Guadalupe Bayou Flow and Inundation Study

Final Report

by

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PURSUANT TO SENATE BILL 1 AS APPROVED BY THE 83RD TEXAS LEGISLATURE, THIS STUDY REPORT WAS FUNDED FOR THE PURPOSE OF STUDYING ENVIRONMENTAL FLOW NEEDS FOR TEXAS RIVERS AND ESTUARIES AS PART OF THE ADAPTIVE MANAGEMENT PHASE OF THE SENATE BILL 3 PROCESS FOR ENVIRONMENTAL FLOWS ESTABLISHED BY THE 80TH TEXAS LEGISLATURE. THE VIEWS AND CONCLUSIONS EXPRESSED HEREIN ARE THOSE OF THE AUTHOR(S) AND DO NOT NECESSARILY REFLECT THE VIEWS OF THE TEXAS WATER DEVELOPMENT BOARD.

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Executive Summary

This report is the conclusion of one year of work of lidar analyses, field data collection, and modeling. The focus was improving our understanding of the relationships between flow and inundation in the bayou and canal system between Green Lake and Mission Lake.

The lidar analysis in this study provides a coherent and complete digital elevation model (DEM) at a 1 x 1 m resolution (approximately 3.3 x 3.3. ft) that can be used by other researchers, the GBRA, SAWS, or other members of the BBASC as they seek to better understand the behavior of the delta system. The key improvements over the prior DEM are: (1) the effects of water hyacinth have been removed, and (2) known and estimated bathymetry have been integrated into the "no-data" pixels that previously represented open water. Although the focus of the present work is on the bayous, the processing of the lidar data includes Green Lake and the full delta below the saltwater barrier in the Guadalupe River. However, it does not include the entire local catchment area for Green Lake or the further upstream segments of the San Antonio and Guadalupe Rivers; thus, the data set would require further extension if future larger-scale hydrological analyses are of interest.

The field study emplaced sensors at key locations to continuously record data (at 6 minute intervals) for water levels, temperature, and conductivity (salinity). Because of flooding during the installation of the field equipment, several of the planned sensor locations could not be safely reached, and we were unable to collect data in at critical locations in the bayous. Nevertheless, future analysis of the field data should provide insight into inundation within the delta and bayou.

The hydrodynamic modeling uses the data from the 1 x 1 m DEM produced in the lidar study to create a 15 x 15 m grid that is more practical for a hydrodynamic model. Note that working directly with the 1 x 1 m DEM in a hydrodynamic model possible, but not practical as it would require use of significant supercomputer time. The first-level calibration of the hydrodynamic model has been accomplished through bathymetric adjustments, which provide the correct connectivity of the streams within the bayous. Second-level calibration (for flows) has not been conducted as we lack sufficient data. The hydrodynamic model has been used to analyze likely inundation areas in the bayou associated with different flow rates through the Guadalupe River. Note that the analyzed scenarios do not reflect either actual or recommended operating conditions for the GBRA canal system. The scenarios were chosen based on input from the BBASC and to show how the connectivity in the bayous is affected by flow rates.

Because of the short time frame available for this study, the results provided should be considered preliminary and subject to future revision.

1 Introduction

1.1 Overview

This report presents the methods and results of the mapping, field work, and modeling of the Guadalupe bayou system. This study was recommended by the Guadalupe and San Antonio Basin and Bay Stakeholder Committee in early 2014, and funded by the State of Texas through the Texas Water Development Board with the contract signed 8/21/2014.

This study covers three complementary issues:

1. ***Inundation mapping***, which uses topographical analyses to estimate potential flooded areas as a function of elevation;

2. ***Hydrodynamic modeling***, which solves flow equations to estimate flooded areas as a function of flow rates;

3. ***Field data***, which can be analyzed in the future to better understand the bayou system and validate the models.

The time frame from contract to the writing of this report was less than 12 months, so for each task the study team focused on building the baseline models, methods, and data as specified by the contract. Exhaustive testing, evaluation, and applications are subjects for future work.

Figure 1. Drainage to Guadalupe River Delta

1.2 Study area

The Guadalupe River delta and estuary system provides the discharge of the Guadalupe River along the Gulf Coast in South Central Texas. The delta drains both the Guadalupe and San Antonio River basins into greater San Antonio Bay (Figure 1).

The delta is located about 20 miles southeast of Victoria, Texas, and 10 miles southwest of Port Lavaca (Figure 2). Although the entire system below the confluence of the San Antonio and Guadalupe

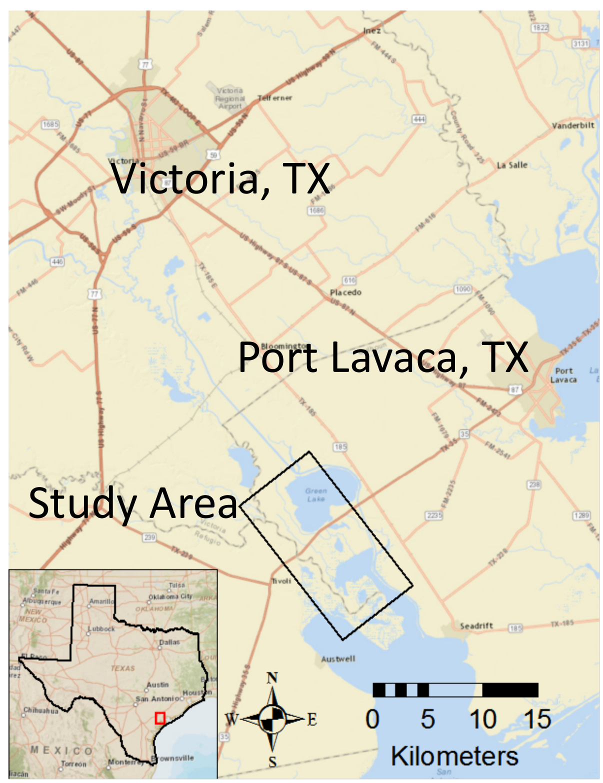

Figure 2. Study area along Gulf Coast

rivers is of interest for scientific, ecological, and water management reasons, the flows only through the bayou systems are the focus in the present study.

1.3 Canal system

Throughout the delta/bayou system, there are a number of artificial restrictions and channels that modify natural flows. A system of gates, canals, natural bayous, and siphons provides the upstream portion of the Guadalupe Blanco River Authority (GBRA) Calhoun Canal System, which was designed to transport fresh water from the Guadalupe River to Calhoun County for municipal, industrial, and agricultural use[1]. The locations of key artificial structures are shown in Figure 3.

Fresh water flow in the canal system is diverted from the Guadalupe River through the upper diversion canal starting about 150 yards upstream of the GBRA salt barrier. The salt barrier consists of two inflatable bladders that extend across the width of river. Inflation of the bladders prevents upstream salt migration in the Guadalupe River and allows the canal system to deliver fresh water to Calhoun County under low flow conditions.

The upper diversion canal is 0.9 miles in length, with artificial embankments that isolate the furthest upstream portion of Schwings Bayou (0.3 miles in length) so that the canal can connect directly with Hog Bayou to the northeast. The canal flow is controlled by a gate adjacent to the canal's connection to the Guadalupe River. This gate is operated by GBRA based on contracts with water users in the Calhoun Canal System. Water exiting the diversion canal flows southeasterly within the natural confines of Hog Bayou. The flow is split into two paths where the bayou joins with the upstream end of another diversion canal. The junction (without control structures) is approximately 3.2 miles upstream from Hog Bayou's terminus in Mission Lake. A second canal, starting at this junction, runs parallel to Texas Highway 35 (TX-35) and discharges into the upstream end of Goff Bayou. From there, water is siphoned under the Victoria Barge Canal for users to the east in Calhoun County. As the users require fresh rather than brackish water, control gates have been installed in the bayous and are operated by GBRA to prevent upstream salt water migration.

[1] Guadalupe-Blanco River Authority : Water Resource Division. (n.d.). Retrieved July 31, 2015, from http://www.gbra.org/operations/waterresource.aspx

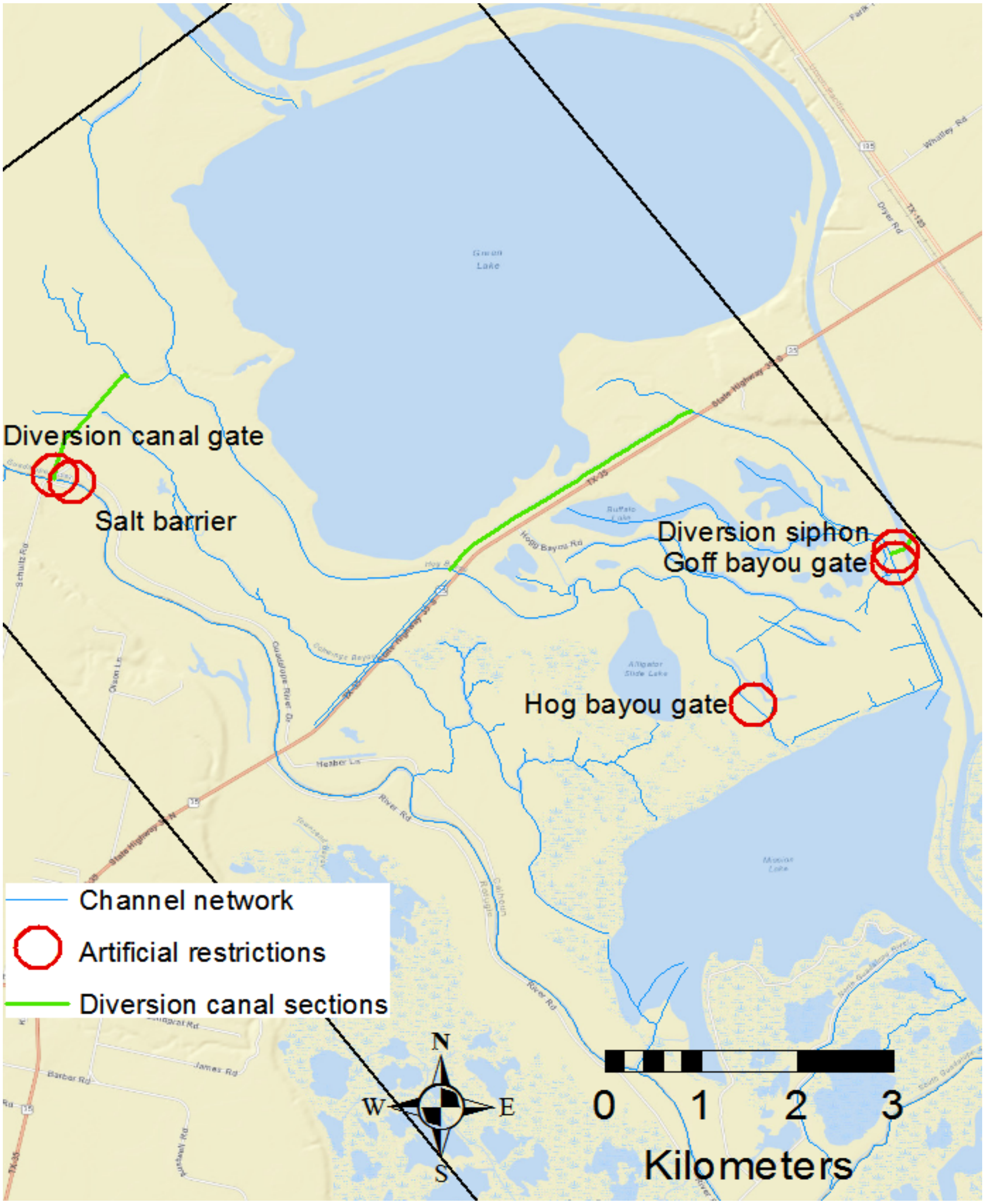

Figure 3. Channels, restrictions and control structures.

1.4 Bayou system

The present study focuses on the four bayou systems bounded by (clockwise from north in Figure 4) Green Lake, Victoria Barge Canal, Mission Lake, and the Guadalupe River south of the salt barrier. From west to east along the shore of Mission Lake the bayous are named Schwings, Mamie, Hog, and Goff**.** Schwings and Mamie bayous are tidally influenced as they connect without control structures to Mission Lake. The Guadalupe River diversion canal isolates the northern end of Schwings Bayou (except during major floods), which likely changes the hydrological connections and fate of local rainfall runoff in the upper reaches. The lower reaches of Schwings Bayou have a flow connection with the lower Guadalupe River through a culvert and a slough south of TX-35 beneath River Road.

Hog Bayou extends from the northwestern edge of Green Lake, down along the lake's southwestern edge, and has its terminus at Mission Lake after passing north and east of Alligator Slide Lake. Although the connection between Hog Bayou and TX-35 diversion canal is about 3.2 miles upstream, the control gate to prevent saltwater migration is installed only 0.3 miles upstream from Mission Lake. As a result, the only flow in Hog Bayou south of the junction with the TX-35 diversion canal is (1) during high-water flows into Alligator Slide Lake, (2) when the gate to Mission Lake is open, or (3) during flood events.

During high water, Hog Bayou can overflow across a road and into Alligator Slide Lake. The lake contains visible terraces constructed to minimize wind waves, thereby promoting waterfowl habitation. The lake is tidally influenced as it is fed by and drained through Mamie Bayou. However, this connection is narrow and convoluted, which limits potential tidal exchange.

Goff Bayou is separated from the western edge of the Victoria Barge Canal by relatively high embankments. At its upstream end, the bayou connects to the downstream end of the TX-35 diversion canal. Goff Bayou is artificially separated into marine and freshwater sections by gates that are slightly downstream from the siphon under the Victoria Barge Canal, which connects to canals in Calhoun County to the east.

Buffalo Lake and smaller unnamed ponds lie between Goff and Hog bayous, south of TX-35. It appears that these water bodies were once part of the Goff Bayou system, but have been separated from it by small control structures, roads, and embankments. These lakes appear to have minor pathways connecting directly to Mission Lake, but do not appear to be tidally-influenced given the amount of vegetation, the narrowness of the connections, and the relatively small tidal range of Mission Lake. Based on modeling in this report, freshwater connections between Goff Bayou and the Buffalo Lake system appear to be active only with higher water levels.

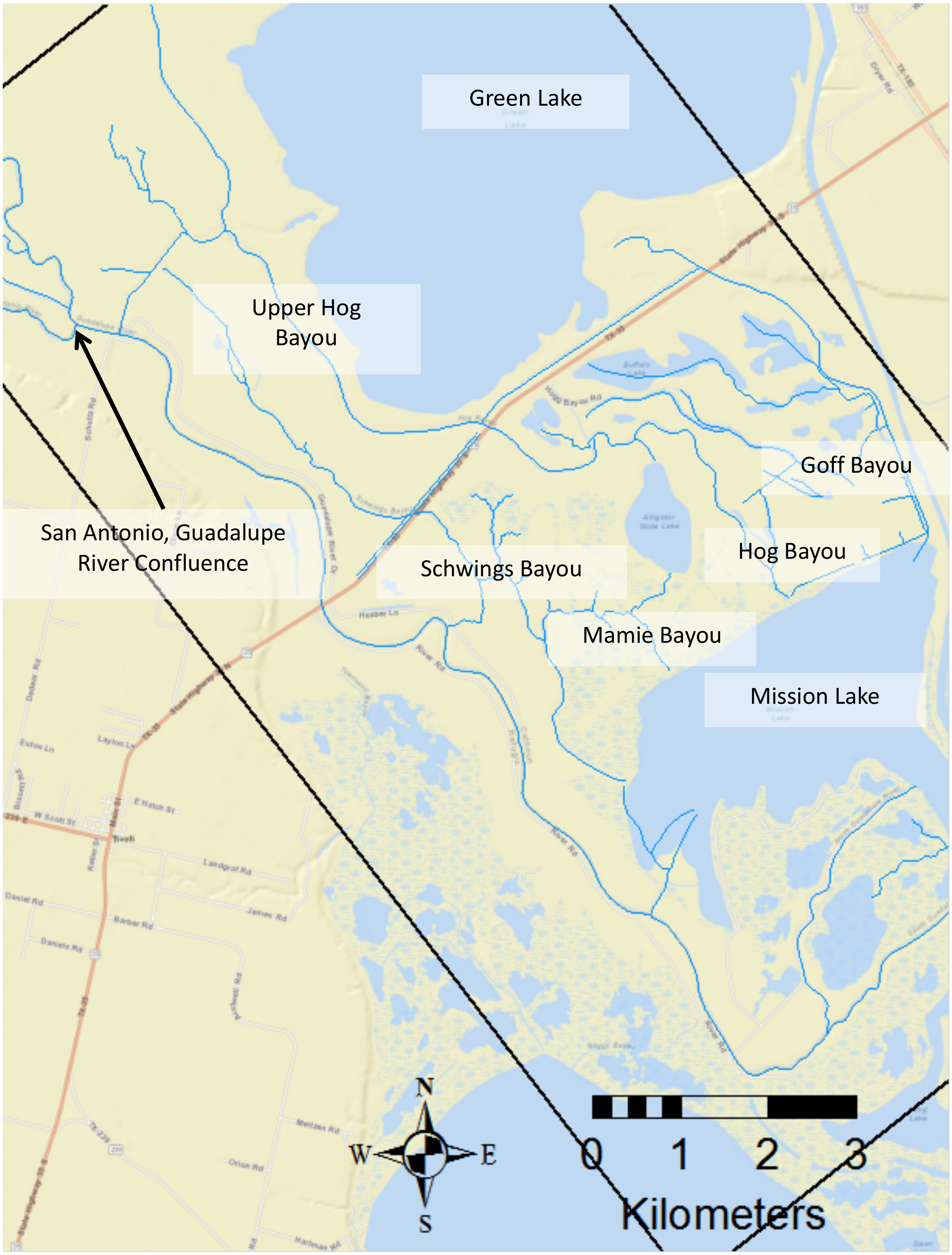

Figure 4. Bayous that are the focus of the present study.

1.5 Guadalupe Delta Wilderness Management Area

The Guadalupe Delta Wilderness Management Area (WMA) Mission Lake unit (Figure 5) covers a large portion of the study area, extending from the eastern shore of Schwings bayou to the Victoria Barge Canal and bordered to the north and south by TX-35 and Mission Lake. The WMA is operated by the Texas Parks and Wildlife Department and is open to the public during the week for hunting and other outdoor activities.

