by the Coastal Hydraulic Laboratory. WIS data was binned and sorted to represent the appropriate approach directions and seasons for finer analysis. The WIS data was then used as the boundary conditions for STWave models to simulate nearshore wave transformation as the deep water waves approach the shoreline. STWave results provided design wave conditions for breakwater design and boundary conditions for harbor response modeling. The last phase of modeling primarily used the FUNWAVE model to simulate wave propagation through the harbor alternatives developed for the study sites. The model development process and run results will be presented for each site separately.

5.1. Elevation Data

A large section of the Bering Sea covering the Pribilof Islands was modeled bathymetrically in SMS to create a baseline scatter set from which numerical models could be run. Bathymetric data was collected from the National Oceanographic Service (NOS) website. The NOS website contains a database of digitized survey data that can be used to build elevation models of site bathymetry. The surveys used for the elevation model are H07914, H07948, H08002, H08003, H08004, H08072, H08074, H08075, H08121 and H11095. Most of this survey data covers bathymetry around the Pribilof Islands and was collected between 1950 and 1955. H11095 was a coastline survey of St. George Island performed in 2006 using LiDAR, however weather conditions for that season were not favorable and this survey is considered to have a high degree of uncertainty and should be validated with new site survey information as the study progresses. Project condition surveys for St. Paul harbor were added to the NOS data to provide high resolution data of the harbor. Surveys performed by TERASOND at Zapadni Bay in 2013 and 2016 were added to provide better nearshore and harbor bathymetry. Topography for the village of St. George was added by tracing survey contours from the community map published by the State of Alaska.

5.2. Wave Data Collection

Efforts were made to collect wave data at Zapadni Bay prior to this study. Three Acoustic Doppler Current Profilers (ADCPs) were deployed to the seabed in the harbor and offshore at Zapadni Bay in 2013. These instruments recorded the free water surface and velocity profiles from September 18 to November 17, 2013. The sensors were set to record data at half-second intervals for a 20 minute period over each hour of the deployment period. On November 7, the sensors captured a long period storm event which is shown as run number 17 in Table 13. This event was used to measure the moeling process effectiveness at reproducing observed problems in the harbor. Water depths measured during the peak event are shown in Figure 21.

Figure 20. ADCP deployment locations from HDR Baseline Conditions Report (2014).

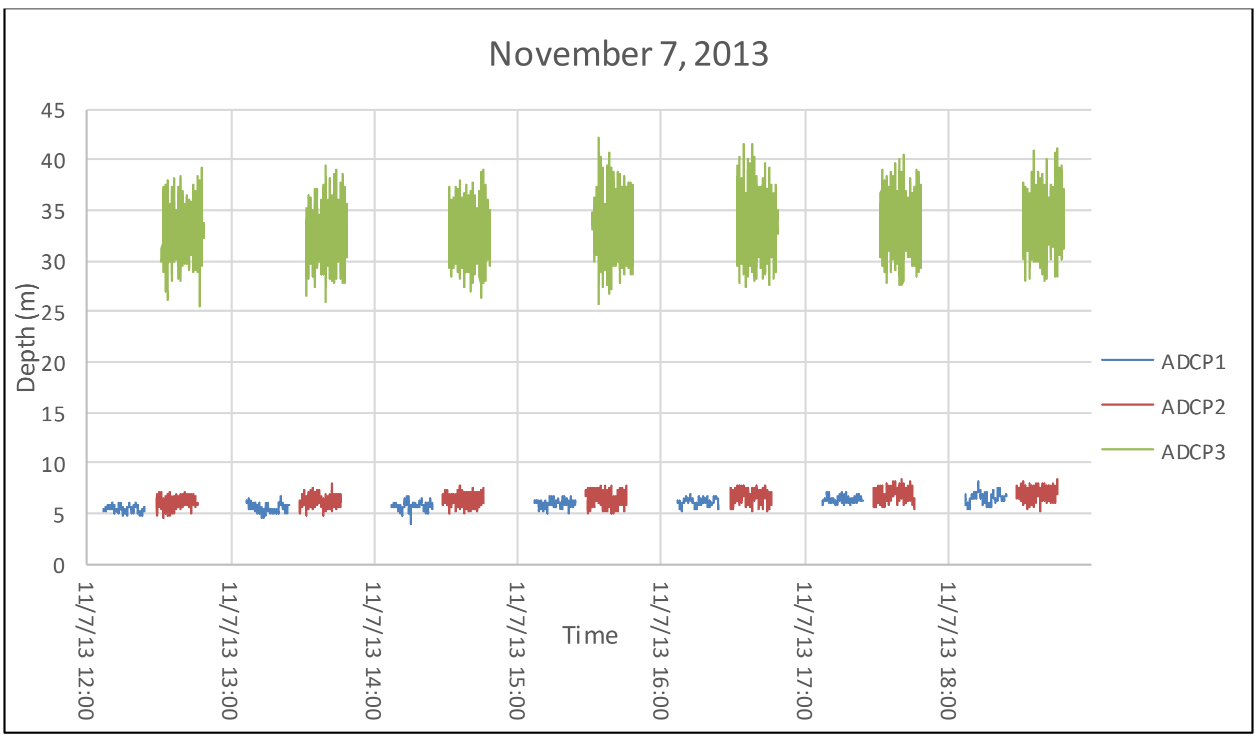

Figure 21. ADCP measurements during November 7, 2013 storm

5.3. Deep Water Conditions

A wave hindcast was performed by the Corps' Engineer Research and Development Center (ERDC). Deep water wave conditions have been hindcast at offshore points along the entire coast of Alaska in the Alaska Wave Information Study (WIS). It should be noted that St. George Island is not represented in the WIS model grid and the sheltering effect of the island for energy generated from different directions is only accounted for at St. Paul. To account for the sheltering effect of St. George Island from different storm directions, WIS points around St. Paul Island were taken from the same relative position to that island as St. George. The wave energy at the WIS points around St. Paul were then applied to locations around St. George Island at the same depths and representing similar orientation relative to the island. Since the two islands are only 50 miles apart and both are more than 200 miles away from the nearest landmasses, it is assumed that storms passing through the region will create very similar deep water conditions around both islands. Also, due to the depth-limited nature of wave energy dissipation along the coastline of St. George, differences in offshore climate between St. Paul and St. George are washed out in the nearshore zone wave transformation process.

5.3.1. Zapadni Bay Offshore Wave Climate (WIS)

Wave height results based on 1985-2014 wind and pressure fields for WIS Station 82265 are applicable for Zapadni Bay. This station is located southwest of St. Paul in water depths of approximately 71 meters. The station occupies an appropriate relative position to St. Paul Island to represent waves affecting St. George (Figure 22). The 50-year wave height is estimated at 15.19 meters using the log relationship developed for WIS Station 82265 as shown in Figure 23. Wave periods are estimated to be in the 16 to 22 second range. The frequency of occurrence relationship for waves at WIS Station 82265 is shown in Table 11. The location of Zapadni Bay on the southwest coastline of St. George Island exposes the harbor to waves originating from the south, southwest and west sectors and shelters the harbor from northerly and easterly directions. The strongest storm signals in the region tend to originate from the southwest and west directions, so the non-directional wave height frequency of occurrence relationship for this station would adequately represent the west and southwest storms expected to affect the site.

Table 11. Southern exposure WIS Station analysis, H_{m0} in meters

AEP	Return Period (years)	82264	82265	82266	82267
0.5	2	10.24	9.91	9.73	9.77
0.1	10	12.82	12.55	12.37	12.26
0.05	20	13.92	13.69	13.50	13.34
0.02	50	15.39	15.19	15.00	14.76
0.01	100	16.50	16.33	16.13	15.84

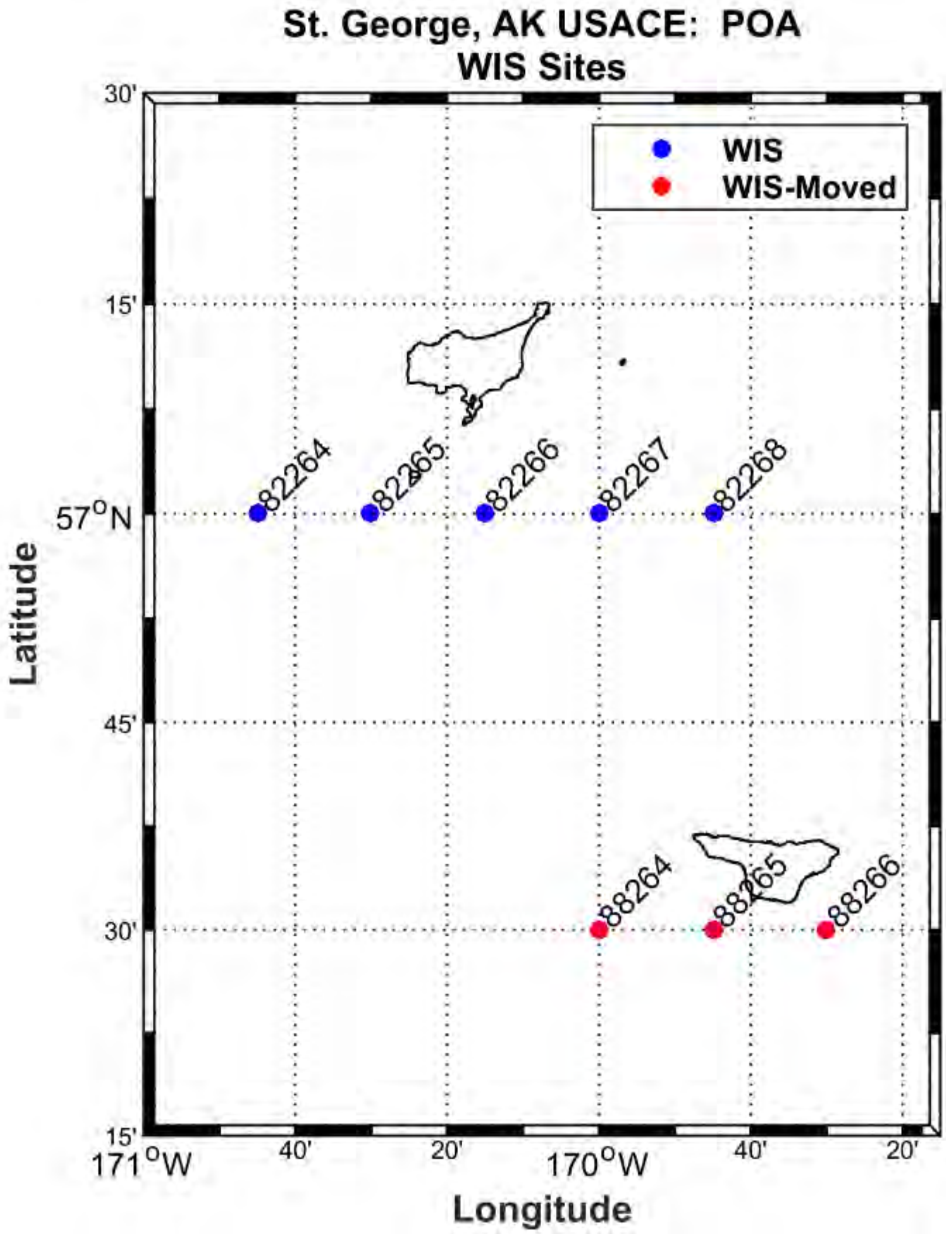

Figure 22. Location of south exposure WIS station at St. Paul and super positioning to St. George

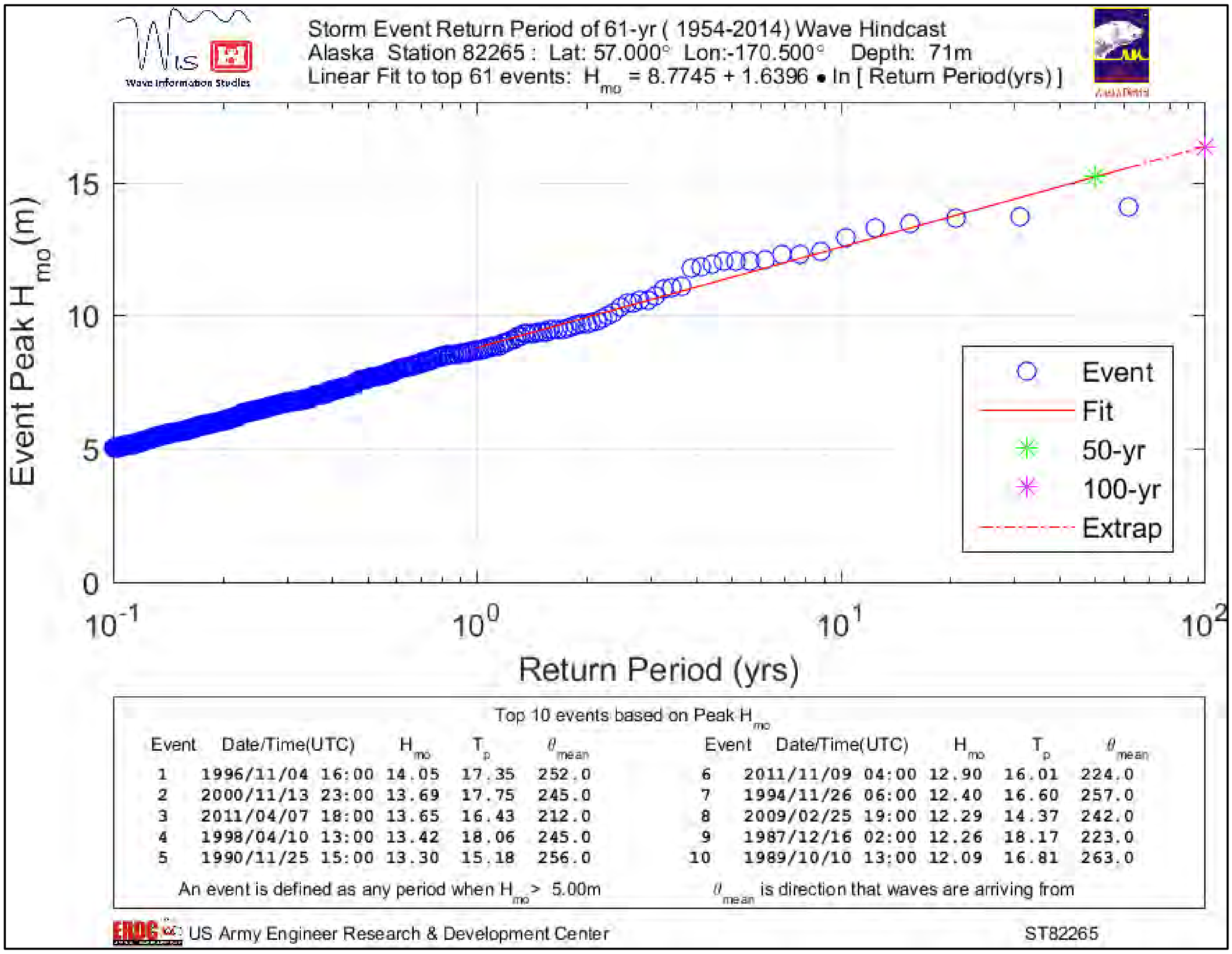

Figure 23. Analysis figure for WIS station 82265 (Jensen, 2011)

The top nineteen hindcast storm events affecting the site were extracted from the data and run as storm scenarios for STWave and FUNWAVE moeling efforts. These storms were selected by CHL staff and represented the 19 largest events as determined by peak spectral wave height. The storms were filtered so that only storms originating from the arc from 180 degrees (due south) to 300 degrees (west-northwest) were considered. Storms originating from other directions were assumed to be filtered by the presence of the island. The storm simulations range in peak spectral height from 8.85 meters to 14.05 meters and peak spectral periods from 13.27 seconds to 19.12 seconds.

5.3.1.1. WIS Station 82265 Duration Exceedance Analysis

A duration analysis of the ONELINES data of WIS Station 82265 was also performed to determine availability of the harbor and docks for navigation and mooring purposes. This was performed by evaluating the hourly data from 1985 to 2014 with a series of thresholds. The data was first binned into 15 degree arcs. The data in the arcs from 180 to 300 degrees were assumed to affect the site at Zapadni Bay. This section describes modeled wave conditions confined to this arc, however as the study progressed, it was decided that long period waves from 120 degrees to 180 degrees would also affect conditions at the harbor entrance and were included in the site comparison analysis. Data with waves originating from other directions were treated as zeros. Occurrence of waves were compared to data thresholds of half meter wave height increments. The percentage of time for wave heights exceeding the threshold was calculated in comparison to the duration of the entire record and duration exceedance curves developed for each 15 degree bin and for the whole arc under consideration. The data was sorted by direction and by month to determine any trends in high wave events. Sorting the data by direction, there was a noticeable tendency for waves to originate from the southwest with a noticeable peak between 240 and 255 degrees (Figure 24).

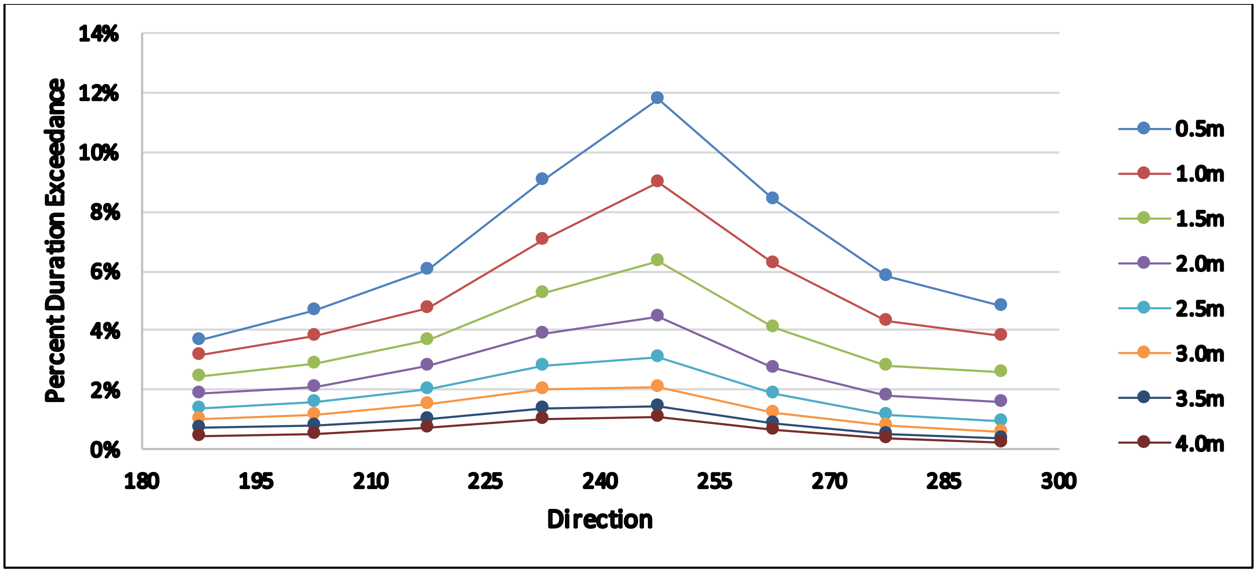

Figure 24. WIS Station 82265 Wave Height Exceedance from 180 degrees to 300 degrees.

Aggregate wave height exceedance throughout the entire arc was calculated. This analysis is simply a sum of all directional bins within the arc (Figure 25).

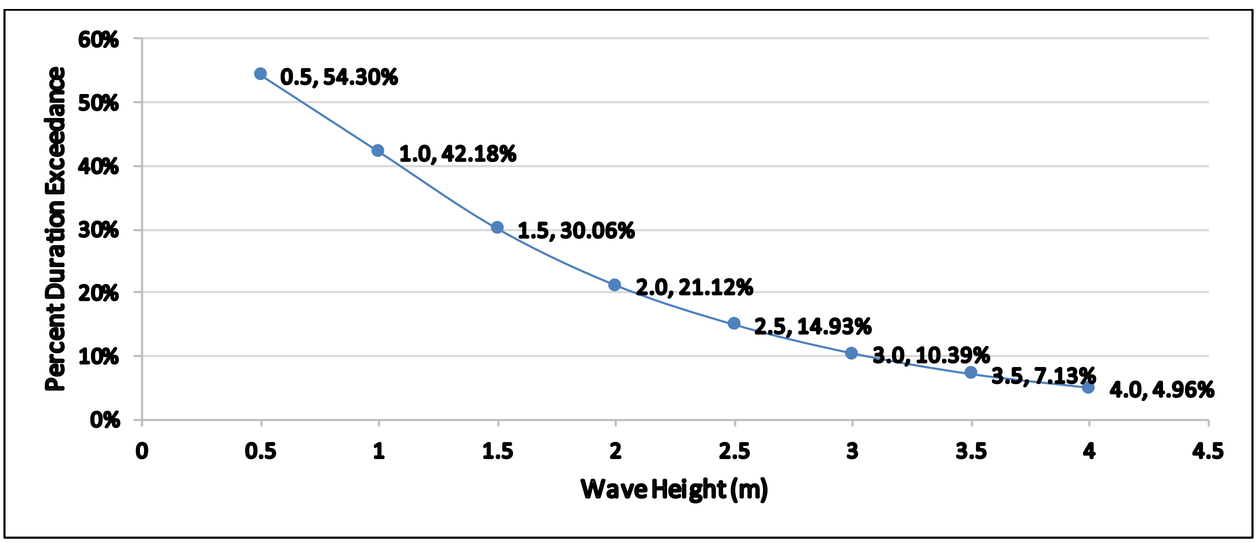

Figure 25. WIS Station 82265 Annual Wave Height Exceedance from 180 to 300 degrees.

Sorting the data by month, conditions were noticeably rougher in the November and December period and calmer in the June and July period (Figure 26). This agrees well with local knowledge of the timing of storms which typically occur in the fall and winter.

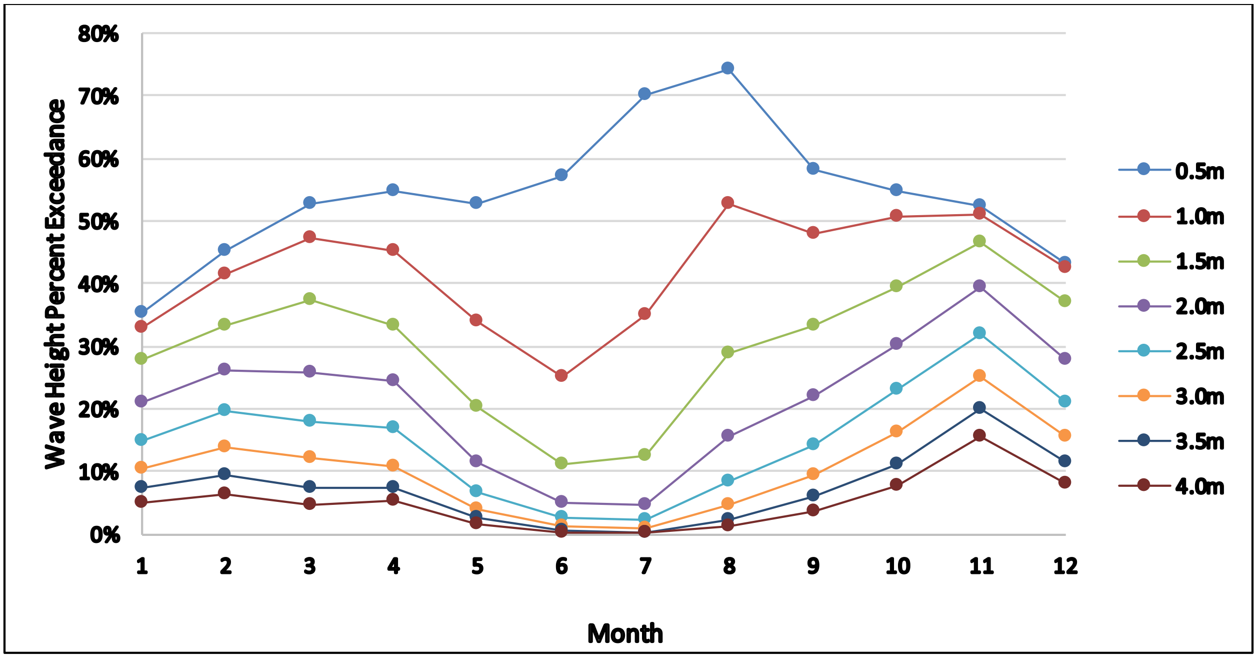

Figure 26. WIS Station 82265 Wave Height Exceedance by Month from 180 degrees to 300 degrees.

A final duration exceedance analysis was performed of the station from the months of October through March of each year to simulate offshore conditions during the anticipated crabbing season. The results of this curve were slightly different than the annual curve. Wave heights in excess of 4 meters occurred for a longer duration over the crabbing season than over the entire year. The duration exceedance analysis provides information regarding the potential benefits of project alternatives.

5.3.2. North Site Offshore Wave Climate (WIS)

Wave height results based on 1985-2014 wind and pressure fields for WIS Station 82255 are applicable for the north site. This station is located northeast of St. Paul in water depths of approximately 71 meters. These stations occupy an appropriate relative position to St. Paul Island to represent waves affecting St. George (Figure 27).

Figure 27. WIS Station transformation for North Site Analysis.

The 50-year wave height is estimated at 12.76 meters using the log relationship developed for WIS Station 82255 as shown in Figure 28. Wave periods are estimated to be in the 12 to 16 second range. The frequency of occurrence relationship for waves at WIS Station 82255 is shown in

Table 12. The location of the north site exposes potential harbors to waves originating from the west, northwest and north sectors and shelters the harbor from southerly directions. The strongest storm signals in the region tend to originate from the southwest and west directions. The position of Station 82255 tends to filter some of the southwest energy as storms pass over St. Paul Island, however some long period energy is expected to wrap around the island and converge again before reaching the WIS Station. Directional sorting of the ONELINES data

shows a decrease in maximum wave heights when waves from the southerly directions are excluded.

Table 12. North Site WIS Station analysis, H_{m0} in meters

AEP	Return Period (years)	82254	82255	82256
0.5	2	9.00	9.13	9.13
0.1	10	11.03	10.94	10.90
0.05	20	11.90	11.72	11.66
0.02	50	13.05	12.76	12.67
0.01	100	13.92	13.54	13.43

Periods associated with storm events were interpreted from the storm records. Directional analysis of the distribution of spectral peak periods showed that storms originating from the west generally had periods in the 14 to 16 second range while storms originating from the northwest through the east generally had peak periods in the 12-13 second range.

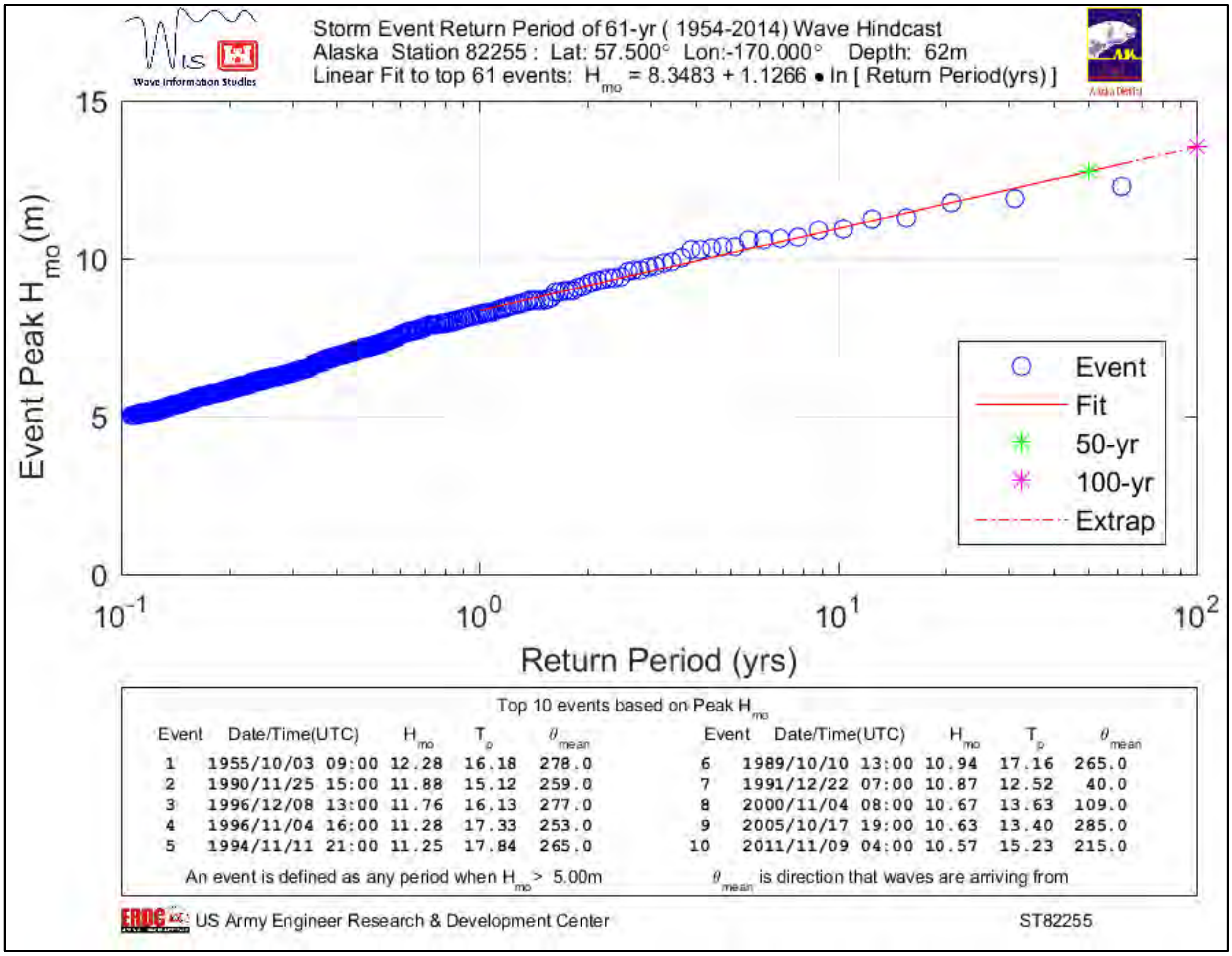

Figure 28. Analysis figure for WIS station 82265 (Jensen, 2011)

The data from this WIS station was developed in two ways. A series of nineteen hindcast storm events affecting the site were extracted from the data and run as storm scenarios for STWave and FUNWAVE moeling efforts. These storms were selected by CHL staff to represent events with the largest peak spectral wave height and the largest peak period in the station record. The storms were filtered so that only storms originating from the arc from 270 degrees (due west) to 000 degrees due north) were considered. Storms originating from other directions were assumed to be filtered by the presence of the island or proposed harbor geometry. The storm simulations range in peak spectral height from 8 meters to 11.76 meters and peak spectral periods from 12 seconds to 16.13 seconds

5.4. Nearshore Wave Transformation

The WIS data from stations 82255 and 82265 represent the offshore condition at the study sites. To model harbor response to storm events, the offshore conditions need to be transformed to a nearshore condition to allow a harbor model to run. Using STWave as an intermediate model allows energy from the transformed WIS station location to be propagated over measured bathymetry and transformed into reasonable boundary conditions for a high resolution harbor model to run.

5.4.1. STWave Model Parameters

The STWave model simulates depth-induced wave refraction and shoaling, current induced refraction and shoaling, depth and steepness induced wave breaking, diffraction, wind-wave growth and wave-wave interaction and whitecapping that redistribute and dissipate energy in a growing wave field. Source energy at the deep water boundary of the model is defined by a wave spectrum. The spectrum is characterized by a spectral peak wave height and period which define conditions at the maximum energy density. The spectrum is given a direction of propagation at the model boundary. For the purpose of this study, STWave was operated in a half-plane mode and a propagation only mode without current interaction, so the only source of wave energy in the model was the spectrum derived from the WIS output analysis discussed previously. Simulations were run at a water level of +1.8 meters MLLW to represent elevated water levels at high tide during a storm event.

5.4.2. Zapadni Bay Nearshore Wave Transformation (STWave)

The STWave domain for Zapadni Bay covers the area from a depth of about 75 meters offshore to the shoreline of St. George Island. The model grid covered the area from Rush point to the west of Zapadni Bay to the Red Bluffs to the south of Zapadni Bay as shown in Figure 29.

The model grid used to perform the nearshore wave transformation was extracted from NOS bathymetry of the size and placed on a 20 meter by 20 meter grid. The grid was oriented at 25 degrees in SMS which corresponds to waves approaching from 245 degrees. The model grid has 360 cells in the i direction and 432 cells in the j direction for overall grid dimensions of 7200 by 8640 meters. The model was run in the half-plane mode with propagation of the boundary conditions only, no wind propagation. The water level for all STWave runs was set to +1.8 meters MLLW to account for additional depth of storm surge and setup.

Output stations were selected near the shoreline of Zapadni Bay to allow a smaller finer grid to be developed for the FUNWAVE runs for the harbor. The STWave model produced results as expected in a depth limited environment. While storms of varying wave heights between 8.85 and 14.05 meters were run from the offshore boundary, results at the output points near the harbor all fell within a narrower band of wave heights between 9.18 and 11.34 meters. While input directions varied from 202 to 273 degrees, the wave vectors at the FUNWAVE model boundary generally fell within a 30 degree band centered about waves directly entering the outer breakwaters of the existing harbor. This is caused by diffraction of the incident wave energy over the nearshore bathymetry of the island. Storm simulation run results over the STWave model are shown in Table 13. The table shows the input spectral wave height, period and direction extracted from the WIS data (HWAM, TWAM, THWAM) and the output conditions in the STWave grid (HSTWave, TSTWave, THSTWave). Note that while the wave direction from the WAM model is meteorologic, the direction of resultant waves from STWave are based on the orientation of the grid. A positive direction indicates angle counterclockwise of the i direction of the STWave grid. Storm simulations were run at ERDC on the TOPAZ HPC to facilitate processing of the storm events.

The STWave model generally showed wave reduction from the WIS point to the wavemaker location, however some instances of wave growth were observed. These cases occurred with boundary wave conditions less than 11 meters and generally saw more growth for longer period waves. This may be a function of the bathymetric data set; the surveyed data was generally shallower than the digitized NOS data and this may have produced the effect of focusing wave energy outside of the harbor.

Table 13. Simulated Zapadni Bay Storm STWave model results

RUNNO	HWAM (m)	TWAM (s)	THWAM (degrees)	HSTWave (m)	TSTWave (s)	THSTWave (degrees)
1	14.05	17.35	252	11.18	17.99	10
2	13.69	17.75	245	11.34	19.8	20
3	13.65	16.43	212	10.98	16.34	27
4	13.42	18.06	245	11.18	17.99	17
5	13.3	15.18	256	10.98	16.34	6
6	12.9	16.01	224	11.18	17.99	16
7	12.4	16.6	257	10.98	16.34	7
8	12.29	14.37	242	10.75	14.86	14
9	12.26	18.17	223	11.34	19.8	20
10	12.09	16.81	263	11.18	17.99	3
11	12.03	17.69	261	11.18	17.99	4
13	12.01	17.57	221	11.18	17.99	23
14	11.91	15.86	273	10.98	16.34	1
15	11.79	16.08	241	10.98	16.34	14
16	11.78	16.27	202	10.15	16.34	30
17	11.07	19.12	256	11.34	19.8	12
18	11.02	17.4	246	11.18	17.99	10
24	10.45	15.11	251	10.88	16.34	7
32	9.65	13.5	272	9.23	13.51	3
33	9.62	13.55	227	9.59	13.51	17
36	9.48	15.37	249	10.97	16.34	9
37	9.48	14.92	242	9.18	14.86	15
40	9.38	13.77	256	10	14.86	6
44	9.31	16.39	229	10.85	16.34	15
45	9.31	14.78	256	10.07	14.86	6

47	9.21	14.59	234	10.2	16.34	14
49	9.08	13.27	246	9.31	13.51	8
51	8.99	16.6	223	10.33	17.99	18
52	8.96	16.89	245	10.87	17.99	11
54	8.85	14.45	243	9.59	14.86	11

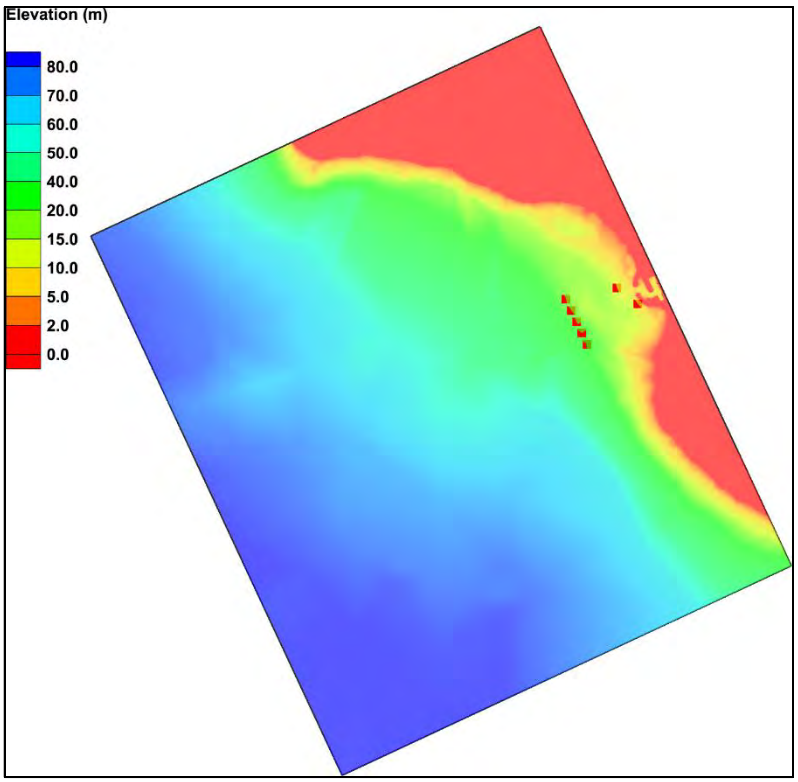

Figure 29. STWave grid bathymetry and output locations.

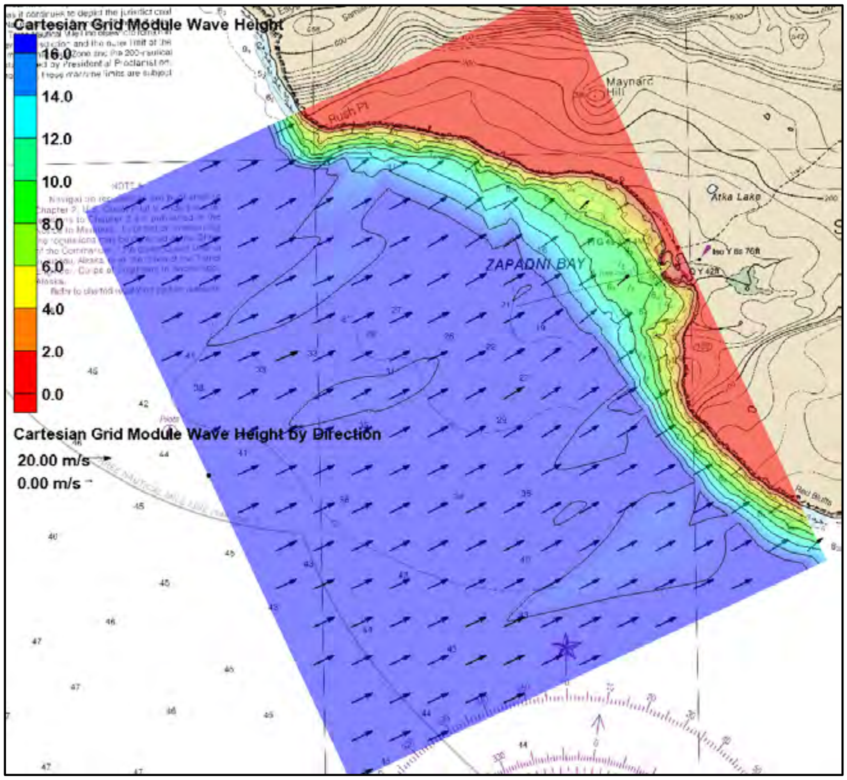

Figure 30. STWave results for Hm0 = 16.33 m and Tp = 22 s.

5.4.3. North Site Nearshore Wave Transformation (STWave)

WIS data from station 82255 represents the offshore condition at the north site. To model harbor response to storm events, an STWave model was used in the same manner as for developing conditions at Zapadni Bay. The STWave domain for the north site covers the area from a depth of about 75 meters offshore to the shoreline of St. George Island. The model grid was oriented to propagate storms originating from the northwest as shown in Figure 31.

The model grid used to perform the nearshore wave transformation was extracted from NOS bathymetry of the size and placed on a 25 meter by 25 meter grid. The grid was oriented at 25 degrees in SMS which corresponds to waves approaching from 315 degrees. The model grid has 360 cells in the i direction and 432 cells in the j direction for overall grid dimensions of 7200 by 8640 meters. The model was run in the half-plane mode with propagation of the boundary conditions only, no wind propagation. The water level for all STWave runs was set to +1.8 meters MLLW to account for additional depth of storm surge and setup.

Output stations were selected near the shoreline of the north site to allow a smaller finer grid to be developed for the FUNWAVE runs for the harbor. The STWave model produced results as expected in a depth limited environment. While storms of varying wave heights between 8.9 and 12.3 meters were run from the offshore boundary, results at the output points near the harbor were between 3.8 and 7.1 meters. While input directions varied from 278 to 4 degrees, the wave vectors at the FUNWAVE model boundary generally bent towards a shore-normal direction approaching perpendicular to proposed harbor entrance. This is caused by diffraction of the incident wave energy over the nearshore bathymetry of the island. Storm simulation run results over the STWave model are shown in Table 14. Note that while the wave direction from the WAM model is meteorologic, the direction of resultant waves from STWave are based on the orientation of the grid. A positive direction indicates angle counterclockwise of the i direction of the STWave grid. Storm simulations were run at ERDC on the TOPAZ HPC to facilitate processing of the storm events.

Table 14. Simulated North Site Storm STWave model results.

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW
201	12.28	16.18	278	7.13	16.34	38.1
212	10.35	11.16	326	4.25	12.29	21.2
234	8.98	12.05	4	3.76	13.51	19.1
100	1.2	6	20	1.2	6	20
101	3	8	20	3	8	20
102	3	12	20	3	12	20
103	3	16	20	3	16	20
104	7	8	20	7	8	20
105	7	12	20	7	12	20
106	7	16	20	7	16	20

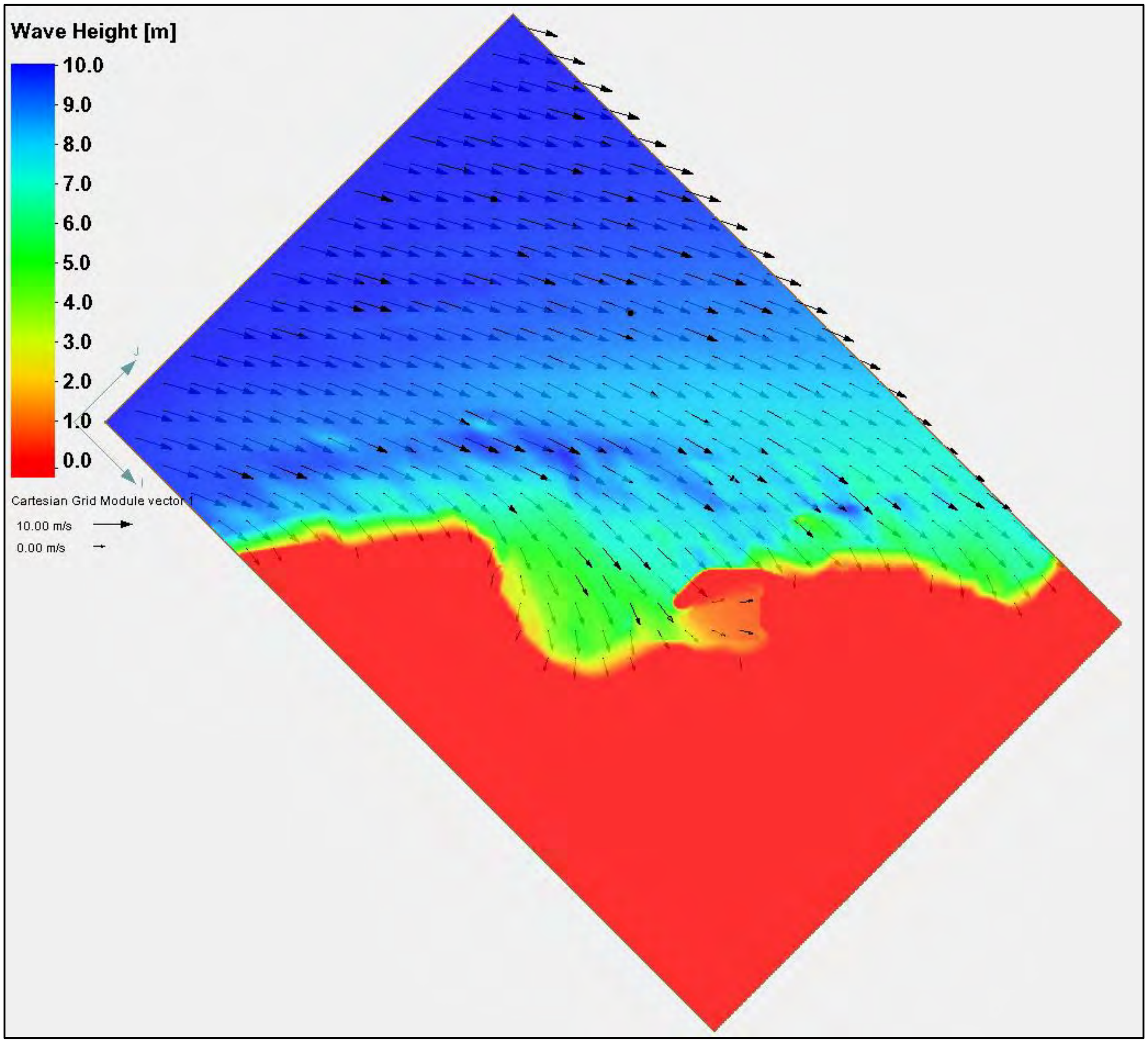

Figure 31. STWave results for Hm0 = 10 m and Tp = 12 s. Bathymetry representing the proposed harbor location was added to show directional effects around the proposed harbor entrance.

5.5. Harbor Response Modeling

Wave modeling inside the existing harbor and harbor alternatives requires a small model domain with a high resolution grid to adequately calculate wave interaction with the bottom, shorelines and structures. The FUNWAVE model was used for this study to replicate baseline harbor conditions and measure changes from baseline measurements for different harbor configurations. This model uses a Bousinnesq equation to simulate the free water surface and velocity through the water column. It should be noted that as of June, 2019, FUNWAVE is the Hydraulic, Hydrologic and Coastal (HH&C) Community of Practice (CoP) preferred model for modeling coastal processes. The use of BOUSS2D is allowed by the CoP, however it is noted that the use of FUNWAVE is preferred over the use of BOUSS2D at this time.

5.5.1. FUNWAVE Model Parameters

The study initially used FUNWAVE version 2.1 to model harbors at Zapadni Bay. During the course of the study, version 3.0 was released and used to include new features that allow for internal sponge layers to be added to dampen wave energy inside the model grid. FUNWAVE is a phase-resolving, time stepping Boussinesq model that calculates the free water surface of an expanse of ocean as energy is propagated from a simulated wavemaker. The wavemaker can produce a variety of signals ranging from solitary and monochromatic waves to wave spectrums which include a distribution of wave height and period signals. Source signals were generated from STWave model results and propagated through the harbor grids. FUNWAVE models shoaling, diffraction, refraction and reflection of wave energy from boundary surfaces. The ability to model wave reflection was considered critical to the success of accurately modeling wave conditions in the existing harbor at Zapadni Bay. Water levels are controlled by globally altering the bathymetry of the grid; for St. George simulations, all bathymetry was deepened by 1.8 meters to simulate high tide and storm surge effects. Wind and current interactions were not simulated. Reflection from model grid boundaries is dampened by using energy absorbing sponges along all of the water boundaries of the model. Bottom friction was set to zero for all simulations.

5.5.2. Zapadni Bay FUNWAVE Model

Bathymetry was extracted from the survey data and plotted to a 2 meter by 2 meter grid. Bathymetry was adjusted at the seaward end of the model domain to accommodate a wave maker. Early runs of the model revealed that wave breaking near the wave maker caused model instability and invalidated run results. Since the wave climate is depth limited and the scale of the FUNWAVE model includes only nearshore bathymetry, wave breaking occurred along the seaward edge of most wave scenarios. To compensate for this, the bathymetry along the seaward edge of the domain was deepened to create a wave basin where the waves could develop across a full wavelength before breaking. The net effect of this modification would be an amplification of wave energy outside the harbor, which then breaks when it encounters the natural bathymetry. Model runs were performed at a water level of +1.8 meters MLLW to include the effects of surge and setup.

Wave maker conditions were determined from the results of the STWave analysis of the simulated storm events. For these scenarios, the spectra of the wave maker was modeled as a TMA spectra based on the output wave height and periods found at the monitoring stations. Additional model analysis was performed using 81 auxiliary storms which have a range of peak wave heights and periods to perform sensitivity analysis of the harbor response to differing conditions. Wave spectra were developed by the Coastal Hydraulics Laboratory Coastal Process Branch with peak wave heights and peak periods as shown in Table 15.

Table 15. Auxiliary Storm wave spectral peak wave height and period.

Hm0 (m)	Tp (s)										
	6	8	10	12	14	16	18	20	22	24	26
0.5	X	X	X								
1	X	X	X								
1.5	X	X	X								
2	X	X	X	X	X	X	X	X	X	X	X
2.5	X	X	X								
3	X	X	X								
3.5	X	X	X								
4	X	X	X	X	X	X	X	X	X	X	X
6 (-15°)			X	X	X	X	X	X	X	X	X
6			X	X	X	X	X	X	X	X	X
6 (+15°)			X	X	X	X	X	X	X	X	X
8			X	X	X	X	X	X	X	X	X
10							X	X	X	X	X

While the STWave analysis showed that nearshore processes tend to diffract waves such that the wave direction at the outer breakwater entrance is nearly perpendicular to the shoreline, directional sensitivity was tested using 6 meter waves directed ±15 degrees from a head-on bearing. In total, 100 wave and period scenarios were simulated over the existing bathymetry and run through the existing harbor model to determine design storm cases to be used for alternative analysis. Model output was measured at selected grid cells to see how the harbor responded to different storm and wave scenarios. Stations of particular interest are shown in Table 16.

Table 16. Monitoring Stations of Interest in the FUNWAVE Model.

Station ID	Location
19	Entrance Channel between the Outer breakwaters
17	Entrance Channel at the Inner Breakwater
16	Mooring Basin at the Ice Plant Dock
11	Mooring Basin at the Fuel Docks
18	Mooring Basin at Mooring Pile Structure (Location of ADCP 1)

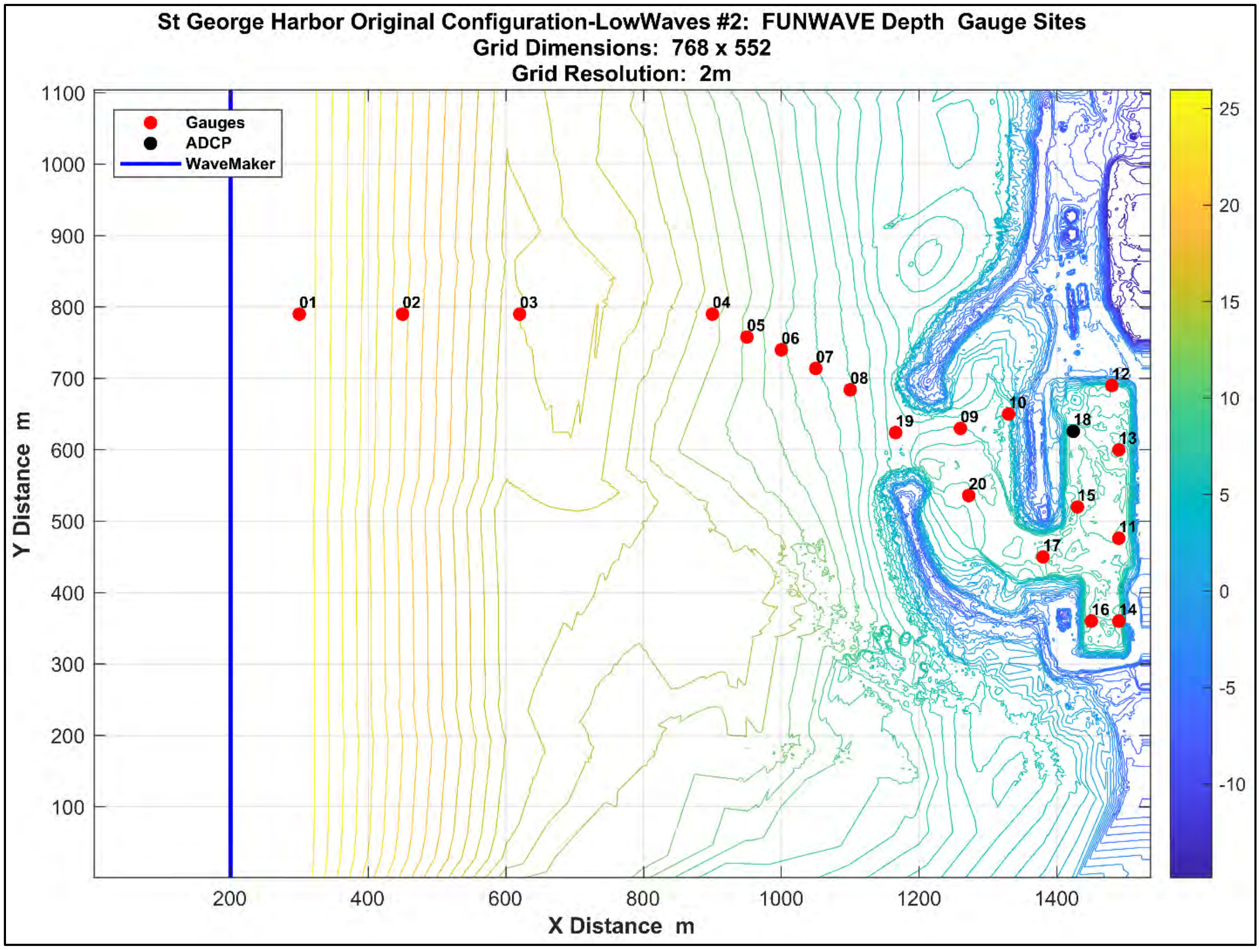

Figure 32. FUNWAVE model grid and monitoring stations of existing harbor.

5.5.2.1. FUNWAVE Model Calibration

The FUNWAVE model was calibrated to the ADCP data collected in 2013. Storm conditions from the November 2013 event were extracted from the WIS data and run through the STWave grid to determine FUNWAVE boundary conditions. The initial FUNWAVE grid runs performed with bottom friction set to zero showed good results when the amplitude and frequency of the water surface deviations were compared to the ADCP data for sensors 1 and 2 (Figure 33). The longer period of the signal in the inner harbor is clearly seen at Station 18 when compared to the signals of stations 17 and 19 just outside the inner basin. This indicates that the FUNWAVE model was able to model the seiche condition observed locally and measured by ADCP 1.

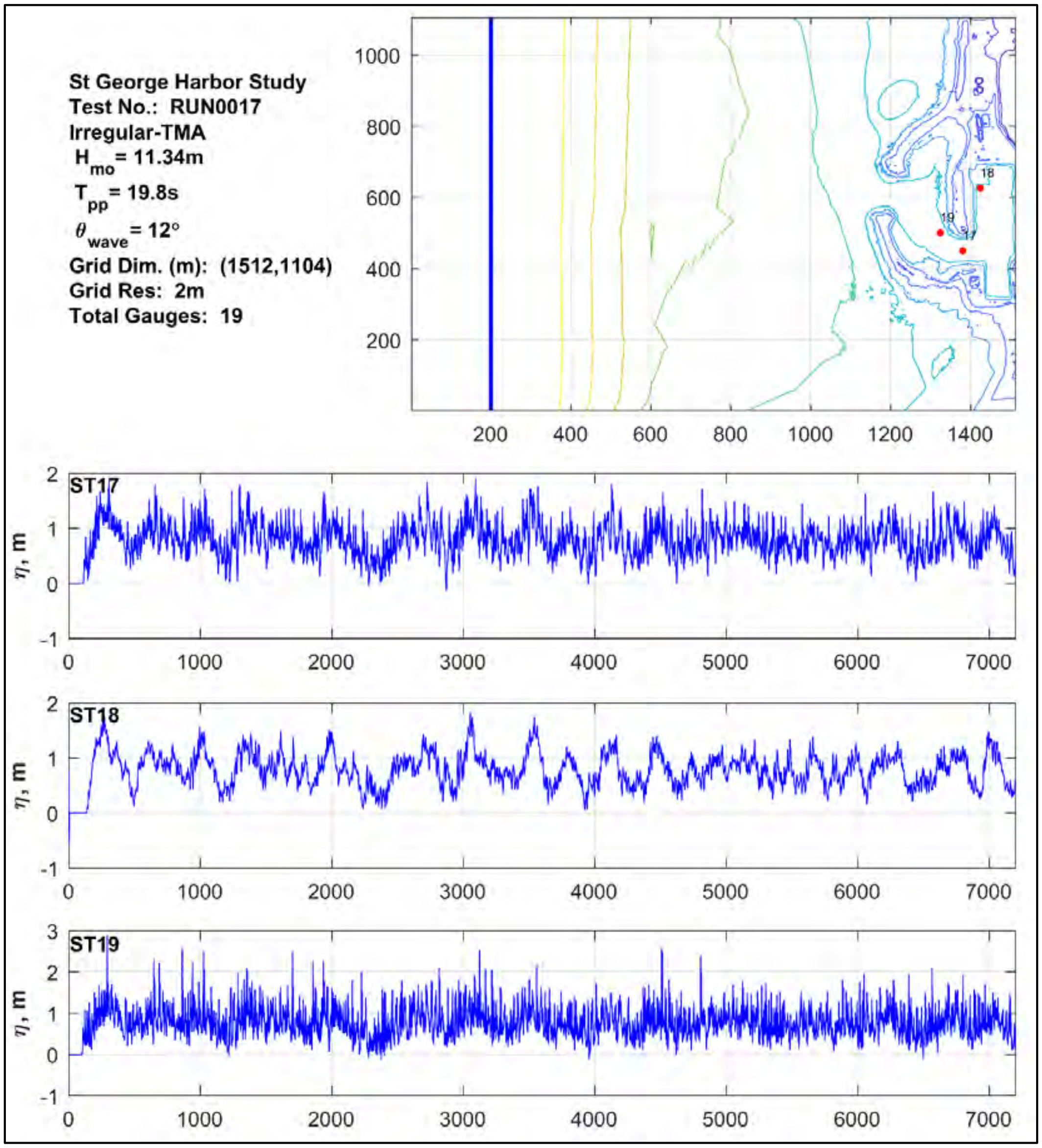

Figure 33. Free water surface elevation at gages 17, 18 and 19. Gage 18 corresponds to ADCP 1 and Gage 19 corresponds to ADCP 2.

5.5.3. North Site FUNWAVE Model

The North Site is ungaged and there are no data sets available with which to validate model performance. Since the FUNWAVE model of the existing harbor at Zapadni Bay matched measured ADCP data fairly well, it was initially assumed that running the FUNWAVE model at the North Site would produce comparably close approximations to shoreline and harbor responses. Initial testing of North Site alternatives showed considerably less wave attenuation than expected and significant long period harbor response. It was expected that with shallow sloping shorelines, wave energy would dissipate on the shoreline enclosed by proposed breakwaters. The high level of wave response indicated that wave energy was reflecting off these boundaries.

5.5.4. St. Paul Harbor FUNWAVE Model

To test the assumption that wave reflection off inner harbor boundaries was causing the unexpected wave response at the North Site, the team developed a FUNWAVE model of St. Paul Harbor to see if wave reflection would be found at a known site with shallow harbor slopes. St. Paul Harbor includes a spending beach constructed at a 5H:1V slope and has a natural beach along its eastern perimeter. Both of these boundaries are known to absorb and dissipate wave energy inside the harbor from operational experience. When modeled in FUNWAVE, wave amplification was modeled along the constructed spending beach and along the perimeter of the harbor (Figure 34). To compensate for this effect, a newer version of FUNWAVE with code developed during the course of this study was tested over the St. Paul model grid (Figure 35). This code allows for adding internal dampening, or sponge boundaries to cells inside the grid. At the time of implementation, no guidance for the effectiveness or application of these sponge boundaries was available. Since St. Paul Harbor has been operating for over 30 years, it was decided to target expected wave conditions for the inner and outer harbor areas (0.3 and 1 meters respectively) as a cursory step towards calibration. A set of sponges was applied to the boundaries of St. Paul Harbor to match the expected wave response conditions (Figure 36).

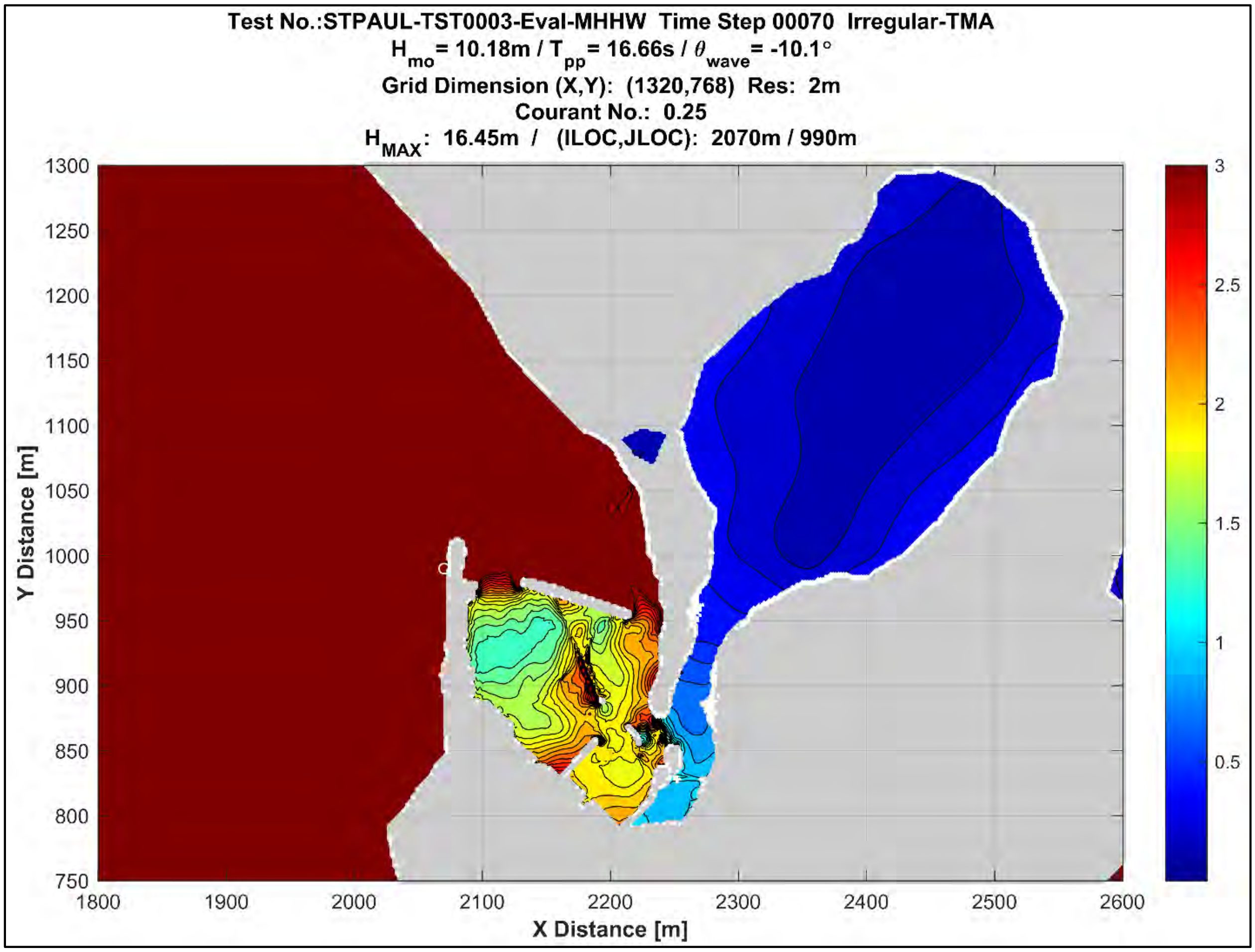

Figure 34. Significant wave height results of undamped model grid at St. Paul Harbor. The red areas inside the harbor at the south end of the spending beach and the inner breakwater show waves in 2 to 3 meter range indicating reflection modeled off these structures.

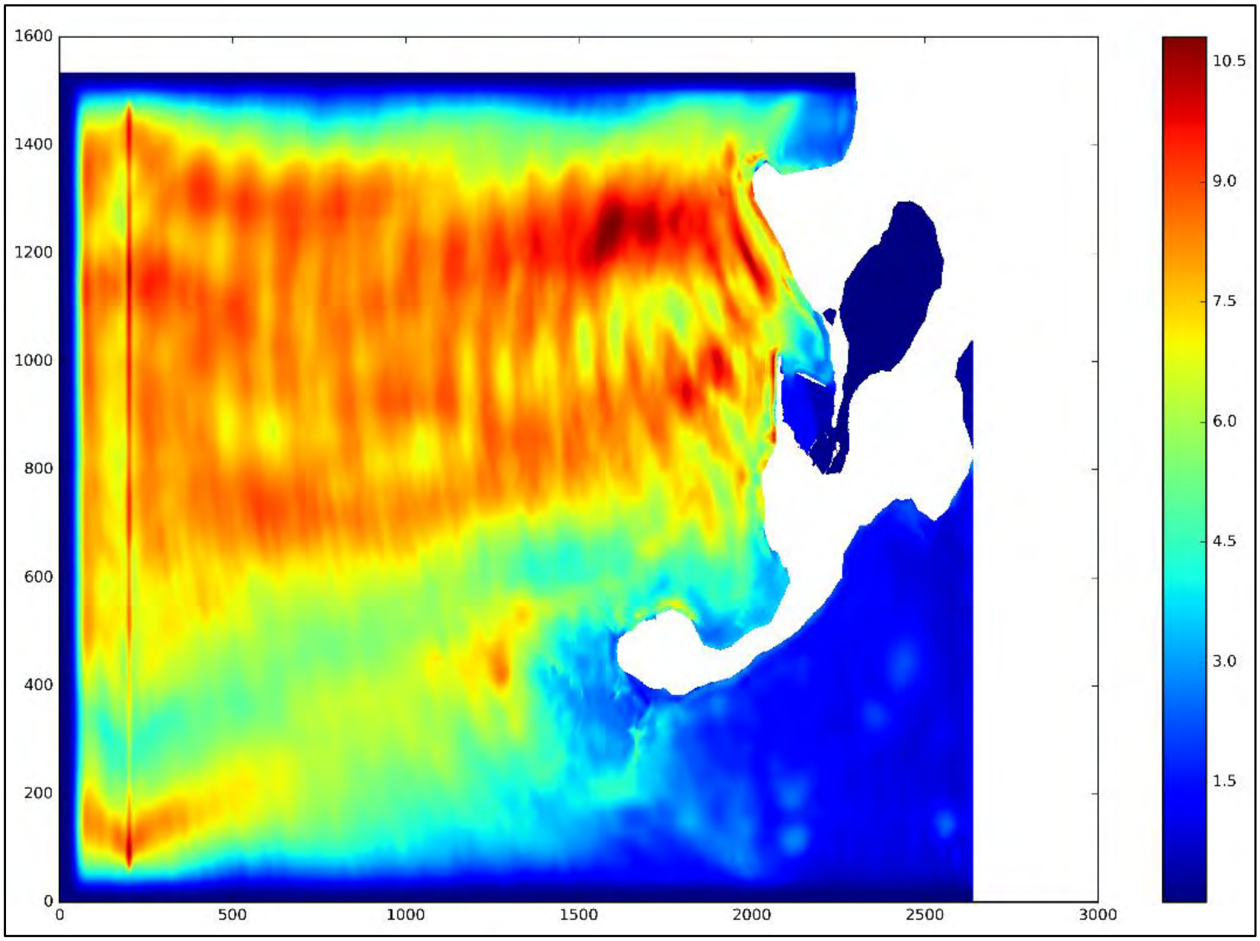

Figure 35. St. Paul Harbor FUNWAVE model domain. The domain includes the harbor and the Salt Lagoon to the north of St. Paul.

Use of sponge boundaries improved expected model output significantly. Using 15 meter wide sponges on beaches, 10 meter wide sponges on porous rock slopes and 5 meter wide sponges on harbor slopes, the model was able to produce wave responses of about 1 meter in the outer harbor and 0.3 meters in the inner harbor (Figure 37).

The St. Paul test indicates that the inclusion of internal sponge boundaries can approximate wave energy dissipation on spending beaches and in porous structures. Initial applications of 15 meter, 10 meter and 5 meter sponges to harbors at St. George did not yield reasonable results and the application of internal sponge boundaries for this study is under investigation at the time of the writing of this appendix.

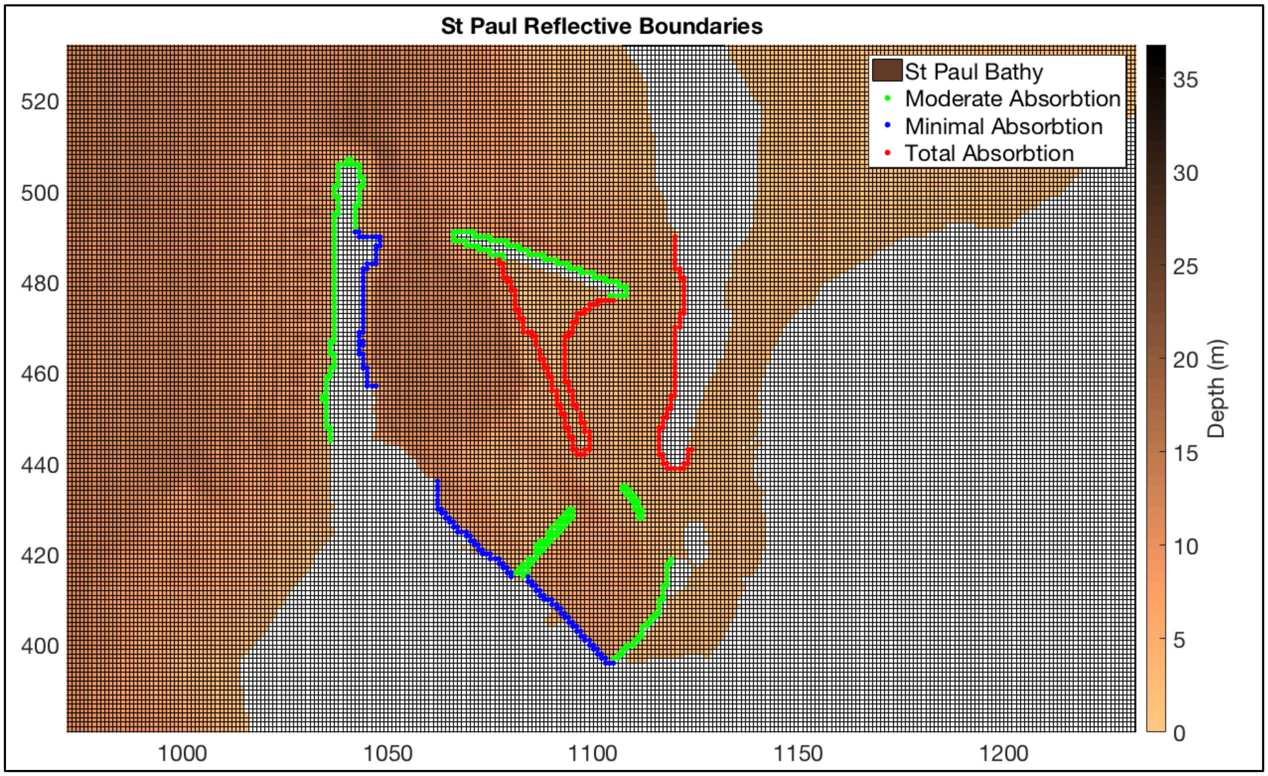

Figure 36. Internal absorption or sponge boundaries for the St. Paul Harbor grid.

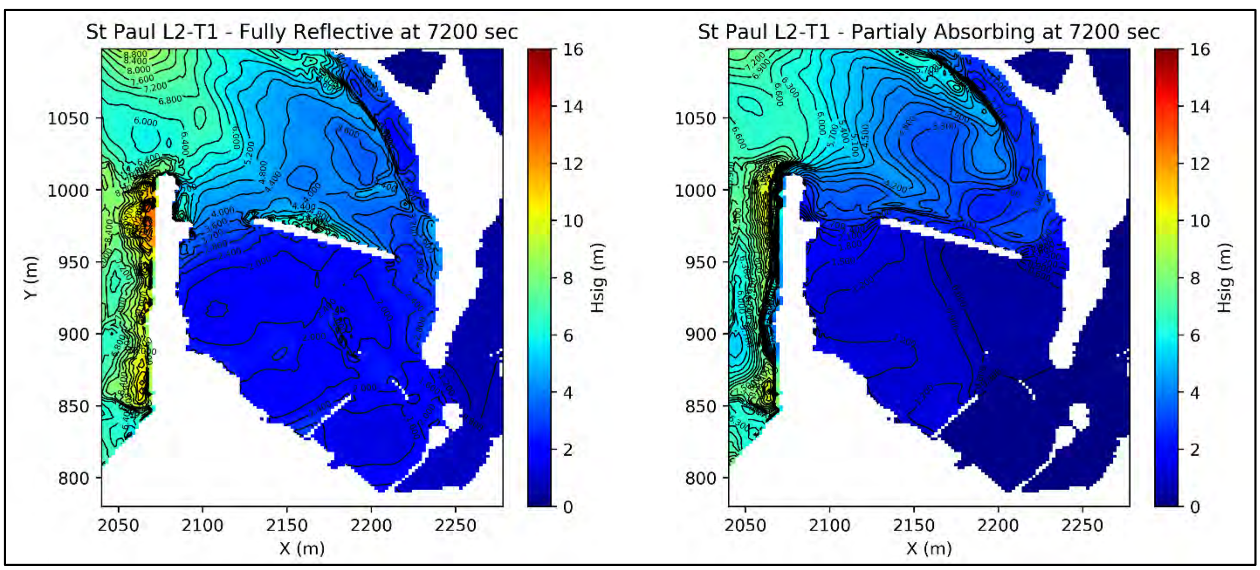

Figure 37. St. Paul FUNWAVE results without sponge boundaries (left) and with sponge boundaries (right). Waves at the spending beach without sponges are about 2.4 meters whereas with the sponges, wave heights are about 0.9 meters.

5.5.5. FUNWAVE Model Results Interpretation

Results from the FUNWAVE models give an indication of relative harbor performance and represent a good screening tool for determining the relative merits of the harbor alternatives considered in the study. Due to the lack of detailed survey and wave data at the North Site, FUNWAVE results are considered qualitative and will need further investigation in the preconstruction engineering design (PED) phase of the project. Further refinement of North Site models may be pursued in the study to better qualify the effectiveness of the north site alternatives. Final harbor response modeling will be performed in a physical model study to support the development of plans and specifications for construction. See Section 12.0 of this report for further investigations that will be required during the PED phase of the project. This effort may indicate the need to alter breakwater lengths and orientations and to modify the approach shoreline and inner harbor boundaries with spending beaches. These types of features would be required for all north site alternatives and would not change the relative merits of the alternatives investigated in the study phase of the project.

6.0 ZAPADNI BAY ALTERNATIVES

All Zapadni Bay alternatives developed and tested were found to be ineffective at providing the wave environment required for vessels to transfer cargo during storm conditions. Rough order of magnitude costs were developed and it was found that the cost to provide a safe mooring environment was very high. The descriptions of alternatives presented here is for information only to demonstrate the level of effort expended to attempt to find a solution at the existing harbor. None of these alternatives are recommended for further development. Most of these alternatives share the same concept for breakwater design where breakwater modifications were considered. Breakwaters exposed to the open ocean environment were designed as a 3 layer rubble mound breakwater with 30 ton armor stone and a crest elevation of +35 feet MLLW (Figure 38).

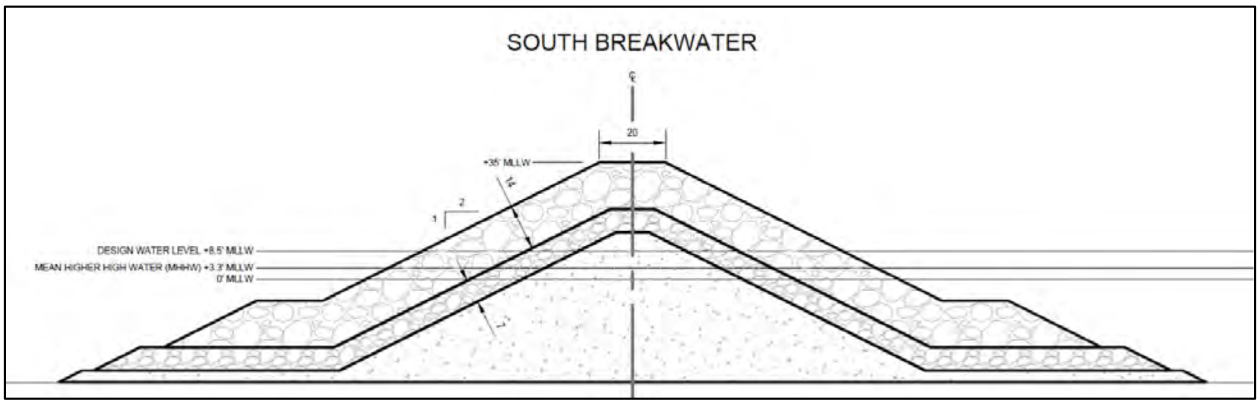

Figure 38. Typical Breakwater Cross Section for Zapadni Bay Alternatives.

Some variations of this design are indicated in some alternatives. Some of the inner breakwaters were designed with lower crest elevations and steeper side slopes to take advantage of wave attenuation from the primary breakwater.

Quantities and costs for these alternatives are included for comparison of relative effort of construction for each alternative. The costs presented in this appendix are rough order of magnitude project costs using the quantities estimated from CAD three dimensional surface models of the alternatives and assumptions for design and construction administration costs. These cost estimates do not include risk based contingency estimates and differ from the numbers found in the main report. These estimates were only used for comparison purposes to determine relative costs between alternatives and are only reported in this appendix.

6.1. Alternative Z-1: South Breakwater Extension

This alternative includes constructing an 800 foot long extension to the existing south breakwater with a crest elevation of +35 feet MLLW, a 500 foot jetty off the existing north breakwater with a crest elevation of +10 feet MLLW, three 1,000 foot long submerged reefs with crest elevations of -12 feet MLLW, a new inner breakwater with a crest elevation of +20 feet MLLW with a spending beach sloped at 10H:1V and a new navigation channel with a depth of -24 feet MLLW and a new turning basin with a depth of -20 feet MLLW. This alternative re-routes vessel traffic to the north end of the harbor in an attempt to reduce the occurrence of storm waves entering the harbor from the southwest direction (Figure 39). This navigation pattern is expected to improve barge access to the harbor.

