Guana Project Report

Project Title: Combining high-resolution surveys and numerical modeling to optimize water level management and contain nutrient levels in the Guana River Lake

DEP Agreement Number: G3300
Revision date for this submittal: 06/29/2023
Organizations performing work for this project: University of Florida, GTMNERR
Principal Investigators involved in the project: Daniele Pinton, Alberto Canestrelli, Nikki Dix
Grant Award Amount: $63,500.00
Anticipated Benefits: By combining numerical models and data collection, we will be able to understand the dynamics of the Guana Lake and identify guidelines for the dam operation, with the final goal of containing nutrient levels in the Lake.

1. Introduction

1.1. Brief Historical Overview

Eutrophication is harming estuaries worldwide. In the majority of the Guana-Tolomato-Matanzas (GTM) estuary, high tidal flushing favors the dilution and transport of nutrients to the sea, and water quality standards for nutrients are met. An exception is Guana River "Lake" (Figure 1), an impounded estuary that receives water from a highly urbanized watershed (i.e., the Ponte Vedra area). A water control structure (i.e., the Guana Dam) separates the natural portion of Guana River from the impounded Guana "Lake" where tidal flushing is reduced, causing accumulation of excess nutrients and algal blooms.

Since the Guana system provides important wildlife habitat and recreation opportunities for the community, and because development pressure in the watershed is a public concern, a public-private water quality partnership aimed at assessing current ecosystem conditions was established in 2017. The resulting study, conducted by GTM National Estuarine Research Reserve (GTMNERR), Guana River Marsh Aquatic Preserve, and Florida Fish and Wildlife Conservation Commission staff, concluded that the Guana system suffers from excess nutrients, regular occurrence of potentially harmful algal blooms, and a clear gradient of human influence from north to south (Dix et al., 2019).

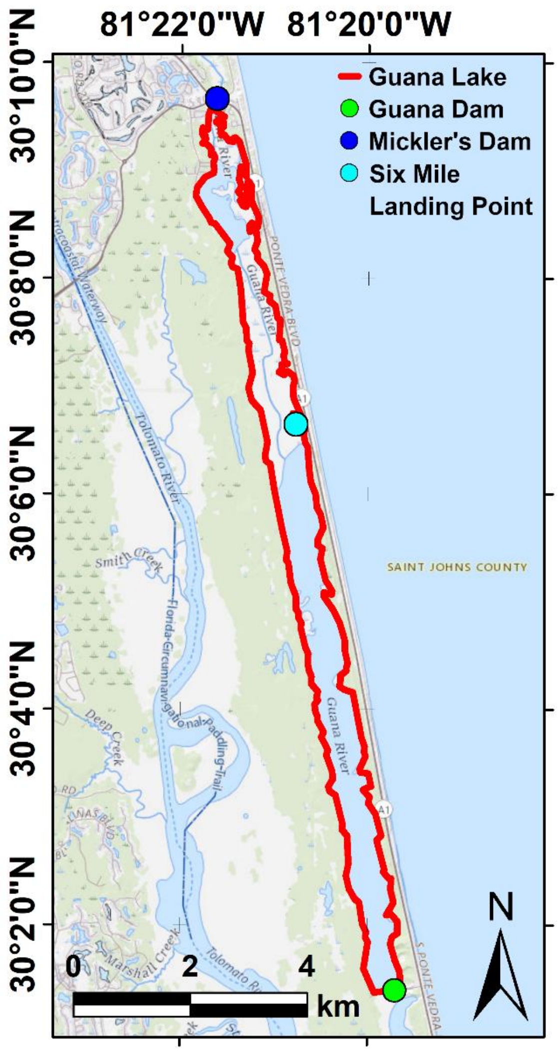

Figure 1. The Guana Lake, which boundaries are defined by the continuous red line. The Lake is connected to the Guana River in the south, through the Guana Dam (green dot) and in the north, through the Mickler's Dam (blue dot). The Six Mile public landing point is also indicated in the map (light blue dot). On the background, the USGS National Map.

1.2. *Project Purpose and Objectives*

The GTM estuary is a highly flushed ecosystem that rarely experiences negative consequences of eutrophication. However, in Guana Lake, tidal flushing varies seasonally to meet specific environmental and recreational needs. As a result, Guana Lake provides an ideal laboratory for exploring different degrees of tidal flushing to reduce nutrient accumulation, meet water quality standards, ensure flood protection, and preserve valued recreational and commercial uses. Dix et al. (2019) suggest that a better understanding of nutrient quantity, sources, and fates throughout the watershed and along a nutrient and salinity gradient in Guana Lake is necessary to develop remediation strategies. This critical need led the GTMNERR to prioritize the development of a detailed hydrologic and pollutant source model for designing remediation and limiting nutrient accumulation.

In the next sections, we will present the results obtained during the first 6 months of a 2-year effort. The long-term (i.e. 2 years) objectives are:

- Develop a coupled hydrological, hydrodynamic, and water quality model for the Guana Lake and its watershed.
- Collect field observations to calibrate and validate the numerical model using the recently purchased YSI HYCAT, an Autonomous Surface Vehicle (ASV) for remote monitoring of water quality, bathymetry, and velocities/discharge.
- Test the feasibility of using the HYCAT for water research and management. Document challenges, limitations, effort, cost, and future opportunities. Develop protocols.

- Host a stakeholder workshop to explain how watershed actions and dam operation impact water quality in the Guana system.
- Collaborate with end-users to develop a water quality remediation plan containing a list of best management practices to fine-tune dam operations and improve water and habitat quality within Guana Lake.

2. Method

2.1. Project Schedule

The main tasks of the present Guana Project are described below and summarized in Table 1. All tasks were completed in time by our team during the Project.

- Taks 1 - Quality Assurance Project Plan: We prepared, submitted, and received approval on a Quality Assurance Project Plan (QAPP) before the commencement of any monitoring associated with the project. The original start and end dates of this task were January 1st, 2023, and February 28th, 2023, respectively. Since we needed more time for the literature review, instruments acquisition, and training, the end date of this task was moved to April 4th, 2023.
- Task 2 – Bathymetry and Hydrodynamic and Water Quality Model of Guana Lake:
  - **Subtask 2a:** we collected bathymetric, hydrodynamic (i.e., water depth), and water quality (see Section 2.3.1) data in the Guana Lake, by using the HYCAT ASV (i.e., the ADCP and the YSI EXO2) and the SUNA V2.
  - **Subtask 2b:** data were extracted from the instruments, and analyzed by using MATLAB scripts we generated for this purpose.
  - **Subtask 2c:** we implemented a Delft3D-FLOW numerical model describing the Guana Lake. The model bathymetry assigned to the model was the one we collected and analyzed in the previous tasks.
  - **Subtask 2d:** data collected were presented at the Technical Advisory Group (TAG) Meeting at the GTMNERR.
  - **Subtask 2e:** data were summarized in a Google Drive folder shared of the project, shared with the FDEP.

  The original start and due dates of subtasks 2a, 2b, and 2c were February 28th, 2023, and June 30th, 2023. However, the start date was changed to April 4th, 2023 to match the end date of Task 1. The data were presented at the TAG meeting on May 17th, 2023, as required, and the presentation was submitted to the FDEP Grant Manager before May 31st, 2023, as required.
- Task 3 - Final Report: we prepared the present Final Report summarizing the results of the project, including all tasks in the Grant Work Plan. This task started after the

completion of Task 2. The due date of this task was June 30th, 2023. This report was submitted to the FDEP Grant Manager, as required, by June 30th, 2023. A copy is located in the Google Drive folder shared of the project, shared with the FDEP.

Table 1. Project schedule and tasks summary.

Task No.	Task or Deliverable Title	Task Start Date	Task End Date	Deliverable Due Date
Task 1	**Quality Assurance Project Plan**	01/01/2023	02/28/2023	04/15/2023
Task 2	**Hydrodynamic and Water Quality Model of Guana Lake with Bathymetry**	Upon the completation of Task 1	6/30/2023	6/30/2023
2a	Data Collection		6/30/2023	6/30/2023
2b	Data Analysis		6/30/2023	6/30/2023
2c	Numerical Model Implementation		6/30/2023	6/30/2023
2d	Presentation at the TAG meeting		5/31/2023	5/31/2023
2e	Data summary		6/30/2023	6/30/2023
Task 3	**Final Report**	Upon the completation of Task 2	6/30/2023	6/30/2023

2.2. Task 1 - Quality Assurance Project Plan

The QAPP meets the minimum requirements for the description of the Research Field and Laboratory Procedures according to Rule 62-160, F.A.C.. The QAPP summarizes the methods we used to collect, analyze, store, and use the bathymetry and water quality survey in the Guana Lake. These methods are reported in Section 2.3. The QAPP is stored in the Google Drive folder of the project, shared with the FDEP.