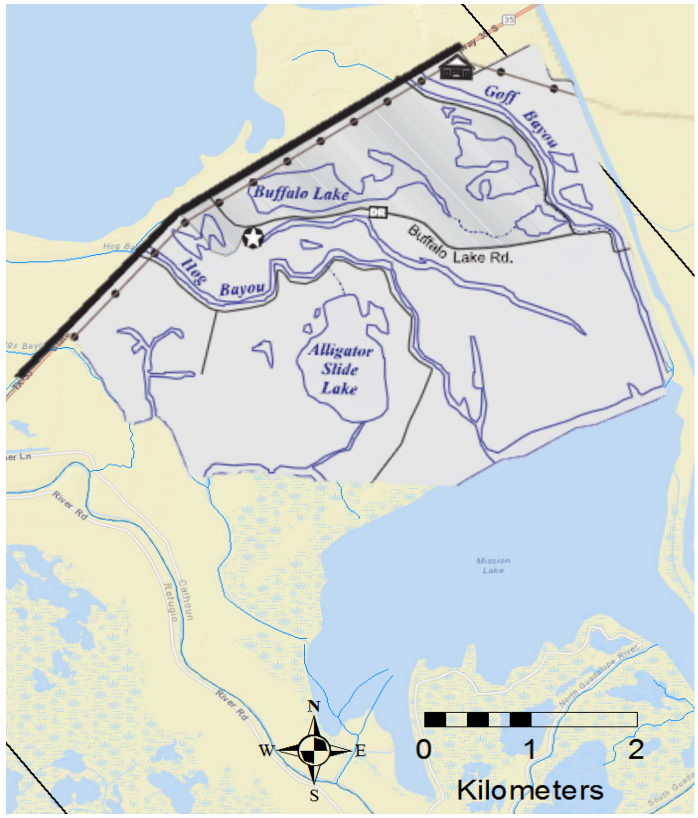

Figure 5. TPWD Guadalupe Delta WMA, Mission Lake Unit

1.6 Water hyacinth

Persistent in the area is the invasive species water hyacinth (*Eochhornia crassipes*). Originating in the Amazon Basin, water hyacinth is a floating aquatic plant that can choke off bayou flow and clog waterways. Periodically, the GBRA sprays the hyacinth with a herbicide to control the plant growth. When unchecked, the hyacinth can completely blanket waterways. The presence of water hyacinth causes problems in interpreting remotely sensed data and boating in the waterways. Figure 6 shows the diversion canal along TX 35 in January of 2013 before herbicide application and near the same location after herbicide application in November of 2014.

Figure 6. TX 35 diversion canal choked by water hyacinth in 2013 and after herbicide application in 2014. Circled in red is a public boat ramp. Photographs by the authors.

1.7 Study objectives

The primary objectives of this study were :

1) ***Inundation Mapping:*** perform an analysis of system connectivity at different inundation depths from the available topographic lidar and process the dataset for model input.

2) ***Field Study:*** execute a series of field campaigns to gather system temperature, depth, and conductivity readings for future model validation.

3) ***Hydrodynamic Model Development:*** create the Guadalupe Bayou Hydrodynamic Model (GBHM) and validate using available data.

1.8 Organization of this report

This report provides documentation of the study methodology and results. The techniques developed for processing the lidar dataset, methods for gathering the field data, and steps taken to model the hydrodynamic flows through the system are outlined in §2. The results of this work are summarized and discussed in §3. Associated appendices at the end of the report further detail of methodologies and results.

2 Methodology overview

2.1 Introduction

This section provides a synopsis of the methods used for each study objective. Detail on the methods are provided in the appendices of this report.

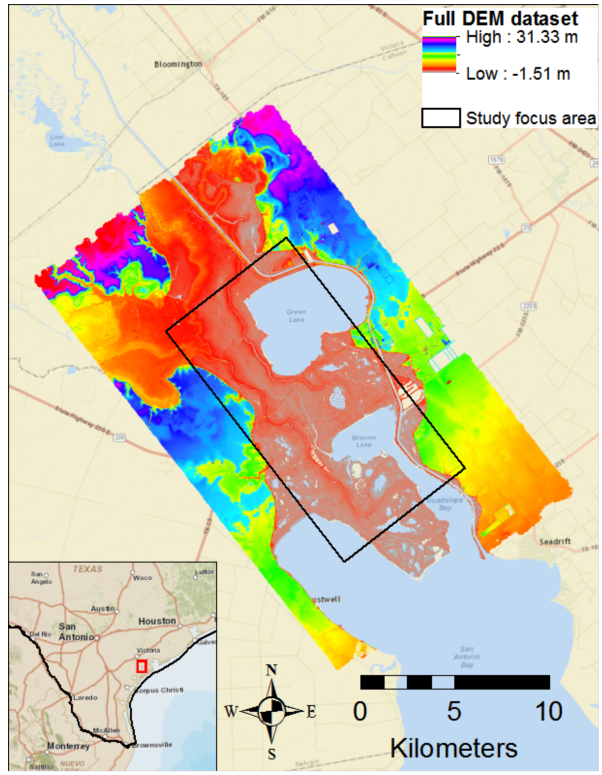

Figure 7. UT-BEG developed airborne lidar based DEM. Study area is boxed in black.

The foundational data for mapping and modeling in this study is the lidar data previously collected over the bayou area (Figure 7). Lidar is a sophisticated method for collecting high-resolution topographical information, commonly using an airborne laser system. Raw lidar data consists of billions of data points that must be processed into a Digital Elevation Model (DEM) for practical use. The present study uses data from an airborne topographic lidar mission that was flown January 17-19, 2013. The data were subsequently analyzed and processed to 1 m resolution by the University of Texas Bureau of Economic Geology (UT-BEG). The DEM from UT-BEG uses the North American Vertical Datum of 1988 (NAVD88) and is accurate to roughly 5 cm. The total dataset is approximately 375 square kilometers (i.e. 375 million data points, or pixels, at 1 m resolution).

The focus of this study is on the area outlined in black in Figure 7, which consists of approximately 150 million data points at 1 x 1 m resolution. These data were directly used for the inundation mapping. The data were processed to a coarser 15 x 15 m resolution for hydrodynamic modeling with more than 570,000 grid cells.

2.2 Lidar processing

Inundation mapping and hydrodynamic modeling both require DEMs for the entire landscape, including submerged portions. The UT-BEG 1x1 m lidar DEM cannot be directly used for either purpose due to (1) *no-data* pixels in locations with open water, and (2) *false-data* pixels where water hyacinth obscures water-filled channels. That is, the lidar system used for the Guadalupe lidar mission does not receive any return from open water (no-data) while those areas covered with water hyacinth actually provide lidar returns (false-data) that do not represent the bottom of the channel.

Our DEM analyses used a modified version of a river network extraction toolbox developed by Passalacqua et al (2010)[2]. Water channels obscured by vegetation within the dataset were identified, digitized, and removed so that the hyacinth-covered areas appeared as open water (no-data) in a modified DEM. The open-water areas were merged with available bathymetric data to develop a DEM that included elevations of areas submerged during the lidar overflight. Comprehensive data for the submerged channels are not available for the entire study area. However, detailed bathymetry for portions of the lower Guadalupe River were available from a HEC-RAS model developed by the GBRA. Additionally a GBRA survey of the diversion canal system from above the salt barrier across to Goff Bayou provided bathymetric data for the principal flow paths of the canal system. For Mission Lake, bathymetric data originating from a UT storm surge model was provided by the TWDB from their modeling systems. In other areas we used estimates based on nearby data and scientific judgment. It was not possible to conduct a comprehensive bathymetric survey within the time available for the field work in this study. A detailed description of the lidar processing methodology is provided in Appendix A

2.3 Inundation mapping

Inundation mapping requires a baseline water surface elevation map for the entire the study area. That is, the water surface has gradients across the landscape, which need to be known or estimated to obtain a reasonable picture of inundated areas without recourse to a hydrodynamic model. As there are only two water surface elevation gages in the area (both along the Guadalupe River) it is not possible to build an inundation map from measured historical data. Instead, we used the lidar data to identify the land-water interface along each stream reach. These data were interpolated across the landscape to provide the measured water surface at the time of the lidar overflight. This baseline water surface elevation was then incremented to different levels to produce inundation maps. Further details on inundation mapping methods are provided in Appendix B

2.4 Field campaigns

A series of four field excursions were performed to install sensors to gather data for model validation. Measurements of absolute pressure in air and water, water temperature, and water conductivity were recorded every six minutes by a set of sensors installed throughout the bayou system. The initial field campaign (Nov. 21, 2014) consisted of an area reconnaissance to evaluate feasible sites for sensor installation. A total of 14 sensors were installed during the second field campaign (Mar. 18-20, 2015). The third campaign (May 19-22, 2015) was to collect data from installed sensors, then reset and redeploy the sensors for ongoing data collection. At this time, three new sensors were installed. A final field campaign (Aug. 2015) will collect all the deployed sensors for final data recovery. A detailed description of sensor installation equipment, methods, and locations is available in Appendix C. The field campaign was smaller than originally planned for several reasons: (1) gaining property access, which

[2] Passalacqua, P., T. Do Trung, E. Foufoula-Georgiou, G. Sapiro, and W. E. Dietrich (2010), A geometric framework for channel network extraction from lidar: Nonlinear diffusion and geodesic paths, J. Geophys. Res., 115, F01002, doi:10.1029/2009JF001254.

delayed the initial field work, (2) greater difficulty in deploying instruments than originally envisioned, and (3) extraordinary weather that hampered much of the planned spring field studies as it was simply unsafe to be on the water during flooding. The field campaign was reduced in the following ways: (1) we were unable to conduct a river bathymetric survey, (2) the number of water level sensors was significantly reduced, and (3) the locations of the sensors was limited. Because the field program was reduced below the original scope of work, unexpended funds were returned to the State of Texas.

2.5 Hydrodynamic modeling

The **Guadalupe Bayou Hydrodynamic Model** (GBHM) was developed using the Fine Resolution Environmental Hydrodynamics (Frehd) code, which was previously used to develop the Nueces Delta Hydrodynamics Model (NDHM)[3]. For the GBHM, the Frehd code was applied as a two-dimensional (2D) depth-averaged solution of the hydrostatic Navier-Stokes equations – commonly known as the shallow water equations. The model was created using a set of Cartesian (square) grid cells with 15 x 15 m resolution (approximately 50 x 50 ft). The baseline model time step was 60 seconds, with subtime-stepping protocols used as needed for model stability during high flow conditions. With this grid resolution and time step, the model typically can run at about 5 to 7 times faster than real time on a desktop workstation (i.e. 1 day of computer time to compute 1 week of simulated bayou flows). With a multiprocessor computer and 64 GB of memory, it is possible to run 7 simulations at the same time on a single machine. Using the 15 x 15 m grid was selection as a compromise between model speed and accuracy. We tested grid resolutions of 5 x 5 m and 10 x 10 m, but these resolutions required model time steps of 20 s and 40 s, respectively, and led to model run times that were slower than real time (i.e. more than 1 day of computer time to simulate 1 day of bayou flows).

The GBHM includes all the capabilities of its predecessor, the NDHM, which includes modules for simulation of tidal flooding, rainfall, river flooding, and wind-driven flows. However, the scope of the present study did not allow all of the modules within the GBHM to be tested and analyzed.

The key task in model development was creating a bathymetric DEM at a coarser grid scale (15 x 15 m) that represents the connectivity, flow paths, embankment blocking, and inundation areas within the bayou system. The differences between the fine and coarser resolutions are small, as shown in Figure 8. However, small channels (less than 15 m wide) must be made wider at the coarse grid scale to provide flow paths through grid cell center. Conversely, embankments narrower than 15 m are represented as thin blocking features along grid cell edges[4]. The first-level calibration of the model consisted of checking flow paths and blockage to provide system connectivity. The widening of the channels to maintain connectivity has the side effect of allowing water to flow more quickly through the channels than would occur in the real system. In a second-level calibration (not within the scope of the present

[3] A.J. Ryan and B.R. Hodges , *Modeling Hydrodynamic Fluxes in the Nueces River Delta*. Center for Research in Water Resources, University of Texas at Austin, CRWR Online Report 11-07, 92 pages, October 2011. http://www.crwr.utexas.edu/online.shtml

[4] B.R. Hodges, "Representing hydrodynamically-important blocking features in coastal or riverine lidar topography," *Natural Hazards and Earth System Sciences*, 15:1011-1023, May 2015. http://dx.doi.org/10.5194/nhess-15-1011-2015

study), the channel roughness will need to be artificially increased so as to correctly represent the slower flow in narrower channels.

The topographic model of the Guadalupe bayous we developed through lidar analysis does not include depths in the channels where there was water during the lidar survey. These depths were estimated in the model based on observations of typical depths during the field campaign. The impact of this issue is complicated by the artificial widening of channels (discussed above) to the minimum 15 m of the model grid. It is well understood that the flow in any channel is a function of the width, depth, roughness, and the driving water-surface elevation gradient. In the main stem of a river, where water surface elevation gradients are relatively large, the interplay between width, depth and roughness is crucial to getting the correct relationship between water surface elevation and flow rate. However, over a flat landscape such as the Guadalupe bayous, the water surface elevation gradient is extremely small because the water elevation and flow rates are principally controlled by a few choke points – constrictions such as the gates at the bottom of Goff and Hog bayous, and the saltwater barrier in the Guadalupe River. Channel velocities are very small, and the dynamics associated with friction (bottom roughness) and the flow rate are weak. Thus, the overall inundation does not have a strong response to the cross-sectional area and roughness, but instead to the channel connectivity. The net result of these effects is that the model results should be used with caution and the flow rates considered qualitative rather than quantitative indications of the behavior.

There are several limitations to the present GBHM:

1. With existing data and computational power it was not practical to include the entire upstream catchment and Green Lake within the GBHM. Thus, many of the flow paths and water sources for flood events are not included in the model.

2. The GBHM includes neither the exchange of surface water with groundwater nor groundwater transport paths through the bayous. Thus, groundwater flow paths that maintain isolated low areas as marshes or ponds are not represented.

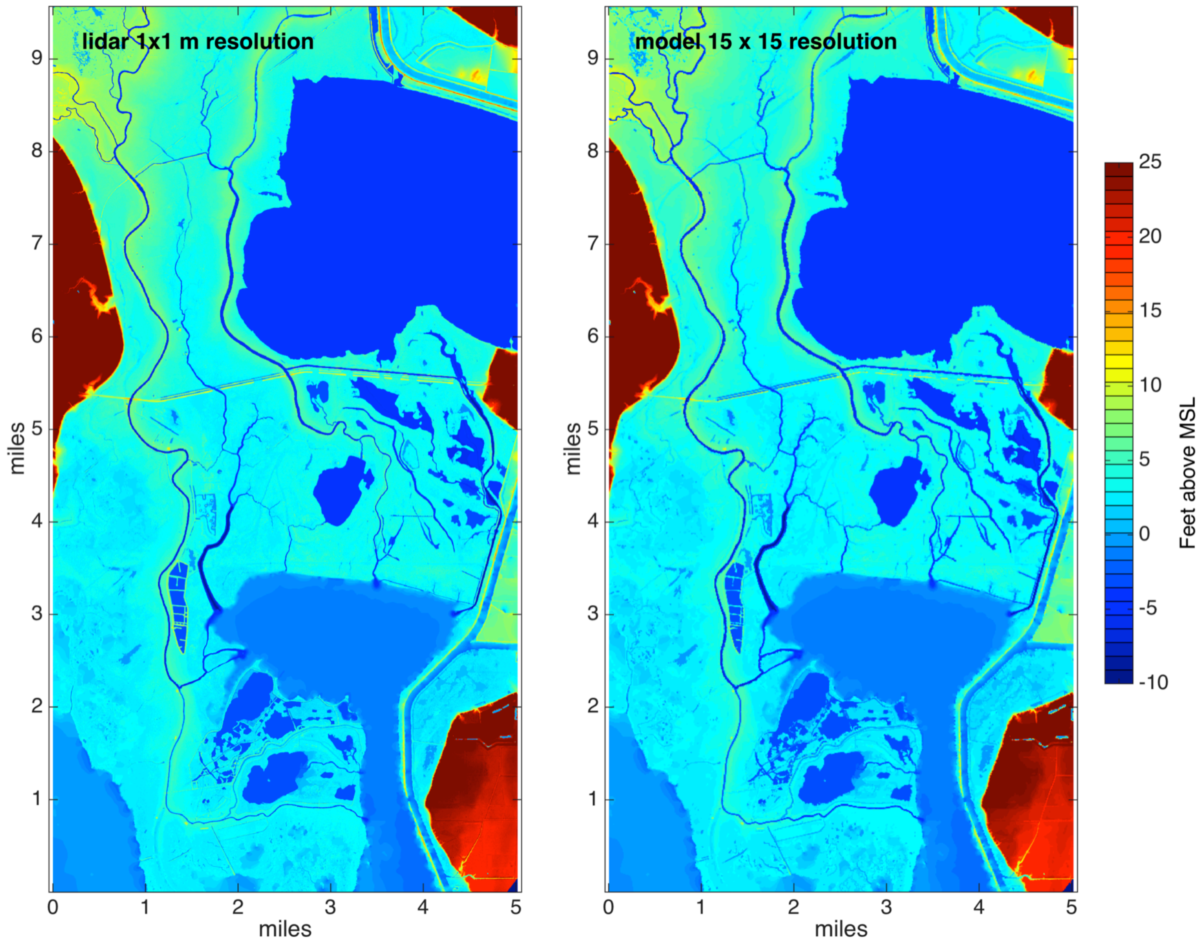

Figure 8. Guadalupe Bayou lidar DEM (1 x 1 m resolution) and model bathymetry (15 x 15 m resolution)

3. Important pieces of the water budget are not included: (1) water supply by rainfall, (2) losses due to evaporation, and (3) freshwater demands from Calhoun County. The Frehd code is capable of representing these within existing sub-models (assuming sufficient data is available). However the increased complexity of adding these features to the GBHM could not be addressed within the scope of the present project.

4. The hydrodynamic model does not (at this time) have accurate representation of any of the hydraulic gates in the bayous. The model is capable of representing these gates and their operation, but further data will be needed from GBRA to include these within the model.

As a result of the above limitations, the GBHM is *not* a predictive tool for the precise behavior of the bayous. Instead, the model is a comparative tool that shows the likely scales of different effects. For example, with the available data we cannot *quantitatively* assess the model accuracy in predicting inundation at 140 cfs flow in the Guadalupe river. However, a comparison of the modeled inundation at 140, 280, 560 cfs (etc.) provides *qualitative* insight as to the scales of increased inundation with increasing flow rate.