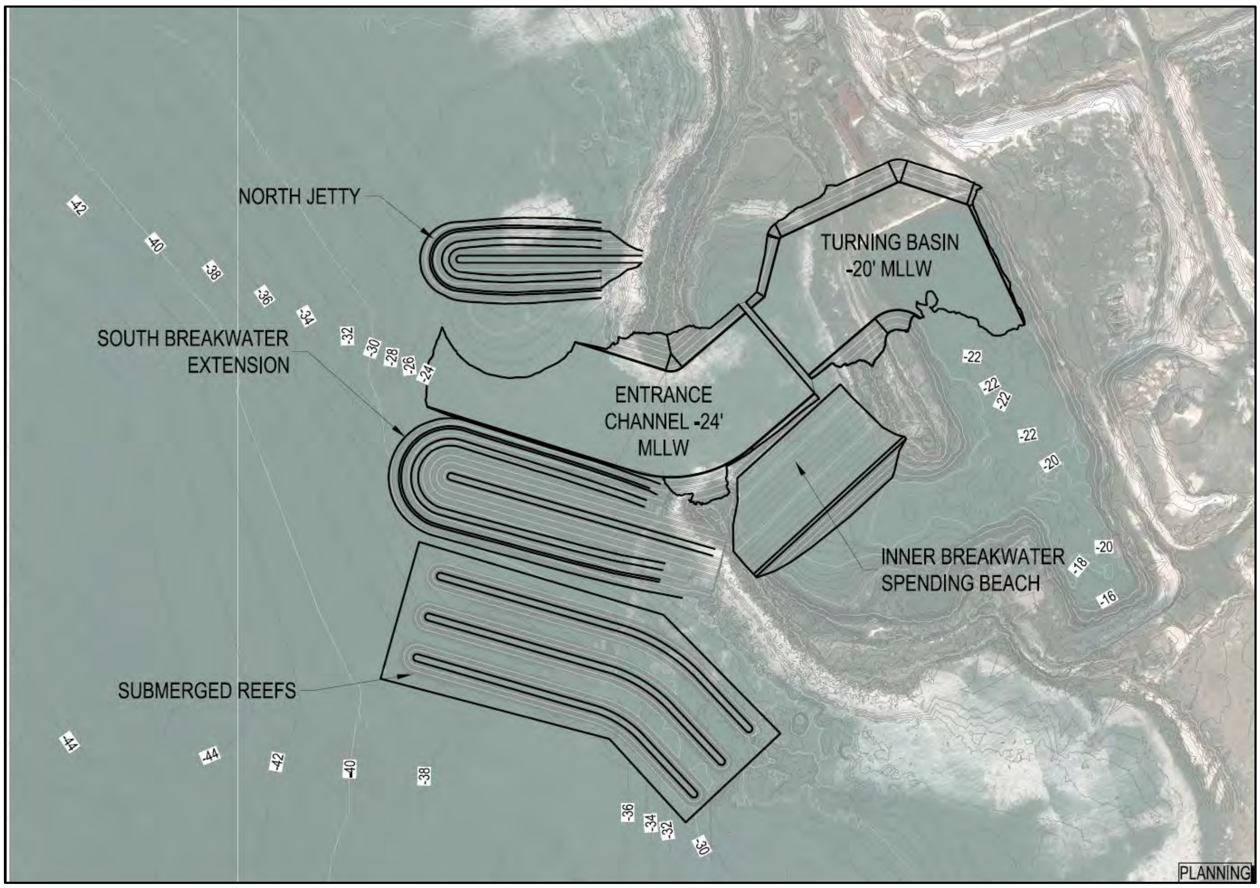

Figure 39. Alternative Z-1 Concept Plan

6.1.1. Structural Design

The South Breakwater extension and North Jetty are subject to storm waves from the southwest and use a design wave height of 23 feet. This results in an average armor stone weight of 30 tons when constructed at a 2H:1V slope. Due to the long period of the storm waves, energy is assumed to diffract around the breakwater heads and also transmit through the breakwater section requiring both sides of the breakwater and jetty to be armored. The North Jetty was designed with a lower crest since wave overtopping would not produce any detriment to navigation; overtopping wave energy would be transmitted to the north of the entrance channel and not affect the harbor. The reefs were designed by referencing the existing reefs in place at nearby St. Paul Harbor with a stone size of 1.5 tons.

6.1.2. FUNWAVE Analysis

A FUNWAVE grid off this harbor was created to determine the effectiveness of the navigation features at providing a wave climate usable by vessels for transferring cargo (Figure 40). The storms used to analyze the existing harbor shown in Table 13 and Table 15 were run over this grid to determine harbor response. Selected gages were analyzed to measure harbor response. The critical gages on this grid are gages 11, which is at the existing fuel dock and 16 which is at the existing ice plant dock. The model run results did not produce wave heights at the docks less than 0.5 meters in any scenario and the sea climate outside the harbor required for vessels to safely moor was not found.

6.1.3. Harbor Effectiveness

This harbor configuration did not improve moorage conditions at the existing docks at Zapadni Bay. It is believed that the wider entrance channel and open westerly exposure allows too much wave energy to pass directly into the inner harbor area. Additionally, the rerouting of the navigation channel eliminated area for waves to dissipate after passing through the outer breakwaters at the north end of the existing inner breakwater. Instead of dissipating, energy is channelized into the inner harbor resulting in degraded mooring conditions.

6.1.4. Alternative Quantities and Cost

Quantities for this alternative were based on volumetric calculations of TIN surface modeling of the harbor features in Autodesk Civil3D. These quantities were calculated to the nearest cubic yard, however due to uncertainties in terrain modeling, should only be considered accurate to two significant figures. Rounded quantities for this alternative are shown in

Table 17. The estimated project cost for this alternative is $167 million without contingency cost.

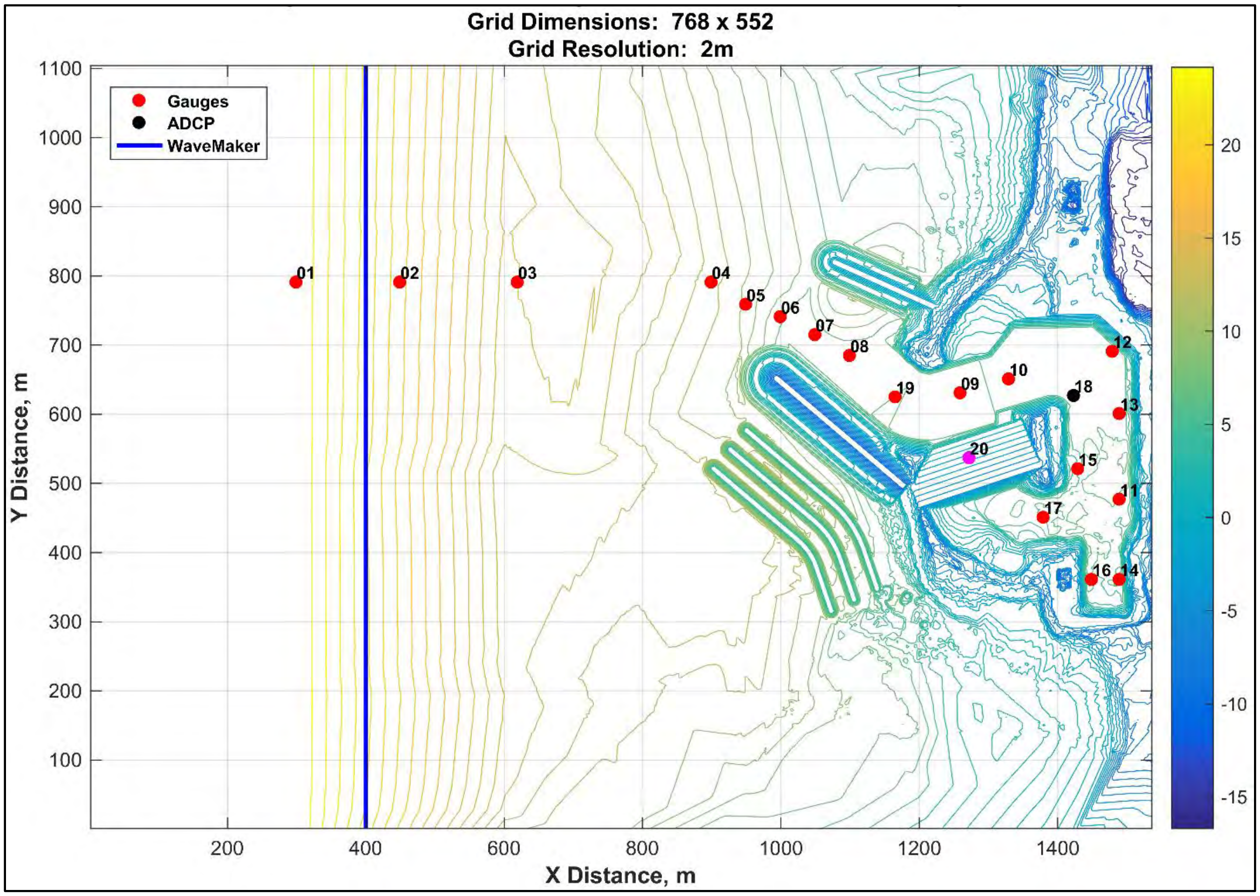

Figure 40. FUNWAVE model grid for Alternative Z-1. Note, wavemaker location shown is incorrect, the wavemaker is located at X = 200m. Gages 11 and 16 were used to measure wave height at the dock faces.

Table 17. Alternative Z-1 Quantities

South Breakwater Extension		North Jetty	
A-Rock	110,000 CY	A-Rock	14,000 CY
B-Rock	35,000 CY	B-Rock	12,000 CY
C-Rock	57,000 CY	C-Rock	7,700 CY
Inner Breakwater - Spending Beach		Reefs	
A-Rock	13,000 CY	Reef 1	37,000 CY
B-Rock	7,800 CY	Reef 2	43,000 CY
C-Rock	14,000 CY	Reef 3	43,000 CY
Rock Spalls	68,000 CY	Bedding Layer	36,000 CY
Dredging			
Drill, Blast and Dredge	230,000 CY		

6.2. Alternative Z-2: South Breakwater Overlap

This alternative includes constructing a 1,050 foot long cap and extension to the existing south breakwater with a crest elevation of +35 feet MLLW, a 400 foot jetty north of the new breakwater breakwater with a crest elevation of +10 feet MLLW and a new navigation channel with a depth of -22 feet MLLW and a new turning basin with a depth of -18 feet MLLW (Figure 41). The existing north breakwater would be demolished to allow vessels to pass through this area. The construction provides a breakwater overlap of the inner harbor facilities in an attempt to provide improved protection for the existing docks. The new channel alignment includes wider turning sections than the existing harbor. This navigation pattern is expected to improve barge access to the harbor.

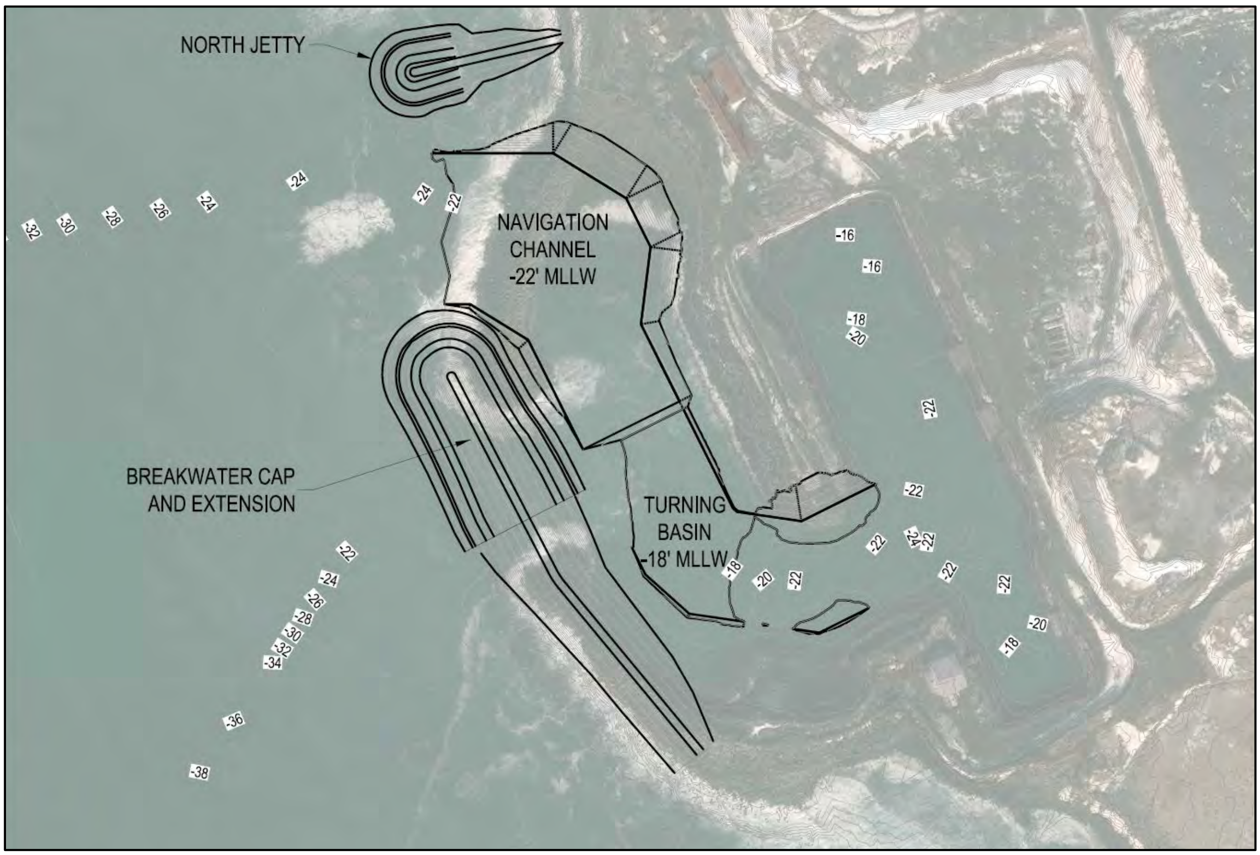

Figure 41. Alternative Z-2 Concept Plan

6.2.1. Structural Design

The South Breakwater extension and North Jetty are subject to storm waves from the southwest and use a design wave height of 23 feet. This results in an average armor stone weight of 30 tons when constructed at a 2H:1V slope. Due to the long period of the storm waves, energy is assumed to diffract around the breakwater heads and also transmit through the breakwater section requiring both sides of the breakwater and jetty to be armored. The North Jetty was designed with a lower crest since wave overtopping would not produce any detriment to navigation; overtopping wave energy would be transmitted to the north of the entrance channel and not affect the harbor.

6.2.2. FUNWAVE Analysis

A FUNWAVE grid off this harbor was created to determine the effectiveness of the navigation features at providing a wave climate usable by vessels for transferring cargo (Figure 42). The storms used to analyze the existing harbor shown in Table 13 and Table 15 were run over this grid to determine harbor response. Selected gages were analyzed to measure harbor response. The critical gages on this grid are gages 11, which is at the existing fuel dock and 16 which is at the existing ice plant dock. The model run results indicate that waves outside the harbor at the wavemaker location need to be less than 2.39 meters in height to produce wave heights at the docks less than 0.5 meters. It is estimated that sea conditions exceed this height approximately 19% of the time annually which is within 1% of the existing condition.

6.2.3. Harbor Effectiveness

This harbor configuration did not improve moorage conditions at the existing docks at Zapadni Bay. It is believed that the alignment of the entrance channel and the presence of the jetty to the north channelize incident wave energy causing it to propagate efficiently through the channel to the inner harbor. As with Alternative Z-1, the dissipation area north of the inner breakwater was lost resulting in degraded mooring conditions.

6.2.4. Alternative Quantities and Cost

Quantities for this alternative were based on volumetric calculations of TIN surface modeling of the harbor features in Autodesk Civil3D. These quantities were calculated to the nearest cubic yard, however due to uncertainties in terrain modeling, should only be considered accurate to two significant figures. Rounded quantities for this alternative are shown in Table 18. The estimated project cost for this alternative is $102 million without contingency cost.

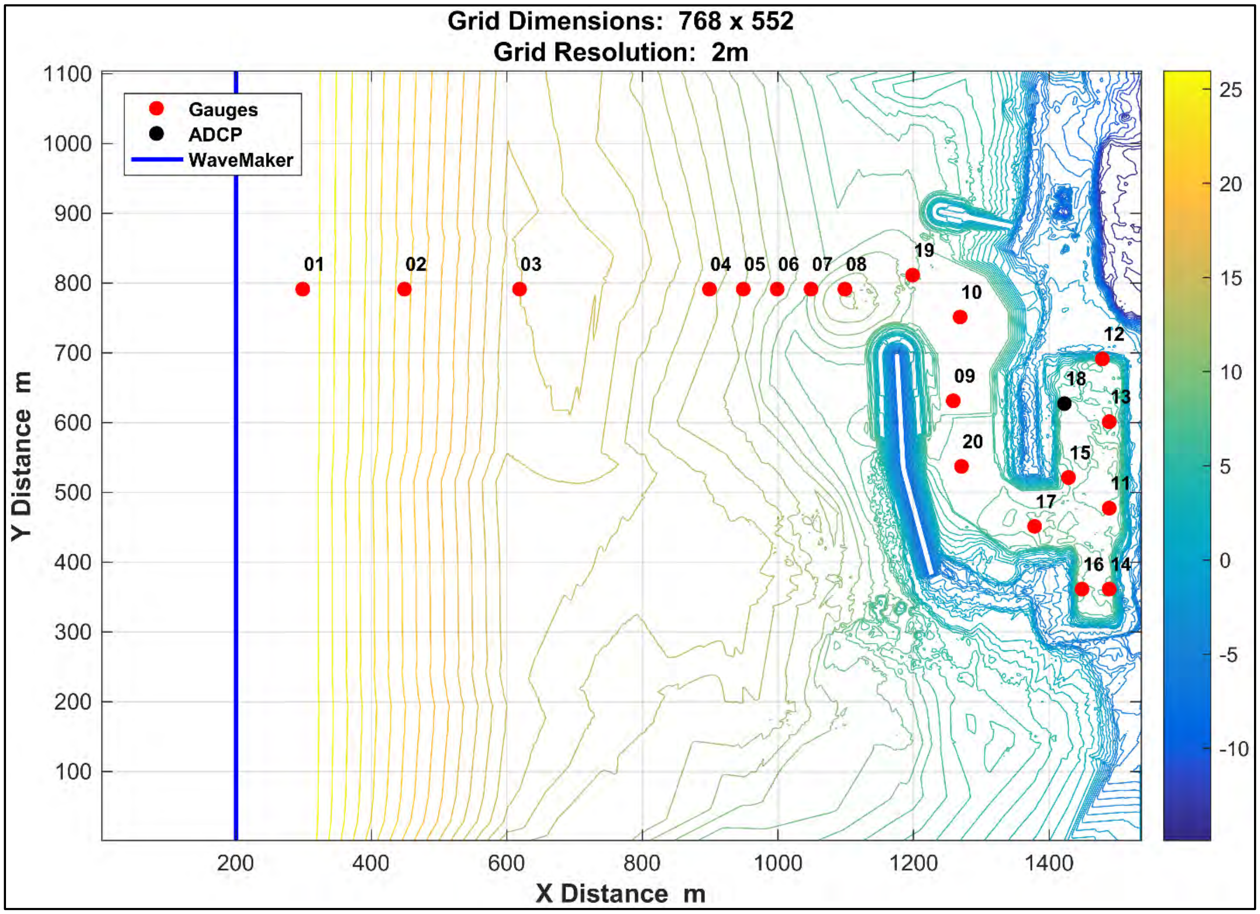

Figure 42. FUNWAVE model grid for Alternative Z-2. Gages 11 and 16 were used to measure wave height at the dock faces.

Table 18: Alternative Z-2 Quantities

South Breakwater Extension		North Jetty	
A-Rock	110,000 CY	A-Rock	14,000 CY
B-Rock	35,000 CY	B-Rock	12,000 CY
C-Rock	57,000 CY	C-Rock	7,700 CY
Breakwater Nose Demolition			
Rock Removal	140,000 CY		
Dredging			
Drill, Blast and Dredge	150,000 CY		

6.3. Alternative Z-3: Inland Basin

This alternative includes constructing a new 700 foot long by 500 foot wide mooring basin to the northeast of the existing harbor. The new basin would be connected to the existing harbor by a 200 foot wide navigation channel. Excavation of the new mooring basin included excavation to construct a road around its perimeter to allow vehicles to traverse the perimeter of the harbor. The north end of the existing inner basin and the new inner basin would be sloped at 5H:1V to reduce wave reflection within the mooring basins. The existing harbor breakwaters would remain in their existing condition and the existing channel would be widened to a minimum of 200 feet at the head of the inner breakwater and dredged to a depth of -22 feet MLLW (Figure 43). The navigation channel widens the pinch point around the inner breakwater and is expected to improve barge navigation to the harbor.

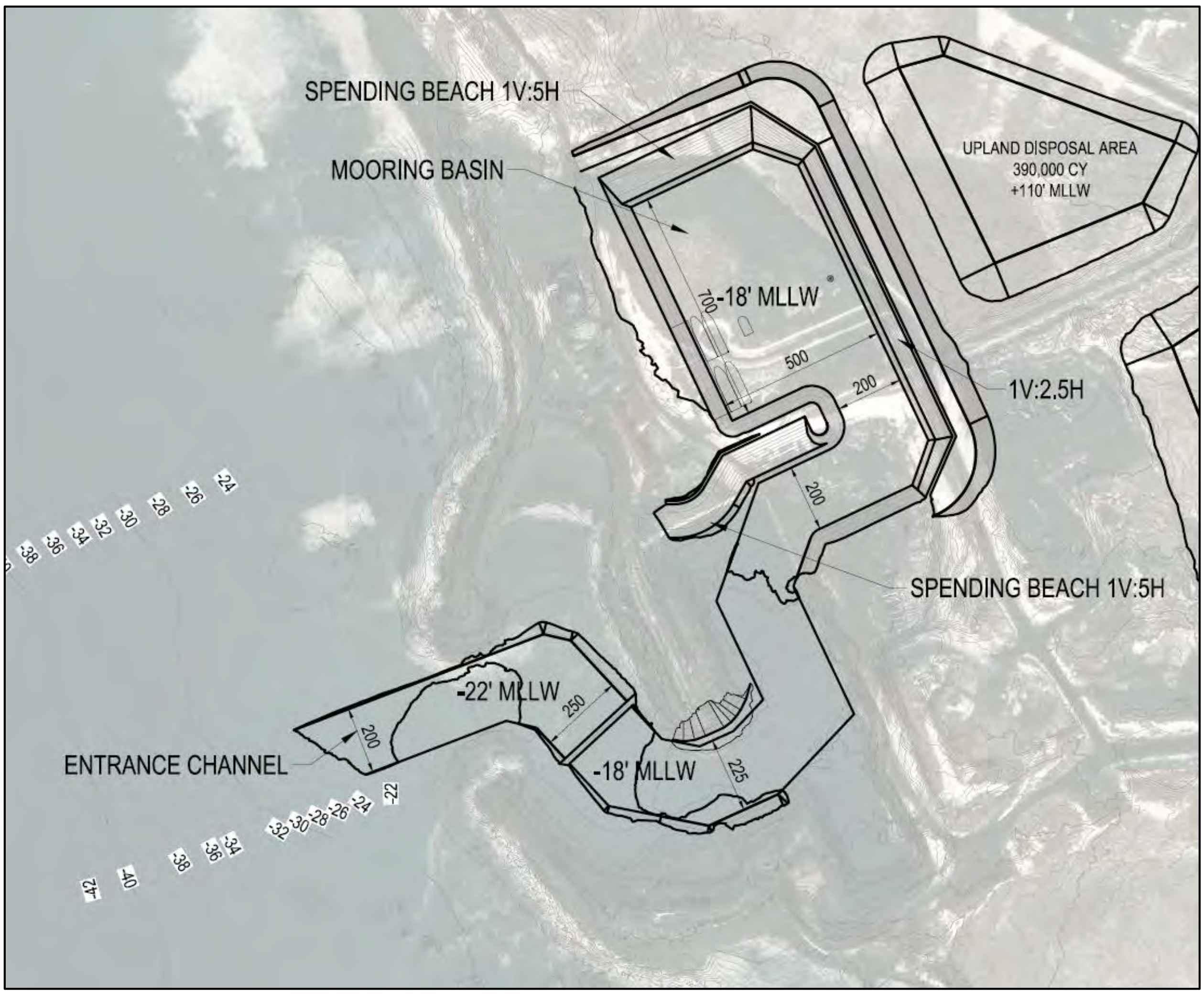

Figure 43. Alternative Z-3 Concept Plan

6.3.1. Structural Design

Primary construction of this harbor design would be through excavation and dredging. No new rock structures would be placed. Slope protection rock would be provided where the native rock was determined to be too small to provide slope protection under the expected wave conditions inside the harbor under storm conditions.

6.3.2. FUNWAVE Analysis

A FUNWAVE grid off this harbor was created to determine the effectiveness of the navigation features at providing a wave climate usable by vessels for transferring cargo (Figure 44). To reduce the processing time required to generate wave heights at the docks, a smaller set of three simulated storms and nine auxiliary storms were run through the FUNWAVE grid. Storm definitions are shown in Table 19 and

Table 20.

Table 19. Simulated Storm wave spectral peak wave height and period.

Run No.	Hm0 (m)	Tp (s)	Dir (deg)
1	14.05	17.35	252
2	13.69	17.75	245
17	11.07	19.12	256

Table 20. Auxiliary Storm wave spectral peak wave height and period.

Hm0 (m)	Tp (s)		
	10	20	26
2	X	X	X
6	X	X	X
8	X		
10		X	X

Selected gages were analyzed to measure harbor response. The critical gages on this grid are gages 11, which is at the existing fuel dock and 16 which is at the existing ice plant dock and gage 26 which is the location of a proposed new dock in the new mooring basin. The model run results indicate that waves outside the harbor at the wavemaker location need to be less than 4.14 meters in height to produce wave heights at the docks less than 0.5 meters. It is estimated that sea conditions exceed this height approximately 8% of the time annually.

6.3.3. Harbor Effectiveness

This harbor configuration did not improve moorage conditions at the existing docks at Zapadni Bay. The new dock location in the new basin showed improved wave conditions, however still showed a significant percentage of time where the dock would be unusable. It was also found that there is a secondary seiche in the new basin. It is believed that the seiche conditions in the existing inner harbor create forcing conditions through the new navigation which sets up a secondary seiche in the new mooring basin during storm events. This harbor also requires a significant excavation volume on the order of 2,000,000 cubic yards of material requiring disposal outside of the harbor area.

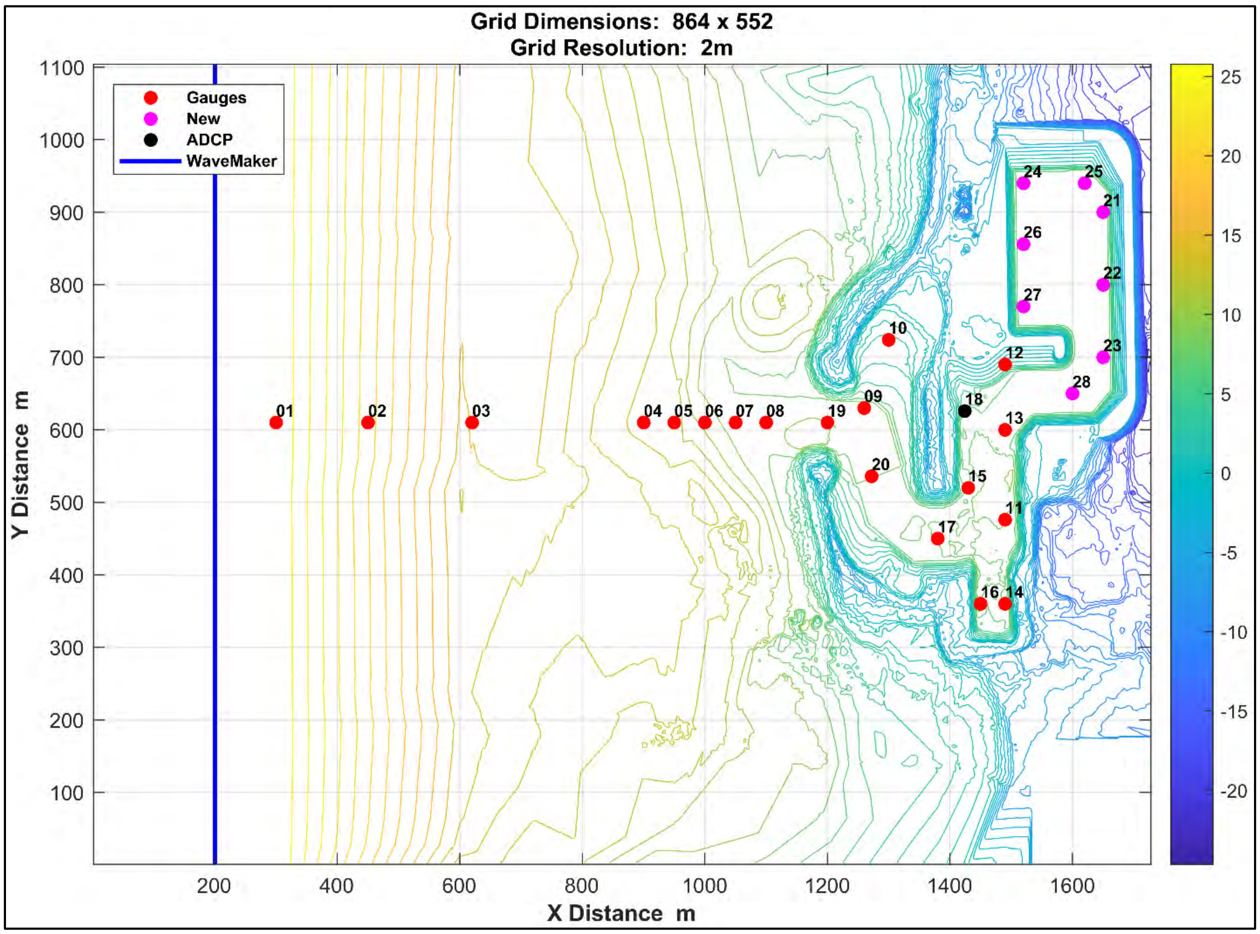

Figure 44. FUNWAVE model grid for Alternative Z-3. Gages 11 and 16 were used to measure wave height at the existing dock faces. Gage 26 was used to measure wave height at a proposed new dock location.

6.3.4. Alternative Cost

Quantities for this alternative were based on volumetric calculations of TIN surface modeling of the harbor features in Autodesk Civil3D. These quantities were calculated to the nearest cubic yard, however due to uncertainties in terrain modeling, should only be considered accurate to two significant figures. Rounded quantities for this alternative are shown in Table 21. The estimated project cost for this alternative is $74 million without contingency cost.

Table 21. Alternative Z-3 Quantities

Dredging		Breakwater Shortening	
Mooring Basin	2,000,000 CY	Inner Breakwater	11,000 CY
Entrance Channel	23,000 CY		

6.4. Alternative Z-4: Overall Harbor Concept (OHC)

This alternative was developed by the State of Alaska Department of Transportation and Public Facilities (AKDOT&PF) and HDR Inc. prior to initiation of the USACE feasibility study effort. The AKDOT&PF plan was modified to meet navigation requirements for the fuel barge to enter the harbor, however the parallel jetties would still pose an impediment for the barge to clear the outer breakwaters. This alternative includes constructing 400 foot long jetties at the ends of the north and south breakwaters with a crest elevation of +35 feet MLLW, a 500 foot inner north breakwater with a crest elevation of +20 feet MLLW and a north mooring basin with a depth of -10 feet MLLW to allow for moorage of the subsistence fleet (Figure 45). The jetties restrict the available approach headings for barges to enter the harbor and further restrict barge access to make deliveries.

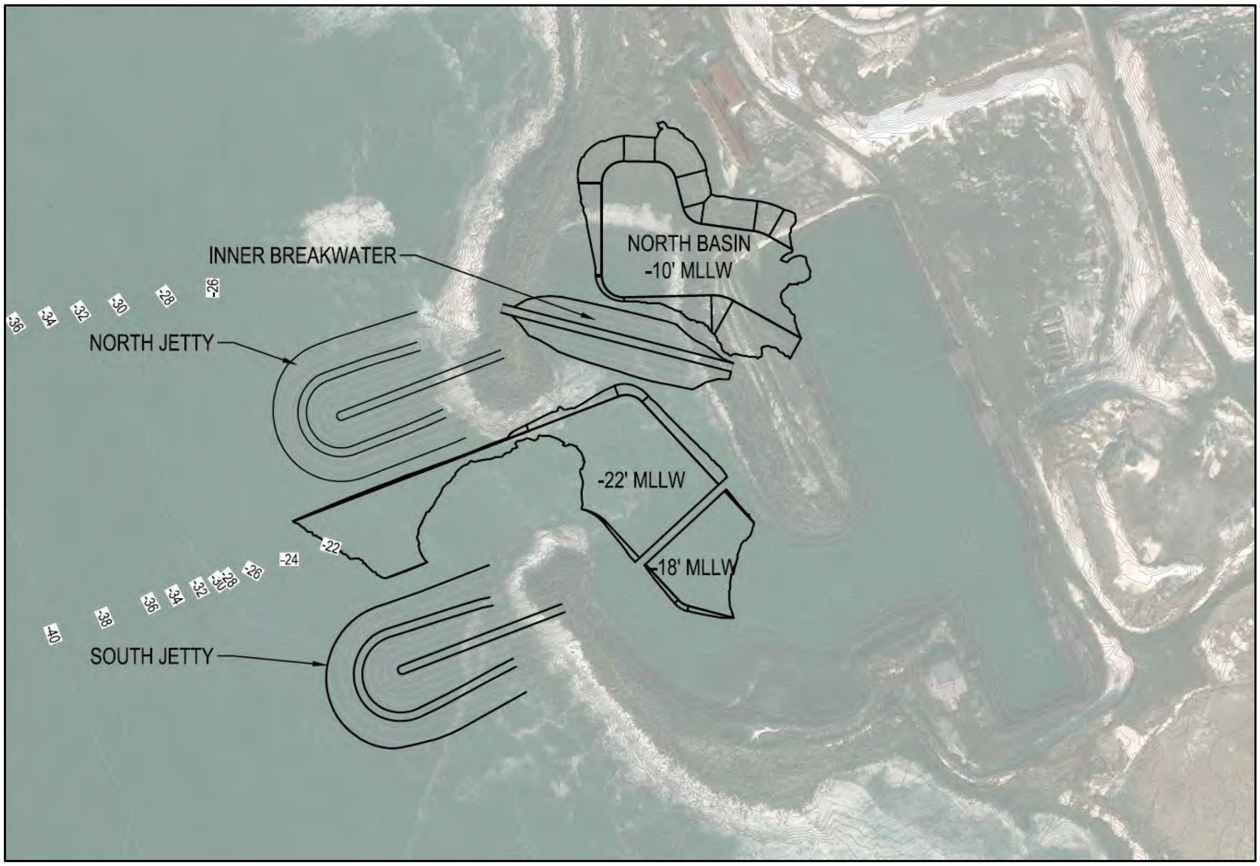

Figure 45. Alternative Z-4 Concept Plan

6.4.1. Navigation Design

The north and south jetties are subject to storm waves from the southwest and use a design wave height of 23 feet. This results in an average armor stone weight of 30 tons when constructed at a 2H:1V slope. The new inner breakwater is also armored with 30 ton stone due to its proximity to the harbor entrance.

6.4.2. FUNWAVE Analysis

A FUNWAVE grid off this harbor was created to determine the effectiveness of the navigation features at providing a wave climate usable by vessels for transferring cargo (Figure 46). The storms shown in Table 19 and

Table 20 were run over this grid to determine harbor response. Selected gages were analyzed to measure harbor response. The critical gages on this grid are gages 11, which is at the existing fuel dock and 16 which is at the existing ice plant dock. The model run results indicate that waves outside the harbor at the wavemaker location need to be less than 2.44 meters in height to produce wave heights at the docks less than 0.5 meters. It is estimated that sea conditions exceed this height approximately 19% of the time annually which is within 1% of the existing condition.

6.4.3. Harbor Effectiveness

This harbor configuration did not improve moorage conditions at the existing docks at Zapadni Bay. Conditions at the existing docks were found to be essentially the same as the existing condition. STWave runs showed that incoming storm waves generally diffract to a shore-normal direction which propagates straight through the existing harbor entrance. The jetties extend this entrance into deeper water, but do little to reduce wave energy from this direction. Allowing the seiche conditions seen in the existing harbor to develop.

Table 22. Alternative Z-4 Quantities

South Jetty		North Jetty	
A-Rock	48,000 CY	A-Rock	42,000 CY
B-Rock	31,000 CY	B-Rock	28,000 CY
C-Rock	52,000 CY	C-Rock	44,000 CY
Inner Breakwater			
A-Rock	12,000 CY		
B-Rock	8,000 CY		
C-Rock	13,000 CY		
Dredging			
Drill, Blast and Dredge	96,000 CY		

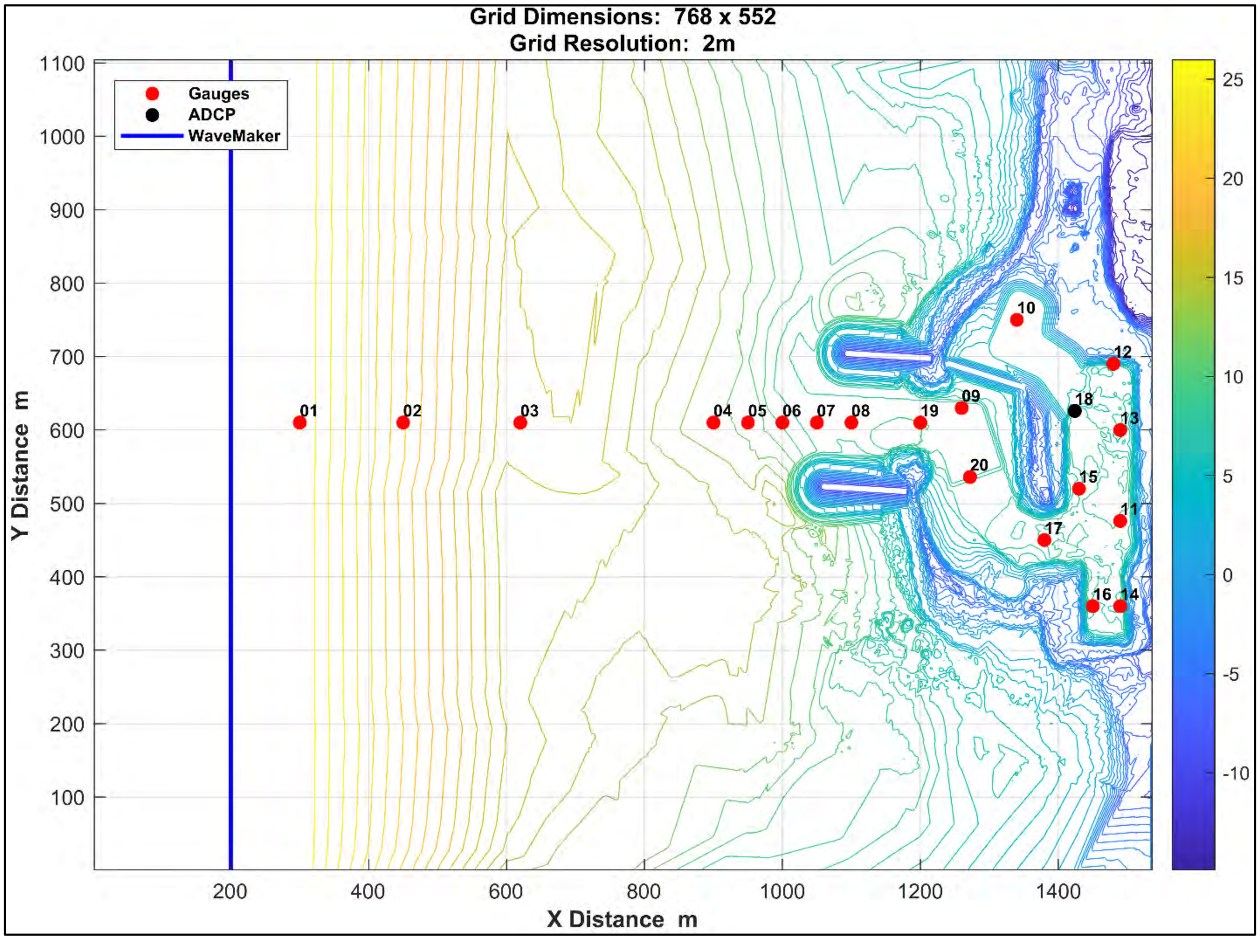

Figure 46. FUNWAVE model grid for Alternative Z-4. Gages 11 and 16 were used to measure wave height at the existing dock faces.

6.4.4. Alternative Cost

Quantities for this alternative were based on volumetric calculations of TIN surface modeling of the harbor features in Autodesk Civil3D. These quantities were calculated to the nearest cubic yard, however due to uncertainties in terrain modeling, should only be considered accurate to two significant figures. Rounded quantities for this alternative are shown in Table 22. The estimated project cost for this alternative is $85million without contingency cost.

6.5. Alternative Z-5: Expanded Harbor

This alternative includes demolishing the existing south breakwater and constructing an 3,000 foot long breakwater from the ice plant to an overlap position seaward of the existing north breakwater with a crest elevation of +35 feet MLLW. A 300 foot long extension of the north breakwater would be constructed with a crest elevation of +20 feet MLLW perpendicular to the new breakwater to define the mooring basin behind the new breakwater. New docks would be constructed on the inside of the new main breakwater with the entire basin enclosed by the new breakwaters being dredged to -22 feet MLLW. The back slope of the existing inner harbor would be filled at a 10H:1V slope to provide a spending beach in the new mooring basin (Figure 47). The navigation pattern for this alternative is very similar to St. Paul Harbor and the wider channel around the breakwater is expected to improve barge navigation to the harbor.

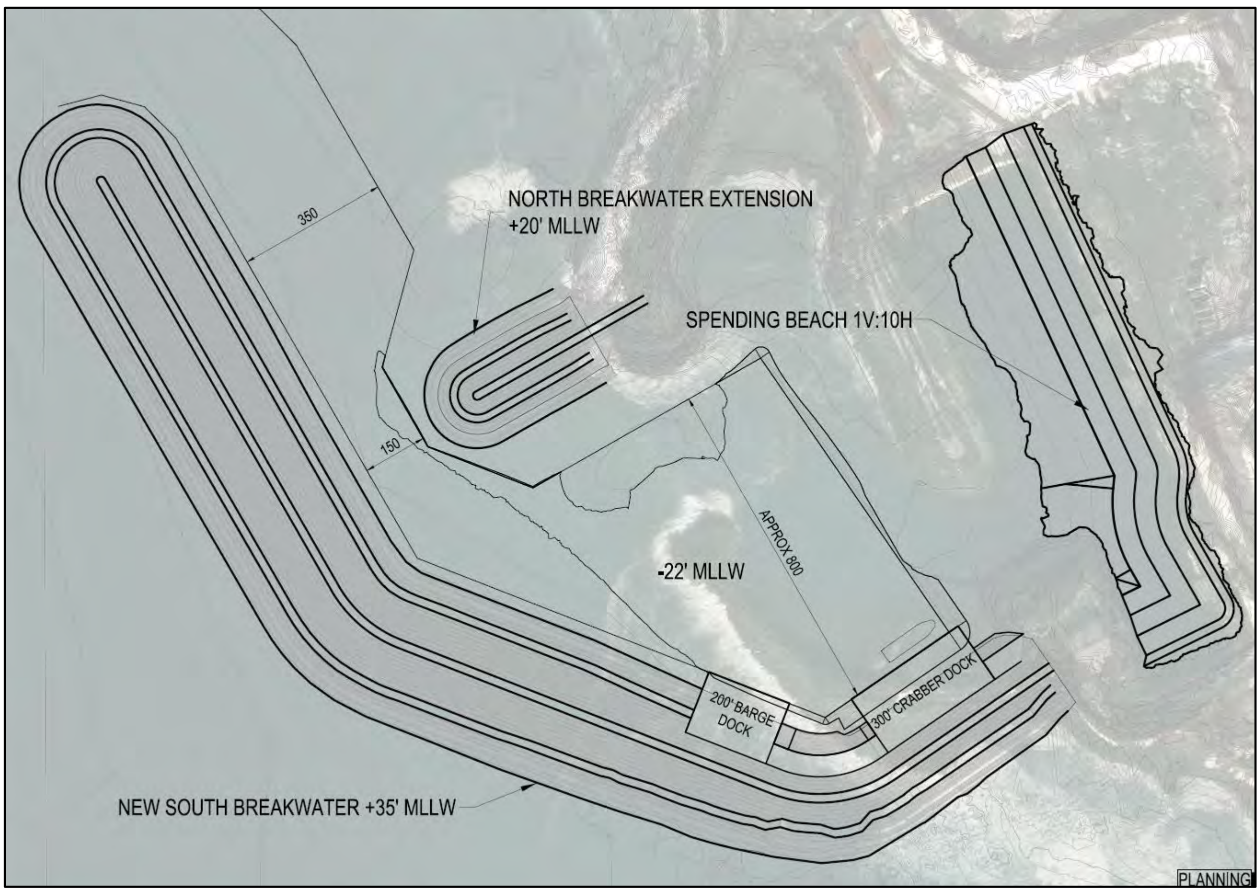

Figure 47. Alternative Z-5 Concept Plan

6.5.1. Navigation Design

The new breakwaters are subject to storm waves from the southwest and use a design wave height of 23 feet. This results in an average armor stone weight of 30 tons when constructed at a 2H:1V slope. The new inner breakwater is also armored with 30 ton stone due to its proximity to the harbor entrance. The inner breakwater was designed with a lower crest based on the assumption that incident waves would interact with the South Breakwater before entering the harbor and inner breakwater. Model results showed wave heights at this breakwater were under 2 meters.

6.5.2. FUNWAVE Analysis

A FUNWAVE grid off this harbor was created to determine the effectiveness of the navigation features at providing a wave climate usable by vessels for transferring cargo (Figure 48). The storms shown in Table 19 and

Table 20 were run over this grid to determine harbor response. Selected gages were analyzed to measure harbor response. The critical gages on this grid are gages 11 and 14 which are at the location of proposed new docks. The model run results indicate that waves outside the harbor at the wavemaker location need to be less than 6.9 meters in height to produce wave heights at the docks less than 0.5 meters. It is estimated that sea conditions exceed this height approximately 2% of the time.

6.5.3. Harbor Effectiveness

This harbor substantially improves moorage availability but would still require vessels to leave the dock during storm events to avoid damage. While this design is essentially functional, the quantities of rock required to construct the breakwater would take a substantial amount of time to produce and place and phased construction over several years would be required.

6.5.4. Alternative Cost

Quantities for this alternative were based on volumetric calculations of TIN surface modeling of the harbor features in Autodesk Civil3D. These quantities were calculated to the nearest cubic yard, however due to uncertainties in terrain modeling, should only be considered accurate to two significant figures. Rounded quantities for this alternative are shown in Table 23. The estimated project cost for this alternative is $437 million without contingency cost.

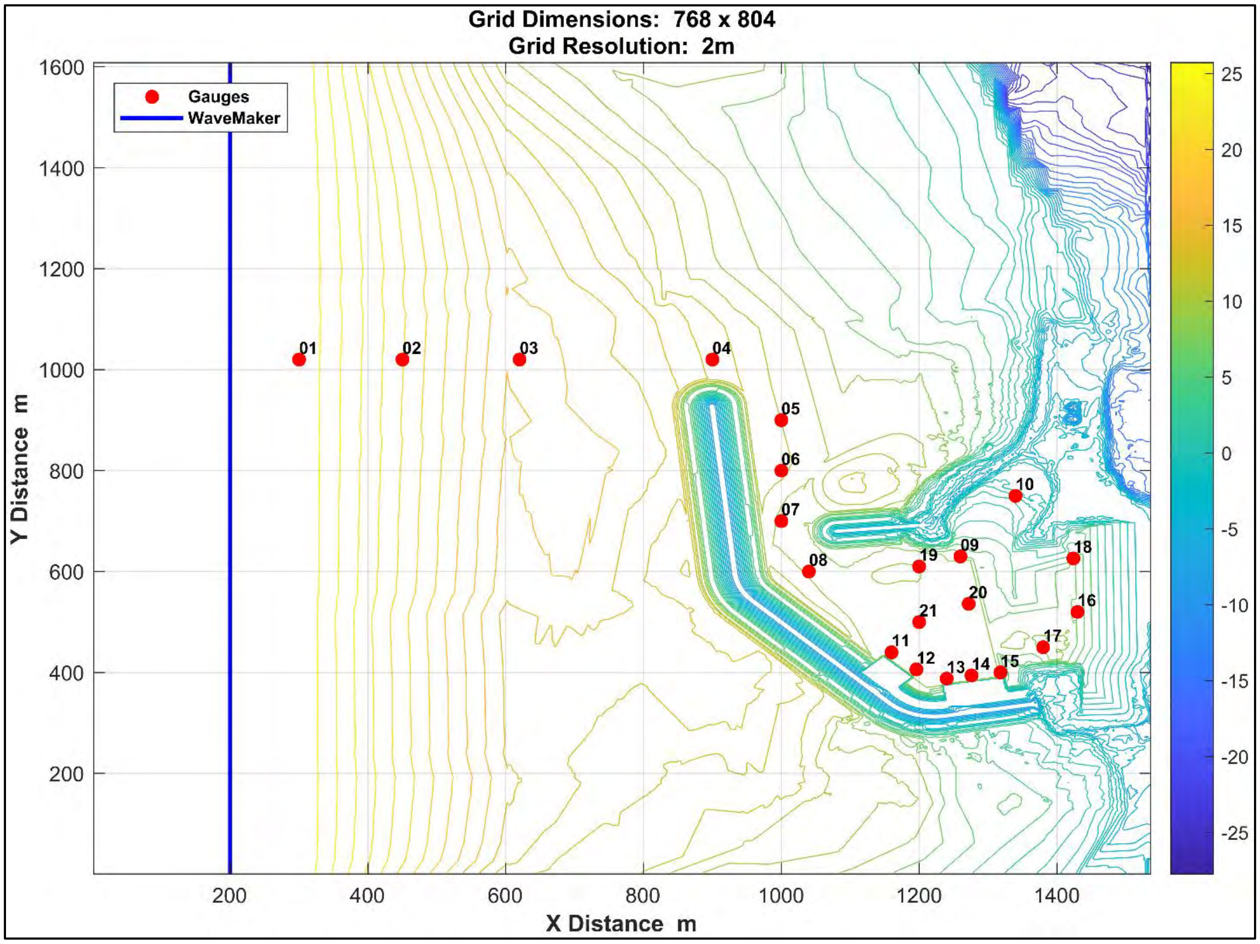

Figure 48. FUNWAVE model grid for Alternative Z-5. Gages 11 and 14 were used to measure wave height at the new dock faces.

Table 23. Alternative Z-5 Quantities

New South Breakwater		North Breakwater Spur	
A-Rock	420,000 CY	A-Rock	30,000 CY
B-Rock	250,000 CY	B-Rock	22,000 CY
C-Rock	540,000 CY	C-Rock	23,000 CY
Breakwater Demolition			
South Breakwater	220,000 CY		
Inner Breakwater	130,000 CY		
Dredging		Upland Fill	
Drill, Blast and Dredge	241,000 CY	Causeway	31,000 CY

6.6. Alternative Z-6: Berm Breakwater

This alternative adapts the original berm breakwater design of St. George Harbor to the current shoreline. The design includes the original design locations for the breakwater utilizing a berm cross section with a crest elevation of +26 ft. MLLW. This would entail complete removal of both existing North and South breakwaters to allow for the new construction. The existing harbor geometry was modified by adding spending beaches at a 1V:10H slope to both ends of the inner harbor basin (Figure 49). The navigation channel widens the pinch point around the inner breakwater and is expected to improve barge navigation to the harbor. Dredge areas for entrance and outer basin maneuvering are designed to -22 ft. MLLW and -18 ft. MLLW respectively.

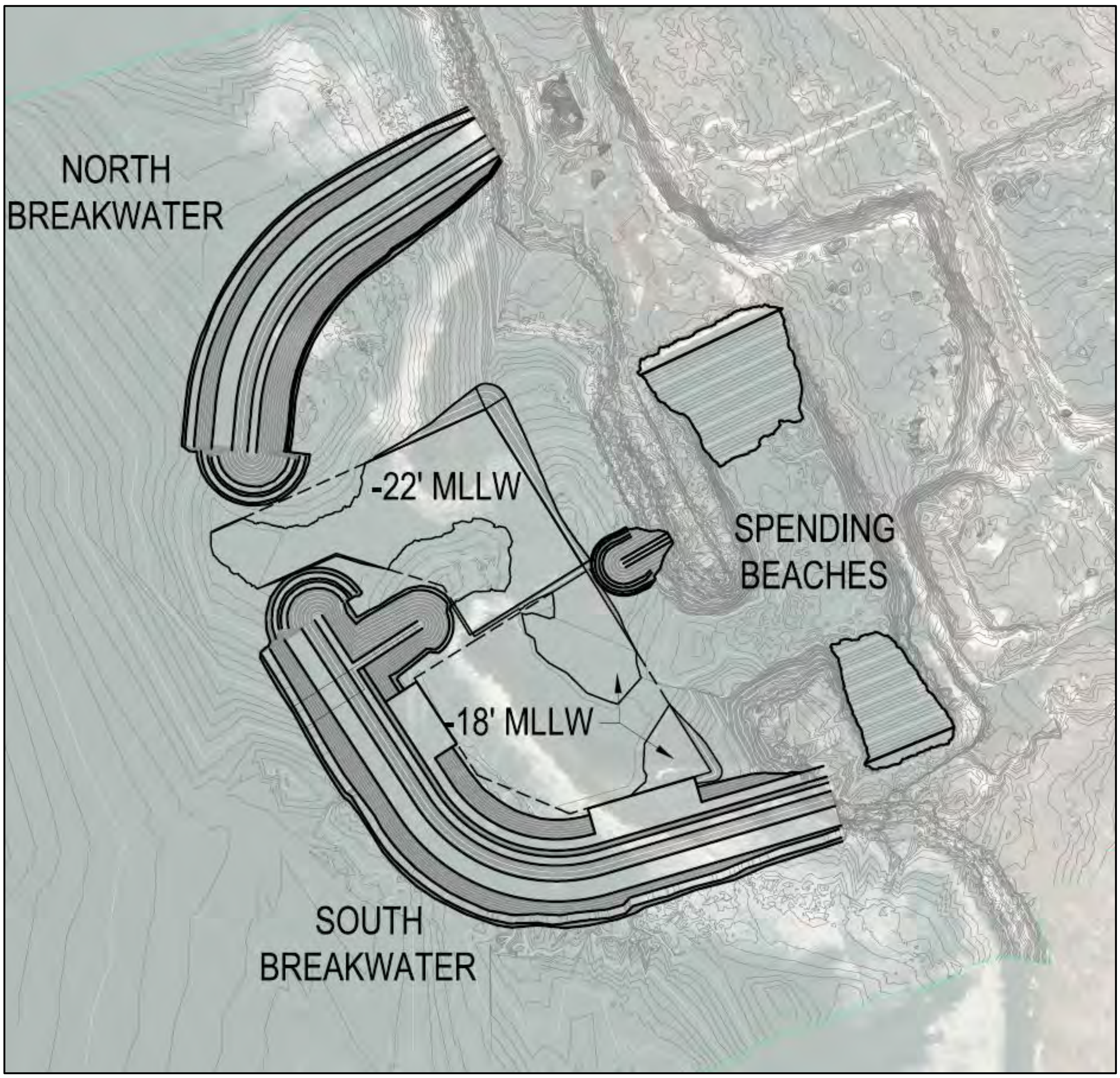

Figure 49. Alternative Z-6 Concept Plan

6.6.1. Navigation Design

The new breakwaters would be subject to the same approximate conditions as the existing harbor. For Estimating purposes, it was assumed that the existing rock gradation of 1.7 to 10 ton stone would be used to construct the new breakwaters.

6.6.2. FUNWAVE Analysis

A FUNWAVE grid off this harbor was created to determine the effectiveness of the navigation features at providing a wave climate usable by vessels for transferring cargo (Figure 50). The storms shown in Table 19 and

Table 20 were run over this grid to determine harbor response. Selected gages were analyzed to measure harbor response. The model run results indicate that waves outside the harbor at the wavemaker location need to be less than 2 meters in height to produce wave heights at the docks less than 0.5 meters. The model run results did not produce wave heights at the docks less than 0.5 meters in any scenario and the sea climate outside the harbor required for vessels to safely moor was not found.

6.6.3. Harbor Effectiveness

This harbor configuration did not improve moorage conditions at the existing docks at Zapadni Bay. Since the docks are constructed against the breakwaters of the outer harbor, there is less area to dissipate wave energy than the current configuration which leads to less moorage time at the docks.

6.6.4. Alternative Cost

Quantities for this alternative were based on volumetric calculations of TIN surface modeling of the harbor features in Autodesk Civil3D. These quantities were calculated to the nearest cubic yard, however due to uncertainties in terrain modeling, should only be considered accurate to two significant figures. Rounded quantities for this alternative are shown in Table 25. The estimated project cost for this alternative is $177 million without contingency cost.

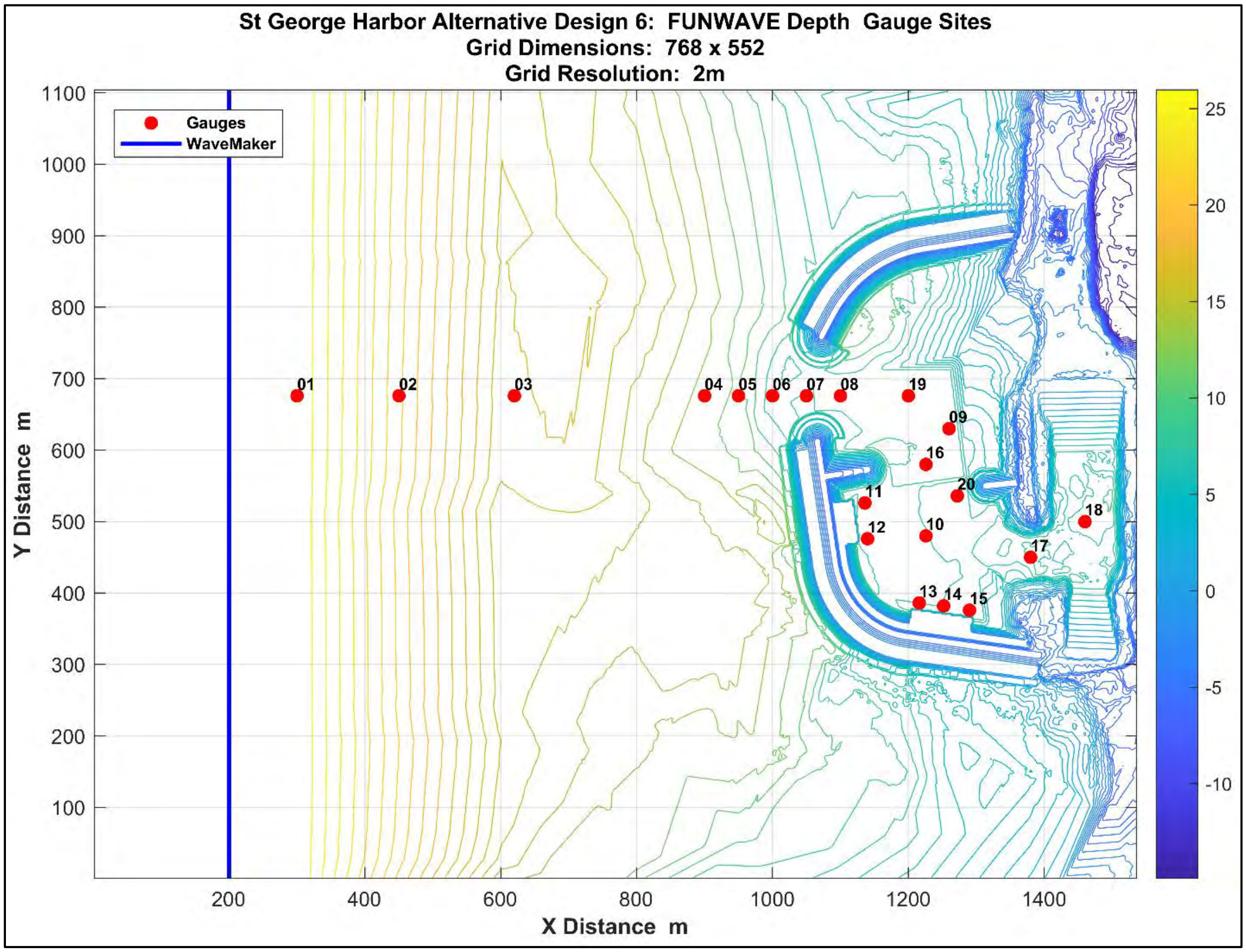

Figure 50. FUNWAVE model grid for Alternative Z-6. Gage 26 was used to measure wave height at the new dock faces.

Table 24: Alternative Z-6 Quantities

South Breakwater		Inner Breakwater	
All Rock	480,000 CY	All Rock	35,000 CY
North Breakwater			
All Rock	330,000 CY		
Spending Beaches			
South Beach	35,000 CY		
North Beach	45,000 CY		
Dredging		Upland Fill	
Drill, Blast and Dredge	45,000 CY	Causeway	32,000 CY

6.7. Alternative Z-7: Half-Moon Harbor

This alternative includes constructing a new 900 foot radius semi-circular mooring basin into the eastern edge of the existing inner harbor. The side slope of the new basin would be 10H:1V to reduce reflection in the mooring area. Excavation of the new mooring basin included excavation to construct a road around its perimeter to allow vehicles to traverse the perimeter of the harbor. The existing harbor breakwaters would remain in their existing condition and the existing channel would be widened to a minimum of 200 feet at the head of the inner breakwater and dredged to a depth of -22 feet MLLW (Figure 51). The navigation channel widens the pinch point around the inner breakwater and is expected to improve barge navigation to the harbor.

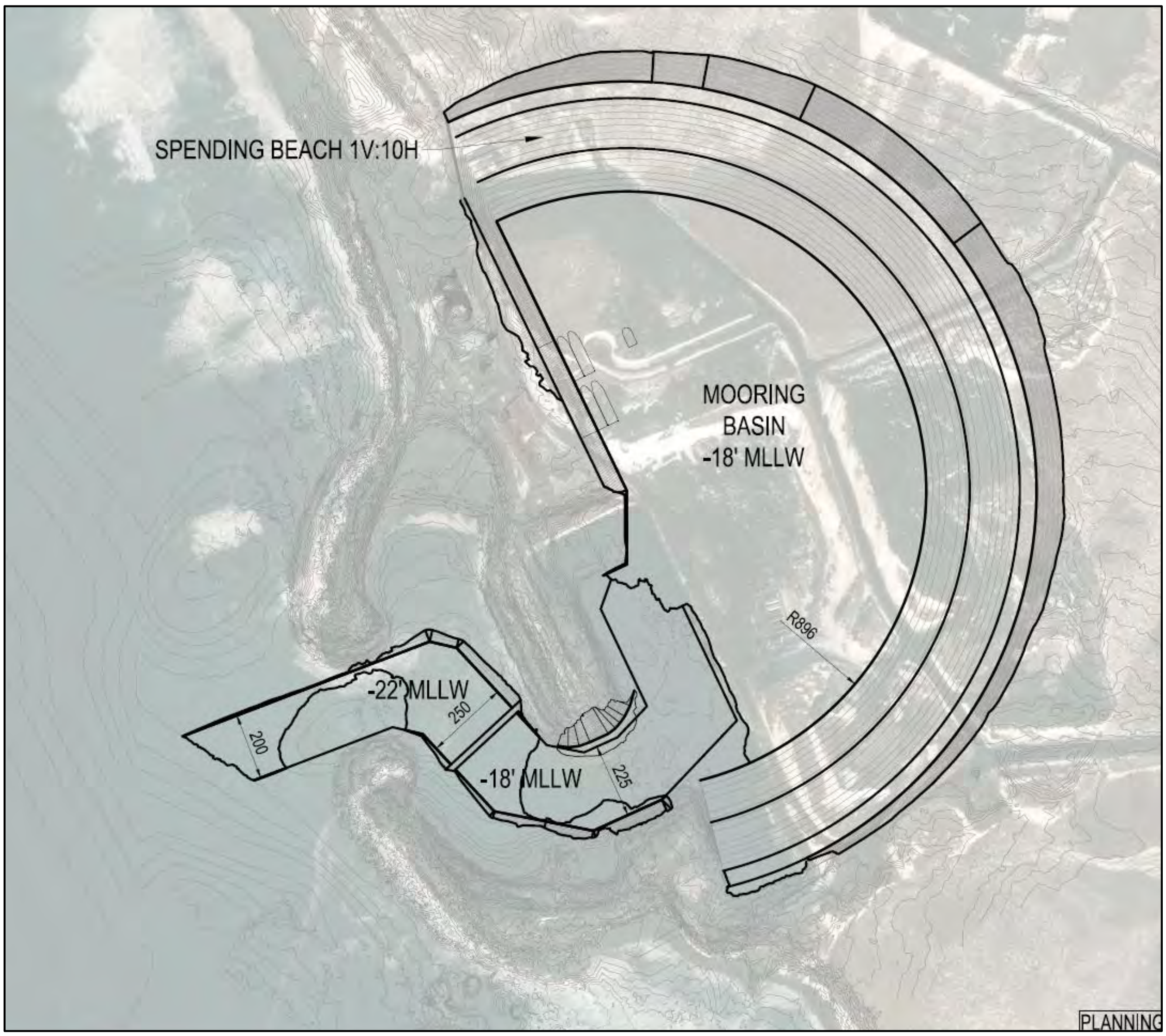

Figure 51. Alternative Z-7 Concept Plan

6.7.1. Navigation Design

Primary construction of this harbor design would be through excavation and dredging. No new rock structures would be placed. Slope protection rock would be provided where the native rock was determined to be too small to provide slope protection under the expected wave conditions inside the harbor under storm conditions.

6.7.2. FUNWAVE Analysis

A FUNWAVE grid off this harbor was created to determine the effectiveness of the navigation features at providing a wave climate usable by vessels for transferring cargo (Figure 52). The storms shown in Table 19 and

Table 20 were run over this grid to determine harbor response. Selected gages were analyzed to measure harbor response. The critical gage on this grid is gage 26 which is at the location of proposed new docks. The model run results indicate that waves outside the harbor at the wavemaker location need to be less than 5.49 meters in height to produce wave heights at the docks less than 0.5 meters. It is estimated that sea conditions exceed this height approximately 4% of the time.

6.7.3. Harbor Effectiveness

The new dock location in the new basin showed improved wave conditions, however still showed a small percentage of time where the dock would be unusable. While the results show that the wave conditions in the mooring basin are improved, there are some responses with peak periods in the 650 to 820 second range indicating that there is still some degree of seiching occurring.

6.7.4. Alternative Cost

Quantities for this alternative were based on volumetric calculations of TIN surface modeling of the harbor features in Autodesk Civil3D. These quantities were calculated to the nearest cubic yard, however due to uncertainties in terrain modeling, should only be considered accurate to two significant figures. Rounded quantities for this alternative are shown in Table 25. The estimated project cost for this alternative is $176 million without contingency cost.

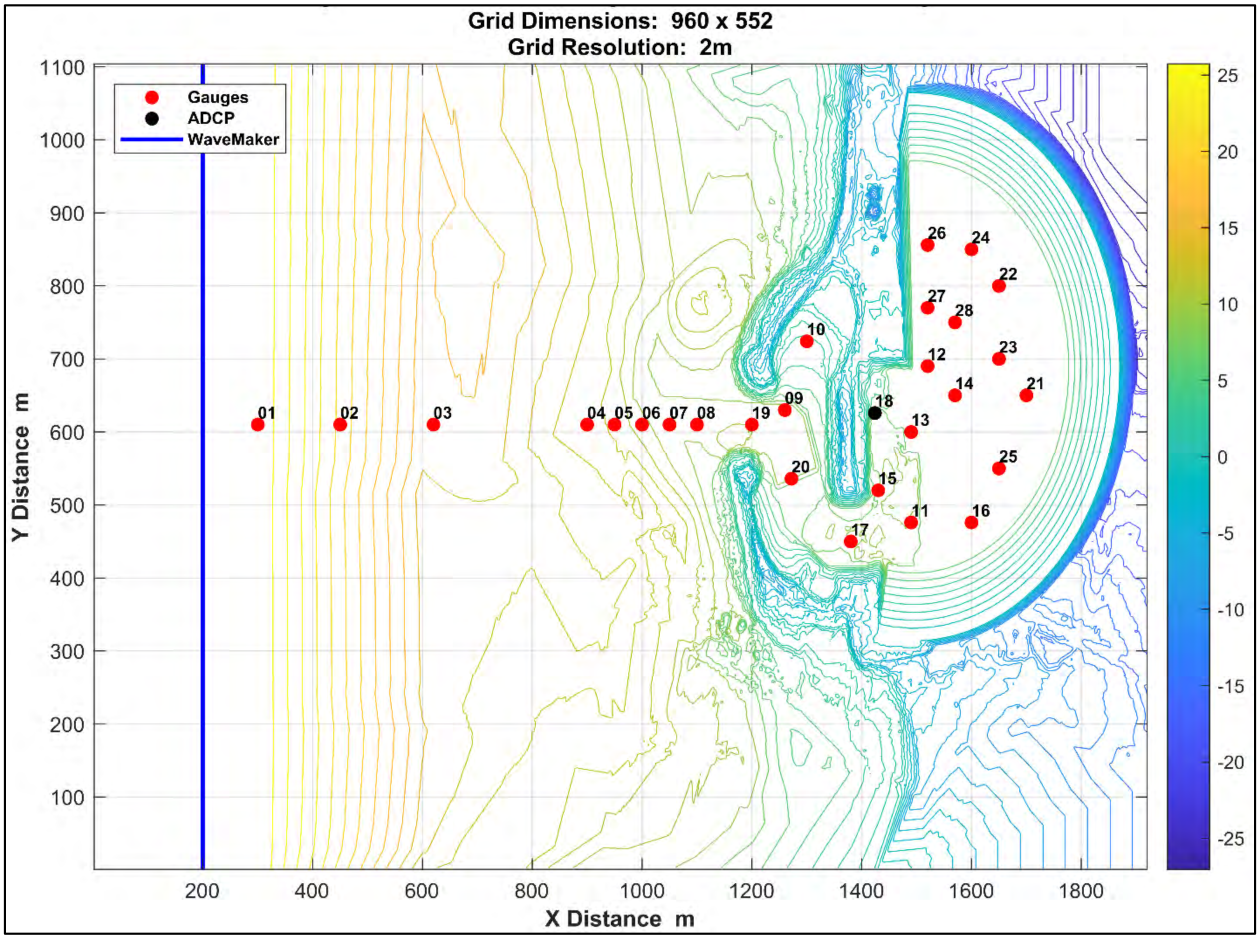

Figure 52. FUNWAVE model grid for Alternative Z-7. Gage 26 was used to measure wave height at the new dock faces.

Table 25. Alternative Z-7 Quantities

Dredging		Breakwater Shortening	
Mooring Basin	6,000,000 CY	Inner Breakwater	11,000 CY
Entrance Channel	23,000 CY		

7.0 NORTH SITE ALTERNATIVES

The North Site was found to have a lower design wave at the location new breakwaters were considered. This resulted in significant differences in the size and quantity of rock needed to protect an area from the open ocean environment. One alternative at this site was selected as the Tentatively Selected Plan. Most of these alternatives share the same concept for breakwater design. Breakwaters exposed to the open ocean environment were designed as a 3 layer rubble mound breakwater with 10 ton armor stone and a crest elevation of +25 feet MLLW (Figure 38). For these breakwaters, the sea side of the breakwater was designed at a 2H:1V slope and the harbor side was designed at a 1.5H:1V slope.

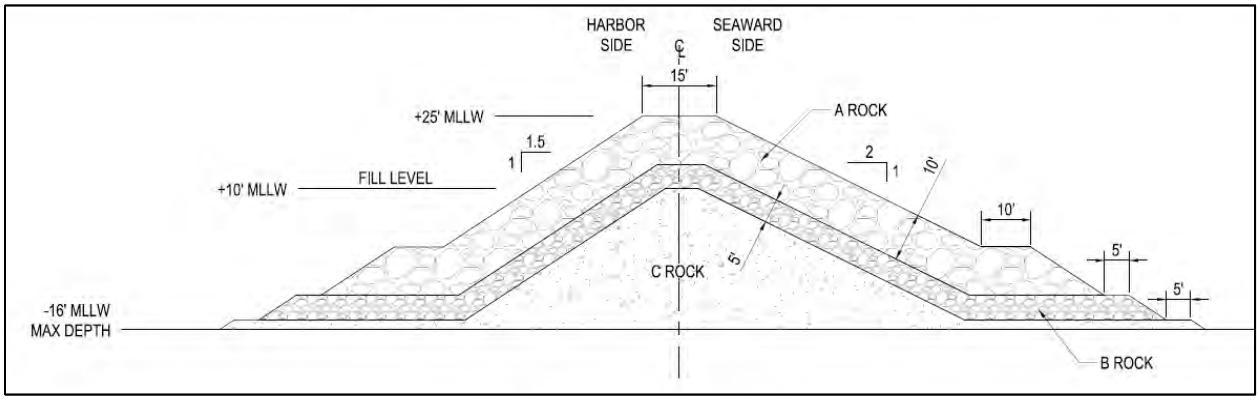

Figure 53: Typical Breakwater Cross Section for North Site Alternatives.

Some variations of this design are indicated is some alternatives.

Numerical model evaluations to determine the effectiveness of these alternatives are believed to be high based on the model test performed for St. Paul Harbor. This affects the FUNWAVE results for modeling of alternatives N-2 and N-3. This suggests that it is likely that the harbors designed for N-2 and N-3 reduce the wave environment inside the harbors more effectively than reported in this appendix. Since N-2 and N-3 are identical except for project depths, FUNWAVE results were not used as a discriminator between these two alternatives. FUNWAVE was used to show that a harbor on the north side of the island could be constructed to allow a vessel to moor under all conditions under which it might enter the harbor. Evaluation of the selected alternative will need to be performed in a physical model environment during the PED phase of the project to ensure that the wave climate in the harbor adequately produces moorable conditions to meet the objectives of this study.

Quantities and costs for these alternatives are included for comparison of relative effort of construction for each alternative. The costs presented in this appendix are rough order of magnitude project costs using the quantities estimated from CAD three dimensional surface models of the alternatives and assumptions for design and construction administration costs. These cost estimates do not include risk based contingency estimates and differ from the numbers found in the main report. These estimates were only used for comparison purposes to determine relative costs between alternatives and are only reported in this appendix.

7.1. Alternative N-1: Subsistence Fleet Launch

This alternative includes constructing protected boat launch and recovery area for the local subsistence fleet. A new 700 foot long breakwater with 10 ton armor stone and a crest elevation of +25 feet MLLW would protect a new concrete launch ramp and launching basin. The launching basin would be dredged to -8 feet MLLW to provide full tide access for the fleet and connected to the Bering Sea with a 50 foot wide channel dredged to -10 feet. New uplands would be constructed inside the breakwater to provide a staging area for the subsistence fleet to launch and recover. Barge and fishing vessel access to St. George would continue to rely on the existing harbor at Zapadni Bay and would be unchanged by this alternative.

7.1.1. Structural Design

The new breakwater is subject to storm waves from the north and use a design wave height of 15 feet. This results in an average armor stone weight of 10 tons when constructed at a 2H:1V slope. The inner slopes of the breakwater would be constructed at 1.5H:1V except at the breakwater nose where the 2H:1V slope is wrapped around and carried through for 50 feet (Figure 54). Where uplands abut the breakwater, the A rock extends over the crest for the full width but is omitted from the harbor side slope. This results in upland fill being placed against B rock.

7.1.2. FUNWAVE Analysis

A FUNWAVE grid of this alternative has not been developed. Model reflectivity issues encountered when analyzing Alternative N-2 would be an issue for this alternative. Also, no moorage analysis of this alternative is warranted; the harbor is designed for launch and recovery operations only, so the only wave criteria needed to analyze this harbor's effectiveness is the vessel access criteria, which is 4 feet for the subsistence fleet. Since this Alternative was not selected as the TSP, no further analysis is planned.

7.1.3. Harbor Effectiveness

Harbor effectiveness for Alternative N-1 is based solely on changes in vessel access which is a function of the site conditions measured at the WIS Station. Due to the harbor geometry and beach slopes of the coastline, seiching is not expected to be an issue.

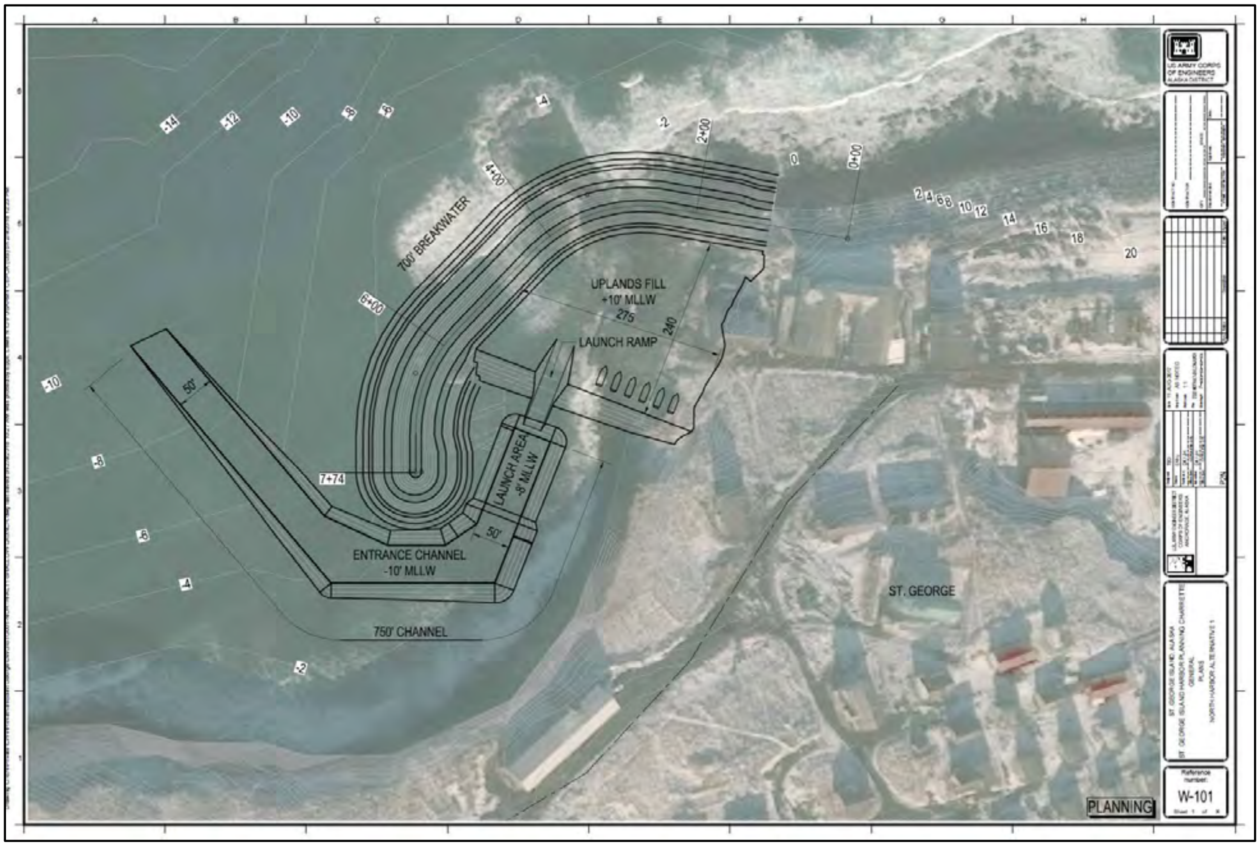

Figure 54. Plan view of Alternative N-1.

7.1.4. Alternative Quantities and Cost

Quantities for this alternative were based on volumetric calculations of TIN surface modeling of the harbor features in Autodesk Civil3D. These quantities were calculated to the nearest cubic yard, however due to uncertainties in terrain modeling, should only be considered accurate to two significant figures. Rounded quantities for this alternative are shown in Table 26. The estimated project cost for this alternative is $24 million without contingency cost.

Table 26: Alternative N-1 Quantities

North Breakwater			
A-Rock	19,000 CY		
B-Rock	16,000 CY		
C-Rock	17,000 CY		
Dredging		Upland Fill	
Drill, Blast and Dredge	10,000 CY	Fill	22,000 CY

7.2. Alternative N-2: Fuel and Supply Barge Harbor

This alternative includes constructing a protected basin to provide access for the fuel barge and boat launch and recovery area for the local subsistence fleet. A new 1,730 foot long North Breakwater with 10 ton armor stone and a crest elevation of +25 feet MLLW would protect a new 550 foot by 450 foot maneuvering basin, a 300 foot dock and concrete launch ramp. A Spur Breakwater with 10 ton armor stone and a crest height of +20 feet would be constructed inside the North Breakwater from the base of the cliffs along the south edge of the harbor to filter waves diffracted around the nose of the North Breakwater. These waves reached a maximum height of 2.1 meters in model simulation and overtopping is not expected to occur. The maneuvering basin would be dredged to -16 feet MLLW with a transition zone and an entrance channel dredged to -18 feet MLLW. This depth allows for barge access and potential access for 25% of the crabber fleet. The entrance channel maintains a 300 foot width from deep water to the end of the breakwater and includes widened turning section outside the breakwater nose. The channel narrows to 250 feet wide at the breakwater nose. The wind and wave climate as well as the wider entrance channel are expected to improve barge access to St. George.

7.2.1. Structural Design

The new breakwater is subject to storm waves from the north and use a design wave height of 15 feet. This results in an average armor stone weight of 10 tons when constructed at a 2H:1V slope. The inner slopes of the breakwater would be constructed at 1.5H:1V except at the breakwater nose where the 2H:1V slope is wrapped around and carried through for 50 feet (Figure 55). Where uplands abut the breakwater, the A rock extends over the crest for the full width but is omitted from the harbor side slope. This results in upland fill being placed against B rock. The launch ramp will be a precast concrete structure constructed at a 13% slope with vertical curves meeting highway design guidance to allow vehicular launching and recovery operations. The dock is planned as a concrete deck on steel piles with a marine fendering system. The deck would be precast and post-tensioned in place to minimize the volume of concrete and grout required to be cast in place on site.