2.3. Task 2 – Bathymetry and Hydrodynamic and Water Quality Model of Guana Lake

2.3.1. Data Collected and Instruments Used

In this project, we collected bathymetry and water quality data from the Guana Lake using a HYCAT ASV (Figure 2A) and a SUNA V2 (Figure 2B). Water quality, bathymetric, and water velocity data were collected using the SonTek RiverSurveyor M9 Acoustic Doppler Current Profiler (ADCP, Figure 2C), and the YSI/Xylem EXO2 MultiParameter Water Quality Sonde (Figure 2D) mounted on the HYCAT. Water quality data are water temperature, conductivity, salinity, Dissolved Oxygen (DO), pH, turbidity, and chlorophyll-a. Also, Nitrate (NO_3) concentration was collected in the study area by using a SeaBrid SUNA V2 Nitrate Sensor. NO_3, Nitrite (NO_2), Ammonia (NH_4), and Total Nitrogen (TN) concentrations will also be obtained from water samples collected in the Guana Lake.

2.3.2. Fieldwork Description

The survey was performed as follows. The Guana Lake area was divided into four areas, each of which can be surveyed in eight hours. The four areas of the Lake, from south to north, were surveyed on April 19th, April 20th, April 21st, and May 2nd, 2023. The sampling frequency for hydrodynamic, water quality, and nutrient data was ~1 Hz. The sampling approach involved a combination of a shoreline perimeter path and a zigzag cross-lake path (see Figure 3). The zigzag path was created before the start of the survey. It was chosen to optimize the survey time and bathymetry accuracy and resolution. The HYCAT speed during data collection did not exceed 2 knots, except for rare situations for short times. This low speed was chosen to avoid turbulence around the sensor and to maximize the battery life of the HYCAT.

For bathymetric and hydrodynamic surveys, a SonTek RiverSurveyor M9 Acoustic Doppler Current Profiler (ADCP) was mounted on the HYCAT ASV. For monitoring water quality, a YSI/Xylem EXO2 MultiParameter Water Quality Sonde was mounted on the HYCAT. As for monitoring nutrient concentrations, a SUNA V2 Nitrate Sensor was mounted on the boat used to follow the HYCAT.

Water samples were collected uniformly along the Guana Lake to post-calibrate the nutrient data obtained by the SUNA V2 Nitrate Sensor. A sample was collected at the beginning and the end of the paths surveyed over the four days of the survey. Along each path, samples were collected at a rate of 1 every ~2-3 hours.

At each sampling location, a dark leak-proof high-density polyethylene (HDPE) bottle will be used to collect a water sample of 500 ml. Bottles will be cleaned and sterilized before each survey. Samples will be manually grabbed at a depth of 0.5 m, and bottles were labeled with the date, time, and number of the sample (progressive, starting from 1 each day). At the same location, a YSI Model 30 Handheld meter (https://www.ysi.com/File%20Library/Documents/Manuals%20for%20Discontinued%20Products/030136-YSI-Model-30-Operations-Manual-RevE.pdf), and a YSI ProDSS Handheld meter (https://www.ysi.com/prodss) were used to measure the vertical profile of temperature, conductivity, salinity, DO, turbidity, and Chlorophyll-a concentration. Data were used to validate HYCAT measurements (see QAPP). Data were collected every 0.1 m in depth. Water temperature, conductivity, salinity, DO, turbidity, and chlorophyll-a were measured at 0.5 m depth and recorded on a field data sheet. NO_3, NO_2, and NH4 samples will be filtered through a 0.45-μm filter (using filtration towers that have been acid-washed before the sampling day) and acidified to pH<2 with H_2SO_4 at the station (see attachment n.1 for more info about the procedure). Bottles were stored on ice until the end of the daily survey. At the end of the day, samples were stored at a temperature of 4°C, as required by the lab performing the analysis on nutrient concentrations.

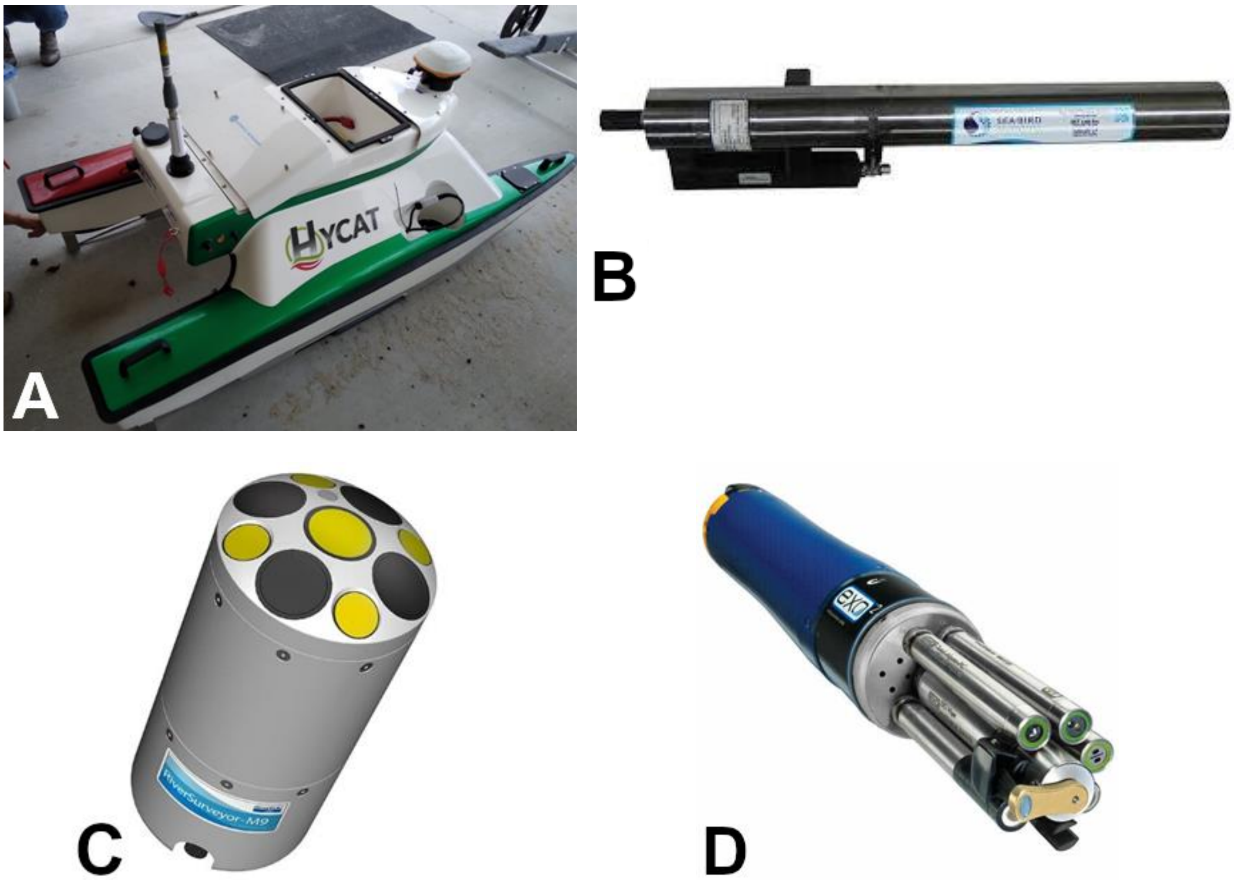

Figure 2. The instruments we used for the bathymetry and water quality survey in the Guana Lake. (A) The HYCAT Autonomous Surface Vehicle. (B) The SUNA V2 Nitrogen sensor. (C) The SonTek RiverSurveyor M9 Acoustic Doppler Current Profiler (taken from https://www.ysi.com/riversurveyor-s5-m9). (D) The YSI/Xylem EXO2 MultiParameter Water Quality Sonde (taken from https://www.ysi.com/exo2).

Samples were delivered to the UF/IFAS Analytical Services Laboratories (ANSERV Lab, https://arl.ifas.ufl.edu/ARL%20Analysis.asp) for nutrient concentration analysis. According to the procedure indicated in their ANSERV Lab's QA Manual, they will be delivered to ANSERV Lab acidified, at a temperature of 4°C, and in 20 ml scintillation vials. The ANSERV Lab's QA Manual includes information on the MDL/PQL the method of analysis for the bottle samples collected in the field, the calibration procedures of their instruments, and their Chain of Custody procedures. Details on the ANSERV Lab and the nutrient concentration analysis they perform are reported in the Laboratory Analysis section.

2.3.3. Data Analysis

Once extracted from the HYCAT and the SUNA V2, bathymetric and water quality data were analyzed by using MATLAB (Release R2020b) scripts we developed. The scripts:

- Extract the data collected by the ADCP, the YSI EXO2, and the SUNA V2, store them in a MATLAB structure, and save them in a .mat file.
- Organize them in arrays, by using an Inverse Distance Weighted (IDW) method, and provide as output ASCII and XYZ files of the bathymetry and water quality data collected in the field.

