Hydrologic Restoration and Conceptual Plan Report

The Salinas Project

Long Island, Bahamas

Prepared For:



International Conservation Fund of Canada
44 Queen Street Chester
Nova Scotia, B0J 1JO
www.icfcanada.org

Prepared By:



Applied Technology & Management (ATM)
941 Houston Northcutt Boulevard, Suite 201
Mount Pleasant, South Carolina 29464
www.appliedtm.com

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1.0 Introduction

1.1 Project Background

The Salinas property project comprises over 10,000 acres of tidal and impounded lagoon systems with accompanying uplands and shoreline on the southwest, leeward coast of Long Island, Bahamas. The extensive wetlands system that runs throughout the property was untouched prior to the 1970s when significant commercial salt production facility was constructed which included an extensive system of berms and dikes that drastically altered the flow of water throughout the lagoons. The heart of the industrial operation included 640 acres of hyper-saline ponds used to extract sea salt from water. Although the operation was abandoned in the 1980s, alterations to the natural ecosystem remain and have perpetuated widespread environmental degradation. Additionally, hurricanes and extreme storm events continually modify water exchange with the offshore through the opening and closing of new and historical inlets along the site shoreline.

The Salinas project envisions restoration and enhancement of the site through improvement in overall flow and exchange of water with the ocean. Anticipated key interventions include re-opening and connection of internal lagoon areas via dike and berm removals, as well restoring existing or creating new additional open ocean inlet connections. In support of this effort, Geosyntec (Bahamas) Limited (herein referred to as Applied Technology & Management, a Geosyntec Company, or ATM), was contracted by the International Conservation Fund of Canada (ICFC or Client) to conduct field studies, hydrodynamic modeling, alternatives analysis, and conceptual planning for proposed select restoration activities.

Figure 1 provides a location and overview of the Salinas site.

ATM has prepared this Hydrologic Restoration and Conceptual Plan Report in support of the project and in coordination with other project team members, including SvN Architects + Planners (SvN), Islands by Design (IBD), and ICFC. This report is being delivered to ICFC as the project lead.

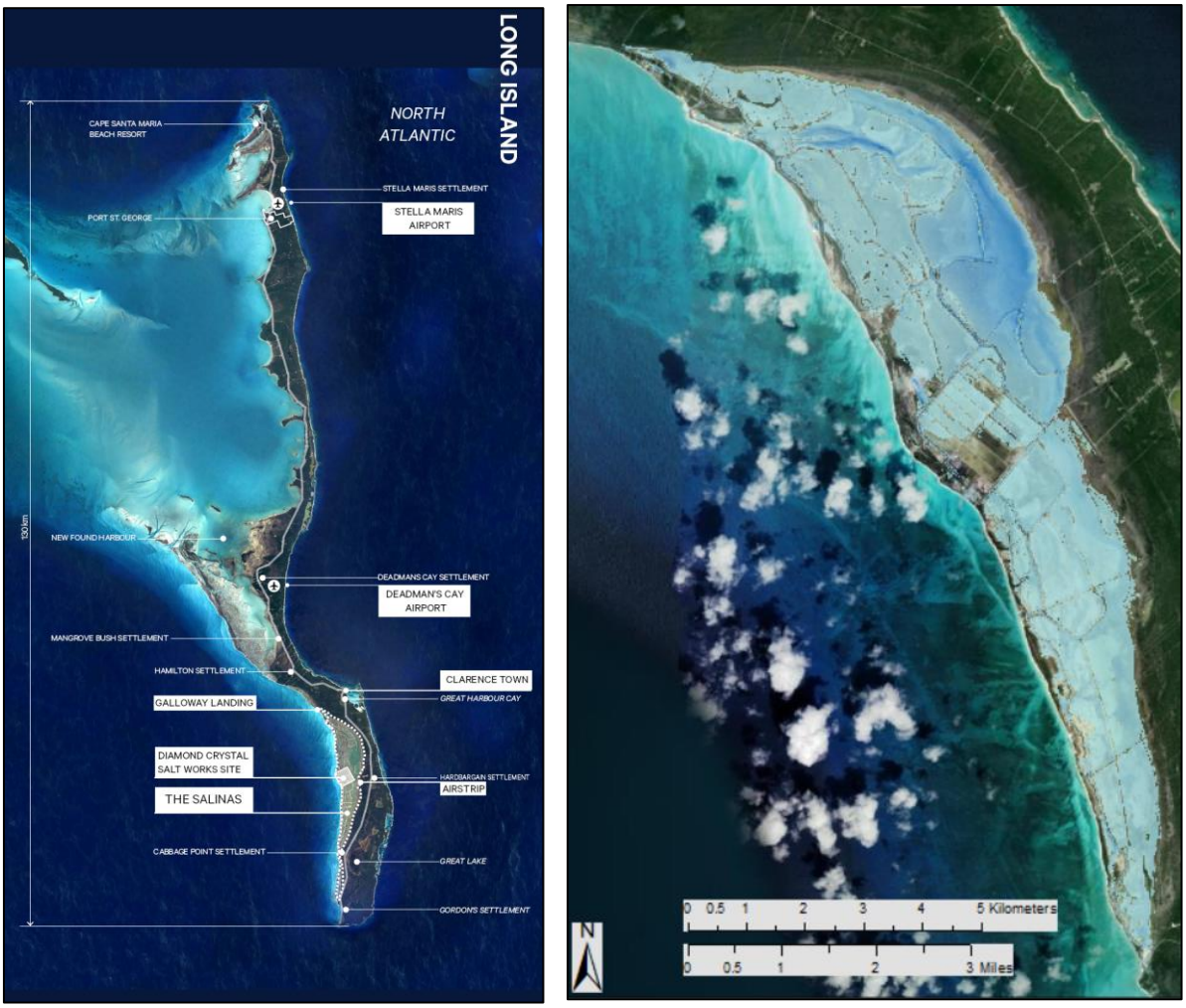

Figure 1. Salinas project location on Long Island (left, from SvN) and site overview with highlighted lagoon systems (right).

2.0 Field Investigations

To inform project planning and as input data for development and validation of subsequent numerical modeling analyses, several field investigations were conducted, including:

- Initial Site Assessment and Reconnaissance (October 18-21, 2022)
  - Visual observations of shoreline, existing open ocean inlets, and interior lagoons.
  - Site logistics and field observations to support future data collection and modeling.

- Baseline Data Collection
  - Initial Collection Event and Instrument Deployment (February 6-10, 2023)
    - Deployment weather station and water level loggers
    - Two days of ADCP flow measurements (Spring tidal conditions)

- Spot-check (point) measurements for conductivity and temperature.
- Additional reconnaissance of site flow connections for baseline model grid construction.

- Second Collection Event and Instrument Recovery (February 27-March 3, 2023)
  - Two days of ADCP flow measurements (Neap tidal conditions)
  - Spot-check (point) measurements for conductivity and temperature.
  - Additional reconnaissance of site flow connections for baseline model grid construction.
  - Recovery of weather station and water level loggers.

Data measurements from field investigations are summarized in the following sections and figures.

2.1 Data Collection Locations

The following figures indicate locations of short-term, event based, and spot-check (point) data collection activities. ADCP instrumentation measured current velocities and total flow through the existing inlets during event-based monitoring of typical spring and neap tidal cycles. ADCP measurements also document inlet depth (cross sections). Water level and temperature instruments (HOBO brand/identifier) were deployed for the short-term observational period, along with the meteorological station. Salinity and temperature point measurements were taken during course of the deployment and recovery efforts.

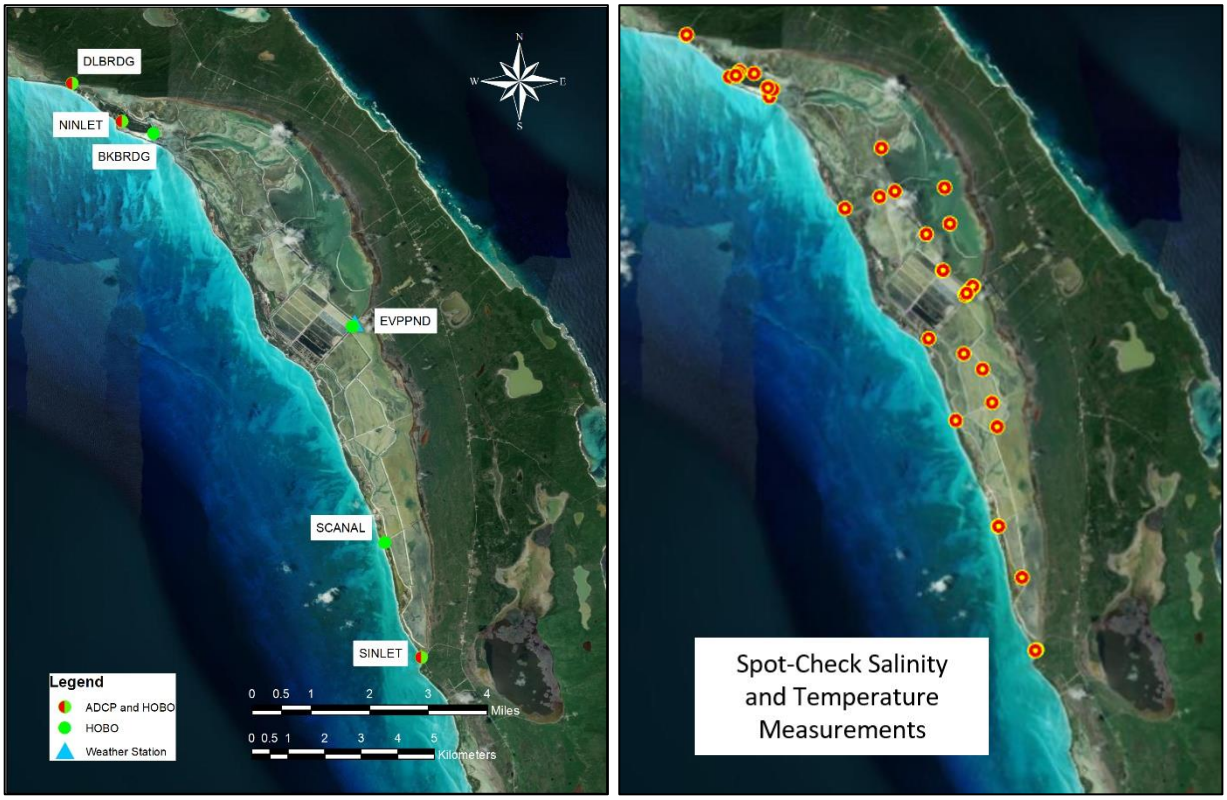

Figure 2. Short-term and event-based data monitoring stations (left) and spot-check salinity and temperate collection locations (right). Referenced station location names noted on left.

