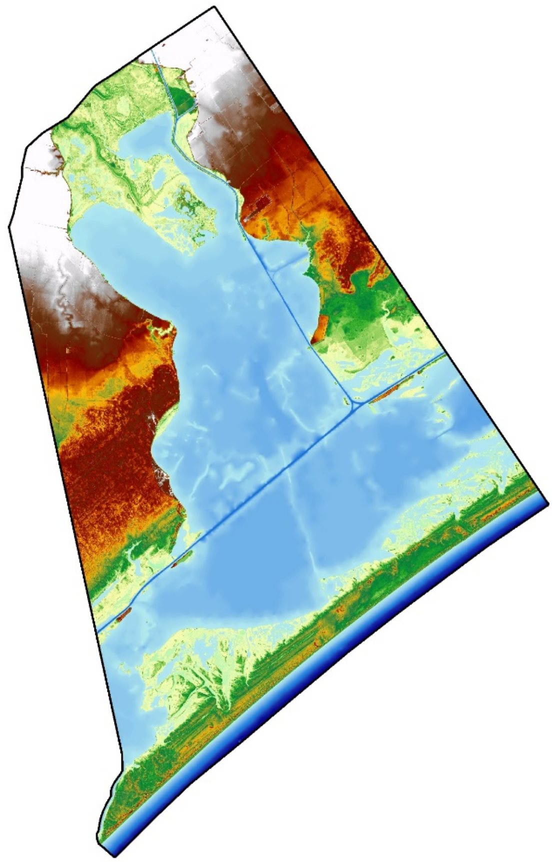
REVISION OF THE ELEVATION GRID AND BATHYMETRY DATA FOR THE SAN ANTONIO BAY EDYS MODEL TO INCORPORATE LIDAR DATA: PHASE 3 TASK 1 FINAL REPORT



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February 2015

INTRODUCTION

San Antonio Bay is one of the six major bays on the Texas Coast. The San Antonio River flows into the Guadalupe River approximately 12 miles northwest of the mouth of the Guadalupe River, from which the combined flow enters San Antonio Bay. The San Antonio River Authority (SARA) has the dual responsibility of managing water quality and quantity in the San Antonio River and its tributaries. The relative proportions of freshwater and saltwater and the quality of the freshwater entering the Bay are important to SARA, in part because the San Antonio River is a major source of freshwater to the San Antonio Bay and decisions made by SARA affect both the quality and quantity of this freshwater supply.

SARA recognizes the importance of making good management decisions relative to both the San Antonio River and the San Antonio Bay ecosystems. However, both of these are complex ecological systems and simple, often single-factor, approaches are not adequate to provide the necessary tools for effective management of these linked systems. One tool that would be of substantial benefit for decision making in the San Antonio River-San Antonio Bay complex is a dynamics ecological simulation model that could integrate hydrological and ecological responses in a practical and scientifically valid manner.

EDYS is a general ecosystem simulation model that is mechanistically based and spatially explicit. It has been widely used for ecological simulations, watershed management, land management decision making, environmental planning, regulatory compliance, and revegetation and restoration design analysis by federal and state agencies, municipal and water authorities, and corporations in Texas, 11 other states, and internationally.

SARA is in the process of having an EDYS model developed as an integrated management tool for use on the San Antonio River watershed, including San Antonio Bay. KS2 Ecological Field Services (KS2) submitted a proposed Scope of Work (SOW) entitled “Development of an Ecological Model of the San Antonio Bay Based on the EDYS Ecological Model” to SARA in May 2011. That SOW included a multi-phase approach to the development of the model. In June 2011, SARA authorized KS2 to proceed with Phase 1. The objectives of Phase 1 were to 1) develop a spatially realistic model of plant community distribution (terrestrial and marsh) over the San Antonio Bay footprint and 2) realistically simulate changes in vegetation response of the marsh and adjacent terrestrial vegetation to change in water levels and change in salinity. Phase 1 was completed in June 2012.

SARA authorized KS2 to proceed with Phase 2 of the development of the San Antonio Bay model in July 2012. Phase 2 contained tasks concentrating on 1) providing some limited field verifications of spatial data included in the Phase 1 model, 2) the inclusion of additional literature data on salinity and submergence effects on vegetation and on decomposition and mineralization dynamics, 3) inclusion of a fine-scale sub-model, 4) increasing the complexity of the aquatic model, and 5) evaluating varied precipitation levels across the spatial grid. Based on results of Phase 2, SARA authorized KS2 to proceed on Phase 3 development of the model in October 2013.

In 2013, KS2 and Texas Tech University (TTU) began the process of transferring further development of the EDYS model to TTU. Key personnel associated with the EDYS model and the development of the San Antonio Bay EDYS model are now employees of TTU and also keep an associate status with KS2. In October 2014, a Master Services Agreement was entered into between SARA and TTU for the purpose of continuing work on the EDYS models for San Antonio Bay and the San Antonio River watershed, as well as other ecological and hydrological projects. In December 2014, SARA authorized TTU to proceed on Phase 4 of the development of the San Antonio Bay EDYS model.

Phase 3 of the development of the San Antonio Bay EDYS model contains ten tasks: 1) update the elevation grid by inclusion of recently available LIDAR elevation data, 2) complete the development of the multi-layer aquatic and the decomposition and mineralization sub-modules, 3) include additional field verification of vegetation and topographic spatial data, 4) establish vegetation validation plots, 5) compare methods of sheet-flow calculations between the EDYS and TXRR models, 6) evaluate methods of modeling circulation patterns, 7) determine the effort required to link the EDYS and TXBLEND models, 8) attend meetings with SARA and various State, regional, and local agencies, 9) provide an EDYS workshop for SARA personnel, and 10) provide for project management. Task 4 was completed in December 2014 (McLendon 2014).

This report (Revision of the Elevation Grid and Bathymetry Data for the San Antonio Bay EDYS Model to Incorporate LIDAR Data: Phase 3 Task 1 Final Report) is the deliverable for Task 1 of Phase 3. It is presented in two parts: 1.0 Revision of the Elevation Grid and 2.0 Revision of Bathymetry Data.

1.0 REVISION OF THE ELEVATION GRID

1.1 Development of 1-m DEM

Landscape topography (elevations) is an important component in EDYS model of the San Antonio Bay. For the San Antonio Bay model, representation of terrestrial and bathometric elevations are necessary inputs to the model. Models developed for Phases 1 and 2 relied on USGS Digital Elevation Models (DEM) with 10-m horizontal resolution. This level of resolution is adequate for simulating large-scale dynamics but it is inadequate for simulating small scale dynamics. Many important ecological interactions in bay and estuarine systems are affected by variations in topography over distances of < 1 m. Small-scale elevation data from light detection and ranging (LIDAR) measurements were obtained from SARA and used to develop a 1-m resolution representation of elevations within the San Antonio Bay model domain.

Collection of LIDAR measurements use an active laser transmission and detection sensor array to estimate distances from the sensor to a target. The sensor transmits a laser pulse and the time between transmission and subsequent return detection by the sensor is recorded, allowing distance to be calculated. Ground surface LIDAR measurements generally use an airplane mounted sensor and can produce data sets with measurements on the order of 1-3 m apart. The laser pulses, however, can be returned from interception by any solid or semi-solid object and the pulse can be re-returned more than one time. Certain characteristics of the returns, e.g., intensity and return order, can be recorded by the sensor and used to classify the type of object encountered by the pulse as vegetation, ground/solid object, or water. Returns classified as being returned by ground, or ground points, can be effectively used to estimate terrestrial surface elevations.

More than 135 GB of LIDAR related data for the San Antonio Bay area were obtained from SARA. These data included > 1200 Laser Point Files (LAS) identified as being collected by three different agencies in three different years: 70% of the files were collected by USGS in 2011, 29% by FEMA in 2006, and 1% by TNRIS in 2009. Approximately 220 of these LAS files were required to represent the terrestrial area in the San Antonio Bay model domain. When possible, LAS files from the USGS 2011 data were used. In total, 212 USGS_2011 and 8 FEMA_2006 files were used in development of the new San Antonio Bay DEM. The 220 LAS files contained > 518.4 million LIDAR measurement points and these points had a median point spacing of ~ 1.5 m, as estimated by ArcGIS 10.2 (ESRI 2014).