7.2.2. FUNWAVE Analysis

A FUNWAVE grid off this harbor was created to determine the effectiveness of the navigation features at providing a wave climate usable by vessels for transferring cargo. The storms shown in Table 19 and

Table 20 were run over this grid to determine harbor response. The model run results indicate that waves outside the harbor at the wavemaker location need to be less than 3.41 meters in height to produce wave heights at the docks less than 0.5 meters. It is estimated that sea conditions exceed this height approximately 7% of the time. Through study of a known harbor, it was determined that the FUNWAVE model was reflecting too much energy off the inner surfaces of the harbor and amplifying wave energy inside the protected area. Based on this information, it is assumed that a properly calibrated damped model would show a higher wavemaker wave threshold required to induce unmoorable conditions at the dock and reduce the percent of unmoorable time compared to these results.

7.2.3. Harbor Effectiveness

The new dock location in the new basin showed improved wave conditions compared to the existing harbor at Zapadni Bay, however still showed a small percentage of time where the dock would be unusable.

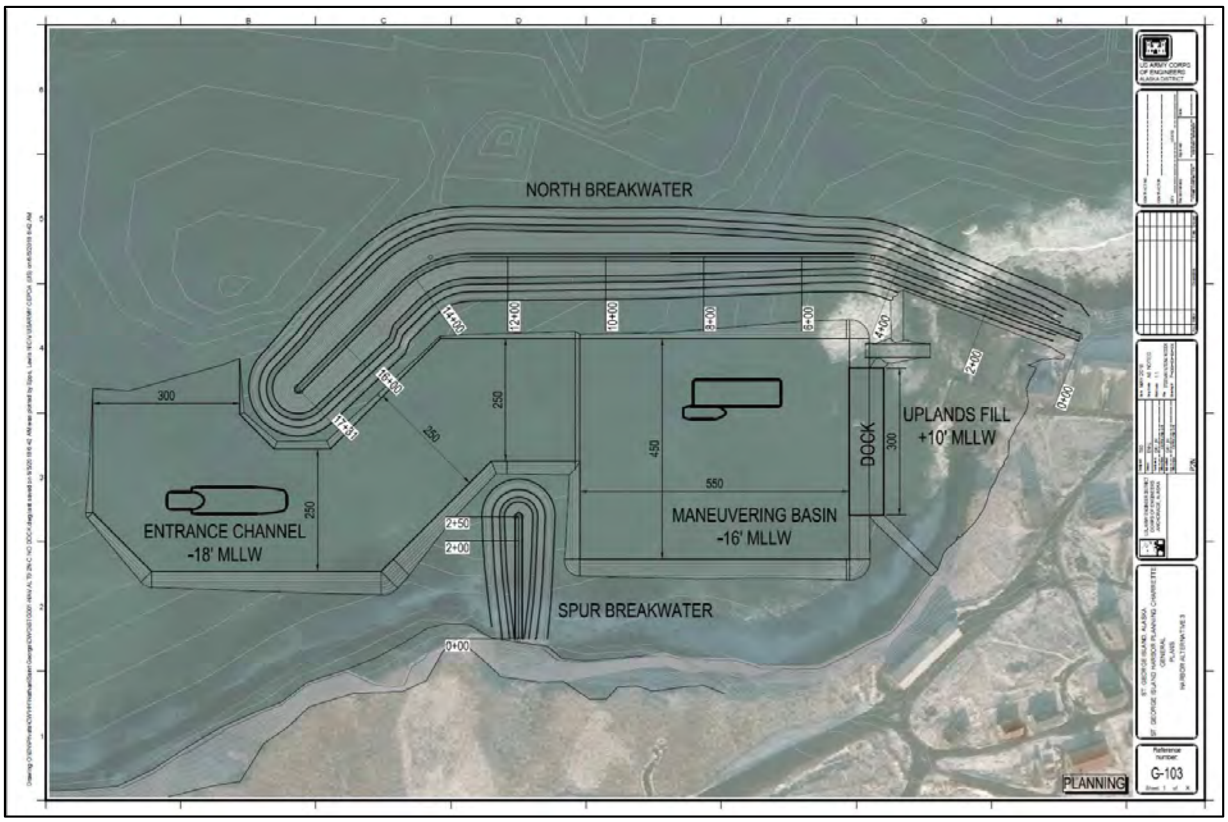

Figure 55. Plan view of Alternative N-2.

7.2.4. Alternative Quantities and Cost

Quantities for this alternative were based on volumetric calculations of TIN surface modeling of the harbor features in Autodesk Civil3D. These quantities were calculated to the nearest cubic yard, however due to uncertainties in terrain modeling, should only be considered accurate to two significant figures. Rounded quantities for this alternative are shown in Table 27. The estimated project cost for this alternative is $89 million without contingency cost.

Table 27: Alternative N-2 Quantities

North Breakwater		Spur Breakwater	
A-Rock	85,000 CY	A-Rock	8,900 CY
B-Rock	54,000 CY	B-Rock	6,500 CY

C-Rock	80,000 CY	C-Rock	4,800 CY
Dredging		Upland Fill	
Drill, Blast and Dredge	230,000 CY	Fill	44,000 CY

7.3. Alternative N-3: Crabber Fleet Harbor

This alternative is based on the same harbor size and geometry as N-2 with increased channel and basin depths to allow a greater percentage of the fishing fleet to moor. This alternative includes constructing protected boat launch and recovery area for the local subsistence fleet. A new 1,730 foot long North Breakwater with 10 ton armor stone and a crest elevation of +25 feet MLLW would protect a new 550 foot by 450 foot maneuvering basin, a 300 foot dock and concrete launch ramp. A Spur Breakwater with 10 ton armor stone and a crest height of +20 feet would be constructed inside the North Breakwater from the base of the cliffs along the south edge of the harbor to filter waves diffracted around the nose of the North Breakwater. These waves reached a maximum height of 2.1 meters in model simulation and overtopping is not expected to occur. The maneuvering basin would be dredged to -20 feet MLLW with a transition zone and an entrance channel dredged to -25 feet MLLW. This channel depth would allow 85% of the crabber fleet to access this harbor. The entrance channel maintains a 300 foot width from deep water to the end of the breakwater and includes widened turning section outside the breakwater nose. The channel narrows to 250 feet wide at the breakwater nose. The wind and wave climate as well as the wider entrance channel are expected to improve barge access to St. George.

7.3.1. Structural Design

The new breakwater is subject to storm waves from the north and use a design wave height of 15 feet. This results in an average armor stone weight of 10 tons when constructed at a 2H:1V slope. The inner slopes of the breakwater would be constructed at 1.5H:1V except at the breakwater nose where the 2H:1V slope is wrapped around and carried through for 50 feet (Figure 56). Where uplands abut the breakwater, the A rock extends over the crest for the full width but is omitted from the harbor side slope. This results in upland fill being placed against B rock. The launch ramp will be a precast concrete structure constructed at a 13% slope with vertical curves meeting highway design guidance to allow vehicular launching and recovery operations. The dock is planned as a concrete deck on steel piles with a marine fendering system. The deck would be precast and post-tensioned in place to minimize the volume of concrete and grout required to be cast in place on site.

7.3.2. FUNWAVE Analysis

Alternative N-3 has not been modeled in FUNWAVE. The breakwater geometry is identical to Alternative N-2 with only minor changes in channel and basin depth.

7.3.3. Harbor Effectiveness

The new dock location in the new basin showed improved wave conditions compared to the existing harbor at Zapadni Bay, however still showed a small percentage of time where the dock would be unusable.

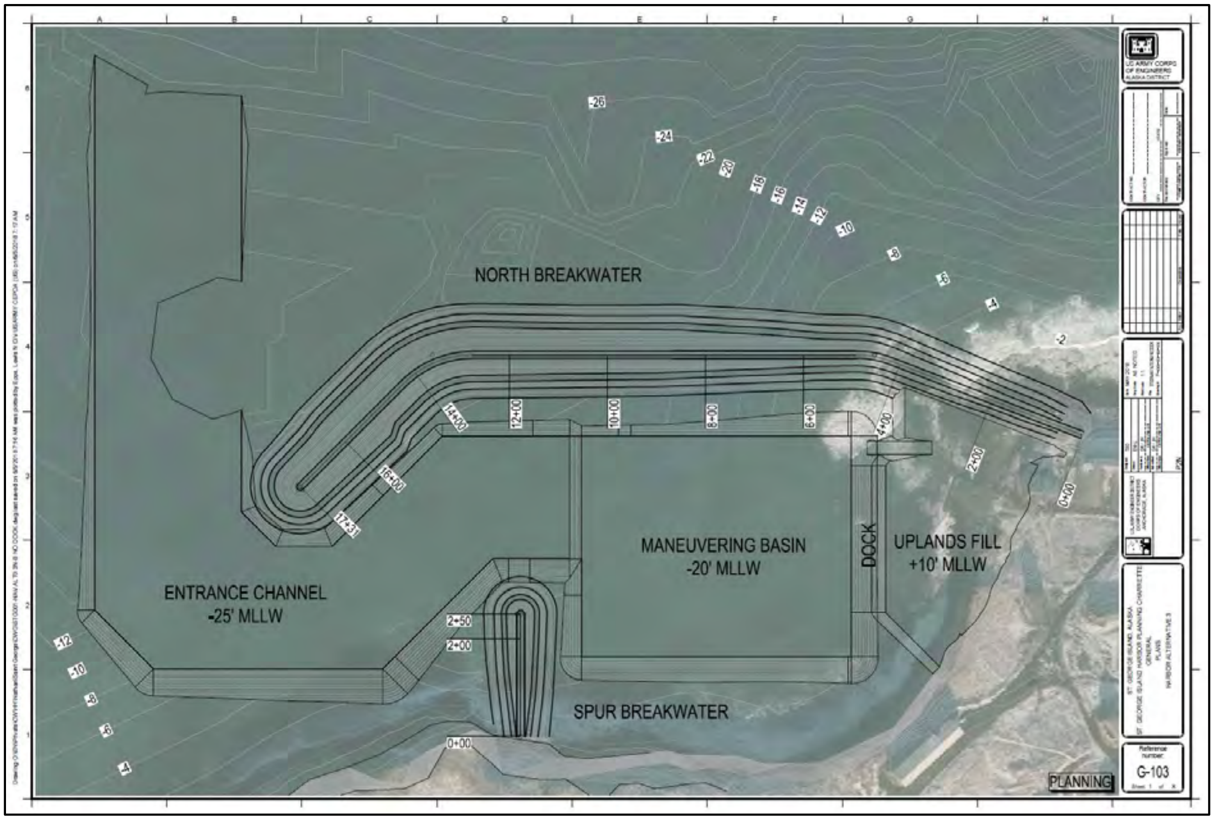

Figure 56. Plan view of Alternative N-3.

7.3.4. Alternative Quantities and Cost

Quantities for this alternative were based on volumetric calculations of TIN surface modeling of the harbor features in Autodesk Civil3D. These quantities were calculated to the nearest cubic yard, however due to uncertainties in terrain modeling, should only be considered accurate to two significant figures. Rounded quantities for this alternative are shown in Table 28. The estimated project cost for this alternative is $101 million without contingency cost.

Table 28. Alternative N-3 Quantities

North Breakwater		Spur Breakwater	
A-Rock	85,000 CY	A-Rock	8,900 CY
B-Rock	54,000 CY	B-Rock	6,500 CY
C-Rock	80,000 CY	C-Rock	4,800 CY
Dredging		Upland Fill	

Drill, Blast and Dredge	430,000 CY	Fill	44,000 CY

8.0 OTHER ALTERNATIVE CONSIDERED

Based on cost estimates for the North Site alternatives, an additional harbor configuration was considered to investigate the potential for creating a minimal use harbor for the primary purpose of providing access for the fuel barge. The harbor consists of an 1100 foot long north breakwater, an entrance channel dredged to -18 feet MLLW and a turning basin dredged to -16 feet MLLW. The plan also features a boat launch ramp to provide access for the subsistence fleet.

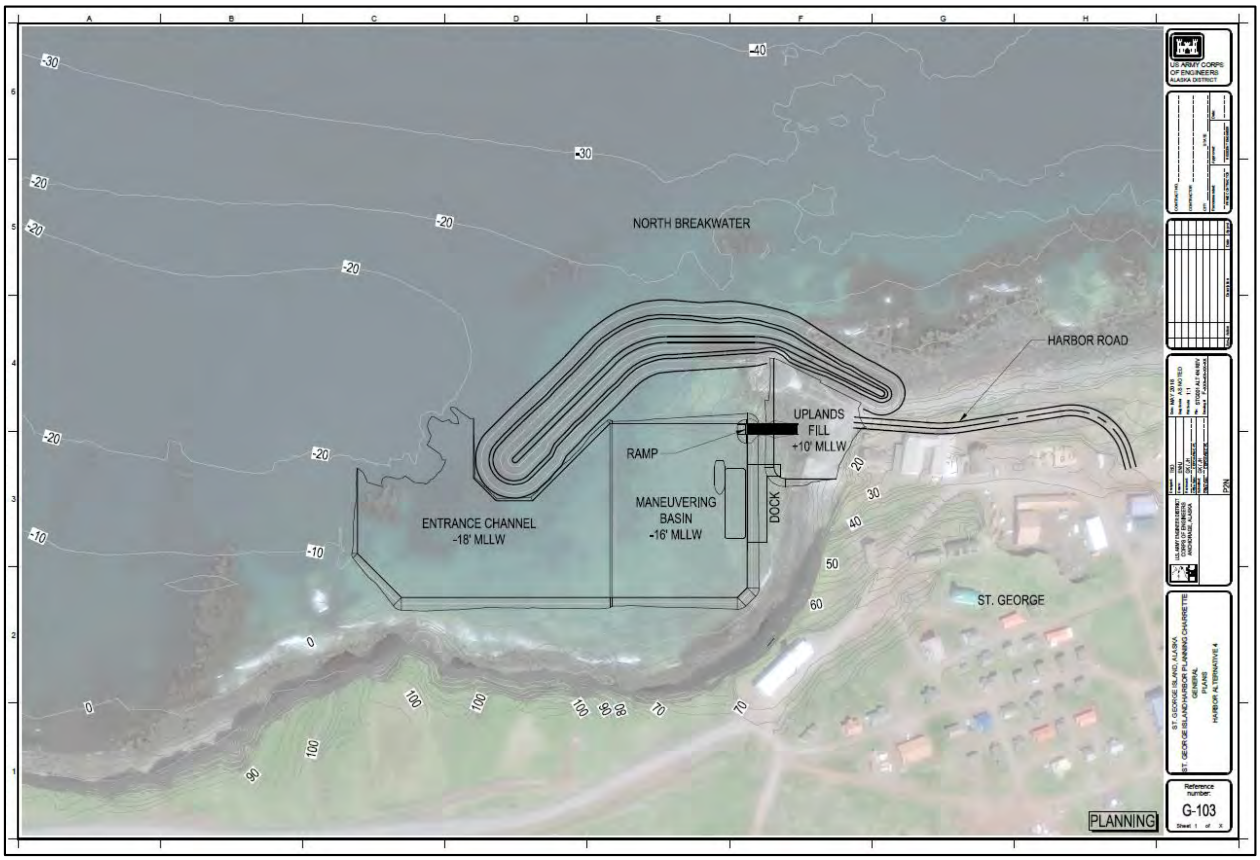

Figure 57. Plan view of Alternative N-4.

8.1. Harbor Purpose

This harbor has a limited purpose; it was designed to support fuel deliveries on the north side of the island to take advantage of better offshore conditions and to support launch and recovery of the subsistence fleet. The harbor would improve access for these operations. The harbor basin was sized for single vessel use making support of fishing operations limited. The basin would not allow for a floating fish processor to work in the harbor while a fishing vessel offloaded product. Fishing vessel support would be limited to cargo transfer to land-based facilities.

8.2. Harbor Effectiveness Analysis

Alternative N-4 was designed to accommodate vessels during relatively mild conditions. Breakwaters were designed to provide moorable wave conditions at the dock face during sea conditions represented by a wave spectra with a peak significant wave height of 1 meter at a period of 6 seconds. Diffraction diagram analysis shows that the dock would be usable in conditions up to 2.5 meters at a 6 second period. This level of protection also supports launching and recovery of the subsistence fleet. Diffraction analysis used the diffraction diagrams for the Shore Protection Manual (1984) which were digitized into an image file and overlaid on the harbor plan in CAD.

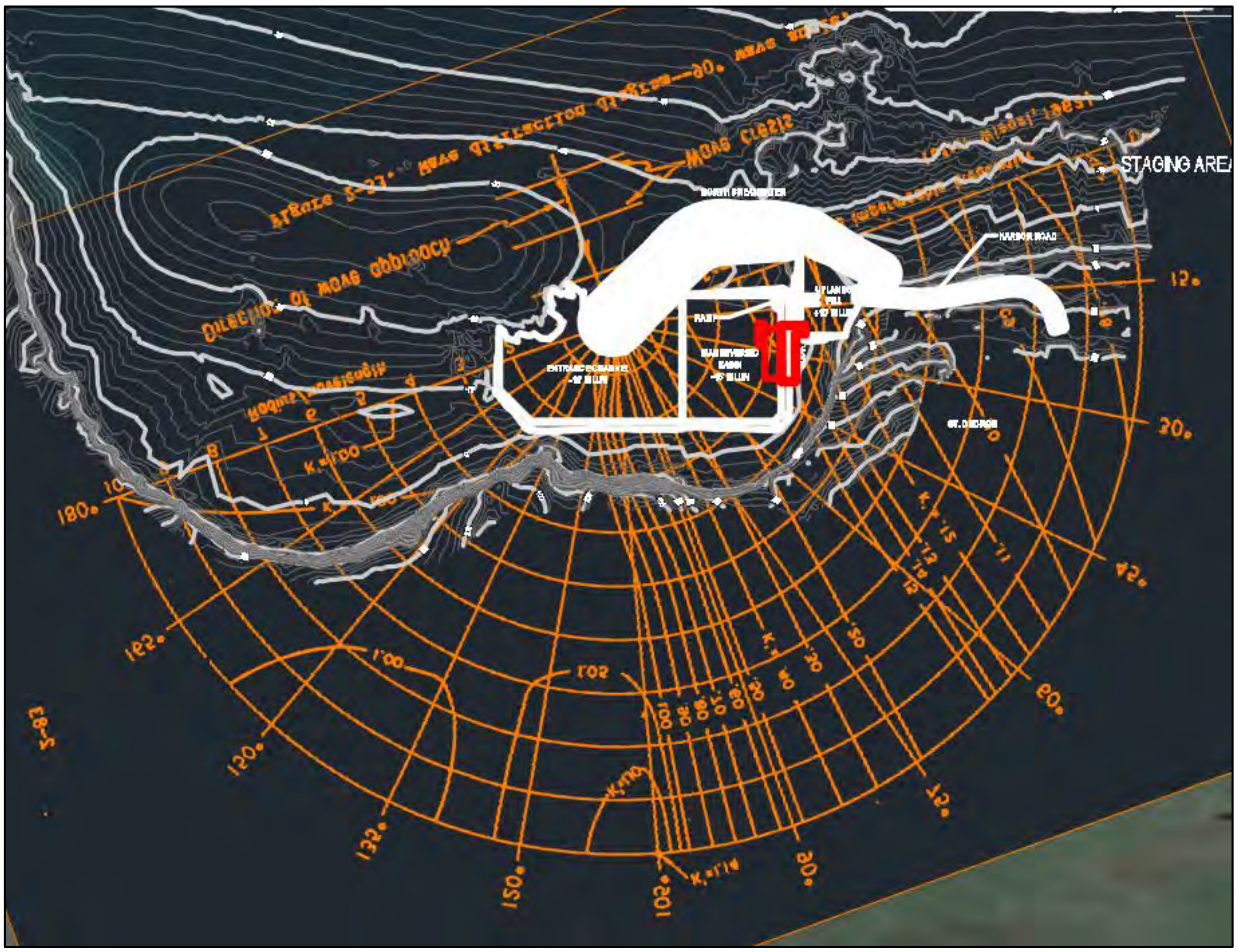

Figure 58. Diffraction analysis of N-4.

Since N-4 is not intended to support mooring or anchorage during storm events, numerical modeling of this alternative was not conducted. It should be noted that the moorable conditions at the dock occur less frequently than sea conditions which support fishing vessel access. While use of this harbor for fishery support is possible, potential benefits would be limited by moorable time rather than harbor access and represents a potential reduction in moorage availability versus the current conditions at Zapadni Bay. Based on this finding, a more rigorous analysis of benefits for the fishing fleet was not conducted.

9.0 TENTATIVELY SELECTED PLAN OPTIMIZATION

9.1. Plan Selection

Economic analysis determined that Alternative N-3 was a best buy plan and since it most effectively met the study objectives, was selected at the Tentatively Selected Plan (TSP). After selection of N-3 as the TSP, additional information became available; new topographic and hydrographic surveys of the site were conducted and additional wave modeling was performed. This section will describe the data gathering and modeling efforts that were performed after selection of the TSP.

9.2. Site Survey and Harbor Modification

9.2.1. Site Survey

A new site survey was conducted of August, 2018. The survey better defended the without project conditions at the site. During the survey, the hydrographic crew encountered difficulties performing the survey due to inclement weather at Zapadni Bay. For about two weeks, calm conditions existed at the North Site, but the survey crew was unable to launch a boat at the Zapadni Bay harbor due to inclement conditions on the southwest side of the island. One of the key findings was that depths at the site were about 4 feet lower overall than had been modeled using NOAA data. This produces changes in material quantities required to construct the project (Figure 59).

9.2.2. Harbor Modifications

Due to the greater depth of the project site, dredge quantities reduced and breakwater quantities increased. The maneuvering basin was expanded to 650 feet in length as opposed to 550 and shifted slightly. This resulted in increasing the North Breakwater length about 100 feet and shifting the Spur Breakwater west. The dock length was also increased to 400 feet to allow better moorage for two fishing vessels. Local Service Facilities (LSF) were more completely defined. These changes includes modifying the uplands area to fit the new survey data and defining the access road to connect the upland fill area to the existing road network. The structural design of the breakwaters and dredging assumptions were not changed.

9.2.3. Impacts to Previous Alternative Analysis

Changes to bathymetry and fleet requirements affected all north site alternatives in a similar manner. The cost increases to the North Site alternatives did not significantly change the merit of using the North Site compared to Zapadni Bay and Alternative N-3 continued to be carried forward as the TSP.

9.2.4. Updated Quantities

For purposes of estimating the cost of the TSP, new quantities were calculated based on the survey. The following quantities were applied to the current cost estimate. A separate ROM estimate was not made since the decision was made to carry N-3 forward as the TSP. Quantities were also updated for final cost estimates for N-1, N-2, and N-4.

Table 29: TSP Quantities

North Breakwater		Spur Breakwater	
A-Rock	100,423 CY	A-Rock	7,445 CY
B-Rock	63,068 CY	B-Rock	5,007 CY
C-Rock	119,782 CY	C-Rock	3,734 CY
Dredging		Upland Fill	
Drill, Blast and Dredge	353,052 CY	Fill	51,116 CY

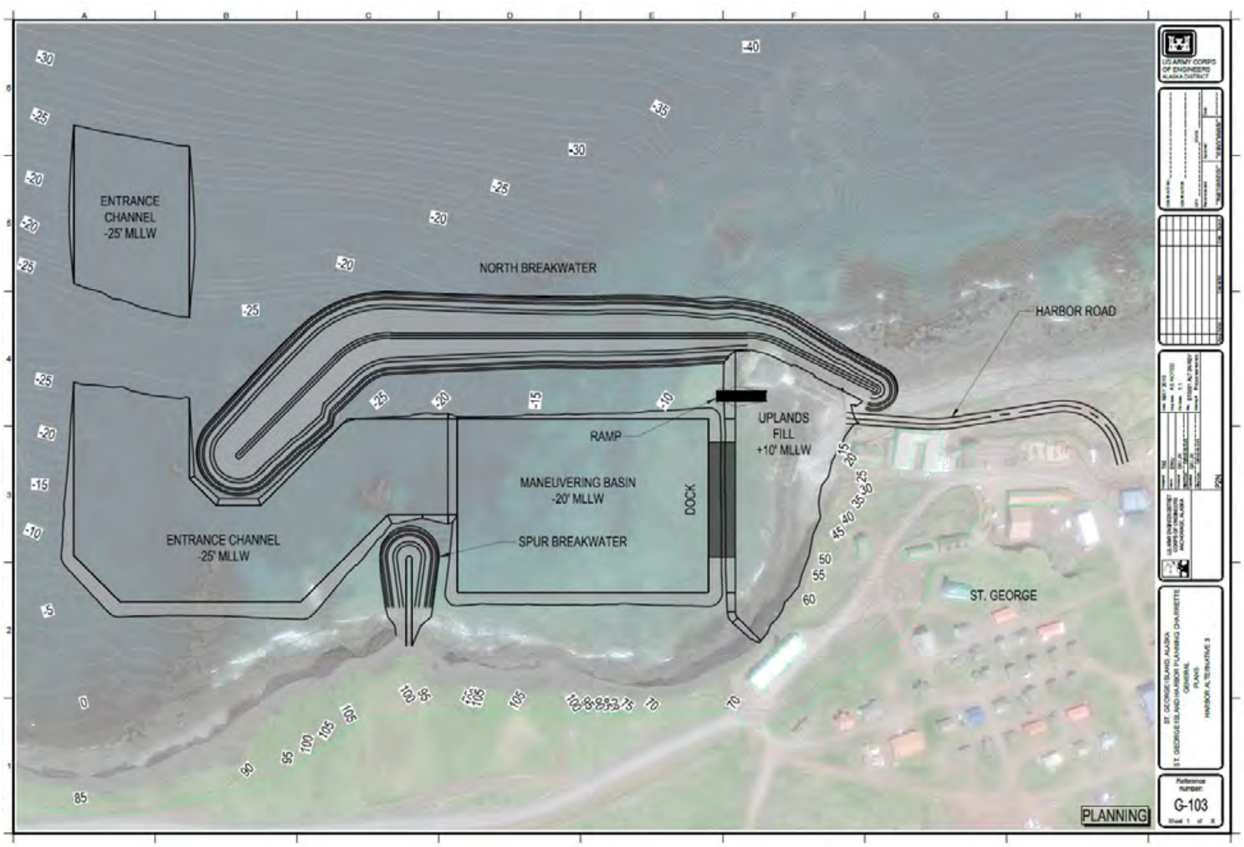

Figure 59. Plan view of Optimized TSP

9.3. Harbor Effectiveness

Access to the North Site remains unchanged due to offshore conditions and the increase in accessibility by moving the harbor to the north side of the island is realized with the optimized TSP. Additional numerical modeling efforts were pursued to measure the effectiveness of this harbor; additional FUNWAVE runs were planned in conjunction with CHL to add dampening layers to the model domain and a separate BOUSS2D moeling program was initiated with HDR. A new array of offshore conditions was selected to analyze the harbor. As before, wave conditions were defined at the WIS point in a depth of approximately 60 meters. Wave conditions modeled are shown in Table 30. The first 8 cases are idealized scenarios based on WIS output; cases 9 through 11 are peak event conditions extracted from the ONELINES record. It should be noted that as of June, 2019, FUNWAVE is the Hydraulic, Hydrologic and Coastal (HH&C) Community of Practice (CoP) preferred model for modeling coastal processes. The use of BOUSS2D is allowed by the CoP, however it is noted that the use of FUNWAVE is preferred over the use of BOUSS2D at this time. For the purpose of this project, BOUSS2D was selected as a supplementary model to run as a check for the FUNWAVE results.

Table 30. Offshore Conditions wave spectral peak wave height and period.

Run No.	Hm0 (m)	Tp (s)	Dir (deg)
1	1.00	6.00	315
2	1.20	6.00	315
3	2.00	8.00	315
4	3.00	10.00	315
5	4.00	11.00	315
6	5.00	12.00	315
7	6.00	14.00	315
8	7.00	17.00	315
9	7.13	16.34	325.9
10	4.25	12.29	323.8
11	13.51	13.51	306.9

9.3.1. FUNWAVE Analysis

The new array of offshore conditions was run through an STWAVE grid similar to the previous investigations to determine wave conditions for the FUNWAVE domain. This model included internal dampening layers around the shorelines and breakwaters of the harbor to reduce reflection off porous boundaries such as breakwaters and rock beaches. Discussions with the model developer and the coastal research team have indicated that the application of internal sponges to the model is an arbitrary matter at this time and no guidance on the level of dampening has been developed to represent these structures. Ultimately, it was found that the internal sponge layers were essentially retaining water above the free water surface of the simulation and introduced problems when analyzing results. Final harbor performance values were extracted from model runs conducted without internal sponges as these runs seemed to show response more characteristic of wave interactions with shorelines.

9.3.2. BOUSS2D Analysis

A BOUSS2D model of the TSP was built collaboratively between the Alaska District and HDR Inc, who performed the modeling service as a task order under an IDIQ contract with the Alaska District. Bathymetry files containing existing site conditions and the harbor geometry were transferred directly to HDR for development of model grids. Model development was performed in a two-step process; first, wave transformation was modeled with a MIKE21 SW model to determine the effects of wave propagation through the offshore domain to the wave maker location of the BOUSS2D domain (Figure 60).

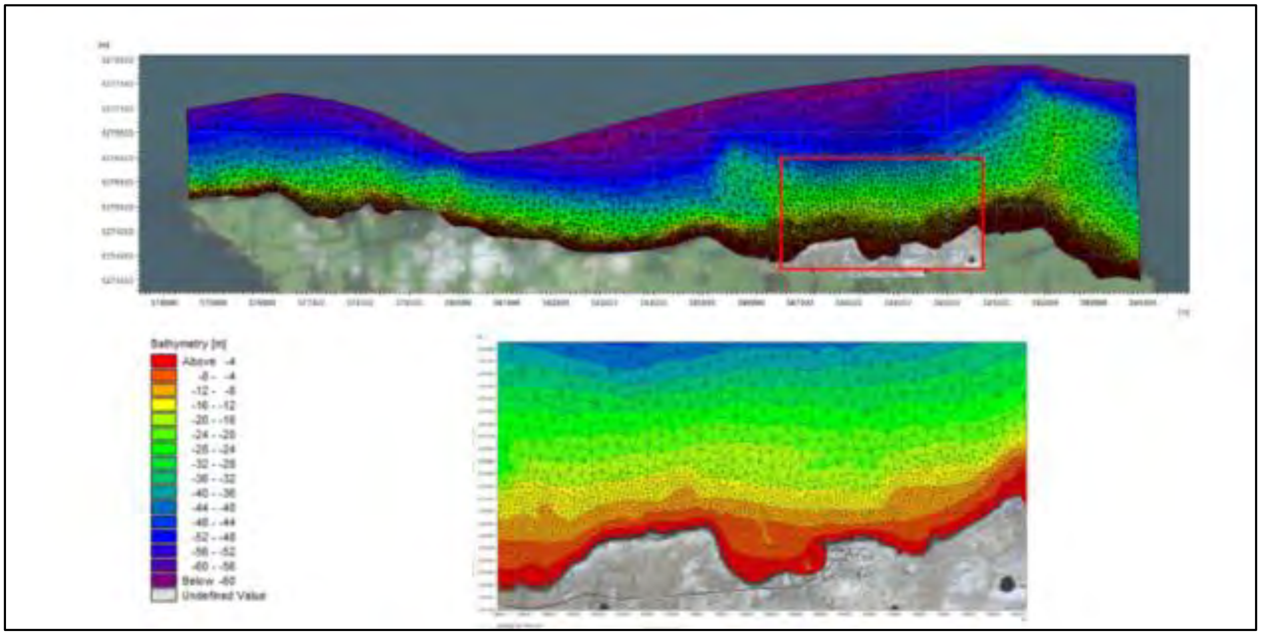

Figure 60. Mike21 SW Model Domain.

The output was used to run the BOUSS2D model. The BOUSS2D model domain was oriented such that waves propagated from the wave maker orthogonal to the grid to minimize the effects of reflection off the model boundary. Bathymetry of the BOUSS2D model was modified to provide a constant depth under the wave maker to assure a uniform source condition. Maximum depths for the grids varied from 20 to 30 meters (Figure 61).

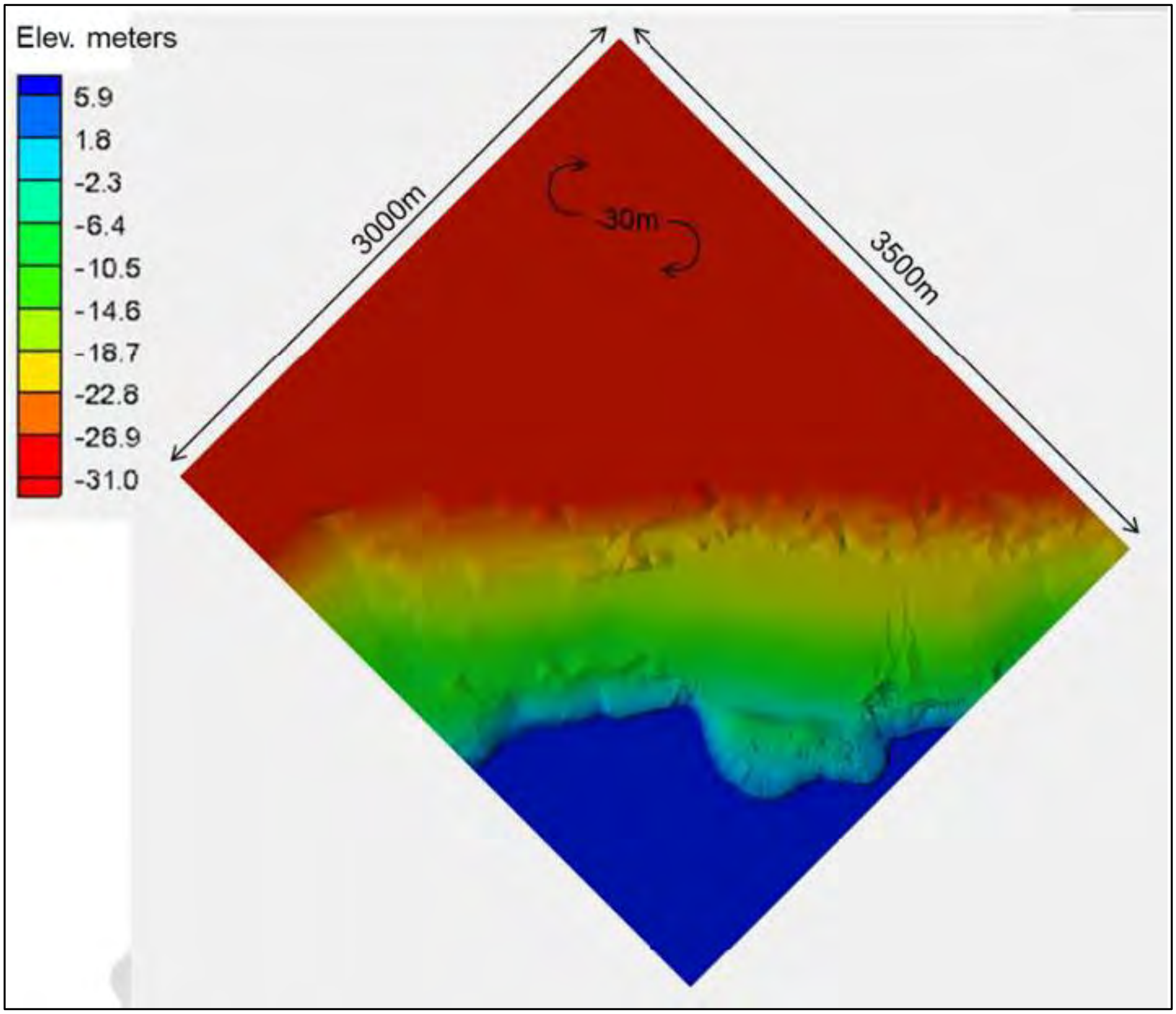

Figure 61. BOUSS2D model domain, existing condition shown.

As with the FUNWAVE modeling, observation stations were established in the model grid to record output (Figure 62).

Figure 62. Output locations for the BOUSS2D Model.

9.3.3. BOUSS2D Results

In general, the BOUSS2D model showed that the harbor meets effectiveness criteria for significant spectral peak wave height of 3 meters, which also matches accessibility criteria for the fishing fleet. Effectively, the dock in the harbor will be usable for all conditions in which the fleet can get in or out. However, above 3 meters, the model shows wave heights in the harbor in excess of the wave criteria in the harbor (0.5 meters). A model report including model development details and output tables and figures is attached to this Appendix. A review of model data suggests that like the FUNWAVE model, BOUSS2D treats boundary conditions as highly reflective; large wave growth was observed seaward of the north breakwater indicating wave reflection off the breakwater increasing wave heights. For the larger storm events with longer periods, seiche conditions were also observed in the harbor basin.

9.4. Results Discussion

Both FUNWAVE and BOUSS2D show indications of modeling shorelines as reflective boundaries which does not correlate with field observed conditions at St. Paul Harbor. It is possible that storm conditions in the vicinity of St. George Island require a harbor with a larger area than was investigated to dissipate energy on the protected side of a breakwater. The results may also indicate that the conditions modeled at this site are beyond the capabilities of the numerical models used to accurately represent the energy transformation that occurs. The design of this harbor will require further investigation which can only occur in a laboratory physical model setting. Only under scale conditions using porous materials for structure conditions will a conclusive information about the effectiveness of the harbor design be collected. It will be imperative to perform this effort during the preconstruction engineering and design phase of the project to assure that the harbor design will be adequate to provide sufficient safe moorage time for the fleet to perform its purposes.

10.0 PROJECT IMPLEMENTATION

10.1. Breakwaters

Breakwater and causeway construction would typically be performed under a USACE administered contract to ensure that minimum construction requirements are met as the port alternatives are built. The breakwater and causeways would use several layers of stone armor to achieve wave protection and filtering criteria. All material used in the construction of these project features would be of a self-compacting nature consisting of rock spalls or dredged tailings that can be placed underwater by excavator bucket, skip box, or dump scow. Fill prisms and "C" rock layers would be randomly placed and controlled by construction survey to assure that design elevations and layer thicknesses were met. Larger stone, typically "B" rock and "A" rock layers would be placed selectively by an excavator with an articulated thumb or crane with rock tongs to achieve minimum stone to stone contact requirements. Placement of stone would likely be performed by equipment mounted on a barge until the breakwaters were built up above the tide range, then placement would be with an excavator on the top of the breakwater.

10.2. Dredging

The material at all sites is assumed to require blasting and mechanical dredging equipment to reach design depths. Dredging features typically include a 2 foot allowance for overdredge to ensure that the minimum required depth is met. Blasting also requires a minimum 2 foot depth allowance to ensure that minimum depth is achieved, so blasting patterns would need to be established to loosen material to 4 feet below the minimum required depths designed for the selected plan. The dredge machinery would load a scow, which would deliver the dredged material to an offshore disposal site. Multiple scows may be used to provide for continuous dredging operations. The authorized dredge depth for the navigation channel will be -25 feet MLLW and the authorized depth of the maneuvering basin will be -20 feet MLLW. Payment for dredging below the authorized depth would be allowed during initial construction of the harbor to ensure that the minimum depth requirement is met.

The intent is to allow the contractor to "overdredge" during initial construction to ensure that the authorized depth is achieved. Cursory research of blasting techniques indicates that the blasting prism may need to be 4 feet below the minimum depth for these conditions. It is reasonable to compensate the construction contractor for removal of material up to 2 feet below the minimum depth. In maintenance cycles, the minimum required depth for dredging will be -25 feet MLLW in the navigation channel with a maximum payment depth of -27 feet MLLW; -20 feet MLLW minimum required depth in the maneuvering basin with a max pay depth of -22 feet MLLW.

10.3. Local Service Facilities

For each of the three alternatives, it is assumed that the local service facilities would be constructed under the same contract for the Federal features of the project. Local service facilities include the non-Federal dredging areas, docks, fendering systems, mooring dolphins and bollards, launch ramps, utilities, fuel tanks, access roads, and road bed surfaces. The non-Federal dredging portions of the project are represented by the area adjacent to the proposed dock faces out to an offset distance of approximately two vessel beams in width.

Upland staging and laydown areas are also local service facilities. These would be constructed concurrently with the harbor project.

10.4. Aids to Navigation

As part of the construction of the project, concrete navigation marker bases would be constructed at locations determined by the U.S. Coast Guard, typically at the heads of the new breakwaters. Coordination with the U.S. Coast Guard Aids to Navigation Office will be conducted to ensure adequate base construction to support installation of navigational aids.

10.5. Construction Schedule

Major construction features for the TSP include rubblemound north and spur breakwaters, dredging, pile supported docks, and upland fill areas. The material source for A and B rock would be offsite from an established quarry such as Cape Nome or Granite Cove on Kodiak Island. The material source would most likely be far enough away from the site that rock production would need to significantly lead placement operations to ensure that the construction crew on site has enough material delivered to the site for a full season of work. Stone production in the quarry and delivery to the site would likely be the first project tasks undertaken.

Construction of the North Breakwater is most likely to be performed with land based equipment. The breakwater core would be constructed to above the tide range to allow the placing equipment to drive the breakwater core and place B and A rock layers to protect the work in progress. Core rock would likely be transported and staged on the breakwater with off-road dump trucks, then shaped to the design prism by an excavator. Near the west end of the breakwater, an excavator on a barge may be required to shape the toe and benches of the breakwater where the seabed is deeper. Uplands would be constructed concurrently with the breakwater to build a staging area for breakwater material.

Dredging could occur concurrently with stone production; initial dredging and blasting is expected to be a winter activity to protect nearby fur seal rookeries. Dredging opportunities during these months are limited due to adverse weather and the blasting program could take three years to complete. Some dredging prior to constructing the breakwaters would provide access for construction barges to the breakwater sites. The total estimated performance period for construction the project is a minimum of 3 years and likely would be 5 years.

11.0 OPERATIONS AND MAINTENANCE

The non-Federal operator of the harbor would be responsible for operation and maintenance of the completed mooring areas and local service facilities portion of the project. The Federal Government would be responsible for maintenance of the breakwaters, entrance channels and maneuvering basin portions of the project. The Alaska District, U.S. Army Corps of Engineers would visit the site(s) periodically to inspect the breakwaters and perform hydrographic surveys at 3- to 5-year intervals for the dredged areas. The hydrographic surveys would be used to verify whether the predicted maintenance dredging was warranted for the entrance channel and maneuvering areas. Maintenance requirements for breakwaters would be determined from the surveys and inspections. Local and Federal dredging requirements, if necessary, would probably be combined, so there would be only a single mobilization and demobilization cost.

The breakwaters were designed to be stable for the 50-year predicted wave conditions. Therefore, no significant loss of stone from the rubblemound structures is expected over the life of the project. It is estimated that at the worst case, 2.5 percent of the armor stone would need to be replaced every 25 years. Because stone quality would be strictly specified in the project construction contracts, little to no armor stone degradation would be anticipated. For the TSP, Alternative N-3, a quantity of 2,100 cubic yards of A-Rock would be required for replacement on the North and Spur Breakwaters at year 25.

Maintenance dredging would be conducted on an estimated 10-year cycle. The entrance channel and maneuvering area would require dredging of approximately 10,000 cubic yards. A dredged material management plan would be developed for the project in which a long-term disposal option would be identified. For purposes of this study, it is assumed that the entrance channel and maneuvering area material would be disposed of in the offshore disposal area east of the harbor. Clamshell bucket dredging equipment with a scow barge would likely be used for maintenance dredging. Dredged material characteristics should be easier to remove than construction dredging of the area and no blasting would be required for maintenance.

12.0 REQUIRED FURTHER DESIGN STUDIES

The hydraulic modeling effort performed in the study phase was sufficient to determine the necessity for selecting a harbor site on the north side of the island and to evaluate relative merits of different harbor designs at the selected harbor site. Due to lack of site data, numerical models cannot be calibrated to local conditions and further investigations will be necessary to design harbor structures. The following are items that require further study in the preconstruction engineering design (PED) phase of the project before plans for construction can be published.

12.1. Geotechnical Investigation

Geotechnical investigation and analysis of subsurface materials at the North Site to determine the physical characteristics and chemical composition, dredging methods and equipment requirements, and suitability as foundation materials for the proposed causeways, breakwaters, docks, and upland facilities.

12.2. Physical Model Study

A detailed physical model study in a facility that is capable of simulating wave spectra originating from multiple directions of approach. This step is necessary to validate numerical model results and to identify harbor-specific hydrodynamic issues that the numerical models are not capable of replicating. This study needs to be performed in a facility dedicated to wave modeling run by full time research engineering staff. The Corps of Engineers owns and operates the necessary facilities at the ERDC Coastal Hydraulics Laboratory in Vicksburg, MS. This work is an essential step in the design process and needs to be completed before plans and specifications for construction can be created. The physical model study will also incorporate additional numerical wave modeling to refine input wave conditions at the offshore boundary of the physical model domain.

13.0 REFERENCES

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14.0 ATTACHMENTS

1. FUNWAVE model results tables
2. BOUSS2D model report

DEFINITIONS

Storm Simulations	synthetic storms extracted from the WIS data. Storms were
Auxiliary Storms	artificial wave spectra generated at the FUNWAVE wave maker

HEADER INFO

RUNNO	Input conditions number
HWAM	meters, Peak spectral wave height, at the WIS point for storm runs, at the FUNWAVE wave maker for auxiliary storms
TWAM	seconds, Peak spectral wave period, at the WIS point for storm runs, at the FUNWAVE wave maker for auxiliary storms
THWAM	degrees, wave direction at the WIS point for storm simulations, at the wave maker for auxiliary storms
HSTW	meters, Peak spectral wave height, at the STWAVE output location corresponding to the FUNWAVE wave maker location for storm runs, same as WAM value for auxiliary storms
TSTW	seconds, Peak spectral wave period, at the STWAVE output location corresponding to the FUNWAVE wave maker location for storm runs, same as WAM value for auxiliary storms
THSTW	degrees, Peak spectral wave direction, at the STWAVE output location corresponding to the FUNWAVE wave maker location for storm runs, same as WAM value for auxiliary storms
HFW_	meters, FUNWAVE output significant wave height
TFW_	seconds, FUNWAVE output peak period
CFW_	meters per second, FUNWAVE output maximum velocity.

NOTES

These tables are sorted by alternative; at the end of each set of tables is a schematic of the harbor alternative with the locations of the monitoring stations. The numbers of the stationscorrespond to the HFW_, TFW_ and CFW_ header numbers in the tables.

Alternative Design 1 Extreme Storm Event Results (Sub-Set / 20 Gauge Sites)

Gauge Locations Identical to Original Configuration See Bathymetry Figure for Alternative Design 1

The numbering convention remains abour the same

Generated REJ (11/06/2017)

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	HFW_1	HFW_2	HFW_3	HFW_4	HFW_5	HFW_6	HFW_7	HFW_8	HFW_9	HFW_10
1	14.05	17.35	252	11.18	17.99	10	9.408	9.667	9.198	8.093	7.678	7.399	5.844	4.528	2.249	1.527
2	13.69	17.75	245	11.34	19.8	20	8.781	8.747	9.134	8.213	7.735	7.463	5.667	4.192	2.168	1.560
17	11.07	19.12	256	11.34	19.8	12	9.011	9.353	8.870	8.266	7.806	7.584	5.837	4.402	2.239	1.541
RUNNO	**HWAM**	**TWAM**	**THWAM**	**HSTW**	**TSTW**	**THSTW**	**HFW_11**	**HFW_12**	**HFW_13**	**HFW_14**	**HFW_15**	**HFW_16**	**HFW_17**	**HFW_18**	**HFW_19**	**HFW_20**
1	14.05	17.35	252	11.18	17.99	10	1.228	1.523	1.299	1.708	1.144	1.730	1.091	1.394	3.100	2.243
2	13.69	17.75	245	11.34	19.8	20	1.302	1.620	1.392	1.765	1.204	1.799	1.082	1.450	3.057	2.329
17	11.07	19.12	256	11.34	19.8	12	1.326	1.618	1.379	1.798	1.235	1.814	1.126	1.438	3.172	2.322
RUNNO	**HWAM**	**TWAM**	**THWAM**	**HSTW**	**TSTW**	**THSTW**	**TFW_1**	**TFW_2**	**TFW_3**	**TFW_4**	**TFW_5**	**TFW_6**	**TFW_7**	**TFW_8**	**TFW_9**	**TFW_10**
1	14.05	17.35	252	11.18	17.99	10	17.067	17.067	17.067	17.067	17.067	17.067	17.067	14.629	11.378	102.400
2	13.69	17.75	245	11.34	19.8	20	20.480	17.067	17.067	17.067	17.067	20.480	20.480	17.067	20.480	468.114
17	11.07	19.12	256	11.34	19.8	12	20.480	20.480	20.480	17.067	17.067	20.480	17.067	14.629	8.533	102.400
RUNNO	**HWAM**	**TWAM**	**THWAM**	**HSTW**	**TSTW**	**THSTW**	**TFW_11**	**TFW_12**	**TFW_13**	**TFW_14**	**TFW_15**	**TFW_16**	**TFW_17**	**TFW_18**	**TFW_19**	**TFW_20**
1	14.05	17.35	252	11.18	17.99	10	468.114	102.400	102.400	102.400	468.114	102.400	468.114	102.400	20.480	20.480
2	13.69	17.75	245	11.34	19.8	20	468.114	102.400	102.400	102.400	468.114	102.400	468.114	102.400	20.480	20.480
17	11.07	19.12	256	11.34	19.8	12	468.114	102.400	102.400	102.400	468.114	102.400	468.114	102.400	20.480	20.480
RUNNO	**HWAM**	**TWAM**	**THWAM**	**HSTW**	**TSTW**	**THSTW**	**CFW_1**	**CFW_2**	**CFW_3**	**CFW_4**	**CFW_5**	**CFW_6**	**CFW_7**	**CFW_8**	**CFW_9**	**CFW_10**
1	14.05	17.35	252	11.18	17.99	10	5.284	5.924	5.974	6.784	6.521	6.367	5.547	4.023	2.593	1.093
2	13.69	17.75	245	11.34	19.8	20	4.561	5.493	6.220	6.573	6.227	6.840	5.002	4.003	2.044	1.230
17	11.07	19.12	256	11.34	19.8	12	4.610	5.178	6.549	6.596	6.534	6.421	5.426	4.208	2.481	1.236
RUNNO	**HWAM**	**TWAM**	**THWAM**	**HSTW**	**TSTW**	**THSTW**	**CFW_11**	**CFW_12**	**CFW_13**	**CFW_14**	**CFW_15**	**CFW_16**	**CFW_17**	**CFW_18**	**CFW_19**	**CFW_20**
1	14.05	17.35	252	11.18	17.99	10	1.402	1.243	1.027	1.033	1.655	1.339	3.282	5.136	2.873	0.929
2	13.69	17.75	245	11.34	19.8	20	1.589	1.130	1.153	1.308	1.862	1.185	3.365	5.496	2.829	1.134
17	11.07	19.12	256	11.34	19.8	12	1.485	1.291	1.191	1.344	1.972	1.371	3.672	5.632	2.968	1.151

Alternative Design 1 Auxiliary Simulation Results(768 Cols) 20 Gauge Sites

Sub-Set Simulations as identified by N. Epps / Same Run Numbers

Changed the offshore locations (1-8) for consistency with Alternative 2 (See Alternative Design 1 graphic for details)

Generated REJ (11/06/2017)

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	HFW_1	HFW_2	HFW_3	HFW_4	HFW_5	HFW_6	HFW_7	HFW_8	HFW_9	HFW_10
100	2	10	0	2	10	0	1.899	1.794	1.828	1.755	1.896	2.090	1.574	1.099	0.646	0.353
102	6	10	0	6	10	0	5.568	5.338	5.174	4.625	4.661	4.808	3.826	2.496	1.489	0.956
103	8	10	0	8	10	0	7.373	7.103	6.870	6.569	6.396	6.039	4.780	3.181	2.049	1.309
131	2	20	0	2	20	0	1.506	1.632	1.750	1.798	1.988	1.807	1.701	1.370	0.796	0.614
133	6	20	0	6	20	0	4.547	4.949	5.241	4.918	4.809	4.911	4.412	3.415	1.819	1.240

135	10	20	0	10	20	0	7.787	8.341	8.156	7.023	6.758	6.771	5.536	4.200	2.175	1.404
152	2	26	0	2	26	0	1.343	1.450	1.552	1.345	1.543	1.465	1.327	1.146	0.619	0.475
154	6	26	0	6	26	0	3.881	4.378	4.431	4.089	4.145	4.292	3.733	2.952	1.530	1.012
156	10	26	0	10	26	0	6.595	7.474	7.605	6.791	6.638	6.615	5.342	4.144	2.151	1.408

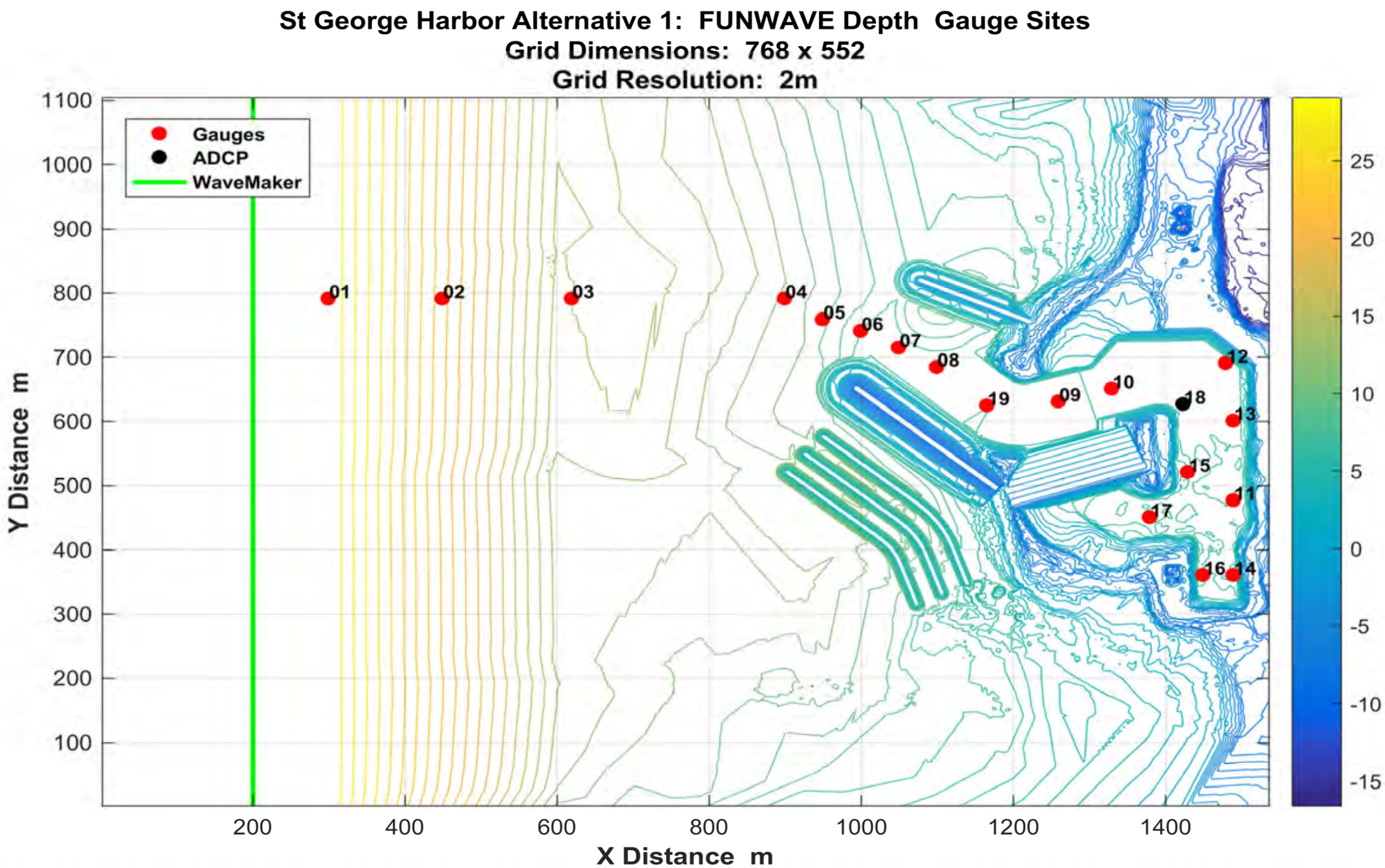
RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	HFW_11	HFW_12	HFW_13	HFW_14	HFW_15	HFW_16	HFW_17	HFW_18	HFW_19	HFW_20
100	2	10	0	2	10	0	0.223	0.272	0.235	0.264	0.215	0.271	0.187	0.330	0.787	0.589
102	6	10	0	6	10	0	0.448	0.712	0.594	0.804	0.451	0.826	0.368	0.813	1.945	1.035
103	8	10	0	8	10	0	0.652	0.949	0.823	1.076	0.659	1.106	0.647	1.123	2.851	1.255
131	2	20	0	2	20	0	0.668	0.595	0.486	0.456	0.343	0.615	0.282	0.585	1.053	1.151
133	6	20	0	6	20	0	0.921	1.208	0.987	1.210	0.762	1.278	0.600	1.089	2.388	1.796
135	10	20	0	10	20	0	1.077	1.470	1.277	1.618	0.993	1.647	0.888	1.374	3.285	2.222
152	2	26	0	2	26	0	0.482	0.481	0.434	0.372	0.320	0.534	0.243	0.524	0.851	1.217
154	6	26	0	6	26	0	0.761	1.041	0.847	1.153	0.673	1.191	0.501	0.944	1.911	1.683
156	10	26	0	10	26	0	1.067	1.456	1.240	1.740	0.977	1.745	0.854	1.340	2.958	2.220

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	TFW_1	TFW_2	TFW_3	TFW_4	TFW_5	TFW_6	TFW_7	TFW_8	TFW_9	TFW_10
100	2	10	0	2	10	0	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240
102	6	10	0	6	10	0	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240
103	8	10	0	8	10	0	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240
131	2	20	0	2	20	0	14.629	14.629	14.629	20.480	14.629	20.480	14.629	14.629	20.480	20.480
133	6	20	0	6	20	0	20.480	20.480	20.480	20.480	14.629	20.480	20.480	14.629	20.480	20.480
135	10	20	0	10	20	0	20.480	20.480	20.480	20.480	20.480	20.480	20.480	14.629	11.378	102.400
152	2	26	0	2	26	0	25.600	25.600	25.600	20.480	14.629	25.600	20.480	25.600	25.600	20.480
154	6	26	0	6	26	0	25.600	25.600	25.600	20.480	25.600	25.600	20.480	14.629	20.480	20.480
156	10	26	0	10	26	0	25.600	20.480	20.480	20.480	25.600	20.480	20.480	14.629	11.378	102.400

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	TFW_11	TFW_12	TFW_13	TFW_14	TFW_15	TFW_16	TFW_17	TFW_18	TFW_19	TFW_20
100	2	10	0	2	10	0	468.114	102.400	102.400	102.400	468.114	102.400	468.114	10.240	10.240	10.240
102	6	10	0	6	10	0	102.400	102.400	102.400	102.400	102.400	102.400	102.400	10.240	10.240	10.240
103	8	10	0	8	10	0	102.400	102.400	102.400	102.400	102.400	102.400	468.114	10.240	10.240	10.240
131	2	20	0	2	20	0	20.480	20.480	20.480	102.400	20.480	20.480	14.629	20.480	20.480	20.480
133	6	20	0	6	20	0	20.480	102.400	102.400	102.400	102.400	102.400	468.114	102.400	20.480	20.480
135	10	20	0	10	20	0	102.400	102.400	102.400	102.400	102.400	102.400	468.114	102.400	20.480	20.480
152	2	26	0	2	26	0	20.480	20.480	20.480	102.400	25.600	20.480	468.114	20.480	20.480	25.600
154	6	26	0	6	26	0	20.480	102.400	102.400	102.400	102.400	102.400	409.600	102.400	20.480	25.600
156	10	26	0	10	26	0	102.400	102.400	102.400	102.400	102.400	102.400	546.133	102.400	20.480	25.600

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	CFW_1	CFW_2	CFW_3	CFW_4	CFW_5	CFW_6	CFW_7	CFW_8	CFW_9	CFW_10
100	2	10	0	2	10	0	0.739	0.829	1.039	1.540	1.524	1.971	2.335	1.458	0.521	0.204
102	6	10	0	6	10	0	2.224	2.332	2.856	2.957	3.445	3.789	2.987	3.059	1.575	0.534
103	8	10	0	8	10	0	2.764	2.962	3.731	4.413	4.214	4.111	3.743	3.791	1.846	0.665
131	2	20	0	2	20	0	0.630	0.841	1.222	1.591	1.657	1.939	1.514	1.408	0.656	0.507
133	6	20	0	6	20	0	2.094	3.018	4.484	5.410	4.748	4.927	4.107	3.063	1.575	0.895
135	10	20	0	10	20	0	4.182	5.337	5.778	6.264	6.609	6.745	4.983	4.033	2.388	1.059
152	2	26	0	2	26	0	0.613	0.809	1.008	1.037	1.302	1.804	1.932	1.345	0.531	0.483
154	6	26	0	6	26	0	2.049	3.025	3.709	3.900	4.140	5.530	4.484	3.068	1.737	0.991
156	10	26	0	10	26	0	3.689	4.667	5.223	6.193	6.322	6.369	5.500	4.508	2.267	1.416

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	CFW_11	CFW_12	CFW_13	CFW_14	CFW_15	CFW_16	CFW_17	CFW_18	CFW_19	CFW_20
100	2	10	0	2	10	0	0.262	0.262	0.191	0.238	0.344	0.245	1.266	2.400	0.864	0.274
102	6	10	0	6	10	0	0.680	0.611	0.476	0.524	0.766	0.776	2.868	3.778	1.648	0.524
103	8	10	0	8	10	0	0.925	0.822	0.617	0.724	1.128	1.107	3.154	3.987	2.119	0.657
131	2	20	0	2	20	0	0.527	0.472	0.726	0.641	0.551	0.385	1.006	3.293	0.773	0.622
133	6	20	0	6	20	0	0.988	0.877	1.034	0.987	1.148	1.199	2.646	4.599	2.172	0.997
135	10	20	0	10	20	0	1.365	1.076	1.119	1.089	1.503	1.361	3.300	5.293	2.864	0.978
152	2	26	0	2	26	0	0.328	0.417	0.666	0.576	0.430	0.292	1.016	3.362	0.682	0.542
154	6	26	0	6	26	0	0.963	0.777	1.101	1.044	1.185	1.069	2.677	4.524	2.148	0.726
156	10	26	0	10	26	0	1.498	1.245	1.397	1.428	1.657	1.518	3.397	5.615	2.452	1.106



Alternative Design 2 Extreme Storm Event Results (Sub-Set / 20 Gauge Sites)

Moved the Gauge Locations See Bathymetry Figure for Alternative Design 2

The numbering convention remains abour the same but some locations have changed

Generated REJ (11/03/2017)

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	HFW_1	HFW_2	HFW_3	HFW_4	HFW_5	HFW_6	HFW_7	HFW_8	HFW_9	HFW_10
1	14.05	17.35	252	11.18	17.99	10	9.561	9.615	8.914	8.134	7.969	7.462	6.948	6.730	2.004	4.000
2	13.69	17.75	245	11.34	19.8	20	8.602	8.495	8.628	8.243	7.996	7.510	7.047	6.691	2.087	3.978
17	11.07	19.12	256	11.34	19.8	12	8.989	9.569	9.167	8.490	8.026	7.488	6.921	6.622	2.057	4.110
RUNNO	**HWAM**	**TWAM**	**THWAM**	**HSTW**	**TSTW**	**THSTW**	**HFW_11**	**HFW_12**	**HFW_13**	**HFW_14**	**HFW_15**	**HFW_16**	**HFW_17**	**HFW_18**	**HFW_19**	**HFW_20**
1	14.05	17.35	252	11.18	17.99	10	1.357	1.657	1.328	1.820	1.254	1.774	1.408	1.426	5.842	1.824
2	13.69	17.75	245	11.34	19.8	20	1.345	1.529	1.384	1.965	1.256	1.918	1.424	1.293	6.014	1.810
17	11.07	19.12	256	11.34	19.8	12	1.369	1.607	1.238	2.177	1.252	2.115	1.454	1.339	5.909	1.828
RUNNO	**HWAM**	**TWAM**	**THWAM**	**HSTW**	**TSTW**	**THSTW**	**TFW_1**	**TFW_2**	**TFW_3**	**TFW_4**	**TFW_5**	**TFW_6**	**TFW_7**	**TFW_8**	**TFW_9**	**TFW_10**
1	14.05	17.35	252	11.18	17.99	10	17.067	17.067	17.067	17.067	17.067	17.067	17.067	17.067	102.400	17.067
2	13.69	17.75	245	11.34	19.8	20	20.480	17.067	17.067	17.067	17.067	17.067	20.480	17.067	102.400	20.480
17	11.07	19.12	256	11.34	19.8	12	20.480	20.480	20.480	14.629	17.067	17.067	20.480	17.067	102.400	17.067
RUNNO	**HWAM**	**TWAM**	**THWAM**	**HSTW**	**TSTW**	**THSTW**	**TFW_11**	**TFW_12**	**TFW_13**	**TFW_14**	**TFW_15**	**TFW_16**	**TFW_17**	**TFW_18**	**TFW_19**	**TFW_20**
1	14.05	17.35	252	11.18	17.99	10	409.600	102.400	102.400	102.400	409.600	102.400	409.600	102.400	17.067	102.400
2	13.69	17.75	245	11.34	19.8	20	364.089	102.400	364.089	102.400	364.089	102.400	364.089	102.400	17.067	102.400
17	11.07	19.12	256	11.34	19.8	12	468.114	102.400	102.400	102.400	409.600	102.400	468.114	102.400	17.067	102.400
RUNNO	**HWAM**	**TWAM**	**THWAM**	**HSTW**	**TSTW**	**THSTW**	**CFW_1**	**CFW_2**	**CFW_3**	**CFW_4**	**CFW_5**	**CFW_6**	**CFW_7**	**CFW_8**	**CFW_9**	**CFW_10**
1	14.05	17.35	252	11.18	17.99	10	5.059	5.949	6.137	6.328	6.534	6.585	6.206	6.273	1.063	4.179
2	13.69	17.75	245	11.34	19.8	20	4.783	5.821	6.315	6.595	6.484	6.421	6.916	5.472	0.983	4.323
17	11.07	19.12	256	11.34	19.8	12	4.613	5.586	6.104	6.557	6.760	6.567	6.384	5.890	1.050	4.820
RUNNO	**HWAM**	**TWAM**	**THWAM**	**HSTW**	**TSTW**	**THSTW**	**CFW_11**	**CFW_12**	**CFW_13**	**CFW_14**	**CFW_15**	**CFW_16**	**CFW_17**	**CFW_18**	**CFW_19**	**CFW_20**
1	14.05	17.35	252	11.18	17.99	10	1.544	1.077	1.081	1.131	1.044	5.379	1.705	1.896	2.590	0.842
2	13.69	17.75	245	11.34	19.8	20	1.643	1.048	1.230	1.405	1.021	5.245	1.564	2.258	2.399	0.889
17	11.07	19.12	256	11.34	19.8	12	1.554	1.153	3.501	1.419	1.012	4.711	1.492	2.105	2.494	0.859

Alternative Design 2 Auxiliary Simulation Results(768 Cols) 20 Gauge Sites

Sub-Set Simulations as identified by N. Epps / Same Run Numbers

Some of the gauge locations have been moved from the Orginal Harbor Configuration (See Alternative Design 2 graphic for details)

Generated REJ (11/03/2017)

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	HFW_1	HFW_2	HFW_3	HFW_4	HFW_5	HFW_6	HFW_7	HFW_8	HFW_9	HFW_10
100	2	10	0	2	10	0	1.959	1.824	1.828	1.705	1.714	1.667	1.648	1.502	0.623	0.929
102	6	10	0	6	10	0	5.622	5.529	5.285	4.913	4.807	4.637	4.491	4.119	1.206	2.737
103	8	10	0	8	10	0	7.254	6.976	6.940	6.245	6.086	5.816	5.545	5.095	1.406	3.167
131	2	20	0	2	20	0	1.582	1.759	1.790	1.829	1.952	1.826	1.780	1.683	0.779	1.308
133	6	20	0	6	20	0	4.609	5.041	5.174	5.022	5.001	4.820	4.831	4.383	1.706	3.358
135	10	20	0	10	20	0	7.950	8.691	8.425	7.553	7.281	6.754	6.590	5.942	2.018	3.949
152	2	26	0	2	26	0	1.484	1.578	1.641	1.481	1.506	1.504	1.423	1.350	0.655	1.094
154	6	26	0	6	26	0	3.937	4.476	4.554	4.080	4.066	4.059	3.943	3.799	1.496	2.887

156	10	26	0	10	26	0	6.629	7.605	7.744	6.752	6.526	6.262	5.908	5.605	1.912	3.713

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	HFW_11	HFW_12	HFW_13	HFW_14	HFW_15	HFW_16	HFW_17	HFW_18	HFW_19	HFW_20
100	2	10	0	2	10	0	0.138	0.186	0.136	0.221	0.190	0.206	0.201	0.164	1.507	0.526
102	6	10	0	6	10	0	0.451	0.721	0.531	0.934	0.451	0.907	0.498	0.598	4.005	0.997
103	8	10	0	8	10	0	0.611	0.966	0.718	1.220	0.601	1.191	0.666	0.807	4.429	1.178
131	2	20	0	2	20	0	0.262	0.416	0.393	0.386	0.294	0.365	0.313	0.294	1.409	0.802
133	6	20	0	6	20	0	0.741	1.059	0.779	1.364	0.671	1.321	0.900	0.860	3.925	1.650
135	10	20	0	10	20	0	1.206	1.554	1.215	1.834	1.120	1.781	1.286	1.320	5.205	1.795
152	2	26	0	2	26	0	0.421	0.420	0.310	0.313	0.289	0.298	0.436	0.330	1.211	0.610
154	6	26	0	6	26	0	0.874	1.023	0.732	1.331	0.601	1.290	0.986	0.832	3.631	1.349
156	10	26	0	10	26	0	1.165	1.502	1.095	2.004	0.938	1.956	1.343	1.247	5.204	1.680

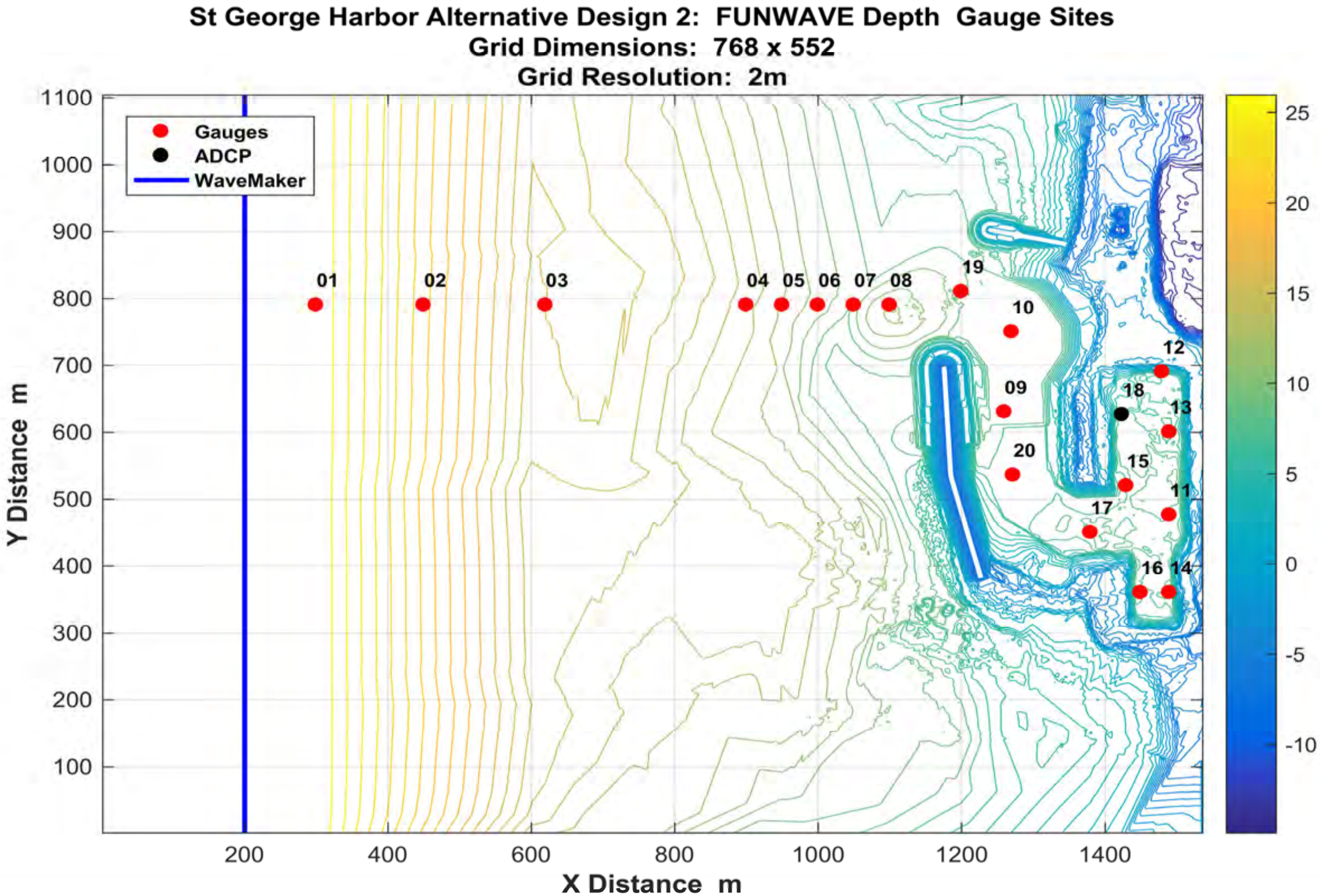
RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	TFW_1	TFW_2	TFW_3	TFW_4	TFW_5	TFW_6	TFW_7	TFW_8	TFW_9	TFW_10
100	2	10	0	2	10	0	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240
102	6	10	0	6	10	0	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240
103	8	10	0	8	10	0	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240
131	2	20	0	2	20	0	14.629	14.629	14.629	17.067	14.629	17.067	20.480	17.067	20.480	20.480
133	6	20	0	6	20	0	20.480	20.480	20.480	20.480	20.480	17.067	20.480	20.480	20.480	20.480
135	10	20	0	10	20	0	20.480	20.480	20.480	20.480	20.480	20.480	20.480	20.480	102.400	20.480
152	2	26	0	2	26	0	25.600	25.600	25.600	25.600	25.600	25.600	25.600	17.067	25.600	20.480
154	6	26	0	6	26	0	25.600	25.600	25.600	20.480	20.480	25.600	20.480	25.600	25.600	20.480
156	10	26	0	10	26	0	25.600	20.480	20.480	20.480	20.480	25.600	20.480	17.067	51.200	20.480

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	TFW_11	TFW_12	TFW_13	TFW_14	TFW_15	TFW_16	TFW_17	TFW_18	TFW_19	TFW_20
100	2	10	0	2	10	0	10.240	102.400	102.400	102.400	10.240	102.400	10.240	102.400	10.240	10.240
102	6	10	0	6	10	0	102.400	102.400	102.400	102.400	409.600	102.400	102.400	102.400	10.240	10.240
103	8	10	0	8	10	0	102.400	102.400	102.400	102.400	468.114	102.400	102.400	102.400	10.240	102.400
131	2	20	0	2	20	0	25.600	20.480	20.480	102.400	17.067	102.400	14.629	102.400	14.629	20.480
133	6	20	0	6	20	0	102.400	102.400	102.400	102.400	409.600	102.400	102.400	102.400	20.480	17.067
135	10	20	0	10	20	0	468.114	102.400	102.400	102.400	468.114	102.400	102.400	102.400	20.480	102.400
152	2	26	0	2	26	0	25.600	25.600	20.480	102.400	25.600	102.400	25.600	25.600	25.600	20.480
154	6	26	0	6	26	0	25.600	102.400	102.400	102.400	25.600	102.400	25.600	102.400	25.600	17.067
156	10	26	0	10	26	0	25.600	102.400	102.400	102.400	364.089	102.400	102.400	102.400	25.600	102.400

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	CFW_1	CFW_2	CFW_3	CFW_4	CFW_5	CFW_6	CFW_7	CFW_8	CFW_9	CFW_10
100	2	10	0	2	10	0	0.782	0.857	1.066	1.285	1.258	1.360	1.426	1.276	0.140	0.877
102	6	10	0	6	10	0	2.315	2.540	3.240	3.328	3.393	3.752	3.500	2.677	0.520	2.358
103	8	10	0	8	10	0	2.769	3.431	4.022	3.900	4.205	4.263	4.382	4.005	0.730	2.517
131	2	20	0	2	20	0	0.727	0.935	1.317	1.605	1.555	1.815	1.854	1.711	0.286	1.440
133	6	20	0	6	20	0	2.198	3.102	5.065	4.183	4.825	5.188	4.747	4.429	0.861	3.509
135	10	20	0	10	20	0	4.055	5.378	5.708	5.899	6.019	6.647	6.030	5.838	1.044	4.297
152	2	26	0	2	26	0	0.579	0.732	1.034	1.221	1.299	1.389	1.592	1.345	0.344	1.166
154	6	26	0	6	26	0	1.892	2.874	3.545	3.450	3.751	4.306	4.732	4.870	0.888	3.294
156	10	26	0	10	26	0	4.383	4.524	5.207	5.567	5.837	6.194	6.028	6.548	1.239	4.242

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	CFW_11	CFW_12	CFW_13	CFW_14	CFW_15	CFW_16	CFW_17	CFW_18	CFW_19	CFW_20
100	2	10	0	2	10	0	0.249	1.129	0.508	0.189	0.163	1.267	0.253	0.443	0.488	0.875
102	6	10	0	6	10	0	0.782	0.498	0.765	0.631	0.518	3.110	0.897	0.883	1.157	1.005

103	8	10	0	8	10	0	0.961	0.629	0.800	0.678	0.602	3.360	1.014	1.276	1.611	0.578
131	2	20	0	2	20	0	0.392	0.936	0.422	0.327	0.328	1.503	0.474	0.602	0.728	0.769
133	6	20	0	6	20	0	1.203	0.814	1.267	0.900	1.054	3.867	1.076	1.563	2.112	0.810
135	10	20	0	10	20	0	1.516	0.971	3.463	1.214	1.004	4.963	1.370	1.829	2.170	0.823
152	2	26	0	2	26	0	0.320	0.273	0.686	0.330	0.303	1.155	0.402	0.621	0.682	0.940
154	6	26	0	6	26	0	1.144	1.014	0.994	0.969	0.854	4.381	0.964	1.340	1.678	0.858
156	10	26	0	10	26	0	1.956	1.291	4.868	1.794	1.307	5.039	1.717	1.812	2.409	1.070



Alternative Design 3 Extreme Storm Event Results New Grid Extended for 'Big Dig' on Added Inner Harbor

Moved the Gauge Locations See Bathymetry Figure for Alternative Design 3

The numbering convention remains abour the same but some locations have changed

Generated REJ (10/20/2017)

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	HFW_1	HFW_2	HFW_3	HFW_4	HFW_5	HFW_6	HFW_7	HFW_8	HFW_9	HFW_10	HFW_11	HFW_12	HFW_13	HFW_14
1	14.05	17.35	252	11.18	17.99	10	9.291	8.779	8.743	7.752	7.398	7.248	6.579	6.592	4.460	2.016	1.294	1.325	1.177	1.454
2	13.69	17.75	245	11.34	19.8	20	8.657	8.581	8.033	7.124	6.843	7.069	6.416	6.520	4.479	1.966	1.248	1.188	1.079	1.447
17	11.07	19.12	256	11.34	19.8	12	8.805	8.614	8.796	7.671	7.332	7.271	6.525	6.756	4.557	1.951	1.335	1.377	1.226	1.567

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	HFW_15	HFW_16	HFW_17	HFW_18	HFW_19	HFW_20	HFW_21	HFW_22	HFW_23	HFW_24	HFW_25	HFW_26	HFW_27	HFW_28
1	14.05	17.35	252	11.18	17.99	10	1.364	1.374	1.731	1.173	6.210	2.939	1.373	1.307	1.222	1.410	1.393	1.358	1.400	1.190
2	13.69	17.75	245	11.34	19.8	20	1.278	1.365	1.693	1.101	5.861	2.866	1.238	1.178	1.089	1.283	1.264	1.223	1.294	1.055
17	11.07	19.12	256	11.34	19.8	12	1.388	1.484	1.753	1.232	6.002	2.938	1.529	1.465	1.361	1.577	1.549	1.502	1.549	1.301