2.2 Water Surface Elevations

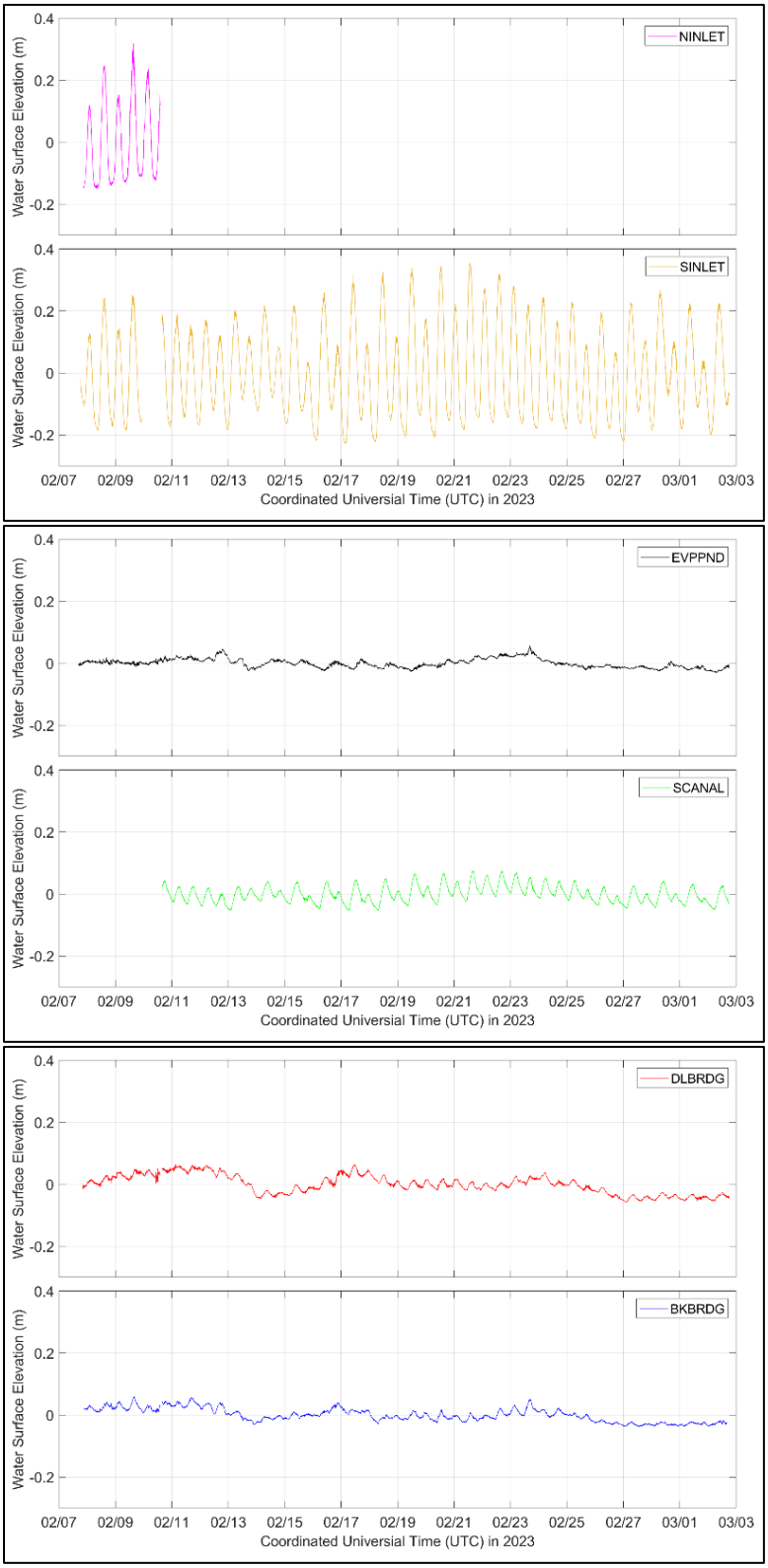

Figure 3. Water surface elevation data from short-term instrument deployments.

2.3 Currents and Flow

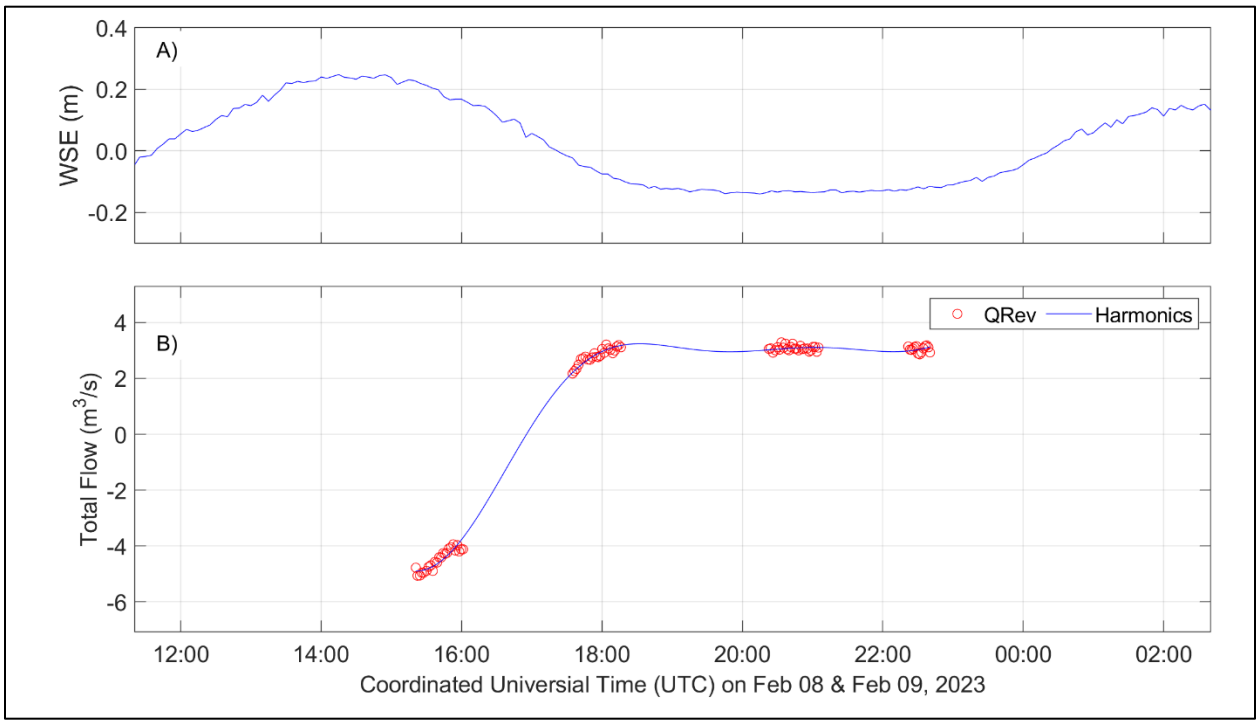

Figure 4. Water surface elevation and ADCP Flow Measurements at NINLET on 02/08/2023

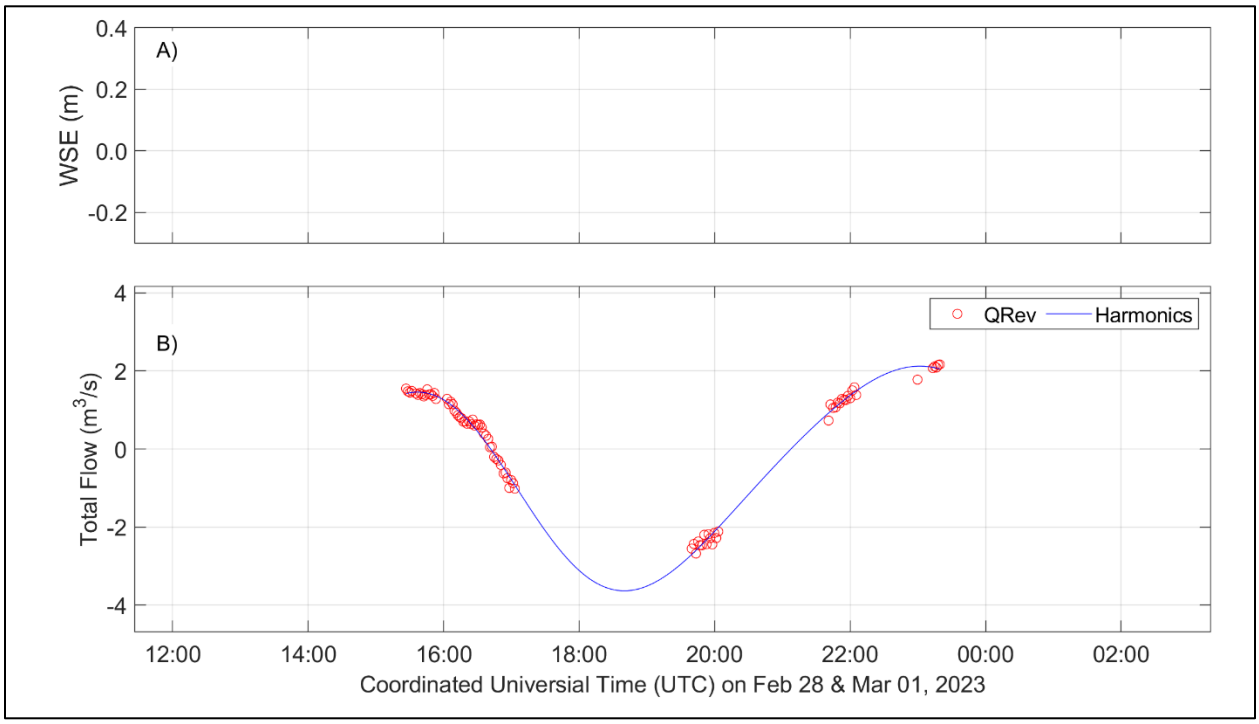

Figure 5. Water surface elevation and ADCP Flow Measurements at NINLET on 02/28/2023

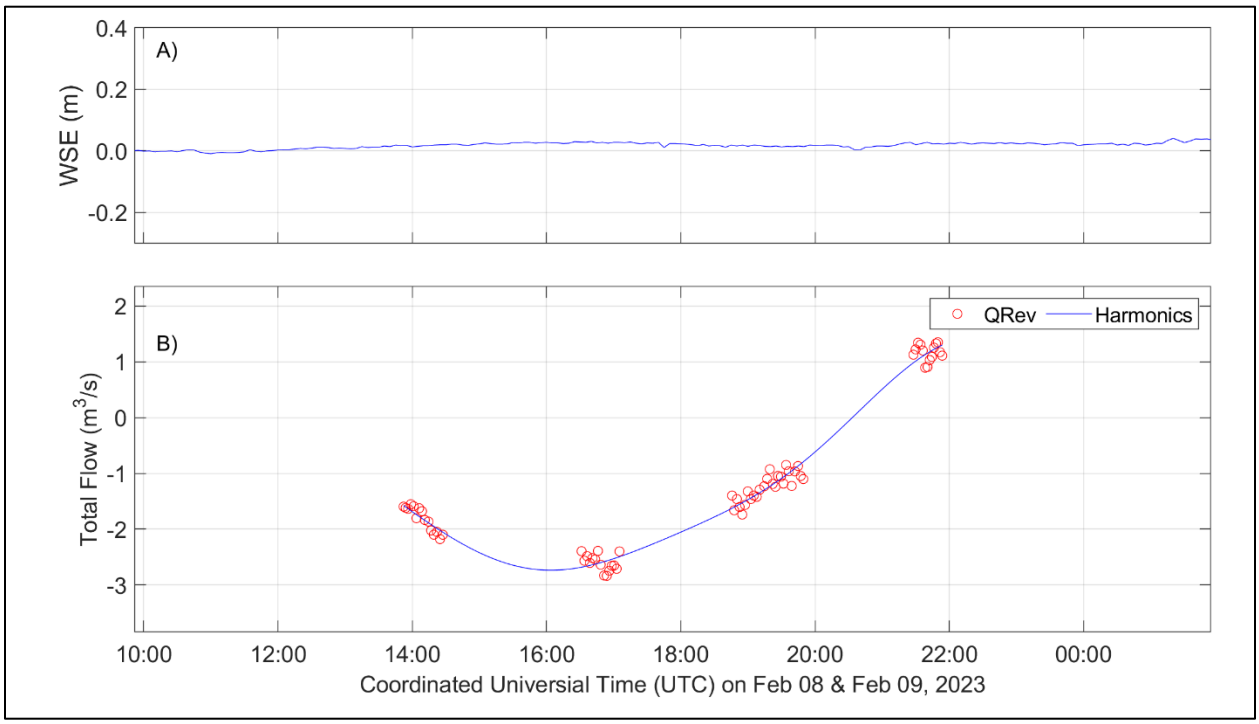

Figure 6. Water surface elevation and ADCP Flow Measurements at DLBRDG on 02/08/2023