3 Results and discussion overview

3.1 Inundation mapping

Figure 9 shows a sample inundation map with water level increases of 1-2 ft. These inundations represent the static rise from the interpolated water surface level of the lidar data, where such rise includes connected pathways within the 1 x 1 m lidar DEM. This approach does not account for water flow dynamics, which require a hydrodynamic model. However, the inundated areas are path-limited to those with flooded connections to either the Guadalupe River or Mission Lake. For example, Green Lake is not affected by a 1-ft level rise because it is not connected to the river (within the study area) or diversion canal system at that inundation level. However, a 2-ft inundation level affects Green Lake through connections to Goff Bayou and along the northern edge of the TX-35 diversion canal.

With a 1-ft water level increase, the inundation is mostly limited to small regions bordering the baseline flooded areas near Goff Bayou and Buffalo Lake. The 2-ft increase leads to substantially increased inundation, including almost complete coverage of the Buffalo Lake area and most of the landscape between Hog and Goff bayous. Likewise, large areas of northern Hog Bayou and central Schwings Bayou become inundated.

In addition to Goff Bayou and the TX-35 diversion canal reaching Greek Lake, another important connection is established between the 1 ft and 2 ft inundation increments. Between these levels, the diversion canal connecting the Guadalupe River to upper Hog Bayou will overbank into Schwings Bayou, which creates direct connections to Mission Lake; however, the flow rates that are needed for this level of inundation would likely prevent any upstream salt intrusion.

Figure 9 shows there is little inundation directly along the banks of the Guadalupe River at the 2 ft inundation level. The river banks are fairly high through this section, so fluctuations of less than 2 ft are within the typical annual tidal range and are not expected to cause flooding. However, some minor flooding connections might have been missed in the lidar processing. The water hyacinth effects are removed from the dataset through a process that estimates bank locations based on slope maxima. It is possible that narrow cuts through a bank of only one or two pixels (1 or 2 m) can be lost. Such lost pixels could represent minor connections that allow inundation at lower elevations.

Further details on inundation mapping are provided in Appendix B.

Figure 9. Inundation levels of 1-2 ft above base estimated water level

3.2 Field work

Figure 10 shows the layout of sensors deployed in the field study. Figures 11 and 12 provide a portion of the data collected. It might be noted that no sensors were deployed within the eastern bayous. Our original plan included placing several sensors in Goff and Hog bayous, but weather, water, and terrain conditions prevented us from obtaining safe access. As this report is being written, the sensors remain in place so that the maximum amount of data can be collected. The final data report will be provided as an addendum.

Within the scope of this project, it was not possible to make a vertical benchmark survey of the water sensors, thus the precise water level relationships between different sensors is unknown. The sensors were installed approximately 18 inches above the channel bottoms, so these data can be analyzed in terms of channel depths.

In Figure 11, the daily tidal variability is apparent in sensors on the lower Guadalupe River (lGuanN, mGuadS) and Schwings Bayou (schN, schS). The daily tidal signature in the northern Schwings Bayou sensor (schN) is suppressed during the high flow period from 4/21/2015 to 5/4/2015. Sensors in the controlled sections upstream of gates – including Hog Bayou (nHogS) and upstream of the salt water barrier (salDiv, salN) – do not show daily fluctuations, but instead water levels that are affected by combination of the Guadalupe River flow and the gate operations.

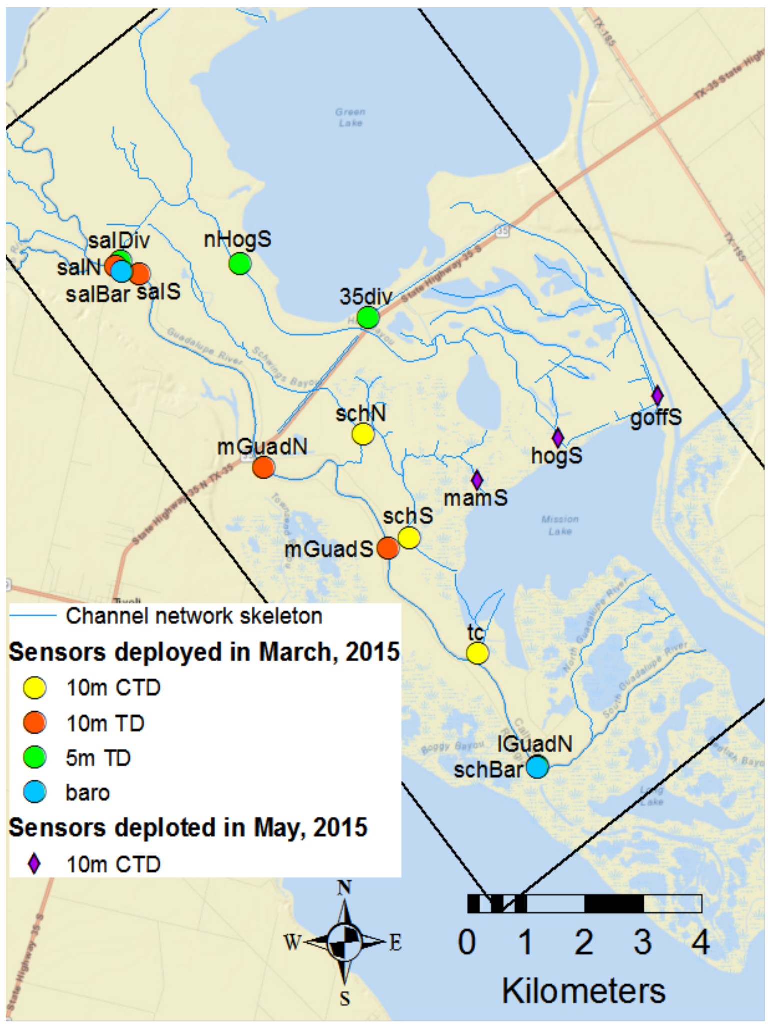

Figure 10. Sensors deployed during course of study

The upstream Guadalupe River sensor (salN) water levels can be compared to the USGS gages near the salt barrier (Figure 12). The overall behavior is similar. The offset in the measured value reflects the installation of salN with the zero datum 18 inches above the local channel bottom, whereas the USGS gages use a different zero datum.

Because of the compressed timeline of the project, it was not possible to conduct detailed analyses of the field data. Further details from the field study are available in Appendix C.

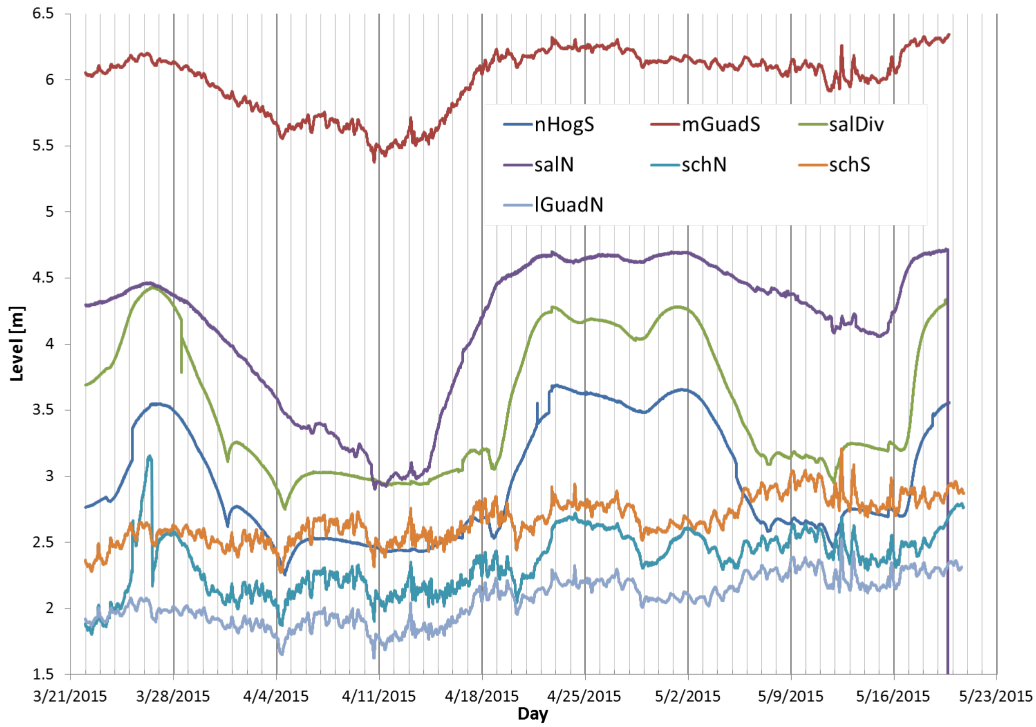

Figure 11. Water level data retrieved during May 23, 2015 field campaign.

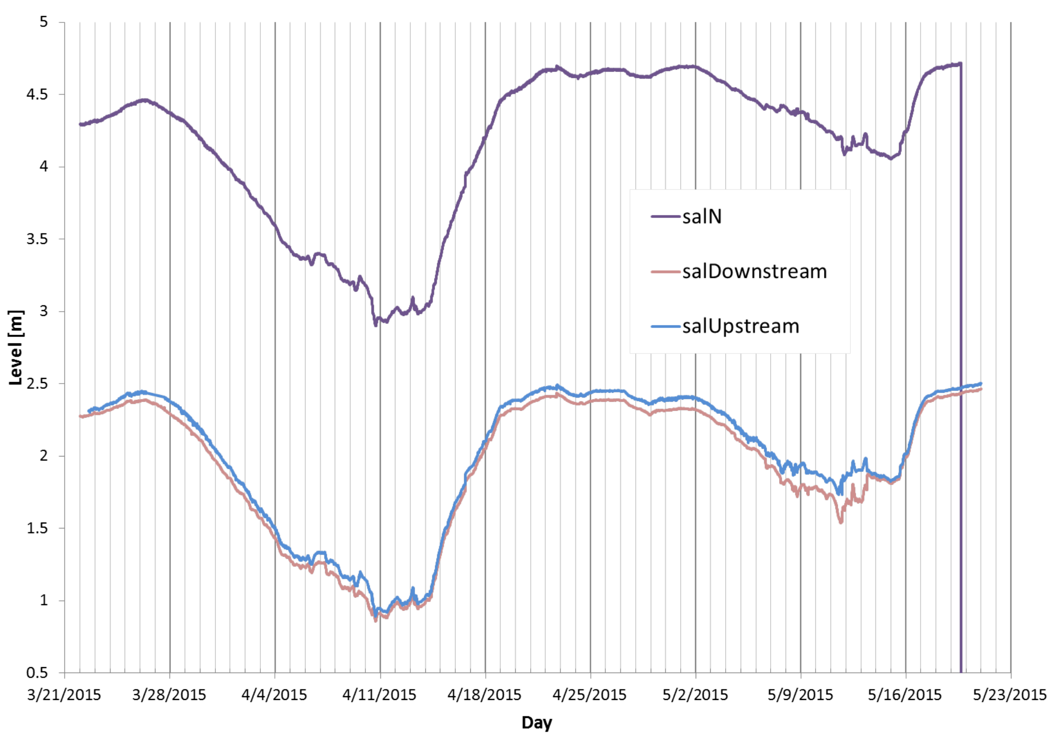

Figure 12. Comparison of water level data collected upstream of salt water barrier (salN) and USGS gages upstream (salUpstream) and downstream (salDownstream) of the barrier.

3.3 Hydrodynamic model (GBHM)

Table 1. Model cases: inflow rates from the Guadalupe River

Flow rates
140 cfs
280 cfs
560 cfs
1120 cfs
1680 cfs
2800 cfs

The GBHM was run for Guadalupe River flow rates shown in Table 1. This covers the range of values discussed in a telephone conversation with several members of the BBASC on 6/18/2015. The value of 280 cfs represents 50,000 ac-ft delivered over a 3 month period, which is considered a low flow condition. The 140 cfs test is used to provide a reference as to the sensitivity of the results at low flow conditions. The 2800 cfs test case represents flood conditions.

The test cases are designed to provide insight into the connectivity and maximum possible inundation of the bayou system and are *not* intended to represent either an actual operating condition or a recommended operating condition. All these tests are with the gates at Hog Bayou and Goff Bayou completely closed, unrestricted flow through the upper diversion canal, the salt water barrier completely inflated, and no water diverted to Calhoun County canals. Thus, these scenarios represents the maximum possible diversion of water from the main stem of the Guadalupe River into the bayous through the canal system. The maximum inundation of the bayou system is achieved by modeling the Hog and Goff bayou gates as closed. Each model was run for 14,440 time steps, which provides simulations of 10 days with constant inflow.

To visualize the model results, we included two tracers in the model that represent: (1) initial bayou water, i.e. an *Initial Tracer,* and (2) inflowing water from the Guadalupe River, i.e. an *Inflow Tracer*. These tracers show the transport of water over the course of the simulation. Each tracer is modeled as a relative concentration from 0 to 1.0. The *Initial Tracer* has a value of 1.0 everywhere in the bayous at the start of the simulation. This can be thought of as providing a dye concentration to the water. Inflowing water from the river has a *Initial Tracer* value of 0.0 throughout the simulation; thus, the value of the Initial Tracer in a grid cell is the fraction of water that was originally within the bayous at the start of the simulation. Conversely, the *Inflow Tracer* has a value of 0.0 everywhere at the start of the simulation and has a value of 1.0 in the inflowing water. Thus, the *Inflow Tracer* in a grid cell represents the fraction of the water that originated in the river inflow. This approach allows us to see how inflowing water displaces water that is initially in the bayous.

For example, the 280 cfs case is shown in Figure 13. Although the salt water barrier is fully inflated, the Guadalupe River inflow over the top of the barrier is sufficient to push inflowing water into the lower Guadalupe, but not all the way to Mission Lake during the 10 day period. The water level backup caused by the salt barrier is sufficient to allow inflowing water to push over the top of the gate at Hog Bayou, leading to flow into Mission Lake through this path. However, this flow appears greater than we expected at this flow rate, so further analysis is required to confirm that the model is correctly representing the water surface elevations and fluxes over the top of the gates at the mouth of Hog Bayou. At Goff Bayou, the gates are not overtopped, but flooding connections in flat areas to the west of the bayou provide a path for water to bypass the gates and reach the lower (saline) section of Goff Bayou. The new inflow into Goff Bayou pushes water to the west and northwest out of Goff Bayou, as shown by the initial tracer, providing increased inundation in the Buffalo Lake area. The Guadalupe River flow does not significantly impact Schwings Bayou. There is some flow into Alligator Slide Lake over the upstream blockage, but the flushing rate is relatively slow.

Figure 13 illustrates the fundamental connectivity within the bayous with the main stem of the Guadalupe River without overbanking flows and the importance of the diversion canals. It can be seen that the *Inflow Tracer* reaches upper Hog Bayou only through the upper diversion canal, without any connections through Schwings Bayou. Similarly, the *Inflow Tracer* shows the connection to Goff Bayou through the diversion canal south of Green Lake. We see the *Inflow Tracer* reaching lower Hog Bayou as well as through Alligator Slide Lake and Mamie Bayou as a result of the connections of upper Hog Bayou to the river through the upper diversion canal. The *Initial Tracer* shows that the lower reaches of Schwings Bayou are tidally flushed, but there are no significant intrusions of river water at the 280 cfs inflow rate. Figures illustrating the tracers for a range of flow rates (see Appendix D) show that for any flow rates less than 1120 cfs there is neither significant overbanking nor channel connections to Schwings Bayou, and the distribution of flow is dominated by the diversion canals for 10 days of flow. Note that these simulations are artificial in that the hydraulic gates are not modeled, so flooding that would be caused by the constriction of the gates at the end of Goff and Hogg Bayous is not represented. As a note of caution, these results should be interpreted qualitatively rather than quantitatively; that is, the model indicates that there are some low-to-moderate flow rates for which inflow water reaches Hog and Goff Bayou but not Schwings bayou, and there are higher flow rates where all the bayous will be reached. The exact flow rate where such transitions occur cannot be predicted by the model, but the general behavior should follow the patterns illustrated.

Further detail on the model and results is provided in Appendix D.

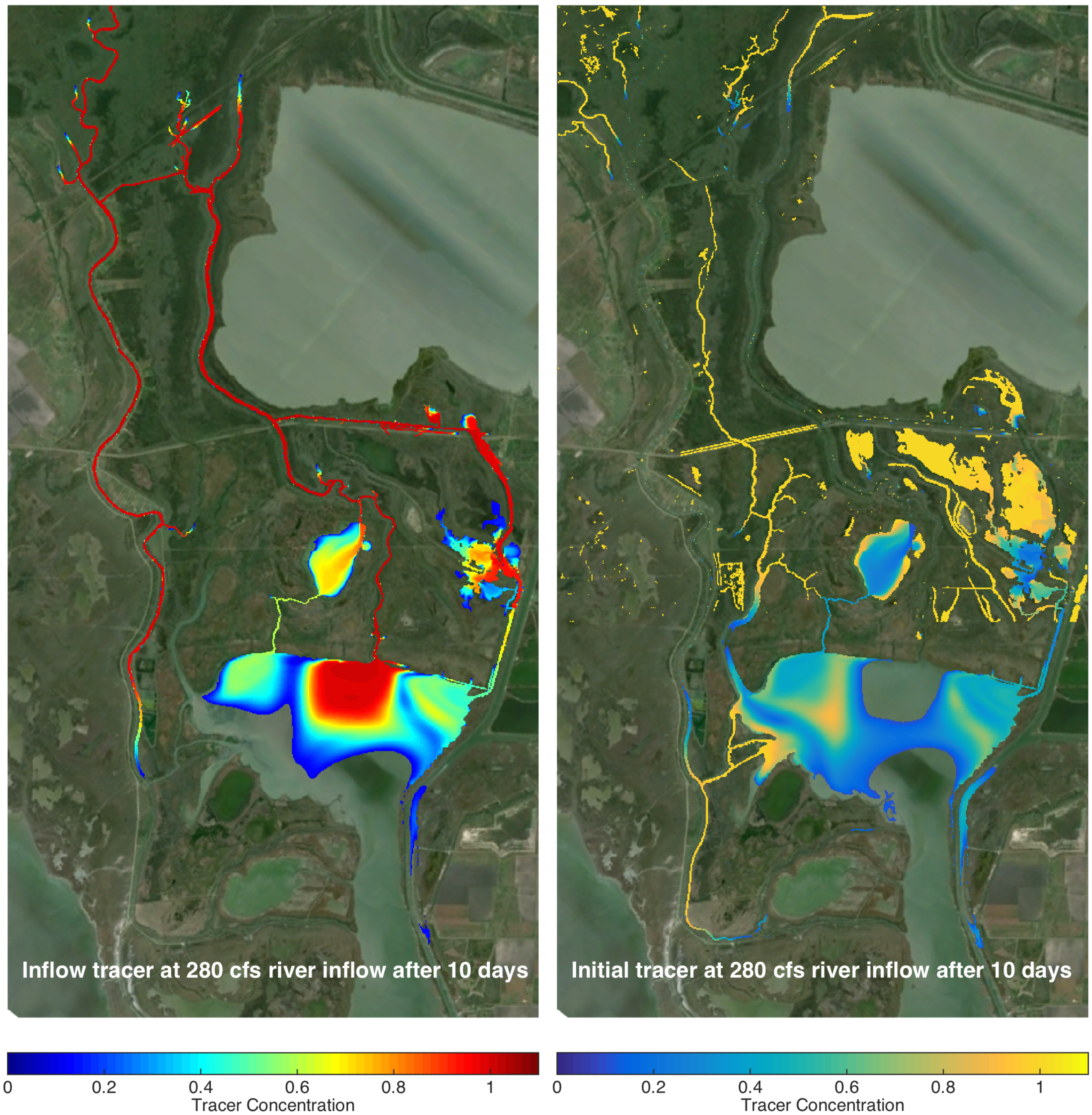

Figure 13. Inflow (left) and Initial (right) tracers after 10 days of simulation at 280 cfs. Note that the colormap for these figures extends beyond the [0,1] range of tracer concentrations for better contrast with the satellite image.