1.1.1 LIDAR Data Set

A group of tools within ArcGIS 10.2 called the LIDAR data set tools (ESRI 2014) facilitate the analysis, organization, and visualization of LIDAR data. These tools in ArcGIS 10.2 were used to derive a fine-scale DEM from the available LIDAR measurement points specifically classified as ground points. An initial LAS Data Set was constructed by importing the 220 LAS files and implementing the 'Ground' filter. Additional characteristics within the LAS Data Set were defined using various types of surface constraint shapefiles. The extent (or outside edge) of the LAS Data Set was defined by including the San Antonio Bay model domain shapefile as a soft clip surface constraint layer (ESRI 2014). A shapefile representing the areas of missing and un-classified LIDAR measurement points was used as a soft erase surface constraint layer to define areas that should be represented as 'NoData' in the initial LAS Data Set.

The ArcGIS LIDAR data set tools allow a temporary (i.e., stored in virtual memory) visualization of small areas, e.g., an area of 4 × 6 km on a 19-inch computer screen, of LAS Data Sets as point clouds or surfaces (Fig. 1 and 2). Investigation of the surface visualization from the initial LAS Data Set indicated that elevation representations in the terrestrial areas seemed reasonable in magnitude and variability. Elevation representations for the surfaces of perennial water bodies, however, exhibited considerable variability and did not seem reasonable.

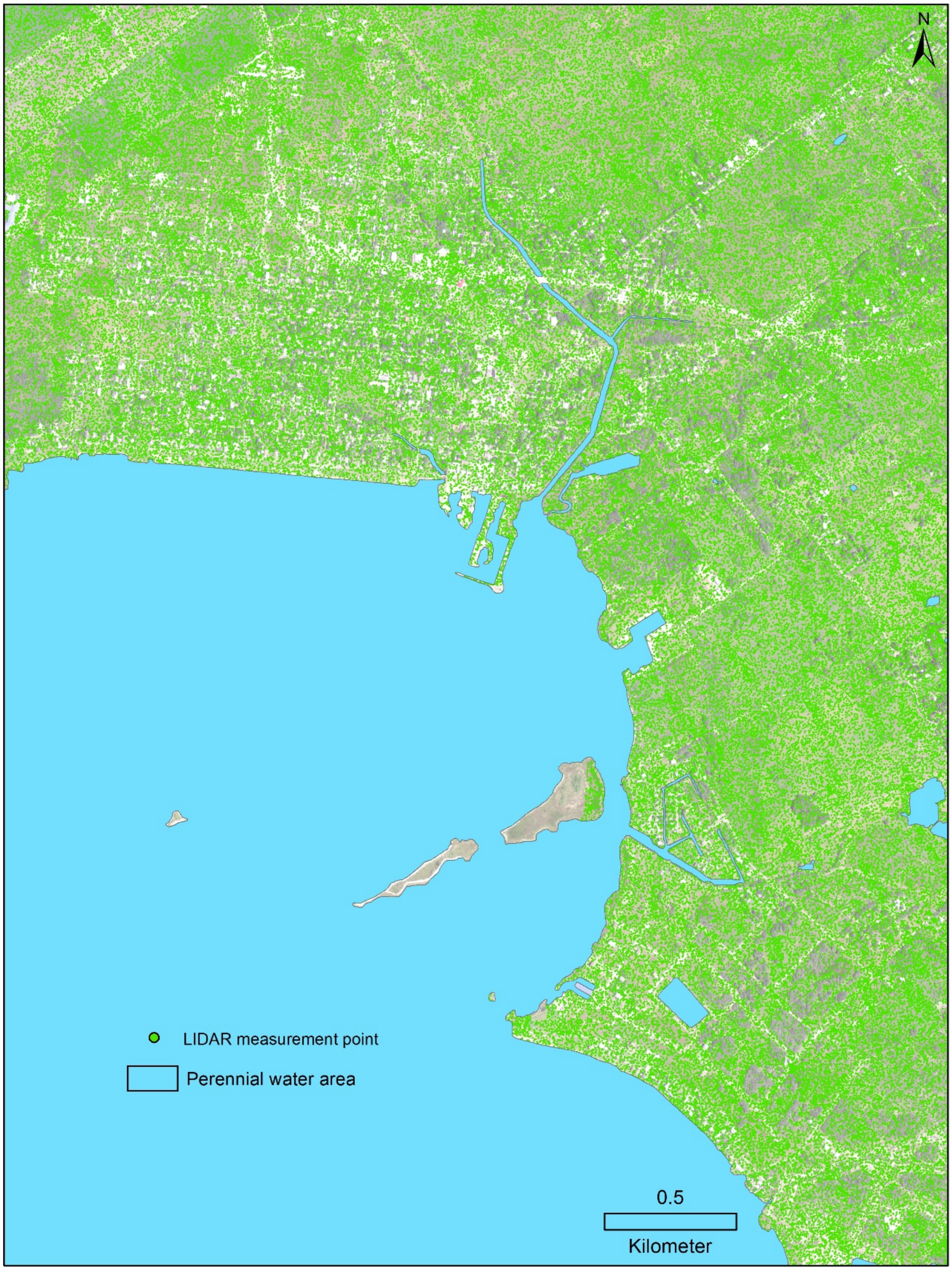

Figure 1. Example of the LIDAR measurement point cloud, perennial water areas, and missing LIDAR measurement points on offshore islands south of Seadrift, TX.

