VOLUME 3

WATERSHED ASSESSMENT

VOLUME 3A

HYDROLOGIC & HYDRAULIC ASSESSMENT REPORT

Escambia County
Pensacola, Florida

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Wood Project No.: 600643

CARPENTER CREEK AND BAYOU TEXAR WATERSHED MANAGEMENT PLAN HYDROLOGIC & HYDRAULIC (H&H) MODEL DEVELOPMENT (Task 3.1.1) & SIMULATION REPORT (Task 3.1.2)
Tasks 3.1 and 3.2

CARPENTER CREEK AND BAYOU TEXAR WATERSHED MANAGEMENT PLAN
HYDROLOGIC & HYDRAULIC (H&H) MODEL DEVELOPMENT (Task 3.1.1)
& SIMULATION REPORT (Task 3.1.2)
Tasks 3.1 and 3.2

Prepared for

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DOCUMENT REVISION HISTORY

DATE	VERSION	DESCRIPTION	CHANGES MADE
July 29, 2020	Version 1.0	Initial Draft Model Methodology Approach	N/A
August 28, 2020	Version 2.0	Final Model Methodology Approach	In response to County and City comments and related meetings, clarifying language was added to Section 1, and County deviations were identified in the attachment.
November 20, 2020	Version 3.0	Revised Final Model Methodology Approach	Added additional language for; modelling percolation links (Section 6.2.2.2.7), incorporation of neighboring subbasin model features (Sections 5.2.2, 6.1.1.2, and 6.2.1.2), and utilizing "Walk the WBID" issue locations to assist with model verification efforts (Section 8.2.2)
January 13, 2022	Version 4.0	H&H Model Development & Simulation Report	Modified based on new findings obtained during the development of the hydrologic & hydraulic (H&H) model, and since the delivery of Version 3.0 of the Model Methodology Approach. Modified version merges original Modeling Methodology Approach with model simulation results, for one concise document
February 24, 2022	Version 5.0	Executive Summary added per County review comment	Final version, including revisions pertaining to County review of Draft report. Executive Summary added to document.

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EXECUTIVE SUMMARY

H&H Model Development & Simulation Report Purpose

This report serves to document the methodology and results of the hydrologic & hydraulic (H&H) analysis for the Carpenter Creek and Bayou Texar watersheds, as part of the comprehensive Watershed Management Plan (WMP) aimed at providing a roadmap for identifying, addressing, and recommending actions for the following categorical objectives: Water Quantity and Quality, Fish & Wildlife Habitat, Public Access and Recreation, and Community Resiliency.

The WMP H&H analysis was completed using ICPR4. The WMP model used portions of the existing ICPR4 City model. The final model includes City and Unincorporated areas and provides flooding results for design storms and sea-level rise. The sections below describe the methodology to develop the model and results.

City of Pensacola's Stormwater Master Plan

Section 3 of this report summarizes key details regarding the H&H model developed as part of the City of Pensacola's Stormwater Master Plan (SWMP) completed in July of 2019. An ICPR4 model was developed for the entire City extent and limited areas beyond the City limits determined to contribute hydrologically or hydraulically to the City's watersheds. The modeled area is approximately 22.7 square miles. A portion of the City's model (referred to as Existing Watersheds 04, 05, 06, and 09 in the City's model) was used in the development of the comprehensive WMP H&H model due to its overlap with the WMP study area.

The City's model was generally used as-is, except where explicitly discussed in this report, as the base model upon which the unincorporated portion of the study area was added. Section 3 of this report provides details related to the assumptions, limitations, and methods followed when using the City's model files for the WMP. The following bullets summarize the notable adjustments made to the City's model features/parameters during the development of the comprehensive H&H WMP model:

- Updated to reflect the final design plans for the 9th Avenue bridge (redesigned as a box culvert since the date of the City's SWMP).
- Adjusted the model stage/area nodes and links in the area of the future Baptist Hospital, which is to include five new retention ponds.
- Added a minimum storage area of 5,000 ft^2 to City nodes that had no associated storage to allow the comprehensive model to run successfully.
- Used the 2019 land use shapefiles from the Northwest Florida Water Management District (NWFWMD) and the Natural Resources Conservation Service (NRCS) 2018 soils layer to develop curve number (CN) values for the subbasins in the City and unincorporated area of the watershed.

Topographic Datasets and Vertical Elevation Datum Utilized

Topographic Datasets

For the unincorporated portion of the model:

- The 2017 LiDAR DEM was used for model feature development and parameterization, retrieved from the NWFWMD and provided in the NAVD88 vertical datum.
- The ESRI 2020 aerial imagery, along with other data sources, were used for comparison to the 2017 DEM to review for topographic voids and areas of new development that may have occurred between the 2017 LiDAR fly-date and 2020.
- The 2017 DEM was updated as needed to reflect ground conditions where new development areas were observed.

A Digital Elevation Model (DEM), based on the NWFWMD 2006 Light Detection and Ranging (LiDAR) data, was used to develop the City's SWMP H&H model. The 2006 LiDAR was the best-available data at the time of developing the City's SWMP.

As the City's model was generally utilized as-is, the Wood team did not evaluate differences between the 2006 DEM and the 2017 DEM. However, at the County's request, the 2017 DEM was updated within the City's modeled area at the site of the future Baptist Hospital at Brent Avenue, which includes five new retention ponds.

Vertical Elevation Datum

Due to the completion date of the City's SWMP (July 2019), the Wood team assumed that the elevation data supplied within the City's model is presented in the NAVD88 vertical datum.

The elevation data for the Carpenter Creek/Bayou Texar WMP's model is presented in the NAVD88 vertical datum, which corresponds to the 2017 DEM. For specific data sources, it was necessary to convert elevation data from the NGVD29 vertical datum to the NAVD88 vertical datum. The Wood team adopted the mean conversion factor of -0.14 ft for use throughout the unincorporated area of the watershed to convert from the NGVD29 datum to the NAVD88 datum, as necessary (NGVD29 elevation + (-0.14 ft) = NAVD88 elevation).

Model Feature Development and Parameterization

Subbasins

In summary, 1,754 subbasins from the City's existing model scenarios (Existing Watersheds 04, 05, 06, and 09) were included in the Carpenter Creek/Bayou Texar model. Within the unincorporated area, 304 subbasins were delineated to a regional scale. In total, the Carpenter Creek/Bayou Texar comprehensive H&H model consists of 2,058 subbasins. For each modeled subbasin, parameters include unit hydrograph, curve number (CN), and time of concentration.

For runoff unit hydrograph generation, the National Resources Conservation Service (NRCS) (formerly the Soil Conservation Service (SCS)) unit hydrograph method, with a peak rate factor of 323, was used in both the City and unincorporated model subbasins.

The 2019 land use shapefiles from the NWFWMD and the NRCS 2018 soils layer were used to develop CN values in ICPR4 for all subbasins. Directly Connected Impervious Area (DCIA) was not accounted for in infiltration calculations.

In the unincorporated area, the subbasins' times of concentration were developed using the 2017 project-area DEM and guidelines from the USDA's Urban Hydrology for Small Watersheds, Technical Release TR-55. The times of concentration values for the City's subbasins were used generally as-is and were assumed to have been based upon the NWFWMD 2006 DEM, given that the 2006 DEM was the best-available data during the time the City's SWMP was underway.

<u>Nodes</u>

The nodes from the City's Existing Watersheds 04, 05, 06, and 09 model scenarios, a total of 2,669 nodes, were included in the comprehensive Carpenter Creek/Bayou Texar model. Of these nodes, 2,593 are assigned as stage/area type, 74 as time/stage type, and 2 as stage/volume type. The tailwater elevation used in the City's model for Escambia Bay and Pensacola Bay is 1.10 feet NAVD88.

For the unincorporated area, a stage/area loading node was assigned to each subbasin developed. Additional stage/area nodes (with nominal storage) were placed as necessary to account for significant junctions, bends, or diameter changes along a series of pipes. Furthermore, nodes were set so channel lengths were generally kept to a maximum length of 1,000 feet, and channel segments are approximately uniform in length to the greatest extent possible.

In the unincorporated area, one time/stage boundary node was added to represent a connection between the adjacent Escambia County Beverly Parkway basin study and the Carpenter Creek watershed. Another time/stage node was placed as a sink for percolation links added to the model. Additional boundary nodes were placed as needed to model the unincorporated area appropriately. Pensacola Bay's tidal boundary conditions were based on the mean high-water elevations. The 1.10 ft (NAVD88) for the Escambia Bay and Pensacola Bay tidal boundary stages was also utilized in the unincorporated area of the model.

For each subbasin developed within the unincorporated area, one stage/area node was assigned to account for the subbasin's storage, using the underlying 2017 project-area DEM. It is presumed that the City's model used the NWFWMD 2006 DEM, along with information from previous studies, plans, and possibly field verification, to develop the stage/area relationships for its nodes. Only 150 stage/area nodes from the City's model scenarios (Existing Watersheds 04, 05, 06, and 09) contained related stage/area data. To allow the model to run successfully for large storm events, the model requires nodes to have a minimum storage area of 5,000 ft^2. Therefore, as necessary for City model nodes, the minimum nodal storage of 5,000 ft^2 was added to the City's nodes to allow for successful model simulations.

For the unincorporated areas of the model, Initial Water Surface Elevations (IWSEs) were first set to seasonal high-water levels (SHWLs) based on the best available information (i.e., wetland SHWL evaluations, control structure operating schedules, etc.). Where SHWL or other starting elevations was not available, the overflow elevation for the node was assumed for the initial water level based on the 2017 DEM. For the outfall structures that connect to the stormwater conveyance systems, the initial stages in the developed areas were set at the minimum control elevations. Downstream conditions (e.g., structure inverts or other water level controls) were considered when establishing IWSEs. After these initial IWSEs were set, a dry condition with no rainfall was simulated for 200 hours to establish new initial stages after any surges evened out in the model.

The City's SWMP report noted that tailwater elevations for drainage systems discharging into lakes, ponds, and creeks were determined based on water surface data, 2006 DEM elevations, or surveyed information. The City's IWSEs were primarily left as is, except for specific instances noted in this report.

Links

All links, a total of 2,661, within the City model's Existing Watersheds 04, 05, 06, and 09 were imported and utilized in the comprehensive Carpenter Creek/Bayou Texar WMP model generally as-is, except where noted in this report.

Within the unincorporated area, an inventory of existing drainage structures and conveyance features was developed from data compiled from County GIS databases, County plans, ERPs, FDOT plans, and findings from field reconnaissance and survey efforts. Survey data was collected to fill data gaps for structures and conduits where information could not be obtained from plans. In total, 267 individual locations were surveyed. The compiled hydraulic inventory resulted in the development of 923 model link features within the unincorporated area, including 227 pipe links, 32 drop structure links, 581 weir links, 45 channel links, 36 percolation links, and 2 rating curves. In the unincorporated area, 520 overland weirs were also developed. The 2017 DEM was utilized to determine the invert elevations for the overland weir features. Other link parameters included entrance, exit, and bend losses, Manning's n values, weir discharge coefficients, and contraction and expansion coefficients. Information gleaned from field reconnaissance, survey, or as-built plans were taken as best-available data and superseded overlapping or contradictory data provided in design drawings, aerial imagery estimations, or the County's GIS databases.

As noted in the City's SWMP report, invert elevations in the City's model were generally derived and entered from the obtained construction plans or previous survey efforts. The NWFWMD 2006 DEM was used to determine rim elevations in the City model, then inverts were globally specified using an algorithm in GIS, which assumed three feet of cover from the crown of the pipe.

There was a total of 74 channel links imported from the City model's Existing Watersheds 04, 05, 06, and 09. Of the imported City model channels, 55 were modeled with irregular type geometries, with inputted cross-sections. There is no documentation provided in the City's SWMP report or model file to denote the methodology employed, or sources utilized, to determine the inputted cross-sections.

There were 89 weir links imported from the City model's Existing Watersheds 04, 05, 06, and 09. Ten of these weirs are designated as having "irregular" geometry, which means they are assigned to an inputted cross-section in the model. Notably, there are no percolation links provided in the City's model.

For overland weir features, the corresponding cross-section elevation data was generated by utilizing the underlying DEM and GIS automated toolsets. Information from a Federal Emergency Management Agency (FEMA) Map Modernization study, completed by AECOM circa 2006, provided relevant topographic data at certain locations along Carpenter Creek. For the WMP, channel cross-sections were developed along the channel utilizing the AECOM data where available and using the 2017 DEM to interpolate between the AECOM cross-sections, where needed.

The Carpenter Creek/Bayou Texar watershed is comprised of several depressional areas with sandy soils likely to exhibit high rates and volumes of percolation. Furthermore, during field reconnaissance, and after a preliminary review of permit and plan data, several ponds were found to be constructed with sand chimneys meant to allow the underlying permeable soil layer to percolate to the aquifer and improve overall pond recovery performance. For these reasons, percolation links were included in the unincorporated areas of the model, as warranted.

Model Calibration and Verification

Model calibration was noted to have been conducted as part of the City's SWMP modeling effort. Therefore, the City's model was used as-is, and calibration and verification efforts were focused within the unincorporated areas of the watershed only.

Wood utilized the April 2014 storm event, which occurred between April 29th and April 30th, 2014, to calibrate the unincorporated portion of the model. This storm was classified by the National Weather Service (NWS) as a record 24-hour storm event for the City of Pensacola and the southern portion of Escambia County.

HDR Engineering, Inc. (HDR) developed a storm event recreation for this April 2014 event, dated January 27, 2015. HDR completed a radar-based assessment of the period of heavy rainfall associated with this storm. They analyzed archived NOAA radar data for the event and reviewed gaged data for verification and calibration purposes. The rainfall data was used to create a calibration model simulation for the unincorporated area.

The April 2014 calibration simulation results were compared to recorded flood elevations and noted flood complaints from the April 2014 event to ensure successful model calibration. Model verification occurred after successful model calibration. The verification step consisted of comparing the calibrated model with another storm event to confirm the accuracy of the results.

Data from Hurricane Sally, which made landfall in September 2020, was used for this purpose. Model verification efforts were focused only within the unincorporated area of the model, as the City's model was used as-is. The Hurricane Sally data used for model verification includes information from the County's "Walk the Waterbody ID (WBID) Field Event" and field reconnaissance conducted following Hurricane Sally. Information from the County's "Walk the WBID Field Event" was only qualitative. Limited quantitative data was collected during the post-Hurricane Sally field reconnaissance effort. High water mark elevations were surveyed and used to compare to model results.

Model Simulations and Results

The rainfall depths used in the City's model for the 8-hour and 24-hour storm events were noted to be calculated using the FDOT Intensity-Duration-Frequency (IDF) curves for Florida Zone 1. The FDOT 100-year, 8-hour storm event, with a rainfall depth of 9.44 inches, was selected as the design storm event.

Aligning with the City model, rainfall volumes for the unincorporated areas were based on the FDOT rainfall IDF curves for Florida - Zone 1 for storm durations up to 24 hours. However, for storm durations of 3, 7, and 10 days, recorded rainfall depths at NOAA Station ID 08-6997 were used.

For the consolidated City/unincorporated model, design storm simulations were developed for the 10-yr and 100-yr storm events, for durations of 1, 2, 4, 8, 24, 72, 168, and 240 hours, to determine the critical storm duration (storm event resulting in the highest maximum stages). The results of these simulations determined that a duration of 8 hours was most appropriate for critical storm analysis.

The 100-year, 24-hour floodplain in the unincorporated area is generally both reasonable and useful, showing flooding at expected regions along Carpenter Creek, at stormwater ponds, at other water bodies, at wetlands, at other undrained depressional areas, and at locations noted to have seen flooding in the April 2014 storm. As described in relevant sections of this report, there were potential limitations to using the City's model results confidently. Therefore, the floodplains were generally only assessed in the unincorporated area.

Also, model simulations were developed for the intermediate-low and intermediate-high sea level rise (SLR) scenarios for the years 2040 and 2070. As the model's boundary condition time/stage nodes for Carpenter Creek and Bayou Texar were established at an elevation of 1.1 ft (NAVD88), the SLR projections were then added to the boundary condition elevations, resulting in adjusted SLR boundary conditions of 1.76 ft, 2.41 ft, 2.28 ft, and 4.25 ft, respectively.

The City and County each provided the Wood team with guidance in selecting and determining critical infrastructure locations in the modeled area. Two hundred twenty-three unique critical infrastructure locations were determined throughout the City and unincorporated area. From the critical infrastructure locations provided by the County and utilized as a part of this analysis, there were no threats to the critical infrastructure identified in the unincorporated areas based on the resulting floodplains from the model simulations, including the SLR model simulations, generated. There also doesn't appear to be a negative impact on the identified wetlands in the unincorporated area.

Due to limited confidence in the model results from the City's existing model, detailed analysis related to projected SLR floodplains and the potential inundation of critical infrastructure and wetlands was not a focus within the City limits.

1.0 INTRODUCTION

Wood Environment & Infrastructure Solutions, Inc. (Wood) was contracted by Escambia County (County) to develop a comprehensive watershed management plan (WMP) for the Carpenter Creek and Bayou Texar watersheds to address legacy impairments, develop best management practices (BMPs), and identify future site-specific projects and activities through stakeholder engagement and best available science. Funding for the development of the WMP was secured through the Escambia County Resources and Ecosystems Sustainability, Tourist Opportunities, and Revived Economies of the Gulf Coast States Act (RESTORE Act) Direct Component allocation (Pot 1).

A key component of the WMP is the development of a comprehensive hydrologic & hydraulic (H&H) stormwater model for the Carpenter Creek and Bayou Texar watersheds. Wood developed the H&H model using the Interconnected Channel and Pond Routing Model Version 4 (ICPR4) software. This comprehensive H&H ICPR4 model will be used to assist with providing quantitative data for the water quality and stream analysis and will serve as a testing bed for alternative analysis scenarios.

In November of 2020, Wood outlined a comprehensive H&H Modeling Methodology Summary (MMS) that served to detail the original methodology proposed to develop the Carpenter Creek and Bayou Texar H&H model. Since November of 2020 and throughout the development of the H&H model, new information became available that warranted revisions to the MMS. Ultimately, the revised MMS was incorporated into this document, which now provides a single comprehensive document that contains all the most relevant information for the Carpenter Creek and Bayou Texar WMP H&H model development and simulations. This report details relevant background information, methodologies of model development, and the results of the H&H model simulations, which include design storm event simulations and sea-level rise (SLR) scenario simulations.

2.0 BACKGROUND

The first major deliverable associated with the WMP was the Carpenter Creek & Bayou Texar Watershed Evaluation Report (WER), which was completed in August 2020. The WER summarized the findings of Wood's extensive literature and data review and discussed the characterization of the Carpenter Creek and Bayou Texar watersheds in detail. It detailed such items as the community outreach efforts to date, water quality gap analysis and sampling efforts, and the existing hydrologic and hydraulic features of the watersheds, to name a few. References to the WER are made throughout this report.

Between April 29th and April 30th, 2014, a period of heavy rainfall occurred, leading to heavy flooding in the City of Pensacola and Escambia County. As a result, widespread flooding caused major damage in many locations in and around Pensacola and Escambia County. On behalf of Escambia County, HDR Engineering Inc. (HDR) performed a radar-based assessment of the period of heavy rainfall associated with the observed flooding. The results of the HDR study and associated report are referenced throughout this report, as needed, as the "April 2014" storm event was utilized to assist with the WMP's model calibration.

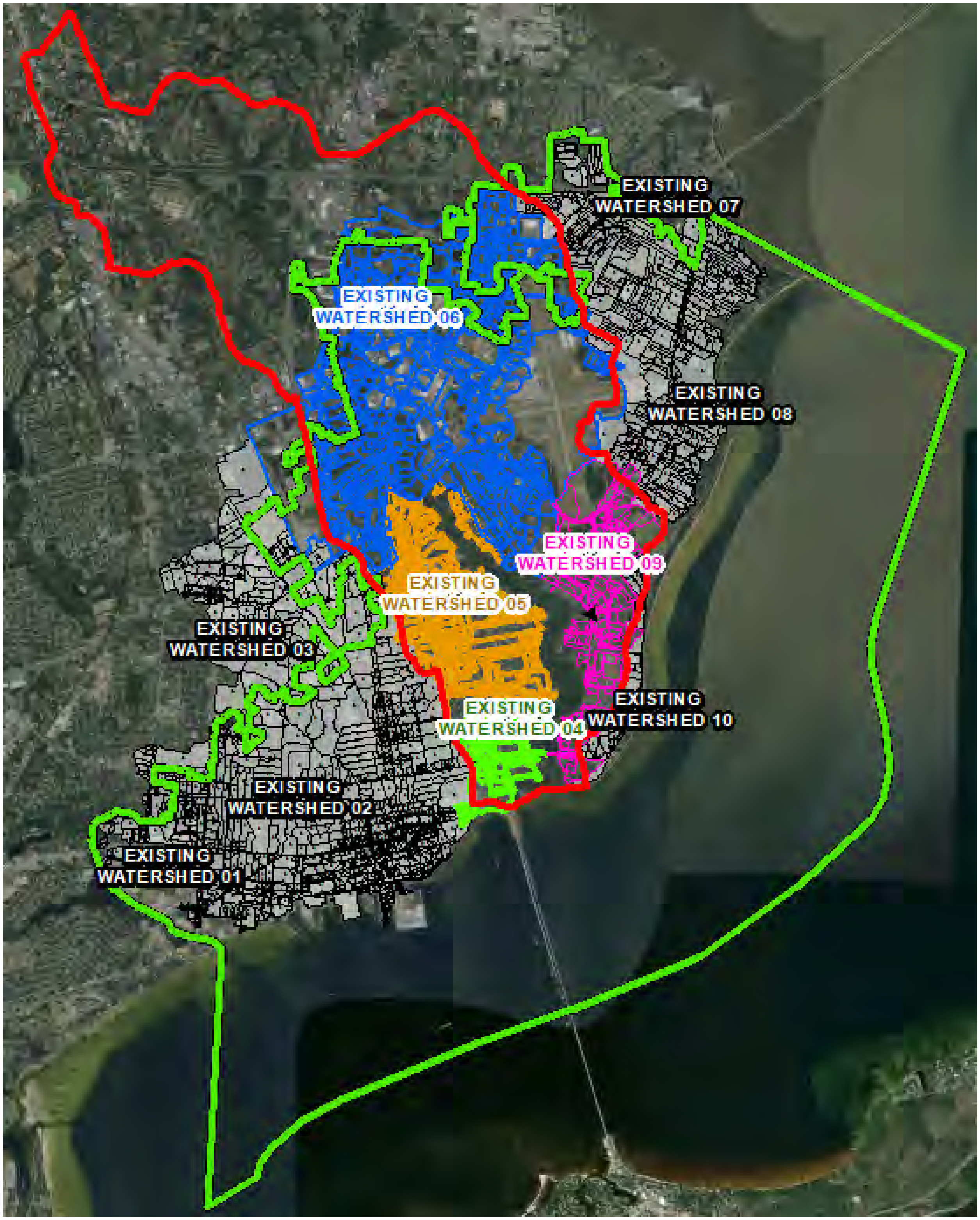
In July of 2019, Mott MacDonald completed a Stormwater Master Plan (SWMP) for the City of Pensacola (City). As part of the City's SWMP, Mott MacDonald developed an H&H stormwater model using the ICPR Version 4.04.00 software. The ICPR4 model was developed for the entire City extent, which covers approximately 22.7 square miles, and includes limited areas beyond the City limits that were determined to contribute hydrologically/hydraulically to the City's modeled area. Per the Mott MacDonald report, the City model does not include inputs from the upstream portions of Carpenter Creek and associated drainage areas.

The City's model includes 10 scenarios or basin groups, to represent the existing watershed conditions at the time of the City's study, labelled as "Existing Watershed 01 – 10" in the model. **Figure 2-1** below shows the City's 10 existing conditions scenarios and includes the City limits and the County project's study area for reference. The City's model also included multiple proposed conditions scenarios, developed to demonstrate the results of the City study's proposed recommendations. However, due to the July 2019 date of completion for the City's study, the proposed conditions scenarios will not be relevant for consideration during this project. Therefore, only the Existing Watershed 01-10 scenarios were considered for establishing a base model to build upon for this project. In the end, only scenarios 04, 05, 06, and 09 were used in the comprehensive H&H model as they overlapped with the study area as seen in **Figure 2-1**.

Per discussions with the County and City staff, Wood generally used the City model as provided by the City and only made alterations when necessary. These alterations are discussed in later sections of the report. The City was not able to provide the project team with model results from the calibrated model to verify that the project team was starting with the calibrated model and associated inputs. There is an inherent risk in using the model as-is without the ability to verify the starting model and results; however, the team determined the best course of action was to start with the City model provided and develop the comprehensive H&H WMP model onto the City's base model. **Section 3.0** provides more details on the assumptions, limitations, and methods followed when using the City model files for the comprehensive H&H WMP model.

Going forward, this report will use "City's modeled area" as a label when discussing subbasins, nodes, links, and other model elements that are originally part of the City model. Likewise, the "unincorporated area" label will refer to the areas of the watershed that were not incorporated in the original City model and have now been included in the comprehensive WMP H&H model developed by Wood. In general, the Wood team adhered to the Escambia County Basin Study Guidelines and Specifications (BGS), dated September 2013, for the development of the model in the unincorporated area.

FIGURE 2-1
City's Existing Model Subbasins



3.0 USING THE CITY MODEL

This section outlines assumptions and criteria that have been gleaned or implied from the information received from the City's model and SWMP report, discusses limitations and issues with using the City model, and outlines Wood's general solutions or workarounds to those problems.

3.1 Assumptions Outlined in City's SWMP Report

The City's SWMP report, dated July 2019, outlines key assumptions and criteria utilized during the completion of the City's study. As the Carpenter Creek and Bayou Texar WMP include the adoption of a portion of the City's SWMP model, it is imperative to note the assumptions and criteria that may have relevance to the development and results of the Carpenter Creek/Bayou Texar WMP model.

- City's SWMP replaces the original Stormwater Master Plan completed by the City of Pensacola Engineering Division in December 1987.
- External stormwater flow contributions, such as those from the upper reaches of Carpenter Creek, were not included in the City's SWMP model as there was no existing compatible stormwater modeling for this system to accurately simulate the timing and flow contributions from areas outside of the City limits. Future coordination with the County was encouraged for the incorporation of any stormwater modeling to be done under the Carpenter Creek and Bayou Texar WMP.
- The analysis level of detail for the City's SWMP was set at the "primary drainage system", consisting of open ditches, streams, ponds, and lakes draining an area of 50 acres or more, in addition to closed conveyances with an equivalent diameter of 12 inches or more.
- The ICPR Version 4.04.00 modeling software was utilized under the City's SWMP.
- The basis for the City's SWMP model is the ICPR Version 3 models from HDR's Pensacola Bay Basin Study, which included five major drainage areas within the Pensacola Bay Basin; A Street, Coyle Street, Eastern (the largest model including downtown Pensacola up to approximately Fairfield Drive), Gregory Street, and Western (from B Street to G Street). The five models were independently imported into ICPR Version 4 and georeferenced using available GIS data provided for the models. The models were then merged into a single ICPR Version 4 model file and combined with the final City SWMP model. The majority of basin delineations and link connectivity originally developed by HDR was maintained in the City's July 2019 SWMP; however, some subbasins were altered as necessary to coincide with adjacent subbasins when combining models or to more accurately assign contributing subbasins to the model stormwater piping networks. Furthermore, link connectivity was corrected as necessary, based on ground-truthing or information from plans.
- Stormwater infrastructure included in the City's SWMP model was derived from the Pensacola Atlas Map (circa 1954) and validated or supplemented through desktop review of plans and ground-truthing.

- Base maps for soil zones and land use cover are utilized by ICPR to perform hydrologic computations. ICPR utilizes user-generated lookup tables to assign a curve number (CN) to each subbasin based on the land use and soil type combinations that occur within its boundary. For the City's SWMP, land use GIS data was obtained from the Florida Department of Environmental Protection's (FDEP's) Geospatial Open Data – Statewide Land use Cover for the City of Pensacola. The dataset from the Northwest Florida Water Management District (NWFWMD) (NWFWMD 2015-2016) is a compilation of the land use/land cover datasets created by the water management districts in Florida. The land use data was processed in GIS and shapefiles were created for each land-use area for import into ICPR. For the soils map layer, information from the Natural Resources Conservation Service (NRCS) Web Soil Survey was used. The soil zone information was processed in GIS and shapefiles were generated for each soil zone to import into ICPR.
- A Digital Elevation Model (DEM), based on the NWFWMD 2006 LiDAR data, was created and used for the City's SWMP.
- Florida Department of Transportation (FDOT) 2016 aerial imagery was utilized during the City's SWMP development.
- The City provided 50 plan sets for review and incorporation into the SWMP. Due to poor scanning quality and conflicting data, not all plan sets were utilized or incorporated into the SWMP model.
- Construction plans, permitted through the Environmental Resource Permitting (ERP) program, were obtained from the FDEP Map Direct website, from 1982-present (present at the time of the City's project) and utilized to develop the City's model.
- Other miscellaneous construction plans were utilized for model development, too, obtained from private engineering consultants.
- Inverts in the City's model were generally derived and entered from the obtained construction plans, or previous survey efforts. However, the City's model employs several assumptions and relied on computer software to aid in determining invert elevations that could not be determined from existing data sources. The 2006 DEM was used to determine rim elevations, then inverts were globally specified using an algorithm in ArcMap, which assumed three feet of cover from the crown of the pipe. Also, inverts were manually rectified in areas where the use of the algorithm resulted in adverse pipe slopes/runs.
- The FDOT 100-year, 8-hour storm event, with a rainfall depth of 9.44 inches, was selected as the design storm event for the City's model.
- Tailwater elevations for drainage systems discharging into lakes, ponds, and creeks were determined based on water surface data, 2006 LiDAR elevations, or surveyed information. The tailwater elevation for drainage systems discharging into Escambia and Pensacola Bay was based on the mean high water elevations. The tailwater elevation used in the City's model for Escambia Bay and Pensacola Bay is 1.10 feet.
- For City model calibration, once the hydraulic model was complete and simulations were executed, the predicted flooding areas were compared with known flooding areas. Areas in which flooding conditions were predicted were catalogued and a list of the most significant areas was provided to the City for verification as known points of

flooding. City staff subsequently provided a list of areas for detailed study and conceptual design.

- The results of the City model were noted to identify existing hydraulic deficiencies and potential flooding areas within each watershed. Mott MacDonald met with City staff to discuss the model results and potential flooding areas. Based on a review of the results from the existing model scenarios, several locations were identified, based upon roadway flooding significance, on which Mott MacDonald further focused their investigation during their subsequent analysis. Based on the results from the existing models, the following locations were identified to evaluate proposed drainage improvements: drainage system on West Strong Street, Barrancas Avenue, L Street south of Barrancas Avenue, Main Street, Langley Avenue/Spanish Trail, and Aragon Street and South 9th Avenue.
- Opinions of probable costs were developed for each of the proposed project areas identified in the City's SWMP. Each proposed project was also evaluated, and a numeric score was assigned, for six separate criteria. The scores were then summed per project to determine their cumulative score. The drainage improvement rankings were based on the benefited drainage area, environmental sensitivity, potential contamination, community impacts, and construction sequence.

3.2 Applied Assumptions and Limitations Related to Use of City Model Files

The City's SWMP report provides limited detail regarding the methodology employed for the development of model parameters in the City's model. Therefore, assumptions have been made regarding the City's methodology, as summarized throughout this section. Unless otherwise noted, the Wood team used the City's model as-is, without updates or alterations.

- No documentation explicitly notes the vertical datum used in the City's ICPR4 model. The City's SWMP report notes that the information for the infrastructure in the model came from various previous studies and miscellaneous sources. The City's SWMP report does not explain if or how the vertical datums were determined, or whether a conversion factor was applied to convert elevation data from the National Geodetic Vertical Datum of 1929 (NGVD29) to the North American Vertical Datum of 1988 (NAVD88) if required. Due to the completion date of the City's SWMP, the Wood team assumed that the elevation data supplied within the City's model is entirely in the NAVD88 vertical datum.
- No documentation explicitly notes the methodology or source utilized to develop the cross-sections for the City's modeled channel links. The Wood team utilized the City's cross-section data as-is, without manipulation or verification.
- On April 15, 2020, a phone meeting took place and included staff from the FDOT, the County, and the Wood team. At the time of the meeting on April 15, and as of the date of this report, only three ongoing/planned FDOT projects were noted to be located within the watersheds and deemed relevant to the WMP. Of the three projects, the 9th Avenue bridge project was noted as being fully designed, with construction estimated to begin around December of 2020. This project is located within the City's modeled

area, and the final approved design differs from what is presented in the City's SWMP model. Therefore, the Wood team agreed to update the City's model to reflect the final design plans for the 9th Avenue Bridge.

- On September 29th, 2021, a meeting took place and included staff from the County and Wood teams. During the meeting, it was discussed to include the Baptist Hospital development occurring in the City's model area on Brent Road in the model. The Wood team agreed and the project DEM, model stage/area nodes, and links were adjusted in the area to reflect the drainage and storage qualities of the completed Baptist Hospital.
- There appear to be only ten (10) irregular weirs modeled in the City's ICPR Existing Watersheds 04, 05, 06, and 09. Overland weirs are typically modeled as irregular weirs in ICPR4. In the absence of modeled overland weirs, the model has no mechanism to allow for the flow of water between subbasins other than through the structural links modeled (pipes, for example). In some cases, this will cause the subbasin to "stage up" higher than it would in reality because it has not been provided a model mechanism for an overland path to take over to the adjacent subbasin. Per email discussions between the City and the Wood team in June of 2021, clarification was requested and received related to very high peak stages observed in the model results, based on the City model simulation generated by the Wood team. In the email exchange, the City noted a discussion with Mott MacDonald on this issue and described that the high max stages were likely a result of a lack of overland flow weir paths in the City's model, which was done deliberately to avoid an excessive amount of additional nodes. The Wood team is scoped to utilize the City's model as-is, and the City did concur that significant additional effort would be required by the Wood team to add the "missing" overland weir features. Therefore, the ultimate decision was made to continue to utilize the City's model as-is, without the addition of overland weir features in the City's model.
- In the City's model, there were a significant number of nodes observed to have no attributed stage/area data. To allow for the model to run successfully for the large storm events, the model requires nodes to have a minimum storage area of 5,000 ft^2. Therefore, the Wood team added a minimum storage area of 5,000 ft^2 to City nodes that had no associated storage.
- The City's model did not include spatial features for subbasins (they did have the spatial nodes and links, but no subbasins). However, the City had previously provided an AutoCAD dxf file that displayed only subbasins. The Wood team performed a comparison between the City's model features and the dxf file and came to a reasonable conclusion that the subbasins previously provided in the dxf file seem to correspond to the subbasins modeled for the Existing Watersheds 01-10 scenarios in the City's model. Therefore, the Wood team converted the subbasin polygons (only provided in dxf format) into GIS shapefiles. However, the subbasins provided in the dxf had no assigned subbasin names. As a work-around to this issue, the Wood team utilized GIS tools to assign names of the GIS subbasin polygons based on the corresponding names of the storage nodes that fall within them.

- Although the City noted in their SWMP that they utilized the NWFWMD 2015-2016 land use/land cover dataset and the NRCS Web Soil Survey data for the development of their curve number (CN) values for their subbasins, these native files were not provided by the City with the ICPR model. The Wood team collected the datasets noted to be utilized by the City for their WMP development. However, on a subbasin level, it wasn't clear exactly how the City developed its CN values, and it was not possible to directly correlate the City's CN values to the base files used for land use and soils. In addition, the rainfall data proposed to be utilized for the calibration storm event (April 2014) was provided to the Wood team in a grid format. To utilize the gridded rainfall data provided for the calibration storm, the Wood team required the actual shapefiles for land use and soils on a subbasin level. As those files were not provided, and the exact version of the City's native files could not be verified or recreated, the Wood team used the 2019 land use shapefiles from the NWFWMD and the NRCS 2018 soils layer to develop CN values in ICPR4 for the subbasins in the City and unincorporated area of the watershed.
- There were no model output files or floodplains provided with the information received from the City. Therefore, there is no record of the actual output produced by the City's model at its time of completion/submittal. However, the Wood team is making the reasonable assumption that the City's model files can be re-run and will produce results that coincide with the results observed in the final SWMP submittal.
- Upon initial investigation, topology errors were observed within the City model's GIS feature classes (Example: "floating" nodes that aren't attached to the endpoint of a link). These topology errors were evaluated and corrected where needed for proper modeling.

4.0 <u>TOPOGRAPHIC DATA AND VERTICAL DATUM</u>

4.1 Digital Elevation Model (DEM) Utilized

This section discusses the LiDAR-derived DEMs utilized in the City's modeled area and the unincorporated area of the model and discusses updates to these DEMs in the form of topographic corrections. These topographic corrections fall into two categories: topographic errors and topographic voids. Topographic voids are areas where the available topographic information in the DEM does not represent the actual current ground terrain due to new development or other land-use changes that have occurred since the LiDAR was flown. Topographic errors are occurrences where the LiDAR data is either missing or erroneous and leads to no data cells or unnatural stretching of the DEM which can result in low points where there shouldn't be, such as through the middle of a building footprint.

4.1.1 <u>City's Modeled Area</u>

A DEM, based on the NWFWMD 2006 LiDAR data, was developed and used for the City's SWMP. The City's SWMP report does not note any corrections made to the 2006 DEM based on observed topographic errors or voids in the dataset, so it is unclear as to whether any corrections were applied to the 2006 DEM during the course of the SWMP. It is assumed that the NWFWMD 2006

DEM was provided in the NAVD88 vertical datum. As the City's model is to be utilized as-is, the Wood team did not evaluate for differences between the 2006 DEM (utilized in the City's model area) and the 2017 DEM utilized within the City's modeled area. However, at the County's request, the 2017 DEM was updated within the City's modeled area at the site of the future Baptist Hospital at Brent Avenue, which includes five new retention ponds. Sixteen topographic voids and 3 topographic errors were corrected when updating the DEM at the Baptist Hospital site. The resulting updated stage/area data from the topographic corrections are incorporated into the final H&H model, which pertains to the City's subbasin that contains the Baptist Hospital.

4.1.2 Unincorporated Area

For the unincorporated portion of the model, the Wood team used the 2017 LiDAR DEM, retrieved from the NWFWMD, provided in the NAVD88 vertical datum. For the unincorporated area, the ESRI 2020 aerial imagery, along with other data sources, were used for comparison to the 2017 DEM to review for topographic voids and areas of new development that may have occurred between the 2017 LiDAR fly-date and 2020. Within the unincorporated area, the 2017 DEM was updated as needed to reflect ground conditions where areas of new development were observed. In total, 11 topographic voids and 12 topographic errors were addressed within the model area.

Topographic corrections were made primarily by using data from available plan sets. Plan documents were used in two different ways. The first was to correct topographic errors by using the plan's finished floor elevations for buildings that falsely showed up as significant low spots in the DEM. **Figure 4.1-1** shows an example of these errors and how they were corrected. The ERP plan shown in **Figure 4.1-1** is Sheet C421 of a 2007 plan for permitting and construction of a warehouse and rail unloading facility prepared by Mactec (these plans are included in the electronic deliverable package that accompanies this report).

Secondly, plan documents were used to correct topographic voids by using the plans' pond details to overwrite the 2017 DEM with the new ponds that were constructed, or in construction, after the date, the LiDAR was collected (2017). Examples of these corrections are around the Monarch Lane and Cardinal Cove subdivisions, which have been at least partially constructed beyond the date of the 2017 DEM. For these corrections, plans were georeferenced, and the ponds' contours were drawn in GIS and used to define the geometry and elevation profile of the ponds. **Figure 4.1-2** shows how the DEM was altered to represent the Monarch Lane subdivision pond. Monarch Lane's plans (Monarch Place Approved Construction Plans, Hammond Engineering, Inc., July 2020) also introduced new structures and percolation information incorporated in the model, as shown in the figure. The Monarch Place Approved Construction Plans are included in the electronic deliverable package that accompanies this report.

FIGURE 4.1-1
Topographic Void Correction for False Sinks

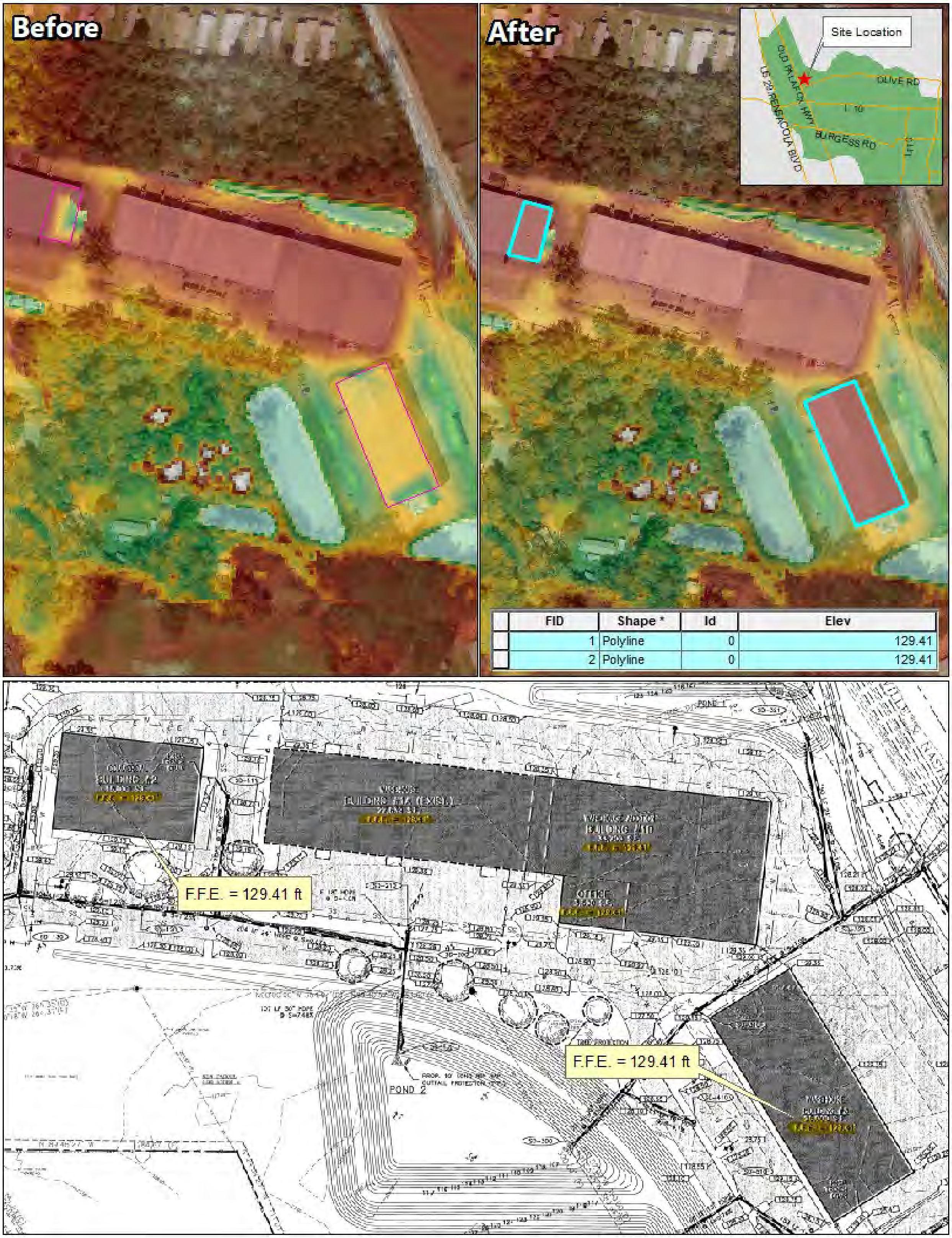
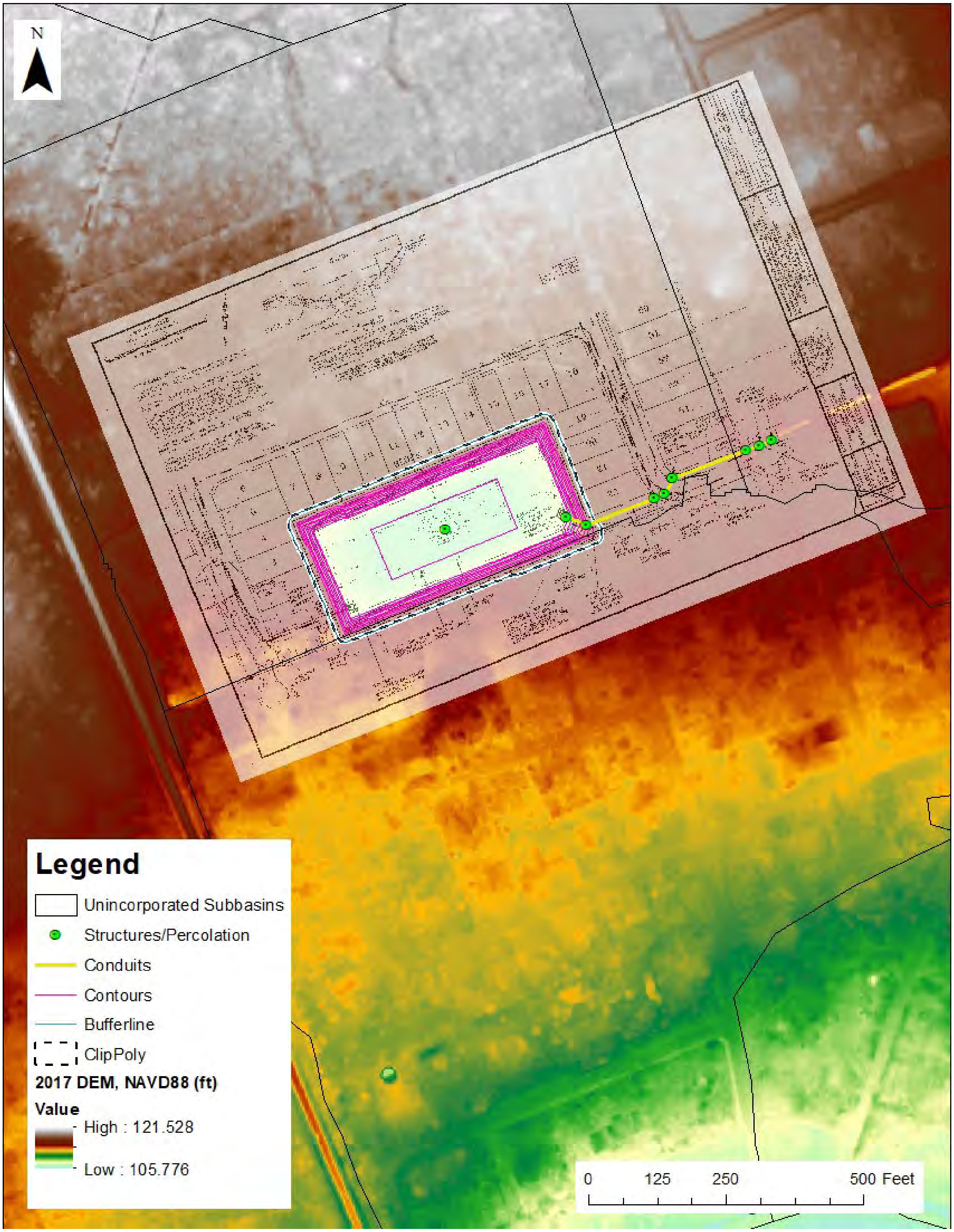


FIGURE 4.1-2
Topographic Void Correction at Monarch Lane



4.2 Vertical Elevation Datum

4.2.1 City's Modeled Area

No documentation explicitly notes the vertical datum used in the City's ICPR4 model or provides a specific datum conversion that may have been used to convert between the NGVD29 and NAVD88 datums. The City's SWMP report notes that the information for the infrastructure in the model came from various previous studies and miscellaneous sources. Due to the completion date of the City's SWMP (July 2019), the Wood team assumed that the elevation data supplied within the City's model is presented in the NAVD88 vertical datum.

4.2.2 Unincorporated Area

The elevation data for the Carpenter Creek/Bayou Texar WMP and model is presented in the NAVD88 vertical datum, which corresponds to the 2017 DEM. It was necessary, for certain data sources, to convert provided elevation data from the NGVD29 vertical datum to the NAVD88 vertical datum. Using the U.S. Army Corps of Engineers' CORPSCON tool, it was determined that, within the unincorporated area of the watershed boundary, the conversion factors range from -0.09 ft to -0.16 ft, with a mean conversion factor of -0.14 ft (rounded from -0.136667 ft). The Wood team adopted the mean conversion factor of -0.14 ft for use throughout the unincorporated area of the watershed boundary to convert from the NGVD29 datum to the NAVD88 datum, as necessary (NGVD29 elevation + (-0.14 ft) = NAVD88 elevation).

When utilizing plan sets as the source for elevation data, if the elevation data (invert elevation, for example) originated from a plan set (ERPs, FDOT plans, etc.) dated before 1988 that did not have a noted vertical datum, the assumption was made that the plan set was in the NGVD29 datum, and the conversion factor of -0.14 ft was applied to transfer it to NAVD88 datum. However, if the plan set was dated post-1988 and did not have a noted vertical datum, the assumption was made that the plan set was already referencing the NAVD88 datum. Otherwise, when noted, the vertical datum was gleaned from the plans, and the NGVD29 to NAVD88 conversion was applied. A sensibility check of structures with information from plans with assumed datums was done by viewing the structure and DEM to make sure the elevations made sense.

5.0 WATERSHED BOUNDARY AND SUBBASIN DELINEATION

5.1 Watershed Boundary Definition

As part of the project, the Wood team was tasked with refining the "watershed boundary" as needed, based on the hydrologic and hydraulic characteristics of the area. Ultimately, the watershed boundary coincides with the edges of the subbasins that are to be modeled as part of the Carpenter Creek and Bayou Texar WMP and is inclusive of areas that are hydrologically and/or hydraulically connected to Carpenter Creek and Bayou Texar.

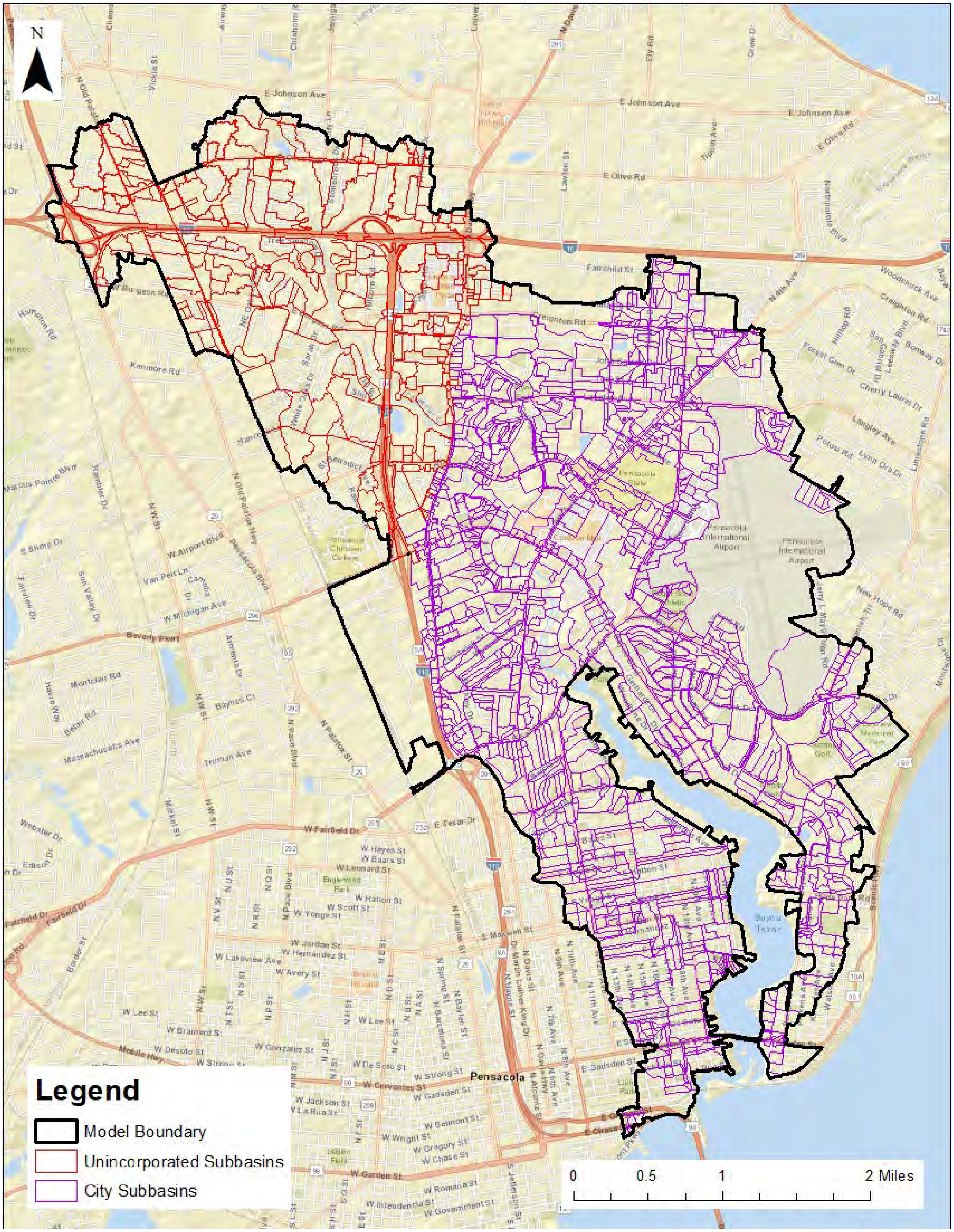
5.2 Subbasin Delineations

5.2.1 City's Modeled Area

As part of the watershed boundary refinement, the Wood team reviewed the edges of the City's existing model subbasins for accuracy, from a hydrologic and hydraulic standpoint. As shown in **Figure 2-1**, the City's Existing Watersheds 03, 04, 05, 06, 07, 08, 09, and 10 include subbasins that are within or adjacent to the study area and were therefore reviewed to determine eligibility for inclusion in the Carpenter Creek/Bayou Texar watershed boundary. Utilizing the 2017 LiDAR-derived DEM, in conjunction with the nodes and links included in the City's model, the Wood team determined that the subbasins included in the City model's Existing Watersheds 04, 05, 06, and 09 scenarios were appropriate for inclusion within the Carpenter Creek and Bayou Texar watershed boundary. No subbasins from the City's other model scenarios were deemed as appropriate for inclusion in the Carpenter Creek and Bayou Texar watershed boundary.

In summary, a total of 1,754 subbasins from the City's existing model scenarios are proposed for inclusion in the Carpenter Creek/Bayou Texar model, as shown in **Figure 5.2-1**. These 1,754 subbasins range in size from less than an acre to approximately 655 acres, with an average acreage of 4.3.

FIGURE 5.2-1
Model Subbasins



5.2.2 Unincorporated Area

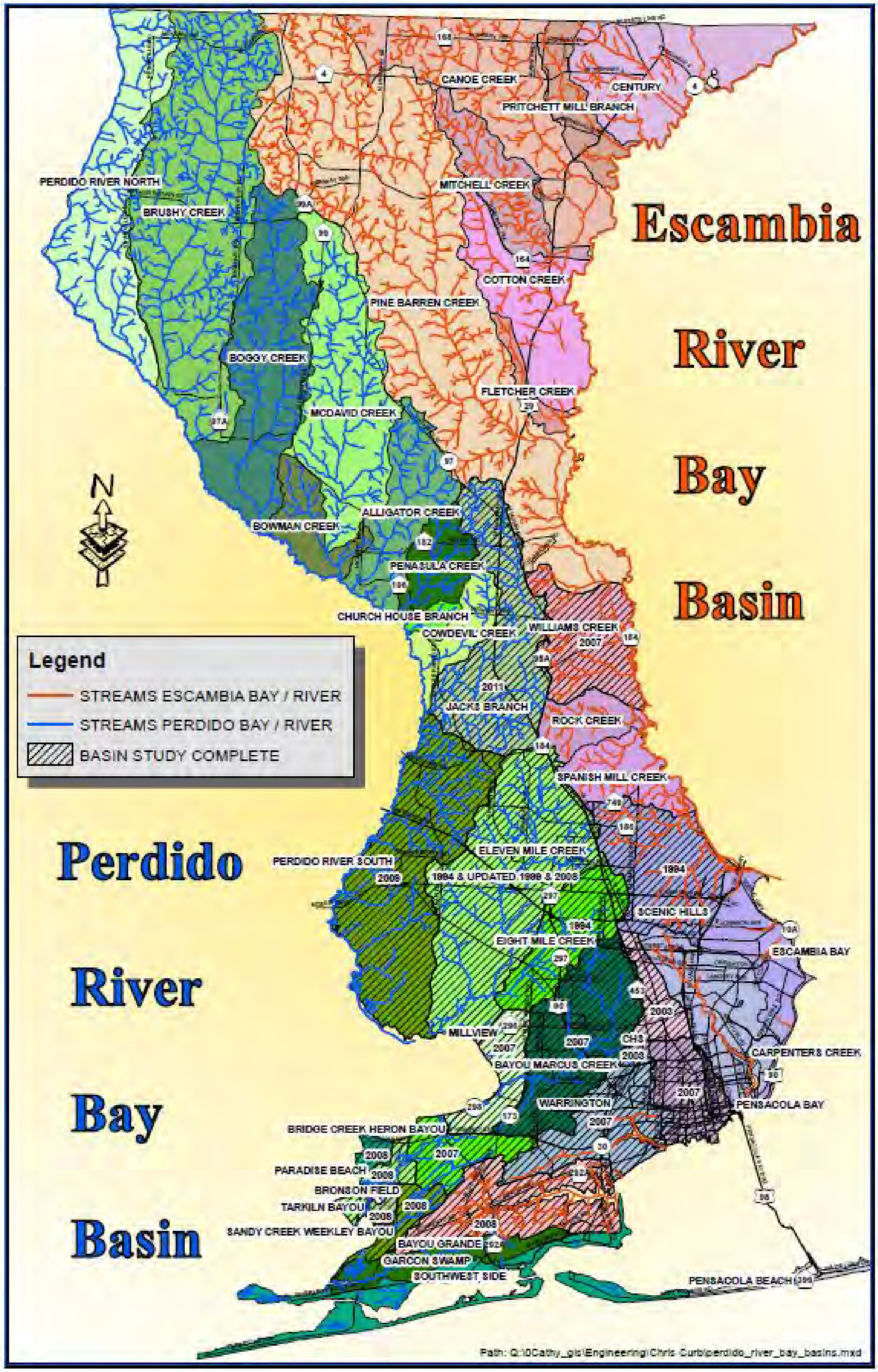
Within the unincorporated area, subbasins were delineated using a combination of GIS-based ArcHydro tools, followed by manual manipulation. The ArcHydro tools generate rough subbasin delineations based on the underlying DEM (2017 DEM, for this project) and a user-specified minimum drainage area. Although these tools are effective in generating very rough subbasins, manual manipulation was needed to further define and edit the subbasins, especially in urban environments where infrastructure is prevalent. Manual manipulation of subbasins was conducted based on information from the 2017 DEM, recent aerial imagery, and drainage infrastructure patterns presented in information sources that included Environmental Resource Permits (ERPs), County residential and roadway plan sets, and FDOT plan sets, and from field reconnaissance and survey efforts.

Generally, and to the highest degree practical based on available information, the subbasin level of detail mimicked the level of detail established in the City's model, which was found to be of a regional scale. In other words, subbasins were delineated around local storages such as ponds or significant drainage divides such as highways and bridges. In contrast, at a more local scale, subbasins may be broken out at a higher level of detail to model the capacity of individual curb inlets, driveway culverts, or other local drainage features. A local level of detail is generally needed for development design purposes and would be more expected for a model meant to capture the drainage of a mall parking lot rather than a watershed.

Additionally, given the primary objective of simulating flooding associated with Carpenter Creek itself, some of the smaller subbasins were merged into larger subbasins to allow for aggregated representation of runoff and flows into the creek system. The subbasin delineation process resulted in 304 subbasins in the unincorporated area, shown in **Figure 5.2-1** above, ranging from approximately 0.26 to 98.81 acres, with an average acreage of 11.10.

As shown in **Figure 5.2-2** below, the County has completed basin master plans for many of the County's major basins. In particular, the Scenic Hills, Beverly Parkway, Pensacola Bay, and Escambia Bay basins are adjacent to the Carpenter Creek/Bayou Texar study area. The Scenic Hills, Beverly Parkway, and Pensacola Bay basins are denoted as being completed in 1994, 2003, and 2007 respectively. Wood received subbasin delineations in GIS format for the Beverly Parkway and Pensacola Bay basins, and in pdf format for the Beverly Parkway basin. As part of the initial subbasin delineations for the Carpenter Creek/Bayou Texar WMP, Wood reviewed the adjoining subbasin delineations for the completed basins.

FIGURE 5.2-2
County Basin Study Map



5.3 Subbasin Parameterization

5.3.1 Unit Hydrograph

A unit hydrograph, by definition, is the hydrograph resulting from one inch of direct runoff (rainfall excess) generated uniformly over a subbasin area at a constant rate during a specified time interval. Generally, lower peak rate factors and corresponding unit hydrographs are used for flatter terrains and higher peak rate factors are used for steeper terrains.

5.3.1.1 City's Modeled Area

For runoff hydrograph generation for subbasins within the Existing 04, 05, 06, and 09 scenarios, the City's model uses the National Resources Conservation Service (NRCS) (formerly the Soil Conservation Service (SCS)) Unit Hydrograph method, with a peak rate factor of 323.

5.3.1.2 Unincorporated Area

Per the County's BGS, the unit hydrograph/peak rate factor shall be based on average overland slopes of the subbasins as follows: less than 0.5 percent – 256, 0.5 to 1.5 percent – 323, greater than 1.5 percent – 484. Due to the proximity of the City's modeled area to the unincorporated area, and to ensure consistency between the City's model input and the input for the unincorporated area, Wood utilized a peak rate factor of 323 for model development in the unincorporated area.

5.3.2 Infiltration Method

ICPR uses base maps for soil zones and land use cover to perform hydrologic computations. User-generated lookup tables are used to assign a curve number (CN) to each subbasin based on the land use and soil type combinations that occur within its boundary. The following subsections describe the data used in the model to develop the curve numbers.

5.3.2.1 City's Modeled Area

Although the City noted in their SWMP that they utilized the NWFWMD 2015-2016 land use/land cover dataset and the NRCS Web Soil Survey data for the development of their curve number values for their subbasins, these native files were not provided by the City with the ICPR model. The Wood team acquired the datasets noted to be utilized by the City for their WMP development. However, on a subbasin level, it wasn't clear exactly how the City developed its CN values, and it was not possible to directly correlate the City's CN values to the base files noted to be used for land use and soils.

The rainfall data utilized for the Wood team's calibration storm event (April 2014) was provided in a grid format, developed as part of the HDR study. To utilize the gridded rainfall data provided for the calibration storm, the Wood team required the shapefiles for land use and soils on a subbasin level. As those files were not provided, and the exact version of the City's native files could not be verified or recreated, the Wood team used the 2019 land use shapefiles from the

NWFWMD and the NRCS 2018 soils layer to develop CN values in ICPR4 for the subbasins in the City, as well as in the unincorporated area.

The City's model did not appear to account for Directly Connected Impervious Area (DCIA) in its infiltration calculations. DCIA includes impervious surfaces that are directly connected to the subbasin design point without flowing over pervious surfaces.

5.3.2.2 Unincorporated Area

For the unincorporated area, CN values were calculated per subbasin. As part of the Carpenter Creek/Bayou Texar WMP, 2019 land use shapefiles from the NWFWMD were utilized. The 2019 land-use file, in conjunction with the NRCS 2018 soils layer, was used to develop CN values in ICPR4 for the subbasins in the unincorporated area of the watershed boundary. **Figure 5.3-1** and **Figure 5.3-2** show the 2019 Land use Cover and 2018 Hydrologic Soil Groups (HSG), respectively, with land use cover represented by Florida Land Use Cover Classification System codes, and Soils represented by their HSG; both attributes used in model parameterization for curve numbers.

FIGURE 5.3-1
2019 Land Use Cover

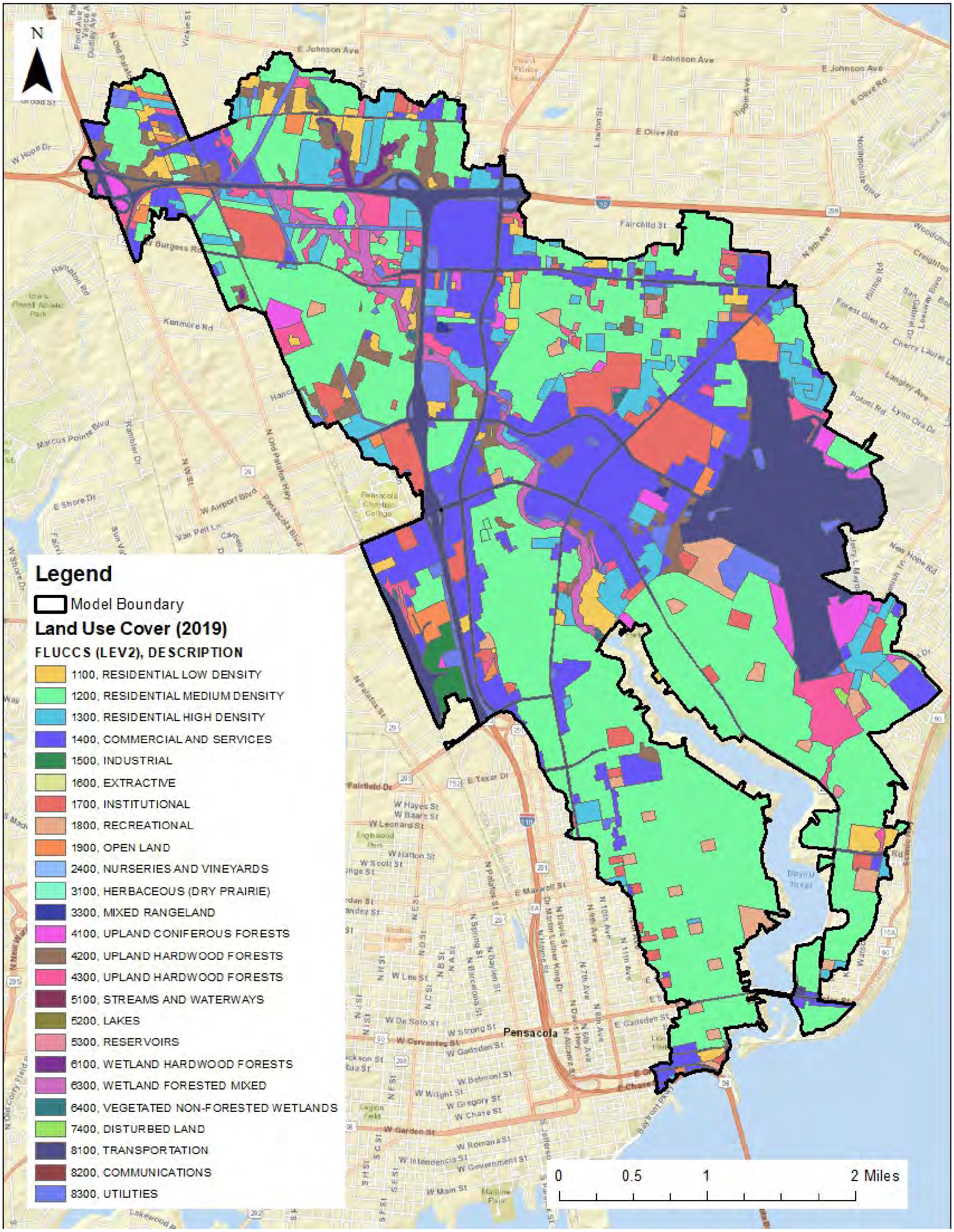
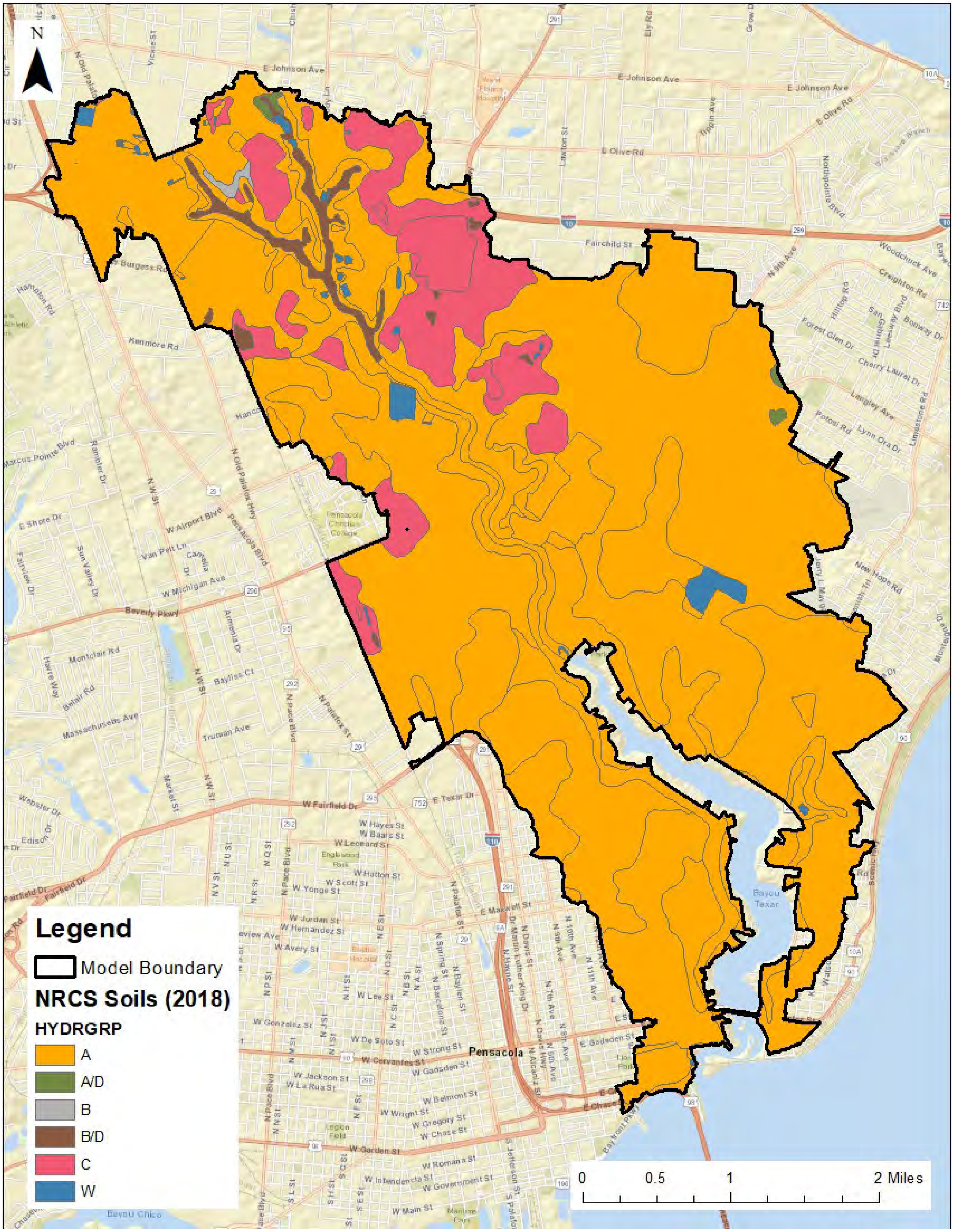


FIGURE 5.3-2
2018 Hydrologic Soil Groups



Per the County's BGS, DCIA may also be delineated separately if sufficient data is available (e.g., Escambia County GIS layers) or values may be assumed for particular land use. DCIA data was requested from the County on July 8, 2020, and it was confirmed that the County does not have such a dataset for use. Therefore, the Wood team calculated CN values for each subbasin but did not calculate DCIA. This is also consistent with the methodology utilized for the City's model.

Utilizing the lookup tables for the revised existing land use and soils layers, ICPR4 will automatically calculate CN values, as presented in **Figure 5.3-3** below:

FIGURE 5.3-3

Runoff Curve Numbers for Urban Areas

Chapter 2 | Estimating Runoff | Technical Release 55 Urban Hydrology for Small Watersheds

Table 2-2a Runoff curve numbers for urban areas [1]

Cover description		Curve numbers for hydrologic soil group			
Cover type and hydrologic condition	Average percent impervious area [2]	A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.) [3]:					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only) [4]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation) [5]		77	86	91	94
Idle lands (CN's are determined using cover types similar to those in table 2-2c).					

[1] Average runoff condition, and $I_a = 0.2S$.
[2] The average percent impervious area shown was used to develop the composite CN's. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. CN's for other combinations of conditions may be computed using figure 2-3 or 2-4.
[3] CN's shown are equivalent to those of pasture. Composite CN's may be computed for other combinations of open space cover type.
[4] Composite CN's for natural desert landscaping should be computed using figures 2-3 or 2-4 based on the impervious area percentage (CN = 98) and the pervious area CN. The pervious area CN's are assumed equivalent to desert shrub in poor hydrologic condition.
[5] Composite CN's to use for the design of temporary measures during grading and construction should be computed using figure 2-3 or 2-4 based on the degree of development (impervious area percentage) and the CN's for the newly graded pervious areas.

5.3.3 Time of Concentration (Tc)

5.3.3.1 City's Modeled Area

There were no spatial features provided to illustrate the longest flow path lines that may have been utilized for Tc calculations in the City's model. Therefore, it is not possible to review the reasonableness of the methodology of the longest flow path development or the resulting Tc calculations in the City's model.

The Tc values in the City's model range from a minimum of 10 minutes to a maximum of 100 minutes for the subbasins within the Existing Watersheds 04, 05,06, and 09 scenarios. Although the methodology and assumptions utilized for Tc calculations were not explicitly outlined in the City's SWMP report, it is presumed that the NWFWMD 2006 DEM, along with information from previous studies, plans, and possibly field verification may have been utilized for this purpose.

5.3.3.2 Unincorporated Area

For Tc development in the unincorporated area of the watershed boundary, the Wood team used the guidelines from the United States Department of Agriculture's (USDA's) Urban Hydrology for Small Watersheds, Technical Release TR-55, which provides a popular method for determining the longest flow path and the Tc.

Using this method, flow in the longest flow path was divided into sheet flow (overland flow) and shallow concentrated flow. Sheet flow generally occurs in the headwater area of a subbasin. Calculations assume the initial 100 feet as sheet flow and then the remaining flow is attributed to shallow concentrated flow. Tc for each subbasin is computed by summing all the travel times along the longest flow path in the subbasin. The GIS-based ArcHydro toolset was used to automate the generation of the longest flow paths, utilizing the 2017 project-area DEM. Manual visual checks were performed to provide a "sanity check" on the generated longest flow path lines.

Once the longest flow path lines were developed, Tc values were calculated from an automated process (ArcGIS python code), which automates a succession of steps as follows:

- Calculates the length and slope for each flow type along the longest flow path. The slope for each flow type is calculated by dividing the elevation difference between the two ends of the flow path section by flow length. The code automatically extracts these elevations from the DEM.
- Determines the hydraulic parameters (such as Manning's n, velocity) for each flow type. Manning's n was determined for each land use type using the manning's roughness coefficient for sheet flow table from TR-55, as shown in **Figure 5.3-4** below:

FIGURE 5.3-4

Manning's Roughness Coefficients for Sheet Flow

Table 15–1 Manning's roughness coefficients for sheet flow (flow depth generally ≤ 0.1 ft)

Surface description	***n*** [1]
Smooth surface (concrete, asphalt, gravel, or bare soil)	0.011
Fallow (no residue)	0.05
Cultivated soils:	
Residue cover ≤ 20%	0.06
Residue cover > 20%	0.17
Grass:	
Short-grass prairie	0.15
Dense grasses [2]	0.24
Bermudagrass	0.41
Range (natural)	0.13
Woods: [3]	
Light underbrush	0.40
Dense underbrush	0.80

1 The Manning's *n* values are a composite of information compiled by Engman (1986).
2 Includes species such as weeping lovegrass, bluegrass, buffalo grass, blue grama grass, and native grass mixtures.
3 When selecting *n*, consider cover to a height of about 0.1 ft. This is the only part of the plant cover that will obstruct sheet flow.

- Using the County's latest GIS parcels layer in combination with the updated existing land use layer, the Python code denotes the shallow concentrated flow paths as either paved or unpaved. For subbasins that have a shallow concentrated flow path that travels over both paved and unpaved areas, the assignment of paved or unpaved was based on which line segment is longest.
- Calculates the travel time for each flow type:
  - Sheet Flow Calculation:
    - The commonly used formula for sheet flow calculation is provided by the TR-55, as follows:

$$T_{ts} = \frac{0.007(nLs)^{0.8}}{P^{0.5}S_s^{\ 0.4}} \qquad (1)$$

where:

T_{ts} = travel time of sheet flow (*hr*)

n = Manning's roughness coefficient (see **Figure 5.3-4**)

L_s = length of sheet flow (*ft*)

P = 2-year, 24-hour rainfall amount in inches

S_s = slope of overland (*ft/ft*).

P is determined according to FDOT's Drainage Manual.

- Shallow Concentrated Flow Calculation
  - After 100 *ft*, sheet flow becomes shallow concentrated flow. Travel time for shallow concentrated flow is proportional to flow length and inverse to average flow velocity, expressed as:

$$T_{tc} = \frac{L_c}{3600V_c} \quad (2)$$

where:

T_{tc} = travel time of shallow concentrated flow (*hr*)

L_c = length of shallow concentrated flow (*ft*)

V_c = average velocity of shallow concentrated flow (*ft/s*).

  - The average velocity (Vc) is a function of watercourse slope and type of channel (paved or unpaved). According to TR-55, velocity is determined by the following equations

$$V_c = 16.1345(S_c)^{0.5}, \quad \textit{for unpaved} \quad (3)$$
$$V_c = 20.3282(S_c)^{0.5}, \quad \textit{for paved} \quad (4)$$

where:

S_c = slope of shallow concentrated flow (*ft/ft*).

- Pipe and Open Channel Flow Calculation
  - As presented in the County's BGS, when necessary, pipe flow shall be assumed to be 3 feet/second, unless other information is available to support a different velocity or travel time.
  - For open channel flow, the Tc flow paths were truncated to the point that correlates to the initial stage within the channel, as the channel flow time is inherently accounted for in the channel feature itself.
- For each subbasin, Tc is the sum of the travel time of the three flow types.

6.0 NODE AND LINK DEVELOPMENT AND PARAMETERIZATION

6.1 Node Features

6.1.1 Node Feature Development

The following subsections serve to provide information related to the methodology of node feature or parameter development for the WMP model. Little information related to node development and parameterization was provided in the City's SWMP report or provided model files. Therefore, in terms of the City model discussion, this section will serve to summarize the City's nodes and parameters, rather than describe the employed methodology.

6.1.1.1 City's Modeled Area

The Wood team incorporated the nodes from the City's Existing Watersheds 04, 05, 06, and 09 model scenarios into the Carpenter Creek/Bayou Texar model. **Table 6.1-1** below summarizes the numbers of model nodes imported from the City's model.

TABLE 6.1-1
City Nodes to be Incorporated from City's Model

Existing Watershed ID	Node Count
04	182
05	487
06	1,685
09	315
TOTALS	**2,669**

There is a total of 2,669 nodes, within the City's Existing Watersheds 04, 05, 06, and 09 scenarios, incorporated into the Carpenter Creek/Bayou Texar WMP model. Of these nodes, 2,593 are assigned as stage/area type, 74 as time/stage type, and 2 as stage/volume type. Stage/area nodes consist of user-defined areas assigned to specific vertical elevations, representing the available storage for each modeled node. Stage/volume nodes are similar, but they consist of user-defined volumes assigned to specific vertical elevations, representing the available volume storage for each modeled node. Time/stage nodes are referred to as boundary nodes and consist of time elements assigned to specific vertical elevations.

For boundary nodes, these elevations are typically set at a constant value that represents the tailwater elevations. As noted within the City's SWMP report, the tailwater elevation used in the

City's model for Escambia Bay and Pensacola Bay is 1.10 feet. A total of 74 time/stage boundary nodes from the City model were included in the consolidated model, all but two of which relate to City links tying into Carpenter Creek and Bayou Texar.

There is no mention in the City's SWMP report of model simulations conducted to evaluate sea-level rise (SLR) scenarios, so it is presumed that the City's SWMP did not include this analysis.

6.1.1.2 Unincorporated Areas

For the unincorporated area of the watershed, a stage/area loading node was assigned to each subbasin developed. Additional stage/area nodes (with nominal storage) were placed as necessary to account for significant junctions, bends, or diameter changes that occur along with a series of pipes. Furthermore, per the County's BGS, nodes were placed so that channel lengths are generally kept to a maximum length of 1,000 feet and channel segments are approximately uniform in length to the greatest extent possible. The maximum spacing of 1,000 feet was adhered to during the placement of the channel nodes in the unincorporated area.

Boundary conditions are modeled as time/stage nodes. In the unincorporated area, one time/stage node was added to represent a connection between the adjacent Beverly Parkway basin study and the Carpenter Creek watershed. Another time/stage node was placed to serve as a sink for percolation links added to the model. This boundary condition was set to zero (sea-level) based on NWFWMD data originally developed for the Florida Aquifer Vulnerability Assessment (FAVA) model. More details on the percolation link parameters are discussed in **Section 6.2.2.2.7**.

Additional boundary nodes were placed as needed to appropriately model the unincorporated area. Pensacola Bay's tidal boundary conditions were based on the mean high water elevations. Based on observed National Oceanic and Atmospheric Administration (NOAA) Gulf of Mexico tide gage 8729840, the tailwater elevation of 1.10 ft that was used in the City's model for Escambia Bay and Pensacola Bay was found to be acceptable. Wood also proposed to utilize the 1.10 ft for the Escambia Bay and Pensacola Bay tidal boundary stages in the unincorporated area of the model.

6.1.2 Node Parameterization

6.1.2.1 Stage/Area Relationships

6.1.2.1.1 City's Modeled Area

The City's model contains 2,593 stage/area type nodes and 2 stage/volume type nodes within the Existing Watersheds 04, 05, 06, and 09 scenarios. It is presumed that the City's model made use of the NWFWMD 2006 DEM, along with information from previous studies, plans, and possibly field verification to develop the stage/area relationships, although this was not explicitly outlined in the City's SWMP report.

Through further examination of the City's model, the Wood team observed that only 150 stage/area nodes from the City's model scenarios (Existing Watersheds 04, 05, 06, and 09) contained related stage/area data. To allow for the model to run successfully for the large storm events, the model requires nodes to have a minimum storage area of 5,000 ft^2. Therefore, as necessary for City model nodes, the Wood team added the minimum nodal storage of 5,000 ft^2 to have success in model simulations.

6.1.2.1.2 Unincorporated Area

For each of the subbasins developed within the unincorporated area of the watershed boundary, one stage/area node was assigned to account for the subbasin's storage. The stage/area nodes contain vertical elevations and their respective storage areas, in increments up to the subbasin's rim elevation. Generally, ArcHydro tools were utilized to develop the stage/area relationships per node, using the underlying 2017 project-area DEM. However, other data sets were utilized, when available, for a more accurate representation of stage/area information, such as as-built drawings that provide details for onsite ponds. In certain cases, field recon and/or survey information was used to provide more reliable data, on an as-needed basis.

For modeled channel links, GIS polygons were drawn to represent the area associated with them, based on their dimensions/cross-sections. The area associated with these channel polygons was removed from the total subbasin area used to calculate the available stage/area for each subbasin's storage node. This was necessary to prevent "double-counting" of available subbasin storage as channel cross-sections already capture the storage within the channel.

Although only one stage/area node was included per subbasin to represent the subbasin's storage, additional stage/area type nodes were included for modeling purposes. These additional stage/area nodes include no storage (no storage beyond the minimum 5,000 ft^2 required for modeling purposes) and are modeled to represent such things as changes in pipe sizes, connectivity junctions, etc. In total, there are 395 stage/area nodes in the unincorporated area of the model. Of these nodes, 304 are associated with subbasins and contain storage information, and the remaining 91 are "dummy" nodes that contain no storage. Note that 11 nodes are shared with the City model, as they were included in the City's model and were retained in the consolidated model after the subbasins along the City/unincorporated boundary were merged.

6.1.2.2 Initial Water Surface Elevations

Initial water surface elevations (IWSEs) for nodes are the water surface elevations (or ground elevation if the node is dry) expected at the onset of a simulation. Initial flows through model links are calculated based on the initial stages, so care must be given in setting the most appropriate values. Below is a description of the methodology used to assign these IWSE values.

6.1.2.2.1 City's Modeled Area

The precise methodology utilized for the development of IWSEs in the City's model was not presented in the City's SWMP report. However, the City's report did note that tailwater elevations for drainage systems discharging into lakes, ponds, and creeks were determined based on water surface data, 2006 LiDAR elevations, or surveyed information. Although the City's IWSEs were primarily left as is, there are exceptions. For City subbasins that were merged, re-delineated, updated with new storages, or had the outfall changed, such as in the case of the 9th Avenue bridge's subbasin, the IWSE was also updated to reflect the changes to the subbasin.

6.1.2.2.2 Unincorporated Area

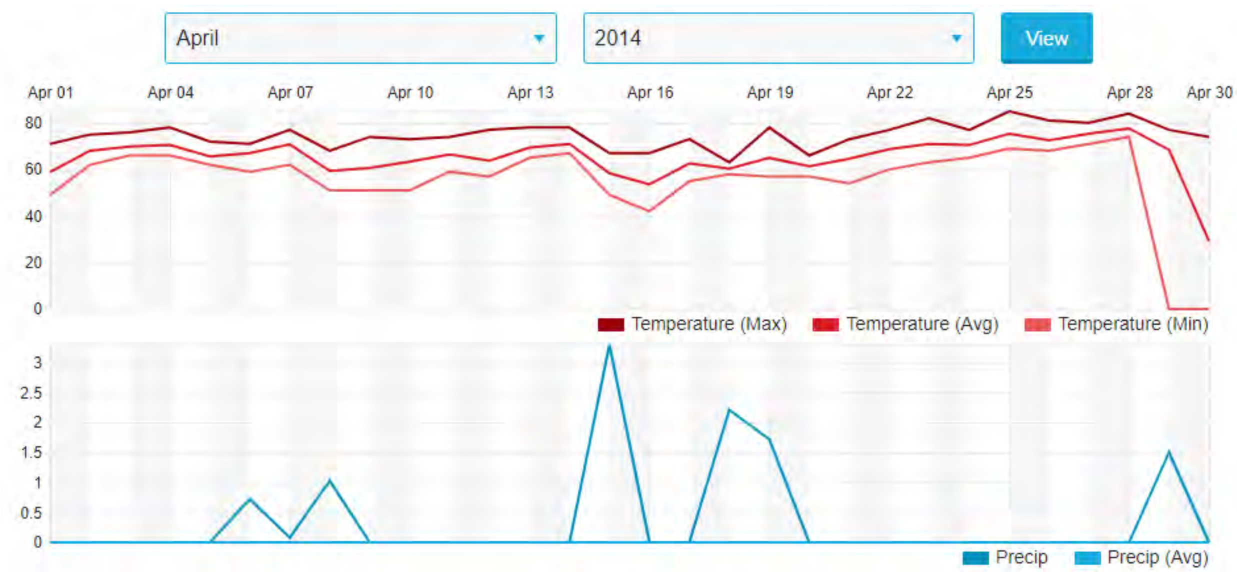
For the unincorporated areas of the model, and per the County's BGS, IWSEs was first set to seasonal high water levels (SHWL) based on the best available information (i.e., wetland SHWL evaluations, control structure operating schedules, etc.). For water bodies and undeveloped wetland areas where documentation of the SHWL or other starting elevations is not available, the overflow elevation for the node was assumed for the initial water level in the node based on the 2017 DEM. For the outfall structures that connect to the stormwater conveyance systems, the initial stages in the developed areas were set at the minimum control elevations. Downstream conditions (e.g., structure inverts or other water level controls) were considered when establishing initial water surface elevations.

Initial conditions in the unincorporated area were evaluated by inspecting model time series results for unexpected flows in the model at the onset of a simulation (i.e., time = 0 hours). Such flow rates typically result from incorrect and unbalanced initial water surface elevations. If baseflow is intended at the simulation onset, then initial node stages in the unincorporated areas were defined in such a way as to produce those baseflows without system drawdown and baseflow rates were entered into the appropriate node location(s) to maintain that baseflow rate.

After these initial IWSEs were set, a dry condition with no rainfall was simulated for 200 hours in the model to establish new initial stages after any surges evened out in the model. The mean annual storm event was then run using the node stage elevation at time 100 hours, from the no-rainfall simulation, as the initial stage in the mean annual simulation. This method is known as the "hot start" method. All the design storm model simulations used the "hot start" function based on the results of the mean annual model simulation at time 100 hours, thereby setting the post-storm mean annual node stages as the initial stages for the larger storm event simulations. Also, for time-stage nodes (boundary conditions), elevations that correlate with the time zero were used as initial stages.

Wood evaluated the pre-condition (2 weeks) of the 2014 storm (April 29-30, 2014) calibration event. There were approximately 7.23 inches of total precipitation (**Figure 6.1-1**) occurring between April 15-April 20, 2014 (Pensacola International Airport Station, Weather Underground). Therefore, Wood set up the 2014 storm calibration event using the stages from time 100 hours of the mean annual simulation as the initial stages considering the ponds and wetlands could still have standing water.