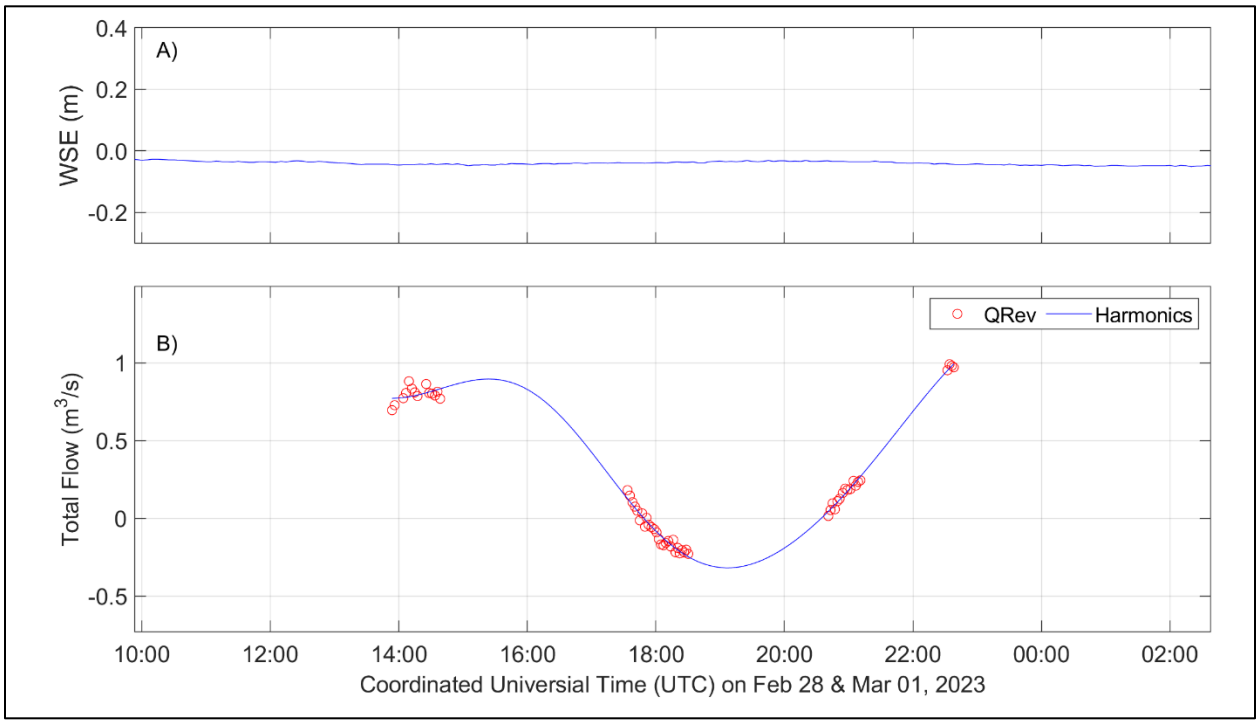

Figure 7. Water surface elevation and ADCP Flow Measurements at DLBRDG on 02/28/2023

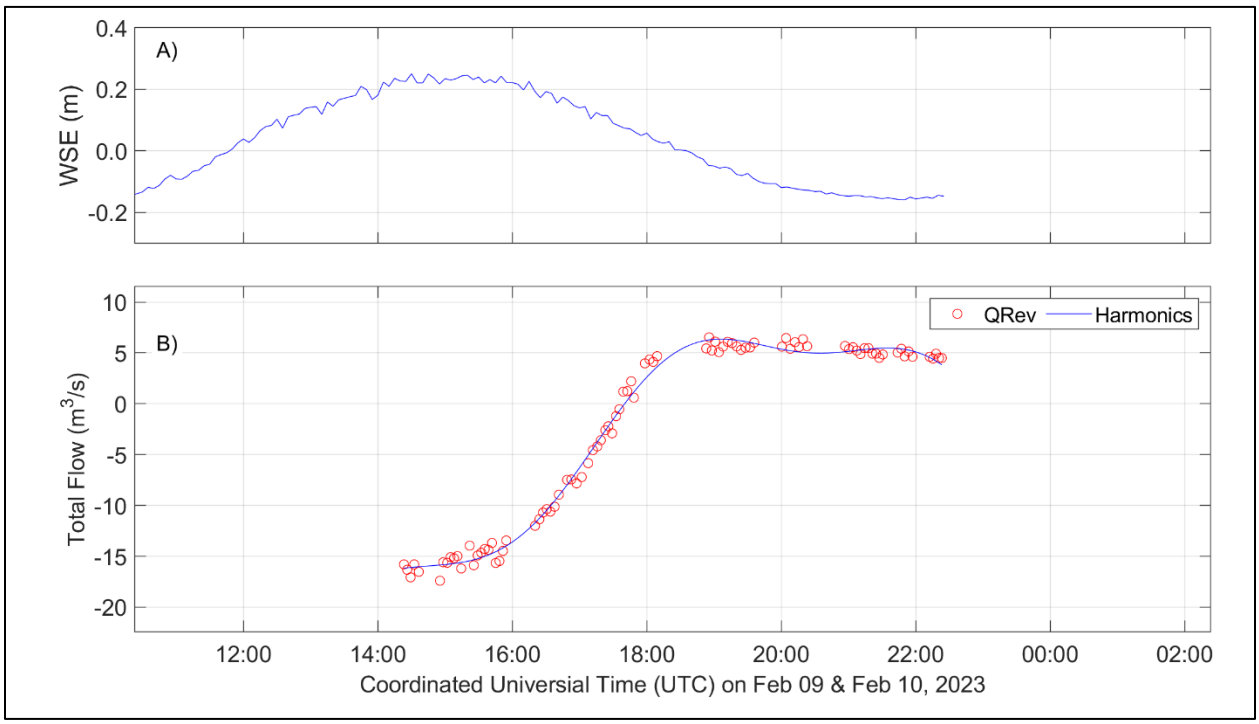

Figure 8. Water surface elevation and ADCP Flow Measurements at SINLET on 02/09/2023

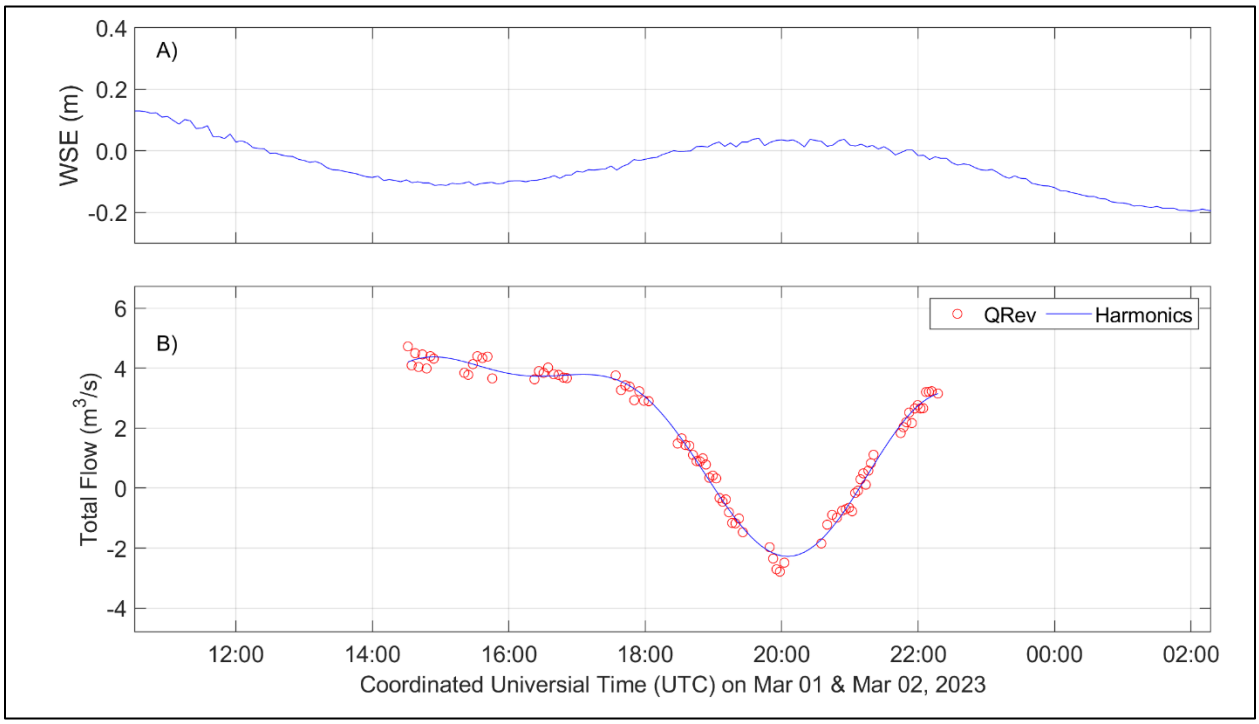

Figure 9. Water surface elevation and ADCP Flow Measurements at SINLET on 03/01/2023

2.4 Wind

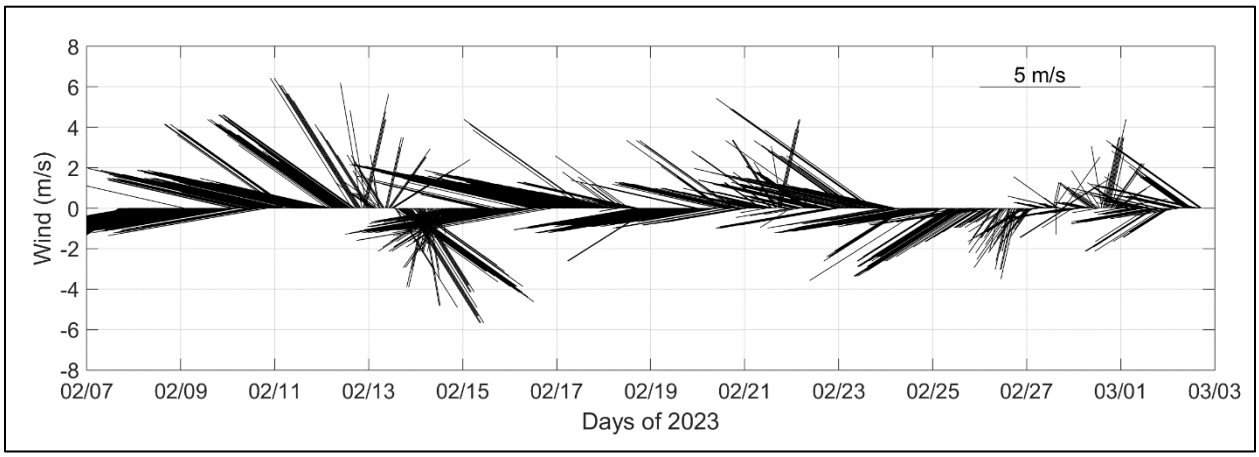

Figure 10. Wind speed and direction timeseries from short-term measurements.

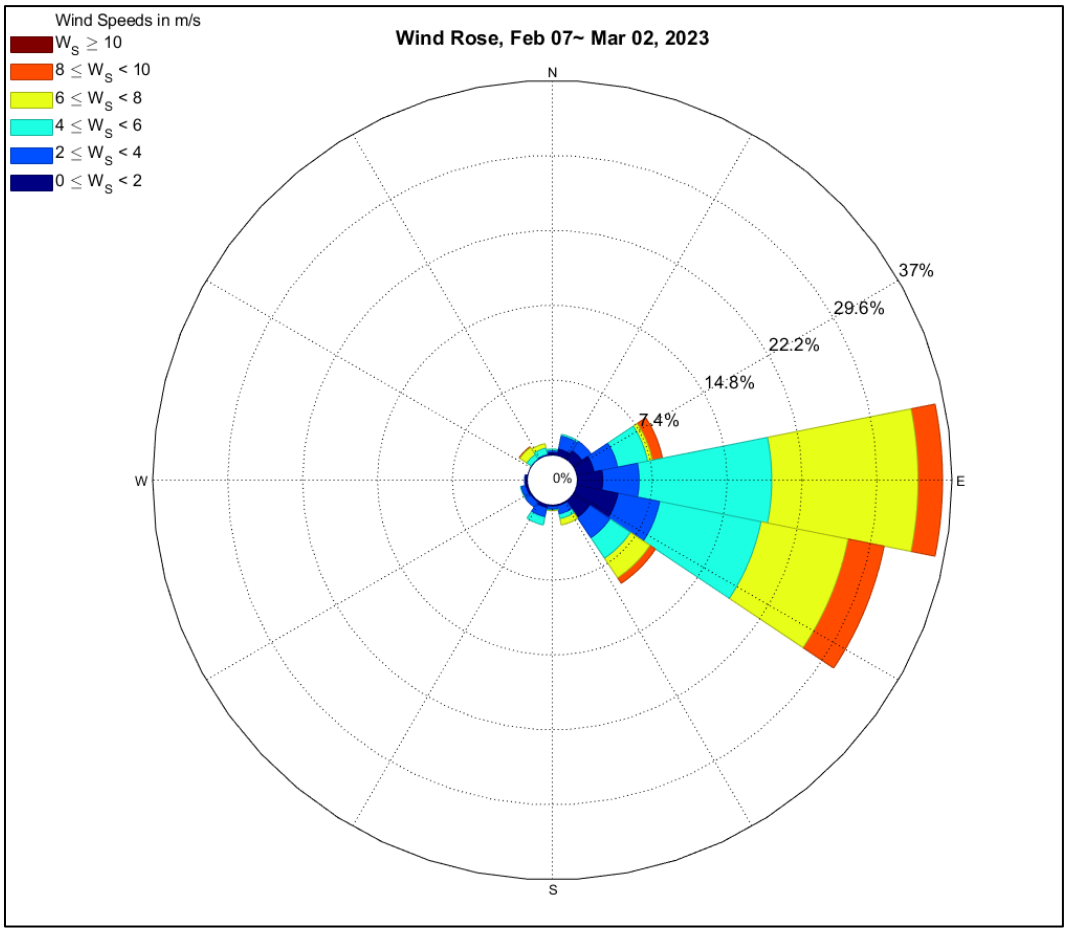

Figure 11. Wind rose summary from short-term measurements.