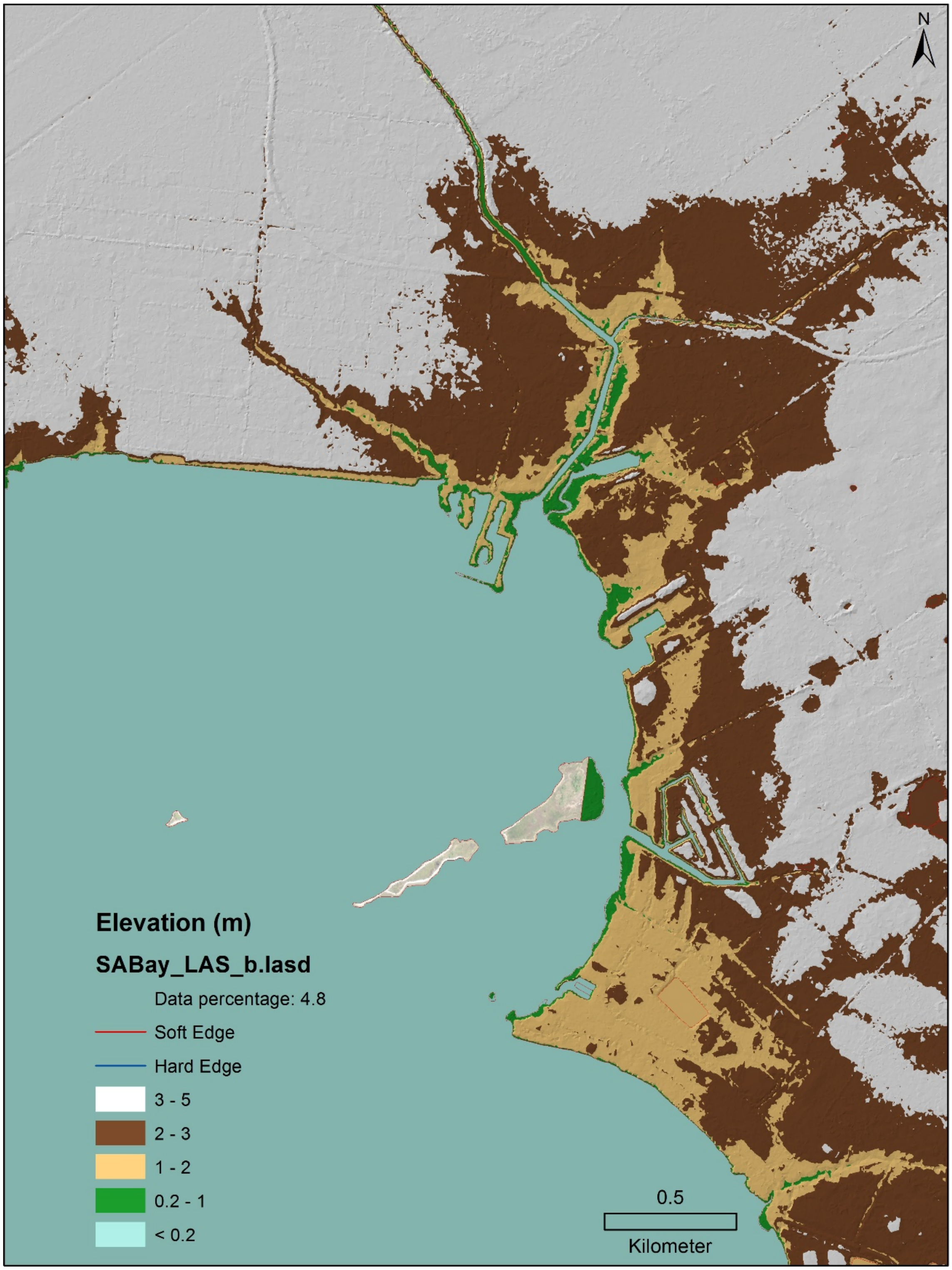

Figure 2. Example of the LAS Data Set surface visualization, soft and hard surface constraint edges, and missing LIDAR areas on offshore islands south of Seadrift, TX.

Visualization of the point cloud indicated that few LIDAR measurement points were available for the perennial water areas. This would be expected since only ground classified points were being used and any measurement points from areas of water should have been classified as water points. It was necessary to develop a surface constraint layer to represent the surface of each perennial water body as a separate area of uniform elevation.

The U.S. Fish and Wildlife Service maintains the National Wetlands Inventory, identifying and classifying wetland areas and providing this data in ESRI compatible formats. Wetland inventory data were available for Texas and were downloaded as a polygon shapefile from the National Wetlands Inventory website (http://www.fws .gov/wetlands/Data/State-Downloads.html). The Texas Wetland Inventory shapefile was clipped to the San Antonio Bay model domain shapefile to create a wetlands inventory layer for the San Antonio Bay model domain. One attribute contained within the wetlands files was wetland type. It was determined that perennial water bodies were represented as four wetland types: estuarine and marine deepwater, lake, pond, and riverine. Polygons classified as these four wetland types were selected and exported to a new shapefile representing perennial water bodies.

Open water polygons classified as estuarine and marine deepwater were determined to correspond to Bay water and the narrow strip of Gulf water south of Matagorda Island. These polygons within the new perennial water shapefile were inspected, and polygons that were not directly connected to the open Bay and Gulf water were removed from the Bay and Gulf wetland type. These select polygons that did not seem to be characteristic of open Bay or Gulf water were reclassified into the lake wetland type. Gulf and Bay polygons were assigned an elevation of 0.1 m in a new column called LevelElev added to the shapefile attribute table. The Zonal Statistics tool in ArcGIS 10.2 was used to calculate to the average of all LIDAR measurement points within each separate water polygon. These average values were assigned to each lake, pond, and riverine polygon as the LevelElev value. Riverine polygons associated with Goff Bayou, the GBRA Diversion Canal/Hog Bayou, and the Guadalupe River were inspected to ensure that each upstream polygon was assigned a LevelElev value greater than all downstream polygons. This adjustment of the riverine polygons was done to support a theoretical flow towards the Bay.

The perennial water body shapefile was imported into the LAS Data Set as a hard replace surface constraint layer, indicating that elevations within each of the shapefiles’s polygons were replaced with the LevelElev value. Including the perennial water surface constraint provided a second iteration of the LAS Data Set visualization that used only ground classified LIDAR measurement points in the terrestrial areas and a uniform elevation value within each unique perennial water body. The areas of missing and not classified LIDAR data (Fig. 3) were still represented as NoData.

At this point the LAS Data Set was converted to a 1-m resolution DEM raster file using the LAS Data Set to Raster tool in ArcGIS 10.2. This conversion tool creates a permanent raster file from the temporary visualization defined by the LAS Data Set. The conversion process retains the characteristics of the LAS Data Set visualization, including the classification filters and surface constraint definitions. The LAS Data Set to Raster tool was set to use an average elevation value for each 1 × 1-m pixel that contained at least one LIDAR measurement point and used a natural neighbor interpolation routine to estimate elevation values for pixels that did not contain LIDAR measurement points. Implementation of the conversion tool created a permanent, 1-m resolution DEM with the same characteristics as the LAS Data Set visualization described in the paragraph above.

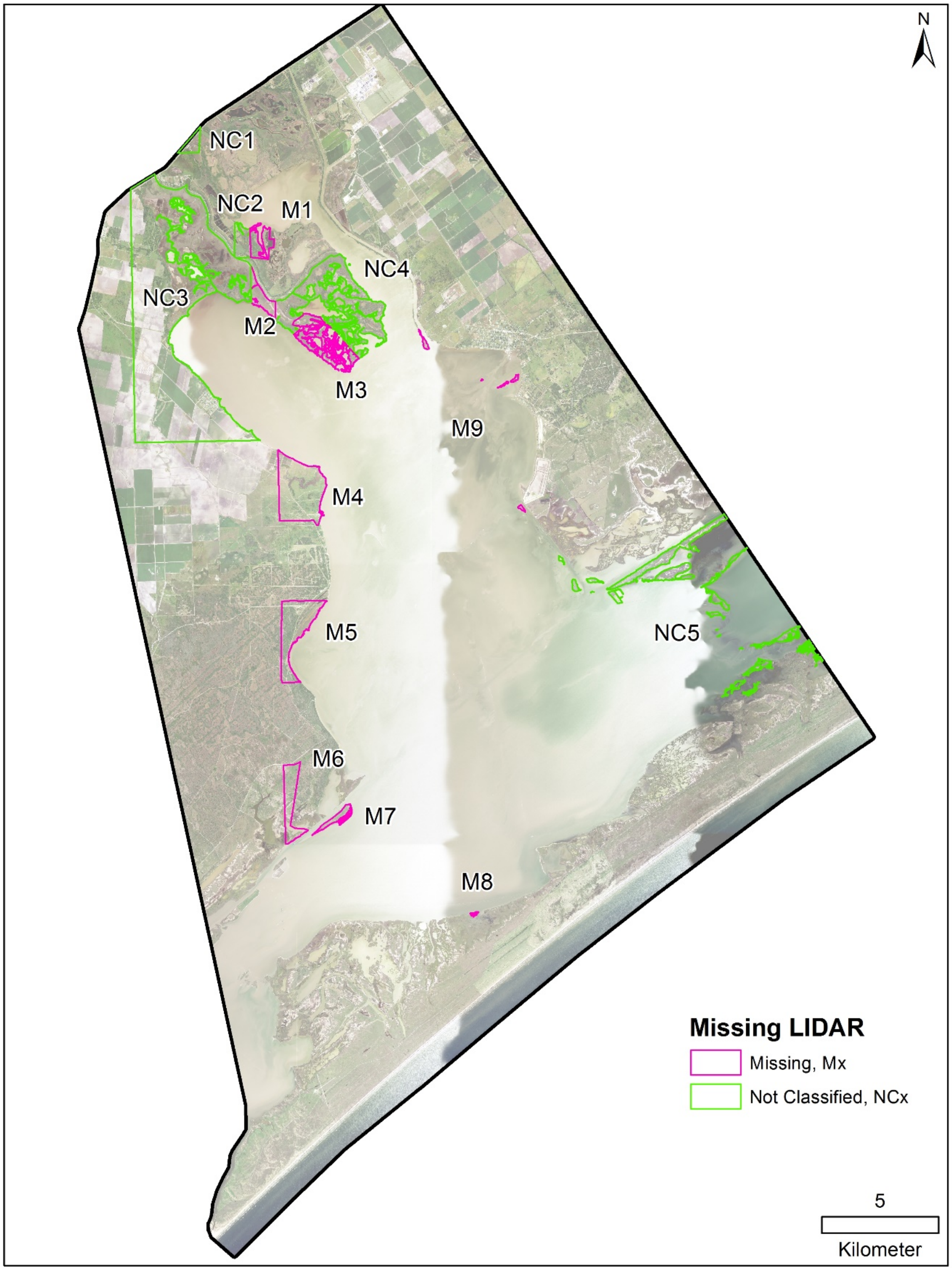

Figure 3. Areas of missing and un-classified LIDAR data in the San Antonio Bay model domain.