FIGURE 6.1-1
April 2014 Storm Event Precipitation



Wood also developed model simulations for the intermediate-low and intermediate-high sea-level rise scenarios for the horizon years 2040 and 2070, making no adjustments to rainfall intensity. The projected SLR values were based on the June 2016 Coastal Vulnerability Assessment for Escambia County, Florida. Due to its proximity to the study area, the Wood team proposed to utilize SLR data directly from the NOAA tide gage identified as 8729840, with no interpolation between other regional gages. As such, the intermediate-low and intermediate-high scenarios were run for the 100-year, 24-hour storm event, associated with the following respective NOAA SLR projections (source: Sea-level Rise and Coastal Flooding Impacts (noaa.gov)):

- Year 2040 Intermediate-low: 0.66 feet;
- Year 2040 Intermediate-high: 1.31 feet;
- Year 2070 Intermediate-low: 1.18 feet; and
- Year 2070 Intermediate-high: 3.15 feet.

The City model's boundary condition time/stage nodes tied to Carpenter Creek and Bayou Texar have a depth of 1.1 ft, which is then added to the SLR projections for the SLR scenario boundary condition. This results in 1.76 ft, 2.41 ft, 2.28 ft, and 4.25 ft respectively. These scenarios were evaluated for impacts to wetlands as defined by the 2019 Land Use Cover lists of critical infrastructure provided by the City and County.

6.2 Link Features

6.2.1 Hydraulic Connectivity and Link Development

6.2.1.1 City's Modeled Area

All links, a total of 2,661, within the City model's Existing Watersheds 04, 05, 06, and 09 were imported and utilized in the Carpenter Creek/Bayou Texar WMP model. **Table 6.2-1** below summarizes the numbers of model links imported from the City's model.

TABLE 6.2-1

City Links to be Incorporated from City's Model

Existing Watershed ID	Model Link Count per Type				
	Pipe	Weir	Drop Structure	Channel	Rating Curve
04	152	6	3	6	0
05	456	8	8	7	1
06	1,523	69	70	55	2
09	281	6	1	6	1
TOTALS	**2,412**	**89**	**82**	**74**	**4**

There were seven instances where alterations were made to City link features. Five of the alterations pertain to simply renaming of link features due to the marrying of the City and unincorporated model areas along Davis Highway. Another alteration is due to an update to the upstream cross-section of a City channel link. The final alteration pertains to an update to the City link representing the 9th Avenue bridge connection. The alteration at 9th Avenue was done to account for the recent design and construction at that location and involved a model update from a pipe link (box culvert) to a channel link that adopts the concrete trapezoidal channel features detailed in the 2020 FDOT project plans (Project ID 437178-1-52-01).

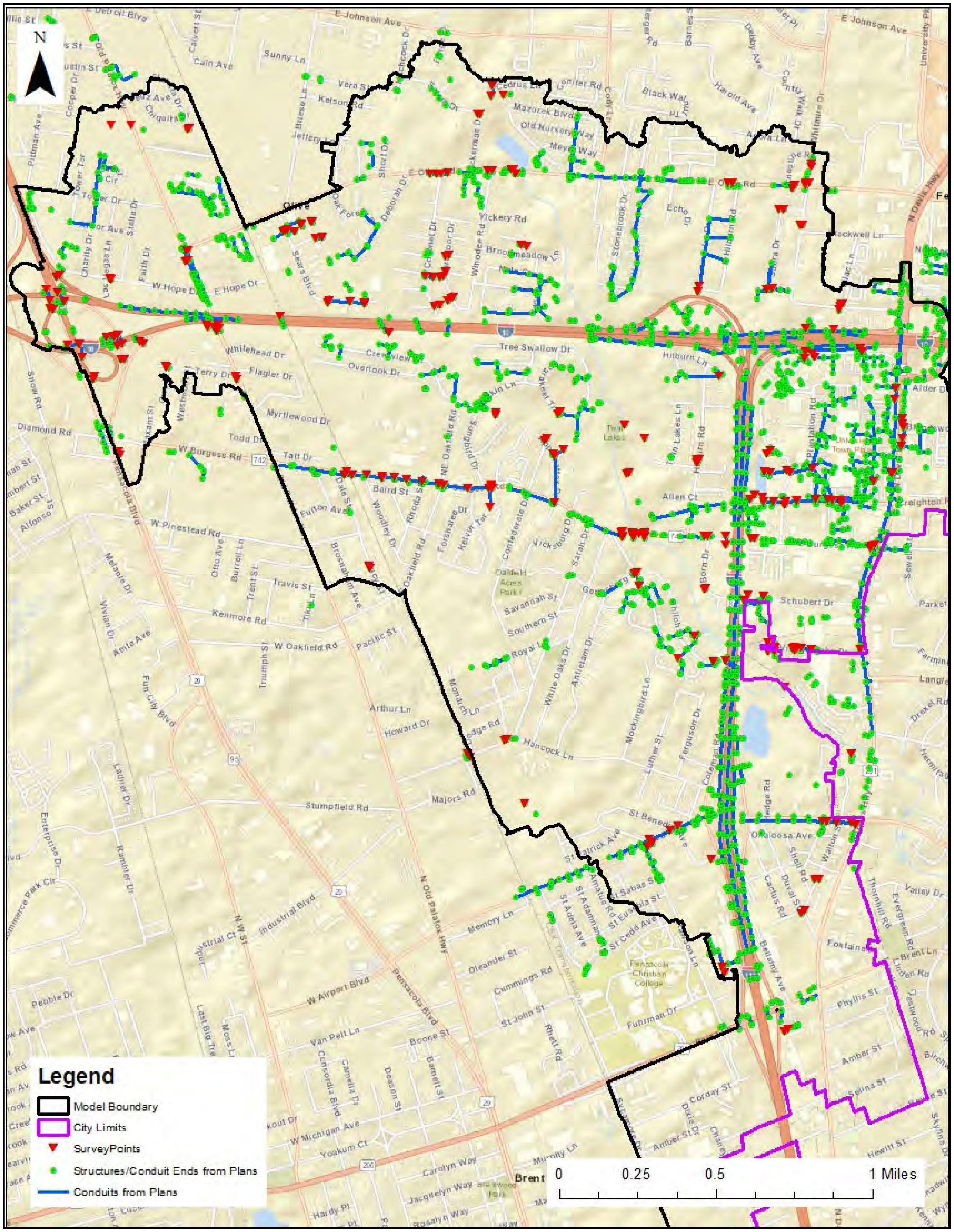
6.2.1.2 Unincorporated Area

The Wood team developed an inventory of existing drainage structures and conveyance features from the data and primary drainage system information compiled from County GIS databases, County plans, ERPs, FDOT plans, and findings from field reconnaissance and survey efforts.

In total, approximately 217 different ERP plans were collected from the NWFWMD, the FDEP, the FDOT, and the County, among other sources. Of the collected plans, approximately 203 of these plans included drainage information and were evaluated for pertinent information. Approximately 90 were used to develop subbasins, drainage network features, and/or to correct the DEM for topographic voids, primarily due to areas of new development that have occurred beyond the LiDAR's fly date in 2017.

Survey data was collected to fill data gaps for structures and conduits where information could not be obtained from ERPs. In total, 267 individual survey locations were collected by Wood. The survey includes key invert elevations and dimensions for conduits and control structures that connect two or more subbasins in the unincorporated area. **Figure 6.2-1** shows the location of the 267 survey locations as well as structures and conduits located from plan sets.

FIGURE 6.2-1
Survey Locations and Hydraulic Inventory Developed in Unincorporated Area



The compiled hydraulic inventory resulted in the development of 923 model link features within the unincorporated model portion. A total of 227 pipe links, 32 drop structure links, 581 weir links, 45 channel links, 36 percolation links, and 2 rating curves were developed for the model in the unincorporated area.

Within the unincorporated area, overland weir features were generated for subbasins that demonstrated the need for such features based on the results of the 100-year, 24-hour storm event. In the unincorporated area, 520 overland weirs were developed, although 21 of these are structural overflow weirs. These overland weir links are necessary to prevent “glass walls”, or false flood staging, from occurring by providing a mechanism to allow overland flow between subbasins. The 499 non-structural overland weir feature links utilized the underlying 2017 DEM to determine the lowest elevation along each subbasin boundary, which corresponded to the point at which the overland weir link features were drawn to cross the subbasin boundary. The elevation at this link crossing became the invert elevation for the overland weir feature, for modeling purposes. Additional information on the development of the cross-sections for the overland weir features is described in **Section 6.2.2.2.6: Cross-Sections**.

6.2.2 Link Parameterization

6.2.2.1 City’s Modeled Area

Little information related to the methodology of link parameter development was provided in the City’s SWMP report or provided model files. Therefore, this section will serve to summarize the City’s link parameters, rather than describe the employed methodology.

As noted in the City’s SWMP report, invert elevations in the City’s model were generally derived and entered from the obtained construction plans, or previous survey efforts. However, the City’s model employs several assumptions and relied on computer software to aid in determining invert elevations that could not be determined from existing data sources. The NWFWMD 2006 DEM was used to determine rim elevations, then inverts were globally specified using an algorithm in GIS, which assumed three feet of cover from the crown of the pipe. Also, inverts were manually rectified in areas where the use of the algorithm resulted in incorrect pipe slopes.

The City model’s pipe depths range from a minimum of 0.011 ft to a maximum of 15 ft. The upstream inverts of these pipe links range from a minimum elevation of -0.69 ft to a maximum elevation of 115.9 ft, and the downstream inverts of these pipes range from a minimum elevation of -5.09 ft to a maximum elevation of 115 ft. These elevations are presumed to correlate to the NAVD88 vertical datum. The entrance and exit losses for the City’s modeled pipes are within a range varying from 0 to 1. The Manning’s n values assigned to pipes in the City model include values of 0.011, 0.012, 0.013, and 0.024.

There was a total of 74 channel links imported from the City model’s Existing Watersheds 04, 05, 06, and 09. The channel links’ lengths range from a minimum of 14.71 ft to a maximum of 1,953.42 ft. The channels’ upstream inverts range from a minimum elevation of 1 ft to a maximum elevation of 109.5 ft, and the downstream inverts range from a minimum elevation of 0 ft to a maximum elevation of 105 ft. These elevations are presumed to correlate to the NAVD88 vertical datum. Of the proposed imported City model channels, 55 were modeled with irregular type geometries, with inputted cross-sections. There is no documentation provided in the City's SWMP report or model file to denote the methodology employed, or sources utilized, to determine the inputted cross-sections. Four of the 74 channels were modeled with parabolic geometries, while 15 were modeled as trapezoidal type.

There were 89 weir links imported from the City model's Existing Watersheds 04, 05, 06, and 09. Fourteen of the weirs are assigned as trapezoidal type, while 64 are assigned as rectangular type, and one weir is assigned as an arch structural plate type. Ten of these weirs are designated as having "irregular" geometry, which means they are assigned to an inputted cross-section in the model.

Typically, overland weirs, or weirs that are to represent overland flow connections, are modeled as "irregular" weirs, with inputted cross-sections that are derived from the DEM or some other surveyed data source. In a watershed-scale model, overland weirs are important as they provide the modeled subbasins a mechanism by which to discharge, in addition to any structural mechanisms, when peak stages surpass the rim elevation of a subbasin. The absence of the overland weir features can theoretically cause the model to create false peak stages per subbasin. In the case of the City's model, there are relatively few overland, irregular-type, weir features modeled. Per email discussions between the City and the Wood team in June of 2021, clarification was requested and received related to very high peak stages observed in the model results, based on a base City model simulation generated by the Wood team. In the email exchange, the City noted a discussion with Mott MacDonald on this issue and described that the high max stages, observed by the Wood team, were likely a result of a lack of overland flow weir paths in the City's model, which was done deliberately to avoid an excessive amount of additional nodes, which could impact model run times.

The invert elevations of the 89 modeled weir links range from a minimum of 2.19 ft to a maximum of 119.5 ft. The City's model has an orifice discharge coefficient of 0.6 assigned to each weir, and a weir discharge coefficient value of 2.8 for each weir, except for two (City model weirs LSW-10420W and L-12760W have weir coefficient values of 3).

There are two rating curve links modeled in the Existing Watershed 06 scenario, one modeled in the Existing Watershed 05 scenario, and one modeled in the Existing Watershed 09 scenario, as detailed below:

- Rating Curve Link L-10130RC (Existing Watershed 05) – comment within the City's model states "Force Main 6", per City of Pensacola 12th Avenue and Cross Street Pond Reconstruction Plans. Pump Rate estimated based upon plan specified capacity of 1,270 GPM."
- Rating Curve Link L-7650RC (Existing Watershed 06) – comment within the City's model states "Force Main 18 inch"
- Rating Curve Link L-0950RC (Existing Watershed 06) – no comment provided in City's model file

- Rating Curve Link L-S0010RC (Existing Watershed 09) – comment within the City's model states "Force Main 12", Estimated Elevations on/off"

Notably, there are no percolation links provided in the City's model.

6.2.2.2 Unincorporated Area

6.2.2.2.1 Geometry, Length, and Invert Elevations

For the unincorporated area of the watershed, information related to the geometry, material, invert elevations, and lengths of pipes, drop structures, channels, and weirs were recorded from various information sources including County GIS databases, County plans, ERPs, FDOT plans, and findings from field reconnaissance and survey efforts. Information gleaned from field reconnaissance, survey, or as-built plans were taken as best-available data and superseded overlapping or contradictory data provided in design drawings, aerial imagery estimations, or the County's GIS databases.

Invert elevations for the model were input in the NAVD88 vertical datum, which also corresponds to the 2017 DEM being utilized for the project. When necessary to convert between NGVD29 and NAVD88 datums, a conversion factor of -0.14 ft was applied for elevation data within the unincorporated area (NGVD29 + (-0.14ft)) = NAVD88).

6.2.2.2.2 Entrance, Exit, and Bend Losses

ICPR4 utilizes user-assigned entrance, exit, and bend losses to modeled pipes and channels for model computations. For each modeled pipe link, an entrance loss coefficient is manually assigned based on its type of inlet design, as provided in **Figure 6.2-2** below:

FIGURE 6.2-2

Entrance Loss Coefficients for Pipes

Type of Structure and Design of Entrance	Coefficient K_e
• Pipe, Concrete	
Projecting from fill, socket end (groove-end)	0.2
Projecting from fill, sq. cut end	0.5
Headwall or headwall and wingwalls	
Socket end of pipe (groove-end	0.2
Square-edge	0.5
Rounded (radius = D/12	0.2
Mitered to conform to fill slope	0.7
*End-Section conforming to fill slope	0.5
Beveled edges, 33.7^0 or 45^0 bevels	0.2
Side- or slope-tapered inlet	0.2
• Pipe. or Pipe-Arch. Corrugated Metal	
Projecting from fill (no headwall)	0.9
Headwall or headwall and wingwalls square-edge	0.5
Mitered to conform to fill slope, paved or unpaved slope	0.7
*End-Section conforming to fill slope	0.5
Beveled edges, 33.7^0 or 45^0 bevels	0.2
Side- or slope-tapered inlet	0.2
• Box, Reinforced Concrete	
Headwall parallel to embankment (no wingwalls)	
Square-edged on 3 edges	0.5
Rounded on 3 edges to radius of D/12 or B/12 or beveled edges on 3 sides	0.2
Wingwalls at 30^0 to 75^0 to barrel	
Square-edged at crown	0.4
Crown edge rounded to radius of D/12 or beveled top edge	0.2
Wingwall at 10^0 to 25^0 to barrel	
Square-edged at crown	0.5
Wingwalls parallel (extension of sides)	
Square-edged at crown	0.7
Side- or slope-tapered inlet	0.2

*Note: "End Sections conforming to fill slope," made of either metal or concrete, are the sections commonly available from manufacturers. From limited hydraulic tests they are equivalent in operation to a headwall in both inlet and outlet control. Some end sections, incorporating a closed taper in their design have a superior hydraulic performance. These latter sections can be designed using the information given for the beveled inlet.

Source: FHWA, "Hydraulic Design of Highway Culverts, Third Edition", April 2012 (Report No. FHWA-HIF-12-026, Hydraulic Design Series No. 5, Table C-2).

Exit losses for pipes are also manually inputted and range in values from 0 to 1. In general, the value assigned depends on the differences in velocities between the outlet of the pipe and immediately downstream of the outlet. Engineering judgment must be exercised when selecting the appropriate exit loss coefficient.

If the velocity in a pipe is expected to drop to zero, or nearly zero, immediately upon exit, the exit loss was set to a value of 1. An example of this scenario is a pipe discharging into a pond, lake, or reservoir, or perpendicular to a channel. Conversely, if the exit velocity from the pipe is expected to be unchanged as it leaves the pipe to the next downstream link, then the exit loss was set to a value of zero. Otherwise, the exit loss coefficient could be set between 0 and 1 based on the differences in velocities between the pipe outlet and the entrance of the next downstream link.

Bend losses were also considered for pipe links, as needed, based on values shown in **Figure 6.2-3** below:

FIGURE 6.2-3

Bend Loss Coefficients (FHWA Table 5.1)

Table 5.1. Loss Coefficients for Bends.

	Angle of Bend in Degrees)		
Radius of Bend / Pipe Diameter	90°	45°	22.5°
1	0.50	0.37	0.25
2	0.30	0.22	0.15
4	0.25	0.19	0.12
6	0.15	0.11	0.08
8	0.15	0.11	0.08

Source: FHWA, "Hydraulic Design of Highway Culverts, Third Edition", April 2012 (Report No. FHWA-HIF-12-026, Hydraulic Design Series No. 5, Table 5-1).

The entrance loss for a channel link is a function of the velocity head at its upstream end, which is typically negligible. In most cases, the entrance loss coefficient should be set to zero. However, if a channel link is leaving a large water body, like a lake, and the entrance configuration warrants additional minor losses, engineering judgment shall be used to determine an appropriate entrance loss coefficient.

The exit loss for a channel link is a function of the velocity heard at its downstream end. Although exit losses associated with channels are typically minor and the exit loss coefficient is set to zero, there are some situations where it may be appropriate to include an exit loss. Engineering judgment was exercised when selecting an exit loss coefficient. If the velocity of a channel is expected to drop to zero after leaving the outlet of the channel, like in the case of a channel discharging into a pond, lake, or reservoir then exit loss was set to a value of 1. Conversely, if the velocity of the channel is expected to be carried to the next downstream link, then the exit loss was set to zero.

6.2.2.2.3 Manning's n Values

The roughness coefficient (Manning's n) is related to structure size, shape, and materials. **Figure 6.2-4** below lists appropriate Manning's n values for pipe links, based on the type of culvert being modeled.

FIGURE 6.2-4

Manning's n Values for Culverts

B.1. Manning's n Values for Culverts.[1]			
Type of Culvert	Roughness or Corrugation	Manning's n	Reference
Concrete Pipe	Smooth	0.010-0.011	Straub et al. 1960 May et al. 1986 Tullis 1986 & 1991a
Concrete Boxes	Smooth	0.012-0.015	FHWA 1961
Spiral Rib Metal Pipe	Smooth	0.012-0.013	Tullis 1983 & 1991b
Corrugated Metal Pipe[2] (Helical Corrugations)	2-2/3 by 1/2 in 68 by 13 mm	0.011-0.023	FHWA 1980 Tullis 1991c
Corrugated Metal Pipe[2] (Helical Corrugations)	6 by 1 in 150 by 25 mm	0.022-0.025	FHWA 1980
Corrugated Metal Pipe[2], Pipe-Arch and Box (Annular Corrugations)	2-2/3 by 1/2 in 68 by 13 mm	0.022-0.027	FHWA 1980
Corrugated Metal Pipe[2], Pipe-Arch and Box (Annular Corrugations)	5 by 1 in 125 by 25 mm	0.025-0.026	FHWA 1980
Corrugated Metal Pipe[2], Pipe-Arch and Box (Annular Corrugations)	3 by 1 in 75 by 25 mm	0.027-0.028	FHWA 1980
Corrugated Metal Structural Plate[2] (Annular Corrugations)	6 by 2 in 150 by 50 mm	0.033-0.035	FHWA 1980
Corrugated Metal Structural Plate[2] (Annular Corrugations)	9 by 2-1/2 in 230 by 64 mm	0.033-0.037	FHWA 1980
Corrugated Polyethylene	Smooth	0.009-0.015	Barfuss & Tullis 1988 Tullis et al. 1990
Corrugated Polyethylene	Corrugated	0.018-0.025	Clyde 1980 USBR 1985
Polyvinyl chloride (PVC)	Smooth	0.009-0.011	Neale and Price 1964 Bishop and Jeppson 1975

[1]The Manning's n values indicated in this table were obtained in the laboratory and are supported by the provided reference. Actual field values for culverts may vary depending on the effect of abrasion, corrosion, deflection, and joint conditions.

[2]See Figure B.3, Manning's n varies with barrel size.

Source: FHWA, "Hydraulic Design of Highway Culverts, Third Edition", April 2012 (Report No. FHWA-HIF-12-026, Hydraulic Design Series No. 5, Table B-1).

For channel link features modeled as irregular type, ICPR4 allows for variable roughness coefficients to be used across the cross-section. A Manning's n value is specified for each station and elevation along the cross-section. The Manning's n value is based on the channel bottom material, as detailed in **Table 6.2-2** below.

TABLE 6.2-2
Manning's Value Selection

Type of Channel and Description	n value	Notes
Lined or Built-Up Channels		
Concrete w/ Trowel Finish	0.013	Smooth Concrete.
Gravel Bottom with sides of Formed Concrete	0.020	Fabriform.
Gravel Bottom with sides of Rubble Riprap	0.033	Loose Rocks.
Excavated or Dredged		
Earth, straight and uniform:		
Clean	0.022	
Gravel	0.025	
With Short Grass, few weeds	0.027	Maintained roadside swales.
Earth, winding and sluggish:		
No vegetation	0.025	
Grass, some weeds	0.030	
Dense weeds or aquatic plants in deep channels	0.035	
Channels not maintained, weed and brush uncut:		
Clean bottom, brush on sides	0.050	
Dense weeds, high as flow depth	0.080	
Dense weeds, high as flow depth & brush in the channel	0.120	
Natural Streams - Minor Streams (top width at flood stage <100 ft.)		
Clean, straight, full stage, no rifts or deep pools	0.030	
Same as above, but more stones and weeds	0.035	
Clean, winding, some pools, and shoals	0.040	
Same as above, but some stones and weeds	0.045	
Sluggish reaches, weedy, deep pools	0.070	
Very weedy reaches, deep pools	0.100	
Natural Streams - Flood Plains		
Pasture, no brush:		
Short grass	0.030	May also be used for overbank flow areas in developed areas.
High grass	0.035	

TABLE 6.2-2 - CONTINUED

Manning's Value Selection

Type of Channel and Description	n value	Notes
Cultivated areas:		
No crop	0.030	
Mature row crops	0.035	
Mature field crops	0.040	
Brush:		
Scattered brush, heavy weeds	0.050	
Light brush and trees	0.060	
Medium to dense brush	0.150	Only used in extremely overgrown sections.
Natural Streams -Major Streams (top width at flood stage> 100 ft.)		
Regular section with no boulders or brush	0.043	
Irregular and rough section	0.068	

6.2.2.2.4 Weir Discharge Coefficients

Weir coefficients can be obtained from standard hydraulic handbooks such as Brater and King "Handbook of Hydraulics". Per the County's BGS, the weir discharge coefficient for sharp-crested weirs ranges from about 3.0 to 3.2, and for broad crested weirs ranges from about 2.4 to 2.8, but these coefficients may vary depending on specific conditions. Also, per the County's BMP, the orifice discharge coefficient will range between 0.6 and 0.7, but these coefficients may vary depending on specific conditions.

6.2.2.2.5 Contraction and Expansion Coefficients

Eddy losses account for contracting or expanding flow from one end of a link to the other. The eddy loss for a channel link is a function of the velocity heads at their upstream and downstream ends. **Table 6.2-3** below, provides general guidelines for setting appropriate contraction and expansion coefficients.

TABLE 6.2-3

Subcritical Flow Contraction and Expansion Coefficients

Description	Contraction Coefficient	Expansion Coefficient
No Transition Loss Computed	0.0	0.0
Gradual Transitions	0.1	0.3
Typical Bridge Sections	0.3	0.5
Abrupt Transitions	0.6	0.8

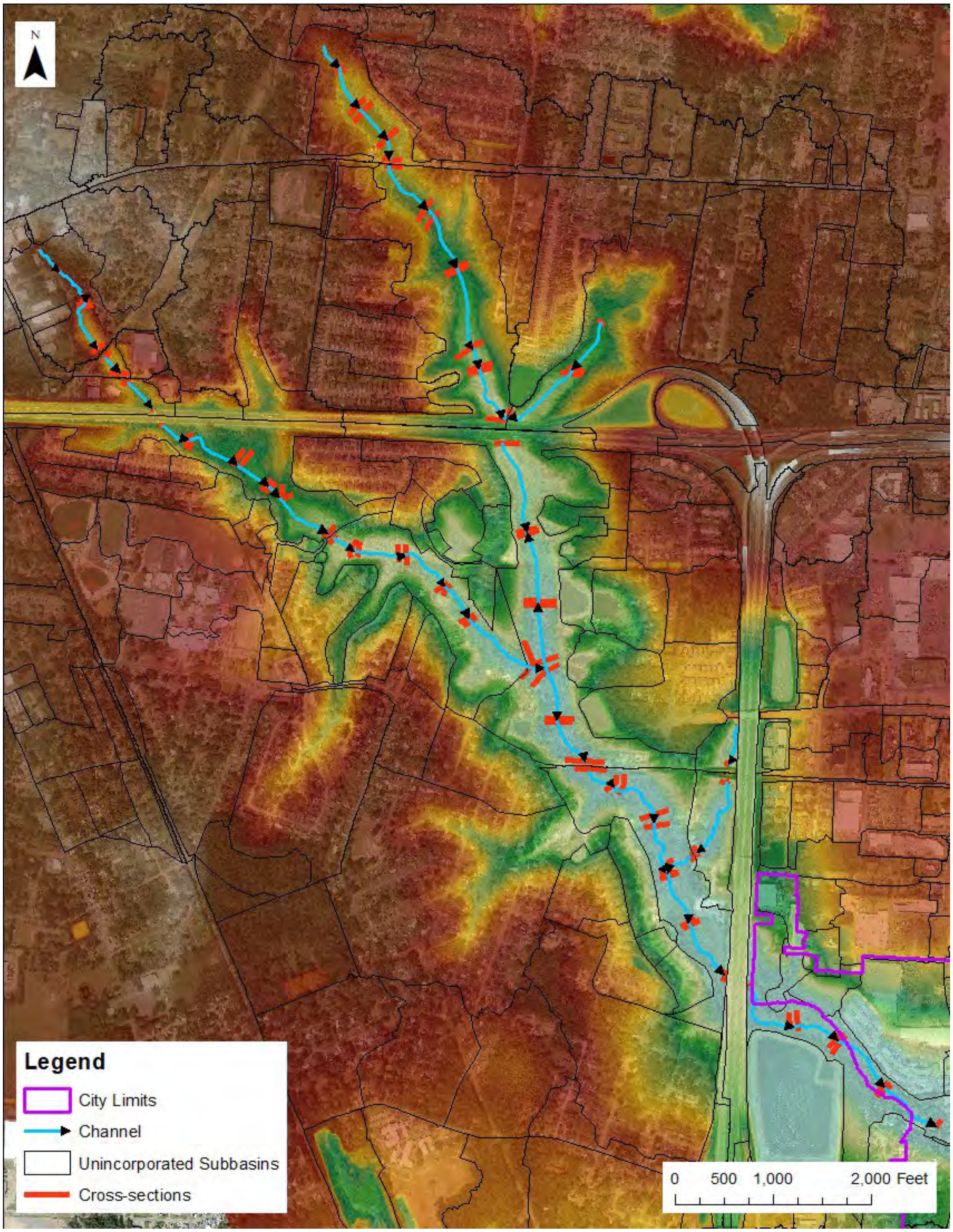
6.2.2.2.6 Cross-Sections

For overland weir features, the corresponding cross-section elevation data was generated by utilizing the underlying DEM and GIS automated toolsets. Cross-sections cut from the DEM included enough points to adequately characterize the overland flow and included the lowest overflow point elevation. This included some "thinning" processes, where non-critical points are removed while the overall shape of the cross-section is preserved.

For wet channels, or channels that normally have standing or flowing water, utilization of the DEM and the automated GIS toolsets is not applicable, as the DEM will likely be reflective of water surface elevations instead of the channel bottom. During the project, the Wood team learned of a Federal Emergency Management Agency (FEMA) Map Modernization study completed by AECOM circa 2006, which was mentioned to have relevant topographic data at certain locations along Carpenter Creek. For the WMP, channel cross-sections (**Figure 6.2-5**) were developed at regular intervals and at junctions and bends along the channel utilizing the AECOM data where available, and utilizing the DEM to interpolate between the AECOM cross-sections, where needed. The AECOM cross-section data was limited to the top of bank to top of bank area. Wood extended these cross-sections to include overbanks and floodplain areas by collecting elevation data from the 2017 DEM at each station along the cross-section.

FIGURE 6.2-5

Channel Cross-section Locations



6.2.2.2.7 Percolation

The Carpenter Creek/Bayou Texar watershed is comprised of several depressional areas with sandy soils likely to exhibit high rates and volumes of percolation. The majority of the watershed (approximately 86% of the area) is characterized by Type A, well-drained soils. Furthermore, during field reconnaissance, and after a preliminary review of permit and plan data, several ponds were found to be constructed with sand chimneys meant to allow the underlying permeable soil layer to percolate to the aquifer and improve overall pond recovery performance. For these reasons, Wood included percolation links in the unincorporated areas of the model to account for these sand chimneys, where visible. For the percolation links that represent these sand chimney features, percolation parameters were derived from plan sets when available.

In addition to the specific sand chimney locations, hydrologic characteristics within the unincorporated portion of the watershed were evaluated on the whole to identify locations suitable for modeling percolation. Percolation links are typically recommended in the presence of hydrologic soil group type A, well-drained sandy soils, coupled with a relatively deep water table (3 feet or deeper). Much of the watershed meets these standards. Therefore, percolation links were specified for stormwater ponds of interest and other areas with high infiltration rates (as deemed necessary). Percolation links for stormwater ponds were based on the as-built, or best available, plans for each pond. Likewise, stormwater ponds with sand chimneys have percolation links based on the as-built design details of those sand chimneys. Where no plans are available, aerial imagery was used to measure the approximate area of sand chimneys and ponds.

Site-specific percolation parameterization from studies or ERPs is preferential to the more generalized soil-based/potentiometric surface parameterization. In the absence of site-specific data from ERP documents, percolation parameters needed for the model, such as horizontal and vertical conductivity, fillable porosity, and water table conditions, were estimated based on Escambia County soils data, FDEP data, NRCS' Soil Survey Geographic Database (SSURGO database) (accessed through the NRCS Web Soil Survey), and from NWFWMD data originally developed for the Florida Aquifer Vulnerability Assessment (FAVA) model, as approximate values for use in the parameterization of the percolation links. For the percolation calculations in ICPR4, three perimeter lengths (P1, P2, and P3) must be specified for saturated horizontal flow. The P1 perimeter represents the edge of the unsaturated vertical flow zone and P2 and P3 perimeters were buffered out 50 feet and 500 feet, respectively, from the P1 perimeter. The percolation perimeters were created using an in-house ArcGIS python tool. Since the model will focus on design storm events, dynamic groundwater flow and its interaction with surface water (using pond control volume) were not simulated.

7.0 MODEL NOMENCLATURE

7.1 City's Modeled Area

Although the City's SWMP report does not explain the methodology behind the nomenclature assigned to the City's model features, this section provides at least a summary of the City's model's nomenclature. It is possible that much of the nomenclature in the City's model comes from the previous studies the City's model was built upon, but this is not stated in the SWMP report explicitly. Wood did not change or alter the nomenclature within the City's model as part of the Carpenter Creek/Bayou Texar WMP, except for select instances where a City subbasin, link, or node may have been altered during the merging with the unincorporated portion of the watershed.

Within the Existing Watershed 04, 05, 06, and 09 model scenarios, the subbasins are named with a prefix of "B" for basin, followed by either "BA", "BAA", "BL", "BLL", "BSA", "BSWA", "BZA" and some numerical, and in few instances alphabetical, values (i.e. B-006, BSA-3380). Similarly, each subbasin's loading node appears to be named with a prefix of "N" followed by the same characters that succeed the corresponding subbasin's name.

It does not appear that the links in the City's model were named to correlate with their related subbasins or nodes. For pipe features, the City's model nomenclature consists of a prefix of "L", "LS", "L-S", "LL", "LAA", or "LA", followed by some form of numeric values and a suffix of "P". For weir features, the City's model nomenclature consists of a prefix of "L", "LS", or "LSW" followed by some form of numeric values and a suffix of "W". For channel features, the City's model nomenclature consists of a prefix of "L" followed by some form of numeric values and a suffix of "C". For drop structures, the City's model nomenclature consists of a prefix of "L", "LL", "LS", or "LSW", followed by some form of numeric values and a suffix of "DS". There are limited rating curve links in the City's model, but the City's model nomenclature for rating curves consists of a prefix of "L" followed by some form of numeric values and a suffix of "RC". For cross-sections, the City's model nomenclature consists of a prefix of "X", "XS", or "XSW", followed by some form of numeric values and a suffix of "C" or "W" for channel and weir, respectively.

7.2 Unincorporated Area

For the nomenclature of the model network features developed within the unincorporated area of the watershed, Wood generally followed the guidelines outlined in the County's BGS.

All elements of the ICPR4 model network (subbasins, nodes, links, and cross-sections) were labeled with a designation that includes a master index number, a character tributary designation, a sequential sub-system number, and a model element type designation. The master index number corresponds to the major basin. For the Carpenter Creek/Bayou Texar WMP, the Carpenter Creek is the master basin, which has an index number of "11".

Next, the tributary designations were labeled alphabetically beginning with the main tributary and continuing with lateral tributaries starting with the downstream-most outfall. In the case of subbasins that require more tributary designations than A through Z, the tributary designations continue with double letters (i.e. AA, BB, CC, etc.) The sequential portion of the designations indicates the relative positioning of the model location within a given tributary beginning at the downstream limit. These designations were identified using values that are incremented by 10's (e.g. 010, 020, etc.) thus leaving room for additional elements to be inserted later.

Element designations began with nodes. Subbasins have the same designation as the node to which it drains. If multiple subbasins are to be assigned to the same node, then designations were suffixed with a numeric value. Links leaving the node have the same numeric designation as the node with the last character changed to reflect the link type. Designations often need to account for multiple links at a given location. Such situations included a suffix with a numeric value (beginning with the lowest or first flowing link).

An example model designation would be "11A150P1". The "11" designates the Carpenter Creek master basin, the letter "A" designates tributary "A" of Carpenter Creek (succeeding tributary systems would use remaining letters of the alphabet), the number "150" is the number of the element in downstream to upstream order along tributary "A", the letter "P" signifies the type of element, as shown in **Table 7.2-1** below, and the "1" signifies it's the first pipe of multiple pipes associated with the particular node.

TABLE 7.2-1
Model Element Type Designations

ICPR Element	Model Code	ICPR Element	Model Code
Sub-basin	B	Node	N
Cross-Section	X	Pipe	P
Channel	C	Weir	W
Drop Structure	D	Bridge	G
Rating Curve	R	Breach	E

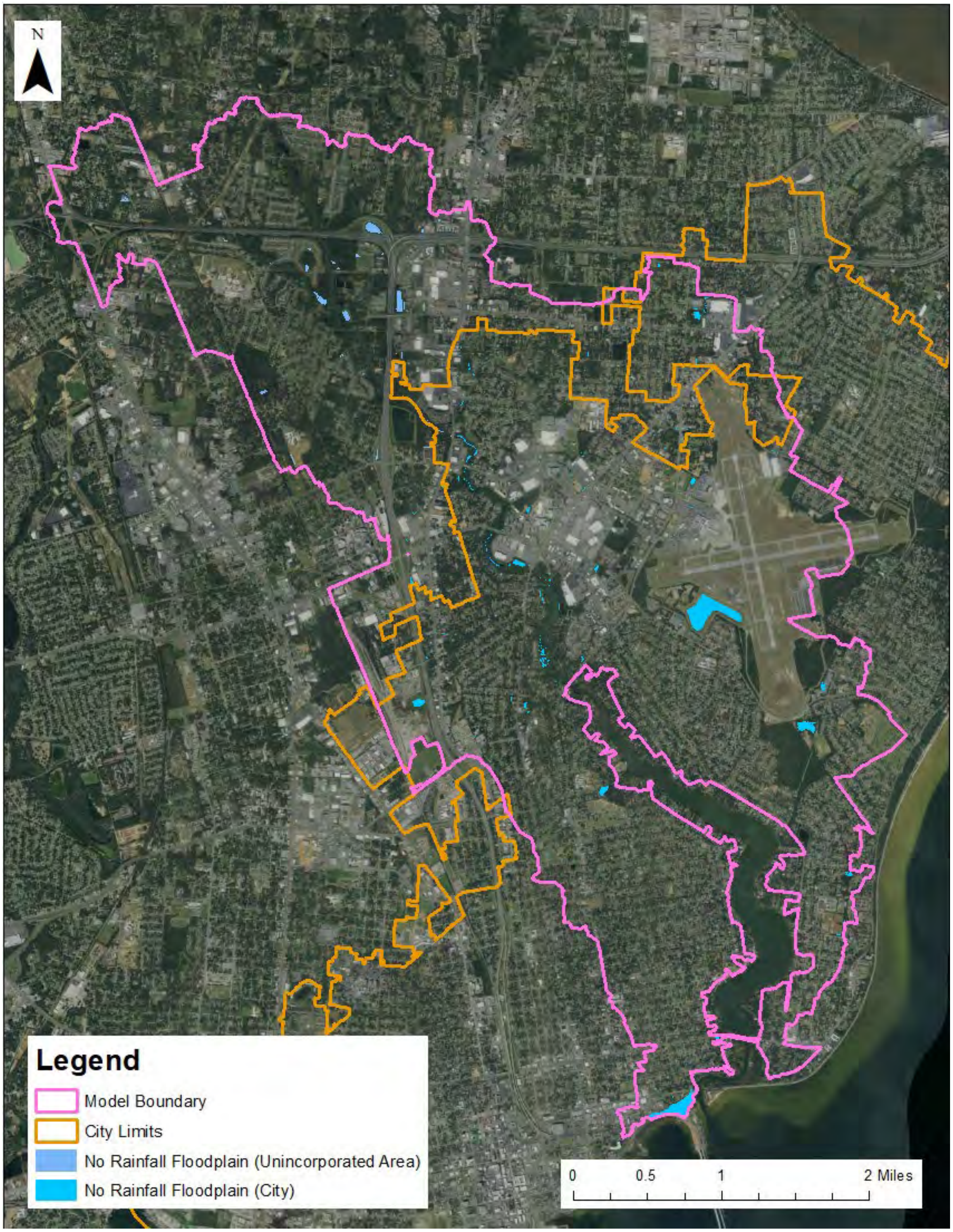
8.0 CALIBRATION AND VERIFICATION

Model calibration typically makes use of historic gage data or other available data that represents rainfall, flood stage, and discharge rates for specific storms. The goal of this process is to produce model output results that are similar to observed conditions in flooding area extent, depth, and timing. The following steps describe the methods used for this study.

8.1 Preliminary Simulations for Initial Setup

Model simulations for the 100-yr/1-day storm event and a "no-rainfall" event were developed to assess the model's stability and to aid in setting up the initial conditions. **Figure 8.1-1** shows the floodplain results in the unincorporated area and City area for the no-rainfall simulation. As expected, only ponds and wetlands, which have initial conditions that correlate to base water levels, show up as "flooded" regions. The preliminary simulations concluded that the model was set up correctly and ready for calibration.

FIGURE 8.1-1
No-Rainfall Floodplains



8.2 Model Calibration

8.2.1 City's Modeled Area

As model calibration was noted to have been conducted as part of the City's SWMP modeling effort, Wood utilized the City's model as-is and focused calibration and verification efforts within the unincorporated areas of the watershed only. The following is an excerpt from the City's SWMP, describing the methodology utilized for model calibration in the City's modeled area:

"Once the existing hydraulic model development was complete, the model rainfall event simulations were executed, and the predicted flooding areas were compared with known flooding areas. Areas in which flooding conditions were predicted were cataloged and a list of the most significant areas was provided to the City for verification as known points of flooding. City staff subsequently provided a list of areas for detailed study and conceptual design. The ICPR Model was further refined within the areas of detailed study to ensure that simulated results met reasonable hydraulic expectations. At worst, the comparison indicates that the model provides moderately conservative results within the selected areas of interest, which would diminish with lesser storm events. Therefore, the model is considered acceptable for evaluation of the existing watershed, for identification of the causes of flooding, and for development of the proposed improvement to mitigate areas of flooding, within the areas selected for detailed study."

The City's SWMP mentions a comparison of the "predicted flooding areas" with "known flooding areas". Wood did not receive information related to these areas.

8.2.2 Unincorporated Area

Wood utilized the April 2014 storm event, which occurred between April 29th and April 30th, 2014, to calibrate the unincorporated portion of the model. This storm was classified by the National Weather Service (NWS) as a record 24-hour storm event for the City of Pensacola and the southern portion of Escambia County.

HDR Engineering, Inc. (HDR) developed a storm event recreation for this April 2014 event, dated January 27, 2015. HDR completed a radar-based assessment of the period of heavy rainfall associated with this storm, where they analyzed archived radar data for the event from the NOAA but also reviewed the gaged data for verification and calibration purposes. As part of this study, HDR developed electronic files for hydrologic input over the region. The files were noted to consist of .csv files that contain 5-minute temporal data for every grid cell within the 1km x 1km and 0.5 km x 0.5 km fields, for each of the two waves of precipitation that accompanied this storm. Wood received the files for the rainfall data and used these files to create a calibration model simulation for the unincorporated area. **Figure 8.2-1** shows the total rainfall, in inches, per 4 km^2 grid, from the HDR study.

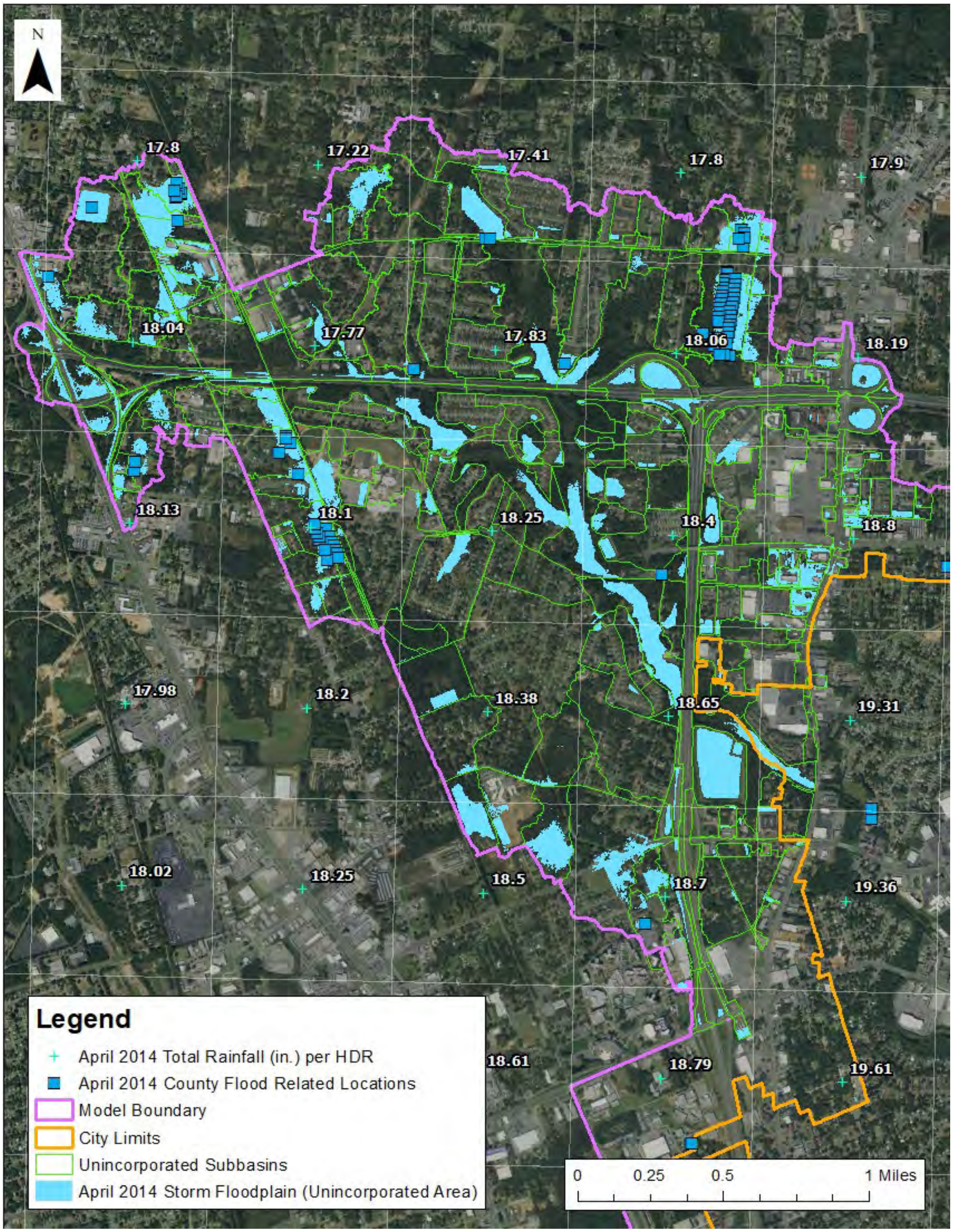
Wood compared the April 2014 calibration simulation results to recorded flood elevations and noted flood complaints from the April 2014 event. Per the County's BGS, a High Water Mark Database (HWMDB) is under continuous development and is available to be used during model calibration efforts to supplement gage data or in place of gage data if such data do not exist. However, Wood requested the HWMDB from the County, and it was stated that this database is not available. The County provided the following GIS shapefiles related to the April 2014 storm event, and the details related to the data provided within each layer are described below:

- "Public Works Damage Assess April 2014 Flood"
    - There are 53-point locations within the City/unincorporated subbasins (41 locations are located within the unincorporated area, and 12 locations are within City limits).
        - Of the 41 locations within the unincorporated area, all had a note pertaining to flooding or drainage types of issues.
            - Only 1 of the 41 locations in the unincorporated area contained data of quantitative nature. The other 40 locations contained notes of qualitative nature related to flood-related observations due to the April 2014 storm event.
        - Of the 12 locations within the City limits, all had a note pertaining to flooding or drainage types of issues.
            - Only 3 of the 12 locations within the City limits contained data of quantitative nature. The other 9 locations contained notes of qualitative nature related to flood-related observations due to the April 2014 storm event.
- "BID Damage Assess April 2014 Flood"
    - There are 77-point locations within the City/unincorporated subbasins (64 locations within the unincorporated area, and 13 locations within City limits).
        - Of the 64 locations within the unincorporated area, 62 locations had a recorded flood depth. There were 2 locations with no noted flood depth.
        - All of the 13 locations within the City had recorded flood depths.
- "County/Citizen Flood Reports April 2014 Flood"
    - There is only 1 point location within the unincorporated subbasins. There are no point locations within the City limits.
        - The one location within the unincorporated area provides a depth of flooding observed at a home, related to the April 2014 storm event.

The Wood team assessed the data, provided by the County, for reasonableness and overall relevance to model calibration, and utilized applicable data to further refine the model results were warranted. **Figure 8.2-1** below shows the results from the April 2014 calibration storm event floodplains in relation to pertinent locations noted by the County as exhibiting flood-related issues.

FIGURE 8.2-1

April 2014 Calibration Model Floodplains, with April 2014 Rainfall and County Flood-related Records



Note: April 2014 rainfall based on 1km x 1km grid data from HDR study

The calibration model produced results within the acceptable ranges established and resulted in floodplains that visually aligned well with the damage and flood-complaint locations related to the April 2014 event as shown in **Figure 8.2-1**. The modeled floodplains also occurred in areas where there were no corresponding County records, but this is not unexpected, as not every flood occurrence results in a complaint or documented record.

Table 8.2-1 compares the calibration model results to the recorded depths of water in the County-provided April 2014 damage and flood-related complaints records, specifically for the locations at which quantitative data was provided. Using the 2017 DEM, Wood converted the recorded depths of water from the County's April 2014 records to elevations (NAVD88), based on the corresponding DEM elevation at the location of each spatial point referenced. **Table 8.2-1** summarizes the differences, in feet, between the simulated and historically observed flood elevations for those specific locations that had a recorded depth of water.

Mean error (ME) and mean-absolute error (MAE) values for the calibration model results were computed with this dataset of comparison points, and calibration was deemed successful as the MAE value was less than 1 foot (0.79 ft) and ME value was less than 6 inches (0.07 ft). **Table 8.2-1** shows the calibration model's results for each node.

TABLE 8.2-1
April 2014 Calibration Storm Flood Elevations vs. County-Recorded Values

Corresponding Model Node	County Shapefile ObjectID	County-recorded Depth of Water (ft.)	Elevations (ft. NAVD88) based on County-recorded Depths	April 2014 Modeled Storm Event Elevations (ft. NAVD88)	Elevation Difference (ft.)
11D450N	60*	3	118.59	118.01	0.58
11D450N	61*	4	119.01	118.01	1
11D450N	62*	3	118.13	118.01	0.12
11D450N	63*	3	118.63	115.63	0.62
11D450N	64*	2	118.23	116.23	0.22
11D410N	127*	1	118.9	117.9	0.86

TABLE 8.2-1 - CONTINUED

April 2014 Calibration Storm Flood Elevations vs. County-Recorded Values

Corresponding Model Node	County Shapefile ObjectID	County-recorded Depth of Water (ft.)	Elevations (ft. NAVD88) based on County-recorded Depths	April 2014 Modeled Storm Event Elevations (ft. NAVD88)	Elevation Difference (ft.)
11C100N1	158*	1	115.62	115.06	0.56
11C110N	159*	2	116.61	114.61	-1.12
11C100N1	160*	2	116.59	115.06	1.53
11C100N1	161*	2	116.3	115.06	1.24
11C100N1	162*	1	115.71	115.06	0.65
11C100N1	163*	1	115.78	115.06	0.72
11C110N	176*	0.33	115.99	115.66	-1.74
11C110N	178*	0.5	116.44	115.94	-1.29
11C110N	179*	0.5	117.09	116.59	-0.64
11C110N	180*	1	117.45	116.45	-0.28
11C110N	181*	0.83	116.45	115.62	-1.28
11C110N	182*	0.2	115.03	114.83	-2.7
11C110N	183*	0.83	115.54	114.71	-2.19
11C110N	184*	0.17	115.13	114.96	-2.6
11C100N1	185*	0.5	115.44	115.06	0.38
11D450N	218*	1	117.72	116.72	-0.29

TABLE 8.2-1 - CONTINUED

April 2014 Calibration Storm Flood Elevations vs. County-Recorded Values

Corresponding Model Node	County Shapefile ObjectID	County-recorded Depth of Water (ft.)	Elevations (ft. NAVD88) based on County-recorded Depths	April 2014 Modeled Storm Event Elevations (ft. NAVD88)	Elevation Difference (ft.)
11D490N	219*	1	118.39	117.39	0.38
11D490N	220*	1	117.76	116.76	-0.25
11D490N	221*	1	117.83	116.83	-0.18
11D490N	222*	1	118.2	117.2	0.19
11D490N	223*	1.5	118.9	117.4	0.89
11D450N	224*	1	118.33	117.33	0.32
11D410N	237*	0.5	117.1	116.6	-0.94
11D410N	238*	1	117.48	116.48	-0.56
11D490N	240*	0.5	118.09	117.59	0.08
11D490N	241*	1	117.34	116.34	-0.67
11C300N	304*	1.5	119.68	118.18	0.14
11C290N	305*	1.5	119.81	118.31	0.26
11C300N	348*	0.42	119.27	118.85	-0.27
11A650N	356*	0.5	99.27	98.77	0.49
11D610N	2123*	1	123.38	122.38	0.97
11C290N	2176*	2	120.81	118.81	1.26

TABLE 8.2-1 - CONTINUED

April 2014 Calibration Storm Flood Elevations vs. County-Recorded Values

Corresponding Model Node	County Shapefile ObjectID	County-recorded Depth of Water (ft.)	Elevations (ft. NAVD88) based on County-recorded Depths	April 2014 Modeled Storm Event Elevations (ft. NAVD88)	Elevation Difference (ft.)
11C290N	2177*	2	121.01	119.01	1.46
11C290N	2223*	1.5	119.81	118.31	0.26
11C290N	2224*	1.5	119.35	117.85	-0.2
11C290N	1**	0.38	118.69	118.31	-0.87

: From County's "BID Damage Assess April 2014 Flood" GIS shapefile

*****: From County's "County/Citizen Flood Reports April 2014_Flood" GIS shapefile***

8.3 Model Verification

Model verification occurred after successful model calibration. The verification step consisted of comparing the calibration model results (April 2014 storm event) with another storm event to confirm the accuracy of the results. Wood used data available from Hurricane Sally, which made landfall in September 2020, for this purpose. Model verification efforts were focused only within the unincorporated area of the model, as the City's model was to be used as-is, and the City's model was noted in the City's SWMP as being previously calibrated and verified for accuracy.

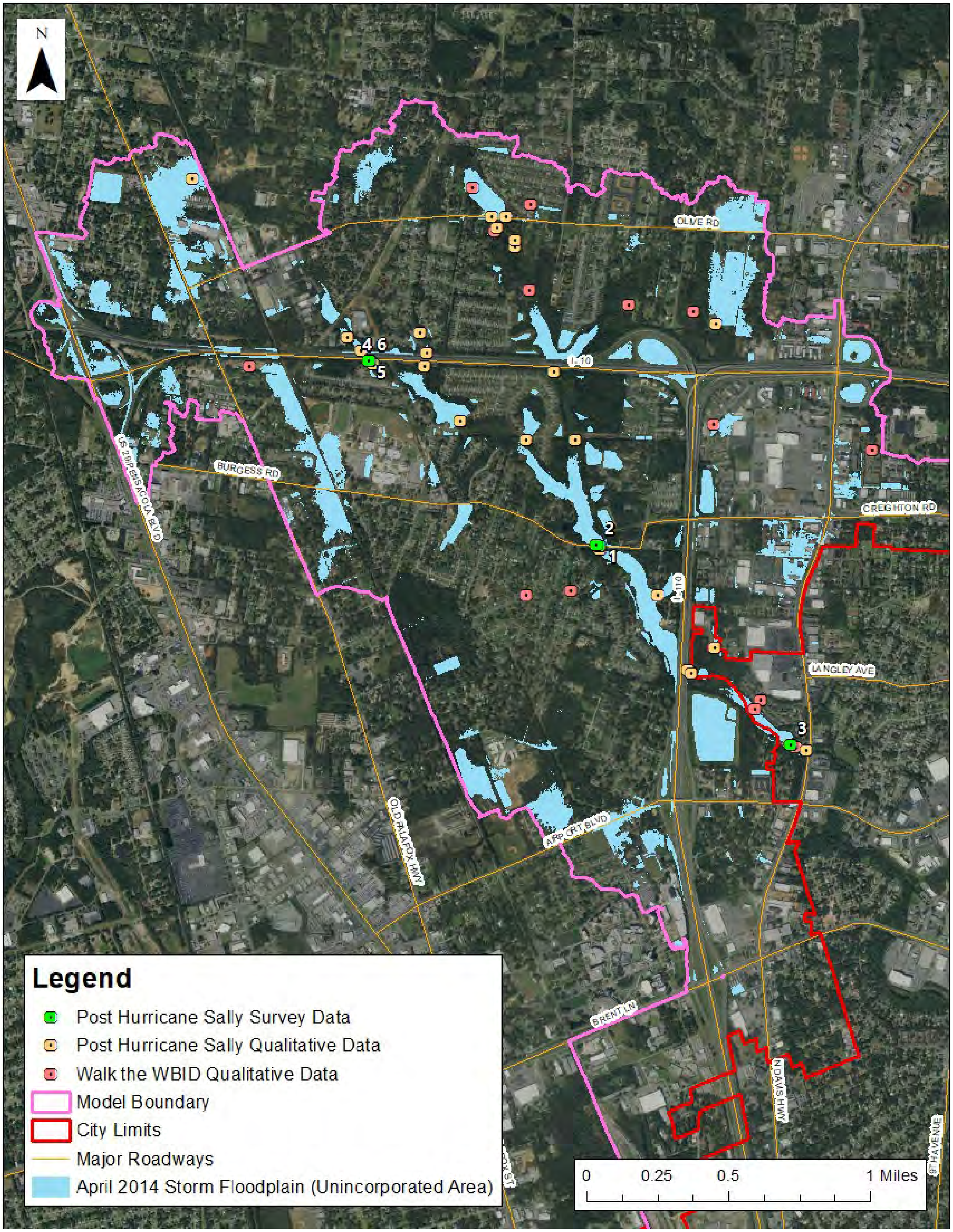
Hurricane Sally was estimated to have the same rainfall as the April 2014 event, therefore the calibration model was not adjusted for the verification event. The Hurricane Sally data that was used for model verification includes information from the County's "Walk the Waterbody ID (WBID) Field Event," and field reconnaissance conducted by the Wood team following Hurricane Sally. Information from the County's "Walk the WBID Field Event" was only qualitative. Limited quantitative data was collected during the post-Hurricane Sally field reconnaissance effort. High water mark elevations were surveyed and used to compare to model results. **Table 8.3-1** lists the field reconnaissance notes and surveyed elevations for six specific locations where data was collected following Hurricane Sally, which are shown in **Figure 8.3-1**.

TABLE 8.3-1
Post-Hurricane Sally Elevation Locations, used for Model Verification

Validation Point	Qualitative Note	Survey Elevation (NAVD88)
1	Top of Concrete Headwall - Sally flooding noted to this point	58.780
2	Top of Concrete Headwall - Sally flooding noted to this point	59.183
3	Four corners of elevated deck surveyed. During Sally, the creek rose to 1ft below elevated deck elevations	45.032, 45.577, 45.754, 45.872
4	Top of Concrete Headwall - Sally flooding noted to this point	93.502
5	Top of Concrete Headwall - Sally flooding noted to this point	93.501
6	Top of Concrete Headwall - Sally flooding noted to this point	94.078

Figure 8.3-1 shows the locations of all records used during verification. As most available data was qualitative, verification consisted mostly of comparing the calibrated model floodplains, shown in **Figure 8.3-1**, against the locations that were noted as demonstrating flooding issues. Likewise, select records that specifically indicated no flooding were compared to calibration model results to confirm the lack of floodplain in certain locations.

FIGURE 8.3-1
Locations of Model Verification Information



9.0 MODEL SIMULATIONS AND RESULTS

This section provides information on the rainfall simulated and summarizes the results of modeling efforts related to the design storm, critical storm, and sea-level rise (SLR) scenario simulations. These simulation results will ultimately be relied upon to inform decision-making related to watershed-scale improvements for flood relief and other benefits.

9.1 Simulated Rainfall

9.1.1 City's Modeled Area

The City's SWMP model used rainfall depths as summarized in **Table 9.1-1** below for the 8-hour and 24-hour storm events:

TABLE 9.1-1
Rainfall Utilized in City's SWMP Model

Storm	8-hr	24-hr
25-year	7.44	10.5
100-year	9.44	13.4

The rainfall depths used in the City's model were noted to be calculated using the FDOT Intensity-Duration-Frequency (IDF) curves for Florida Zone 1. The FDOT 100-year, 8-hour storm event, with a rainfall depth of 9.44 inches, was selected as the design storm event.

9.1.2 Unincorporated Area

Aligning with the City model, rainfall volumes for the unincorporated areas were based on the FDOT rainfall IDF curves for Florida - Zone 1 for storm durations up to 24 hours. However, for storm durations of 3, 7, and 10 days, recorded rainfall depths at NOAA Station ID 08-6997 were used. The location of the NOAA station is shown in **Figure 9.1-1** below, and the related rainfall data from the station is shown in **Figure 9.1-2** below.

FIGURE 9.1-1
Location Map for NOAA Station ID 08-6997

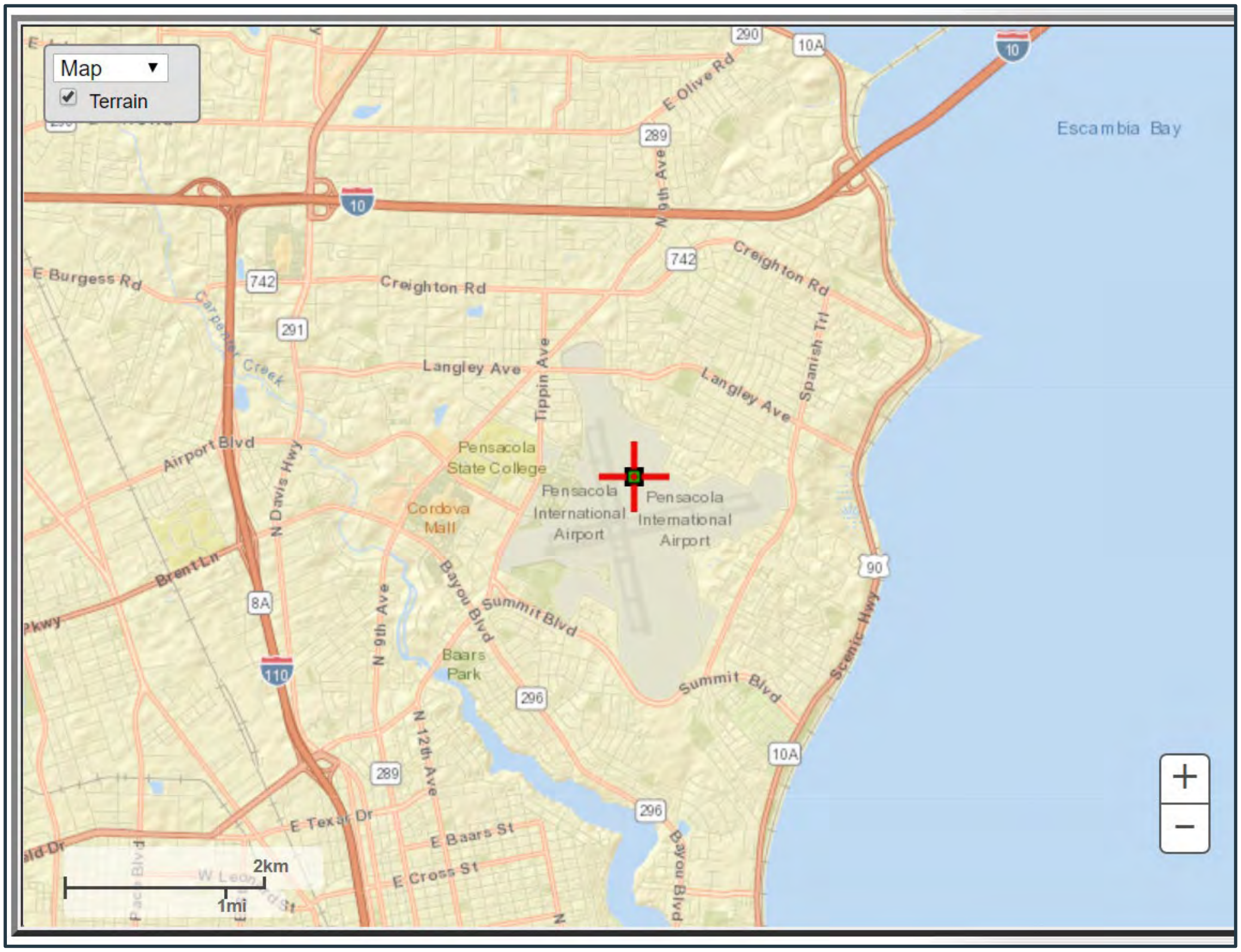


FIGURE 9.1-2

NOAA Point Precipitation Estimates from Station ID 08-6997

NOAA Atlas 14, Volume 9, Version 2 PENSACOLA RGNL AP
Station ID: 08-6997
Location name: Pensacola, Florida, USA*
Latitude: 30.4781°, Longitude: -87.1869°
Elevation:
Elevation (station metadata): 112 ft**
* source: ESRI Maps
** source: USGS

POINT PRECIPITATION FREQUENCY ESTIMATES

Sanja Perica, Deborah Martin, Sandra Pavlovic, Ishani Roy, Michael St. Laurent, Carl Trypaluk, Dale Unruh, Michael Yekta, Geoffery Bonnin

NOAA, National Weather Service, Silver Spring, Maryland

PF_tabular | PF_graphical | Maps_&_aerials

PF tabular

PDS-based point precipitation frequency estimates with 90% confidence intervals (in inches)[1]

Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	0.570 (0.488-0.671)	0.657 (0.563-0.775)	0.797 (0.679-0.942)	0.909 (0.769-1.08)	1.06 (0.854-1.29)	1.17 (0.918-1.45)	1.28 (0.960-1.62)	1.38 (0.986-1.81)	1.51 (1.03-2.05)	1.61 (1.06-2.22)
10-min	0.834 (0.715-0.983)	0.962 (0.824-1.14)	1.17 (0.994-1.38)	1.33 (1.13-1.58)	1.55 (1.25-1.89)	1.71 (1.35-2.12)	1.87 (1.41-2.38)	2.02 (1.44-2.65)	2.22 (1.51-3.00)	2.36 (1.56-3.26)
15-min	1.02 (0.872-1.20)	1.17 (1.00-1.38)	1.42 (1.21-1.68)	1.62 (1.37-1.93)	1.89 (1.53-2.30)	2.09 (1.64-2.59)	2.28 (1.72-2.90)	2.47 (1.76-3.23)	2.70 (1.84-3.65)	2.88 (1.90-3.97)
30-min	1.57 (1.34-1.85)	1.78 (1.52-2.10)	2.13 (1.82-2.53)	2.43 (2.06-2.89)	2.85 (2.31-3.50)	3.18 (2.51-3.96)	3.51 (2.65-4.49)	3.85 (2.76-5.08)	4.31 (2.94-5.85)	4.66 (3.08-6.44)
60-min	2.15 (1.84-2.53)	2.43 (2.08-2.87)	2.91 (2.48-3.44)	3.32 (2.81-3.95)	3.92 (3.19-4.83)	4.39 (3.47-5.50)	4.89 (3.70-6.28)	5.42 (3.89-7.16)	6.14 (4.20-8.35)	6.70 (4.43-9.25)
2-hr	2.73 (2.36-3.20)	3.08 (2.65-3.61)	3.68 (3.15-4.32)	4.21 (3.58-4.97)	4.98 (4.08-6.12)	5.61 (4.46-6.99)	6.27 (4.78-8.02)	6.98 (5.04-9.18)	7.96 (5.48-10.8)	8.74 (5.81-12.0)
3-hr	3.11 (2.69-3.63)	3.51 (3.02-4.09)	4.20 (3.61-4.92)	4.83 (4.12-5.68)	5.77 (4.75-7.09)	6.55 (5.23-8.15)	7.38 (5.64-9.42)	8.27 (6.00-10.9)	9.52 (6.59-12.9)	10.5 (7.03-14.4)
6-hr	3.76 (3.26-4.36)	4.26 (3.69-4.93)	5.17 (4.46-6.01)	6.03 (5.17-7.05)	7.36 (6.12-9.06)	8.51 (6.85-10.6)	9.75 (7.52-12.4)	11.1 (8.14-14.6)	13.1 (9.13-17.7)	14.7 (9.89-20.0)
12-hr	4.42 (3.85-5.09)	5.04 (4.39-5.80)	6.24 (5.41-7.21)	7.41 (6.38-8.61)	9.30 (7.82-11.5)	11.0 (8.90-13.6)	12.8 (9.96-16.3)	14.9 (11.0-19.5)	17.9 (12.6-24.1)	20.4 (13.8-27.5)
24-hr	5.10 (4.47-5.84)	5.89 (5.15-6.74)	7.44 (6.48-8.54)	8.98 (7.77-10.4)	11.5 (9.72-14.1)	13.7 (11.2-17.0)	16.2 (12.7-20.6)	19.0 (14.1-24.7)	23.1 (16.3-30.9)	26.5 (18.0-35.5)
2-day	5.87 (5.17-6.67)	6.82 (6.00-7.76)	8.70 (7.62-9.92)	10.6 (9.18-12.1)	13.6 (11.5-16.6)	16.2 (13.3-20.0)	19.2 (15.1-24.2)	22.5 (16.8-29.1)	27.4 (19.5-36.4)	31.4 (21.5-41.9)
3-day	6.41 (5.66-7.25)	7.38 (6.50-8.35)	9.31 (8.17-10.6)	11.2 (9.79-12.8)	14.4 (12.3-17.5)	17.2 (14.1-21.1)	20.3 (16.0-25.5)	23.8 (17.9-30.7)	29.0 (20.7-38.4)	33.3 (22.9-44.1)
4-day	6.85 (6.06-7.73)	7.81 (6.90-8.82)	9.75 (8.57-11.0)	11.7 (10.2-13.3)	14.9 (12.7-18.1)	17.7 (14.6-21.7)	20.9 (16.6-26.2)	24.5 (18.4-31.5)	29.8 (21.4-39.3)	34.2 (23.6-45.3)
7-day	7.92 (7.04-8.89)	8.93 (7.92-10.0)	10.9 (9.65-12.3)	12.9 (11.3-14.6)	16.2 (13.9-19.5)	19.0 (15.8-23.1)	22.3 (17.7-27.7)	25.9 (19.6-33.0)	31.2 (22.5-40.9)	35.6 (24.7-46.8)
10-day	8.87 (7.90-9.92)	9.96 (8.85-11.1)	12.1 (10.7-13.5)	14.1 (12.4-15.9)	17.3 (14.9-20.7)	20.2 (16.8-24.3)	23.3 (18.6-28.8)	26.8 (20.3-34.1)	31.9 (23.1-41.7)	36.2 (25.2-47.4)
20-day	11.6 (10.4-12.9)	13.0 (11.6-14.5)	15.5 (13.8-17.2)	17.7 (15.6-19.8)	20.9 (17.9-24.4)	23.6 (19.6-27.9)	26.5 (21.1-32.1)	29.5 (22.4-36.9)	33.8 (24.5-43.5)	37.3 (26.1-48.5)
30-day	13.9 (12.4-15.3)	15.6 (13.9-17.2)	18.4 (16.4-20.4)	20.8 (18.4-23.2)	24.1 (20.6-27.9)	26.8 (22.3-31.4)	29.5 (23.5-35.5)	32.3 (24.6-40.0)	36.1 (26.2-46.1)	39.0 (27.5-50.6)
45-day	16.7 (15.0-18.4)	18.8 (16.9-20.7)	22.1 (19.8-24.4)	24.8 (22.1-27.6)	28.5 (24.3-32.5)	31.3 (26.0-36.3)	34.0 (27.1-40.5)	36.7 (27.9-45.0)	40.1 (29.2-50.7)	42.7 (30.1-55.1)
60-day	19.0 (17.2-20.9)	21.5 (19.3-23.6)	25.3 (22.7-27.9)	28.4 (25.3-31.4)	32.4 (27.6-36.8)	35.3 (29.4-40.8)	38.2 (30.5-45.3)	40.9 (31.2-50.0)	44.3 (32.3-55.8)	46.8 (33.1-60.2)

[1] Precipitation frequency (PF) estimates in this table are based on frequency analysis of partial duration series (PDS).

Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and average recurrence interval) will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.

Please refer to NOAA Atlas 14 document for more information.

The rainfall for the multi-day storms was taken from the average precipitation amounts shown in **Figure 9.1-2**. **Table 9.1-2** below summarizes the rainfall depths used for the unincorporated area. As the City area did not originally include multi-day storm events, Wood used the same rainfall across both areas for the 3-, 7-, and 10-day storm events as shown in **Table 9.1-3**. The sea-level rise scenarios also used the 100-year, 24-hour rainfall listed in **Table 9.1-2**.

TABLE 9.1-2

Proposed Rainfall Depths (inches) for Unincorporated Area

Storm	1-hr	2-hr	4-hr	8-hr	24-hr
10 year	3.20	4.16	5.16	6.40	9.12
100 year	4.58	6.00	7.60	9.44	13.40

TABLE 9.1-3

Proposed Rainfall Depths (inches) for Multi-Day Storms for Entire Model

Storm	3-day	7-day	10-day
10 year	11.20	12.90	14.10
100 year	20.30	22.30	23.30

9.2 Critical and Design Storms

9.2.1 Critical Storm Determination

For the consolidated City/unincorporated model, design storm simulations were developed for the 10-yr and 100-yr storm events, for durations of 1, 2, 4, 8, 24, 72, 168, and 240 hours, to determine the critical storm duration (storm event resulting in the highest maximum stages). From the results of these simulations, it was determined that a duration of 8 hours was most appropriate for critical storm analysis.

Table 9.2-1 shows a random selection of six nodes in the unincorporated portion of the model for 10- and 100-year storms at durations of 1, 2, 4, 8, 24, and 72 hours. Although the 168- and 240-hour durations were also simulated, **Table 9.2-1** excludes those model results simply to abbreviate the table for viewing purposes. However, the peak stages were observed to decline as the durations increased. For both the 10- and 100-year storm events, 8 hours is shown to be the critical storm duration (i.e. have the highest maximum stage) for all six nodes and was indicative of the modeling results overall.

TABLE 9.2-1
Design Storm Peak Stage Results for Select Nodes in Unincorporated Area

Node	Simulation Results (in ft. NAVD88)											
	10y,1h	*10y,2h*	*10y,4h*	*10y,8h*	*10y,24h*	*10y,72h*	*100y,1h*	*100y,2h*	*100y,4h*	*100y,8h*	*100y,24h*	*100y,72h*
11A010N1	39.41	40.38	40.91	41.12	40.14	39.96	40.78	41.76	42.56	42.8	41.06	41.24
11A1040N	99.62	99.8	100.22	100.47	99.47	99.43	100.78	100.82	100.85	100.89	100.42	100.62
11A1070N	131.52	131.54	131.49	131.58	131.22	131.12	131.86	131.87	131.74	131.83	131.37	131.31
11A420N	85.67	85.78	85.87	85.9	85.1	84.9	86.62	86.81	86.97	86.98	85.55	85.42
11A520N2	59.35	62.15	63.76	63.9	63.03	63.21	63.99	65.14	66.37	66.65	64.72	65.09
11A880N1	69.97	69.98	69.96	70.01	69.86	69.84	70.16	70.17	70.12	70.19	69.98	70.14

9.2.2 100-year, 24-hour Storm Analysis

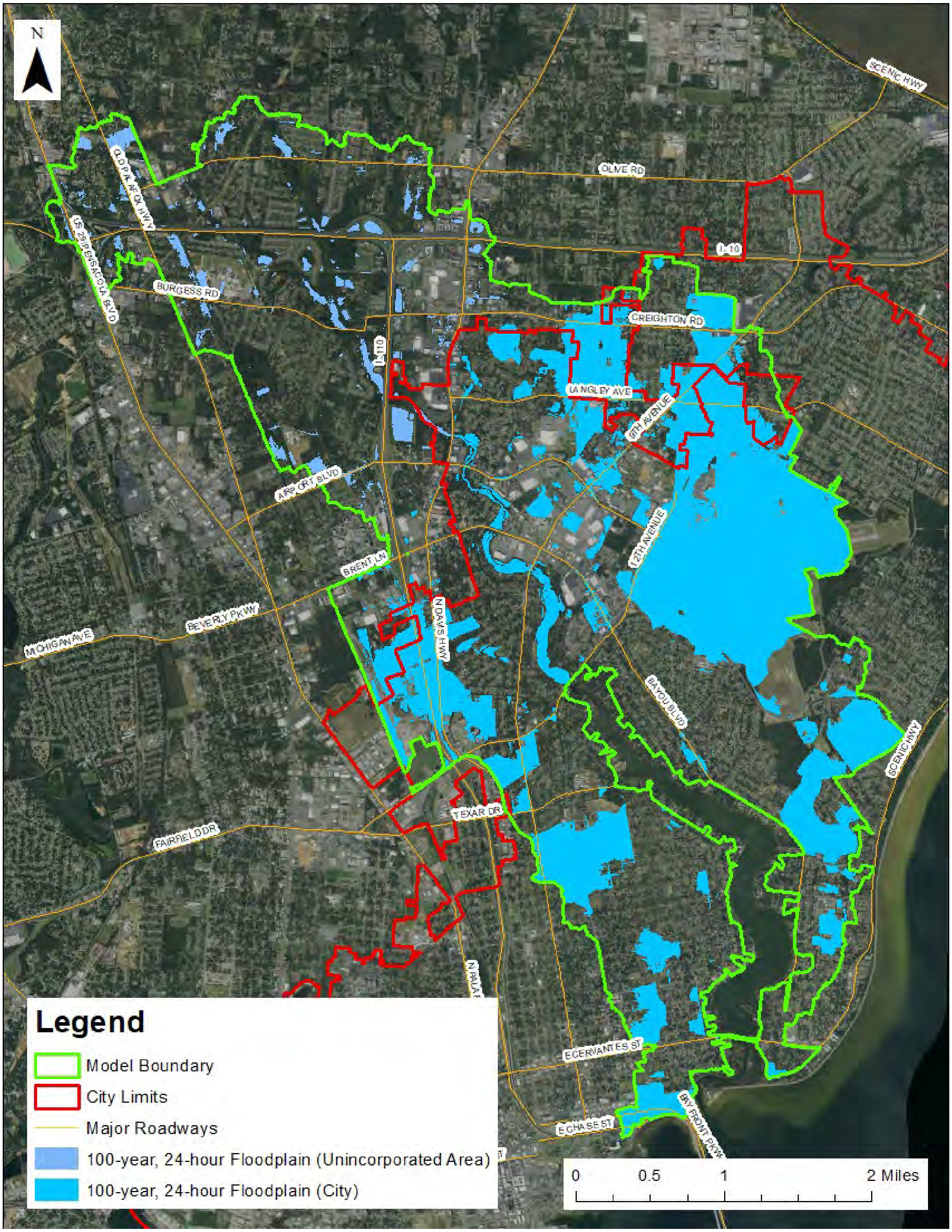
Figure 9.2-1 shows the 100-year, 24-hour floodplain results for both the City and unincorporated area of the model. As shown in **Figure 9.2-1**, and as observed through the multiple design storm simulations of the consolidated City/unincorporated model, there were questionable and likely inaccurate results generated from the City's model. An example of these questionable peak stages is at and around the Pensacola International Airport, which shows as completely flooded. It is Wood's opinion that these questionable peak stages could likely be due to the methodology discrepancies outlined in **Section 3.0**, specifically, the lack of overland weir features and associated nodal storage.

Due to the questionable results obtained from it, the City's model was deemed as generally unfit for use in identifying specific flood issues in the City with much confidence. Subsequently, the City's model limitations will hinder the identification of proper flood-control best management practice (BMP) recommendations in the City area under future project tasks. However, the City's model results are not expected to inhibit Wood's ability to identify BMP recommendations within the City related to stream restoration, water quality, fish & wildlife habitat, public recreation, and community resiliency.

The 100-year, 24-hour floodplain in the unincorporated area is generally both reasonable and useful, showing flooding at expected regions along Carpenter Creek, at stormwater ponds, at other water bodies, at wetlands, at other undrained depressional areas, and at locations noted to have seen flooding in the April 2014 storm.

FIGURE 9.2-1

100-year, 24-hour Floodplain, Unincorporated Area



9.2.3 Critical Storm Analysis

After the critical storm duration of 8 hours was determined, the 3-, 10-, 25-, 50-, and 100-year, 8-hour storm events were simulated. The rainfall volumes for these storm events were based on the FDOT IDF curves for Florida – Zone I and are provided in **Table 9.2-2**. The following sections summarize key findings in the results in both the unincorporated and City areas.

TABLE 9.2-2
Total Rainfall for Critical Duration Storm Event

Year	Duration (Hour)	Total Rainfall (inches)
3	8	5.12
10	8	6.40
25	8	7.44
50	8	8.72
100	8	9.44

Figure 9.2-2 shows the floodplains for the 100-year, 8-hour critical duration storm event in comparison to the 100-year, 24-hour storm event. As expected, the higher peak stages from the 8-hour event result in a floodplain that expands beyond that of the 24-hour storm; however, the floodplain generally appears in the same subbasins and exhibits similar patterns for both storm events. Most of the increased floodplain area occurs in Carpenter Creek. In the unincorporated area, the April 2014 calibration storm resulted in a larger floodplain than both the 100-year, 8-hour storm, and the 100-year, 24-hour storm, as shown in **Figure 9.2-3**.

FIGURE 9.2-2

100-year, 8-hour and 24-hour Floodplains (City and Unincorporated Area)

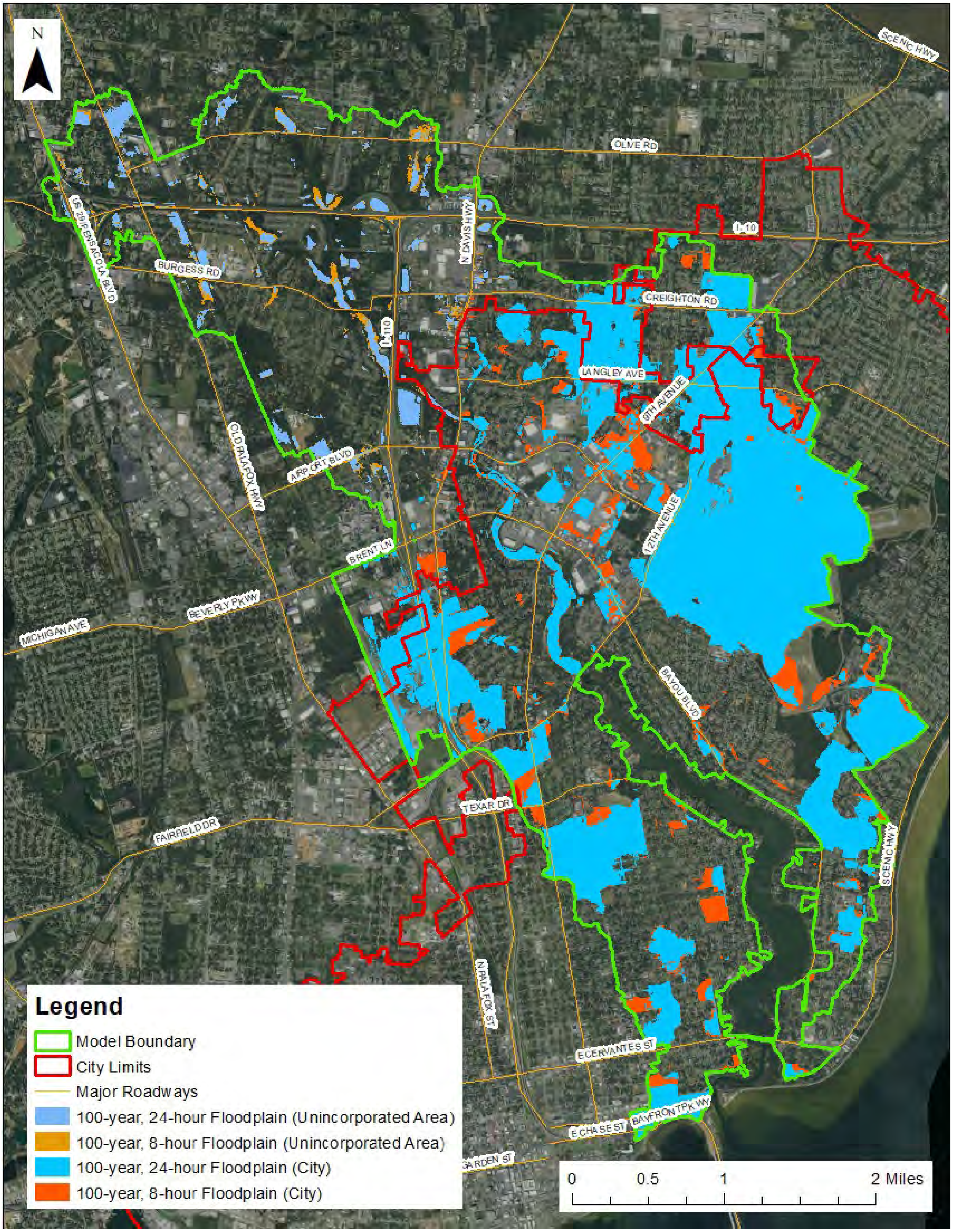
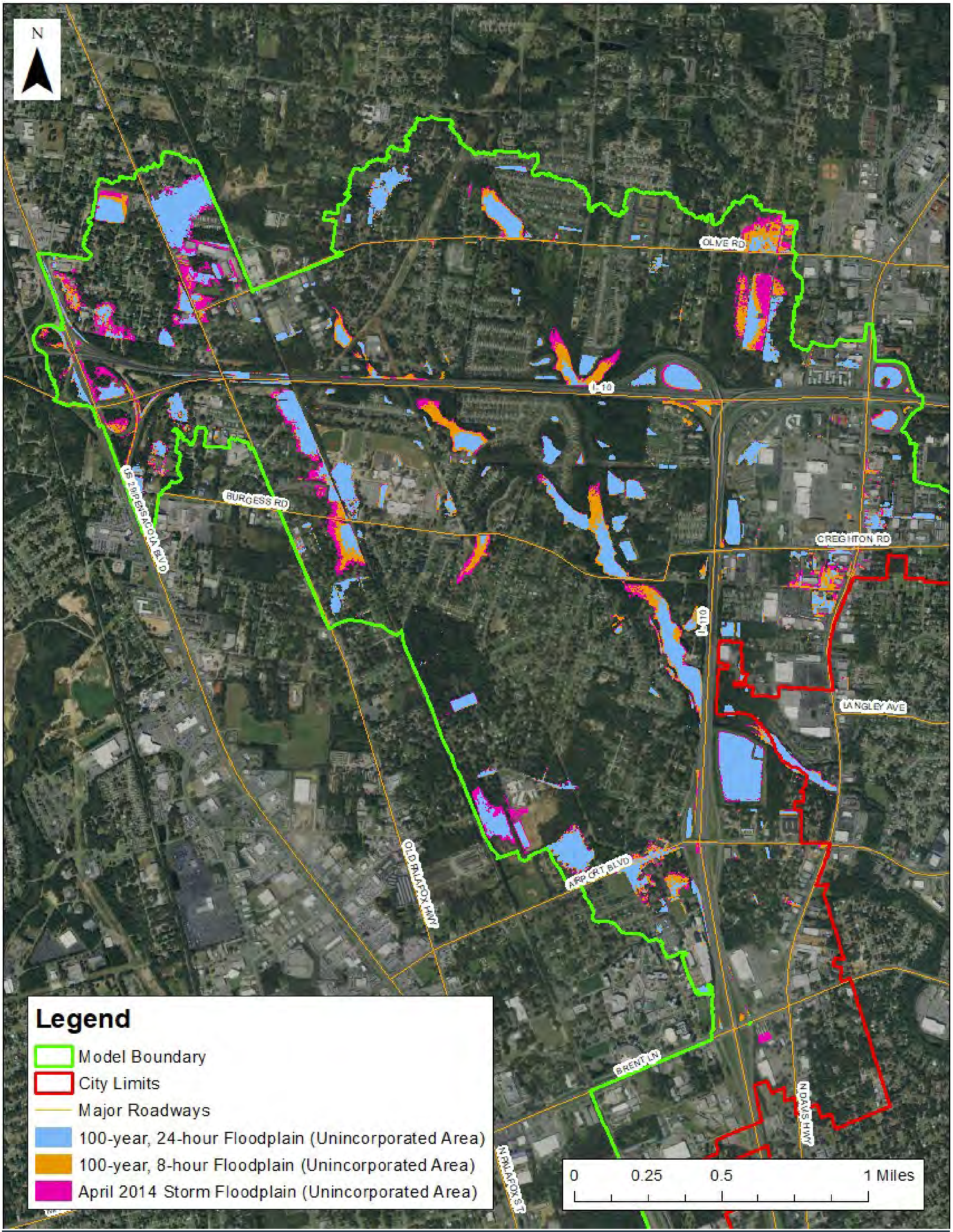


FIGURE 9.2-3

Calibration Storm and 100-year, 8-hour and 100-year, 24-hour Floodplains (Unincorporated Area)



9.3 Design Storm Flooding Examples and Discussion

As described earlier, the Wood team concluded there were potential limitations to using the City's model results with much confidence. Therefore, this section focuses specifically on model results and floodplains within the unincorporated area of the model. Specific instances of flooding in the unincorporated area are discussed below and shown in the following **Figures 9.3-1 through 9.3-4**. Floodplains from the 100-year/24-hour, 100-year/8-hour, and the April 2014 calibration storm event, as well as the locations of specific County-noted areas of flood-related issues, are shown on the figures for additional context.

Figure 9.3-1 shows a large area of floodplain along the railroad tracks that run parallel to Palafox Street, starting south of Burgess Road, and continuing north towards I-10. The model results corroborate the flood complaints and damage assessment locations from the County's 2014 storm event records.