2.5 Precipitation

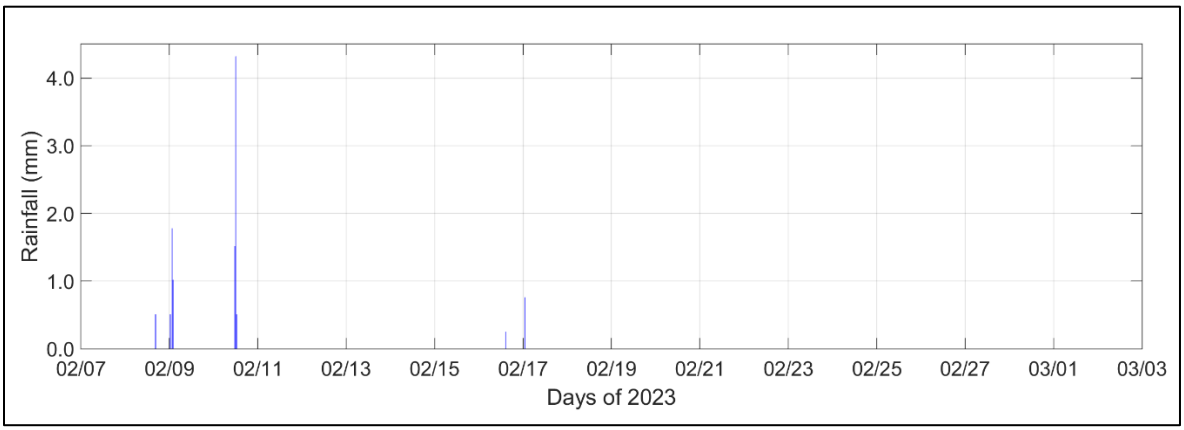

Figure 12. Precipitation timeseries from short-term measurement.

2.6 Temperature and Salinity

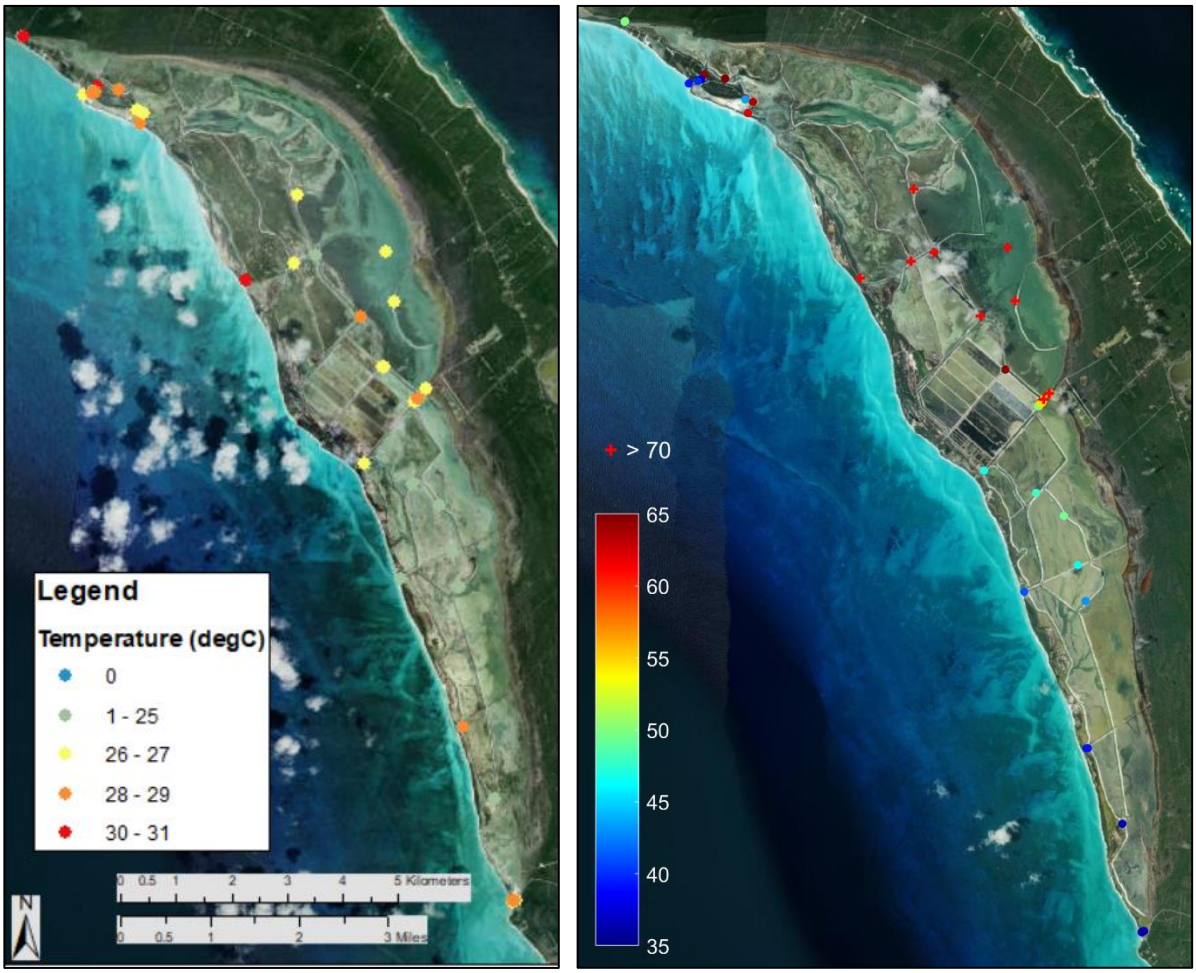

Figure 13. Temperature (left) and Salinity (right) point spot-check measurements.

2.7 Remote Sensing Data

Field data was supplemented by remote sensing (satellite derived) data including:

- bathymetry,
- seafloor/land cover classification, and
- digital terrain and surface models.

The primary remote sensing data used for the hydrological restoration efforts summarized herein is the bathymetry and digital terrain and surface models. Appendix A provides the delivery report from the third-party remote sensing data supplier (EOMAP).

3.0 Baseline and Governing Processes

The hydrologic and water quality characteristics of the existing site are governed primarily by tidal hydrodynamics and wind-driven circulation. In general, these two governing processes are significantly impeded which contribute to the degraded water quality of the system. Precipitation and evaporation play a supplementary role exacerbating the already high salinity levels. The primary baseline conditions and governing processes are discussed below.

3.1 Water Levels

Water levels along the open coastline of the site are mainly influenced by daily tide fluctuations. Extreme event storm surges and long-term sea level rise also impact the site but are not considered a governing condition for targeted hydrologic restoration of the system for the proposed project.

The nearest long-term monitoring water level gauge with tidal datums is the United States (US) National Oceanographic and Atmospheric Administration (NOAA). The station location and water levels are now actively reported by the Intergovernmental Oceanographic Commission (IOC). NOAA's tidal datums are shown in Figure 14. Without a long-term tidal study at the site, the NOAA tidal datums are expected to provide the best available tidal datum information representative of the region. Harmonic analysis of measured tide data as the site was used to drive the model boundary.

Datum	Meters (MSL)	Description
MHHW	0.488	Mean Higher-High Water
MHW	0.415	Mean High Water
MTL	-0.002	Mean Tide Level
MSL	0.000	Mean Sea Level
DTL	0.021	Mean Diurnal Tide Level
MLW	-0.419	Mean Low Water
MLLW	-0.446	Mean Lower-Low Water

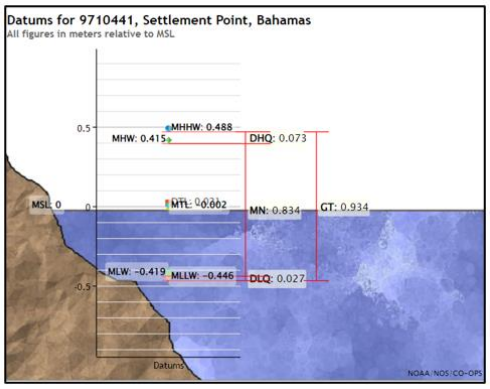

Figure 14. NOAA Tidal Datums - Settlement Point, Bahamas - Station ID: 9710441

3.2 Winds

The nearest readily available long-term wind observational data set is from the airport at Nassau, Bahamas. The wind rose summary of data from 2000 to 2023 (Figure 15) shows prevailing easterly winds consistent with measured data at the site during field investigations.

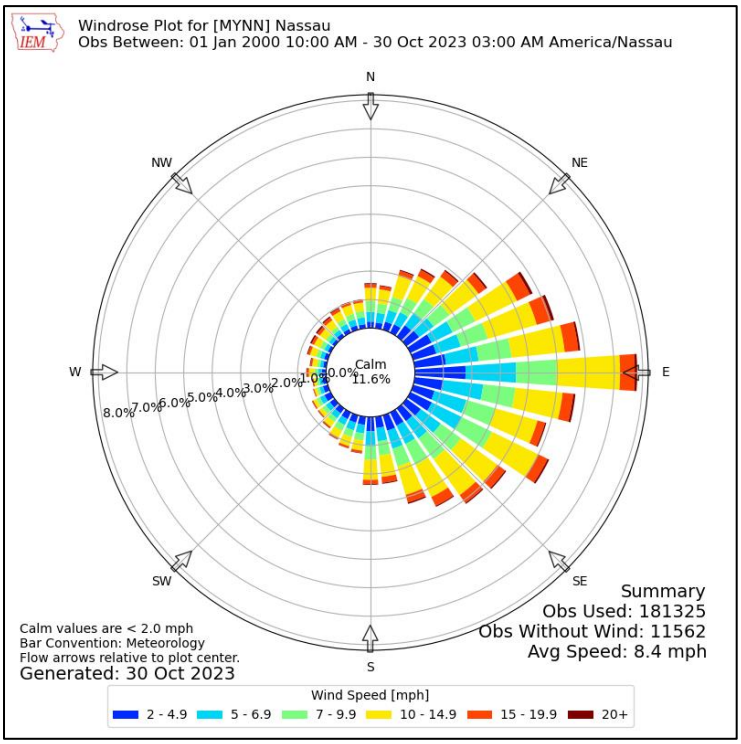

Figure 15. Wind Rose Summary for Nassau, Bahamas (Iowa State Environmental Mesonet)

3.3 Tidal Dampening, Inlet Restriction, and Tidal Prism

Initial analytical evaluation of existing inlets current velocity/flow, governing cross section (depths/widths), and water level data indicated significant tidal dampening within the system. That is, the inlets and interior system of the site restrict the amount of water volume able to move into and out of the system during a typical tide cycle (i.e., the tidal prism). Tidal prism hydrodynamics is the primary driver of the hydrologic system, flushing, and water quality. The tidal dampening and inlet restrictions were identified as major items for restoration activities.

Initial estimates indicated interior tidal fluctuations during flood conditions ranged from +0.1 to +0.15 meters above mean sea level (MSL). Total flood tide flow into the system through existing inlets was estimated at 48,000 cubic meters. These 48,000 cubic meters of inflow translate to roughly 1/100th of the theoretical tidal prism within the system. This deficit significantly contributes to the lack of flushing and poor water quality conditions found within the existing system.