4 Summary

The key insight to draw from this study is that the water levels and inundation within the bayou can be artificially controlled through the combination of the saltwater barrier, the canal system, and gates that have been installed within the bayou system. Whether or not this is a good idea cannot be discerned from the present work. The overall bayou system has been significantly modified from its natural state through the connectivity of the diversion canals. We did not develop a “natural state” model with the gates and canals removed; however, it is clear from the connectivity of the system that without these canal features the bayous would function independently from the flow in the Guadalupe River. That is, the *only* significant direct channel connections between Goff and Hog bayous and the Guadalupe River are the diversion canals.

This project provides fundamental building blocks for increasing our understanding of the bayou and the delta in the future. The high resolution (1 x 1 m) DEM and the baseline water surface elevation map can be used to quickly look at more detailed questions about connectivity and water levels. Creating new inundation maps is a relatively fast process as compared to hydrodynamic modeling, with the caveat that the inundation maps do not include the flow dynamics that are captured by a hydrodynamic model.

As a limitation on the DEM, the channel bottom elevations within the bayous have been estimated where no data existed. We had hoped to conduct depth surveys through Goff and Hog bayous, but this proved to be impractical within the short time frame of the project and the resources available. Fortunately, these channel depths are not critical in hydrodynamic modeling of the system connectivity over the restricted flow conditions illustrated in Appendix D.

The hydrodynamic model (GBHM) has been developed to a baseline level by solving the most difficult implementation problem, which was creating a practical model DEM that represents channel connectivity and blockages. The model can be used in its present form to look at inundation levels at different flow rates with the GBRA gates either completely closed or if we imagined the gates completely removed. Modeling the hydraulics of the flow through the gates at different openings to mimic actual (or proposed) operating conditions will require further data from GBRA and possibly additional field surveys to set the correct gate elevations relative to the NAVD88 vertical datum.

The field data collected during this project has not been analyzed, which was recognized as impractical within the project time frame and was not part of the contracted work. Future analysis of this data could provide insight into water levels during the spring 2015 floods. It should be noted that collecting data within these bayous is challenging and time consuming – both to access different areas and to move along the water channels.

Appendix A: Lidar Processing

Overview

The pervasive presence of water hyacinth at the time the lidar was flown obscures water surfaces within the DEM. While it is possible to visually identify likely hyacinth covered water features within the dataset (Figure A.1), manually digitizing bank locations and removing "false" topography for such an extended area has major drawbacks. First, manually drawing in polygons in ArcGIS representing water surfaces would be extremely time-consuming. Second, the resulting polygons would be entirely subjectively created based on the GIS technician's ability to identify the likely water surfaces. Finally, as a result of this, the methodology would be entirely irreproducible. To address these issues, an automated method for digitizing water channels obscured by vegetation has been developed.

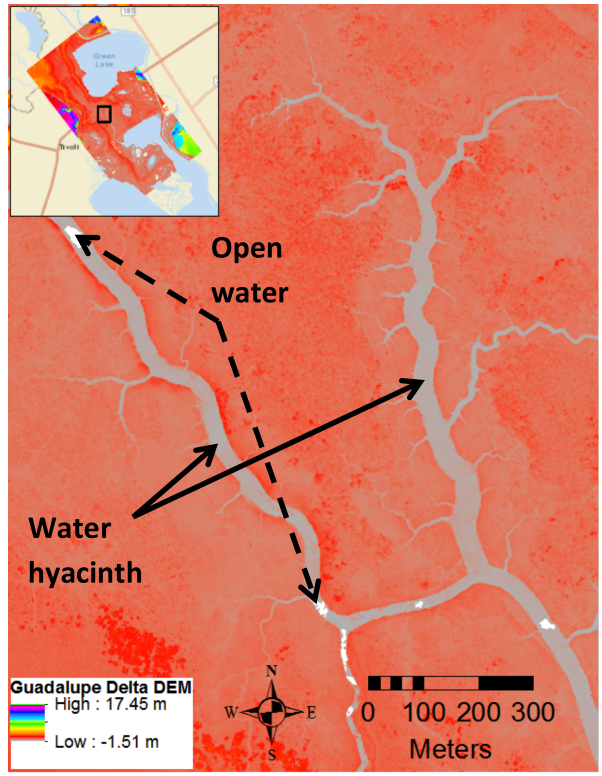

Figure A.1. Water hyacinth covered water features identified visually. Open water is seen as holes in the dataset.

Using a modified subroutine within the GeoNet feature extraction toolbox developed by Passalacqua et al (2012)[5], channel bank locations are estimated along cross-sections cut along channel centerlines. The bank locations are connected in ArcGIS to form water channel polygons and are subsequently removed from the dataset. Channel bathymetry is interpolated when possible and estimated in other locations. Finally, the bathymetry is combined with the edited topography to create the preprocessed lidar input for the GBHM. The remainder of this appendix explains these steps in greater detail.

ArcGIS and GeoNet bathymetry processing

Channel centerlines ("flowlines") for the streams can be obtained from the National Hydrography Dataset (NHD)[6]. However, the NHD flowlines were either incomplete or inaccurate in many locations, so these lines were manually modified to produce a custom flowline set for the study area (Figure A.2.a) To prepare the centerline for input into GeoNet, an ArcGIS model was built to convert the lines to a series

[5] Passalacqua, P., P.Belmont, and E.Foufoula-Georgiou (2012), Automatic geomorphic feature extraction from lidar in flat and engineered landscapes, Water Resour. Res., 48, W03528, doi:10.1029/2011WR010958.

[6] Get NHD Data. (n.d.). Retrieved July 31, 2014, from http://nhd.usgs.gov/data.html

of points spaced at one meter utilizing an ArcPy script[7]. At typical detail is shown in Figure A.2.b. The points are grouped for by an identification number unique to each reach section and are exported as a shapefile for GeoNet processing.

GeoNet reads both the study area DEM and the shapefile of the centerline points. To read the shapefile into MATLAB without access to a MATLAB mapping toolbox license, an open source shapefile reading code is required[8]. The DEM is filtered, and a slope DEM is calculated from the filtered DEM. The code then marches along the centerline points. At each point a cross-section of user-prescribed length is created orthogonal to the centerline (Figure A.2.c). Along each cross-section, the maximum slope is identified on either side of the centerline. These points are the likely left and right bank edges.

The left and right bank locations are based on maximum slope, so error is more likely introduced with wider cross-sections. In areas where a road or levee borders the channel, false bank locations can be produced. To minimize these errors and post-processing clean-up, the cross-section lengths are selected for each individual stream reach based on the widest part of the channel within the reach. Otherwise, the code defaults to a user defined cross-section length.

The left and right bank locations for each reach are exported by the GeoNet subroutine as a csv file and imported to ArcGIS as a point feature class (Figure A.2.d)**.** Following a manual clean-up to remove false bank edges, the points are connected as lines and then as polygons. The combinations of these polygons represent the estimated water surface extent (Figure A.2.e). When the DEM is clipped around the water surface polygons, the result is DEM provides an estimated data set without the influence of water hyacinth, i.e. no-data for all water surfaces (Figure A.2.f).

Insertion of bathymetry to DEM

There are three sources of bathymetric data available to fill the open water (no-data) pixels in the DEM: (1) the lower Guadalupe River cross-sections from the GBRA HEC-RAS model, diversion canal cross-sections from GBRA, and the Mission Lake grid for the TWDB model. These data locations are shown **in** Figure A.3. Between these known data, channel base elevations are interpolated linearly along the channel centerline points (obtained from the DEM GeoNet processing described above). In all areas where data was unavailable, the channel centerline elevations are estimated from surrounding features and engineering judgment.

To approximate the general shape of the channel where cross-sections were not available, a U-shape was prescribed. In wider channels, it was assumed that the channel bed reached 80% of its minimum elevation three meters from the bank location. To achieve this effect, the water surface extent polygons are buffered down three meters and converted to line features. The line features are then converted to point features. Using these centerline points along with 3 m buffer lines, bank edge elevations, and the

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[7] Wynne, D. (2013, September 13). Create Points From Line. Retrieved October 1, 2014, from http://www.arcgis.com/home/item.html?id=a2a41c8345e24ab6a9dd2ae215710b39

[8] Pawlowicz's, R. (2014, September 1). M_Map: A mapping package for Matlab. Retrieved October 1, 2014, from http://www.eos.ubc.ca/~rich/map.html

known (or estimated) centerline depth, we create a triangulated irregular network (TIN) within the channel that provides an approximation of the expected submerged bathymetry. Finally, the TIN is converted to a raster at the 1 x 1 m resolution and used to fill in the blank water features in the DEM. This process creates the final "drained" DEM at 1 x 1 m resolution (Figure A.4)

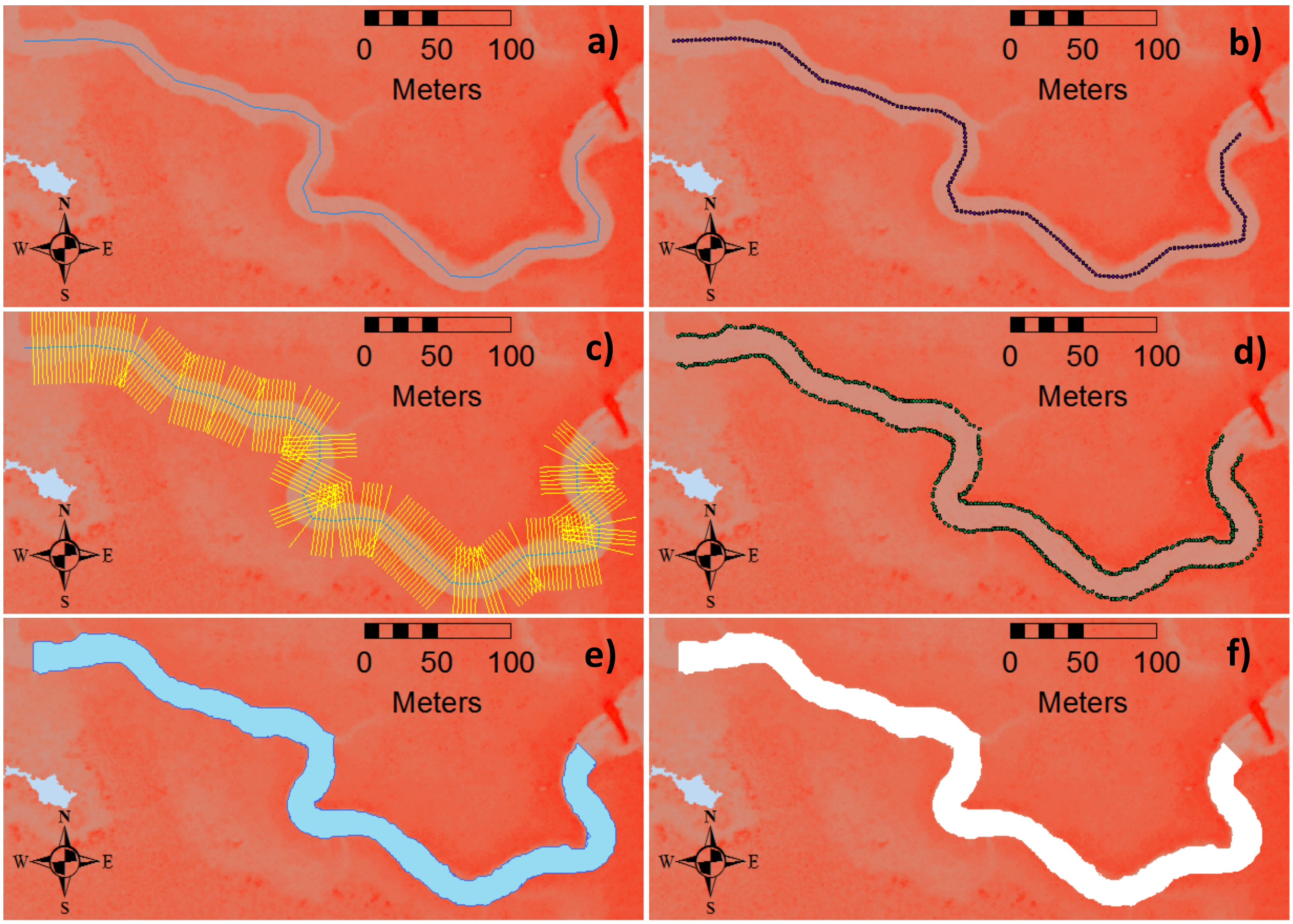

Figure A.2. Development of water channel extent polygon in sample area. a) Custom centerlines are developed along major channels. b) Lines are converted to point features uniquely identified by reach. c) Points are read by GeoNet, and cross sections are struck at user defined intervals. d) Bank locations are estimated based on maximum slope along cross sections and printed as a csv. E) Bank locations are converted to polygon features representing the estimated water channel surface. f) Water surface extent is removed from dataset allowing for insertion of bathymetry.

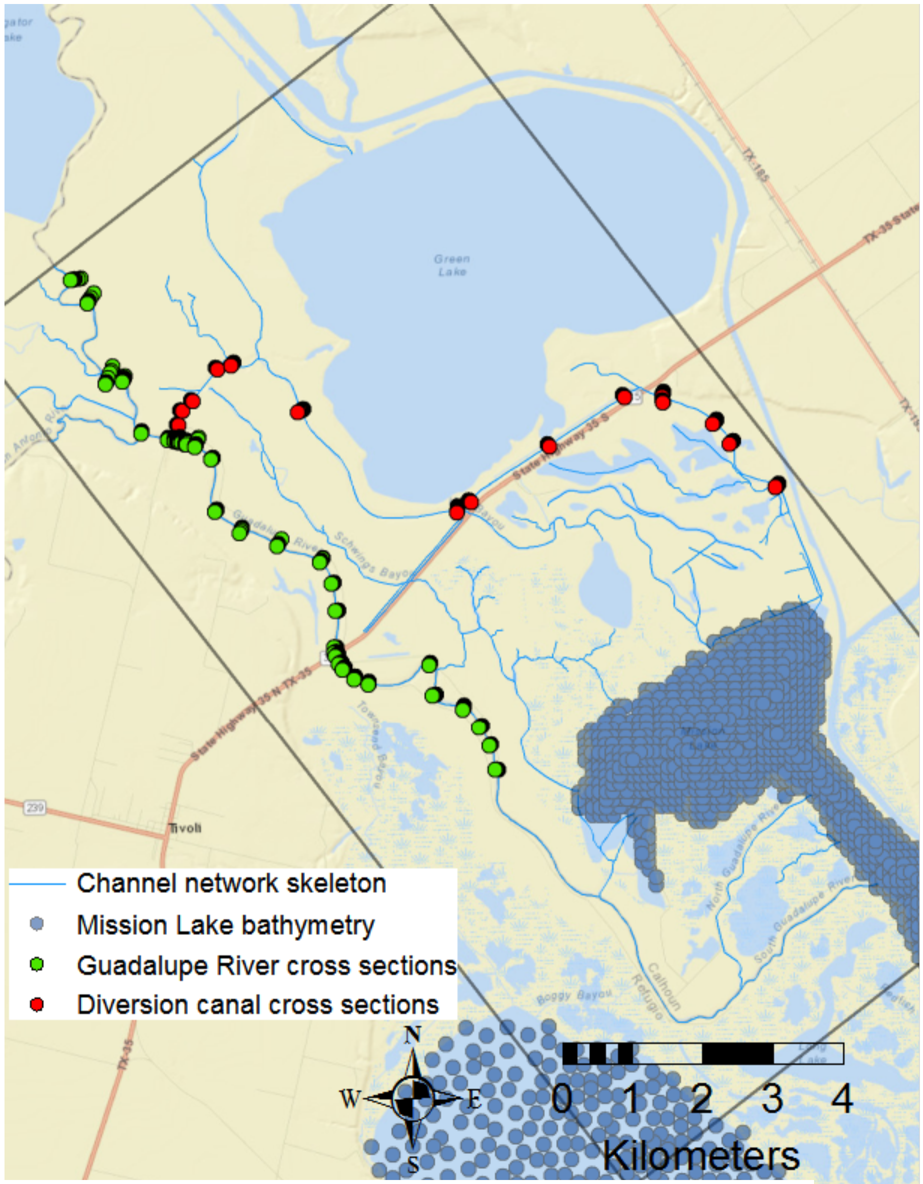

Figure A.3. Sources available for estimation of area bathymetry. For all water (blue) areas without data, estimations were made for depths based on surrounding topography and engineering judgment.