The ASCII files are imported in ArcMap (release 10.7) to generate maps of the collected datasets, for visual purposes. The XYZ bathymetric file is imported in QUICKIN (a Delft3D plugin) to assign the bathymetry to the Delft3D-FLOW numerical model we implemented for this project. Finally, both ASCII and XYZ files of the water quality parameters will be used to calibrate the numerical model.

The script and the files are contained in the Google Drive folder of the project, shared with the FDEP.

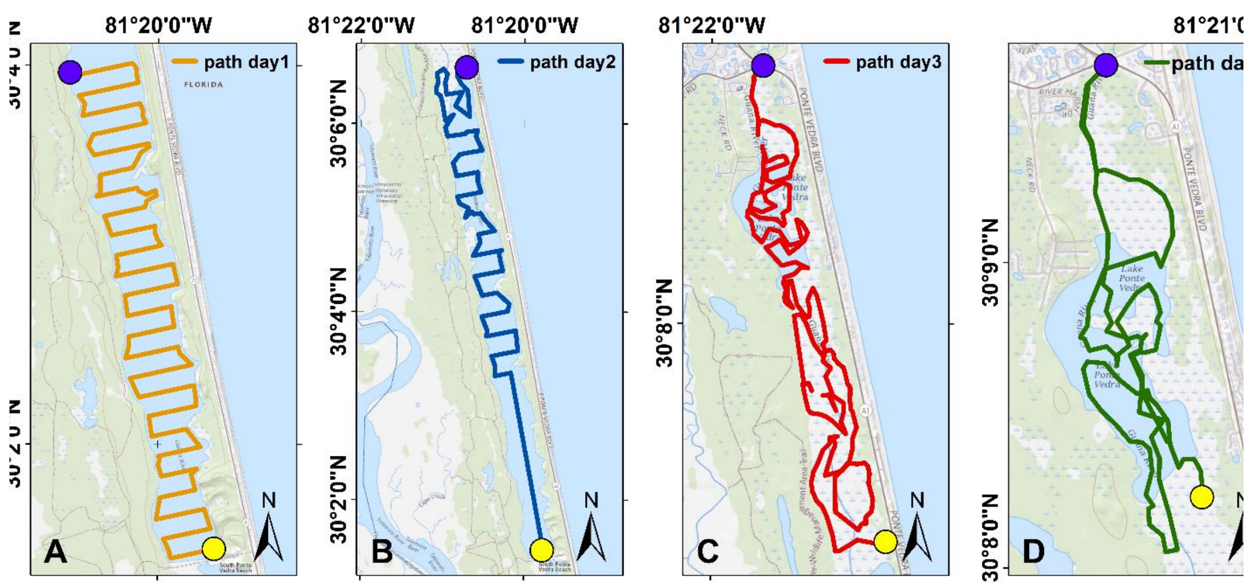

Figure 3. The path followed by the HYCAT during the four days of the survey in the Guana Lake (1 to 4, from A to D). In the figures, the yellow and violet dots indicate the starting and ending points of the survey, respectively.

2.4. *Hydrodynamic Model Details*

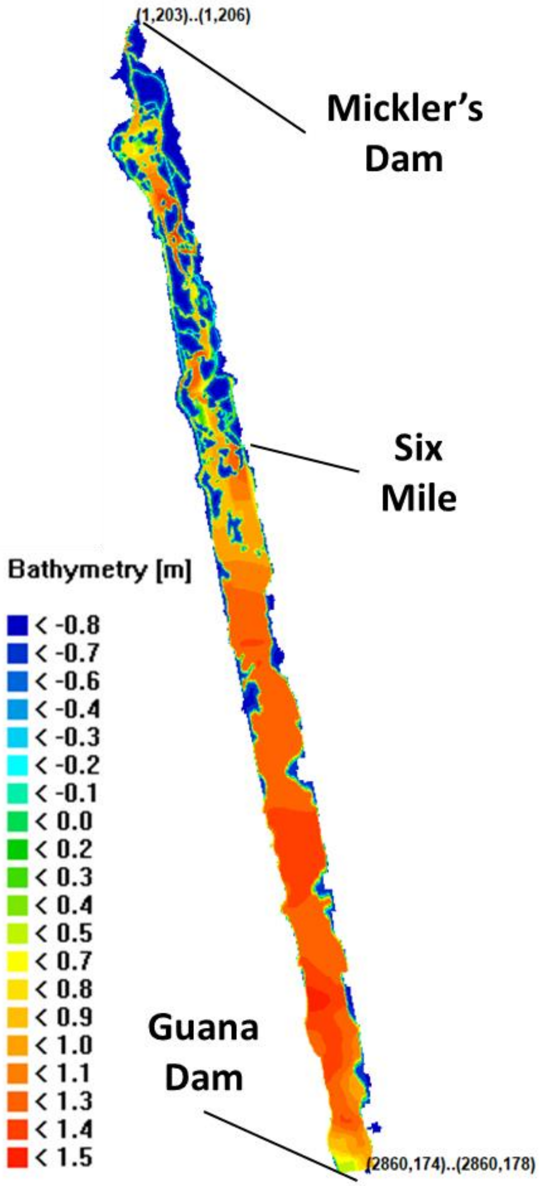

Figure 4. Grid and bathymetry of the Delft-3D model describing the Guana Lake. Values are expressed in Delft3D notation: positive and negative values indicate the elevation below and above the MSL, respectively.

We used the Delft3D-FLOW model (https://oss.deltares.nl/web/delft3d) to solve the hydrodynamics and the water quality in the Guana Lake. It calculates non-steady flow resulting from the hydrodynamic (tide and river flow) and meteorological forcing on a regular, boundary-fitted grid. We used a structured curvilinear grid encompassing approximately 10.50 km^2 to describe the Guana Lake.

The model domain, shown in Figure 4, encompasses the Guana Lake, from Mickler's Dam (30°09'39.6" N 81°21'37.4" W) to Guana Dam (30°01'23.7" N 81°19'42.3" W). The grid cell dimensions varied along the lake, growing from approximately 5 m × 25 m at the Guana Dam, in the southern part of the Lake, to about 5 m × 5 m at Mickler's Dam, in the northern part of the Lake.

The bathymetric data used in the model are those obtained with the survey we perform in the Lake (see section 2.3), by using the ASV HYCAT. We assigned an elevation equal to 0.80 m to the marshes located in the northern part of the lake (see Figure 4). Ground elevation will be assigned by using the lidar and DEM datasets available in the NOAA inventory (https://coast.noaa.gov/dataviewer/#/). These elevation data will be validated and complemented by using either a GPS-RTK or a laser scanner system mounted on an Unmanned Aerial Vehicle (UAV) (Pinton et al., 2020, 2021).

2.4.1. Model Scenario

At this stage of the research, a scenario describing the survey days cannot be run, since data forming the boundary conditions at the Mickler's Dam and the Guana Dam are missing. These data are the water level, the water discharge, the water temperature, and the water salinity at the Mickler's Dam and the Guana Dam. This data will be collected at the next stage of this research project.

In the model scenario that we ran for this project, we tried to reach a steady state condition in the water temperature and salinity in the Guana Lake. The simulation lasted for 30 days, from May 13th, 2023 to June 13th, 2023. The initial salinity and temperature uniformly assigned to the model domain are 15 ppt and 15°C, respectively. The harmonic constituents used to describe the tide at the Guana Dam are reported in Table 2. The water discharge (Q) entering the Lake from Mickler's Dam is obtained by using the following formula for a rectangular weir:

$$Q = c_q \, h^{3/2} \, B \, \sqrt{2g}, \tag{1}$$

where c_q is a discharge coefficient equal to 0.41, h is the water depth above the weir, and B is the length of the rectangular weir. Based on a visual survey we performed at the Mickler's Dam, we used h and B equal to 0.15 m and 2 m. In the next phase of the project, we will calibrate the weir equation using discharge measured by the HYCAT and the water level will be provided by a pressure sensor.

At the Guana Dam, we applied the water temperature and salinity measured at the GTMNERR "Pine Island" station (30°03'03" N, 81°22'03" W) in the simulated period. At Mickler's Dam, we assumed, as a first approximation, that the water temperature is equal to the air temperature measured at the GTMNERR "Pellicer Creek" station (29°39'28" N, 81°13'58" W). In addition, we assumed that water entering the Lake from Mickler's Dam is fresh, with a salinity of 0 ppt. In the next phase of the project, water temperature and salinity will be collected at each dam by using a YSI CTD.

Finally, we applied the meteorological forcings, corresponding to relative humidity, air temperature, wind direction, and wind speed to the entire model domain. These data were measured at the GTMNERR meteorological station "Pellicer Creek".

A list of all the datasets used in the numerical model is reported in Table 3.

Table 2. The harmonic constituents used to describe the tide at the Guana Dam in the Delft3D-FLOW numerical model.