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	TFW_1	TFW_2	TFW_3	TFW_4	TFW_5	TFW_6	TFW_7	TFW_8	TFW_9	TFW_10	TFW_11	TFW_12	TFW_13	TFW_14
1	14.05	17.35	252	11.18	17.99	10	17.067	17.067	17.067	17.067	17.067	17.067	17.067	17.067	17.067	102.400	546.133	546.133	546.133	102.400
2	13.69	17.75	245	11.34	19.8	20	17.067	17.067	17.067	17.067	17.067	20.480	20.480	20.480	20.480	102.400	546.133	546.133	546.133	102.400
17	11.07	19.12	256	11.34	19.8	12	17.067	17.067	17.067	17.067	17.067	17.067	17.067	20.480	20.480	102.400	546.133	546.133	546.133	102.400

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	TFW_15	TFW_16	TFW_17	TFW_18	TFW_19	TFW_20	TFW_21	TFW_22	TFW_23	TFW_24	TFW_25	TFW_26	TFW_27	TFW_28
1	14.05	17.35	252	11.18	17.99	10	546.133	102.400	546.133	546.133	17.067	17.067	546.133	546.133	546.133	546.133	546.133	546.133	546.133	546.133
2	13.69	17.75	245	11.34	19.8	20	546.133	102.400	218.453	546.133	20.480	20.480	546.133	546.133	546.133	546.133	546.133	546.133	546.133	546.133
17	11.07	19.12	256	11.34	19.8	12	546.133	102.400	546.133	546.133	17.067	17.067	546.133	546.133	546.133	546.133	546.133	546.133	546.133	546.133

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	CFW_1	CFW_2	CFW_3	CFW_4	CFW_5	CFW_6	CFW_7	CFW_8	CFW_9	CFW_10	CFW_11	CFW_12	CFW_13	CFW_14
1	14.05	17.35	252	11.18	17.99	10	5.234	6.069	7.377	6.841	6.612	6.960	6.636	5.963	1.235	3.488	1.617	1.423	1.150	1.153
2	13.69	17.75	245	11.34	19.8	20	5.016	6.443	5.855	5.740	5.537	5.749	6.754	5.548	1.151	3.673	1.644	1.386	1.049	1.118
17	11.07	19.12	256	11.34	19.8	12	4.787	5.849	6.780	6.765	6.560	6.776	6.895	5.792	1.414	3.465	2.057	1.769	1.270	1.194

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	CFW_15	CFW_16	CFW_17	CFW_18	CFW_19	CFW_20	CFW_21	CFW_22	CFW_23	CFW_24	CFW_25	CFW_26	CFW_27	CFW_28
1	14.05	17.35	252	11.18	17.99	10	0.985	4.883	2.008	2.938	4.739	1.640	1.108	1.213	0.987	1.055	1.079	0.991	0.997	1.110
2	13.69	17.75	245	11.34	19.8	20	1.030	4.721	1.915	2.728	5.146	1.605	1.179	1.166	1.208	1.035	1.064	1.003	1.261	1.150
17	11.07	19.12	256	11.34	19.8	12	1.060	4.908	1.928	2.894	4.870	1.603	1.197	1.195	1.199	1.330	1.068	0.963	1.062	1.392

Alternative Design 3 Auxiliary Simulation Results New Grid (864 Cols) for 'Big Dig' New Inner Harbor

Sub-Set Simulations as identified by N. Epps / Same Run Numbers

Some of the gauge locations have been moved from the Orginal Harbor Configuration (See Alternative Design 3 graphic for details)

Generated REJ (10/20/2017)

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	HFW_1	HFW_2	HFW_3	HFW_4	HFW_5	HFW_6	HFW_7	HFW_8	HFW_9	HFW_10	HFW_11	HFW_12	HFW_13	HFW_14
100	2	10	0	2	10	0	1.812	1.736	1.633	1.636	1.722	1.779	1.826	1.787	0.984	0.744	0.227	0.137	0.182	0.203
102	6	10	0	6	10	0	5.210	4.938	4.600	4.469	4.547	4.619	4.583	4.364	2.714	1.353	0.601	0.461	0.498	0.680
103	8	10	0	8	10	0	6.888	6.022	5.587	5.714	5.728	5.730	5.494	5.382	3.470	1.540	0.847	0.722	0.714	0.890
131	2	20	0	2	20	0	1.463	1.534	1.537	1.864	1.852	1.997	2.310	2.164	1.885	0.896	0.328	0.472	0.302	0.426
133	6	20	0	6	20	0	4.470	4.665	4.814	5.284	5.291	5.449	5.314	5.254	4.006	1.654	0.867	0.936	0.762	1.154
135	10	20	0	10	20	0	7.493	7.454	7.279	7.513	7.379	7.214	6.713	6.650	4.681	1.975	1.193	1.184	1.053	1.461
152	2	26	0	2	26	0	1.431	1.361	1.462	1.729	1.732	1.909	1.932	2.135	1.965	0.842	0.481	0.673	0.309	0.400
154	6	26	0	6	26	0	4.156	3.947	4.120	4.701	4.730	4.821	4.840	4.924	4.006	1.639	0.994	0.958	0.755	1.130
156	10	26	0	10	26	0	6.856	6.479	6.584	6.554	6.433	6.376	6.237	6.114	4.593	2.001	1.291	1.198	1.004	1.495

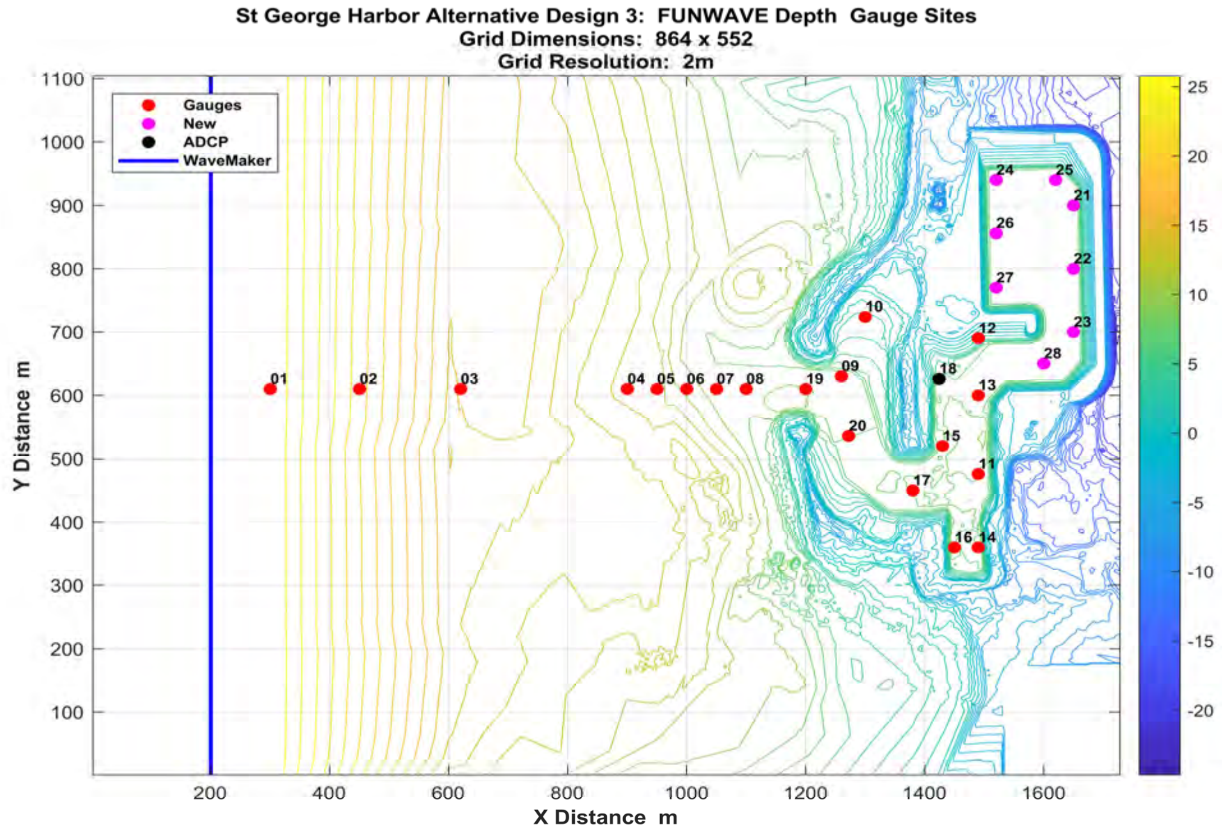
RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	HFW_15	HFW_16	HFW_17	HFW_18	HFW_19	HFW_20	HFW_21	HFW_22	HFW_23	HFW_24	HFW_25	HFW_26	HFW_27	HFW_28
100	2	10	0	2	10	0	0.289	0.200	0.339	0.152	1.969	0.925	0.090	0.095	0.128	0.095	0.125	0.083	0.117	0.146
102	6	10	0	6	10	0	0.694	0.629	0.834	0.468	4.183	2.117	0.437	0.411	0.413	0.472	0.486	0.423	0.500	0.430
103	8	10	0	8	10	0	0.913	0.829	1.079	0.702	5.240	2.341	0.760	0.714	0.689	0.786	0.790	0.747	0.777	0.675
131	2	20	0	2	20	0	0.376	0.379	0.475	0.324	2.004	1.114	0.221	0.228	0.240	0.216	0.221	0.212	0.263	0.266
133	6	20	0	6	20	0	0.939	1.057	1.240	0.795	4.809	2.311	0.770	0.736	0.745	0.799	0.797	0.754	0.893	0.759
135	10	20	0	10	20	0	1.246	1.381	1.628	1.064	5.967	2.843	1.191	1.139	1.096	1.250	1.227	1.172	1.267	1.069
152	2	26	0	2	26	0	0.435	0.343	0.575	0.420	1.834	0.890	0.301	0.300	0.283	0.232	0.238	0.244	0.305	0.290
154	6	26	0	6	26	0	0.908	1.073	1.273	0.818	4.641	2.093	0.766	0.760	0.741	0.804	0.812	0.772	0.853	0.760
156	10	26	0	10	26	0	1.178	1.431	1.637	1.030	5.940	2.678	1.075	1.059	1.014	1.135	1.131	1.080	1.217	1.016

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	TFW_1	TFW_2	TFW_3	TFW_4	TFW_5	TFW_6	TFW_7	TFW_8	TFW_9	TFW_10	TFW_11	TFW_12	TFW_13	TFW_14
100	2	10	0	2	10	0	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240	102.400	10.240	102.400
102	6	10	0	6	10	0	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240	102.400	102.400	546.133	102.400
103	8	10	0	8	10	0	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240	102.400	655.360	655.360	655.360	102.400
131	2	20	0	2	20	0	17.067	17.067	14.629	14.629	17.067	14.629	14.629	17.067	20.480	20.480	51.200	20.480	20.480	51.200
133	6	20	0	6	20	0	17.067	17.067	17.067	14.629	17.067	17.067	14.629	20.480	20.480	102.400	102.400	20.480	546.133	102.400
135	10	20	0	10	20	0	17.067	17.067	17.067	17.067	17.067	17.067	17.067	20.480	20.480	102.400	655.360	546.133	655.360	102.400
152	2	26	0	2	26	0	14.629	14.629	14.629	14.629	25.600	14.629	14.629	25.600	25.600	25.600	25.600	25.600	25.600	102.400
154	6	26	0	6	26	0	14.629	14.629	14.629	14.629	25.600	20.480	25.600	25.600	25.600	102.400	25.600	25.600	546.133	102.400
156	10	26	0	10	26	0	14.629	14.629	14.629	14.629	25.600	20.480	25.600	25.600	25.600	102.400	546.133	546.133	546.133	102.400

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	TFW_15	TFW_16	TFW_17	TFW_18	TFW_19	TFW_20	TFW_21	TFW_22	TFW_23	TFW_24	TFW_25	TFW_26	TFW_27	TFW_28
100	2	10	0	2	10	0	10.240	102.400	10.240	10.240	10.240	10.240	546.133	546.133	10.240	102.400	11.378	546.133	51.200	10.240
102	6	10	0	6	10	0	10.240	102.400	11.378	102.400	10.240	10.240	546.133	546.133	546.133	546.133	546.133	546.133	51.200	546.133
103	8	10	0	8	10	0	655.360	102.400	10.240	655.360	10.240	10.240	546.133	546.133	546.133	546.133	546.133	546.133	546.133	546.133
131	2	20	0	2	20	0	17.067	51.200	17.067	51.200	17.067	20.480	20.480	655.360	20.480	655.360	655.360	655.360	51.200	20.480
133	6	20	0	6	20	0	546.133	102.400	51.200	546.133	17.067	20.480	546.133	546.133	546.133	546.133	546.133	546.133	546.133	546.133
135	10	20	0	10	20	0	655.360	102.400	655.360	655.360	17.067	20.480	546.133	546.133	546.133	546.133	546.133	546.133	546.133	546.133
152	2	26	0	2	26	0	25.600	102.400	25.600	25.600	25.600	20.480	25.600	34.133	25.600	34.133	34.133	25.600	34.133	25.600
154	6	26	0	6	26	0	546.133	102.400	25.600	546.133	25.600	17.067	546.133	546.133	546.133	546.133	546.133	546.133	51.200	546.133
156	10	26	0	10	26	0	546.133	102.400	102.400	546.133	25.600	17.067	546.133	546.133	546.133	546.133	546.133	546.133	546.133	546.133

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	CFW_1	CFW_2	CFW_3	CFW_4	CFW_5	CFW_6	CFW_7	CFW_8	CFW_9	CFW_10	CFW_11	CFW_12	CFW_13	CFW_14
100	2	10	0	2	10	0	0.614	0.788	0.972	1.154	1.229	1.418	1.710	1.906	0.312	1.359	0.294	0.152	0.354	0.207
102	6	10	0	6	10	0	1.875	2.219	3.180	3.644	3.367	3.576	3.877	3.918	0.716	1.608	0.731	0.584	0.841	0.586
103	8	10	0	8	10	0	3.835	3.189	3.695	4.185	3.971	4.228	4.884	4.777	0.885	2.042	1.119	0.926	0.894	0.605
131	2	20	0	2	20	0	0.675	0.809	1.167	1.634	1.894	2.086	2.173	2.854	0.333	1.853	0.483	0.348	0.381	0.391
133	6	20	0	6	20	0	2.095	2.778	3.983	5.339	5.408	5.754	5.452	5.523	0.881	3.629	1.398	0.876	1.298	1.055
135	10	20	0	10	20	0	3.770	6.077	5.869	6.560	6.437	7.089	7.196	5.887	1.124	3.952	1.759	1.473	1.234	1.342
152	2	26	0	2	26	0	0.661	0.688	1.014	1.479	1.582	1.771	2.713	2.464	0.493	1.594	0.481	0.313	0.478	0.457
154	6	26	0	6	26	0	2.082	2.960	3.562	5.217	5.331	5.270	5.323	4.718	1.077	2.926	1.100	0.968	0.909	0.945
156	10	26	0	10	26	0	3.650	4.837	5.942	6.352	6.288	6.748	6.735	5.763	1.168	3.614	1.992	1.475	1.209	1.192

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	CFW_15	CFW_16	CFW_17	CFW_18	CFW_19	CFW_20	CFW_21	CFW_22	CFW_23	CFW_24	CFW_25	CFW_26	CFW_27	CFW_28
100	2	10	0	2	10	0	0.170	1.584	0.374	0.643	1.231	0.250	1.169	1.156	1.037	1.004	0.983	1.023	1.087	0.668
102	6	10	0	6	10	0	0.503	3.592	1.121	2.396	3.238	0.768	1.196	1.136	1.022	1.004	1.071	1.081	1.026	0.636
103	8	10	0	8	10	0	0.572	4.280	1.300	2.421	3.453	0.895	1.114	1.206	1.036	0.943	1.063	1.028	1.059	0.741
131	2	20	0	2	20	0	0.377	2.293	0.588	1.275	2.414	1.006	1.311	1.225	0.962	1.083	1.054	1.051	1.055	0.411
133	6	20	0	6	20	0	0.746	3.720	1.450	2.110	4.528	1.652	1.265	1.185	1.006	1.236	1.080	0.938	1.006	1.130
135	10	20	0	10	20	0	1.042	4.894	2.011	2.616	5.195	1.454	1.234	1.125	1.247	1.111	1.047	1.079	1.242	1.322
152	2	26	0	2	26	0	0.400	2.370	0.673	1.362	2.117	1.064	1.308	1.210	0.984	1.082	1.052	1.019	0.997	0.406
154	6	26	0	6	26	0	0.742	4.835	1.559	2.241	4.224	1.475	1.269	1.214	0.996	1.239	1.006	0.960	0.997	0.710
156	10	26	0	10	26	0	1.008	4.852	2.016	2.609	5.641	1.466	1.370	1.216	1.053	1.134	1.088	1.123	1.018	1.156


St George Harbor Alternative Design 3: FUNWAVE Depth Gauge Sites
Grid Dimensions: 864 x 552
Grid Resolution: 2m
Gauges
New
ADCP
WaveMaker
Y Distance m
X Distance m
01
02
03
04
05
06
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Alternative Design 4C Extreme Storm Event Results (Some grid smoothing near south breakwater head)
Moved the Gauge Locations See Bathymetry Figure for Alternative Design 4
The numbering convention remains abour the same but some locations have changed
Generated REJ (10/27/2017)

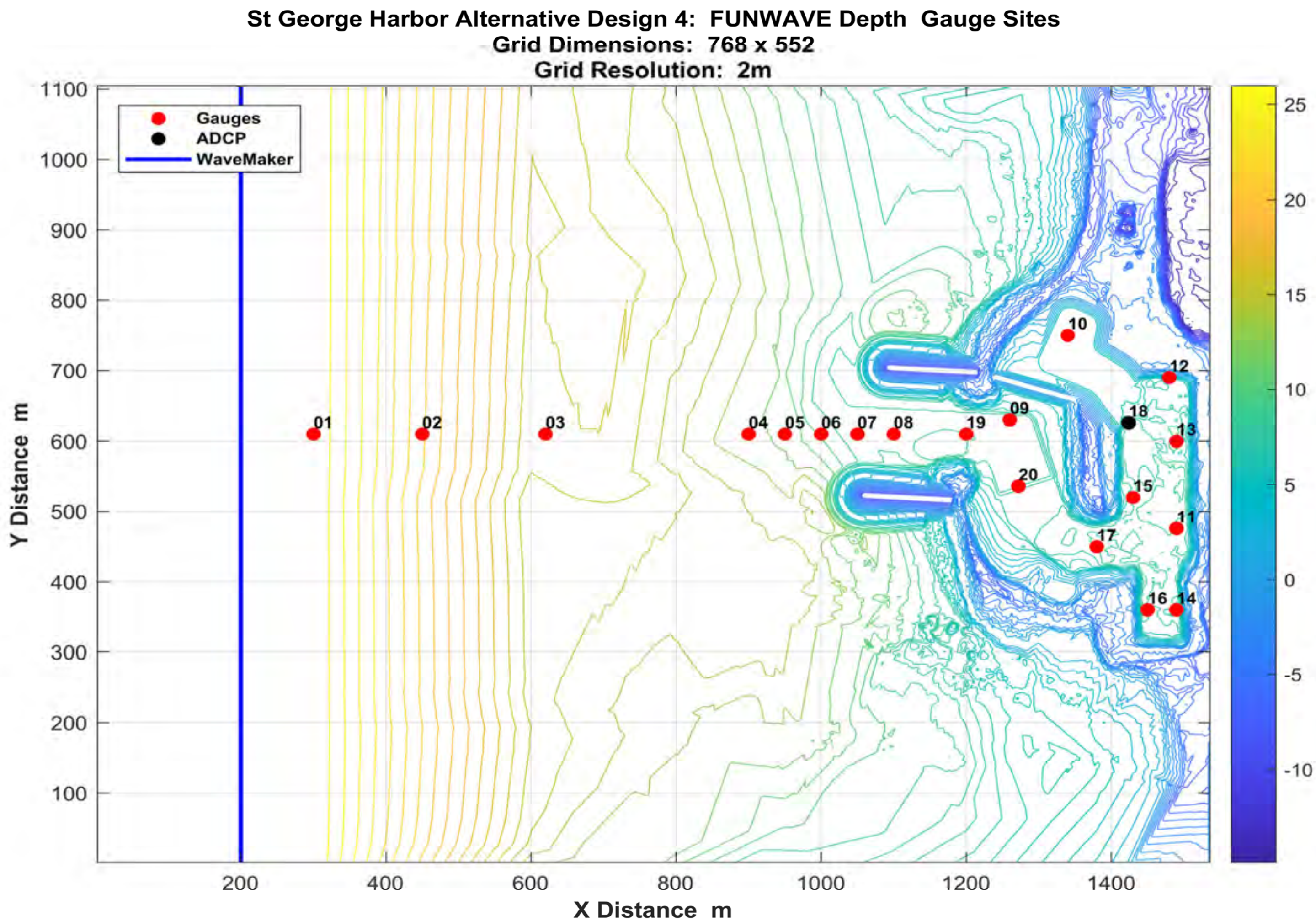
RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	HFW_1	HFW_2	HFW_3	HFW_4	HFW_5	HFW_6	HFW_7	HFW_8	HFW_9	HFW_10
1	14.05	17.35	252	11.18	17.99	10	9.200	8.873	8.998	7.906	7.972	8.107	7.553	6.821	3.190	1.331
2	13.69	17.75	245	11.34	19.8	20	8.639	9.207	8.563	7.456	7.411	7.425	7.316	6.580	3.063	1.372
17	11.07	19.12	256	11.34	19.8	12	8.453	7.938	8.498	7.867	7.848	7.938	7.411	6.596	3.141	1.373
RUNNO	**HWAM**	**TWAM**	**THWAM**	**HSTW**	**TSTW**	**THSTW**	**HFW_11**	**HFW_12**	**HFW_13**	**HFW_14**	**HFW_15**	**HFW_16**	**HFW_17**	**HFW_18**	**HFW_19**	**HFW_20**
1	14.05	17.35	252	11.18	17.99	10	1.155	1.398	1.178	1.730	1.229	1.666	1.549	1.174	5.192	2.604
2	13.69	17.75	245	11.34	19.8	20	1.244	1.503	1.247	1.768	1.214	1.690	1.558	1.247	5.057	2.566
17	11.07	19.12	256	11.34	19.8	12	1.177	1.387	1.100	1.703	1.160	1.631	1.493	1.238	4.973	2.439
RUNNO	**HWAM**	**TWAM**	**THWAM**	**HSTW**	**TSTW**	**THSTW**	**TFW_1**	**TFW_2**	**TFW_3**	**TFW_4**	**TFW_5**	**TFW_6**	**TFW_7**	**TFW_8**	**TFW_9**	**TFW_10**
1	14.05	17.35	252	11.18	17.99	10	17.067	14.629	14.629	17.067	17.067	17.067	17.067	17.067	51.200	102.400
2	13.69	17.75	245	11.34	19.8	20	17.067	17.067	17.067	20.480	17.067	20.480	17.067	20.480	51.200	468.114
17	11.07	19.12	256	11.34	19.8	12	17.067	17.067	17.067	17.067	17.067	17.067	17.067	20.480	51.200	468.114
RUNNO	**HWAM**	**TWAM**	**THWAM**	**HSTW**	**TSTW**	**THSTW**	**TFW_11**	**TFW_12**	**TFW_13**	**TFW_14**	**TFW_15**	**TFW_16**	**TFW_17**	**TFW_18**	**TFW_19**	**TFW_20**
1	14.05	17.35	252	11.18	17.99	10	102.400	546.133	546.133	102.400	546.133	102.400	102.400	546.133	7.877	17.067
2	13.69	17.75	245	11.34	19.8	20	468.114	468.114	468.114	102.400	468.114	102.400	468.114	468.114	10.240	20.480
17	11.07	19.12	256	11.34	19.8	12	468.114	102.400	102.400	102.400	468.114	102.400	102.400	468.114	10.240	20.480
RUNNO	**HWAM**	**TWAM**	**THWAM**	**HSTW**	**TSTW**	**THSTW**	**CFW_1**	**CFW_2**	**CFW_3**	**CFW_4**	**CFW_5**	**CFW_6**	**CFW_7**	**CFW_8**	**CFW_9**	**CFW_10**
1	14.05	17.35	252	11.18	17.99	10	4.974	5.845	7.030	6.661	6.118	5.892	6.140	5.495	1.168	1.342
2	13.69	17.75	245	11.34	19.8	20	5.453	6.124	6.000	5.611	5.499	5.591	5.768	5.244	0.942	1.107
17	11.07	19.12	256	11.34	19.8	12	5.047	5.212	6.223	6.495	6.409	6.664	7.452	5.788	1.203	1.435
RUNNO	**HWAM**	**TWAM**	**THWAM**	**HSTW**	**TSTW**	**THSTW**	**CFW_11**	**CFW_12**	**CFW_13**	**CFW_14**	**CFW_15**	**CFW_16**	**CFW_17**	**CFW_18**	**CFW_19**	**CFW_20**
1	14.05	17.35	252	11.18	17.99	10	3.010	1.080	4.228	1.582	1.391	2.516	1.100	1.445	4.238	0.895
2	13.69	17.75	245	11.34	19.8	20	2.547	0.882	4.742	1.589	1.153	2.347	1.068	1.582	3.673	1.063
17	11.07	19.12	256	11.34	19.8	12	2.573	1.014	4.560	1.342	1.734	2.261	1.001	1.767	3.745	1.050

Alternative Design 4 Auxiliary Simulation Results Some Grid Smoothing Southern Breakwater Head
Sub-Set Simulations as identified by N. Epps / Same Run Numbers
Some of the gauge locations have been moved from the Orginal Harbor Configuration (See Alternative Design 4) graphic for details
Generated REJ (10/27/2017)

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	HFW_1	HFW_2	HFW_3	HFW_4	HFW_5	HFW_6	HFW_7	HFW_8	HFW_9	HFW_10
100	2	10	0	2	10	0	1.851	1.710	1.690	1.625	1.661	1.711	2.043	1.637	0.815	0.185
102	6	10	0	6	10	0	5.114	4.769	4.495	4.557	4.638	4.768	5.062	4.805	2.101	0.825
103	8	10	0	8	10	0	6.780	6.251	6.391	6.220	6.240	6.350	6.627	6.294	2.631	1.171
131	2	20	0	2	20	0	1.502	1.571	1.626	1.851	2.017	2.132	2.036	1.822	0.920	0.283
133	6	20	0	6	20	0	4.416	4.682	4.851	5.622	5.952	6.295	5.993	5.788	2.747	0.967
135	10	20	0	10	20	0	7.336	7.458	7.406	7.920	7.832	7.779	7.248	6.503	3.329	1.520
152	2	26	0	2	26	0	1.488	1.358	1.454	1.789	1.657	1.927	1.789	1.829	1.410	0.266
154	6	26	0	6	26	0	4.163	3.944	4.156	5.054	5.059	5.308	5.344	5.305	2.976	1.093

156	10	26	0	10	26	0	6.834	6.433	6.647	6.930	6.941	6.958	6.902	6.278	3.512	1.395
RUNNO	**HWAM**	**TWAM**	**THWAM**	**HSTW**	**TSTW**	**THSTW**	**HFW_11**	**HFW_12**	**HFW_13**	**HFW_14**	**HFW_15**	**HFW_16**	**HFW_17**	**HFW_18**	**HFW_19**	**HFW_20**
100	2	10	0	2	10	0	0.174	0.209	0.160	0.216	0.173	0.206	0.220	0.176	1.247	0.771
102	6	10	0	6	10	0	0.682	0.777	0.719	0.928	0.675	0.872	0.880	0.745	3.648	2.100
103	8	10	0	8	10	0	0.927	1.019	0.984	1.214	0.912	1.142	1.149	1.017	4.684	2.376
131	2	20	0	2	20	0	0.322	0.496	0.385	0.427	0.382	0.403	0.441	0.327	1.477	0.827
133	6	20	0	6	20	0	0.947	1.190	0.975	1.357	0.968	1.294	1.277	0.953	4.484	2.352
135	10	20	0	10	20	0	1.297	1.543	1.312	1.659	1.282	1.586	1.561	1.321	5.081	2.466
152	2	26	0	2	26	0	0.549	0.616	0.427	0.382	0.466	0.358	0.560	0.530	1.483	0.846
154	6	26	0	6	26	0	0.983	1.232	0.902	1.353	0.901	1.287	1.248	0.917	4.478	2.196
156	10	26	0	10	26	0	1.217	1.539	1.193	1.781	1.147	1.715	1.486	1.211	5.242	2.445
RUNNO	**HWAM**	**TWAM**	**THWAM**	**HSTW**	**TSTW**	**THSTW**	**TFW_1**	**TFW_2**	**TFW_3**	**TFW_4**	**TFW_5**	**TFW_6**	**TFW_7**	**TFW_8**	**TFW_9**	**TFW_10**
100	2	10	0	2	10	0	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240	468.114
102	6	10	0	6	10	0	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240	468.114
103	8	10	0	8	10	0	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240	468.114
131	2	20	0	2	20	0	17.067	17.067	14.629	14.629	17.067	14.629	14.629	14.629	20.480	102.400
133	6	20	0	6	20	0	17.067	17.067	14.629	14.629	17.067	14.629	14.629	20.480	10.240	102.400
135	10	20	0	10	20	0	17.067	17.067	17.067	17.067	20.480	17.067	17.067	20.480	51.200	468.114
152	2	26	0	2	26	0	14.629	14.629	14.629	14.629	14.629	14.629	25.600	25.600	25.600	102.400
154	6	26	0	6	26	0	14.629	14.629	14.629	14.629	25.600	14.629	25.600	25.600	25.600	172.463
156	10	26	0	10	26	0	14.629	14.629	14.629	25.600	25.600	14.629	25.600	25.600	25.600	546.133
RUNNO	**HWAM**	**TWAM**	**THWAM**	**HSTW**	**TSTW**	**THSTW**	**TFW_11**	**TFW_12**	**TFW_13**	**TFW_14**	**TFW_15**	**TFW_16**	**TFW_17**	**TFW_18**	**TFW_19**	**TFW_20**
100	2	10	0	2	10	0	468.114	102.400	102.400	102.400	468.114	102.400	10.240	102.400	10.240	10.240
102	6	10	0	6	10	0	468.114	102.400	468.114	102.400	468.114	102.400	468.114	468.114	10.240	10.240
103	8	10	0	8	10	0	468.114	102.400	468.114	102.400	468.114	102.400	468.114	468.114	10.240	10.240
131	2	20	0	2	20	0	20.480	102.400	20.480	102.400	20.480	102.400	17.067	102.400	20.480	20.480
133	6	20	0	6	20	0	468.114	102.400	102.400	102.400	468.114	102.400	102.400	102.400	7.314	20.480
135	10	20	0	10	20	0	468.114	468.114	468.114	102.400	468.114	102.400	102.400	468.114	10.240	20.480
152	2	26	0	2	26	0	25.600	25.600	25.600	102.400	25.600	102.400	25.600	25.600	25.600	25.600
154	6	26	0	6	26	0	468.114	102.400	102.400	102.400	468.114	102.400	102.400	102.400	25.600	8.533
156	10	26	0	10	26	0	546.133	102.400	102.400	102.400	546.133	102.400	102.400	102.400	25.600	102.400
RUNNO	**HWAM**	**TWAM**	**THWAM**	**HSTW**	**TSTW**	**THSTW**	**CFW_1**	**CFW_2**	**CFW_3**	**CFW_4**	**CFW_5**	**CFW_6**	**CFW_7**	**CFW_8**	**CFW_9**	**CFW_10**
100	2	10	0	2	10	0	0.637	0.788	0.875	1.355	1.403	1.671	1.762	1.389	0.981	0.204
102	6	10	0	6	10	0	1.911	2.275	2.909	3.645	3.560	3.874	4.205	4.378	1.045	0.657
103	8	10	0	8	10	0	2.422	2.978	3.837	4.232	4.835	5.098	5.268	5.112	0.934	0.919
131	2	20	0	2	20	0	0.695	0.773	1.149	1.928	1.830	1.928	2.230	1.926	1.179	0.396
133	6	20	0	6	20	0	2.335	3.133	3.948	4.851	4.912	4.817	5.137	4.554	0.976	1.168
135	10	20	0	10	20	0	3.970	4.769	5.727	6.305	6.150	6.806	5.962	5.481	1.160	1.164
152	2	26	0	2	26	0	0.632	0.746	1.014	1.518	1.573	1.685	2.096	1.834	1.192	0.594
154	6	26	0	6	26	0	2.042	2.379	3.725	5.522	5.418	5.368	5.004	4.762	1.128	1.063
156	10	26	0	10	26	0	3.737	4.752	6.229	6.320	6.036	6.285	6.177	5.254	1.127	1.177
RUNNO	**HWAM**	**TWAM**	**THWAM**	**HSTW**	**TSTW**	**THSTW**	**CFW_11**	**CFW_12**	**CFW_13**	**CFW_14**	**CFW_15**	**CFW_16**	**CFW_17**	**CFW_18**	**CFW_19**	**CFW_20**
100	2	10	0	2	10	0	0.494	0.180	1.148	0.216	0.157	0.306	0.578	0.225	0.685	0.194
102	6	10	0	6	10	0	1.639	0.653	3.304	0.727	0.537	1.353	0.443	0.913	2.247	0.639

103	8	10	0	8	10	0	2.054	0.901	3.342	0.858	0.668	1.702	0.584	1.190	2.728	0.788
131	2	20	0	2	20	0	0.790	0.430	1.311	0.380	0.373	0.636	0.476	0.448	1.239	0.368
133	6	20	0	6	20	0	2.110	0.914	3.427	1.016	1.023	1.566	0.982	1.061	3.413	0.931
135	10	20	0	10	20	0	2.634	1.244	4.317	1.479	1.225	2.037	1.137	1.585	3.973	1.142
152	2	26	0	2	26	0	0.912	0.478	1.368	0.386	0.549	0.683	0.495	0.425	1.364	0.408
154	6	26	0	6	26	0	2.110	1.267	3.406	1.076	1.040	1.909	0.992	1.098	3.376	1.000
156	10	26	0	10	26	0	2.528	1.363	4.207	1.569	1.308	2.176	1.060	1.573	4.085	1.052



Alternative Design 5 Extreme Storm Event Results Increased the number of rows (to 804)

Moved the Gauge Locations See Bathymetry Figure for Alternative Design 5 (Gauge Sites 21 sites did NOT plot Gauge 10)

The numbering convention remains abour the same but some locations have changed

Generated REJ (11/01/2017)

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	HFW_1	HFW_2	HFW_3	HFW_4	HFW_5	HFW_6	HFW_7	HFW_8	HFW_9	HFW_10
1	14.05	17.35	252	11.18	17.99	10	9.484	8.913	8.649	7.124	2.898	2.054	1.745	1.149	0.691	0.791
2	13.69	17.75	245	11.34	19.8	20	9.150	9.241	9.251	7.677	2.918	1.910	1.596	0.977	0.633	0.699
17	11.07	19.12	256	11.34	19.8	12	9.244	9.069	8.672	7.250	2.922	2.070	1.707	1.081	0.698	0.752

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	HFW_11	HFW_12	HFW_13	HFW_14	HFW_15	HFW_16	HFW_17	HFW_18	HFW_19	HFW_20	HFW_21
1	14.05	17.35	252	11.18	17.99	10	0.869	0.720	0.726	0.793	0.803	0.770	0.734	0.684	0.734	0.766	0.859
2	13.69	17.75	245	11.34	19.8	20	0.810	0.654	0.636	0.756	0.758	0.709	0.683	0.621	0.666	0.689	0.803
17	11.07	19.12	256	11.34	19.8	12	0.829	0.703	0.732	0.795	0.801	0.745	0.728	0.681	0.735	0.753	0.848

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	TFW_1	TFW_2	TFW_3	TFW_4	TFW_5	TFW_6	TFW_7	TFW_8	TFW_9	TFW_10
1	14.05	17.35	252	11.18	17.99	10	17.067	17.067	17.067	17.067	17.067	17.067	14.629	17.067	546.133	546.133
2	13.69	17.75	245	11.34	19.8	20	20.480	20.480	20.480	20.480	20.480	102.400	102.400	102.400	546.133	102.400
17	11.07	19.12	256	11.34	19.8	12	14.629	20.480	20.480	20.480	20.480	20.480	12.800	102.400	546.133	102.400

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	TFW_11	TFW_12	TFW_13	TFW_14	TFW_15	TFW_16	TFW_17	TFW_18	TFW_19	TFW_20	TFW_21
1	14.05	17.35	252	11.18	17.99	10	546.133	546.133	546.133	546.133	546.133	546.133	546.133	546.133	546.133	546.133	546.133
2	13.69	17.75	245	11.34	19.8	20	25.600	546.133	102.400	546.133	546.133	546.133	546.133	546.133	655.360	546.133	546.133
17	11.07	19.12	256	11.34	19.8	12	25.600	546.133	546.133	546.133	546.133	546.133	546.133	546.133	546.133	546.133	546.133

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	CFW_1	CFW_2	CFW_3	CFW_4	CFW_5	CFW_6	CFW_7	CFW_8	CFW_9	CFW_10
1	14.05	17.35	252	11.18	17.99	10	5.479	5.855	6.729	6.856	5.520	5.205	4.239	1.977	1.913	1.583
2	13.69	17.75	245	11.34	19.8	20	4.890	5.503	6.079	6.641	5.707	4.966	3.939	1.952	1.756	1.448
17	11.07	19.12	256	11.34	19.8	12	5.118	6.107	6.574	6.659	5.816	5.444	4.504	2.181	1.824	1.461

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	CFW_11	CFW_12	CFW_13	CFW_14	CFW_15	CFW_16	CFW_17	CFW_18	CFW_19	CFW_20	CFW_21
1	14.05	17.35	252	11.18	17.99	10	0.825	0.812	0.913	0.794	0.842	1.234	0.604	1.021	0.946	1.145	1.145
2	13.69	17.75	245	11.34	19.8	20	0.805	0.768	1.043	0.774	0.868	1.171	0.650	0.905	0.946	0.996	1.062
17	11.07	19.12	256	11.34	19.8	12	0.784	0.801	1.057	0.756	0.906	1.218	0.617	1.012	0.921	1.035	1.147

Alternative Design 5 Auxiliary Simulation Results (Added Rows Top to 804) / Courant Number = 0.125

Sub-Set Simulations as identified by N. Epps / Same Run Numbers

Some of the gauge locations have been moved from the Orginal Harbor Configuration (See Alternative Design 5) graphic for details Did not analyze Gauge 10

Generated REJ (11/01/2017)

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	HFW_1	HFW_2	HFW_3	HFW_4	HFW_5	HFW_6	HFW_7	HFW_8	HFW_9	HFW_10
100	2	10	0	2	10	0	1.723	1.799	1.850	1.977	0.660	0.314	0.212	0.162	0.088	0.165
102	6	10	0	6	10	0	4.973	5.053	5.313	5.504	1.704	0.805	0.604	0.558	0.555	0.672
103	8	10	0	8	10	0	6.774	6.946	6.847	6.603	2.050	0.879	0.720	0.601	0.508	0.650
131	2	20	0	2	20	0	1.432	1.630	1.676	1.371	0.793	0.522	0.396	0.321	0.182	0.380
133	6	20	0	6	20	0	4.554	4.815	4.994	4.351	2.027	1.359	1.059	0.643	0.365	0.488
135	10	20	0	10	20	0	7.975	8.027	8.078	6.796	2.889	2.023	1.640	1.016	0.612	0.707
152	2	26	0	2	26	0	1.329	1.281	1.454	1.589	0.812	0.577	0.446	0.299	0.358	0.559
154	6	26	0	6	26	0	3.795	3.693	4.019	4.343	2.082	1.421	1.298	0.722	0.488	0.641
156	10	26	0	10	26	0	6.358	6.552	6.904	6.671	2.929	1.981	1.817	1.069	0.671	0.861

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	HFW_11	HFW_12	HFW_13	HFW_14	HFW_15	HFW_16	HFW_17	HFW_18	HFW_19	HFW_20	HFW_21
100	2	10	0	2	10	0	0.137	0.137	0.157	0.161	0.161	0.119	0.110	0.097	0.107	0.111	0.115
102	6	10	0	6	10	0	0.598	0.606	0.629	0.642	0.649	0.602	0.605	0.599	0.547	0.570	0.565

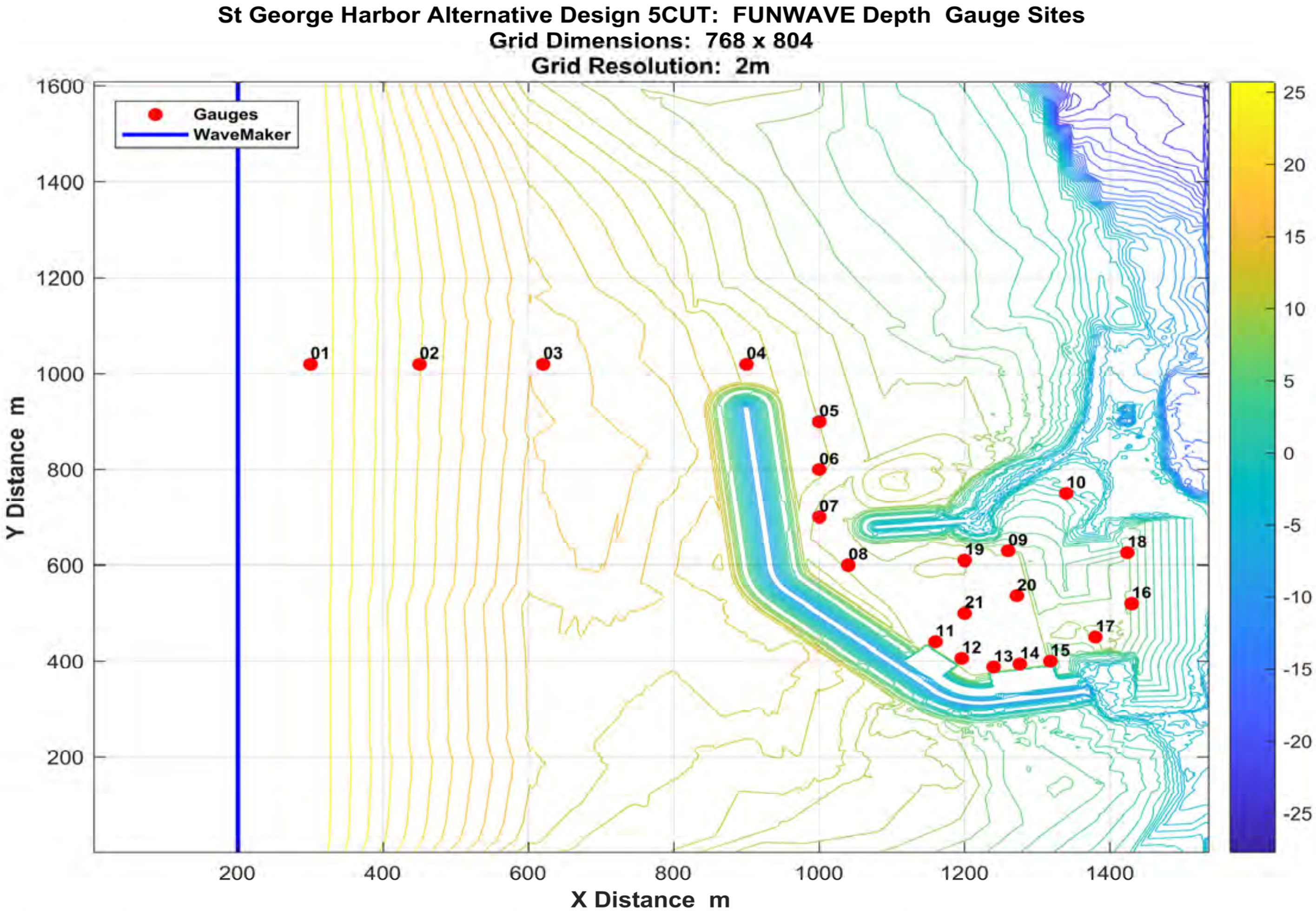
103	8	10	0	8	10	0	0.629	0.625	0.637	0.704	0.737	0.592	0.584	0.576	0.499	0.544	0.579
131	2	20	0	2	20	0	0.382	0.321	0.297	0.342	0.344	0.231	0.268	0.187	0.254	0.244	0.307
133	6	20	0	6	20	0	0.564	0.390	0.396	0.444	0.443	0.408	0.400	0.343	0.418	0.445	0.486
135	10	20	0	10	20	0	0.823	0.589	0.623	0.694	0.705	0.647	0.646	0.587	0.648	0.680	0.780
152	2	26	0	2	26	0	0.587	0.306	0.359	0.353	0.333	0.215	0.269	0.199	0.303	0.220	0.378
154	6	26	0	6	26	0	0.894	0.466	0.538	0.528	0.517	0.493	0.463	0.378	0.472	0.505	0.669
156	10	26	0	10	26	0	1.033	0.660	0.711	0.748	0.746	0.692	0.682	0.605	0.683	0.740	0.853

RUNNO	**HWAM**	**TWAM**	**THWAM**	**HSTW**	**TSTW**	**THSTW**	**TFW_1**	**TFW_2**	**TFW_3**	**TFW_4**	**TFW_5**	**TFW_6**	**TFW_7**	**TFW_8**	**TFW_9**	**TFW_10**
100	2	10	0	2	10	0	9.309	9.309	9.309	9.309	10.240	9.309	9.309	9.309	51.200	51.200
102	6	10	0	6	10	0	9.309	9.309	9.309	9.309	10.240	655.360	546.133	546.133	546.133	546.133
103	8	10	0	8	10	0	9.309	9.309	9.309	9.309	10.240	102.400	10.240	468.114	468.114	468.114
131	2	20	0	2	20	0	14.629	14.629	14.629	20.480	14.629	14.629	20.480	14.629	20.480	17.067
133	6	20	0	6	20	0	14.629	14.629	20.480	20.480	20.480	20.480	20.480	102.400	546.133	102.400
135	10	20	0	10	20	0	14.629	20.480	20.480	20.480	20.480	20.480	25.600	102.400	409.600	102.400
152	2	26	0	2	26	0	25.600	25.600	25.600	25.600	25.600	25.600	25.600	25.600	25.600	25.600
154	6	26	0	6	26	0	25.600	25.600	25.600	25.600	25.600	25.600	25.600	34.133	25.600	25.600
156	10	26	0	10	26	0	25.600	25.600	25.600	25.600	25.600	25.600	25.600	34.133	1638.400	102.400

RUNNO	**HWAM**	**TWAM**	**THWAM**	**HSTW**	**TSTW**	**THSTW**	**TFW_11**	**TFW_12**	**TFW_13**	**TFW_14**	**TFW_15**	**TFW_16**	**TFW_17**	**TFW_18**	**TFW_19**	**TFW_20**	**TFW_21**
100	2	10	0	2	10	0	25.600	51.200	51.200	9.309	9.309	51.200	51.200	102.400	10.240	9.309	17.067
102	6	10	0	6	10	0	546.133	546.133	546.133	546.133	546.133	546.133	546.133	546.133	546.133	546.133	546.133
103	8	10	0	8	10	0	468.114	468.114	468.114	468.114	468.114	468.114	468.114	468.114	468.114	468.114	468.114
131	2	20	0	2	20	0	20.480	20.480	34.133	20.480	14.629	14.629	14.629	17.067	20.480	14.629	20.480
133	6	20	0	6	20	0	20.480	102.400	102.400	102.400	51.200	546.133	546.133	102.400	546.133	546.133	20.480
135	10	20	0	10	20	0	25.600	102.400	102.400	102.400	102.400	273.067	409.600	273.067	409.600	409.600	409.600
152	2	26	0	2	26	0	25.600	34.133	25.600	25.600	34.133	25.600	25.600	25.600	25.600	34.133	25.600
154	6	26	0	6	26	0	25.600	25.600	25.600	25.600	102.400	409.600	409.600	102.400	25.600	34.133	25.600
156	10	26	0	10	26	0	25.600	1638.400	51.200	1638.400	1638.400	1638.400	1638.400	1638.400	1638.400	1638.400	25.600

RUNNO	**HWAM**	**TWAM**	**THWAM**	**HSTW**	**TSTW**	**THSTW**	**CFW_1**	**CFW_2**	**CFW_3**	**CFW_4**	**CFW_5**	**CFW_6**	**CFW_7**	**CFW_8**	**CFW_9**	**CFW_10**
100	2	10	0	2	10	0	0.589	0.743	1.023	1.270	0.875	0.742	0.209	0.144	0.447	0.125
102	6	10	0	6	10	0	1.846	2.072	3.107	4.112	3.487	2.631	0.907	0.549	1.342	0.333
103	8	10	0	8	10	0	4.358	2.886	4.354	4.511	4.261	3.386	1.558	0.835	1.190	0.646
131	2	20	0	2	20	0	0.779	0.815	1.074	1.304	0.726	0.656	0.497	0.371	1.197	0.266
133	6	20	0	6	20	0	2.886	3.054	5.534	4.290	5.166	4.208	3.530	1.763	1.078	1.504
135	10	20	0	10	20	0	3.926	5.027	5.991	6.762	5.853	4.965	4.010	1.992	1.862	1.502
152	2	26	0	2	26	0	0.571	0.768	0.875	1.247	0.793	0.664	0.573	0.412	1.519	0.279
154	6	26	0	6	26	0	3.286	3.172	3.458	4.393	5.173	4.646	3.571	1.876	1.474	1.519
156	10	26	0	10	26	0	3.410	4.957	5.727	5.591	5.385	5.509	4.026	2.343	2.064	1.475

RUNNO	**HWAM**	**TWAM**	**THWAM**	**HSTW**	**TSTW**	**THSTW**	**CFW_11**	**CFW_12**	**CFW_13**	**CFW_14**	**CFW_15**	**CFW_16**	**CFW_17**	**CFW_18**	**CFW_19**	**CFW_20**	**CFW_21**
100	2	10	0	2	10	0	0.126	0.130	0.141	0.101	0.109	0.100	0.145	0.103	0.097	0.136	0.133
102	6	10	0	6	10	0	0.313	0.298	0.455	0.264	0.278	0.311	0.367	0.309	0.297	0.376	0.418
103	8	10	0	8	10	0	0.508	0.476	0.568	0.423	0.413	0.450	0.392	0.499	0.352	0.591	0.588
131	2	20	0	2	20	0	0.239	0.249	0.358	0.252	0.256	0.227	0.206	0.203	0.195	0.327	0.437
133	6	20	0	6	20	0	0.770	0.797	0.978	0.897	0.777	1.066	0.661	0.982	0.829	0.883	0.886
135	10	20	0	10	20	0	0.803	0.848	1.056	0.774	0.819	1.202	0.663	1.037	0.996	0.983	1.094
152	2	26	0	2	26	0	0.360	0.318	0.533	0.221	0.254	0.255	0.227	0.227	0.263	0.529	0.412
154	6	26	0	6	26	0	0.841	0.852	0.980	0.912	0.890	1.127	0.670	0.989	0.922	1.161	1.046
156	10	26	0	10	26	0	0.862	0.886	1.070	1.069	1.011	1.312	0.719	1.053	1.194	1.142	1.183


St George Harbor Alternative Design 5CUT: FUNWAVE Depth Gauge Sites
Grid Dimensions: 768 x 804
Grid Resolution: 2m
Gauges
WaveMaker
Y Distance m
X Distance m
01
02
03
04
05
06
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Alternative Design 6 Extreme Storm Event Results

Moved the Gauge Locations See Bathymetry Figure for Alternative Design 6

The numbering convention remains abour the same but some locations have changed

Generated REJ (10/30/2017)

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	HFW_1	HFW_2	HFW_3	HFW_4	HFW_5	HFW_6	HFW_7	HFW_8	HFW_9	HFW_10
1	14.05	17.35	252	11.18	17.99	10	9.253	8.845	8.694	8.040	8.455	7.982	6.702	5.516	2.484	1.371
2	13.69	17.75	245	11.34	19.8	20	8.661	9.145	8.539	7.616	8.321	7.882	6.626	5.212	2.421	1.483
17	11.07	19.12	256	11.34	19.8	12	8.898	8.642	8.607	7.859	8.333	7.929	6.765	5.531	2.503	1.515
RUNNO	**HWAM**	**TWAM**	**THWAM**	**HSTW**	**TSTW**	**THSTW**	**HFW_11**	**HFW_12**	**HFW_13**	**HFW_14**	**HFW_15**	**HFW_16**	**HFW_17**	**HFW_18**	**HFW_19**	**HFW_20**
1	14.05	17.35	252	11.18	17.99	10	1.126	1.114	1.251	1.239	1.338	1.851	1.065	0.840	3.401	2.149
2	13.69	17.75	245	11.34	19.8	20	1.158	1.101	1.277	1.256	1.374	1.913	1.084	0.836	3.216	2.169
17	11.07	19.12	256	11.34	19.8	12	1.160	1.191	1.315	1.267	1.388	1.973	1.078	0.846	3.294	2.215
RUNNO	**HWAM**	**TWAM**	**THWAM**	**HSTW**	**TSTW**	**THSTW**	**TFW_1**	**TFW_2**	**TFW_3**	**TFW_4**	**TFW_5**	**TFW_6**	**TFW_7**	**TFW_8**	**TFW_9**	**TFW_10**
1	14.05	17.35	252	11.18	17.99	10	17.067	17.067	17.067	17.067	17.067	17.067	17.067	17.067	17.067	20.480
2	13.69	17.75	245	11.34	19.8	20	17.067	17.067	17.067	17.067	20.480	17.067	20.480	20.480	20.480	20.480
17	11.07	19.12	256	11.34	19.8	12	17.067	17.067	17.067	17.067	20.480	17.067	20.480	20.480	20.480	20.480
RUNNO	**HWAM**	**TWAM**	**THWAM**	**HSTW**	**TSTW**	**THSTW**	**TFW_11**	**TFW_12**	**TFW_13**	**TFW_14**	**TFW_15**	**TFW_16**	**TFW_17**	**TFW_18**	**TFW_19**	**TFW_20**
1	14.05	17.35	252	11.18	17.99	10	34.133	17.067	17.067	17.067	20.480	20.480	364.089	204.800	17.067	17.067
2	13.69	17.75	245	11.34	19.8	20	34.133	20.480	17.067	17.067	20.480	20.480	819.200	192.753	20.480	20.480
17	11.07	19.12	256	11.34	19.8	12	17.067	20.480	17.067	17.067	20.480	20.480	655.360	655.360	17.067	17.067
RUNNO	**HWAM**	**TWAM**	**THWAM**	**HSTW**	**TSTW**	**THSTW**	**CFW_1**	**CFW_2**	**CFW_3**	**CFW_4**	**CFW_5**	**CFW_6**	**CFW_7**	**CFW_8**	**CFW_9**	**CFW_10**
1	14.05	17.35	252	11.18	17.99	10	4.992	5.961	6.084	7.003	6.589	7.253	5.800	4.624	1.380	1.159
2	13.69	17.75	245	11.34	19.8	20	4.618	6.241	6.959	6.603	6.291	7.248	6.114	4.091	1.389	1.187
17	11.07	19.12	256	11.34	19.8	12	5.067	5.408	6.481	6.269	6.144	7.702	6.082	4.172	1.323	1.212
RUNNO	**HWAM**	**TWAM**	**THWAM**	**HSTW**	**TSTW**	**THSTW**	**CFW_11**	**CFW_12**	**CFW_13**	**CFW_14**	**CFW_15**	**CFW_16**	**CFW_17**	**CFW_18**	**CFW_19**	**CFW_20**
1	14.05	17.35	252	11.18	17.99	10	1.252	1.207	2.295	1.514	0.709	1.305	3.332	2.139	2.782	1.330
2	13.69	17.75	245	11.34	19.8	20	1.182	1.222	2.315	1.544	0.702	1.183	3.281	2.290	2.483	1.308
17	11.07	19.12	256	11.34	19.8	12	1.150	1.137	2.281	1.631	0.689	1.168	2.955	2.372	2.604	1.324

Alternative Design 6 Auxiliary Simulation Results (RUN0156: Cr=0.1875 / All Others 0.25)

Sub-Set Simulations as identified by N. Epps / Same Run Numbers

Some of the gauge locations have been moved from the Orginal Harbor Configuration (See Alternative Design 6) graphic for details

Generated REJ (10/30/2017)

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	HFW_1	HFW_2	HFW_3	HFW_4	HFW_5	HFW_6	HFW_7	HFW_8	HFW_9	HFW_10
100	2	10	0	2	10	0	1.921	1.712	1.782	1.723	1.861	2.158	2.484	2.045	1.075	0.377
102	6	10	0	6	10	0	5.200	4.880	5.224	5.539	5.704	6.116	5.651	4.432	2.357	0.658
103	8	10	0	8	10	0	6.892	6.267	6.512	7.154	7.481	7.398	6.782	5.500	2.822	0.845
131	2	20	0	2	20	0	1.429	1.711	1.879	2.134	2.023	2.732	1.845	2.232	1.204	0.823
133	6	20	0	6	20	0	4.555	5.129	5.927	6.588	7.430	7.431	6.495	5.750	2.625	1.650
135	10	20	0	10	20	0	7.457	7.936	8.255	7.522	8.361	7.980	7.178	5.979	2.826	1.769
152	2	26	0	2	26	0	1.459	1.444	1.618	1.820	1.937	2.032	1.905	1.900	1.062	0.716
154	6	26	0	6	26	0	3.993	4.121	4.814	6.032	6.395	6.319	6.289	5.110	2.472	1.415

156	10	26	0	10	26	0	6.607	6.717	7.319	8.078	8.131	7.968	7.667	5.861	2.917	1.633

RUNNO	**HWAM**	**TWAM**	**THWAM**	**HSTW**	**TSTW**	**THSTW**	**HFW_11**	**HFW_12**	**HFW_13**	**HFW_14**	**HFW_15**	**HFW_16**	**HFW_17**	**HFW_18**	**HFW_19**	**HFW_20**
100	2	10	0	2	10	0	0.250	0.285	0.294	0.362	0.377	0.744	0.256	0.180	1.260	0.562
102	6	10	0	6	10	0	0.521	0.573	0.588	0.638	0.653	1.488	0.630	0.537	2.528	1.250
103	8	10	0	8	10	0	0.630	0.693	0.727	0.786	0.796	1.697	0.747	0.601	3.139	1.460
131	2	20	0	2	20	0	0.752	1.023	1.082	0.924	0.900	1.072	0.496	0.260	1.533	1.191
133	6	20	0	6	20	0	1.047	1.252	1.318	1.285	1.352	1.910	0.933	0.712	3.450	2.258
135	10	20	0	10	20	0	1.277	1.319	1.403	1.354	1.509	2.239	1.194	0.926	3.601	2.503
152	2	26	0	2	26	0	0.742	0.776	0.851	0.688	0.627	1.045	0.659	0.295	1.188	0.825
154	6	26	0	6	26	0	1.165	1.080	1.167	1.051	1.118	1.881	1.065	0.684	3.175	1.893
156	10	26	0	10	26	0	1.386	1.222	1.350	1.217	1.374	2.427	1.361	0.904	3.612	2.312

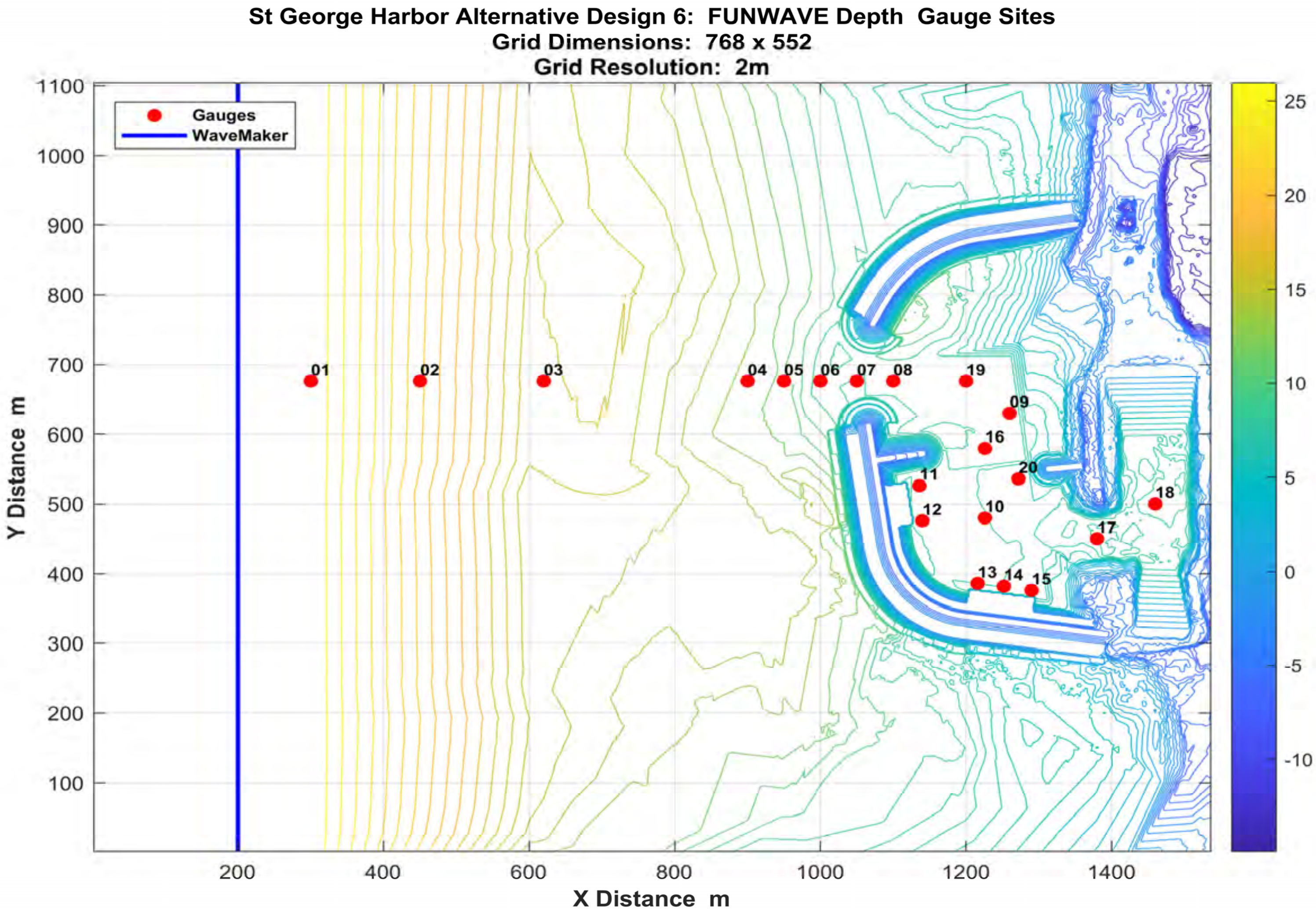
RUNNO	**HWAM**	**TWAM**	**THWAM**	**HSTW**	**TSTW**	**THSTW**	**TFW_1**	**TFW_2**	**TFW_3**	**TFW_4**	**TFW_5**	**TFW_6**	**TFW_7**	**TFW_8**	**TFW_9**	**TFW_10**
100	2	10	0	2	10	0	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240	9.309
102	6	10	0	6	10	0	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240	11.378
103	8	10	0	8	10	0	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240	11.378
131	2	20	0	2	20	0	14.629	14.629	14.629	14.629	20.480	14.629	20.480	17.067	20.480	20.480
133	6	20	0	6	20	0	17.067	17.067	14.629	14.629	20.480	14.629	20.480	20.480	20.480	20.480
135	10	20	0	10	20	0	17.067	17.067	14.629	14.629	20.480	17.067	20.480	20.480	20.480	20.480
152	2	26	0	2	26	0	14.629	14.629	25.600	25.600	20.480	14.629	25.600	20.480	25.600	25.600
154	6	26	0	6	26	0	14.629	25.600	14.629	25.600	20.480	17.067	25.600	20.480	20.480	20.480
156	10	26	0	10	26	0	14.629	14.629	14.629	25.600	20.480	20.480	25.600	20.480	20.480	20.480

RUNNO	**HWAM**	**TWAM**	**THWAM**	**HSTW**	**TSTW**	**THSTW**	**TFW_11**	**TFW_12**	**TFW_13**	**TFW_14**	**TFW_15**	**TFW_16**	**TFW_17**	**TFW_18**	**TFW_19**	**TFW_20**
100	2	10	0	2	10	0	10.240	10.240	10.240	10.240	10.240	10.240	364.089	364.089	10.240	10.240
102	6	10	0	6	10	0	468.114	10.240	468.114	10.240	10.240	10.240	468.114	468.114	10.240	10.240
103	8	10	0	8	10	0	468.114	10.240	17.617	10.240	10.240	9.309	468.114	468.114	10.240	10.240
131	2	20	0	2	20	0	17.067	14.629	14.629	14.629	20.480	14.629	17.067	14.629	17.067	20.480
133	6	20	0	6	20	0	17.067	20.480	17.067	20.480	20.480	20.480	17.067	655.360	17.067	20.480
135	10	20	0	10	20	0	17.067	20.480	17.067	20.480	20.480	20.480	3276.800	3276.800	20.480	20.480
152	2	26	0	2	26	0	25.600	14.629	14.629	20.480	20.480	25.600	25.600	409.600	14.629	20.480
154	6	26	0	6	26	0	34.133	20.480	17.067	17.067	20.480	25.600	25.600	218.453	11.378	20.480
156	10	26	0	10	26	0	34.133	20.480	17.067	17.067	20.480	25.600	25.600	546.133	11.378	20.480

RUNNO	**HWAM**	**TWAM**	**THWAM**	**HSTW**	**TSTW**	**THSTW**	**CFW_1**	**CFW_2**	**CFW_3**	**CFW_4**	**CFW_5**	**CFW_6**	**CFW_7**	**CFW_8**	**CFW_9**	**CFW_10**
100	2	10	0	2	10	0	1.125	1.738	2.526	2.902	2.900	2.993	2.897	2.494	0.921	0.687
102	6	10	0	6	10	0	2.786	3.540	3.728	5.304	5.834	5.976	5.636	3.919	1.128	0.870
103	8	10	0	8	10	0	2.632	2.608	4.074	6.140	6.480	6.623	5.894	4.075	1.226	0.894
131	2	20	0	2	20	0	0.748	0.964	1.355	1.600	1.842	2.090	2.281	1.953	0.675	0.671
133	6	20	0	6	20	0	4.079	4.954	5.360	5.394	5.641	6.558	5.881	4.134	1.333	1.299
135	10	20	0	10	20	0	3.914	6.227	6.106	5.944	6.398	7.403	6.189	4.226	1.347	1.211
152	2	26	0	2	26	0	0.716	0.816	1.098	2.264	2.463	2.730	2.628	2.210	0.853	0.730
154	6	26	0	6	26	0	3.371	4.144	5.532	6.592	5.836	6.251	5.830	3.962	1.355	1.226
156	10	26	0	10	26	0	3.627	5.015	6.082	6.331	6.408	8.275	6.833	4.416	1.396	1.351

RUNNO	**HWAM**	**TWAM**	**THWAM**	**HSTW**	**TSTW**	**THSTW**	**CFW_11**	**CFW_12**	**CFW_13**	**CFW_14**	**CFW_15**	**CFW_16**	**CFW_17**	**CFW_18**	**CFW_19**	**CFW_20**
100	2	10	0	2	10	0	0.505	0.393	1.274	0.448	0.239	0.751	1.677	0.983	1.238	0.641
102	6	10	0	6	10	0	1.054	0.860	2.064	0.753	0.340	0.860	2.872	1.740	2.345	0.734

103	8	10	0	8	10	0	1.065	0.839	2.169	0.818	0.365	0.920	2.990	1.973	2.863	0.872
131	2	20	0	2	20	0	0.904	0.921	1.145	0.631	0.316	0.791	1.608	1.004	1.489	0.931
133	6	20	0	6	20	0	1.189	1.099	2.077	1.309	0.646	1.133	3.306	1.999	2.759	1.153
135	10	20	0	10	20	0	1.332	1.129	2.255	1.530	0.716	1.330	3.167	2.291	2.587	1.241
152	2	26	0	2	26	0	0.834	0.691	1.086	0.579	0.404	0.993	1.518	1.248	1.189	0.767
154	6	26	0	6	26	0	1.178	1.181	2.130	1.145	0.588	1.374	3.171	2.123	2.683	1.178
156	10	26	0	10	26	0	1.318	1.284	2.418	1.375	0.748	1.761	3.215	2.379	3.028	1.406



Alternative Design 7 Extreme Storm Event Results

Moved the Gauge Locations See Bathymetry Figure for Alternative Design 7 (Gauge Sites)

The numbering convention remains abour the same but some locations have changed

Generated REJ (10/31/2017)

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	HFW_1	HFW_2	HFW_3	HFW_4	HFW_5	HFW_6	HFW_7	HFW_8	HFW_9	HFW_10	HFW_11	HFW_12	HFW_13	HFW_14
1	14.05	17.35	252	11.18	17.99	10	9.384	8.610	8.822	7.631	7.229	7.146	6.433	6.640	4.303	1.918	0.968	0.720	0.786	0.718
2	13.69	17.75	245	11.34	19.8	20	8.579	8.634	7.947	7.428	7.120	7.105	6.449	6.511	4.509	1.911	0.911	0.735	0.789	0.722
17	11.07	19.12	256	11.34	19.8	12	9.227	8.809	8.849	7.656	7.387	7.269	6.582	6.743	4.456	1.868	1.022	0.829	0.894	0.809

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	HFW_15	HFW_16	HFW_17	HFW_18	HFW_19	HFW_20	HFW_21	HFW_22	HFW_23	HFW_24	HFW_25	HFW_26	HFW_27	HFW_28
1	14.05	17.35	252	11.18	17.99	10	1.104	0.857	1.571	0.898	6.127	3.077	0.816	0.817	0.715	0.783	0.789	0.852	0.823	0.778
2	13.69	17.75	245	11.34	19.8	20	0.988	0.834	1.459	0.917	5.741	2.754	0.791	0.810	0.707	0.794	0.775	0.843	0.827	0.780
17	11.07	19.12	256	11.34	19.8	12	1.137	0.911	1.609	1.043	6.069	3.010	0.866	0.896	0.796	0.876	0.845	0.935	0.944	0.890

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	TFW_1	TFW_2	TFW_3	TFW_4	TFW_5	TFW_6	TFW_7	TFW_8	TFW_9	TFW_10	TFW_11	TFW_12	TFW_13	TFW_14
1	14.05	17.35	252	11.18	17.99	10	17.067	17.067	14.629	17.067	17.067	17.067	17.067	17.067	17.067	102.400	819.200	819.200	819.200	819.200
2	13.69	17.75	245	11.34	19.8	20	17.067	17.067	17.067	17.067	17.067	20.480	20.480	20.480	20.480	102.400	819.200	655.360	655.360	655.360
17	11.07	19.12	256	11.34	19.8	12	17.067	17.067	17.067	17.067	17.067	17.067	20.480	17.067	20.480	102.400	655.360	655.360	655.360	655.360

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	TFW_15	TFW_16	TFW_17	TFW_18	TFW_19	TFW_20	TFW_21	TFW_22	TFW_23	TFW_24	TFW_25	TFW_26	TFW_27	TFW_28
1	14.05	17.35	252	11.18	17.99	10	819.200	819.200	102.400	819.200	17.067	17.067	655.360	655.360	655.360	655.360	819.200	655.360	655.360	655.360
2	13.69	17.75	245	11.34	19.8	20	819.200	655.360	102.400	55.539	20.480	17.067	655.360	655.360	655.360	655.360	655.360	655.360	655.360	655.360
17	11.07	19.12	256	11.34	19.8	12	655.360	655.360	102.400	55.539	17.067	17.067	655.360	655.360	655.360	655.360	655.360	655.360	655.360	655.360

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	CFW_1	CFW_2	CFW_3	CFW_4	CFW_5	CFW_6	CFW_7	CFW_8	CFW_9	CFW_10	CFW_11	CFW_12	CFW_13	CFW_14
1	14.05	17.35	252	11.18	17.99	10	5.274	6.681	7.017	6.554	6.365	6.917	6.702	6.078	3.210	1.170	0.871	1.156	0.753	2.693
2	13.69	17.75	245	11.34	19.8	20	5.347	6.018	5.538	6.068	6.354	6.371	6.917	6.569	3.224	1.272	0.744	0.990	0.783	3.608
17	11.07	19.12	256	11.34	19.8	12	5.873	5.594	6.067	6.766	6.595	6.795	6.803	6.140	3.655	1.339	0.859	0.760	0.847	3.228

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	CFW_15	CFW_16	CFW_17	CFW_18	CFW_19	CFW_20	CFW_21	CFW_22	CFW_23	CFW_24	CFW_25	CFW_26	CFW_27	CFW_28
1	14.05	17.35	252	11.18	17.99	10	0.998	2.021	0.920	2.117	5.014	0.890	1.087	0.935	1.208	0.736	4.908	1.280	0.762	0.934
2	13.69	17.75	245	11.34	19.8	20	1.017	1.972	0.758	1.990	5.840	0.833	0.835	0.888	1.211	0.964	4.909	1.251	0.768	0.982
17	11.07	19.12	256	11.34	19.8	12	1.106	1.835	0.830	2.107	5.535	0.979	1.202	0.890	1.178	0.855	4.855	1.020	0.886	1.034

Alternative Design 7 Auxiliary Simulation Results (Cr=0.25)

Sub-Set Simulations as identified by N. Epps / Same Run Numbers 28 Gauge Sites

Some of the gauge locations have been moved from the Orginal Harbor Configuration (See Alternative Design 7) graphic for details

Generated REJ (10/31/2017)

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	HFW_1	HFW_2	HFW_3	HFW_4	HFW_5	HFW_6	HFW_7	HFW_8	HFW_9	HFW_10	HFW_11	HFW_12	HFW_13	HFW_14
100	2	10	0	2	10	0	1.809	1.719	1.623	1.630	1.698	1.736	1.796	1.764	0.999	0.781	0.256	0.113	0.128	0.126
102	6	10	0	6	10	0	5.202	4.889	4.678	4.652	4.659	4.740	4.701	4.552	2.963	1.409	0.629	0.459	0.485	0.453
103	8	10	0	8	10	0	7.114	6.839	6.202	5.887	5.803	5.823	5.564	5.230	3.329	1.495	0.789	0.606	0.628	0.594
131	2	20	0	2	20	0	1.461	1.543	1.549	1.903	1.928	2.024	2.345	2.216	1.911	0.898	0.315	0.227	0.245	0.217
133	6	20	0	6	20	0	4.459	4.597	4.738	5.128	5.289	5.405	5.316	5.299	4.056	1.668	0.676	0.514	0.573	0.484
135	10	20	0	10	20	0	7.339	7.268	7.136	7.783	7.680	7.481	6.898	6.756	4.736	1.925	0.966	0.827	0.871	0.801
152	2	26	0	2	26	0	1.441	1.350	1.465	1.760	1.782	1.908	2.011	2.174	1.972	0.886	0.360	0.210	0.246	0.234
154	6	26	0	6	26	0	4.150	3.941	4.166	4.842	4.856	4.927	4.943	4.947	3.991	1.574	0.714	0.509	0.547	0.508
156	10	26	0	10	26	0	6.846	6.291	6.331	6.468	6.439	6.372	6.194	6.023	4.513	1.907	0.869	0.635	0.672	0.643

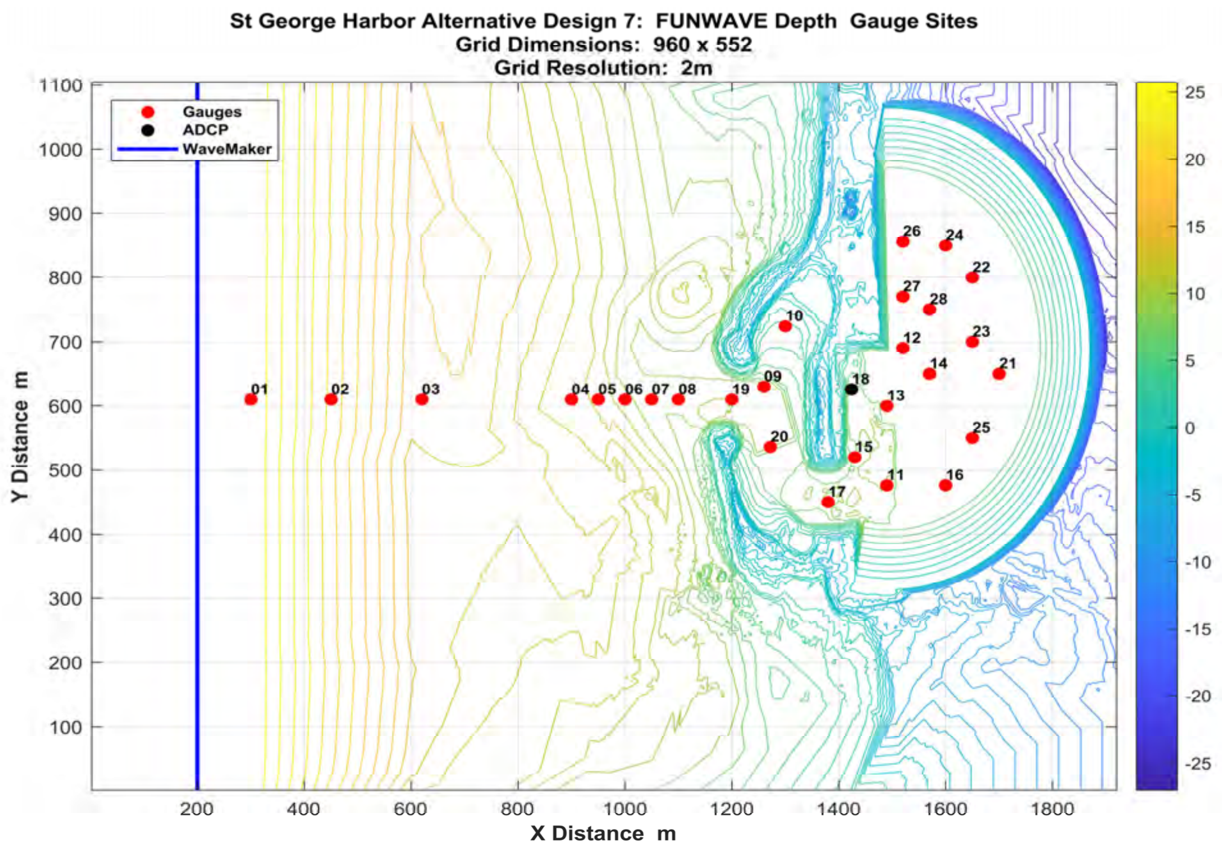
RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	HFW_15	HFW_16	HFW_17	HFW_18	HFW_19	HFW_20	HFW_21	HFW_22	HFW_23	HFW_24	HFW_25	HFW_26	HFW_27	HFW_28
100	2	10	0	2	10	0	0.241	0.218	0.315	0.161	1.935	0.912	0.184	0.187	0.120	0.124	0.162	0.125	0.130	0.119
102	6	10	0	6	10	0	0.639	0.566	0.881	0.467	4.228	2.130	0.481	0.494	0.431	0.450	0.518	0.481	0.488	0.446
103	8	10	0	8	10	0	0.779	0.679	1.085	0.594	4.971	2.369	0.612	0.626	0.558	0.584	0.636	0.626	0.624	0.579
131	2	20	0	2	20	0	0.381	0.257	0.441	0.300	2.041	1.114	0.271	0.297	0.203	0.233	0.249	0.204	0.223	0.227
133	6	20	0	6	20	0	0.763	0.577	1.121	0.716	4.855	2.224	0.569	0.588	0.475	0.554	0.532	0.543	0.565	0.521
135	10	20	0	10	20	0	1.035	0.895	1.477	0.909	5.826	2.770	0.865	0.894	0.788	0.865	0.849	0.910	0.913	0.876
152	2	26	0	2	26	0	0.361	0.365	0.504	0.296	1.904	0.894	0.338	0.310	0.231	0.294	0.297	0.215	0.240	0.206
154	6	26	0	6	26	0	0.769	0.623	1.169	0.632	4.607	1.986	0.601	0.574	0.471	0.577	0.579	0.582	0.543	0.497
156	10	26	0	10	26	0	0.922	0.789	1.429	0.789	5.628	2.465	0.727	0.717	0.595	0.695	0.705	0.716	0.662	0.665

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	TFW_1	TFW_2	TFW_3	TFW_4	TFW_5	TFW_6	TFW_7	TFW_8	TFW_9	TFW_10	TFW_11	TFW_12	TFW_13	TFW_14
100	2	10	0	2	10	0	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240	102.400	102.400	819.200
102	6	10	0	6	10	0	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240	655.360	655.360	655.360
103	8	10	0	8	10	0	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240	10.240	819.200	819.200	819.200	819.200
131	2	20	0	2	20	0	17.067	17.067	14.629	14.629	14.629	14.629	14.629	17.067	20.480	20.480	17.067	102.400	17.067	17.067
133	6	20	0	6	20	0	17.067	17.067	17.067	14.629	17.067	17.067	14.629	17.067	20.480	102.400	102.400	102.400	102.400	102.400
135	10	20	0	10	20	0	17.067	17.067	17.067	17.067	17.067	17.067	20.480	20.480	20.480	102.400	655.360	655.360	655.360	655.360
152	2	26	0	2	26	0	14.629	14.629	14.629	14.629	25.600	14.629	14.629	25.600	25.600	20.480	25.600	102.400	25.600	34.133
154	6	26	0	6	26	0	14.629	14.629	14.629	14.629	25.600	20.480	25.600	25.600	25.600	102.400	25.600	102.400	102.400	102.400
156	10	26	0	10	26	0	14.629	14.629	14.629	25.600	25.600	20.480	25.600	25.600	20.480	102.400	655.360	102.400	102.400	655.360