FIGURE 9.3-1
Flood Case 1, Unincorporated Area

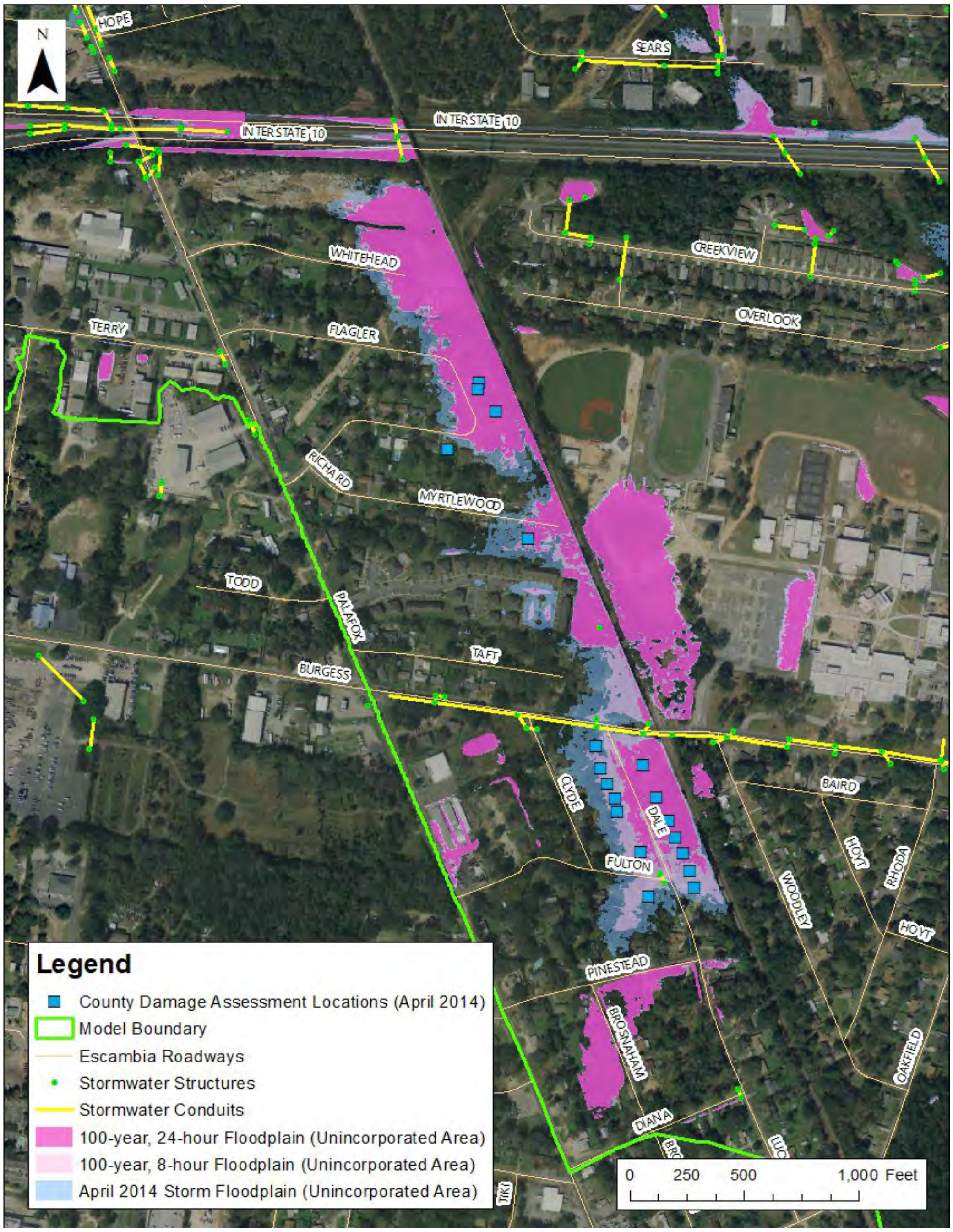


Figure 9.3-2 shows a large floodplain in a low-density residential area in the northwestern portion of the watershed. This area does correlate with County residential flood complaints as well as the DEM, which shows the large floodplain between Palafox Rd and the railroad as resting within a low-lying area between Palafox Rd and the railroad.

FIGURE 9.3-2
Flood Case 2, Unincorporated Area

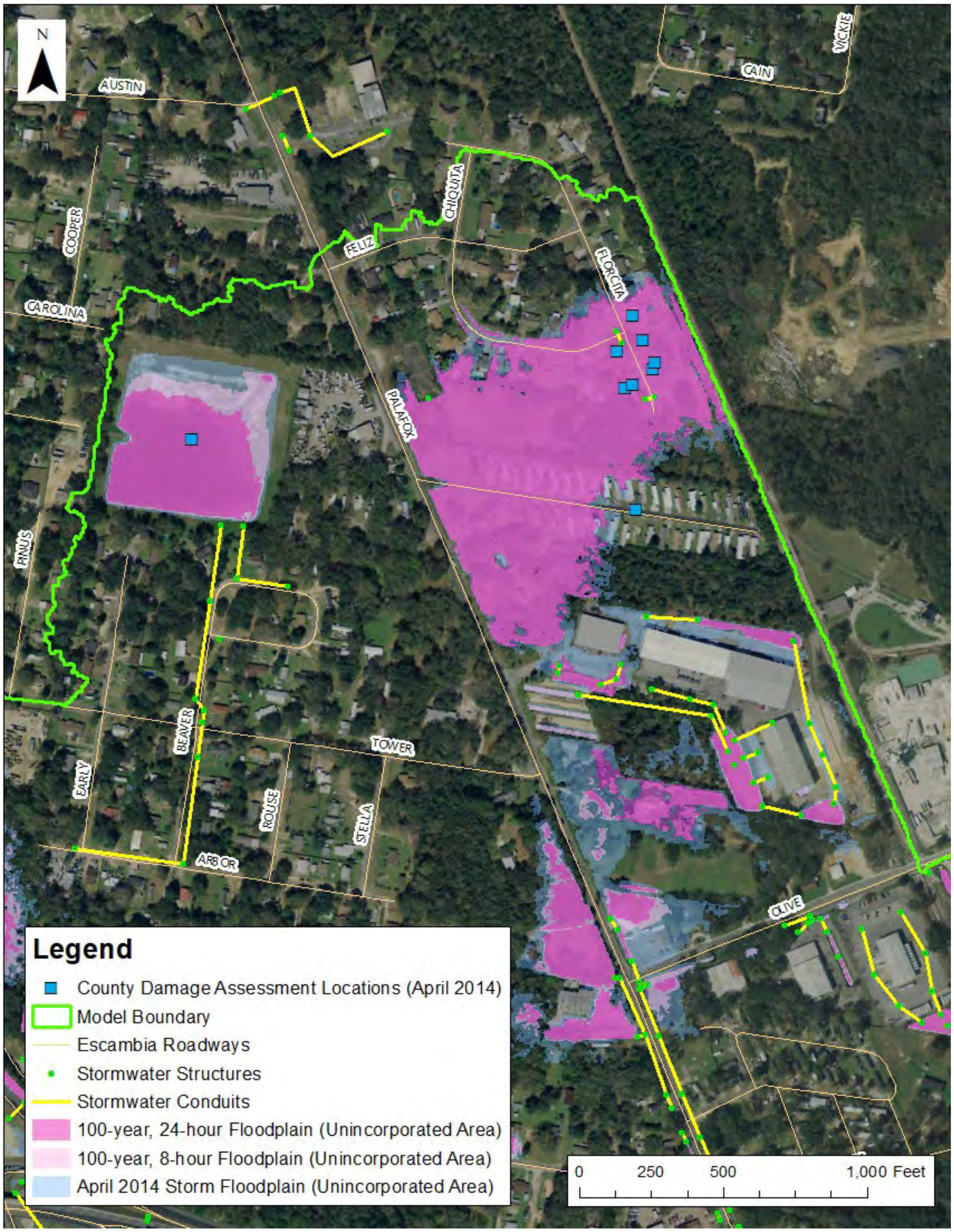


Figure 9.3-3 shows another area at which the modeled floodplains generally correlate with County-noted flood complaints and damage assessments. In this area, the model does include critical elements of the drainage network along Sabra Drive, Olive Road, and Whitmire Drive, but

from the model results, it appears the current drainage network may not be sufficient to service the needs of larger storm events.

FIGURE 9.3-3

Flood Case 3, Unincorporated Area

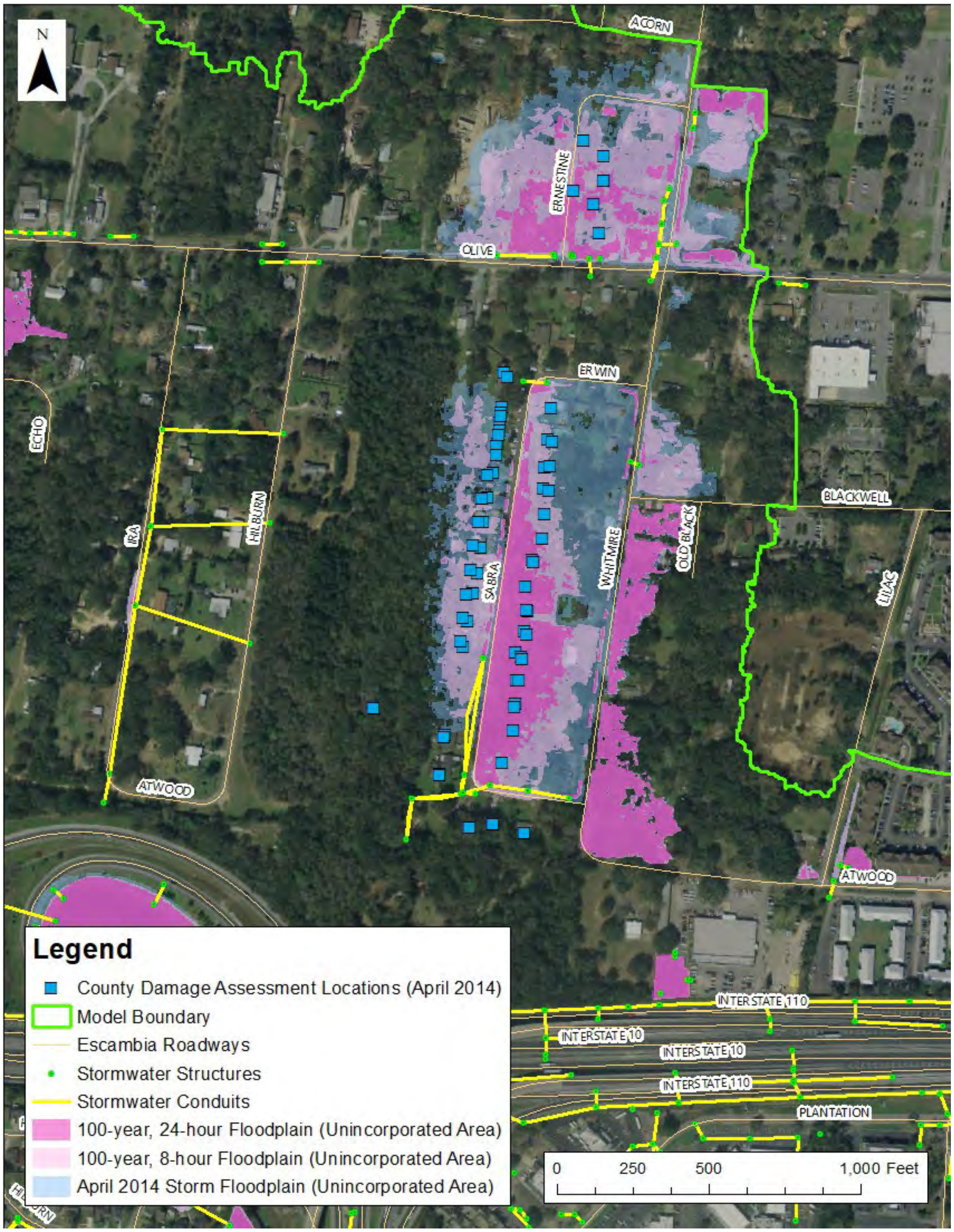
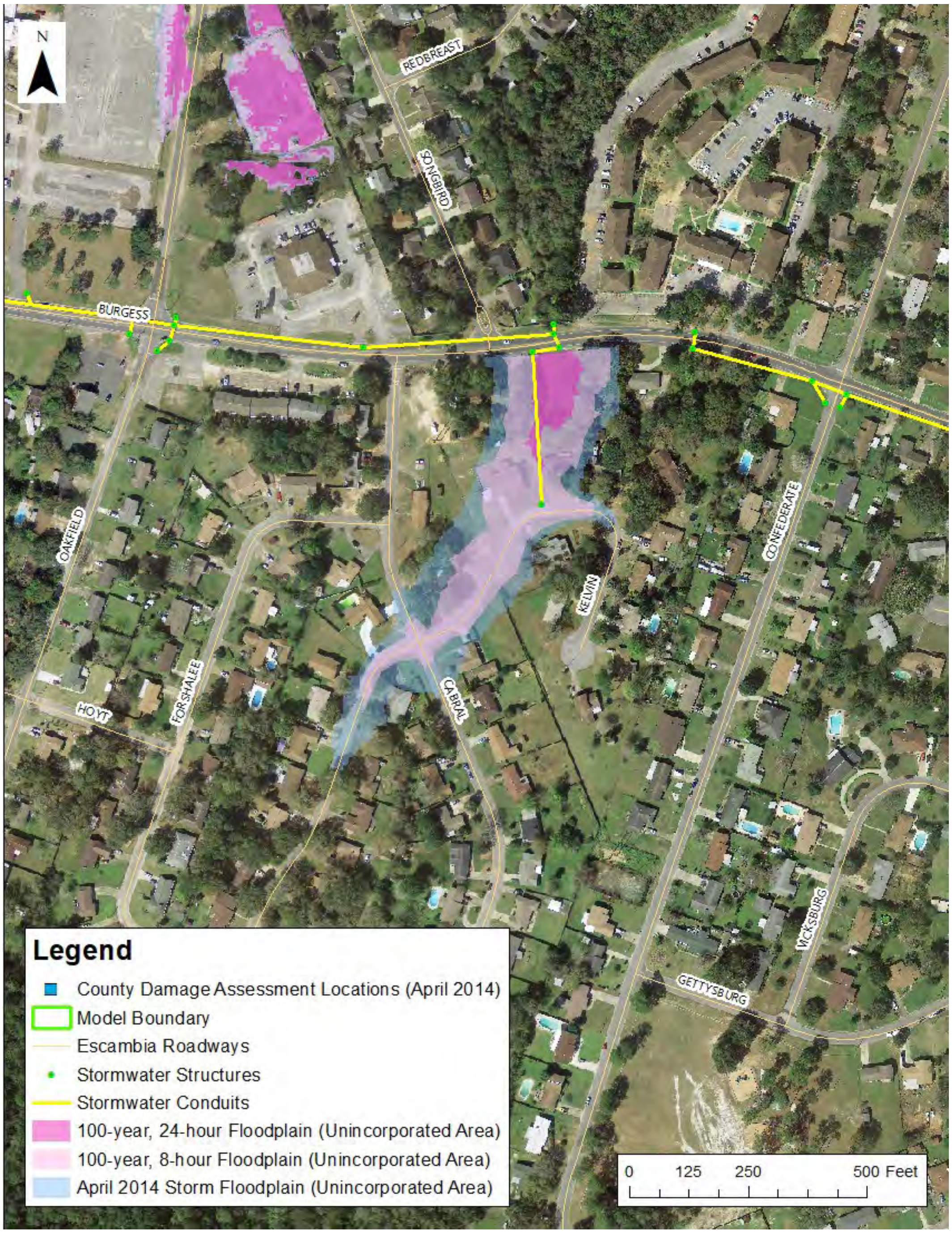


Figure 9.3-4 demonstrates an area where residential lots were developed in an area adjacent to a tributary of Carpenter Creek. The area is graded in such a way as to direct flow into Carpenter Creek, creating a depressional valley that feeds into the tributary north of Burgess Rd. The modeled floodplains in this area seem to be realistic, based on the conditions in this location.

FIGURE 9.3-4
Flood Case 4, Unincorporated Area



9.4 Sea-Level Rise Scenarios

The sea-level rise (SLR) scenarios were based on the NOAA's Sea-level Rise and Coastal Flooding Impacts projections for NOAA tide gage 8729840, with no interpolation between other regional gages. As such, the intermediate-low and intermediate-high scenarios were run for the 100-year, 24-hour storm event, associated with the following NOAA SLR projections:

- Year 2040 intermediate-low: 0.66 ft;
- Year 2040 intermediate-high: 1.31 ft;
- Year 2070 intermediate-low: 1.18 ft; and
- Year 2070 intermediate-high: 3.15 ft.

The City model's boundary condition time/stage nodes for Carpenter Creek and Bayou Texar have an elevation of 1.1 ft (NAVD88). The SLR projections noted above were then added to the boundary condition elevations, resulting in adjusted SLR boundary conditions of 1.76 ft, 2.41 ft, 2.28 ft, and 4.25 ft, respectively. These SLR scenarios were then assessed for impacts to wetlands, as defined by the 2019 Land use Cover, and the City's and County's critical infrastructure.

9.4.1 Critical Infrastructure Determination

The City and County each provided the Wood team with guidance in selecting and determining critical infrastructure locations in the modeled area. Further discussions with the County and City led to the following categories of features being classified as critical infrastructure, for the purpose of the WMP:

- Assisted Living Facility (which includes nursing homes);
- Call Center;
- Dialysis Center;
- Emergency Services;
- Fire Station;;
- Hospice;
- Hospital
- Law Enforcement;
- Military;
- Municipal Property;
- Non-Profit;
- School
- Transportation; and
- Utilities.

The address for each critical infrastructure record was used to create a spatial point (GIS shapefile) to represent each location. In total, 223 unique critical infrastructure locations were determined throughout the City and unincorporated area, as shown in **Figures 9.4-3 through 9.4-6** below.

9.4.2 Results and Discussion

Figure 9.4-1 shows similarities between the model-simulated 2070 intermediate-high floodplain and the 100-year, 24-hour floodplain and also shows NOAA's 2070 intermediate-high projected sea-level rise for reference, for the entire model. **Figure 9.4-2** shows NOAA's 2070 intermediate-high projected sea-level rise projection with aerial imagery as shown on the NOAA Sea-Level Rise Viewer. The 2070 SLR projections are shown to mostly affect properties right along the water's edge in Bayou Texar, without much flooding further inland.

Figures 9.4-3 through **9.4-6** also demonstrate similarities between the multiple SLR scenarios, in both the City and unincorporated areas. The similarities between the SLR model simulation results and the results from the design storm simulations are not entirely surprising. In part, the similarities in the results could be due to the fact that the same rainfall data (100-year/24-hour) was used between all simulations. Also, as the unincorporated area of the model is further removed from SLR impacts due to its distance from the surrounding bays, it's expected that SLR impacts would be less exaggerated in the unincorporated area rather than in the City's model area.

From the critical infrastructure locations provided by the County and utilized as a part of this analysis, there were no threats to the critical infrastructure identified in the unincorporated areas based on the resulting floodplains from the model simulations generated. There also doesn't appear to be a negative impact on the identified wetlands in the unincorporated area, as shown in **Figures 9.4-3** through **9.4-6,** and in **Figure 9.4-7,** which provides a zoomed-in view of the 2070 intermediate-high SLR projection floodplain specifically in the unincorporated area. As shown in **Figure 9.4-7**, many of the model-area wetlands are around Carpenter Creek or its tributaries and are conditioned to be inundated with water most of the year, specifically those denoted with Florida Land Use Cover and Forms Classification (FLUCCS) codes 617 and 630. The model results don't demonstrate peak stages that present ecological concern for these wetland types.

As noted previously, due to limited confidence in the model results from the City's existing model, detailed analysis related to projected SLR floodplains and the potential inundation of critical infrastructure and wetlands was not a focus within the City limits.

FIGURE 9.4-1

2070 Intermediate-High SLR and 100-year, 24-hour Floodplain Comparison

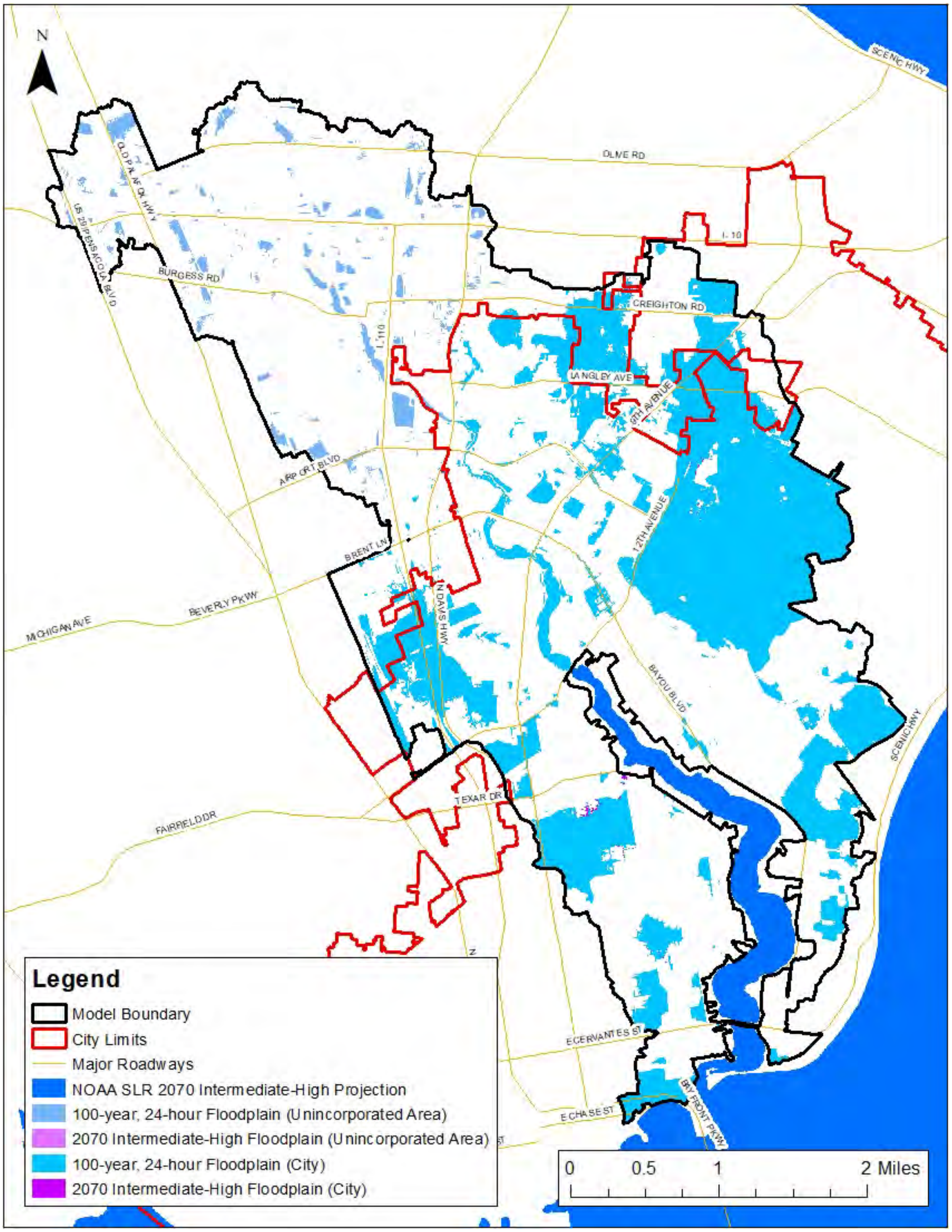
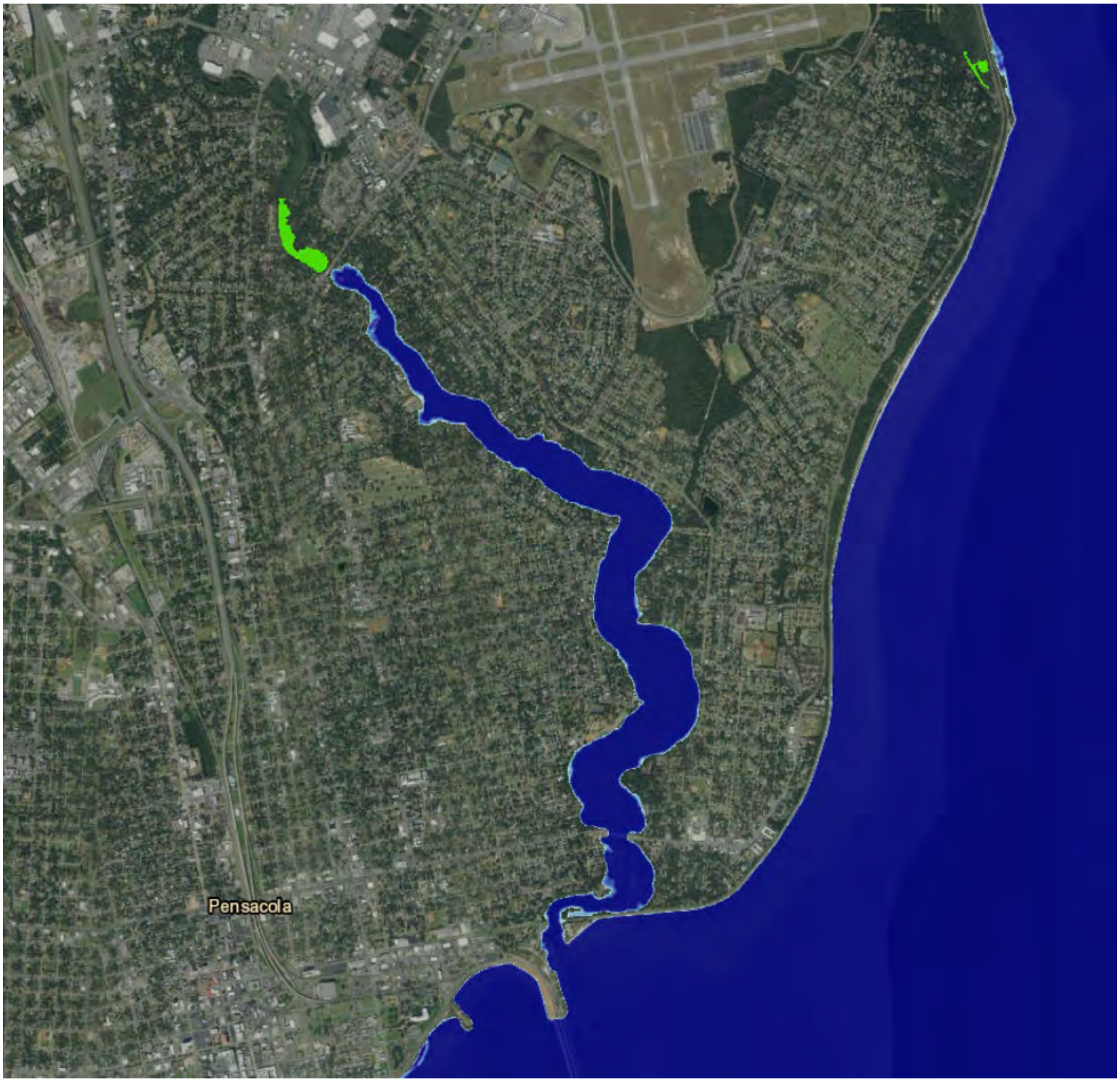


FIGURE 9.4-2
NOAA Sea-level Rise Viewer, 2070 Intermediate-High SLR



Source: NOAA Sea-level Rise Viewer For 2070 intermediate-high projection with green polygons showing "low-lying areas".

FIGURE 9.4-3
2040 Intermediate-Low SLR Projection

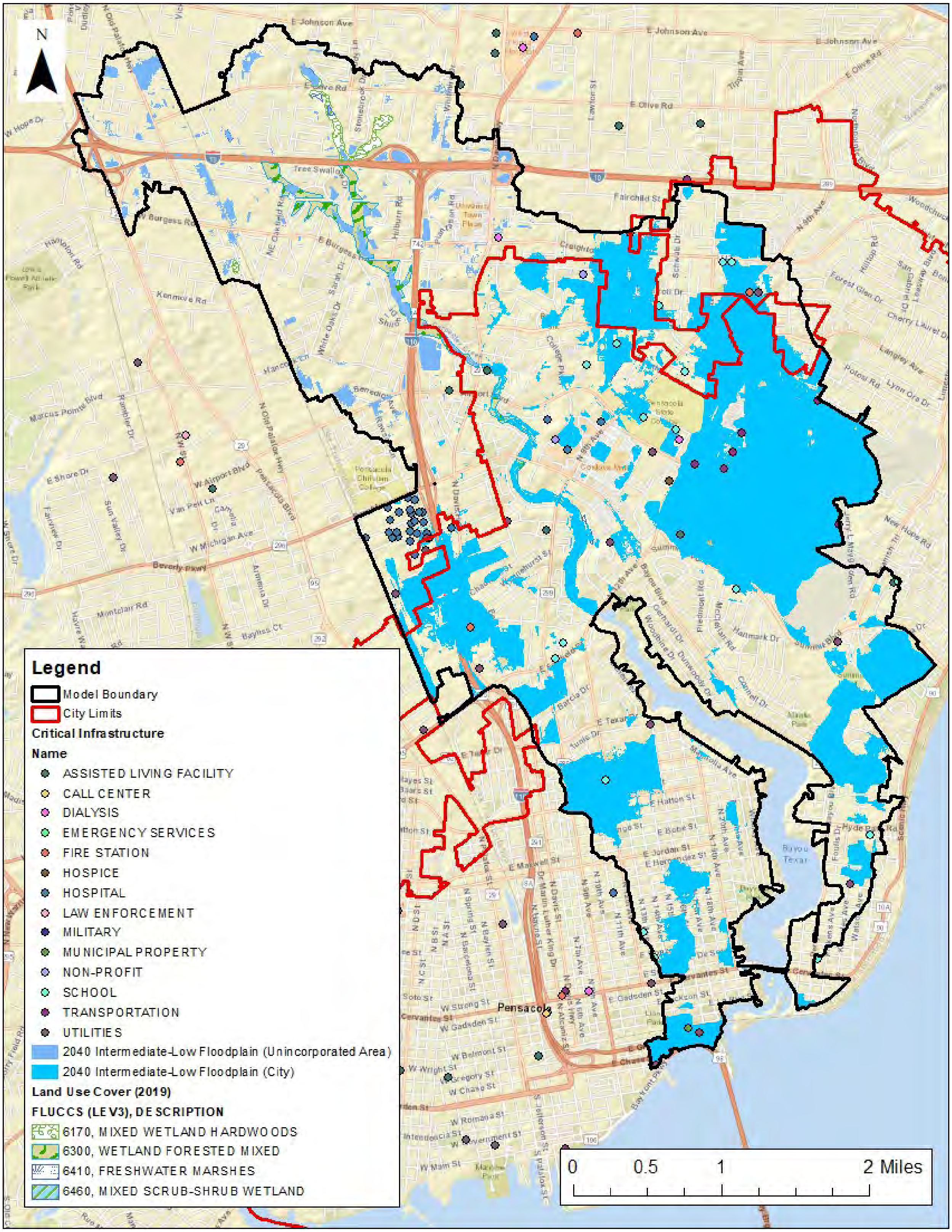


FIGURE 9.4-4
2040 Intermediate-High SLR Projection

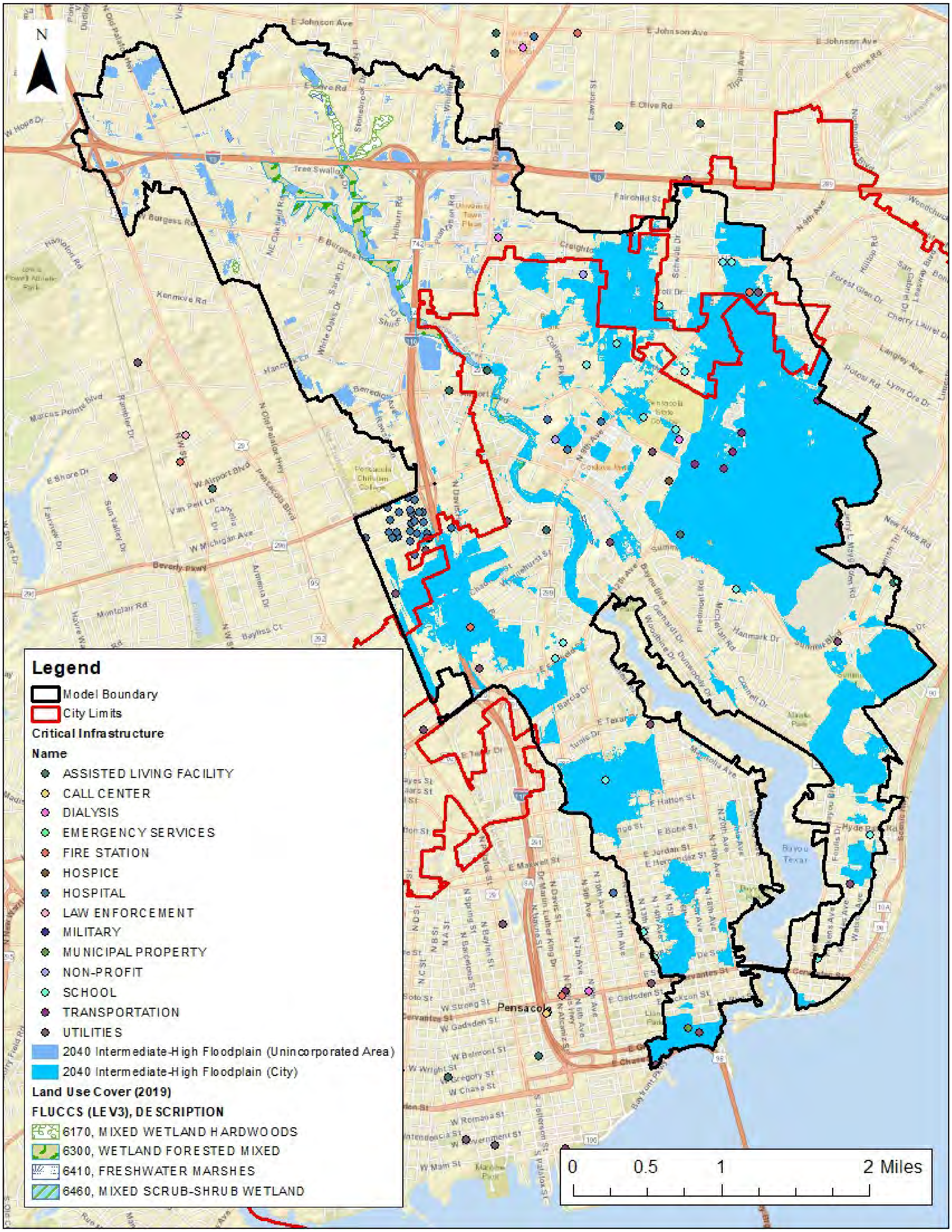


FIGURE 9.4-5
2070 Intermediate-Low SLR Projection

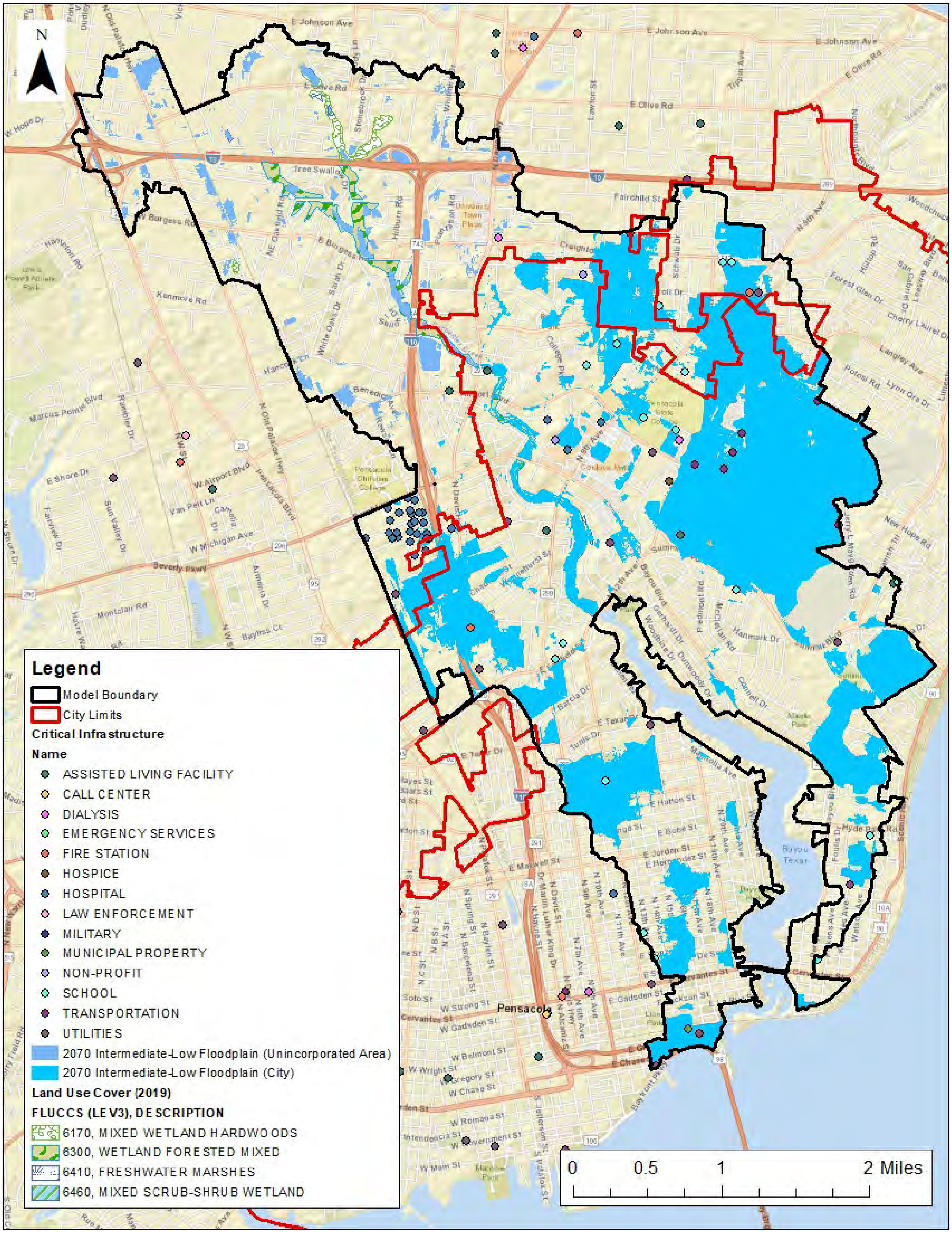


FIGURE 9.4-6
2070 Intermediate-High SLR Projection

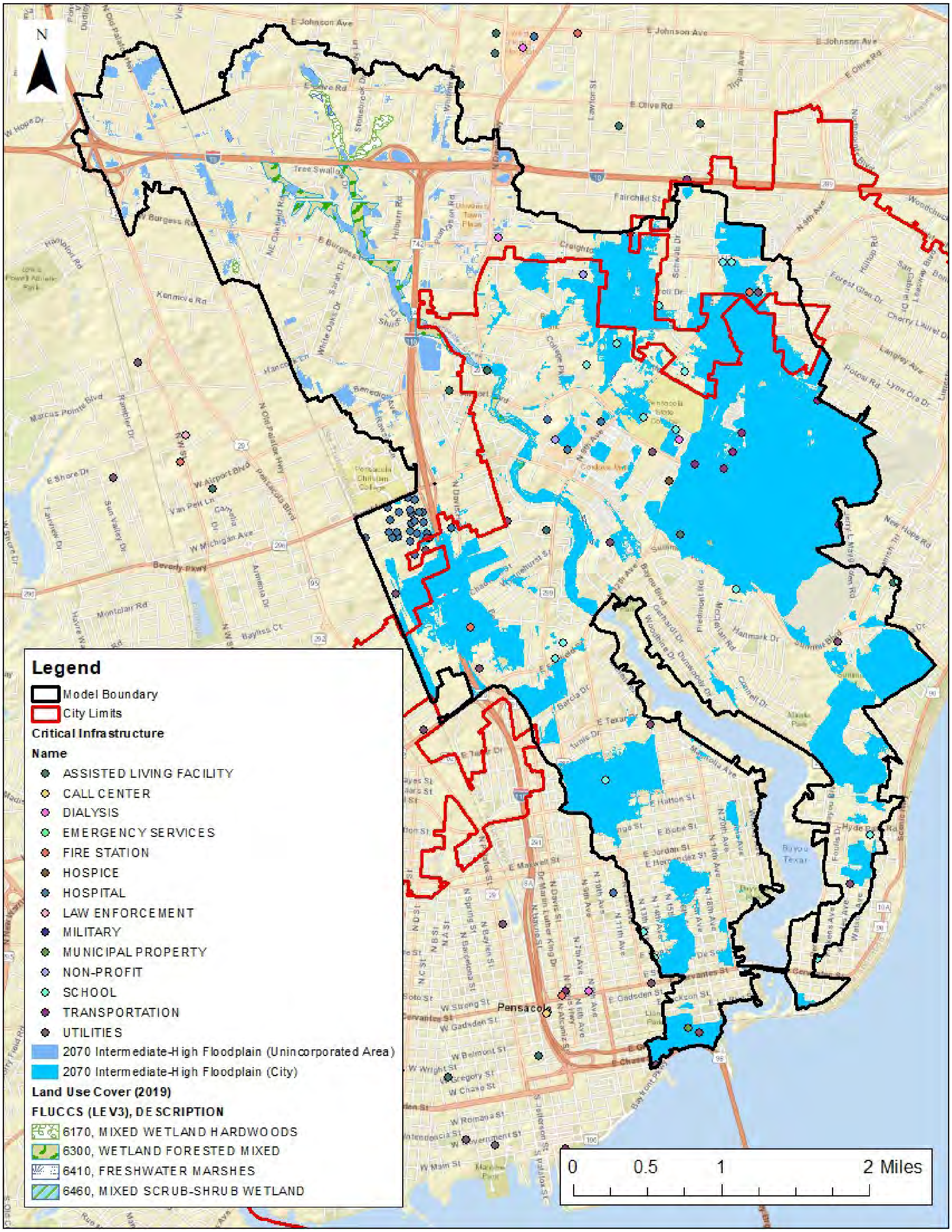
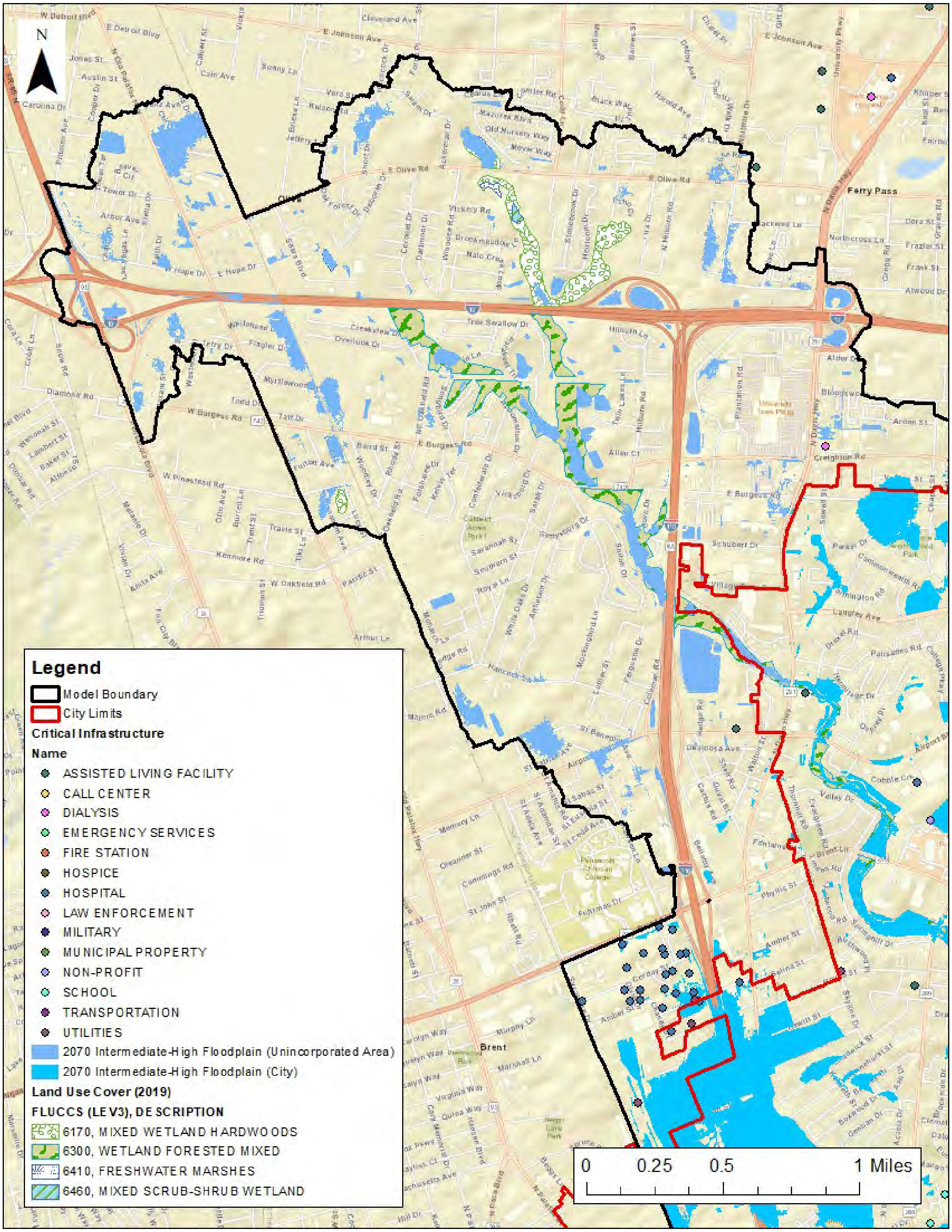


FIGURE 9.4-7
2070 Intermediate-High SLR Projection (Unincorporated Area Only)



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VOLUME 3B

WATER QUALITY ASSESSMENT REPORT

Escambia County
Florida

September 2021
Wood Project No.: 600643

Carpenter Creek & Bayou Texar Watershed Management Plan

CARPENTER CREEK & BAYOU TEXAR
WATERSHED MANAGEMENT PLAN

Task #3.2

WATER QUALITY ASSESSMENT REPORT

Prepared for

Escambia County
Water Quality & Land Management Division
3363 West Park Place
Pensacola, FL 32505

Escambia County PD 17-18.086, PO#191526

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Wood Project No. 600643

November 2021

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Date	Version	Description	Changes Made
September 20, 2021	Version 1.0	Initial Water Quality Assessment Report	N/A
November 1, 2021	Version 2.0	Revised Water Quality Assessment Report	Additional statistical analyses and discussion points have been added

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EXECUTIVE SUMMARY

A Surface Water Resource Assessment (SWRA) was conducted for the Carpenter Creek/ Bayou Texar watershed to identify trends, potential impairment risks, potential sources, hot spots, and to document any noteworthy water quality issues that may be impacting the watershed. For assessment purposes, the SWRA project area, or "watershed" was split into two sub-basins based on Water Body Identification (WBID) area. Carpenter Creek is WBID 676 and Bayou Texar is WBID 738.

Both Carpenter Creek and Bayou Texar have been verified by the Florida Department of Environmental Protection (FDEP) as impaired for fecal coliform bacteria. In 2012, FDEP adopted a fecal coliform Total Maximum Daily Load (TMDL) for both waterbodies. Bacteria reductions are necessary for these waterbodies to meet surface water quality standards. However, fecal coliform bacteria is no longer the applicable bacteria parameter for this waterbody classification and the FDEP has since designated that *E. coli* (for freshwater) and *Enterococci* (for marine) will be listed as the fecal indicator bacteria (FIB) for impairments. Additional potential impairments were identified during the Water Quality Assessment portion of the SWRA.

Carpenter Creek is the only significant freshwater tributary entering Bayou Texar and is classified as a predominantly freshwater stream. For the informal assessment period of 2010 – 2020 total nitrogen (TN) exceeded the FDEP's Numeric Nutrient Criteria (NNC) 8 out of 10 annual geometric means (AGMs) while total phosphorus (TP) and Corrected Chlorophyll-a (Chl-a) are not impaired since all observations were below the applicable NNC limit. Although TN was not increasing significantly over the period of record evaluated, it appears that Carpenter Creek may be impaired for TN. The Carpenter Creek portion of the watershed is highly urbanized and built out with residential, commercial, and industrial areas. The high degree of impervious surfaces, relatively well-drained soils, and presence of multiple pollutant sources contribute to water quality issues within the watershed. The pollutant load model results suggested that loading hot spots fall primarily within the Carpenter Creek WBID portion of the overall watershed. The potential hot spot areas within the Carpenter Creek WBID for both TN and TP coincide with areas developed after 1982, which are subject to stormwater treatment criteria. This suggests that existing stormwater treatment efforts in these areas may not be sufficient to treat the current volume of stormwater. Retrofitting existing stormwater ponds or implementing additional BMPs may help to address existing and future loads to the waterbody. Manicured lawns and septic tanks in the residential neighborhoods along the west bank of Carpenter Creek should also be considered as likely contributing sources of nitrogen. Aquifer vulnerability maps indicated several areas throughout the Carpenter Creek WBID that are highly vulnerable to aquifer contamination. Due to the presence of septic tanks and stormwater ponds, a groundwater seepage study would help identify the potential impact that groundwater sources may have on surface water quality.

Bayou Texar does not have established estuarine NNC, however, TN values appear to be elevated, based on a comparison against the NNC for the receiving waterbody, Pensacola Bay. Bayou Texar has low TP, but fecal indicator bacteria criteria were exceeded for nearly 27% of the number of samples collected from 2010-2020. The Bayou Texar portion of the watershed is highly urbanized and primarily consists of residential development. Anthropogenic modification of the shoreline in the upper and middle portions of the WBID, and urban stormwater from local parks and residential areas that drain to Texar Bayou are likely contributing to water quality issues. Several TN hot spots were identified at recreational areas and communities built prior to the implementation of the stormwater rule, which likely contributes to high pollutant loads in the form of untreated stormwater runoff. Future efforts to improve water quality should consider the implementation of stormwater treatment BMPs, specifically LID projects throughout the watershed. Based on the characterization of sediments within the Bayou, a layer of fine-grained sediments is present across most of the Bayou. Fine-grained organic sediments can be a significant nutrient load contributor from an internal cycling perspective. Reducing stormwater inflows into these areas and/or targeted removal are ways to reduce sediment accumulation in the Bayou.

1.0 INTRODUCTION

Wood Environment & Infrastructure Solutions, Inc. (Wood) was contracted by Escambia County to conduct a Surface Water Resource Assessment (SWRA) to assess water quality impacts and potential sources in the Carpenter Creek and Bayou Texar watersheds. The results and recommendations of the SWRA are an important component of the comprehensive watershed management plan (WMP) for Carpenter Creek and Bayou Texar. This report summarizes the work performed for **Task 3.2.2** – Water Quality Assessment and **Task 3.2.3** – Existing Conditions Pollutant Loading Analysis.

For **Task 3.2.2**, water quality data were assessed to identify trends, potential impairment risks, potential sources, hot spots, and to document any noteworthy water quality issues that may be impacting the watersheds. Additionally, water quality data were assessed against the Florida Department of Environmental Protection's (FDEP) Numeric Nutrient Criteria (NNC) to evaluate any potential impairments. Exploratory statistical data analyses were conducted to get an understanding of the distribution of these data and to assess relationships between certain parameters (e.g., nutrients, chlorophyll-a, fecal indicator bacteria, etc.). Additionally, a field reconnaissance was conducted as part of a qualitative assessment for Bayou Texar. For **Task 3.2.3**, watershed hydrology (surface and groundwater) and structural/point source issues that may influence water quality were analyzed using the Pollutant Loadings Assessment (PLA) tool. A synthesis of the analysis is provided in **Section 7**. The watershed summary and recommendations are included in **Section 9**.

As specified in the technical memorandum completed for **Task 3.2.1** – Water Quality Assessment Approach, preliminary recommendations for enhancements to the monitoring program and water quality improvement projects and/or BMPs at high-priority pollutant hot spot areas are also included. The information presented in this report will be used to make additional specific recommendations for **Task 4** – Watershed Management Recommendations.

2.0 WATERSHED BACKGROUND

The SWRA project area, referenced in this report as the "watershed", spans approximately 10,443 acres in southeast Escambia County. The watershed boundary, developed as part of **Task 3.1** – Hydrologic and Hydraulic Model Development, is inclusive of areas that are hydrologically and/or hydraulically connected to Carpenter Creek and Bayou Texar Water Body Identification (WBID) areas. For assessment purposes, the watershed was split into two sub-basins based on WBID, as shown in **Figure 2-1** and summarized in **Table 2-1**. The watershed is located entirely within Escambia County with the downstream portion of the creek and the entirety of the bayou located within the political boundary of the City of Pensacola. It should be noted that the watershed boundary does not include the entirety of the Carpenter Creek WBID boundary.

The upstream, freshwater portion of the watershed (Carpenter Creek) is designated by the FDEP as WBID number 676, occupying approximately 5,461 acres within the watershed. The headwaters of the creek are in south-central Escambia County, north of Interstate 10 (I-10) and west of Interstate 110 (I-110). Carpenter Creek generally flows southeast under Olive Road, I-10, Burgess Road, I-110, Davis Highway, Airport Boulevard, Brent Lane, 9th Avenue, and 12th Avenue before entering Bayou Texar.

The Carpenter Creek portion of the watershed is primarily comprised of urban land, with the remaining area consisting of rangeland, water, wetlands, upland forest, and barren land. The area immediately north of the headwaters is comprised of poorly drained soils; however, the soils in the remaining portion of the WBID are predominately well-drained. Displaced sediments from channel modifications and erosion in the upper headwaters have accumulated in the lower reaches of the creek and have significantly altered the mouth of Carpenter Creek that discharges into upper Bayou Texar.

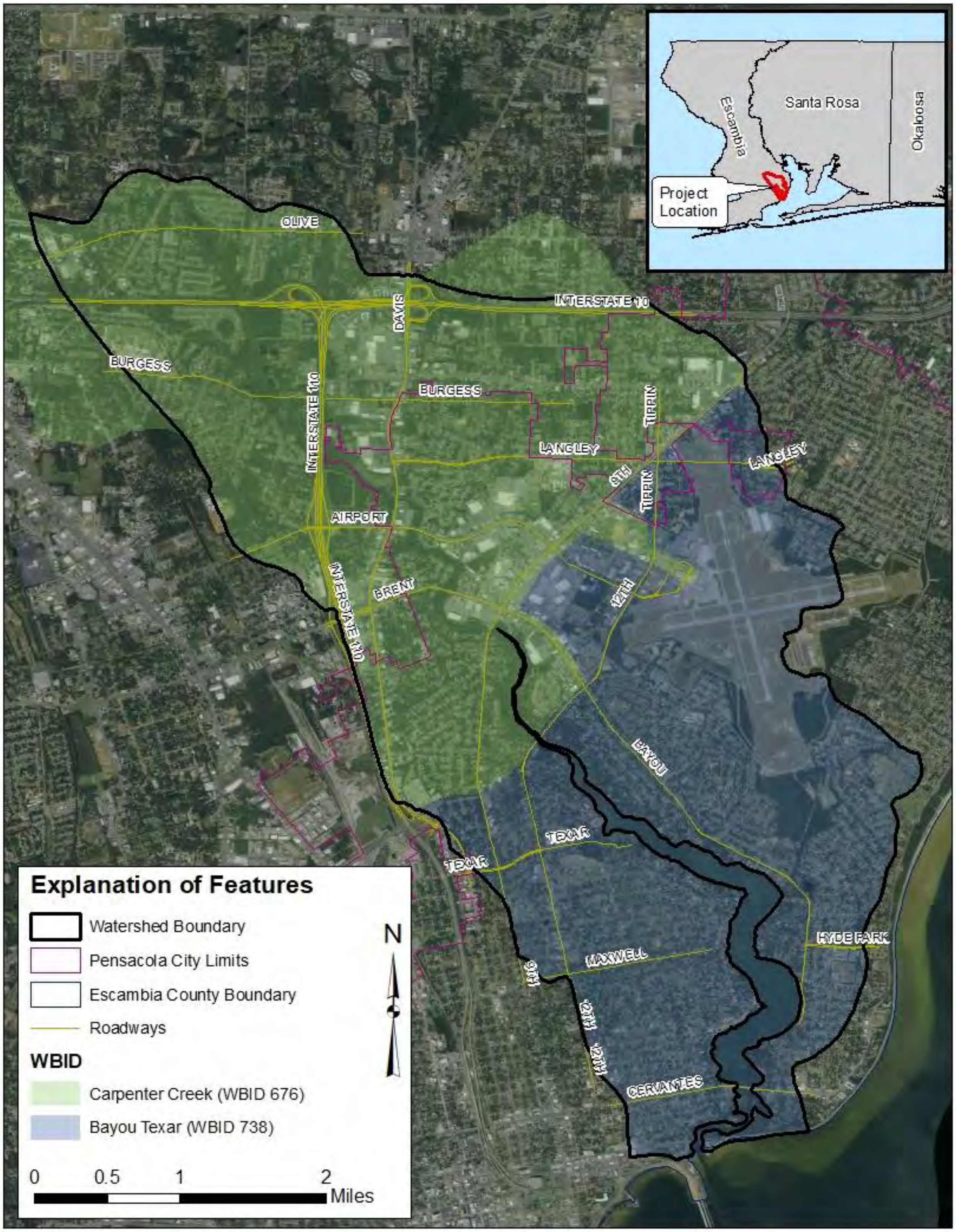
Bayou Texar is the lower estuarine portion of the watershed. The bayou includes approximately 4,939 acres of additional drainage area not already included with the Carpenter Creek portion of the watershed. Bayou Texar is designated by the FDEP as WBID number 738. Carpenter Creek is the sole significant tributary to Bayou Texar. The bayou is approximately 3.7 miles long, generally oriented in a north/south direction, with channel widths varying from over 1,000 feet in the south to less than 150 feet in the north.

The area is characterized by primarily residential and commercial land use and well-drained soils. The riparian areas of the bayou are almost fully developed with single-family residential homes. Numerous studies have documented contamination by fecal coliform and Enterococcus bacteria in the bayou, likely in part originating from sedimentation inputs from Carpenter Creek and various stormwater outfalls discharging into the bayou (Liebens et al., 2006 and Mohrherr et al., 2005)

Table 2-1: Watershed characteristics by WBID

WBID Name	Area (Ac)	Hydrologic Soil Group (HSG)	Land Use
Carpenter Creek	5,461	A, A/D, B, B/D, C	Medium-Density Residential, Commercial, High-Density Residential, Institutional
Bayou Texar	4,938	A, A/D	Medium-Density Residential, Commercial, High-Density Residential, Low-Density Residential

Figure 2-1: Watershed and WBID boundaries



3.0 WATER QUALITY ASSESSMENT METHODS

Detailed water quality methods including data retrieval, processing, and statistical analyses are listed in **Appendix B1**. Condensed methods are provided below.

3.1. Data Retrieval and Processing

Several sources of water quality data were used, which included the FDEP's (IWR and WIN public access databases) and Escambia County. LakeWatch data were not included in this assessment, per County request. Hydrologic data were retrieved from the United States Geological Survey (USGS)(Stations: Carpenter Creek at Pensacola, FLA (#02376079) and Carpenter Creek Nr Pensacola, FLA (#02376077)). Precipitation data were downloaded from NOAA (Station USW00013899, Pensacola Regional Airport).

FDEP and Escambia County water quality data were compiled into a single database and then aggregated by sampling location. Sampling locations that were listed under multiple station location identifiers were converted to county nomenclature so that all data for each sampling location was associated with a single location identifier. Additionally, data collected from multiple sampling locations less than 500 feet apart without any overlap in the period of record (POR) were aggregated to create a single sampling location identifier per site. The complete list of aggregated sampling locations and additional station characteristics is provided in **Appendix B2**. The final aggregated stations consisted of a total of eight stations in Carpenter Creek, and seven stations in Bayou Texar (**Figure 3-1**). Of these stations, only five stations in Carpenter Creek and five stations in Bayou Texar had sufficient data for trend and correlation analyses (**Table 3-1** and **Figure 3-2**). Tributary monitoring locations currently do not have enough data for impairment or trend assessments but were reviewed as part of the monitoring program. Spatial assessment of selected parameters between existing sites provided insight into potential upstream drivers of water quality in the main stem of Carpenter Creek and is discussed in **Section 8.1.3**.

Water quality data were processed based on laboratory and/or field-assigned qualifiers associated with these data. Duplicate values, and replicate samples were also identified and processed as described in **Appendix B1** during the data processing subtask.

The following water quality parameters were evaluated as part of this effort:

- Total Nitrogen (TN)
- Total Phosphorus (TP)
- Chlorophyll-a (Chl-a) corrected
- Fecal Coliform
- E. Coli (freshwater sampling locations only)
- Enterococci (marine sampling locations only)
- Total Suspended Solids (TSS)
- Specific Conductance
- Dissolved Oxygen (DO)
- Temperature
- Color
- pH
- Aluminum
- Magnesium
- Orthophosphate (Ortho-P)
- Iron
- Calcium

Figure 3-1: Original sampling stations (left), and aggregated water quality sampling stations (right)

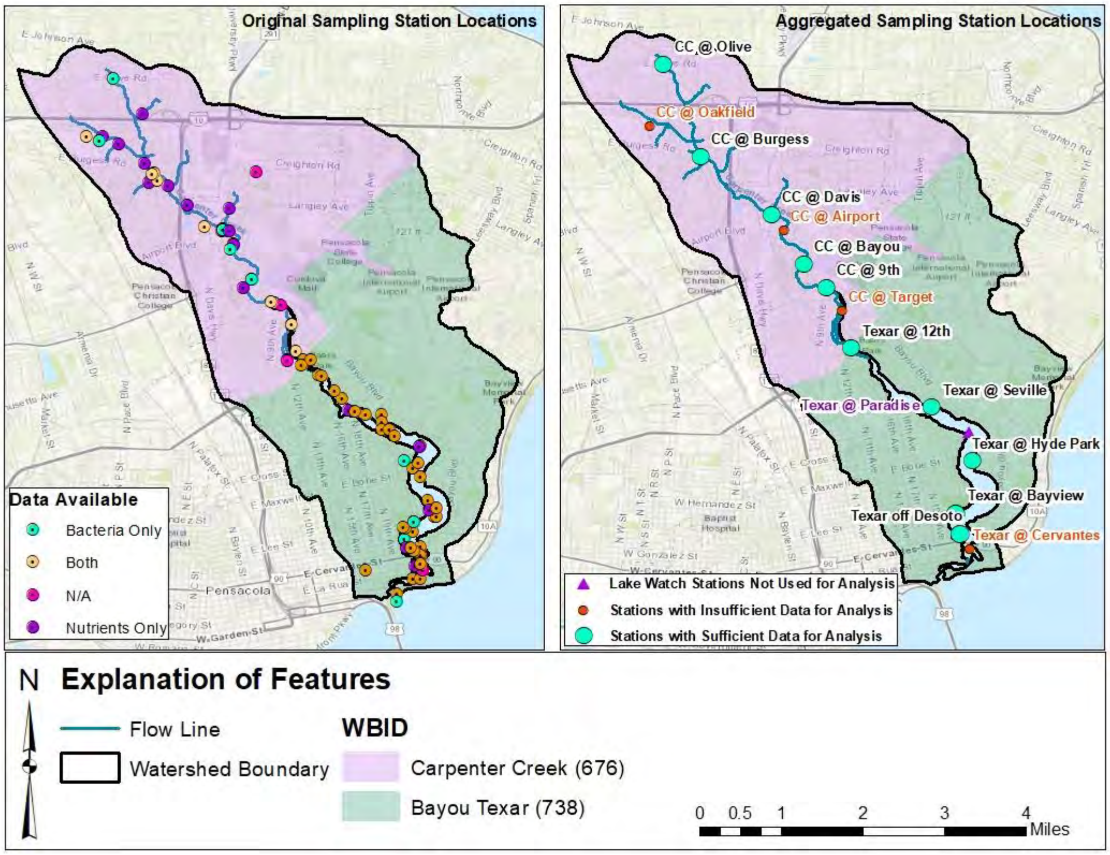
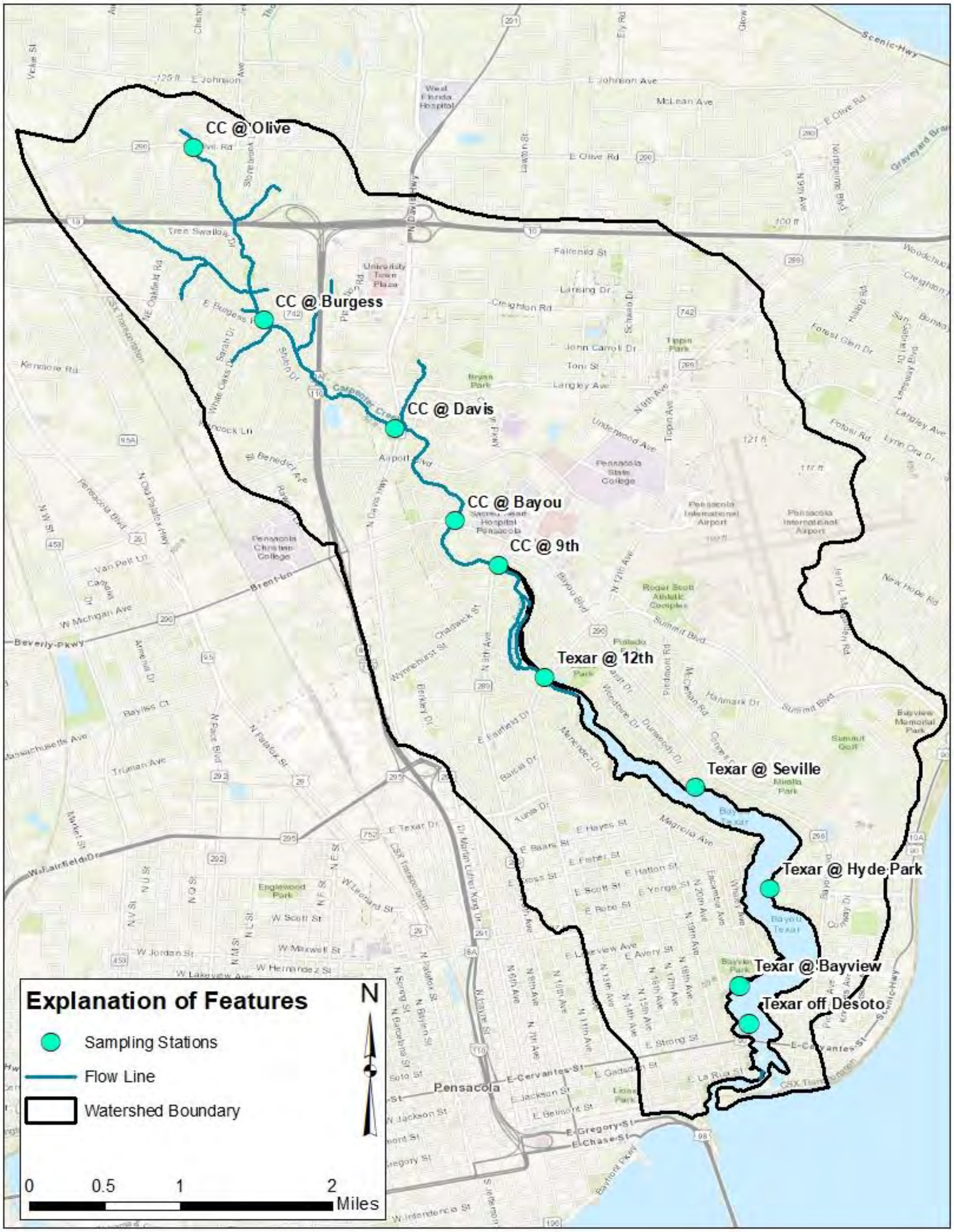


Table 3-1: Final aggregated water quality stations POR

Station Name	WBID	POR Start Date	POR End Date	Sampling Type
CC @ 9th	**676**	**3/5/89**	**6/3/21**	**Both**
CC @ Airport	676	3/5/12	3/26/12	Bacteria Only
CC @ Bayou	**676**	**3/5/12**	**4/20/21**	**Both**
CC @ Burgess	**676**	**6/28/71**	**4/20/21**	**Both**
CC @ Davis	**676**	**3/5/89**	**4/20/21**	**Both**
CC @ Oakfield	676	6/28/71	3/5/12	Both
CC @ Olive	**676**	**2/12/73**	**4/20/21**	**Both**
CC @ Target	676	3/5/12	3/22/17	Both
Texar @ 12th	**738**	**7/6/70**	**12/16/20**	**Both**
Texar @ Bayview	**738**	**3/2/86**	**3/1/20**	**Both**
Texar @ Cervantes	738	7/6/70	7/30/14	Both
Texar @ Paradise	738	9/16/70	4/28/77	Both
Texar @ Hyde	**738**	**7/6/70**	**12/16/20**	**Both**
Texar @ Seville	**738**	**7/6/70**	**12/16/20**	**Nutrients Only**
Texar off DeSoto	**738**	**2/9/17**	**5/24/21**	**Nutrients Only**

Note: **Bolded** values represent stations with sufficient data for trend and correlation analyses. "**Both"** means both nutrients and bacteriological data were available for this station.

Figure 3-2: Final aggregated water quality stations with sufficient data for trend and correlation analyses



3.2. Impairment Assessment

Carpenter Creek and Bayou Texar have previously been identified as impaired for fecal coliform bacteria (by FDEP). In 2012 the FDEP adopted a fecal coliform Total Maximum Daily Load (TMDL) for both waterbodies with a requirement of bacteria reductions necessary to meet the surface water quality standards. These waterbodies were impaired for fecal coliform and were placed in category 4a because there is a FDEP Adopted - EPA Approved Fecal Coliform TMDL. The TMDL requires a fecal coliform reduction of 28% and 49% for the creek and bayou, respectively. However, fecal coliform bacteria is no longer the applicable bacteria parameter for this waterbody classification and the FDEP has since designated that *E. coli* (for freshwater) and *Enterococci* (for marine) will be listed as the fecal indicator bacteria (FIB) for impairments. The 2020-2022 Biennial Assessment Draft Assessment lists Bayou Texar as verified impaired for *Enterococci,* while Carpenter Creek has been placed on the study list (assessment category 4e) for *E. coli* due to the ongoing restoration activities in place to address the impairment, documented in the Bacteria Pollution Control Plan for WBID 676 (FDEP 2021).

To assess potential impairments, an informal water quality impairment analysis was conducted by comparing metrics computed from available data (e.g. annual geometric mean concentrations) against NNC and FIB. The informal impairment methods used for the assessment are described in **Appendix B1**.

Carpenter Creek (WBID 676) is subject to the Panhandle West freshwater stream NNC (20 ug/L Chl-a, 0.67 mg/L TN, and 0.06 mg/L TP) expressed as annual geometric means (AGM), not to be exceeded more than once in a three-year period (**Table 3-2**). Carpenter Creek is considered impaired for TN based on the annual geometric means exceeding the nutrient threshold more than once in a 3-year period; however, this parameter has formerly been placed in assessment category 4d based on insufficient supporting biological data, therefore cannot be listed as verified impaired until sufficient data are available.

Bayou Texar (WBID738) is a tidally influenced non-Estuary Nutrient Region WBID, subject to an NNC of 11 ug/L Chl-a expressed as an AGM, not to be exceeded more than once in a 3-year period. In order to assess downstream impacts, TN and TP values of Bayou Texar were compared to the Upper Pensacola Bay nutrient criteria (0.77 mg/L TN, 0.084 mg/L TP) not to be exceeded in more than 10% of measurements over a 7.5 year period.

For FIB, Carpenter Creek is subject to the freshwater *E. coli* criteria of 410 Colony Forming Units (CFU)/100 mL, not to be exceeded in 10% of samples during a 30-day period. Bayou Texar is subject to the marine *Enterococci* criteria of 130 CFU/100 mL, not to be exceeded in 10% of samples during a 30-day period.

Table 3-2: State water quality standards for Carpenter Creek (WBID 676) and Bayou Texar (WBID 738)

WBID	TN Criteria	TN Frequency	TP Criteria	TP Frequency	Chl-a Criteria	Chl-a Frequency	Bacteria Criteria	Bacteria Frequency
676	0.67 mg/L AGM	≤1 in 3 years	0.06 mg/L AGM	≤1 in 3 years	20 µg/L	≤1 in 3 years	410 CFU/100 mL E. coli	<10% in any 30-day period
738	0.77 mg/L[1]	≤10% in 7.5 years[1]	0.084 mg/L[1]	≤10% in 7.5 years[1]	11 µg/L	≤1 in 3 years	130 CFU/100 mL Enterococci	<10% in any 30-day period
[1]- Criteria are applicable to the Upper Pensacola Bay, downstream of Bayou Texar								

In addition to the impairment assessments as discussed above, Wood also examined parameters not used in NNC evaluations that can be indicators of groundwater influence. These parameters include, but are not limited to, pH, specific conductance, dissolved forms of nitrogen, aluminum, magnesium, color, total phosphorous, orthophosphate, iron, calcium, and TSS.

3.3. Trend Analysis

Trends in water quality parameters were analyzed using the Mann-Kendall non-parametric trend test. The detailed methods are listed in **Appendix B1**. Trend analyses were conducted on the following parameters: TN, nitrate-nitrite (NOx), TP, Chl-a, DO, and either *E. coli* (in Carpenter Creek) or *Enterococci* (in Bayou Texar). Trend analyses were conducted on both WBIDs from 2010 through 2020. Trend analyses were conducted at the station scale from 2017 through 2020, due to gaps in data prior to 2017. Additional trend analyses were conducted on four stations with longer periods of record in Carpenter Creek (CC @ 9^{th} and CC @ Davis) and Bayou Texar (Texar @ 12^{th} and Texar @ Bayview) using data from 2010 to 2020. If there was evidence of serial correlation, the trend analysis result was adjusted for this serial correlation. If there was no evidence of serial correlation, the Seasonal Mann-Kendall test was used to test for significant trends. Trends were considered significant at a p-value of less than 0.05.

3.4. Correlation Analysis

Non-parametric correlation analyses were conducted to explore the relationships between water quality variables and precipitation (seven-day cumulative antecedent rainfall) throughout Carpenter Creek and Bayou Texar. Spearman correlations were calculated for stations in both Carpenter Creek and Bayou Texar. Additionally, correlations between Carpenter Creek and Bayou Texar were performed to explore one-to-one associations between water quality conditions in the creek and the bayou. Correlation analyses were based on available data from 2017 through 2020, aggregated to monthly resolutions. Detailed methods are listed in **Appendix B1**.

4.0 WATER QUALITY ASSESSMENT RESULTS

The following section will provide a summary of results from the impairment assessment, trend, and correlation analyses. Additional figures, tables, and more detailed results are provided in **Appendices B1 and B2**. A discussion and synthesis of the water quality assessment results in respect to other analyses are provided in a later section.

4.1. Impairment Assessment

The informal impairment assessment concluded, that between 2010 and 2020, Carpenter Creek never exceeded the Chl-a (20 µg/L) nor the TP (0.06 mg/L) criteria (**Table 4-1**). However, the TN criterion (0.67 mg/L) was exceeded 8 times, and 10% or more of *E. coli* samples had concentrations greater than 410 CFU/100 mL in the 6 years that data were available. The frequencies of these TN and *E. coli* exceedances indicate that Carpenter Creek may be listed as impaired for these parameters during the next assessment cycle.

Table 4-1: Impairment assessment for Carpenter Creek (WBID 676)

Year	Chl-a AGM (mg/L)	TN AGM (mg/L)	TP AGM (mg/L)	E. coli Exceedance (%)*
2010	*ID*	**0.73**	0.01	*ID*
2011	*ID*	0.59	0.01	*ID*
2012	*ID*	**0.69**	0.01	*ID*
2013	*ID*	**0.74**	0.01	*ID*
2014	0.46	**0.82**	0.01	**42**
2015	*ID*	0.63	0.01	*ID*
2016	*ID*	0.55	0.01	**43**
2017	0.76	**0.87**	0.01	**44**
2018	0.54	**0.87**	0.01	**35**
2019	0.53	**0.94**	0.01	**22**
2020	1.38	**0.80**	0.01	**33**

Note: *Italicized* values are below the minimum data requirements to properly assess the parameter (ID – Insufficient Data). **Bold** values exceed the criteria for that year. *- Both fecal coliform and *E. coli* data were collected in 2014, however only the *E.coli* data were used in the impairment assessment since that is what FDEP uses as the impairment criterion for fecal indicator bacteria.

Between 2010 and 2020, surface water in Bayou Texar did not exceed the Chl-a criterion (11 µg/L, **Table 4-2**). Additionally, 2014 was the only year with greater than 10% of samples above the TP criterion (0.084 mg/L). However, every year between 2010 and 2020 had greater than 10% of samples above both the TN criterion (0.77 mg/L) and *Enterococci* criterion (130 CFU/100mL).

Table 4-2: Impairment assessment of Bayou Texar (WBID 738)

Year	WBID	Chl-a AGM (mg/L)	TN Exceedances[1] (%)	TP Exceedances[1] (%)	Enterococci Exceedances (%)
2010	738	*ID*	**50**	0	**13**
2011	738	*ID*	**50**	0	**30**
2012	738	*ID*	**63**	0	**15**
2013	738	*ID*	**75**	0	**15**
2014	738	*ID*	**63**	13	**37**
2015	738	*ID*	**29**	0	**39**
2016	738	*ID*	**29**	0	**25**
2017	738	2.7	**40**	0	**18**
2018	738	3.0	**59**	0	**35**
2019	738	2.9	**71**	0	**29**
2020	738	4.6	**63**	4	**27**

Note: [1]- Criteria are applicable to the Upper Pensacola Bay, downstream of Bayou Texar.

Italicized values are below the minimum data requirements to properly assess the parameter (ID – Insufficient Data). **Bold** values exceed the criteria for that year.

4.2. Trend Analysis

Significant trends in water quality are presented in **Table 4-3**. The trend analyses resulted in eight statistically significant ($p < 0.05$) trends in water quality. At the station level, there was evidence ($p < 0.05$) of long-term (2010-2020) decreasing trends of TN, NOx, and DO at the 9th Ave. Carpenter Creek station. In contrast, the more recent POR (2017-2020) suggests that TN may be increasing at this same station. It should be noted that a minimum of five years is recommended for valid trend analysis results. However, TN should be re-evaluated to confirm whether TN is still increasing over the most recent five-year period (2017-2021).

Aggregating at the WBID scale, there was evidence ($p < 0.05$) of decreasing concentrations of TP and DO in Carpenter Creek (WBID 676), and declining NOx and DO in Bayou Texar (WBID 738). Although not statistically significant ($p = 0.06$), Chl-a appears to be increasing in Bayou Texar.

Table 4-3: Significant trends in water quality, as determined by Mann-Kendall trend tests

Station or WBID	Time Period	Parameter	Sen's Slope	Tau	*p*-value	Trend
CC @ 9th	2010-2020	Total Nitrogen	-0.02	-0.25	0.04	Significant Decreasing Trend
	2017-2020	Total Nitrogen	0.07	0.61	0.03	Significant Increasing Trend
	2010-2020	Nitrate-Nitrite	-0.07	-0.33	<0.001	Significant Decreasing Trend
	2010-2020	Dissolved Oxygen	-0.03	-0.30	<0.01	Significant Decreasing Trend
CC@Davis	2010-2020	Nitrate-Nitrite	0.01	0.01	0.01	Significant Increasing Trend
Texar@12th	2010-2020	Nitrate-Nitrite	-0.03	-0.32	<0.01	Significant Decreasing Trend
Texar@Bayview	2010-2020	Dissolved Oxygen	-0.08	-0.27	<0.05	Significant Decreasing Trend
WBID 676	2010-2020	Total Phosphorus	-0.01	-0.25	0.03	Significant Decreasing Trend
WBID 676	2010-2020	Dissolved Oxygen	-0.09	-0.27	0.03	Significant Decreasing Trend
WBID 738	2010-2020	Nitrate-Nitrite	-0.03	-0.38	<0.01	Significant Decreasing Trend
WBID 738	2010-2020	Dissolved Oxygen	-0.07	-0.28	0.03	Significant Decreasing Trend

Note: Full Mann-Kendall trend test results are available in **Table B2-7**.

4.3. Correlation Analysis

Correlations are used to measure the strength of the linear relationships between variables. Correlation analyses are useful in water quality analyses, with a large number of variables. While correlation does not imply causation, it can provide insights on potential relationships between variables (i.e., is Chl-a more closely associated with TN or TP). Correlation matrix plots are located in **Appendix B2**. The Spearman correlation analyses identified significant ($p < 0.05$) correlations between water quality parameters at stations in Carpenter Creek and Bayou Texar. Additionally, the correlation analysis using the 2017-2020 POR identified a significant positive correlation between TN and TP between the two waterbodies but found a slight negative significant correlation between TN and TP using the full dataset (n=46). No significant correlation for Chl-a between the two waterbodies was identified. A summary of correlations among water quality parameters at select sampling locations is presented in **Table 4-4**.

Table 4-4: Significant ($p < 0.05$) correlations at select water quality stations

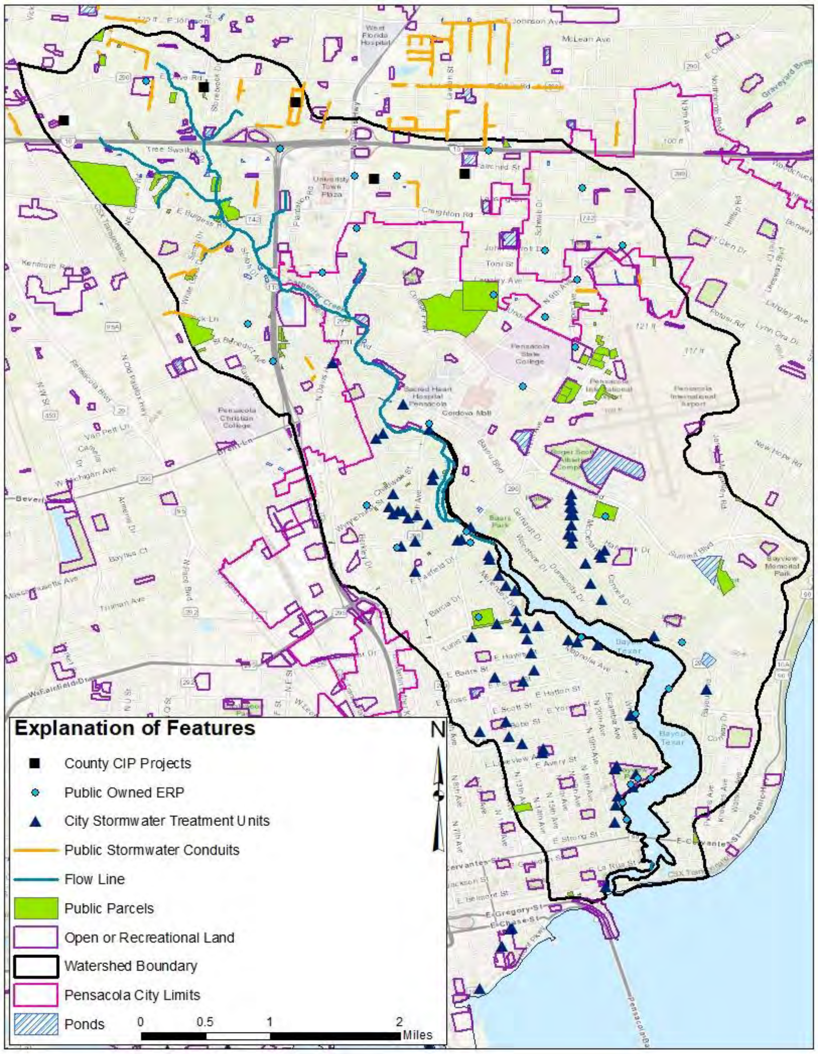
Station	Parameters	Positive Correlations	Negative Correlations
CC @ 9th	TP	TSS, Turbidity	TN
	TN	-	TP, TSS, Turbidity, Chl-a
	Chl-a	TP, TSS	TN, Specific Conductance
	E. Coli	Turbidity, Precipitation, Temperature	Specific Conductance
CC @ Bayou	E. Coli	Turbidity, Precipitation, Temperature	-
CC @ Davis	E. Coli	Turbidity, Precipitation, Temperature	DO
CC @ Burgess	E. Coli	Turbidity	DO
Texar @ 12th	TN	-	TSS
	Enterococci	Turbidity and Temperature	-
Texar @ Hyde	Enterococci	-	DO
Texar @ Seville	TP	Turbidity, TSS, Chl-a	-
	Chl-a	Turbidity, TSS, TP	-
	Enterococci	Turbidity	-
Texar off DeSoto	TP	Turbidity	DO, Specific Conductance
	Chl-a	TP, Precipitation, Temperature	-

5.0 FACTORS POTENTIALLY AFFECTING WATER QUALITY

5.1. Geospatial Assessment

In conjunction with the geospatial source identification for monitoring plan review, Wood reviewed the geospatial data (e.g., land use, wastewater, public reclaim, septic, agriculture, fertilizer sources, soil and aquifer data) to identify, locate, and prioritize potential pollutant sources to Carpenter Creek and Bayou Texar via surface conveyance or groundwater connectivity. Public GIS data such as public lands, parks, parcels, conservation easements, and future land use were assessed to begin developing an inventory of areas that could potentially be used for BMPs and treatment projects (**Figure 5-1**).

Figure 5-1: Potential Areas for Future BMPs



5.2. Pollutant Gross Load from Stormwater Runoff

Stormwater runoff is collected and conveyed to Carpenter Creek / Bayou Texar through the existing storm sewer infrastructure located throughout the 10,444 acres +/- watershed. Stormwater runoff is also conveyed to these waters through overland flow. Quantification of the pollutant loads associated with stormwater runoff is an important component of the overall pollutant load contribution into the receiving body. Additionally, a gross pollutant load analysis allows for the identification of potential treatment areas and water quality 'hot spots' throughout the watershed. The methodology for quantification of pollutant loads associated with stormwater runoff is described in the following sections.

5.2.1. Methodology for Pollutant Load Gross Estimate

Pollutant load modeling was conducted for the existing and future land use conditions to estimate representative pollutant loads discharging into Carpenter Creek / Bayou Texar. A 200' x 200' grid across the watershed was developed, and pollutant loads were derived for the created grid to identify "hot spots" or areas that are relatively rich in TN and TP stormwater runoff. The pollutant load modeling was accomplished using a Microsoft® Excel spreadsheet tool referred to as the Pollutant Loadings Assessment (PLA). This tool was developed in-house by Wood and is based on criteria developed by FDEP and the Water Management Districts when a Statewide Stormwater Rule was being considered (FDEP & Water Management Districts, 2010). The PLA tool utilizes the modified U.S. Environmental Protection Agency's (EPA) Simple Method (Schueler, 1987). The Simple Method estimates stormwater pollutant loads as the product of annual runoff volume and pollutant concentrations.

The Simple Method is a three-step calculation (Ohrel, 2000):

1. Runoff coefficient calculation, Rv:

   $Rv = 0.05 + 0.009 * I$

   Where:

   Rv = Mean runoff coefficient

   I = Percent of site imperviousness

2. Runoff volume (acre-feet per year) (ac-ft./yr.) calculation:

   $R = (P * Pj * Rv / 12) * A$

   Where:

   R = Runoff volume (ac-ft./yr.)

   P = Annual rainfall depth (inches)

   Pj = Fraction of rainfall events that produce runoff (normally equal to 0.9)

   A = Study area (acres)

3. Annual pollutant loads (pounds per year)

   $L = 2.72 * R * C$

   Where:

   L = Annual pollutant load (lb./year)

   C = Event mean concentration of the pollutant (mg/l)

   2.72 = Conversion factor (from mg/l to lb./ac-ft.)

For this investigation, the Simple Method calculation of runoff volume was modified to calculate annual runoff as follows:

$$Q = 0.083 * c * i * A$$

Where:

Q = Runoff Volume (ac-ft./yr.)

c = Runoff coefficient determined based on Florida Meteorological Zones as classified in the draft Stormwater Quality Applicant's Handbook, March 2010 Draft.

i = Annual rainfall depth (in)

0.083 = Conversion factor (inches to feet)

A = Area (ac)

Annual average rainfall of 65.27" is the 30-year normal annual rainfall total for Pensacola and was used for this analysis (Northwest Florida Water Management District, NWFWMD Rainfall). The runoff coefficient 'c' is determined on the drainage basin's non-directly connected impervious area curve number (NDCIA CN) and percentage of directly connected impervious area (DCIA) combination and the meteorological zone within which the project area falls. The March 2010 Draft Stormwater Quality Applicant's Handbook has the runoff coefficients published for each Non-DCIA CN/% DCIA combination and each meteorological zone in Florida (DEP 2010). Among the five meteorological zones defined in Florida, Escambia County is within Zone 1. Published runoff coefficients for Zone 1 are tabulated in **Table C-1** in **Appendix C**. The CN and DCIA for the various land use and soil types comprising the drainage basins were determined by using the lookup table provided in this report as **Table C-2** in **Appendix C**. District 2016 Landuse data were updated as needed according to FDOT 2019 aerial imagery to represent existing landuse conditions. Project-specific landuse DCIA values were derived based on representative landuse and DCIA conditions within Carpenter Creek and Bayou Texar WBIDs. These values provide a representative basis for stormwater runoff and pollutant load estimation.