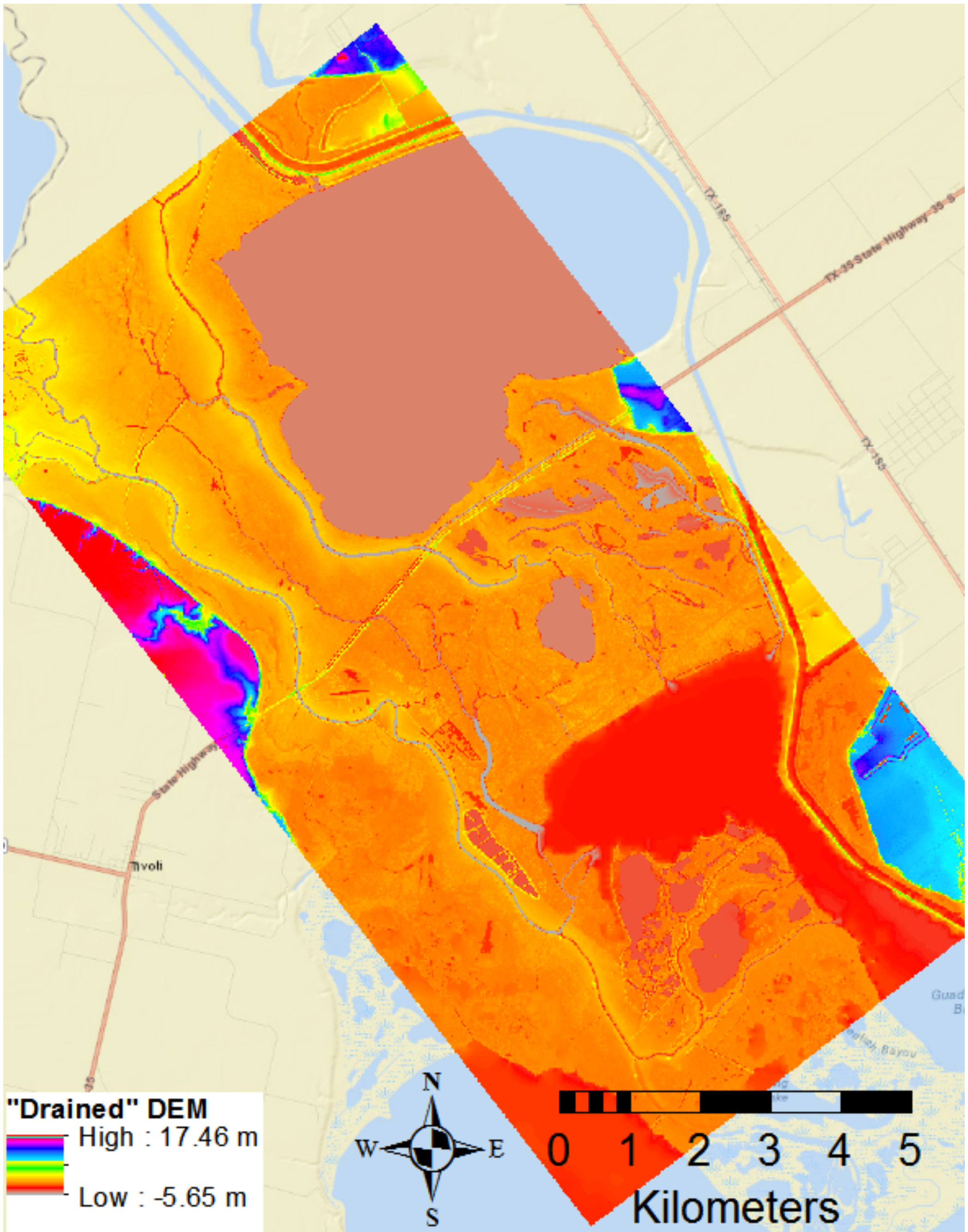

Figure A.4 "Drained" DEM. Preprocessing of the DEM for the model is completed by removing hyacinth obscured channels and inserting the estimated bathymetry.

Appendix B: Inundation mapping

Overview

According to National Oceanic and Atmospheric Association (NOAA) Coastal Services Center[9], there are three general approaches to preparing water levels for mapping coastal inundation: 1) modeled water surfaces, 2) single value water surfaces, and 3) interpolated water surfaces. Herein, the first approach is accomplished with the hydrodynamic model (Appendix D). The second approach (single valued) can only provide a simple bathtub inundation model that does not represent the water elevation gradients from upstream to downstream – so this approach is not used herein. The third approach (interpolation) typically is accomplished using directly measured values from gages, but there are only two in the present study site and they cannot be extended to estimate the water surfaces over the entire bayou.

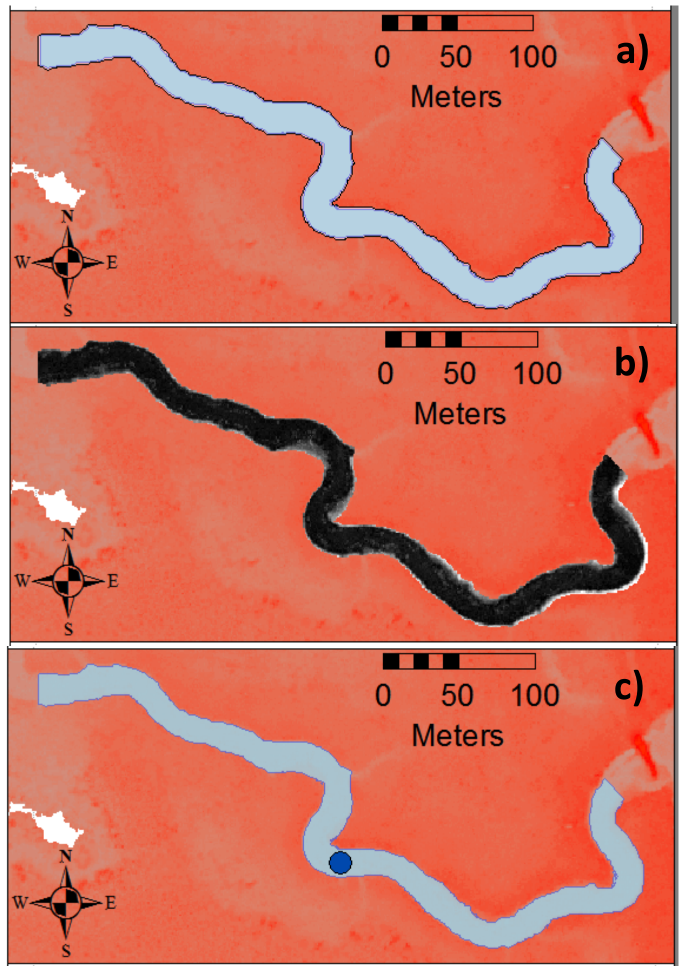

Figure B.1. Sample methodology for estimating water surface elevation points. a) Water channel polygons are buffered by 1 m to select DEM pixels along banks and within polygons. b) DEM is extracted by buffered polygon mask, and converted to individual points. c) Statistics are taken for points associated with each channel polygon, and the minimum elevation value is assigned as the reach water elevation at a point in center of the polygon.

Fortunately, the lidar overflight provides a synoptic snapshot of water surface elevations. In our approach, the lidar data is used to estimate the water surface level gradient at the time of the overflight. This gradient is assumed to represent a reasonable estimate of the water surface gradient expected at other inundation levels. Although this assumption is not precisely correct, it is a better estimate than applying a constant water level across the entire system (i.e. single-valued surfaces)

The lidar DEM provides elevations along the banks of all water features. The minimum values from the DEM along any particular reach is a reasonable approximation for the water surface elevation in that specific area. At steep banks, this approach has the potential for overstating the water surface elevation; however, the combination of the high resolution (1 x 1 m) DEM and the methods described below makes this problem

[9] *Mapping Coastal Inundation Primer*. (2012). Charleston, South Carolina: NOAA Coastal Services Center.

negligible. The minimum elevation values for pixels bordering water features (identified in GIS processing discussed above) are taken as approximate measurements for the water surface elevation within that reach. These data are used to create a water surface elevation map.

Water surface level estimation

To identify the pixels bordering the water features within the DEM, the water channel polygons developed in the lidar processing are used. The polygons are buffered by 1 m and used to clip the DEM so that the only remaining pixels are those within 1 m of the water polygons. These pixels are converted to point features and are spatially joined with the individual reach water polygons, thereby associating each of the points with a unique polygon. The minimum elevation point within each polygon is then assigned to the polygon itself. Finally, the polygon is converted to a center point that has the minimum elevation value bordering water within that reach. This approach minimizes the effect of locally steep banks on the estimated water surface elevation. As a final step, the polygon center points and associated water surface elevations are used to create an interpolated water surface across the study area. A manual review of the data is necessary to remove obvious outliers The final baseline water surface elevation is shown as Figure B.2

Inundation Results

Simple inundation maps for different water surface levels is obtained by adding or subtracting from the baseline water surface elevation (Figure B.2), then subtracting the topographic DEM from the surface elevation. Only those pixels with positive values can possibly be flooded. However, many of these pixels may be isolated from the stream network within the bayou system; that is, there can be ponds formed that have no visible path for inundation by surface water. Such ponds might actually fill through groundwater movement or by overtopping during a flood. However, for the present purposes we used a connection algorithm to remove ponds that did not have a flow path connection to either Mission Lake or the Guadalupe River.

Figures B.3 through B.7 provide inundation maps at increments of 1 ft above the baseline measured during the lidar overflight. It can be seen that the 1 ft increment provides a small increase of inundation. The 2 ft increment shows a substantial increase in inundation around Goff Bayou and the lower portions of Schwings Bayou. At 3 ft and above, the bayou system is essentially flooded.