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	TFW_15	TFW_16	TFW_17	TFW_18	TFW_19	TFW_20	TFW_21	TFW_22	TFW_23	TFW_24	TFW_25	TFW_26	TFW_27	TFW_28
100	2	10	0	2	10	0	9.309	10.240	9.309	10.240	10.240	10.240	10.240	10.240	819.200	819.200	9.309	819.200	102.400	819.200
102	6	10	0	6	10	0	655.360	655.360	11.378	102.400	10.240	10.240	655.360	655.360	655.360	655.360	655.360	655.360	655.360	655.360
103	8	10	0	8	10	0	819.200	819.200	11.378	102.400	10.240	10.240	819.200	819.200	819.200	819.200	819.200	819.200	819.200	819.200
131	2	20	0	2	20	0	17.067	17.067	12.800	102.400	17.067	20.480	17.067	17.067	17.067	20.480	17.067	102.400	51.200	17.067
133	6	20	0	6	20	0	17.067	102.400	51.200	102.400	17.067	17.067	655.360	655.360	655.360	655.360	102.400	102.400	51.200	102.400
135	10	20	0	10	20	0	655.360	655.360	102.400	102.400	20.480	17.067	655.360	655.360	655.360	655.360	655.360	655.360	655.360	655.360
152	2	26	0	2	26	0	25.600	25.600	25.600	25.600	25.600	17.067	25.600	25.600	25.600	25.600	25.600	34.133	34.133	25.600
154	6	26	0	6	26	0	819.200	102.400	102.400	102.400	25.600	17.067	655.360	655.360	655.360	655.360	655.360	655.360	102.400	102.400
156	10	26	0	10	26	0	655.360	655.360	102.400	102.400	25.600	17.067	655.360	655.360	655.360	655.360	655.360	655.360	102.400	655.360

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	CFW_1	CFW_2	CFW_3	CFW_4	CFW_5	CFW_6	CFW_7	CFW_8	CFW_9	CFW_10	CFW_11	CFW_12	CFW_13	CFW_14
100	2	10	0	2	10	0	0.617	0.782	0.955	1.201	1.297	1.446	1.594	1.895	1.204	0.257	0.879	0.777	0.147	0.637
102	6	10	0	6	10	0	1.900	2.246	3.254	3.327	3.513	3.861	4.003	4.221	1.720	0.665	0.374	0.982	0.369	2.284
103	8	10	0	8	10	0	3.522	3.691	4.275	4.455	4.375	4.409	4.538	4.467	1.909	0.802	0.422	1.201	0.454	2.691
131	2	20	0	2	20	0	0.670	0.785	1.169	1.890	1.923	2.235	2.258	2.932	1.598	0.307	0.236	1.006	0.281	1.074
133	6	20	0	6	20	0	1.978	2.692	4.282	4.881	5.285	5.434	5.432	5.063	2.895	0.865	0.709	1.071	0.578	2.669
135	10	20	0	10	20	0	4.206	4.732	5.747	6.150	6.324	6.585	7.047	5.827	3.356	1.199	0.815	1.035	0.893	2.989
152	2	26	0	2	26	0	0.655	0.702	0.977	1.580	1.587	1.847	2.564	2.403	1.641	0.362	0.257	1.000	0.290	1.276
154	6	26	0	6	26	0	2.344	2.776	3.756	5.068	4.918	5.388	5.738	5.129	2.659	0.782	0.771	0.975	0.613	2.394
156	10	26	0	10	26	0	3.951	4.697	5.770	6.381	6.448	6.552	6.421	5.557	3.481	1.027	0.614	1.116	0.838	2.612

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	CFW_15	CFW_16	CFW_17	CFW_18	CFW_19	CFW_20	CFW_21	CFW_22	CFW_23	CFW_24	CFW_25	CFW_26	CFW_27	CFW_28
100	2	10	0	2	10	0	0.210	0.330	0.120	0.352	1.169	0.323	1.157	0.688	1.262	0.743	1.619	1.050	0.340	1.095
102	6	10	0	6	10	0	0.592	0.982	0.445	1.092	3.086	0.969	1.142	0.843	1.233	0.794	3.892	1.020	0.463	0.943
103	8	10	0	8	10	0	0.563	1.158	0.484	1.344	3.403	0.799	0.985	1.089	1.035	1.058	4.415	1.005	0.545	1.084
131	2	20	0	2	20	0	0.347	0.600	0.256	0.735	2.596	0.872	0.928	0.871	1.095	0.958	2.182	1.234	1.002	1.085
133	6	20	0	6	20	0	0.672	1.298	0.641	1.545	4.469	0.592	0.895	0.992	1.264	1.016	3.870	1.214	0.530	1.107
135	10	20	0	10	20	0	0.966	1.699	0.831	1.987	4.893	0.767	1.233	0.960	1.186	1.001	4.828	1.126	0.798	1.171
152	2	26	0	2	26	0	0.325	0.479	0.216	0.653	2.040	0.936	1.321	0.650	1.133	1.013	2.116	1.076	1.062	1.017
154	6	26	0	6	26	0	0.653	1.062	0.519	1.512	4.390	0.508	1.317	1.067	1.047	0.991	4.316	1.072	0.555	1.222
156	10	26	0	10	26	0	0.825	1.410	0.619	1.744	4.738	0.676	1.226	0.861	1.239	1.096	4.683	1.079	0.651	1.012


St George Harbor Alternative Design 7: FUNWAVE Depth Gauge Sites
Grid Dimensions: 960 x 552
Grid Resolution: 2m
Gauges
ADCP
WaveMaker
Y Distance m
X Distance m
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ALTERNATIVE N-2

St George Harbor Alt-Des-1A (SPUR) NORTH Storm Events (201,212,234) Auxiliary Sims (100-106)

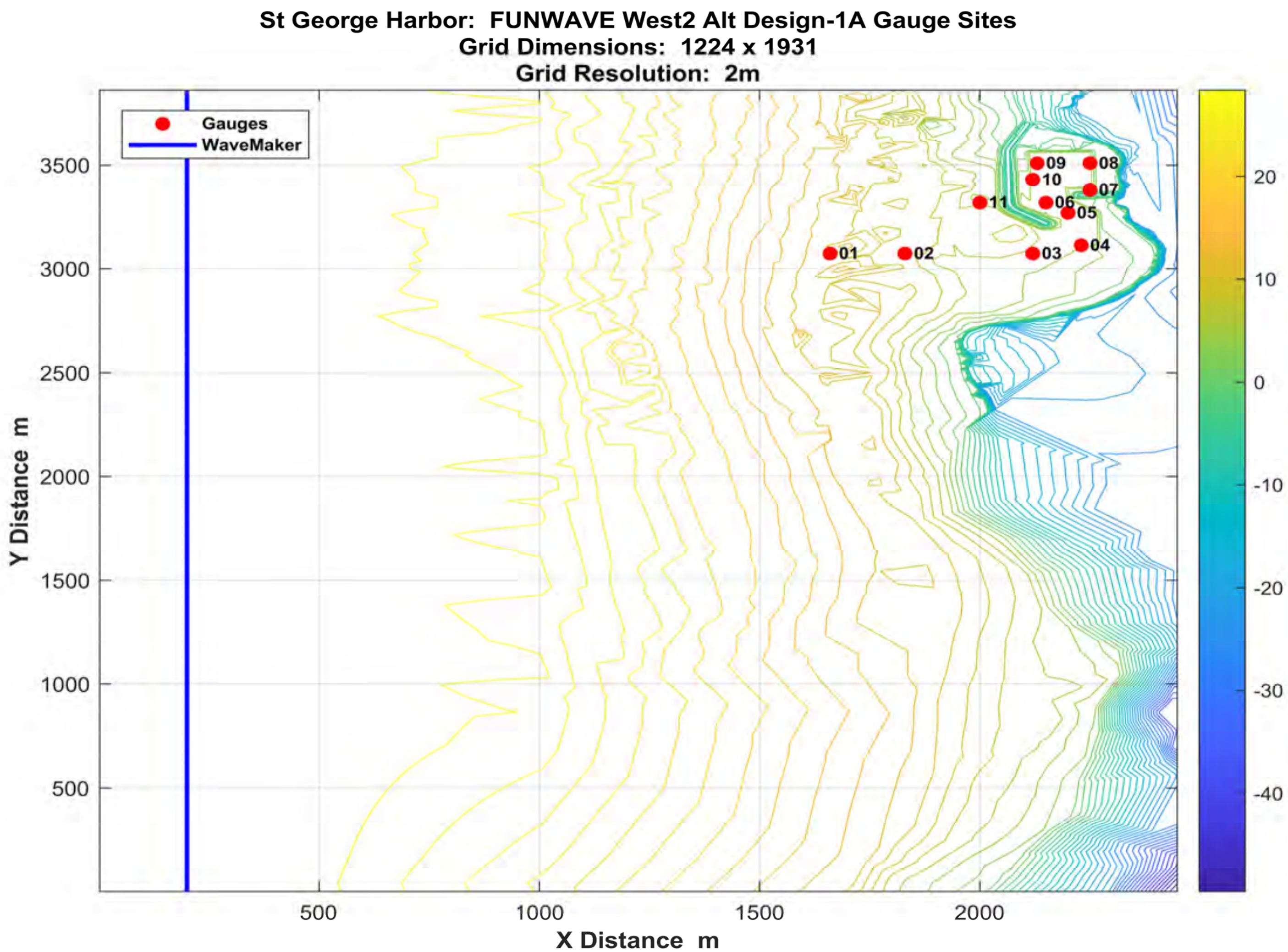
Station Location Provided in Graphic

Generated RE Jensen 03/12/2018

Corected the order of the currents

WAM INPUT FOR Auxiliary Simulations are irelevant- FORCED BY STW Input Conditions

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	HFW_1	HFW_2	HFW_3	HFW_4	HFW_5	HFW_6	HFW_7	HFW_8	HFW_9	HFW_10	HFW_11
201	12.28	16.18	278	7.13	16.34	38.1	5.933	6.185	4.873	3.827	2.022	1.566	1.447	1.453	1.446	1.518	6.393
212	10.35	11.16	326	4.25	12.29	21.2	4.045	4.202	4.021	3.073	1.329	0.860	0.768	0.760	0.795	0.845	5.044
234	8.98	12.05	4	3.76	13.51	19.1	3.894	3.904	4.090	3.576	1.312	1.043	0.911	0.890	0.935	0.981	5.160
100	1.2	6	20	1.2	6	20	0.630	0.613	0.690	0.522	0.139	0.076	0.037	0.040	0.071	0.065	0.614
101	3	8	20	3	8	20	2.242	2.292	2.276	1.946	0.600	0.410	0.354	0.298	0.353	0.378	3.062
102	3	12	20	3	12	20	2.914	2.989	3.264	2.668	0.948	0.651	0.574	0.544	0.583	0.634	3.951
103	3	16	20	3	16	20	3.004	2.983	3.663	2.843	1.026	0.789	0.688	0.647	0.655	0.719	5.067
104	7	8	20	7	8	20	4.647	4.579	3.821	2.944	1.426	0.973	0.797	0.818	0.886	0.941	4.845
105	7	12	20	7	12	20	6.136	5.862	4.737	3.794	1.826	1.333	1.270	1.291	1.311	1.351	6.020
106	7	16	20	7	16	20	6.468	6.140	4.810	3.857	1.915	1.472	1.472	1.488	1.474	1.507	6.661
RUNNO	**HWAM**	**TWAM**	**THWAM**	**HSTW**	**TSTW**	**THSTW**	**TFW_1**	**TFW_2**	**TFW_3**	**TFW_4**	**TFW_5**	**TFW_6**	**TFW_7**	**TFW_8**	**TFW_9**	**TFW_10**	**TFW_11**
201	12.28	16.18	278	7.13	16.34	38.1	17.067	17.067	17.067	17.067	468.114	468.114	468.114	468.114	468.114	468.114	17.067
212	10.35	11.16	326	4.25	12.29	21.2	12.800	12.800	12.800	12.800	11.378	102.400	1092.267	1092.267	1092.267	1092.267	12.800
234	8.98	12.05	4	3.76	13.51	19.1	12.800	12.800	12.800	12.800	102.400	468.114	468.114	468.114	468.114	468.114	14.629
100	1.2	6	20	1.2	6	20	6.024	6.024	6.024	6.400	6.827	12.800	12.800	6.400	12.800	12.800	5.689
101	3	8	20	3	8	20	7.877	7.877	7.877	7.877	7.877	3276.800	3276.800	468.114	468.114	468.114	7.877
102	3	12	20	3	12	20	11.378	11.378	11.378	11.378	11.378	468.114	468.114	468.114	468.114	468.114	12.800
103	3	16	20	3	16	20	14.629	14.629	14.629	14.629	102.400	102.400	468.114	468.114	468.114	468.114	14.629
104	7	8	20	7	8	20	7.877	7.877	7.877	8.533	3276.800	468.114	468.114	468.114	468.114	468.114	7.877
105	7	12	20	7	12	20	11.378	11.378	11.378	11.378	468.114	468.114	468.114	468.114	468.114	468.114	12.800
106	7	16	20	7	16	20	14.629	14.629	17.067	17.067	102.400	102.400	409.600	409.600	409.600	409.600	14.629
RUNNO	**HWAM**	**TWAM**	**THWAM**	**HSTW**	**TSTW**	**THSTW**	**CFW_1**	**CFW_2**	**CFW_3**	**CFW_4**	**CFW_5**	**CFW_6**	**CFW_7**	**CFW_8**	**CFW_9**	**CFW_10**	**CFW_11**
201	12.28	16.18	278	7.13	16.34	38.1	5.253	4.891	6.616	5.877	2.280	1.677	1.272	1.305	1.177	1.415	8.942
212	10.35	11.16	326	4.25	12.29	21.2	3.957	3.926	4.595	3.645	2.065	1.064	0.978	1.221	1.165	0.915	6.781
234	8.98	12.05	4	3.76	13.51	19.1	3.809	3.920	5.549	3.936	2.265	1.101	1.067	1.190	1.092	1.069	7.164
100	1.2	6	20	1.2	6	20	0.369	0.397	0.507	0.439	0.136	0.069	0.830	1.254	1.125	0.901	0.597
101	3	8	20	3	8	20	2.002	2.178	2.971	2.388	1.377	0.472	0.971	1.071	1.241	0.970	2.796
102	3	12	20	3	12	20	2.756	2.849	3.439	2.967	2.068	0.883	1.052	1.016	0.991	0.919	5.563
103	3	16	20	3	16	20	3.153	3.074	4.255	3.312	1.564	0.894	0.820	1.168	0.981	0.964	4.577
104	7	8	20	7	8	20	3.963	4.651	5.836	3.922	2.145	1.190	0.918	1.243	1.228	0.904	5.439
105	7	12	20	7	12	20	4.731	4.842	6.440	4.268	2.791	1.728	1.284	1.144	1.114	1.192	8.334
106	7	16	20	7	16	20	5.524	5.498	5.457	5.011	2.209	1.955	1.600	1.204	1.399	1.603	9.255


St George Harbor: FUNWAVE West2 Alt Design-1A Gauge Sites
Grid Dimensions: 1224 x 1931
Grid Resolution: 2m
Gauges
WaveMaker
01
02
03
04
05
06
07
08
09
10
11
Y Distance m
X Distance m
3500
3000
2500
2000
1500
1000
500
500
1000
1500
2000
20
10
0
-10
-20
-30
-40

ST GEORGE NORTH New Scatter Set (2019-07)

NO HARBOR

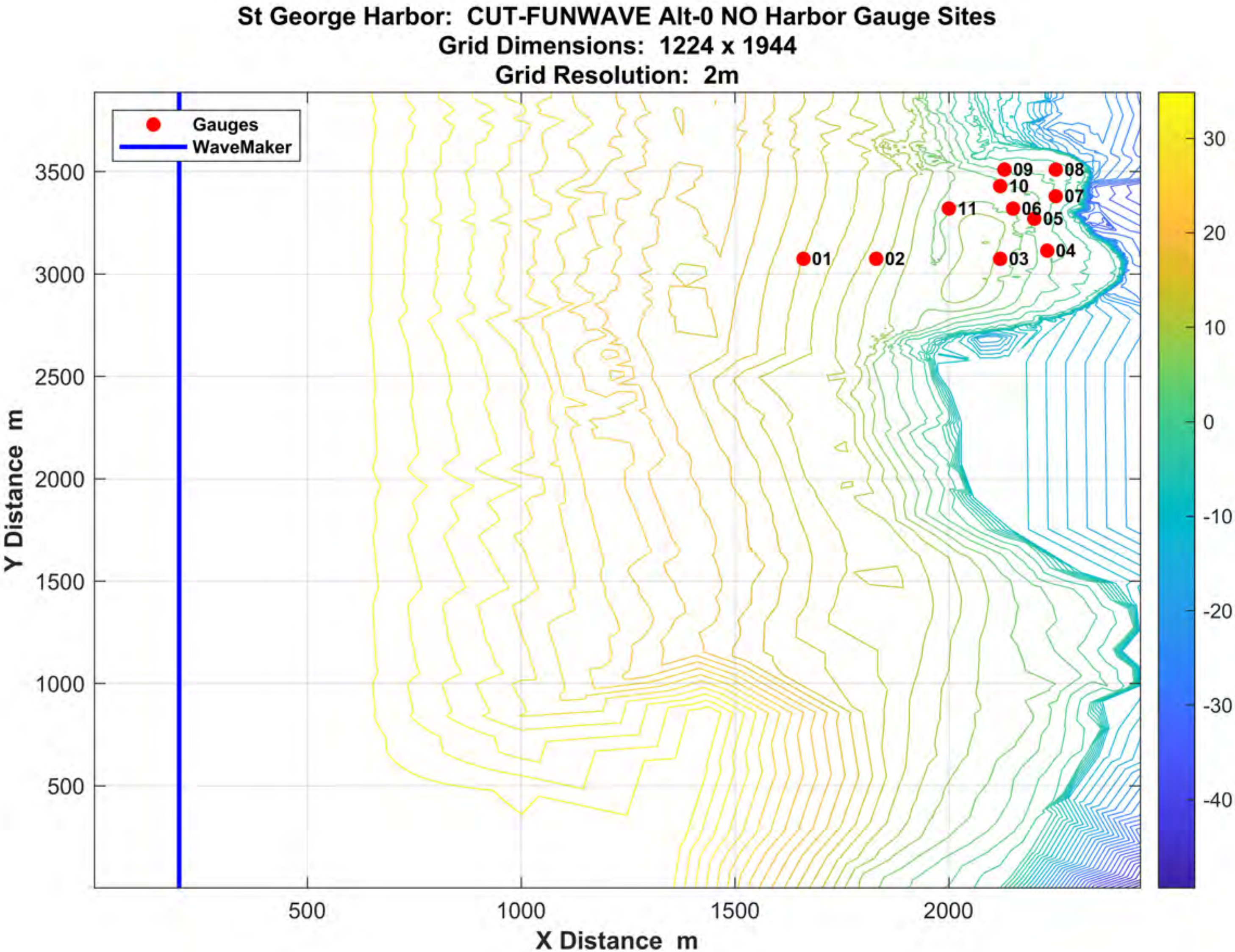
INPUT CONDITIONS (1-8 TEST CASES / 9-11 REAL CASES FROM EXTREMES)

R.E. Jensen Run 2019-11

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	HFW_1	HFW_2	HFW_3	HFW_4	HFW_5	HFW_6	HFW_7	HFW_8	HFW_9	HFW_10	HFW_11
301	1	6	20	1	6	20	0.615	0.547	0.437	0.412	0.466	0.379	0.368	0.238	0.311	0.384	0.446
302	1.2	6	20	1.2	6	20	0.733	0.648	0.523	0.492	0.546	0.464	0.447	0.274	0.362	0.456	0.532
303	2	8	20	2	8	20	1.530	1.466	1.361	1.417	1.280	1.526	1.469	1.096	1.283	1.429	1.582
304	3	10	20	3	10	20	2.384	2.330	2.313	2.387	2.259	2.472	2.230	1.626	1.999	2.457	2.363
305	4	11	20	4	11	20	3.188	3.440	3.135	3.020	3.174	2.949	2.642	1.925	2.359	2.979	3.186
306	5	12	20	5	12	20	5.828	5.904	4.545	3.906	4.132	4.620	3.466	2.545	3.230	4.131	5.087
307	6	14	20	6	14	20	5.828	5.904	4.545	3.906	4.132	4.620	3.466	2.545	3.230	4.131	5.087
308	7	17	20	7	17	20	5.959	6.042	4.910	4.343	4.657	4.690	3.735	2.878	3.512	4.343	5.316
309	12.28	16.18	278	7.13	16.34	38.1	6.127	5.882	4.781	3.979	4.510	4.442	3.430	2.991	3.505	4.538	5.172
310	10.35	11.16	326	4.25	12.29	21.2	4.098	4.186	3.688	3.207	3.552	3.813	3.077	2.192	2.625	3.393	4.026
311	8.98	12.05	4	3.76	13.51	19.1	3.959	4.277	3.809	3.590	3.489	3.582	2.961	2.151	2.652	3.426	3.912

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	TFW_1	TFW_2	TFW_3	TFW_4	TFW_5	TFW_6	TFW_7	TFW_8	TFW_9	TFW_10	TFW_11
301	1	6	20	1	6	20	6.024	6.024	6.400	6.400	6.024	6.024	6.024	6.400	6.024	6.024	6.024
302	1.2	6	20	1.2	6	20	6.024	6.024	6.400	6.400	6.400	6.024	6.024	6.400	6.024	6.024	6.024
303	2	8	20	2	8	20	7.877	7.877	8.533	8.533	7.877	7.877	7.877	7.877	7.877	7.877	7.877
304	3	10	20	3	10	20	9.309	9.309	10.240	10.240	9.309	9.309	10.240	10.240	10.240	9.309	9.309
305	4	11	20	4	11	20	10.240	10.240	10.240	10.240	11.378	11.378	11.378	11.378	11.378	11.378	11.378
306	5	12	20	5	12	20	12.800	12.800	12.800	12.800	12.800	12.800	14.629	102.400	12.800	12.800	12.800
307	6	14	20	6	14	20	12.800	12.800	12.800	12.800	12.800	12.800	14.629	102.400	12.800	12.800	12.800
308	7	17	20	7	17	20	17.067	17.067	17.067	17.067	17.067	17.067	17.067	102.400	17.067	17.067	17.067
309	12.28	16.18	278	7.13	16.34	38.1	17.067	17.067	17.067	17.067	17.067	17.067	17.067	102.400	17.067	17.067	17.067
310	10.35	11.16	326	4.25	12.29	21.2	12.800	12.800	12.800	12.800	12.800	12.800	12.800	102.400	11.378	11.378	12.800
311	8.98	12.05	4	3.76	13.51	19.1	12.800	12.800	12.800	12.800	12.800	12.800	12.800	12.800	12.800	12.800	12.800

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	CFW_1	CFW_2	CFW_3	CFW_4	CFW_5	CFW_6	CFW_7	CFW_8	CFW_9	CFW_10	CFW_11
301	1	6	20	1	6	20	0.271	0.356	0.309	0.620	0.407	0.593	0.688	0.517	0.507	0.387	0.548
302	1.2	6	20	1.2	6	20	0.319	0.399	0.376	0.664	0.534	0.724	0.825	0.598	0.609	0.521	0.686
303	2	8	20	2	8	20	0.831	1.134	1.463	1.816	2.386	2.339	1.929	2.324	2.514	2.263	1.929
304	3	10	20	3	10	20	1.397	1.909	3.673	3.096	3.109	3.348	3.030	3.677	3.085	3.054	4.150
305	4	11	20	4	11	20	3.840	4.085	2.885	4.481	4.049	4.260	3.669	4.829	4.908	3.777	4.481
306	5	12	20	5	12	20	3.756	4.980	4.684	5.043	5.774	5.241	4.680	6.093	5.776	6.475	5.777
307	6	14	20	6	14	20	3.756	4.980	4.684	5.043	5.774	5.241	4.680	6.093	5.776	6.475	5.777
308	7	17	20	7	17	20	4.417	5.081	5.915	5.994	5.745	5.815	5.711	6.857	5.740	6.324	7.238
309	12.28	16.18	278	7.13	16.34	38.1	4.739	4.819	5.762	6.209	4.761	5.428	4.924	5.697	6.153	6.053	6.407
310	10.35	11.16	326	4.25	12.29	21.2	3.713	4.156	5.864	4.574	4.765	4.591	3.562	5.072	4.681	5.016	5.090
311	8.98	12.05	4	3.76	13.51	19.1	3.288	4.286	4.434	4.693	4.549	5.254	4.190	4.849	4.254	4.980	5.519


St George Harbor: CUT-FUNWAVE Alt-0 NO Harbor Gauge Sites
Grid Dimensions: 1224 x 1944
Grid Resolution: 2m
Gauges
WaveMaker
01
02
03
04
05
06
07
08
09
10
11
Y Distance m
X Distance m
3500
3000
2500
2000
1500
1000
500
500
1000
1500
2000
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20
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0
-10
-20
-30
-40

ST GEORGE NORTH New Scatter Set (2019-07)

ALTERNATIVE-1 HARBOR DESIGN CONFIGURATION (with spur)

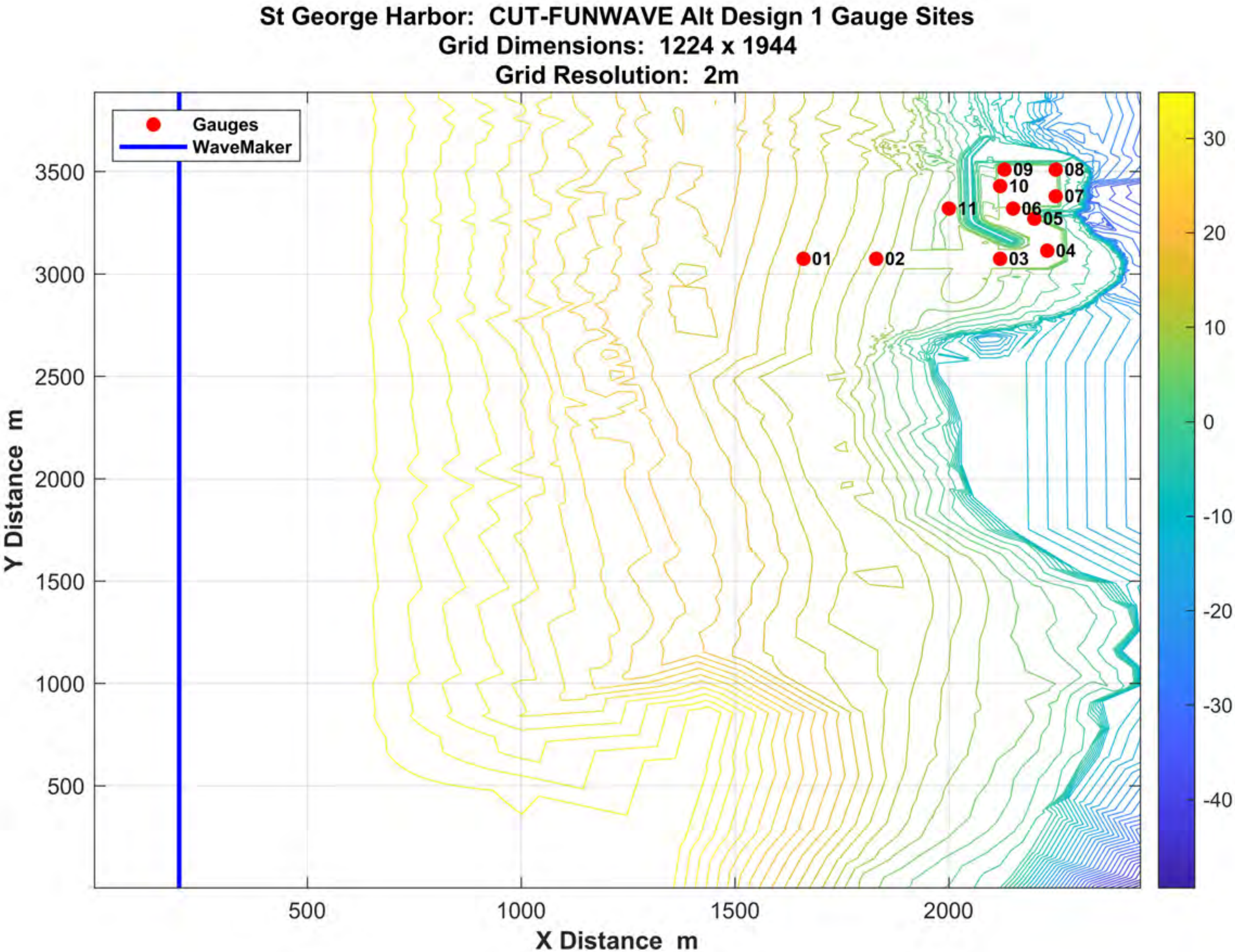
INPUT CONDITIONS (1-8 TEST CASES / 9-11 REAL CASES FROM EXTREMES)

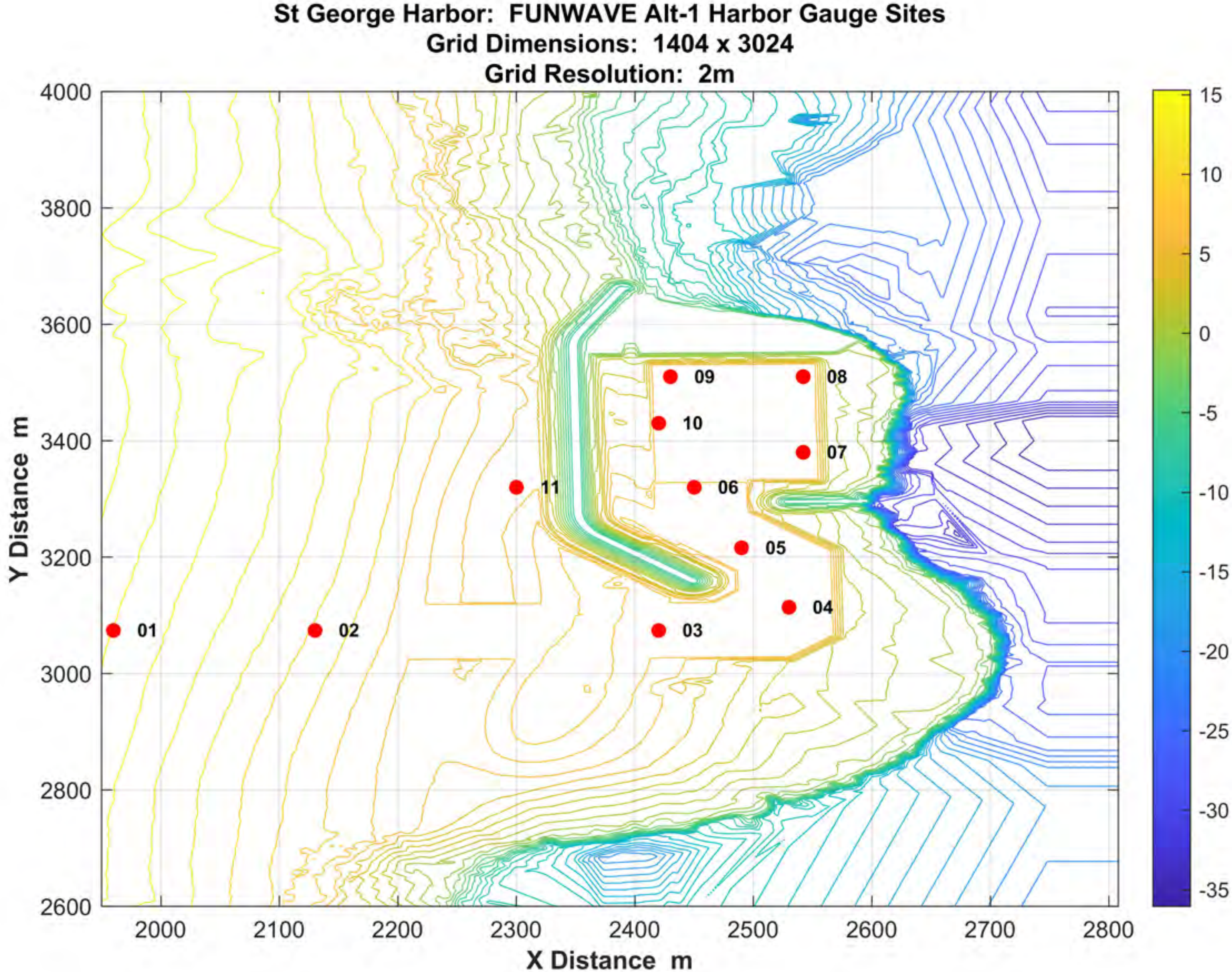
R.E. Jensen Run 2019-11

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	HFW_1	HFW_2	HFW_3	HFW_4	HFW_5	HFW_6	HFW_7	HFW_8	HFW_9	HFW_10	HFW_11
401	1	6	20	1	6	20	0.614	0.588	0.454	0.358	0.105	0.058	0.038	0.039	0.053	0.044	0.603
402	1.2	6	20	1.2	6	20	0.736	0.696	0.545	0.429	0.130	0.070	0.047	0.048	0.067	0.052	0.718
403	2	8	20	2	8	20	1.585	1.566	1.723	1.103	0.392	0.229	0.173	0.180	0.200	0.214	1.558
404	3	10	20	3	10	20	2.419	2.405	2.099	1.693	0.638	0.428	0.369	0.367	0.440	0.431	3.274
405	4	11	20	4	11	20	3.376	3.484	3.366	2.338	1.037	0.712	0.645	0.703	0.773	0.722	4.268
406	5	12	20	5	12	20	5.858	5.787	4.947	3.291	1.576	1.273	1.195	1.370	1.329	1.315	5.514
407	6	14	20	6	14	20	5.858	5.787	4.947	3.291	1.576	1.273	1.195	1.370	1.329	1.315	5.514
408	7	17	20	7	17	20	6.083	6.148	5.963	3.922	1.969	1.533	1.369	1.478	1.526	1.478	5.475
409	12.28	16.18	278	7.13	16.34	38.1	6.072	5.987	5.822	4.231	1.833	1.363	1.172	1.262	1.305	1.295	5.231
410	10.35	11.16	326	4.25	12.29	21.2	4.145	4.301	3.911	2.561	1.163	0.908	0.896	0.946	1.014	0.933	4.736
411	8.98	12.05	4	3.76	13.51	19.1	4.118	4.178	4.122	2.587	1.134	0.797	0.745	0.790	0.862	0.854	4.405

RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	TFW_1	TFW_2	TFW_3	TFW_4	TFW_5	TFW_6	TFW_7	TFW_8	TFW_9	TFW_10	TFW_11
401	1	6	20	1	6	20	6.024	6.400	6.024	6.400	12.800	6.024	51.200	12.800	12.800	6.827	6.024
402	1.2	6	20	1.2	6	20	6.024	6.400	6.024	6.400	12.800	12.800	51.200	12.800	12.800	12.800	6.024
403	2	8	20	2	8	20	7.877	7.877	8.533	8.533	8.533	102.400	102.400	102.400	51.200	7.877	9.309
404	3	10	20	3	10	20	9.309	10.240	10.240	9.309	11.378	468.114	468.114	102.400	102.400	468.114	10.240
405	4	11	20	4	11	20	10.240	10.240	10.240	10.240	11.378	409.600	409.600	409.600	409.600	409.600	11.378
406	5	12	20	5	12	20	12.800	12.800	12.800	12.800	655.360	655.360	655.360	655.360	655.360	655.360	12.800
407	6	14	20	6	14	20	12.800	12.800	12.800	12.800	655.360	655.360	655.360	655.360	655.360	655.360	12.800
408	7	17	20	7	17	20	17.067	17.067	17.067	17.067	3276.800	409.600	409.600	409.600	409.600	409.600	8.533
409	12.28	16.18	278	7.13	16.34	38.1	17.067	17.067	14.629	17.067	102.400	409.600	409.600	409.600	409.600	409.600	8.533
410	10.35	11.16	326	4.25	12.29	21.2	12.800	12.800	12.800	12.800	102.400	468.114	468.114	468.114	468.114	468.114	12.800
411	8.98	12.05	4	3.76	13.51	19.1	12.800	12.800	12.800	12.800	102.400	102.400	409.600	102.400	409.600	409.600	12.800

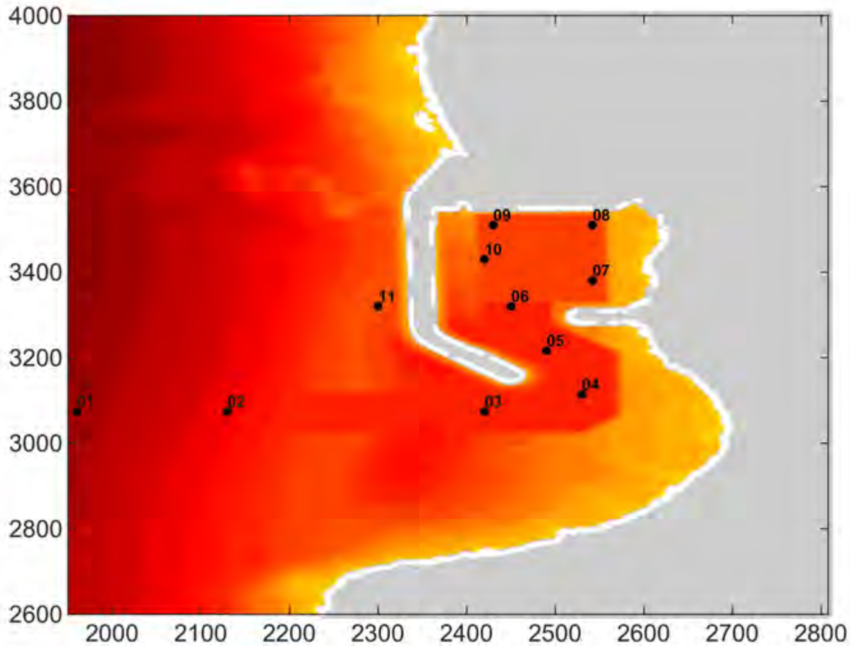
RUNNO	HWAM	TWAM	THWAM	HSTW	TSTW	THSTW	CFW_1	CFW_2	CFW_3	CFW_4	CFW_5	CFW_6	CFW_7	CFW_8	CFW_9	CFW_10	CFW_11
401	1	6	20	1	6	20	0.286	0.339	0.360	0.136	0.098	0.038	0.033	0.030	0.046	0.377	0.277
402	1.2	6	20	1.2	6	20	0.341	0.390	0.467	0.169	0.147	0.049	0.039	0.037	0.058	0.448	0.338
403	2	8	20	2	8	20	0.845	1.064	1.135	0.779	0.444	0.191	0.188	0.187	0.470	2.049	1.183
404	3	10	20	3	10	20	2.232	2.420	2.399	1.635	0.599	0.295	0.373	0.339	0.607	3.801	3.211
405	4	11	20	4	11	20	2.446	3.491	3.683	2.693	0.850	0.474	0.451	0.472	0.733	4.505	3.611
406	5	12	20	5	12	20	5.138	5.625	5.670	3.016	1.227	0.857	0.933	0.977	0.974	7.160	4.954
407	6	14	20	6	14	20	5.138	5.625	5.670	3.016	1.227	0.857	0.933	0.977	0.974	7.160	4.954
408	7	17	20	7	17	20	4.759	5.384	7.788	3.425	1.689	1.150	1.201	0.978	1.264	8.746	4.589
409	12.28	16.18	278	7.13	16.34	38.1	4.351	5.041	5.525	2.666	1.497	1.027	0.868	0.932	1.171	8.645	3.672
410	10.35	11.16	326	4.25	12.29	21.2	4.114	4.949	4.341	3.159	1.059	0.657	0.727	0.754	0.847	6.884	3.944
411	8.98	12.05	4	3.76	13.51	19.1	3.446	3.562	4.184	2.728	0.865	0.587	0.671	0.790	0.751	5.797	3.653

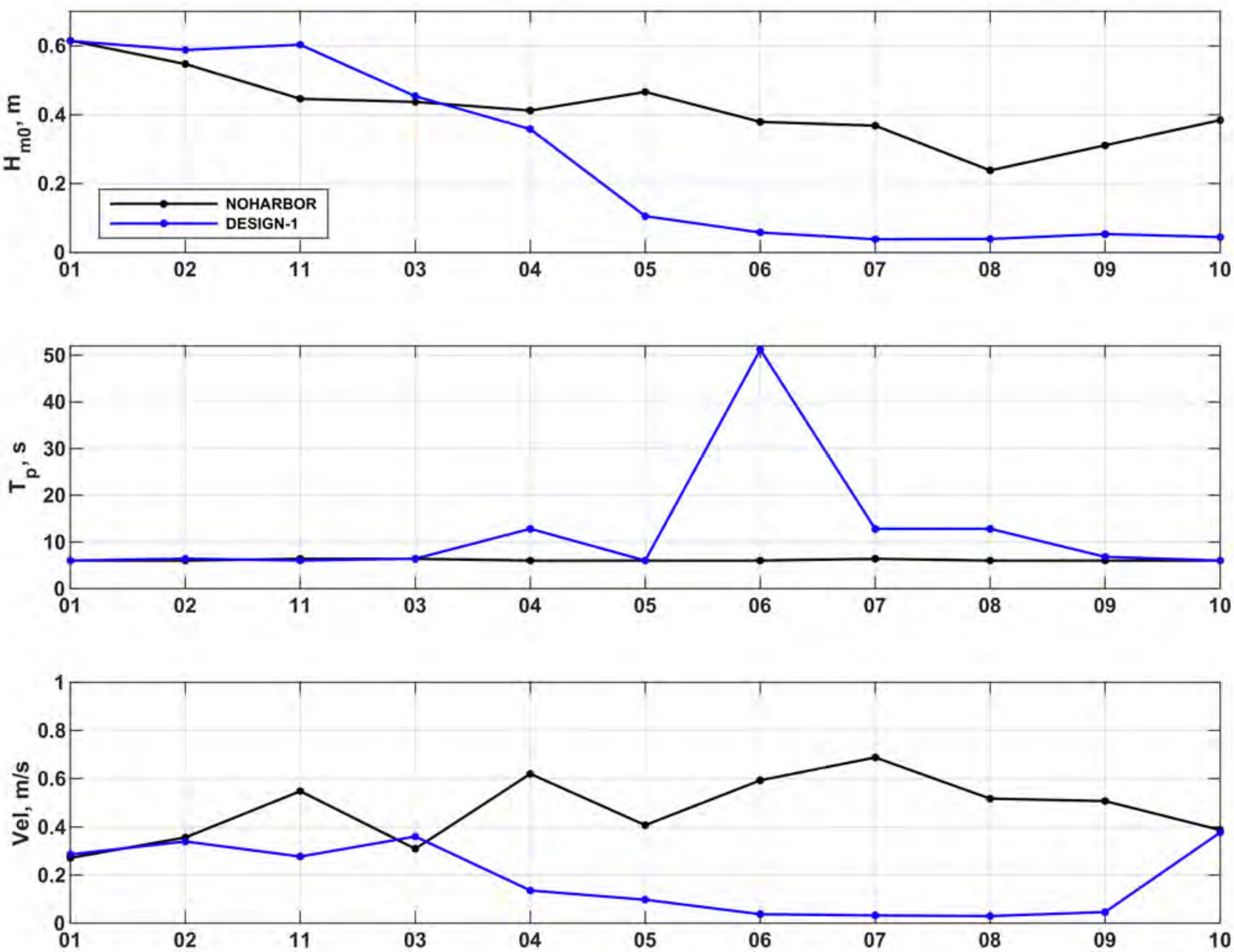

St George Harbor: CUT-FUNWAVE Alt Design 1 Gauge Sites
Grid Dimensions: 1224 x 1944
Grid Resolution: 2m
Gauges
WaveMaker
01
02
03
04
05
06
07
08
09
10
11
Y Distance m
X Distance m
500
1000
1500
2000
2500
3000
3500
30
20
10
0
-10
-20
-30
-40



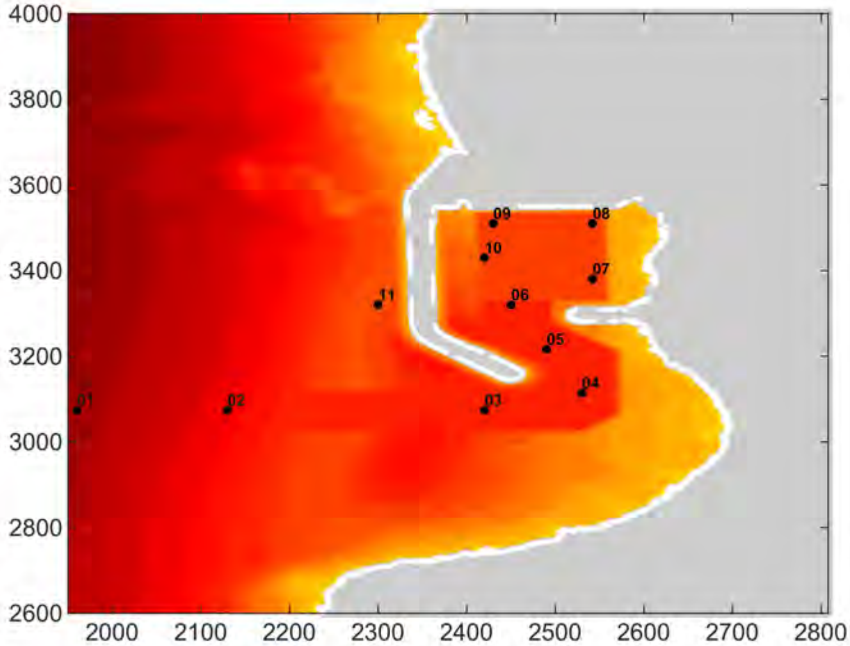
St George Harbor: FUNWAVE Alt-1 Harbor Gauge Sites
Grid Dimensions: 1404 x 3024
Grid Resolution: 2m
Y Distance m
X Distance m
4000
3800
3600
3400
3200
3000
2800
2600
2000
2100
2200
2300
2400
2500
2600
2700
2800
01
02
03
04
05
06
07
08
09
10
11
15
10
5
0
-5
-10
-15
-20
-25
-30
-35

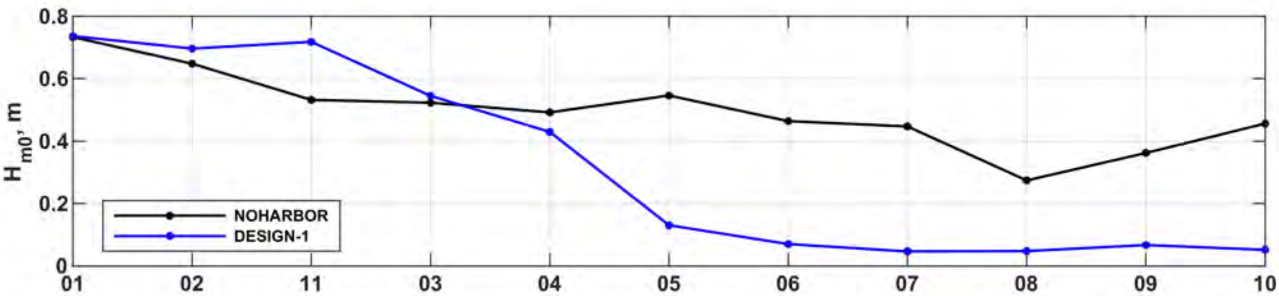
St George Harbor Study
RUN-301-401
H_{mo} = 1.00m
T_{pp} = 6.00s
θ_{wave} = 20.0°
Grid Dim. (m): (2808,6048)
Grid Res: 2m
Total Gauges: 11

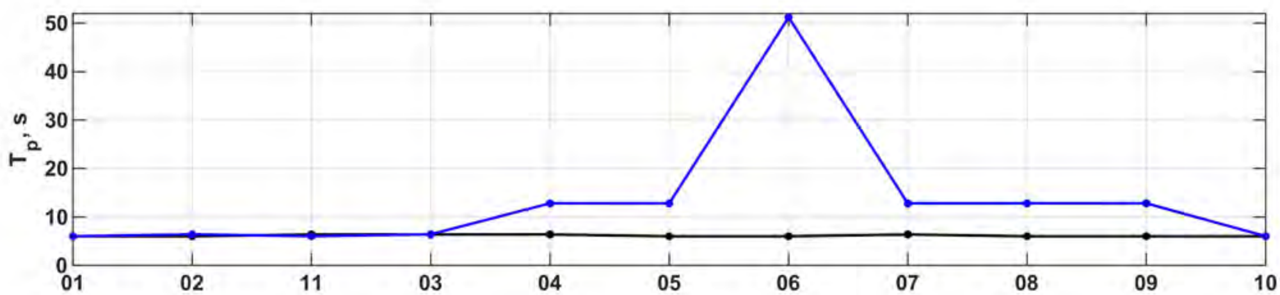


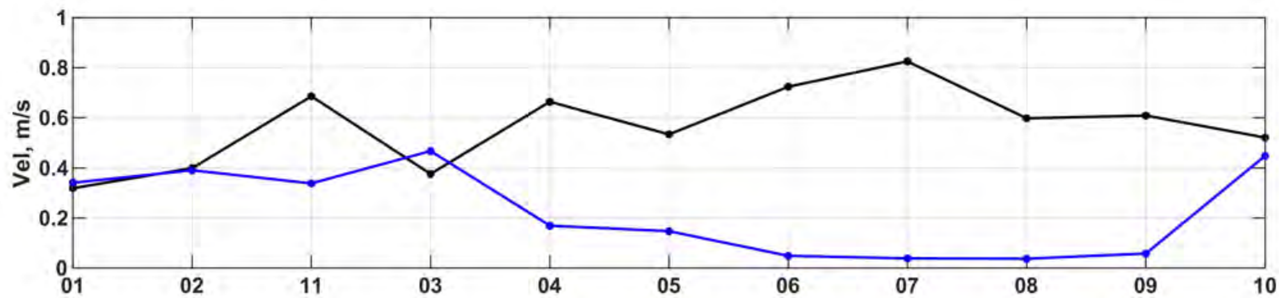


St George Harbor Study
RUN-302-402
H_{mo} = 1.20m
T_{pp} = 6.00s
θ_{wave} = 20.0°
Grid Dim. (m): (2808,6048)
Grid Res: 2m
Total Gauges: 11

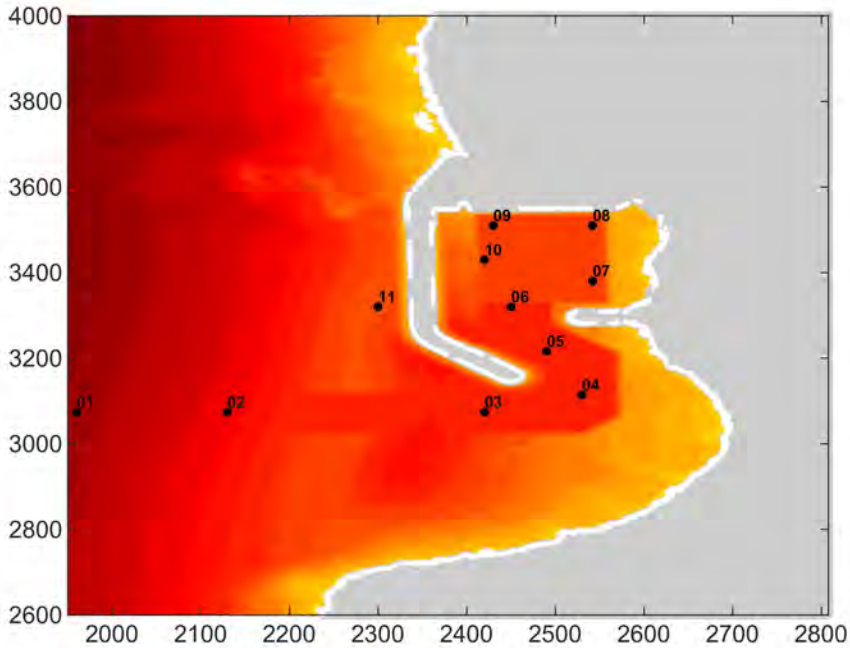


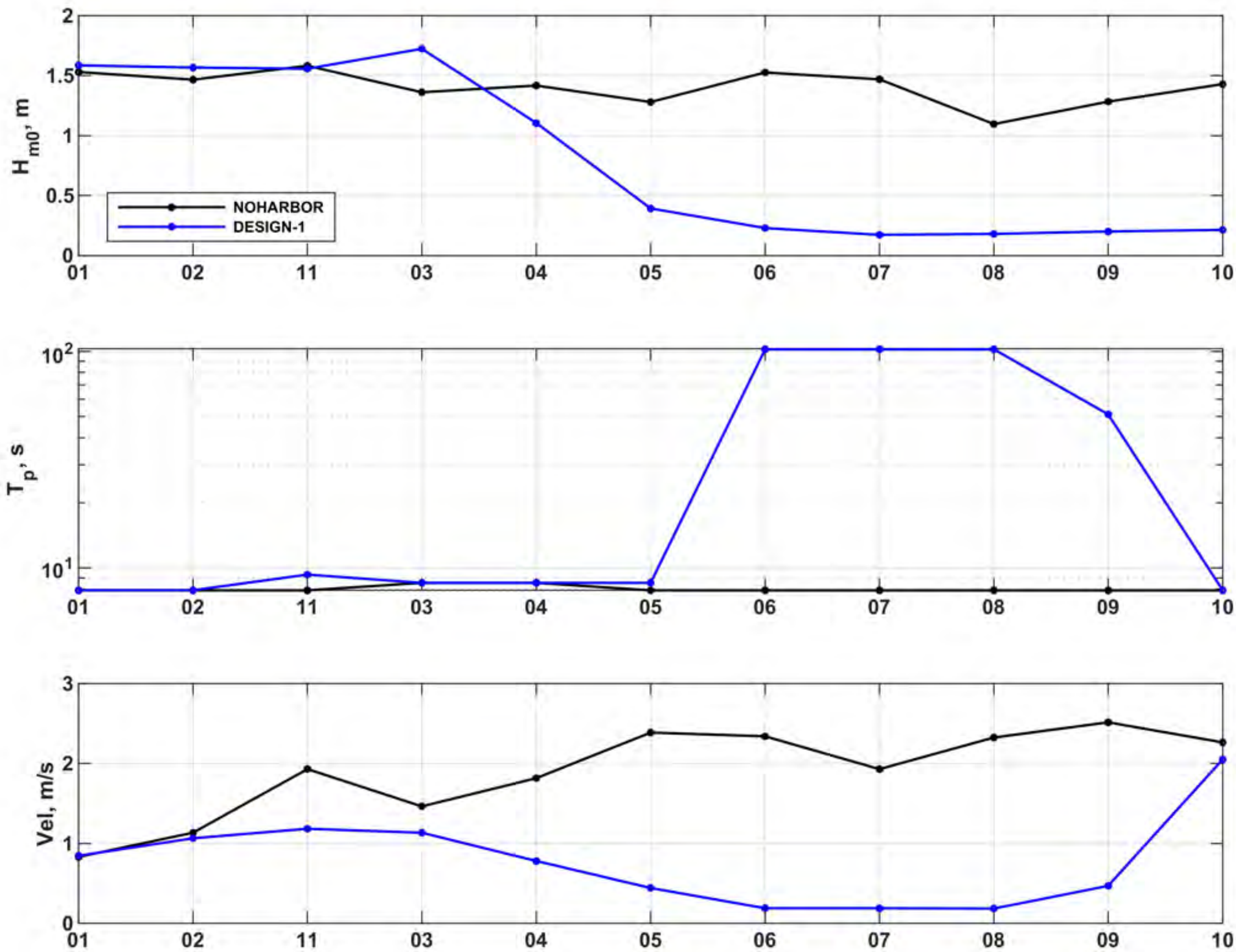




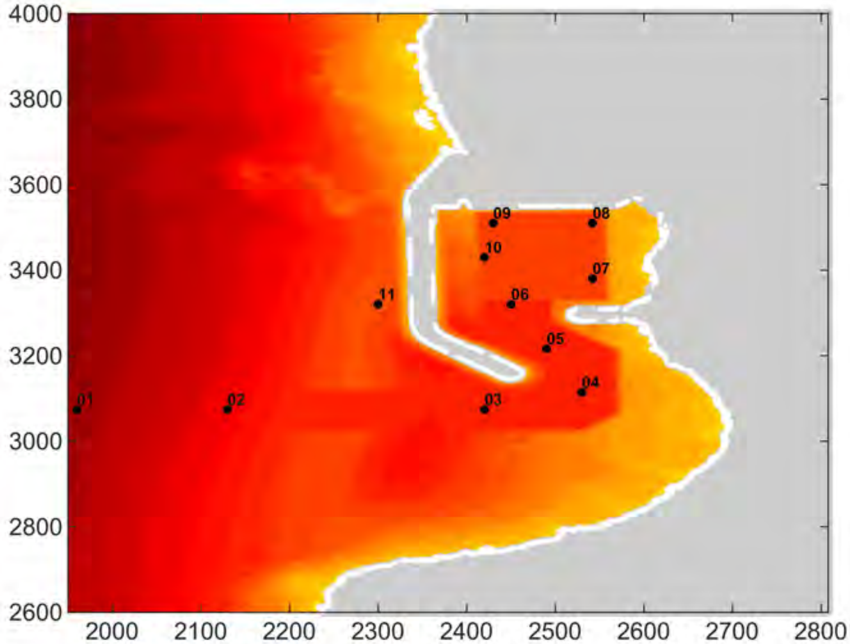


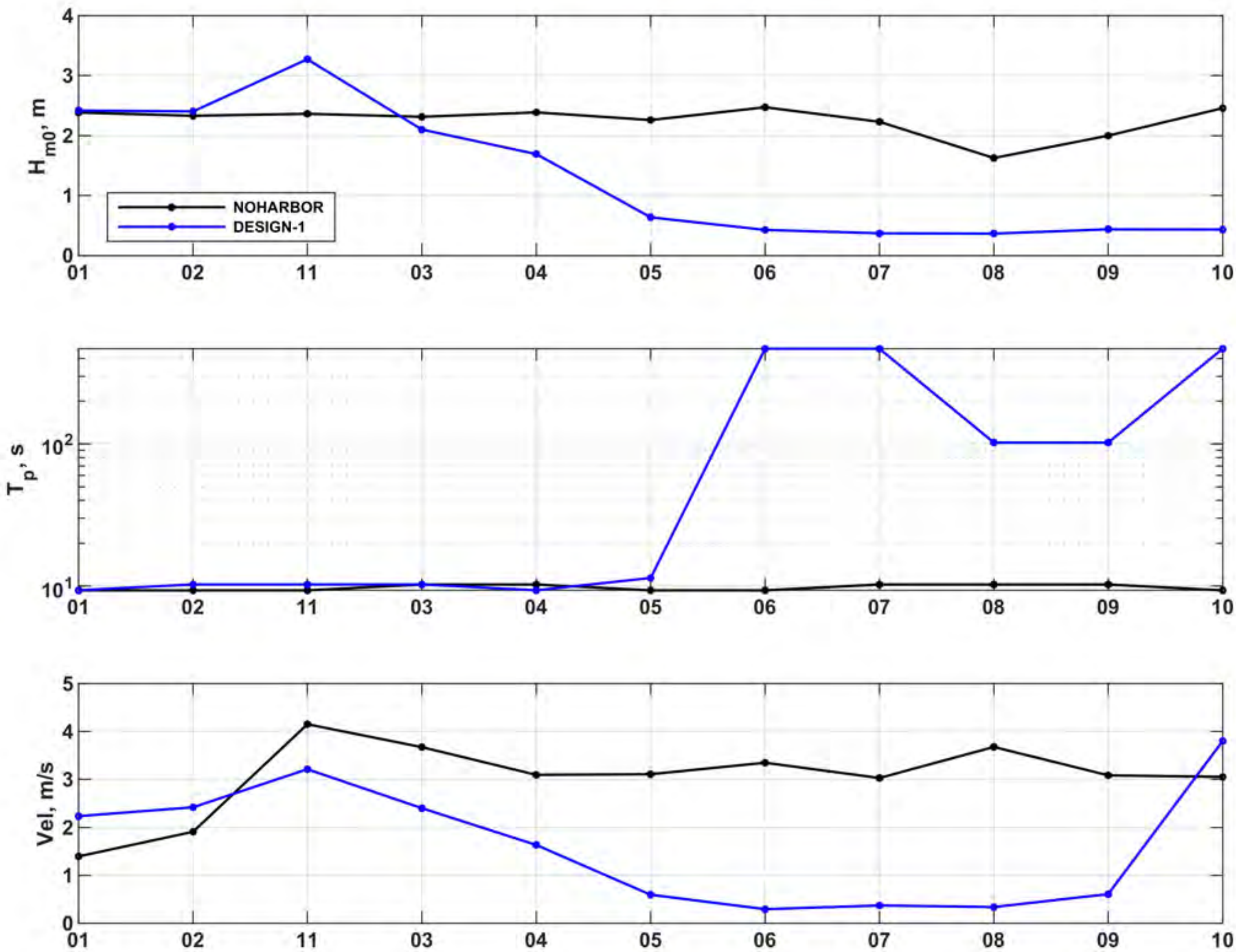
St George Harbor Study
RUN-303-403
H_{mo} = 2.00m
T_{pp} = 8.00s
θ_{wave} = 20.0°
Grid Dim. (m): (2808,6048)
Grid Res: 2m
Total Gauges: 11



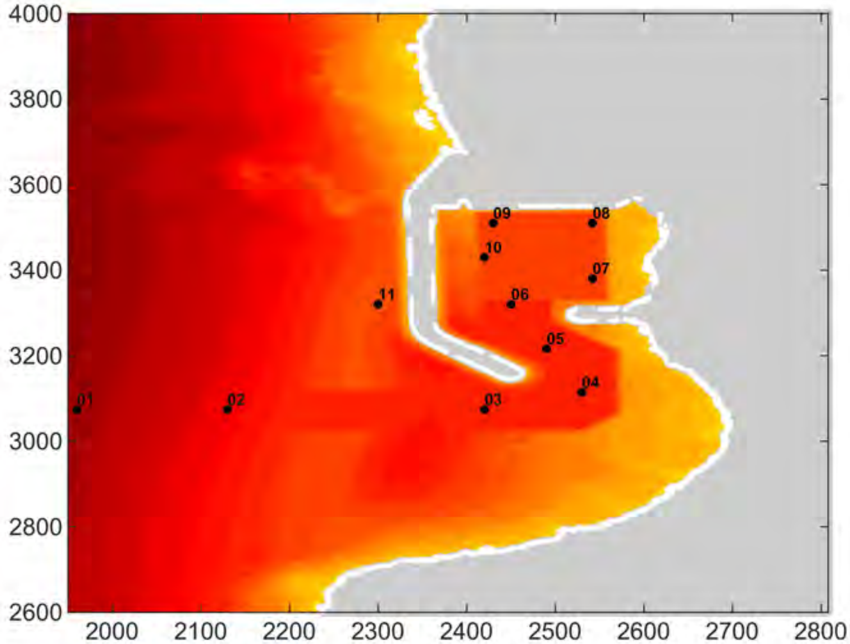


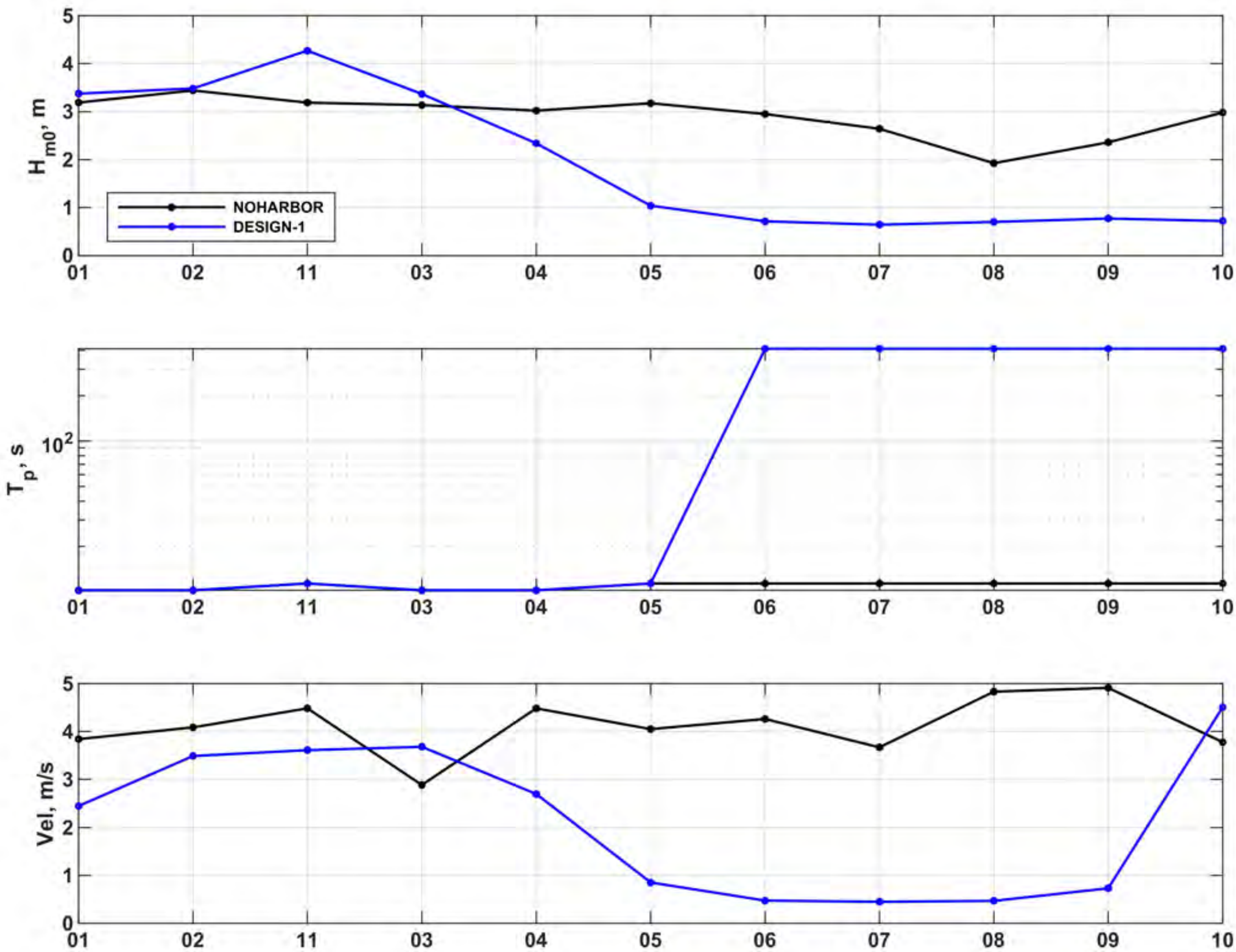
St George Harbor Study
RUN-304-404
H_{mo} = 3.00m
T_{pp} = 10.00s
θ_{wave} = 20.0°
Grid Dim. (m): (2808,6048)
Grid Res: 2m
Total Gauges: 11

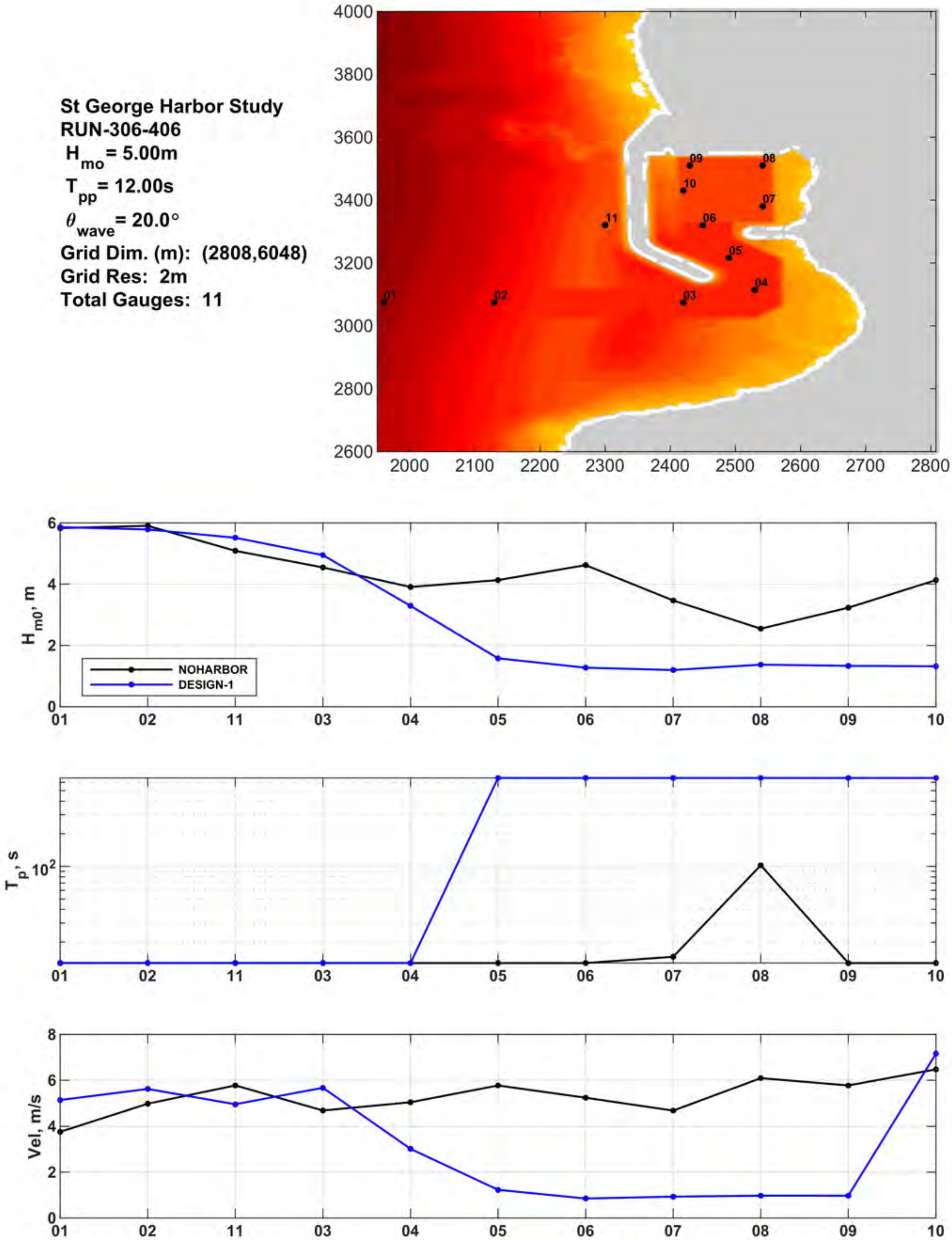




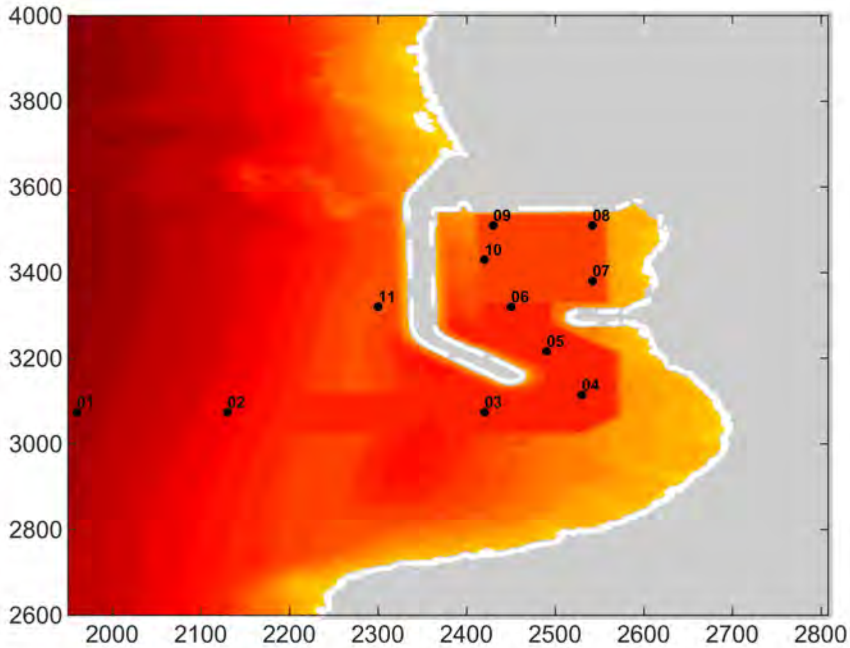
St George Harbor Study
RUN-305-405
H_{mo} = 4.00m
T_{pp} = 11.00s
θ_{wave} = 20.0°
Grid Dim. (m): (2808,6048)
Grid Res: 2m
Total Gauges: 11

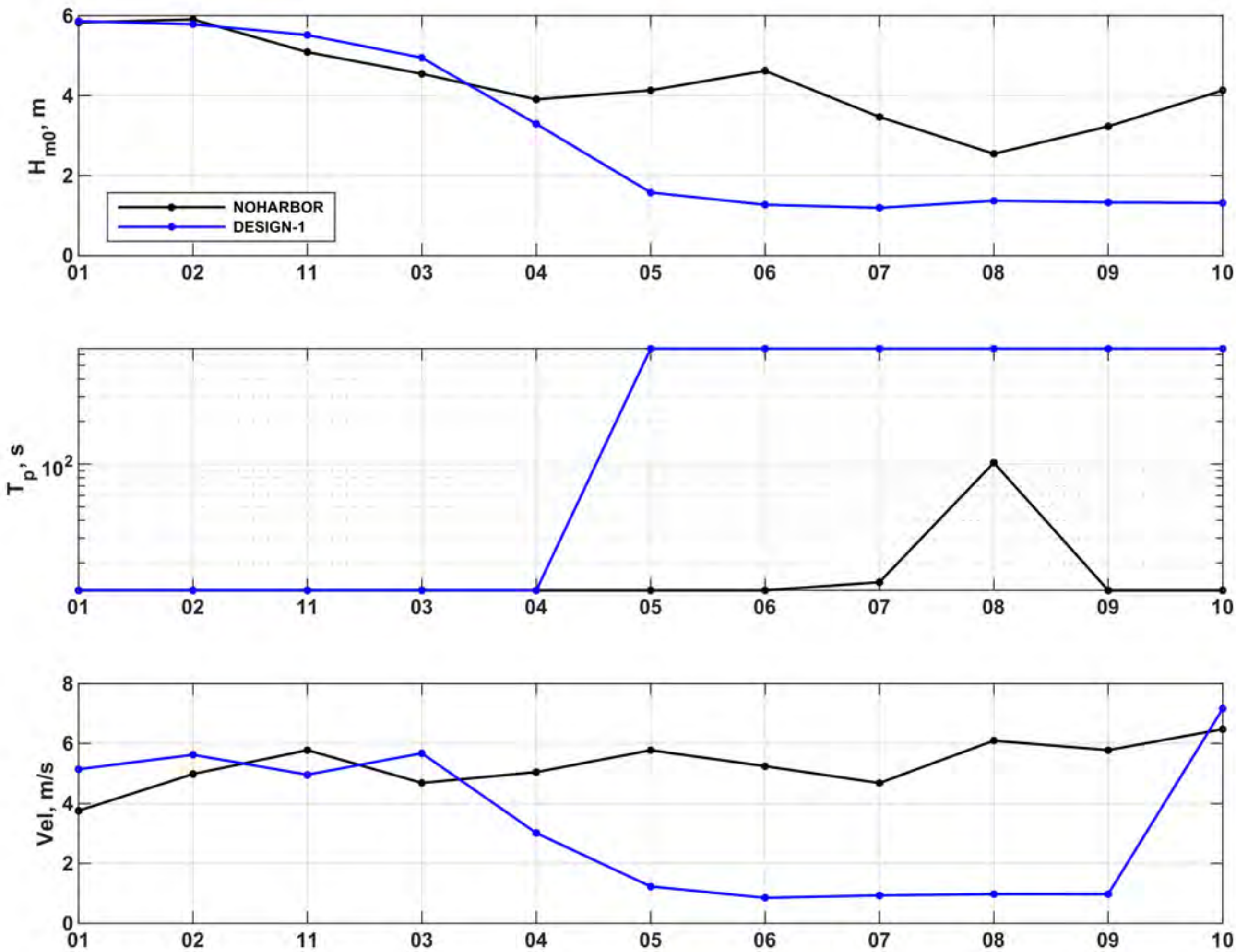




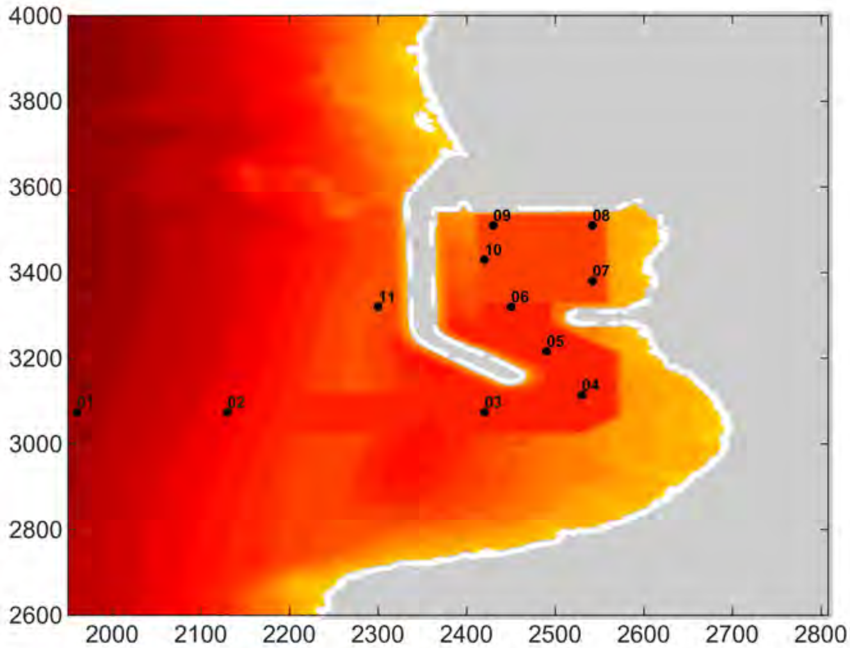

St George Harbor Study
RUN-306-406
H_{mo} = 5.00m
T_{pp} = 12.00s
θ_{wave} = 20.0°
Grid Dim. (m): (2808,6048)
Grid Res: 2m
Total Gauges: 11
NOHARBOR
DESIGN-1
H_{m0}, m
T_p, s
Vel, m/s