Although the Simple Method is accepted as an appropriate and reasonably accurate planning level technique to estimate the pollution loading contributed by stormwater runoff, it does have several limitations (Center 2003):

- This method cannot be used to estimate the pollutant loads generated by base flow, only the loads generated during the storm.
- This technique may not accurately estimate pollutant loads for construction sites, heavily traveled highways, croplands, and undeveloped areas.

The method only accounts for watershed pollutants carried by stormwater runoff but does not account for loads caused by unnatural streambank erosion caused by urban stream syndrome (a secondary effect from the rainfall-runoff response).

Despite the above limitations, the Simple Method is an accepted tool for comparing pollutant loads of different drainage subbasins for prioritization purposes.

Table C-3 (Refer to **Appendix C**) lists the event mean concentrations (EMC) used to estimate pollutant loads for the Carpenter Creek and Bayou Texar subbasins. EMCs were developed using land-use-specific pollutant concentrations obtained from past monitoring activities conducted throughout the State of Florida and were derived from several sources as noted in the documentation. EMCs were developed for total nitrogen (TN), total phosphorous (TP), biological oxygen demand (BOD), total suspended solids (TSS), lead (Pb), copper (Cu), and zinc (Zn).

5.2.2. Methodology to Apply Existing and Future BMP Load Reduction

Best Management Practice (BMP) areas were identified using a multi-step process. The Carpenter Creek and Bayou Texar contributing basins were overlaid with the District's Environmental Resource Permit (ERP) coverage, which included private and public BMPs. Additional stormwater pond coverage provided by the County and the City of Pensacola were also reviewed. Aerial imagery of the intersecting areas between the ERP coverage and contribution basins were manually reviewed to identify BMP areas. When necessary, the ERP/ contribution area intersect was edited to provide representative treatment within the contributing basins. BMP "type" classification was based on the corresponding aerial imagery, treatment specified by the permit, or treatment specified by the City of Pensacola (as applicable). BMPs were assigned as dry retention or wet detention. Seven of the stormwater ponds identified by the City as "wet detention" were re-assigned as "dry retention" based on aerial imagery and discussion with the County. The BMP treatment for areas within the ERP/ contribution area intersects that did not have visible dry or wet stormwater treatment facilities was assigned "none" for treatment. Individual ERP documents/plans were not reviewed for this effort.

To accurately quantify pollutant loading, a load reduction factor was applied to the raw stormwater loads where BMPs were present. The "Adjusted" pollutant load provides basin pollutant loads minus the treatment provided by the onsite BMP. BMP treatment was assigned as wet, dry (retention), or none for all the contributing basins. Wet pond pollution removal efficiencies were based on an assumed 14-day hydraulic residence time. Dry pond pollution removal efficiencies were based on an assumed 0.50 inches of retention volume. Pollutant load reductions are based on the methodology presented in Figures 13.2 and 13.3 from the March 2010 DEP/WMD draft document for Zone 1. Published mean annual mass removal efficiencies for 0.50-inches of Retention in Zone 1 are provided in the FDEP 2010 document. Future land-use data were obtained from Task 2.11 and utilized to derive representative estimates for pollutant loading associated with future land-use conditions. Future developed land-use areas were assigned a "Wet" detention BMP factor for the purposes of this analysis. The baffle boxes, Vortec units, and bay saver treatment units within the watershed were not assigned a nutrient reduction, as these units primarily remove sediments/trash and nutrient removal is typically nominal.

Best management practices and catch basins within the project limits are routinely cleaned out / maintained by the City of Pensacola, Escambia County, and the FDOT on an as-needed basis. Additionally, street sweeping is performed on roadways on a monthly frequency. These maintenance activities are associated with considerable pollutant load removals but were not accounted for in the existing/future analyses, as this level of detail exceeds the model. Street sweeping is estimated to provide removal of 332 mg/kg TP and 610 mg/kg TN; catch basin cleanout is estimated to provide removal of 378 mg/kg TP and 785 mg/kg TN, and BMP cleanout is estimated to provide removal of 328 mg/kg TP and 1054 mg/kg TN (FSA 2019).
The total annual estimated "Adjusted" loading for the existing land use condition and future land-use conditions (Standard BMP Efficiencies) are summarized in **Table 5-1**. Also provided in the below table is a "Reduced BMP Efficiencies" condition for both Existing and Future conditions. This condition reduces the treatment as described below, assuming an "un-maintained" condition:

- "Dry" Retention – Assumes all removal efficiencies reduced by 10% (i.e. less infiltration due to sediment accumulation);
- "Wet" Detention – No change; properly designed sumps can take decades of sediment and continue to have the same detention time.

Table 5-1: Summary of Stormwater Runoff Estimates for Carpenter Creek / Bayou Texar Watershed Existing vs Future Land Use Conditions

Scenario	Estimated Annual TN Load (lb)	Estimated Annual TP Load (lb)	Estimated Annual BOD Load (lb)	Estimated Annual TSS Load (lb)
Existing Condition – Standard BMP Efficiencies	51,105	7,616	223,799	1,382,167
Existing Condition – Reduced BMP Efficiencies	51,890	7,731	227,861	1,410,954
Future Condition – Standard BMP Efficiencies	52,663	7,864	228,294	1,427,060
Future Condition – Reduced BMP Efficiencies	53,447	7,979	232,353	1,455,831

Note: The above Pollutant Loads are adjusted for urban BMPs as described in the text.

As shown in **Table 5-1,** the TN and TP pollutant loads are estimated to increase by 3%, respectively, in the future condition (as compared to existing). This increase is based on the previous assumption, which assumes a "Wet" detention treatment for locations that exhibit a land use change between existing and proposed conditions. This assumption is likely slightly conservative as dry retention systems may be implemented in portions of the watershed and have better pollutant removal efficiencies than the wet detention alternative.

5.2.3. Methodology to Identify Pollutant Hotspots within Carpenter Creek and Bayou Texar

In general, hot spots may be identified by reviewing the applicable land use and soils data to estimate stormwater runoff and the associated pollutant loads. The pollutant loading model methodology was used to generate hot spot maps, which are the same pollutant loads but shown in a grid format to represent the spatial variation in pollutant load yield throughout the watershed. Annual loading for total nitrogen (TN) and total phosphorus (TP) was assigned based on applicable land use/soils within each grid cell (200-ft x 200-ft). Load reductions from existing BMPs (wet/dry ponds) were accounted for when generating the hot spot maps, however, septic and other pollutant loads (such as from groundwater) were not included. **Figure 5-2** and **Figure 5-3** show the TP and TN "Hot Spots" within the watershed. Analysis of the 'Hot Spot' maps will help quickly identify areas that are providing relatively high TN and TP loading within the watershed and would warrant appropriate BMPs to reduce loads to the waterbodies. Identification of hot spots is discussed in **Section 7**.

Figure 5-2: Watershed TP Loading Hot Spot Map

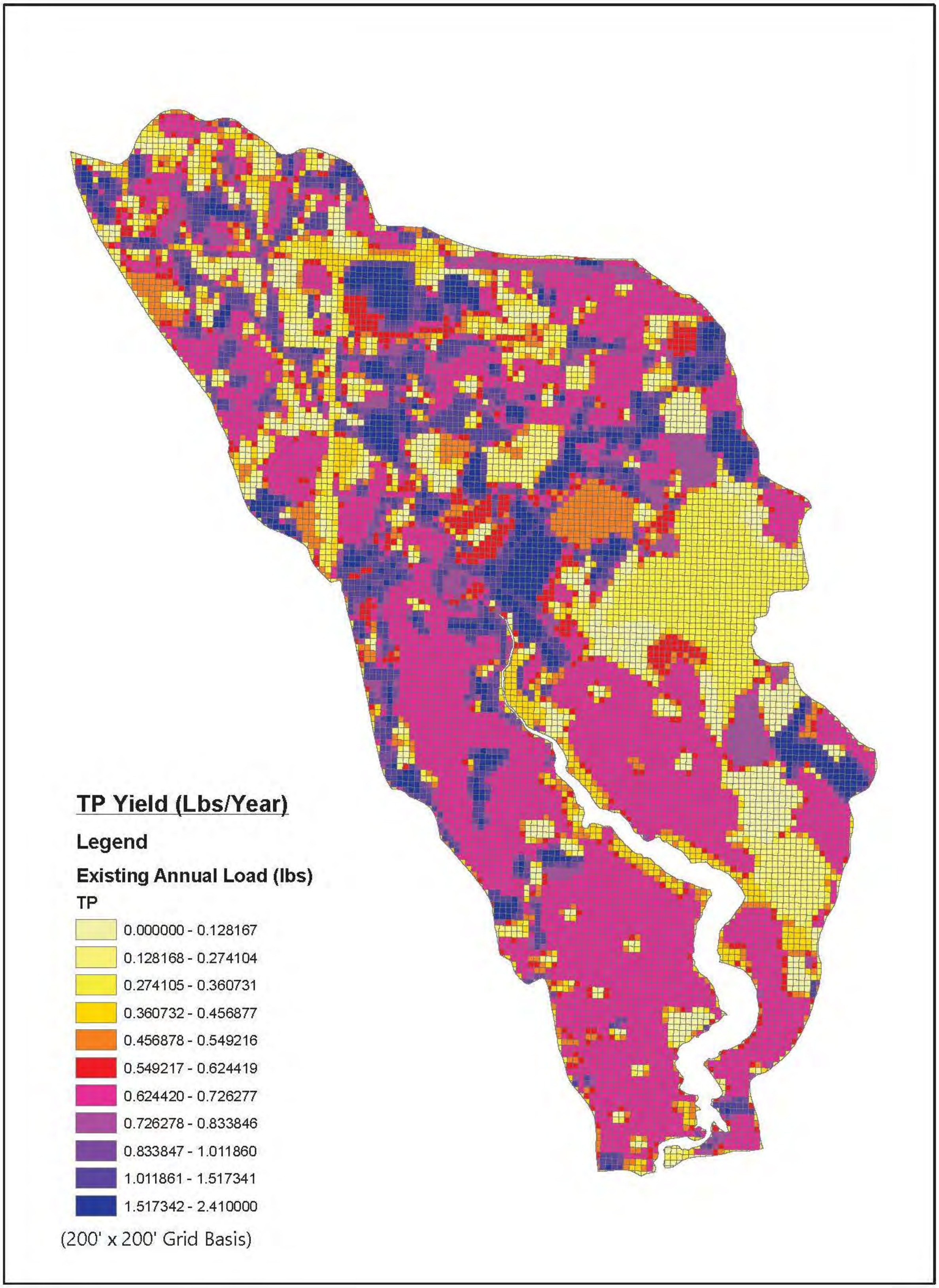
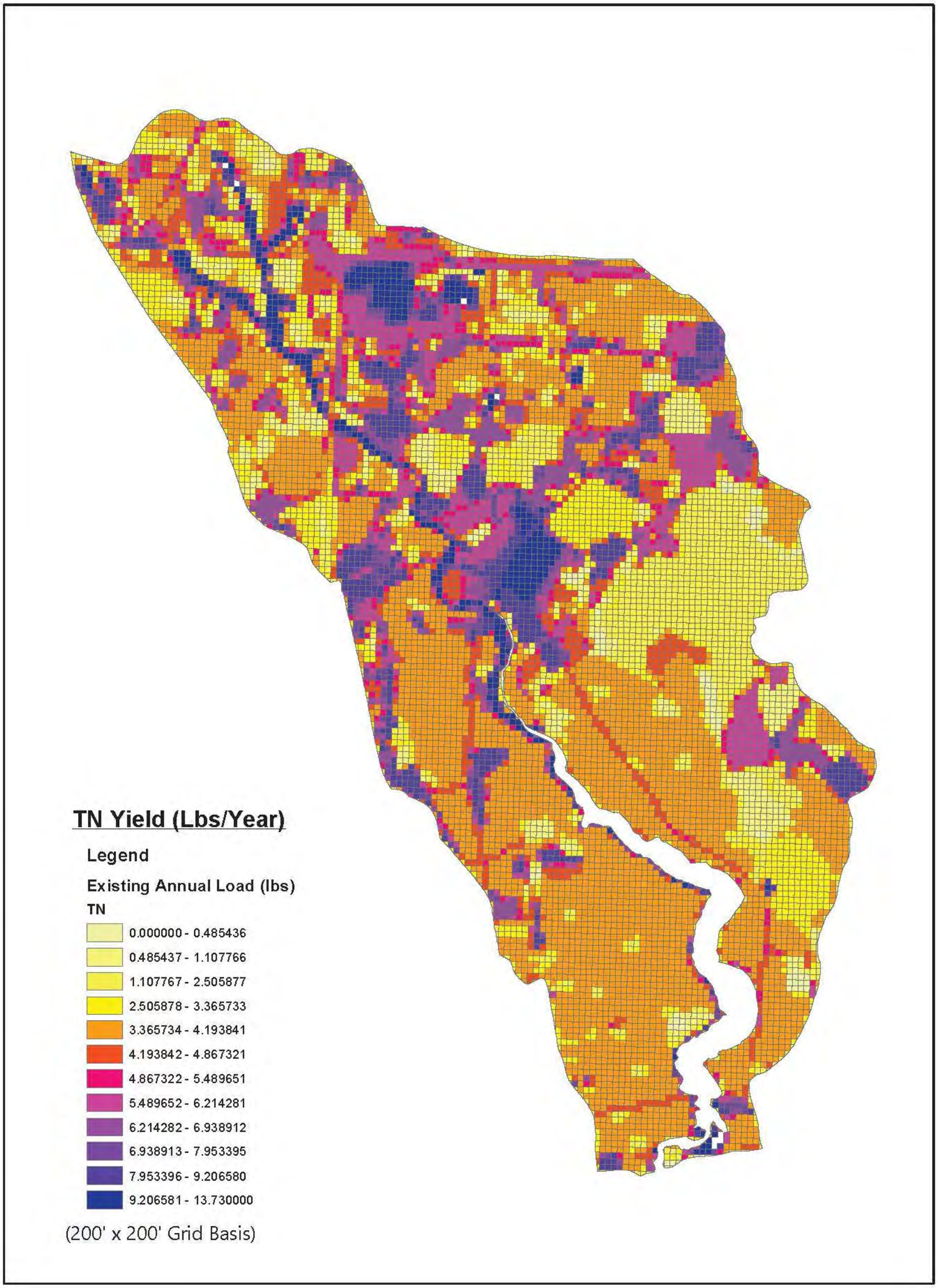


Figure 5-3: Watershed TN Loading Hot Spot Map



5.3. Additional Surface and Groundwater Loading

5.3.1. Septic Tank Pollutant Load Estimates

On-site treatment and disposal systems (OSTDS) or septic tanks may be a significant source of phosphorus and nitrogen loading within an ecosystem. Proper quantification of septic loading is necessary to provide a comprehensive representation of total system loading. The methodology outlined in the Pollutant Loading Estimates, Prepared for the Charlotte Harbor National Estuary Program (Janicki Environmental 2010) was utilized to generate septic loading estimates.

The following data and assumptions were used to estimate the OSTDS TN and TP loads:

- Number of current estimated active septic tanks within the watershed boundary, comprised of estimated OSTDS (232) and known OSTDS (543): 775
- The assumed average rate of failure of septic tanks per soil type: hydrologic soil group (HSG) A Soils 5%, All Other Soils Types 10%
- The assumed average number of people per household using septic tanks: 2.7 people/household (United States Census Bureau 2010)
- Assumed 60 gallons per capita per day water use (Polk County Utilities Division 2014)
- Assumed average influent TN and TP entering septic tank: TN=40 mg/L, TP=10 mg/L
- Assumed average effluent TN and TP load leaving a failing septic tank: TN=40 mg/L, TP=10 mg/L
- Assumed vertical and horizontal soil attenuation rates of TN and TP: Combined TN vertical & horizontal transfer rate=0.1, combined TP vertical & horizontal transfer rate=0.1, TP horizontal transfer rate=0.1 (CDM 1992).

The number of active septic tanks within the study area was estimated based on the following data: permitted septic systems from the Florida Department of Health (FDOH). CHEC (2003) suggests a 5%-10% septic failure rate, an assumed 5% septic failure rate is applied to OSTDS within HSG A areas and a 10% septic failure rate is applied for all non-HSG type A soils. Septic failure rates may also be influenced by seasonal high-water levels (SHWL). Expected failure rates may be higher in areas where the septic tank location is near the SHWL.

Medium strength domestic sewage contains TN concentrations of 40 mg/L and TP concentrations of 10 mg/L (Metcalf and Eddy 1972). The vertical transfer rate accounts for uptake of pollutants in the soil and drain field prior to OSTDS discharge reaching the water table. The horizontal transfer rate accounts for further attenuation as the effluent moves laterally away from the site (CHNEP 2010).

Septic load estimates are broken into two main categories: loading to receiving groundwater from functioning septic systems and loading to receiving surface waterbodies from failed septic tanks. Per capita, water usage multiplied by average occupancy per household and TN/TP wastewater concentrations provides loading to the OSTDS. The total TN and TP load to the OSTDS are then multiplied by a (TN and TP) vertical and horizontal transfer rate to estimate the resultant effluent load to the underlying receiving groundwater.

Estimation of failed septic loads is calculated by multiplying failure rate by total loading to the OSTDS and the respective TN and TP delivery ratios. The delivery ratio estimates the quantity of TN and TP that reaches the receiving body. CHEC (2003) estimated the TN and TP delivery ratio to be 0.8 and 0.5, respectively. **Table 5-2** provides a summary of the annual estimated septic TN and TP loading for functioning and non-functioning septic tanks within the Carpenter Creek watershed. There is much uncertainty in estimating septic tank influences given the allowable level of effort in the project scope and therefore the loading estimates in this report should be considered an upper limit.

Table 5-2: Estimated Annual Septic Loading to Receiving Groundwater and Surface Water for Functioning and Non-Functioning OSTDS

Annual TN Load to Receiving GW Body (lbs)	Annual TP Load to Receiving GW Body (lbs)	Annual TN Load to Receiving SW Body (lbs)	Annual TP Load to Receiving SW Body (lbs)
854	213	683	107

Notes:
SW= Surface Water, GW= Groundwater
The assumed septic failure rate of 9.97% is based on soils for SW load estimation.
Septic Failure assumed TN and TP Delivery Ratio 0.8 and 0.5, respectively (CHEC 2003).

5.3.2. Reflects loading from all OSTDS within Carpenter Creek Watershed. Atmospheric Deposition

The combustion of fossil fuels, electric power generation, residential and agricultural fertilizer applications, and other agricultural activities can generate atmospheric-derived nutrient loads received by surface water bodies (Yates et al., 2011).

Wet atmospheric deposition of TN and TP directly to Carpenter Creek and Bayou Texar was calculated by multiplying the volume of precipitation onto the creek and bayou by TN and TP concentration in rainfall. Pensacola's 30-year normal annual rainfall total was used for this analysis (NWFWMD). The rainfall TN concentration is the sum of NH4 and NO_3 monthly rainfall-weighted average concentrations obtained from the National Atmospheric Deposition Program (NADP) FL96 Site in Pensacola, Florida. Monitoring data for this site were available for the years 2013-2016 and is assumed to be representative of typical concentrations. TP rainfall concentration was estimated using relationships (TP = 0.0126*TN + 0.0011) developed between wet TP and wet TN concentrations as measured during the Tampa Bay Atmospheric Deposition (TBAD) study (Janicki Environmental 2015). Dry deposition is estimated using a seasonal dry-to-wet deposition ratio derived from 5 years of concurrent wet and dry deposition measurements (Yates et al., 2011; Poor and others, 2001). **Table 5-3** summarizes annual TN and TP loading from an atmospheric deposition for the watershed surface area (Janicki Environmental 2015). Based on the estimated atmospheric deposition from 2013 to 2016 the average annual TN and TP atmospheric deposition to Carpenter Creek is 2,176 lbs TN/yr and 38 lbs TP/yr.

Table 5-3: Annual TN and TP Atmospheric Deposition Summary for Carpenter Creek/ Bayou Texar Surface Area

Year	Sum of Rainfall (in) [1]	Annual Total N Deposition (lb/yr)	Annual Total P Deposition (lb/yr)
2013	65.27	2025	36.5
2014	65.27	2217	38.9
2015	65.27	2351	40.6
2016	65.27	2112	37.6
Average (lbs)	**-**	**2176**	**38.4**

(1) Annual rainfall based on Northwest Florida Water Management District 30-year normal annual rainfall total for Pensacola

5.4. Summary of Surface Water Pollutant Loading

5.4.1. Comparison of Surface Water Loading

Table 5-4 and **Table 5-5** summarize the existing and future estimated TN and TP contribution from the previous report sections. Based on the summary tables, over 94% of the estimated TN and TP for both the existing and future conditions is expected to derive from stormwater runoff; therefore, identification of load reduction opportunities associated with stormwater runoff may provide a net TN and TP load reduction.

Table 5-4: Existing Condition Surface Water Pollutant Load Summary

Source	TN (lbs/yr)	TP (lbs/yr)
Existing Condition Stormwater Runoff – Standard BMP Efficiencies	51,105	7,616
Surface Water Loading Associated with Non- Functioning OSTDS	683	107
Atmospheric Deposition	2,176	38
Total	**53,964**	**7,761**

Table 5-5: Future Condition Surface Water Pollutant Load Summary

Source	TN (lbs/yr)	TP (lbs/yr)
Future Condition Stormwater Runoff - Standard BMP Efficiencies	52,663	7,864
Surface Water Loading Associated with Non- Functioning OSTDS	683	107
Atmospheric Deposition	2,176	38
Total	**55,522**	**8,009**

6.0 QUALITATIVE ASSESSMENT SUMMARY

A qualitative assessment for Bayou Texar took place on September 9, 2021, and included general qualitative observations of shoreline conditions, collection of several water quality parameters, and physical characterization of sediments within the Bayou.

The Qualitative Assessment Report completed by Wetland Sciences, attached in **Appendix D**, includes general observations of shoreline conditions throughout the Bayou and site photographs. Key observations include:

- The shoreline between the Cervantes Street bridge and the mouth of the Bayou is largely free from anthropogenic impacts, except for existing dock structures on the western shoreline.
- The shoreline between the Cervantes Street bridge and Gamarra Road is highly impacted by anthropogenic modifications, including vertical seawalls, vertical seawalls faced with rock, rock revetments, manicured lawns that terminate at the mean high water, and shorelines graded to resemble an open beach.
- From Gamarra Road north to the North 12th Avenue bridge, the shorelines are comprised largely of broad low littoral zones dominated by dense coverage of sawgrass (*Cladium jamaicense*).

Physical measurements of water quality parameters included temperature, dissolved oxygen, salinity, conductivity, pH, turbidity, and total dissolved solids.

Based on the characterization of sediments within the Bayou, a layer of fine-grained sediments is present across most of the Bayou. Fine-grain sediment deposits greater than 6-ft. in depth are present along the central portions of the Bayou from the 12th Ave bridge to Cervantes Street bridge. From the open waters of the Bayou to the shoreline, there was an obvious gradient of decreasing fine-grain sediment thickness except for the area between Gamarra Road and the 12th Ave bridge. Fine-grained organic sediments can be a significant nutrient load contributor from an internal cycling perspective where bioavailable dissolved nutrients can desorb and diffuse and/or resuspend from the sediments into the water column. Those nutrients are then available for algal production and growth. Reducing stormwater inflows into these areas and/or targeted removal are ways to reduce sediment accumulation in the Bayou.

Additional information from the field reconnaissance can be found in **Appendix D**.

Wood also conducted a detailed reconnaissance and stream assessment of Carpenter Creek as part of another task (**Task 3.3.1** – Stream Assessment Channel System Classification) where key stream geomorphic processes and current conditions in the stream were mapped and characterized. The information collected included biophysical data such as grade control, bank erosion, riparian zone quality and extent, vegetation in the channel, etc. Zones of concern were classified along the creek and recommendations were provided for improvement.

7.0 WATER QUALITY SYNTHESIS

Overall, the water quality assessment results indicate that TN, FIB, and DO are the major impairment concerns in the watershed. Since the assessment found no exceedances of TP or Chl-a impairment criteria in Carpenter Creek and very few in Bayou Texar, and the only significant trend identified for either parameter was decreasing TP in Carpenter Creek. The following discussion focuses on TN, FIB, and DO. Detailed statistical results for TP, Chl-a, and the other sampled parameters are available in **Appendix B2**.

For this section, boxplots were generated to visualize differences in TN, FIB, and DO between stations. Additionally, the non-parametric Kruskal-Wallis test (with Bonferroni adjustment) was used to determine if differences in the mean values between stations were statistically significant ($p<0.05$). Letters above boxes indicate statistical differences; boxes with different letters were statistically ($p<0.05$) different.

7.1. Total Nitrogen

On a WBID scale, the impairment assessment showed that TN concentrations frequently exceeded the applicable NNC during the 2010-2020 period of record. A box plot comparison of sampling location data in **Figure 7-1** and spatial comparison in **Figure 7-2**. indicates that TN concentrations in Carpenter Creek are highest in the southern portion of the WBID at the CC @ 9^{th} and CC @ Bayou monitoring locations.

Figure 7-1: TN Box Plots by Station, Carpenter Creek, 2010 - Present

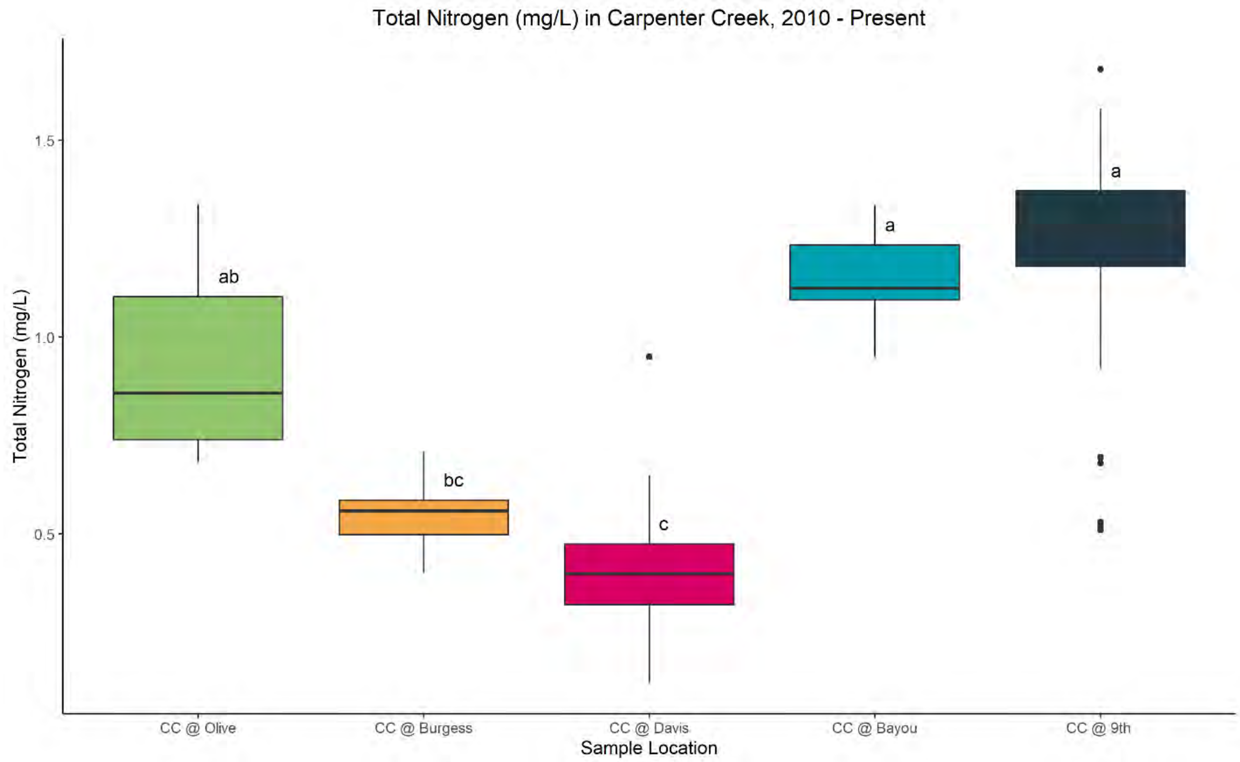
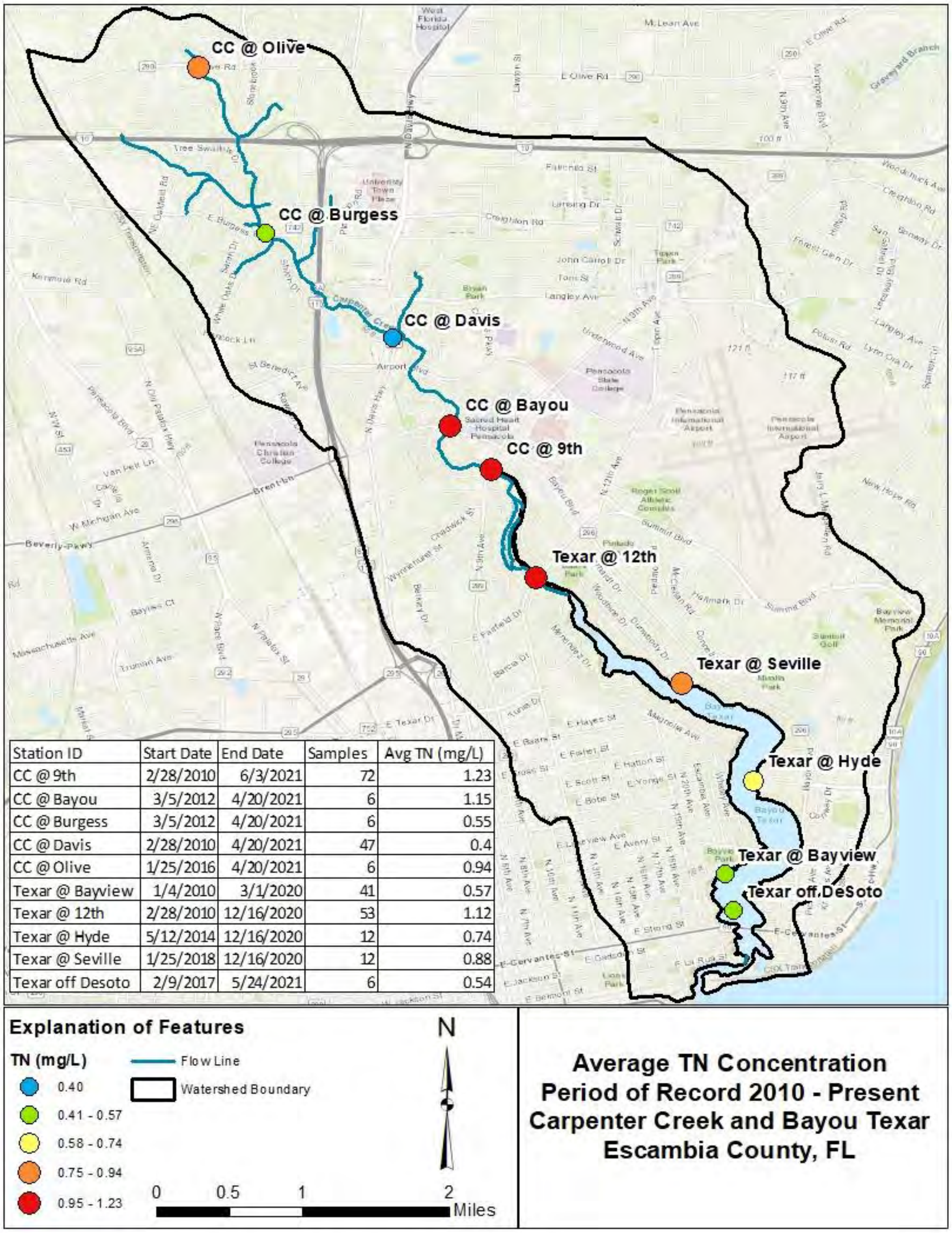


Figure 7-2: Average TN Concentrations, 2010 - Present



Station ID	Start Date	End Date	Samples	Avg TN (mg/L)
CC @ 9th	2/28/2010	6/3/2021	72	1.23
CC @ Bayou	3/5/2012	4/20/2021	6	1.15
CC @ Burgess	3/5/2012	4/20/2021	6	0.55
CC @ Davis	2/28/2010	4/20/2021	47	0.4
CC @ Olive	1/25/2016	4/20/2021	6	0.94
Texar @ Bayview	1/4/2010	3/1/2020	41	0.57
Texar @ 12th	2/28/2010	12/16/2020	53	1.12
Texar @ Hyde	5/12/2014	12/16/2020	12	0.74
Texar @ Seville	1/25/2018	12/16/2020	12	0.88
Texar off Desoto	2/9/2017	5/24/2021	6	0.54

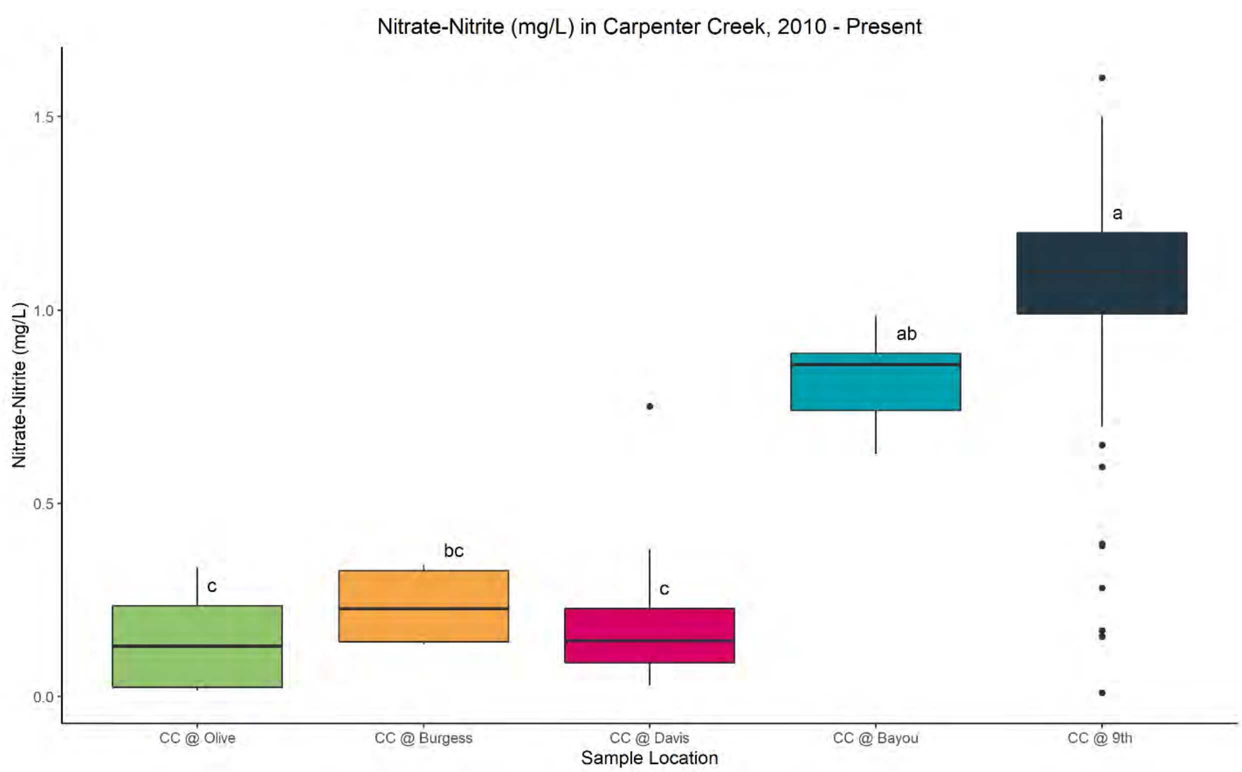
The PLA model results discussed in **Section 6** – Factors Potentially Affecting Water Quality, align with the findings of the water quality analysis. PLM estimates showed high levels of TN loading from the built-up area east of the CC @ 9th and CC @ Bayou sampling locations (bounded by Carpenter Creek on the west and Airport Blvd. and 12th Ave. on the east) and the residential area on the west bank of Carpenter Creek near 9th Ave (**Appendix D**). Along with the statistically significant increasing trend in TN concentrations at the CC @ 9th sampling location, these results suggest the area around 9th Ave. as a critical hot spot for TN in the Carpenter Creek WBID.

The correlation analysis results at the CC@ 9th sampling location indicate a negative relationship between TN and TSS and turbidity, and a box plot comparison of NOx sampling data (**Figure 7-3**) shows the highest NOx concentrations at the CC@ 9th and CC@ Bayou sampling locations, with a significant drop off upstream between the CC @ Bayou and CC @ Davis stations. Taken together, these results indicate that soluble (i.e., dissolved) forms of nitrogen are the predominant component of TN loading in the area of the watershed downstream of the CC @ Davis station. Potential sources of NOx loading between the CC@ Davis and CC @ Bayou stations should be further investigated.

Turfgrass fertilizers are a major source of soluble nitrogen, including nitrates. Heavily landscaped areas around the Ascension Sacred Heart hospital, Cordova Mall, and surrounding shopping centers in the area could be contributing factors. Manicured lawns and septic tanks in the residential neighborhoods along the west bank of Carpenter Creek near 9th Ave. could also be contributing factors. These subdivisions were developed before the statewide stormwater rule (F.A.C. Ch.17-25, 1982) was adopted and may therefore also lack adequate stormwater control measures.

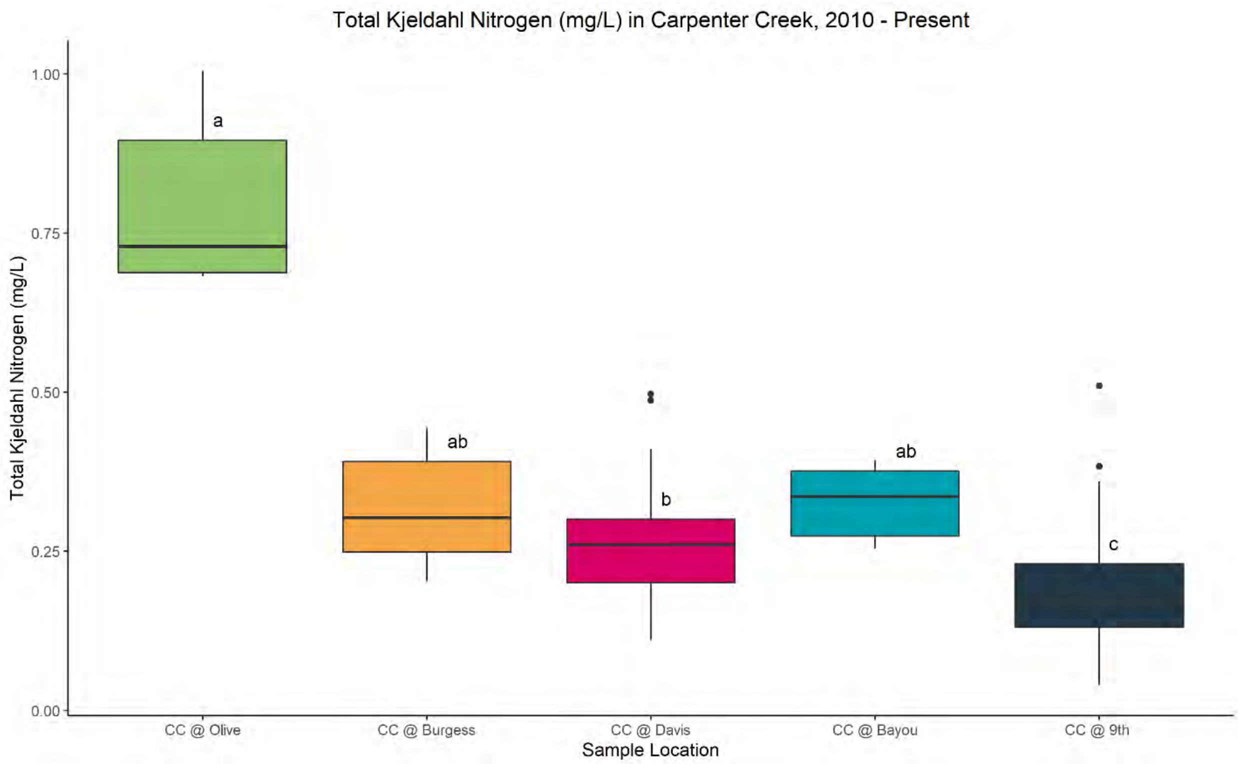
Additionally, the negative correlation between TN and 7-day antecedent precipitation on the WBID scale, taken together with the other factors discussed above, could be an indication of groundwater seepage as a potential source of nitrogen loading.

Figure 7-3: NOx Box Plots by Station, Carpenter Creek, 2010 - Present



Another potential hotspot for TN in the Carpenter Creek WBID includes the residential areas near the Olive Rd sampling location. A box plot comparison of TKN sampling data in Carpenter Creek (**Figure 7-4**) shows the opposite trend as NOx, with TKN concentrations highest at the CC @ Olive station and a significant decline downstream at the CC @ Burgess and other stations. Potential sources of TKN could include wetland soil/debris transport, fertilizers, pet waste, or failing septic tanks and sewage connections.

Figure 7-4: TKN Box Plots by Station, Carpenter Creek, 2010 - Present



To further explore the observed patterns of nitrogen loading, the nitrogen data were used to calculate Dissolved Inorganic Nitrogen (DIN) and Organic Nitrogen (ON), which were then used to calculate the ratio of DIN and ON to TN, This provides additional information as to the major components of nitrogen loading throughout the watershed that can be useful in identifying sources. DIN is calculated as:

$$DIN = NO_3 \text{ (nitrate)} + NO_2 \text{ (nitrite)} + NH_3 \text{ (ammonia)}$$

And ON is calculated as:

$$ON = TKN - NH_3$$

Box plot comparisons of DIN and ON data as a percent of TN at each station in Carpenter Creek is presented in **Figure 7-5** and **Figure 7-6**. DIN as a percent of TN follows a similar trend to NOx, as expected. DIN increases towards the downstream stations and is the major component of nitrogen loading near the CC @ Bayou and CC @ 9th stations. These results indicate that DIN is also the major overall component of nitrogen loading in the watershed since the highest TN concentrations were observed at the same stations. High DIN loading driven by NOx is likely driven by predominantly high-density commercial and residential land uses around this portion of the watershed. Nutrient source tracking (NST) can be utilized in this area to further investigate and identify DIN contributing sources.

ON follows an inverse trend similar to TKN, as expected, with the highest percentage of TN as ON observed at the CC @ Olive station and declining downstream. ON makes up a statistically significant lower portion of TN at the CC @ Bayou and CC @ 9th stations than the other three upstream stations. These results indicate that ON is the predominant component of nitrogen loading in the northern reaches of the watershed, but contributes less to overall loading than DIN.

Figure 7-5: DIN as a Percent of TN Box Plots by Station, Carpenter Creek, 2010 - Present

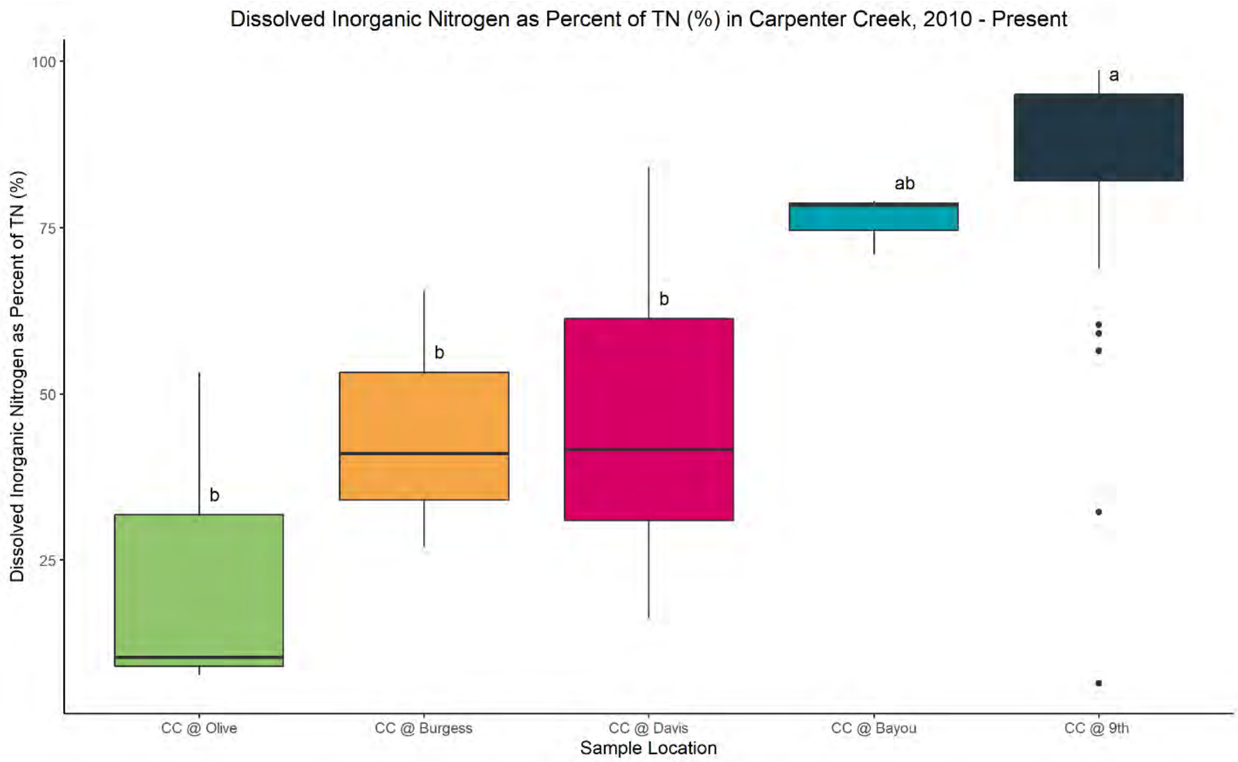
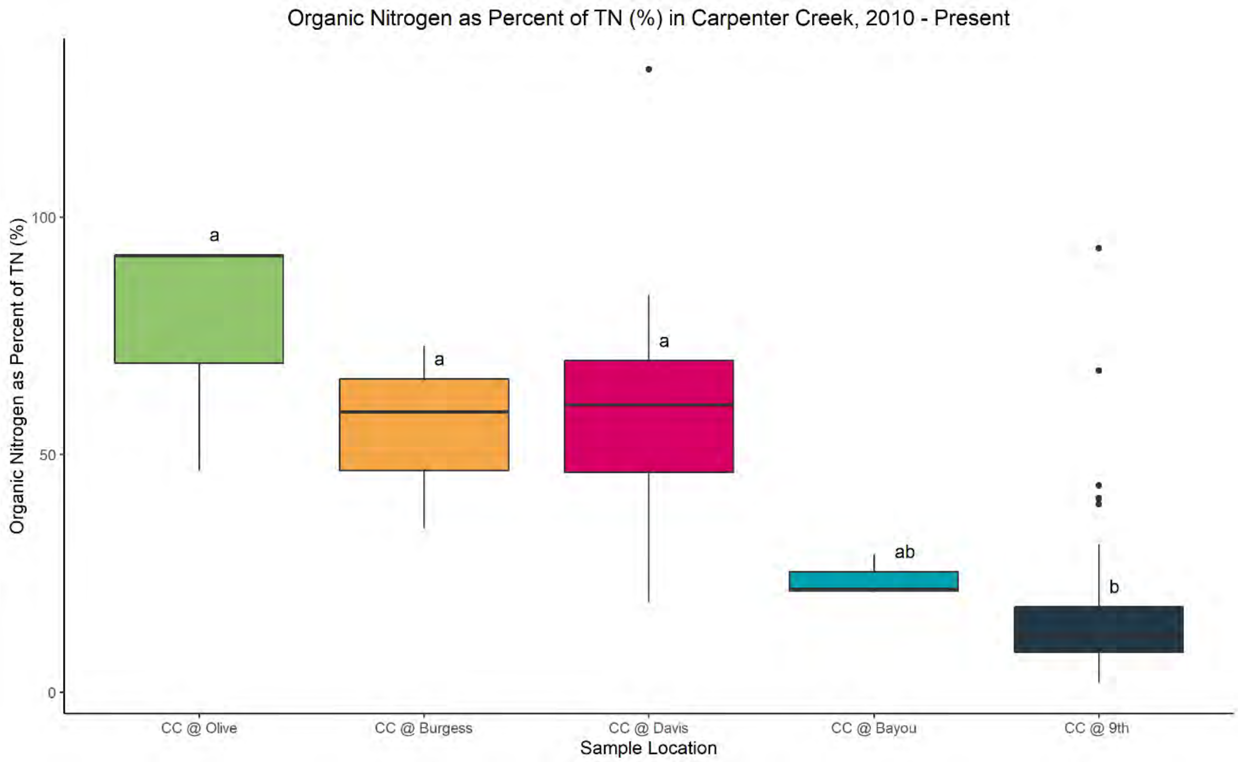


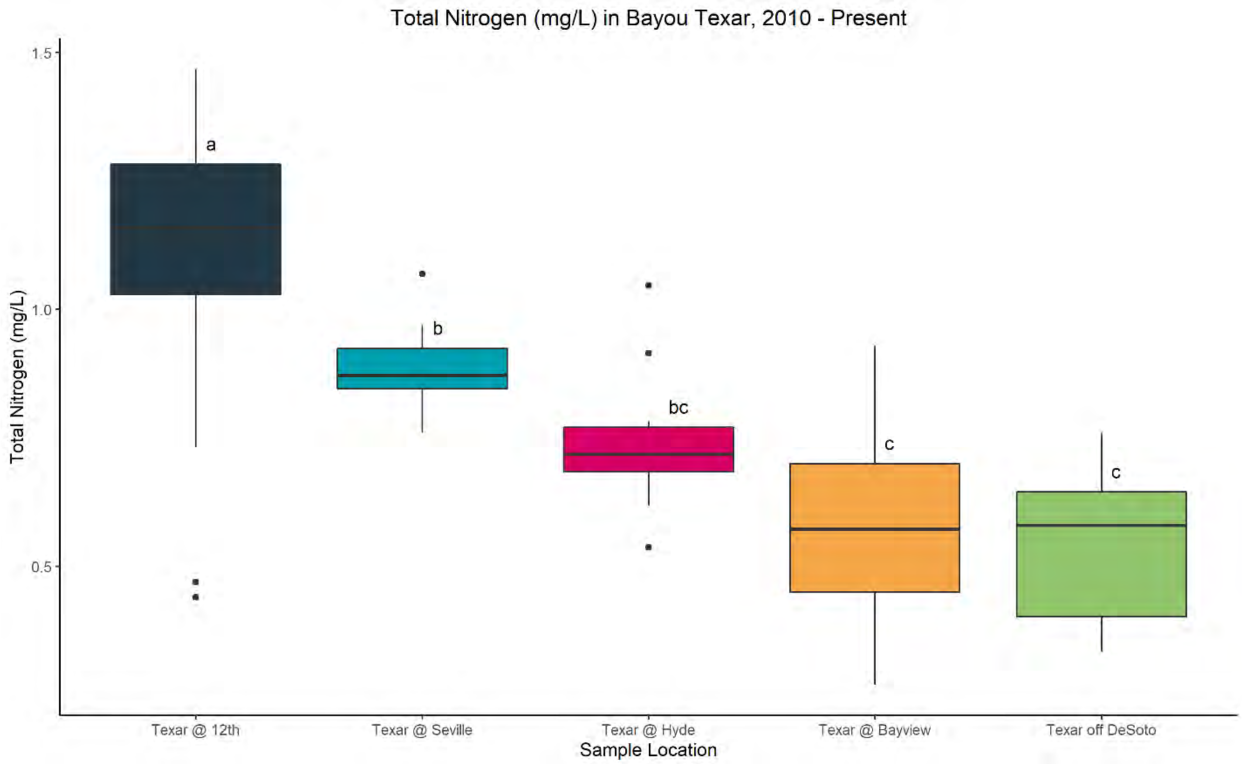
Figure 7-6: ON as a Percent of TN Box Plots by Station, Carpenter Creek, 2010 - Present



Other nitrogen hot spots in Carpenter Creek include the areas draining to Tributary 5 and Tributary 8 as indicated in the tributary sampling results in **Section 8.1.3, Figure 8-4**. Additional pollutant load analysis at the tributary drainage basin scale could provide further insight into the high nutrient concentrations observed at select tributary monitoring stations.

In Bayou Texar, over 50% of sampled TN concentrations exceeded the Upper Pensacola Bay NNC (0.77 mg/L) during the 2010-2020 period of record, with annual exceedances ranging from 29-75%. A box plot comparison of sampling location data in **Figure 7-7** and spatial comparison in **Figure 7-2** indicates that TN concentrations are highest in the northern portion of the Bayou at the Texar @ 12th monitoring location and gradually decline further south near Hyde Park and towards the mouth of the Bayou. This indicates that the Bayou has considerable nutrient attenuation capacity along the downstream longitudinal flow path, with approximately 50% reductions of TN along the flow path from Texar @ 12th to Texar off DeSoto.

Figure 7-7: TN Box Plots by Station, Bayou Texar, 2010 - Present



Although no statistically significant trends were identified for any of the individual sampling locations in Bayou Texar, the statistically significant decreasing trend for NOx at the WBID scale may be an indication of increased stormwater discharge from the contributing basin relative to discharges from Carpenter Creek. The basis for this inference is that rainfall-driven stormwater inflows are typically dominated by particulate nitrogen, and NOx or soluble nitrogen may indicate groundwater contribution. Therefore, the decline in nitrate may indicate a change in overall groundwater contributed nitrogen from the watershed and/or Carpenter Creek. However, the correlation analysis results indicated a statistically significant negative relationship between TN and TSS, suggesting that soluble forms of nitrogen as the predominant component of TN loading to Bayou Texar, which is likely being delivered from Carpenter Creek. Box plot comparisons of sampling location data for NOx and TKN (**Figure 7-8** and **Figure 7-9**) show the highest NOx and lowest TKN concentrations at the Texar @ 12th sampling location, whereas NOx gradually declines further south through the Bayou likely due to denitrification, and TKN is highest near the Texar @ Seville and Texar @ Hyde sampling locations, which could indicate stormwater contributions carrying particulate matter and nitrogen.

Figure 7-8: NOx Box Plots by Station, Bayou Texar, 2010 - Present

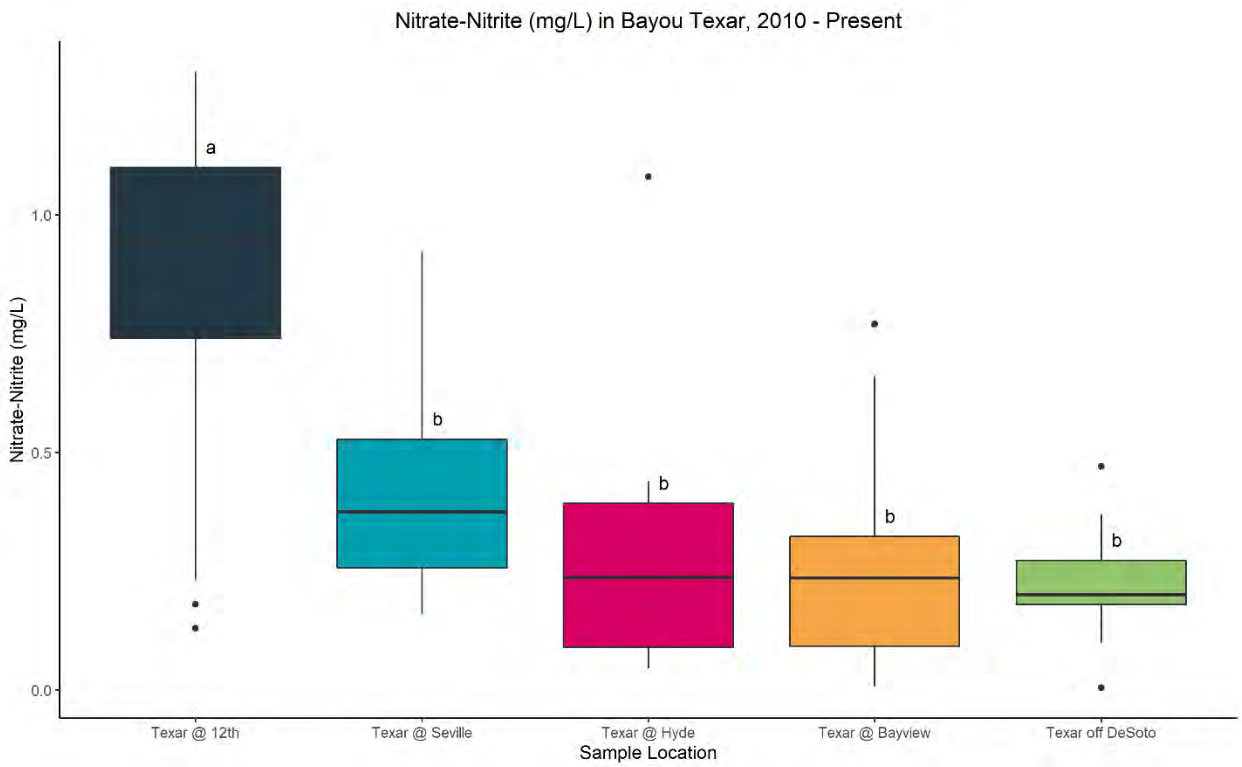
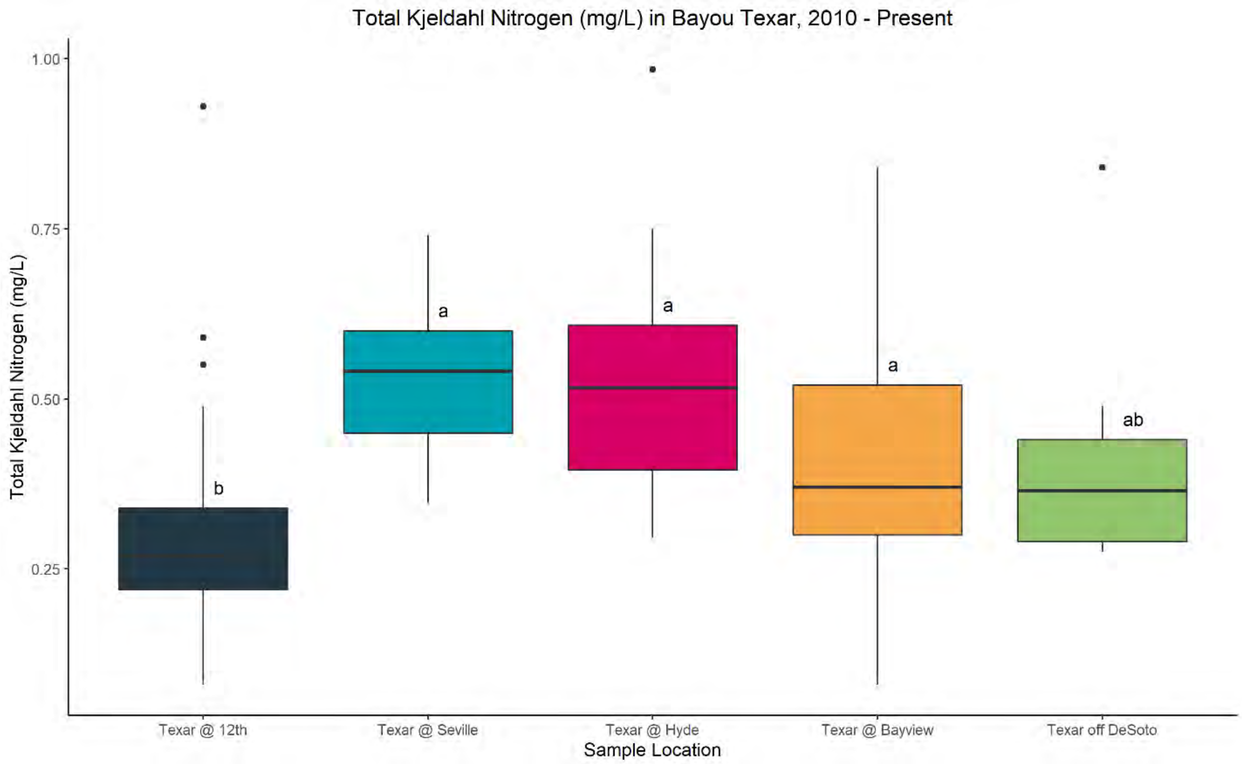


Figure 7-9: TKN Sample Box Plots by Station, Bayou Texar, 2010 - Present



The area draining directly to Bayou Texar consists mostly of residential subdivisions of single-family homes and recreation areas such as parks, sports fields, and marinas. The PLA model results showed mostly uniform TN loading throughout the WBID, with several hot spots located at recreational areas and the Bayview Cemetery. The field reconnaissance also identified many anthropogenic modifications of the shoreline along the middle portion of the Bayou, including well-manicured lawns, vertical seawalls, and graded beaches. Fertilizer use and animal waste should be considered as likely contributing sources of nitrogen to the Bayou. Remedies could include modifications to fertilizer ordinances, education regarding fertilizer use, and living shorelines to reduce nutrient loading into the Bayou.

Box plot comparisons of DIN and ON data as a percent of TN at each station in Bayou Texar is presented in **Figure 7-10** and **Figure 7-11**. Similar to NOx, DIN as a percentage of TN is highest at the Texar @ 12th station and declines towards the mouth of the bayou. This station is located near the high-density commercial and residential area near where Carpenter Creek flows into the bayou and is subject to the same potential urban sources driving higher DIN loads. The highest TN loads to the bayou appear to be driven by DIN in the northern portions of the watershed.

ON as a percentage of TN follows an inverse trend similar to TKN; it is lowest at the Texar @ 12th station and increases towards the mouth of the bayou. The areas of the watershed that drain to the middle and lower portions of the bayou are similar to those surrounding the CC @ Olive station in Carpenter Creek: single-family residential and recreational land uses. It is interesting to note that nitrogen loading from both areas is predominantly ON. Also, tidal activity may be another factor to consider, since it may influence processes such as nitrification and denitrification and can impact the dominant species of nitrogen that are present. The influence of tidal dilution on observed nutrient concentrations was not considered as part of this analysis. A future sampling at these stations on outgoing tide would ensure water quality samples collected are representative of watershed loading conditions with minimal tidal influence.

Figure 7-10: DIN as a Percent of TN Box Plots by Station, Bayou Texar, 2010 - Present

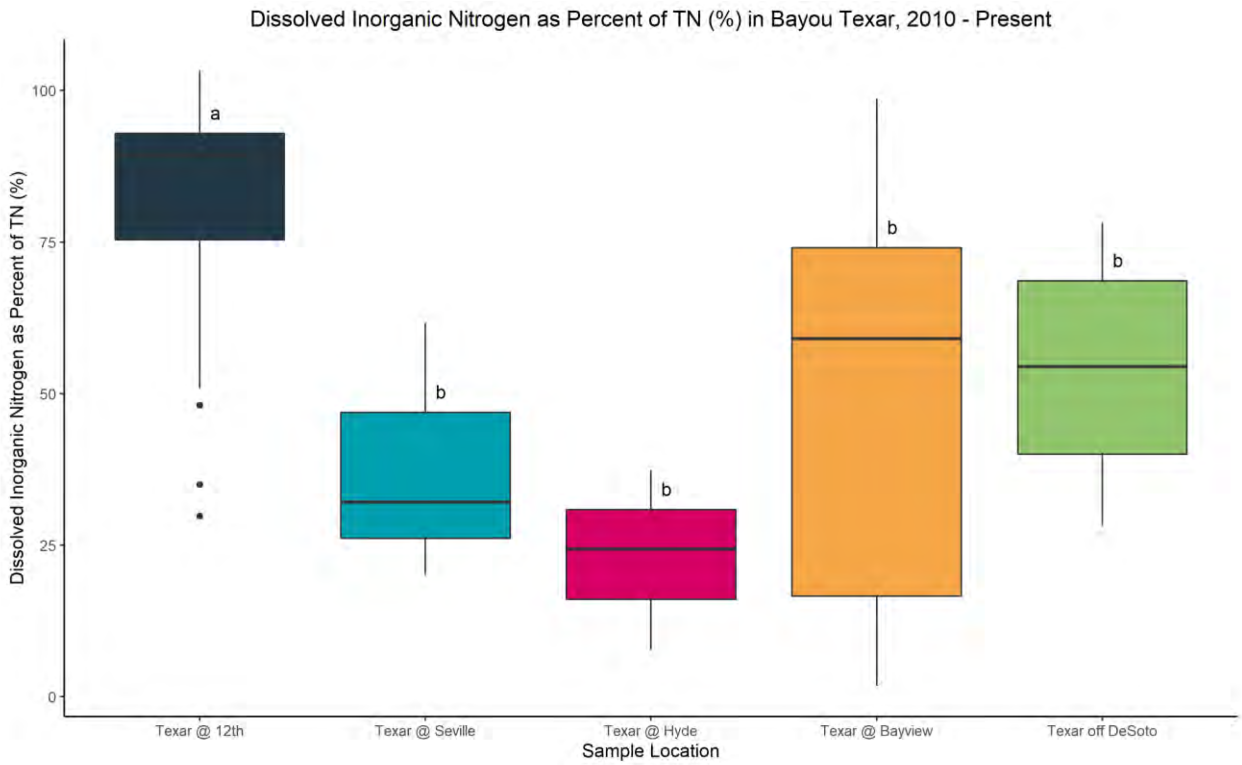
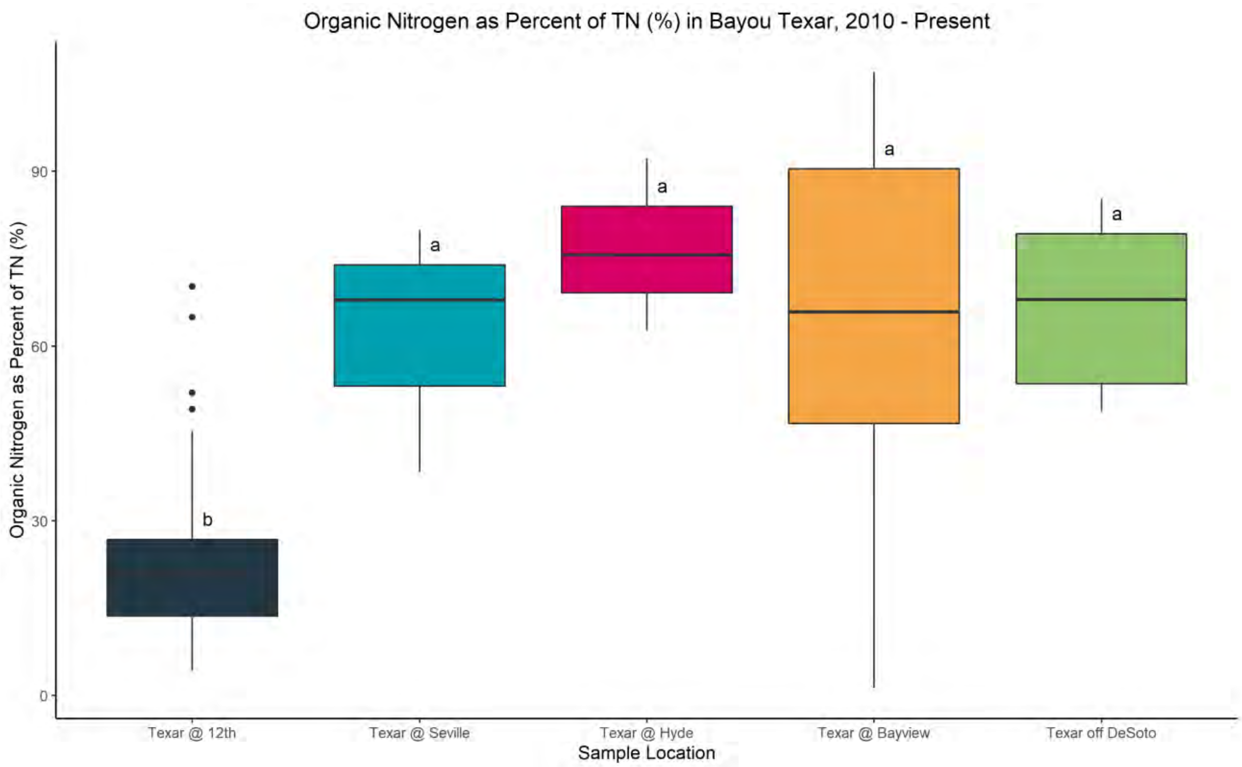


Figure 7-11: ON as a Percent of TN Box Plots by Station, Bayou Texar, 2010 - Present



7.2. Fecal Indicator Bacteria

The impairment assessment for *E. coli* in Carpenter Creek demonstrated exceedances every year with available data during the 2014-2020 period of record. A box plot comparison of sampling location data in **Figure 7-12** and spatial comparison in **Figure 7-13** indicate that *E. coli* counts have been highest at the CC @ Davis sampling location and generally higher in the downstream portion of Carpenter Creek. There is a statistically significant jump in E. coli counts between the CC@ Burgess and CC @ Davis stations, which indicates a likely localized source in the area that drains downstream of Burgess and upstream of Davis. Microbial source tracking (MST) could be implemented in this location to further investigate and identify potential sources. The correlation analysis showed a positive relationship between *E. coli* and turbidity, 7-day antecedent precipitation, and temperature, which indicates a link between *E. coli* and sediment transport and suggests stormwater discharge as a contributing factor to elevated *E. coli* counts. The Carpenter Creek watershed has a moderately high population and is comprised of mostly developed lands, both of which positively correlate with fecal coliform counts in water bodies (Mallin et al., 2001). Additionally, a strong relationship, (r = 0.73) was found between fecal coliform and *E. coli* counts in Carpenter Creek (**Appendix B2, Figure B2.3**), which suggests that prior fecal coliform sampling data could feasibly be used together with the *E. coli* data to enhance future statistical analyses of FIB in Carpenter Creek.

Figure 7-12: *E. Coli* Box Plots by Station, Carpenter Creek, 2014 - Present

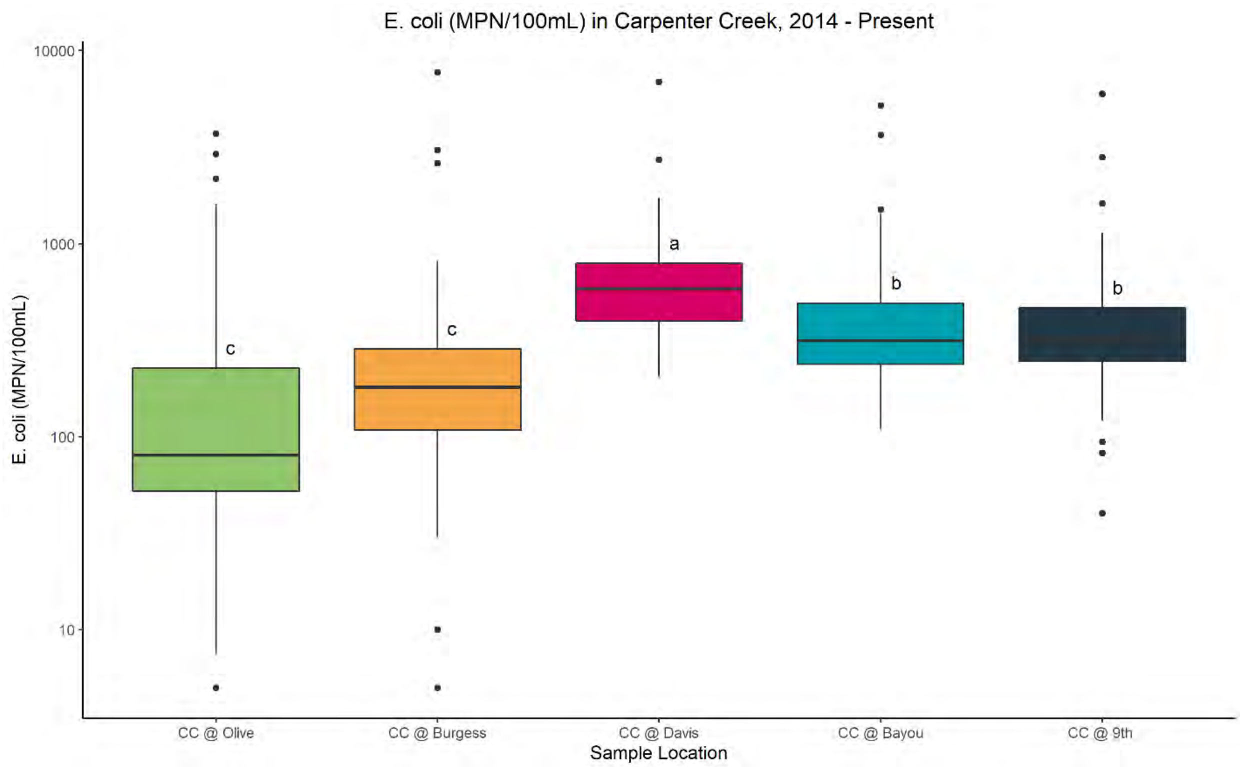
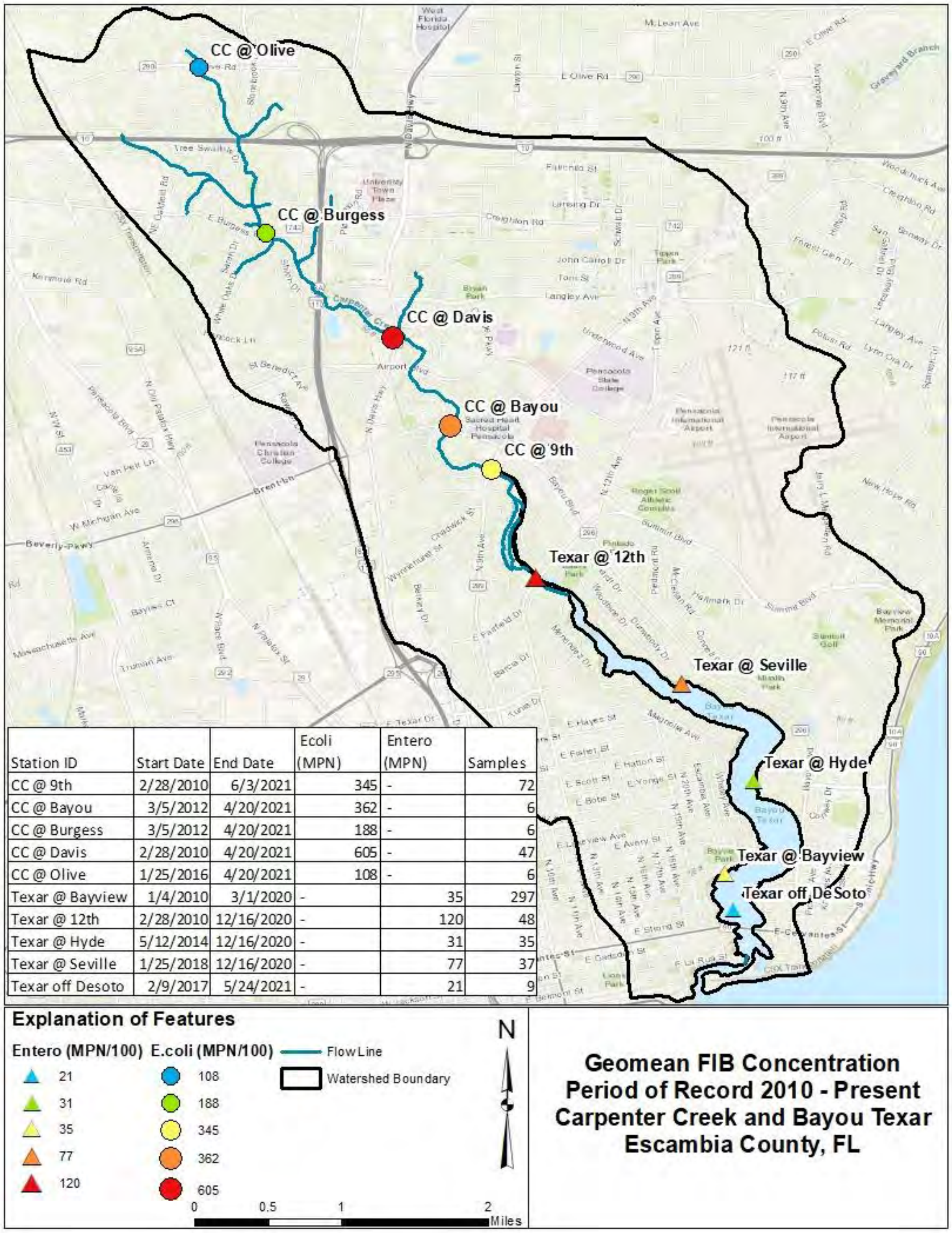


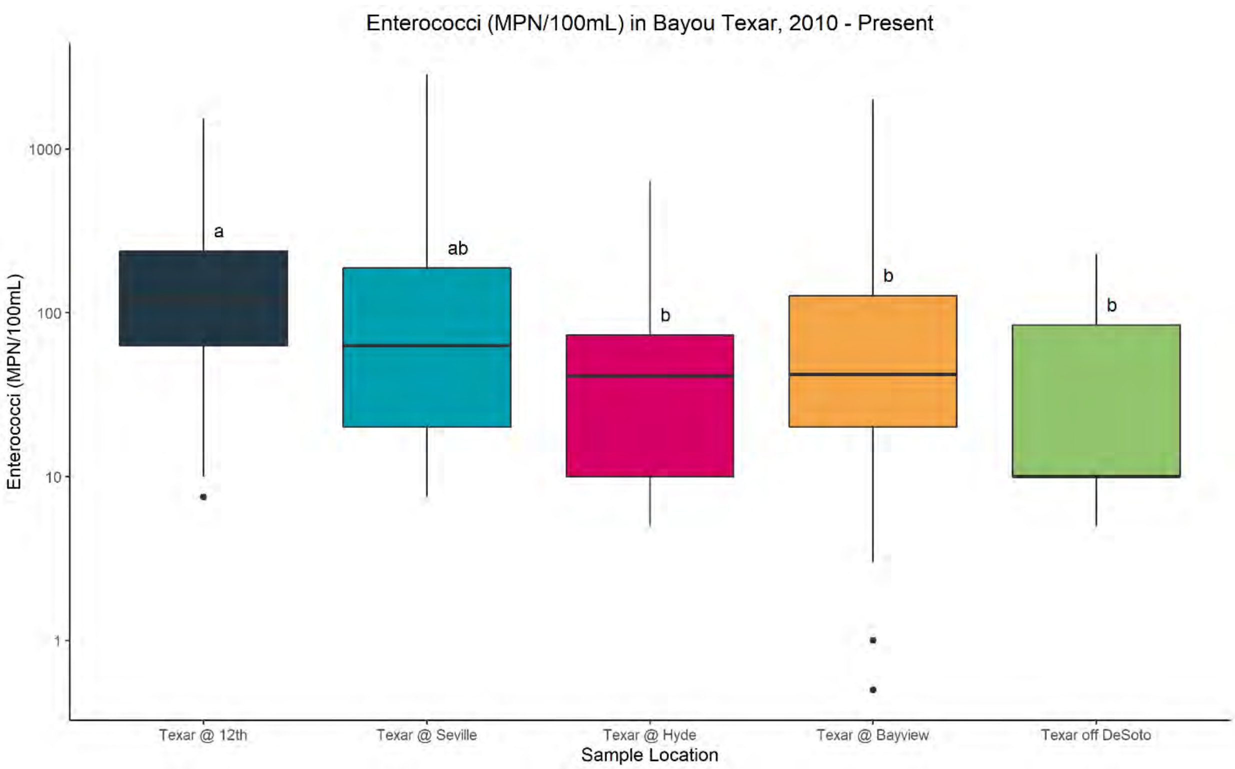
Figure 7-13: Geomean Fecal Indicator Bacteria Concentrations, 2010 - Present



Station ID	Start Date	End Date	Ecoli (MPN)	Entero (MPN)	Samples
CC @ 9th	2/28/2010	6/3/2021	345	-	72
CC @ Bayou	3/5/2012	4/20/2021	362	-	6
CC @ Burgess	3/5/2012	4/20/2021	188	-	6
CC @ Davis	2/28/2010	4/20/2021	605	-	47
CC @ Olive	1/25/2016	4/20/2021	108	-	6
Texar @ Bayview	1/4/2010	3/1/2020	-	35	297
Texar @ 12th	2/28/2010	12/16/2020	-	120	48
Texar @ Hyde	5/12/2014	12/16/2020	-	31	35
Texar @ Seville	1/25/2018	12/16/2020	-	77	37
Texar off Desoto	2/9/2017	5/24/2021	-	21	9

In Bayou Texar, the impairment assessment for *Enterococci* demonstrated annual exceedances of the impairment criterion ranging from 13% to 39% of samples. A box plot comparison of sampling location data in **Figure 7-14** and spatial comparison in **Figure 7-13** show *Enterococci* counts have been highest at the Texar @ 12th and Texar @ Seville stations, with counts, generally decreasing further south towards the mouth of the Bayou. The correlation analysis showed a positive relationship between *Enterococci* and turbidity and 7-day antecedent precipitation at most sampling sites throughout the Bayou, which indicates the possible presence of *Enterococci* in channel sediments and/or contributed via stormwater flows. The field reconnaissance also indicated greater anthropogenic modification of the shoreline in the middle and upper portions of the Bayou where *Enterococci* counts were higher. Dredging related to dock construction, graded beach shorelines, and other modifications may have increased the long-term vulnerability of sediments to erosion and tidal activity, and may also promote conditions ideal for the establishment of *Enterococci* colonies within sediments. Urban stormwater from local parks and residential areas that drain to Texar Bayou is also a likely contributing factor and remedies could include enhanced bioswales along with the extent of the shoreline that intercepts and treats stormwater runoff prior to discharge into the Bayou.

Figure 7-14: *Enterococci* Box Plots by Station, Bayou Texar, 2010 - Present



7.3. Dissolved Oxygen

Trend analyses on a WBID scale indicated statistically significant decreasing trends for DO in both Carpenter Creek and Bayou Texar over the 2010-2020 period of record. Current DO concentrations and trends in Carpenter Creek also meet the exceedance criteria to be included on the IWR 4d planning list. A box plot comparison of sampling location data for Carpenter Creek in **Figure 7-15** and spatial comparison in **Figure 7-16** show that DO is lowest in the upstream reaches at the Olive Rd sampling location, and gradually increases further south in a downstream direction. Differences in DO concentrations are statistically significant between the CC @ Olive and CC @ Davis stations as they steadily increase. The spatial distribution for DO follows a similar overall pattern southward through Carpenter Creek as TN; however, Chl-a concentrations follow the opposite trend and are the highest north at the Olive Rd sampling location.

One possible explanation of the lower DO concentrations at Olive Rd is that the area is the headwaters of the creek, is impounded, and has created an established wetland feature that may be influencing a reduction in DO concentrations under certain conditions such as low flow and stagnant pooling. Wetlands naturally have lower DO due to biogeochemical processing of carbon and reduction of oxygen during the processing cycle. Therefore, the mechanism causing lower DO at Olive Rd may be a natural artifact and not entirely driven by anthropogenic inputs. Therefore, it is recommended that the County challenge a TMDL based on natural conditions. Anthropogenic inputs and reductions in flow and/or other stressors in downstream reaches could be factors in DO dynamics and should be further evaluated if regulatory action is required.

Figure 7-15: DO Box Plots by Station, Carpenter Creek, 2010 - Present

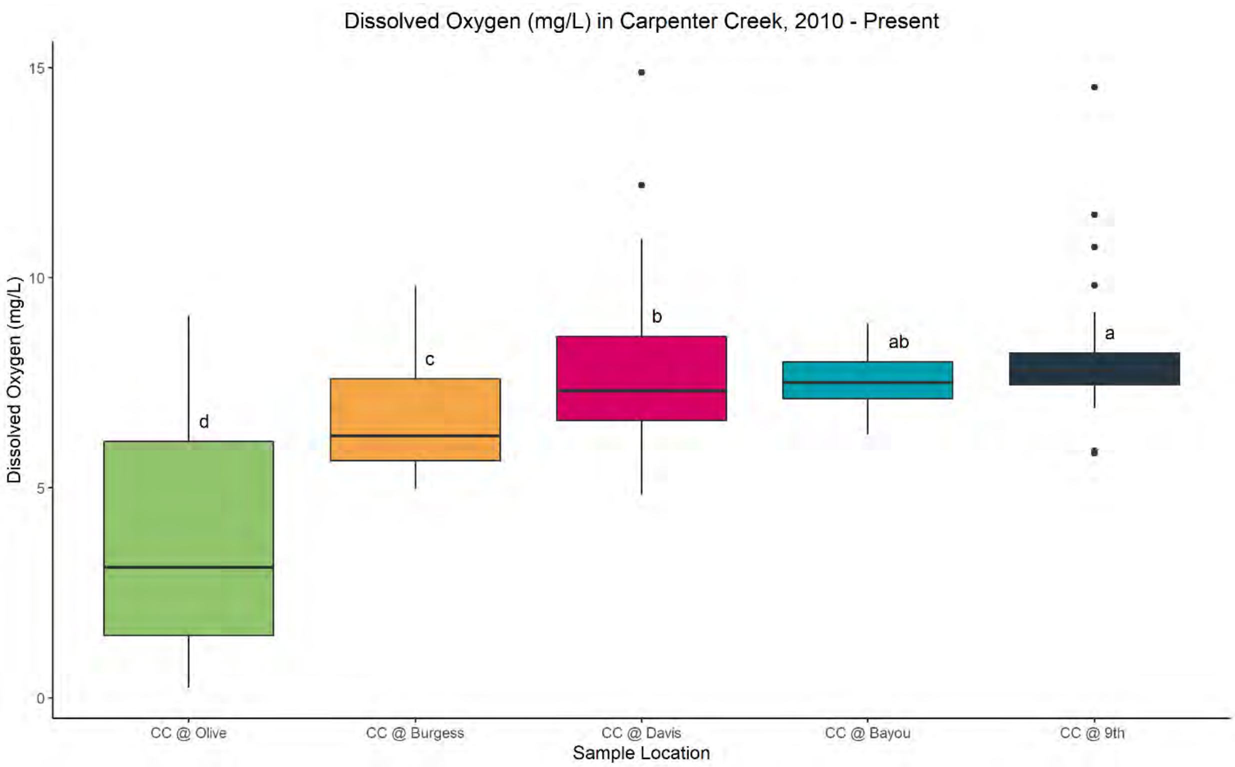
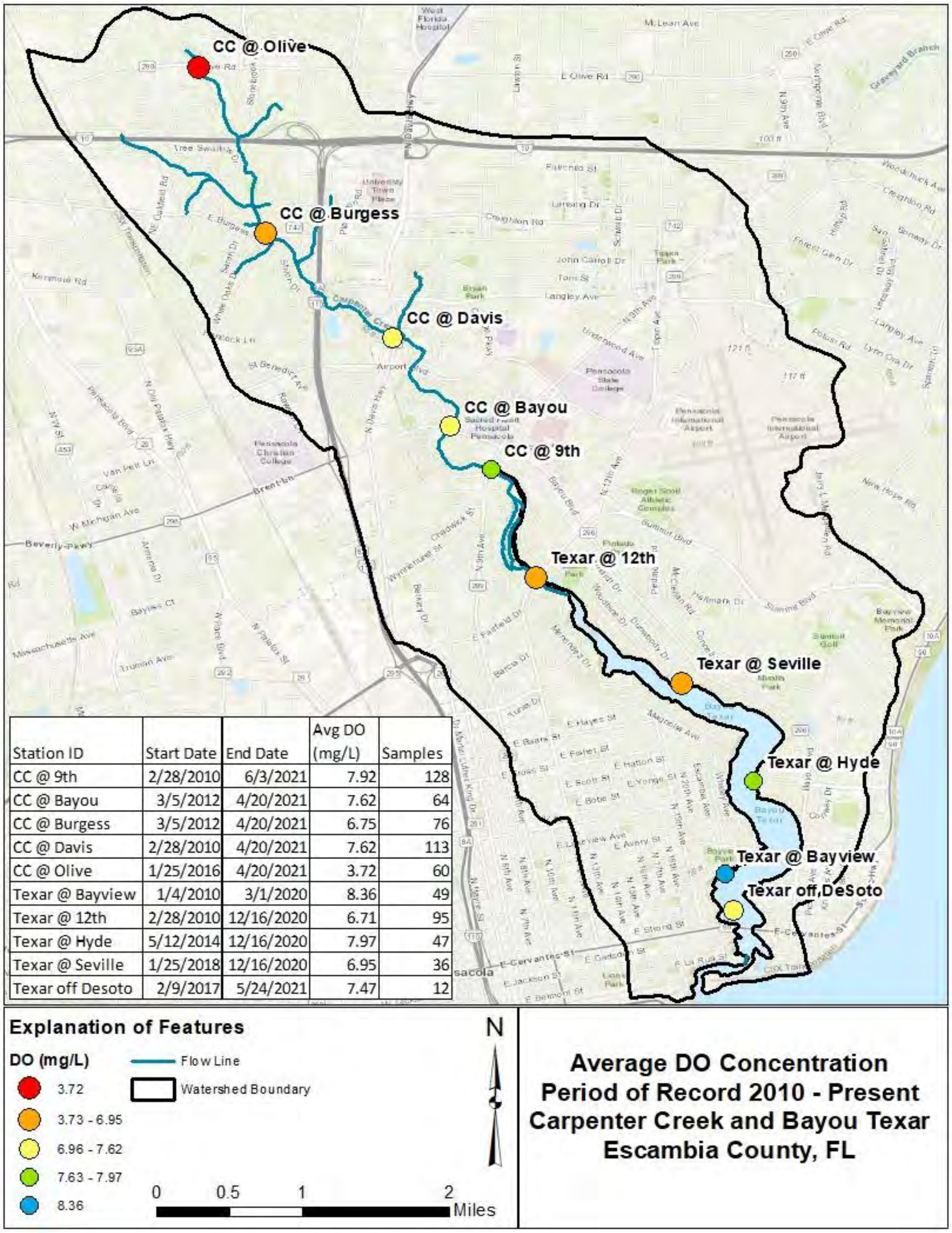


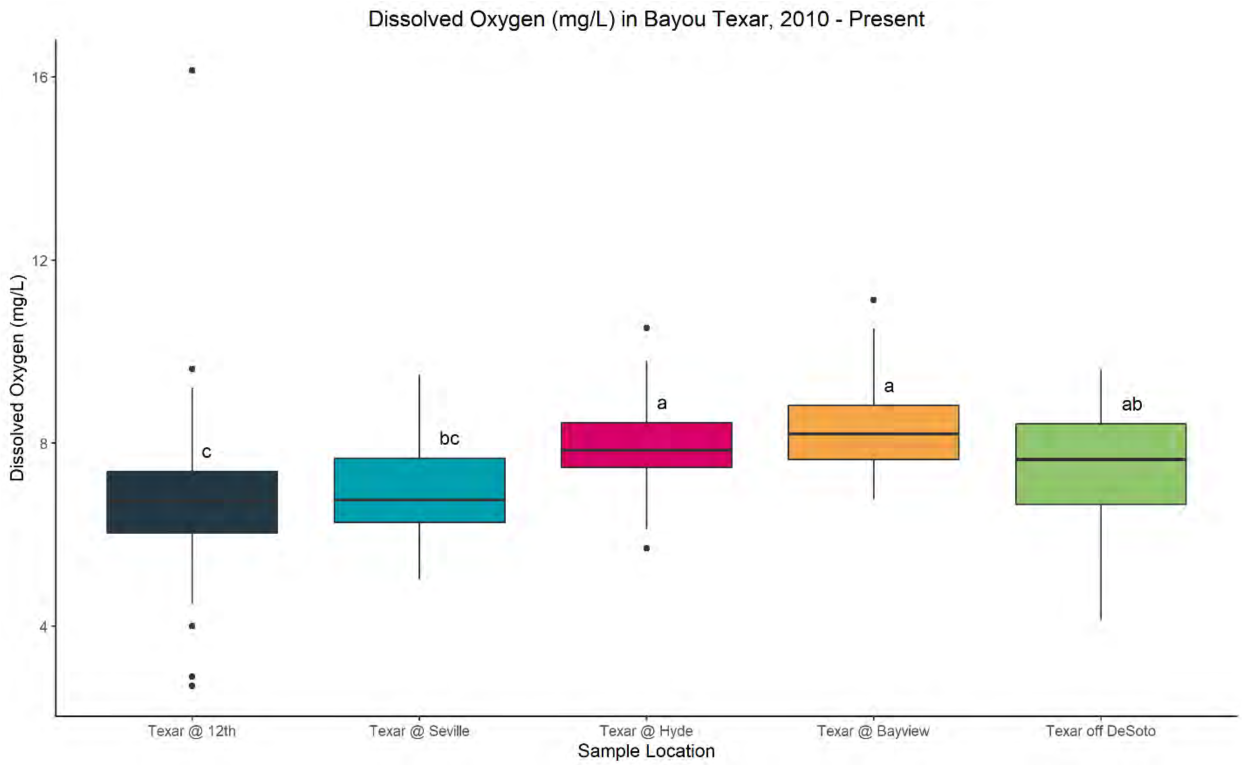
Figure 7-16: Average DO Concentrations, 2010 - Present



Station ID	Start Date	End Date	Avg DO (mg/L)	Samples
CC @ 9th	2/28/2010	6/3/2021	7.92	128
CC @ Bayou	3/5/2012	4/20/2021	7.62	64
CC @ Burgess	3/5/2012	4/20/2021	6.75	76
CC @ Davis	2/28/2010	4/20/2021	7.62	113
CC @ Olive	1/25/2016	4/20/2021	3.72	60
Texar @ Bayview	1/4/2010	3/1/2020	8.36	49
Texar @ 12th	2/28/2010	12/16/2020	6.71	95
Texar @ Hyde	5/12/2014	12/16/2020	7.97	47
Texar @ Seville	1/25/2018	12/16/2020	6.95	36
Texar off Desoto	2/9/2017	5/24/2021	7.47	12

The box plot comparison of sampling location data for Bayou Texar in **Figure 7-17** and spatial comparison in **Figure 7-16** show DO concentrations are lowest at the Texar @ 12th and Texar @ Seville sampling locations, and generally increase further south towards the mouth of the Bayou. The spatial distribution for DO concentrations is inverse to the distribution of TN concentrations, which suggests that TN loading may be a factor influencing eutrophication and declining DO in Bayou Texar. This aligns with the observation of soluble nitrogen as a component of TN loading to the Bayou, as soluble nitrogen is more bioavailable.