1.1.2 Missing and Un-classified LIDAR Data

Although the majority of the area in the San Antonio Bay model domain was represented by LIDAR points that had been classified as ground points, there were several important areas within the San Antonio Bay model domain that were missing LIDAR measurement points or where the data were not classified. There were nine areas of missing LIDAR measurement points and five areas where LIDAR data existed but was not classified (Fig. 3). The areas of missing LIDAR data were communicated to the SARA GIS team and a specific search of the SARA LIDAR data archives was conducted. No additional data for these areas were found. Subsequently, a data request was forwarded to the Texas Natural Resources Inventory System but no additional LIDAR data were available for the missing areas.

Other sources of potential data were investigated to fill in the data gaps shown in Figure 3. Elevation data at a resolution of 3 m has been made available by USGS in the area of San Antonio Bay. A series of 3-m resolution DEM files were downloaded from the USDA-NRCS Geospatial Data Gateway (http://datagateway.nrcs.usda.gov/GDGOrder.aspx). It required a combination of 14 3-m DEM files, each representing an area approximately 12 × 14 km, to cover the San Antonio Bay model domain. These 14 files were mosaicked into one large DEM file and clipped to the San Antonio Bay model domain outline using the Image Analysis tool in ArcGIS 10.2.

The resulting 3-m, USGS DEM (Fig. 4) included elevation data corresponding to the missing and un-classified LIDAR areas M1, M4, M5, M6, NC1, NC2, and the majority of NC3. These USGS DEM data were used to supplement the 1-m DEM derived using ground classified LIDAR measurement points. The Raster Calculator tool in ArcGIS 10.2 was used to implement a conditional function where any pixel assigned as NoData in the 1-m resolution, LIDAR-based DEM would be assigned a spatially corresponding value from the 3-m USGS DEM. The USGS DEM did not, however, provide elevation data for areas M2, M3, M7, M8, M9, NC4, NC5, and a small (approximately 0.004 km^2) triangular area in the northeast part of NC3.

A review of the supporting documentation for the LIDAR measurement points in the NC areas did not provide insight into the reasons that these data were not classified. Area NC4, comprising the southeastern Guadalupe River delta (south of the Guadalupe River), contained pockets of dense vegetation mixed with common bodies and channels of water. This mix of dense vegetation and water bodies likely limited the number LIDAR measurement points that were characteristic of ground measurements, impeding reliable classification of the LIDAR measurement points into ground, vegetation, and water points by the collecting agencies. Similarly area NC5, the islands in the southeastern part of the domain between San Antonio and Espiritu Santo Bays, is characterized by narrow islands with areas of dense vegetation. The configuration of these islands likely limited reliable classification of LIDAR measurement points.

The un-classified LIDAR measurement points in areas NC4, NC5, and the sub-area of NC3 were determined to represent the most reliable elevation data for these areas. A shapefile was created to represent the three areas and used in the LIDAR data set tool as a soft clip surface constraint, creating a LIDAR-based surface specifically for areas NC4 and NC5 and the small sub-area of NC3. This LAS Data Set was converted to a 3-m resolution DEM. The use of 3-m resolution, compared to the 1-m resolution used with ground classified points, was an effort to smooth differences between neighboring LIDAR measurement points that represented vegetation canopy tops and bare ground. The 3-m DEM for areas NC4 and NC5 were used to augment the 1-m DEM. A conditional raster calculation was used where NoData pixels in the 1-m DEM were replaced with spatially corresponding pixels from the 3-m NC4/NC5/NC3 DEM. This process left only areas M2, M3, M7, M8, M9 as NoData in the resulting 1-m DEM.

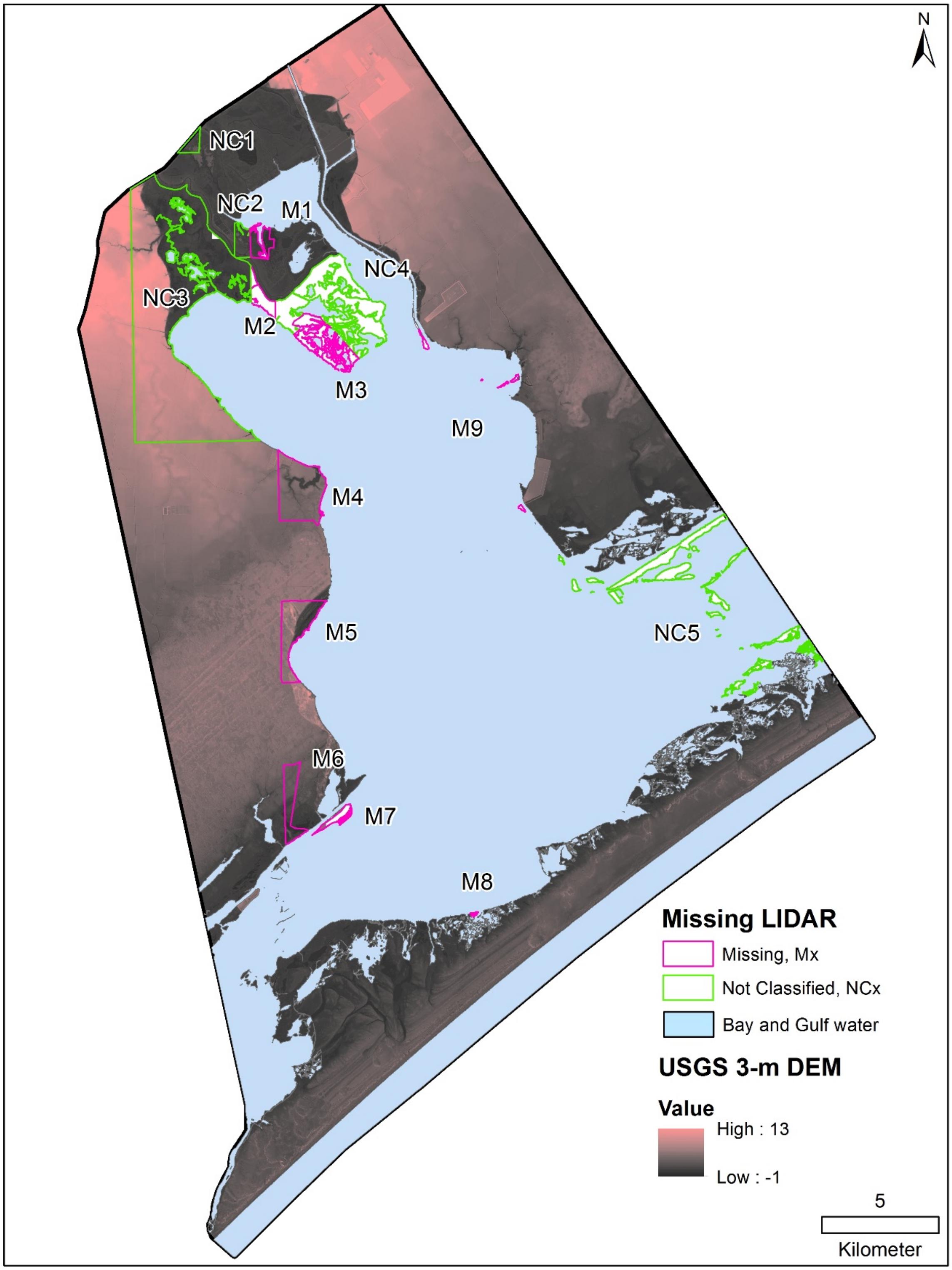

Figure 4. Mosaicked and clipped USGS 3-m DEM for the San Antonio Bay model domain. The DEM is shown in relation to the missing and un-classified LIDAR data areas from Figure 3.