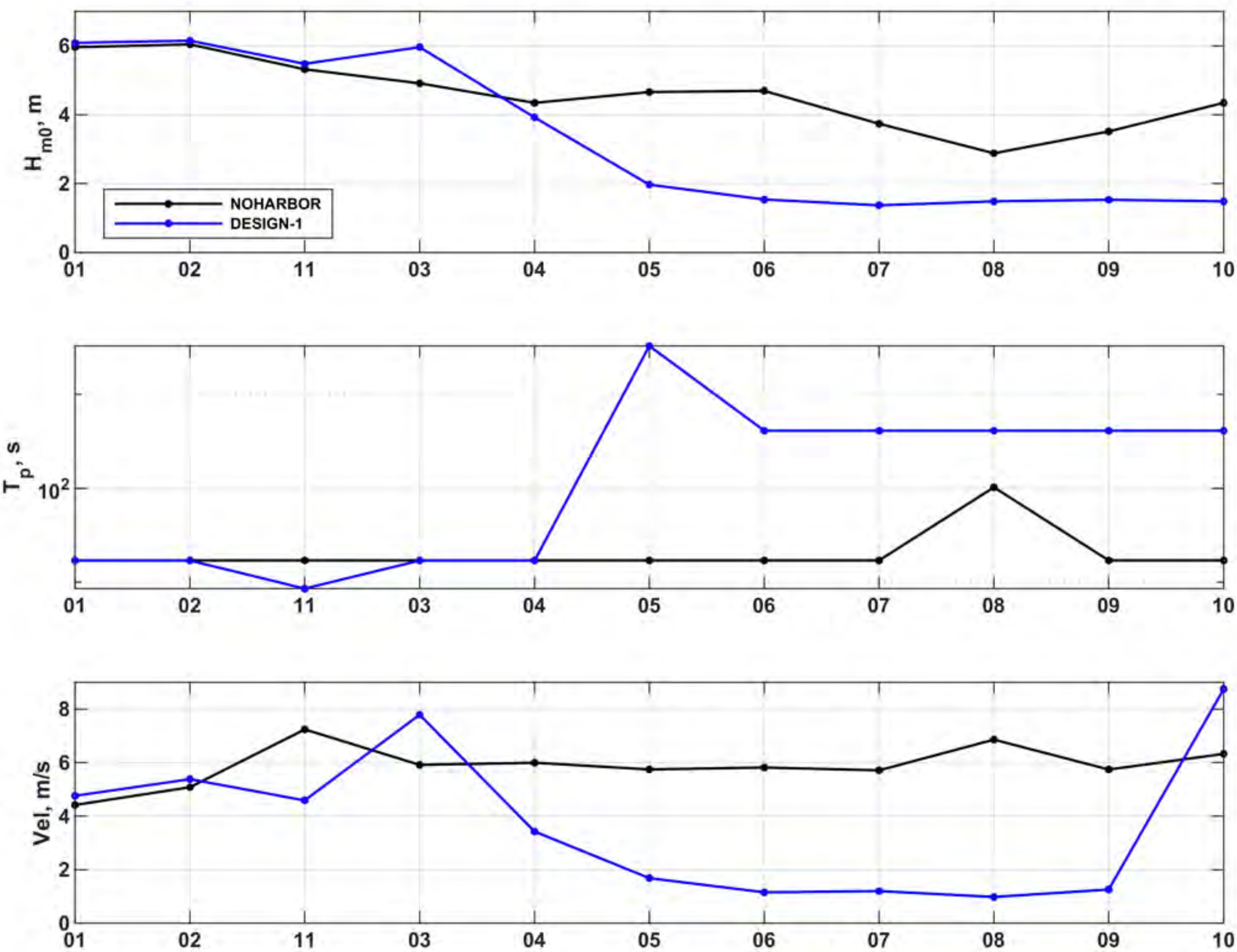
St George Harbor Study
RUN-307-407
H_{mo} = 6.00m
T_{pp} = 14.00s
θ_{wave} = 20.0°
Grid Dim. (m): (2808,6048)
Grid Res: 2m
Total Gauges: 11



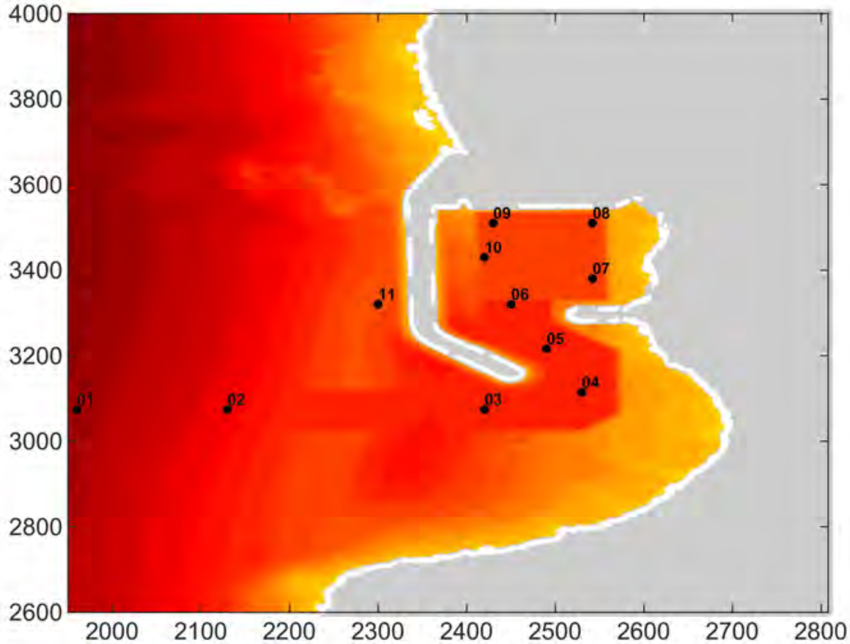


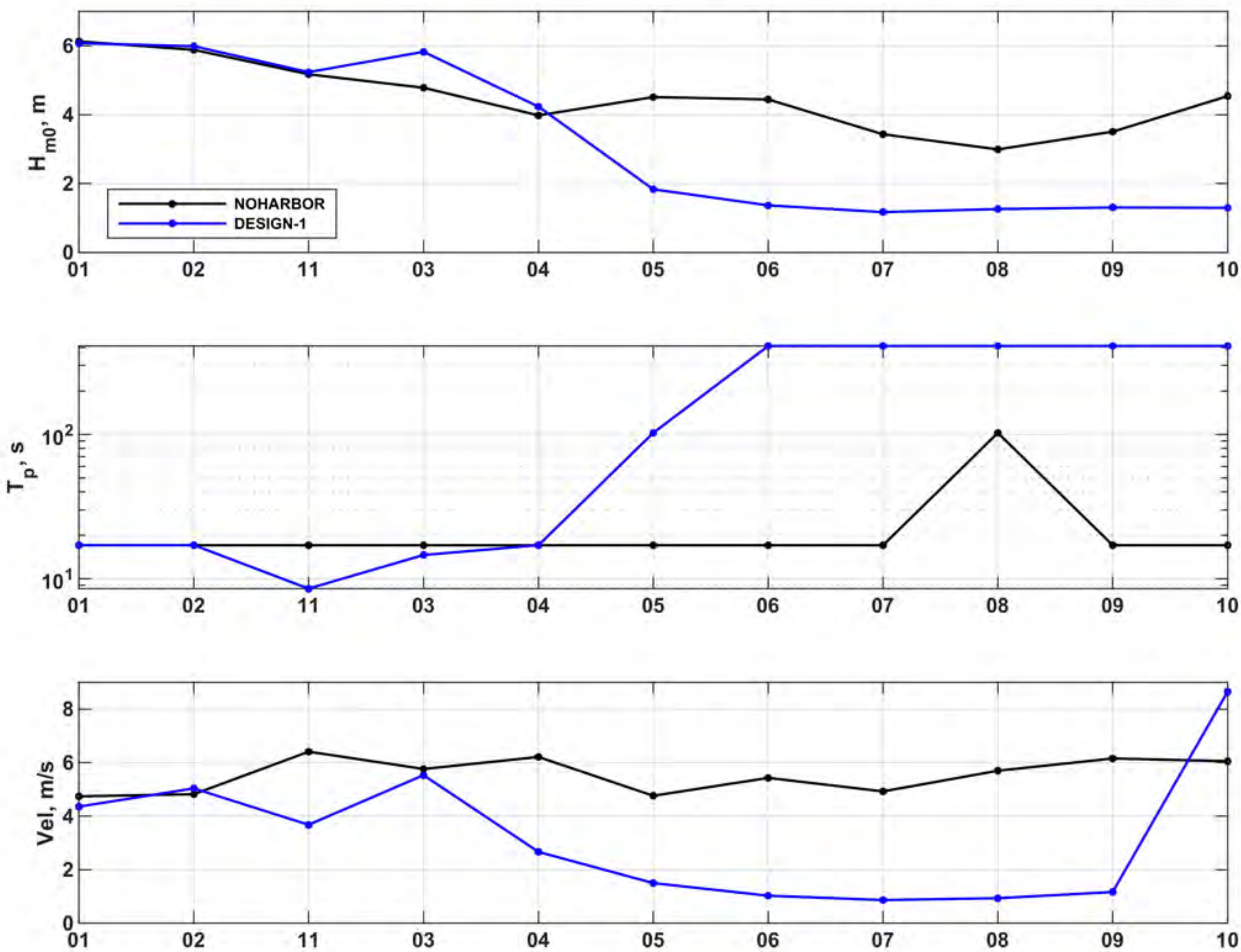
St George Harbor Study
RUN-308-408
H_{mo} = 7.00m
T_{pp} = 17.00s
θ_{wave} = 20.0°
Grid Dim. (m): (2808,6048)
Grid Res: 2m
Total Gauges: 11



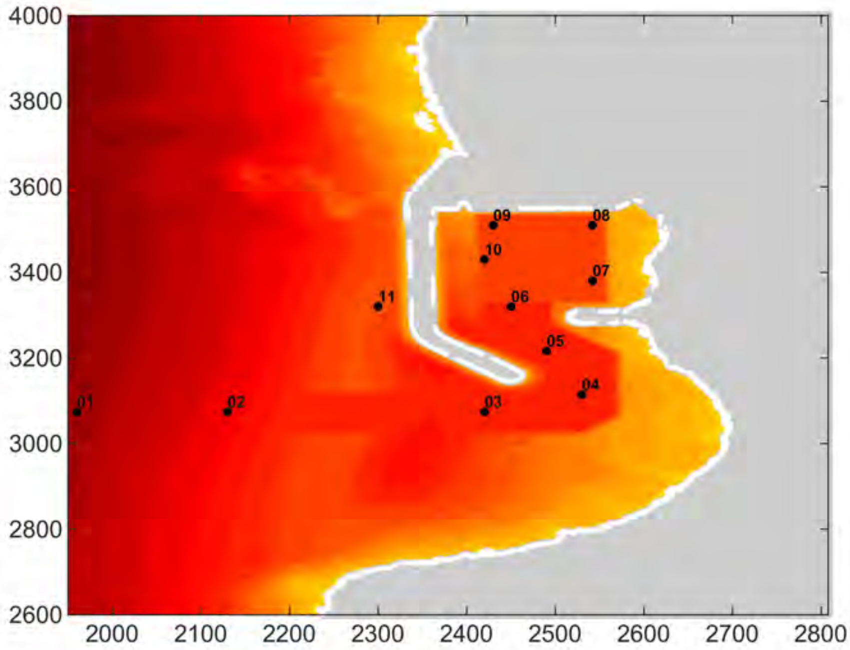


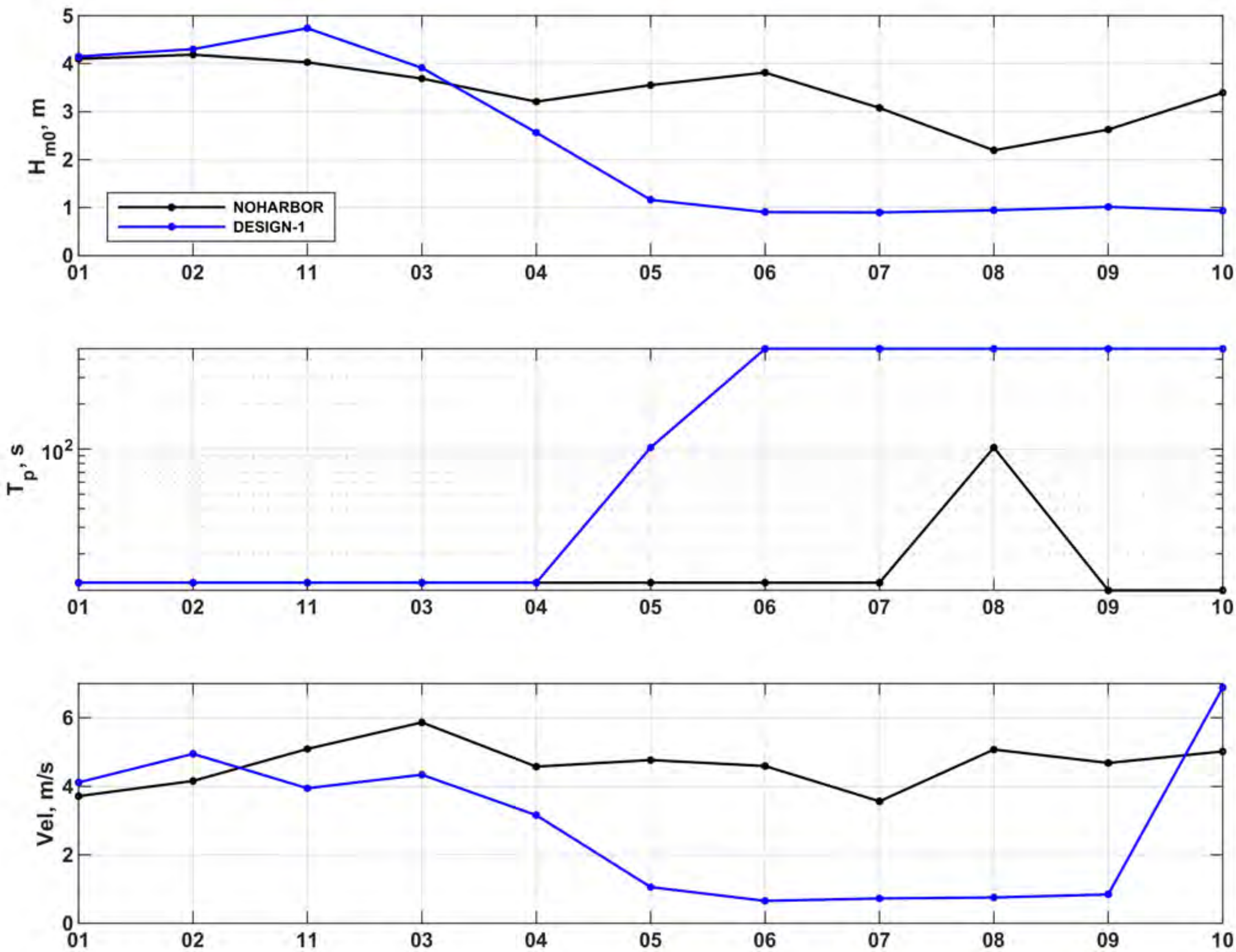
St George Harbor Study
RUN-309-409
H_{mo} = 7.13m
T_{pp} = 16.34s
θ_{wave} = 38.1°
Grid Dim. (m): (2808,6048)
Grid Res: 2m
Total Gauges: 11



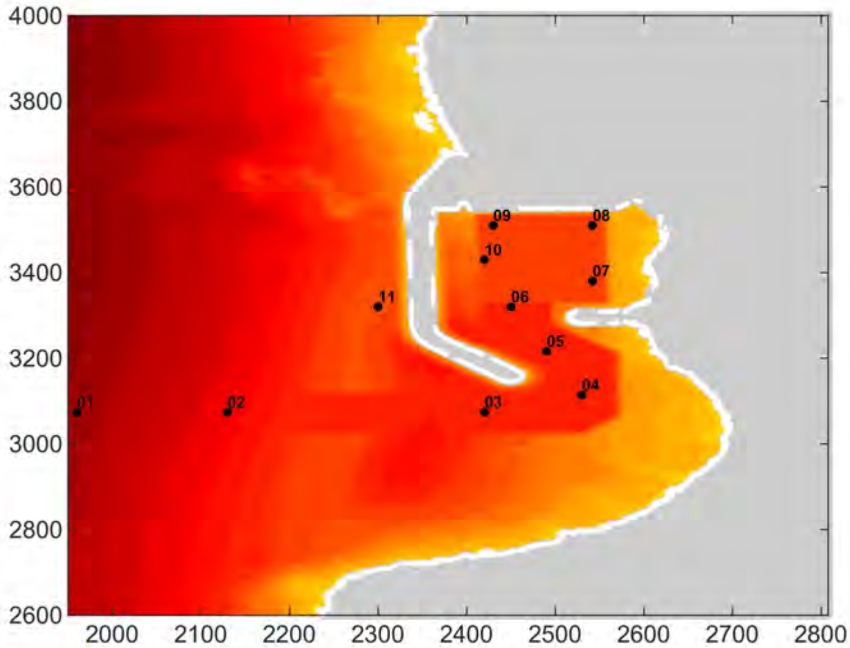


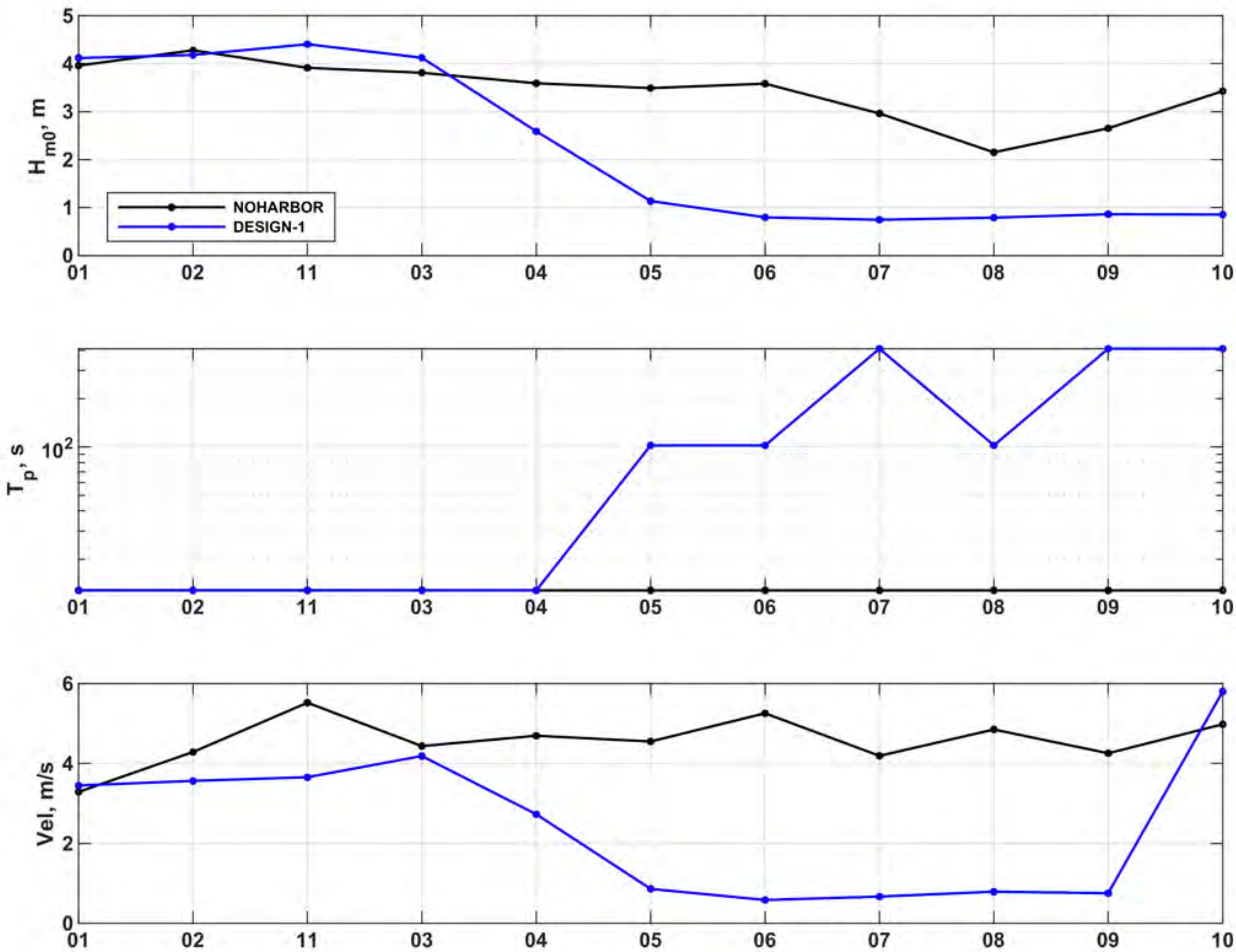
St George Harbor Study
RUN-310-410
H_{mo} = 4.25m
T_{pp} = 12.29s
θ_{wave} = 21.2°
Grid Dim. (m): (2808,6048)
Grid Res: 2m
Total Gauges: 11

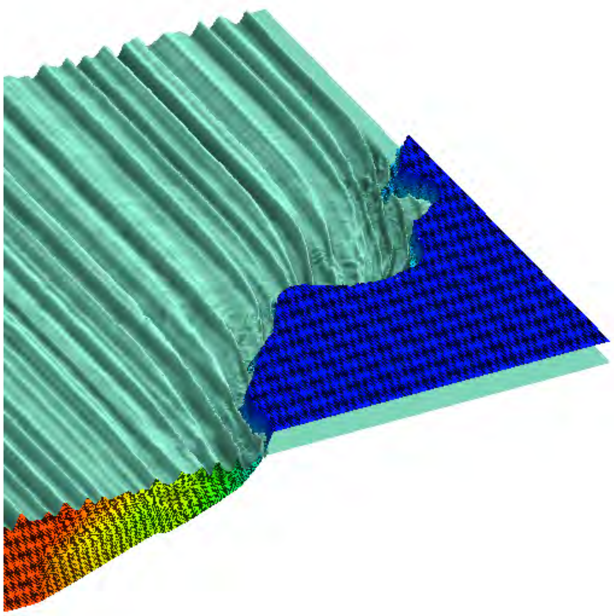




St George Harbor Study
RUN-311-411
H_{mo} = 3.76m
T_{pp} = 13.51s
θ_{wave} = 19.1°
Grid Dim. (m): (2808,6048)
Grid Res: 2m
Total Gauges: 11







North Harbor Site Modeling Report

St. George Harbor Feasibility Study – Wave Modeling

BOUSS-2D model comparing existing conditions with a proposed harbor concept on the north side of St. George Island

St. George, Alaska

September 13, 2019

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Table of Contents

List of Tables

List of Figures

Acronyms and Abbreviations

DHI	Danish Hydraulic Institute
ft^2	square feet
H_{mo}	spectral significant wave height
Hz	Hertz
m^2	square meters
m^2/Hz	spectral energy
MIKE21 SW	MIKE21 Spectral Wave Model FM
MLLW	Mean Lower Low Water
NAD'83	North American Datum of 1983
SI	Standard International
SMS	Surface-water Modeling Suite
SW	Spectral Wave
T_p	peak wave period
USACE	U.S. Army Corps of Engineers
UTM	Universal Transverse Mercator

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Overview

This report documents a wave modeling effort of the northern harbor site at St. George Island as part of the broader U.S. Army Corps of Engineers (USACE) St. George Harbor Feasibility Study. The primary purpose of this modeling is to simulate targeted wave conditions at the northern harbor site for the existing condition (i.e., no harbor improvement) and a single proposed harbor configuration. The model software used to simulate these wave conditions is BOUSS-2D, a time-domain, phase-resolving, Boussinesq model. The computational requirements of the BOUSS-2D model limit the model domain size. Therefore, a regional-scale spectral wave model is used to propagate offshore waves to the BOUSS-2D model boundary. The regional spectral wave model is performed using MIKE21 Spectral Wave (SW) Model FM (MIKE21 SW).

Model parameters, setup, and results of both the MIKE21 SW model and BOUSS-2D model are provided herein.

MIKE21 SW Introduction

A MIKE21 SW numerical model was developed to simulate regional-scale wave propagation from offshore (deep-water) areas to the nearshore areas around the proposed St. George Harbor. The purpose of the model is to efficiently propagate wave characteristics from an offshore depth that is representative of the location in which the input offshore wave conditions were developed to the location of the BOUSS-2D wave model boundary. The results are then applied as input for local the phase-resolved BOUSS-2D model.

MIKE21 SW Setup and Parameters

Model Description

MIKE21 SW, developed by the Danish Hydraulic Institute (DHI), is a spectral wind-wave model based on a flexible (unstructured) mesh. The model simulates growth, decay, and transformation of wind-generated waves and swell in offshore and coastal areas (DHI 2008). MIKE21 SW was applied to analyze wave propagation and transformation from the 60-meter depth contour north of St. George Island to assist in the proposed harbor wave analyses.

Units, Coordinate System, and Datum

All units within the model are in the SI (Standard International) system. Horizontal coordinates are relative to Universal Transverse Mercator (UTM) Zone 2. The horizontal datum is North American Datum of 1983 (NAD’83). The vertical datum is Mean Lower Low Water (MLLW). Units are presented in SI units.

Direction Convention

Wave direction follows the meteorological convention for input and output, indicating direction of origin (direction from which the wave travels).

Model Domain

The model domain parallels the north side of St. George Island with the offshore limit representing the -60-meter contour. This approach allows waves to be forced from a depth representative of the offshore input wave condition. The flexible mesh contains 3,007 elements ranging in size from about 5,000 square meters (m^2) to 50,000 m^2 (54,000 square feet [ft^2] to 538,000 ft^2). Element size was selected to provide adequate resolution near the BOUSS-2D offshore boundary and was increased in regions outside the area of interest to maintain computational efficiency. Bathymetry for the model domain was developed using data provided by the USACE titled "PribilofUTM2m – PRIBILOF-OG.h5." Figure 1 provides a rendering of the wave model domain.

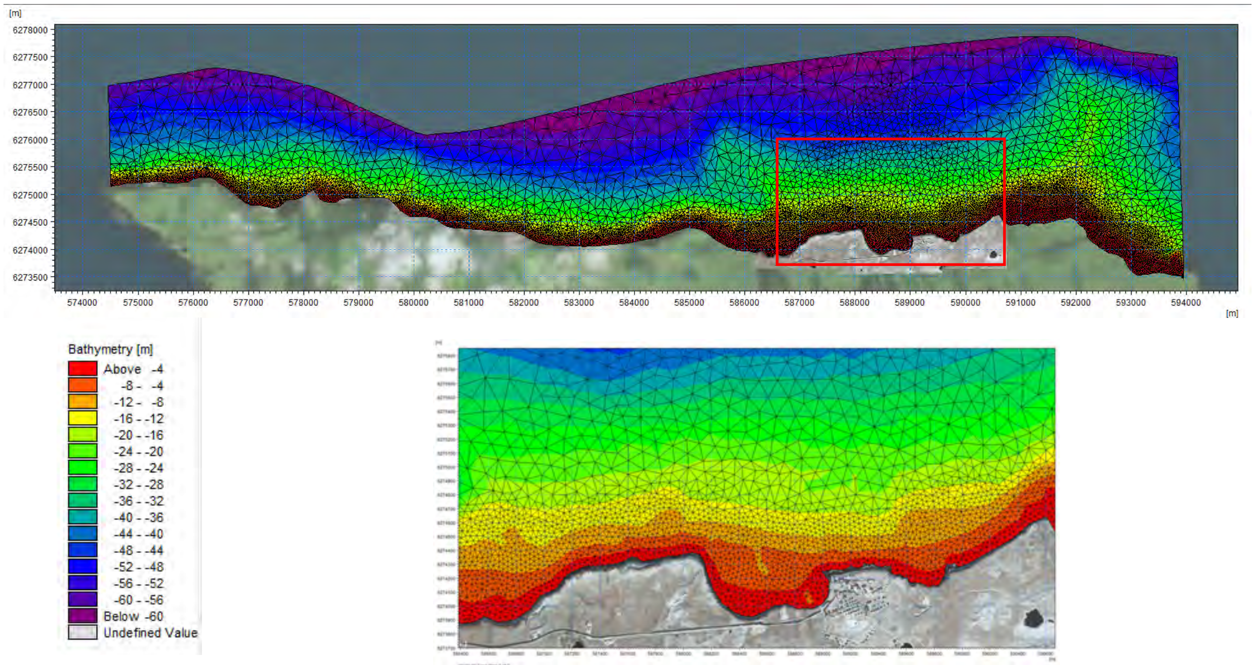

Figure 1. MIKE21 SW Model Domain

Boundary Conditions

The model domain shown in Figure 1 contains two types of boundary conditions: offshore boundary and land boundary. Descriptions of the boundaries are provided below.

- **Offshore Boundary** – The offshore boundary forces all of the waves for the modeling, regardless of wave direction. The offshore boundary is located along the -60-meter contour. Eleven wave conditions were forced along the offshore boundary. For each wave condition, wave height, wave period, and wave direction were provided by the USACE. Spreading index was inferred based on guidance from the USACE (2001a). Table 1 provides the offshore input wave conditions used to force the offshore boundary.

Table 1. MIKE21 SW Offshore Boundary Conditions

Wave Height H_{mo} (m)	Wave Period T_p (s)	Wave Direction ϴ (deg.)	Directional Spreading Index
1.00	6.00	315.0	4
1.20	6.00	315.0	4
2.00	8.00	315.0	4
3.00	10.00	315.0	4
4.00	11.00	315.0	8
5.00	12.00	315.0	10
6.00	14.00	315.0	16
7.00	17.00	315.0	22
7.13	16.34	325.9	20
4.25	12.29	323.8	10
3.76	13.51	306.9	14

Note: m = meters; s = seconds; deg. = degrees

- **Land Boundary** – The land boundary is specified along the shoreline of St. George Island and the domain sides (perpendicular to the shoreline). The boundary is assigned as a “Closed Boundary.” Waves are not allowed to travel through the boundary and are completely absorbed (no reflection). Because of this boundary condition, the model is not considered suitable for detailed analysis of wave conditions within the proposed harbor (the breakwaters and other lateral boundaries within the actual harbor are reflective).

Water Level

As directed by the USACE, water level was maintained at a constant elevation of +1.8 meters MLLW.

Waves

Waves were forced into the domain at the offshore boundary. Wave parameters specified include significant wave height, peak period, mean wave direction, and directional spreading index. From these parameters, the model forces a JONSWAP spectrum along the boundary. The model uses a quasi-stationary formulation, meaning that iterations in the model continue until the conditions reach a steady state for each input condition. Time is an independent variable.

Currents

Currents were not forced within the model as a boundary condition or initial condition. All boundaries of the model domain are closed, meaning that water is not allowed to enter or exit the domain.

Model Parameters

Wave breaking phenomena were addressed in a general manner by specifying a breaker parameter of 0.8. Diffraction was omitted. Bottom friction within the model was ignored to minimize dissipation, leading to a more conservative estimate of wave height.

Other Forcing

No wind forcing is included in the model. Wind-induced waves (along with swell) are generated along the offshore boundary as discussed above in Boundary Conditions.

MIKE21 SW Results

Wave height and period results were extracted at three locations along the anticipated BOUSS-2D offshore boundary. Wave conditions forced along a BOUSS-2D boundary have to be constant along the boundary. Since wave conditions extracted from the MIKE21 SW model along the boundary are not exactly the same, an average is taken to represent the BOUSS-2D offshore boundary. Table 2 provides the results from the MIKE21 SW model.

Table 2. MIKE21 SW Results – BOUSS-2D Offshore Boundary Conditions

Offshore Wave Height H_0 (m)	Offshore Wave Period T_0 (s)	Wave Direction ϴ (deg.)	Averaged Wave Height at BOUSS-2D Boundary H_1 (m)	Averaged Wave Period at BOUSS-2D Boundary T_1 (s)
1.00	6.00	315.0	**0.98**	**5.94**
1.20	6.00	315.0	**1.17**	**5.94**
2.00	8.00	315.0	**1.94**	**7.91**
3.00	10.00	315.0	**2.88**	**10.01**
4.00	11.00	315.0	**3.90**	**11.02**
5.00	12.00	315.0	**4.89**	**12.02**
6.00	14.00	315.0	**5.94**	**13.89**
7.00	17.00	315.0	**7.03**	**16.85**
7.13	16.34	325.9	**7.19**	**16.33**
4.25	12.29	323.8	**4.19**	**12.28**
3.76	13.51	306.9	**3.68**	**13.50**

BOUSS-2D Introduction

A BOUSS-2D wave numerical model was developed to simulate waves propagating from the nearshore area into the proposed St. George Harbor. The purpose of the model is to assess the wave conditions including wind waves, swell, infra-gravity waves, and harbor resonance within the proposed harbor configuration. Two scenarios were modeled with BOUSS-2D: a “baseline” scenario that represents the existing condition at St. George and an “alternative” scenario that represents a single proposed harbor configuration on the north side of the island developed by the USACE. The BOUSS-2D modeling was performed using the Surface-water Modeling Suite (SMS) version 11.2 developed by Aquaveo.

BOUSS-2D has the ability to create animations of wave propagation, including functional water surface (appearance of the actual waves), wave heights, velocity magnitude, and velocity direction (using vector grid). In addition, SMS has post-processing tools that can perform a spectral analysis of the results. Figure 2 provides a “still-frame” example of modeling results for an application at the proposed St. George Harbor.

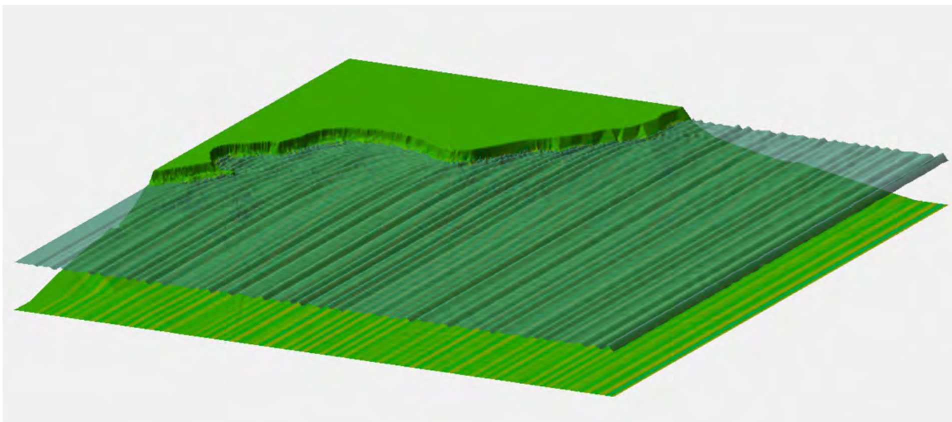

Figure 2. Example Functional Water Surface Results (green represents land/seafloor)

BOUSS-2D Model Description

BOUSS-2D is a software for developing non-linear, phase-resolving, wave numerical models based on a time-domain solution of Boussinesq-type equations. The software can be applied to simulate the propagation and transformation of waves in nearshore regions and harbors, and has the ability to simulate various wave phenomena of interest in these regions such as shoaling and refraction over underwater terrain, reflection and diffraction due to structures, energy dissipation due to wave breaking, cross-spectral energy transfer due to nonlinear wave-wave interactions, breaking-induced longshore and rip currents, wave-current interaction, and wave interaction with porous structures (Demirbilek et al., 2005).

Units, Coordinate System, and Datum

All units within the BOUSS-2D model are in the SI system. Horizontal coordinates are relative to UTM Zone 2. The horizontal datum is NAD’83. The vertical datum is the MLLW. Units are presented in SI units.

Direction Convention

Wave and current direction follow the meteorological convention for input and output, indicating direction of origin (direction from which the wave travels).

Model Domain

Several model domains were created to simulate the various input wave conditions. Both the baseline and alternative model scenarios use the same model domains (varying only in bathymetry) for each corresponding input wave condition. Model domains are aligned with the incident wave direction. This provides efficiency of the grid in that added width of domain is not necessary to compensate for shadow zones.

To satisfy the Boussinesq equations, maximum water depth and minimum wave period are related as shown in the following equation:

$$L(T_{min}) > 2h_{max}$$

Where L = wave length, T_{min} = minimum wave period, and h_{max} = maximum water depth.

Due to this relationship, model scenarios with shorter periods require a shallower maximum depth. Thus, the domain for these model scenarios does not extend as long as model scenarios with longer wave periods. In addition, wave period (wave length) generally dictates the allowable cell size in the grid. Guidance provided in USACE (2001b) states that there should be between 20 and 30 cells per wave length in deep water and approximately 8 cells per wave length in shallow water. The deep water criteria almost always governs. Table 3 provides details of the domains used for each wave scenario. In some circumstances, the cell size was increased to provide numerical stability of the model runs. These runs are noted with an asterisk ("*") in the Cell Size column.

Table 3. BOUSS-2D Model Domain Details

Wave Scenario	Offshore Wave Height H_0 (m)	Offshore Wave Period T_0 (s)	Deep Water Wave Length (m)	Domain Size L (m) x W (m)	Domain Orientation (deg.)	Cell Size (m)	Offshore Water Depth (m)
Case 1	1.00	6.00	54	**2,700X3,000**	**315.0**	**5.0***	**20**
Case 2	1.20	6.00	54	**2,700X3,000**	**315.0**	**5.0***	**20**
Case 3	2.00	8.00	87	**3,000X3,500**	**315.0**	**5.0**	**30**
Case 4	3.00	10.00	137	**3,000X3,500**	**315.0**	**5.0**	**30**
Case 5	4.00	11.00	158	**3,000X3,500**	**315.0**	**5.0**	**30**
Case 6	5.00	12.00	177	**3,000X3,500**	**315.0**	**5.0**	**30**
Case 7	6.00	14.00	213	**3,000X3,500**	**315.0**	**7.0***	**30**
Case 8	7.00	17.00	268	**3,000X3,500**	**315.0**	**10.0***	**30**
Case 9	7.13	16.34	258	**3,000X3,500**	**325.9**	**10.0***	**30**
Case 10	4.25	12.29	182	**3,000X3,500**	**323.8**	**5.0**	**30**
Case 11	3.76	13.51	205	**3,000X3,500**	**306.9**	**5.0**	**30**

*In some circumstances, grid cell size was increased to provide numerical stability of the model.
Note: L = length; W = width

Bathymetry

Bathymetric data for both the baseline scenario and alternative scenario were provided by the USACE. The baseline scenario domains used data from “PribilofUTM2m – PRIBLOF-OG.h5” and the alternative scenario domains used data from “PribilofUTM2m – PRIBLOF-ALT3-REV.h5.” The baseline scenario data were made up of coarse navigational chart data with a nested high-resolution data set from recent survey work performed for this project.

Bathymetric data used in the model domains were slightly processed to smooth the transition from the high-resolution survey data to the coarser navigational data. This was accomplished by blanking data between the datasets and inserting fabricated bathymetric contours that smoothly connect like depths. Similarly, the “Create Coastline” tool in SMS was also used to delineate the shoreline at the zero-elevation contour. This was converted to bathymetric data to create a higher resolution zero-elevation contour line to aid in the grid interpolation. Topographic data above +5 meters were set to +5 meters to create more aesthetic plots.

Boundary Conditions

The baseline scenario models contain four different boundary conditions: Offshore, Lateral, Shoreline, and Full Damping. Figure 3 shows, in plan-view, the locations of the various boundary conditions. A description of the boundaries is provided below.

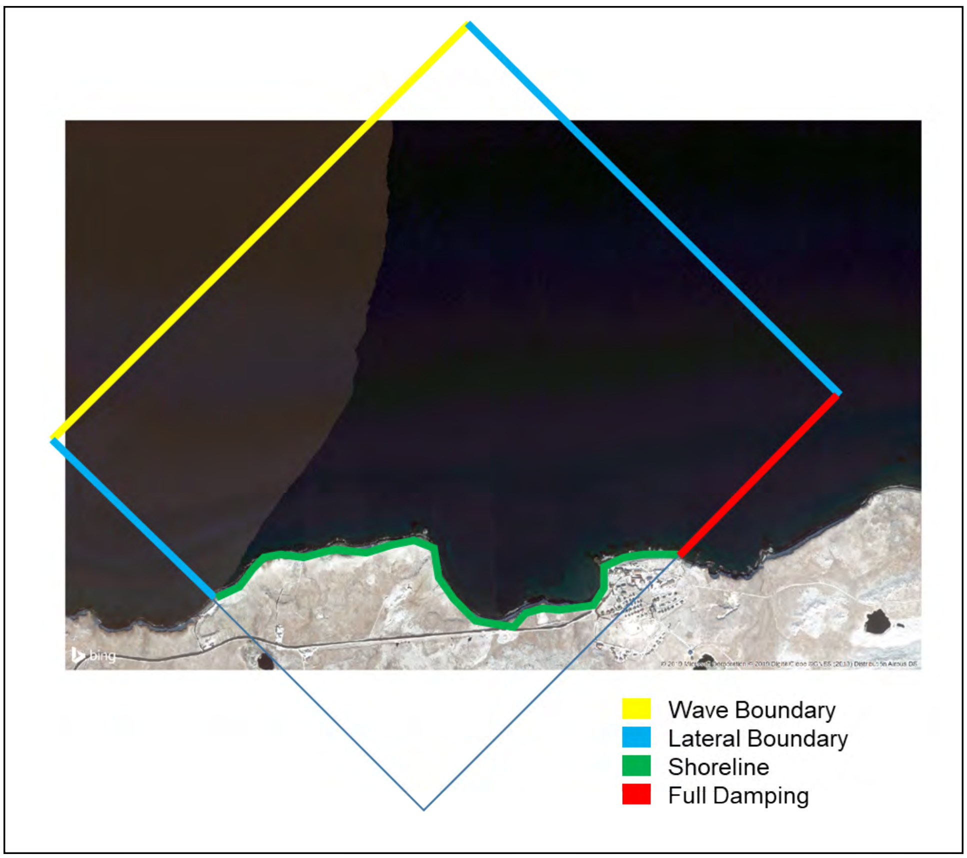

Figure 3. Wave Model Boundaries

- **Offshore Boundary** – The offshore boundary forces all of the waves for the modeling by acting as a wave maker. Waves produced from this boundary vary for each model scenario. Waves are simulated using the irregular wave-maker function and the Bretschneider spectrum. This Bretschneider spectrum was chosen based on guidance from the USACE (2001b) noting that the Bretschneider spectrum is similar to the Pierson-Moskowitz spectrum (which is applicable for deep-water conditions where there is a "local balance between momentum transfer from wind and wave breaking/non-linear cross spectral energy transfer process"), but is defined by the offshore significant wave height and spectral peak frequency. For wave-maker stability, the offshore boundary needs to be a constant depth. Therefore, for all model domains the offshore boundary was set to a constant depth of either 30 or 20 meters, depending on domain size. Bathymetric data deeper than the constant offshore boundary were removed and set to the constant 30 or 20 meter depth to create an artificial flat shelf in deep water. This is shown graphically in Figure 4.

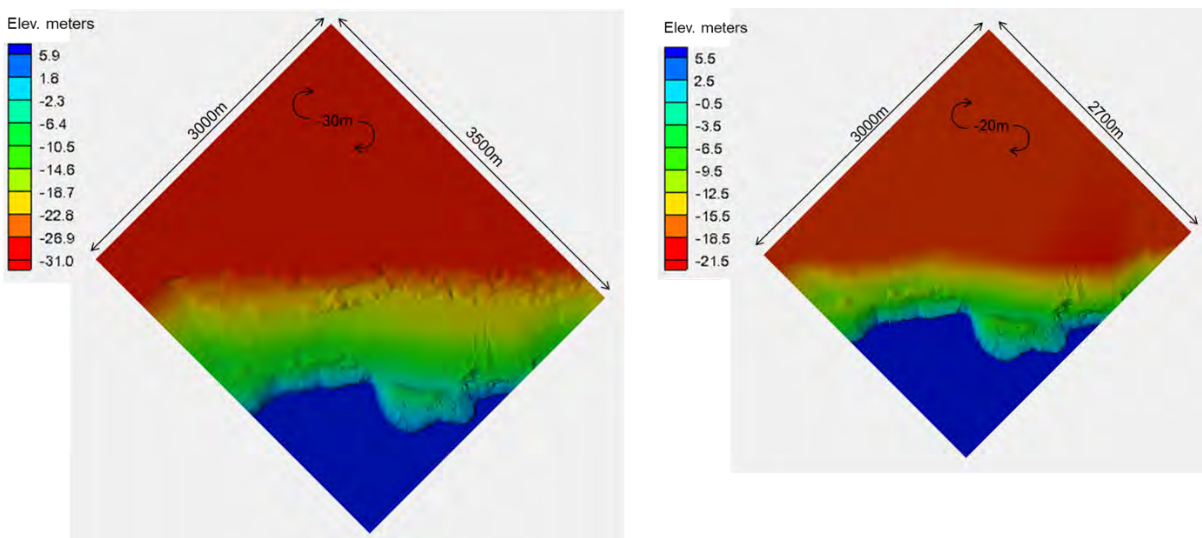

Figure 4. BOUSS-2D Model Domain of the Baseline Condition (left image shows water offshore boundary with -30-meter elevation and right shows offshore boundary with -20-meter boundary)

Note: Colors represent seafloor elevation.

- **Lateral Boundary** – The lateral boundary represents the model boundary open to water but not forcing waves. Since the domain is aligned perfectly with the wave direction, the lateral domain contains no damping to minimize disturbance of the wave (i.e., numerical diffraction) as they propagate to the site. Waves can reflect off the lateral boundaries, such as waves reflecting from the shoreline; however, due to the short duration of the model runs, reflected waves are not likely to impact the area of interest.
- **Shoreline** – The version of BOUSS-2D used does not require the user to distinguish between land and ocean as previous versions did. The model internally determines this boundary. Waves are allowed to reflect off the land boundary with no added damping other than the energy lost due to breaking as the waves approach shallow water.

- **Full Damping** – Due to the orientation of the model domains and to reduce model domain size, a portion of the domain opposite of the wave maker is still in open water. This section is dampened to a value of 1.0 (full damping) to prevent waves from reflecting off the model domain and traveling back to the wave maker.

The alternative scenario models utilizes additional dampening detail along the breakwaters and inner harbor shoreline. Rock breakwater features are assigned a dampening coefficient of 0.008 distributed over a 10-meter width. The inner harbor shoreline is assigned a dampening coefficient of 0.005 distributed over a 10-meter width. The basis for using these values comes from calibrated BOUSS-2D modeling performed previously for the existing harbor on the south side of the island, documented in HDR (2014). Figure 5 provides a graphical representation of the areas where dampening coefficients were applied in the alternative scenario models.

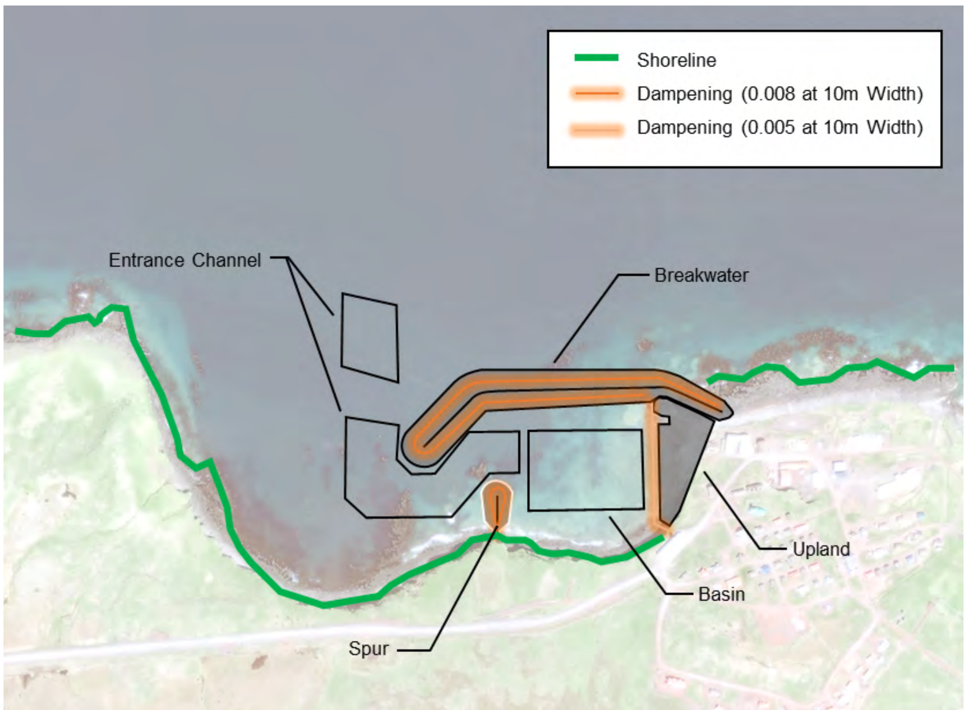

Figure 5. Alternative Scenario Dampening Boundary Conditions

Based on correspondence with the USACE project team during the development of the alternative model, it was requested to implement porosity in lieu of dampening on the breakwater features in the alternative scenario models. Based on USACE experience at St. Paul, Alaska, a porosity of 27 percent was assigned along the breakwater features. Only a portion of the models was able to run successfully through completion when porosity was used. Thus, alternative scenario model findings in the Results section of this document do not include porosity unless explicitly noted. Figure 6 provides a graphical representation of the areas where dampening and porosity coefficients were applied in the alternative scenario models.

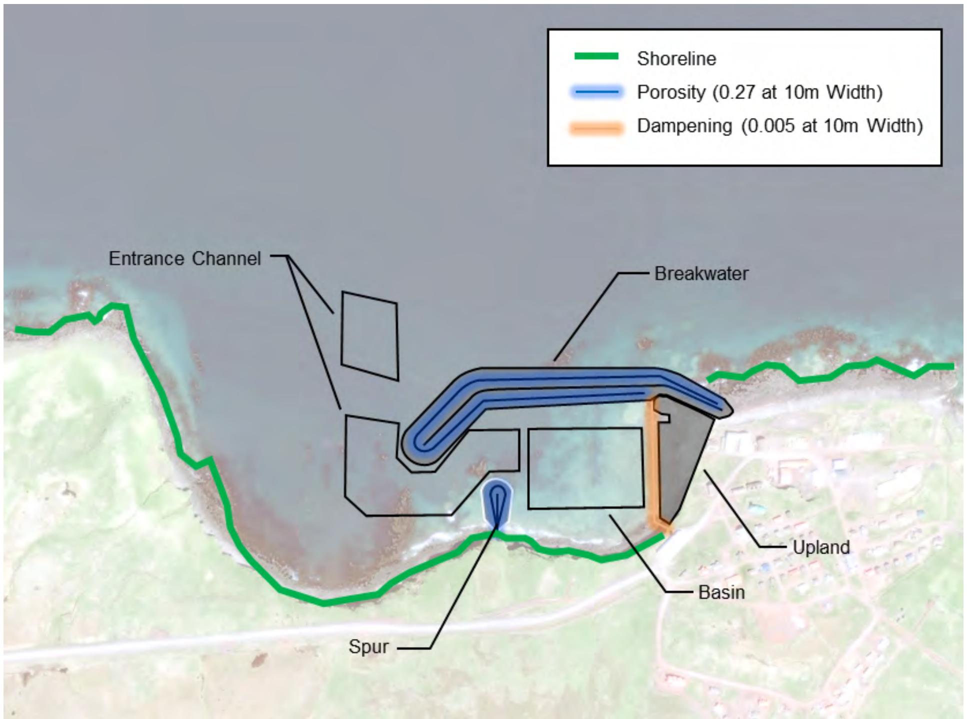

Figure 6. Alternative Scenario Dampening and Porosity Boundary Conditions

Water Level

Water level was held constant at an elevation of +1.8 meter MLLW as directed by the USACE.

Waves

Waves were forced into the model domain at the offshore boundary. The model can be forced using regular waves of a set height and period, irregular waves in single direction using synthesized wave spectrum, multi-directional irregular waves using a synthesized spectrum, and water surface elevation time series in a single direction. The synthesized wave spectrum could be the TMA, JONSWAP, Bretschneider, Pierson-Moskowitz, or Ochi-Hubble Double Peak spectrum. As noted in the boundary condition section, the Bretschneider spectrum was used for all wave forcings.

Currents

BOUSS-2D calculates depth-averaged currents in both magnitude and direction throughout the domain at each time step caused by various hydrodynamic processes (i.e., rip currents, longshore currents, orbital wave velocities) occurring during the model runs. Currents are not forced within the model as a boundary condition or initial condition. All boundaries of the model domain are closed, and water is not allowed to enter or exit the domain.

Model Parameters

Various model parameters can be modified using the SMS interface. These parameters, as well as values applied, are discussed below.

- **Time Step** – The model time step was varied to accomplish a Courant number of less than 0.6 to maintain model stability. For best stability, time steps resulting in a Courant number on the order of 0.2 were used. This resulted in time steps ranging from 0.05 to 0.2 second.
- **Surface Roughness** – The Chezy coefficient was used to simulate surface roughness. A constant roughness coefficient of 30 was used throughout the domain.
- **Eddy Viscosity** – Eddy viscosity was incorporated in the model using the Smagorinsky coefficient. For all model runs, a coefficient of 0.2 was used.
- **Porosity** – Porosity was not included in the baseline scenario model runs. Alternative scenario model runs were attempted using porosity with only partial success. Primary alternative scenario model results do not use porosity.
- **Duration** – Duration of the model runs were all approximately 20 minutes, but varied slightly depending on the recommended SMS maximum duration. Durations for each case are provided in Table 4.

Table 4. BOUSS-2D Model Duration Details

Wave Scenario	Baseline Scenario Duration (s)	Alternative Scenario Duration (s)
Case 1	1,254	1,061
Case 2	1,250	1,250
Case 3	1,238	1,257
Case 4	1,176	1,173
Case 5	1,176	1,173
Case 6	1,176	1,173
Case 7	1,176	1,173
Case 8	1,176	1,173
Case 9	1,176	1,173
Case 10	1,171	1,173
Case 11	1,176	1,173

Other Forcing

No wind forcing is included in the model.

Initial Conditions

Water within the model domain is initially motionless (i.e., no waves or currents) and at a constant level.

Results

Results of the baseline and alternative BOUSS-2D models are provided in this section. Spectral significant wave height (H_{mo}), peak wave periods (T_p), water surface elevation, and spectral energy (m^2/Hertz [Hz]) are the primary parameters exported from each model run.

Model Scenarios

The 11 offshore wave cases identified in Table 3 were run for both the baseline and alternative scenario model domains. An additional set of alternative scenario model runs was performed utilizing porosity along the harbor breakwaters in lieu of dampening. Only a portion of these models was successfully completed without model instability.

Results Extraction/Probe Locations

Model results were extracted from eight locations. These locations were confirmed with the USACE and are intended to assess wave energy dissipation within and approaching the harbor. Two locations are directly along the proposed dock face in the inner-most harbor (denoted as “Dock (North)” and “Dock (South)”). One location is within the harbor located at the spur breakwater (denoted as “Harbor (Spur)”). Four locations are along the entrance channel into the harbor (denoted in order from offshore to harbor as “Entrance (Shoal Removed),” “Entrance (Ocean Side),” “Entrance (Corner),” and “Entrance (Harbor Side)”). Finally, the last location is located offshore (denoted as “Offshore”). Figure 7 provides a map showing the model results’ extraction locations. Probes were also defined in the model runs at the same locations. By defining probes within the model, SMS is able to post-process the results, providing H_{mo}, T_p, and spectral analysis.

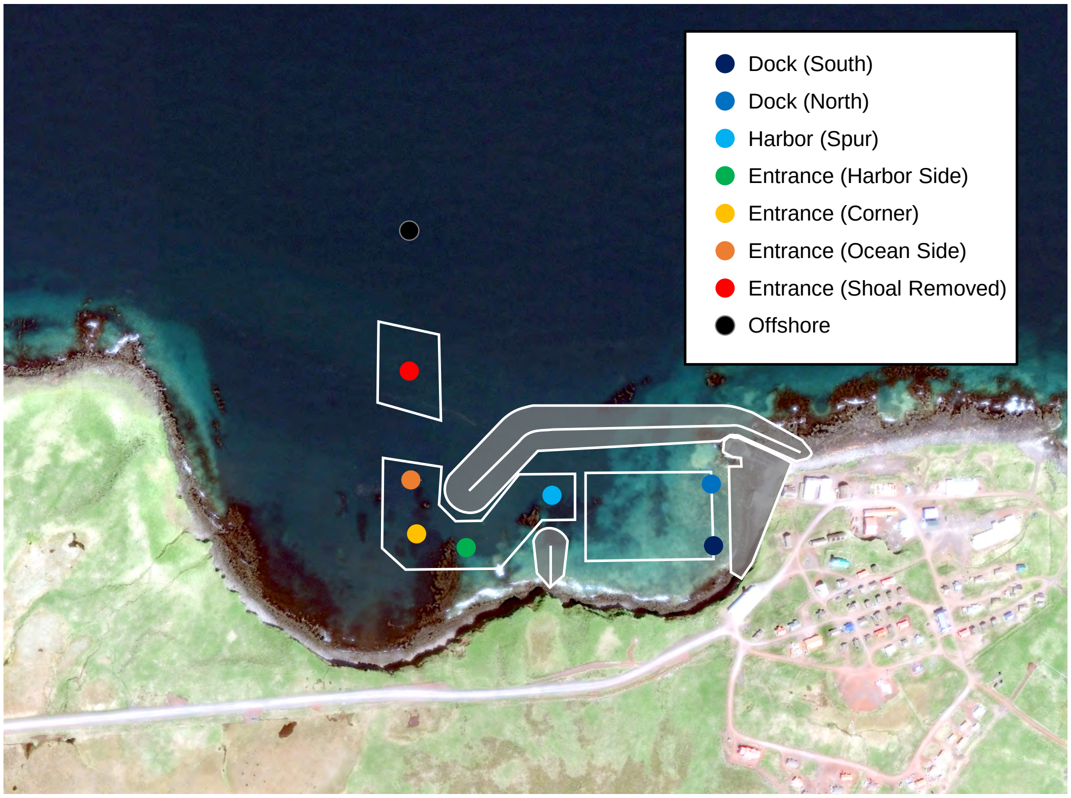

Figure 7. Model Results Probe Location

Wave Height and Peak Wave Period Results

The H_{mo} and T_p were extracted at the eight locations within the model. Tabular results for the baseline scenario and alternative scenario are provided in Table 5 and Table 6, respectively. In some locations, the peak wave period could not be calculated by the SMS post-processing tool and is denoted as "—" in the tabular data.

Table 5. Baseline Model Results - Significant Wave Height and Peak Wave Period

	Case 1		Case 2		Case 3		Case 4		Case 5		Case 6	
	H_{mo}, m	T_p, s	H_{mo}, m	T_p, s	H_{mo}, m	T_p, s	H_{mo}, m	T_p, s	H_{mo}, m	T_p, s	H_{mo}, m	T_p, s
Dock (South)	0.50	6.07	0.60	6.28	1.18	9.10	2.00	10.92	2.49	13.65	2.79	--
Dock (North)	0.41	6.28	0.49	6.28	1.04	8.67	1.82	10.92	2.45	10.60	2.91	--
Harbor (Spur)	0.37	5.87	0.43	6.28	0.90	8.67	1.70	10.92	2.53	13.65	3.35	13.65
Entrance (Harbor Side)	0.49	6.28	0.57	6.74	1.23	8.67	2.31	10.24	3.19	13.65	3.87	14.89
Entrance (Corner)	0.41	5.87	0.45	6.50	0.98	8.67	1.95	10.92	2.86	13.65	3.69	14.89
Entrance (Ocean Side)	0.45	5.87	0.51	6.50	1.07	8.67	1.98	10.92	2.86	13.65	3.68	14.89
Entrance (Shoal Removed)	0.46	5.87	0.52	7.00	1.07	8.27	1.98	10.92	2.86	11.70	3.71	13.65
Offshore	0.52	6.50	0.59	6.74	1.14	8.67	2.00	10.92	2.84	11.70	3.70	13.65
Input Parameter	0.98	5.94	1.17	5.94	1.94	7.91	2.88	10.01	3.90	11.02	4.89	12.02
	Case 7		**Case 8**		**Case 9**		**Case 10**		**Case 11**			
	H_{mo}, m	T_p, s	H_{mo}, m	T_p, s	H_{mo}, m	T_p, s	H_{mo}, m	T_p, s	H_{mo}, m	T_p, s		
Dock (South)	3.12	--	3.84	--	4.55	--	2.91	--	2.86	16.38		
Dock (North)	3.54	--	4.20	--	4.56	--	2.94	--	2.62	--		
Harbor (Spur)	4.61	16.38	5.57	--	5.99	--	3.24	13.65	2.54	14.89		
Entrance (Harbor Side)	4.80	18.20	5.31	20.48	5.53	--	3.75	14.89	3.14	14.89		
Entrance (Corner	4.68	16.38	5.46	20.48	5.80	18.20	3.63	14.89	2.84	16.38		
Entrance (Ocean Side)	4.70	16.38	5.59	20.48	6.06	18.20	3.66	13.65	2.82	16.38		
Entrance (Shoal Removed)	4.71	16.38	5.83	20.48	6.26	20.48	3.50	13.65	2.83	14.89		
Offshore	4.74	16.38	5.88	18.20	6.36	18.20	3.43	13.65	2.87	13.65		
Input Parameter	5.94	13.89	7.03	16.85	7.19	16.33	4.19	12.28	3.68	13.50		

Table 6. Alternative Model Results - Significant Wave Height and Peak Wave Period

	Case 1		Case 2		Case 3		Case 4		Case 5		Case 6	
	H_{mo}, m	T_p, s	H_{mo}, m	T_p, s	H_{mo}, m	T_p, s	H_{mo}, m	T_p, s	H_{mo}, m	T_p, s	H_{mo}, m	T_p, s
Dock (South)	0.06	6.48	0.08	6.50	0.19	--	0.54	--	1.05	--	1.68	--
Dock (North)	0.05	7.09	0.08	--	0.23	--	0.58	--	1.04	--	1.64	--
Harbor (Spur)	0.09	7.09	0.13	7.00	0.27	7.00	0.55	--	0.88	--	1.24	--
Entrance (Harbor Side)	0.28	6.21	0.44	5.87	0.73	8.67	1.47	10.92	2.14	11.70	2.68	11.70
Entrance (Corner)	0.33	7.45	0.44	7.59	1.05	8.67	1.79	10.24	2.50	12.60	3.26	11.70
Entrance (Ocean Side)	0.42	7.09	0.60	7.00	1.19	8.67	2.17	11.70	3.12	12.60	3.89	11.70
Entrance (Shoal Removed)	0.40	6.48	0.57	6.50	1.12	8.27	2.00	10.24	2.92	12.60	3.80	12.60
Offshore	0.43	6.48	0.62	6.74	1.19	8.27	2.08	10.24	2.95	11.70	3.81	12.60
Input Parameter	0.98	5.94	1.17	5.94	1.94	7.91	2.88	10.01	3.90	11.02	4.89	12.02
	Case 7		**Case 8**		**Case 9**		**Case 10**		**Case 11**			
	H_{mo}, m	T_p, s	H_{mo}, m	T_p, s	H_{mo}, m	T_p, s	H_{mo}, m	T_p, s	H_{mo}, m	T_p, s		
Dock (South)	2.54	--	2.81	--	3.00	--	1.53	--	1.33	--		
Dock (North)	2.47	--	2.72	--	2.91	--	1.49	--	1.29	--		
Harbor (Spur)	1.77	--	2.13	--	2.20	--	1.15	--	1.03	--		
Entrance (Harbor Side)	3.20	--	3.82	--	3.42	--	2.34	14.89	2.08	14.89		
Entrance (Corner	4.35	16.38	5.16	18.20	5.27	18.20	3.15	13.65	2.34	14.89		
Entrance (Ocean Side)	4.58	16.38	5.34	--	5.66	10.24	3.62	13.65	2.83	13.65		
Entrance (Shoal Removed)	5.01	18.20	6.12	18.20	6.42	18.20	3.56	12.60	2.90	12.60		
Offshore	4.90	16.38	5.92	18.20	6.43	18.20	3.52	13.65	2.89	13.65		
Input Parameter	5.94	13.89	7.03	16.85	7.19	16.33	4.19	12.28	3.68	13.50		

BOUSS-2D has the capability of providing spectral significant wave height graphically anywhere in the domain. Figure 8 provides an example of the significant wave height graphical model output for Cases 9 through 11 (i.e., storm conditions) for both the baseline scenario and the alternative scenario. The color scale for all three cases is the same, to provide consistency in comparing results.

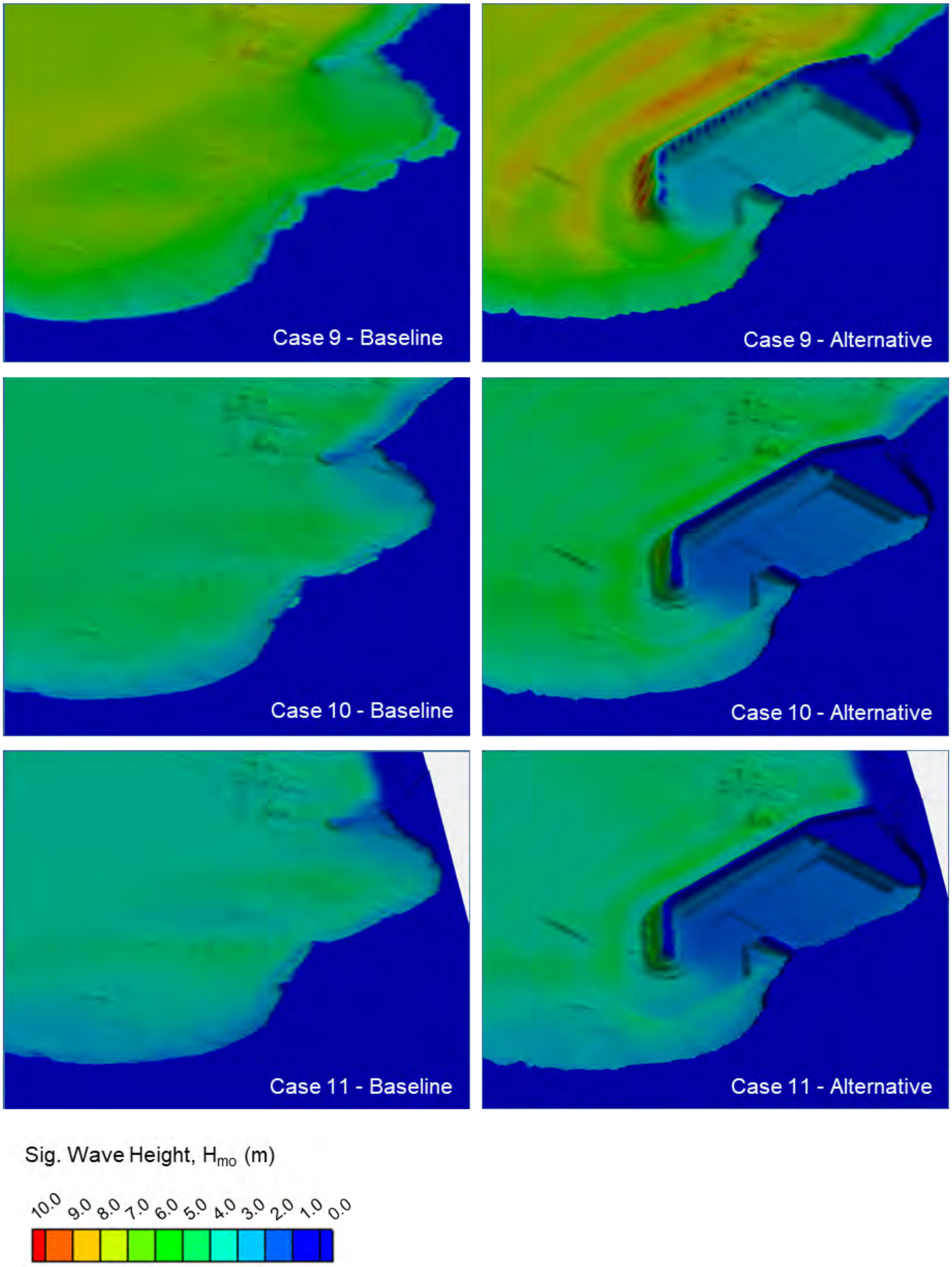

Figure 8. Significant Wave Height Results (Cases 9, 10, and 11)

Spectral Energy Results

Spectral analysis post-processing was performed at the eight locations for all model runs. The spectral analysis plots provide a complimentary picture to the significant wave height results by providing the energy distribution over frequency. These plots indicate the frequency (wave period inverse) at which wave energy has a peak or, in some cases, multiple peaks. Frequency can be converted to wave period by calculating the inverse. Table 7 provides a reference for converting wave frequency to wave period when reviewing the plots.

Table 7. Frequency to Wave Period Conversion Reference

Frequency	Period	Example Type of Wave
0.005 Hz	200 seconds (3.3 minutes)	Long-period, infragravity wave
0.05 Hz	20 Seconds	Swell
0.5 Hz	2 Seconds	Wind-wave chop

Alternative Scenario Harbor Approach

Spectral analysis plots for the alternative scenario model are provided in Figure 9 through Figure 30. Two plots are provided for each case. The first plot provides the overall energy across the frequencies analyzed. The second plot enhances the resolution at the lower frequencies. The colors on the plots correspond to the colors shown in Figure 7. These plots show the decline of the wave energy as waves approach the harbor.

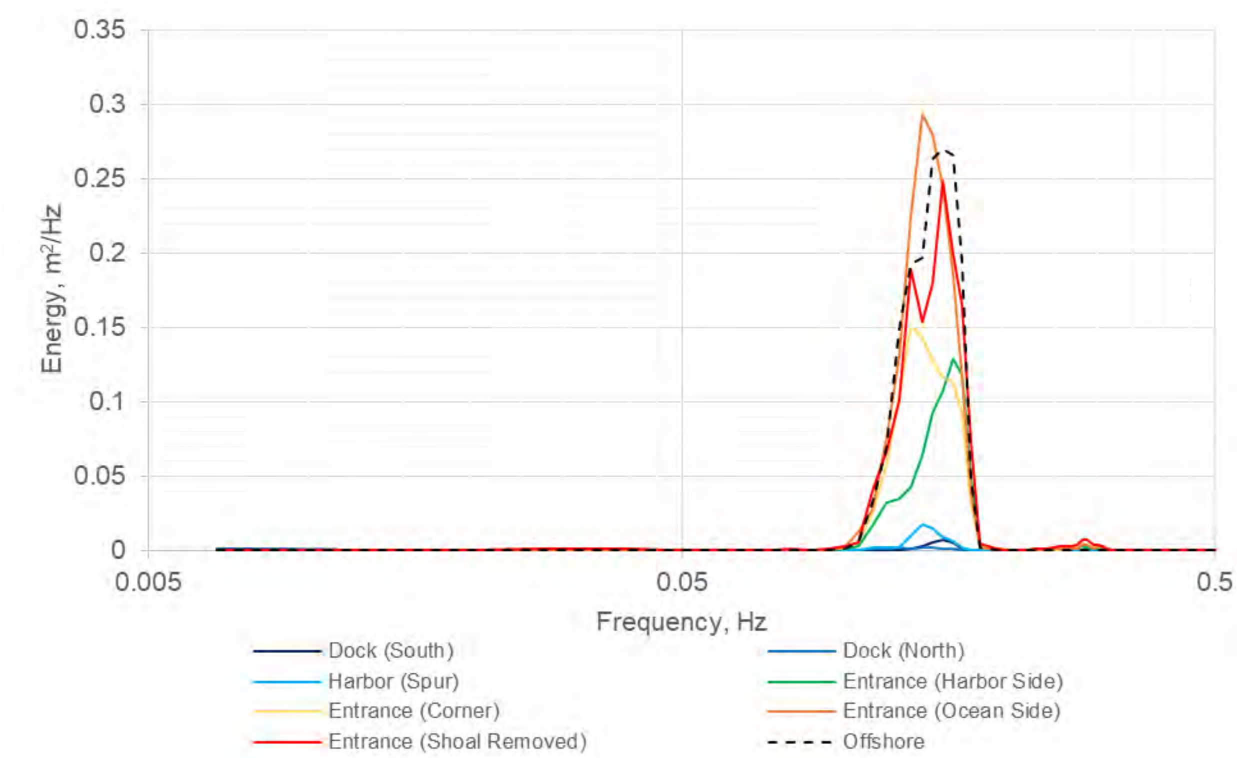

Figure 9. Case 1 Spectral Energy at Probe Locations

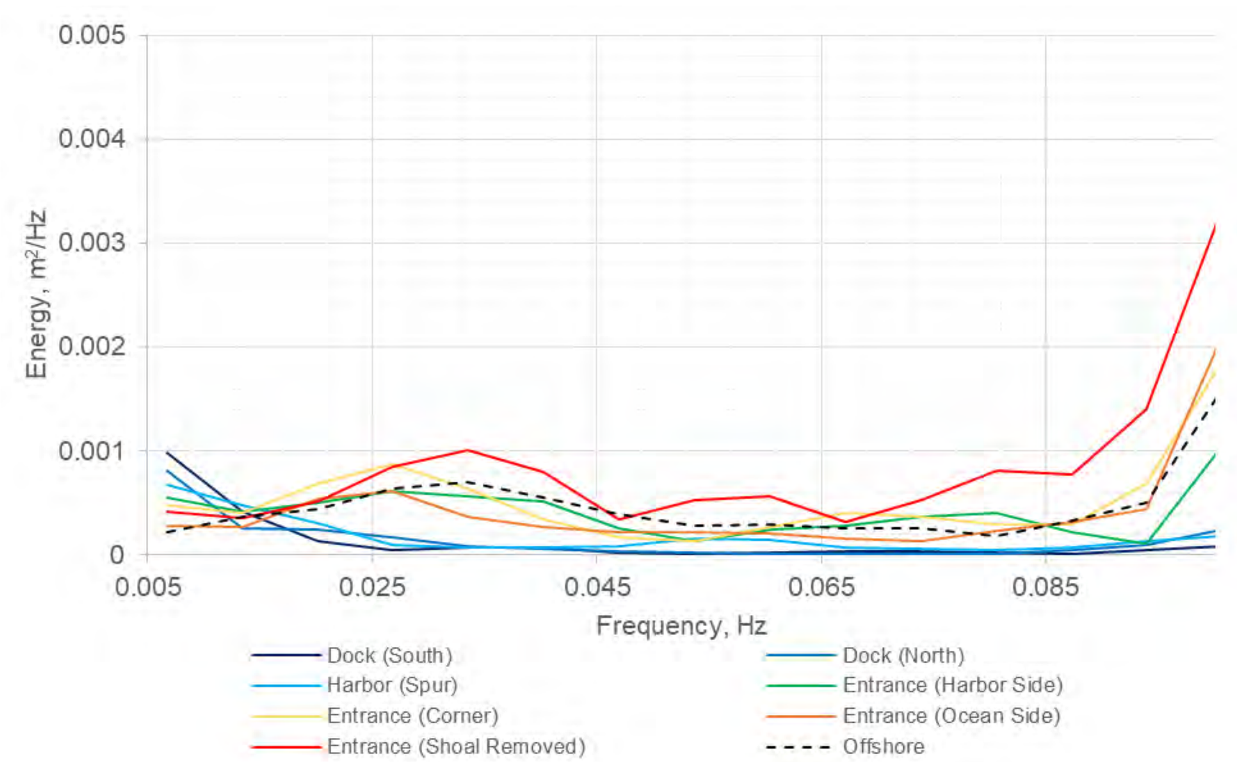

Figure 10. Case 1 Spectral Energy at Probe Locations (Enhanced Resolution at Low Frequencies)

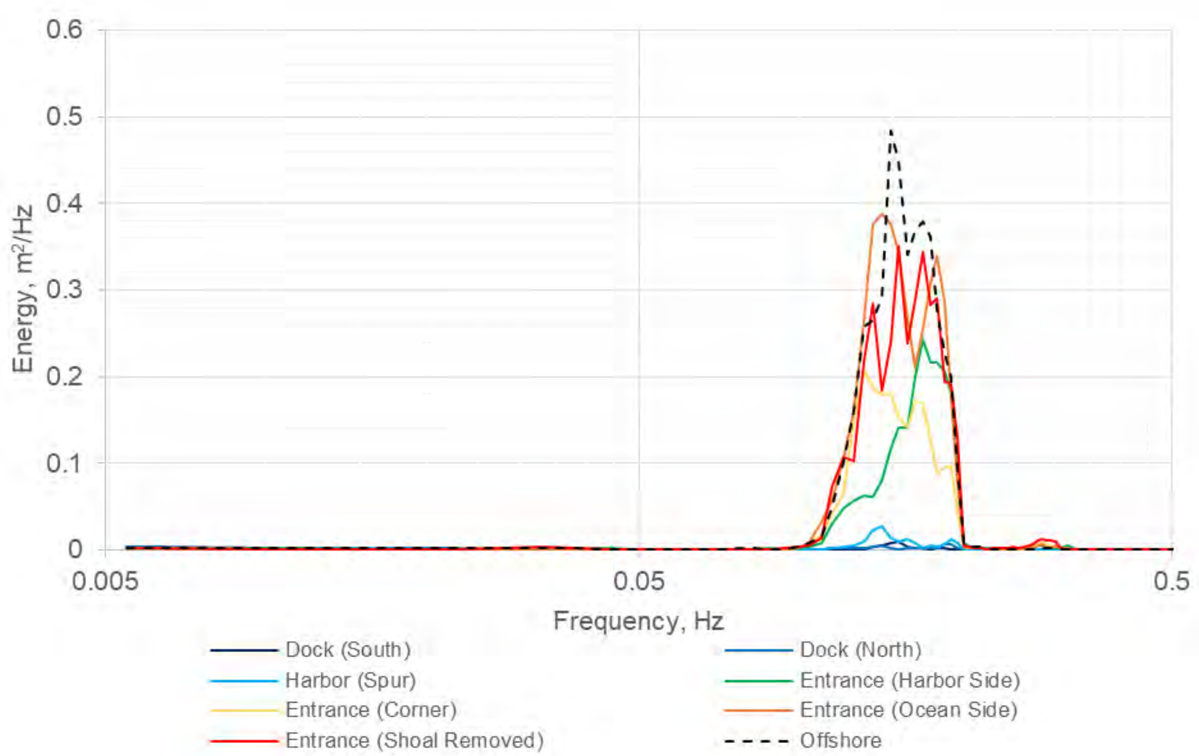

Figure 11. Case 2 Spectral Energy at Probe Locations

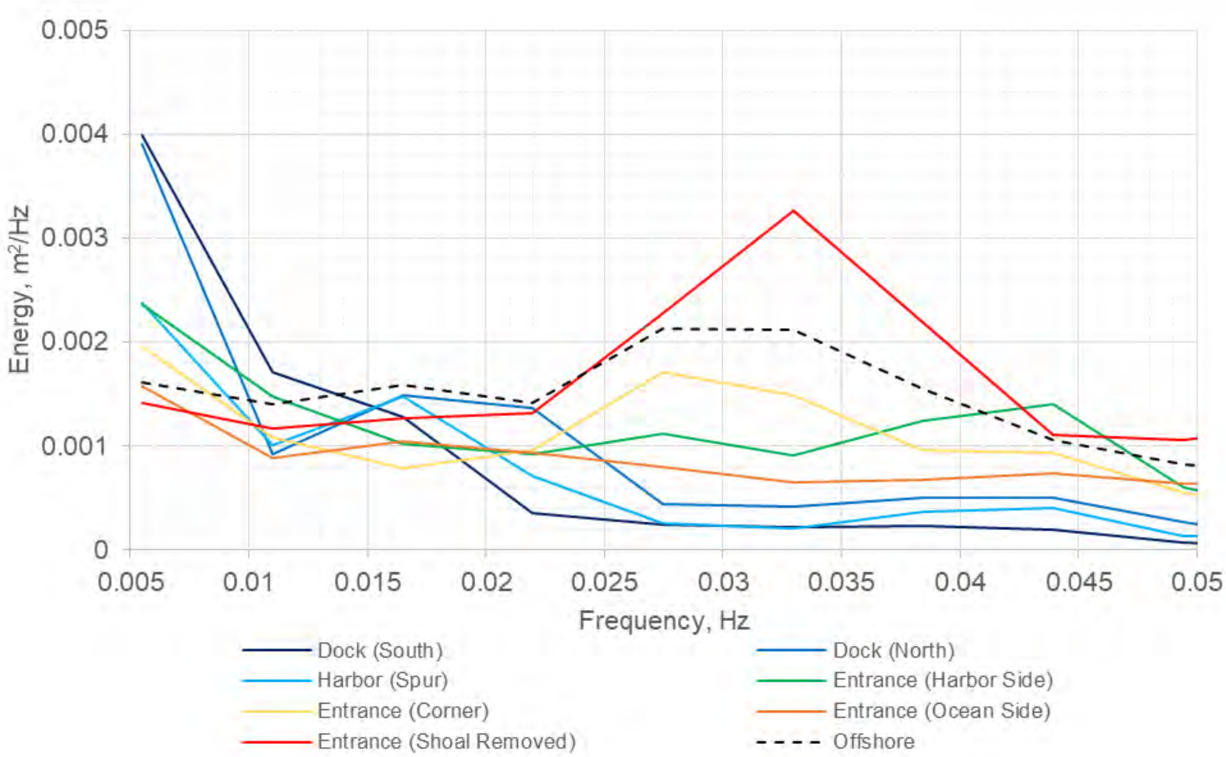

Figure 12. Case 2 Spectral Energy at Probe Locations (Enhanced Resolution at Low Frequencies)