Figure 7-17: DO Box Plots by Station, Bayou Texar, 2010 - Present



The SWRA results suggest that restoration efforts in the watershed should focus on addressing ongoing and potential impairments of TN, FIB, and DO. Restoration efforts should be tailored to identify and address the hydrological and pollutant loading dynamics specific to each WBID, and are further discussed in **Section 9** – Summary and Recommendations.

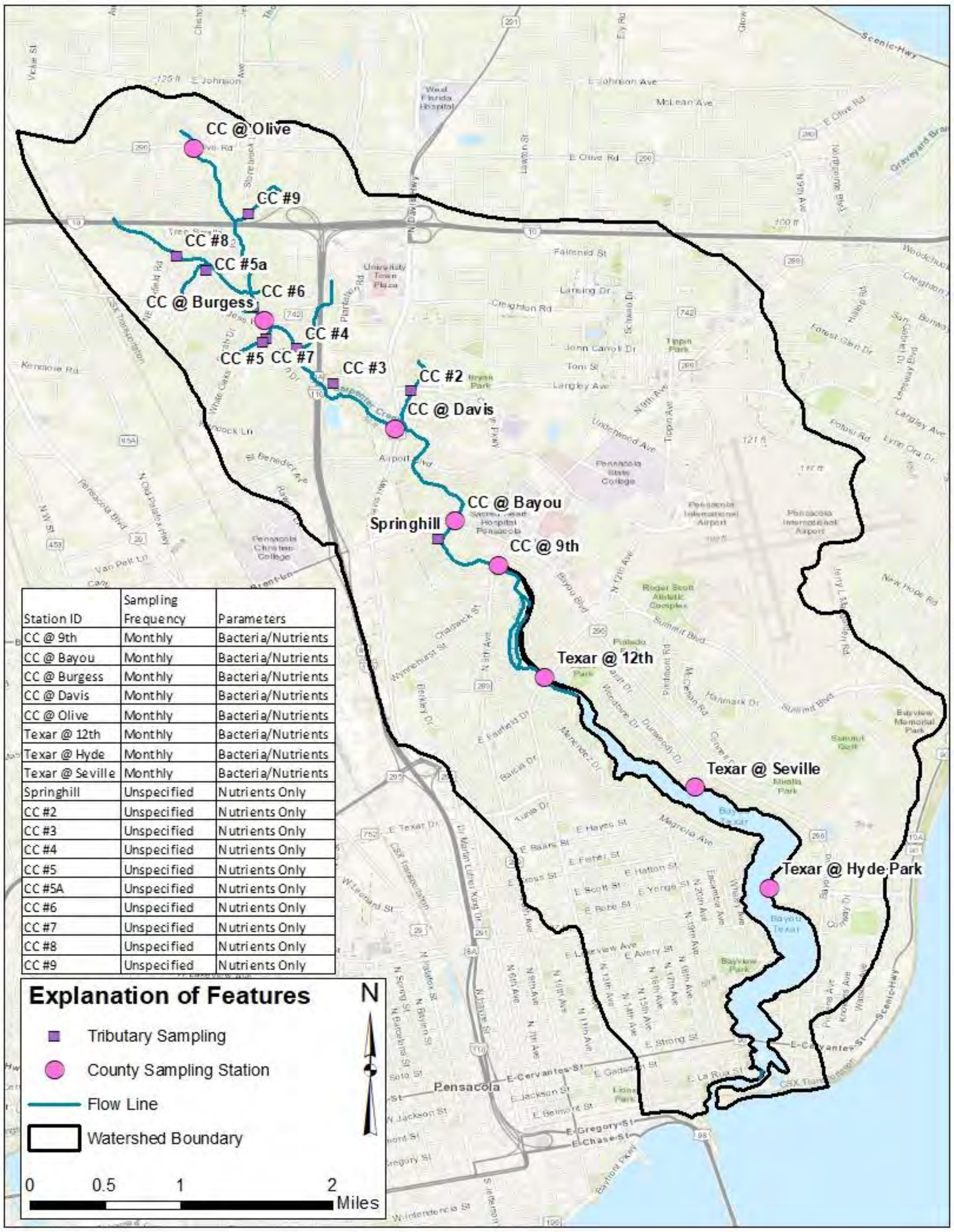
8.0 MONITORING PROGRAM REVIEW

The following sections will discuss Wood's review of the County's existing monitoring program, results from a data gap analysis, and a geospatial analysis that evaluated potential pollutant sources.

8.1. Existing Monitoring Efforts

County efforts for routine water quality monitoring in the Carpenter Creek and Bayou Texar WBIDs began in January of 2016. In March of 2020, Wood provided the County with general recommendations for adjusting sampling frequency and analytes. In June of 2020, Escambia County began collecting additional surface water quality parameters under their existing monitoring program, on a monthly frequency**. Table 8-1** provides the complete list of parameters sampled at a monthly frequency. The County currently collects monthly samples from five stations within the Carpenter Creek WBID and three stations within the Bayou Texar WBID (**Figure 8-1**)**.** In March of 2021, based on Wood's recommendations, the County picked up nine additional nutrient monitoring stations within the Carpenter Creek tributaries (**Figure 8-1**). Five of the tributary stations were sampled in March of 2021, and the remaining four were sampled in April of 2021. The following parameters were collected at these stations: Chl-a, NOx, TKN, TN, TP, and TSS.

Figure 8-1: Existing stations within the Escambia County water quality monitoring network



Station ID	Sampling Frequency	Parameters
CC @ 9th	Monthly	Bacteria/Nutrients
CC @ Bayou	Monthly	Bacteria/Nutrients
CC @ Burgess	Monthly	Bacteria/Nutrients
CC @ Davis	Monthly	Bacteria/Nutrients
CC @ Olive	Monthly	Bacteria/Nutrients
Texar @ 12th	Monthly	Bacteria/Nutrients
Texar @ Hyde	Monthly	Bacteria/Nutrients
Texar @ Seville	Monthly	Bacteria/Nutrients
Springhill	Unspecified	Nutrients Only
CC #2	Unspecified	Nutrients Only
CC #3	Unspecified	Nutrients Only
CC #4	Unspecified	Nutrients Only
CC #5	Unspecified	Nutrients Only
CC #5A	Unspecified	Nutrients Only
CC #6	Unspecified	Nutrients Only
CC #7	Unspecified	Nutrients Only
CC #8	Unspecified	Nutrients Only
CC #9	Unspecified	Nutrients Only

Table 8-1: Surface water quality parameters sampled at mainstem County stations

Parameter
Fecal indicators (*Enterococci* and *E. coli*)
Chlorophyll-a
Chloride
Calcium
Magnesium
Bromide
Alkalinity
Ammonia (N)
Nitrate+Nitrite (N)
Total Kjeldahl Nitrogen
Total Nitrogen*
Orthophosphate
Total Phosphorus
Total Organic Carbon
Sulfate
True Color
Total Suspended Solids

Note: **Bolded** values represent additional parameters added to the sampling program starting in June of 2020.

8.2. Data Gap Analysis

Wood provided preliminary monitoring recommendations in a Technical Memorandum titled "Monitoring Program Options for Carpenter Creek and Bayou Texar" (May 13, 2020), which were revisited based upon new data. Wood reviewed existing and newly collected water quality data to identify any additional monitoring gaps (geospatial, temporal, or additional water quality parameters). The sampling frequency and availability of concurrent data across water quality parameters were examined on multiple temporal and spatial scales to assess mentoring gaps at individual stations and within each waterbody. Complete POR plots for individual stations and each WBID can be found in **Appendix B2**. The monitoring program review informs recommendations for enhancing or reprioritizing the existing monitoring program. Future monitoring recommendations will be a reprioritization with the mindset of source tracking.

Groundwater stations were previously assessed by Wood in 2020 to investigate if certain areas are influenced by potential groundwater contamination upgradient of Carpenter Creek and Bayou Texar. No additional groundwater data were found since the previous assessment. Therefore, it is recommended that groundwater monitoring be implemented in areas with high vulnerability.

The County began sampling existing surface water monitoring stations at a monthly frequency, however, the water quality parameters sampled across sampling events were inconsistent. It should be noted that all data gaps previously identified in the 2020 preliminary gap analysis still stand, however, no additional data gaps were identified during the current monitoring program review.

8.3. Geospatial Source Assessment

The geospatial assessment further investigated monitoring locations for land use, hydrological features, and the locations of potential pollutant sources. There are several potential sources of pollution in Carpenter Creek and Bayou Texar watersheds (for both surface water and groundwater resources) that impact water quality and drive impairments in these waterbodies. Sources include urban development such as stormwater runoff (fertilizer runoff from residential land use, golf courses, and or other sports fields), wastewater (both from facility discharge/sewer and septic systems), etc. **Figure 8-2** shows the distribution of potential sources within the watershed.

Information on when surrounding communities were developed was also reviewed. The statewide stormwater rule (F.A.C. Ch.17-25, 1982) was adopted in 1981 and went into effect the following year; requiring communities that were developed from 1982 onward to implement stormwater BMPs. Most of the single-family residential neighborhoods in the watershed were developed before state or municipal stormwater treatment and/or attenuation requirements were established. There are also numerous stormwater ponds in both Carpenter Creek and Bayou Texar that discharge from outfalls into the respective water bodies. Areas with high potential nutrient loads associated with runoff, identified during the Pollutant Load Analysis, were reviewed as part of this assessment (**Figures A.2 and A.3**, **Appendix A).**

The main groundwater resource underlying Carpenter Creek (and its tributaries) and Bayou Texar in the Sand and Gravel Aquifer, which along with the high presence of Type A soils creates a condition that promotes connectivity of the land surface to groundwater and to surface waters in the region. Aquifer vulnerability was reviewed relative to existing monitoring locations and potential sources of groundwater seepage such as stormwater ponds and septic tanks (**Figure 8-3**). The potentiometric groundwater-surface for the watershed was previously reviewed as part of the Watershed Evaluation Report prepared by Wood (2020). Groundwater tends to travel from the northwest corner of the watershed to the southeast corner, and from the outer edges of the watershed toward the creek and bayou. Areas that are considered vulnerable and most vulnerable to contamination should be prioritized for water quality improvement alternatives such as septic to sewer conversions, and broad application of relatively aggressive (i.e., using additional measures such as bioabsorption media to reduce nutrient loading to groundwater) Low Impact Development (LID) stormwater treatment BMPs to protect the aquifer.

Figure 8-2: Potential Sources of Pollution

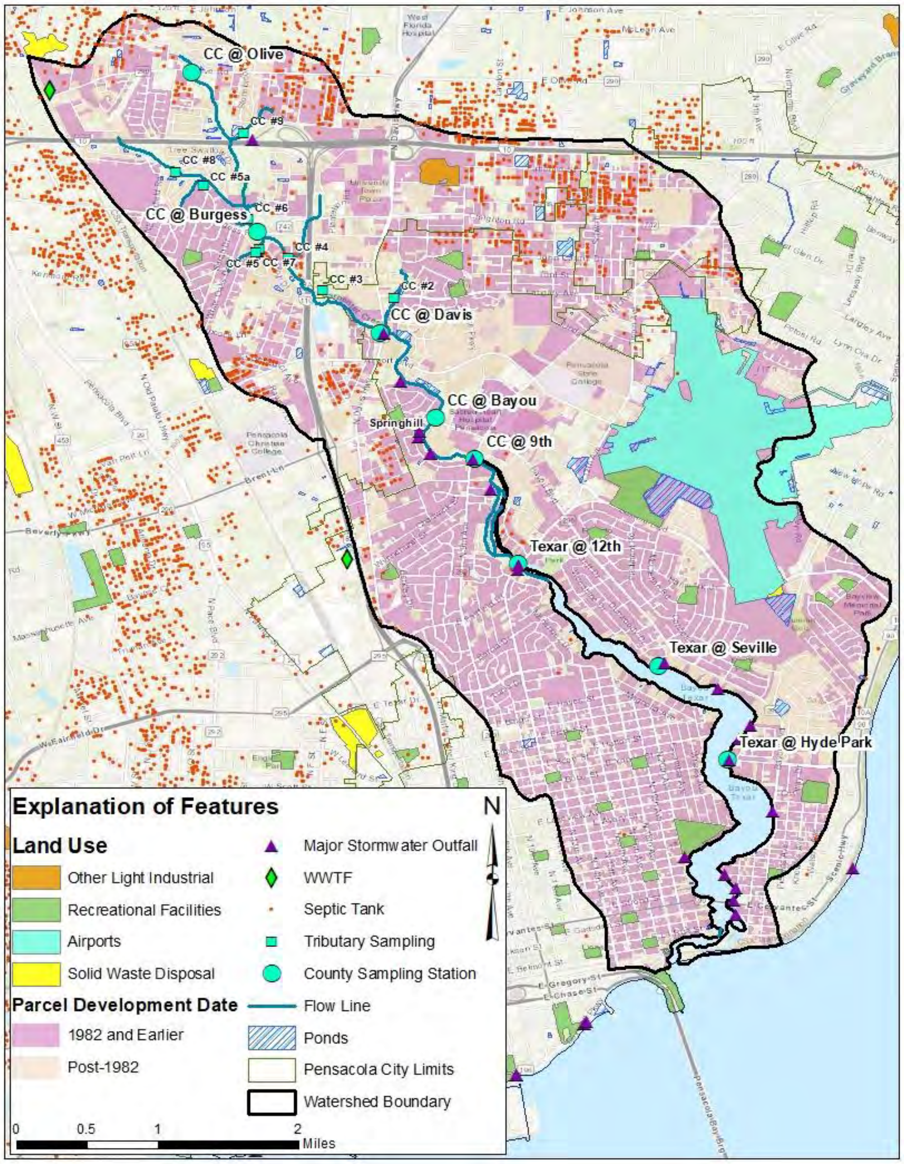
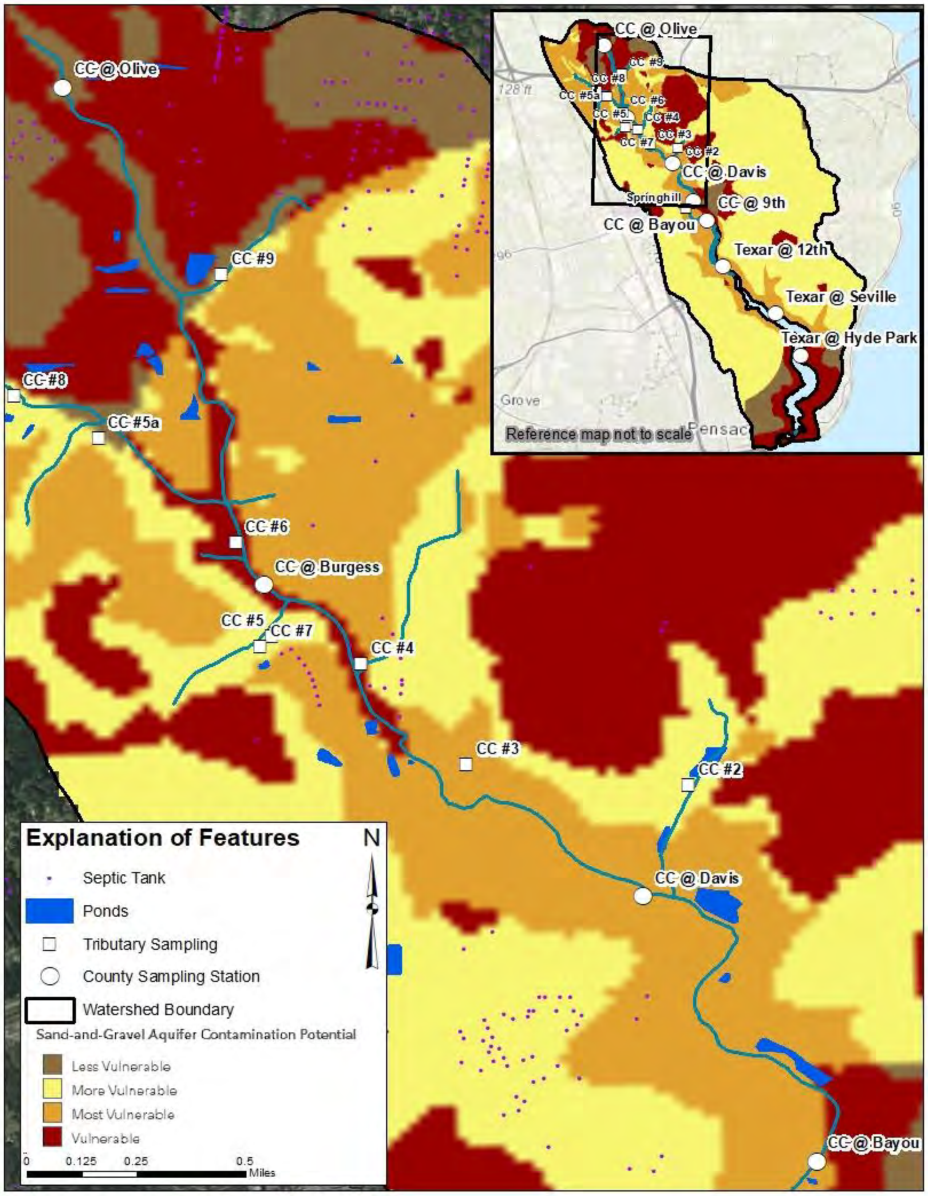


Figure 8-3: Aquifer Contamination Potential and Potential Sources of Groundwater Contamination

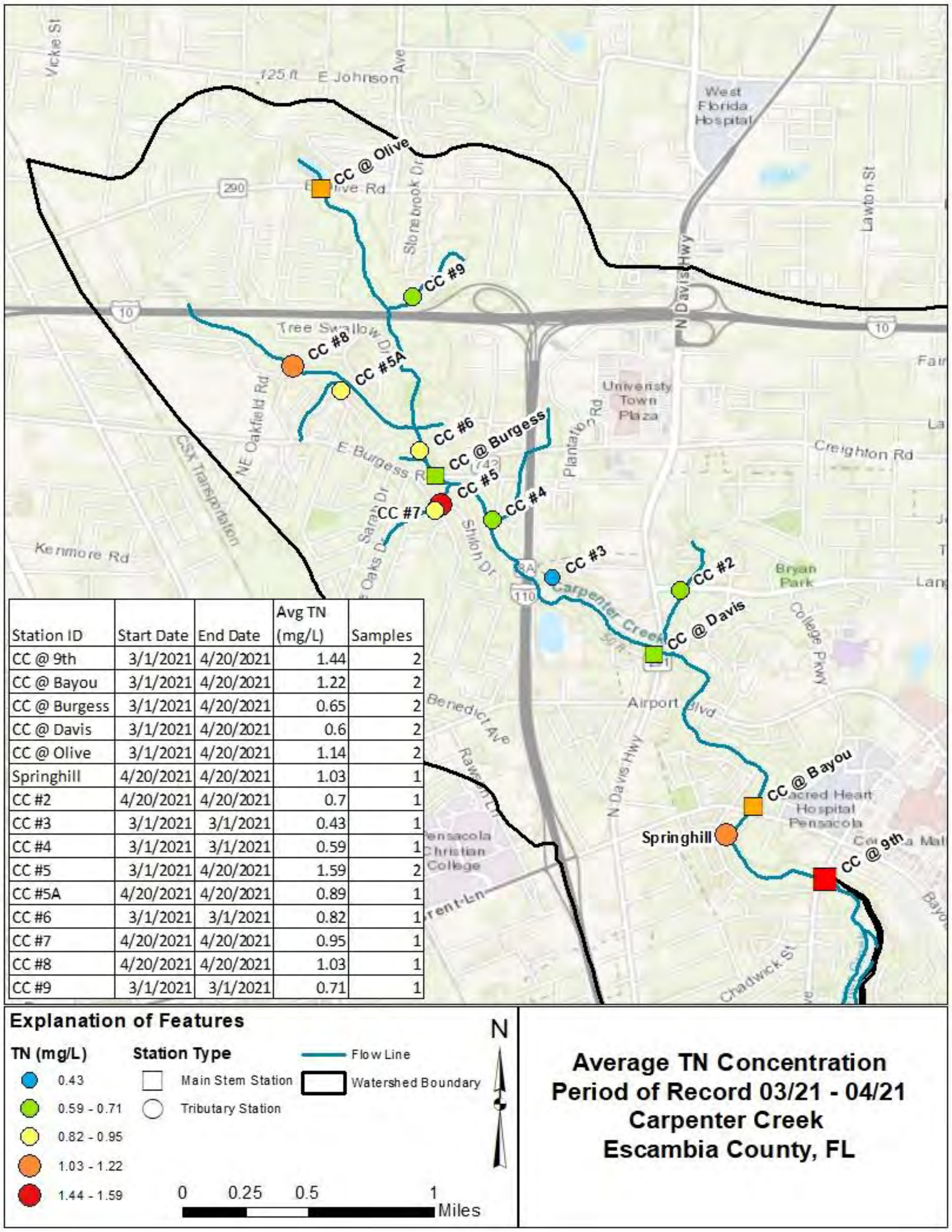


Source: Sand and Gravel Aquifer Contamination Potential Spatial Layer obtained from FDEP

There are currently not enough data points from the inflows (i.e., tributaries) to conduct a source tracking analysis using statistical routines such as random forest analysis (i.e., a machine learning method that requires several years of coincident data). However, a less formal qualitative assessment was conducted using the limited data that were recently collected at the tributary stations to assess which tributaries are the greatest contributors from a relative standpoint. Spatial assessment of selected parameters between existing sites provided insight into potential upstream drivers of water quality in the main stem of Carpenter Creek. Average TN, NOx, and TP concentrations from the two most recent sampling events, where both mainstem and tributary stations were sampled, are spatially presented in **Figure 8-4** through **Figure 8-6**. Based on the assessment, it appears that tributary sites CC#5 had the highest TN concentration, and CC#8 and Springhill sites had relatively high TN concentrations. High NOx concentrations were also observed at the CC#5 and CC#8 stations, as well as the CC @ Davis and CC @ 9th stations. These results indicate that

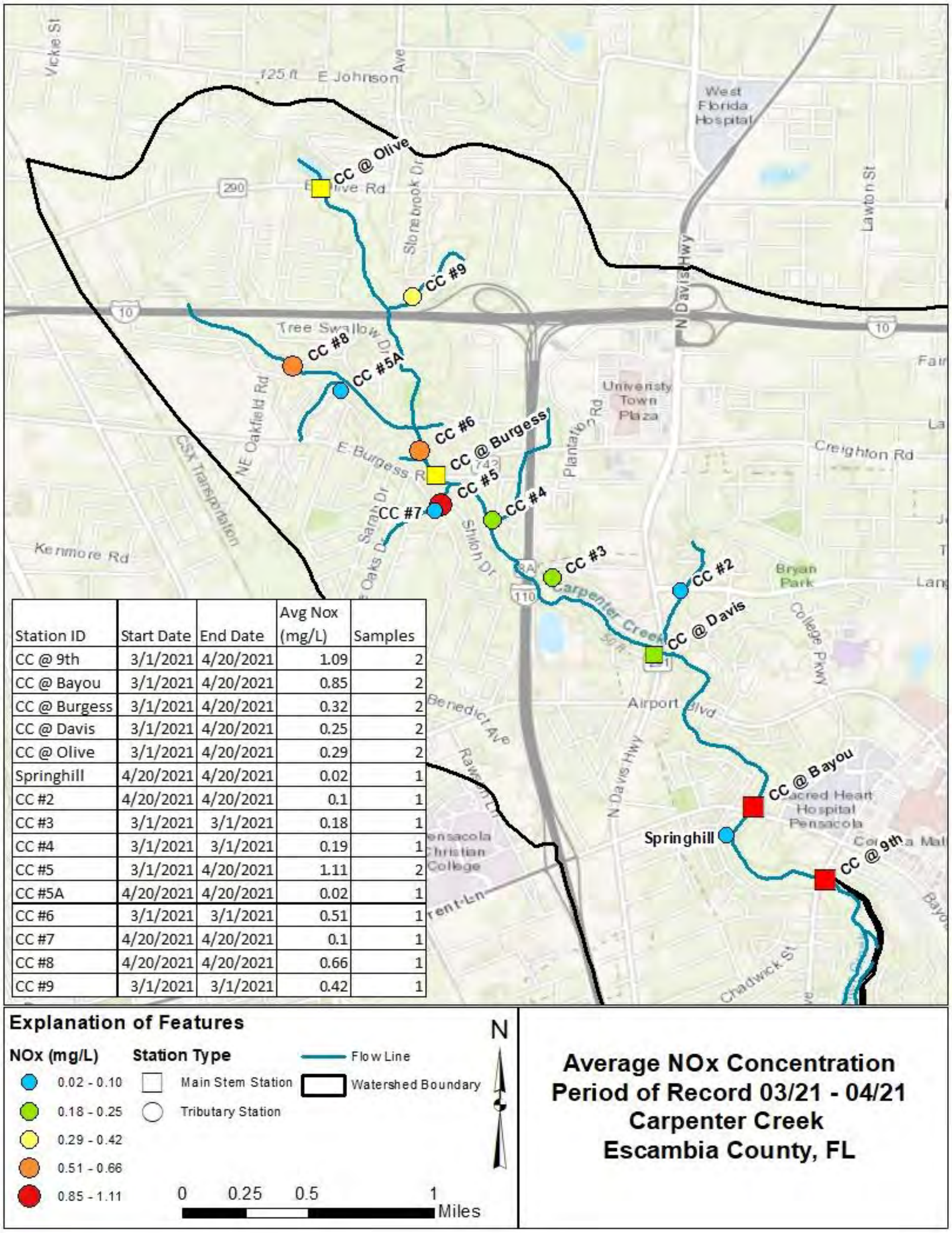
NOx is driving the high TN concentrations in those tributaries and, as previously discussed in **Section 7.1**, in the downstream portion of Carpenter Creek. In terms of TP, Springhill had the highest TP concentrations and CC#2 was the second-highest. Therefore, additional monitoring and water quality treatment options should also be further evaluated and prioritized in the creek and/or subbasins of CC#5, CC#8, CC#2, and Springhill sites.

Figure 8-4: Average TN Concentrations in Carpenter Creek and Tributaries, March 2021 – April 2021



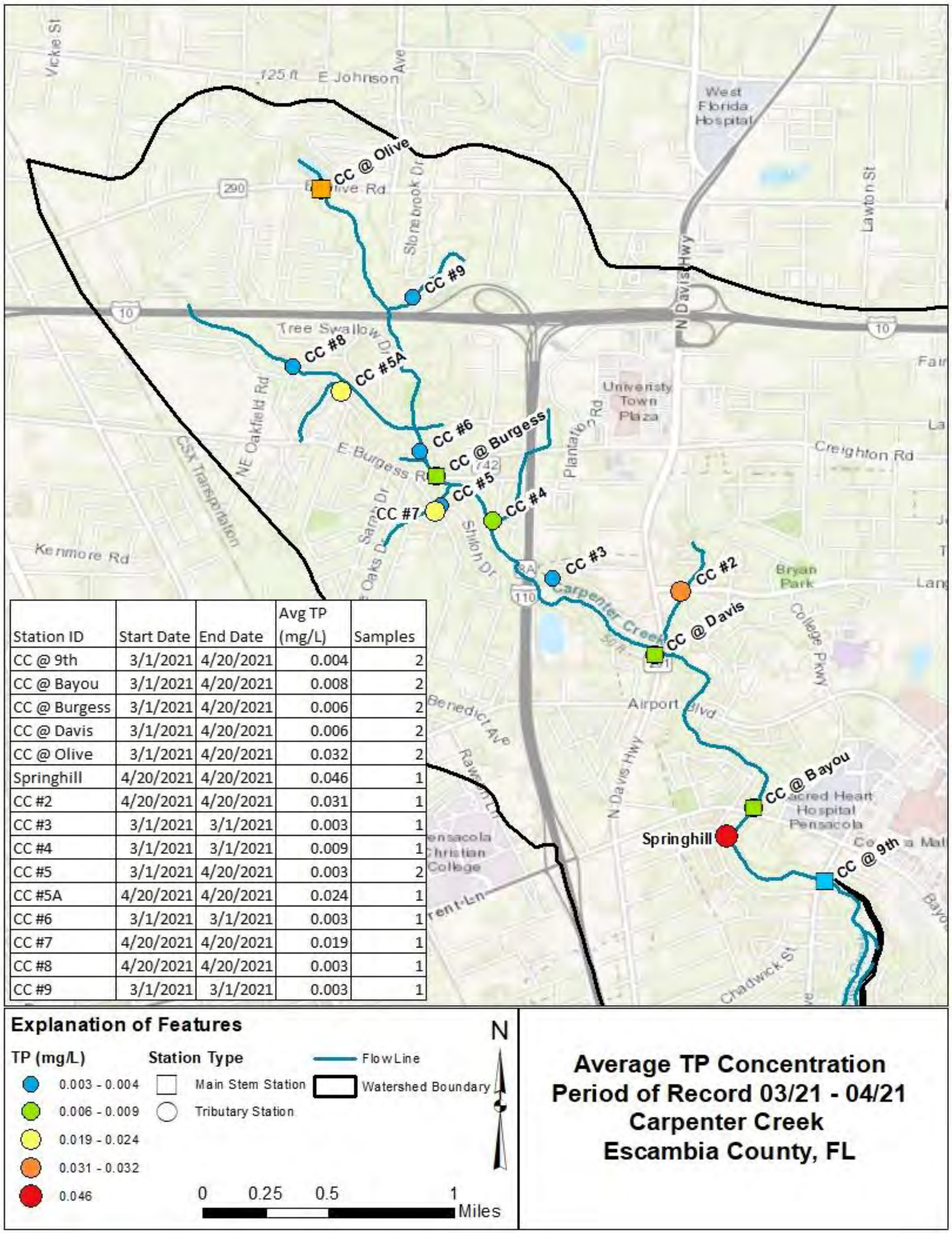
Station ID	Start Date	End Date	Avg TN (mg/L)	Samples
CC @ 9th	3/1/2021	4/20/2021	1.44	2
CC @ Bayou	3/1/2021	4/20/2021	1.22	2
CC @ Burgess	3/1/2021	4/20/2021	0.65	2
CC @ Davis	3/1/2021	4/20/2021	0.6	2
CC @ Olive	3/1/2021	4/20/2021	1.14	2
Springhill	4/20/2021	4/20/2021	1.03	1
CC #2	4/20/2021	4/20/2021	0.7	1
CC #3	3/1/2021	3/1/2021	0.43	1
CC #4	3/1/2021	3/1/2021	0.59	1
CC #5	3/1/2021	4/20/2021	1.59	2
CC #5A	4/20/2021	4/20/2021	0.89	1
CC #6	3/1/2021	3/1/2021	0.82	1
CC #7	4/20/2021	4/20/2021	0.95	1
CC #8	4/20/2021	4/20/2021	1.03	1
CC #9	3/1/2021	3/1/2021	0.71	1

Figure 8-5: Average NOx Concentrations in Carpenter Creek and Tributaries, March 2021 – April 2021



Station ID	Start Date	End Date	Avg Nox (mg/L)	Samples
CC @ 9th	3/1/2021	4/20/2021	1.09	2
CC @ Bayou	3/1/2021	4/20/2021	0.85	2
CC @ Burgess	3/1/2021	4/20/2021	0.32	2
CC @ Davis	3/1/2021	4/20/2021	0.25	2
CC @ Olive	3/1/2021	4/20/2021	0.29	2
Springhill	4/20/2021	4/20/2021	0.02	1
CC #2	4/20/2021	4/20/2021	0.1	1
CC #3	3/1/2021	3/1/2021	0.18	1
CC #4	3/1/2021	3/1/2021	0.19	1
CC #5	3/1/2021	4/20/2021	1.11	2
CC #5A	4/20/2021	4/20/2021	0.02	1
CC #6	3/1/2021	3/1/2021	0.51	1
CC #7	4/20/2021	4/20/2021	0.1	1
CC #8	4/20/2021	4/20/2021	0.66	1
CC #9	3/1/2021	3/1/2021	0.42	1

Figure 8-6: Average TP Concentrations in Carpenter Creek, March 2021 – April 2021



Station ID	Start Date	End Date	Avg TP (mg/L)	Samples
CC @ 9th	3/1/2021	4/20/2021	0.004	2
CC @ Bayou	3/1/2021	4/20/2021	0.008	2
CC @ Burgess	3/1/2021	4/20/2021	0.006	2
CC @ Davis	3/1/2021	4/20/2021	0.006	2
CC @ Olive	3/1/2021	4/20/2021	0.032	2
Springhill	4/20/2021	4/20/2021	0.046	1
CC #2	4/20/2021	4/20/2021	0.031	1
CC #3	3/1/2021	3/1/2021	0.003	1
CC #4	3/1/2021	3/1/2021	0.009	1
CC #5	3/1/2021	4/20/2021	0.003	2
CC #5A	4/20/2021	4/20/2021	0.024	1
CC #6	3/1/2021	3/1/2021	0.003	1
CC #7	4/20/2021	4/20/2021	0.019	1
CC #8	4/20/2021	4/20/2021	0.003	1
CC #9	3/1/2021	3/1/2021	0.003	1

8.4. Monitoring Program Discussion

Discussion of the monitoring program is limited to existing County stations and new data that were not included in the preliminary Monitoring Program review conducted by Wood in 2020. We recommend that the County still highly consider the recommendations provided in the Monitoring Program Options Technical Memorandum (2020), which in addition to surface water quality monitoring enhancements (e.g., stable isotopes, wastewater tracers, and bacterial genetic markers), also include the collection of important components such as routine flow measurements along the creek and bayou to allow the ability to calculate pollutant loads, implementation of a groundwater monitoring network spatially distributed throughout the vulnerable groundwater areas to pinpoint groundwater contamination (via seepage meters and/or monitoring wells), and sediment characterization (at a screening level to inform where sediment flux studies should occur) to identify locations of erosion and organic sediment depositional areas that could be targeted for sediment restoration (i.e., stabilization and/or dredging) to improve water quality.

Regarding surface water, sampling frequency and analytes that are currently being collected for surface water were reviewed and some key parameters were found to be needed to fill out a more comprehensive dataset that can be used to track pollutant sources and groundwater connectivity within the watershed. A detailed review of existing monitoring and potential data gaps for each monitoring station can be found in **Appendix A**. The frequencies for data collection, at both the existing County main stem monitoring stations and the tributary stations, present a temporal data gap. Although the County began sampling existing stations at a monthly frequency in June of 2020, November and December of that year were missing nutrient data. The limited nutrient parameters and single sampling events associated with the tributary stations present a gap in temporal data and water quality parameters. The existing monitoring network is spatially well distributed. The monitoring locations capture areas of high potential pollutant loading from various sources. However, to do a more refined assessment of potential sources within the watershed that are contributing to elevated pollutant loads and impairments, monthly sampling for a comprehensive set of parameters is needed on a consistent spatial distribution. Recommendations for adjusting sampling frequency and analytes are provided in **Section 9.2**.

9.0 SUMMARY AND RECOMMENDATIONS

9.1. Watershed Summary

Overall, the water quality assessment results indicate that TN, FIB, and DO are the major impairment concerns in the watershed. The only significant trend identified was decreasing TP in Carpenter Creek. Therefore, FIB and TN should be further assessed for sources and projects should be developed to attenuate and restore these potential impairments in Carpenter Creek and Bayou Texar. Specifically, the significant increase in TN driven by NOx between the CC @ Davis and CC @ Bayou stations should be further investigated to identify potential sources within the nearby urbanized areas. Nutrient source tracking methods should be implemented in this area to examine differences in isotopic signatures as a first step towards identifying and addressing possible sources of NOx loading. Additionally, a significant increase in *E. coli* between the CC @ Burgess and CC @ Davis stations is indicative of a potential localized FIB source upstream of CC @ Davis and downstream of CC @ Burgess. Microbial source tracking methods specific to the organisms that would be found in this area should be implemented between these two stations to examine differences in molecular signatures associated with different sources of FIB (pet waste, wastewater, etc.) as a first step towards ultimately identifying and addressing localized sources.

Based on the characterization of sediments within Bayou Texar, a layer of fine-grained sediments is present across most of the Bayou, which may be a potential source of nutrients that is contributed by internal loading driven by sediment flux, both diffusive and resuspension mechanisms. Sediment management should be a key focus to improve the health of the Bayou's ecosystem. Sediment quality conditions can shift spatially due to wind, disturbance, and flow paths (e.g., sediment transport driven by erosion during storm events). Therefore, implementation of a regular sediment assessment every few years is recommended that would include a sediment flux study, which can confirm if sediment flux and internal loading is significant factor contributing to overall nutrient loading to Bayou Texar.

The Pollutant Load Analysis identified several TN and TP hot spots throughout the watershed. Although the pollutant load analysis identified stormwater runoff as the highest contributor of loading in the watershed, the hot spot areas within the Carpenter Creek WBID for both TN and TP coincide with areas developed after 1982. Areas of high pollutant loading were concentrated around the Cordova Mall, Sacred Heart Hospital Complex, and the University Town Plaza, all of which currently implement some form of stormwater treatment. This suggests that existing stormwater treatment efforts in these areas may not be sufficient to treat the current volume of stormwater. In contrast to what was seen in Carpenter Creek, pollutant loads in the Bayou Texar portion of the watershed are likely associated with untreated stormwater runoff that drains directly into the waterbody. Future efforts to improve water quality should consider the implementation of stormwater treatment BMPs or retrofitting existing stormwater treatment units, specifically for LID projects throughout the watershed. Fertilizer use and animal waste should also be considered as likely contributing sources of nitrogen.

9.2. Future Monitoring Efforts

The monitoring program review informed recommendations for enhancing the existing monitoring program. The proposed recommendations are simply a reprioritization of existing monitoring stations regarding different levels of effort for source tracking, based on areas that may be influenced by potential groundwater contamination or other pollutant sources identified during the gap analysis. Due to inconsistencies in sampling frequency and parameters sampled, discovered during the monitoring program review (please see **Section 8.4** and **Appendix A**), Wood recommends continued sampling of a consistent set of parameters on at least a monthly basis to allow for robust trend analyses and other statistical analyses to be conducted in the future that could allow for more defined source tracking analysis.

Level 1 Source Tracking involves screening of specific parameters to identify stations with elevated pollutants and stations where water quality may be highly influenced by groundwater connectivity. At least one full year of data, collected monthly, should be analyzed to account for seasonality. The parameters recommended for Level 1 Source Tracking are listed in **Table 9-1.** Flow data for the tributaries and the main stem of Carpenter Creek would allow the ability to measure pollutant loads, which can be compared to modeled pollutant loads. Flow and velocity data would also allow the ability to screen for potential erosive events that may be contributing downstream and accumulating in the Bayou. Wood recommends implementing Level 1 Source Tracking at all existing County stations and monitored tributaries.

Table 9-1: Level 1 Source Tracking Basic Water Quality Parameters (including groundwater indicator parameters)

Parameters	Field or Lab
pH	Field
Specific conductance	Field
Dissolved oxygen	Field
Temperature	Field
Turbidity	Field
Alkalinity	Lab
Aluminum	**Lab**
Ammonia (N)	Lab

Parameters	Field or Lab
Bromide	Lab
Calcium	Lab
Chloride	Lab
Chlorophyll-a	Lab
Fecal indicators	Lab
Iron	**Lab**
Magnesium	Lab
Nitrate+Nitrite (N)	Lab
Orthophosphate	Lab
Sulfate	Lab
Total Kjeldahl Nitrogen	Lab
Total Organic Carbon	Lab
Total Phosphorus	Lab
Total Suspended Solids	Lab
True Color	Lab

Note: **Bolded** values represent parameters that are not sampled under the existing monitoring program.

Level 2 Source Tracking builds on the sampling frequency and parameters from Level 1, but with a period of record of at least 5 years. This sampling effort would produce enough useable data points to run a machine learning random forest model to aid in source tracking within the watershed. Given a large number of potential pollutant sources, a random forest model can identify the sources that most strongly predict downstream water quality conditions. Results are most reliable when the pool of explanatory variables represent conditions from all major inputs and likely sources throughout the basin, and when the data span five or more years. Data collected for Level 2 Source Tracking can also be used for additional data exploration such as trend analysis and correlation analysis. Trend analysis results are most reliable when data are available from the most recent five years at a monthly (or higher) sampling frequency.

Level 3 Source Tracking can be implemented without having to incorporate Level 2 Source Tracking. Advanced source tracking includes the collection of nitrogen and oxygen isotopes, wastewater tracers (i.e. sucralose and pharmaceuticals), and/or microbial source tracking. The frequency of collection is based on screening level results produced from Level 1 Source Tracking. Wood recommends employing Level 3 Source Tracking (stable isotopes and sucralose) at 1) Tributary 5 (CC#5), 2) Tributary 8 (CC#8), 3) Tributary 2 (CC#2), 4) Tributary Springhill, 5) CC @ 9th, 6) CC @ Bayou, and 7) CC @ Davis, based on nitrate concentrations from the March 2021 sampling event and results of the statistical analyses. This level of source tracking would be extremely informative in terms of identifying the dominant source of nutrients. Additional Level 3 Microbial Source Tracking (MST) is recommended at 1) CC @ Davis and 2) Texar @12th to provide guidance on the sources of elevated levels of fecal indicator bacteria found at these sites. MST findings have implications for how stormwater is managed and how water quality is maintained or improved. Site-specific recommendations for Level 3 Source Tracking may be expanded as additional data and information are provided.

The recommendations enhance the existing monitoring program by maintaining a consistent sampling frequency of surface water quality stations and increasing their respective parameters with the mindset of source tracking. A summary of recommendations based on the level of source tracking is provided in **Table 9-2.**

Table 9-2: Recommendations based on level of Source Tracking

Source Tracking Level	Recommendation
1- Screening	Maintain consistent monthly sampling frequency and collection of parameters listed in **Table 9-1** + flow for at least one year
2- Random Forest Analysis	Implement Level 1 sampling for 5 years
3- Advanced	Implement Level 1 sampling and conduct nitrogen and oxygen isotopes, wastewater tracers (i.e., sucralose and pharmaceuticals), and/or microbial source tracking (MST) genetic markers. Frequency-based on Level 1 screening of nutrient parameters

Based on the results from this effort, Wood will prepare recommendations for site-specific BMPs and general recommendations to improve water quality in Carpenter Creek and Bayou Texar in an upcoming task deliverable.

Table 9-3 incorporates the recommendations proposed in **Table 9-2** into the standing recommendations, previously provided to the County, in the Monitoring Program Options Technical Memorandum (Wood 2020).

Table 9-3: Updated Comprehensive Monitoring Recommendations

Data Type	Monitoring Level	Recommendation
Surface Water Quality	Basic	Implement Level 1 Source Tracking as part of the County ambient monitoring program
	Comprehensive	Basic + Level 3 Source Tracking
Stream Stage and Flow	Basic	Install at least one staff gage equipped with a continuous water level recorder and develop a rating curve to calculate flow
	Comprehensive	Basic + 4 additional flow gages, with 2 on Carpenter Creek and 2 on inflowing tributaries; consider side looking at doppler current meters to measure continuous water velocities and level
Groundwater Quality	Basic	Begin monthly sampling at four locations. Detailed location recommendations can be found in Monitoring Program Options for Carpenter Creek and Bayou Texar (Wood 2020)
	Comprehensive	Basic + Level 3 Source Tracking
	Seepage Study	Conduct a groundwater seepage study
Sediment Characterization	Sediment Cycling Evaluation	Conduct pre-screening sediment characterization sampling event and flux incubation study

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Appendix A - MONITORING PROGRAM REVIEW AND GAP ANALYSIS

Appendix A – Monitoring Program Gap Analysis and Geospatial Assessment

To supplement the monitoring program review in the report, details on the period of the record reviewed, data gap identification method and geospatial assessment are included below.

1. Existing Monitoring Program Review and Identification of Potential Data Gaps

Discussion of the monitoring program is limited to existing County stations and new data that were not included in the previous Monitoring Program review conducted by Wood in 2020. The period of record (POR) for data that are representative of the current monitoring program is June 2020- Present, however, it should be noted that the County only provided Wood with monitoring data through April 2021, so the review was limited to that POR. The existing monitoring program was reviewed to identify any additional temporal or water quality parameter monitoring gaps. The period of record plots produced for each monitoring station can be found in **Appendix B2**.

The County currently collects monthly samples from five stations within the Carpenter Creek WBID and three stations within the Bayou Texar WBID **(Figure A.1**). In June of 2020, Escambia County began collecting additional surface water quality parameters under their existing monitoring program, on a monthly frequency (**Table A-1)**. In March of 2021, the County picked up nine additional tributary stations for nutrient monitoring (Chl-a, NOx, TKN, TN, TP, and TSS).

A review of the existing County monitoring efforts identified several temporal data gaps in addition to an inconsistent collection of water quality parameters, which are discussed below.

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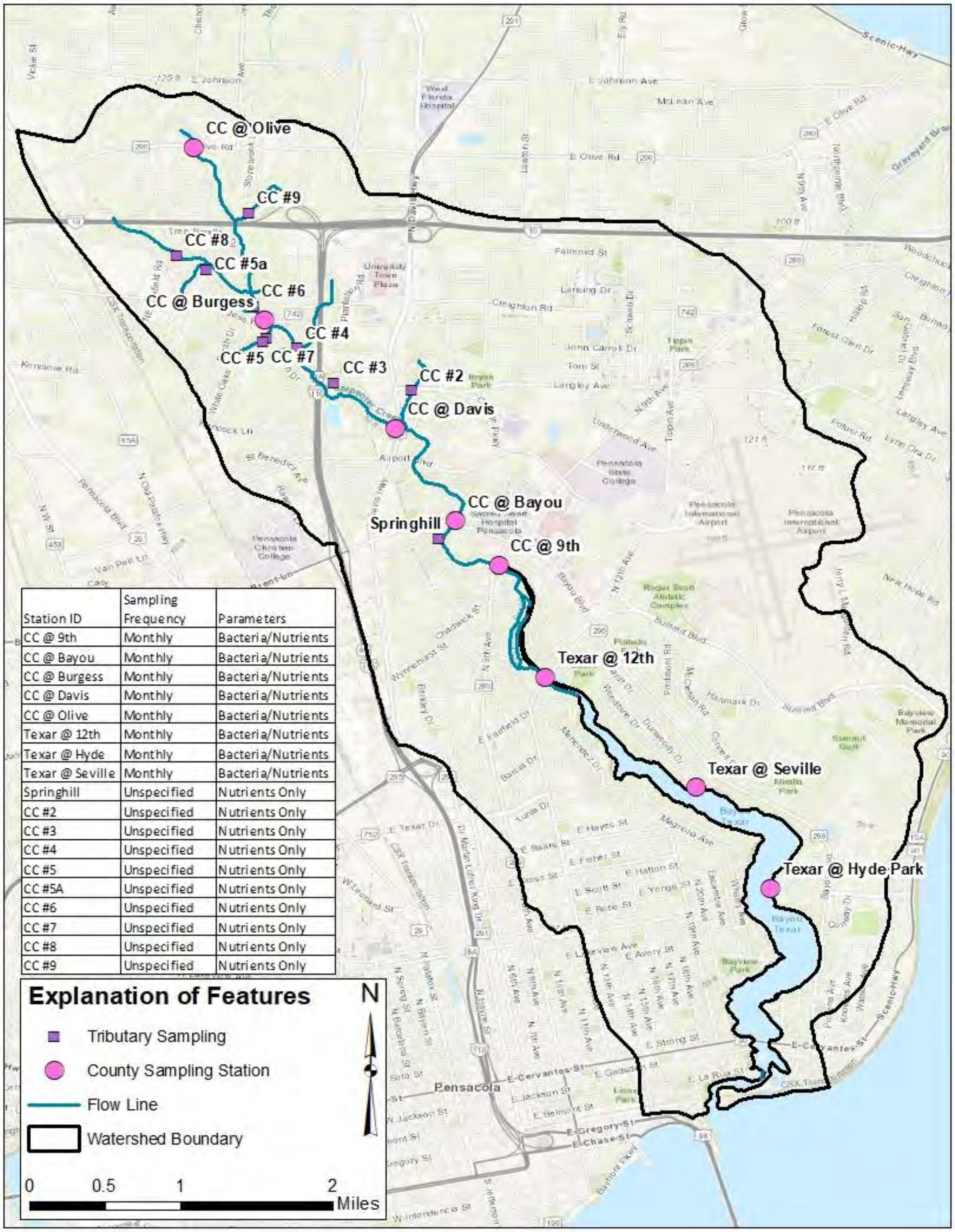
Figure A.1: Existing stations within the Escambia County water quality monitoring network



Station ID	Sampling Frequency	Parameters
CC @ 9th	Monthly	Bacteria/Nutrients
CC @ Bayou	Monthly	Bacteria/Nutrients
CC @ Burgess	Monthly	Bacteria/Nutrients
CC @ Davis	Monthly	Bacteria/Nutrients
CC @ Olive	Monthly	Bacteria/Nutrients
Texar @ 12th	Monthly	Bacteria/Nutrients
Texar @ Hyde	Monthly	Bacteria/Nutrients
Texar @ Seville	Monthly	Bacteria/Nutrients
Springhill	Unspecified	Nutrients Only
CC #2	Unspecified	Nutrients Only
CC #3	Unspecified	Nutrients Only
CC #4	Unspecified	Nutrients Only
CC #5	Unspecified	Nutrients Only
CC #5A	Unspecified	Nutrients Only
CC #6	Unspecified	Nutrients Only
CC #7	Unspecified	Nutrients Only
CC #8	Unspecified	Nutrients Only
CC #9	Unspecified	Nutrients Only

Table A-1: Surface water quality parameters sampled at mainstem County stations

Parameter
Fecal indicators (*Enterococci* and *E. coli*)
Chlorophyll-a
Chloride
Calcium
Magnesium
Bromide
Alkalinity
Ammonia (N)
Nitrate+Nitrite (N)
Total Kjeldahl Nitrogen
Total Nitrogen*
Orthophosphate
Total Phosphorus
Total Organic Carbon
Sulfate
True Color
Total Suspended Solids

Bolded values represent additional parameters added to the sampling program starting in June of 2020.

1.1. Carpenter Creek (WBID 676) Main Stem and Bayou Texar (WBID 738) Stations

Stations identified in **Figure A.1** as "County Sampling Station" are sampled monthly under the current monitoring program. Data were not collected in September of 2020 due to Hurricane Sally. However, two sampling events took place in October 2020 (Oct.7 and Oct. 27) to fill in the data gap from the prior month. The County gave Wood approval to assign data from October 7, 2020, as "September 2020" data.

All parameters listed in **Table A-1** were collected at each station between June 2020 and October 2020. However, only bacterial water quality parameters were collected in November and December 2020, resulting in a temporal gap in nutrient monitoring.

No data were provided for January or February of 2021. Limited nutrient data were collected in conjunction with the tributary sampling events in March and April of 2021, however, these data are limited to stations within the Carpenter Creek WBID.

1.2. Tributary Stations

Stations identified in **Figure A.1** as "Tributary Sampling" are sampled at an unspecified frequency by the County. These stations were added in March of 2021 and are only sampled for nutrient parameters at this time. Five of the stations were sampled in March 2021, while the remaining four stations were sampled in April 2021. Station CC#5 was sampled during both events.

1.3. Data Gaps

Table A-2 provides a summary of the data gaps identified during the review of the existing monitoring program.

Table A-2: Data Gaps Identified Under the Current Monitoring Program

Station ID	Sampling Frequency	Parameters	POR Reviewed	Temporal Data Gap	Water Quality Parameter Data Gap
CC @ 9th	Monthly	Bacteria/Nutrients	June 2020 - April 2021	Nov 2020 - Feb 2021	Nutrients and Bacteria
CC @ Bayou	Monthly	Bacteria/Nutrients	June 2020 - April 2021	Nov 2020 - Feb 2021	Nutrients and Bacteria
CC @ Burgess	Monthly	Bacteria/Nutrients	June 2020 - April 2021	Nov 2020 - Feb 2021	Nutrients and Bacteria
CC @ Davis	Monthly	Bacteria/Nutrients	June 2020 - April 2021	Nov 2020 - Feb 2021	Nutrients and Bacteria
CC @ Olive	Monthly	Bacteria/Nutrients	June 2020 - April 2021	Nov 2020 - Feb 2021	Nutrients and Bacteria
Texar @ 12th	Monthly	Bacteria/Nutrients	June 2020 - April 2021	Nov 2020 - April 2021	Nutrients and Bacteria
Texar @ Hyde	Monthly	Bacteria/Nutrients	June 2020 - April 2021	Nov 2020 - April 2021	Nutrients and Bacteria
Texar @ Seville	Monthly	Bacteria/Nutrients	June 2020 - April 2021	Nov 2020 - April 2021	Nutrients and Bacteria
Springhill	Unspecified	Nutrients Only	June 2020 - April 2021	June 2020 - February 2021	Bacteria
CC #2	Unspecified	Nutrients Only	June 2020 - April 2021	June 2020 - February 2021	Bacteria
CC #3	Unspecified	Nutrients Only	June 2020 - April 2021	June 2020 - February 2021	Bacteria
CC #4	Unspecified	Nutrients Only	June 2020 - April 2021	June 2020 - February 2021	Bacteria
CC #5	Unspecified	Nutrients Only	June 2020 - April 2021	June 2020 - February 2021	Bacteria
CC #5A	Unspecified	Nutrients Only	June 2020 - April 2021	June 2020 - February 2021	Bacteria
CC #6	Unspecified	Nutrients Only	June 2020 - April 2021	June 2020 - February 2021	Bacteria
CC #7	Unspecified	Nutrients Only	June 2020 - April 2021	June 2020 - February 2021	Bacteria
CC #8	Unspecified	Nutrients Only	June 2020 - April 2021	June 2020 - February 2021	Bacteria
CC #9	Unspecified	Nutrients Only	June 2020 - April 2021	June 2020 - February 2021	Bacteria

2. Geospatial Assessment Based on Pollutant Loading

Areas of high nutrient loading, discovered during the pollutant load analysis, were compared to average nutrient concentrations seen at existing water quality stations to examine if the current monitoring network distribution captures areas of concern. Water quality data collected between June 2020 and June 2021 were used to calculate average nutrient concentrations for both TN and TP. Due to temporal data gaps, this period of record (POR) was selected so that all stations in the monitoring network were represented.

2.1. Total Nitrogen

The highest average TN concentrations were seen at CC #5 and CC @9th. It should be noted that there is only one data point for TN at CC #5, and it is unclear if this value is representative of normal conditions at this station. Although there is a spatial gap between station placement along Bayou Texar, there are no "hot spots" for TN loading that would require additional station placement. The spatial distribution of the existing monitoring stations is well dispersed throughout the watershed and appears to capture water quality in areas of high estimated TN loading.

2.2. Total Phosphorous

The highest average TP concentrations were seen at Texar @ Hyde and Springhill. It should be noted that there is only one data point for TP at Springhill, and it is unclear if this value is representative of normal conditions at this station. Although there is a spatial gap between station placement along Bayou Texar, there are no “hot spots” for TP loading that would require additional station placement. The spatial distribution of the existing monitoring stations is well dispersed throughout the watershed and appears to capture water quality in areas of high estimated TP loading.

Figure A.2: Estimated TN "Hot Spots" and Average TN concentrations within the watershed

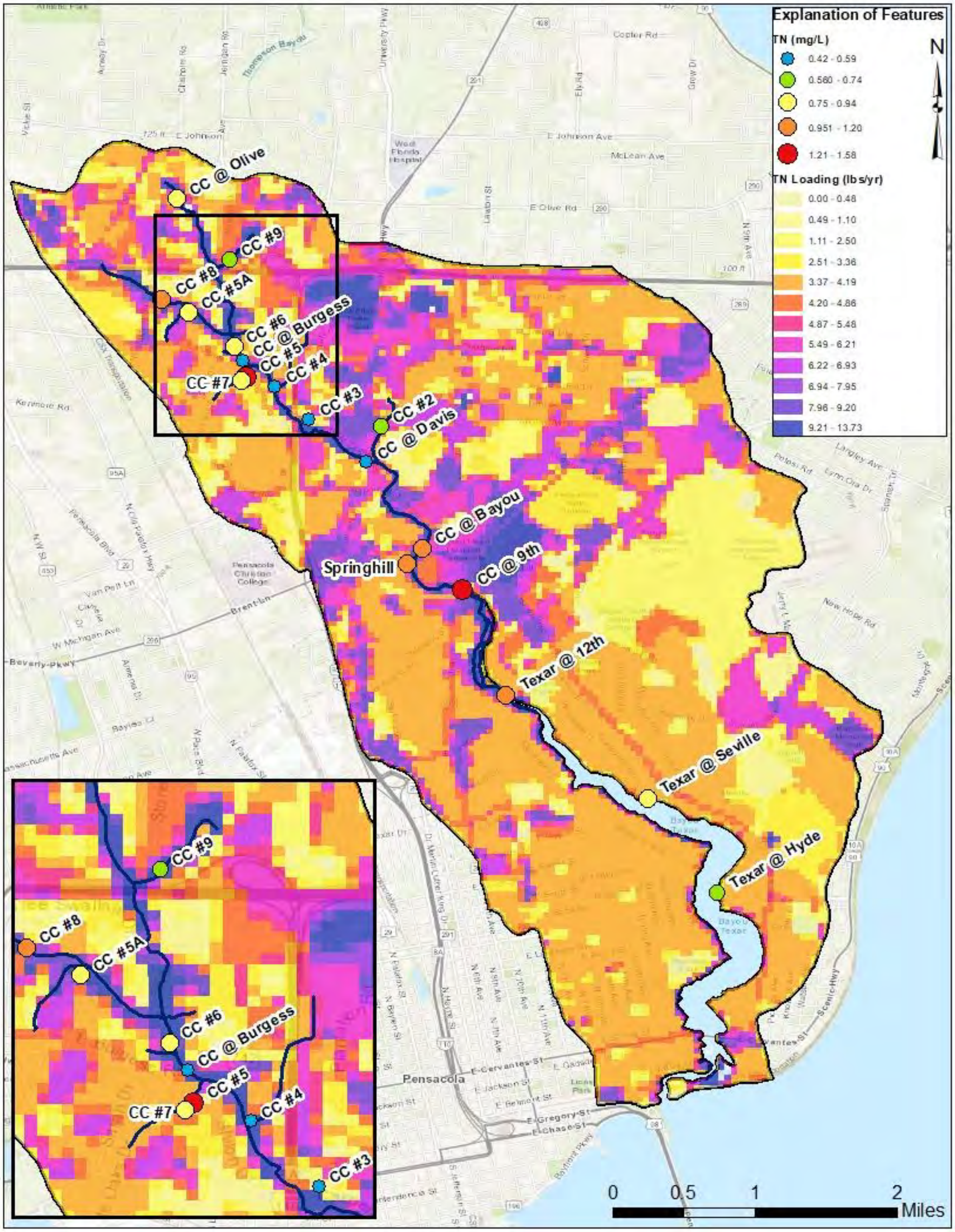


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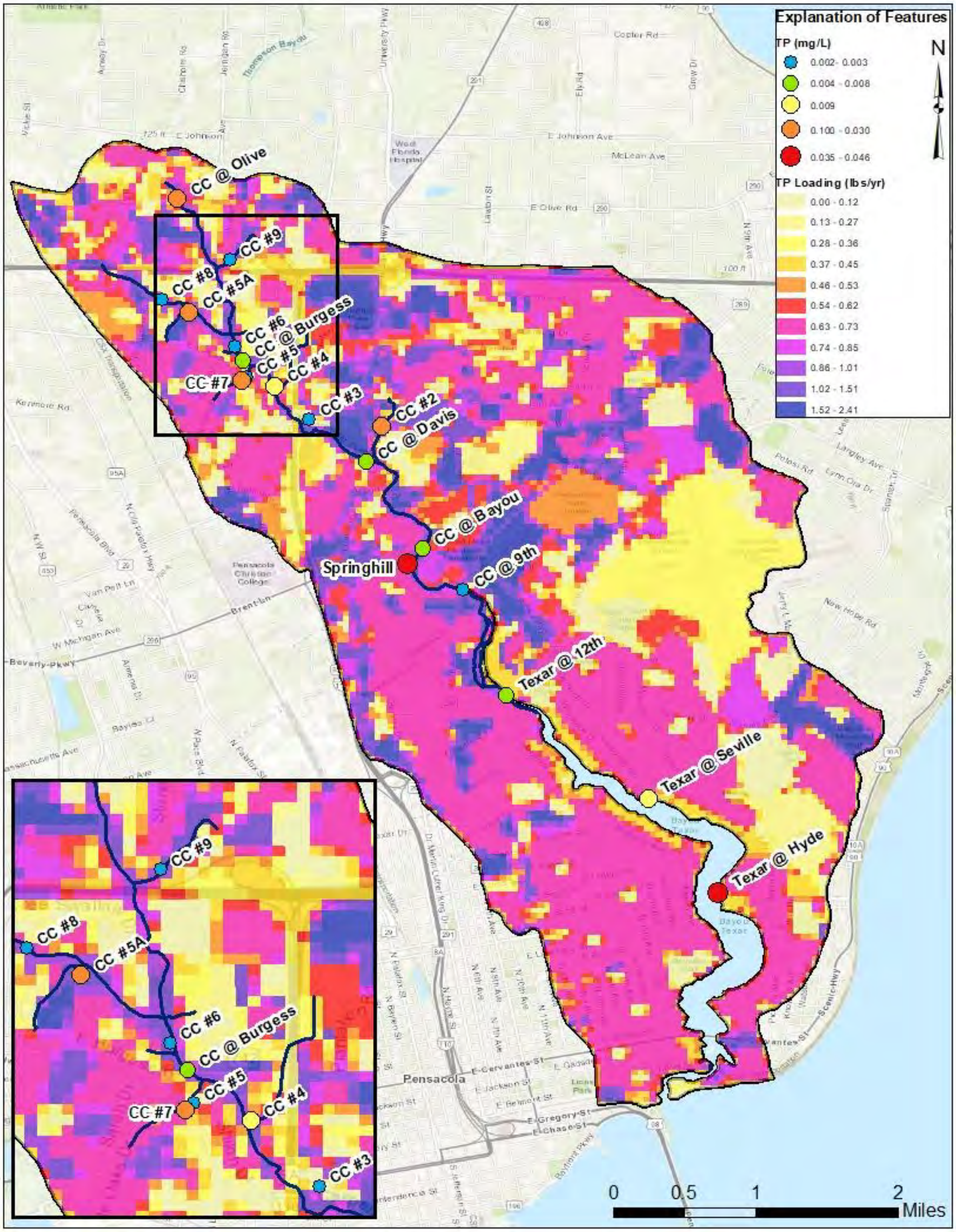
Figure A.3: Estimated TP "Hot Spots" and Average TP concentrations within the watershed



Appendix B1 - STATISTICAL ANALYSIS METHODOLOGIES AND RESULTS

Appendix B1 - Data Compilation and Statistical Methods

To supplement the condensed methods provided in the report, details on the data compilation, statistical methods used for the trend analysis, and exploratory correlation analysis are provided below.

1. Data Compilation

1.1. Hydrologic Data

1.1.1 Flow

Hydrologic data for Carpenter Creek and Bayou Texar were downloaded from the United States Geological Survey (USGS) National Water Information System (NWIS). Only two sites were located within the study area: Carpenter Creek at Pensacola, FLA (#02376079) and Carpenter Creek Nr Pensacola, FLA (#02376077). These data were not used, as they ended in 1977 and 1993, respectively.

1.1.2 Precipitation

Daily summary precipitation data for Pensacola Regional Airport (#USW00013899) were downloaded from the National Ocean and Atmospheric Administration (NOAA) Climate Data Online portal. Data were then checked to confirm that no gaps existed in the dataset. Thereafter rolling sums of 7-day antecedent rainfall were calculated for the period of record.

1.2. Water Quality Data

1.2.1 Groundwater Quality Data

Groundwater data for Carpenter Creek and Bayou Texar were downloaded from the United States Geological Survey (USGS) National Water Information System (NWIS). These data were not used, as they ended in 1989.

1.2.2 Surface Water Quality Data

The primary source of water quality data used in the analysis was the Florida Department of Environmental Protection (FDEP) Impaired Water Rule (IWR) Database, Run 60. Raw data for Carpenter Creek (Waterbody ID [WBID] 676) and Bayou Texar (WBID 748) were exported from the IWR Microsoft Access database. To have the most recent water quality data for these two WBIDs, additional data were retrieved from the FDEP's Watershed Information Network (WIN) using the online WIN Advanced View and Extraction System (WAVES).

The County provided three additional datasets that were included in this analysis. One dataset was from an intensive weekly sampling project focused on fecal coliform, *E. coli,* and field parameters conducted between May and July 2014. The second dataset from the County contained monthly bacteria, nutrient, and field parameter results from January 2020 to December 2020. The County also provided nutrient data collected between March and April 2021 that was part of a special Carpenter Creek tributary sampling event.

Crossover tables were developed for all parameters and stations within these four datasets. Duplicate data points, data from LakeWatch (per the County's request), and data with fatal qualifiers (A, B, F, G, H, K, L, N, O, Q, T, V, Y) were removed from the dataset. Data that were below method detection limits (MDL) were adjusted to one-half the MDL and daily averages were calculated if multiple samples for the same parameter were collected from the same station on the same day. Additionally, sample stations were aggregated if they were less than 500 feet apart. Time series were then plotted to determine which stations had sufficient periods of record to conduct additional correlational and trend analyses.

The following parameters were assessed:

- *Total Nitrogen (TN)*
- *Total Phosphorus (TP)*
- *Temperature*
- *Color*

- *Chlorophyll-a (Chl-a)*
- *Fecal Coliform*
- *Enterococci*
- *Total Suspended Solids (TSS)*
- *Specific conductance*
- *Dissolved Oxygen (DO)*
- *E. coli*
- *pH*
- *Aluminum*
- *Magnesium*
- *Orthophosphate (Ortho-P)*
- *Iron*
- *Calcium*
- *Nitrate-Nitrite (NOx)*

2. Data Analyses

2.2 Impairment Analysis

An informal impairment analysis was conducted on the compiled surface water dataset. Impairment assessments of nutrient-related parameters included Chl-a, TN, and TP while bacteriological-related parameters included *E. coli* (in Carpenter Creek) or *Enterococci* (in Bayou Texar).

Carpenter Creek (WBID 676) is subject to the Panhandle West freshwater stream Numeric Nutrient Criteria (NNC; 20 ug/L Chl-a, 0.67 mg/L TN, and 0.06 mg/L TP) expressed as annual geometric means (AGM), not to be exceeded more than once in a 3-year period. It is also subject to the freshwater *E. coli* criterion of 410 Colony Forming Units (CFU)/100 mL, not to be exceeded in 10% of samples during a 30-day period and/or a monthly geometric mean of 126 CFU, never to be exceeded.

Bayou Texar (WBID 738) is a tidally influenced area that fluctuates between predominately marine and predominately freshwaters during typical climatic and hydrologic conditions. Therefore, nutrient and nutrient response criteria do not apply, and only a Chl-a criterion of 11 ug/L expressed as an AGM, not to be exceeded more than once in a 3-year period, is applicable. However, as part of this informal impairment analysis, Bayou Texar results were assessed against the criteria from the downstream Estuary Nutrient Region (Upper Pensacola Bay) of 0.77 mg/L TN and 0.084 mg/L TP, not to be exceeded in more than 10% of measurements. The waterbody is subject to the marine *Enterococci* criterion of 130 Colony Forming Units (CFU)/100 mL, not to be exceeded in 10% of samples during a 30-day period and/or a monthly geometric mean of 35 CFU, never to be exceeded.

To show potential impairments, AGMs were calculated for all parameters with criteria based on AGMs then plotted. The annual percent exceedances were calculated for all parameters with criteria based on percent exceedances.

2.2 Trend Analysis

To identify potential trends in water quality, the non-parametric seasonal Mann-Kendall tests with the Theil-Sen's Slope, Tau test statistic, and a probability value for the trends were calculated. These tests were performed on the following water quality parameters: TN, nitrate + nitrite (NOx), TP, Chl-a, Dissolved oxygen (DO), and either *E. coli* (in Carpenter Creek) or *Enterococci* (in Bayou Texar). Seasonal trend analyses were conducted at both the waterbody and station scales. At the water body scale, quarterly data between 2010 and 2020 were used. At the station scale, two analyses were performed. At stations with sufficient data, trends were calculated using quarterly data between 2017 and 2020. This period was selected because the greatest number of stations had data between those years. Additionally, two Carpenter Creek stations (CC @ 9th and CC @ Davis) and two Bayou Texar stations (Texar @ 12th and Texar @ Bayview) had longer periods of record and were selected for trend analysis using quarterly data between 2010 and 2020.

Quarterly data were calculated by computing the median value when multiple observations of a water quality parameter were available for a given quarter. When no observations were available for a given quarter, data were not imputed or interpolated, because interpolation would risk artificially decreasing p-values reported by the Mann-Kendall tests and unnecessarily biasing Theil-Sen slope results.

For each water quality parameter at each station, the autocorrelation function (ACF) was first applied to screen for serial correlation before application of a Seasonal Mann-Kendall (SMK) trend test (Marchetto, 2021). If a significant ($p<0.05$) autocorrelation was detected for a given parameter the dataset underwent a "prewhitening" procedure and was then analyzed with the Mann-Kendall trend test (Bronaugh and Werner, 2013). Each Mann-Kendall test estimated a tau parameter whose sign (positive or negative) indicates the direction of the trend (increasing or decreasing) and a p-value. When Mann-Kendall results detected a statistically significant monotonic trend ($p<0.05$), the Theil-Sen estimator was applied to fit a linear trend and estimate its slope. The Theil-Sen slope provides an estimate of the rate at which the parameter linearly increased or decreased. The slope of the trend line is computed as the median of all slopes between all pairs of points. As a non-parametric, median-based regression method, the Theil-Sen estimator makes no assumption about the underlying distribution of the data and is robust to outliers.

2.3 Exploratory Correlation Analysis

Non-parametric correlation analysis (Spearman Correlation) was used to explore the relationships between water quality conditions throughout the Carpenter Creek and Bayou Texar watersheds. The analysis is considered exploratory, because correlation does not necessarily imply causation, however, a lack of correlation does not necessarily imply a lack of causation.

In addition to water quality variables, precipitation was also included in the analysis (using the cumulative 7-day antecedent rainfall). A lack of recent flow data in the watershed precluded the inclusion of flow in the correlation analysis.

Similar to the trend analysis, correlation analyses were performed at both the waterbody and individual station scales. Monthly median values for each waterbody were calculated for data collected from 2010 to 2020. Additionally, daily median values for each station were calculated for data collected from 2017 to 2020. Due to differences in sampling frequencies for nutrients and bacteria, correlations were run separately for these two groups of parameters when data were available. The Florida Department of Health (FDOH) frequently samples Texar @ Bayview for Enterococci, however, no other water quality parameters are collected during these sampling events. Although these results were not used in correlation analysis using daily medians, they were incorporated into the data set when calculating monthly medians at the WBID scale.

Correlation analyses were also performed comparing water quality parameters between Carpenter Creek and Bayou Texar. Two correlation matrices were calculated using the monthly median data from 2010-2020. Correlations were conducted twice: once without Chl-a and with Chl-a as it had a shorter time series, which limited the POR used.

3. Results

3.1 Station Grouping and Data Availability

3.1.1 Hydrologic Data

Flow data from the USGS was limited to observations recorded between 1959 and 1993. The highest frequency of flow data collection occurred at site # 2376079 between 1976 and 1977. Flow data availability is summarized in **Table B2-1**. The lack of recent flow data within Carpenter Creek or Bayou Texar precluded its use in this assessment.

Precipitation data from the station at Pensacola Regional Airport (USW0013899) were available from 1948 to 2021. A rolling sum of seven-day antecedent rainfall totals was calculated from 2009 to 2020. These data were used in the correlation analysis. The daily and seven-day rolling sum precipitation data are presented in **Figure B2.1**.

3.1.2 Groundwater Quality Data

Groundwater quality datasets from Carpenter Creek and Bayou Texar from the USGS were limited to data collected between 1959 and 1989 with most samples collected in the 1970s and 1980s. Groundwater quality data availability is summarized in **Table B2-2**.

3.1.3 Surface Water Quality Data

Surface water quality data from Carpenter Creek and Bayou Texar include data from as early as 1970 with the field parameters, nutrients, and bacteria recording the most samples (**Figure B2.2**). The parameters with the fewest samples include aluminum, alkalinity, calcium, iron, magnesium, and orthophosphate.

Prior to 2011, fecal coliform was sampled in both water bodies. A change in criteria meant that fecal coliform criteria was replaced by *E. coli* in Carpenter Creek and *Enterococci* in Bayou Texar. For some sampling events, both fecal coliform and its replacement (*E. coli* or *Enterococci*) were collected simultaneously. Results from these concurrent bacterial sampling events are presented in **Figure B2.3**. Results in Carpenter Creek come from 2014 and 2016 and show a higher R^2 between the variables, indicating a tighter correlation, even though it is a smaller dataset. The larger dataset from Bayou Texar comes from 2000-2011, has a lower $R^{2,}$ and is based entirely on data collected from the Texar @ Bayview station, the location of the FDOH beach monitoring station.

A total of eight aggregate water quality stations based on current sampling regimes and proximity were identified within Carpenter Creek while seven aggregate stations were identified within Bayou Texar (**Table B2-3**). Period of record plots for parameters of interest was then plotted, which revealed that only five stations in Carpenter Creek and five Stations in Bayou Texar provided periods of record sufficient for correlational and/or trend analyses (**Figure B2.4**). Any data not from these 10 stations were then reclassified as "Other" for further analysis.

3.2 Impairment Assessment

The informal impairment assessment is shown in **Figure Set B2.9**. Annual geometric means (AGM) were calculated and plotted for Chl-a, TN, and TP in Carpenter Creek (**Figure Set B2.9**). Chl-a AGMs never approach the criterion of 20 µg/L, however, one individual sample from CC @ Olive had a Chl-a of 33 µg/L. TN at Carpenter Creek has consistently exceeded the criterion of 0.67 mg/L, including every year since 2016 while TP has not exceeded the criterion of 0.6 mg/L with individual samples or by AGM. TN concentrations at CC @ 9th are consistently above the criterion while concentrations at CC @ Davis are consistently below. More than 10% of *E. coli* samples exceeded 410 CFU/100 mL in every year that data was available (**Table B2-4**) with CC @ Davis exceeding the criterion in 70% of samples from 2010 to the Present (**Table B2-5**).

Chl-a AGMs were calculated and plotted for Bayou Texar (**Figure Set B2-10**). Although the Chl-a AGMs never approach the criteria (11 µg/L), individual samples above this value were observed at Texar @ Seville, Texar @ Hyde, and Texar off DeSoto. More than 10% of samples exceeded the criteria for TN and Enterococci criteria every year between 2010 and 2020 (**Table B2-6**). Ninety-two percent of TN samples at Texar @ 12th and Texar @ Seville exceeded the criteria while 48 percent of *Enterococci* samples at Texar @ 12th exceeded the criteria (**Table B2-7**).

3.3 Trend Results

Within the area of study, eight stations and two WBIDs provided sufficient data for trend analysis for at least one of the parameters of interest using data between 2017-2020. Additionally, four stations and the two WBIDs provided sufficient data for trend analysis for at least one parameter using data from 2010-2020. All trend analysis results, both at the station and WBID scales, are presented in **Table B2-8**.

TN at CC @ 9th was the only parameter/station combination with a significant trend using data from 2017 to 2020. However, six significant trends were detected within the four stations that had sufficient data to analyze trends using

data from 2010 to 2020. Interestingly, although TN showed a significant increasing trend between 2017 and 2020 (*tau* = 0.61, p = 0.05), it occurs within a larger significant decreasing trend in TN seen at CC @ 9^{th} from 2010 to 2020 (*tau* = -0.25, p = 0.04). Additional decreasing trends observed at CC @ 9^{th} between 2010 and 2020 include dissolved oxygen (*tau* = -0.30, $p < 0.01$) and nitrate-nitrite (*tau* = -0.33, $p < 0.01$). Texar @ 12^{th} also had a significant decreasing trend in nitrate-nitrite (*tau* = -0.32, $p < 0.01$) whereas there was a statistically significant (although minor in magnitude) increasing trend in nitrate-nitrite at CC @ Davis (*tau* = 0.01, $p < 0.01$).
All data within the WBIDs were combined to look at trends at the waterbody scale. No significant trends were detected using data from 2017 to 2020. However, two significant trends were detected in each WBID using data from 2010 to 2020. In Carpenter Creek (WBID 676) decreasing trends were observed in total phosphorous (*tau* = -0.25, p = 0.03) and dissolved oxygen (*tau* = -0.27, p = 0.03). In Bayou Texar (WBID 738) decreasing trends were observed in nitrate-nitrite (*tau* = -0.38, $p < 0.01$) and dissolved oxygen (*tau* = -0.28, p = 0.03).

3.4 Correlation Results

Twenty correlation results are presented in **Figure Set B2.11**. Positive correlations are indicated by blue shading while negative correlations are indicated by red shading. Correlations that were not statistically significant ($p > 0.05$) are covered by an 'X'.

Comparing monthly medians from 2010 to 2020 between Carpenter Creek and Bayou Texar (**Figures B2.11a and B2.11b**) shows positive correlations between TKN and Temperature, which were both negatively correlated with DO. Interestingly TN and Chl-a appear to be negatively correlated in Carpenter Creek while TP and Chl-a are positively correlated in Bayou Texar (**Figures B2.11c-f**). Given the number of other variables that are correlated with precipitation (sum of a 7-day antecedent value) in Carpenter Creek (**Figures B2.11g-l**) as compared to Bayou Texar (**Figures B2.11m-t**), it is possible that rainfall plays a more important role within the Creek than the Bayou. TN at CC @ 9^{th}, which is the highest within the WBID, appears to be negatively correlated with TP, TSS, and turbidity. *E. coli* is generally positively correlated with precipitation, turbidity, and temperature.

References

Bronaugh, D., and Werner, A., 2013. zyp: Zhang þ Yue–Pilon trends package. http://cran.r-project.org/package=zyp.

Marchetto, A. 2021. Mann-Kendal Test, Seasonal and Regional Kendall Tests. http://cran.r-project.org/package=rkt.

Appendix B2 - STATISTICAL ANALYSIS FIGURES AND TABLES

Appendix B2 – Supplemental Figures and Tables

This appendix provides supplemental information for the main body of the report. This includes figures and tables.

Figures

Figure B2.1: Daily (blue) and 7-day rolling (black) precipitation data from Pensacola Regional Airport (Station # USW00013899) between 2009 and 2021.

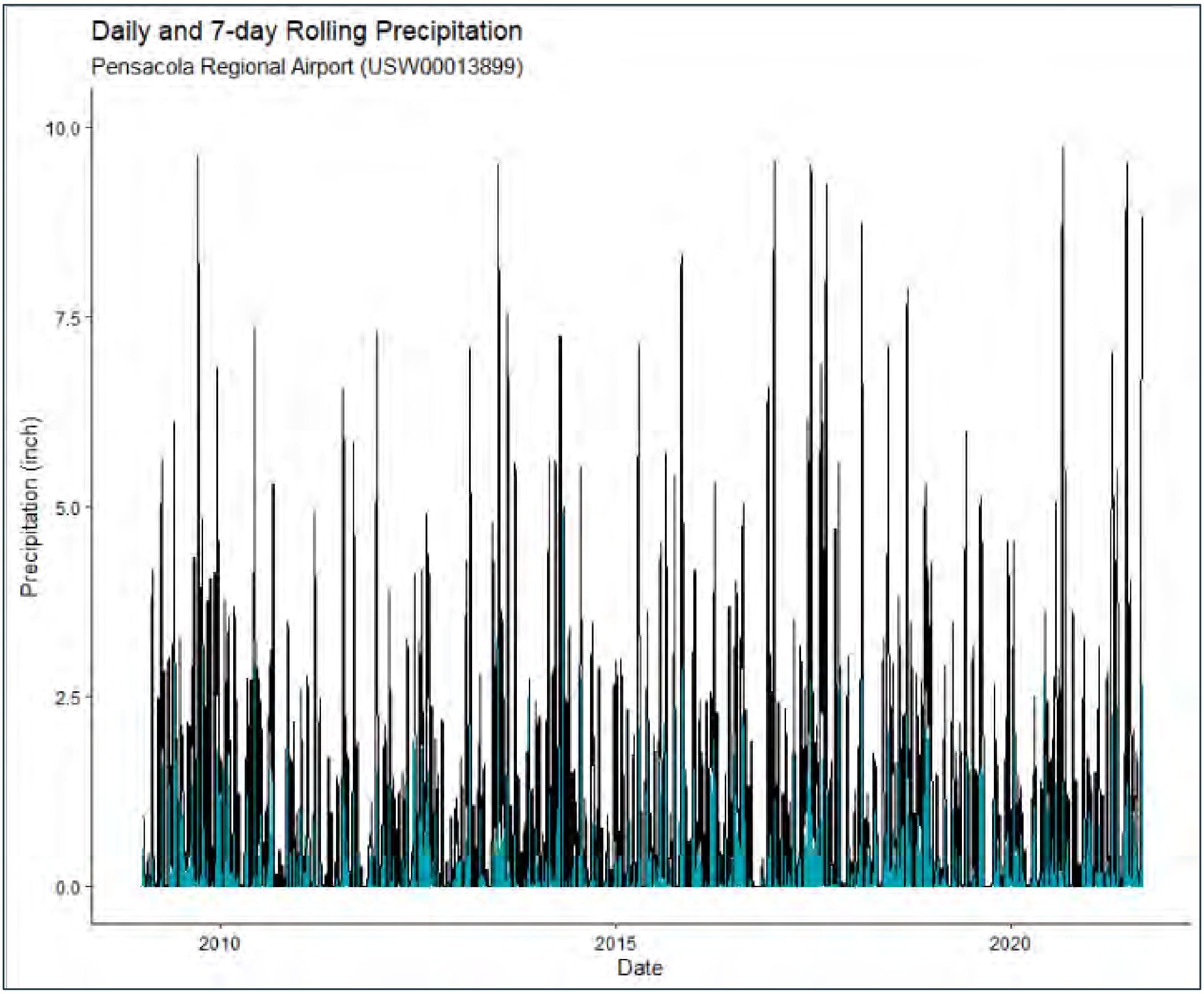


Figure B2.2: Period of record plots of Carpenter Creek (wbid 676) and Bayou Texar (wbid 738) showing sampling frequency from 1970 to the Present.

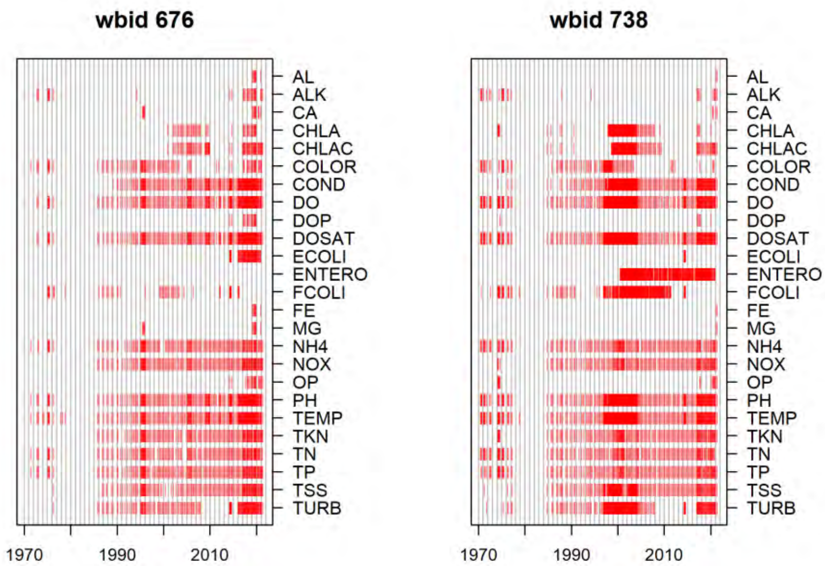
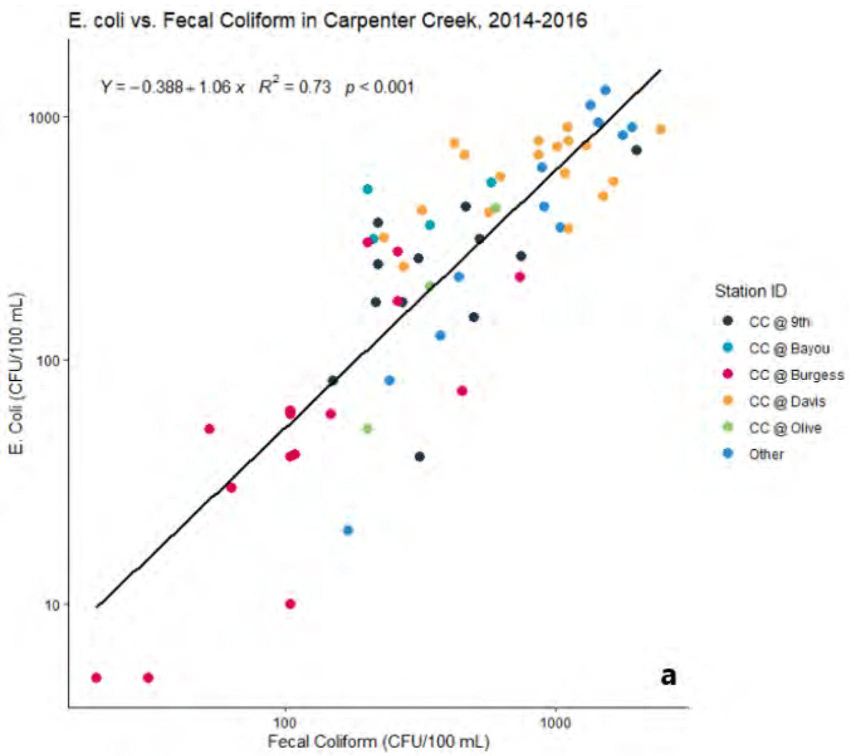


Figure B2.3: Scatter plots of concurrent samples of (a) fecal coliform and *E. coli* in Carpenter Creek (b) fecal coliform and *Enterococci* in Bayou Texar.