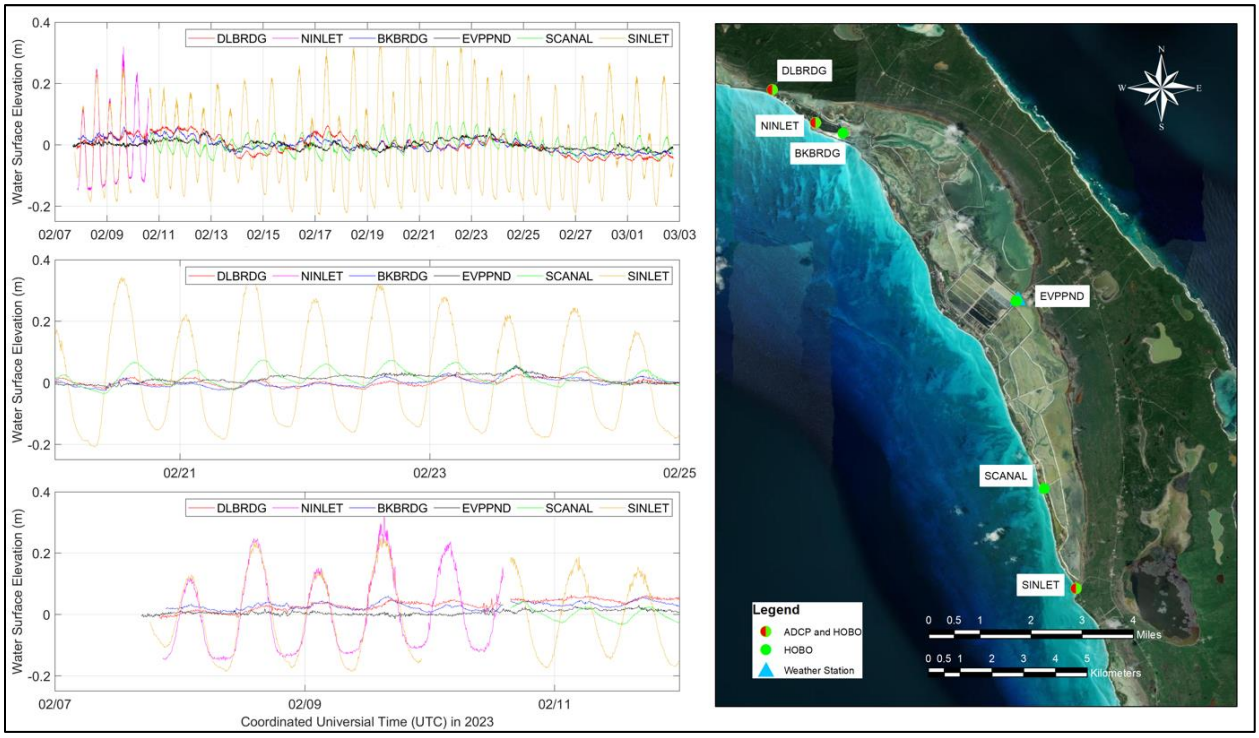

Figure 16. Overview of tidal dampening observations.

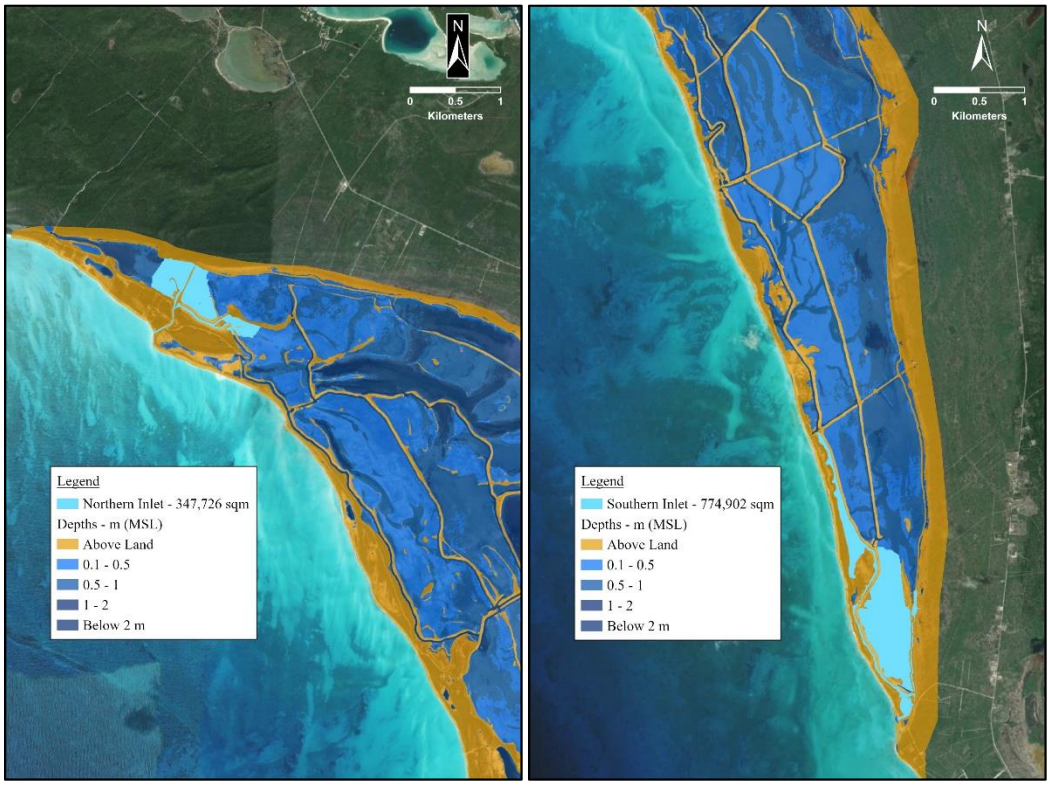

Figure 17. Estimated areas of tidal prism influence at existing north and south inlets.

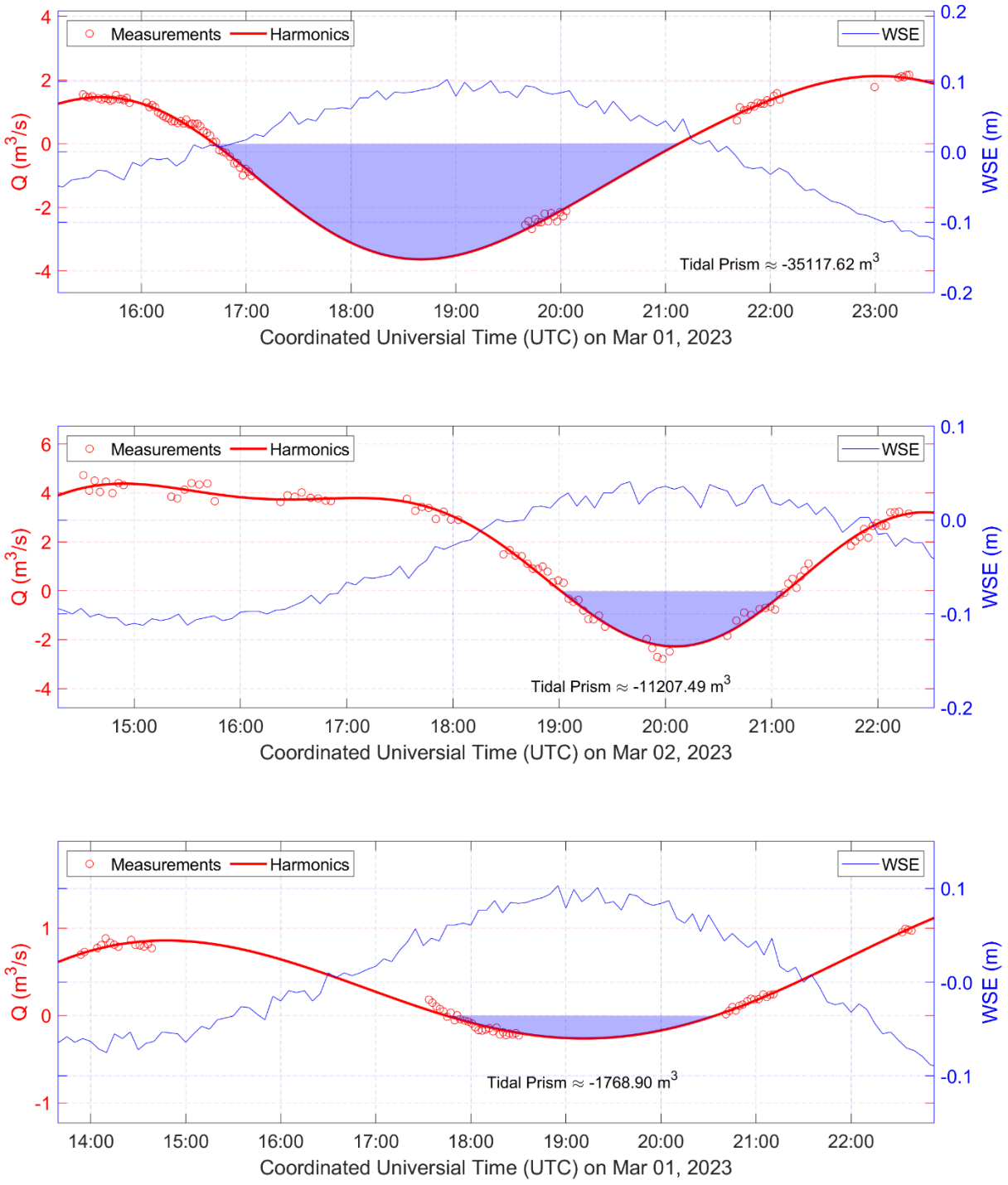

Figure 18. Illustration of flood tide flow (blue area of negative flow, Q) of restricted tidal prism into existing system.

3.4 Wind Driven Circulation and Impediments

Winds are capable of driving hydrodynamic circulation and flushing within lagoon systems, improving water quality, granted certain site and wind conditions are met. Typical characteristics that contribute to wind driven circulation include large areas of open water and large-scale connections between adjacent water bodies, both oriented along prevailing wind directions. Unfortunately the existing site generally does not exhibit these characteristics. The lagoon system is generally oriented in a north-south direction along its long axis. Although the lagoon system can span up to ~3.5 km (primarily in the north lagoon) in the east-west direction, this expanse is significantly obstructed by multiple long-linear earthen dike (berm) features typical throughout the site. So some small connections may exist through these obstructions, wind driven circulation at the site requires much larger-scale open water connections to activate wind-driven circulation of any significance.

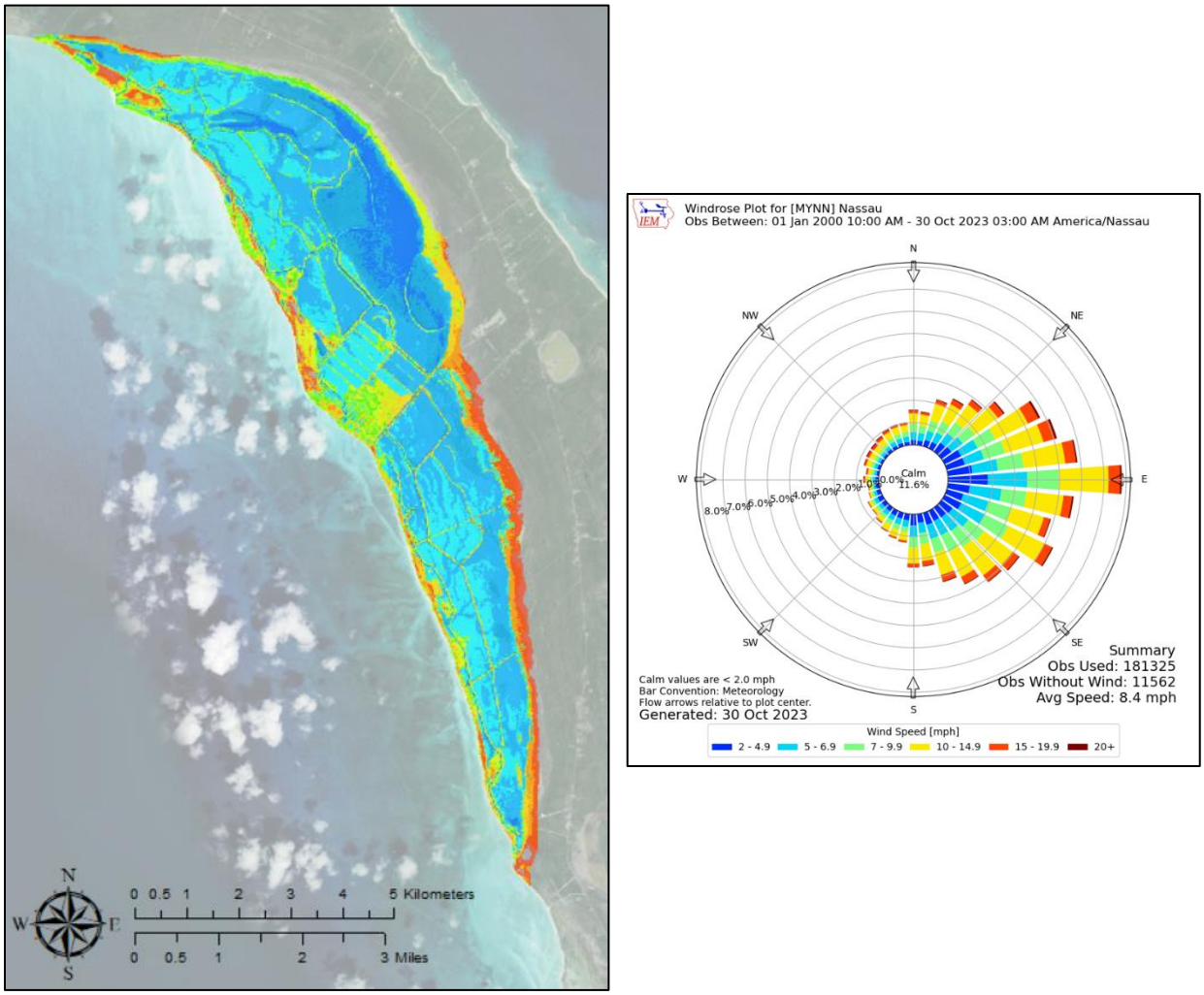

Figure 19. Site orientation, internal berm impediments, and prevailing wind overview.