Name	Amplitude [m]	Phase [deg]	Description
M2	0.62	243	Principal lunar semidiurnal constituent
S2	0.09	261	Principal solar semidiurnal constituent
N2	0.14	231	Larger lunar elliptic semidiurnal constituent
K1	0.1	131	Lunar diurnal constituent
O1	0.07	142	Lunar diurnal constituent
MM	0.05	97.6	Lunar monthly constituent
SSA	0.09	14.2	Solar semiannual constituent
SA	0.15	205	Solar annual constituent
MSF	0.03	128	Lunisolar synodic fortnightly constituent
P1	0.03	126	Solar diurnal constituent

Table 3. List of the datasets used in the Delft3D-FLOW model scenario we ran for this project, and how they were used in the model.

<table>
<tr><th>Station</th><th>Dataset</th><th>Data Usage</th></tr>
<tr><td rowspan="2">GTMNERR – Pine Island</td><td>Water temperature</td><td>Applied at the Guana Dam boundary to describe the local water temperature</td></tr>
<tr><td>Water salinity</td><td>Applied at the Guana Dam boundary to describe the local water salinity</td></tr>
<tr><td rowspan="4">GTMNERR – Pellicer Creek</td><td>Air temperature</td><td>Applied:
• at the Mickler's Dam boundary to describe the local water temperature
• at the entire model domain to calculate the heat fluxes between air and water</td></tr>
<tr><td>Relative humidity</td><td>Applied at the entire model domain to calculate the heat fluxes between air and water</td></tr>
<tr><td>Wind speed</td><td>Applied at the entire model domain to calculate the effect of the wind on the hydrodynamic</td></tr>
<tr><td>Wind direction</td><td>Applied at the entire model domain to calculate the effect of the wind on the hydrodynamic</td></tr>
<tr><td>NOAA – Vilano Beach</td><td>Tide constituents</td><td>Applied at the Guana Dam boundary to describe the local water level. We kept only the ones with an amplitude larger than 3 cm (see Table 2).</td></tr>
</table>

3. Results

3.1. Field Survey

One of the main results reached during this project is the collection of an exhaustive and complete dataset describing the bathymetry of the Guana Lake. Another important result is the collection of water quality data along the Lake, which high-resolution allows the creation of maps.

3.1.1. Guana Lake Bathymetric Map

Bathymetry and water depth data collected in the Guana Lake were analyzed, as indicated in Section 2.3.3. The maps obtained from the analysis are reported in Figure 5. Data are discussed in Section 4.

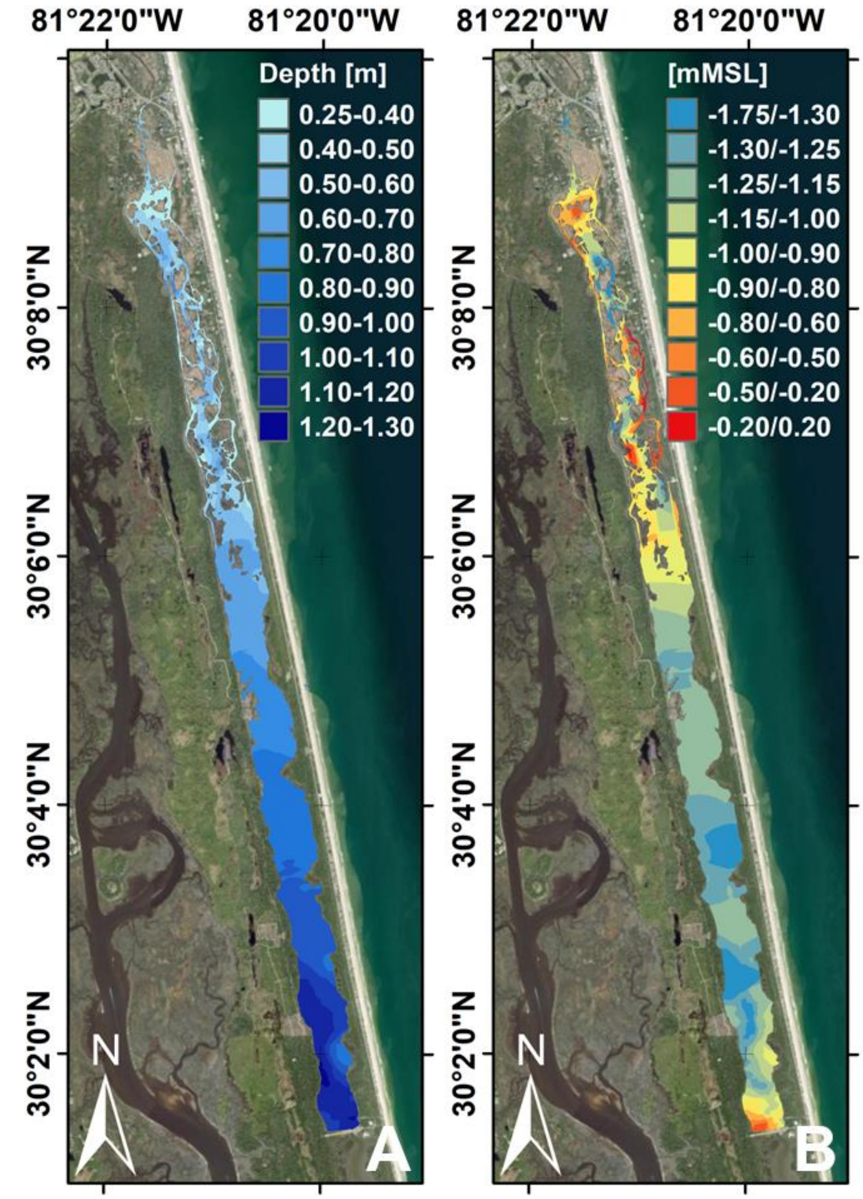

Figure 5. (A) Spatial distribution of the water depth in the Guana Lake. (B) Bathymetry in the Guana Lake. Data were collected in the survey we performed in the Lake by using the ADCP on the HYCAT.

3.1.2. Water Quality Maps – Water Temperature, Conductivity, and Salinity

Water temperature, conductivity, and salinity data collected in the Guana Lake were analyzed, as indicated in Section 2.3.3. The maps obtained from the analysis are reported in Figure 6. Data are discussed in Section 4.