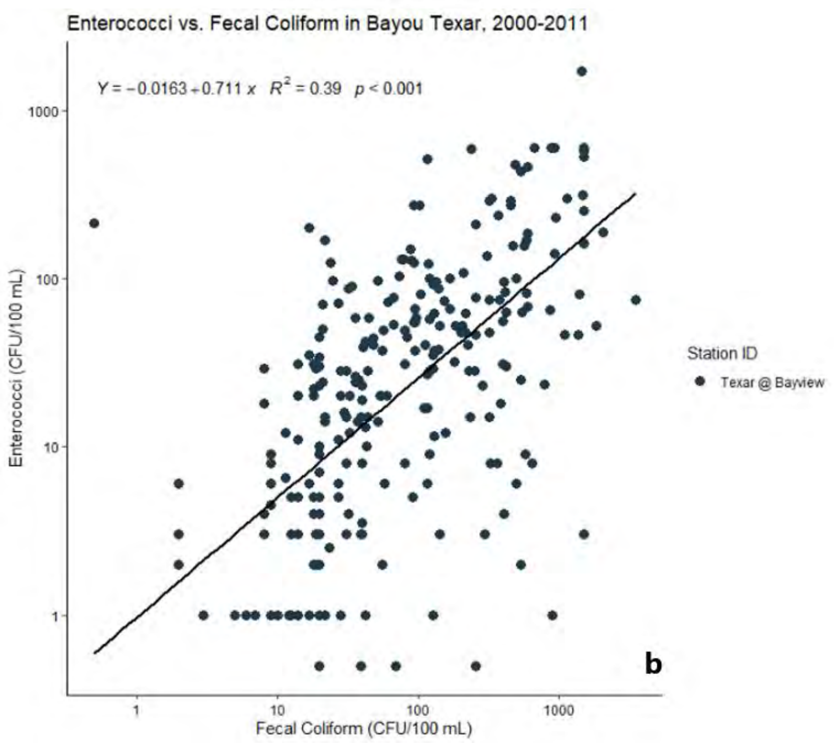


Figure B2.4: Sampling frequency by parameters for the 10 stations with the most robust datasets between 2010 and the Present.

Station TEXAR OFF DESOTO

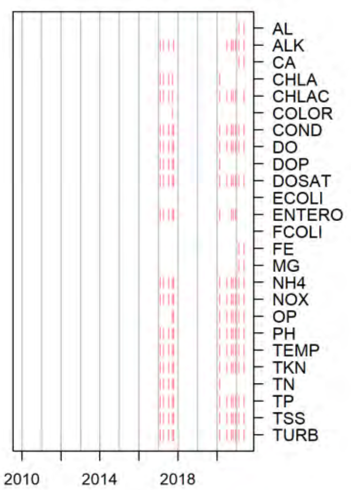
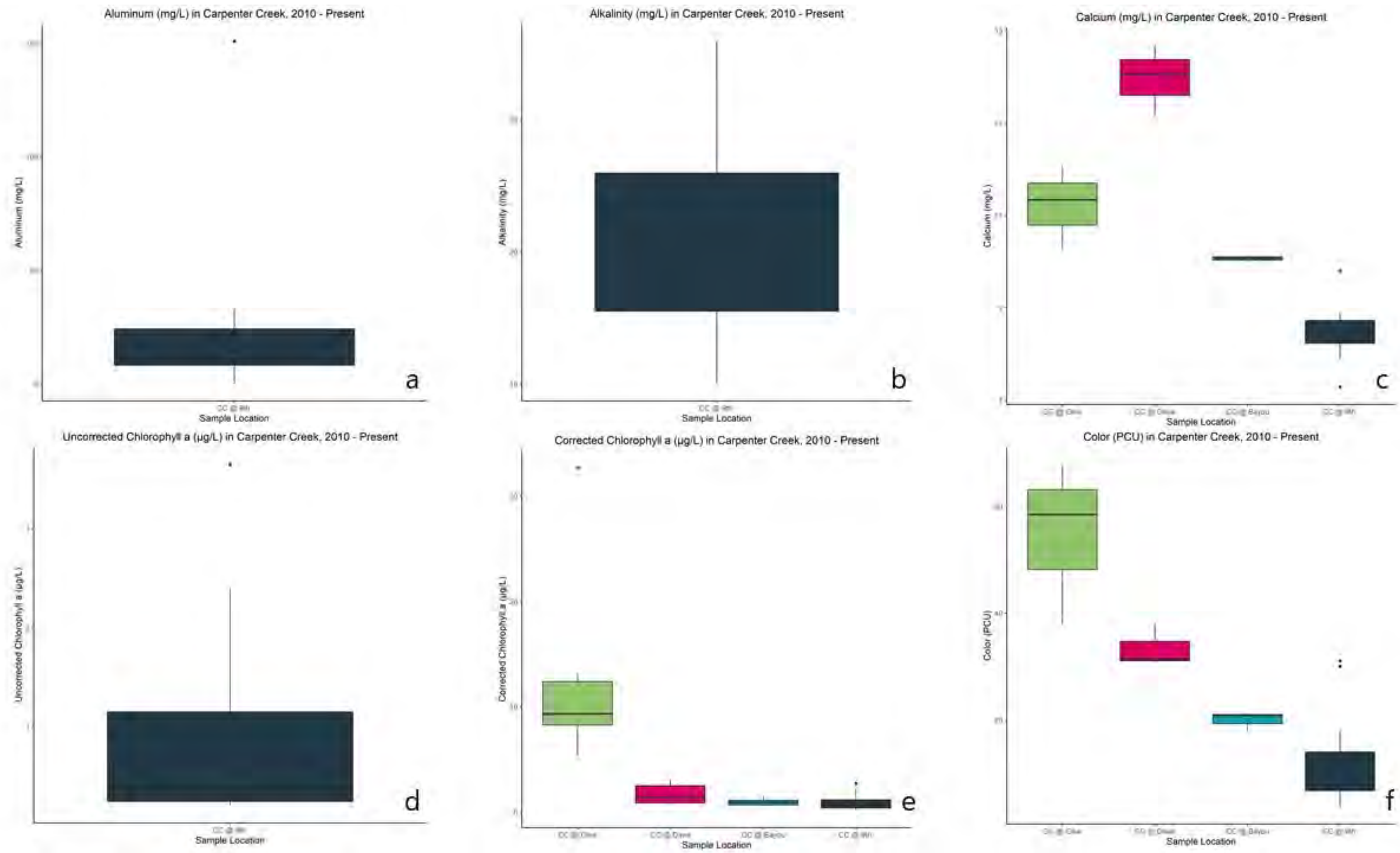
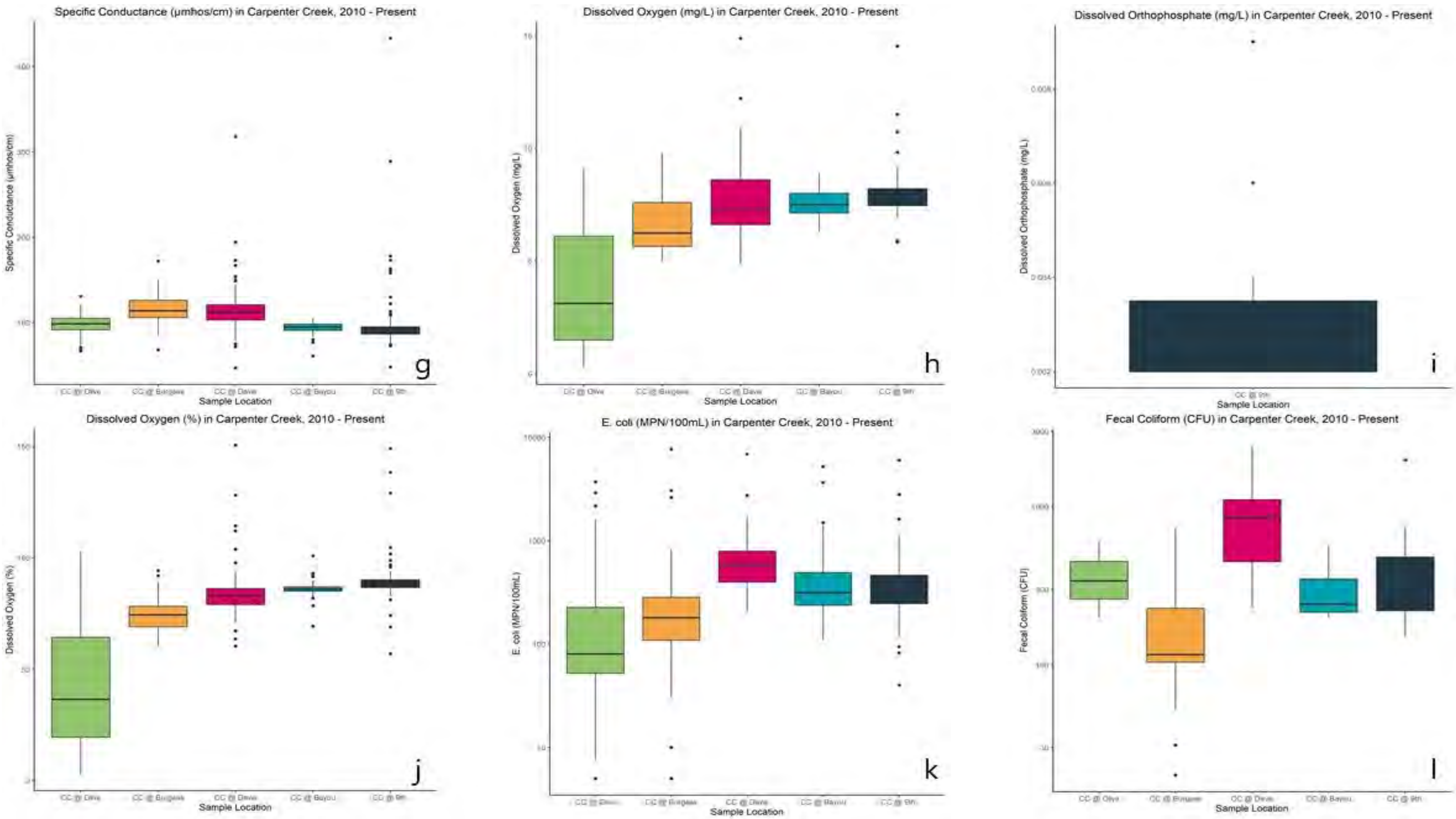
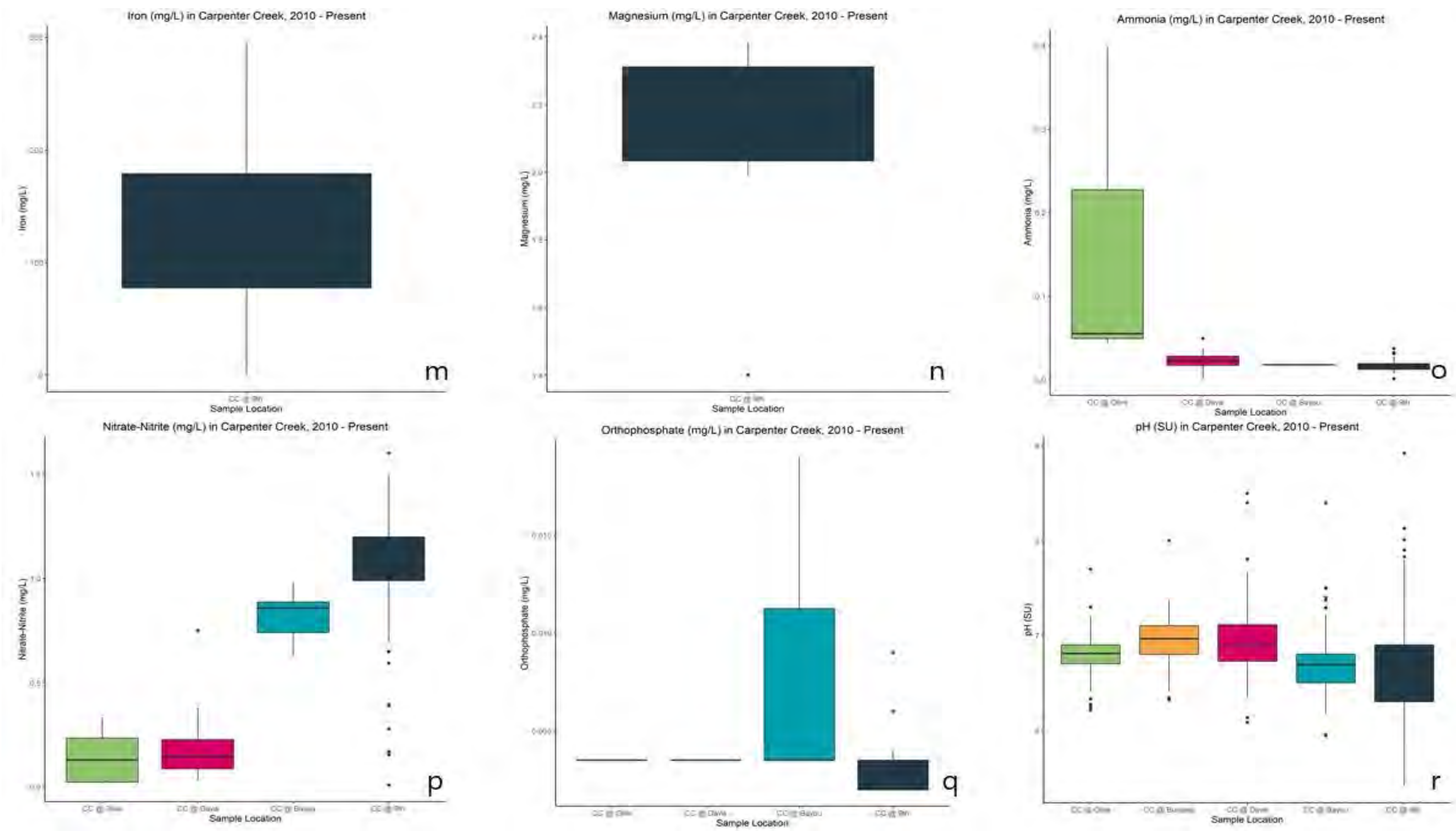
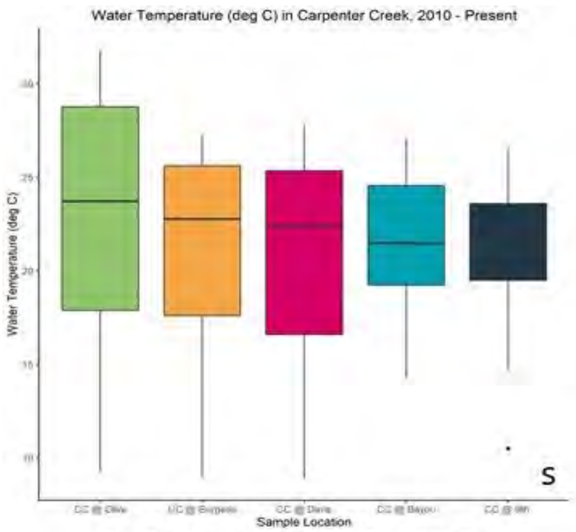


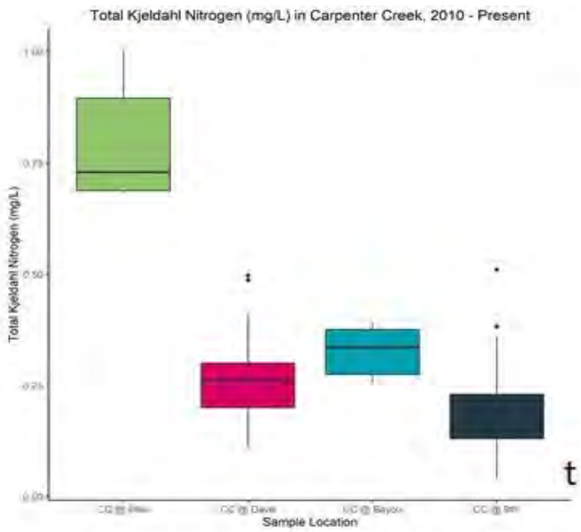
Figure Set B2.5: a-x. Box plots of Carpenter Creek (WBID 676) using data from 2010-Present.

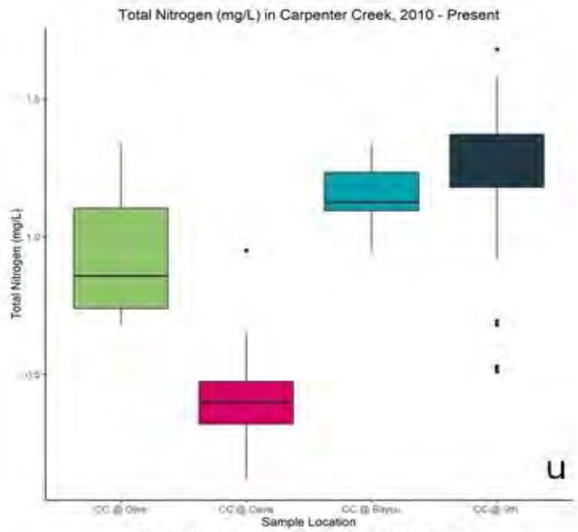


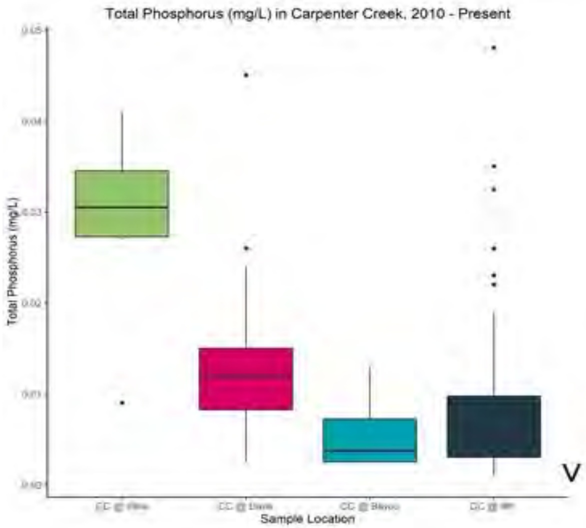

Specific Conductance (µmhos/cm) in Carpenter Creek, 2010 - Present
Specific Conductance (µmhos/cm)
Sample Location
g
Dissolved Oxygen (mg/L) in Carpenter Creek, 2010 - Present
Dissolved Oxygen (mg/L)
Sample Location
h
Dissolved Orthophosphate (mg/L) in Carpenter Creek, 2010 - Present
Dissolved Orthophosphate (mg/L)
Sample Location
i
Dissolved Oxygen (%) in Carpenter Creek, 2010 - Present
Dissolved Oxygen (%)
Sample Location
j
E. coli (MPN/100mL) in Carpenter Creek, 2010 - Present
E. coli (MPN/100mL)
Sample Location
k
Fecal Coliform (CFU) in Carpenter Creek, 2010 - Present
Fecal Coliform (CFU)
Sample Location
l

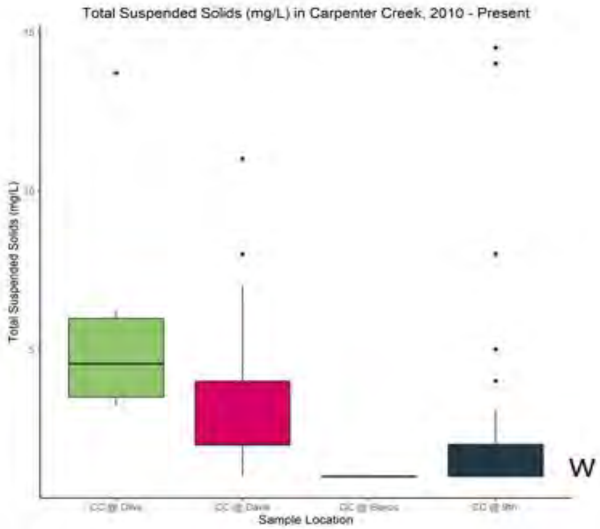

Iron (mg/L) in Carpenter Creek, 2010 - Present
Iron (mg/L)
Sample Location
m
Magnesium (mg/L) in Carpenter Creek, 2010 - Present
Magnesium (mg/L)
Sample Location
n
Ammonia (mg/L) in Carpenter Creek, 2010 - Present
Ammonia (mg/L)
Sample Location
o
Nitrate-Nitrite (mg/L) in Carpenter Creek, 2010 - Present
Nitrate-Nitrite (mg/L)
Sample Location
p
Orthophosphate (mg/L) in Carpenter Creek, 2010 - Present
Orthophosphate (mg/L)
Sample Location
q
pH (SU) in Carpenter Creek, 2010 - Present
pH (SU)
Sample Location
r


Water Temperature (deg C) in Carpenter Creek, 2010 - Present
Water Temperature (deg C)
CC @ Olive
CC @ Burgess
CC @ Davis
CC @ Bayou
CC @ 9th
Sample Location
s


Total Kjeldahl Nitrogen (mg/L) in Carpenter Creek, 2010 - Present
Total Kjeldahl Nitrogen (mg/L)
CC @ Olive
CC @ Davis
CC @ Bayou
CC @ 9th
Sample Location
t


Total Nitrogen (mg/L) in Carpenter Creek, 2010 - Present
Total Nitrogen (mg/L)
CC @ Olive
CC @ Davis
CC @ Bayou
CC @ 9th
Sample Location
u


Total Phosphorus (mg/L) in Carpenter Creek, 2010 - Present
Total Phosphorus (mg/L)
CC @ Olive
CC @ Davis
CC @ Bayou
CC @ 9th
Sample Location
v


Total Suspended Solids (mg/L) in Carpenter Creek, 2010 - Present
Total Suspended Solids (mg/L)
CC @ Olive
CC @ Davis
CC @ Bayou
CC @ 9th
Sample Location
w

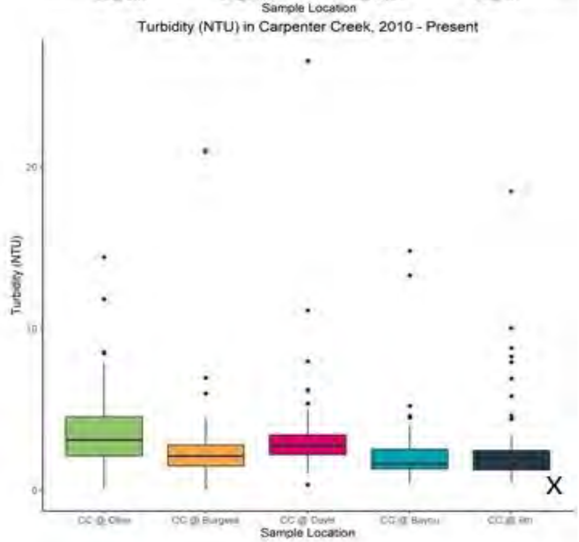
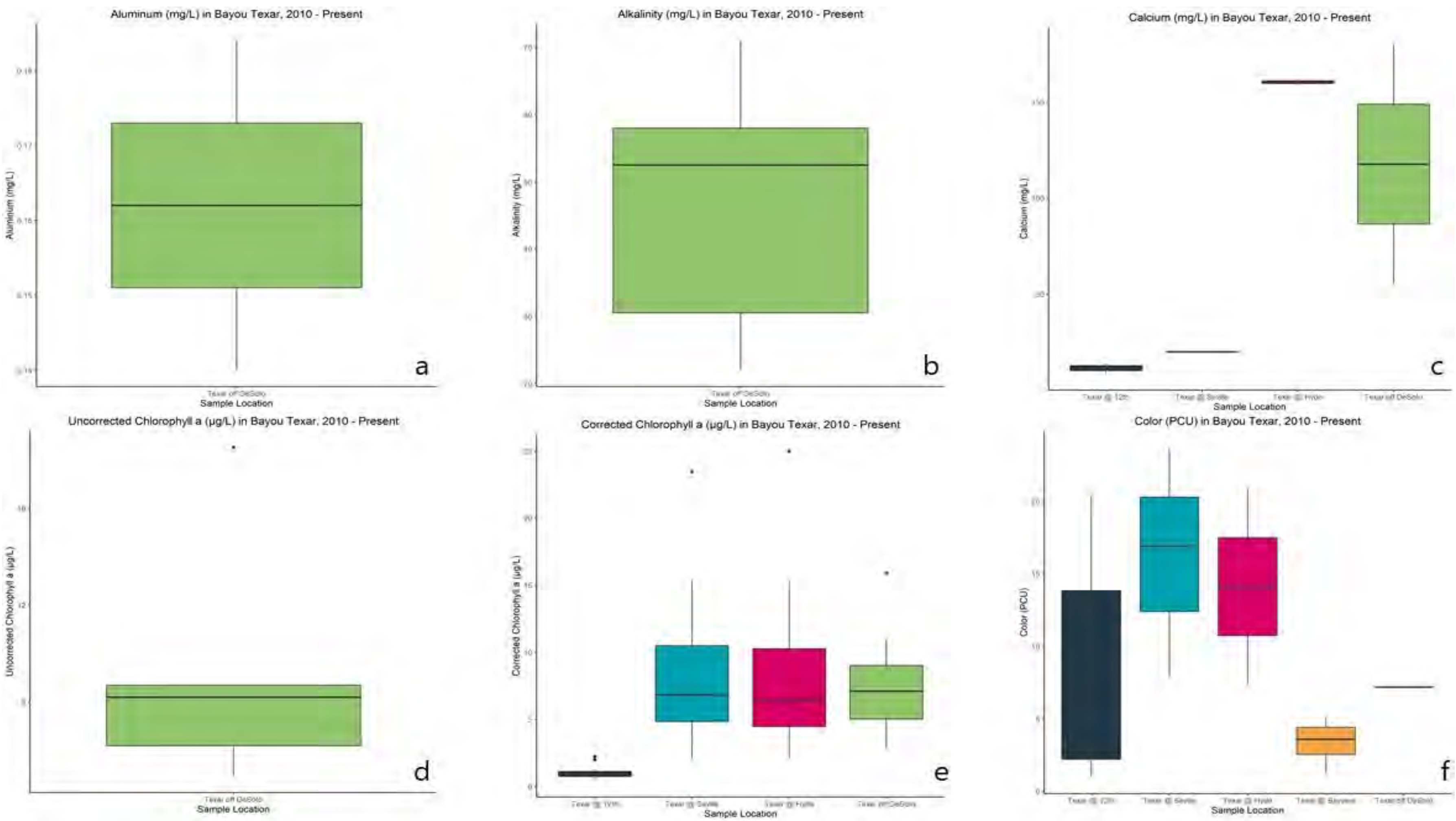
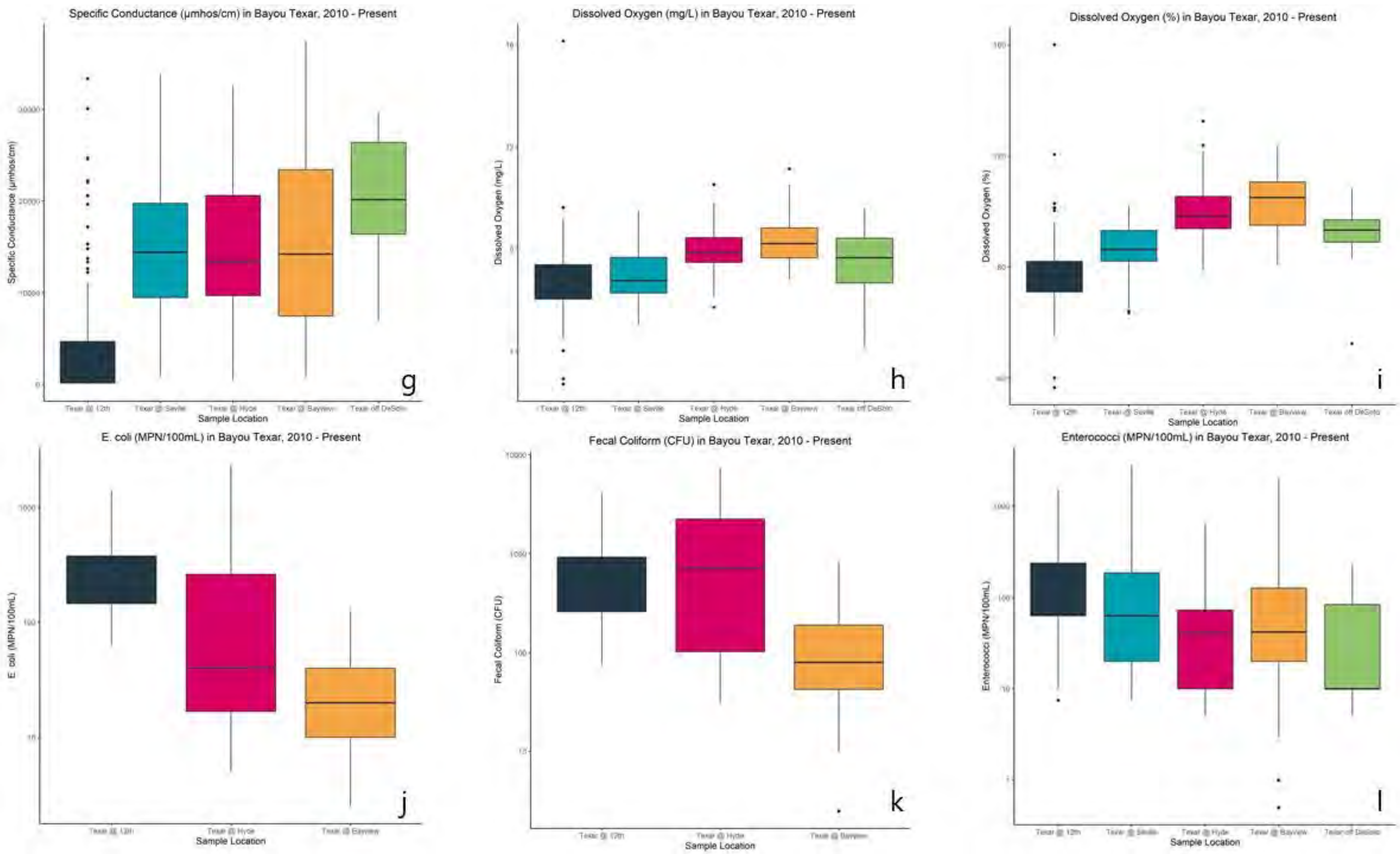
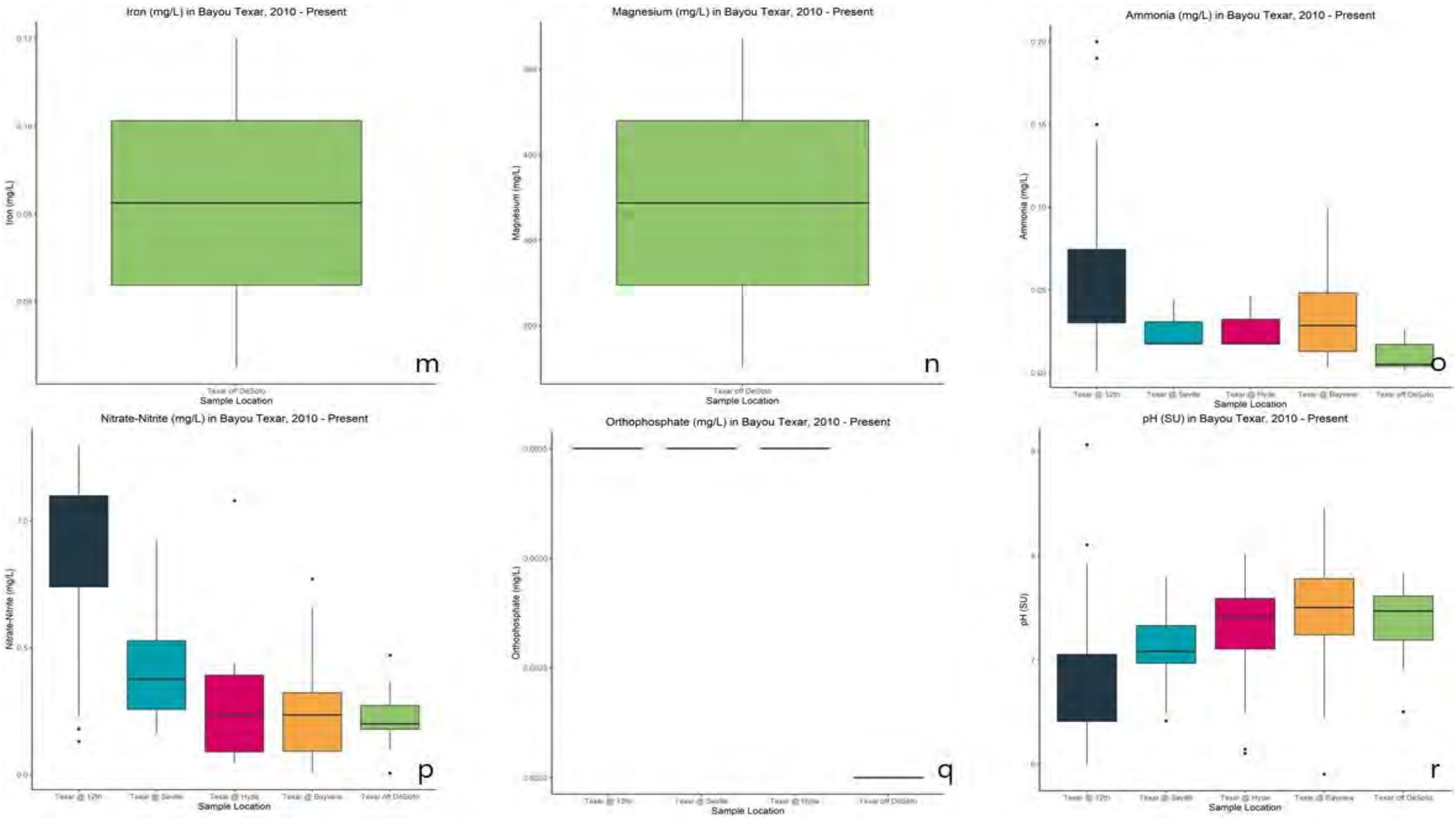

Turbidity (NTU) in Carpenter Creek, 2010 - Present
Turbidity (NTU)
CC @ Olive
CC @ Burgess
CC @ Davis
CC @ Bayou
CC @ 9th
Sample Location
x

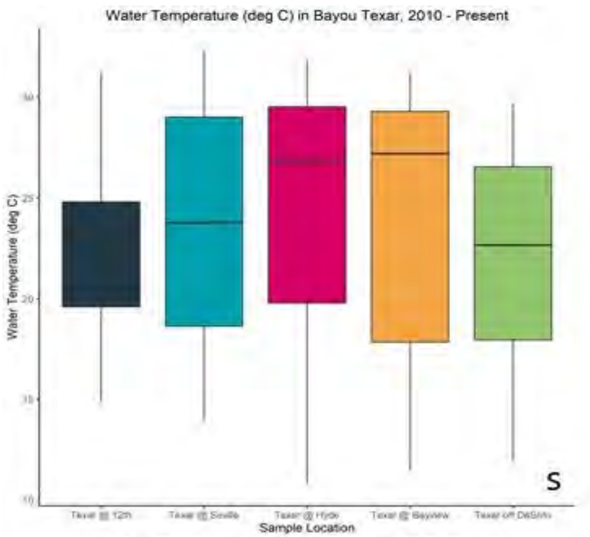
Figure Set B2.6: a-x. Box plots of Bayou Texar (WBID 738) using data from 2010-Present.

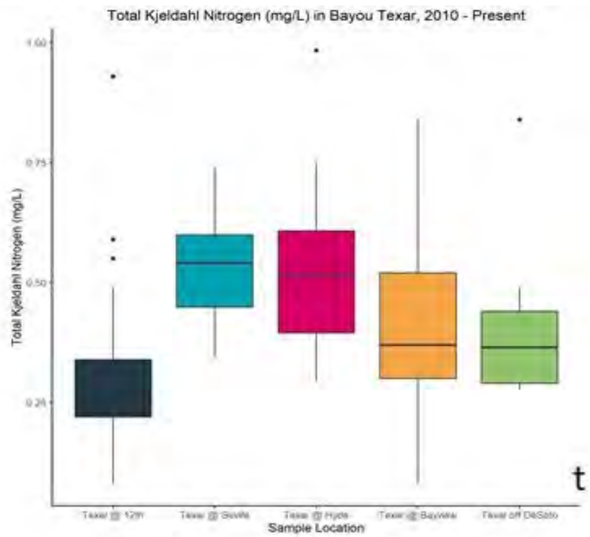


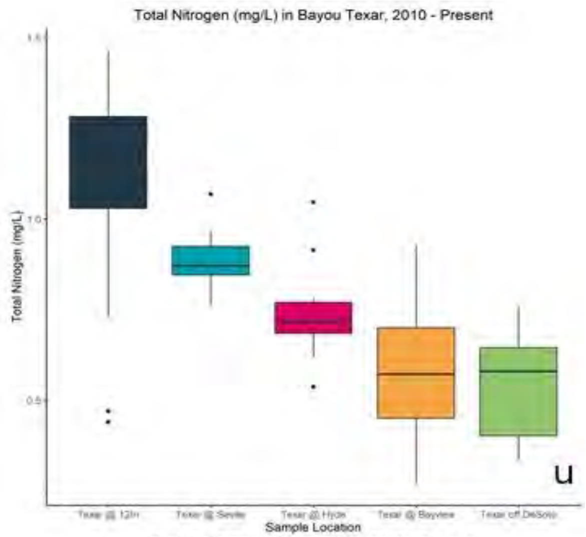

Specific Conductance (µmhos/cm) in Bayou Texar, 2010 - Present
Specific Conductance (µmhos/cm)
Sample Location
g
Dissolved Oxygen (mg/L) in Bayou Texar, 2010 - Present
Dissolved Oxygen (mg/L)
Sample Location
h
Dissolved Oxygen (%) in Bayou Texar, 2010 - Present
Dissolved Oxygen (%)
Sample Location
i
E. coli (MPN/100mL) in Bayou Texar, 2010 - Present
E. coli (MPN/100mL)
Sample Location
j
Fecal Coliform (CFU) in Bayou Texar, 2010 - Present
Fecal Coliform (CFU)
Sample Location
k
Enterococci (MPN/100mL) in Bayou Texar, 2010 - Present
Enterococci (MPN/100mL)
Sample Location
l

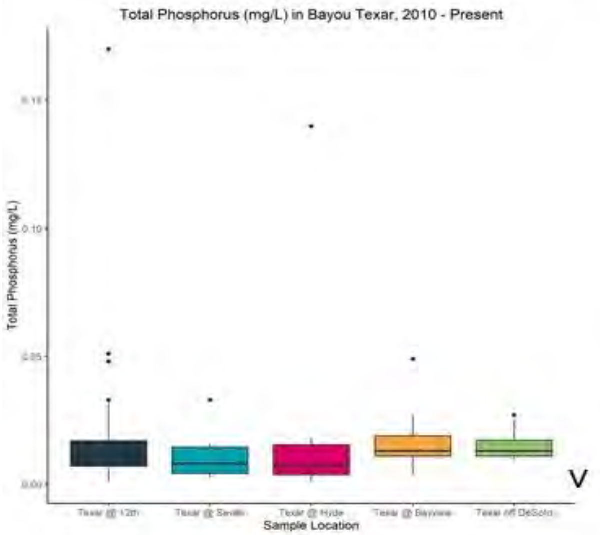
wood.

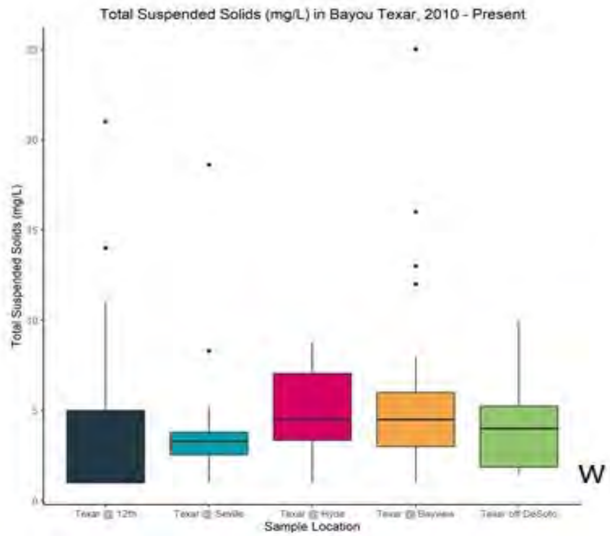

Iron (mg/L) in Bayou Texar, 2010 - Present
Iron (mg/L)
Texar off DeSoto
Sample Location
m
Magnesium (mg/L) in Bayou Texar, 2010 - Present
Magnesium (mg/L)
Texar off DeSoto
Sample Location
n
Ammonia (mg/L) in Bayou Texar, 2010 - Present
Ammonia (mg/L)
Sample Location
o
Nitrate-Nitrite (mg/L) in Bayou Texar, 2010 - Present
Nitrate-Nitrite (mg/L)
Sample Location
p
Orthophosphate (mg/L) in Bayou Texar, 2010 - Present
Orthophosphate (mg/L)
Sample Location
q
pH (SU) in Bayou Texar, 2010 - Present
pH (SU)
Sample Location
r


Water Temperature (deg C) in Bayou Texar, 2010 - Present
Water Temperature (deg C)
Sample Location
s


Total Kjeldahl Nitrogen (mg/L) in Bayou Texar, 2010 - Present
Total Kjeldahl Nitrogen (mg/L)
Sample Location
t


Total Nitrogen (mg/L) in Bayou Texar, 2010 - Present
Total Nitrogen (mg/L)
Sample Location
u


Total Phosphorus (mg/L) in Bayou Texar, 2010 - Present
Total Phosphorus (mg/L)
Sample Location
v


Total Suspended Solids (mg/L) in Bayou Texar, 2010 - Present
Total Suspended Solids (mg/L)
Sample Location
w

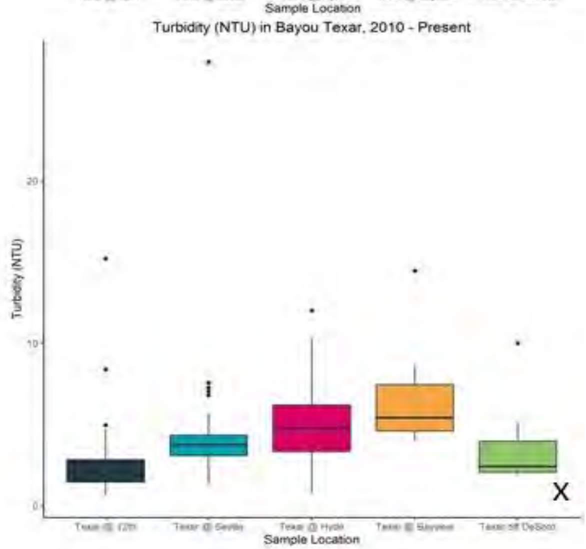
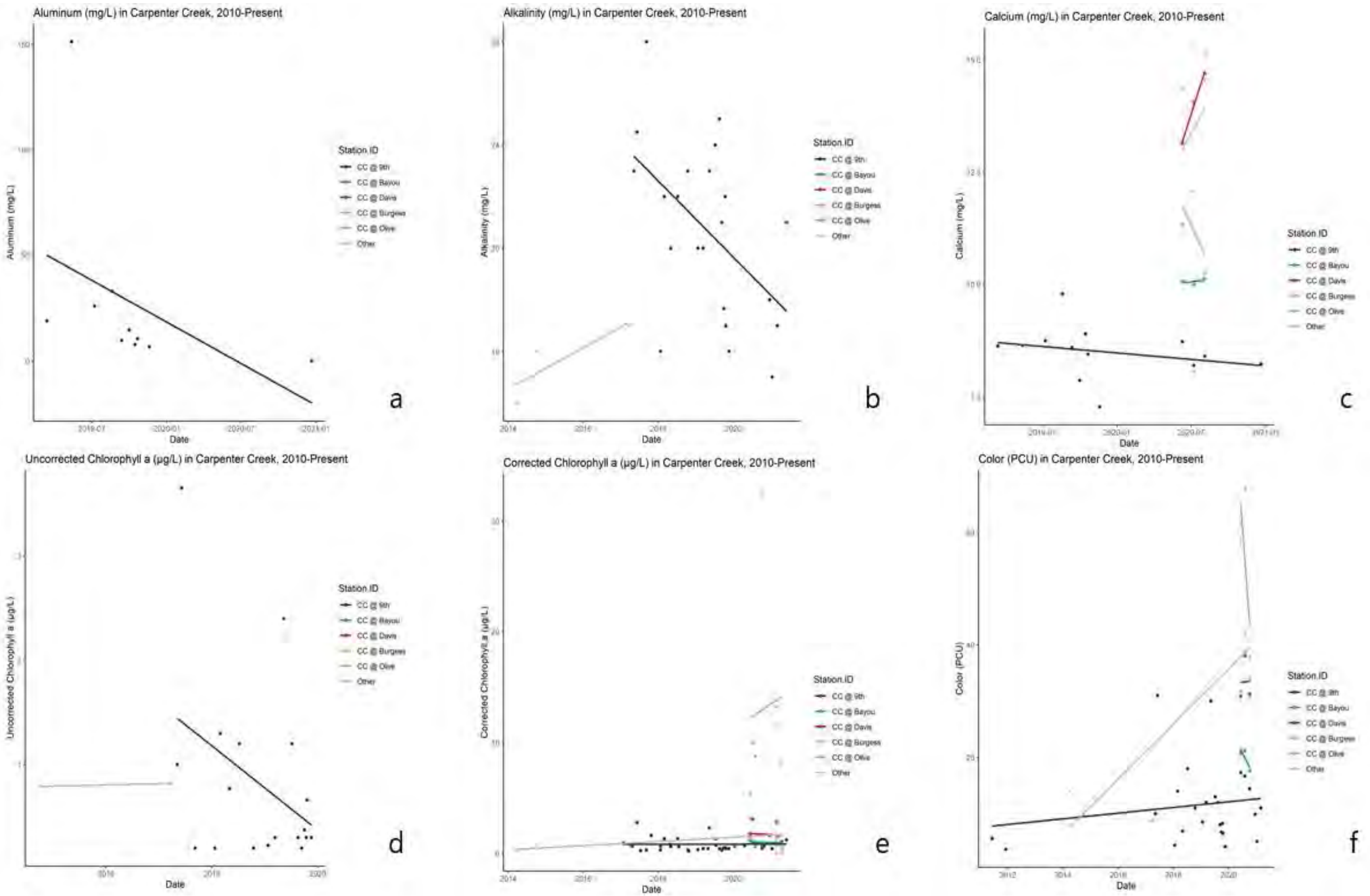
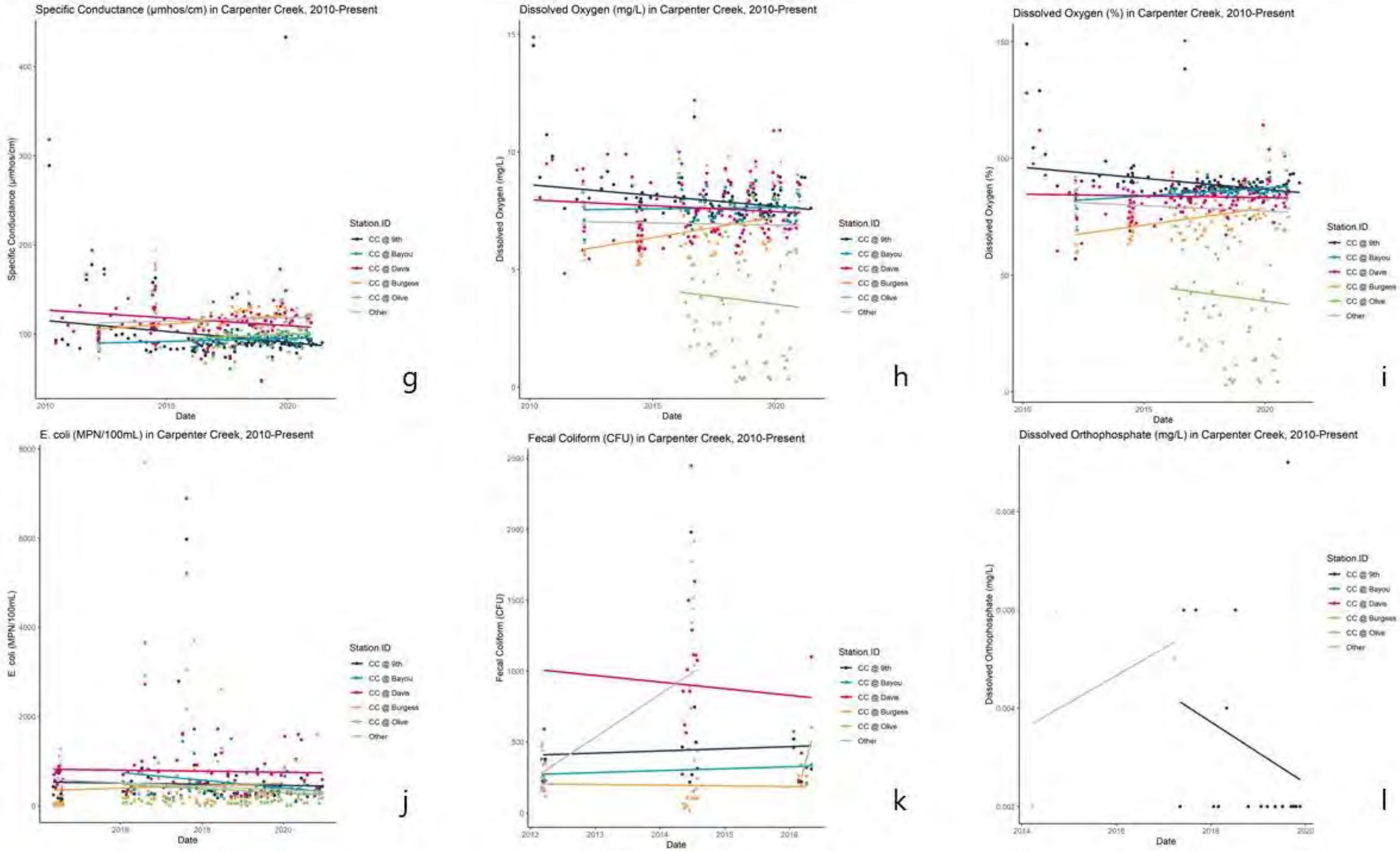
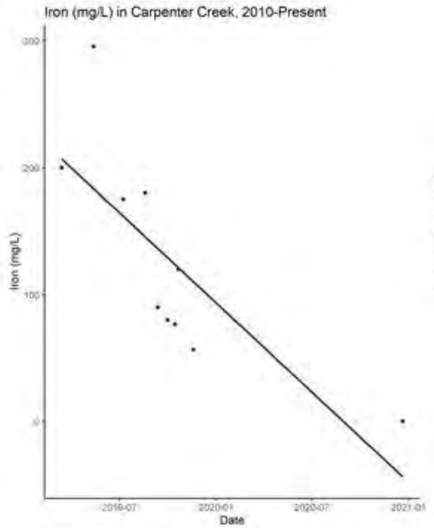

Turbidity (NTU) in Bayou Texar, 2010 - Present
Turbidity (NTU)
Sample Location
x

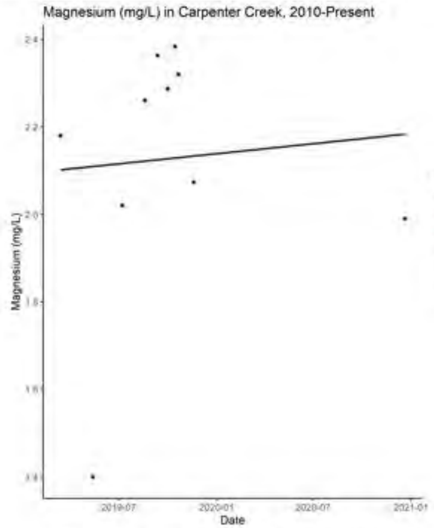
Figure Set B2.7: a-x. Time series of Carpenter Creek (WBID 676) using data from 2010-Present.



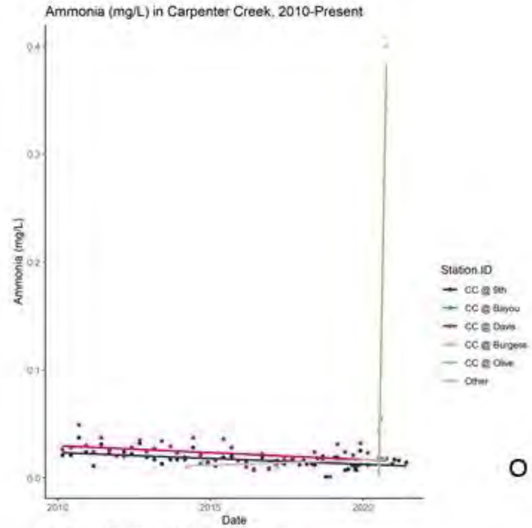

Specific Conductance (µmhos/cm) in Carpenter Creek, 2010-Present
Specific Conductance (µmhos/cm)
Date
g
Dissolved Oxygen (mg/L) in Carpenter Creek, 2010-Present
Dissolved Oxygen (mg/L)
Date
h
Dissolved Oxygen (%) in Carpenter Creek, 2010-Present
Dissolved Oxygen (%)
Date
i
E. coli (MPN/100mL) in Carpenter Creek, 2010-Present
E. coli (MPN/100mL)
Date
j
Fecal Coliform (CFU) in Carpenter Creek, 2010-Present
Fecal Coliform (CFU)
Date
k
Dissolved Orthophosphate (mg/L) in Carpenter Creek, 2010-Present
Dissolved Orthophosphate (mg/L)
Date
l
Station.ID
CC @ 9th
CC @ Bayou
CC @ Davis
CC @ Burgess
CC @ Olive
Other


Iron (mg/L) in Carpenter Creek, 2010-Present
Iron (mg/L)
Date
Station ID
CC @ 9th
CC @ Bayou
CC @ Davis
CC @ Burgess
CC @ Olive
Other

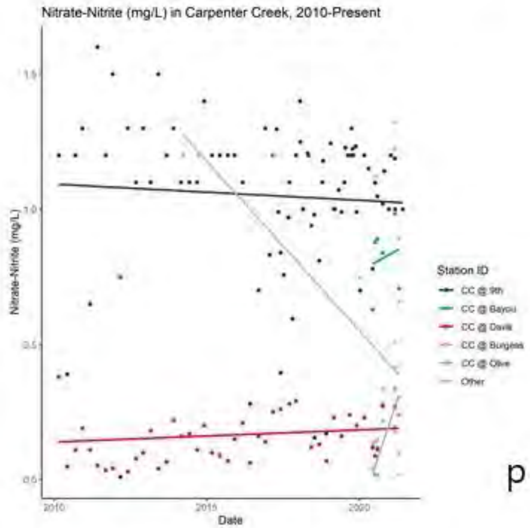
m


Magnesium (mg/L) in Carpenter Creek, 2010-Present
Magnesium (mg/L)
Date
Station ID
CC @ 9th
CC @ Bayou
CC @ Davis
CC @ Burgess
CC @ Olive
Other

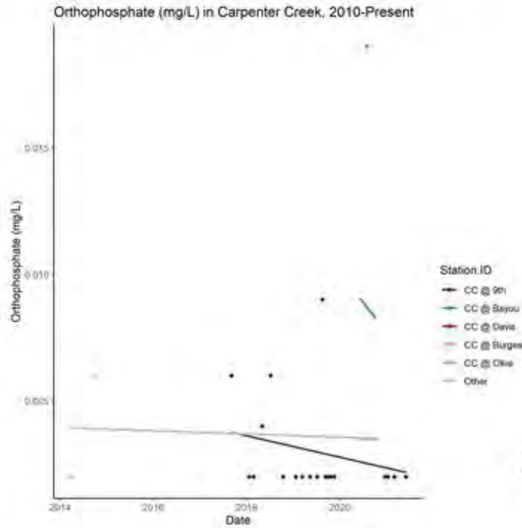
n


Ammonia (mg/L) in Carpenter Creek, 2010-Present
Ammonia (mg/L)
Date
Station ID
CC @ 9th
CC @ Bayou
CC @ Davis
CC @ Burgess
CC @ Olive
Other

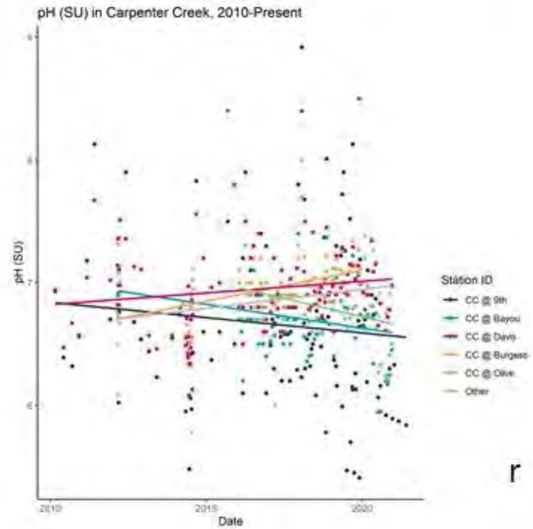
o


Nitrate-Nitrite (mg/L) in Carpenter Creek, 2010-Present
Nitrate-Nitrite (mg/L)
Date
Station ID
CC @ 9th
CC @ Bayou
CC @ Davis
CC @ Burgess
CC @ Olive
Other

p

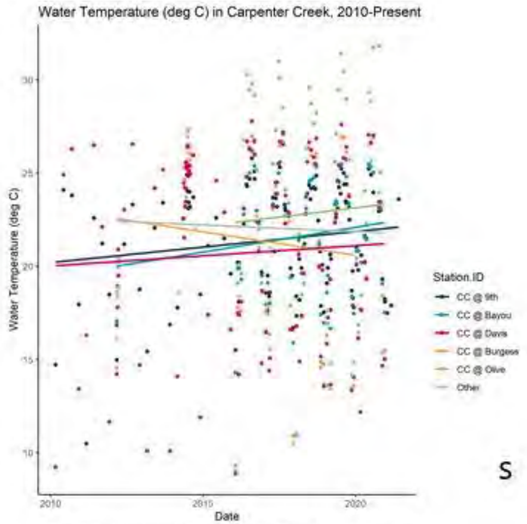

Orthophosphate (mg/L) in Carpenter Creek, 2010-Present
Orthophosphate (mg/L)
Date
Station ID
CC @ 9th
CC @ Bayou
CC @ Davis
CC @ Burgess
CC @ Olive
Other

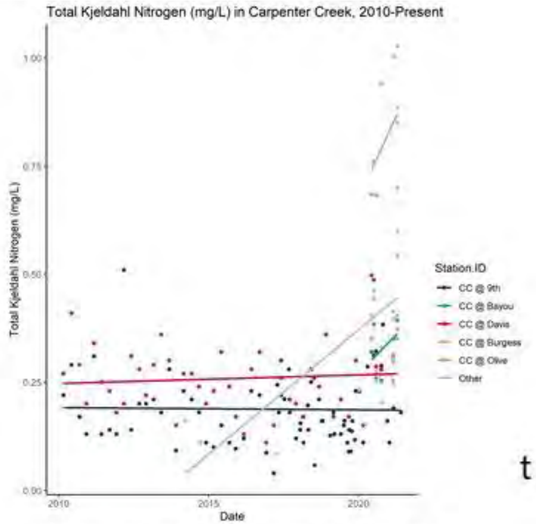
q

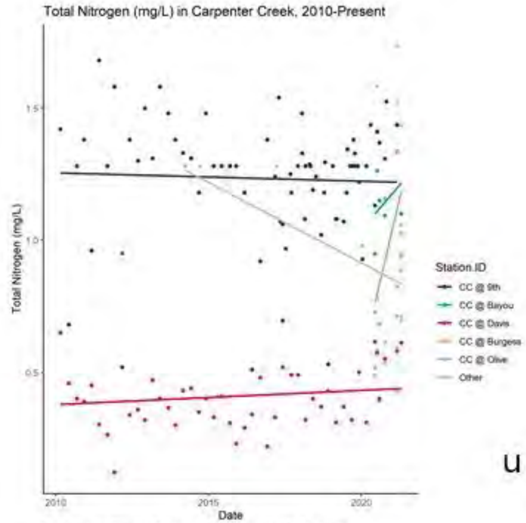

pH (SU) in Carpenter Creek, 2010-Present
pH (SU)
Date
Station ID
CC @ 9th
CC @ Bayou
CC @ Davis
CC @ Burgess
CC @ Olive
Other

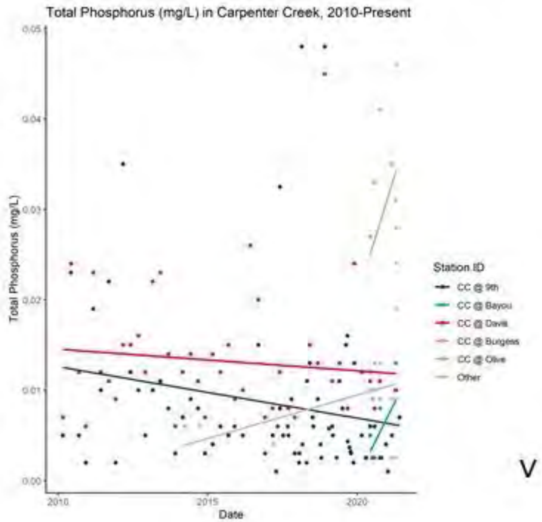
r

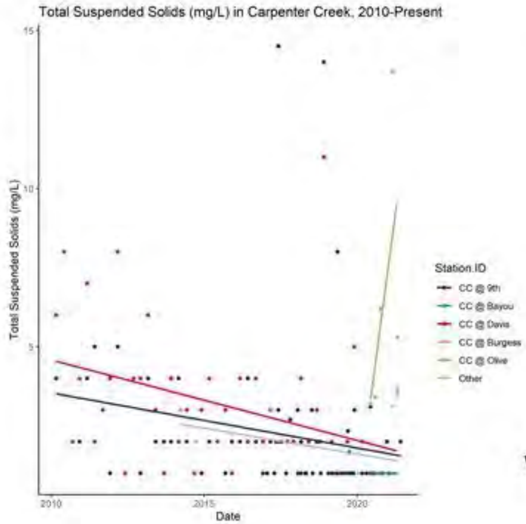
wood.


Water Temperature (deg C) in Carpenter Creek, 2010-Present
Water Temperature (deg C)
Date
Station.ID
CC @ 9th
CC @ Bayou
CC @ Davis
CC @ Burgess
CC @ Olive
Other
s


Total Kjeldahl Nitrogen (mg/L) in Carpenter Creek, 2010-Present
Total Kjeldahl Nitrogen (mg/L)
Date
Station.ID
CC @ 9th
CC @ Bayou
CC @ Davis
CC @ Burgess
CC @ Olive
Other
t


Total Nitrogen (mg/L) in Carpenter Creek, 2010-Present
Total Nitrogen (mg/L)
Date
Station.ID
CC @ 9th
CC @ Bayou
CC @ Davis
CC @ Burgess
CC @ Olive
Other
u


Total Phosphorus (mg/L) in Carpenter Creek, 2010-Present
Total Phosphorus (mg/L)
Date
Station.ID
CC @ 9th
CC @ Bayou
CC @ Davis
CC @ Burgess
CC @ Olive
Other
v


Total Suspended Solids (mg/L) in Carpenter Creek, 2010-Present
Total Suspended Solids (mg/L)
Date
Station.ID
CC @ 9th
CC @ Bayou
CC @ Davis
CC @ Burgess
CC @ Olive
Other
w

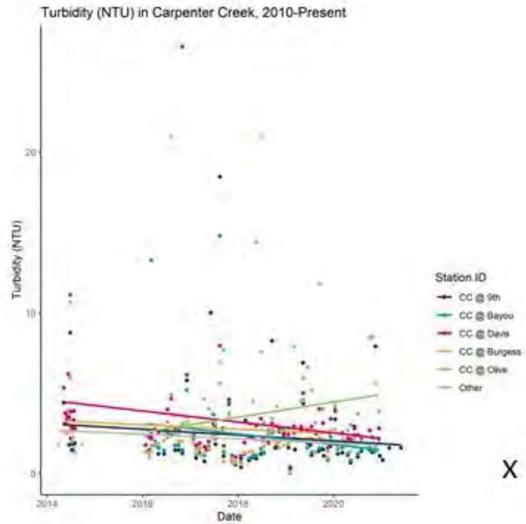
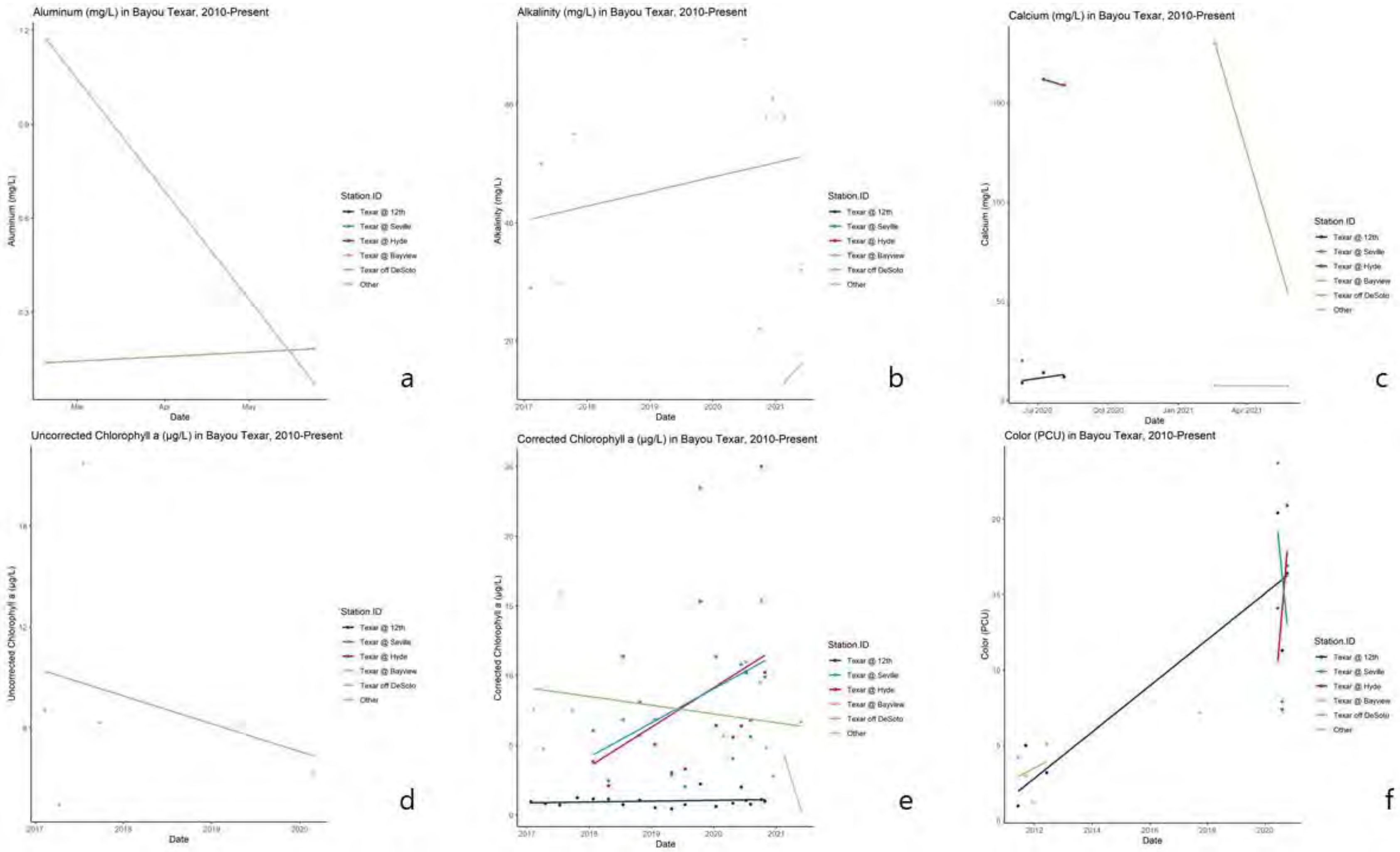
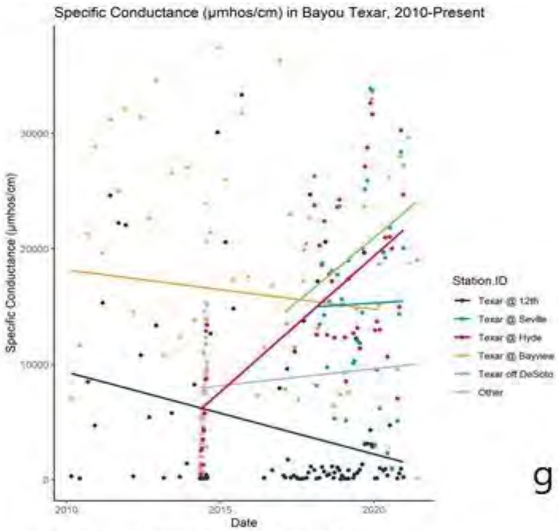
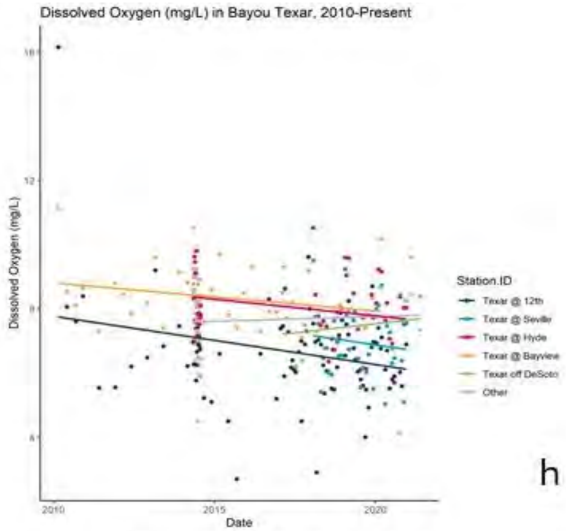
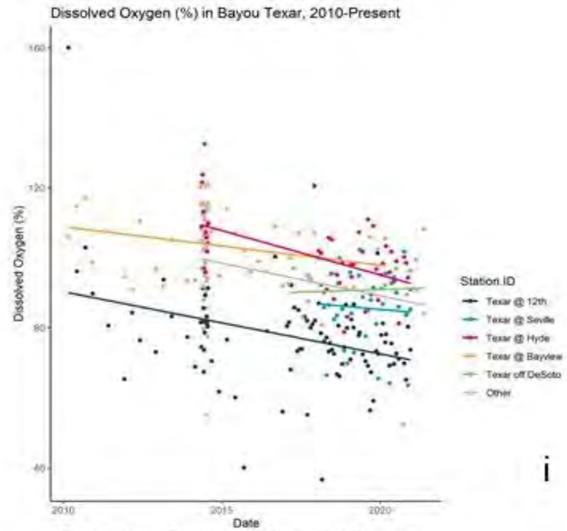

Turbidity (NTU) in Carpenter Creek, 2010-Present
Turbidity (NTU)
Date
Station.ID
CC @ 9th
CC @ Bayou
CC @ Davis
CC @ Burgess
CC @ Olive
Other
x

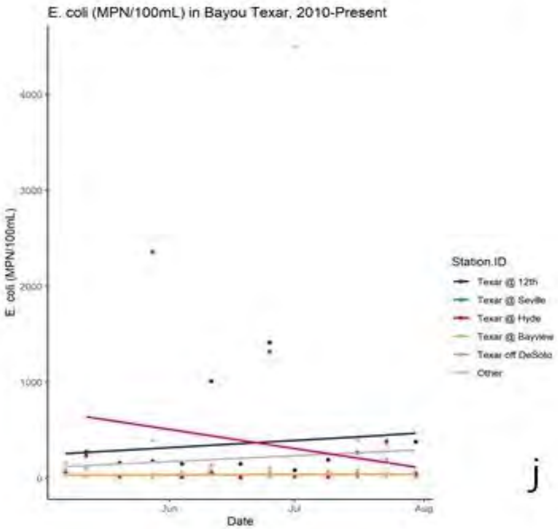
Figure Set B2.8: a-x. Time series of Bayou Texar (WBID 738) using data from 2010-Present.

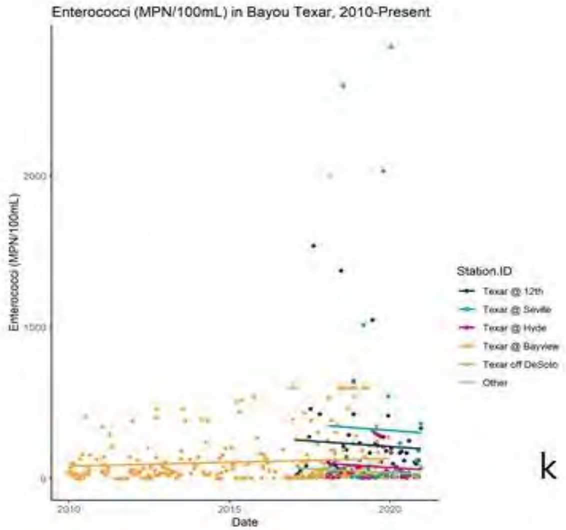


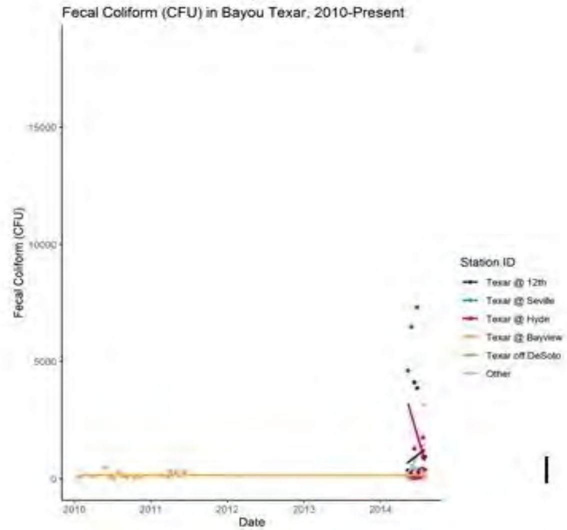

Specific Conductance (µmhos/cm) in Bayou Texar, 2010-Present
Specific Conductance (µmhos/cm)
Date
Station.ID
Texar @ 12th
Texar @ Seville
Texar @ Hyde
Texar @ Bayview
Texar off DeSoto
Other
g

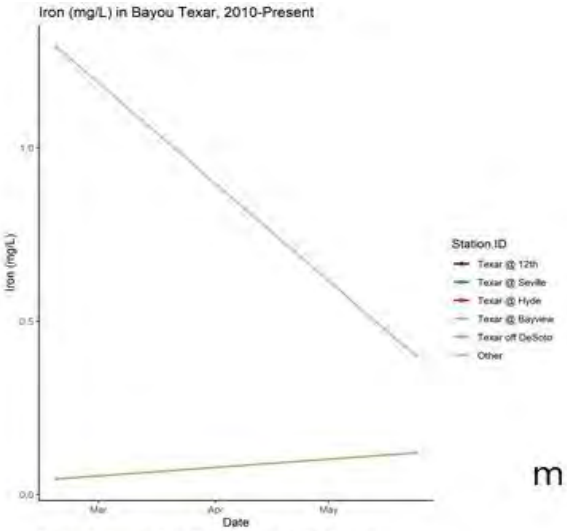

Dissolved Oxygen (mg/L) in Bayou Texar, 2010-Present
Dissolved Oxygen (mg/L)
Date
Station.ID
Texar @ 12th
Texar @ Seville
Texar @ Hyde
Texar @ Bayview
Texar off DeSoto
Other
h


Dissolved Oxygen (%) in Bayou Texar, 2010-Present
Dissolved Oxygen (%)
Date
Station.ID
Texar @ 12th
Texar @ Seville
Texar @ Hyde
Texar @ Bayview
Texar off DeSoto
Other
i

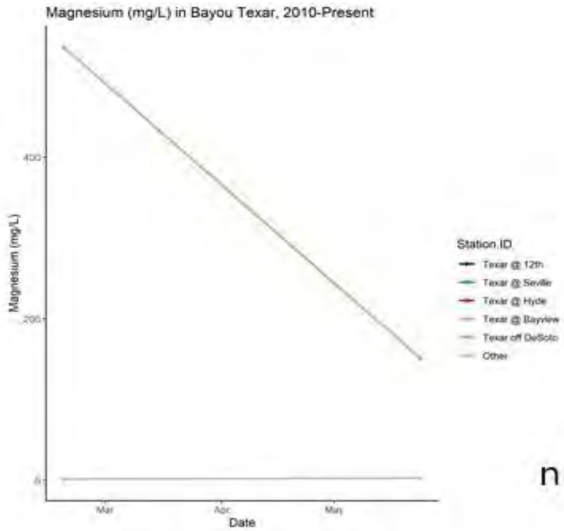

E. coli (MPN/100mL) in Bayou Texar, 2010-Present
E. coli (MPN/100mL)
Date
Station.ID
Texar @ 12th
Texar @ Seville
Texar @ Hyde
Texar @ Bayview
Texar off DeSoto
Other
j


Enterococci (MPN/100mL) in Bayou Texar, 2010-Present
Enterococci (MPN/100mL)
Date
Station.ID
Texar @ 12th
Texar @ Seville
Texar @ Hyde
Texar @ Bayview
Texar off DeSoto
Other
k

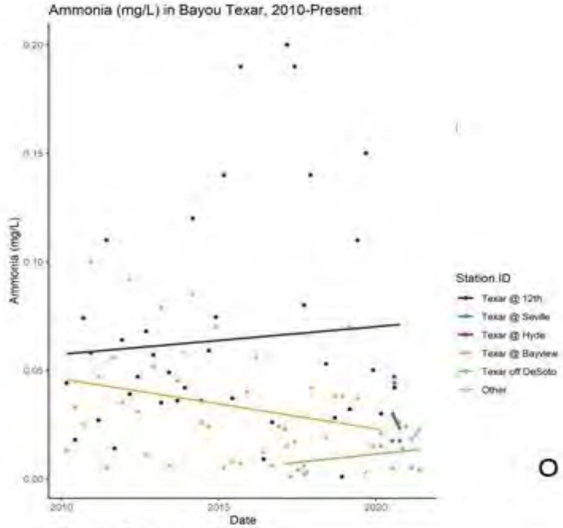

Fecal Coliform (CFU) in Bayou Texar, 2010-Present
Fecal Coliform (CFU)
Date
Station.ID
Texar @ 12th
Texar @ Seville
Texar @ Hyde
Texar @ Bayview
Texar off DeSoto
Other
l


Iron (mg/L) in Bayou Texar, 2010-Present
Iron (mg/L)
Date
Mar
Apr
May
Station.ID
Texar @ 12th
Texar @ Seville
Texar @ Hyde
Texar @ Bayview
Texar off DeSoto
Other

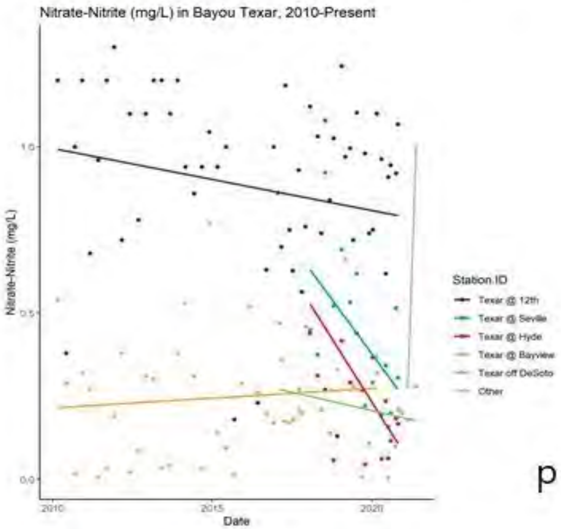
m


Magnesium (mg/L) in Bayou Texar, 2010-Present
Magnesium (mg/L)
Date
Mar
Apr
May
Station.ID
Texar @ 12th
Texar @ Seville
Texar @ Hyde
Texar @ Bayview
Texar off DeSoto
Other

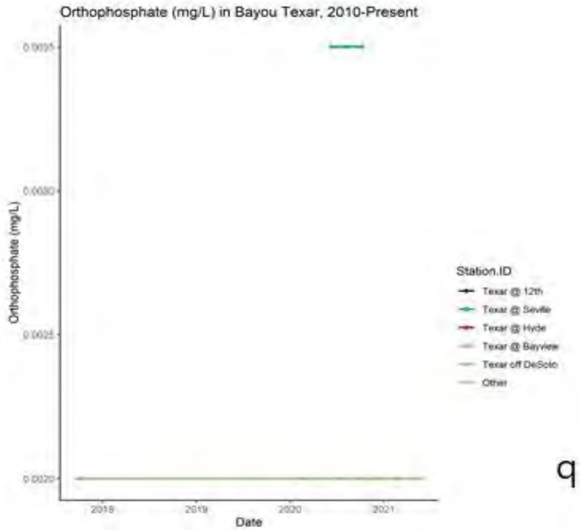
n


Ammonia (mg/L) in Bayou Texar, 2010-Present
Ammonia (mg/L)
Date
2010
2015
2020
Station.ID
Texar @ 12th
Texar @ Seville
Texar @ Hyde
Texar @ Bayview
Texar off DeSoto
Other

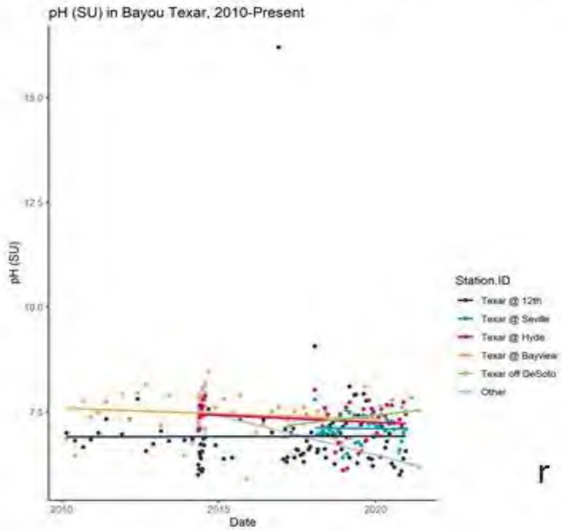
o


Nitrate-Nitrite (mg/L) in Bayou Texar, 2010-Present
Nitrate-Nitrite (mg/L)
Date
2010
2015
2020
Station.ID
Texar @ 12th
Texar @ Seville
Texar @ Hyde
Texar @ Bayview
Texar off DeSoto
Other

p

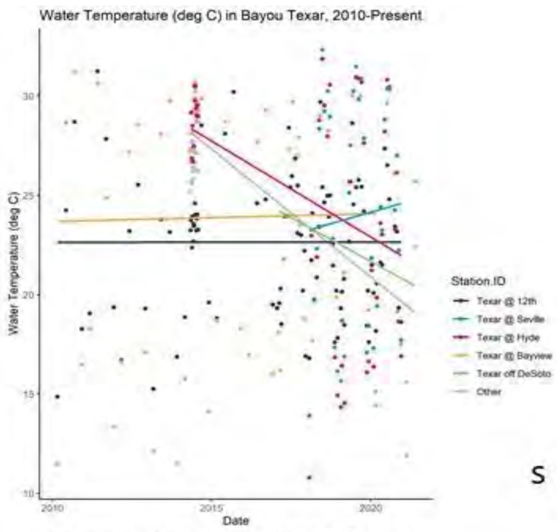

Orthophosphate (mg/L) in Bayou Texar, 2010-Present
Orthophosphate (mg/L)
Date
2018
2019
2020
2021
Station.ID
Texar @ 12th
Texar @ Seville
Texar @ Hyde
Texar @ Bayview
Texar off DeSoto
Other

q

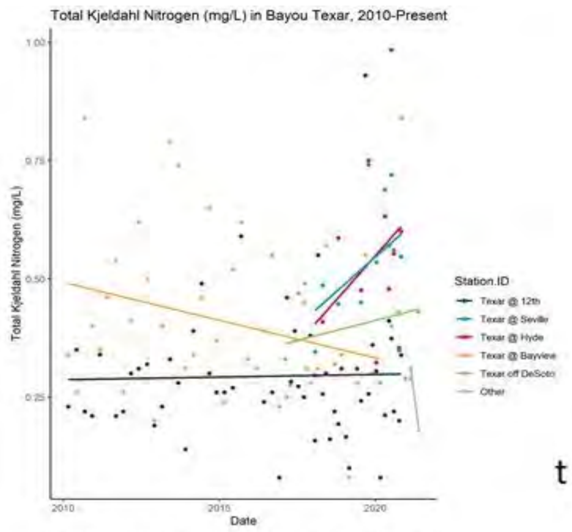

pH (SU) in Bayou Texar, 2010-Present
pH (SU)
Date
2010
2015
2020
Station.ID
Texar @ 12th
Texar @ Seville
Texar @ Hyde
Texar @ Bayview
Texar off DeSoto
Other

r

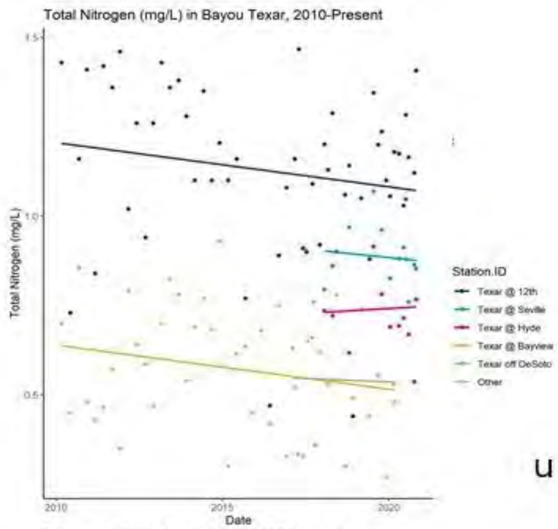
wood.