4.0 Conceptual Planning

The approach to conceptual planning of proposed hydrologic restoration alternatives included:

1. Numerical modeling and evaluation of major physical mechanisms governing the hydrodynamics and water quality of the existing lagoon system.
2. Determination of site characteristics or processes contributing to poor system conditions.
3. Consideration of overarching restoration goals, upland plans, and programming.
4. Development of potential major restoration activity types to address poor system conditions.
5. Consideration of restoration activity requirements, impacts, and implications.
6. Project Team workshops of potential restoration activities and alternative plans.
7. Numerical model simulation of anticipated interior restoration activities and a high-low spectrum of major exterior (new inlet) restoration activities (Alternatives 1 and 2).
8. Project Team workshops reviewing model results, upland programming updates and interaction, and critical restoration needs.
9. Development of a recommended project alternative concept (Alternative 3), rough order of magnitude project quantity estimates, and requested screening level cost/constructability review by contractors.
10. Refinement and final numerical modeling of Alternative 3 restoration concept plan.

Key considerations during concept planning included:

- Upland Plan and Programming
    - Consideration of upland plan areas, development types, vehicular and pedestrian pathways, areas of significance, and other requirements.

- Open Water Inlets
    - Increase tidal prism and flushing through additional inlets.
    - Optimization of location, number, and theoretical sizing.
    - Environmental impact (and construction cost) reduction by locating at historic inlet locations or minimizing footprints.
    - Required major bridge infrastructure to maintain site connectivity.
    - Construction costs, maintenance, protection structures, and coastal process/shoreline impacts.
    - Siting criteria generally included historic natural or man-made inlets, over-wash locations, low topography, and short channel distances to interior lagoon system.
    - Initial dimensions were set to 2 meter depth x 20 meter width to mimic nearshore depths, minimize initial and maintenance dredge events, and minimize required bridge span infrastructure.
    - Figure 20 illustrates open water inlet siting considerations, potential and screened (preferred) locations.

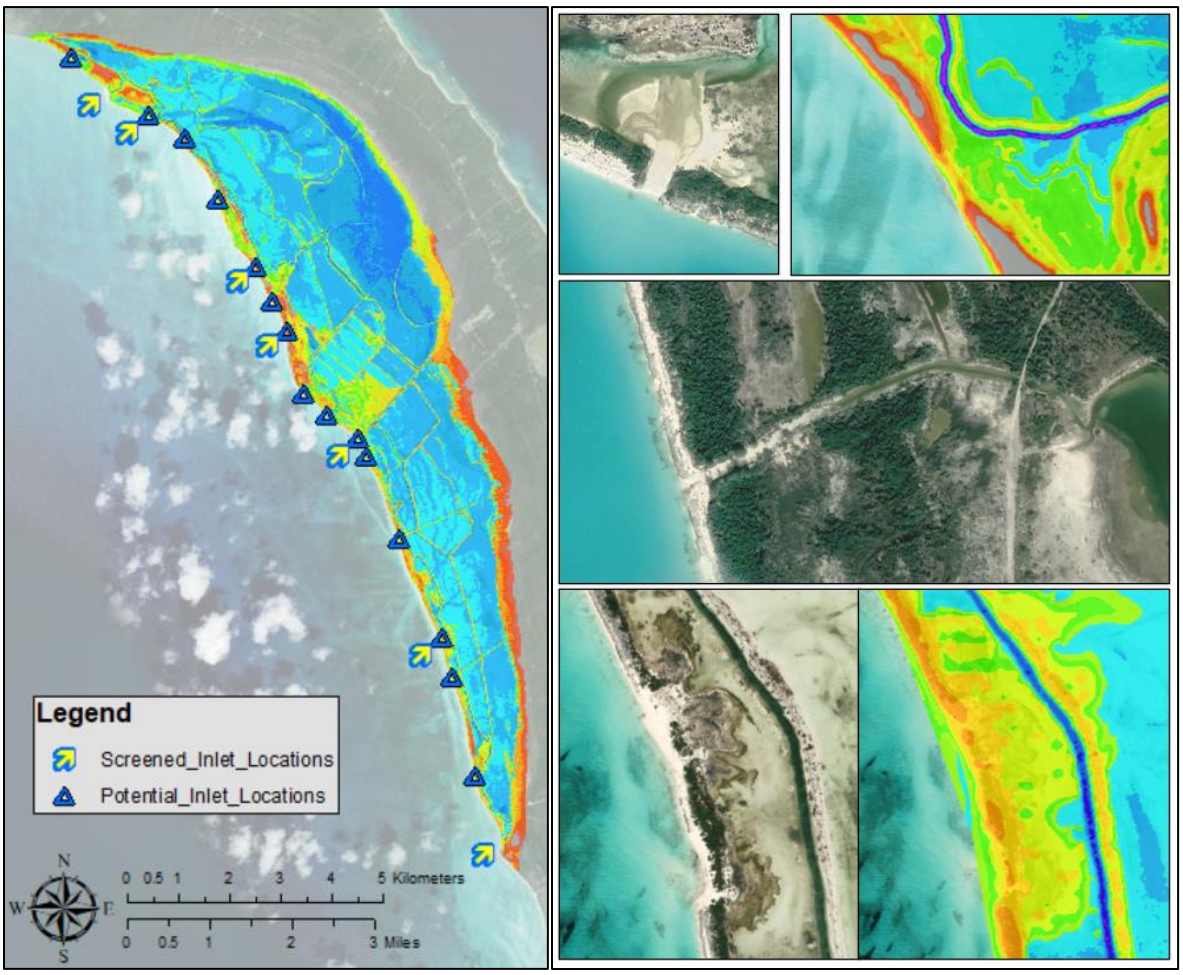

Figure 20. New inlet initial and screened locations (left) and target characteristics (right).

- Berms and Connectivity
  - Promote tidal and wind-driven circulation by reducing the extent of large-scale cross system blockages. Determining location and sizing of large-scale berm section removal.
  - Optimization of location, number, and sizing.
  - Required pedestrian walkway or major bridge infrastructure to maintain site connectivity.
  - Excavated material fate and constructability logistics.
  - Siting criteria generally included one break per "side" of interior lagoon cells (typically four per cell), with sufficient wetted cross section to mimic inlets.
  - Consideration of central area historic salt works as a direct impediment to longitudinal flow through the system as a whole.

- Island Creation and Managed Water Areas
  - Creation/expansion of islands and associate habitat utilizing berm excavation materials.
  - Creation of managed water areas for potential high saline ecosystems (e.g., flamingo feeding areas) or research purposes (within historic salt works central area).

  - Use of island creation and managed water areas to decrease total tidal prism demand on the system.

- Marina/Water Access and Coastal Processes
  - Of particular note are consideration for coastal processes and water (vessel) access for any proposed marina locations.
  - The conceptual plans include jetty structures to protect/stabilize new inlets and minimize potential maintenance issues. Impacts to adjacent hard or sandy shorelines and upland shoreline-dependent programming should be evaluated on a case-by-case basis.
  - Any new inlet could also be utilized for vessel access to marina basins or interior waterways, pending further planning and design.

The restoration concept plan alternatives are illustrated in the figures in the following section.

5.0 Numerical Modeling Study

A detailed hydrodynamic model was developed to cover the entirety of the nearshore and interior lagoon system between the northern and southern inlets described previously. The general-purpose modeling package [Environmental Fluid Dynamics Code, (EFDC)] was used for simulating flow, transport, and biogeochemical processes in surface water. EFDC is open-source software in the public domain, currently supported by the U.S. Environmental Protection Agency (EPA) Office of Research and Development (ORD).

EFDC solves the three-dimensional, hydrostatic, free-surface, turbulent-averaged equations of motions for a variable-density fluid. Dynamically coupled transport equations for turbulent kinetic energy, turbulent length scale, salinity, and temperature are also solved. Two turbulent transport equations implement the Mellor-Yamada level 2.5 turbulence closure scheme. EFDC uses a grid with a stretched or sigma vertical geometry and curvilinear, orthogonal, horizontal geometry.

The model is capable of simulating water levels, hydrodynamics, evaporation, salinity, and temperature. Model boundary forcing and inputs included the measured datasets of typical prevailing conditions, including offshore tidal water levels (produced from harmonic analysis of measured data) and northern boundary connection water levels, winds, precipitation, and evaporation (assumed 6mm/day consistent with typical tropical region values).

5.1 Baseline Modeling

The baseline (existing conditions) model was developed using the remote sensing digital elevation models (bathymetry and topography) updated based on ground-truthing field observations. The EFDC model grid included:

- Three model grid components: offshore, interior channels, and open water areas.
- Hydrologic connections from culvert, channel, or open water connections based on remote sensing data and field observations.
- Water depths and channel cross sections interpolated onto the grid from the processed remote sensing elevation data and field measurements.

The model was validated using the measured data collected during the field investigations and provided confidence in the model's ability to illustrate governing hydrological processes of the existing system.

Figure 21 provides an overview of the baseline (existing conditions) model configuration.

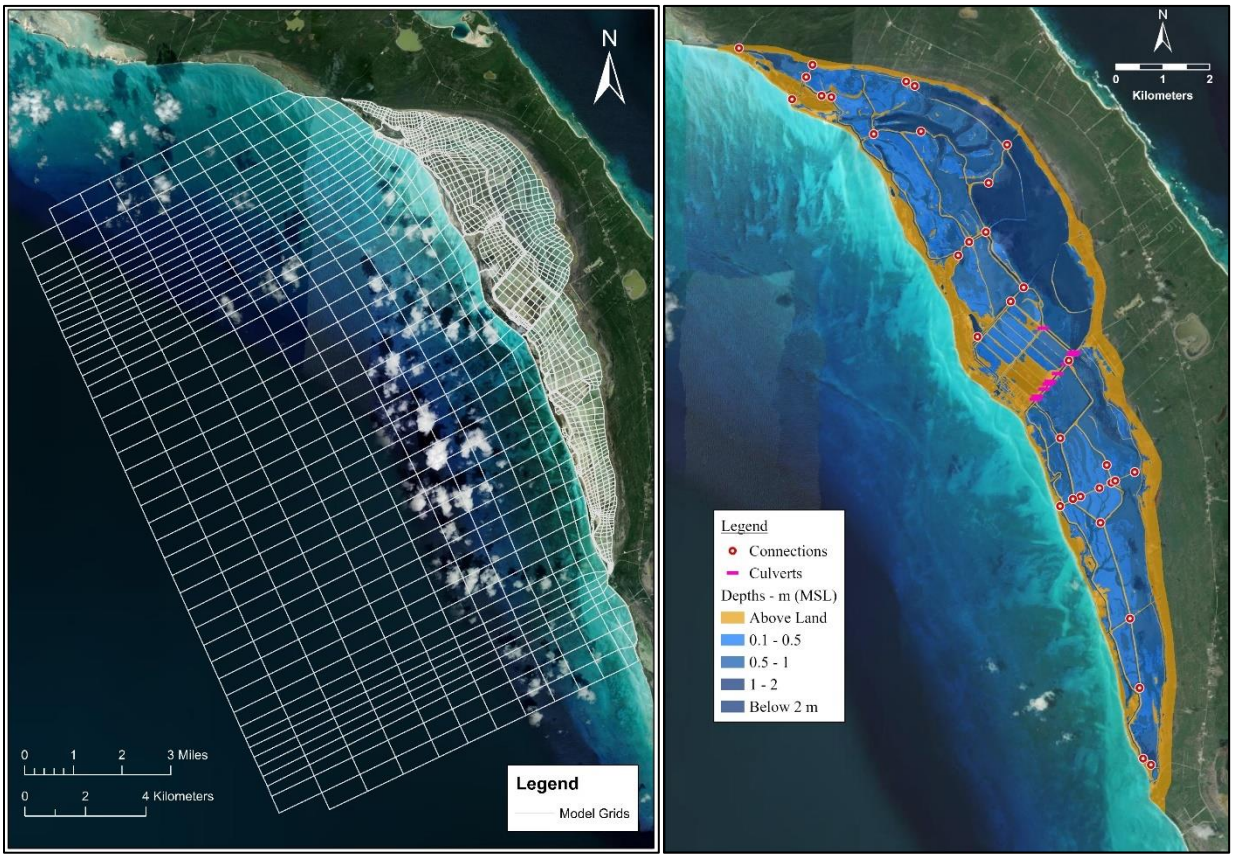

Figure 21. Baseline model grid (left) and depth and hydrologic connection conditions (right) for existing site conditions.