Areas M2 and M3 are areas of missing LIDAR measurement points along the Hynes Bay edge of the Guadalupe River delta and areas M7, M8, and M9 are small islands along the shore of San Antonio Bay. The finest resolution elevation data found for these five areas was 10-m DEM data available from USGS. Visual inspection of this 10-m data, however, indicates that the elevations represented in these areas are less variable than might be expected given the variability of wetland and vegetation community delineations. Although the 10-m elevation data sets seem generalized for these areas, they seem to be the best available data. A conditional raster calculation was used to replace NoData pixels in areas M2, M3, M7, M8, and M9 of the 1-m DEM with elevations from the 10-m DEM.

1.1.3 Discussion

An iterative process was used to develop a 1-m DEM for the San Antonio Bay model domain. Where possible the 1-m DEM was produced using > 203 million ground classified LIDAR measurement points primarily from a 2011 USGS LIDAR archive and secondly from a 2006 FEMA LIDAR archive. The San Antonio Bay model domain covers approximately 953 km^2, and the terrestrial area (i.e., not Bay or Gulf water) is approximately 486 km^2. Ground classified LIDAR measurement points were available for 87.4% of the terrestrial area and were used to interpolate 1-m resolution DEM data where available. Elevation values for the remaining 12.6% of the domain were obtained from other sources. Data from USGS 3-m DEM files were used for 9% of the terrestrial area. Un-classified LIDAR measurement points were used for 2.3% of the terrestrial area. Data from USGS 10-m DEM files were used for 1.3% of the terrestrial area. The resulting terrestrial DEM provides a quantitative representation of small-scale elevation changes associated with natural and anthropogenic features.

In contrast with the 10-m DEM, correspondence can be seen between details in the 1-m DEM and the NAIP aerial photo (Fig. 5). The section of road visible in the southwest corner of Fig. 5 is an anthropogenic feature that can be seen in both the 1-m DEM and the aerial photo, but is not clear in the 10-m DEM. Detail in the DEM allows the profile of the road to be visualized in Profile A. This detail would allow the effect of the raised roadbed on local hydrology to be modeled. The area of Profile B corresponds with the southern group of Aransas Wildlife Refuge validation sample locations (AWR-C through AWR-F). Proximity of this area to the Bay suggests that the complexity of plant communities are related to the dynamic balance between fresh and salt water. Small-scale differences in elevation regulate fresh versus salt water dynamics in such areas and the 1-m DEM provides the detail needed to visualize and model these dynamics.

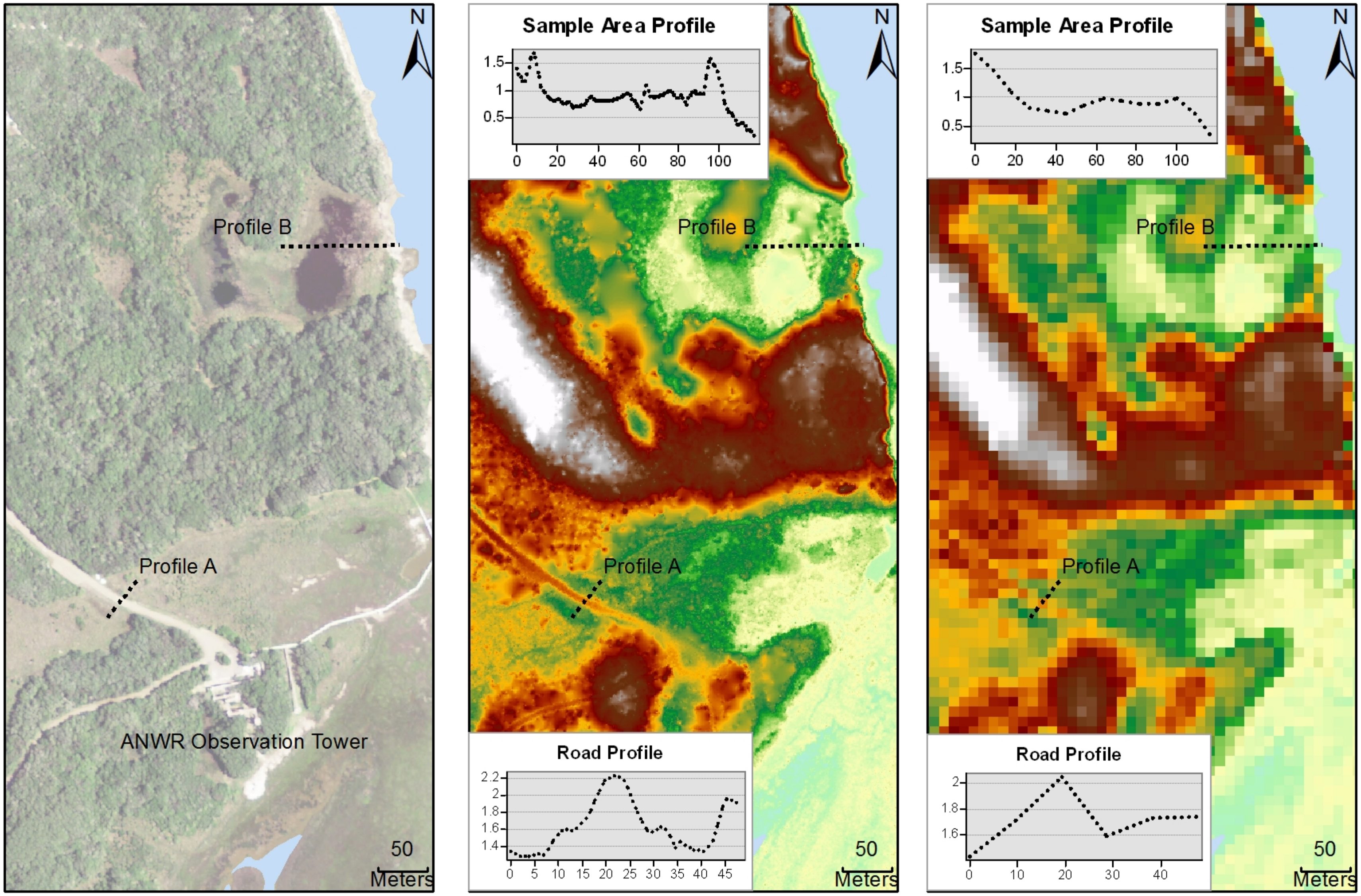

Figure 5. Comparison between the NAIP aerial photo, the 1-m DEM, and the 10-m DEM for an area of Aransas National Wildlife Refuge near the Observation Tower.

2.0 REVISION OF BATHYMETRY DATA

2.1 Development of Bathymetric Depth DEM

In complement to representation of the terrestrial topography, the bathymetric topography of San Antonio Bay will be foundational input for the planned multi-layer aquatic modeling. The floor of San Antonio Bay has several prominent features including relatively flat areas punctuated by shell reefs, several navigation channels flanked by spoil areas, and shallow areas surrounding and inlets amongst numerous islands north of Matagorda Island and within the delta. Unlike the terrestrial area of the model domain, there are no small-scale, quantitative data sets available for the bathymetry of the Bay floor. Additionally, bathymetric topography must be estimated with a median tide level being used as a reference. In the following discussion references to elevation will indicate distance above the median tide level and references to bathymetric depths will indicate distance below the median tide level.

Two primary, quantitative bathymetry data sources were evaluated for use in updating the bathymetry representation used in Phase 1. Both data sets evaluated were obtained from the National Oceanographic and Atmospheric Administration-National Ocean Service (NOAA-NOS). The first was a raster data set produced by the NOS Estuarine Bathymetry program. The second data set was a pair of digital, geo-referenced copies of paper navigational charts published by NOAA-NOS to represent San Antonio Bay. Neither of the NOAA-NOS data sets provided representation of the bathymetry for the narrow strip of Gulf water south of Matagorda Island. A third data set that provided valuable qualitative data was a set of 0.5-m resolution aerial photos taken in winter 2009.