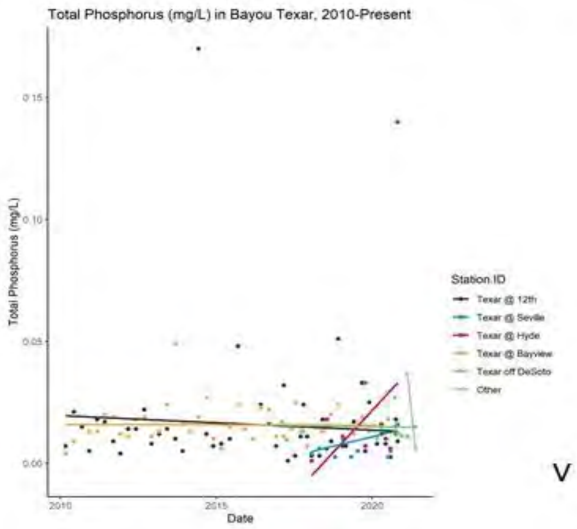
Water Temperature (deg C) in Bayou Texar, 2010-Present
Water Temperature (deg C)
Date
Station.ID
Texar @ 12th
Texar @ Seville
Texar @ Hyde
Texar @ Bayview
Texar off DeSoto
Other
s



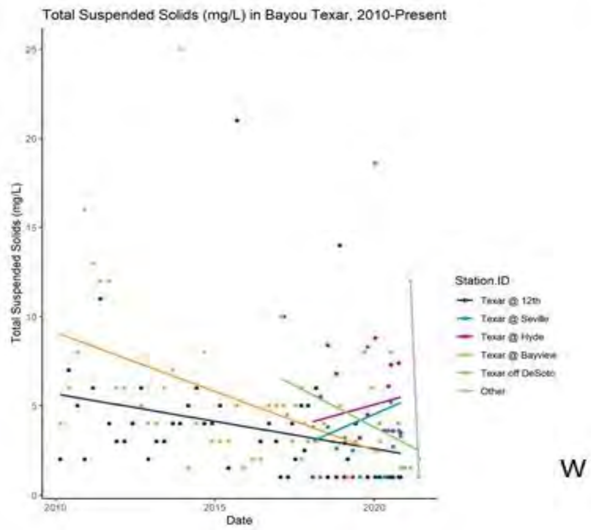
Total Kjeldahl Nitrogen (mg/L) in Bayou Texar, 2010-Present
Total Kjeldahl Nitrogen (mg/L)
Date
Station.ID
Texar @ 12th
Texar @ Seville
Texar @ Hyde
Texar @ Bayview
Texar off DeSoto
Other
t



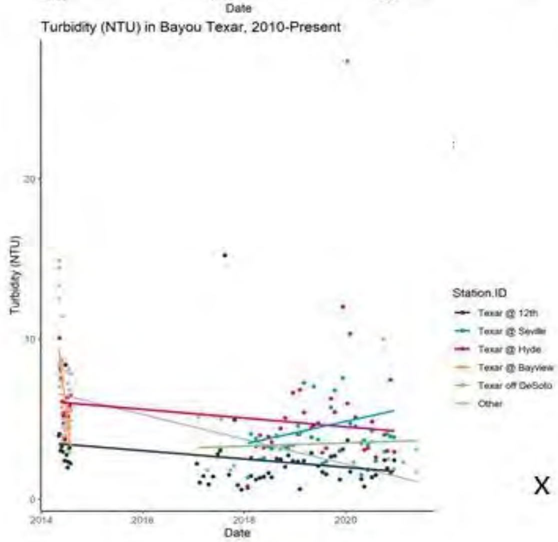
Total Nitrogen (mg/L) in Bayou Texar, 2010-Present
Total Nitrogen (mg/L)
Date
Station.ID
Texar @ 12th
Texar @ Seville
Texar @ Hyde
Texar @ Bayview
Texar off DeSoto
Other
u



Total Phosphorus (mg/L) in Bayou Texar, 2010-Present
Total Phosphorus (mg/L)
Date
Station.ID
Texar @ 12th
Texar @ Seville
Texar @ Hyde
Texar @ Bayview
Texar off DeSoto
Other
v



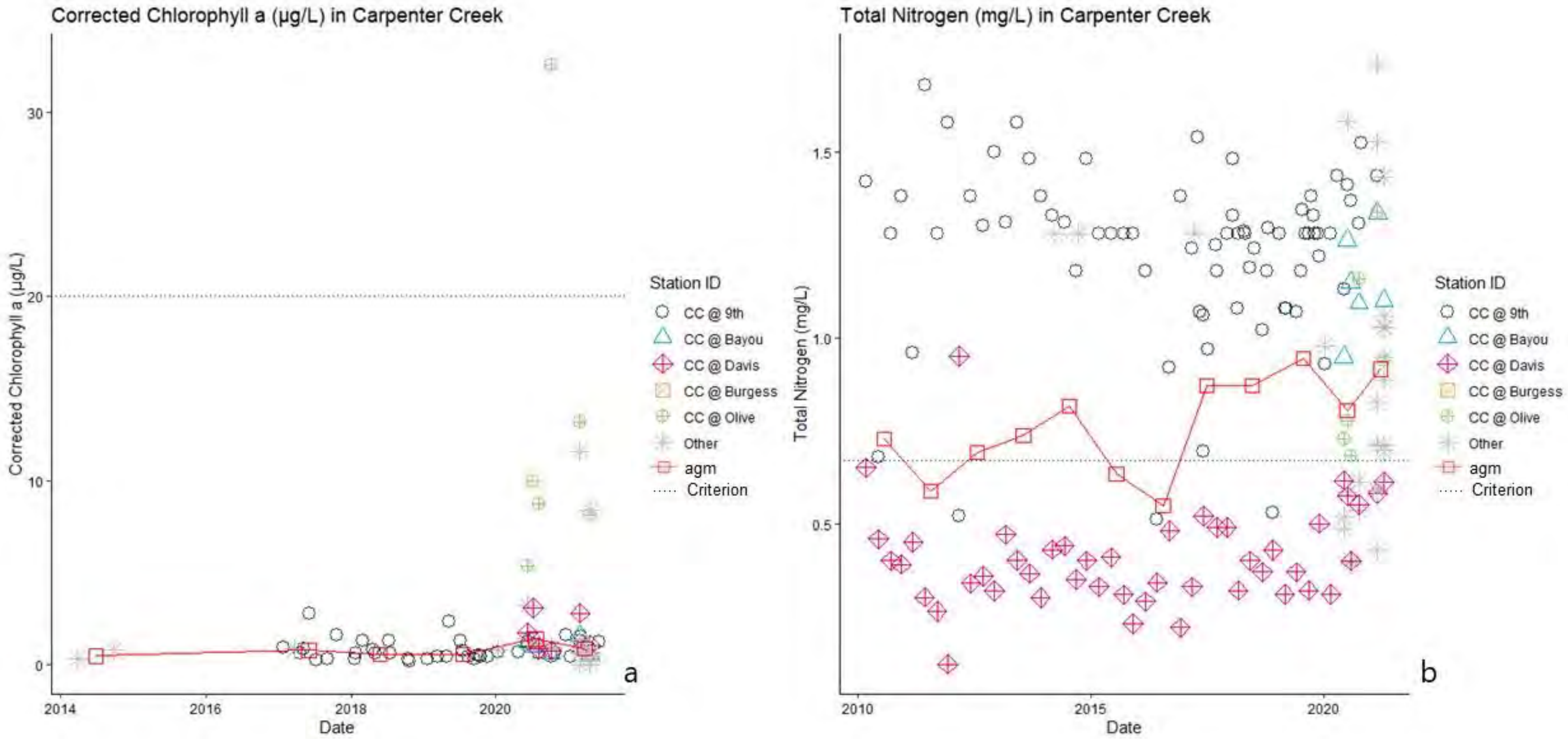
Total Suspended Solids (mg/L) in Bayou Texar, 2010-Present
Total Suspended Solids (mg/L)
Date
Station.ID
Texar @ 12th
Texar @ Seville
Texar @ Hyde
Texar @ Bayview
Texar off DeSoto
Other
w

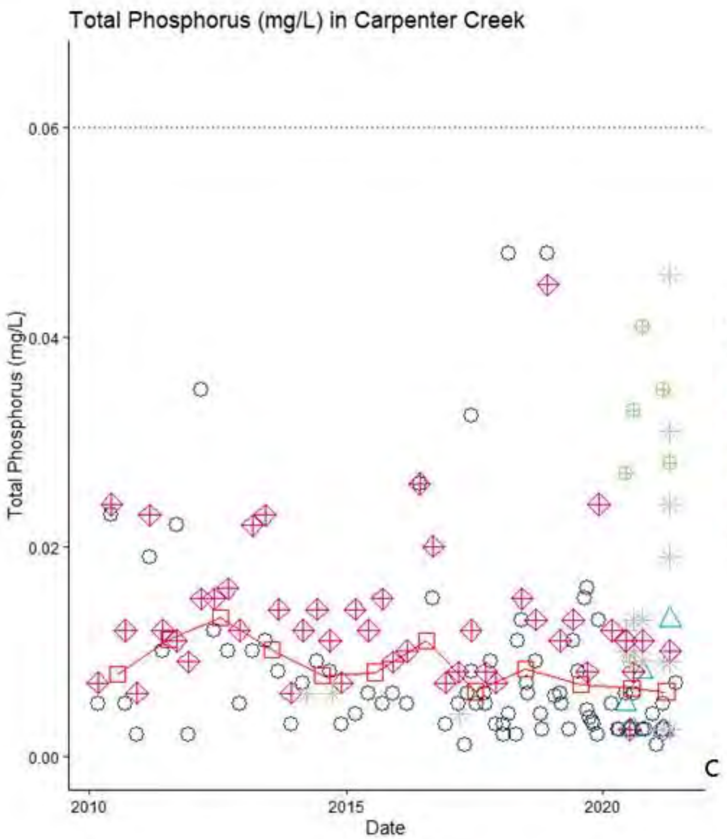


Turbidity (NTU) in Bayou Texar, 2010-Present
Turbidity (NTU)
Date
Station.ID
Texar @ 12th
Texar @ Seville
Texar @ Hyde
Texar @ Bayview
Texar off DeSoto
Other
x

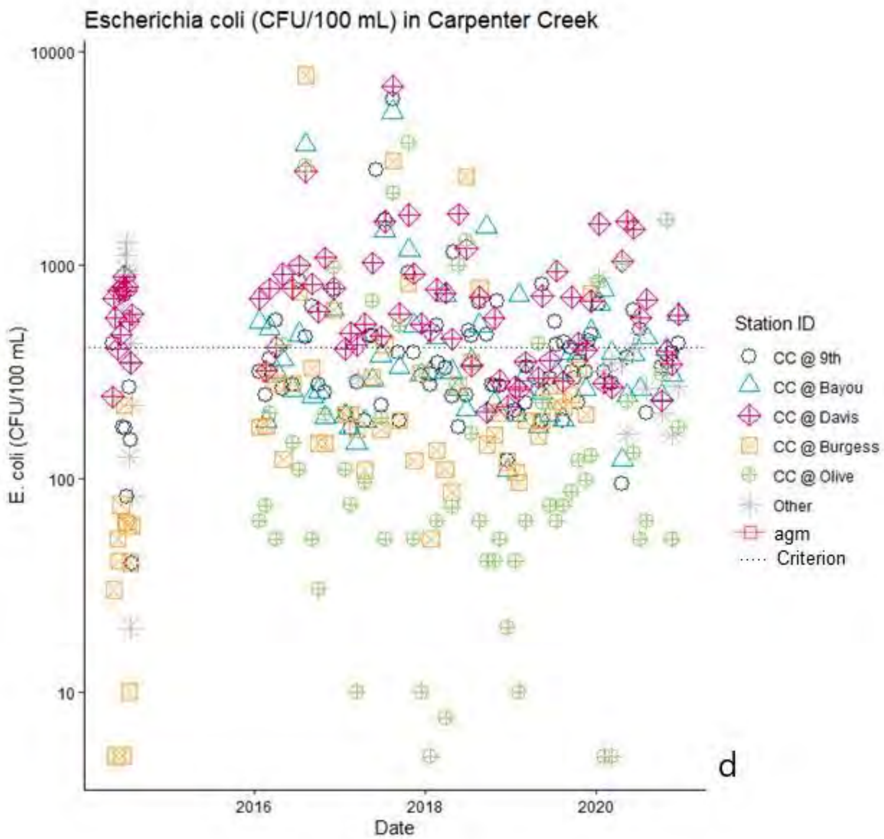
wood.

Figure Set B2.9: a-d. Time series and annual geometric means (AGMs) of Carpenter Creek compared to the water quality criteria.



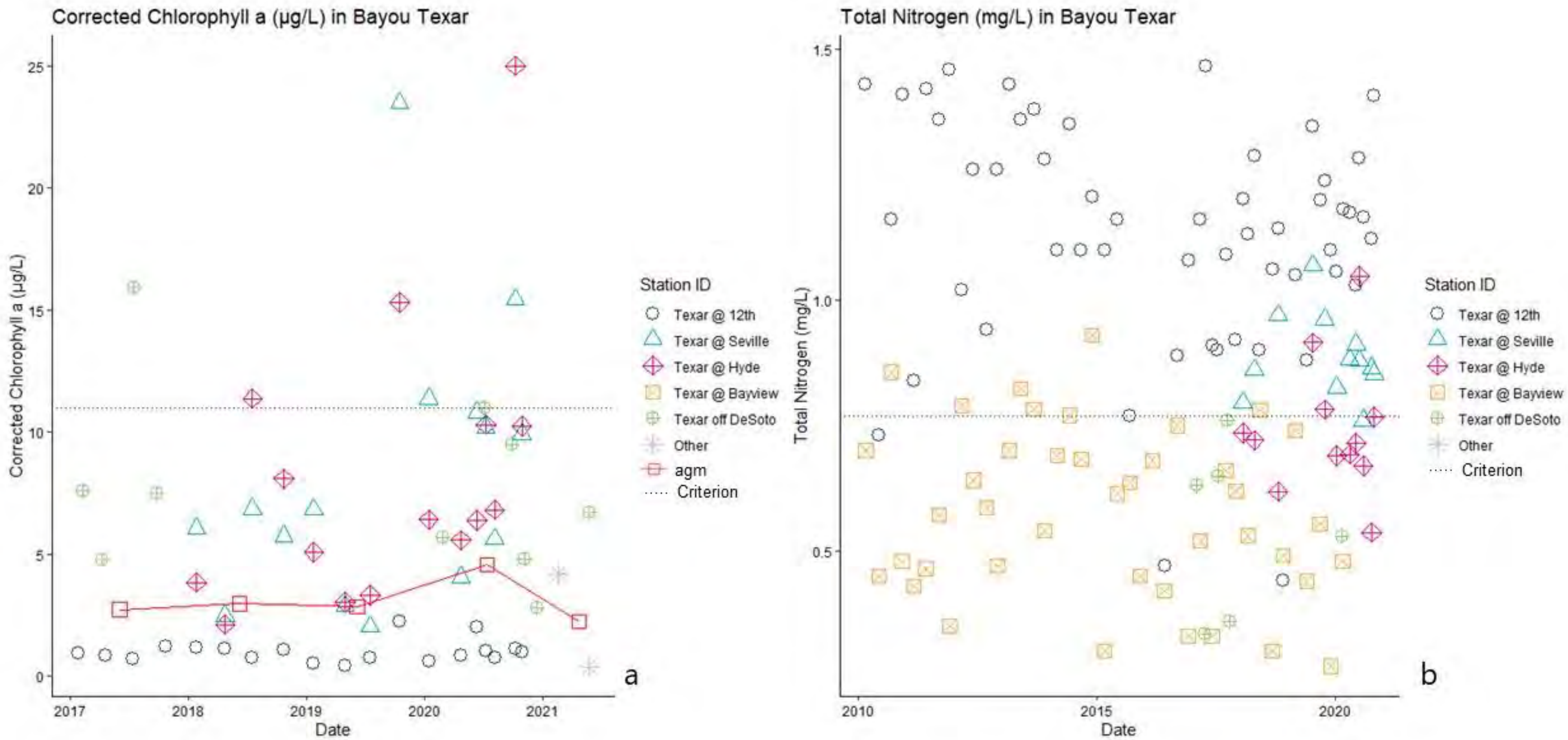


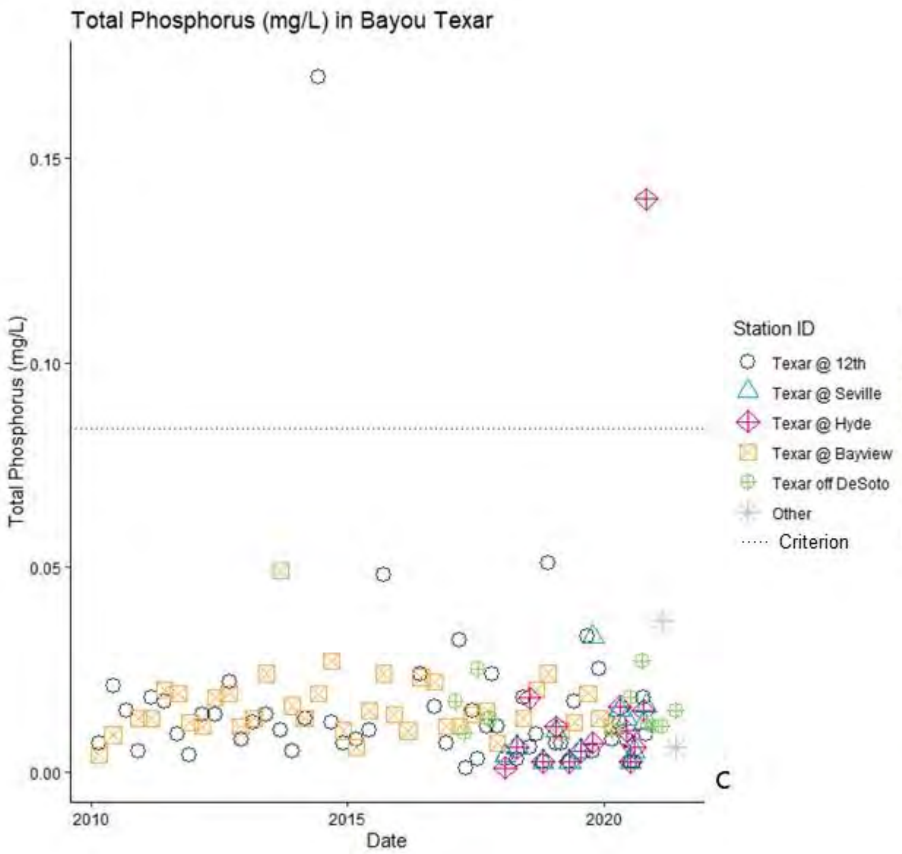
Total Phosphorus (mg/L) in Carpenter Creek
Total Phosphorus (mg/L)
0.06
0.04
0.02
0.00
2010
2015
2020
Date
Station ID
CC @ 9th
CC @ Bayou
CC @ Davis
CC @ Burgess
CC @ Olive
Other
agm
Criterion
c



Escherichia coli (CFU/100 mL) in Carpenter Creek
E. coli (CFU/100 mL)
10000
1000
100
10
2016
2018
2020
Date
Station ID
CC @ 9th
CC @ Bayou
CC @ Davis
CC @ Burgess
CC @ Olive
Other
agm
Criterion
d

Figure Set B2.10: a-d. Time series and annual geometric means (AGMs) of Carpenter Creek compared to the water quality criteria.




Total Phosphorus (mg/L) in Bayou Texar
Total Phosphorus (mg/L)
0.15
0.10
0.05
0.00
2010
2015
2020
Date
c
Station ID
Texar @ 12th
Texar @ Seville
Texar @ Hyde
Texar @ Bayview
Texar off DeSoto
Other
Criterion

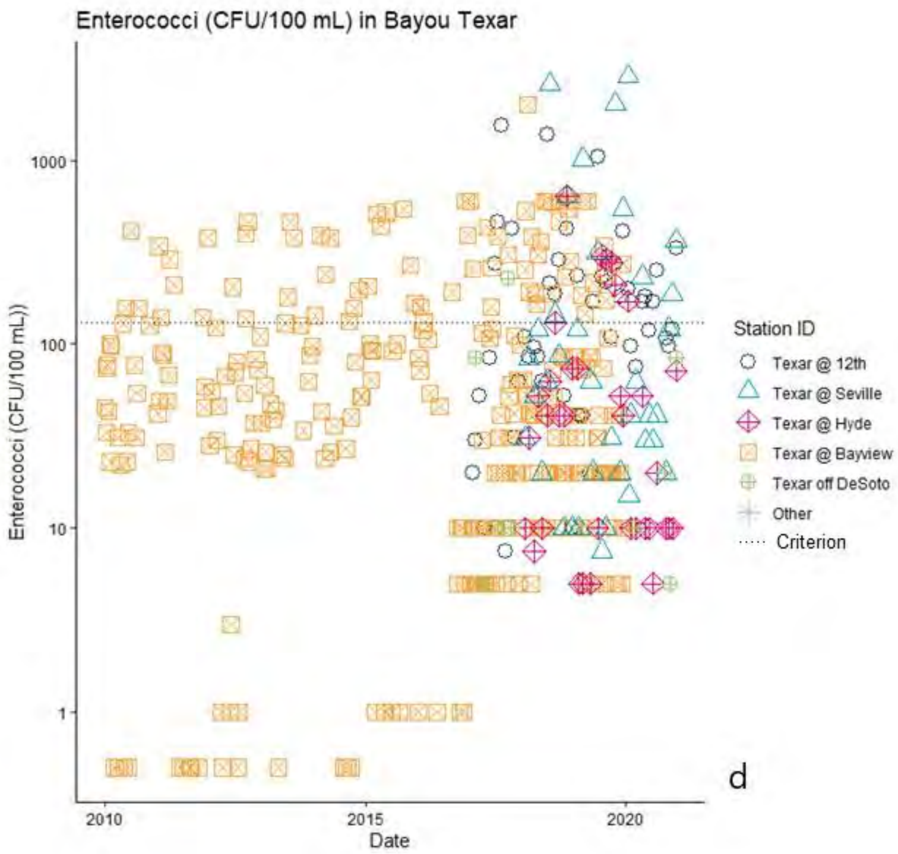
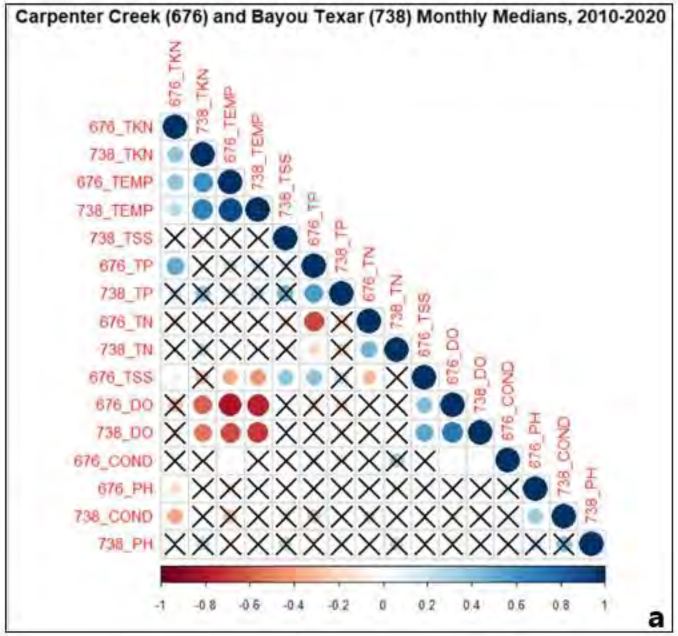
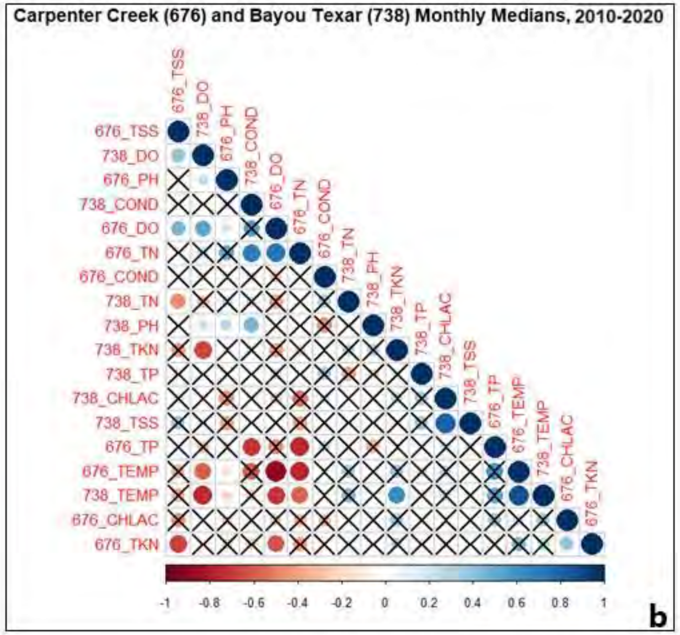

Enterococci (CFU/100 mL) in Bayou Texar
Enterococci (CFU/100 mL))
1000
100
10
1
2010
2015
2020
Date
d
Station ID
Texar @ 12th
Texar @ Seville
Texar @ Hyde
Texar @ Bayview
Texar off DeSoto
Other
Criterion

Figure Set B2.11: a-t. Correlation matrices of wbid and station data from Carpenter Creek (wbid 676) and Bayou Texar (wbid 738)

Monthly medians, wbids combined (2010-2020)





n = 46

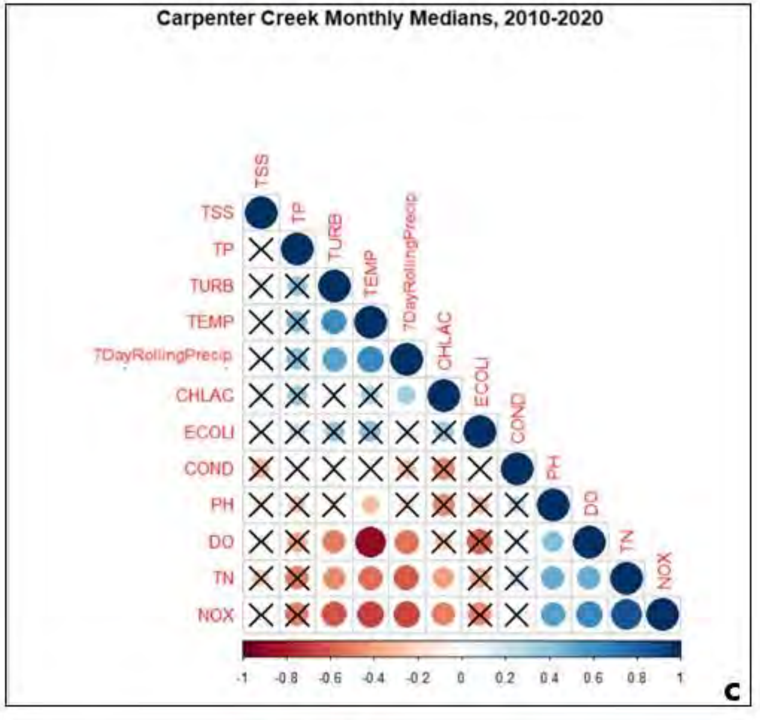
Nutrients, without Chl-a

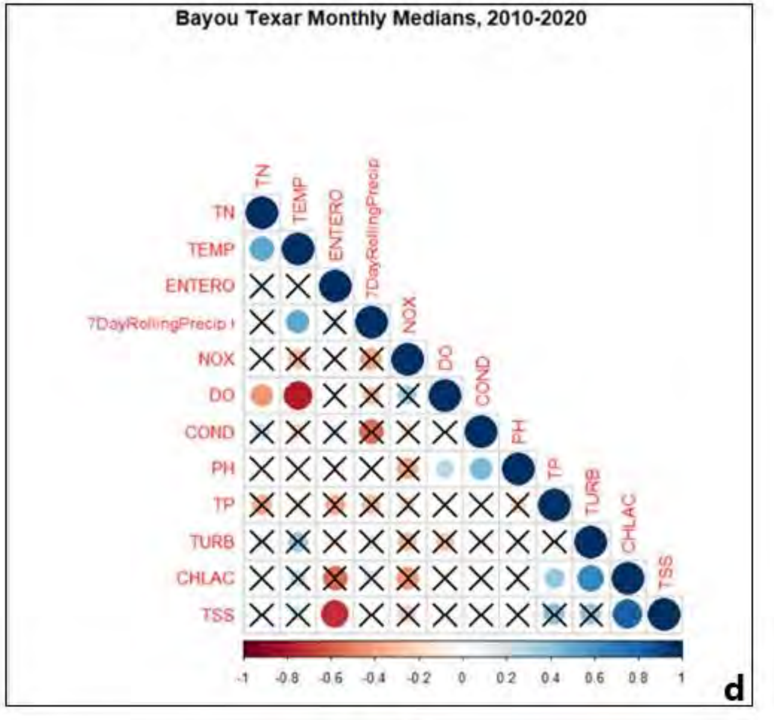
Note:
CHLAC – Corrected Chlorophyll-a | COND – Specific Conductance
DO – Dissolved Oxygen | ECOLI – E. coli | ENTERO – Enterococci | PH = pH
TEMP – Temperature | TURB – Turbidity | TKN – Total Kjeldahl Nitrogen
TN – Total Nitrogen | TP – Total Phosphorus | TSS – Total Suspended Solids
7dayrollingprecip – 7-Day rolling antecedent precipitation

n = 14

Nutrients, with Chl-a

Monthly medians by wbid (2010-2020)





n = 23

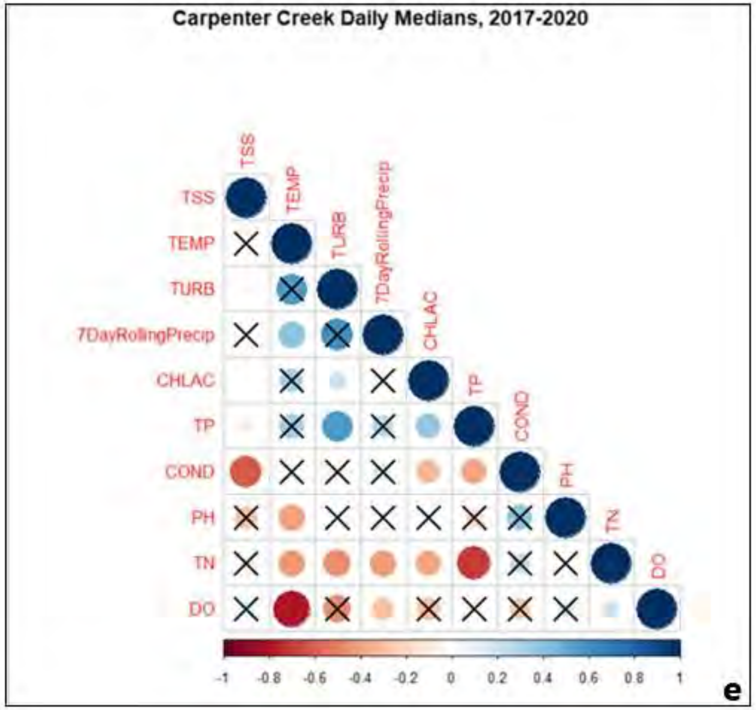
All Parameters

Note:
CHLAC – Corrected Chlorophyll-a | COND – Specific Conductance
DO – Dissolved Oxygen | ECOLI – E. coli | ENTERO – Enterococci | PH = pH
TEMP – Temperature | TURB – Turbidity | TKN – Total Kjeldahl Nitrogen
TN – Total Nitrogen | TP – Total Phosphorus | TSS – Total Suspended Solids
7dayrollingprecip – 7-Day rolling antecedent precipitation

n = 15

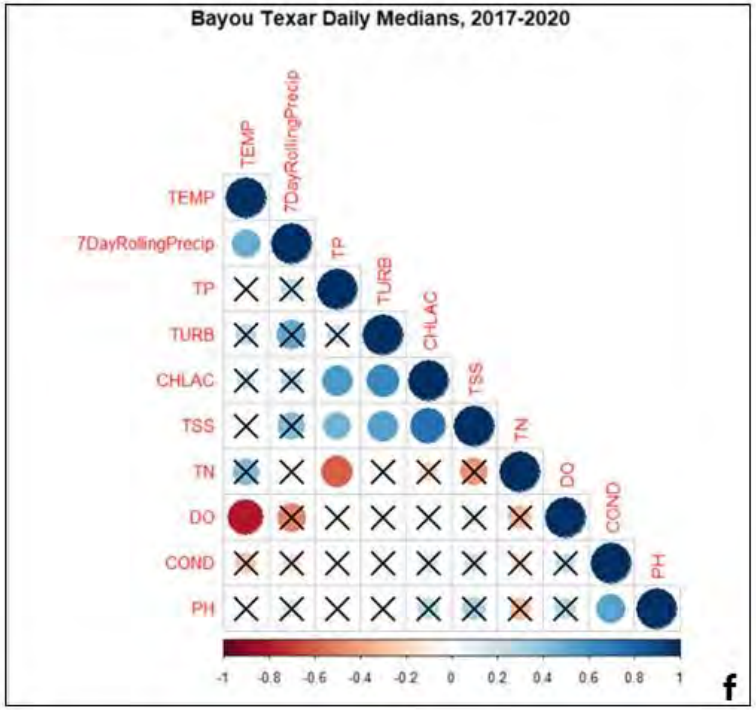
All Parameters

Daily medians by wbid (2017-2020)



n = 29

Nutrients

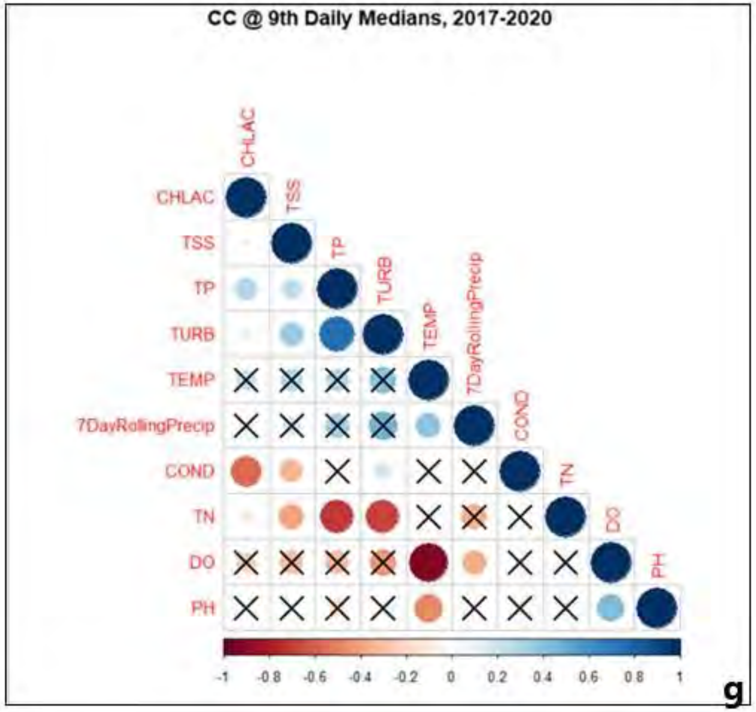


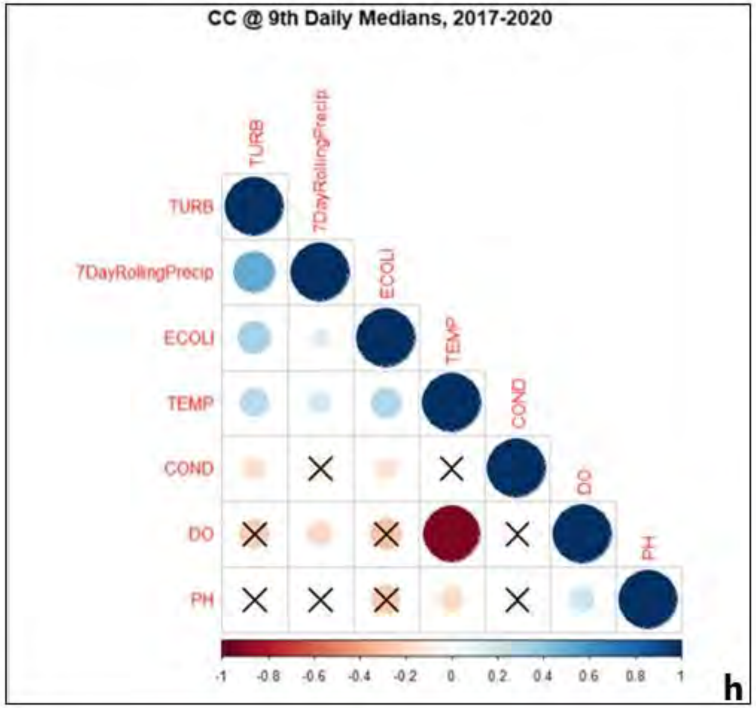
n = 18

Nutrients

Note:
CHLAC – Corrected Chlorophyll-a | COND – Specific Conductance
DO – Dissolved Oxygen | ECOLI – E. coli | ENTERO – Enterococci | PH = pH
TEMP – Temperature | TURB – Turbidity | TKN – Total Kjeldahl Nitrogen
TN – Total Nitrogen | TP – Total Phosphorus | TSS – Total Suspended Solids
7dayrollingprecip – 7-Day rolling antecedent precipitation

Daily medians, CC @ 9th (2017-2020)





n = 28

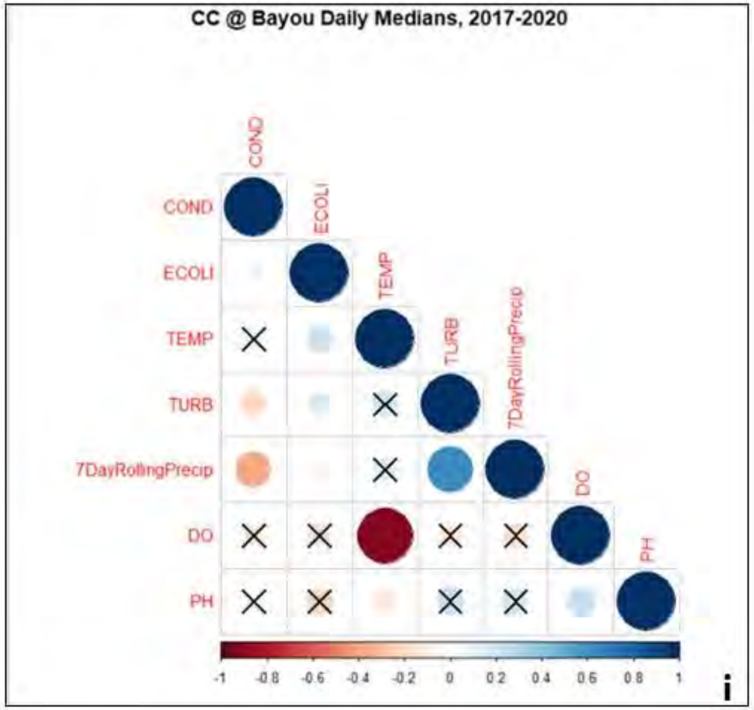
Nutrients

Note:
CHLAC – Corrected Chlorophyll-a | COND – Specific Conductance
DO – Dissolved Oxygen | ECOLI – E. coli | ENTERO – Enterococci | PH = pH
TEMP – Temperature | TURB – Turbidity | TKN – Total Kjeldahl Nitrogen
TN – Total Nitrogen | TP – Total Phosphorus | TSS – Total Suspended Solids
7dayrollingprecip – 7-Day rolling antecedent precipitation

n = 62

Bacteria

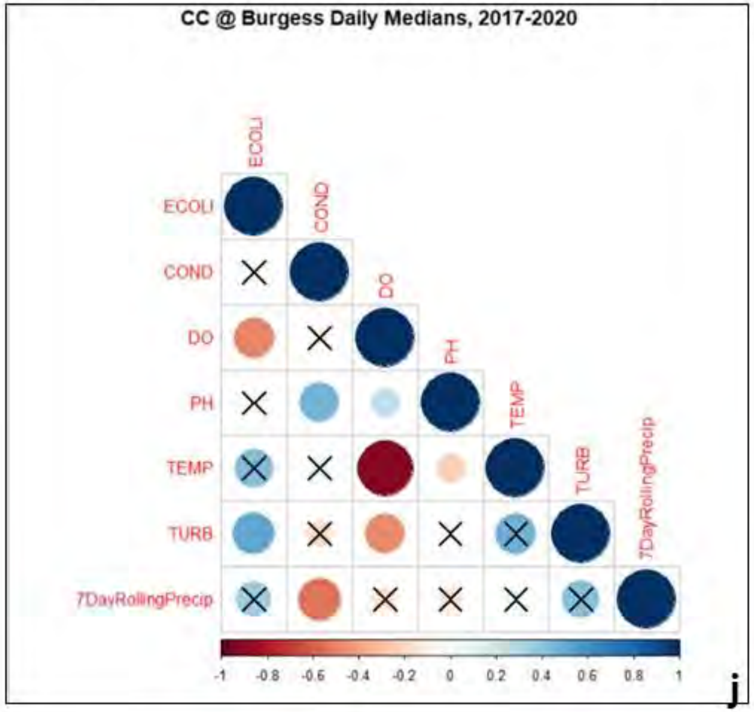
Daily medians, CC @ Bayou (2017-2020)



n = 48

Bacteria

Daily medians, CC @ Burgess (2017-2020)

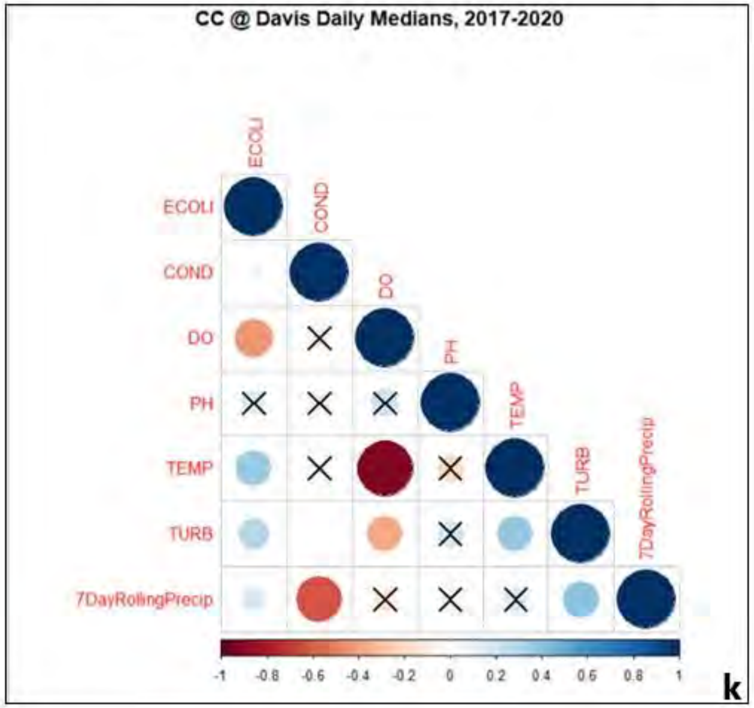


n = 36

Bacteria

Note:
CHLAC – Corrected Chlorophyll-a | COND – Specific Conductance
DO – Dissolved Oxygen | ECOLI – E. coli | ENTERO – Enterococci | PH = pH
TEMP – Temperature | TURB – Turbidity | TKN – Total Kjeldahl Nitrogen
TN – Total Nitrogen | TP – Total Phosphorus | TSS – Total Suspended Solids
7dayrollingprecip – 7-Day rolling antecedent precipitation

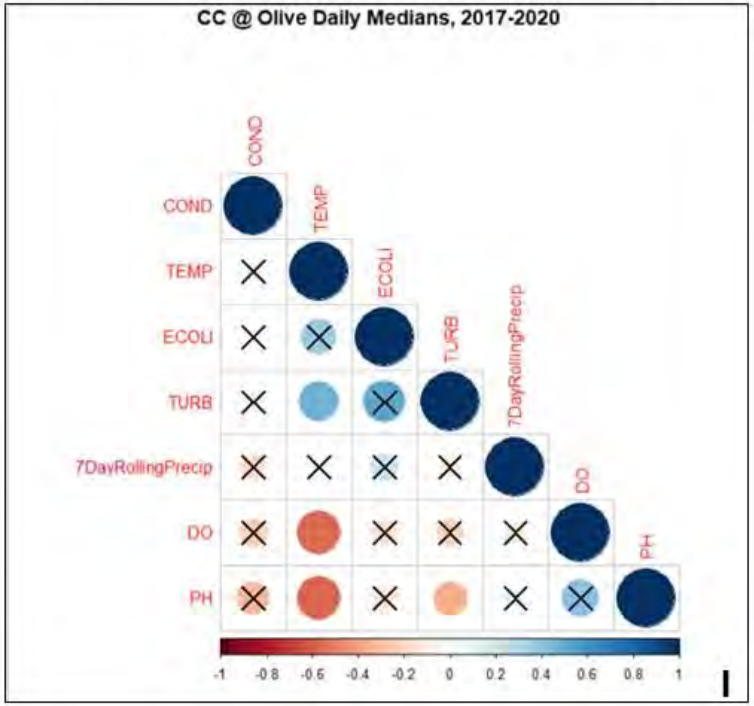
Daily medians, CC @ Davis (2017-2020)



n = 48

Bacteria

Daily medians, CC @ Olive (2017-2020)

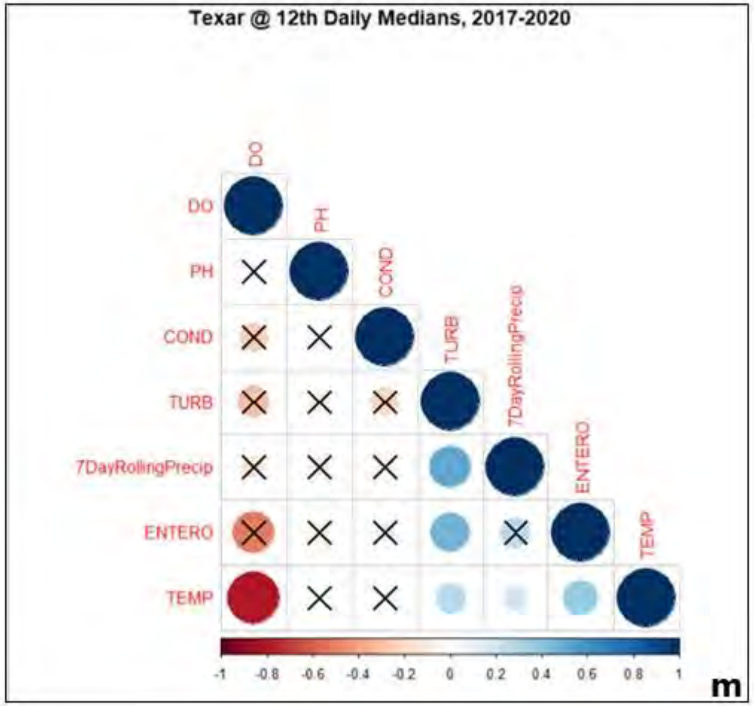


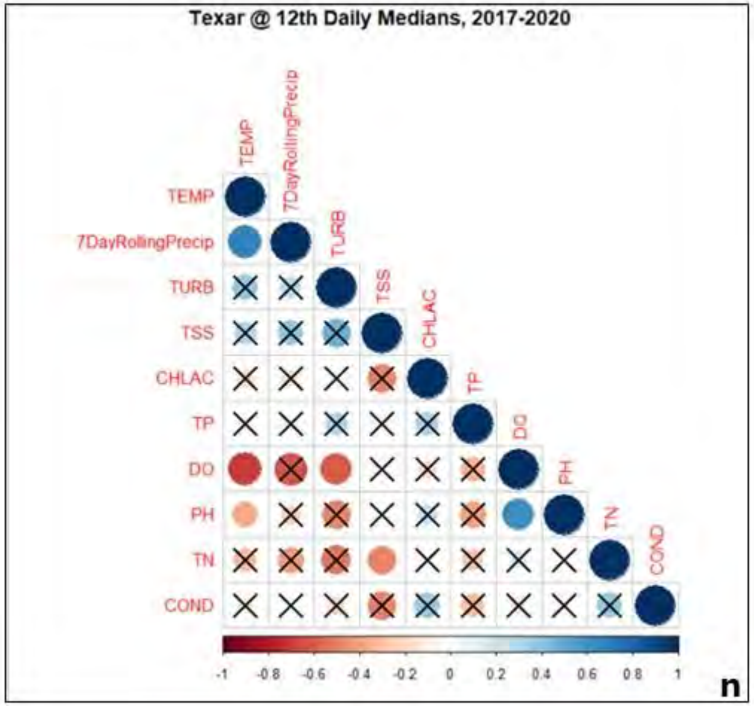
n = 46

Bacteria

Note:
CHLAC – Corrected Chlorophyll-a | COND – Specific Conductance
DO – Dissolved Oxygen | ECOLI – E. coli | ENTERO – Enterococci | PH = pH
TEMP – Temperature | TURB – Turbidity | TKN – Total Kjeldahl Nitrogen
TN – Total Nitrogen | TP – Total Phosphorus | TSS – Total Suspended Solids
7dayrollingprecip – 7-Day rolling antecedent precipitation

Daily medians, Texar @ 12th (2017-2020)





n = 48

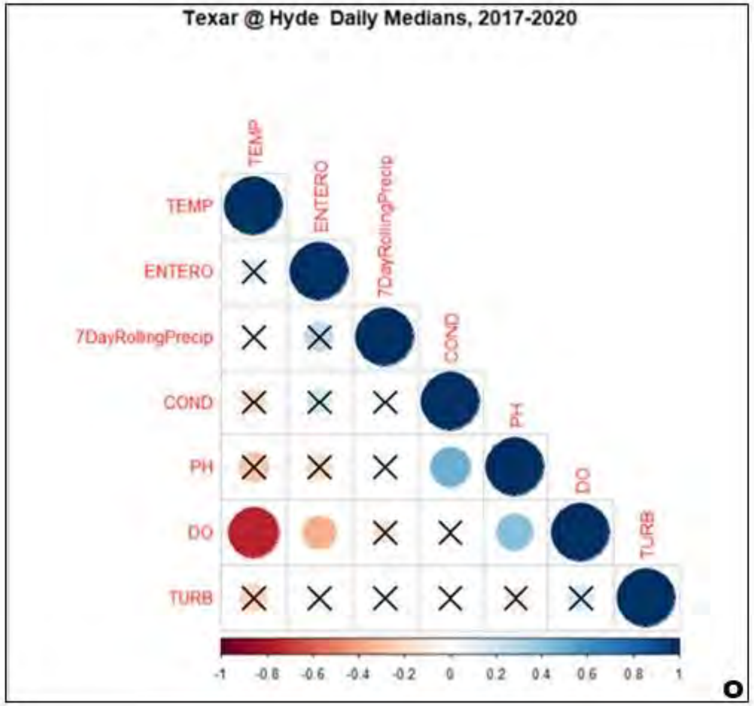
Bacteria

Note:
CHLAC – Corrected Chlorophyll-a | COND – Specific Conductance
DO – Dissolved Oxygen | ECOLI – E. coli | ENTERO – Enterococci | PH = pH
TEMP – Temperature | TURB – Turbidity | TKN – Total Kjeldahl Nitrogen
TN – Total Nitrogen | TP – Total Phosphorus | TSS – Total Suspended Solids
7dayrollingprecip – 7-Day rolling antecedent precipitation

n = 12

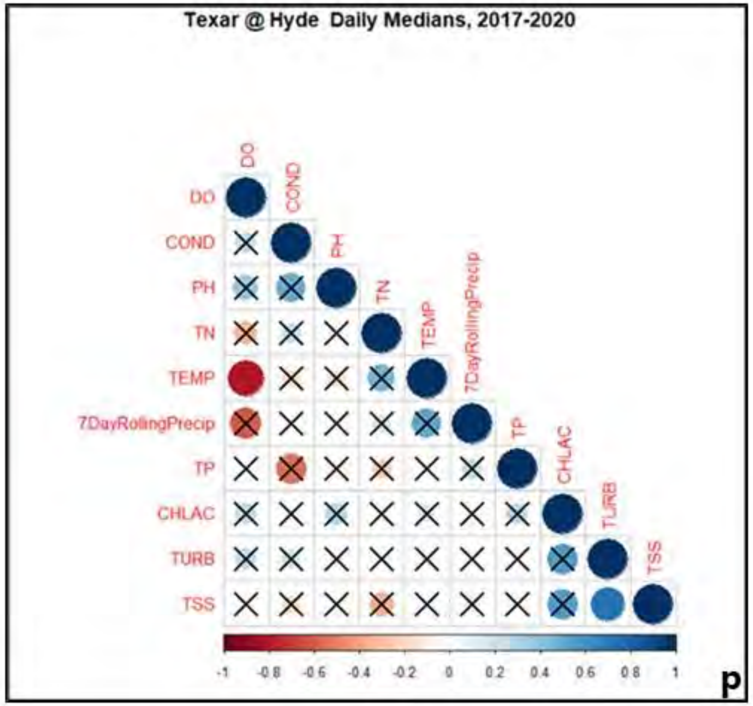
Nutrients

Daily medians, Texar @ Hyde (2017-2020)



n = 34

Bacteria

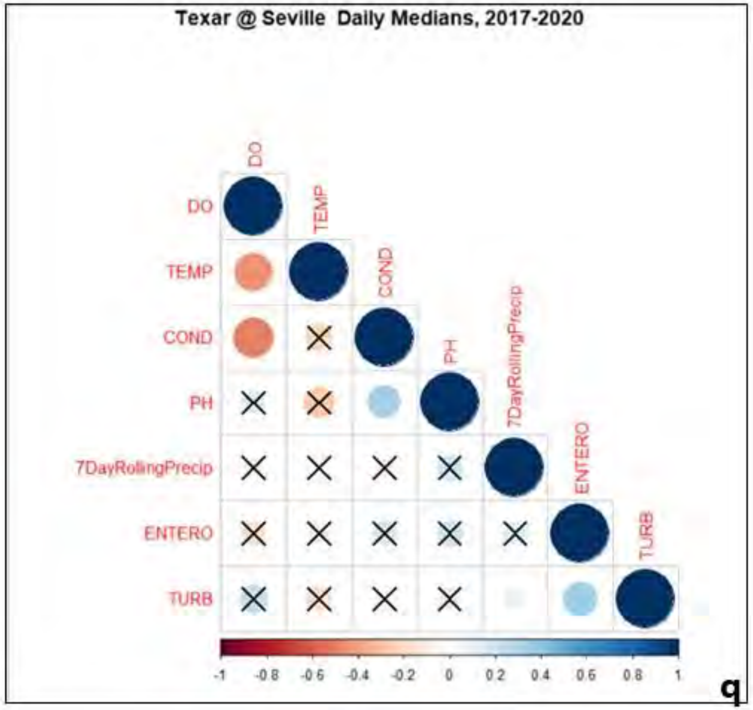


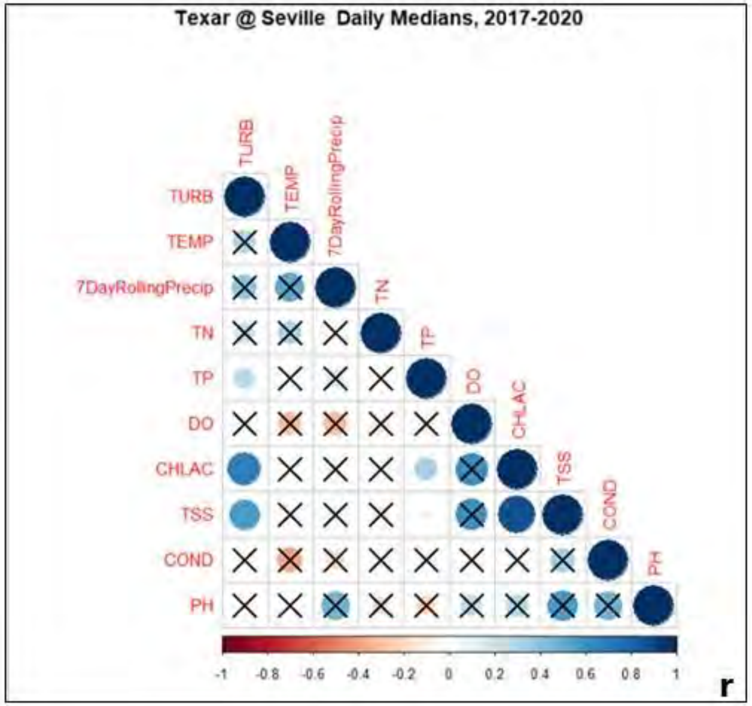
n = 11

Nutrients

Note:
CHLAC – Corrected Chlorophyll-a | COND – Specific Conductance
DO – Dissolved Oxygen | ECOLI – E. coli | ENTERO – Enterococci | PH = pH
TEMP – Temperature | TURB – Turbidity | TKN – Total Kjeldahl Nitrogen
TN – Total Nitrogen | TP – Total Phosphorus | TSS – Total Suspended Solids
7dayrollingprecip – 7-Day rolling antecedent precipitation

Daily medians, Texar @ Seville (2017-2020)





n = 36

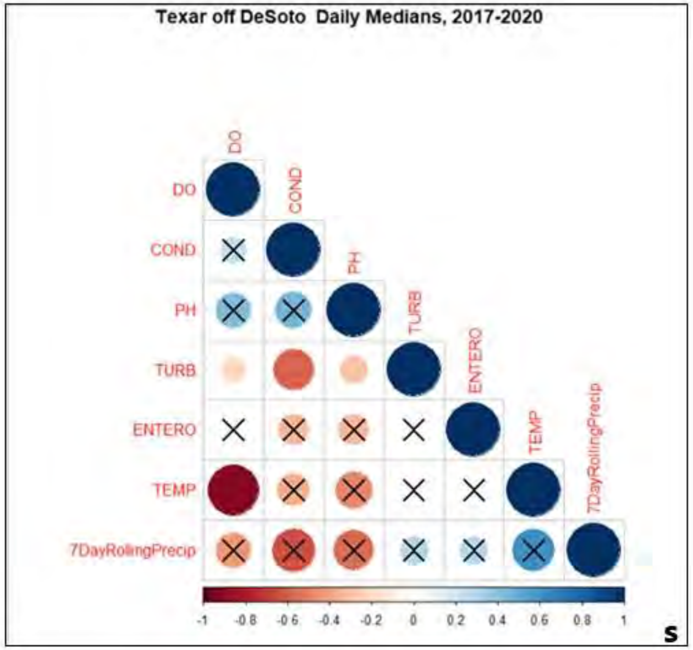
Bacteria

Note:
CHLAC – Corrected Chlorophyll-a | COND – Specific Conductance
DO – Dissolved Oxygen | ECOLI – E. coli | ENTERO – Enterococci | PH = pH
TEMP – Temperature | TURB – Turbidity | TKN – Total Kjeldahl Nitrogen
TN – Total Nitrogen | TP – Total Phosphorus | TSS – Total Suspended Solids
7dayrollingprecip – 7-Day rolling antecedent precipitation

n = 11

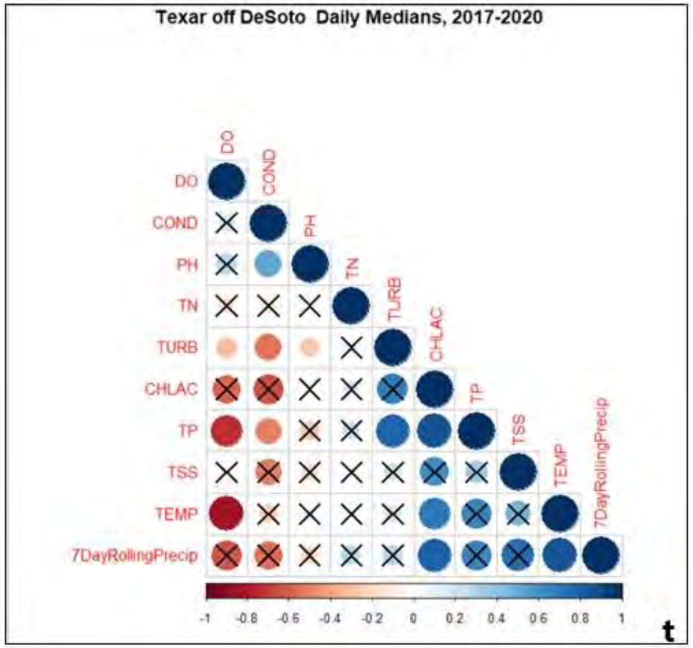
Nutrients

Daily medians, Texar off DeSoto (2017-2020)



n = 9

Bacteria



n = 9

Nutrients

Note:
CHLAC – Corrected Chlorophyll-a | COND – Specific Conductance
DO – Dissolved Oxygen | ECOLI – E. coli | ENTERO – Enterococci | PH = pH
TEMP – Temperature | TURB – Turbidity | TKN – Total Kjeldahl Nitrogen
TN – Total Nitrogen | TP – Total Phosphorus | TSS – Total Suspended Solids
7dayrollingprecip – 7-Day rolling antecedent precipitation

Tables

Table B2-1: Summary of surface water flow data availability within Carpenter Creek and Bayou Texar.

Surface Water Sites				
USGS SW Site No.	USGS SW Site Name	Start Date	End Date	Count
2376077	CARPENTER CREEK NR PENSACOLA, FLA.	10/29/1959	8/26/1993	26
2376079	CARPENTER CREEK AT PENSACOLA, FLA.	01/2/1976	5/12/1977	239

Table B2-2: Summary of groundwater quality data availability within Carpenter Creek and Bayou Texar watersheds from the USGS.

GW Sites				
USGS GW Site No.	USGS GW Site Name	Start Date	End Date	Count
302541087114502	THIA-17TH&GONZALEZ	12/1/1970	8/26/1989	200
302541087114501	TH1-17TH&GONZALEZ ST	12/1/1970	1/13/1987	188
302646087122701	PENSACOLA 12TH AVE. WELL	4/1/1971	4/1/1971	1
302713087124501	ALVIN VOSS-10TH AVE	1/1/1947	1/1/1947	1
302943087133802	WELL NR BRENT	2/7/1972	2/1/1972	1
302943087133801	L. SPILLERS PLANTATN. RD	12/14/1971	12/14/1971	1
302555087122701	WELL 2 NR PENSACOLA, FL	No Data		

Table B2-3: Summary of surface water station aggregations within Carpenter Creek and Bayou Texar.

Final Aggregated Station Name	Original Station Name	Alias	Sampling Agency	WBID	Start Date	End Date	Data Source	Latitude	Longitude
CC @ Target	21FLPNS 33020149	Carpenter Creeks blw Target Stormwater	DEP NW District	676	3/5/2012	3/26/2012	IWR	30.4672222	-87.2104167
CC @ Target	21FLPNS G4NW024 4	Carpenter Creek below Target Stormwater (also, 33020149)	DEP NW District	676	3/25/2014	3/22/2017	IWR	30.46723911	-87.21033539
CC @ Target	G4NW024 4	Carpenter Creek below Target Stormwater Pond	DEP NW District	676	3/25/2014	9/25/2014	WIN	30.46724473	-87.21034024
CC @ 9th	21FLESC CARPENT ERCR10	CARPENTERCR10, Carpenter Creek @ 9th Ave.	ESCAMBIA COUNTY	676	1/25/2016	12/11/2019	IWR	30.47117974	-87.21321808
CC @ 9th	CARPENT ERCR10	Carpenter Cr 10 (9th), 33020048 (CC@9th), CC@9th	ESCAMBIA COUNTY	676	1/14/2020	6/3/2021	County	30.47117974	-87.21321808
CC @ 9th	FD CC @ 9th	33020048 (CC@9th) FD	ESCAMBIA COUNTY	676	1/14/2020	7/8/2020	County	30.47117974	-87.21321808
CC @ 9th	CARPENT ERCR10	Carpenter Creek @ 9th Ave.	ESCAMBIA COUNTY	676	1/25/2016	12/11/2019	WIN	30.47118536	-87.21322292
CC @ 9th	21FLPNS 33020048	CARPENTERS CR 9TH AVE BRIDGE, 21FLPNS 33020148	DEP NW District	676	6/5/2006	3/26/2012	IWR	30.4712008	-87.2133389
CC @ 9th	21FLBFA 33020048	CARPENTERS CREEK AT 9TH AVE	BREAM FISHERMAN ASSOCIATION	676	3/5/1989	3/1/2020	IWR	30.471222	-87.213333
CC @ 9th	33020048	CARPENTERS CREEK AT 9TH AVE	BREAM FISHERMAN ASSOCIATION	676	12/3/2017	3/1/2020	WIN	30.47122762	-87.21333785

Final Aggregated Station Name	Original Station Name	Alias	Sampling Agency	WBID	Start Date	End Date	Data Source	Latitude	Longitude
CC @ 9th	Texar-09	Carpenter's Creek @ Ninth Avenue	ESCAMBIA COUNTY	738	5/7/2014	7/30/2014	2014 Storm Event	30.47118	-87.213218
CC @ 9th	21FLPNS G4NW041 5	Carpenters Creek upstream of 9th Avenue	DEP NW District	676	4/19/2017	12/2/2019	IWR	30.47142	-87.214
CC @ 9th	G4NW041 5	Carpenter Creek upstream of 9th Avenue	DEP NW District	676	9/6/2017	12/2/2019	WIN	30.47142562	-87.21400485
CC @ Bayou	21FLPNS 33020228	Carpenters Creek @ Miller's Ale House	DEP NW District	676	3/5/2012	3/26/2012	IWR	30.47528	-87.21744
CC @ Bayou	21FLPNS 33020058	Carpenters Creek at Brent Lane	DEP NW District	676	3/5/2012	3/26/2012	IWR	30.4752805	-87.2174444
CC @ Bayou	33020058 (Brent)	CC@ Bayou Blvd, Carpenter Cr 20 (Bayou)	ESCAMBIA COUNTY	676	1/14/2020	6/10/2020	County	30.4752805	-87.2174444
CC @ Bayou	CARPENT ERCR20 (Bayou)	33020058 (Brent), CC@ Bayou Blvd	ESCAMBIA COUNTY	676	6/10/2020	4/20/2021	County	30.4752805	-87.2174444
CC @ Bayou	21FLESC CARPENT ERCR20	CARPENTERCR20, Carpenter Creek @ Bayou Blvd.	ESCAMBIA COUNTY	676	1/25/2016	12/11/2019	IWR	30.47540299	-87.217294
CC @ Bayou	CARPENT ERCR20	Carpenter Creek @ Bayou Blvd.	ESCAMBIA COUNTY	676	1/25/2016	12/11/2019	WIN	30.47540861	-87.21729885
CC @ Airport	21FLPNS 33020051	Carpenters Creeek at Airport Blvd	DEP NW District	676	3/5/2012	3/26/2012	IWR	30.480675	-87.2213

Final Aggregated Station Name	Original Station Name	Alias	Sampling Agency	WBID	Start Date	End Date	Data Source	Latitude	Longitude
CC @ Davis	21FLWQSPESC030US	Escambia-Carpenters Creek-1-1 (WBID 676)	FDEP Water Quality Standards and Special projects	676	4/15/2005	12/12/2005	IWR	30.48386	-87.221398
CC @ Davis	2376077		USGS		10/29/1959	8/26/1993	USGS	30.4841458	-87.2225736
CC @ Davis	21FLPNS 33020050	Carpenters Creeek at Davis Hwy	DEP NW District	676	3/5/2012	3/26/2012	IWR	30.4841458	-87.2225736
CC @ Davis	21FLPNS 33020049	CARPENTERS CR DAVIS HIGHWAY BR	DEP NW District	676	6/5/2006	12/9/2009	IWR	30.4841518	-87.2225535
CC @ Davis	21FLESC CARPENTERCR30	CARPENTERCR30, Carpenter Creek @ Davis HWY (SR291)	ESCAMBIA COUNTY	676	1/25/2016	12/11/2019	IWR	30.48418066	-87.22301925
CC @ Davis	33020050 (Davis)	Carpenter Cr 30 (Davis)	ESCAMBIA COUNTY	676	1/14/2020	6/10/2020	County	30.48418066	-87.22301925
CC @ Davis	CARPENTERCR30	Carpenter Cr 30 (Davis), 33020050 (Davis), CC@Davis	ESCAMBIA COUNTY	676	6/10/2020	4/20/2021	County	30.48418066	-87.22301925
CC @ Davis	CARPENTERCR30	Carpenter Creek @ Davis HWY (SR291)	ESCAMBIA COUNTY	676	1/25/2016	12/11/2019	WIN	30.48418628	-87.2230241
CC @ Davis	21FLBFA 33020049	CARPENTERS CREEK AT DAVIS HWY	BREAM FISHERMAN ASSOCIATION	676	3/5/1989	3/1/2020	IWR	30.484278	-87.222583
CC @ Davis	33020049	CARPENTERS CREEK AT DAVIS HWY	BREAM FISHERMAN ASSOCIATION	676	12/3/2017	3/1/2020	WIN	30.48428362	-87.22258785
CC @ Davis	Texar-06	Carpenter's Creek @ Davis Highway	ESCAMBIA COUNTY	676	5/7/2014	5/7/2014	2014 Storm Event	30.484193	-87.222558
CC @ Burgess	21FLPNS 33020053	Carpenters Creek at Burgess Road	DEP NW District	676	6/5/2006	3/26/2012	IWR	30.4940583	-87.2350888

Final Aggregated Station Name	Original Station Name	Alias	Sampling Agency	WBID	Start Date	End Date	Data Source	Latitude	Longitude
CC @ Burgess	21FLA 33020053	CARPENTERS CREEK	DEP NE District	676	6/28/1971	10/30/1987	IWR	30.4942	-87.2347
CC @ Burgess	Texar-07	Carpenter's Creek @ Burgess Road	ESCAMBIA COUNTY	676	7/16/2014	7/30/2014	2014 Storm Event	30.494239	-87.235335
CC @ Burgess	21FLESC CARPENT ERCR40	CARPENTERCR40, Carpenter Creek @ Burgess Rd. (SR742)	ESCAMBIA COUNTY	676	1/25/2016	12/11/2019	IWR	30.49447863	-87.2355557
CC @ Burgess	33020053 (Burgess)	CC @ Burgess (CARPENTERCR40)	ESCAMBIA COUNTY	676	1/14/2020	6/10/2020	County	30.49447863	-87.2355557
CC @ Burgess	CARPENT ERCR40 (Burgess)	33020053 (Burgess), CC@Burgess	ESCAMBIA COUNTY	676	6/10/2020	4/20/2021	County	30.49447863	-87.2355557
CC @ Burgess	CARPENT ERCR40	Carpenter Creek @ Burgess Rd. (SR742)	ESCAMBIA COUNTY	676	1/25/2016	12/11/2019	WIN	30.49448425	-87.23556056
CC @ Oakfield	21FLPNS 33020054	CARPENTERS CREEK NEAR OAKFIELD R	DEP NW District	676	3/5/2012	3/5/2012	IWR	30.5	-87.244444
CC @ Oakfield	21FLA 33020054	CARPENTERS CREEK NEAR OAKFIELD R	DEP NE District	676	6/28/1971	10/30/1987	IWR	30.5	-87.2444
CC @ Olive	21FLESC CARPENT ERCR50	CARPENTERCR50, Carpenter Creek @ Olive Rd. (SR290)	ESCAMBIA COUNTY	676	1/25/2016	12/11/2019	IWR	30.51092346	-87.2422332
CC @ Olive	33020057 (Olive)	CARPENTERCR50 (Olive)	ESCAMBIA COUNTY	676	1/14/2020	6/10/2020	County	30.51092346	-87.2422332
CC @ Olive	CARPENT ERCR50 (Olive)	CC @ Olive	ESCAMBIA COUNTY	676	6/10/2020	4/20/2021	County	30.51092346	-87.2422332

Final Aggregated Station Name	Original Station Name	Alias	Sampling Agency	WBID	Start Date	End Date	Data Source	Latitude	Longitude
CC @ Olive	CARPENT ERCR50	Carpenter Creek @ Olive Rd. (SR290)	ESCAMBIA COUNTY	676	1/25/2016	12/11/2019	WIN	30.51092909	-87.24223806
CC @ Olive	21FLA 33020057	CARPENTERS CR OLIVE RD	DEP NE District	676	2/12/1973	3/5/1989	IWR	30.511	-87.2421
CC @ Olive	21FLPNS 33020057	CARPENTERS CR OLIVE RD	DEP NW District	676	6/5/2006	6/5/2006	IWR	30.5109722	-87.2420833
Texar @ Cervantes	21FLPNS 3302HBT7	lower Bayou Texar TMDL wbid 738-7	DEP NW District	738	3/1/2004	3/1/2004	IWR	30.4249167	-87.1875833
Texar @ Cervantes	21FLA 33020HA2	BAYOU TEXAR 100 FT S CERVANTES S	DEP NE District	738	8/19/1987	8/4/1992	IWR	30.4222	-87.1889
Texar @ Cervantes	21FLA 3302HB11	BAYOU TEXAR AT CERVANTES STREET	DEP NE District	738	7/6/1970	9/4/1985	IWR	30.425	-87.1875
Texar @ Cervantes	Texar-02	Bayou Texar @ Cervantes Bridge Boat Ramp	ESCAMBIA COUNTY	738	5/7/2014	7/30/2014	2014 Storm Event	30.426582	-87.186626
Texar off DeSoto	21FLPNS G4NW040 2	G4NW0402	DEP NW District	738	2/9/2017	2/27/2020	IWR	30.4276	-87.18931
Texar off DeSoto	G4NW040 2	Bayou Texar 200 Meters above Hwy 90 Bridge	DEP NW District	738	9/25/2017	12/14/2020	WIN	30.42760561	-87.18931484
Texar @ Bayview	21FLBFA 3302HC11	BAYVIEW PARK PIER BAYOU TEXAR	BREAM FISHERMAN ASSOCIATION	738	3/5/1989	3/1/2020	IWR	30.4311447	-87.19014176
Texar @ Bayview	Texar-03	Bayou Texar @ Bayview Park	ESCAMBIA COUNTY	738	5/7/2014	7/30/2014	2014 Storm Event	30.432787	-87.187626

Final Aggregated Station Name	Original Station Name	Alias	Sampling Agency	WBID	Start Date	End Date	Data Source	Latitude	Longitude
Texar @ Bayview	21FLPNS 3302HC11	BAYVIEW PARK PIER, BAYOU TEXAR	DEP NW District	738	12/30/1996	4/6/2004	IWR	30.4312179	-87.1905895
Texar @ Bayview	21FLDOH ESCAMBIA 317	Bayou Texar	DOH	738	7/31/2000	12/16/2019	IWR	30.432251	-87.188685
Texar @ Hyde	Texar-04	Bayou Texar @ Hyde Park Road	ESCAMBIA COUNTY	738	5/7/2014	7/30/2014	2014 Storm Event	30.440361	-87.187294
Texar @ Hyde	21FLA 3302HD20	BAYOU TEXAR AT HYDE PARK ROAD	DEP NE District	738	2/17/1970	11/3/1978	IWR	30.4403	-87.1875
Texar @ Hyde	21FLESC TEXARBAY OU30	TEXARBAYOU30	ESCAMBIA COUNTY	738	1/25/2018	12/11/2019	IWR	30.44038436	-87.18731761
Texar @ Hyde	TEXARBAY OU30 (Hyde Park)	Bayou texar @ Hyde Park (TEXARBAYOU30), 3302HED20, Hyde Park	ESCAMBIA COUNTY	738	12/16/2020	12/16/2020	County	30.44038998	-87.18732245
Texar @ Hyde	TEXARBAY OU30	Bayou Texar @ End of Hyde Park Rd.	ESCAMBIA COUNTY	738	1/25/2018	12/11/2019	WIN	30.44038998	-87.18732245
Texar @ Paradise	21FLA 33020HD7	BAYOU TEXAR OFF PARADISE POINT	DEP NE District	738	9/16/1970	4/28/1977	IWR	30.4458	-87.1875
Texar @ Seville	21FLA 3302HE17	BAYOU TEXAR MID BAY ARPT STM DRA	DEP NE District	738	7/6/1970	4/1/1971	IWR	30.45	-87.1944
Texar @ Seville	21FLESC TEXARBAY OU40	TEXARBAYOU40	ESCAMBIA COUNTY	738	1/25/2018	12/11/2019	IWR	30.44999999	-87.194444

Final Aggregated Station Name	Original Station Name	Alias	Sampling Agency	WBID	Start Date	End Date	Data Source	Latitude	Longitude
Texar @ Seville	TEXARBAY OU40 (Seville)	Bayou texar @ Seville, Texar@Seville, 3302HE12, Seville Dr	ESCAMBIA COUNTY	738	12/16/2020	12/16/2020	County	30.44999999	-87.194444
Texar @ Seville	TEXARBAY OU40	Bayou Texar @ 1961 Seville Dr.	ESCAMBIA COUNTY	738	1/25/2018	12/11/2019	WIN	30.45000561	-87.19444884
Texar @ 12th	21FLBFA 33020HF1	BAYOU TEXAR AT 12TH AVE BRIDGE	BREAM FISHERMAN ASSOCIATION	738	3/5/1989	3/1/2020	IWR	30.460028	-87.20875
Texar @ 12th	33020HF1	BAYOU TEXAR AT 12TH AVE BRIDGE	BREAM FISHERMAN ASSOCIATION	738	12/3/2017	3/1/2020	WIN	30.46003362	-87.20875485
Texar @ 12th	21FLESC TEXARBAY OU50	TEXARBAYOU50	ESCAMBIA COUNTY	738	1/24/2017	12/11/2019	IWR	30.46048599	-87.208825
Texar @ 12th	TEXARBAY OU50 (12th)	Bayou Texar @ 12th Ave, Texar @ 12th, 33020HF5 (CC@12th)	ESCAMBIA COUNTY	738	12/16/2020	12/16/2020	County	30.46048599	-87.208825
Texar @ 12th	TEXARBAY OU50	Bayou Texar @ 12th Ave.	ESCAMBIA COUNTY	738	1/24/2017	12/11/2019	WIN	30.46049161	-87.20882985
Texar @ 12th	21FLA 33020HF5	BAYOU TEXAR 100 FT S OF 12TH AVE	DEP NE District	738	8/19/1987	8/19/1987	IWR	30.4611	-87.2083
Texar @ 12th	21FLA 33020HF1	BAYOU TEXAR AT 12TH AVE BRIDGE	DEP NE District	738	7/6/1970	4/5/1992	IWR	30.4625	-87.2097
Texar @ 12th	Texar-05	Bayou Texar @ 12th Avenue	ESCAMBIA COUNTY	738	6/18/2014	6/25/2014	2014 Storm Event	30.460028	-87.20875
CC#2	@ Langley		ESCAMBIA COUNTY	676	4/20/21	4/20/21	2021 Tributary	30.487851	-87.221522

Final Aggregated Station Name	Original Station Name	Alias	Sampling Agency	WBID	Start Date	End Date	Data Source	Latitude	Longitude
CC#5	@ Shiloh Drive		ESCAMBIA COUNTY	676	3/1/21	3/1/21	2021 Tributary	30.492784	-87.235297
CC#5a	SW Corner Ditch Shiloh and Gettysburg		ESCAMBIA COUNTY	676	3/1/21	3/1/21	2021 Tributary	30.499341	-87.241037
CC#8	Siskin		ESCAMBIA COUNTY	676	3/1/21	4/20/21	2021 Tributary	30.500724	-87.24383
Springhill	5170 Springhill		ESCAMBIA COUNTY	676	4/20/21	4/20/21	2021 Tributary	30.473781	-87.218863
CC#7	Beauclerc Apts		ESCAMBIA COUNTY	676	4/20/21	4/20/21	2021 Tributary	30.492438	-87.235673
CC#3	Village Oaks		ESCAMBIA COUNTY	676	3/1/21	3/1/21	2021 Tributary	30.488556	-87.228856
CC#4	Born Drive		ESCAMBIA COUNTY	676	4/20/21	4/20/21	2021 Tributary	30.491872	-87.23234
CC#6	380 E Burgess Rd		ESCAMBIA COUNTY	676	4/20/21	4/20/21	2021 Tributary	30.495886	-87.236495
CC#9	Heirloom		ESCAMBIA COUNTY	676	3/1/21	3/1/21	2021 Tributary	30.504732	-87.236962

Table B2-4: Summary of Chl-a, TN, TP, and *E. coli* data and exceedances in Carpenter Creek.

Year	Chl-a (AGM)	Chl-a (count)	TN (AGM)	TN (count)	TP (AGM)	TP (count)	E. coli (count)	E. coli (exceedances)	Percent E. coli Exceedance
2010	ID	0	**0.73**	4	0.008	4	0	ID	ID
2011	ID	0	0.59	4	0.011	4	0	ID	ID
2012	ID	0	**0.69**	4	0.013	4	0	ID	ID
2013	ID	0	**0.74**	4	0.010	4	0	ID	ID
2014	0.46	2	**0.82**	6	0.008	6	45	19	**42**
2015	ID	0	0.63	4	0.008	4	0	ID	ID
2016	ID	0	0.55	4	0.011	4	60	26	**43**
2017	0.76	8	**0.87**	10	0.006	11	64	28	**44**
2018	0.54	9	**0.87**	12	0.008	13	66	23	**35**
2019	0.53	12	**0.94**	14	0.007	14	68	15	**22**
2020	1.38	8	**0.80**	8	0.006	9	60	20	**33**
2021	0.86	5	**0.92**	2	0.006	5	0	ID	ID

Table B2-5: Exceedances of *E. coli* criterion by the station from 2010 to Present in Carpenter Creek.

Station.ID	E. coli (count)	E. coli (exceedances)	Percent E. coli Exceedance
CC @ 9th	85	30	**35**
CC @ Bayou	60	19	**32**
CC @ Burgess	60	9	**15**
CC @ Davis	73	51	**70**
CC @ Olive	60	13	**22**
Other	25	9	**36**

Table B2-6: Summary of Chl-a, TN, TP, and *E. coli* data and exceedances in Bayou Texar.

Year	Chl-a (AGM)	Chl-a (count)	Total TN (count)	TN (exceedances)	Percent TN Exceedance	Total TP (count)	TP (exceedance)	Percent TP Exceedance	Total Enterococci (count)	Enterococci (exceedances)	Percent Enterococci Exceedance
2010	ID	0	8	4	**50**	7	0	0	24	3	**13**
2011	ID	0	8	4	**50**	8	0	0	20	6	**30**
2012	ID	0	8	5	**63**	8	0	0	27	4	**15**
2013	ID	0	8	6	**75**	8	0	0	20	3	**15**
2014	ID	0	8	5	**63**	8	1	**13**	19	7	**37**
2015	ID	0	7	2	**29**	7	0	0	18	7	**39**
2016	ID	0	7	2	**29**	7	0	0	20	5	**25**
2017	2.7	8	15	6	**40**	16	0	0	65	12	**18**
2018	3.0	4	17	10	**59**	17	0	0	86	30	**35**
2019	2.9	4	14	10	**71**	19	0	0	86	25	**29**
2020	4.6	12	24	15	**63**	28	1	4	41	11	**27**
2021	2.3	2	0	ID	ID	4	0	0	0	ID	ID

Table B2-7: Exceedances of *E. coli*, TN, and TP criterion by the station from 2010 to Present in Bayou Texar.

Station.ID	TN (count)	Total TN (exceedances)	Percent TN Exceedance	Total TP (count)	Total TP Exceedances	Percent TP Exceedance	Total Enterococci (count)	Total Enterococci (exceedances)	Percent Enterococci Exceedance
Texar @ 12th	53	49	**92**	55	1	2	48	23	**48**
Texar @ Bayview	41	6	**15**	39	0	0	297	71	**24**
Texar @ Hyde	12	3	**25**	15	1	7	35	7	**20**
Texar @ Seville	12	11	**92**	14	0	0	37	11	**30**
Texar off DeSoto	6	0	0	12	0	0	9	1	**11**

Table B2-8: Summary Mann-Kendall Trend Test results from individual stations and WBIDs using quarterly data.

ID – Insufficient data to perform analysis. * - Analysis was performed on prewhitened data.

Station or WBID	Time Period	Parameter	Sen's Slope	Tau	p-value	Trend
CC @ 9th	2017-2020	Total Nitrogen	**0.07**	**0.61**	**0.05**	**Significant Increasing Trend**
		Total Phosphorus	-0.01	-0.55	0.08	No Significant Trend
		Chlorophyll a (corrected)	0.14	0.22	0.56	No Significant Trend
		E. coli	-48.67	-0.33	0.33	No Significant Trend
		Nitrate-Nitrite	0.04	0.22	0.56	No Significant Trend
		Dissolved Oxygen*	0.05	0.04	0.88	No Significant Trend
CC @ Bayou	2017-2020	Total Nitrogen	ID	ID	ID	ID
		Total Phosphorus	ID	ID	ID	ID
		Chlorophyll a (corrected)	ID	ID	ID	ID
		E. coli	-50	-0.55	0.08	No Significant Trend
		Nitrate-Nitrite	ID	ID	ID	ID
		Dissolved Oxygen*	0.02	0.02	0.96	No significant Trend
CC @ Burgess	2017-2020	Total Nitrogen	ID	ID	ID	ID
		Total Phosphorus	ID	ID	ID	ID
		Chlorophyll a (corrected)	ID	ID	ID	ID
		E. coli	ID	ID	ID	ID
		Nitrate-Nitrite	ID	ID	ID	ID
		Dissolved Oxygen*	0.92	0.2	0.47	No significant Trend
CC @ Davis	2017-2020	Total Nitrogen	-0.01	-0.125	0.73	No Significant Trend
		Total Phosphorus	-0.01	-0.28	0.42	No Significant Trend
		Chlorophyll a (corrected)	ID	ID	ID	ID
		E. coli	-68.5	-0.17	0.61	No Significant Trend
		Nitrate-Nitrite	-0.03	-0.44	0.17	No Significant Trend
		Dissolved Oxygen*	0.10	0.03	0.89	No Significant Trend
CC @ Olive	2017-2020	Total Nitrogen	ID	ID	ID	ID

Station or WBID	Time Period	Parameter	Sen's Slope	Tau	p-value	Trend
		Total Phosphorus	ID	ID	ID	ID
		Chlorophyll a (corrected)	ID	ID	ID	ID
		E. coli	-2	-0.08	0.87	No Significant Trend
		Nitrate-Nitrite	ID	ID	ID	ID
		Dissolved Oxygen*	0.37	0.02	0.96	No Significant Trend
Texar @ 12th	2017-2020	Total Nitrogen	0.04	0.17	0.61	No Significant Trend
		Total Phosphorus	-0.01	0	1	No Significant Trend
		Chlorophyll a (corrected)	0.03	0.17	0.61	No Significant Trend
		Enterococci	5.25	0.29	0.30	No Significant Trend
		Nitrate-Nitrite*	0.14	0.17	0.39	No Significant Trend
		Dissolved Oxygen*	-0.90	-0.23	0.22	No Significant Trend
Texar @ Bayview	2017-2020	Total Nitrogen	-0.01	0.00	1.00	No Significant Trend
		Total Phosphorus	ID	ID	ID	ID
		Chlorophyll a (corrected)	ID	ID	ID	ID
		Enterococci	ID	ID	ID	ID
		Nitrate-Nitrite*	-0.01	-0.11	0.72	No Significant Trend
		Dissolved Oxygen	0.475	0.33	0.734	No Significant Trend
CC @ 9th	2010-2020	Total Nitrogen	**-0.02**	**-0.25**	**0.04**	**Significant Decreasing Trend**
		Total Phosphorus	-0.01	-0.22	0.06	No Significant Trend
		Chlorophyll a (corrected)	ID	ID	ID	ID
		E. coli	ID	ID	ID	ID
		Nitrate-Nitrite	**-0.07**	**-0.33**	**<0.01**	**Significant Decreasing Trend**
		Dissolved Oxygen	**-0.03**	**-0.30**	**<0.01**	**Significant Decreasing Trend**
CC @ Davis	2010-2020	Total Nitrogen	0.01	0.06	0.61	No Significant Trend
		Total Phosphorus	-0.01	-0.12	0.31	No Significant Trend
		Chlorophyll a (corrected)	ID	ID	ID	ID
		E. coli	ID	ID	ID	ID
		Nitrate-Nitrite	**0.01**	**0.01**	**0.01**	**Significant Increasing Trend**

Station or WBID	Time Period	Parameter	Sen's Slope	Tau	p-value	Trend
		Dissolved Oxygen	-0.04	-0.09	0.51	No Significant Trend
Texar @ 12th	2010-2020	Total Nitrogen	-0.02	-0.20	0.10	No Significant Trend
		Total Phosphorus	-0.01	-0.09	0.50	No Significant Trend
		Chlorophyll a (corrected)	ID	ID	ID	ID
		Enterococci	ID	ID	ID	ID
		Nitrate-Nitrite	**-0.03**	**-0.32**	**<0.01**	**Significant Decreasing Trend**
		Dissolved Oxygen	-0.13	-0.24	0.07	No Significant Trend
Texar @ Bayview	2010-2020	Total Nitrogen	-0.01	-0.19	0.12	No Significant Trend
		Total Phosphorus*	-0.01	-0.01	0.62	No Significant Trend
		Chlorophyll a (corrected)	ID	ID	ID	ID
		Enterococci	-0.61	-0.61	0.65	No Significant Trend
		Nitrate-Nitrite*	0.05	0.07	0.53	No Significant Trend
		Dissolved Oxygen	**-0.08**	**-0.27**	**<0.05**	**Significant Decreasing Trend**
Carpenter Creek (WBID 676)	2017-2020	Total Nitrogen	-0.09	-0.25	0.40	No Significant Trend
		Total Phosphorus	0.01	0.08	0.86	No Significant Trend
		Chlorophyll a (corrected)	0.11	0.25	0.40	No Significant Trend
		E. coli	-1.5	-0.04	1.0	No Significant Trend
		Nitrate-Nitrite	-0.09	-0.33	0.23	No Significant Trend
		Dissolved Oxygen*	-0.10	-0.07	0.75	No Significant Trend
Bayou Texar (WBID 738)	2017-2020	Total Nitrogen	0.09	0.42	0.13	No Significant Trend
		Total Phosphorus	-0.01	-0.04	1.0	No Significant Trend
		Chlorophyll a (corrected)	0.71	0.5	0.06	No Significant Trend
		Enterococci	-1.5	-0.04	1.0	No Significant Trend
		Nitrate-Nitrite	-0.07	-0.42	0.13	No Significant Trend
		Dissolved Oxygen*	-0.28	-0.08	0.69	No Significant Trend
Carpenter Creek (WBID 676)	2010-2020	Total Nitrogen	0.02	0.15	0.21	No Significant Trend
		Total Phosphorus	**-0.01**	**-0.25**	**0.03**	**Significant Decreasing Trend**
		Chlorophyll a (corrected)	0.05	0.31	0.21	No Significant Trend

Station or WBID	Time Period	Parameter	Sen's Slope	Tau	p-value	Trend
		E. coli*	210	0.19	0.26	No Significant Trend
		Nitrate-Nitrite*	0.20	0.09	0.39	No Significant Trend
		Dissolved Oxygen	**-0.09**	**-0.27**	**0.03**	**Significant Decreasing Trend**
Bayou Texar (WBID 738)	2010-2020	Total Nitrogen*	-0.14	-0.13	0.22	No Significant Trend
		Total Phosphorus	-0.01	-0.15	0.21	No Significant Trend
		Chlorophyll a (corrected)	0.71	0.5	0.06	No Significant Trend
		Enterococci	1.48	0.02	1	No Significant Trend
		Nitrate-Nitrite	**-0.03**	**-0.38**	**<0.01**	**Significant Decreasing Trend**
		Dissolved Oxygen	**-0.07**	**-0.28**	**0.03**	**Significant Decreasing Trend**

Appendix C - POLLUTANT LOAD ANALYSIS TABLES

Table C-1: Published runoff coefficients (c) for meteorological zone 1 based on Non-DCIA CN and percent DCIA.