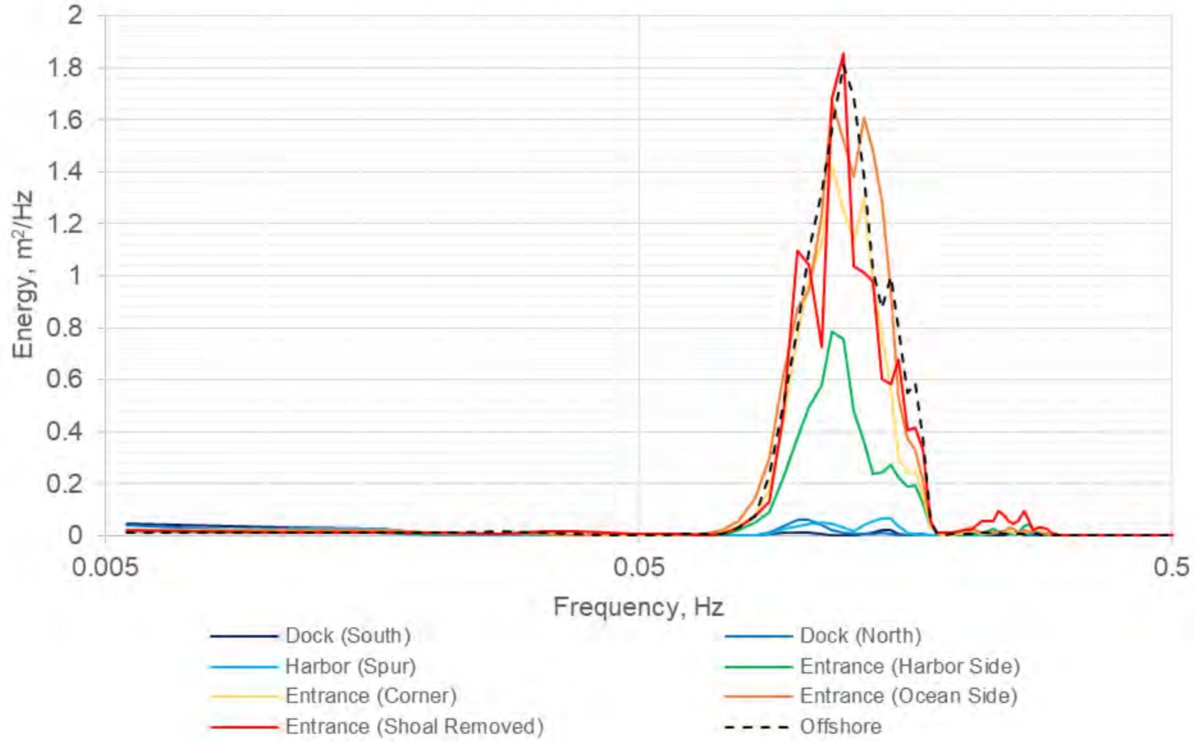

Figure 13. Case 3 Spectral Energy at Probe Locations

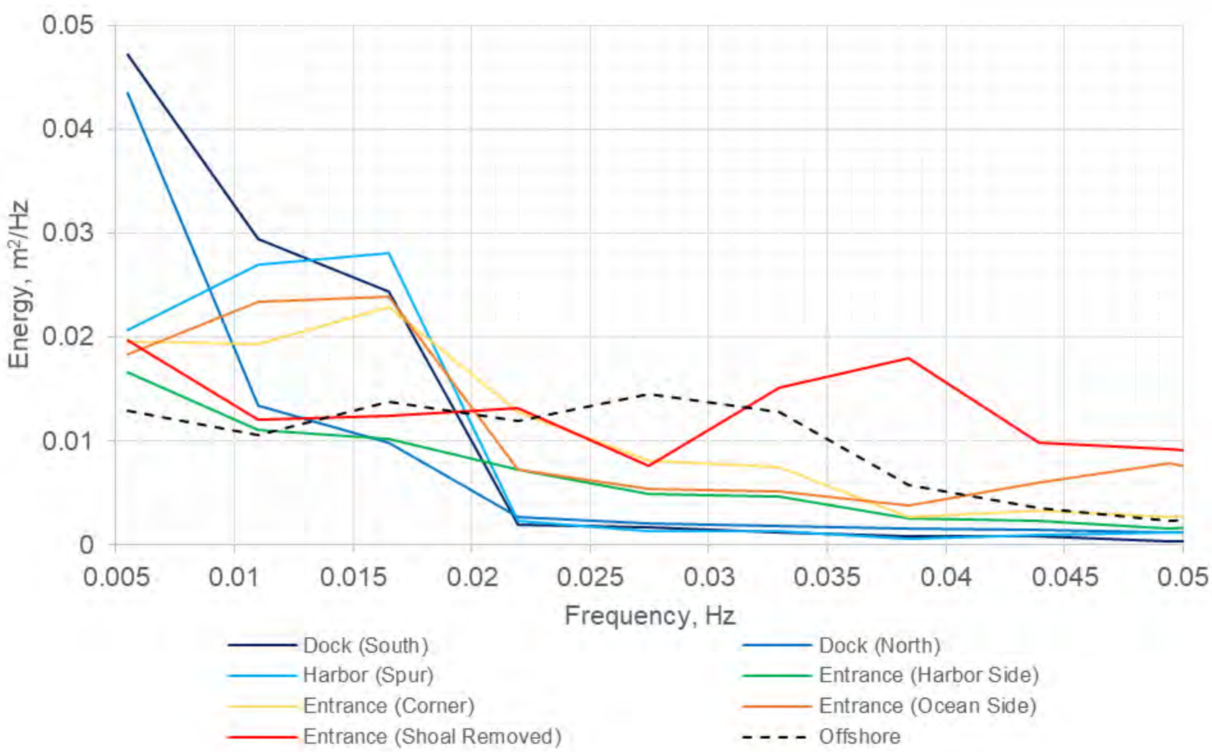

Figure 14. Case 3 Spectral Energy at Probe Locations (Enhanced Resolution at Low Frequencies)

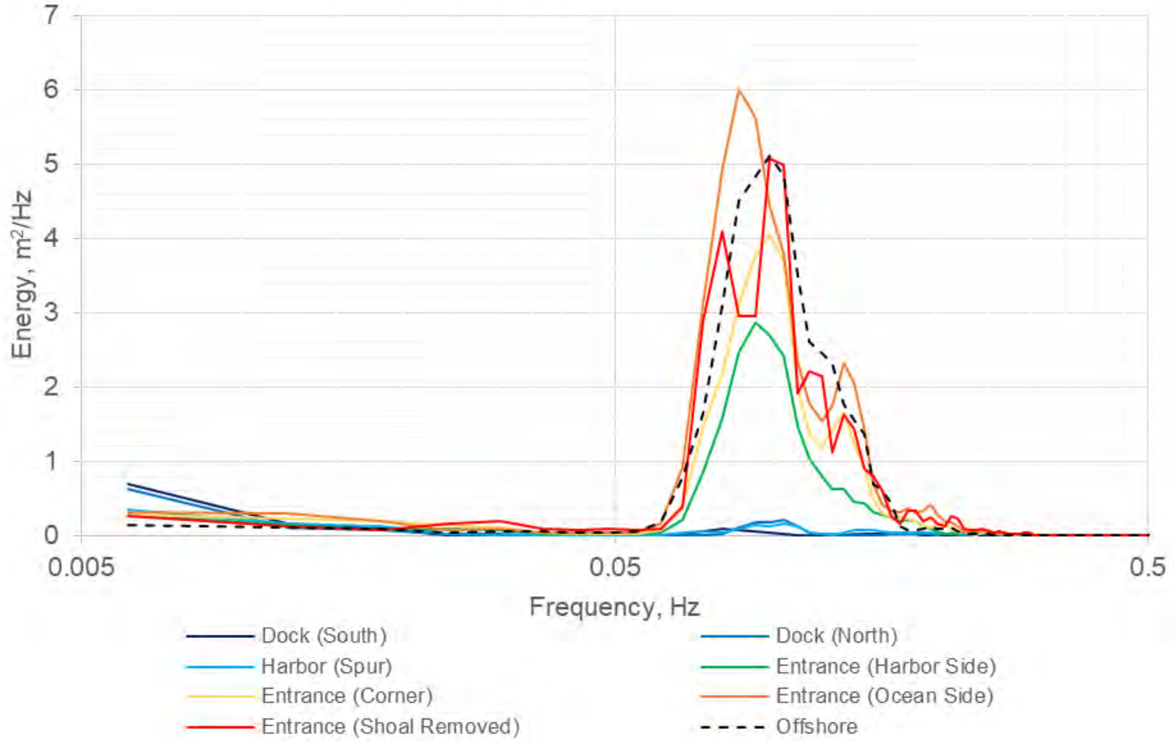

Figure 15. Case 4 Spectral Energy at Probe Locations

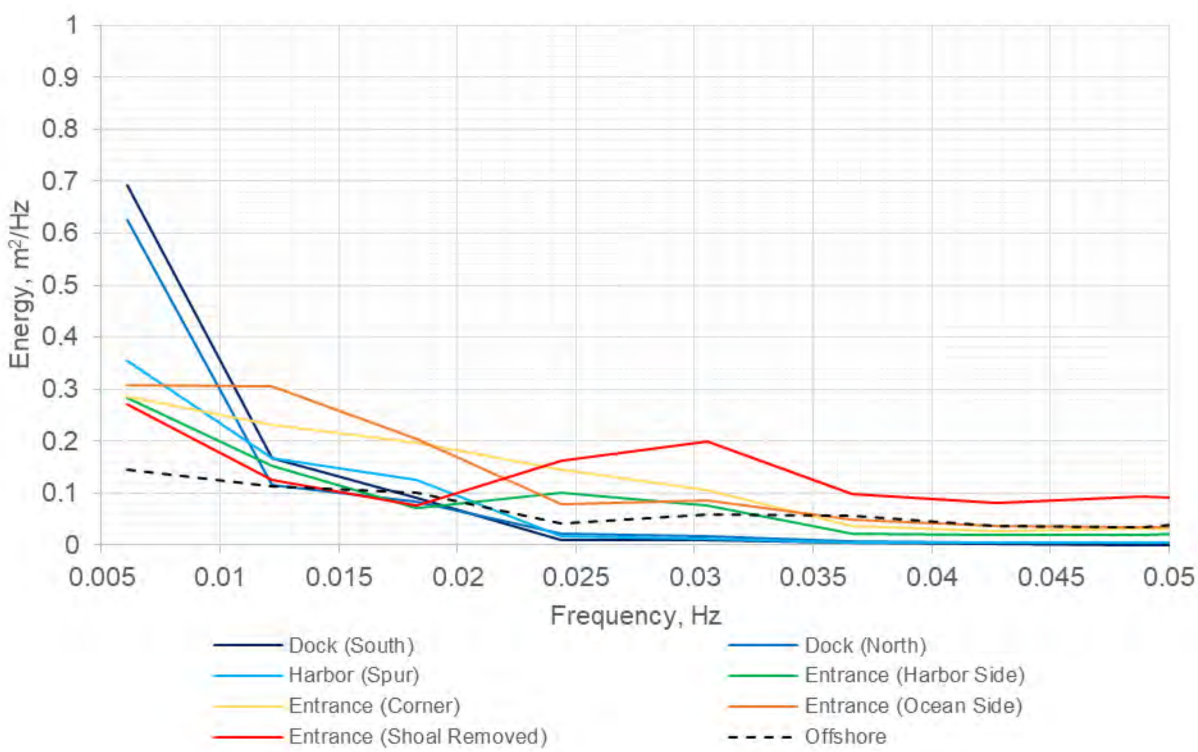

Figure 16. Case 4 Spectral Energy at Probe Locations (Enhanced Resolution at Low Frequencies)

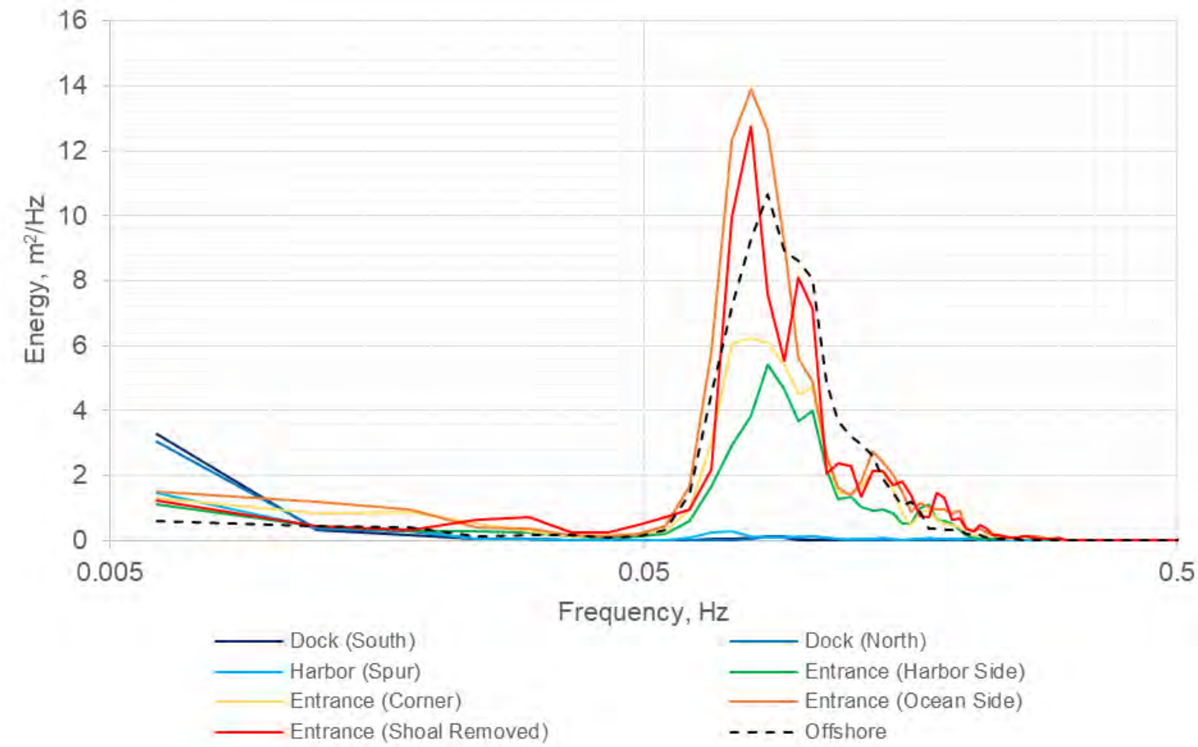

Figure 17. Case 5 Spectral Energy at Probe Locations

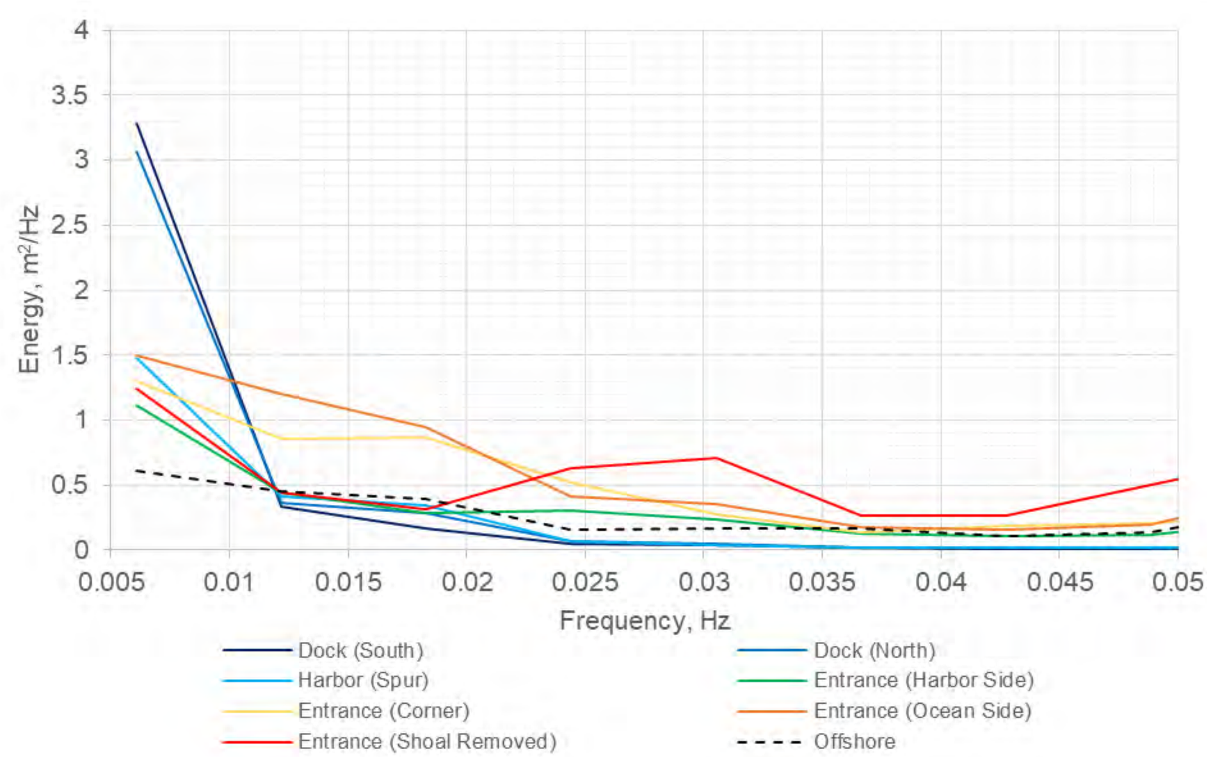

Figure 18. Case 5 Spectral Energy at Probe Locations (Enhanced Resolution at Low Frequencies)

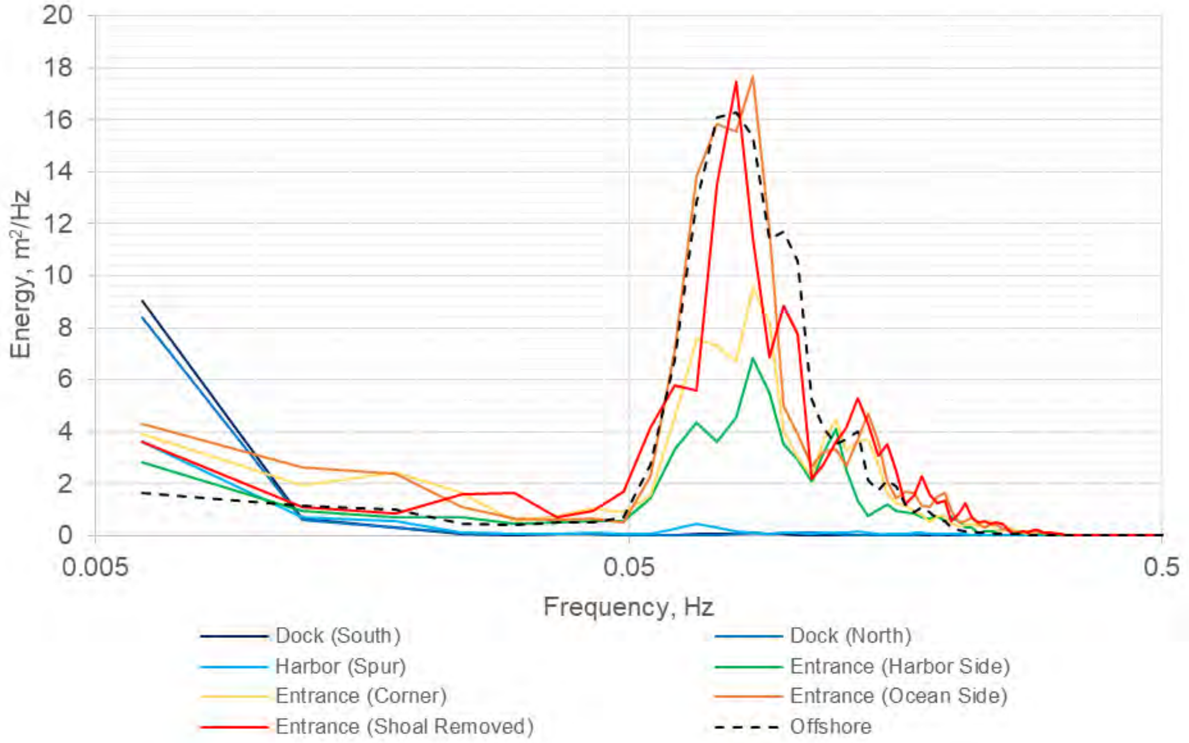

Figure 19. Case 6 Spectral Energy at Probe Locations

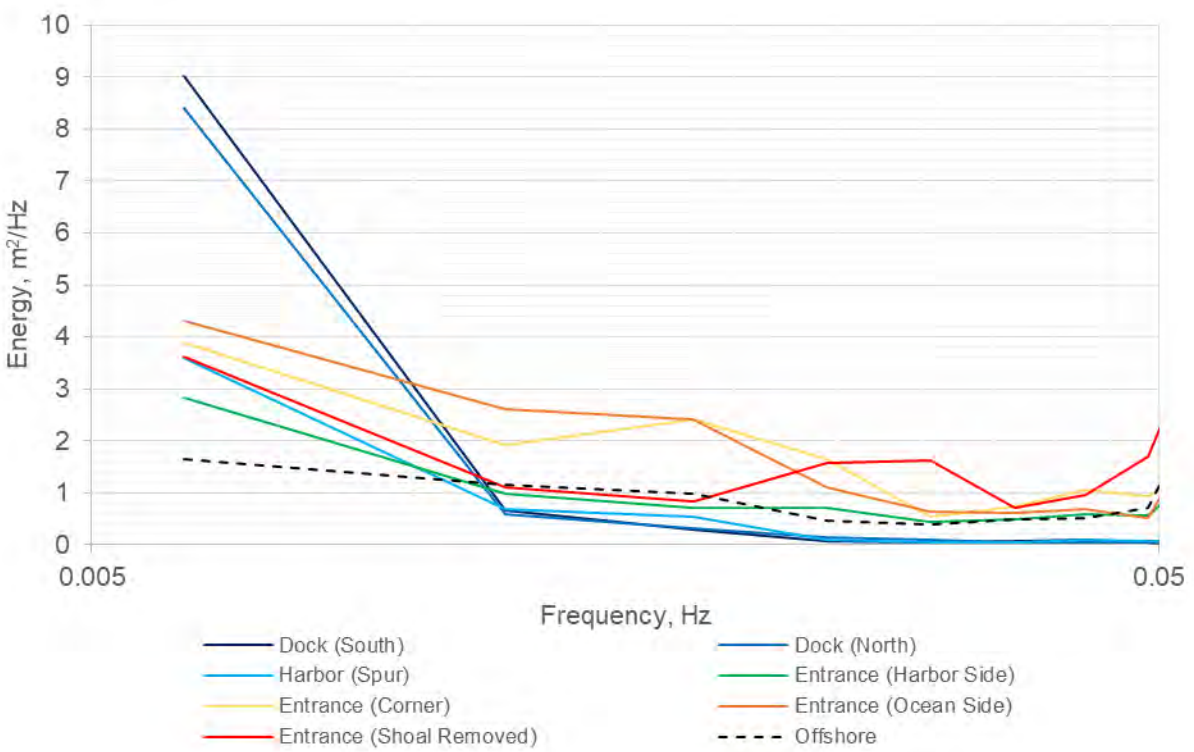

Figure 20. Case 6 Spectral Energy at Probe Locations (Enhanced Resolution at Low Frequencies)

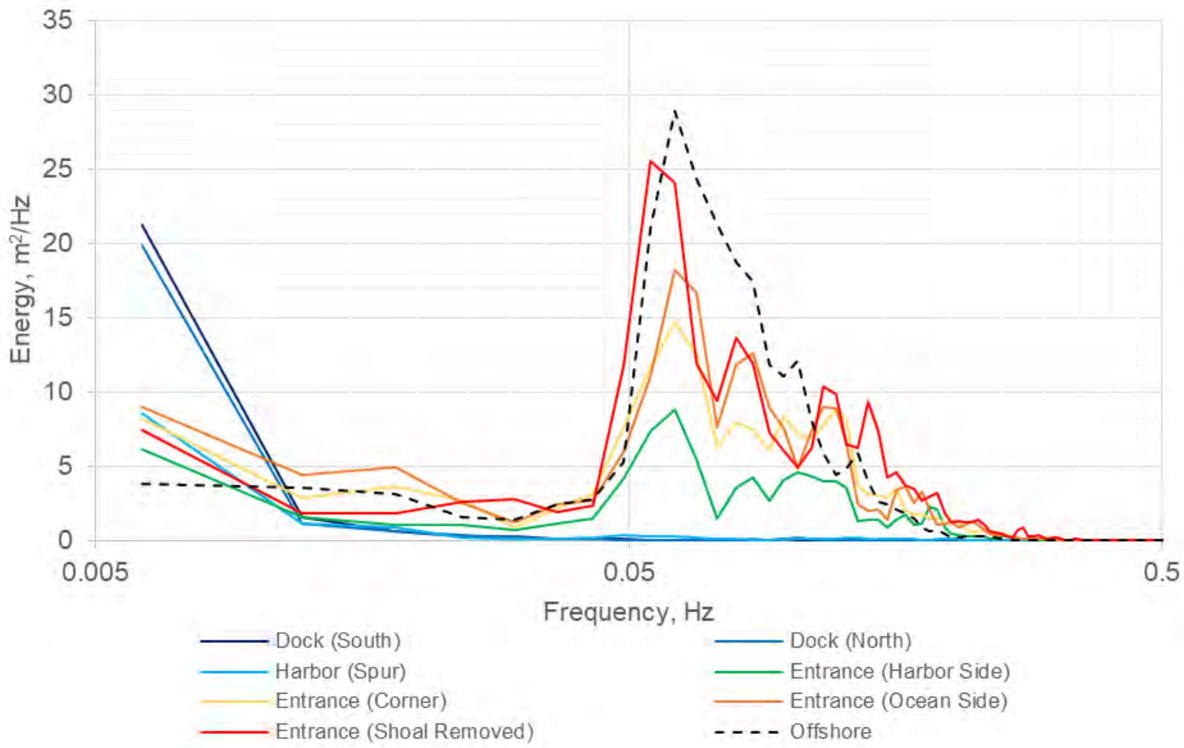

Figure 21. Case 7 Spectral Energy at Probe Locations

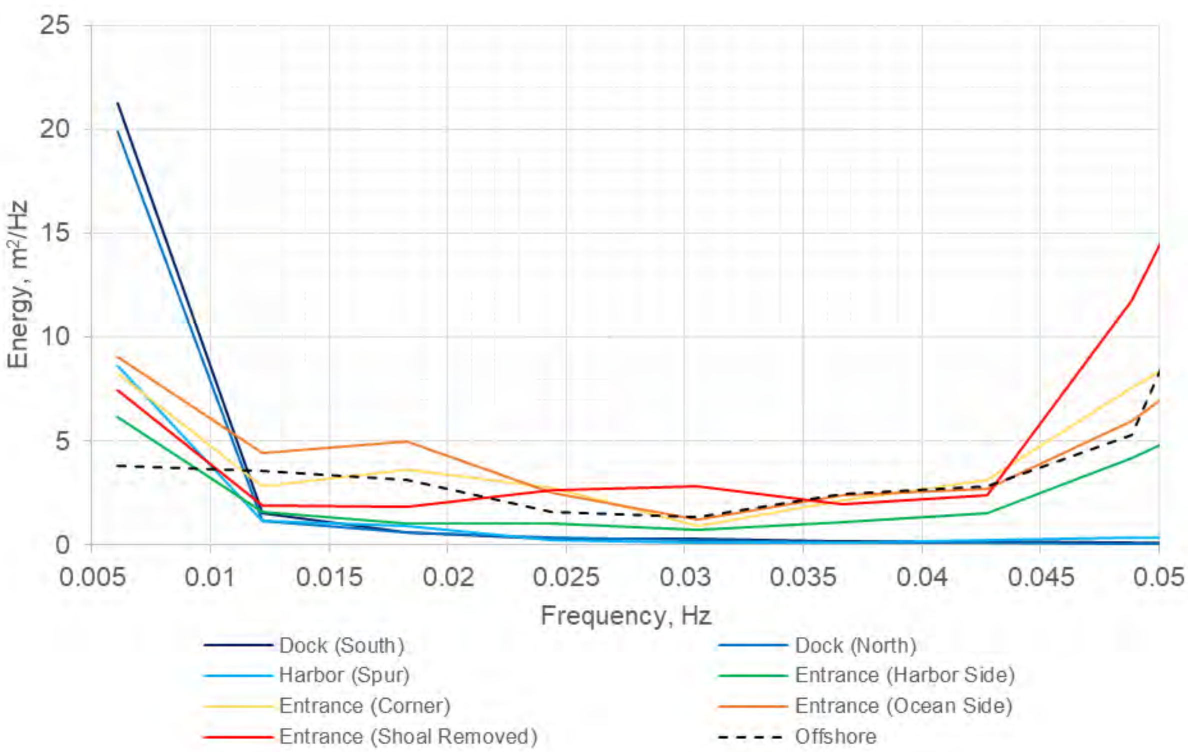

Figure 22. Case 7 Spectral Energy at Probe Locations (Enhanced Resolution at Low Frequencies)

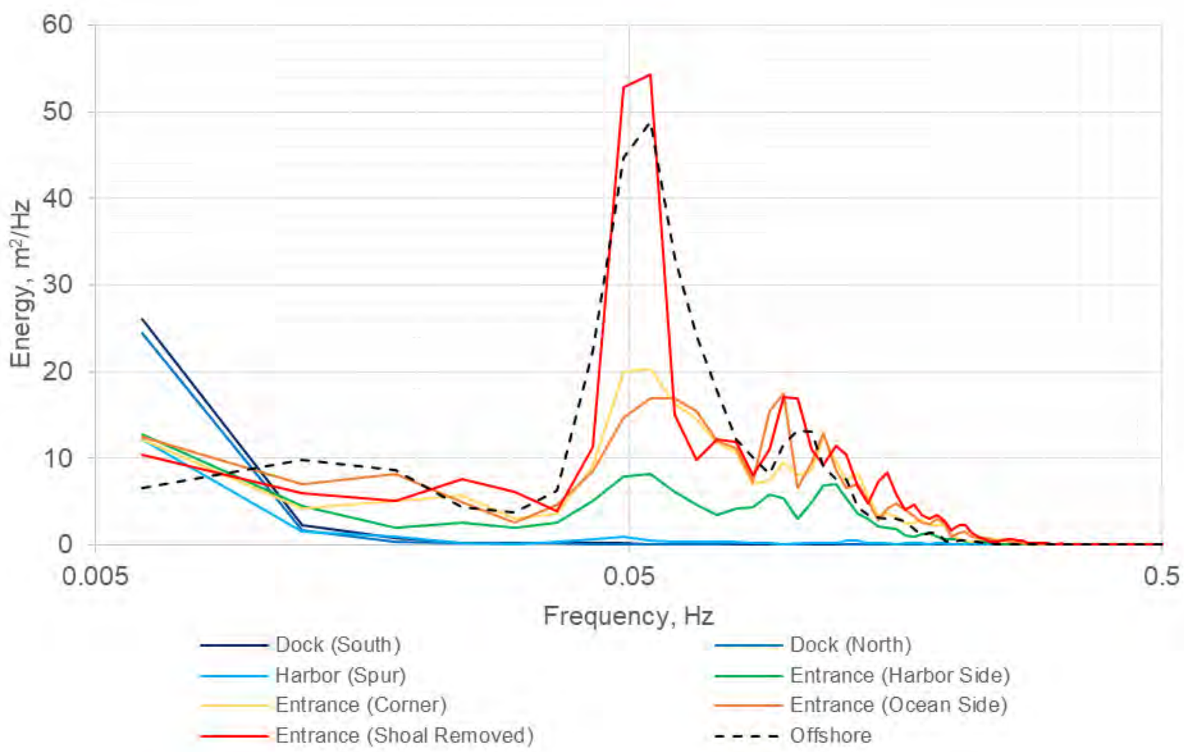

Figure 23. Case 8 Spectral Energy at Probe Locations

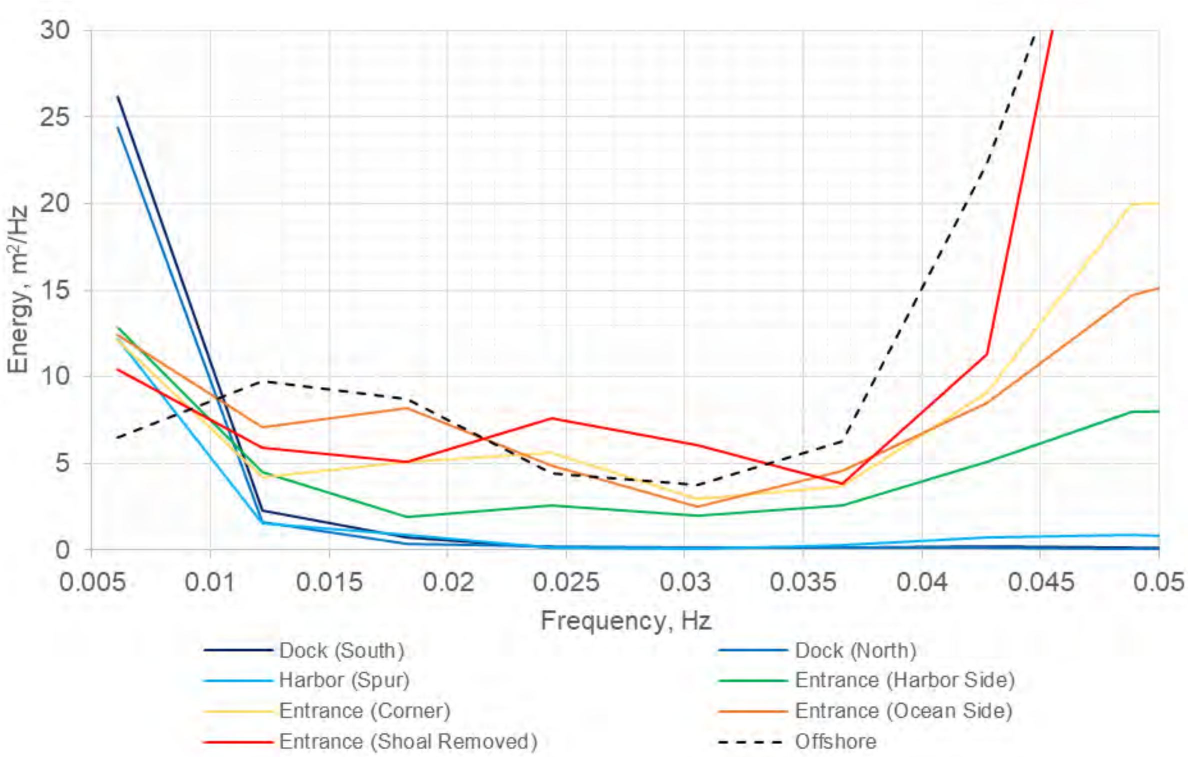

Figure 24. Case 8 Spectral Energy at Probe Locations (Enhanced Resolution at Low Frequencies)

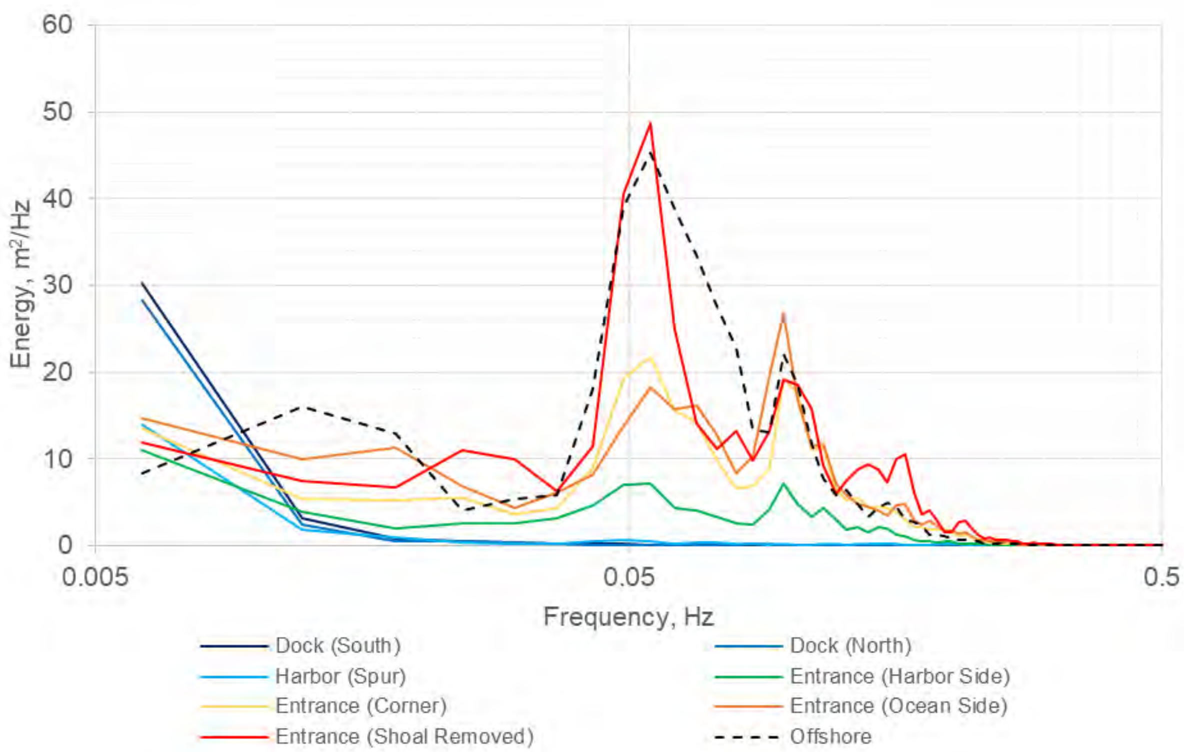

Figure 25. Case 9 Spectral Energy at Probe Locations

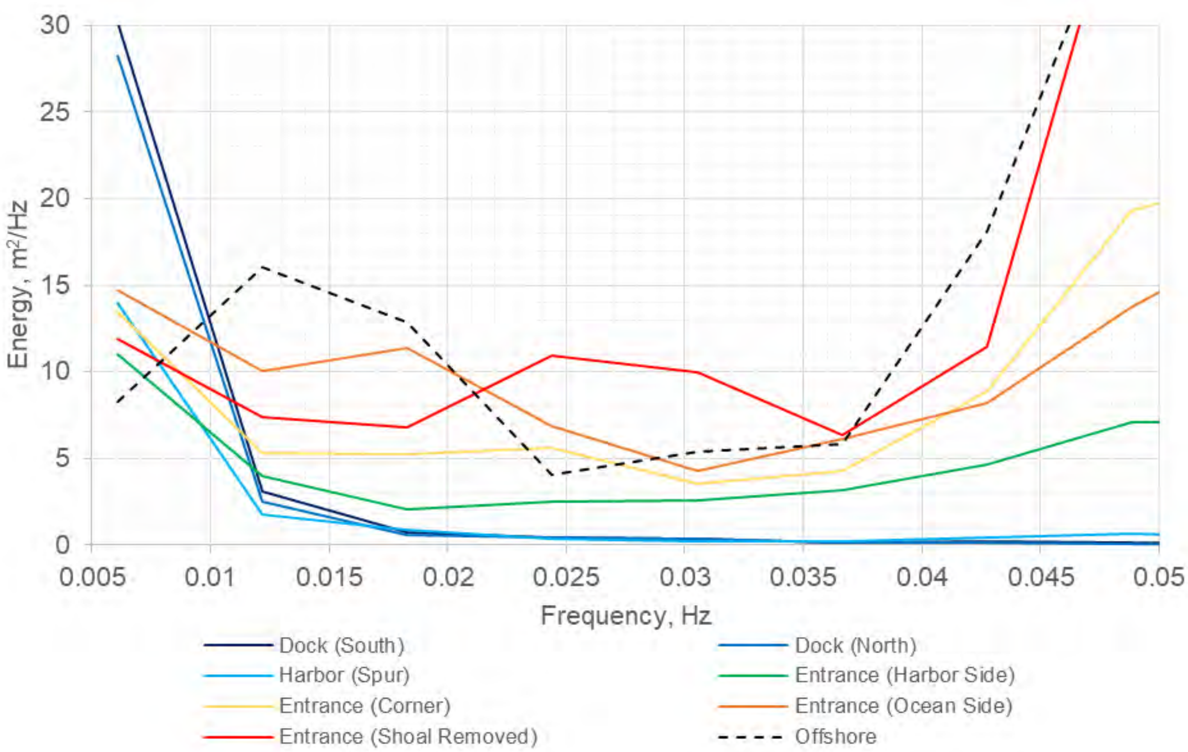

Figure 26. Case 9 Spectral Energy at Probe Locations (Enhanced Resolution at Low Frequencies)

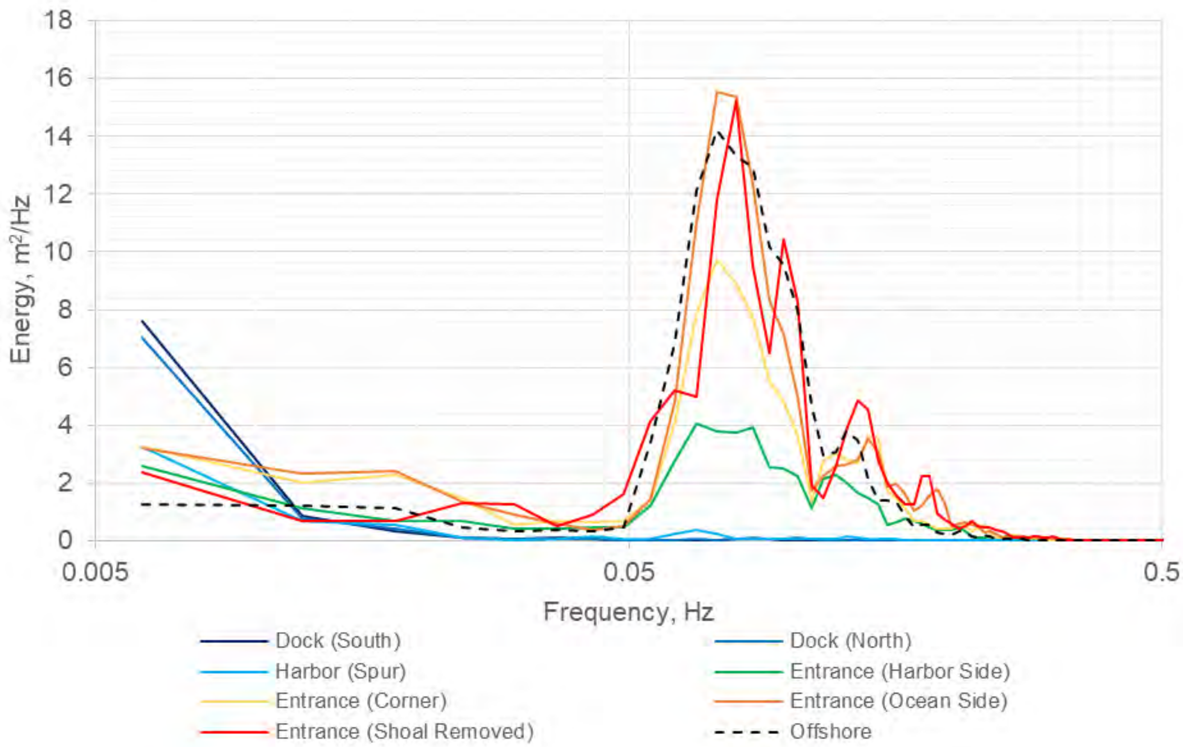

Figure 27. Case 10 Spectral Energy at Probe Locations

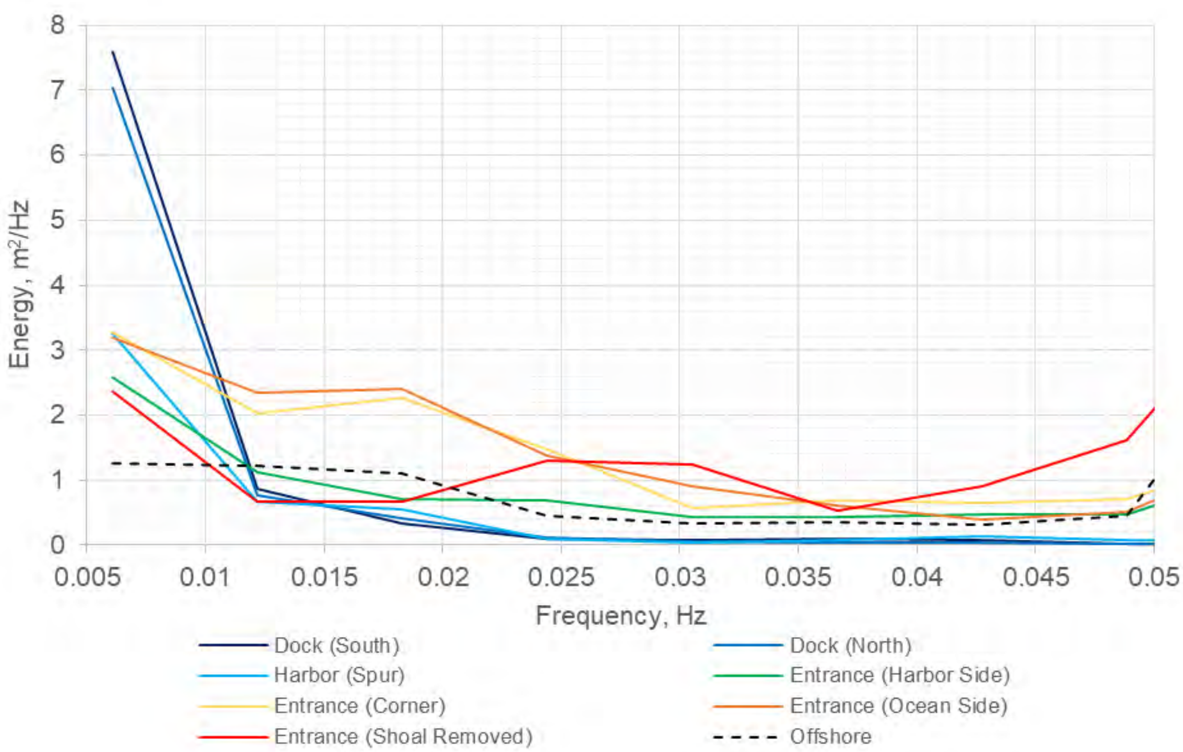

Figure 28. Case 10 Spectral Energy at Probe Locations (Enhanced Resolution at Low Frequencies)

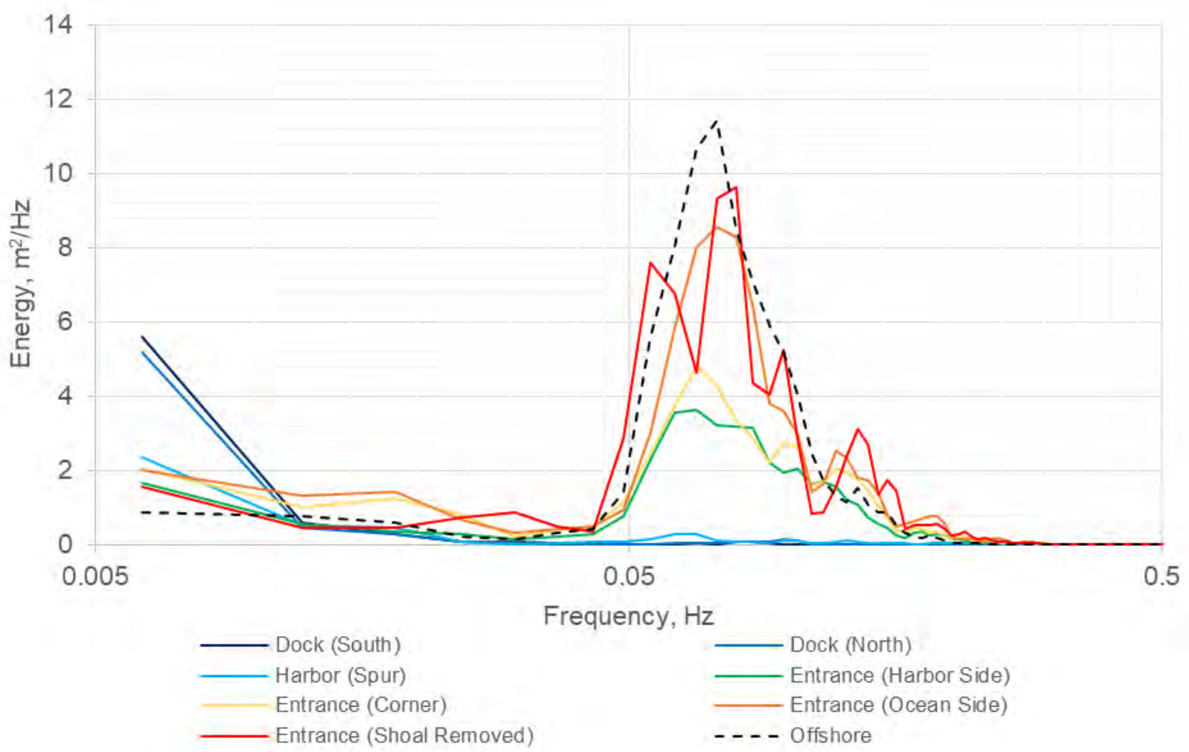

Figure 29. Case 11 Spectral Energy at Probe Locations

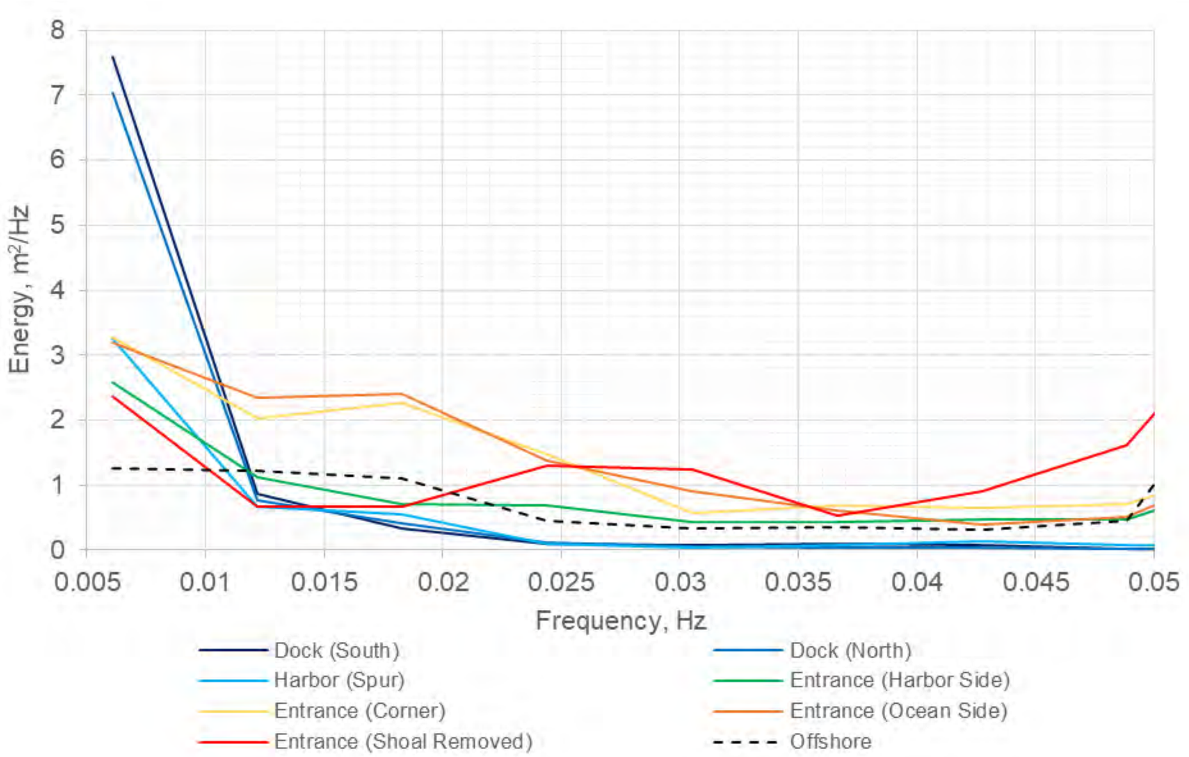

Figure 30. Case 11 Spectral Energy at Probe Locations (Enhanced Resolution at Low Frequencies)

Spectral Analysis Comparison

Spectral analysis plots comparing the baseline scenario and the alternative scenario models are provided in Figure 31 through Figure 41. For clarity, only two extraction locations were selected for these plots: (1) Dock (North) and (2) Harbor (Spur). These two locations provide an indication of the tranquility within the harbor. Of particular interest is the spike in low-frequency waves in Cases 5 through 11.

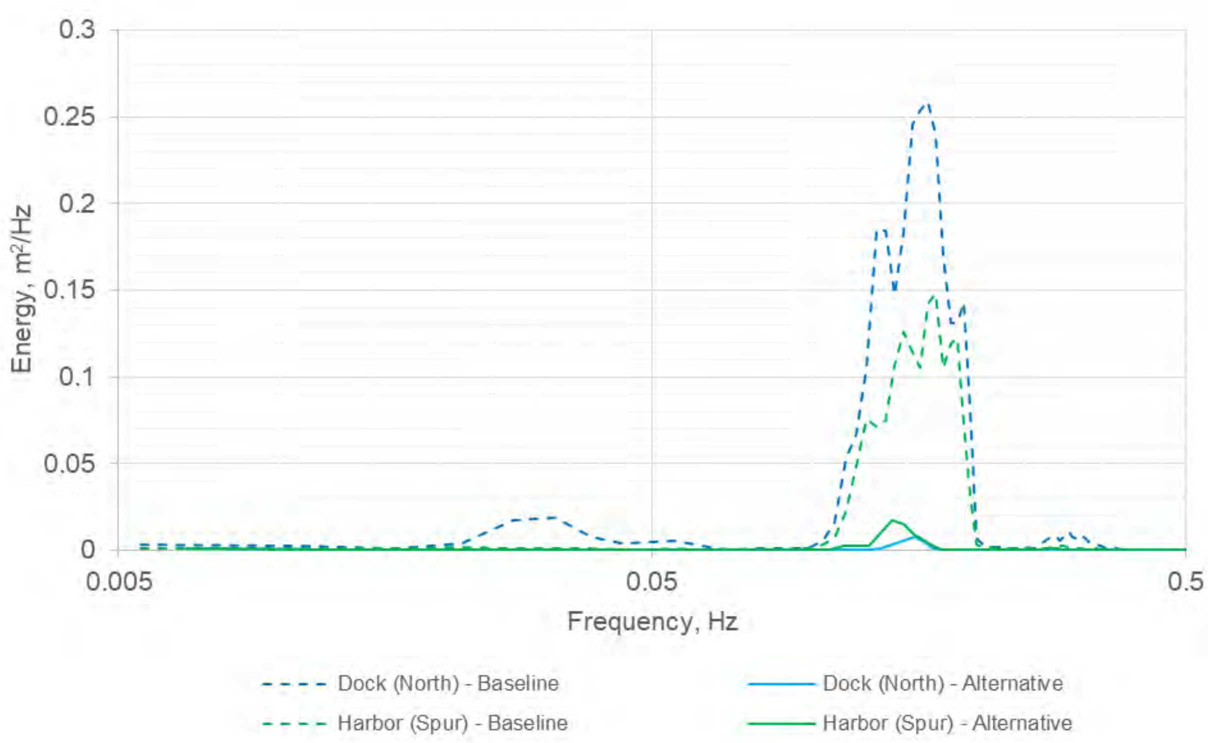

Figure 31. Case 1 Comparison Plot of Baseline and Alternative Models

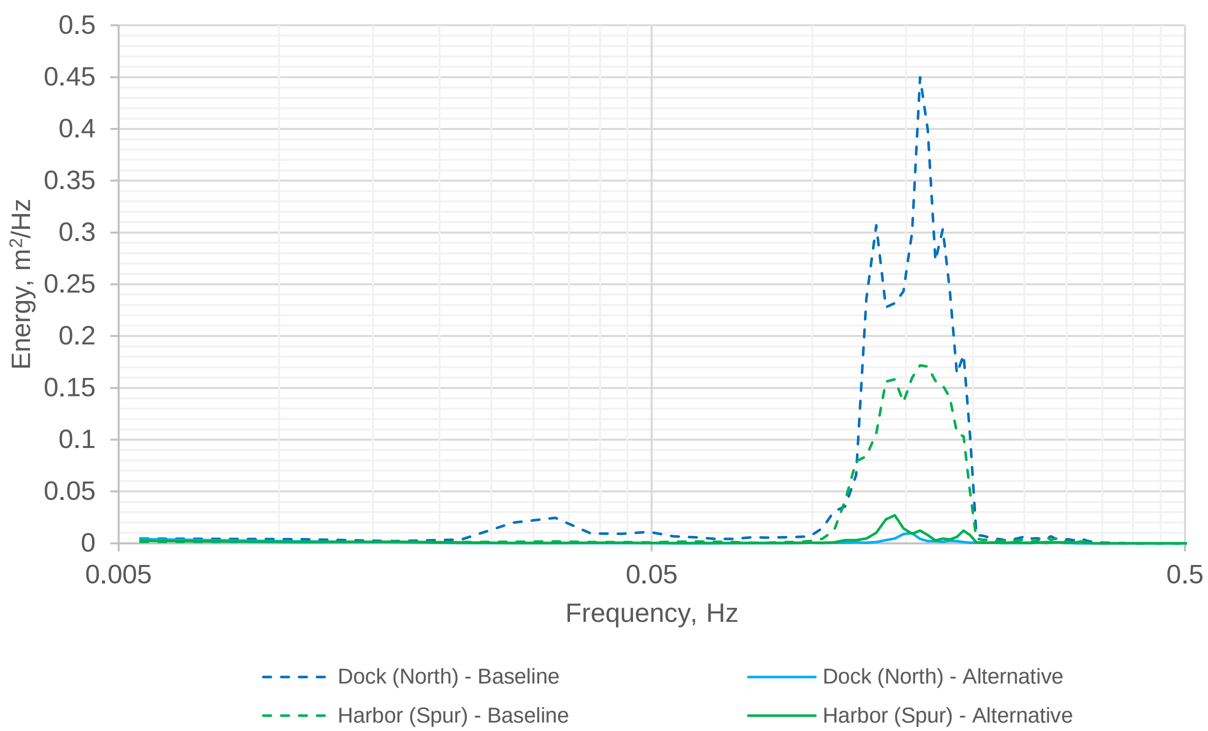

Figure 32. Case 2 Comparison Plot of Baseline and Alternative Models

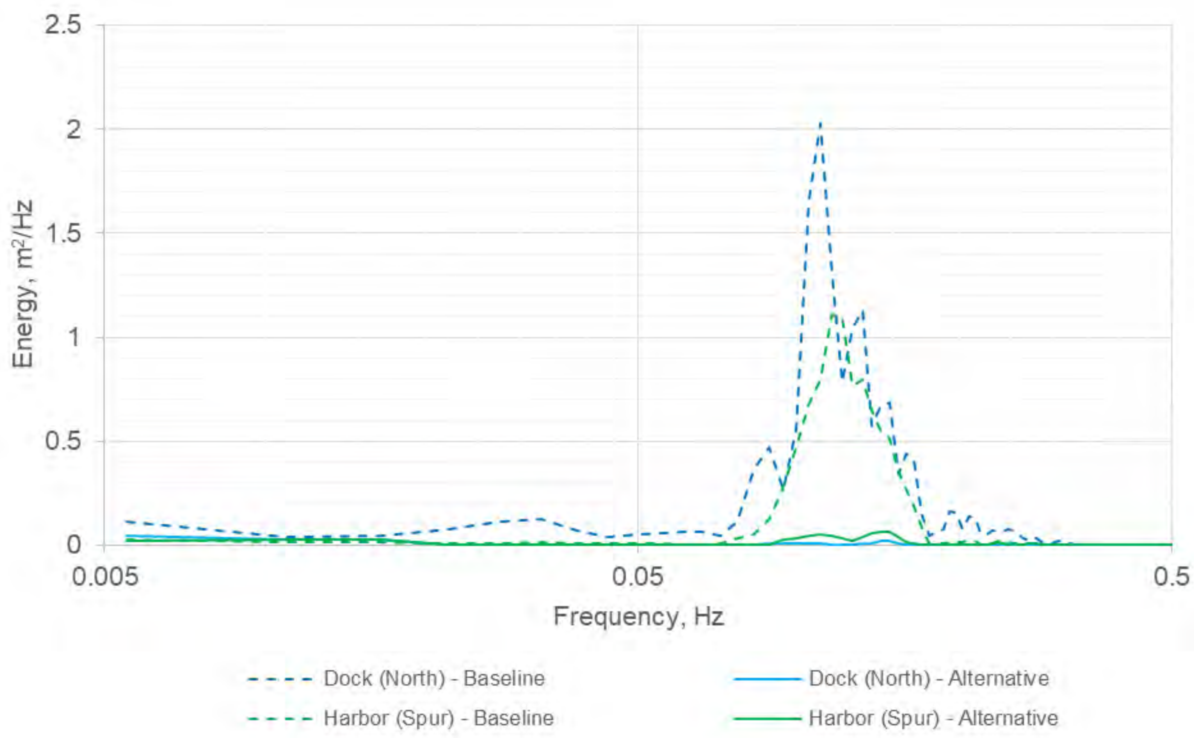

Figure 33. Case 3 Comparison Plot of Baseline and Alternative Models

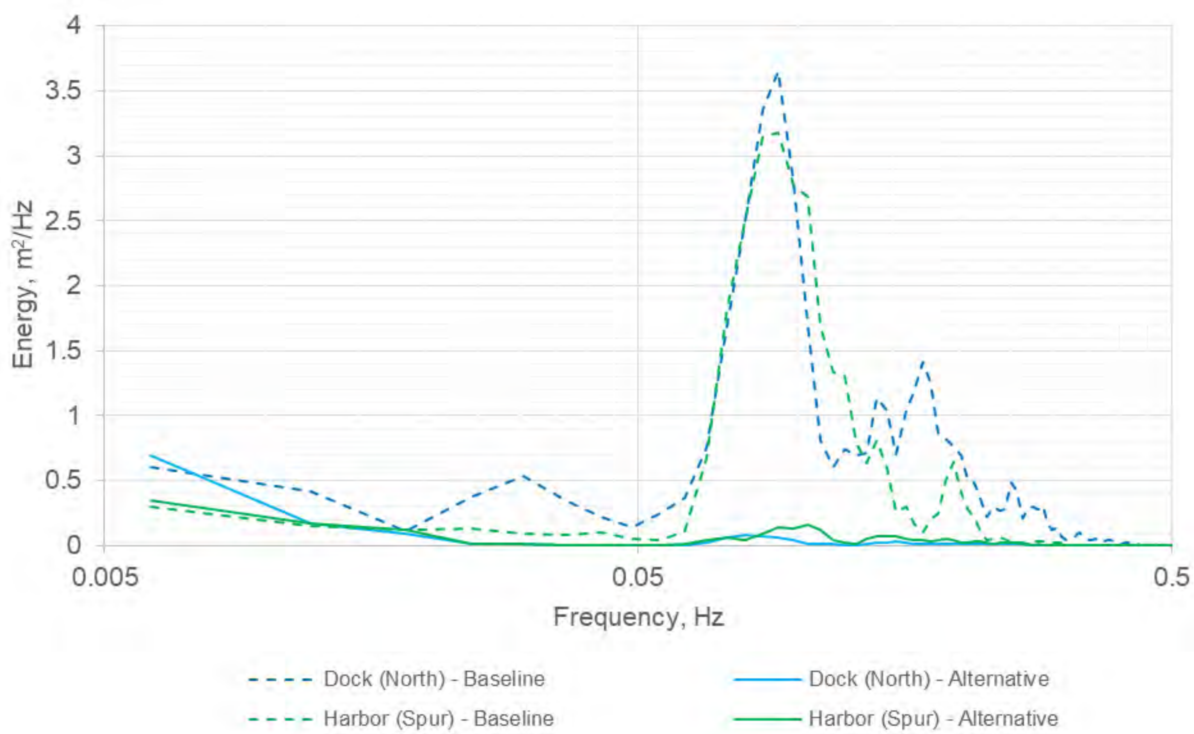

Figure 34. Case 4 Comparison Plot of Baseline and Alternative Models

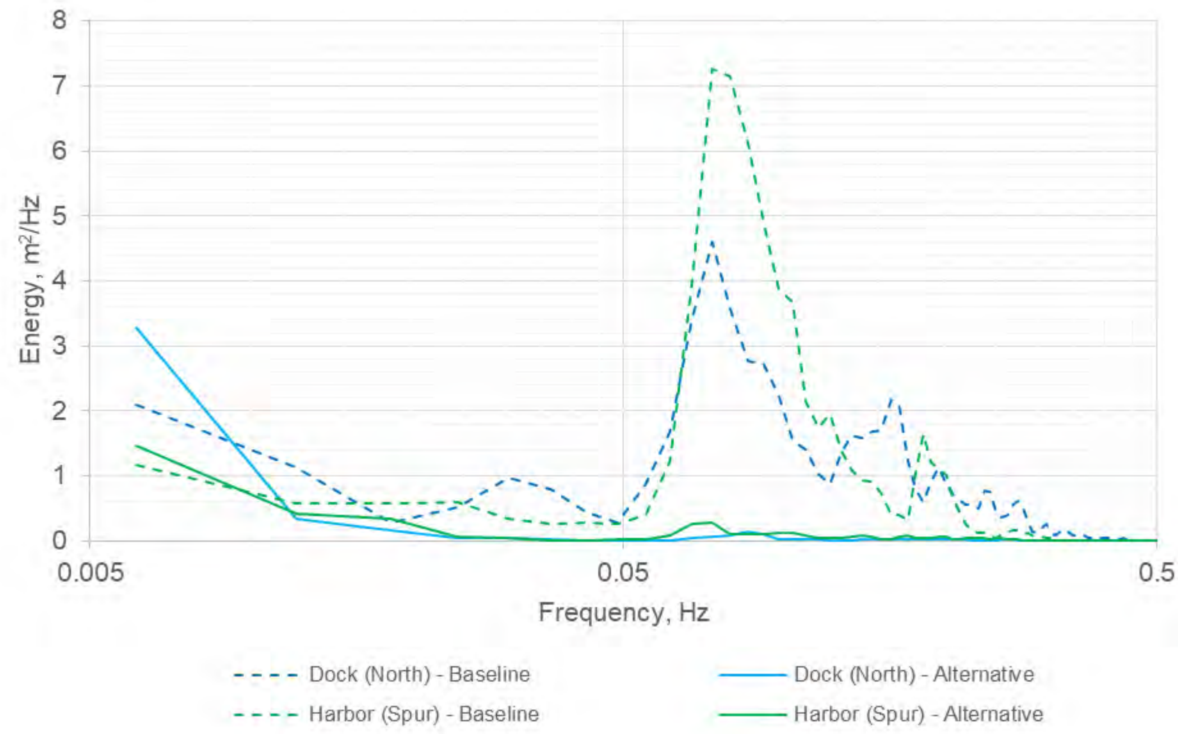

Figure 35. Case 5 Comparison Plot of Baseline and Alternative Models

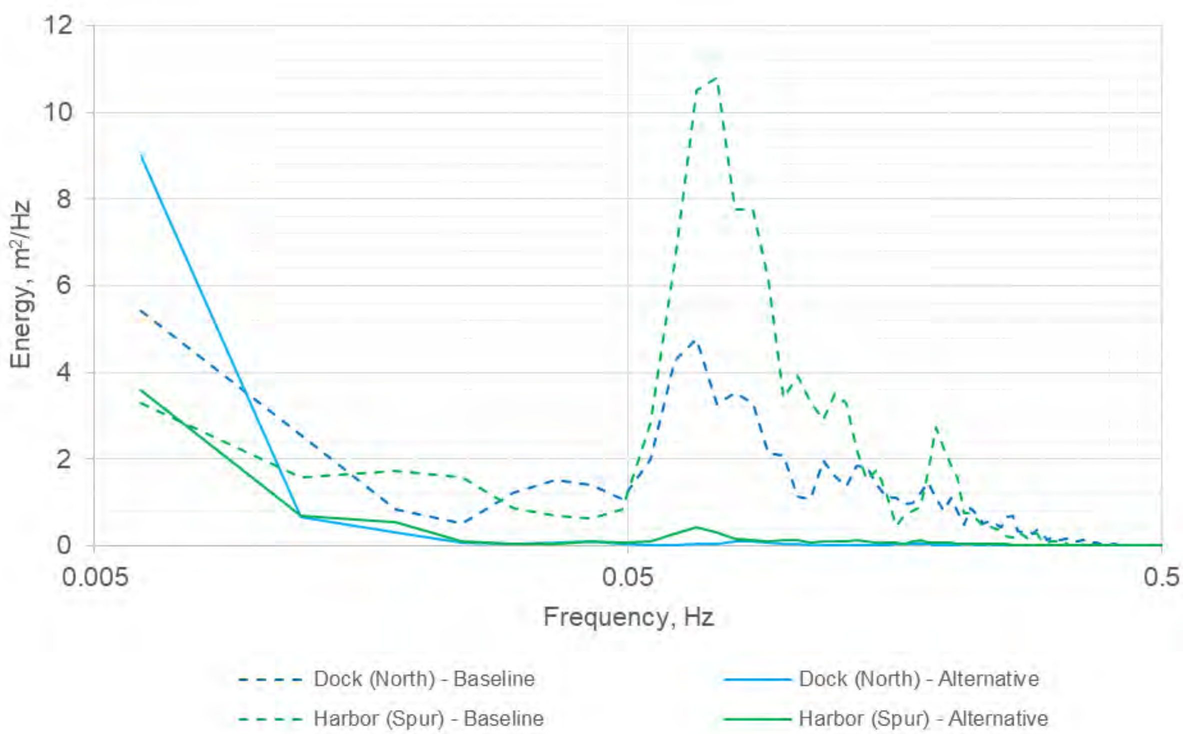

Figure 36. Case 6 Comparison Plot of Baseline and Alternative Models

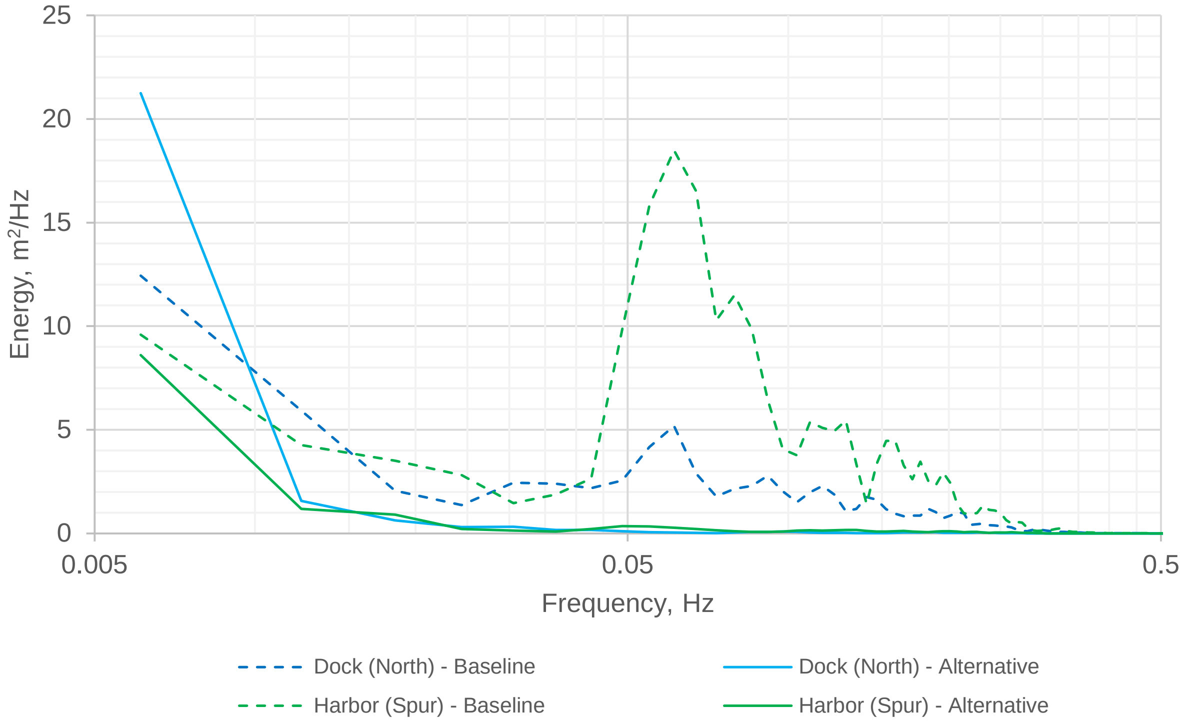

Figure 37. Case 7 Comparison Plot of Baseline and Alternative Models

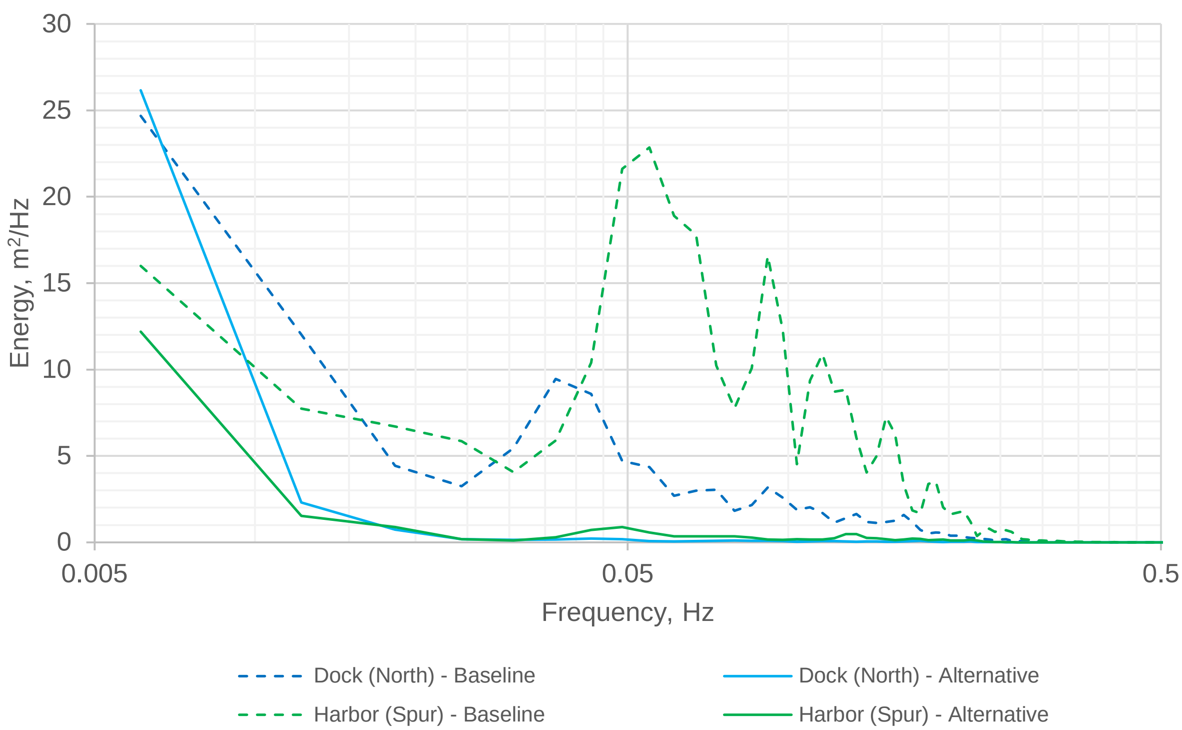

Figure 38. Case 8 Comparison Plot of Baseline and Alternative Models

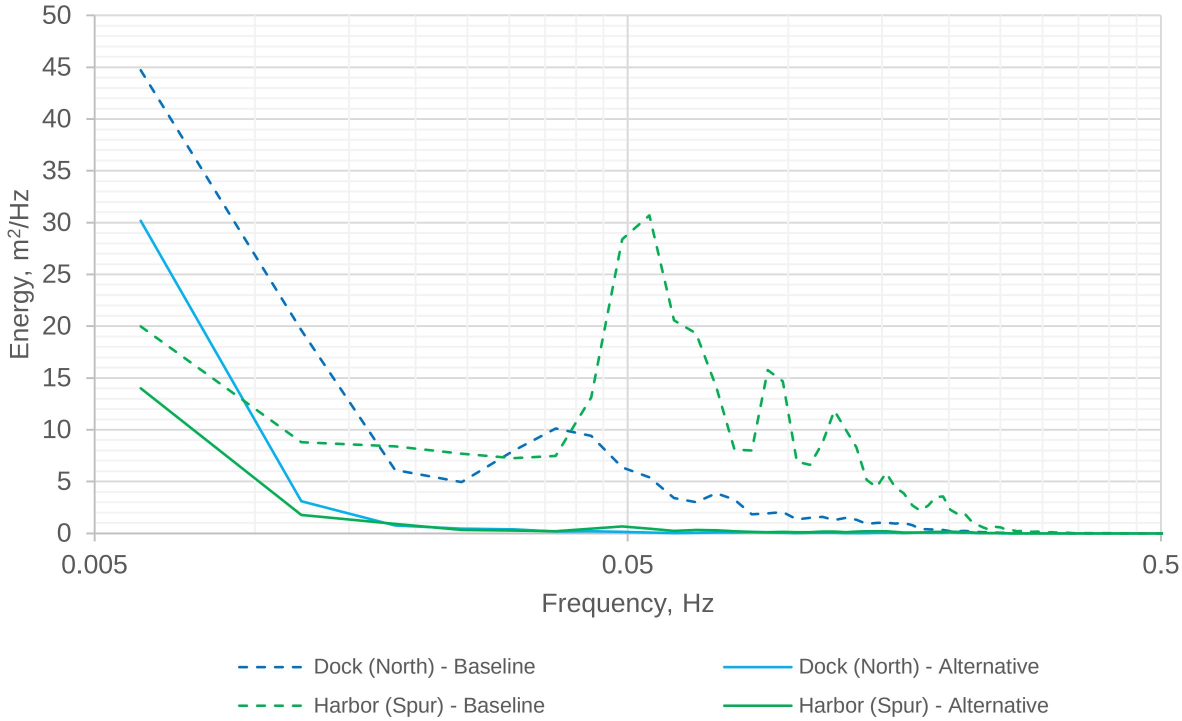

Figure 39. Case 9 Comparison Plot of Baseline and Alternative Models

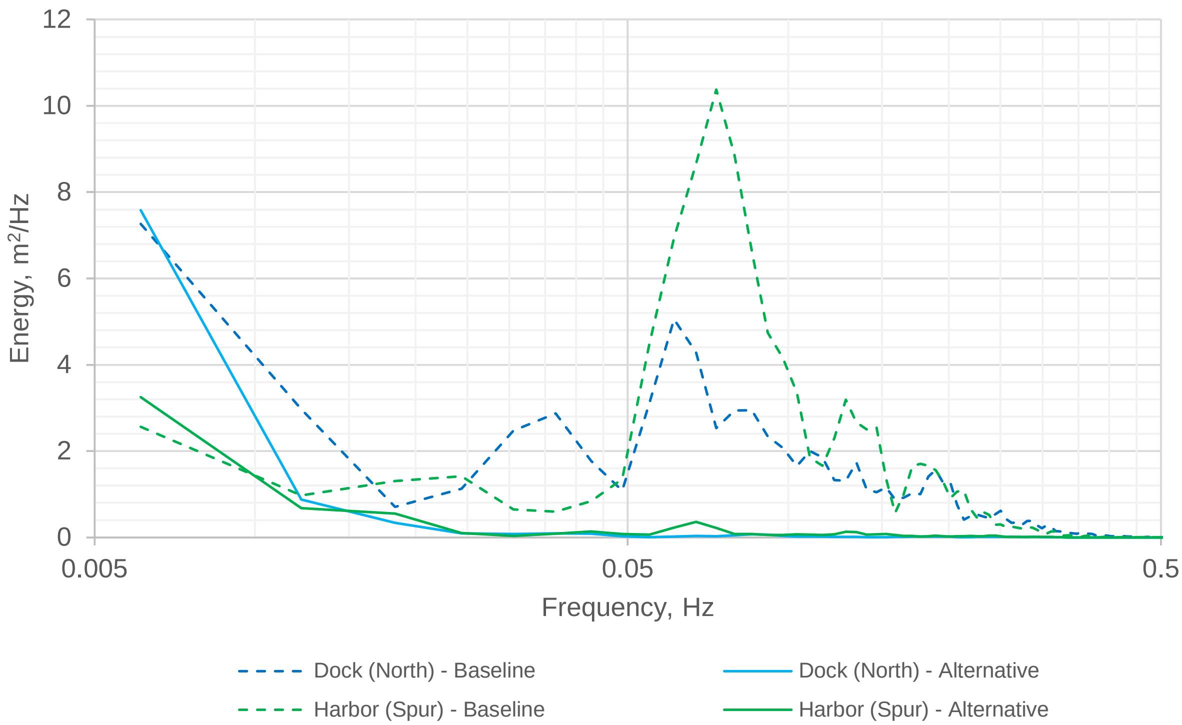

Figure 40. Case 10 Comparison Plot of Baseline and Alternative Models

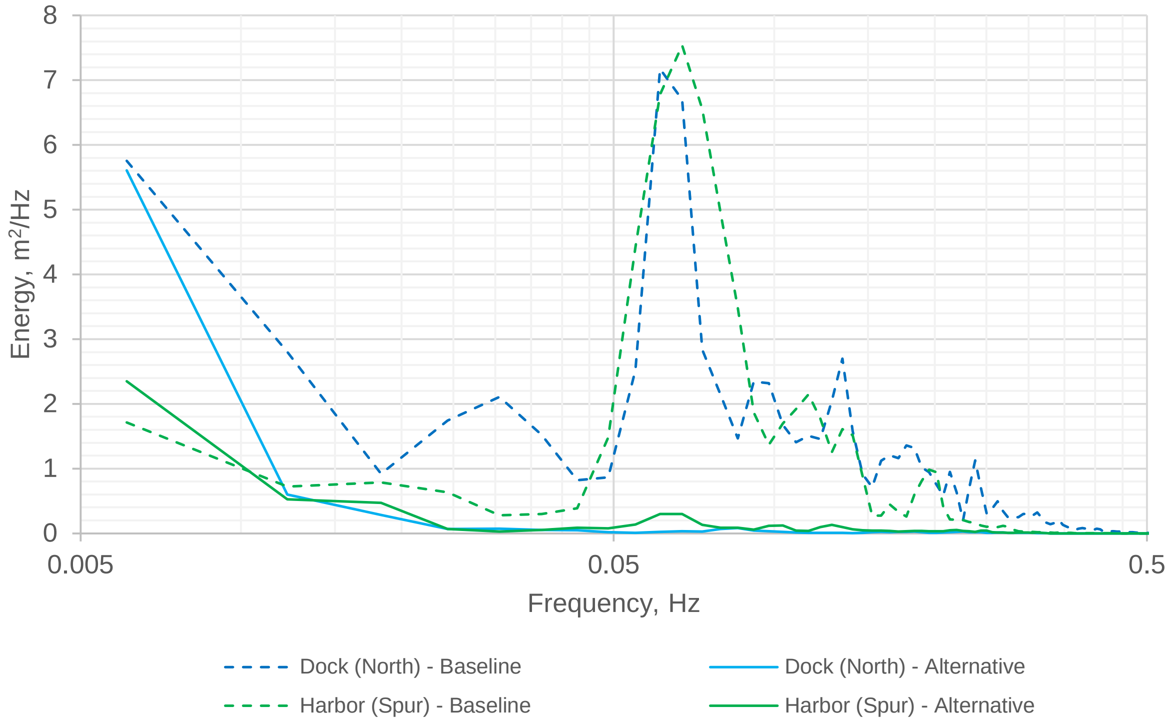

Figure 41. Case 11 Comparison Plot of Baseline and Alternative Models

Water Level Elevation Results

Water level data provide visual representation of wave transformation into the harbor. Water level results are provided at the same two locations used to compare the baseline and alternative scenarios spectral analyses. A Savitzky-Golay filter was run over the water surface elevation data to provide an estimate of the quasi-still water level. This provides a graphical representation of long-period wave energy within the harbor, if present. Figure 42 through Figure 63 provide water surface elevation plots for each wave case at the Dock (North) and Harbor (Spur) locations.