The raster bathymetry data obtained from the NOS Estuarine Bathymetry program were identified as San Antonio Bay (G290) and were downloaded from http://estuarinebathymetry.noaa.gov/bathy _htmls/G290.html. The data set is 30-m resolution and based on soundings collected in 1934 and 1935 with a reported median spacing of ~ 134 m. The NOS raster data represent elevations for the main part of San Antonio Bay including Hynes Bay. The data do not, however, represent elevations for Guadalupe Bay and Mission Lake, the shipping channels, or the shallow inlets associated with the northern part of Matagorda Island and the delta (Fig. 6).

Navigational chart data were downloaded from http://www.charts.noaa.gov/InteractiveCatalog /nrnc.shtml and identified as Nautical Chart 11315, Sides A and B. The charts were marked as being updated in October 2010. Sounding depth entries are recorded on the charts approximately 500 to 600 m apart. Shallow areas such as shell reefs and spoil areas are outlined and/or represented with additional sounding depths and/or contour lines. The location and general widths of the shipping channels are marked and the depths of the channels are noted in the marginalia. Data are provided by the charts for the main part of San Antonio Bay including Hynes and Guadalupe Bays. Data are not provided for Mission Lake or the shallow Matagorda Island and delta inlets (Fig. 7).

Aerial photos taken during January of 2009 were available for the San Antonio Bay model domain and were downloaded from http://earthexplorer.usgs.gov/ under the heading of Aerial Imagery, High Resolution Orthoimagery. Thirty-five separate image files were required to represent the San Antonio Bay model domain. These image files were mosaicked and clipped to the model domain shapefile using the ArcGIS 10.2 Image Analysis tool. Much of the Bay water in these photos was clear enough that bottom features were visible and could be cross-checked with features in the other two data sets. It was determined through comparison to aerial photos from the National Agricultural Inventory Program that the 0.5-m aerial photos were taken during a period of low tide levels within the Bay (Fig. 7).

Figure 6. Coverage of the NOS, 30-m raster data. Data is not provided for Guadalupe Bay, Mission Lake, or the shallow inlets within the delta.

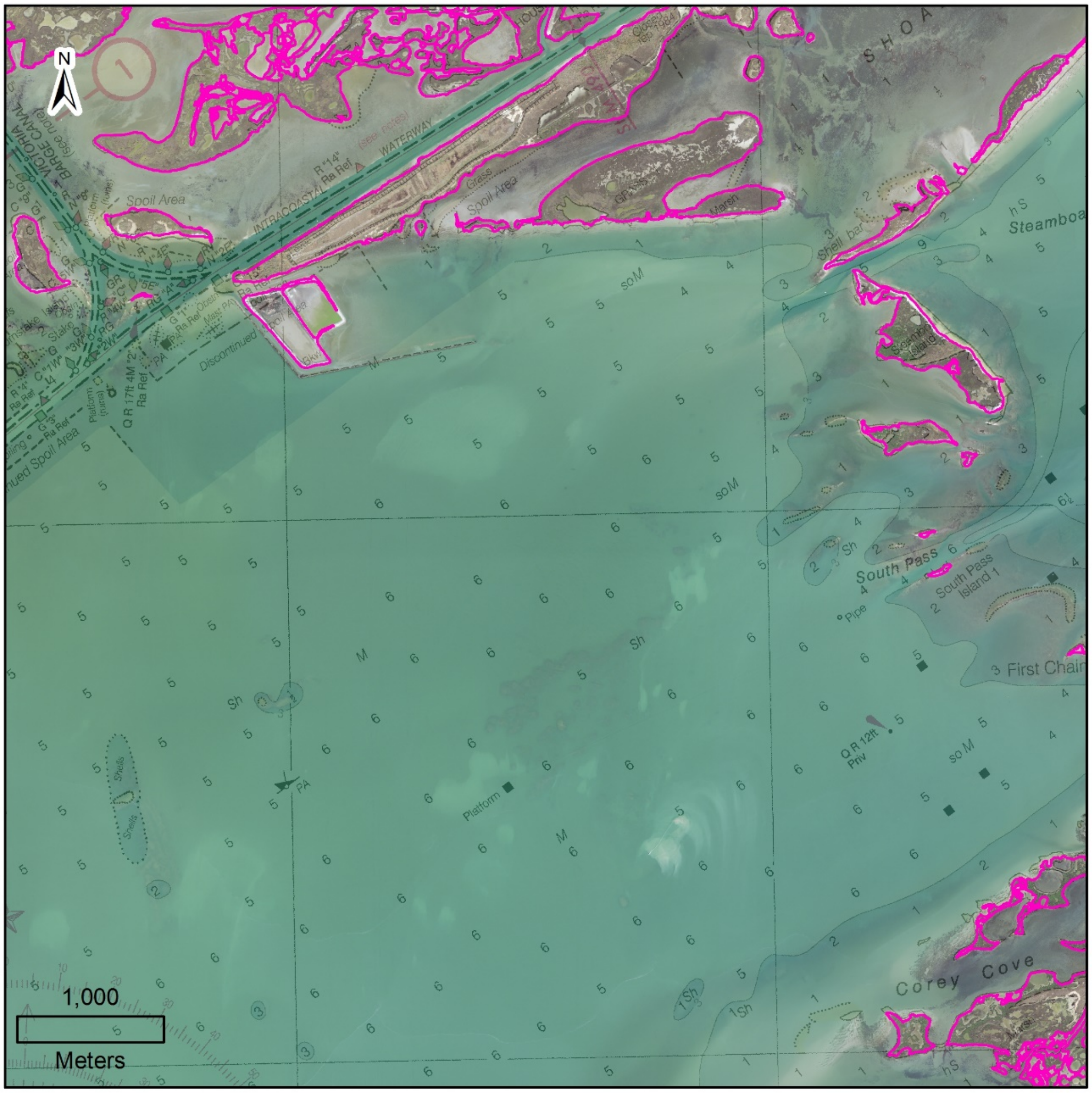

Figure 7. Partially transparent navigational chart data over the 2009, 0.5-m resolution aerial photo. Additional details of bottom features recorded on the navigational chart are visible in the photo.

Bottom features visible in the aerial photos seemed to correspond more often to those recorded on the navigational charts than those shown in the 30-m raster data. The difference in correspondence may be related to the age of the data. While much of the data represented in the navigational charts is likely derived from the 30-m raster data, features on the charts, including the navigation channels and associated spoil piles, have been updated since the 1930’s. It was decided that using the navigational charts in combination with the 0.5-m resolution aerial photos would provide the closest and most contemporary representation of the topography of the Bay floor.

2.2 Interpolation of Data

The ArcGIS 10.2 software has numerous tools for developing raster layers derived from interpolation of continuous vector data, such as elevation points and contour lines. One of the most versatile tool sets for creating an interpolated San Antonio Bay bathymetric depth layer are the triangulated irregular network (TIN) tools. The Create TIN tool (ESRI 2014) can utilize elevation values in the form of points, contour lines, and polygons as input feature types. The input feature classes are quite similar in function to the surface constraint layers used in the LAS Data Set tools that were used to develop the terrestrial elevation layer.

Input feature classes imported into the Create TIN tool can have a height field and must have a surface feature type definition. The height field which indicates the column in the shapefile attribute table that will be used as the elevation value. The surface feature type definition indicates how the surface features will be used in the interpolation, e.g., a clip feature to indicate the outside edge of an interpolation, mass points to indicate point elevations, or breaklines to indicate linear elevation features. The navigational charts provided bathymetric data in the form of sounding depth points and contour lines and tracings of the bottom features visible in the 0.5-m aerial photos provided additional contour lines that could be used as input for the TIN tools.