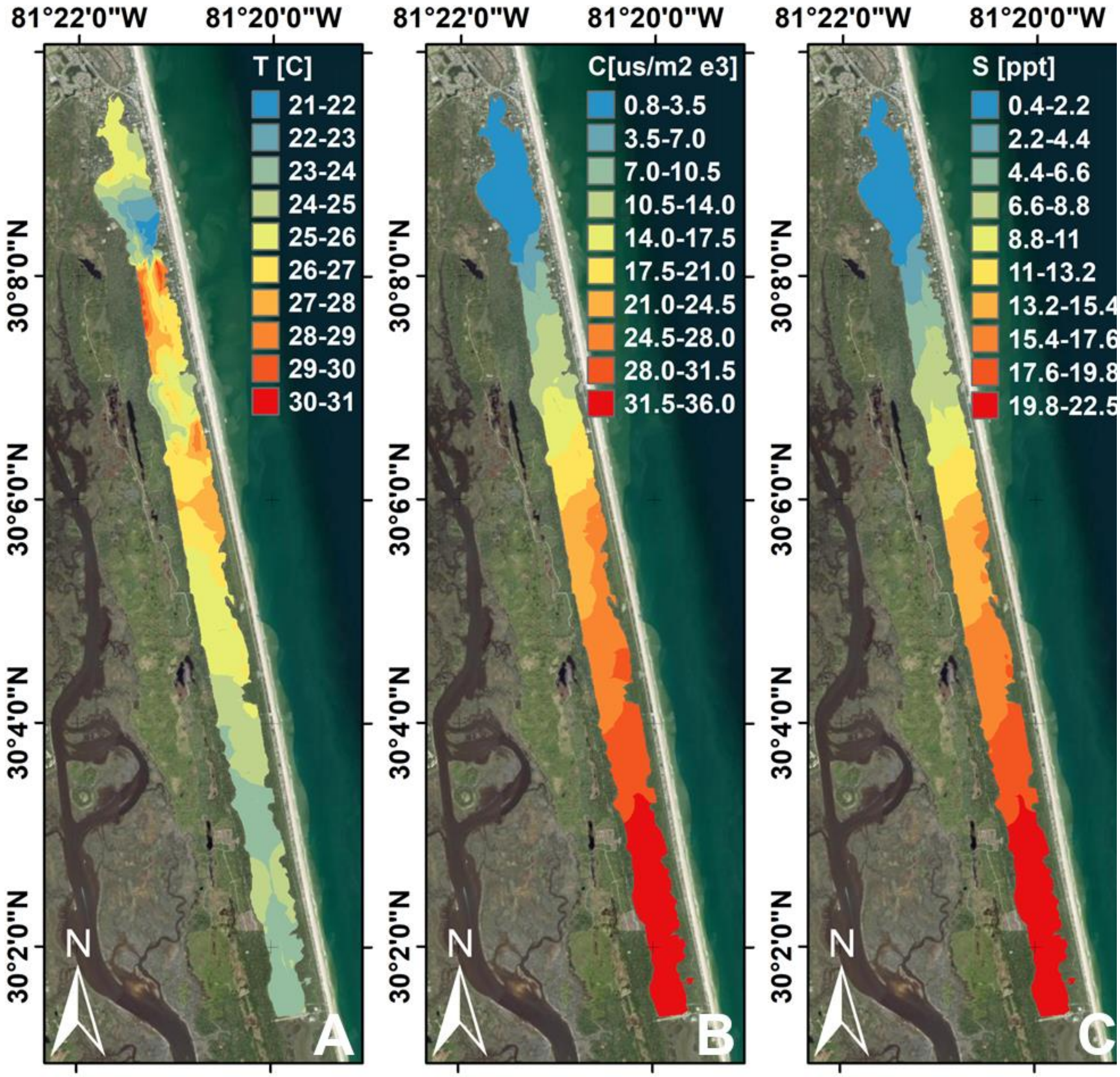

Figure 6. Spatial distribution of: (A) the water temperature in the Guana Lake. (B) The water conductivity in the Guana Lake. (C) The water salinity in the Guana Lake. Data were collected in the survey we performed in the Lake by using the YSI EXO2 on the HYCAT.

3.1.3. Water Quality Maps – Dissolved Oxygen, pH, and Turbidity

Dissolved oxygen concentration, water pH, and water turbidity data collected in the Guana Lake were analyzed, as indicated in Section 2.3.3. The maps obtained from the analysis are reported in Figure 7. Data are discussed in Section 4.

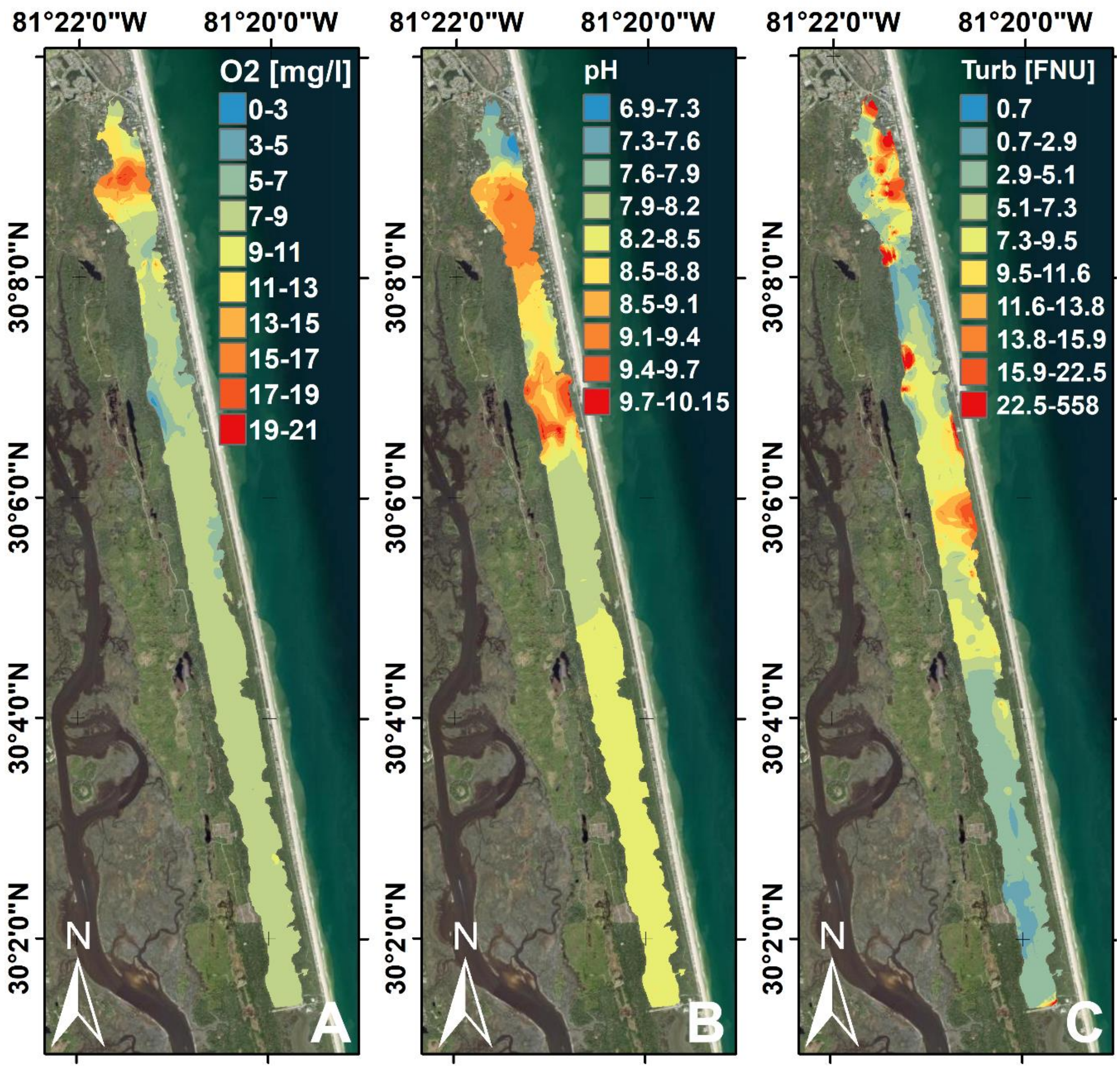

Figure 7. Spatial distribution of: (A) the dissolved oxygen concentration in the Guana Lake. (B) The pH in the Guana Lake. (C) The water turbidity in the Guana Lake. Data were collected in the survey we performed in the Lake by using the YSI EXO2 on the HYCAT.

3.1.4. Water Quality Maps – Chlorophyll-a Concentration and fDOM

Chlorophyll-a concentration and fDOM data collected in the Guana Lake were analyzed, as indicated in Section 2.3.3. The maps obtained from the analysis are reported in Figure 8. Data are discussed in Section 4.