5.2 Restoration Alternatives Modeling

Project alternatives were modeled by altering the existing model grid, hydrologic connections, and elevation data to simulate restoration activities such as:

- excavation (removal) of sections of interior earthen dike (berm) features,
- excavation of new inlet channels connecting open water to the interior system,
- creation of new island features within the system interior,
- dedicated managed water areas (impoundments), and
- modifying hydrologic connection details.

5.2.1 Alternatives 1 and 2

Alternatives 1 and 2 included the following modifications to the baseline (existing condition) configuration:

- Managed Water Areas
  - Intended to be actively managed enclosed basins separated from passive tidal flushing for use in potential high saline ecosystems (e.g., flamingo feeding areas) or research purposes.
- Berm Breaks
  - Sections of berm removal to connect interior open water areas of the system.
  - This includes an item noted "bridge section" indicating the main entrance road that will require partial bridging to improve connection of northern and southern lagoon systems.
- New Inlet Connections
  - New dredge inlets from open water through the shoreline connecting to the interior system.
  - The number and location of open water inlet connections is the only differentiator between Alternative 1 and 2.
    - Alternative 1 only included two (2) new inlets in addition to existing.
    - Alternative 2 included five (5) new inlets in addition to existing.
    - Existing inlets (from baseline model) were left in-place.
    - New inlets were modeled at 2 meter depth x 20 meter width.

Figure 22 provides an overview of the Alternative 1 and 2 model configurations.

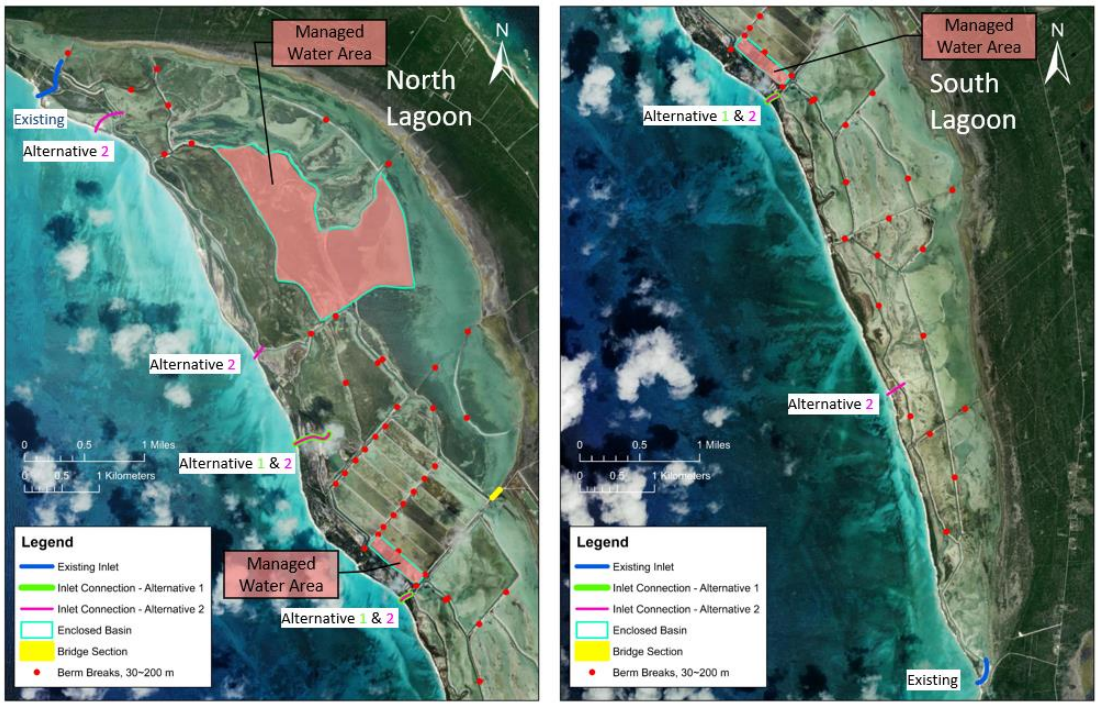

Figure 22. Overview of Alternatives 1 and 2 model configurations.

5.2.1 Alternative 3

Alternative 3 includes much of the Alternative 1 and 2 modification with the following key differentiators in the final configuration:

- Managed Water Areas
  - Large managed water area in north lagoon moved and downsized to north edge of site.
  - Small managed water area in main salt works (central area) unchanged.
- Berm Breaks
  - South lagoon and bridge section unchanged.
  - North lagoon:
    - Modified location and extent of berm breaks
  - Central area – additional hydraulic connections (e.g., culverts) and berm breaks included.
- Island Creation
  - Proposed island creation/expansion utilizing excavated material from berm breaks.
- New Inlet Connections
  - Includes two (2) new inlets in the north lagoon in addition to the one existing.
  - Includes two (2) new inlets in the south lagoon in addition to the one existing.

Figure 23 provides an overview of the Alternative 3 model configuration.

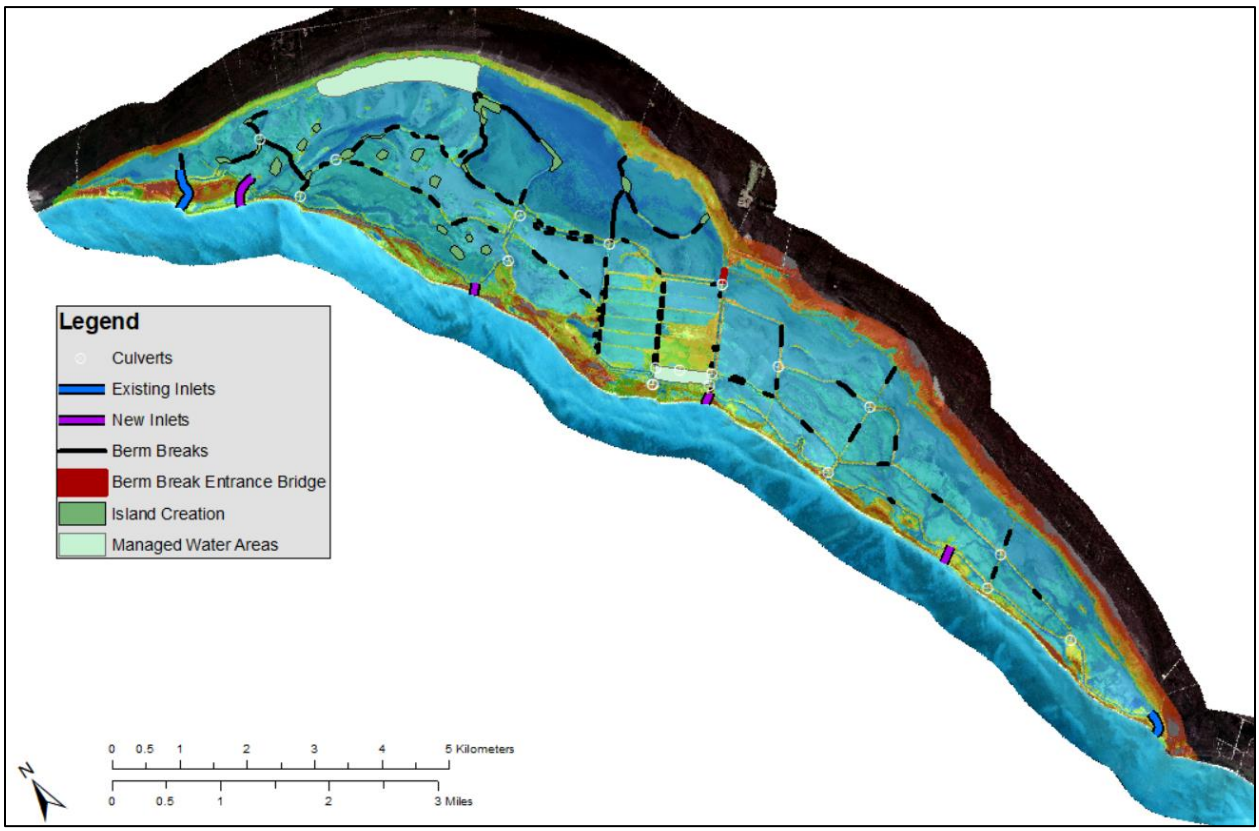

Figure 23. Overview of Alternative 3 model configuration.

5.2.2 Results and Comparison

5.2.2.1 Tidal Dampening

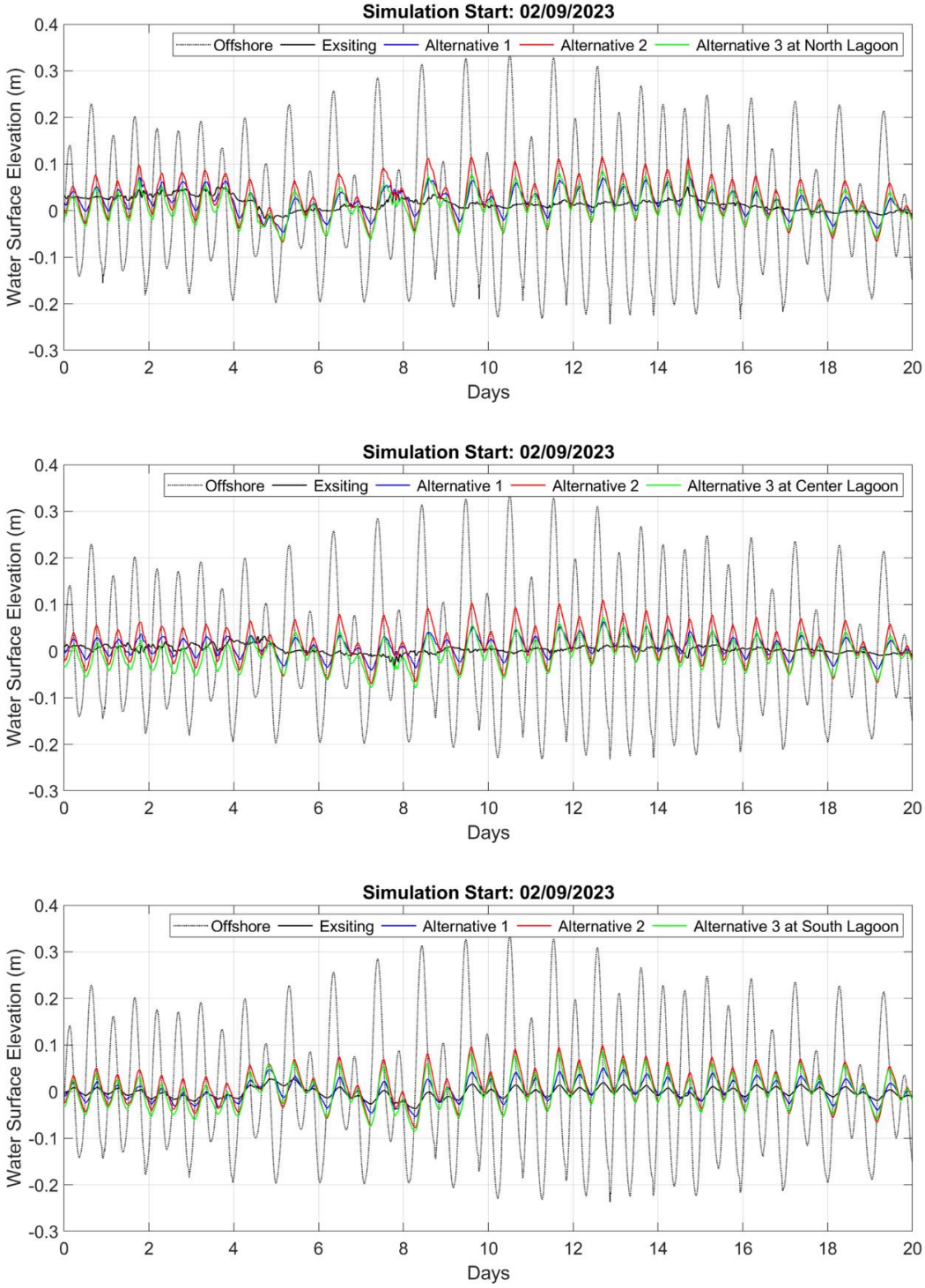

Figure 24. Comparison of tidal dampening from offshore to interior lagoon system locations (north – top, central – middle, and south – bottom) for baseline and alternatives modeling.