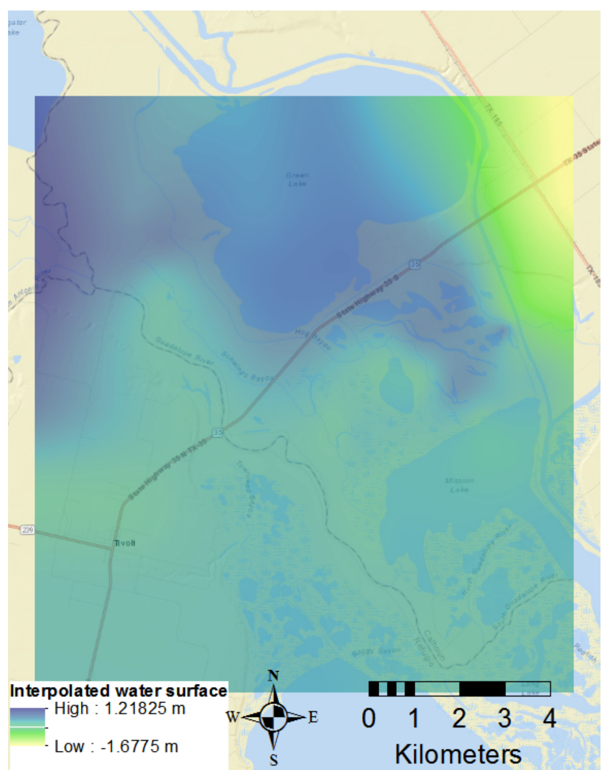

Figure B.2. Interpolated base water surface raster in meters above NAVD88

Figure B.3. Inundation resulting from a 1 ft Base water level increase

Figure B.4. Inundation resulting from a 2 ft Base water level increase

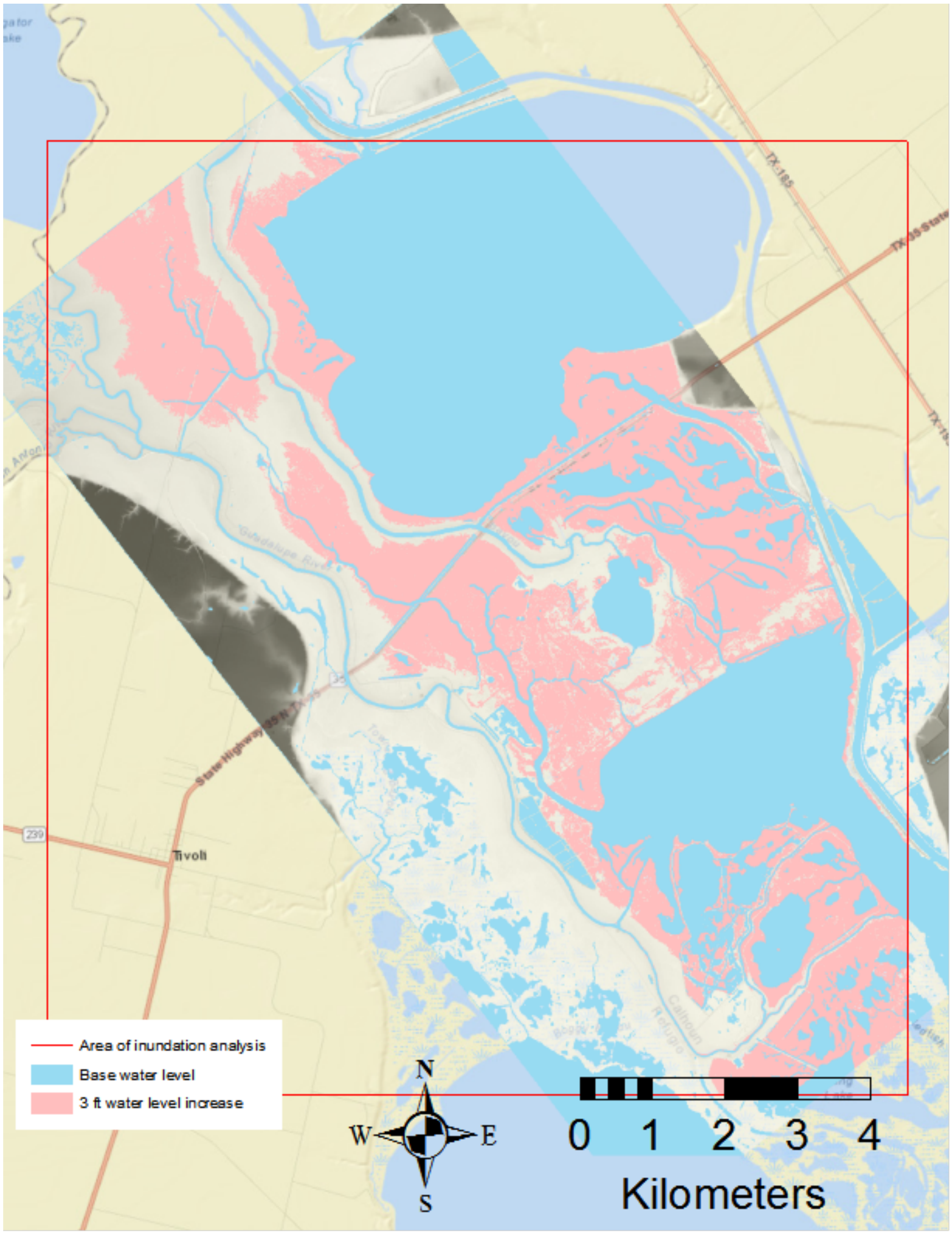

Figure B.5. Inundation resulting from a 3 ft Base water level increase

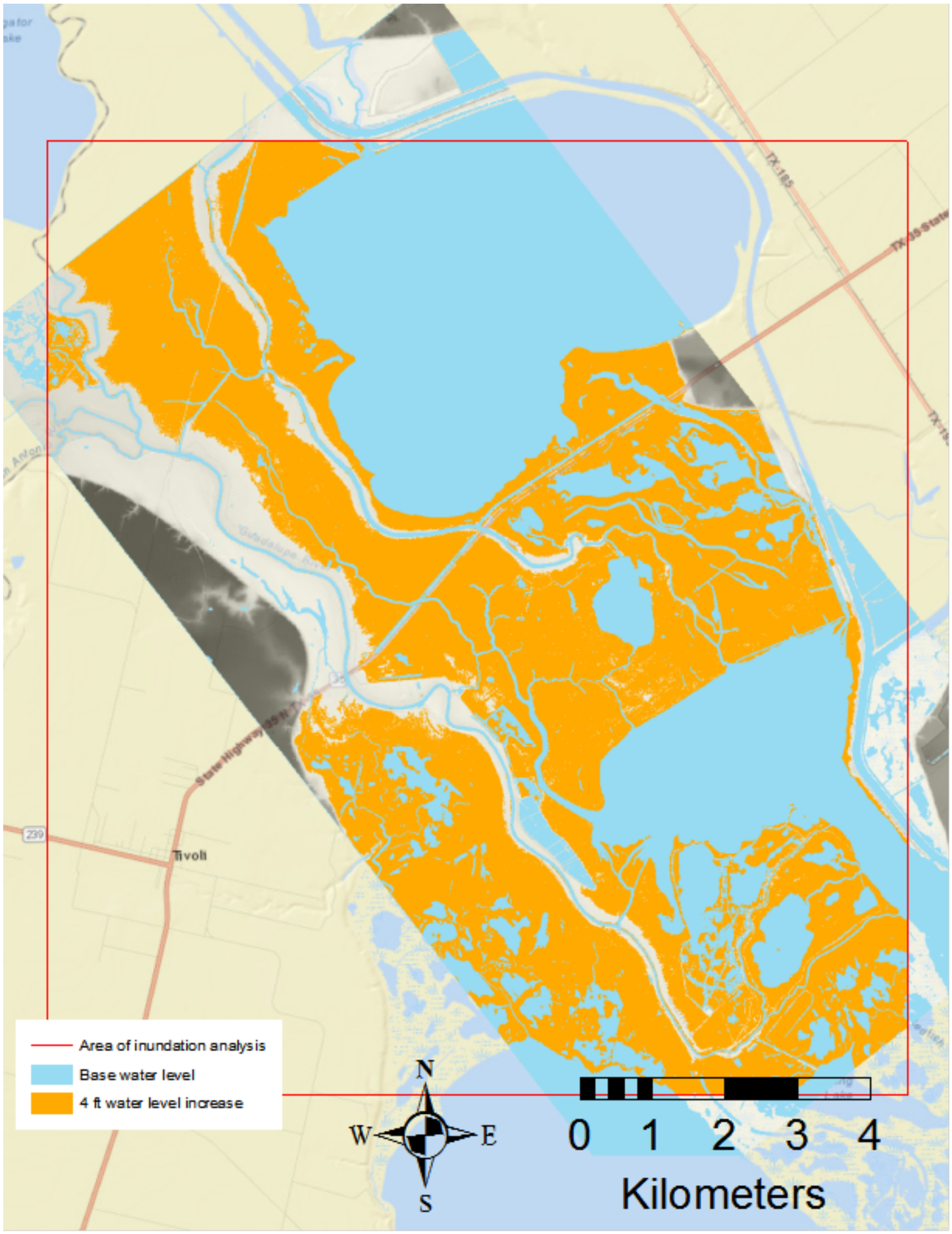

Figure B.6. Inundation resulting from a 4 ft Base water level increase

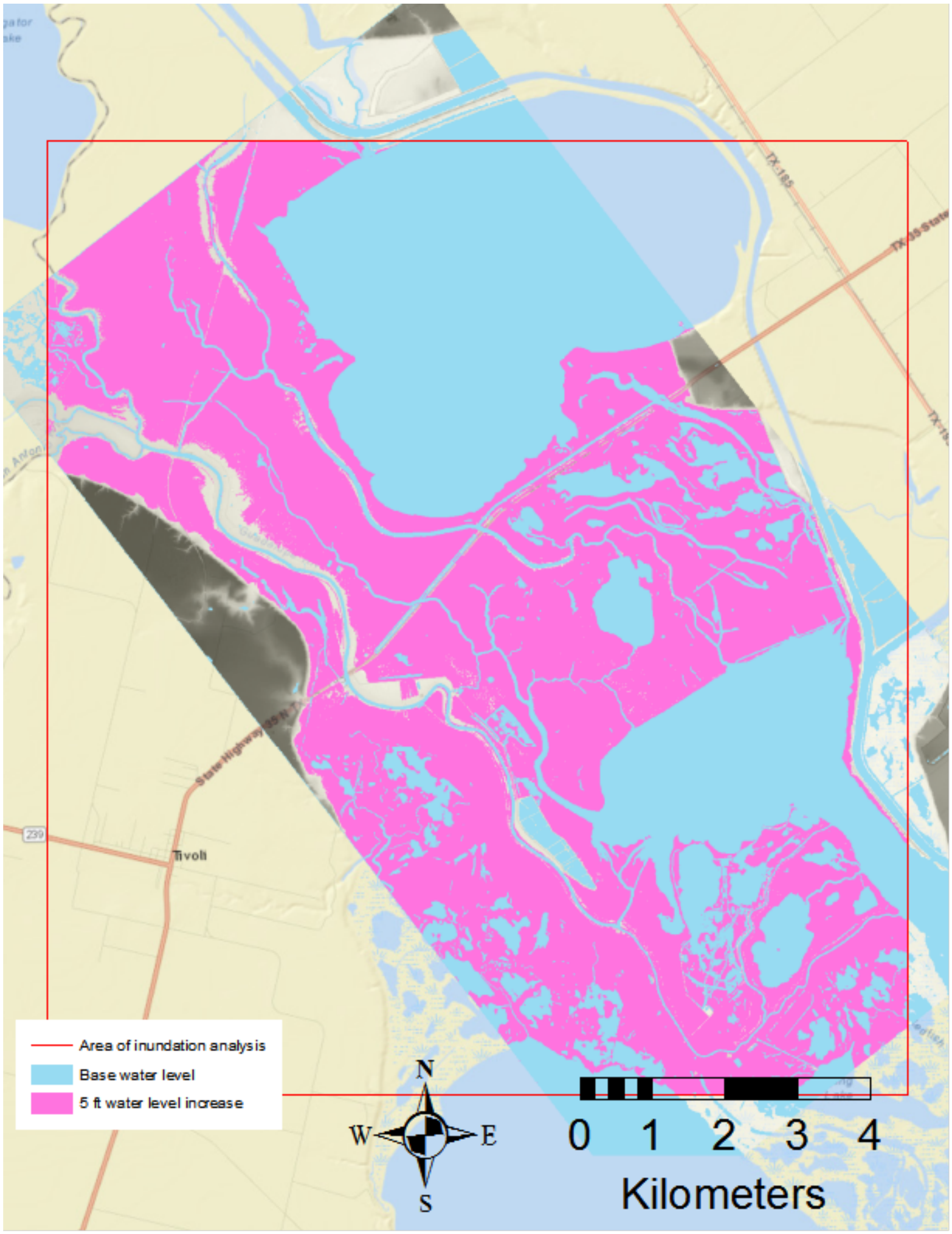

Figure B.7. Inundation resulting from a 5 ft Base water level increase

Appendix C: Field work

Overview

A series of four field expeditions was performed from November of 2014 through August of 2015. The primary purpose was to gather water level, temperature, and conductivity data throughout the bayou system. In all, 18 sensors were deployed over a series of 4 field excursions.

Sensors

Four different sensor types were deployed in the study area. Their specifications are summarized in Table C-1. The sensors were set to take readings at intervals of six minutes, providing ten measurements per hour.

Table C-1. Summary of technical specifications for sensors used in study field work

Type	Metrics	Abbreviation	Effective range	Number installed
Solinst Levelogger Junior Edge 5 m	absolute pressure, temperature	5m TD	5 m	6
Solinst Levelogger Junior Edge 10 m	absolute pressure, temperature	10m TD	10 m	4
Solinst LTC Levelogger Junior 10 m	absolute pressure, temperature, conductivity	10m CTD	10 m	6
Solinst Barologger	absolute pressure	baro	-	2

Solinst Barologger Edge

Two Solinst Barologgers were installed at the northern and southern extents of the study area. These instruments measure air temperature and absolute air pressure; these are used with the pressure measurements from the water level instruments to compute the water depth. The manufacturer claims the instruments are accurate to within ± 0.05°C and ± 0.05 kPa. The Barologger device can be used to compensate any Leveloggers (see below) within a 20 mile radius, which includes all of the instruments we placed in the field.

Solinst Levelogger Junior Edge 5 m and 10 m

The Solinst Leveloggers measure the water absolute pressure and temperature such that, when combined with the Barologger (above) they achieve depth precision of ± 1/2000th of their maximum depth and temperature precision ± 0.1°C. Two Levelogger models were used, with rated 5 m and 10 m depths ranges (abbreviated as 5m TD and 10m TD, for Temperature Depth). Six 5m TD and four 10m TD sensors were installed. To obtain the water depth from the devices, the overlying air pressure (measured by a Barologger) is subtracted from the Levelogger pressure and then converted to depth by the compensation program provided by Solinst.

Solinst LTC Levelogger Junior 10 m

Sonlinst Levelogger 10m LTC sensors are designed to measure temperature, absolute pressure, and water conductivity (the latter used for estimating salinity) – these are typically known as a Conductivity, Temperature, and Depth (CTD) sensors. Temperature and depth accuracy ratings are the same as the 5m and 10m TD models, discussed above. However, these sensors require user calibration to correctly measure conductivity. As suggested by the Solinst sensor user manual, the devices were calibrated with the automated program using a two point calibration at 1,413 µS/cm and 12,880 µS/cm. A total of six CTD sensors were installed.

Figure C.1. Sensor mount and installation setup

Sensor mounts and installation

All TD and CTD sensors were installed on galvanized rods that were 1.5 ft in length and mounted vertically in reinforced concrete disks approximately 4 inches deep with a diameter of 11 inches (Figure C.1). Sensors were oriented so that the sensing end was always at the top of the rod. Sensor mounts were deployed near mid-channel, and attached to the shoreline via ropes connected from u-bolt to shore. Barologgers were installed along fence posts or telephone poles inside perforated 2 inch diameter schedule 40 PVC tubing.

Field campaign 1

The initial field reconnaissance took place on November 21, 2014. The visiting group was escorted by Mr. Dan Alonso of the San Antonio Bay Foundation (SABAY). The trip provided insight into field work feasibility and required land access. Sites visited included the GBRA salt barrier and diversion gate, the highway 35 boat ramp along upper Hog Bayou, the Hog Bayou salt gate within the WMA, and the Traylor Cut (Figure C.2).

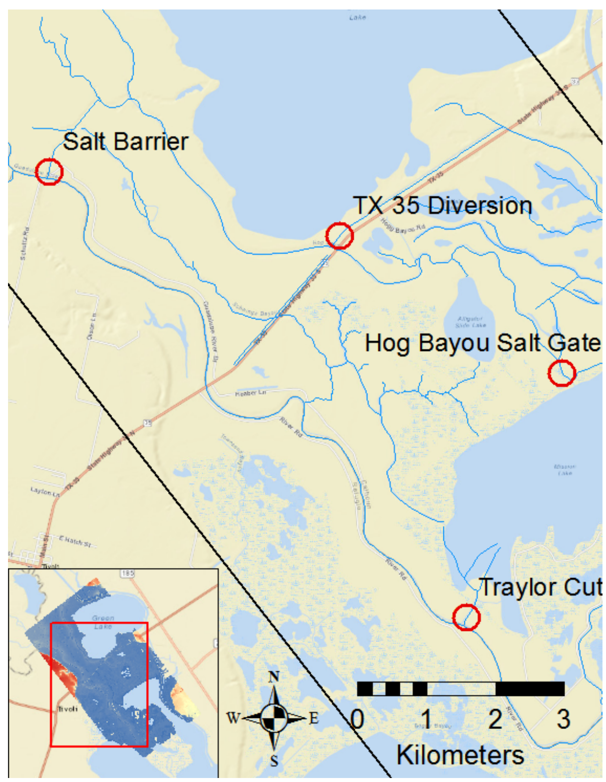

Figure C.2. Field locations visited during field reconnaissance 11/21/2014

Field campaign 2

Between March 18 and March 20 of 2015, we installed 15 sensors (Figure C.3) including three 10m CTD’s, six 5m TD’s, four 10m TD’s, and two Barologgers. As the Guadalupe River was in flood at this time, installation of several sensors within the WMA was not possible due to flooded roads and TPWD concerns over safety (seen as “Inaccessible locations" in Figure C.3). The deployed sensors were activated at 12:00:00 AM the morning of March 21st. During the deployment, one 5m TD sensor was lost.

Field campaign 3

Data was recovered from 9 of the 15 sensors during field campaign from May 20 – 22 of 2015. The 5 m TD sensor at the cut between Schwings Bayou and the Guadalupe River was lost (broken anchor line indicating likely theft or vandalism of unit). Four sensors were unreachable due to high water levels at this time. As before, the WMA locations were inaccessible due to safety concerns. Three more 10m CTD's were installed via boat along the northern shore of Mission Lake, (Figure C.2).

Field campaign 4

The final field campaign to recover all sensors will take place in August 2015.

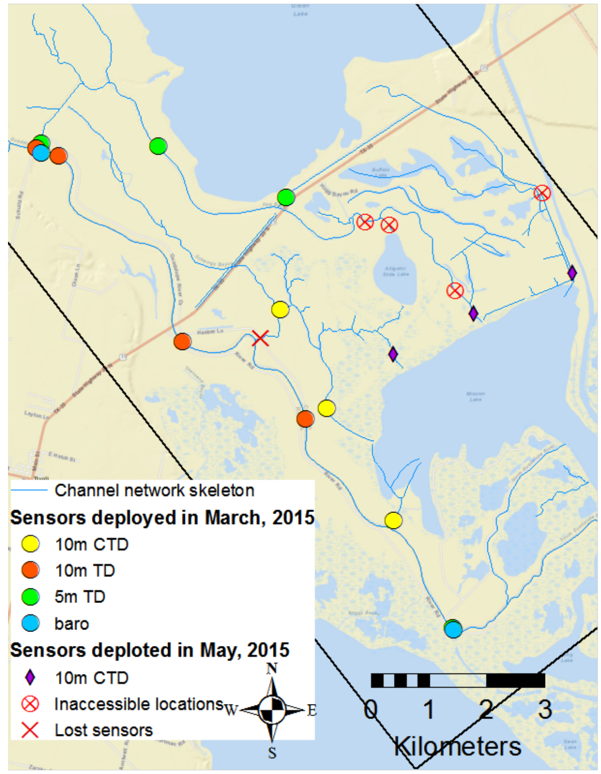

Figure C.3. Sensors deployed throughout the study

Results

Table C-2 provides a summary of all sensor equipment deployed throughout the field work phase of the study. Figures C.4 – C.6 provide graphs of the data collected during the initial data collection phase of the study. The sensor names in the plots refer to the sensors locations seen in Figure 10. Due to safety concerns, we were not able to collect data within the lower reaches of Hog Bayou, at the upstream end of Alligator Slide Lake, or upstream of the gate at Goff Bayou.

Table C-2. Summary table of field work sensor deployment

Sensor name	Sensor type	Latitude	Longitude	Name description	Data time range
tc	10m CTD	28.44769	-96.82485	Traylor Cut	March 18 -Currently deployed
schN	10m CTD	28.48070	-96.84412	north Schwings bayou	March 18 -Currently deployed
schS	10m CTD	28.46517	-96.83625	south Schwings bayou	March 18 -Currently deployed
mamS	10m CTD	28.47346	-96.82425	south Mamie bayou	May 20 -Currently deployed
hogS	10m CTD	28.47953	-96.81002	Hog bayou south of salt gate	May 20 -Currently deployed
goffS	10m CTD	28.48559	-96.79252	Goff bayou south of salt gate	May 20 -Currently deployed
salN	10m TD	28.50634	-96.88655	north of salt barrier Guadalupe River	March 18 -Currently deployed
salS	10m TD	28.50518	-96.88261	south of salt barrier Guadalupe River	March 18 -Currently deployed
mGuadN	10m TD	28.47599	-96.86137	north location middle Guadalupe River	March 18 -Currently deployed
mGuadS	10m TD	28.46357	-96.83996	south location of middle Guadalupe River	March 18 -Currently deployed
salDiv	5m TD	28.50709	-96.88568	diversion canal at salt barrier	March 18 -Currently deployed
nHogS	5m TD	28.50639	-96.86498	south location of north Hog bayou	March 18 -Currently deployed
35div	5m TD	28.49799	-96.84276	TX 35 diversion canal	March 18 -Currently deployed
lGuadN	5m TD	28.43078	-96.81474	north location lower Guadalupe River	March 18 -Currently deployed
schSP	5m TD	28.47630	-96.8475	"Swimming Pen" along Schwings bayou	March 18 -lost
extra1	5m TD	28.47636	-96.84754	replacement for schSP sensor that was lost, also lost	March 18 -lost
salBar	baro	28.50558	-96.88566	barometer at salt barrier along Guadalupe River	March 18 -Currently deployed
schBar	baro	28.43057	-96.81467	barometer meant for Schwings bayou, actually installed with lGuadN	March 18 -Currently deployed

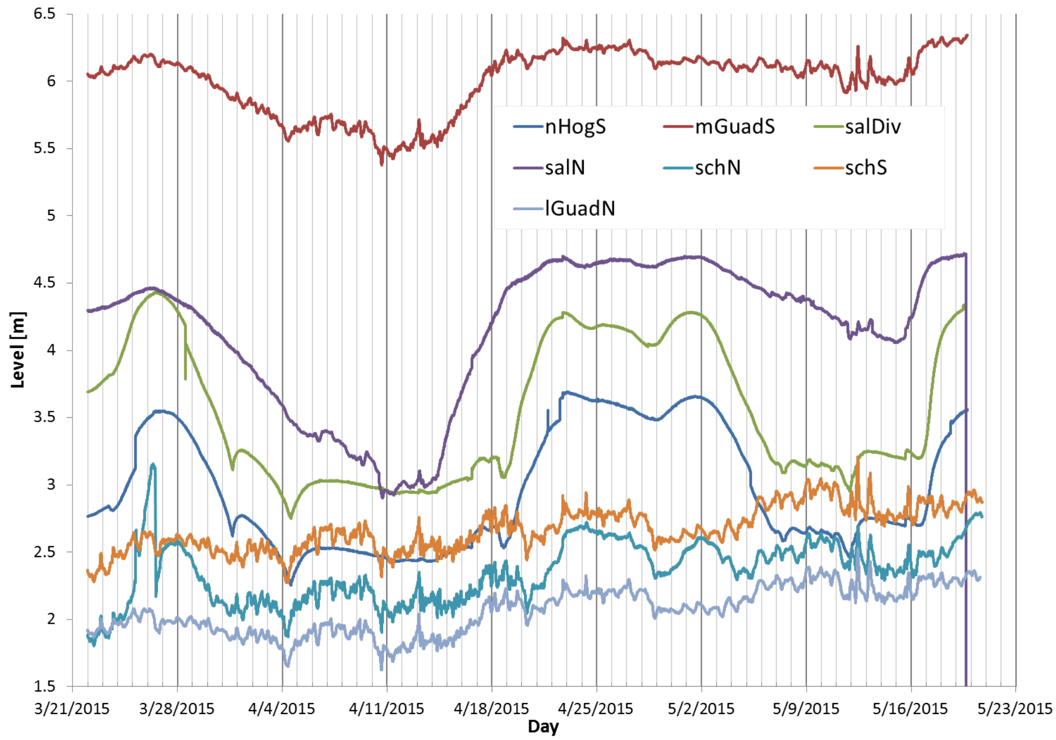

Figure C.4. Water surface elevations for all sensor data retrieved on May 23, 2015.

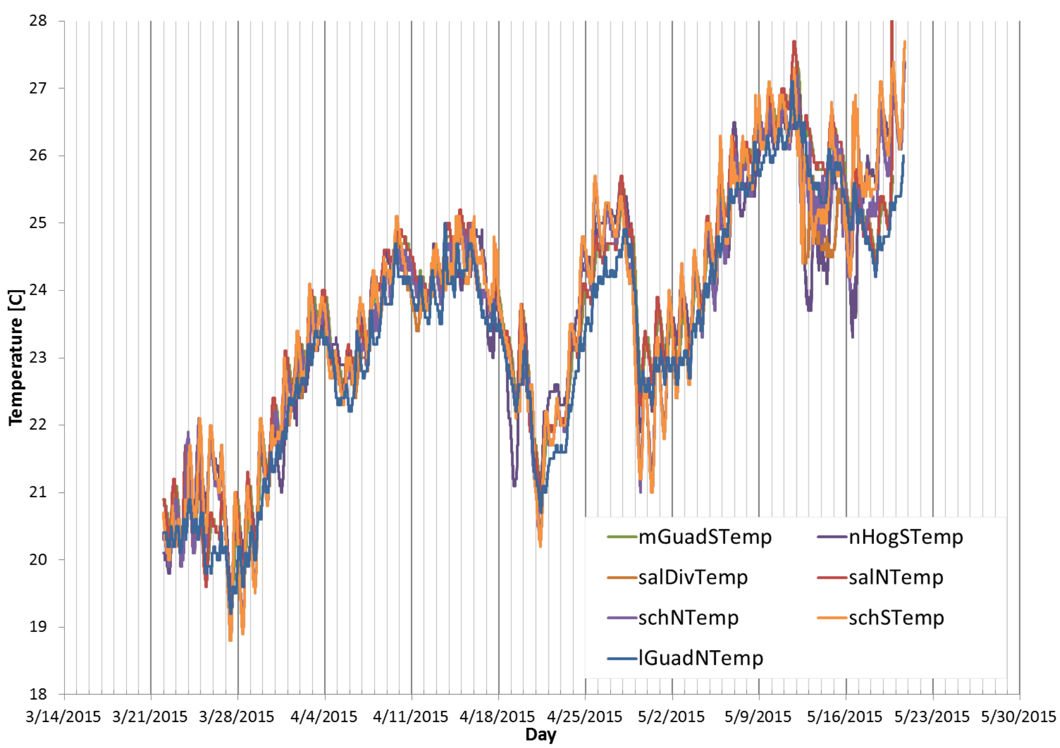

Figure C.5. Water temperatures for all sensor data retrieved on May 23, 2015.