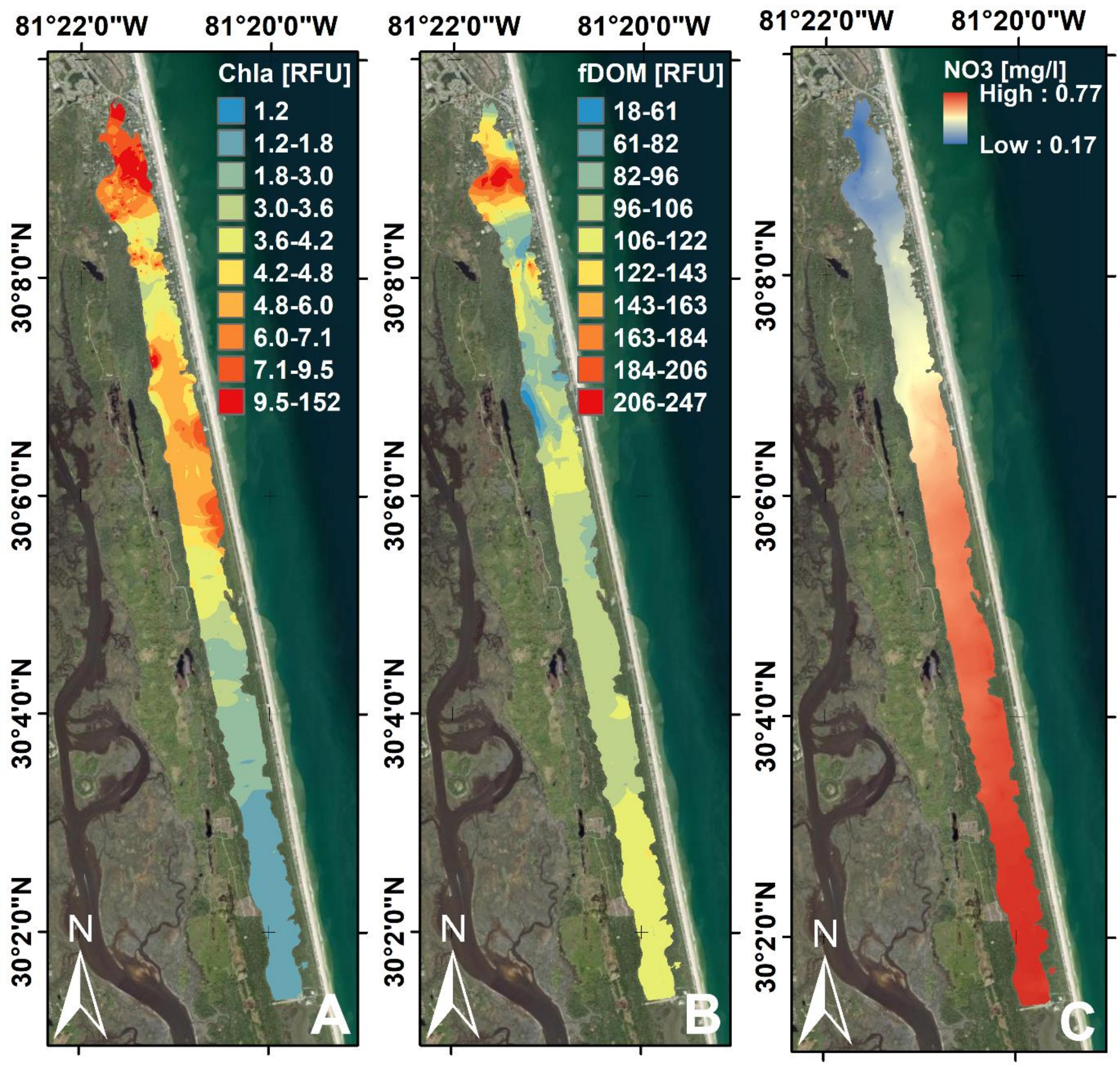

Figure 8. Spatial distribution of: (A) Chlorophyll-a concentration in the Guana Lake. (B) fDOM in the Guana Lake. Data were collected in the survey we performed in the Lake by using the YSI EXO2 on the HYCAT.

3.2. *Numerical Model*

We used the numerical model Delft3D-FLOW to simulate the distribution of water temperature and salinity in Guana Lake. Our goal in this simulation, which is described in Section 2.4.1, was to determine the time required for Guana Lake to reach a stable condition without any regulation. The Guana Dam is modeled in the simulation. Saltwater enters and leaves the Lake through this Dam based on the difference between the Lake's water level and the tide level at the Dam. Additionally, we applied a consistent flow of freshwater at Mickler's Dam, calculated by using Equation (1). The maps obtained from the model are shown in Figure 9 and Figure 10 for the temperature and the salinity, respectively.

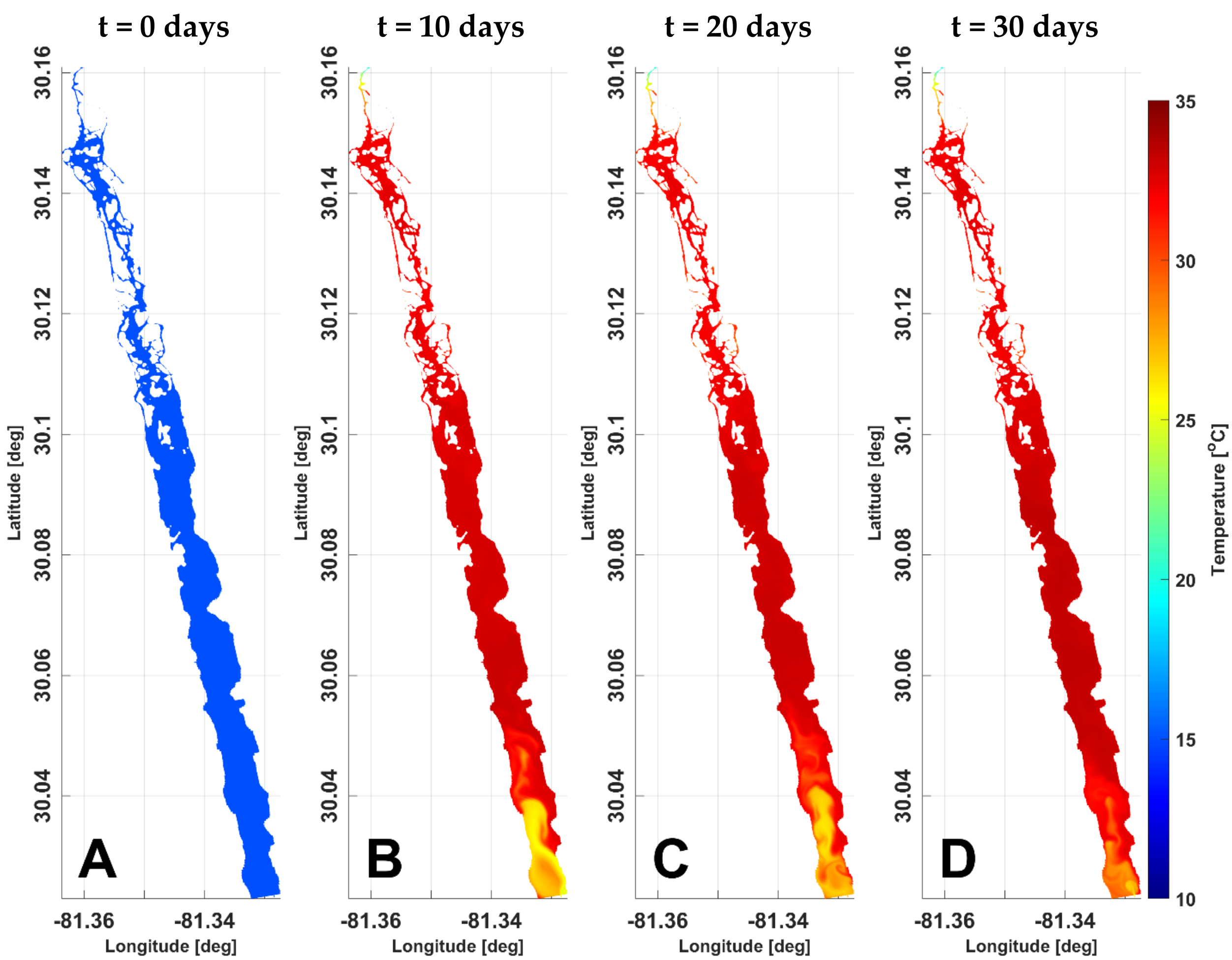

Figure 9. Evolution of the water temperature distribution in the Guana Lake. The images, from left to right, show the water temperature distribution in the Lake after (A) 0, (B) 10, (C) 20, and (D) 30 days of simulation.