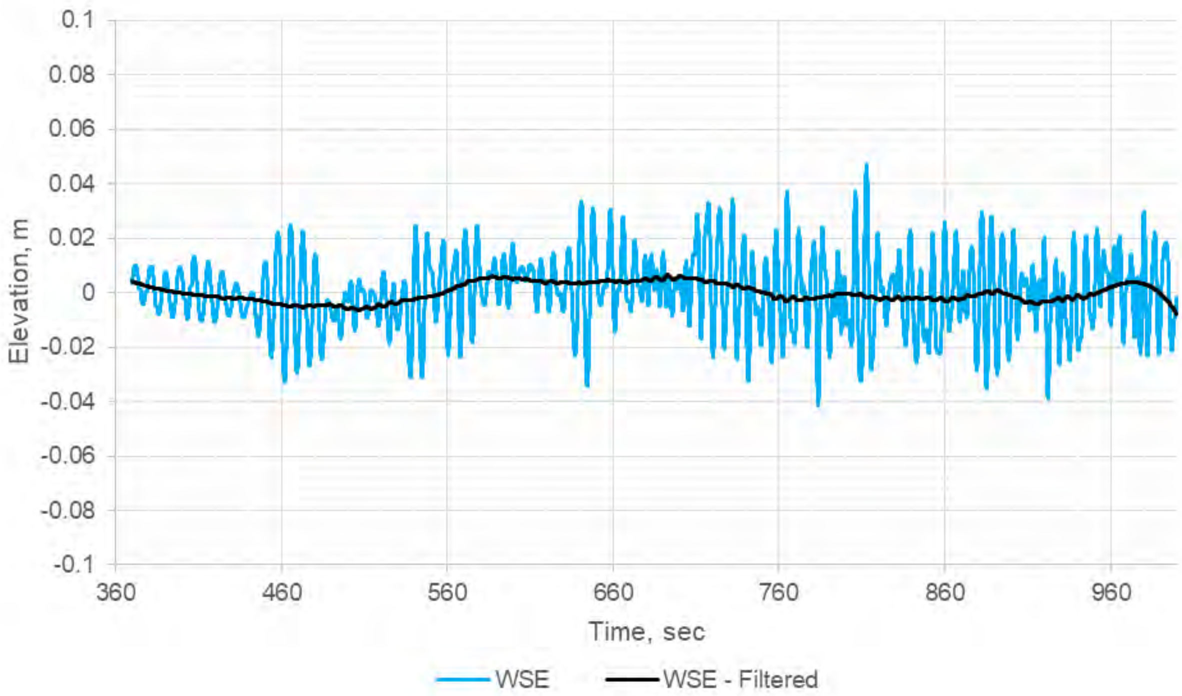

Figure 42. Case 1 - Water Surface Plot at Dock (North Side)

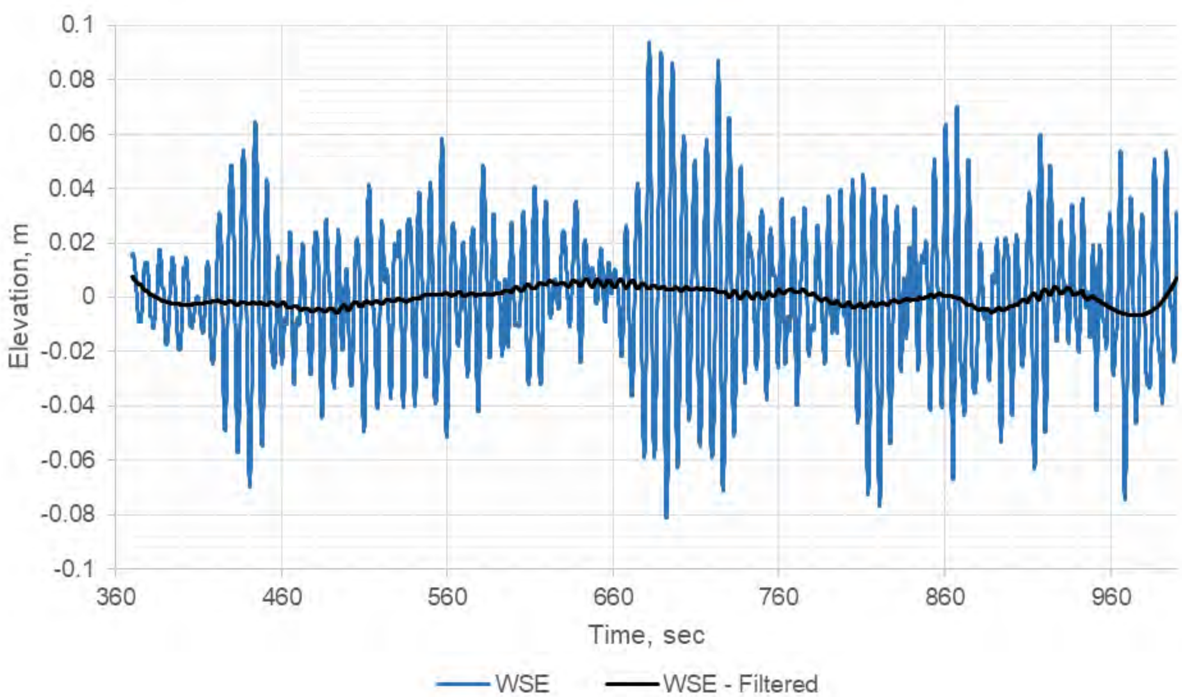

Figure 43. Case 1 - Water Surface Plot at Harbor (Spur)

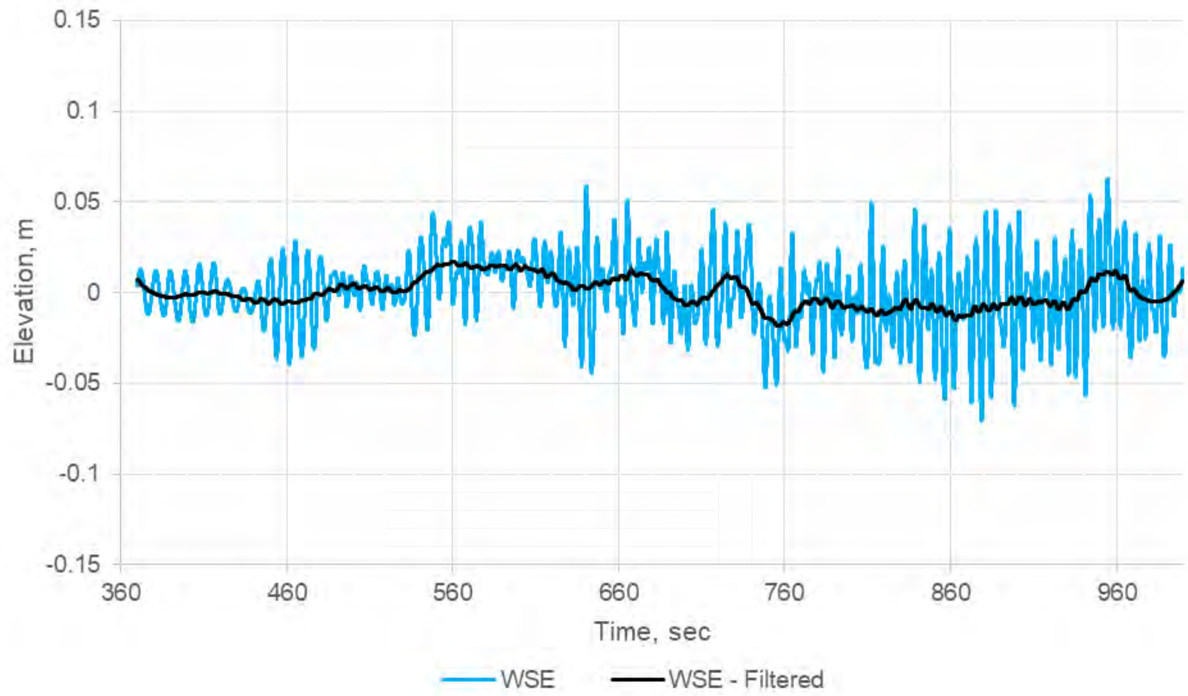

Figure 44. Case 2 - Water Surface Plot at Dock (North Side)

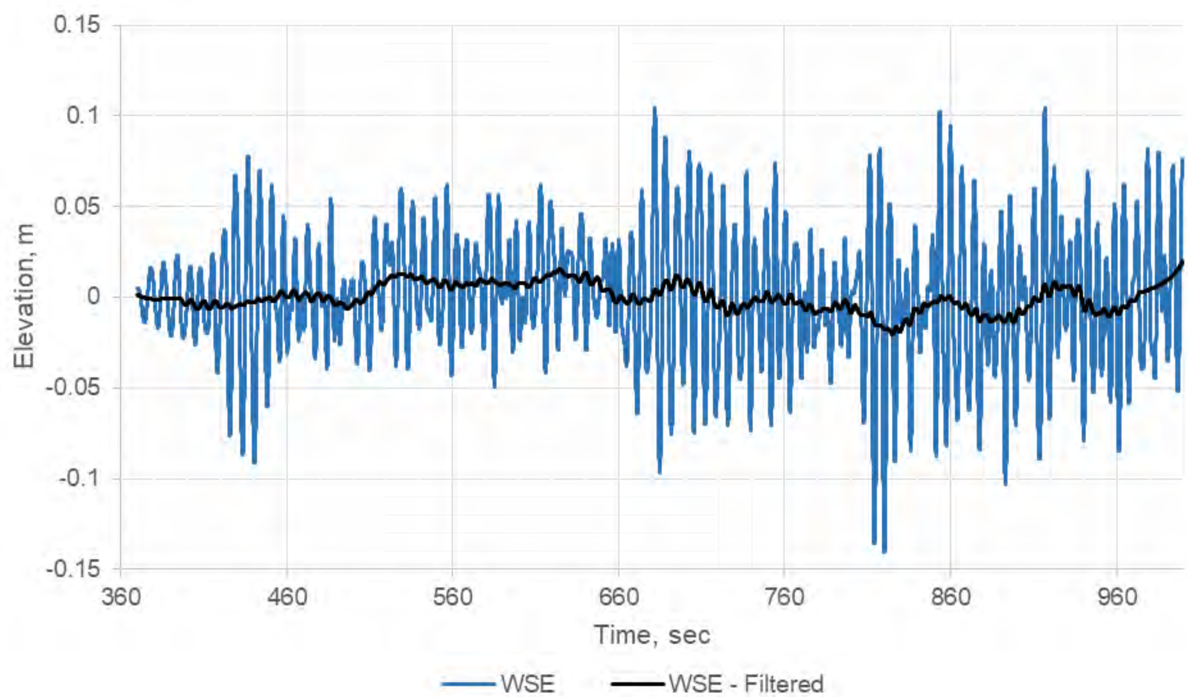

Figure 45. Case 2 - Water Surface Plot at Harbor (Spur)

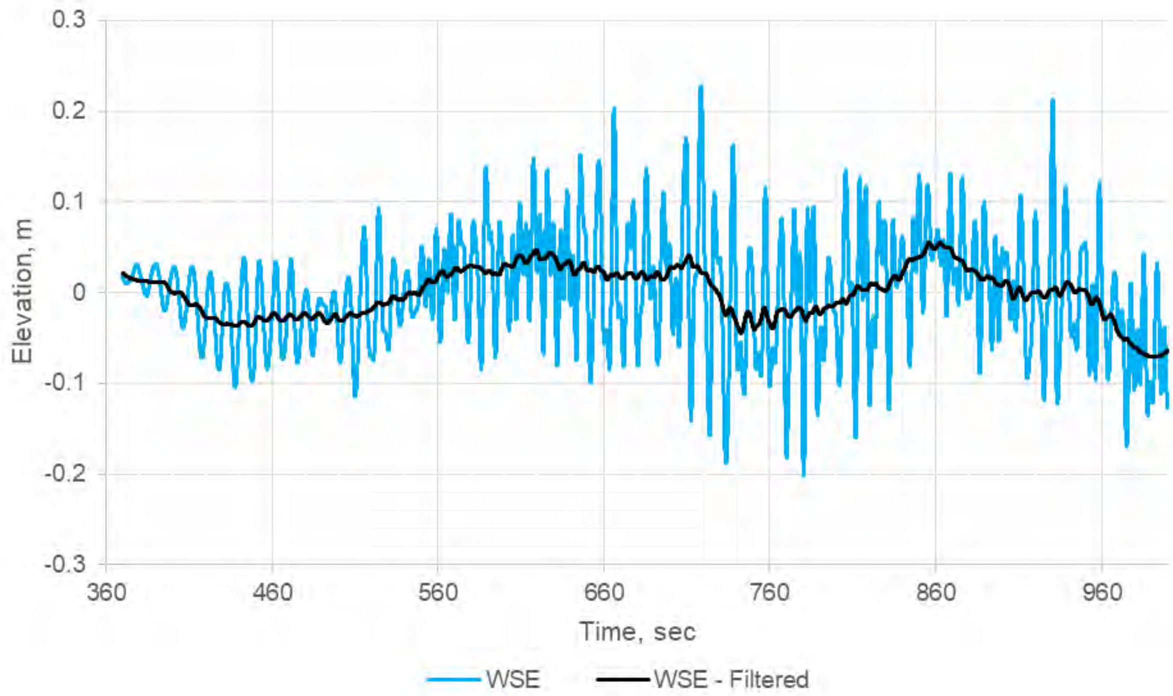

Figure 46. Case 3 - Water Surface Plot at Dock (North Side)

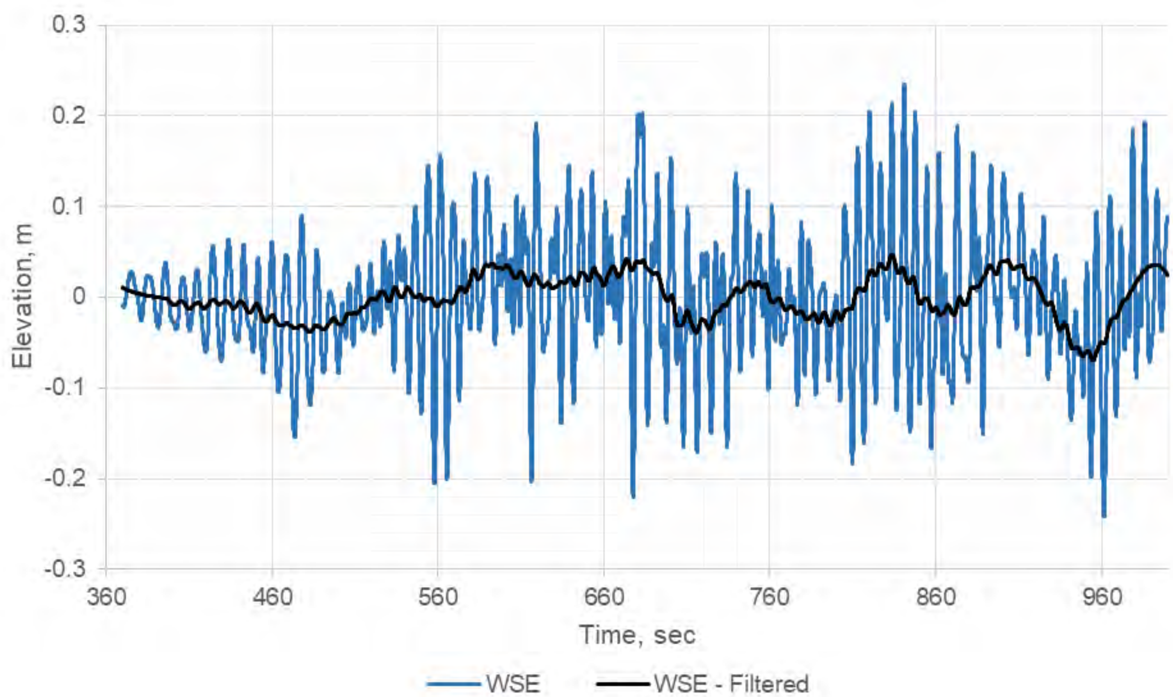

Figure 47. Case 3 - Water Surface Plot at Harbor (Spur)

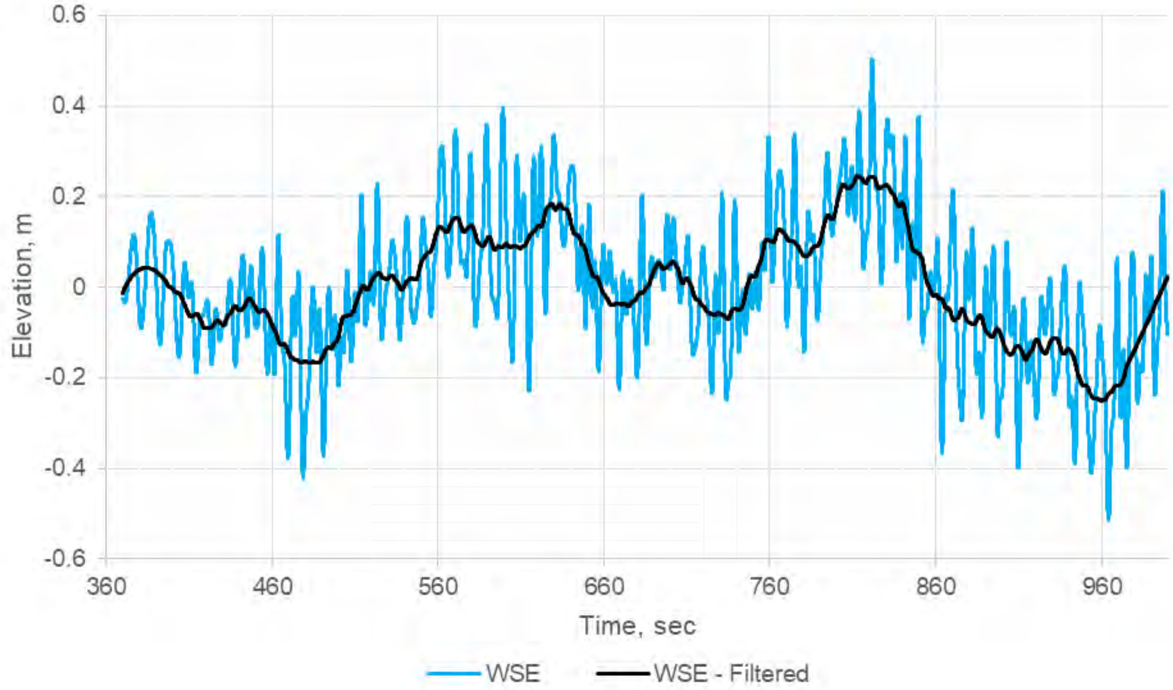

Figure 48. Case 4 - Water Surface Plot at Dock (North Side)

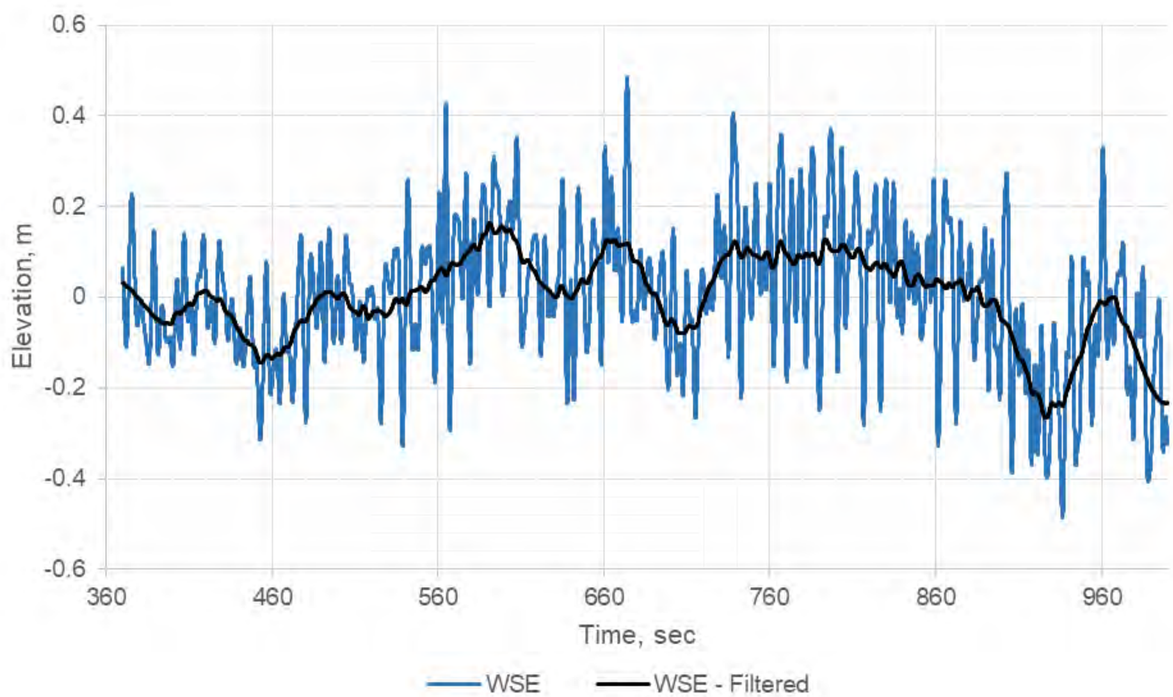

Figure 49. Case 4 - Water Surface Plot at Harbor (Spur)

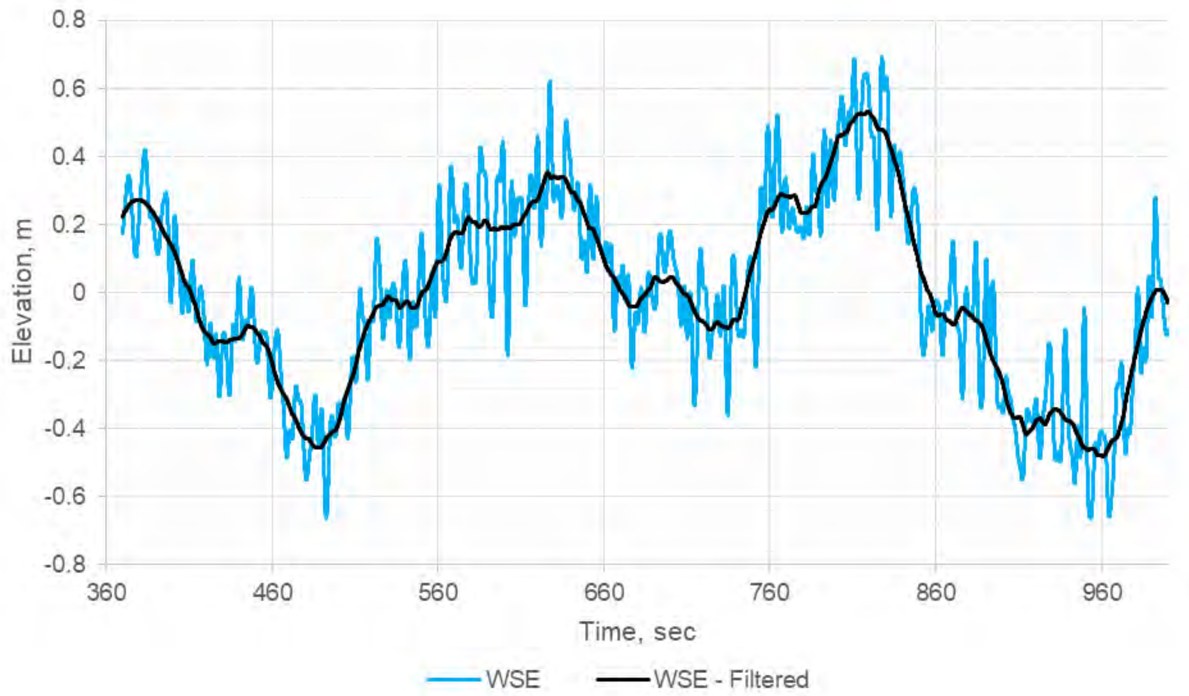

Figure 50. Case 5 - Water Surface Plot at Dock (North Side)

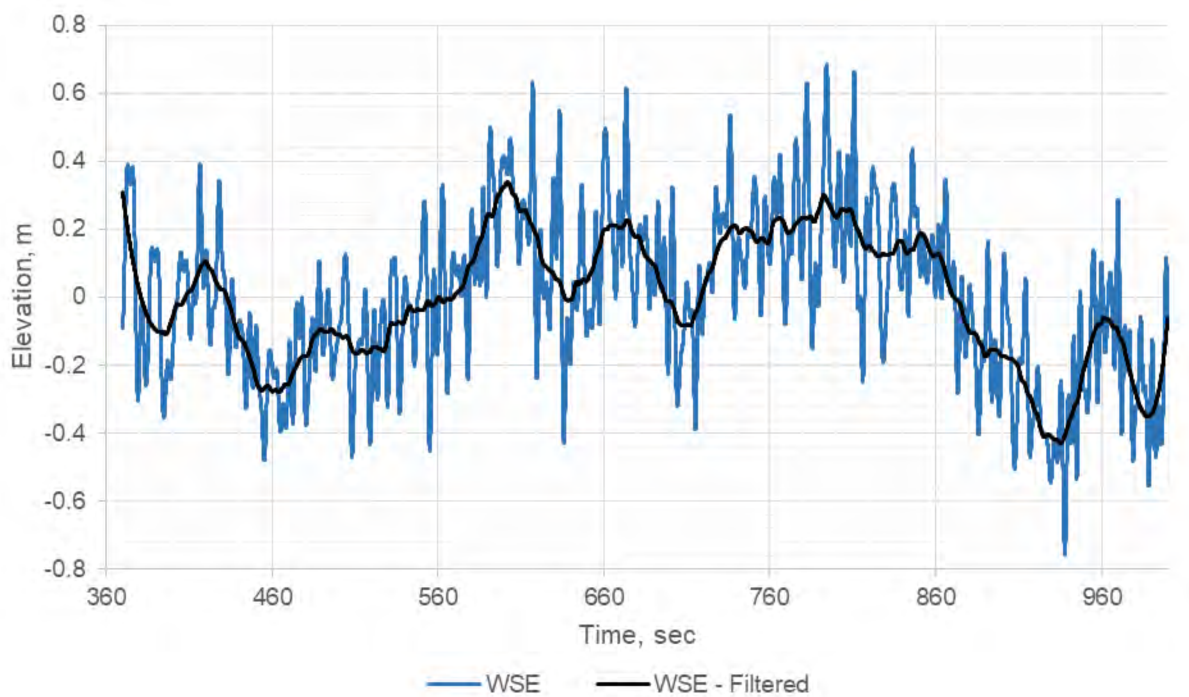

Figure 51. Case 5 - Water Surface Plot at Harbor (Spur)

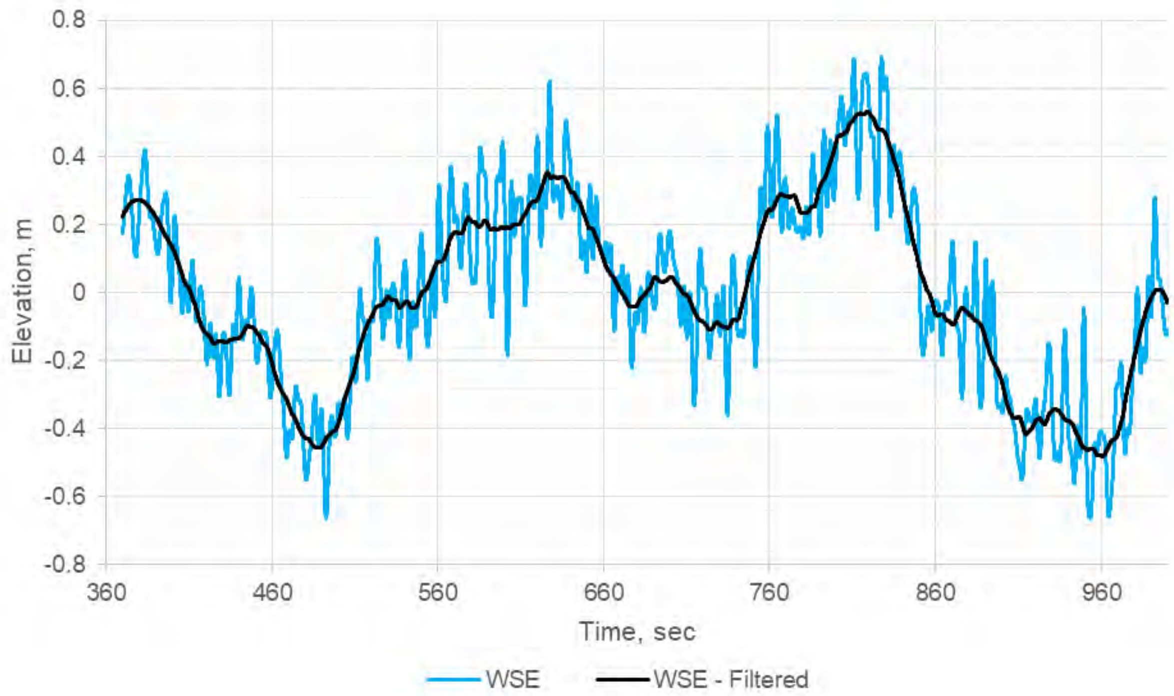

Figure 52. Case 6 - Water Surface Plot at Dock (North Side)

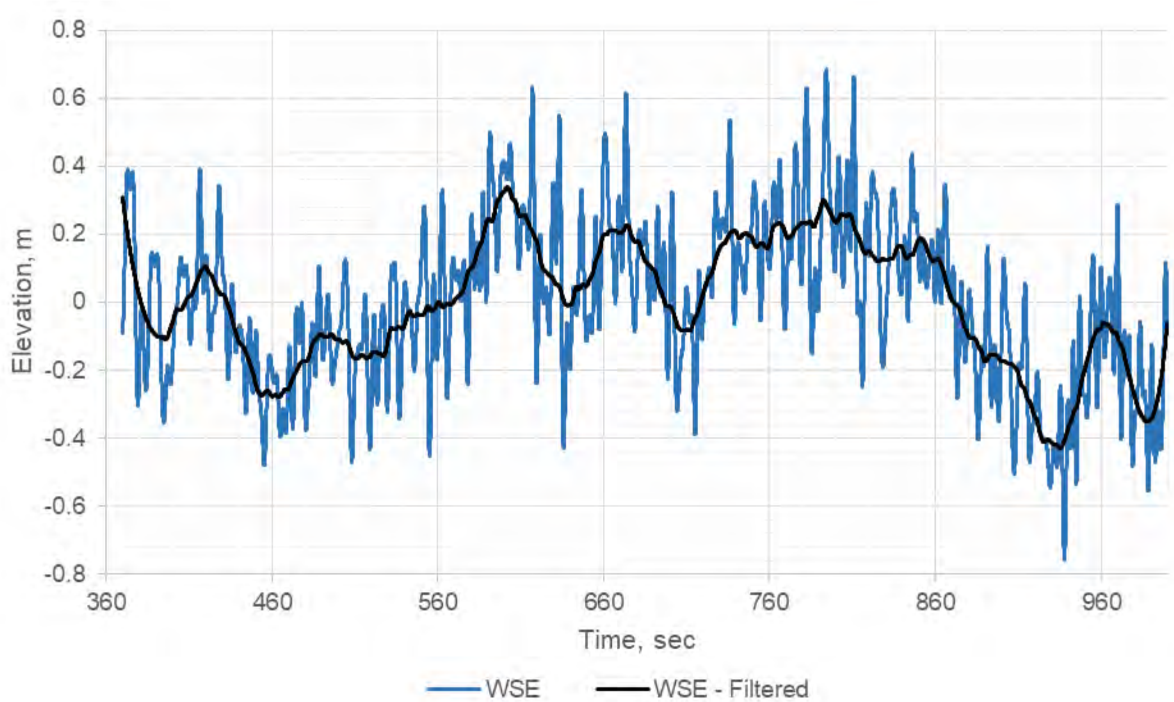

Figure 53. Case 6 - Water Surface Plot at Harbor (Spur)

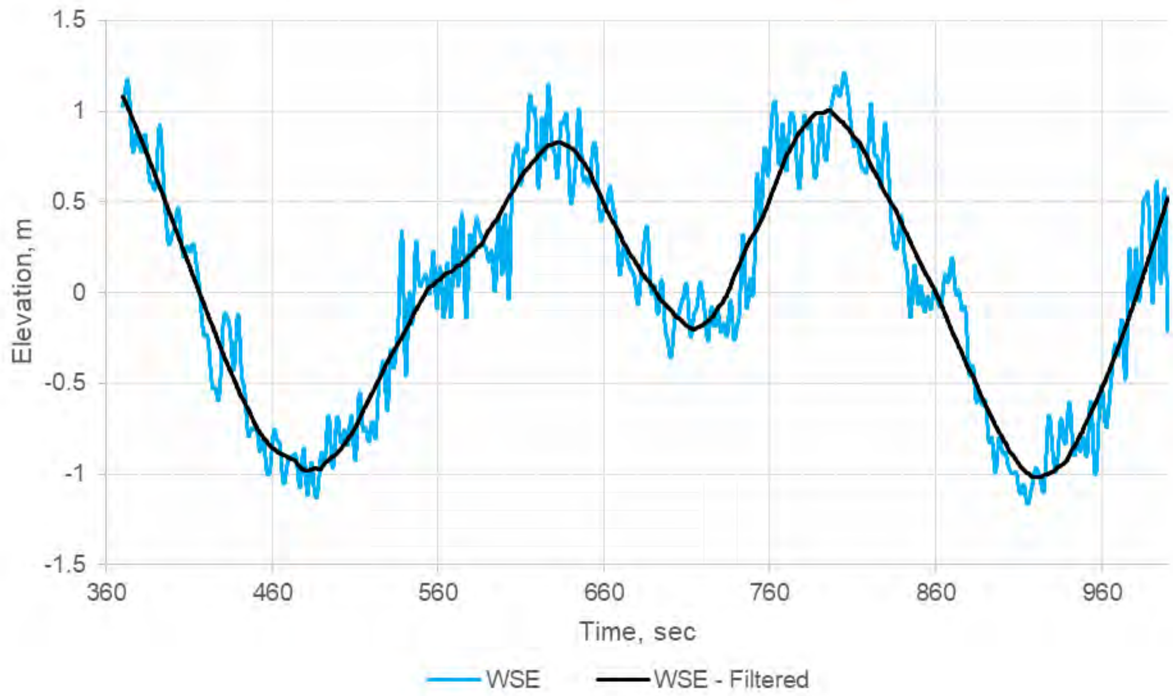

Figure 54. Case 7 - Water Surface Plot at Dock (North Side)

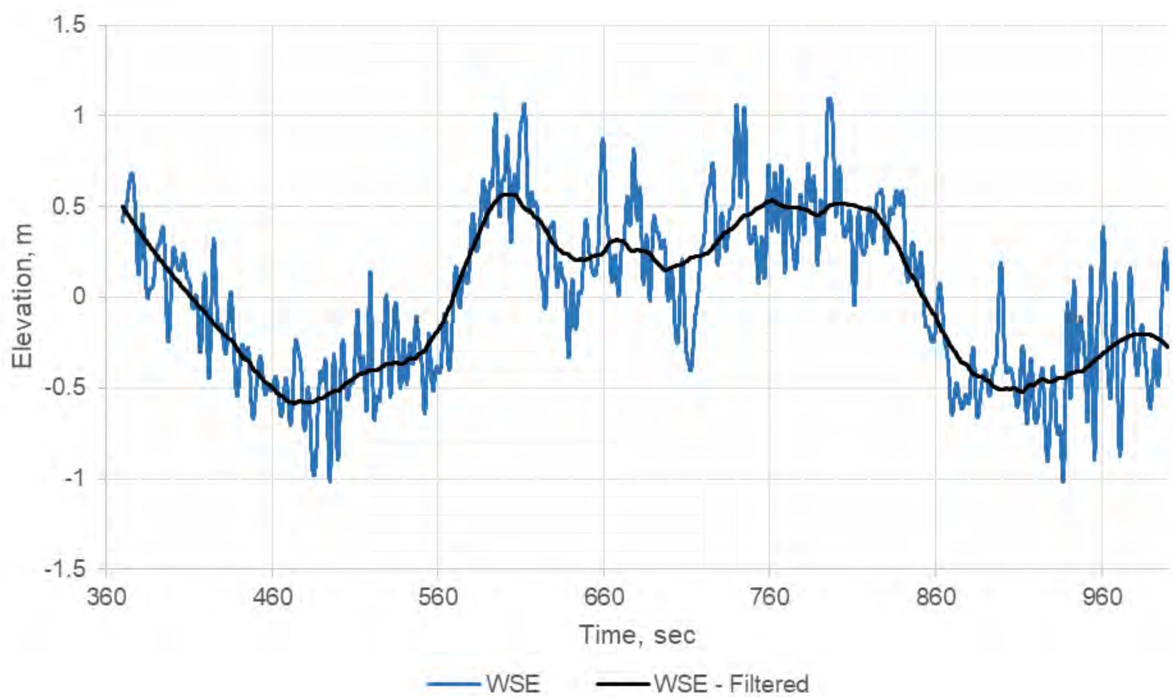

Figure 55. Case 7 - Water Surface Plot at Harbor (Spur)

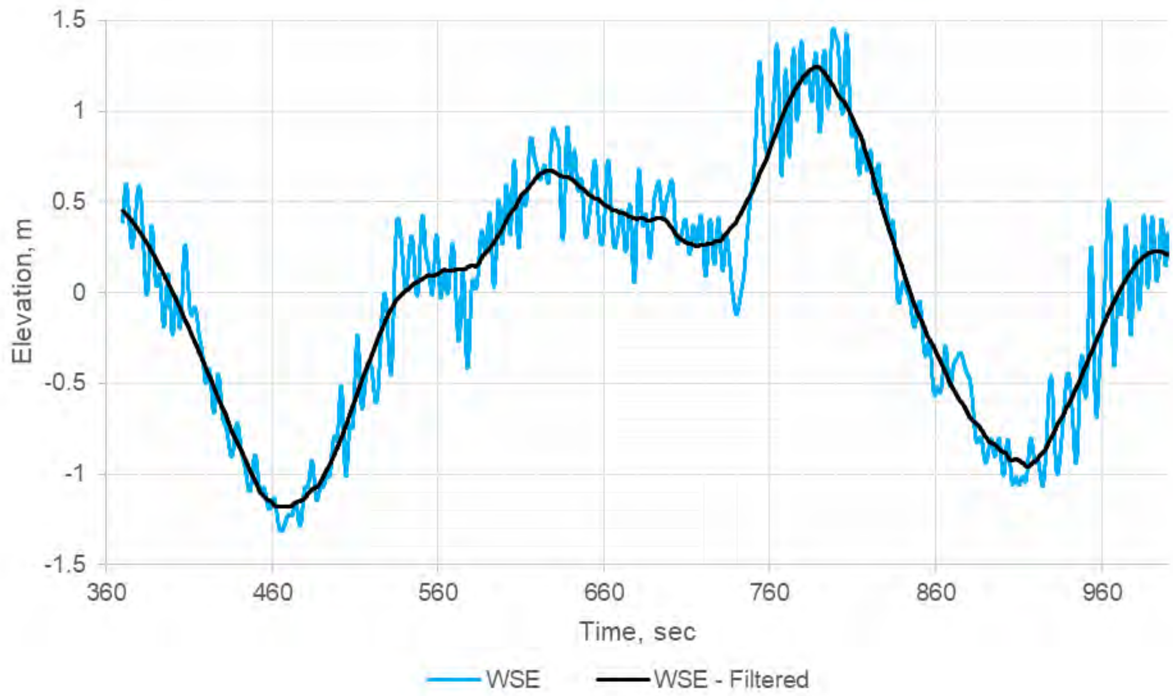

Figure 56. Case 8 - Water Surface Plot at Dock (North Side)

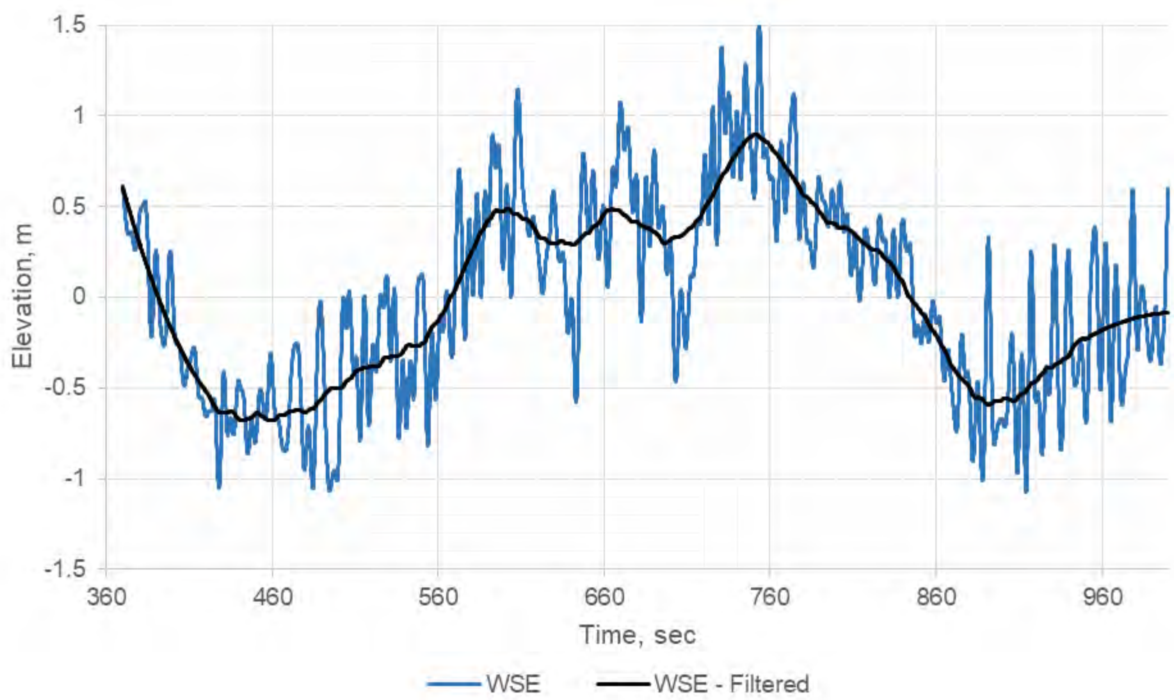

Figure 57. Case 8 - Water Surface Plot at Harbor (Spur)

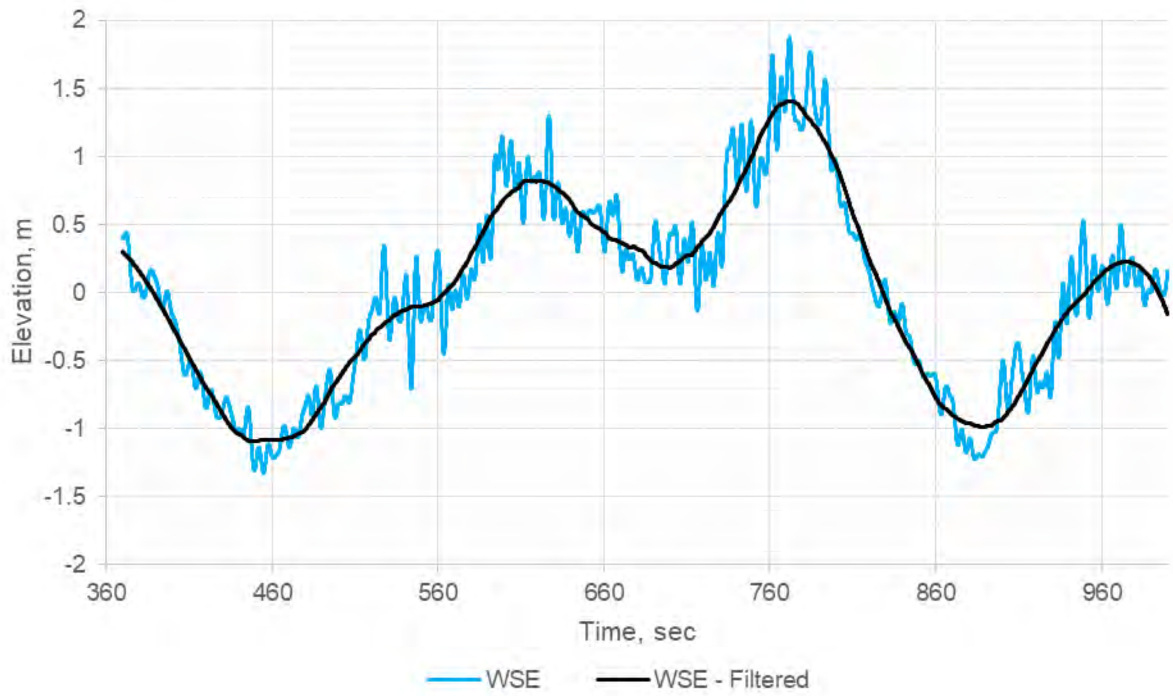

Figure 58. Case 9 - Water Surface Plot at Dock (North Side)

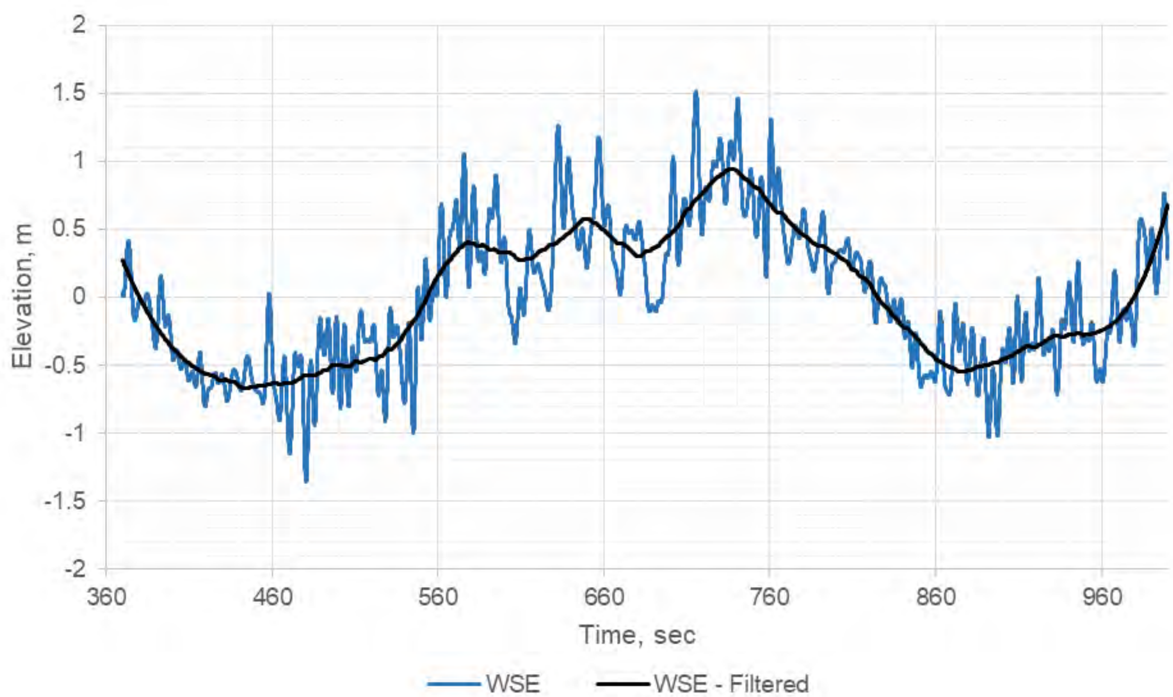

Figure 59. Case 9 - Water Surface Plot at Harbor (Spur)

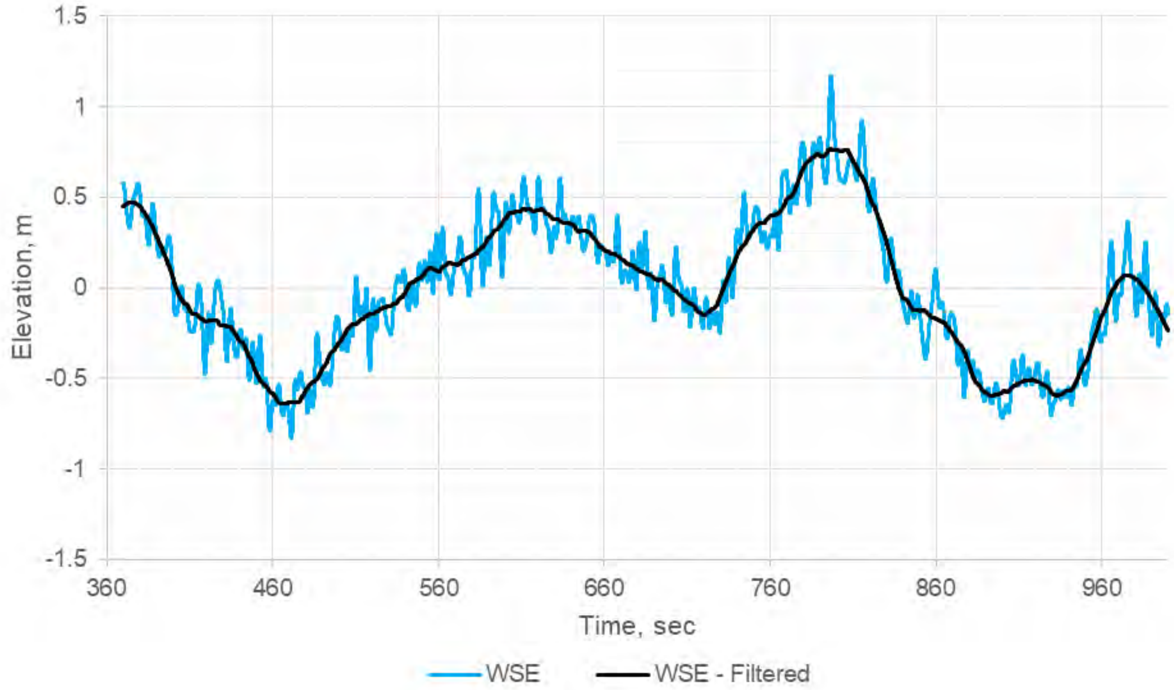

Figure 60. Case 10 - Water Surface Plot at Dock (North Side)

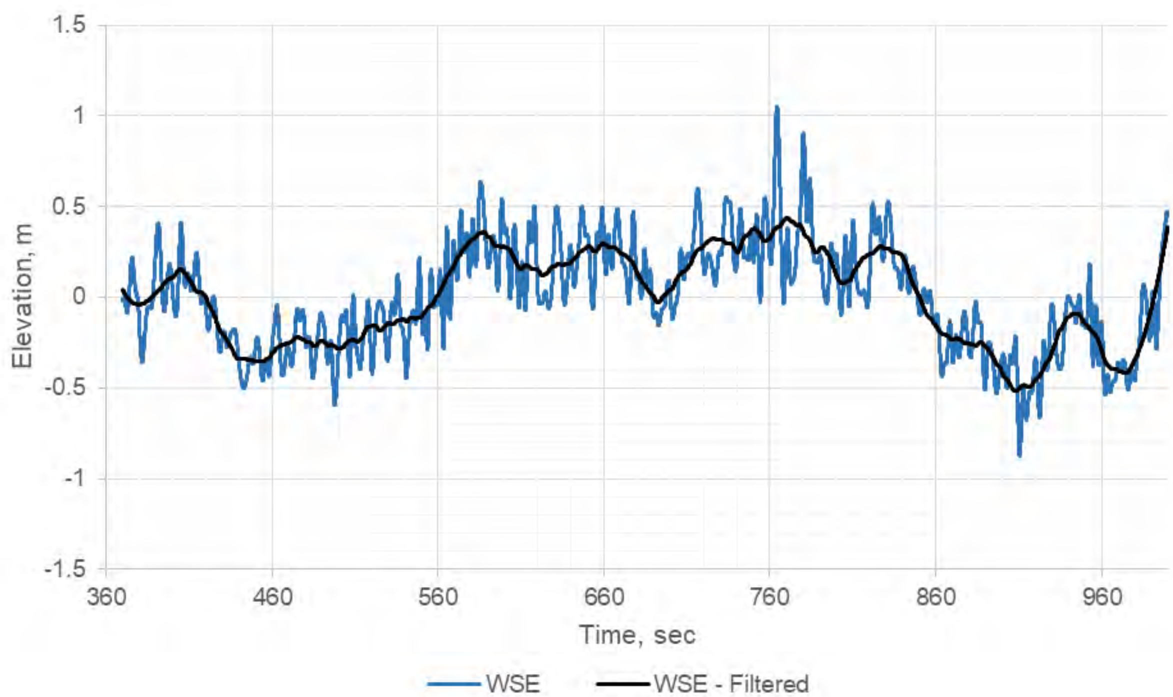

Figure 61. Case 10 - Water Surface Plot at Harbor (Spur)

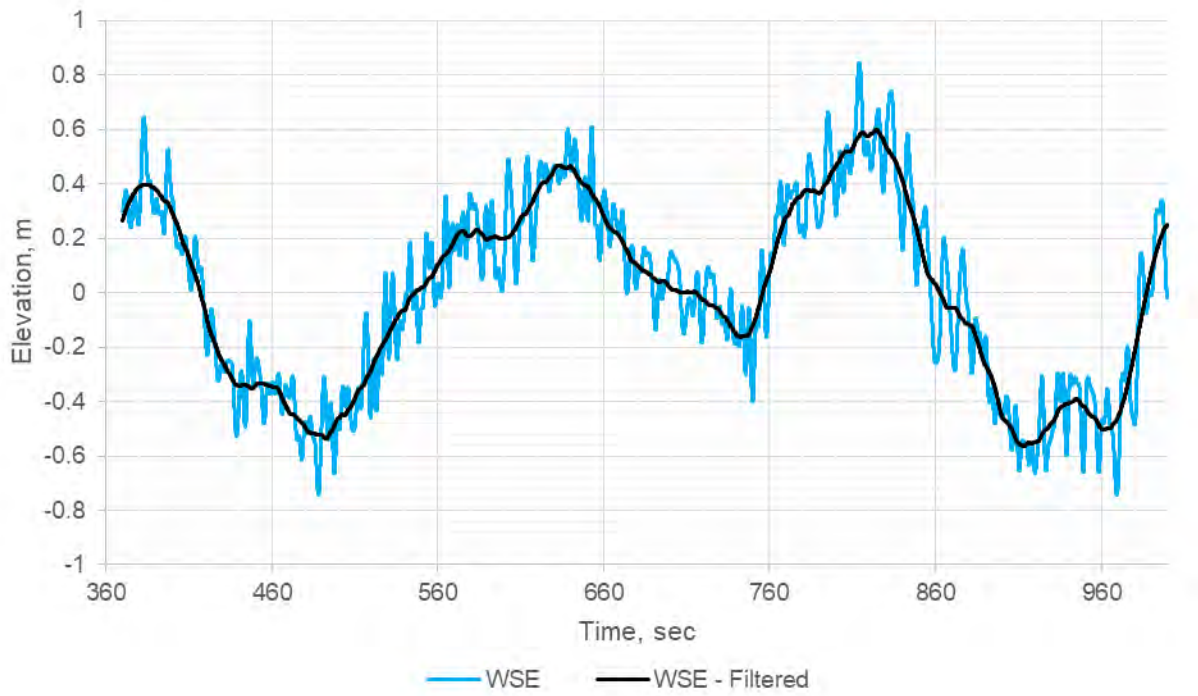

Figure 62. Case 11 - Water Surface Plot at Dock (North Side)

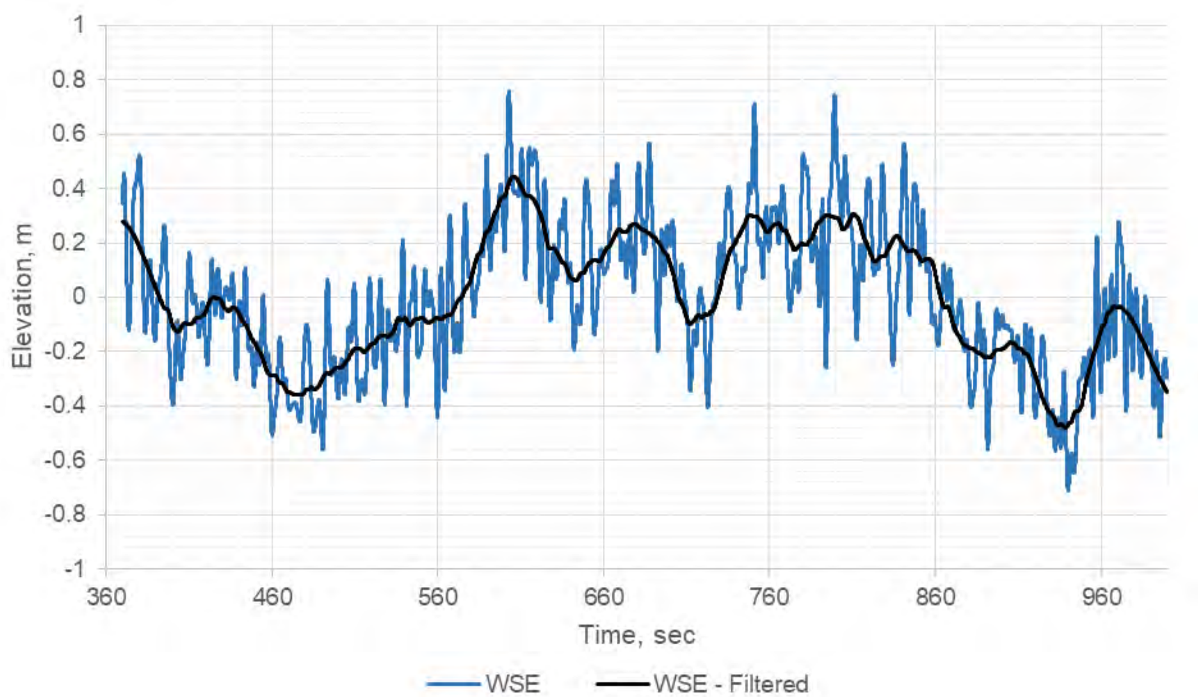

Figure 63. Case 11 - Water Surface Plot at Harbor (Spur)

Dampening vs. Porosity Comparison Results

Alternative scenario model runs that were successfully performed using porosity along the breakwaters (Case 2, Case 4, Case 5, Case 6, Case 7, Case 10, and Case 11) were compared to the dampening model runs (see Figure 64 through Figure 70). For clarity, results from only two locations are shown in the plots: Dock (North) and Harbor (Spur). These locations are intended to represent the general conditions within the harbor. Overall, magnitudes of wave energy were slightly different between the porosity models and the dampening models; however, the energy distribution trends were generally similar in appearance.

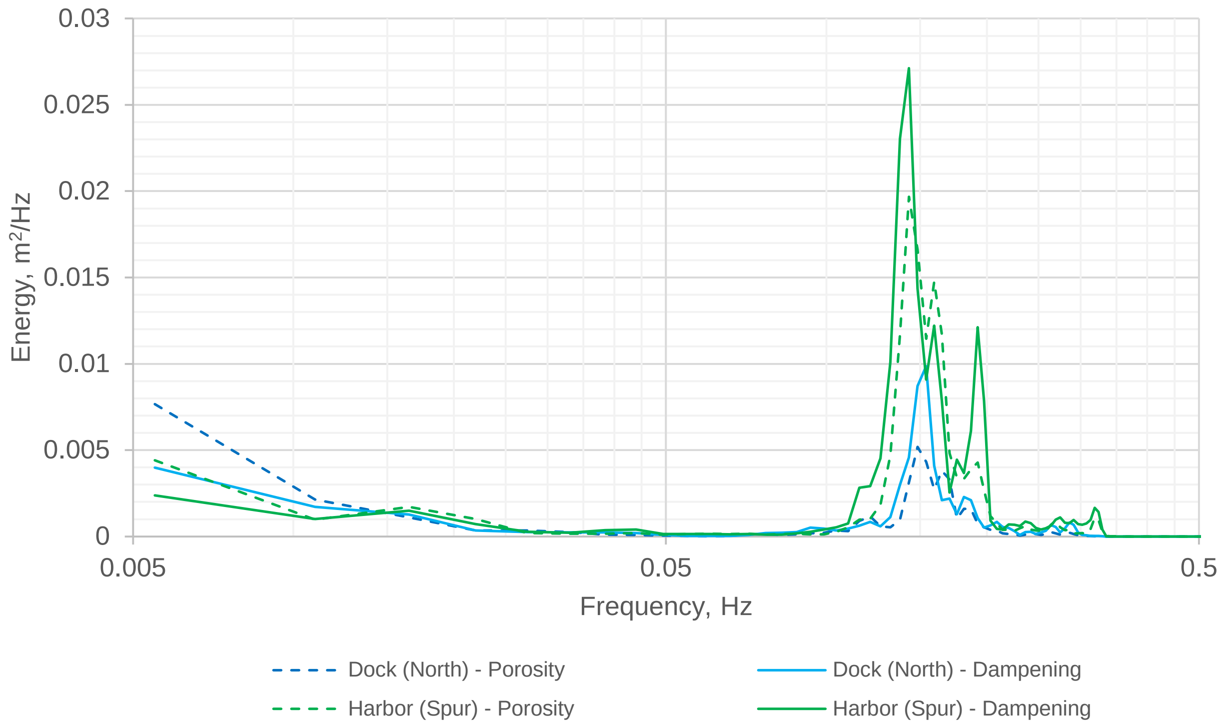

Figure 64. Case 2 Comparison using Dampening and Porosity on Breakwaters

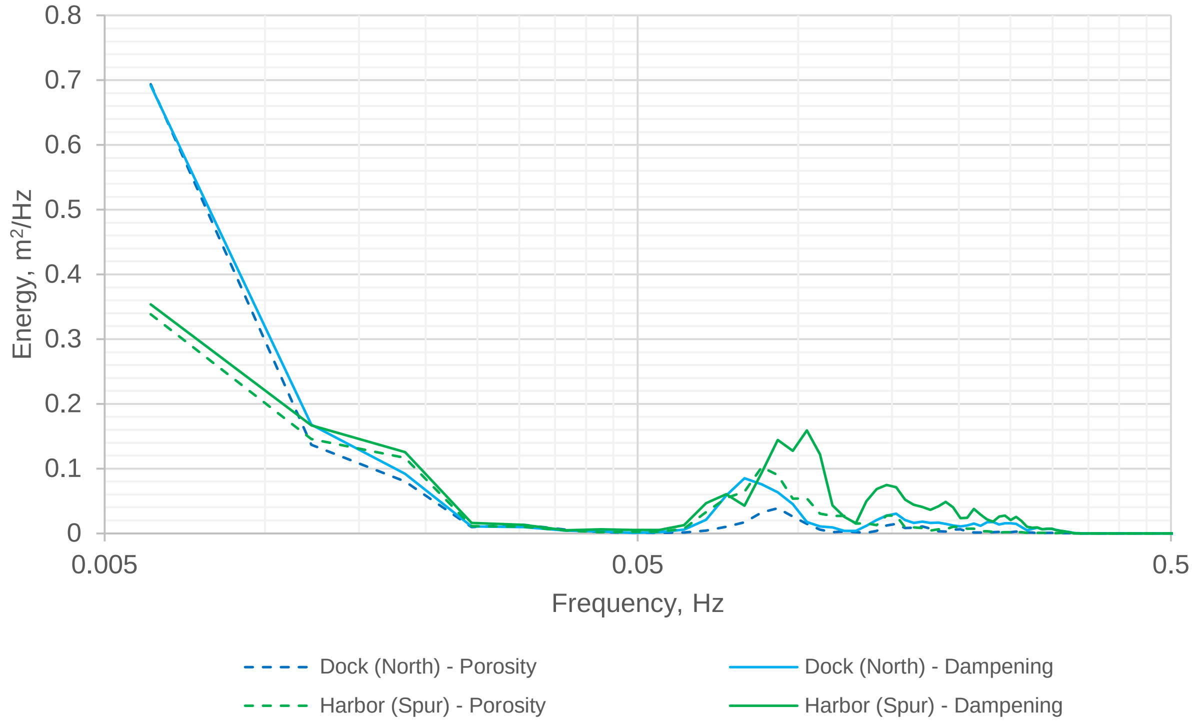

Figure 65. Case 4 Comparison using Dampening and Porosity on Breakwaters

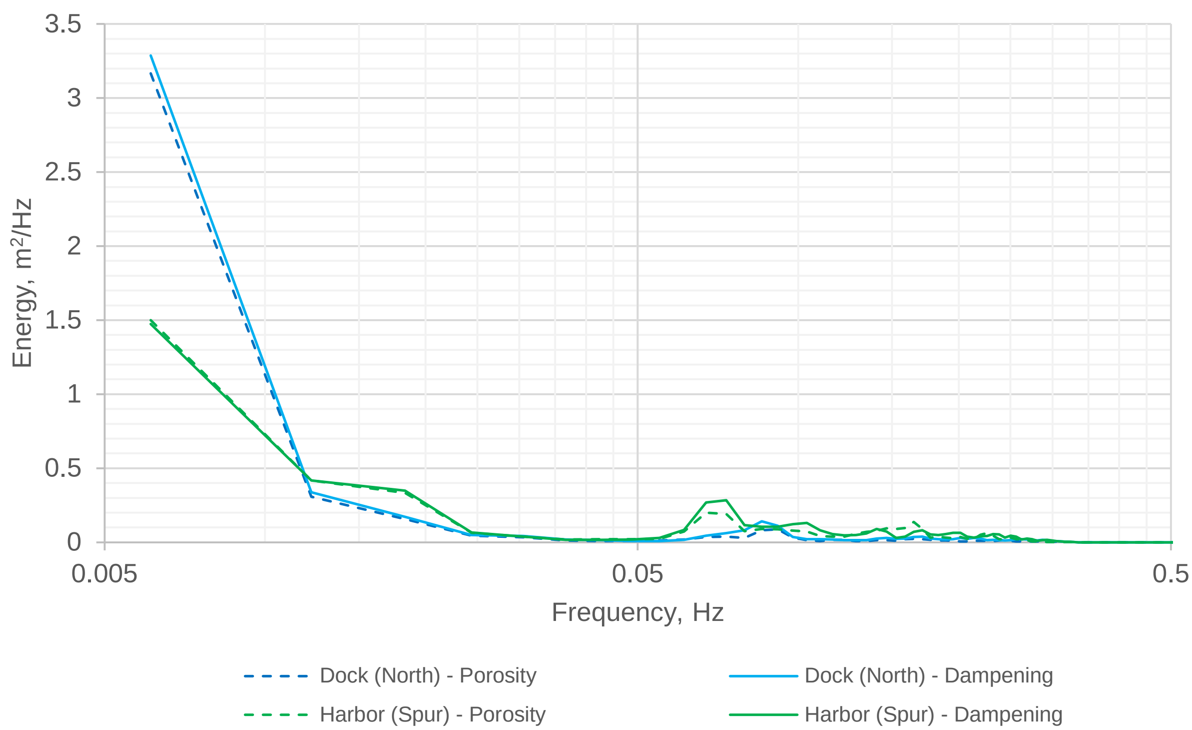

Figure 66. Case 5 Comparison using Dampening and Porosity on Breakwaters

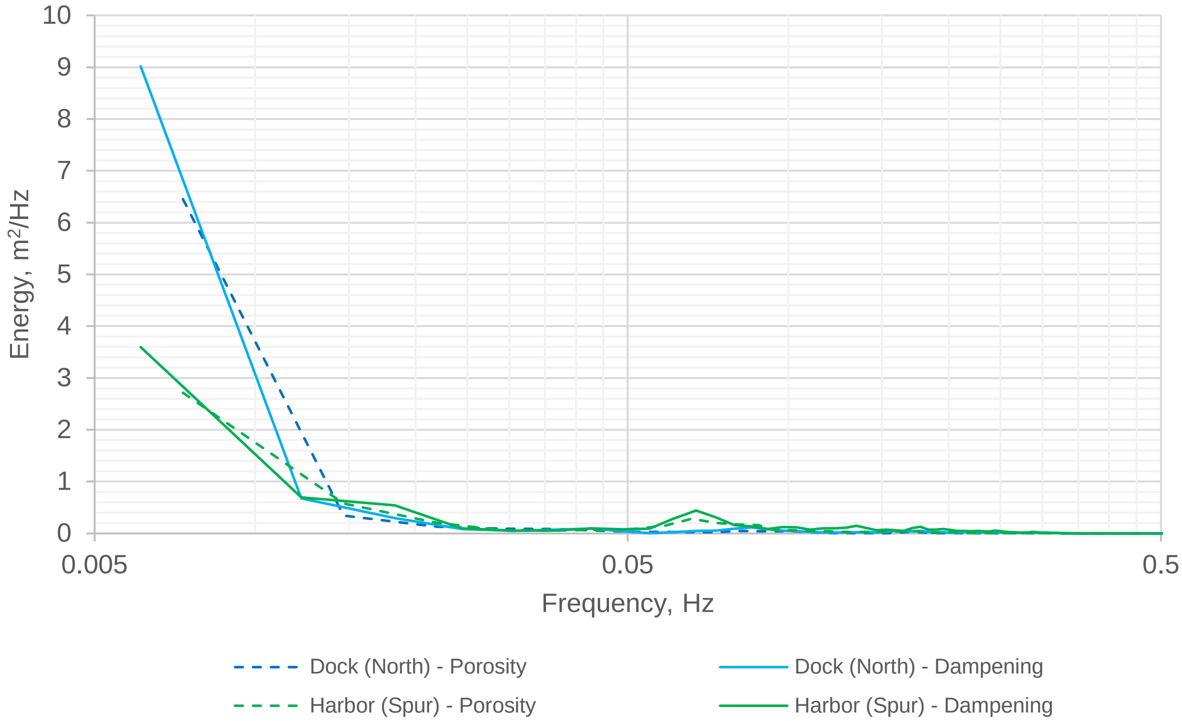

Figure 67. Case 6 Comparison using Dampening and Porosity on Breakwaters

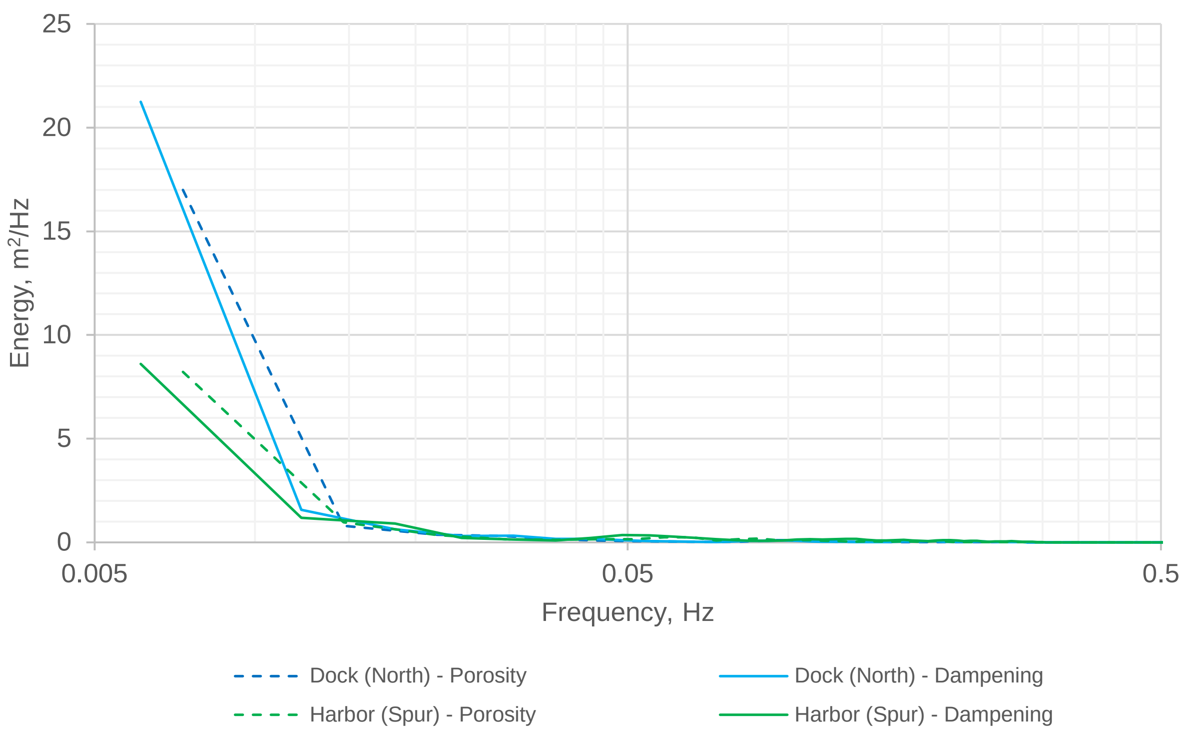

Figure 68. Case 7 Comparison using Dampening and Porosity on Breakwaters

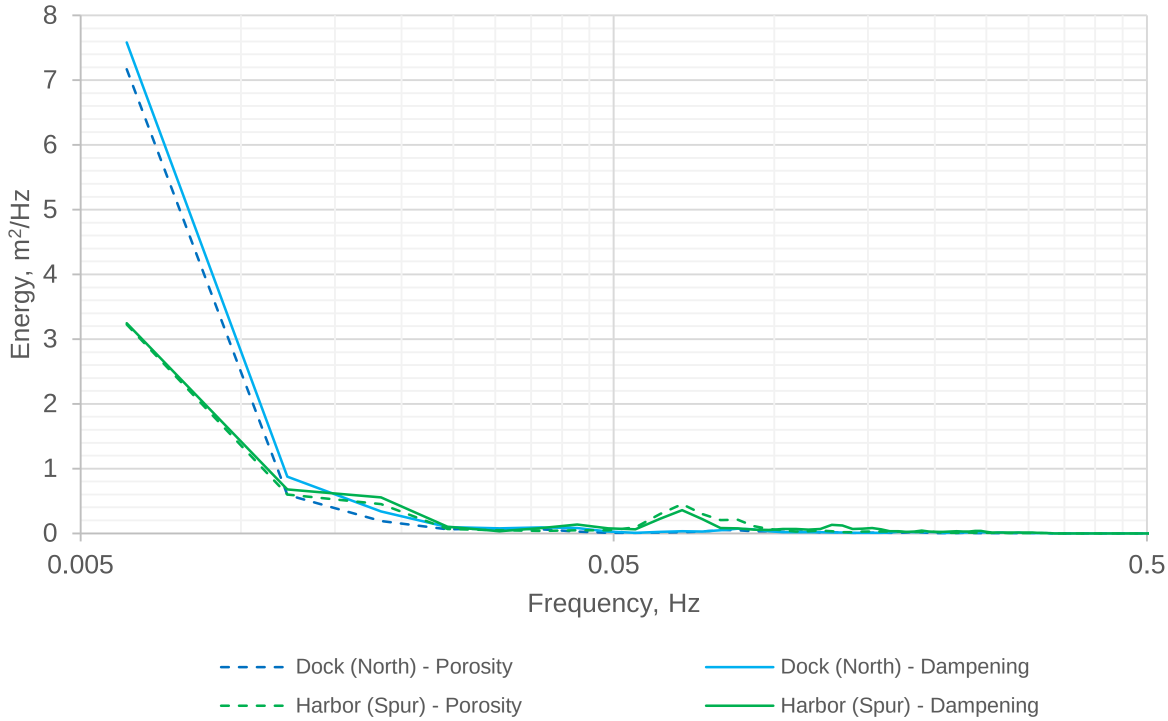

Figure 69. Case 10 Comparison using Dampening and Porosity on Breakwaters

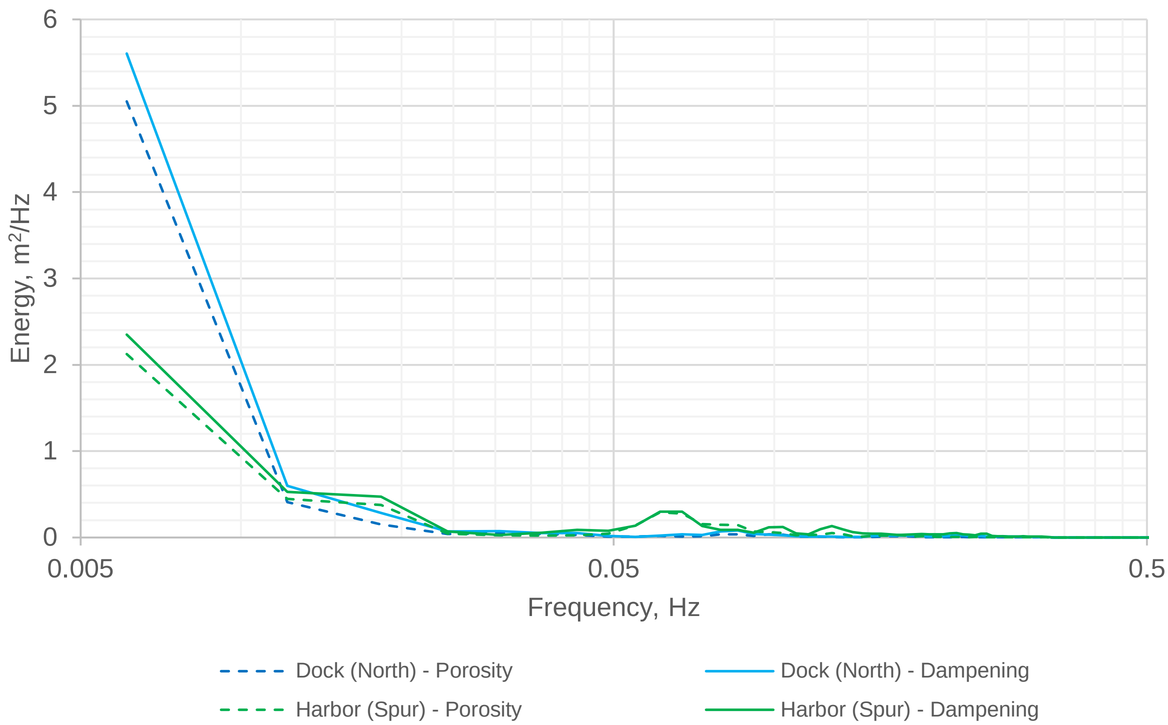

Figure 70. Case 11 Comparison using Dampening and Porosity on Breakwaters

Summary

MIKE21 SW and BOUSS-2D wave numerical models were developed to simulate waves in the nearshore area and proposed harbor on the north side of St. George Island. The MIKE21 SW model is a minor piece of the overall modeling effort and was used to determine offshore wave conditions at the BOUSS-2D model boundary. The purpose of the BOUSS-2D model, the main focus of the modeling effort, was to assess the energy dissipation of the proposed harbor configuration. A baseline scenario BOUSS-2D model was developed that represents the existing condition of the north side of St. George Harbor, and an alternative scenario BOUSS-2D model was developed that represents the proposed harbor. Both the baseline and alternative scenario models were forced with 11 pre-determined wave conditions. Typical wave parameters were extracted at multiple locations within and outside of the harbor to assess overall performance.

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