The bathymetry layer used for the San Antonio Bay model must link directly with the terrestrial elevation representation. Therefore, the outside edge of the bathymetry layer was defined using the perennial water body shapefile. Estuarine and marine deepwater polygons classified as Bay and Gulf water in the shapefile were selected and exported to a new shapefile. These Bay and Gulf water polygons were then merged into two polygons, one representing Bay water and one representing Gulf water. This new Bay and Gulf water outline shapefile was used as a hard clip surface type to define the outside edge of the bathymetry layer. This process ensured that the terrestrial layer and the bathymetry layer shared the same boundary definition. A height field was not assigned to this input feature class.

Prominent features on the navigational charts were the sounding depth points, which are recorded across the charts and range from values of 0.5 to 8 feet (0.15 to 2.4 m). Each of these points were digitized into a new point shapefile, the associated depth record was transcribed into the new shapefile, and the depths were converted from feet to meters. This process created > 1500 bathymetric points across the Bay water area that could be used as mass points in the Create TIN tool. Mass point surface features are useful for interpolating areas that have gradual changes in elevation. Features such as shell reefs, spoil piles, and navigation channels, however, generally exhibit abrupt elevation changes.

Shell reefs, navigation channels, and many of the spoil piles evident across the floor of the Bay are long, narrow features. The abrupt elevation change associated with the width of these features was not represented by the sounding depth points, i.e., the width of most features was less than the 500-m spacing of the points. A new contour line shapefile was developed by digitizing contour lines around these features to better represent their elevation changes. The contour line shapefile was used in the Create TIN tool as a softline surface type. Outlines of many features were recorded on the navigational charts and these outlines were used as a guide for digitizing the new contour line shapefile. To aid the digitizing process, the navigational chart layer was displayed in ArcGIS at a transparency level that allowed the aerial photo to be visible below.

At most locations where shell reef or spoil pile features were outlined on the navigational charts, the full extent of the feature was generally visible on the aerial photo. A contour line was drawn to represent the full extent of the shell reef or spoil pile and the contour line was assigned a bathymetric depth approximated from surrounding sounding depth points. A second contour line was drawn to represent where the feature was estimated to be 0.16 m below the water surface in the aerial photo. It was obvious that the top of many of the shell reefs were above the water line in the 0.5-m photos, due to the low tide level at the time of the photos. The tops of these features, however, were not digitized and assigned a third contour line, as they would generally be below the water surface during median or high tide levels. The navigational charts had two additional sets of contour lines recorded at approximate depths of 1 and 2 m. These contour lines were also digitized into the contour line shapefile (Fig. 8).

Digitization of the sounding depth points and contour lines representing the shell reefs, spoil piles, and chart contour lines provided elevation estimates for the majority of the Bay floor. Several navigational channels, however, were also recorded on the navigational charts and visible on the aerial photos. The geography of these channels, in relation to the surrounding Bay floor, will be important in the planned multi-layer aquatic modeling. The edges of the channels were digitized as contour lines in the contour line shapefile using color changes between shallow and deep water visible on the aerial photos (Fig. 8).

Edge lines for the navigation channels were broken into various segments using neighboring sounding depth points or previously drawn contour lines to estimate each segment's bathometric depth. This process provided two edge contour lines along each segment of channel. Two intermediate contour lines were digitized, each approximately 20% of the channel's width away from the two edge lines, along each segment of the channel. A final contour line was digitized at the approximate middle of the channel. The middle contour line was assigned the control depth listed for the channel on the navigational charts, e.g., the Victoria Barge Canal and the Intracoastal Waterway were assigned a depth of 4 m and the Channel to Seadrift was assigned a depth of 2 m. The two intermediate contour lines were assigned a depth of approximately 90% of the center depth. Addition of these five contour lines to the contour line shapefile represented the channel features' bathymetric profile as relatively steep walls and a U-shaped bottom.

The clarity of the water combined with the low tide level seen in the 0.5-m aerial photos provided a unique opportunity to visualize bottom features in the shallow areas near the shores and islands of the Bay, as well as the shallow inlets among the islands and in the area of the delta. The visibility of the bottom features in these shallow areas supported estimation of bathymetric depth details not addressed in the two NOAA-NOS data sets. The Bay water polygon in the Bay and Gulf water outline shapefile was exported and converted to a contour line in a new shapefile. Segments of the new contour line were removed from the open water areas between San Antonio Bay, Mesquite Bay, and Espiritu Santo Bay. The new contour line shapefile served as a starting elevation line for the bathymetry layer and was assigned the same 0.1 m elevation value corresponding with the 1-m resolution terrestrial elevation layer.

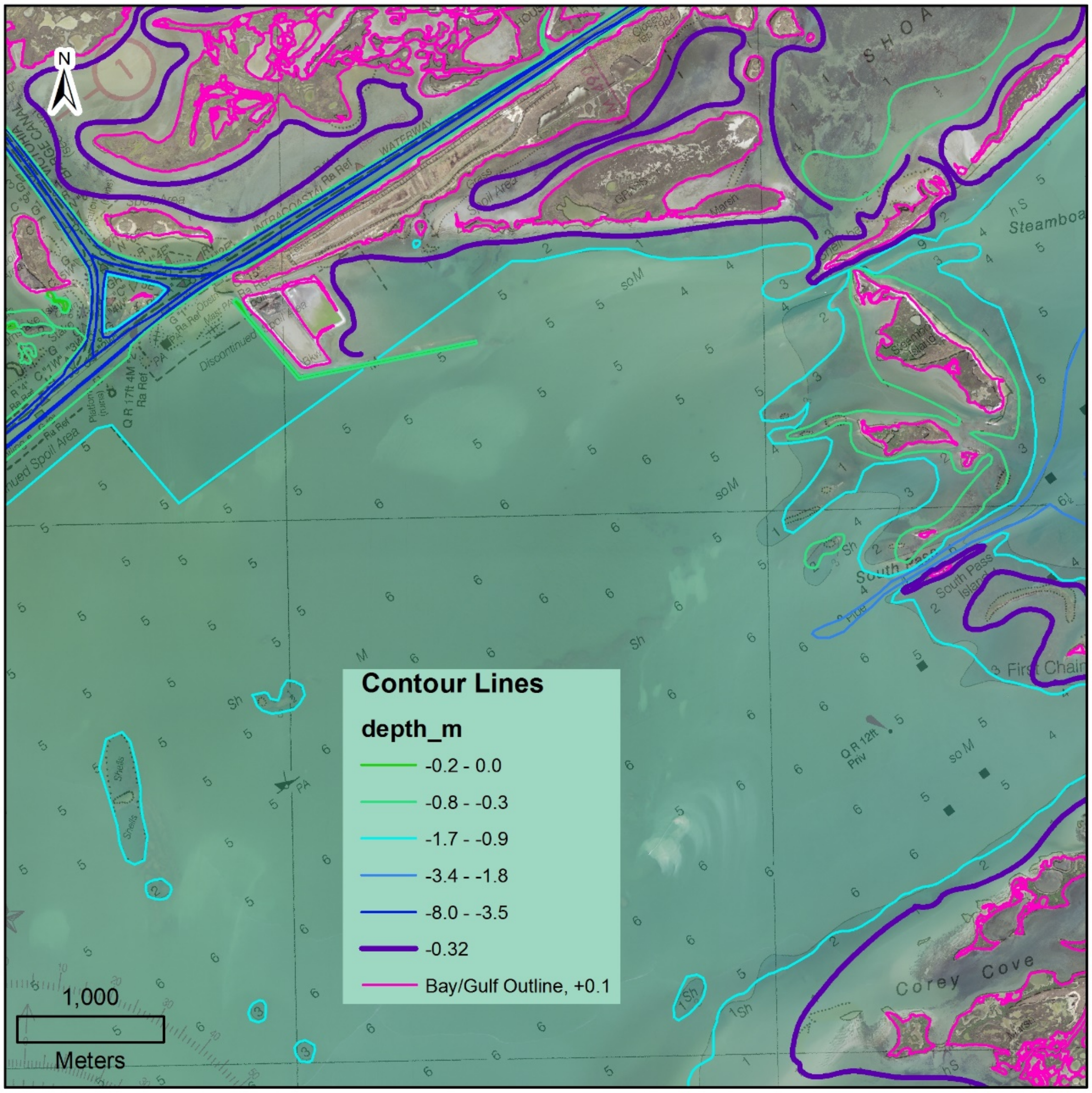

Figure 8. Color coded contour lines used to interpolate the bathymetry of San Antonio Bay. Lines representing navigational channels, shell reefs, spoil piles, an approximation of the 0.32-m depth were digitized based on navigational chart and the aerial photo data. Shorelines were based on the Bay/Gulf Outline shapefile.