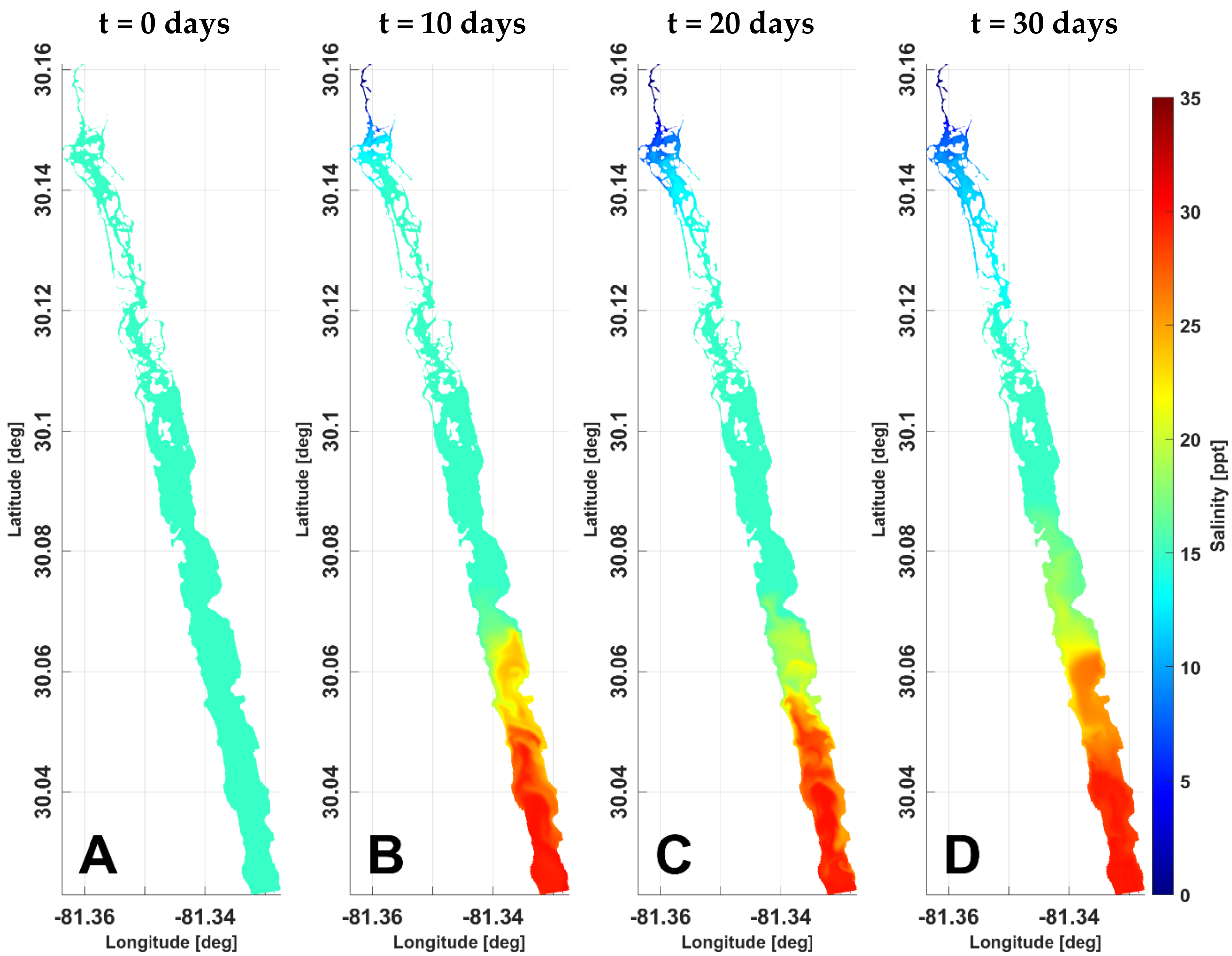

Figure 10. Evolution of the water salinity distribution in the Guana Lake. The images, from left to right, show the water salinity distribution in the Lake after (A) 0, (B) 10, (C) 20, and (D) 30 days of simulation.

4. Discussions

The maps reported in Section 3 show the spatial distribution of the variables measured in the Guana Lake during our fieldwork. Data observed in the maps are described and discussed in the following sections.

4.1. <u>Field Survey</u>

4.1.1. Water Depth

In Guana Lake, the water depth gradually decreases from north to south (Figure 5A). This occurs because water tends to accumulate in the southern part of the lake, thanks to the presence of the Guana Dam. During our survey, we measured the minimum water depth to be around 0.25 meters and the maximum depth to be approximately 1.30 meters. The channels located in the northern part of the Lake have the lowest water depth. This can lead to the impoundment of water in those channels. During the fieldwork, we observed certain indicators of impoundment, such as the smell of sulfur, the absence of vegetation, and the lack of fish in some of these channels.

4.1.2. Bed Elevation

The bed elevation (Figure 5B) varies across the Lake differently from the water depth. In the southern part of the Lake, near the Guana Dam, the elevation is generally low, ranging from approximately -0.50 m AMSL to -1.0 m AMSL. This can be attributed to the accumulation of sediments originating from the north.

Moving north, towards the Six Mile landing point, the elevation gradually decreases until it reaches its maximum of about -1.75 m AMSL. Beyond this point, the elevation starts to rise again, reaching approximately -1.00 mAMSL at the Six Mile landing point. Here, the Lake's morphology changes, and a complex network of narrow channels with spatially varying elevations replaces the open expanse of the southern region.

Most of these channels have elevations ranging between -0.2 m AMSL and -1.00 m AMSL. The bed elevation then decreases once more, reaching another minimum of around -1.75 m AMSL at latitude 30°08’00” N. It subsequently rises to another peak of approximately -0.50 m AMSL, halfway between this point and Mickler's Dam, before declining again to ~-1.75 m AMSL at Mickler's Dam.

4.1.3. Water Temperature

The temperature distribution in the Lake (Figure 6A) varies over the four days of the survey. Each day, we surveyed a portion of the Lake, and the temperature increased from approximately 23°C in the morning to around 28°C in the afternoon. We are unsure if part of this variation is due to a north-south spatial gradient in temperature. We will assess this possibility with the next survey. The starting and ending points of the survey are shown in Figure 6, using yellow and violet dots. They are located at: (i) Guana Dam, (ii) latitude 30°04’00” N, (iii) Six Mile landing point, near latitude 30°07’00” N, (iv) latitude 30°08’00“ N, and (v) Mickler’s Dam.

These findings suggest that solar irradiation plays a significant role in determining the Lake's surface temperature. Once we will constrain the boundary conditions for the temperature at the two dams, we will be able to assess also the role of water fluxes at Mickler's Dam and Guana Dam in modulating the temperature in the Lake.

4.1.4. Water Conductivity and Salinity

The conductivity and salinity of the water gradually increase from north to south (Figure 6B and C). Since salinity and conductivity are related, we will focus on describing the salinity distribution. In the northern part of the Lake, near Mickler's Dam where fresh water is discharged, the salinity is at its lowest, around 0.40 ppt. On the other hand, the highest salinity, approximately 31 ppt, is observed at Guana Dam where salty water from the Guana River enters the Lake. The Lake's brackish environment is created by the interaction between these two sources of fresh water and saltwater. By looking at the map in Figure 6C, we can see that the salinity gradient is less pronounced in the southern and northern parts of the Lake, where the bed elevation is higher, and the water depth is smaller. Conversely, in the area of the Lake occupied by the channel network, the salinity gradient is higher. These results indicate a possible presence of a relationship between the Lake morphology and the surface salinity.

4.1.5. Dissolved Oxygen

In most of the Guana Lake, the oxygen concentration varies between 7 and 9 mg/l, as shown in Figure 7A. These values are within the range commonly found in similar environments according to existing literature (Zhu et al., 2021). However, certain lateral channels show lower oxygen levels, close to 0 mg/l, probably due to poor aeration, resulting in a hypoxic environment. In the northern part of the lake, there is a significant area with high oxygen levels. This is likely due to the abundance of seagrass, which releases a substantial amount of oxygen through photosynthesis. Oxygen concentrations in this area range from 9 to 21 mg/l.

4.1.6. pH

The pH levels in the Lake (Figure 7B) exhibit significant variability. In the southern and central regions, the measured pH falls within the range of 7.9 to 8.5, which is commonly observed in similar environments (Müller et al., 2018). Moving towards the northern part, specifically from the Six Mile landing point to the vicinity of Mickler's Dam, there is a gradual increase in pH. This increase can be attributed to the prevalence of vegetation in the area, which promotes higher pH levels due to photosynthesis. The pH values recorded in this region range from 8.5 to 10.15. However, there is a sudden decrease in pH close to Mickler's Dam, with values ranging from 6.9 to 7.9. This decrease might be a result of nitrogen influx from the Dam into the Lake.

4.1.7. Turbidity

The water in most of the lake has a low turbidity level, measuring below 5.1 FNU (Figure 7C). However, there are significant areas with high turbidity near the landing points and in places where the HYCAT became obstructed by submerged vegetation or stuck due to a higher bed elevation. In these cases, the propellers of the HYCAT, when activated, caused sediment resuspension, resulting in increased turbidity as measured by the YSI EXO2 instrument on the ASV.

The presence of other boats near the landing sites could also contribute to high turbidity in those areas.

4.1.8. Chlorophyll-a Concentration

The concentration of chlorophyll-a (Figure 8A) in the Lake increases as we move from south to north. This is because vegetation gradually becomes more abundant in the northern part of the Lake. Upon visual observation, we noticed that vegetation is absent in the southern part of the Lake, starts to grow in the central part near the Six Mile landing site, and becomes dominant in the northern part.

The presence of vegetation could be due to various factors: (i) the release of nutrients from inhabited lots, which are scarce or absent in the southern region. (ii) The proximity to Mickler's Dam, which is a significant source of nutrients for the Lake. (iii) The presence of floodplains and marshes, which promote the growth of vegetation.

Additionally, when comparing Figure 5 and Figure 8A, we can observe that areas with higher chlorophyll-a concentration coincide with shallow water depths and elevated areas in the Lake.

4.1.9. fDOM

The fDOM concentration (Figure 8B) reveals two distinct hotspots in the Guana Lake. One is situated in the northern region near Mickler's Dam, while the other is located in the southern part near Guana Dam. These hotspots indicate the presence of accumulated nitrogen compounds in these areas, as fDOM serves as a proxy for dissolved carbon and nitrogen concentration (Cumberland & Baker, 2007; Snyder et al., 2018).

The thick and dense layer of submerged vegetation in this area may contribute to increased nitrogen concentration due to the mineralization (i.e., decomposition) of dead seagrass. In the southern part of the lake, the presence of Guana Dam likely causes the accumulation of fDOM.

4.1.10. Nitrogen Concentration

The nitrogen (NO_3) concentration (Figure 8C) in the Lake increases gradually from north to south. This is because nitrogen accumulates as it flows from the north through Mickler's Dam and from the surrounding residential areas. The presence of the Guana Dam limits the ability of pollutants to leave the Lake, thus favoring their accumulation. At the Guana Dam, the nitrogen concentration reaches a maximum of approximately 0.77 mg/l. This value indicates that the water surveyed does not show significant contamination (APHA, 1992). This is likely due to the massive presence of vegetation in the northern part of the lake, which consume NO_3 through photosynthesis (Burkholder & Glibert, 2022).