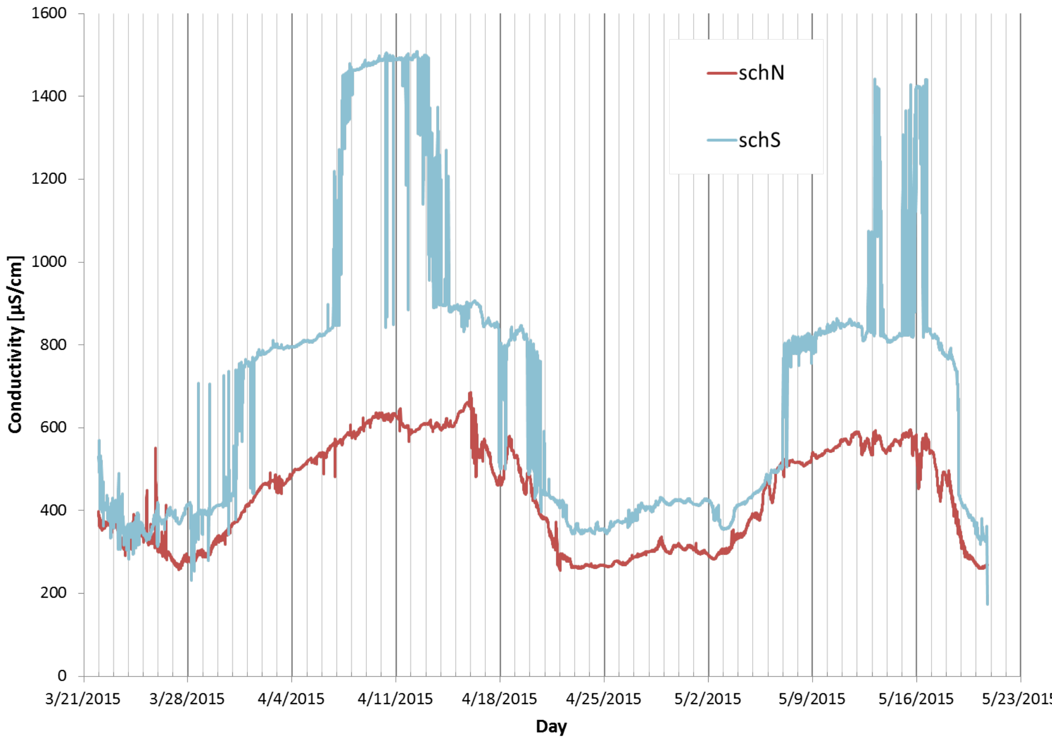

Figure C.6. Water conductivity for all sensor data retrieved on May 23, 2015.

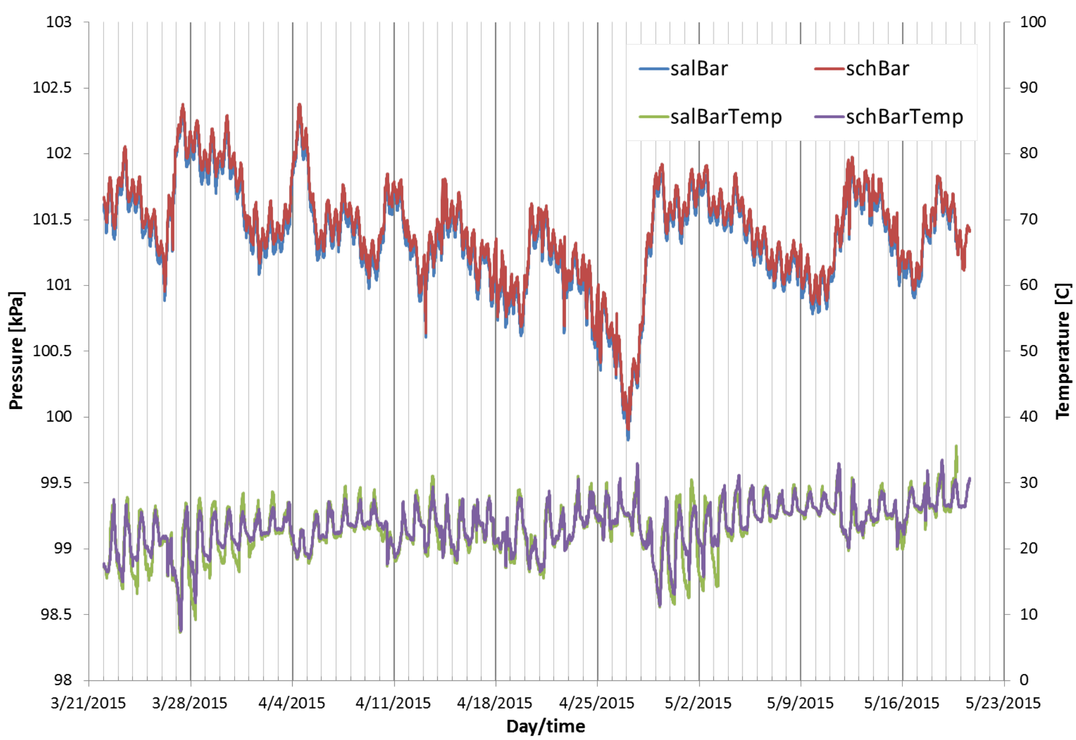

Figure C.7. Pressure for all sensors retrieved on May 23, 2015.

Appendix D: Hydrodynamic Modeling Results

The Guadalupe Bayou Hydrodynamic Model (GBHM) was run for constant inflows ranging from 140 cfs to 2800 cfs. Each model case started from a uniform water surface initial condition based on the tidal elevation on January 15, 2014, which was 0.068 m above NAVD88 datum. The models were run for 10 days of simulation time. Tidal elevations for the San Antonio Bay boundary were based upon a filtered, linear combination of Copano Bay and Port O'Connor tidal gages published by the TCOON network. The Frehd model that forms the basis for the GBHM was run in a 2-dimensional (depth-integrated) mode with uniform density (no salinity effects). Wind, meteorology, temperature, and evaporation modules were turned off. The model time step was 60 s, with subtime-stepping as necessary for tracer transport to maintain scalar conservation and stability.

The system modeled includes only a constant forced inflow at the upstream Guadalupe River boundary and tidal exchange across the southern boundary. Outflows through the siphon across the Victoria Barge Canal are set to zero. The Hog Bayou and Goff Bayou gates are closed, so any flows in these vicinities are either overtopping of the gates (Hog) or connections around the gates through the adjacent landscape (Goff)

Model results are visualized with tracers for the initial water in the system (Figure D.1) and for the inflowing water (see discussion in section 3.3). The distribution of the tracers at the end of 10 days of simulation are shown in Figures. D.2 – D.7. Of particular note is that Schwings Bayou is not well connected to the rest of the system due to the banks of the upper diversion canal; thus, Schwings, will primarily be flushed by local rainfall, which is not included in present model. Hog Bayou appears to see an overflow over the top of gates in all cases; however, this result may indicate there is a problem with the channel and blocking features in the DEM near the gate and further investigation is warranted. Results for 140, 280, and 560 cfs cases show progressively increased flooding through the bayous, with much of the inundation caused by pushing the initial water deeper into the system.

The high flow rate cases (1120, 1680, 2800 cfs) are provided for comparison, but the results should be considered with caution. We do not have any information on whether or not the saltwater barrier can remain inflated at these (or any other) flow rates.

We must emphasize that these model results are intended to test the model capabilities and provide insight into the connectivity within the bayous. These results do not represent either actual operation or expected behavior of the system, particularly for extreme flow events. For simplicity, this model neglects all the local runoff and minor streams north of Green Lake that provide ungauged flows during high water conditions.

Figure D.1. Initial tracer distributed in the bayou and upstream sections of the Guadalupe River at the start of the simulation. Note that the colormap extends beyond the [0,1] range of tracer concentrations for better contrast with the satellite image.

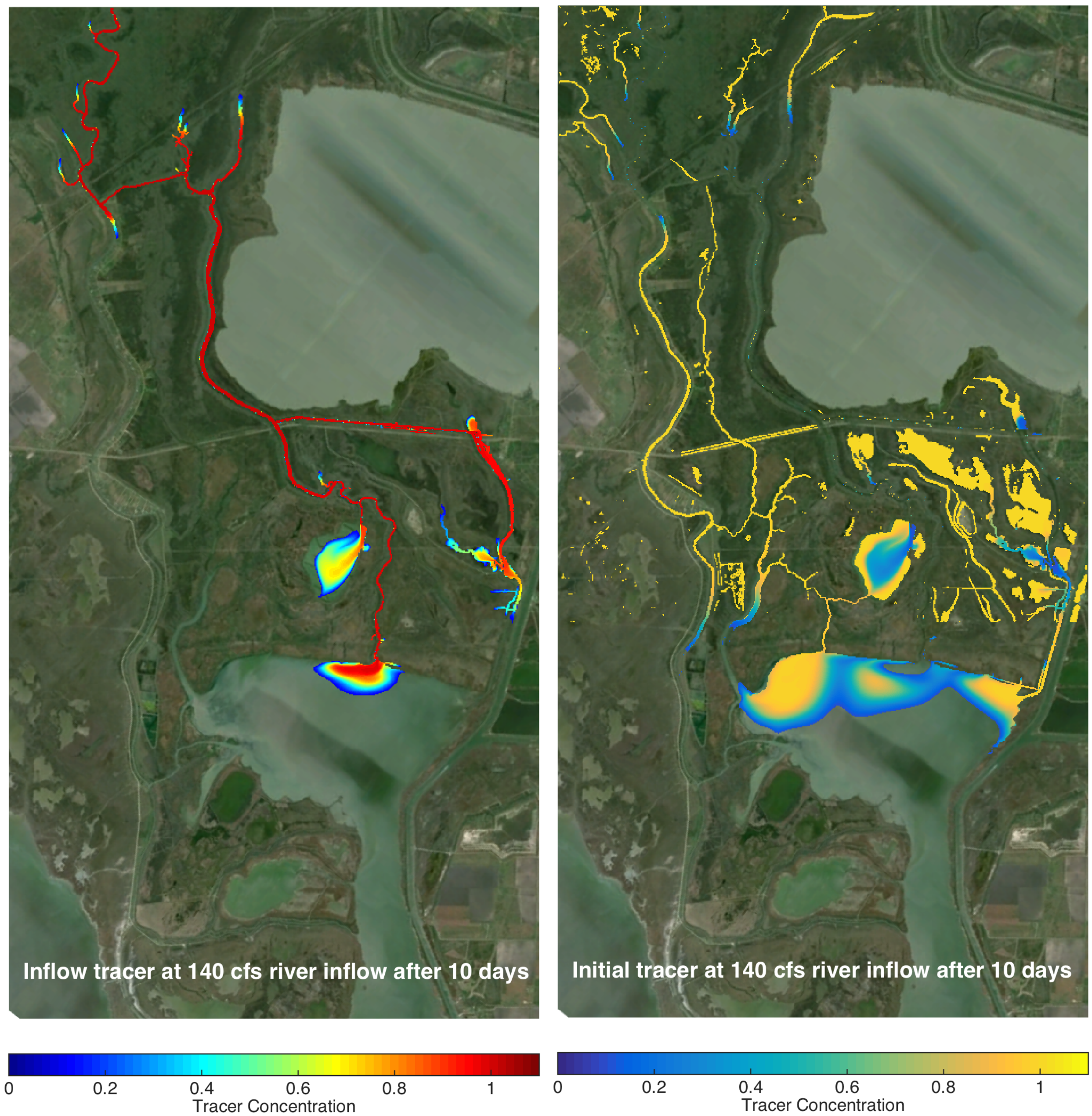

Figure D.2. Modeled tracer distributions for 140 cfs inflow case. Note that the colormaps extend beyond the [0,1] range of tracer concentrations for better contrast with the satellite image.

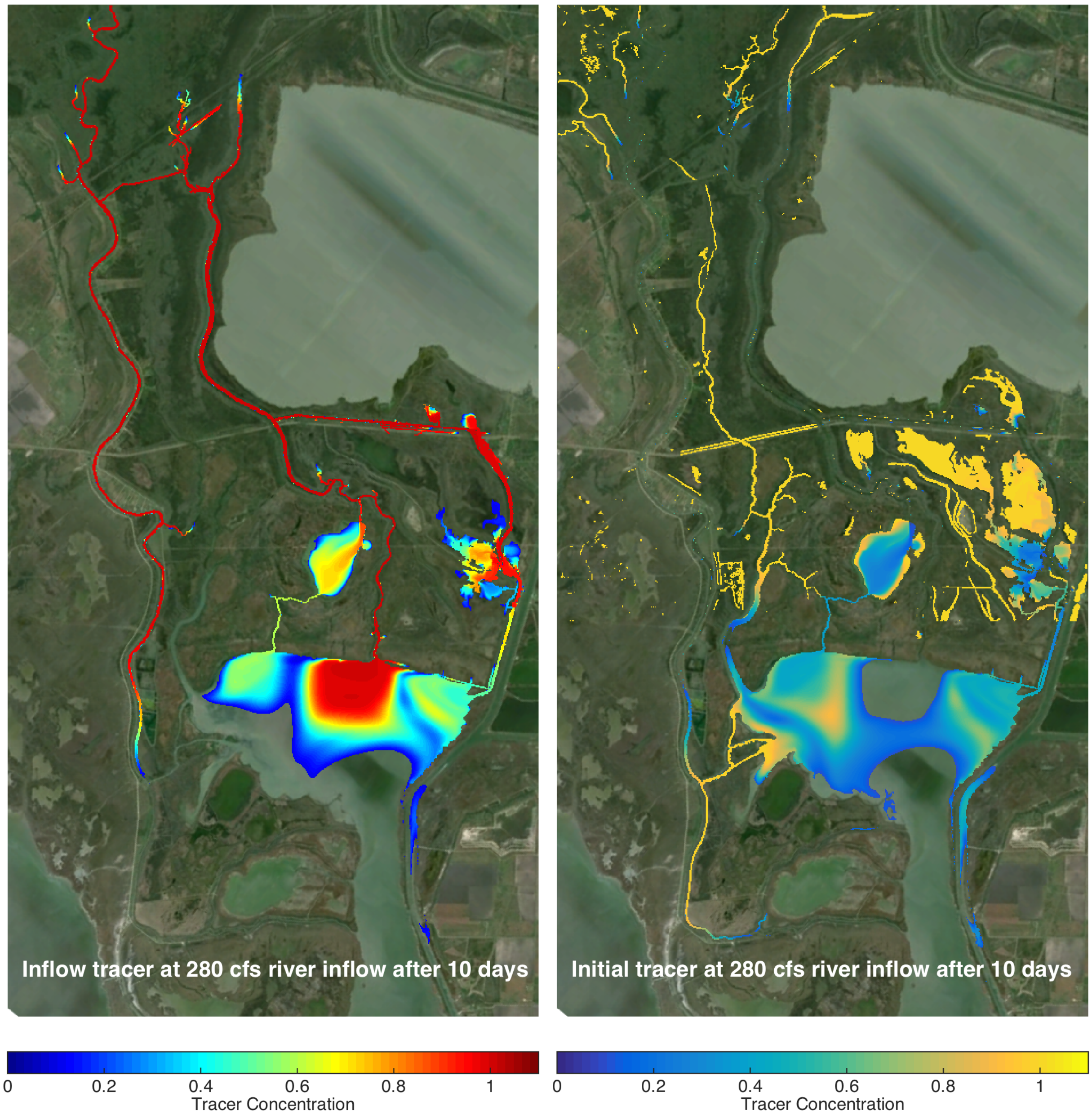

Figure D.3. Modeled tracer distributions for 280 cfs inflow case. Note that the colormaps extend beyond the [0,1] range of tracer concentrations for better contrast with the satellite image.