Two additional contour line shapefiles were created as 5-m and 10-m parallel buffers of the Bay outline. The 5-m buffer was assigned a bathymetric depth of 0.1 m and the 10-m buffer was assigned a bathymetric depth of 0.15 m. These two contours were used to develop a smooth transition of bathymetric depths from the interface with the terrestrial elevation layer. A third contour line shapefile contained hand drawn contour lines at locations where bathymetric depth in the aerial photos was estimated to be approximately 0.32 m. The placement of 0.32-m contour lines was based on color differences and geographical features visible in the aerial photo and 1-foot sounding depth records on the navigational charts when available. The 0.32-m contour lines were used to clarify an approximate transition location between shallow shore depth contour lines derived from the Bay water outline and the deeper Bay contour lines derived from the navigational chart records. The 0.32-m contours were also used to represent deeper centers of inlets along the periphery of the Bay water, e.g., near and amongst islands and within the delta. The 0.1-m, 0.15-m, and 0.32-m bathymetric depth contour line shapefiles were used in the Create TIN tool as softline surface feature classes.

The bathymetry of the strip of Gulf water southeast of Matagorda Island was represented using a separate contour line shapefile comprised of seven approximately parallel contour lines. The first contour line was created by tracing the wave/beach interface and was assigned a depth value of 0.1 m. Six additional contour lines were drawn radiating towards deeper water and assigned depth values of 1, 2, 3, 4, 6, and 7 m. This process provided a generally linear representation of increasing bathymetric depths from the beach area to the deeper water. The Gulf water is not planned to be included in the multi-layer aquatic modeling, and therefore, further refinement of the Gulf water bathymetry was not necessary.

2.3 Discussion

Navigational charts published by NOAA-NOS were used in complement with 0.5-m resolution aerial photos to provide bathymetric data for the San Antonio Bay floor. Over 1500 sounding depth points were digitized from the navigational chart records and more than 540 contour lines were drawn based on the combination of the navigational charts and bottom feature details visible in the aerial photos. These points and contour lines were used as surface feature classes in the ArcGIS 10.2 Create TIN tool to produce an interpolated representation of the San Antonio Bay floor. The new bathymetric DEM links directly with the 1-m terrestrial DEM derived using LIDAR data (Fig. 9).

The clarity of the Bay water in the aerial photos allowed the location, extent, and estimated bathymetric profiles of shell reefs, spoil piles, navigational channels, and shallow inlets to be refined. The location of shell reefs were recorded on the navigational charts. The extent of these shell reefs, however, were represented by generalized shapes and the bathymetric profile was not recorded. Because the reefs were mostly visible on the aerial photo, contour lines could be drawn to refine the representation of the reefs and estimate their bathymetric profile. The location and extent of navigational channels were also recoded on the navigational charts and visible on the aerial photos. Contour lines were drawn to represent the edges of these channels and additional contour lines were drawn between the edges to represent the bathymetric profile. The bathymetry of shallow inlets along the shores of the Bay, within the delta, and amongst the islands of Matagorda Island was not recorded on the navigational charts. Based on the aerial photo contour lines were drawn to estimate the bathymetric depths in these inlets.

Abrupt changes in bathymetry and shallow areas are important for aquatic animal ecology. The resulting bathymetric DEM provides a refined interpolation of the San Antonio Bay floor and includes details that have not been available in previous data sets. Many of the refinements represented in the new DEM specifically address features that are characterized by abrupt bathymetric changes and/or shallow areas. The refined level of detail in the bathymetric DEM will support multi-layer aquatic modeling and is expected to improve the representation of aquatic animal and plant ecology.

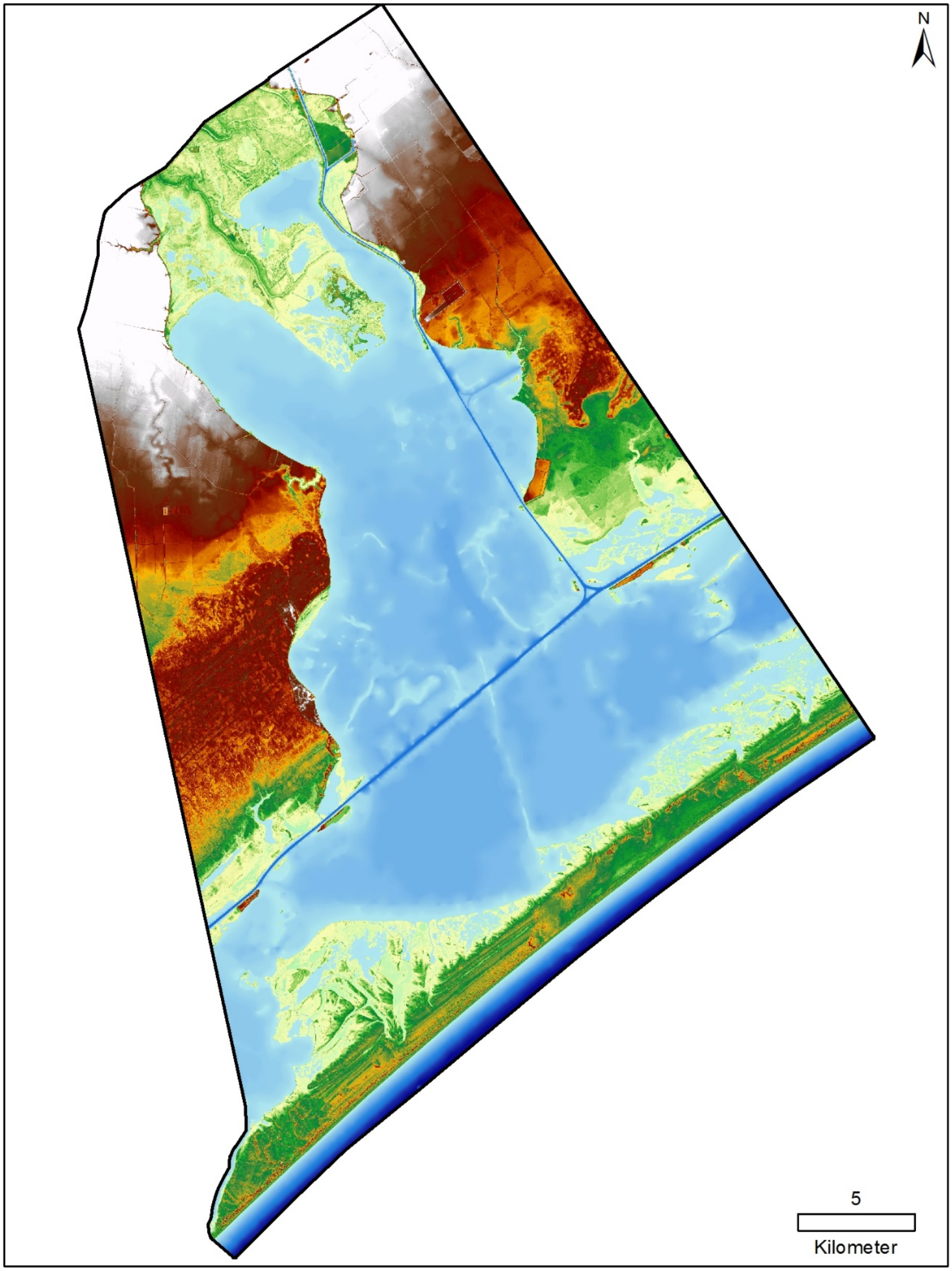

Figure 9. Final bathymetric DEM in combination with the 1-m terrestrial DEM for the San Antonio Bay model domain.

3.0 LITERATURE CITED

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