4.2. Numerical Model

Here we present the preliminary results of the numerical model. We simply modeled the Guana Dam as a spillway with a crest at a -0.7 m AMSL elevation. This is the elevation measured by the HYCAT close to the Dam. Over the next year, the boundary conditions will be improved to add the actual Dam operations, as well as measured temperatures and salinity upstream and downstream. Moreover, the model will be calibrated to match observations. Our simplified model results show that water temperature and salinity in the Lake take different "warm-up" timescales. This period indicates the time the solution takes to forget the initial conditions and be determined by the time-varying boundary conditions. After 10 days of simulation (Figure 9B), the water temperature becomes mostly spatially uniform across the entire Lake, with slight variations near the Guana Dam and the Mickler's Dam. This is because the water entering the Lake through the dams mixes with the existing water, creating a uniform temperature. As the simulation progresses to 20 and 30 days (Figure 9C and D), the distribution of water temperature remains mostly unchanged, except near the Guana Dam. During this time, the variation of temperature due to tidal exchange through the Dam is reduced due to a smaller tide amplitude at neap tide. These results are supported by Figure 11A, C, and E, which show that after 5 days of simulation, the water temperature reaches a similar value at observation points near the Mickler's Dam, Six Mile, and Guana Dam. This value is maintained throughout the simulation, with minimal diel temperature fluctuations at Six Mile and Mickler's Dam. However, there are larger temperature oscillations at the Guana Dam, mainly due to the tide-induced fluxes entering the Lake.

The impact of tidal pumping at the Mickler's Dam on salinity is much smaller compared to the observed impact on water temperature (Figure 10). After a 30-day simulation, the Lake has not yet reached a steady state condition for water salinity (Figure 10D). The time series data presented in Figure 11 confirms these findings, except for the station located at Guana Dam (Figure 11F). At this station, an equilibrium salinity value, similar to that observed in the GTM estuary, is achieved after 5 days of simulation. At Mickler's Dam (Figure 11B), water salinity continues to decrease even after 30 days. Finally, at Six Mile Figure 11F, the influence of water entering the Lake from the two dams is negligible.

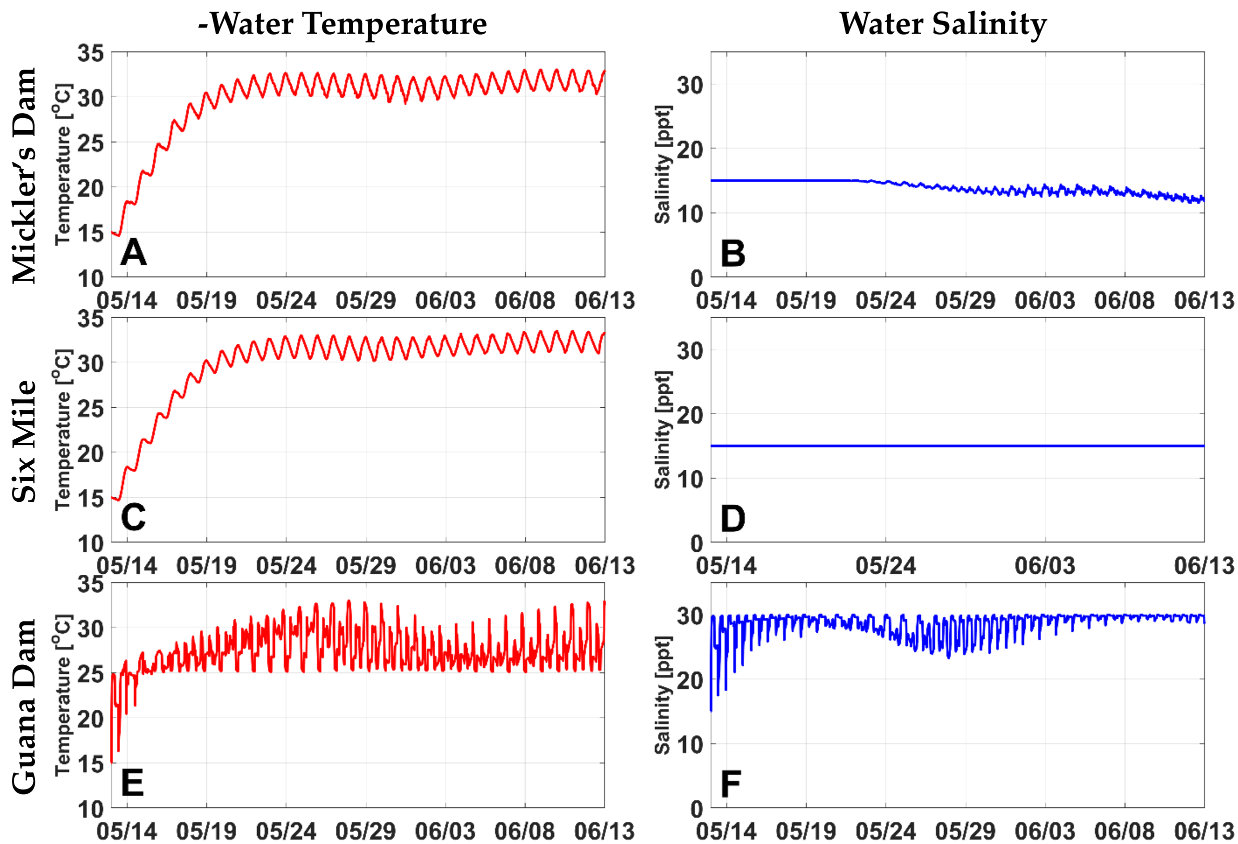

Figure 11. Evolution of the water temperature (left column: A, C, and E) and the water salinity (right column: B, D, and F) in the observation points located at the Mickler's Dam, Six Mile landing point, and Guana Dam (dots in Figure 1).

5. Limitations/Caveats

The following are the limitations we encountered during this project:

- The HYCAT GPS connection is prone to instability, which can result in delays during the survey and, in some cases, force the mission to be aborted if the connection cannot be restored.
- The HYCAT has a battery life of approximately 8 hours when cruising at 2 knots. At a faster speed of 8 knots, the battery life decreases to around 2 hours. This limitation becomes more significant when there is limited time available for a survey. However, it is important to note that data collection may be less precise at higher cruise speeds.
- The low cruise speed required by the HYCAT to maximize battery life and data acquisition accuracy caused overheating problems in the airboat we used to follow the HYCAT.
- The presence of thick seagrass in Guana Lake can affect measurements in several ways. First, it leads to an underestimation of water depth and an overestimation of

bed elevation. Second, it results in an overestimation of Chlorophyll-a and turbidity concentrations. The increase in turbidity is due to the seagrass repeatedly clogging the HYCAT, leading to local sediment resuspension and higher turbidity readings on the YSI EXO2. These errors are higher in the network of creeks in the northern part of the Lake where seagrass is more abundant.

- The repeated clogging of the HYCAT propellers by the submerged vegetation in the northern part of the lake has also caused survey delays.
- The Lake has numerous narrow channels where data collection was hampered. These channels pose a challenge for HYCAT navigation, as they are either too small for it to pass through or hinder the ability to follow it with mud boats or airboats. Although there are some larger channels where both HYCAT and accompanying boats can navigate, the presence of dense vegetation makes the surveys unfeasible. This is because, as indicated before, vegetation (i) causes the clogging of the HYCAT propellers, immobilizing them, and (ii) impedes the collection of correct bathymetric and water quality data.
- During this project phase, we have implemented a numerical model that allows for preliminary analysis of the variation in the water quality parameters in the Guana Lake. However, to effectively reproduce the Guana Lake dynamics, the model requires more precise boundary conditions. Data acquisition will be performed by using a combination of water pressure sensors and YSI instruments (see Section 6). Since part of the sensors were not available in this first part of the project, boundary conditions were simplified.
- Nitrogen samples collected along the Lake have been sent to the IFAS Lab. Lab results will be available soon.

6. Next Steps

During the next project phase, we aim to achieve the following objectives:

- Collect data on water level, water temperature, and water salinity at both the Guana Dam and the Mickler's Dam. To accomplish this, we will utilize a combination of water pressure loggers and YSI instruments.
- Define the geometry of the Guana Dam and the Mickler's Dam through direct surveys and/or technical drawings.
- Create rating curves for both Mickler’s Dam and the Guana Dam. These rating curves will be derived using discharge measured with the HYCAT, as well as using the water level and geometrical characteristics of the dam (see previous bullets). The purpose of these curves is to establish, for each dam, a relationship between the gradient of water

level at the two sides of the dam and the discharge through the dam. These will be the boundary conditions implemented in an improved version of the numerical model.

- Collect water quality data in different seasons, calibrate the model over the seasonal variation of the parameters, and assess how the seasonal dam functioning affects the water quality on the Lake.

By accomplishing these objectives, we can enhance the performance of the numerical model and ensure its effectiveness in reproducing the dynamics of the Guana Lake.

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