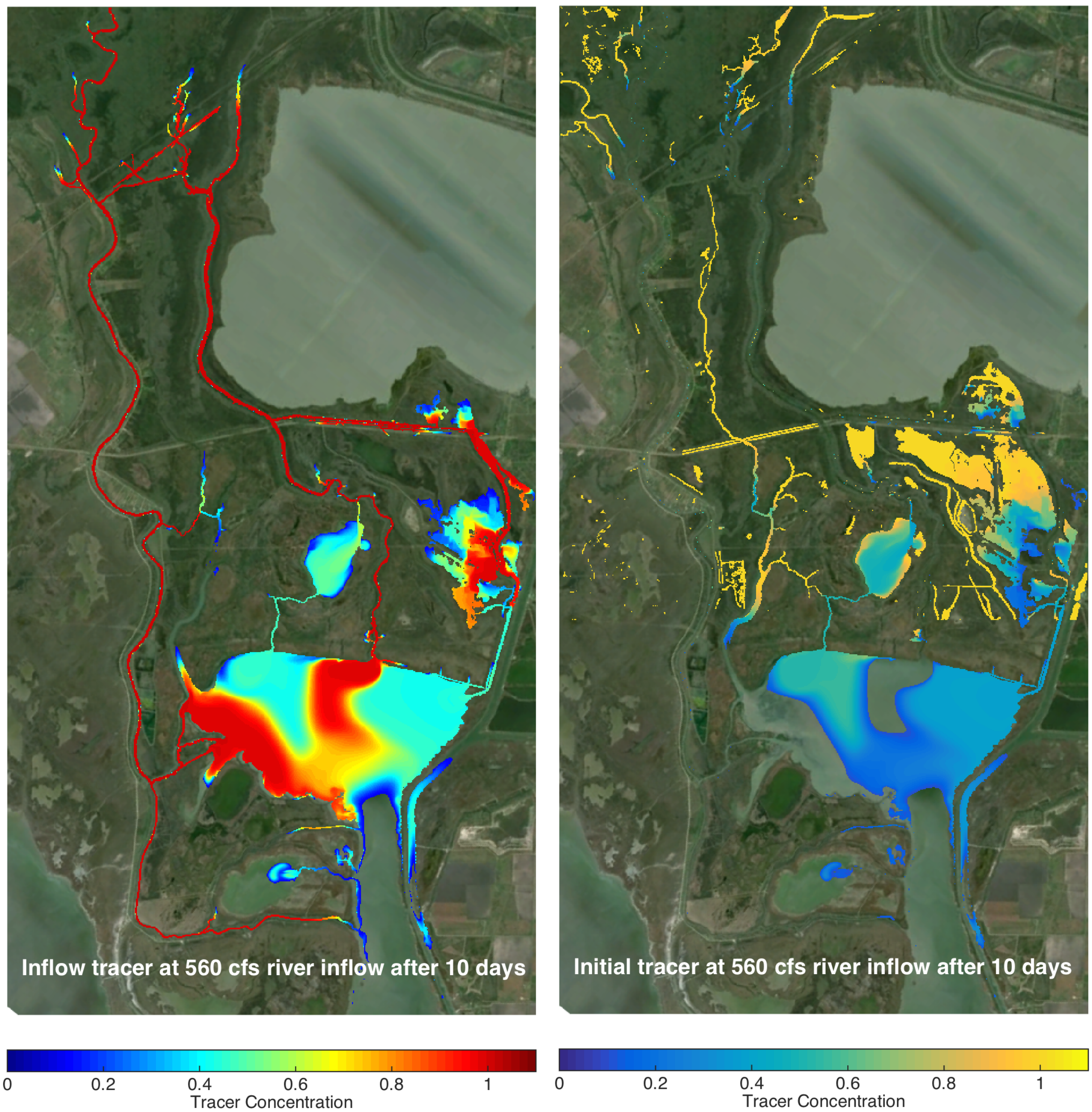

Figure D.4. Modeled tracer distributions for 560 cfs inflow case. Note that the colormaps extend beyond the [0,1] range of tracer concentrations for better contrast with the satellite image.

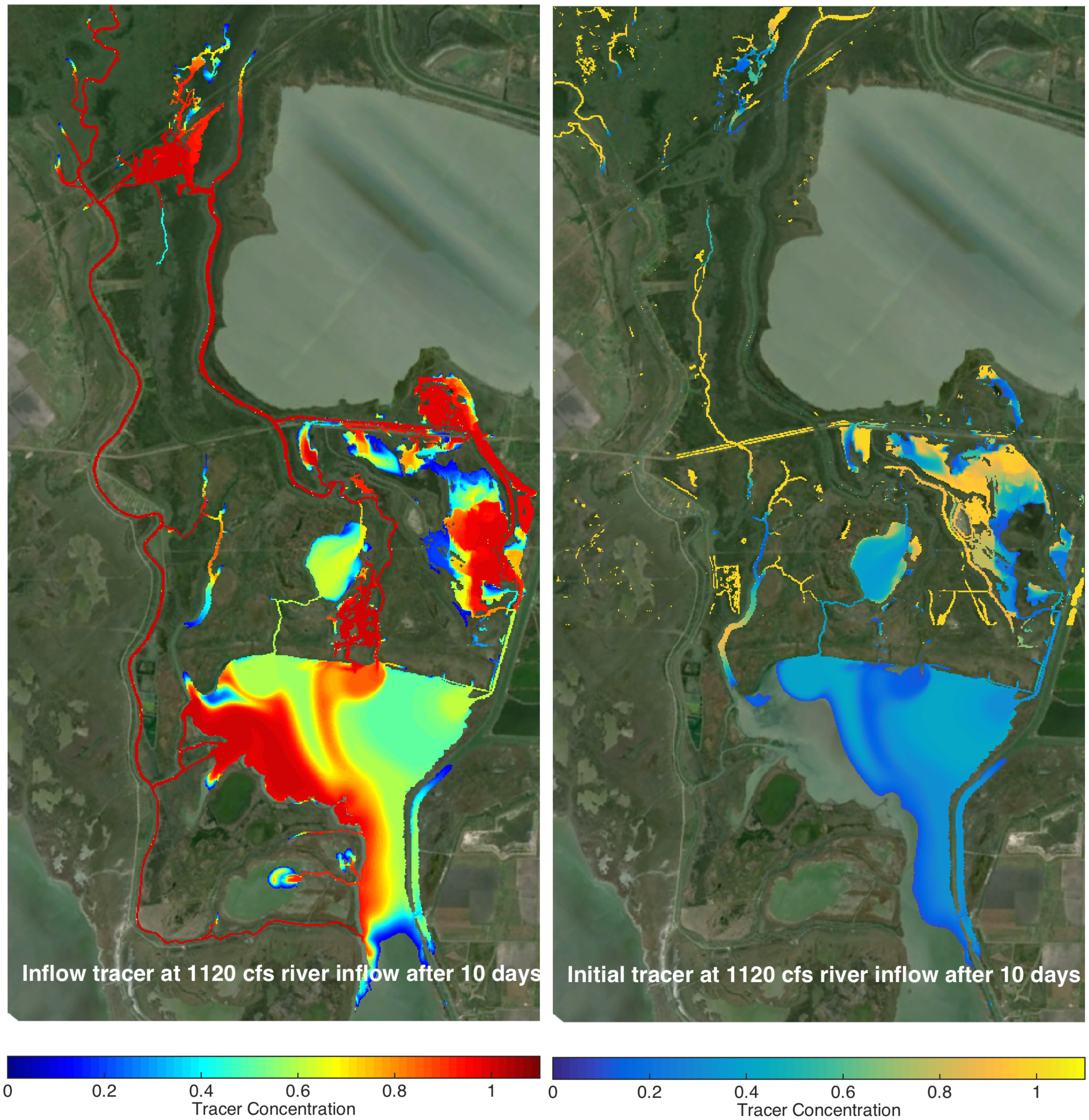

Figure D.5. Modeled tracer distributions for 1120 cfs inflow case. Note that the colormaps extend beyond the [0,1] range of tracer concentrations for better contrast with the satellite image.

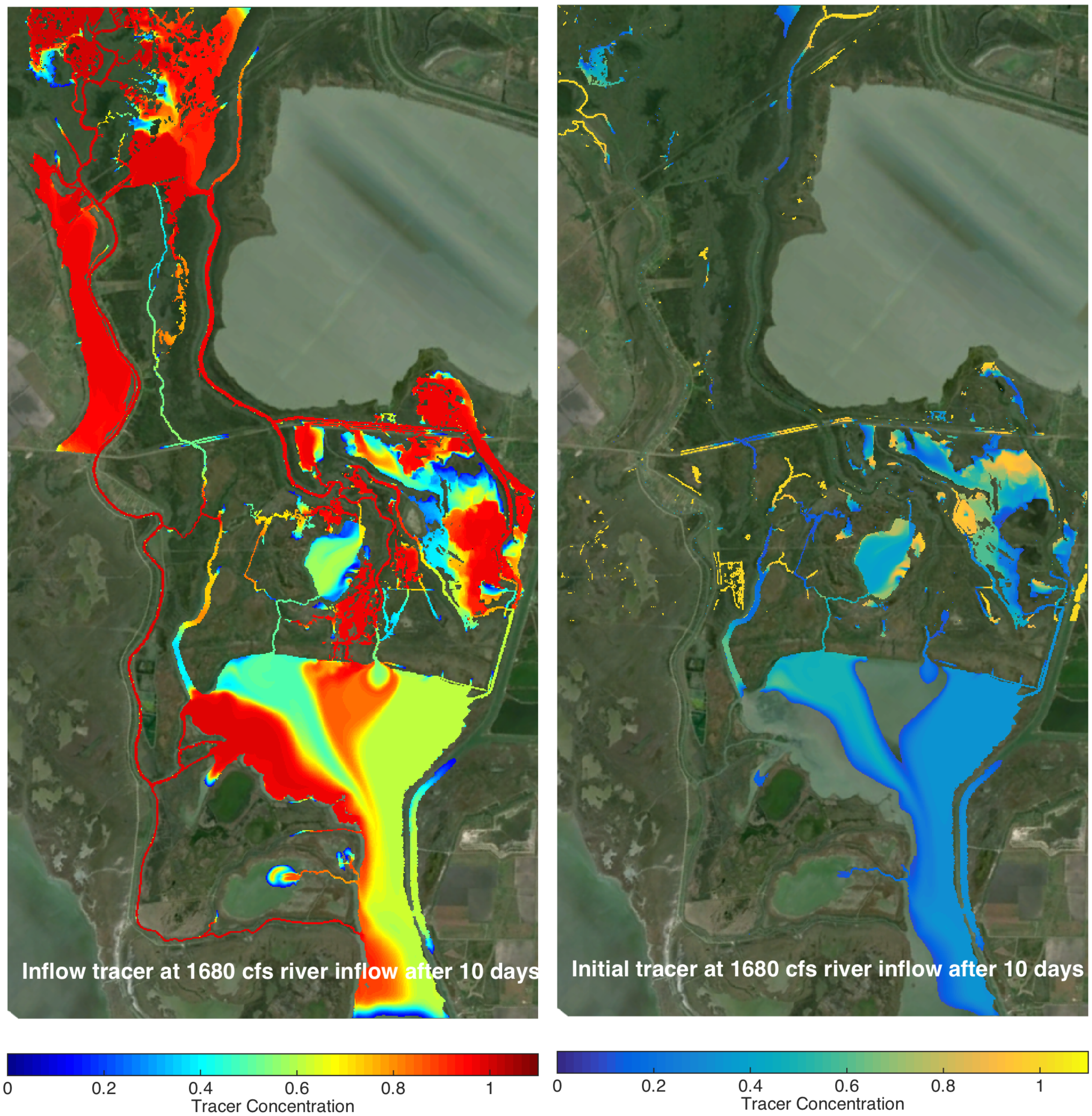

Figure D.6. Modeled tracer distributions for 1680 cfs inflow case. Note that the colormaps extend beyond the [0,1] range of tracer concentrations for better contrast with the satellite image.

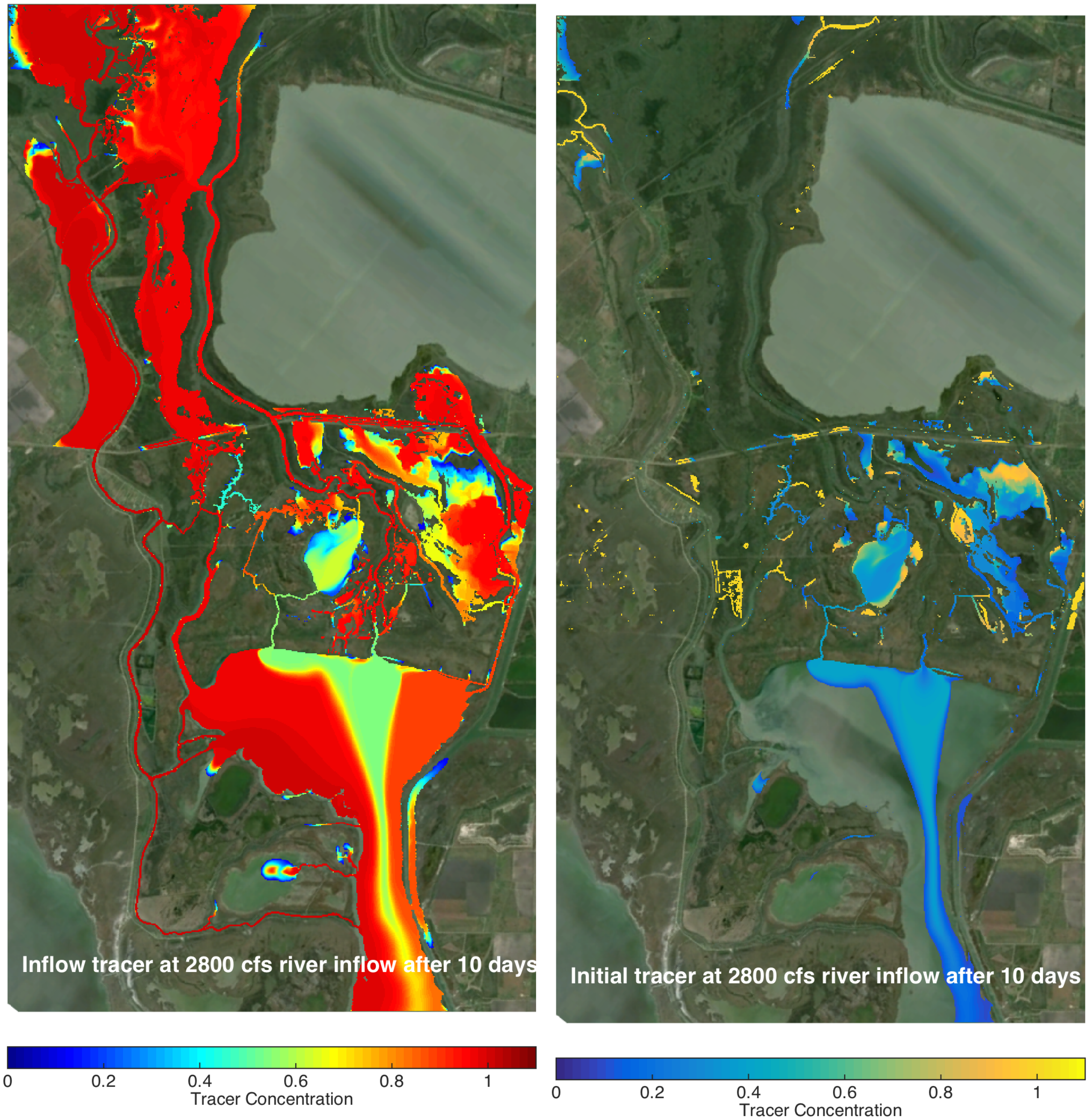

Figure D.7. Modeled tracer distributions for 2800 cfs inflow case. Note that the colormaps extend beyond the [0,1] range of tracer concentrations for better contrast with the satellite image.

Acknowledgements

This work was made possible with the support of the Guadalupe and San Antonio Basin and Bay Stakeholder Committee, the Texas Water Development Board, and the State of Texas.

Guadalupe Bayou Flow and Inundation Study Draft Report

Richard Carothers, Ben R. Hodges, and Paola Passalacqua
Contract #1400011710
TWDB/BBASC Comments to Final Report

REQUIRED CHANGES

General Draft Final Report Comments:

Please add the following statement to the over page of the final report:

PURSUANT TO SENATE BILL 1 AS APPROVED BY THE 83RD TEXAS LEGISLATURE, THIS STUDY REPORT WAS FUNDED FOR THE PURPOSE OF STUDYING ENVIRONMENTAL FLOW NEEDS FOR TEXAS RIVERS AND ESTUARIES AS PART OF THE ADAPTIVE MANAGEMENT PHASE OF THE SENATE BILL 3 PROCESS FOR ENVIRONMENTAL FLOWS ESTABLISHED BY THE 80TH TEXAS LEGISLATURE. THE VIEWS AND CONCLUSIONS EXPRESSED HEREIN ARE THOSE OF THE AUTHOR(S) AND DO NOT NECESSARILY REFLECT THE VIEWS OF THE TEXAS WATER DEVELOPMENT BOARD.

This study scope of work focused on using LIDAR data to produce maps for various inundation levels; field data collection of bathymetry, water levels and photographic evidence of channel conditions; and producing a calibrated hydrodynamic model of flows through the study area. The goal of this study was to utilize existing LIDAR data and develop a hydrodynamic model to evaluate the critical flow patterns and connectivity within the study area. The draft report does not currently meet all of the tasks identified in the scope of work, as the calibration of the hydrodynamic model is incomplete. As such, TWDB may require a second review in which comments should be considered for inclusion into the final report.

Please proofread the document thoroughly for grammar, spelling and typographical errors.

Specific Draft Final Report Comments:

1. As referenced in the Scope of Work, p. 4, 2nd paragraph, 2nd sentence; please address whether the Guadalupe Bayou Hydrodynamic Model incorporates the effects of tidal flooding, rainfall, river flooding, and wind-driven flows.
2. As referenced in the Scope of Work, p. 6, Deliverables item 6a: Please address how the figures and tables "illustrate the effects of freshwater inflow on benthos". However, if this statement was made in error on the Scope of Work, please disregard.
3. Section 3.3, p 18, third paragraph: Please expand this paragraph to further explain the 0 and 1.0 tracer values in each of the tracer scenarios as it relates to how this "approach allows us to see how inflowing water displaces water that is initially in the bayous."
4. Section 4, p. 20, first paragraph, last 2 sentences: Please provide supporting evidence, and/or refer to a specific figure in the document, and/or address the assertions within these sentences prior to the Summary section.
5. Section 4, p. 20, third paragraph, last sentence: Please provide supporting evidence, and/or address the assertion that 'these channel depths are not critical in hydrodynamic

modeling of the restricted flow conditions illustrated in Appendix D' prior to the Summary section.

6. Appendix C, p.34 - 35: Please correct the multiple occurrences of the text "Error! Reference source not found" to properly reference the correct source.

Figures and Tables Comments:

1. Figure 13, p. 19: Please ensure the scale accurately represents the color scale in the figure as the text in Section 3.3, p. 18, third paragraph, third sentence, indicates the relative tracer concentration only varies from 0 to 1.0, whereas the scale in figure 13 depicts tracer values above 1.0.
2. Figure A.3, p. 24: Please indicate the areas where "the channel centerline elevations are estimated from surrounding features and engineering judgement", either on this figure or on an additional figure.
3. Table C-2, p. 33: Please change the title of the table from "Table C-2" to "Table C-1".

SUGGESTED CHANGES

Specific Draft Final Report Comments:

1. Section 2.5, p.13, last paragraph, last sentence: One reviewer asserted that the list of model limitations on pages 12-13 suggests the last sentence on p. 13 should include the qualifier "limited" prior to the phrase "qualitative insight".

Figures and Tables Comments:

1. Figure 3, p. 5: Please remove duplicate artificial restriction demarcations if they exist on this figure.
2. Figure 4, p. 7: Please add arrows or other demarcations to identify the specific location of the Bayous as per the Scope of Work, Figure 1, p. 2.