5.2.2.2 Hydrodynamic Flushing

The model was used to simulate typical tides, winds, rainfall, and evaporation to evaluate hydrodynamic flushing of the existing condition and proposed alternatives. The approach in each case was to "dye" the project area water systems with a constant concentration of 100 milligrams per liter (mg/L), with the offshore areas of the model set to 0 mg/L. This approach provides insight to resident time and flushing quality of the system.

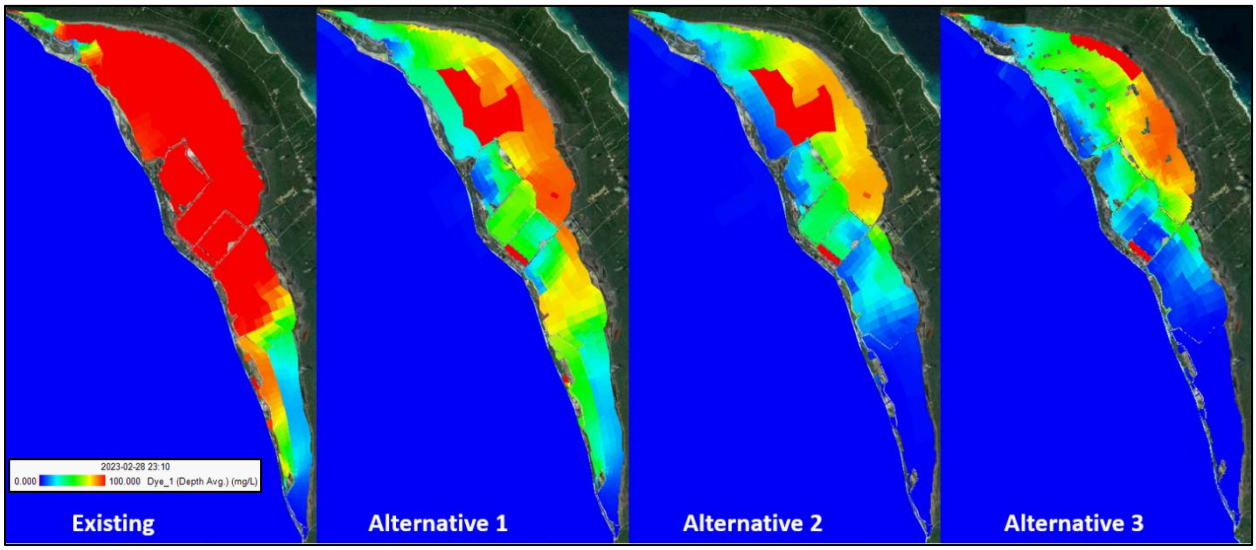

Figure 24. Comparison of 20-day flushing results for baseline and alternatives modeling.

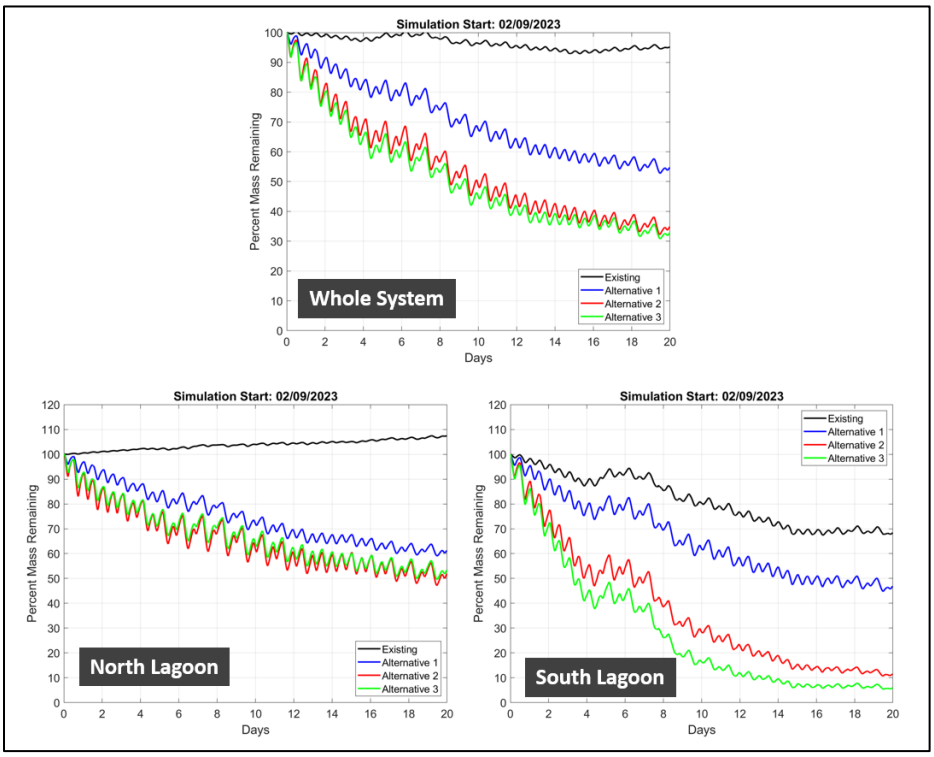

Figure 25. Comparison of dye simulation "mass remaining" for baseline and alternatives modeling.

5.2.2.3 Salinity

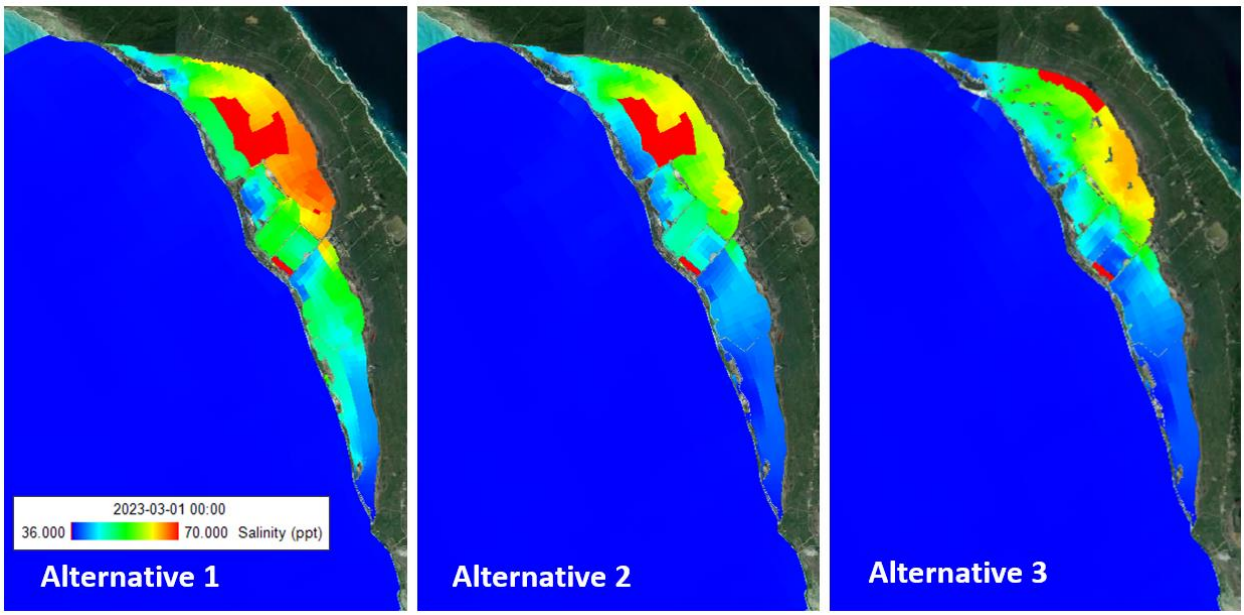

Figure 26. Comparison of 20-day salinity results for alternatives modeling after staring at baseline conditions.

5.2.2.4 Results Summary

Hydrodynamic flushing is the primary metric recommended to evaluate restoration activity improvements to the existing lagoon system targeted at improved hydrologic and water quality. Figure 25 illustrates the measure of flushing as the percent mass remaining during the 20-day dye simulations. Table 1 provides a concise summary and comparison the restoration concept alternative modeling results.

Table 1. Summary of Results

Percent Improvement in Hydrodynamic Flushing Over Baseline			
	Alternative 1	**Alternative 2**	**Alternative 3**
Whole Lagoon	42%	63%	65%
North Lagoon	44%	53%	52%
South Lagoon	32%	84%	91%

**as measured by ~% mass remaining in 20-day dye simulations*

As expected from hydrodynamic flushing characteristics, results indicate interior system tidal dampening is reduced, but still significant as a percentage of total site capacity. Improvements in salinity regimes also follows similar trends as flushing and tidal dampening improvements. In general, Figures 24 and 26 provide visual representation of spatially varying improvements to the system based on the 20-day simulations. It is likely that long-term processes may continue to improve the system based on the restoration activities and cumulative effects over time.

6.0 Summary of Findings and Considerations

6.1 Key Findings

- Field investigations and numerical modeling of existing conditions at the Salinas project site have shown the lagoon system exhibits significantly restricted tidal flushing and impeded wind circulation, exacerbated by evaporation, and that these issues contribute to degraded water quality and ecological conditions currently found at the site.

- This study has shown that hydrological improvements to the entire Salinas system are possible through implementation of restoration activities, primarily new open water inlet creation and interior earthen berm removal.

- Based on the results of numerical modeling and alternatives analysis, a conceptual restoration plan is recommended as the preferred alternative for project consideration.

6.2 Recommended Conceptual Restoration Plan

The recommended conceptual restoration plan includes:

- Four (4) new open ocean inlets (either re-opening and expansion of historic inlets or creation of new), in addition to the 2 existing inlets.

- Removal of multiple sections of internal earth berms across the site and relocation of the material to adjacent berms or island creation areas. Require vehicular bridges or pedestrian boardwalks as needed.

- Hydrologic connections such as culverts that are assumed in-place and active but may also be substituted by berm section removal as appropriate.

- Two actively managed water area features (i.e., the “flamingo pond” and “salt works research area”).

Numerical modeling results indicate the recommended activities will significantly improve flushing and salinity regimes throughout the existing lagoon system to support overall environmental restoration efforts.

A conceptual drawing plan of the preferred alternative for the Salinas restoration project is included as Exhibit A.

6.3 Considerations and Path Forward

During review of the study results and recommended preferred concept restoration plan alternative, key considerations should include:

- Acknowledgment that hydrological modeling is a tool. One of many used in our attempt to predict complex natural processes and theoretical changes.

- Natural processes can be unpredictable, but natural systems are resilient and adaptive.

- Ultimate site conditions prior to and after completion of construction may not exactly mimic those modeled. Storm events, prevailing natural processes, and final design/construction activities will likely result in changes to the final restoration activities, but the strategies and approach for improvement to the system has been shown.

- Restoration activities should implement adaptive design and management. For example:
    - Monitoring of the system to understand how natural hydrological processes equilibrate after major earthwork activities (i.e., inlet creation, berm excavation)
    - More sensitive ecosystem restoration activities and designs should be adapted based on new system characteristics.

Traditional next steps for projects similar to the Salinas include:

- Plan Refinement and Preliminary Design (including sediment transport and coastal structure/inlet dredging design).
- Regulatory Approvals - Environmental Impact Assessment (EIA) process, including Environmental Management Plan.
- Final Design and Construction Documents.
- Bidding and Construction

7.0 References

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NOAA Tides and Currents - Settlement Point, Bahamas - Station ID: 9710441
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Project team partners, workshops, and materials:

SvN Architects + Planners, Islands By Design, International Conservation Fund of Canada

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