NDCIA	Percent DCIA																				
CN	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
30	0.006	0.048	0.090	0.132	0.175	0.217	0.259	0.301	0.343	0.386	0.428	0.470	0.512	0.554	0.596	0.639	0.681	0.723	0.765	0.807	0.849
35	0.009	0.051	0.093	0.135	0.177	0.219	0.261	0.303	0.345	0.387	0.429	0.471	0.513	0.555	0.597	0.639	0.681	0.723	0.765	0.807	0.849
40	0.014	0.056	0.098	0.139	0.181	0.223	0.265	0.307	0.348	0.390	0.432	0.474	0.515	0.557	0.599	0.641	0.682	0.724	0.766	0.808	0.849
45	0.020	0.062	0.103	0.145	0.186	0.228	0.269	0.311	0.352	0.394	0.435	0.476	0.518	0.559	0.601	0.642	0.684	0.725	0.767	0.808	0.849
50	0.029	0.070	0.111	0.152	0.193	0.234	0.275	0.316	0.357	0.398	0.439	0.480	0.521	0.562	0.603	0.644	0.685	0.726	0.767	0.808	0.849
55	0.039	0.079	0.120	0.161	0.201	0.242	0.282	0.323	0.363	0.404	0.444	0.485	0.525	0.566	0.606	0.647	0.687	0.728	0.768	0.809	0.849
60	0.052	0.092	0.132	0.172	0.212	0.252	0.291	0.331	0.371	0.411	0.451	0.491	0.531	0.570	0.610	0.650	0.690	0.730	0.770	0.810	0.849
65	0.069	0.108	0.147	0.186	0.225	0.264	0.303	0.342	0.381	0.420	0.459	0.498	0.537	0.576	0.615	0.654	0.693	0.732	0.771	0.810	0.849
70	0.092	0.130	0.167	0.205	0.243	0.281	0.319	0.357	0.395	0.433	0.471	0.508	0.546	0.584	0.622	0.660	0.698	0.736	0.774	0.812	0.849
75	0.121	0.158	0.194	0.230	0.267	0.303	0.340	0.376	0.412	0.449	0.485	0.522	0.558	0.595	0.631	0.667	0.704	0.740	0.777	0.813	0.849
80	0.162	0.196	0.230	0.265	0.299	0.334	0.368	0.402	0.437	0.471	0.506	0.540	0.574	0.609	0.643	0.678	0.712	0.746	0.781	0.815	0.849
85	0.220	0.252	0.283	0.315	0.346	0.378	0.409	0.441	0.472	0.503	0.535	0.566	0.598	0.629	0.661	0.692	0.724	0.755	0.787	0.818	0.849
90	0.312	0.339	0.366	0.393	0.419	0.446	0.473	0.500	0.527	0.554	0.581	0.608	0.634	0.661	0.688	0.715	0.742	0.769	0.796	0.823	0.849
95	0.478	0.496	0.515	0.533	0.552	0.571	0.589	0.608	0.626	0.645	0.664	0.682	0.701	0.719	0.738	0.757	0.775	0.794	0.812	0.831	0.849
98	0.656	0.666	0.676	0.685	0.695	0.705	0.714	0.724	0.734	0.743	0.753	0.763	0.772	0.782	0.792	0.801	0.811	0.821	0.830	0.840	0.849

Source: Stormwater Quality Applicant's Handbook, Design Requirements for stormwater Treatment Systems in Florida, March 2010 Draft.

Table C-2: Summary of curve numbers based on land use and soil group.

FLUCCS	GENERALIZED LAND USE DESCRIPTION	HYDROLOGIC SOILS GROUP						DCIA
		A	B	B/D	C	D	W	
1100	Residential-Low Density	39	61	61	74	80	99.8	20
1200	Residential-Med Density	39	61	61	74	80	99.8	25
1300	Residential-High Density	39	61	61	74	80	99.8	50
1400	Commercial	39	61	61	74	80	99.8	85
1500	Industrial	39	61	61	74	80	99.8	72
1600	Extractive	39	61	61	74	80	99.8	0
1700	Institutional	39	61	61	74	80	99.8	65
1800	Recreational	39	61	80	74	80	99.8	10
1900	Open Land	39	61	80	74	80	99.8	0
2100	Cropland and Pastureland	39	61	80	74	80	99.8	0
2200	Tree Crops - Citrus	32	58	79	72	79	99.8	10
2300	Feeding Operations	32	58	79	72	79	99.8	10
2400	Nurseries and Vineyards	67	78	89	85	89	99.8	5
2500	Specialty Farms	67	78	89	85	89	99.8	5
2600	Other Open Lands - Rural	39	61	80	74	80	99.8	0
3100	Herbaceous Rangeland	39	61	80	74	80	99.8	0
3200	Shrub and Brush Rangeland	30	48	73	65	73	99.8	0
3300	Mixed Rangeland	30	48	73	65	73	99.8	0
4100	Upland Coniferous Forest	32	58	79	72	79	99.8	0
4200	Upland Hardwood Forests	32	58	79	72	79	99.8	0

Table C-2: Continued
Summary of curve numbers based on land use and soil group.

FLUCCS	GENERALIZED LAND USE DESCRIPTION	HYDROLOGIC SOILS GROUP						DCIA
		A	B	B/D	C	D	W	
4300	MIXED HARDWOOD FORESTS	32	58	79	72	79	99.8	0
4400	TREE PLANTATIONS	32	58	79	72	79	99.8	0
5000	WATER	99.8	99.8	99.8	99.8	99.8	99.8	100
5100	STREAMS AND WATERWAYS	99.8	99.8	99.8	99.8	99.8	99.8	100
5200	LAKES	99.8	99.8	99.8	99.8	99.8	99.8	100
5300	RESERVOIRS	99.8	99.8	99.8	99.8	99.8	99.8	100
6100	WETLAND HARDWOOD FORESTS	99.8	99.8	99.8	99.8	99.8	99.8	100
6200	WETLAND CONIFEROUS FORESTS	99.8	99.8	99.8	99.8	99.8	99.8	100
6300	WETLAND FORESTED MIXED	98	98	98	98	98	99.8	100
6400	VEGETATED NON-FORESTED WETLANDS	98	98	98	98	98	99.8	100
7400	MINING	39	61	80	74	80	99.8	0
8100	TRANSPORTATION / UTILITIES	83	89	89	92	93	99.8	25
8200	COMMUNICATIONS	83	89	89	92	93	99.8	25
8300	UTILITIES	83	89	89	92	93	99.8	25

Table C-3: Summary of literature-based runoff characterization for general land use categories in Florida.

LAND USE CATEGORY	TYPICAL RUNOFF CONCENTRATION (MG/L)						
	TN	TP	BOD	TSS	Cu	Pb	Zn
Low-Density Residential[1]	1.5	0.18	4.7	23	0.008[4]	0.002[4]	0.031[4]
Single-Family	1.85	0.31	7.9	37.5	0.016	0.004	0.062
Multi-Family	1.91	0.48	11.3	77.8	0.009	0.006	0.086
Low-Intensity Commercial	0.93	0.16	7.7	57.5	0.018	0.005	0.094
High-Intensity Commercial	2.48	0.23	11.3	69.7	0.015	--	0.16
Light Industrial	1.14	0.23	7.6	60	0.003	0.002	0.057
Highway	1.37	0.17	5.2	37.3	0.032	0.011	0.126
Pasture	2.48	0.7	5.1	94.3	--	--	--
Citrus	2.31	0.16	2.55	15.5	0.003	0.001	0.012
Row Crops	2.47	0.51	--	19.8	0.022	0.004	0.03
General Agriculture[2]	2.42	0.46	3.8	43.2	0.013	0.003	0.021
Undeveloped / Rangeland / Forest	1.15	0.055	1.4	8.4	--	--	--
Mining / Extractive	1.18	0.15	7.6[3]	60.0[3]	0.003[3]	0.002[3]	0.057[3]
Wetland	1.01	0.09	2.63	11.2	0.001	0.001	0.006
Open Water / Lake	1.6	0.067	1.6	3.1		0.025[5]	0.028

1. Average of single-family and undeveloped loading rates.
2. Mean of pasture, citrus, and row crop land uses.
3. Runoff concentrations assumed equal to industrial values for these parameters.
4. Value assumed to be equal to 50% of single-family concentration.
5. Runoff concentrations assumed equal to wetland values for these parameters.

Notes: This table is a replica of Table 4-17 in the Final Report of "Evaluation of Current Stormwater Design Criteria within the state of Florida" prepared for the Florida Department of Environmental Protection (June 2007). Prepared by Environmental Research & Design, Inc. Harvey H. Harper, Ph.D., P.E. & David M. Baker, P.E. Total N, and Total P EMC values are from Table 3.4 in March 2010 Draft Department of Environmental Protection and Water Management Districts Environmental Resource Permit Stormwater Quality Applicant's Handbook Design Requirements for Stormwater Treatment Systems in Florida. Wetland and Open Water/Lake EMC values are from Table 7 of the Final Report of "Evaluation of Alternative Stormwater Regulations for Southwest Florida". (Revised Sept 08, 2003) Submitted to Water Enhancement & Restoration Coalition, Inc. Prepared by Environmental Research & Design, Inc. Harvey H. Harper, Ph.D., P.E. & David M. Baker, P.E.

Appendix D - QUALITY BAYOU TEXAR ASSESSMENT

WETLAND SCIENCES
INCORPORATED

September 10, 2021

Crissy Mehle
Water Resources Manager
4400 Bayou Boulevard, Suite 31A,
Pensacola, FL 32503

Re: *Qualitative Assessment of Bayou Texar*
Carpenter Creek Watershed Management Plan
WSI Reference #2018-703

Dear Mrs. Mehle,

This letter report shall summarize Wetland Sciences, Inc. qualitative assessment of Bayou Texar in support of the Carpenter Creek Watershed Management Plan. This work was aimed at satisfying task item 3.2 of the agreed scope of work.

Field work was undertaken on Thursday, September 9, 2021. Our efforts were originally scheduled for the week of August 30th but were postponed due to inclement weather from Hurricane Ida which made landfall on August 28 and affected local conditions during the week of August 30th.

The weather during the sampling effort was ideal. Max temperature was 87 degrees with light north winds at 3 mph. High tide was 1:50 AM and 3:42 PM. Low tide was 8:13 AM and 7:33 PM. Tidal amplitude was 1.0-ft.

Our efforts included general qualitative observations of shoreline conditions, collection of several water quality parameters, and physical characterization of submersed sediments within the Bayou.

General qualitative observations of shoreline conditions are summarized in the attached site photographic essay (Exhibit A). Included with this essay is a map key that identifies the location of each photograph. The condition of the shoreline for a variety of locations within the Bayou are summarized. Key observations include:

- The shoreline between Cervantes Street bridge and the mouth of the Bayou is largely free from anthropogenic impacts except for existing dock structures that line the west shoreline. Both the east and west shorelines contain broad bands of emergent wetland vegetation dominated by salt marsh cord grass (*Spartina alterniflora*), black needle rush (*Juncus roemerianus*), and salt grass (*Distichlis spicata*). The submerged lands between the waterward edge of emergent wetland vegetation and the edge of the dredged channel was largely dominated by dense coverage of wild celery (*Vallisneria americana*).
- The shoreline between the Cervantes Street bridge and Gamarra Road is highly manipulated. There are a variety of modifications to the shoreline in this area including vertical seawalls, vertical seawalls faced with rock, rock revetments, manicured lawns that terminate at the mean high water, and shorelines graded to resemble an open beach.
- From Gamarra road north to the bridge at North 12th Avenue the shorelines are comprised largely of broad low littoral zones dominated by dense coverage of sawgrass (*Cladium jamaicense*).

Submerged lands from the waterward edge of the emergent vegetation to depths of -4-ft. were dominated by dense meadows of wild celery.

Again, each of the observed conditions are detailed in the attached site photographic essay.

Physical measurements of water quality parameters including temperature, dissolved oxygen, salinity, conductivity, pH, turbidity, and total dissolved solids were gathered using a YSI ProDSS (digital sampling system) multiparameter instrument. Calibration certificate for this instrument is included in **Exhibit B**. The location of each sample site is depicted in the map appended as **Exhibit C**. Results of the monitoring efforts are appended as **Exhibit D**.

Finally, WSI attempted to characterize submerged sediments within the Bayou. Sediment samples were collected at each location depicted in **Exhibit C**. Physical measurements were made from a 19-ft. recreational watercraft by probing the bottom of the bayou with a 29 mm diameter (1.13-inch) diameter, 16-ft. aluminum range pole with a convex steel cap covering the terminal end. Each section of the range pole was graduated in 0.1-foot increments. At each sample location, the depth of water over sediment was carefully measured to the nearest 0.1 foot using the probe. The probe was then forced downward through the sediment until refusal. A second measurement was taken at depth. The difference between the two measurements was then calculated to determine the thickness of unconsolidated fine-grain sediment. The results of this effort are appended as **Exhibit E**.

Most of the submerged lands of Bayou Texar are covered by a layer of fine-grained sediments. WSI identified fine grain sediment deposits greater than 6-ft. in depth along the central portions of the Bayou from the 12th Ave bridge to Cervantes Street bridge. From the open waters of the Bayou to the shoreline there was an obvious gradient of decreasing fine-grain sediment thickness except for the area between Gamarra Road and the 12th Ave bridge.

This concludes our findings. If you have questions, please do not hesitate to call.

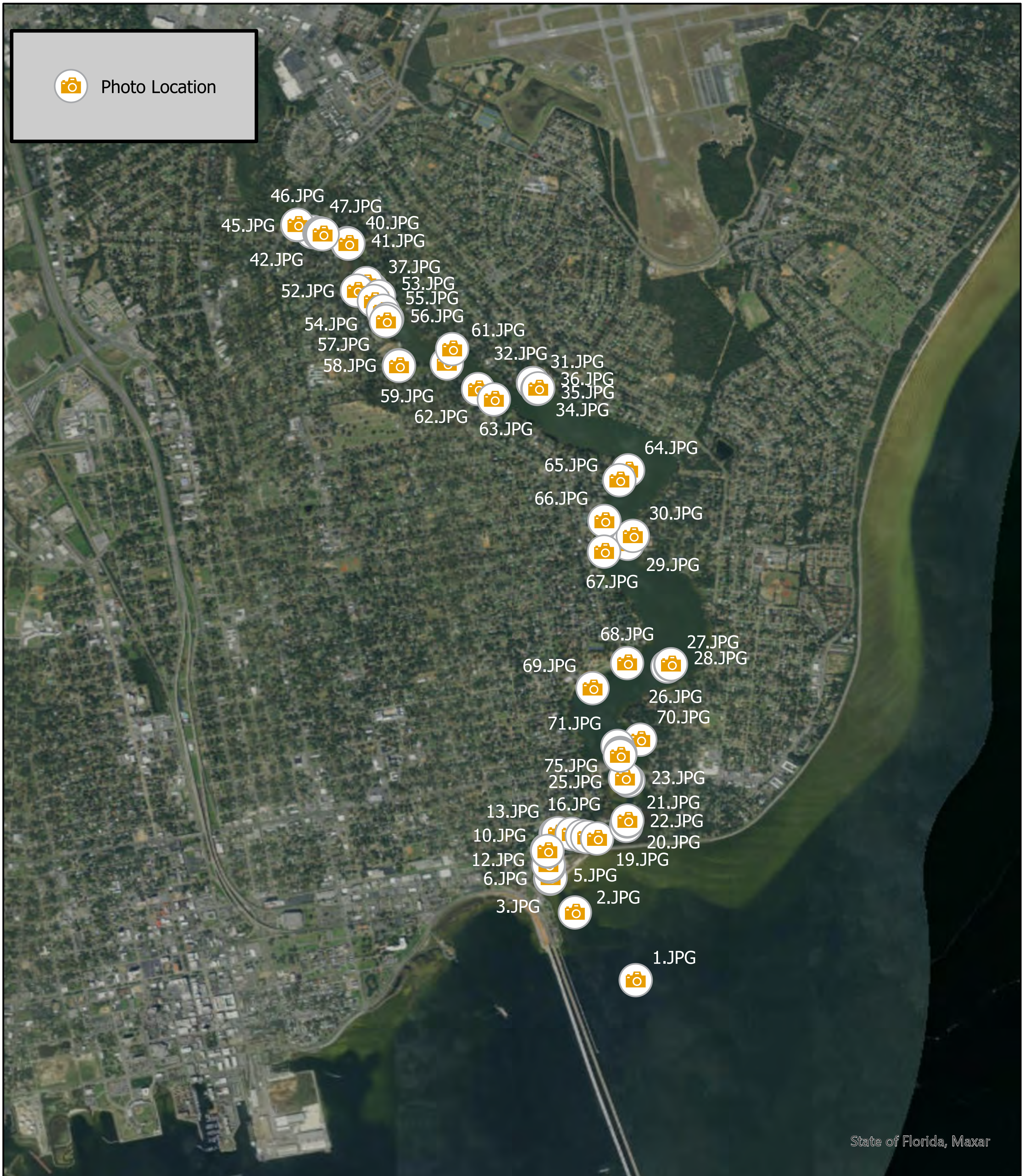
Sincerely,
WETLAND SCIENCES, INC.

Keith Johnson
Environmental Scientist

3308 Gulf Beach Highway | Pensacola, Florida 32507 | 850.453.4700 | keith@wetlandsciences.com

Exhibit A

Site Photographic Essay



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All data within this map are supplied as is, without warranty. This product has not been prepared for legal, engineering, or survey purposes. Users of this information should review or consult the primary data sources to ascertain the usability of the information.

Photo Location Map

Carpenter Creek/Bayou Texar Watershed Management Plan

0 0.2 0.41 0.82 1.23 1.64 Miles

Data Source: WSI
Imagery Source: ESRI

Coordinate System: NAD 1983 FL State Plane North

N W E S

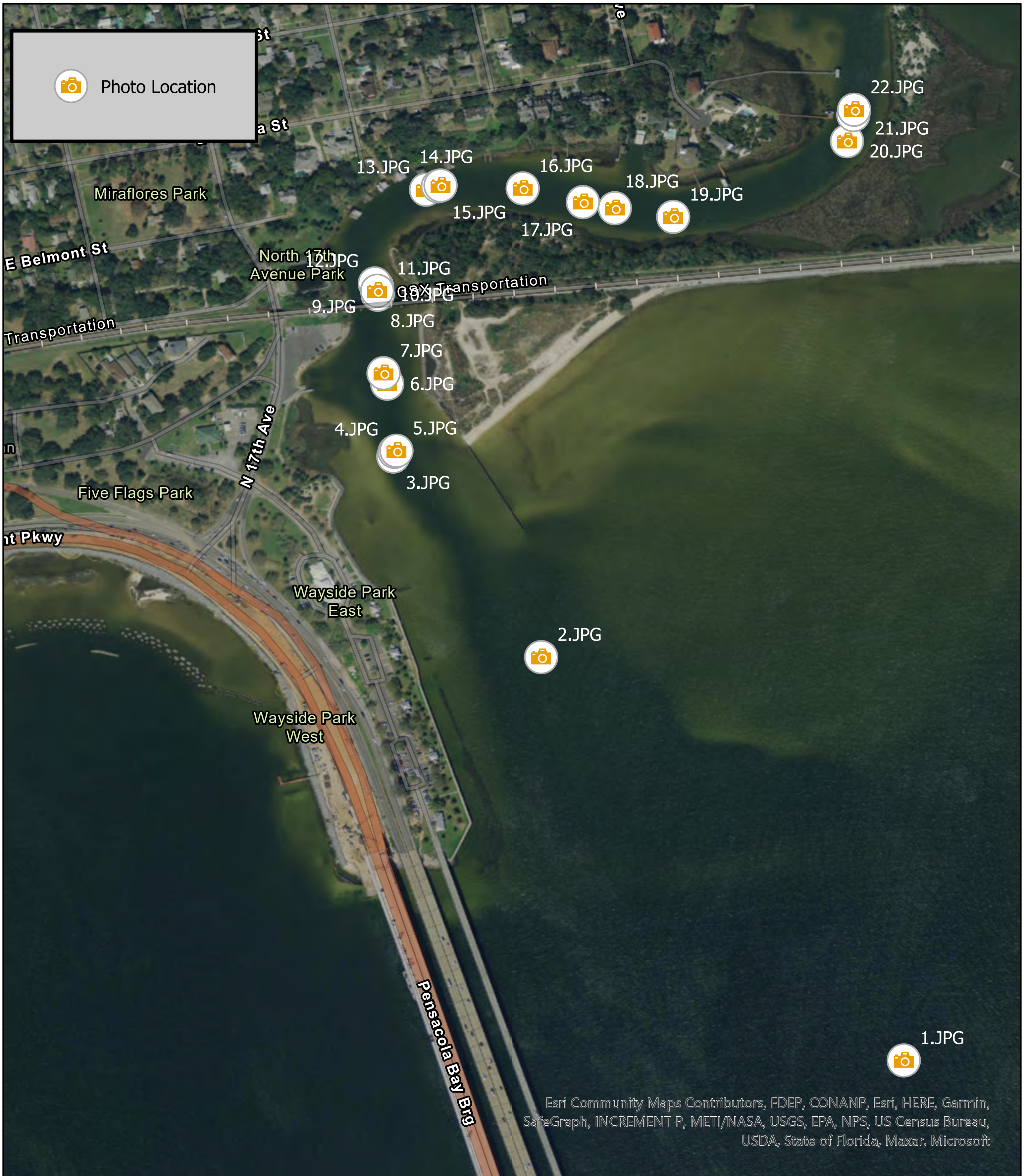

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Photo Location Map

Carpenter Creek/Bayou Texar Watershed Management Plan

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Data Source: WSI
Imagery Source: ESRI

Coordinate System: NAD 1983 FL State Plane North

N W E S

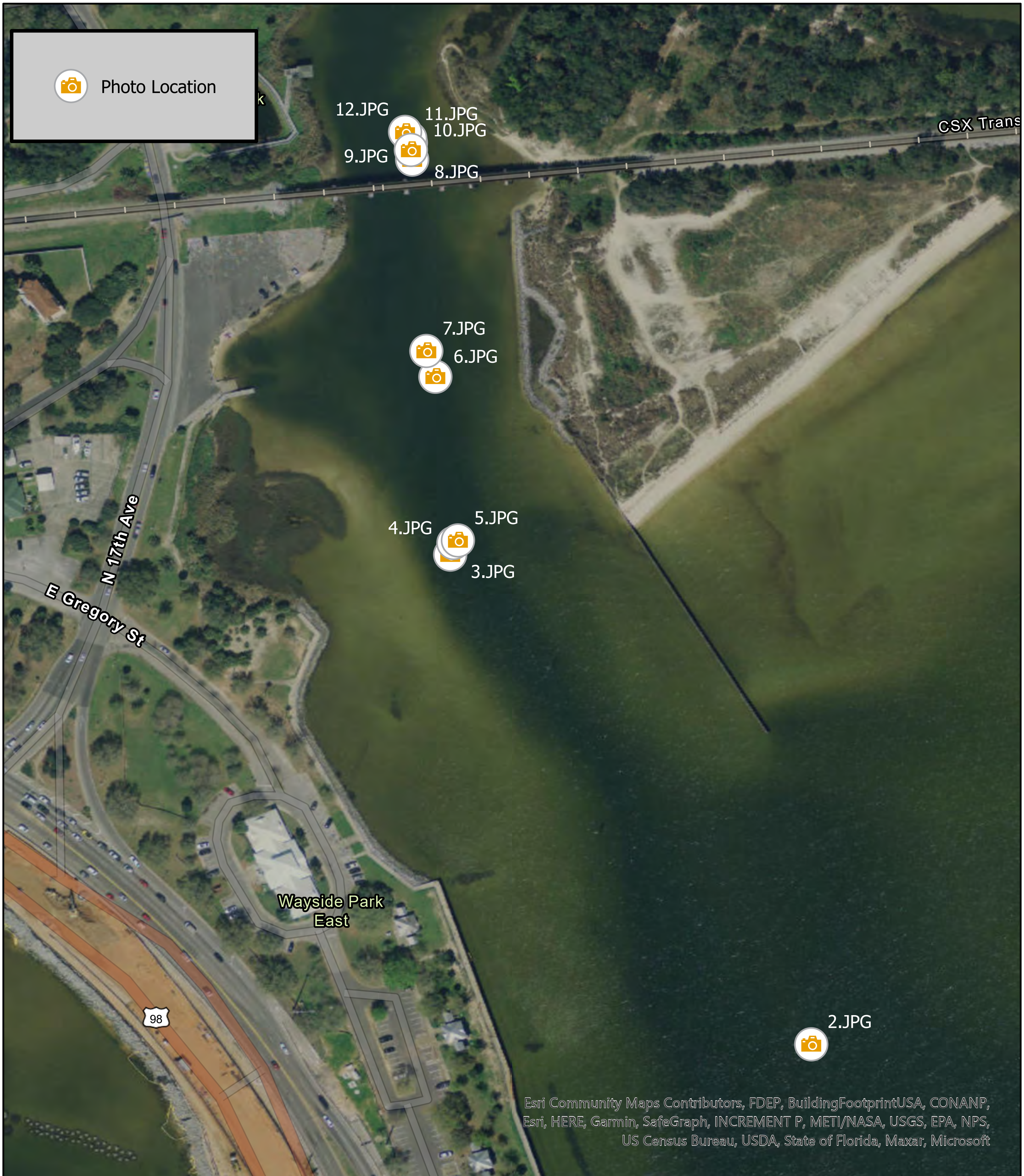

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Photo Location Map

Carpenter Creek/Bayou Texar Watershed Management Plan

0 0.01 0.03 0.06 0.08 0.11 Miles

Data Source: WSI
Imagery Source: ESRI

Coordinate System: NAD 1983 FL State Plane North

N S W E

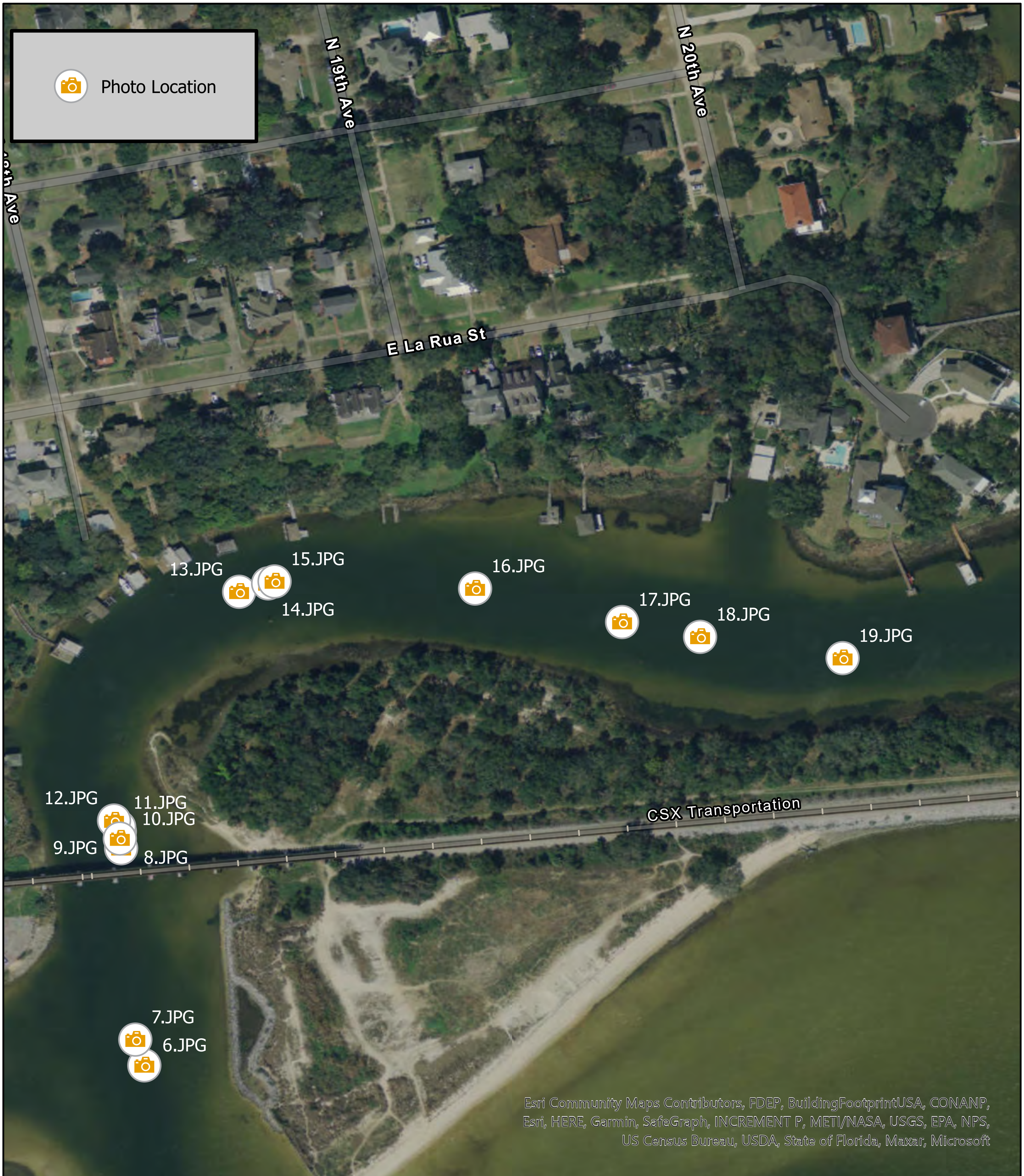

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Photo Location Map

Carpenter Creek/Bayou Texar Watershed Management Plan

0 0.01 0.03 0.06 0.08 0.11 Miles

Data Source: WSI
Imagery Source: ESRI

Coordinate System: NAD 1983 FL State Plane North

N W E S

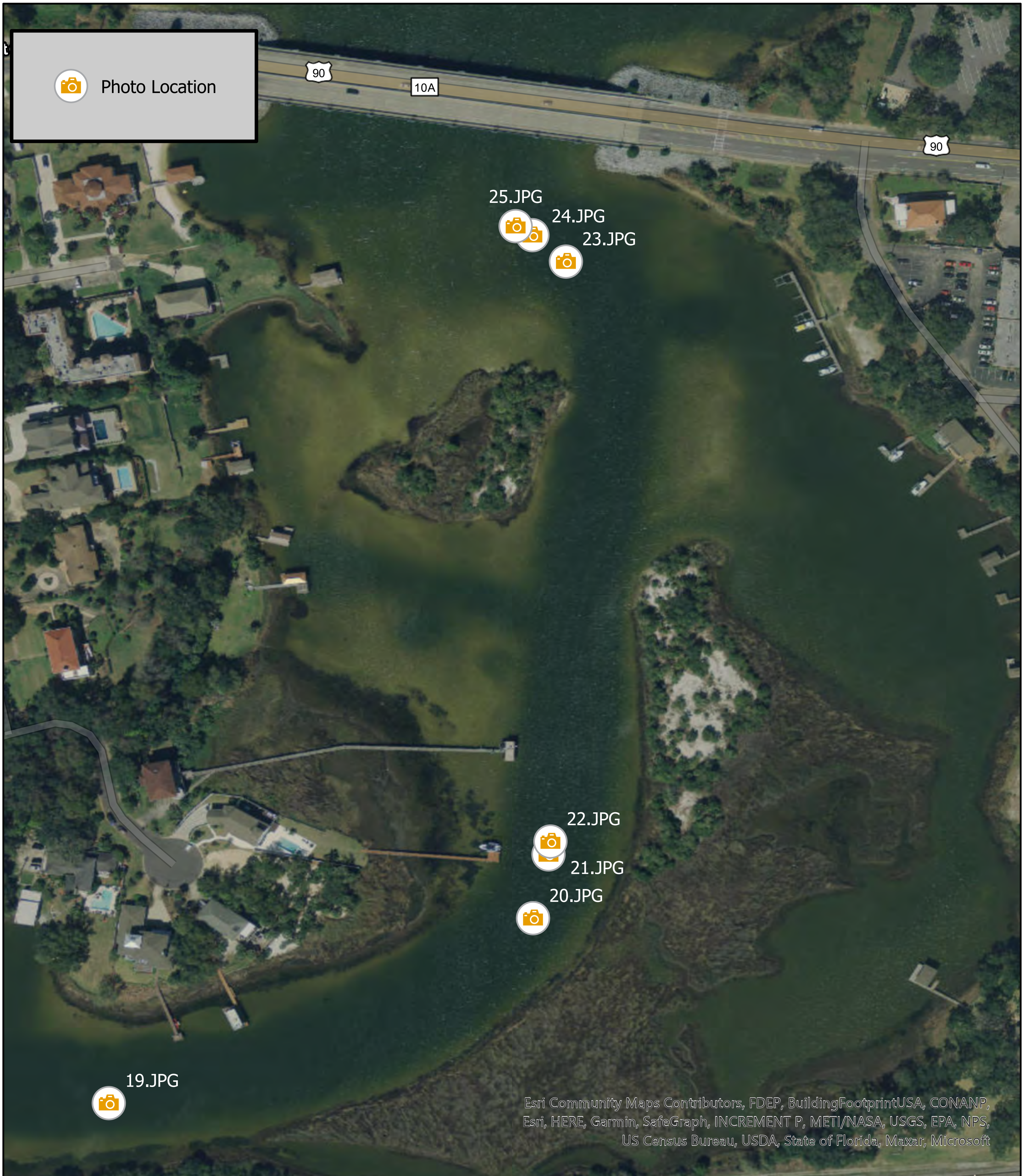

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Photo Location Map

Carpenter Creek/Bayou Texar Watershed Management Plan

0 0.01 0.03 0.06 0.08 0.11 Miles

Data Source: WSI
Imagery Source: ESRI

Coordinate System: NAD 1983 FL State Plane North

N W E S

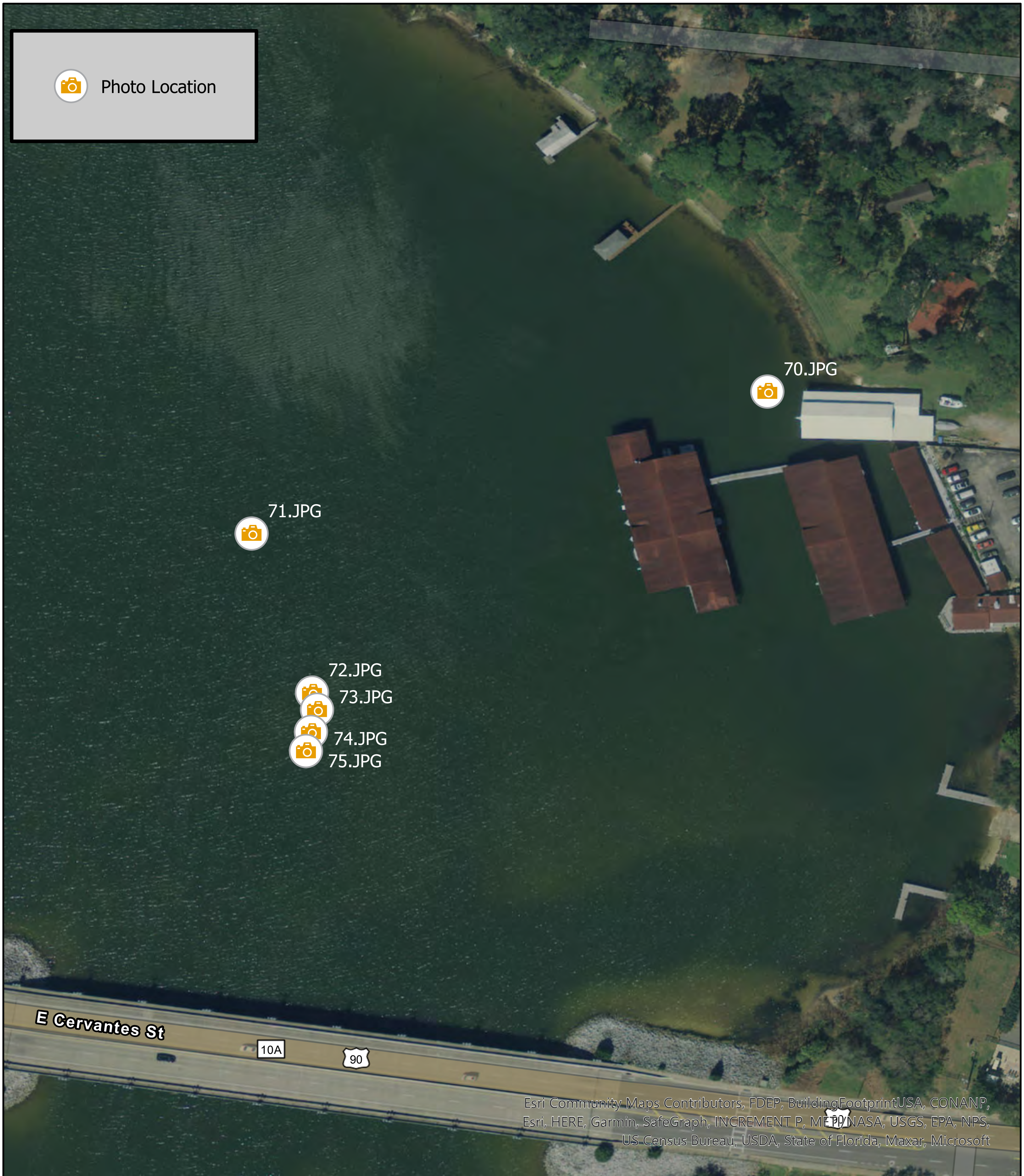

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Photo Location Map

Carpenter Creek/Bayou Texar Watershed Management Plan

0 0.01 0.02 0.04 0.05 0.07 Miles

Data Source: WSI
Imagery Source: ESRI

Coordinate System: NAD 1983 FL State Plane North

N W E S

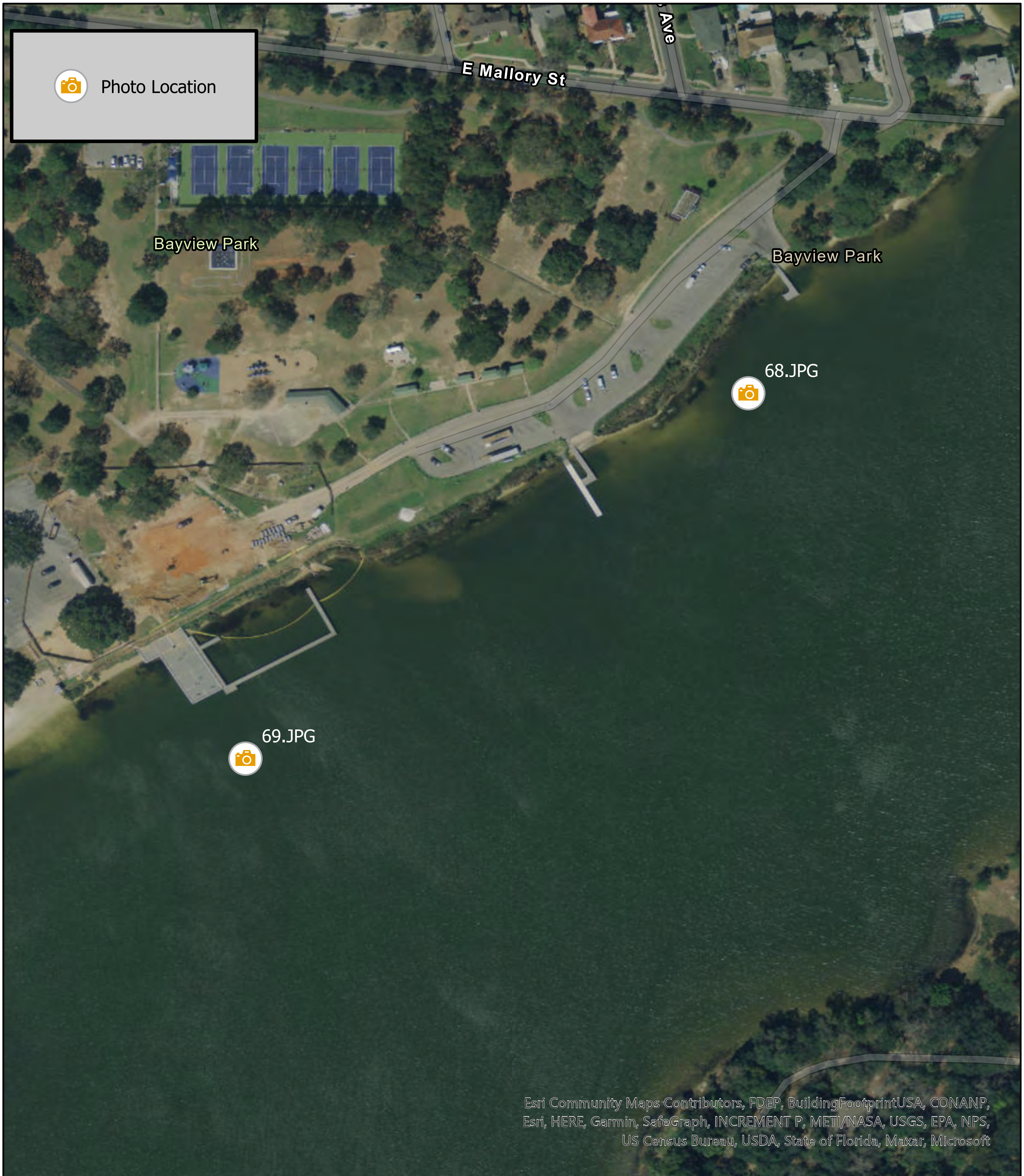

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Photo Location Map

Carpenter Creek/Bayou Texar Watershed Management Plan

0 0.01 0.03 0.06 0.08 0.11 Miles

Data Source:
WSI
Imagery Source:
ESRI

Coordinate System:
NAD 1983 FL
State Plane North

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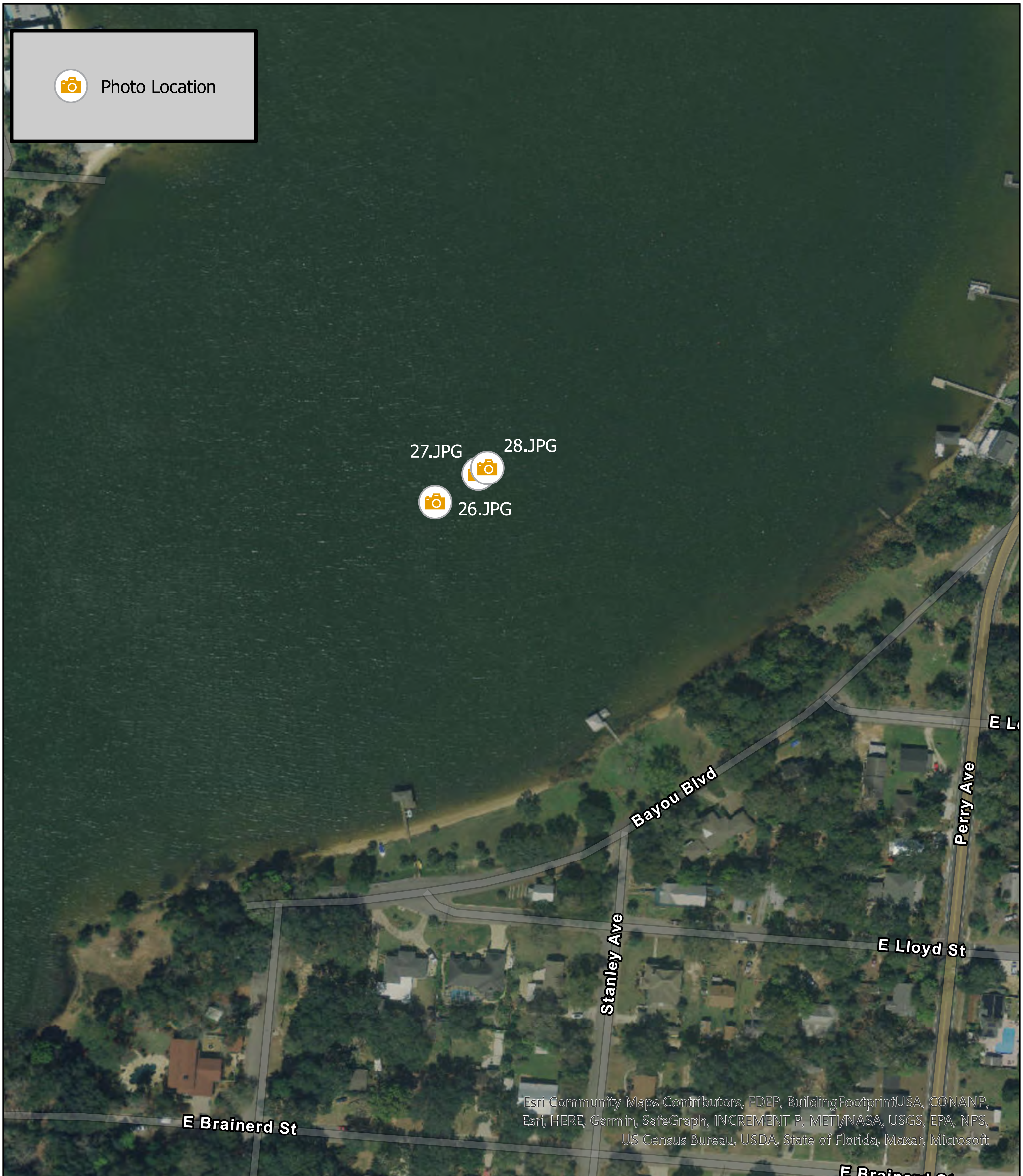

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Photo Location Map

Carpenter Creek/Bayou Texar Watershed Management Plan

0 0.01 0.03 0.06 0.08 0.11 Miles

Data Source:
WSI
Imagery Source:
ESRI

Coordinate System:
NAD 1983 FL
State Plane North

N W E S

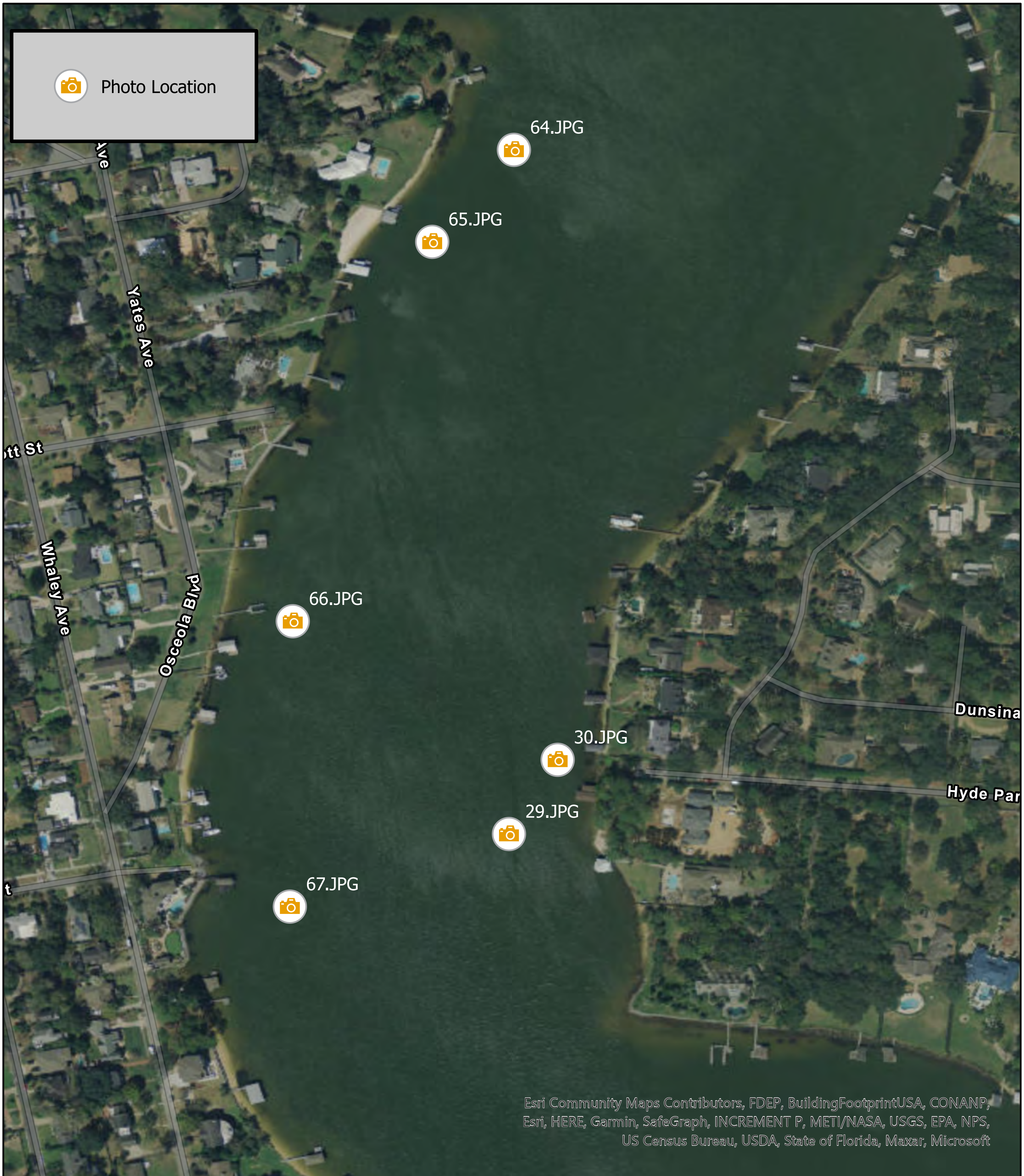

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Photo Location Map

Carpenter Creek/Bayou Texar Watershed Management Plan

0 0.02 0.04 0.09 0.13 0.18 Miles

Data Source: WSI
Imagery Source: ESRI

Coordinate System: NAD 1983 FL State Plane North

N W E S

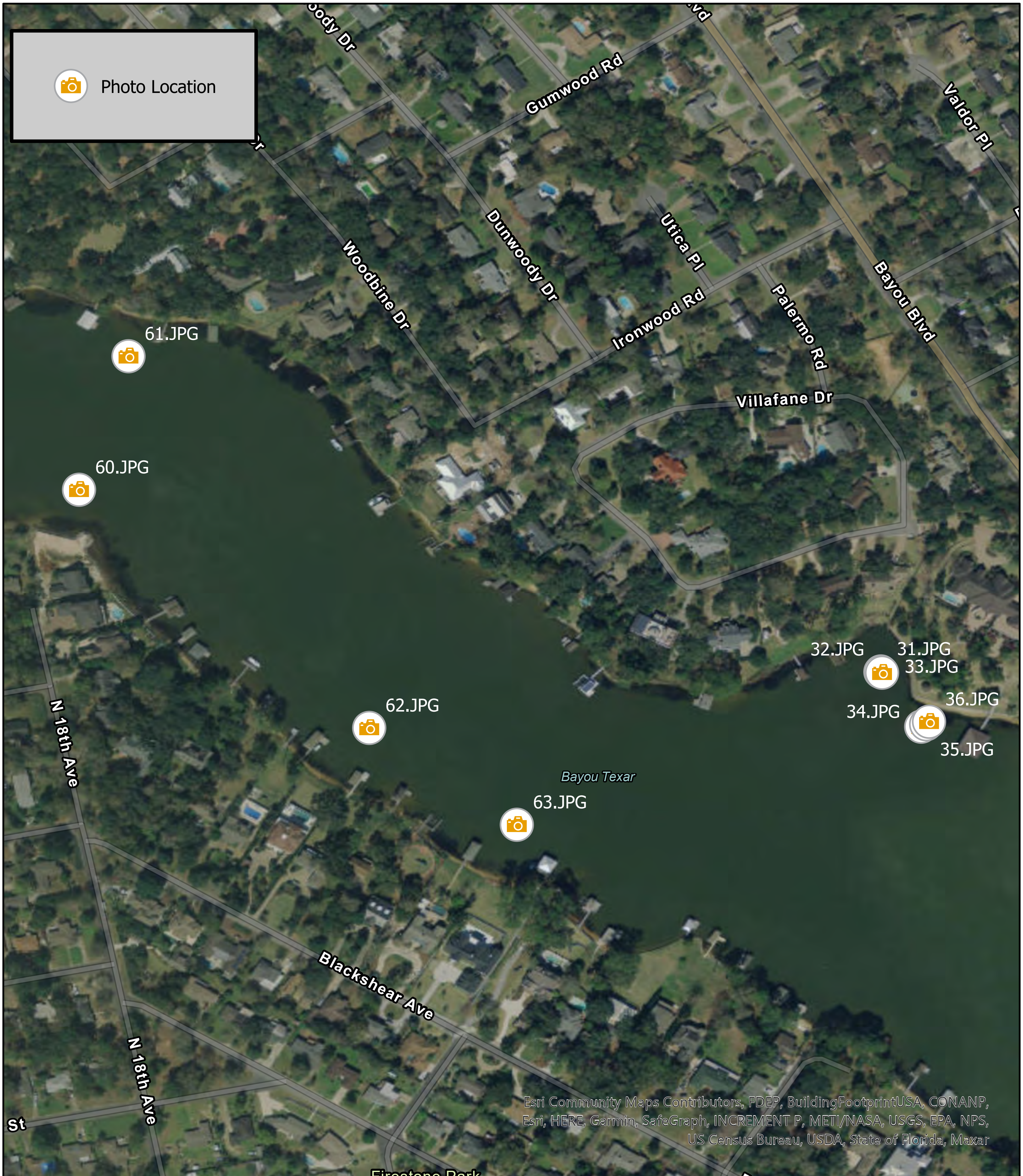

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Photo Location Map

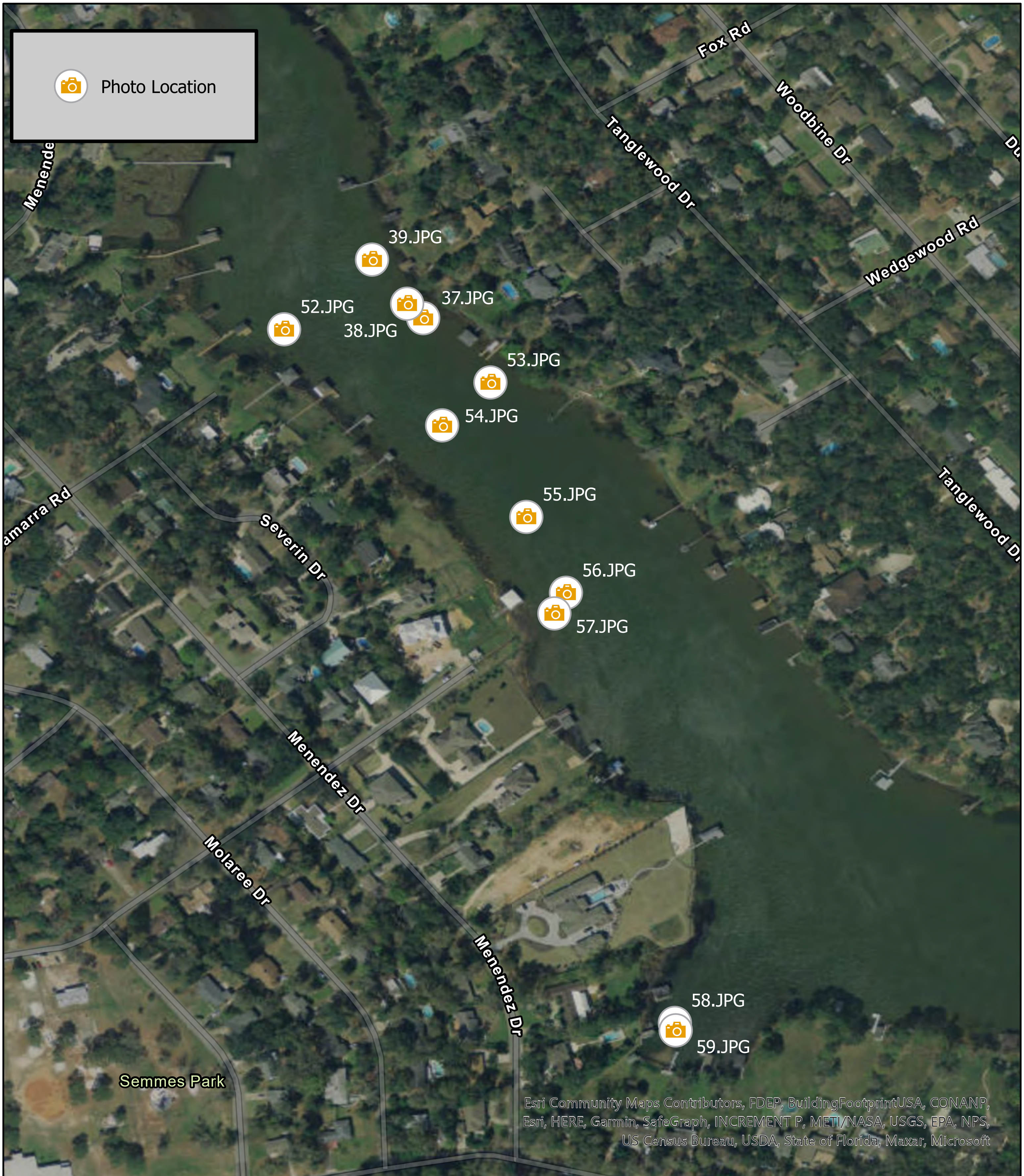
Carpenter Creek/Bayou Texar Watershed Management Plan

0 0.02 0.04 0.09 0.13 0.18 Miles

Data Source: WSI
Imagery Source: ESRI

Coordinate System: NAD 1983 FL State Plane North

N W E S



WETLAND SCIENCES INCORPORATED

All data within this map are supplied as is, without warranty. This product has not been prepared for legal, engineering, or survey purposes. Users of this information should review or consult the primary data sources to ascertain the usability of the information.

Photo Location Map

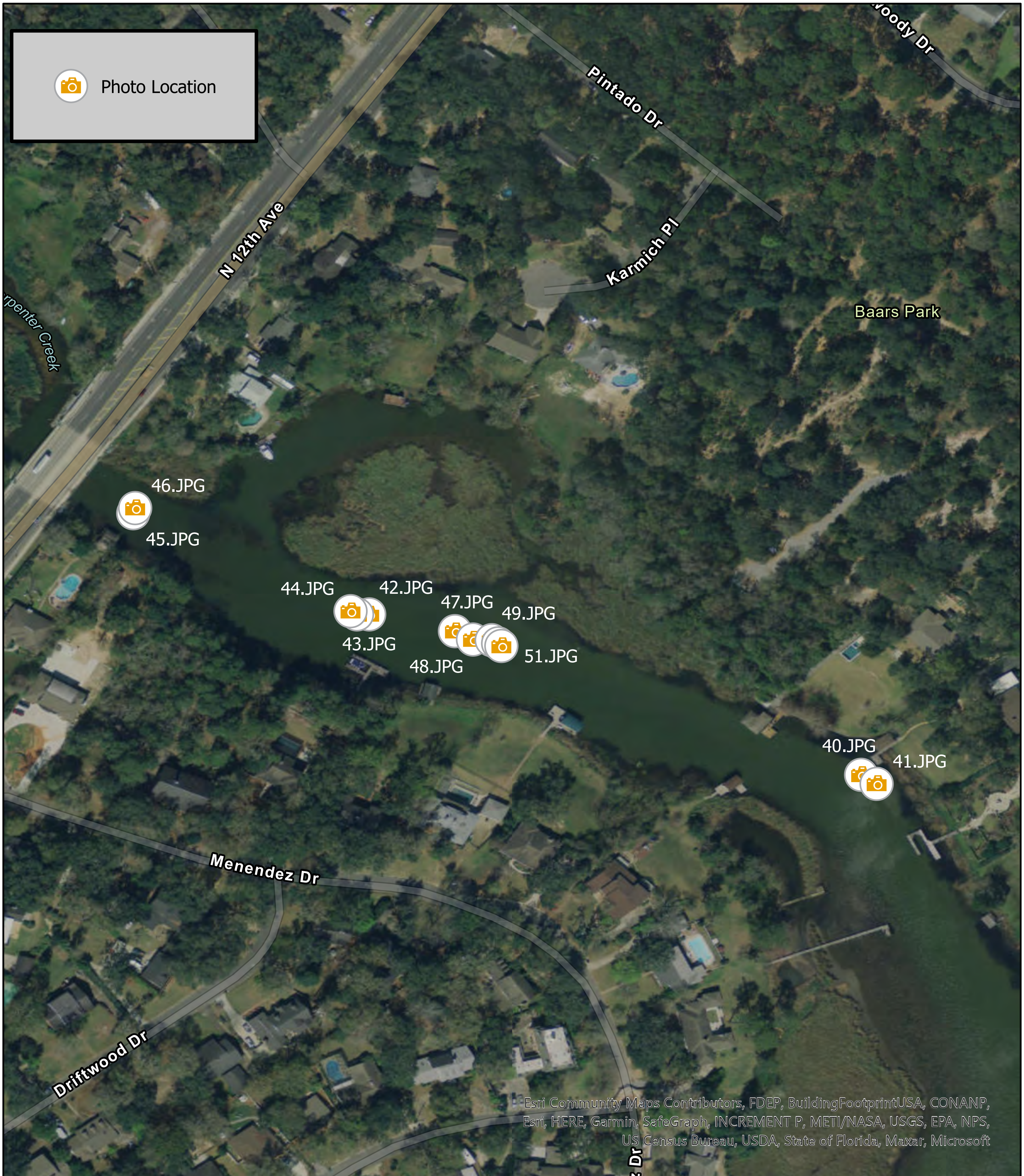
Carpenter Creek/Bayou Texar Watershed Management Plan

0 0.02 0.04 0.09 0.13 0.18 Miles

Data Source: WSI
Imagery Source: ESRI

Coordinate System: NAD 1983 FL State Plane North

N W E S



WETLAND SCIENCES INCORPORATED

Photo Location Map

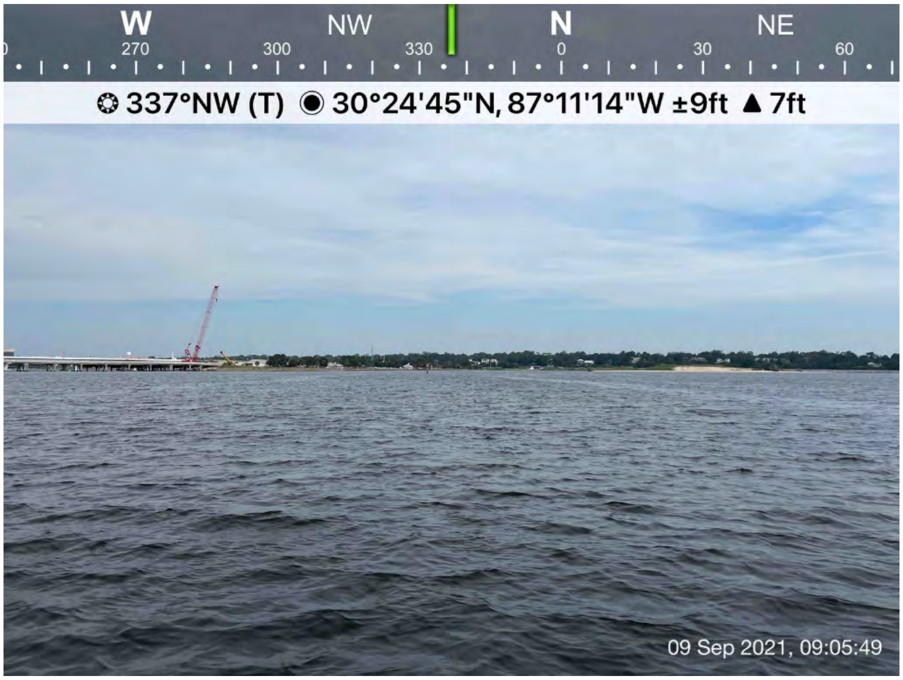
Carpenter Creek/Bayou Texar Watershed Management Plan

0 0.01 0.03 0.06 0.08 0.11 Miles

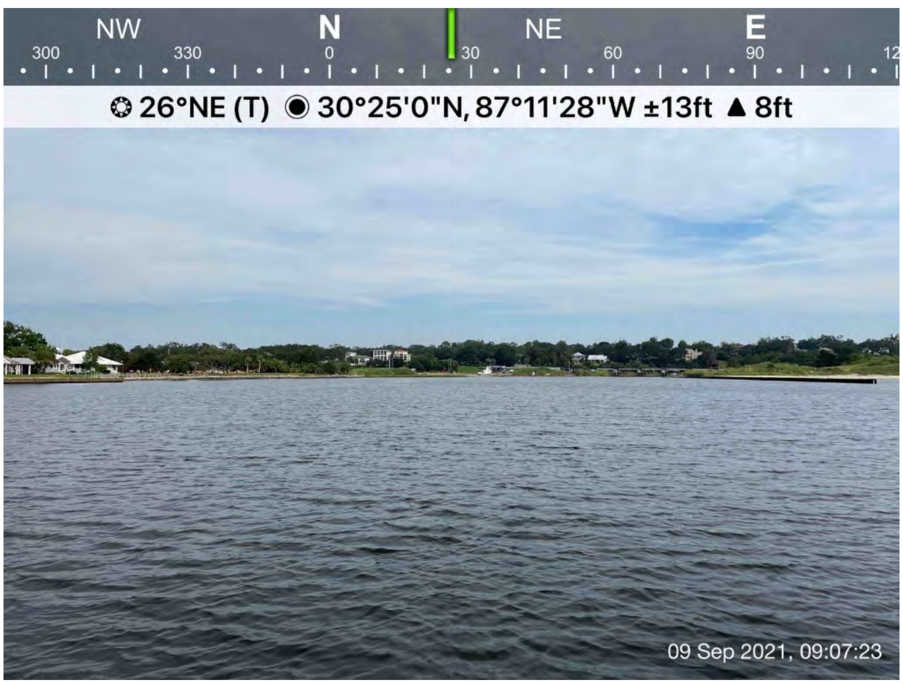
Data Source: WSI
Imagery Source: ESRI

Coordinate System: NAD 1983 FL State Plane North

N W E S

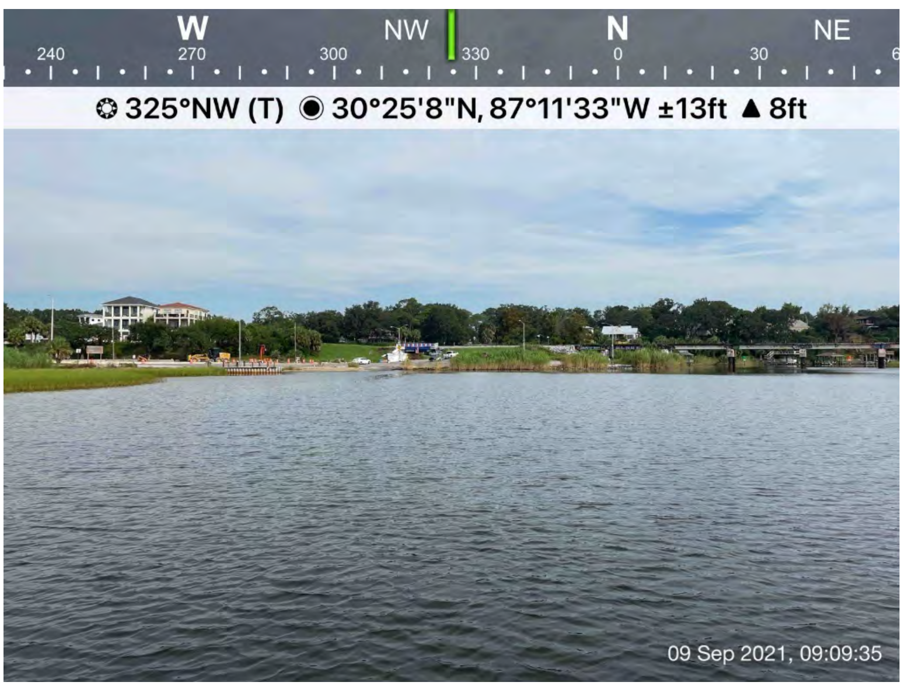


Photograph #1. Photograph taken in Pensacola Bay just south of the entrance to Bayou Texar.

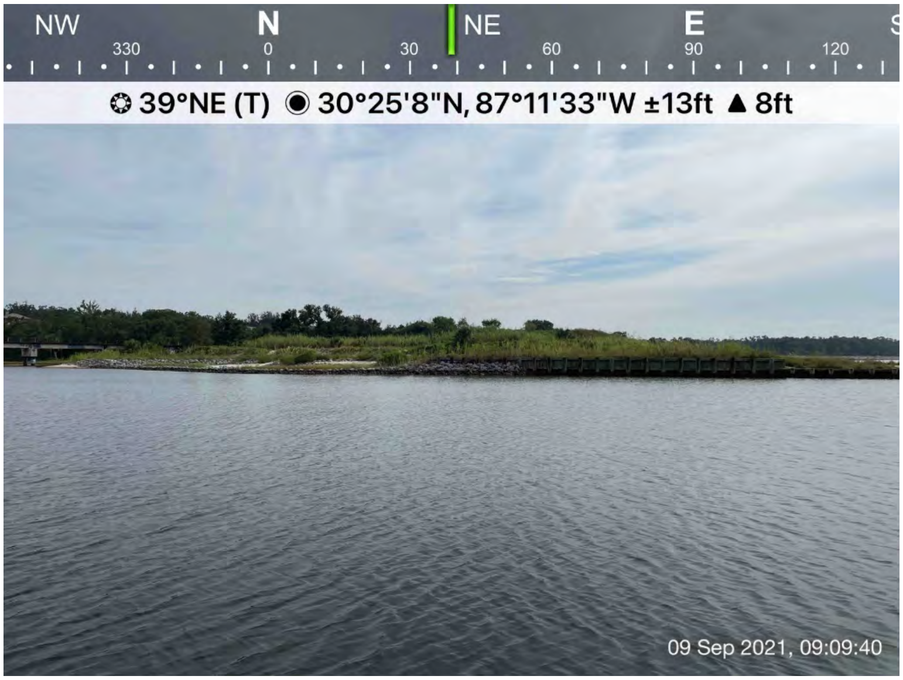


Photograph #2. Mouth of Bayou Texar at Pensacola Bay.

Photograph #3. Area of broad emergent aquatic vegetation located along the west side of the mouth of Bayou Texar. This area is dominated by salt marsh cordgrass (Spartina alterniflora) and common reed (Phragmites australis).

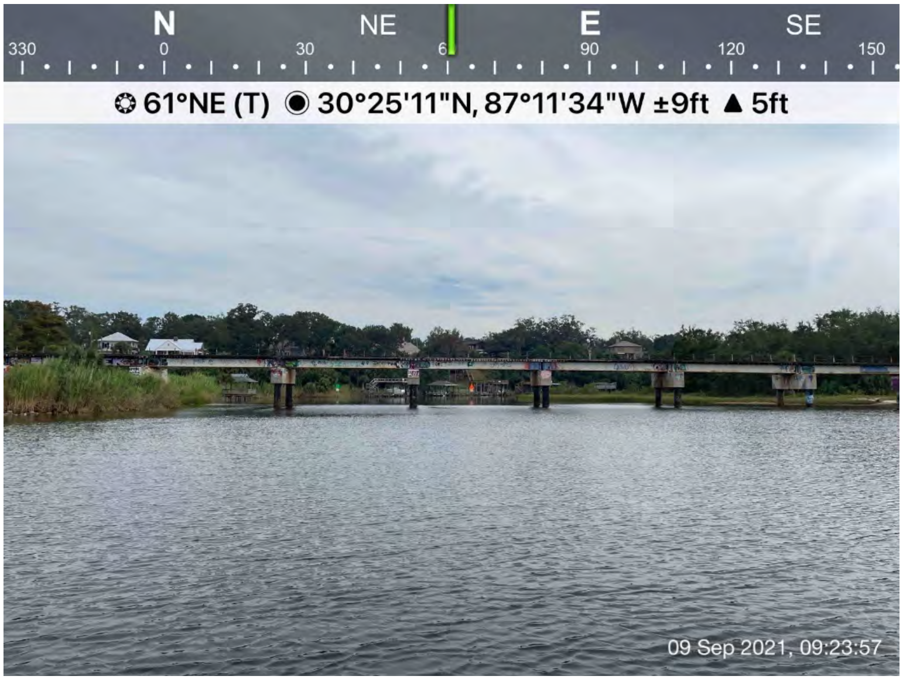


Photograph #4. 17th Ave boat ramp. There is a broad shallow shelf south of the boat ramp that is occupied by salt marsh cordgrass (Spartina alterniflora) and common reed (Phragmites australis). The shoreline north of the boat ramp is occupied by dense populations of common reed (Phragmites australis).

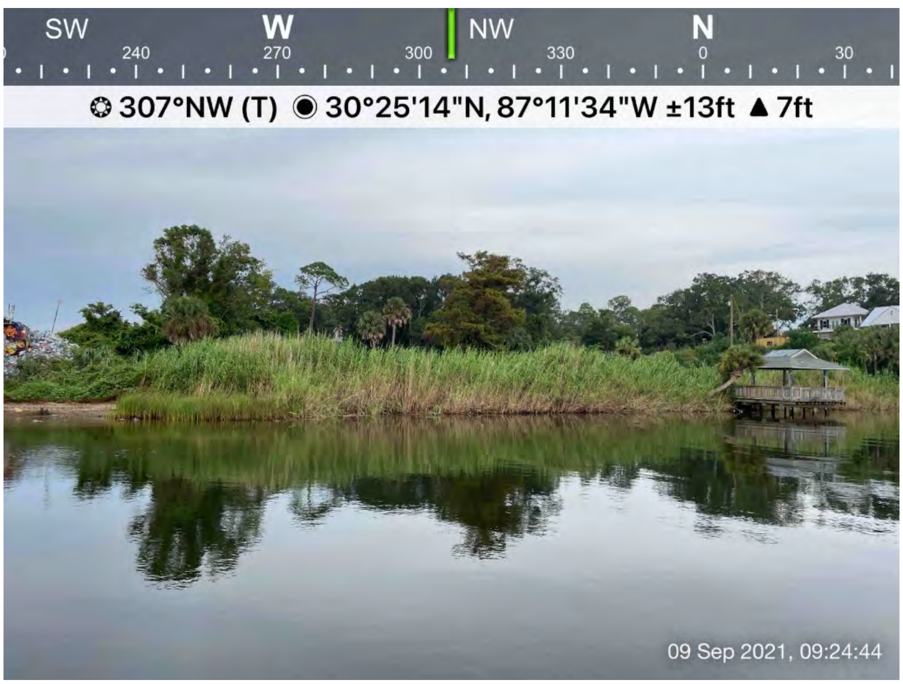


Photograph #5. Eastern shoreline along the mouth of Bayou Texar. This portion of the shoreline is armored with a mixed of vertical wooden retaining wall and limestone rip rap. Areas landward of the armored shoreline are occupied by common reed and salt grass (Distichlis spicata).

Photograph #6. Condition of east shoreline along the mouth of Bayou Texar just south of the railroad bridge. Shoreline armored with quarried limestone. Upland areas landward of the armored shoreline used as a dredge disposal site so native plant communities are altered.



Photograph #7. Railroad bridge that crosses the mouth of Bayou Texar. Structure is supported by steel piles with concrete pile caps.



Photograph #8. Taken just north of the railroad bridge looking northwest along the west shoreline of the Bayou. Shoreline dominated by dense coverage of common reed subtended by salt marsh cordgrass especially along the deeper margins of the littoral zone.

Photograph #9. Taken just north of the railroad bridge looking north at the marked navigation channel that exist between the mouth of the Bayou and the Cervantes Street bridge. There is a significant bluff along the west shoreline between 1720 E Belmont and east toward the terminus of La Rua Landing. Shoreline is largely occupied by broad, dense band of common reed. The bluff is comprised of a mature canopy of live oaks (Quercus virginiana), cabbage palm (Sabal palmetto).

Photograph #10. East shoreline of Bayou texar just between E La Rua Street and the railroad tracks. This area contains a broad shallow littoral zone mostly dominated by salt marsh cordgrass. Submersed aquatic vegetation

(SAVs) located waterward of the emergent vegetation to depths of -3-ft. SAVs primarily dominated by wild celery (Vallisneria americana) subtended by widgeon grass (Ruppia maritima).

Photograph #11. Northeast corner of the railroad track abutment. Littoral zones north of the railroad track largely dominated saltmarsh cordgrass. Xeric hardwood community landward of the emergent wetland community. Shoreline extremely stable and no signs of erosion.

Photograph #12. Northwest corner of the railroad bridge abutment. Shoreline dominate by common reed with limited isolated patches of salt marsh cord grass. Shoreline extremely stable with only disturbance the result of pedestrian access.

Photograph #13. Navigational aids including channel markers and no mooring signs along the entire channel between the railroad bridge and Cervantes Street Bridge. This is east shoreline of the Bayou which has not been affected by land disturbance activities associated with historical residential development. Shoreline dominated by broad shelf of salt marsh cord grass and wild celery. Upland coastal strand/xeric upland hardwood forest landward of the emergent wetland community.

Photograph #14. Submersed reef located along the waterfront of 1817 E La Rua Street along the west shoreline of the Bayou. The reef is obviously purpose built and deployed by the homeowner. It is marked by a sign "danger reef".

Photograph #15. Close up of submersed reef located along the waterfront of 1817 E La Rua Street.

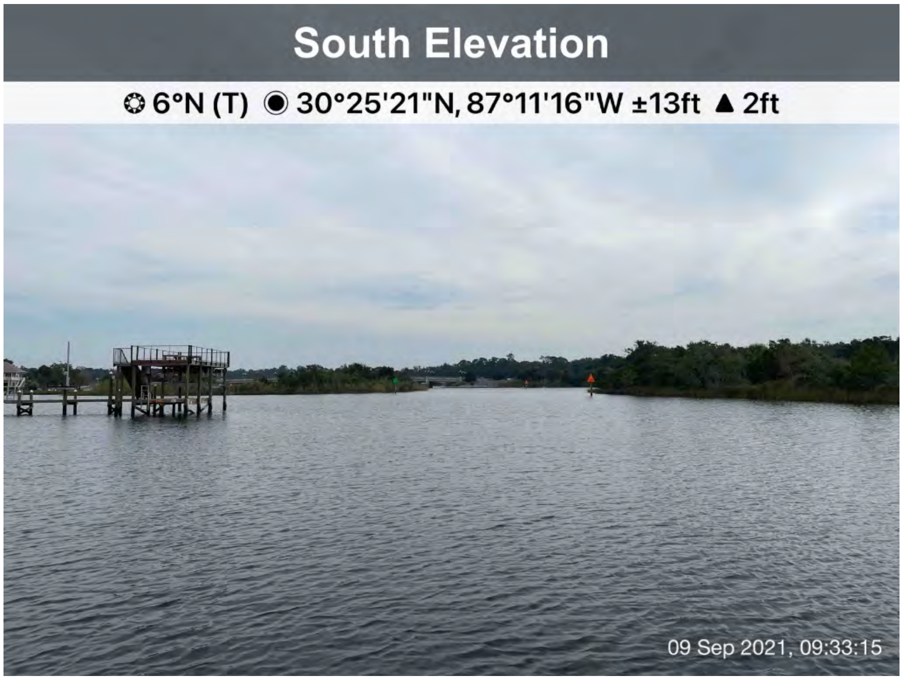
Photograph #16. View of east shoreline

Photograph #17. East shoreline of the Bayou just south of the east terminus of La Rua landing. It's at this location in the bayou where black needle rush (*Juncus romerianus*) begins to dominate the emergent wetland community. Needle rush becomes prevalent just north of Marker 6A (left of picture).

Photograph 18. West shoreline of the Bayou at 1919 E La Rua Street. It's at this location that the bluff subsides and tapers to the east. Manicured lawns terminate at a broad band of emergent and submersed vegetation. Emergent vegetation is dominated by common reed (landward side) and saltmarsh cord grass (waterward side). Submersed vegetation is dominated by wild celery.

Photograph #19. West shoreline of Bayou at 400 La Rua Landing. Single family lots are elevated a few feet above the mean high water line. Manicured lawns end at broad band of emergent and submersed vegetation consisting of salt marsh cord grass and wild celery.

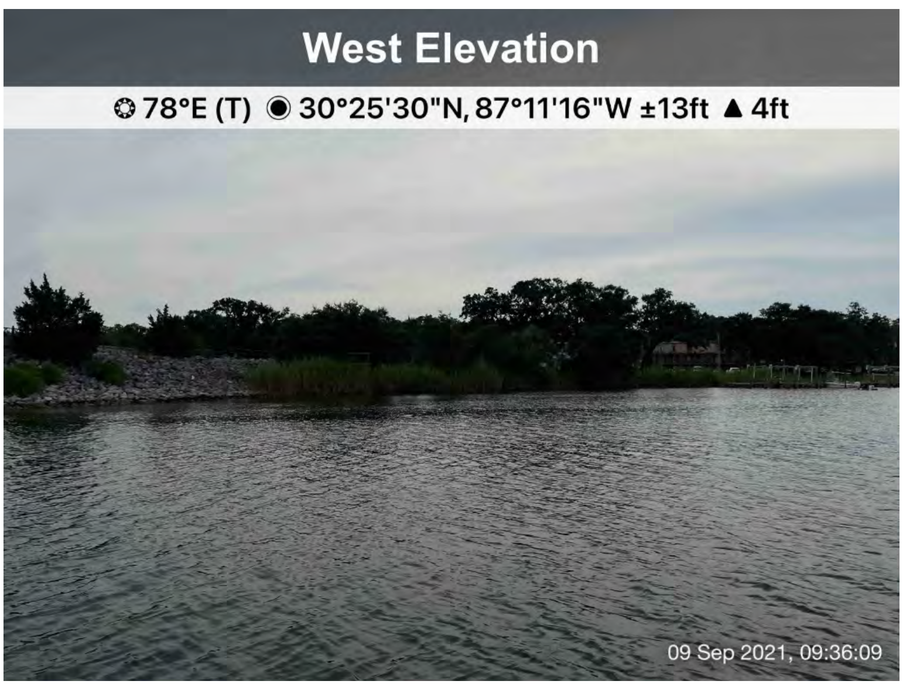
Photograph #20. Tidal flat located between the east shoreline and the center channel of the bayou. This area is dominated by black needle rush subtended by salt marsh cordgrass (along waterward edge). This broad band of vegetation is surrounding by dense meadow of submersed vegetation consisting of wild celery.



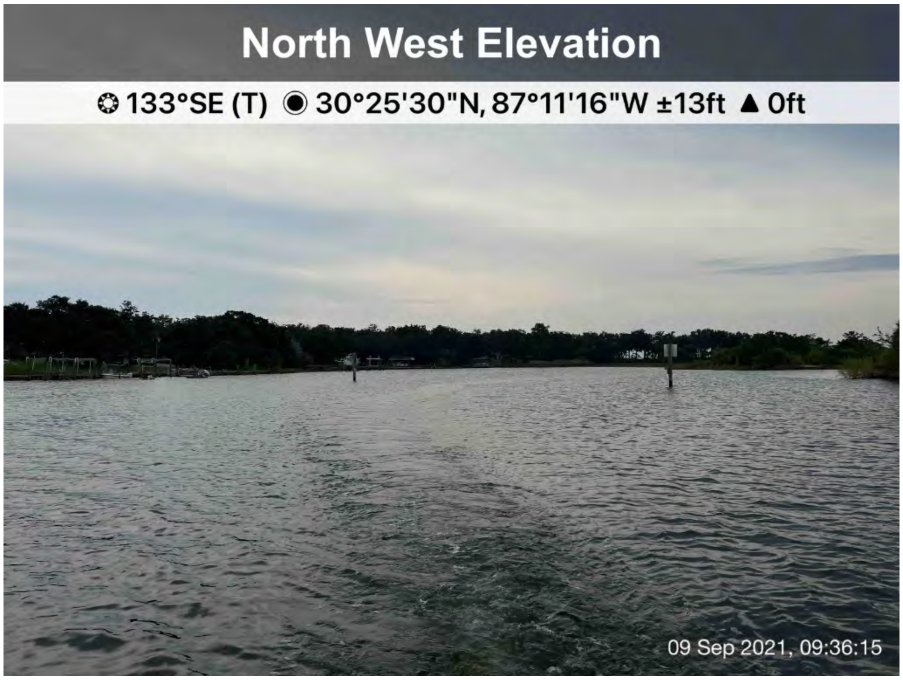
Photograph #21. Taken just east of 406 La Rua Landing looking north toward Cervantes street bridge.

Photograph #22. West shoreline of the bayou at 406 and 408 La Rua Landing. Broad band of emergent wetland vegetation dominated by salt marsh cord grass between the residential structures and the mean high-water line. There is a broad band of submersed band of wild celery between the mean high-water line and the channel. Boardwalk's accessing the riparian waterfront are elevated 5-ft. above grade to comply with dock construction guidelines over marsh.

Photograph #23. West shoreline of Bayou at 2008 E Gadsen Street at the southwest corner of the Cervantes Street bridge abutment. Shoreline of this property altered and resembles open sand beach. The manicured lawn of this property terminates at the open beach. No emergent or submersed vegetation at this location.

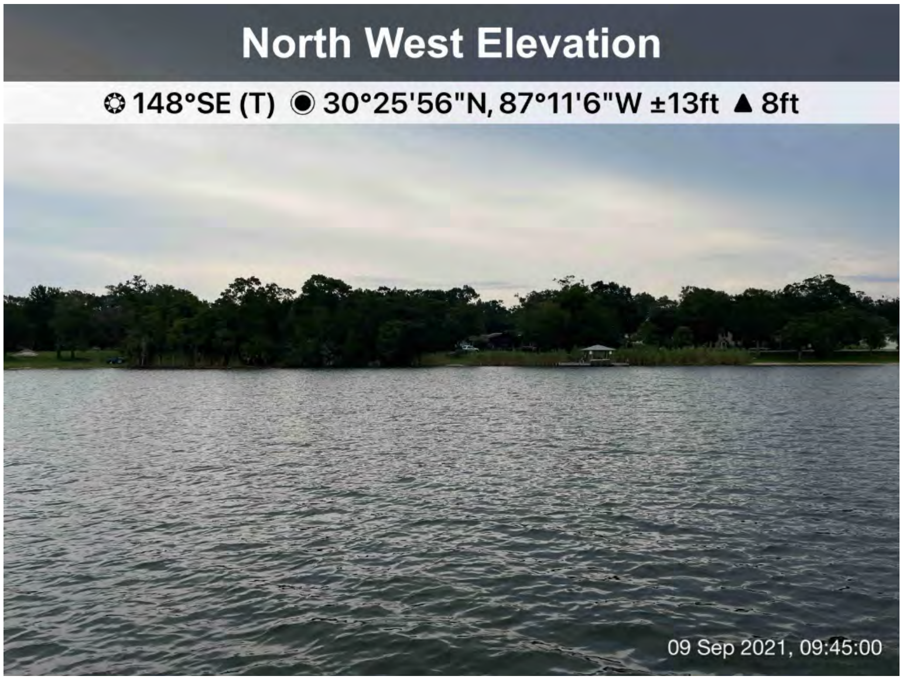


Photograph #24. West shoreline of the bayou at the northwest corner of the Cervantes Street bridge abutment. Abutment is armored by quarried limestone. Broad, dense band of common reed located just north of the bridge abutment along the west shoreline of the property.

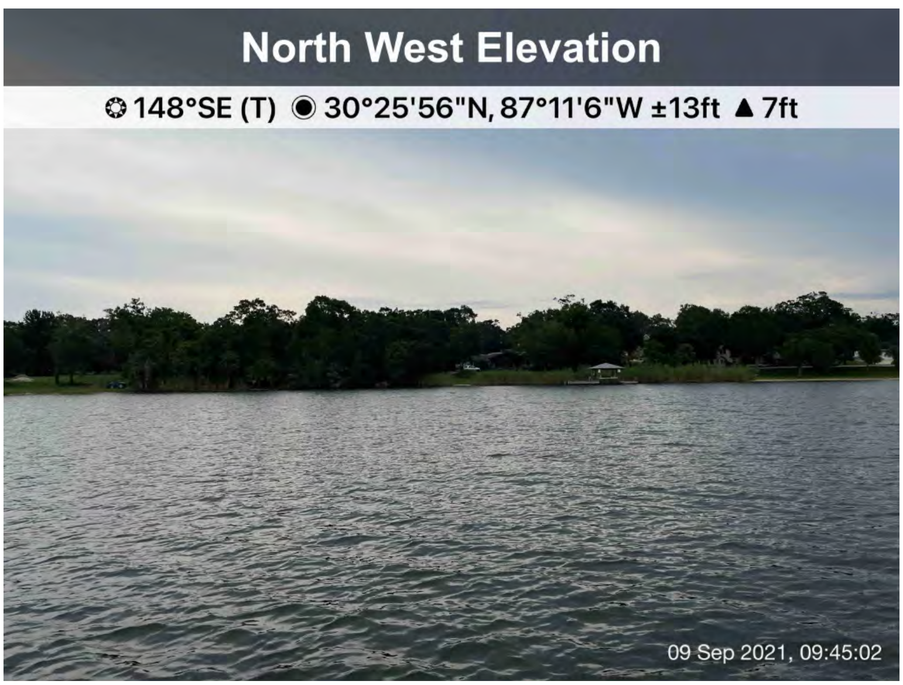


Photograph #25. Taken just south of the Cervantes Street bridge looking south along the center channel of the Bayou.

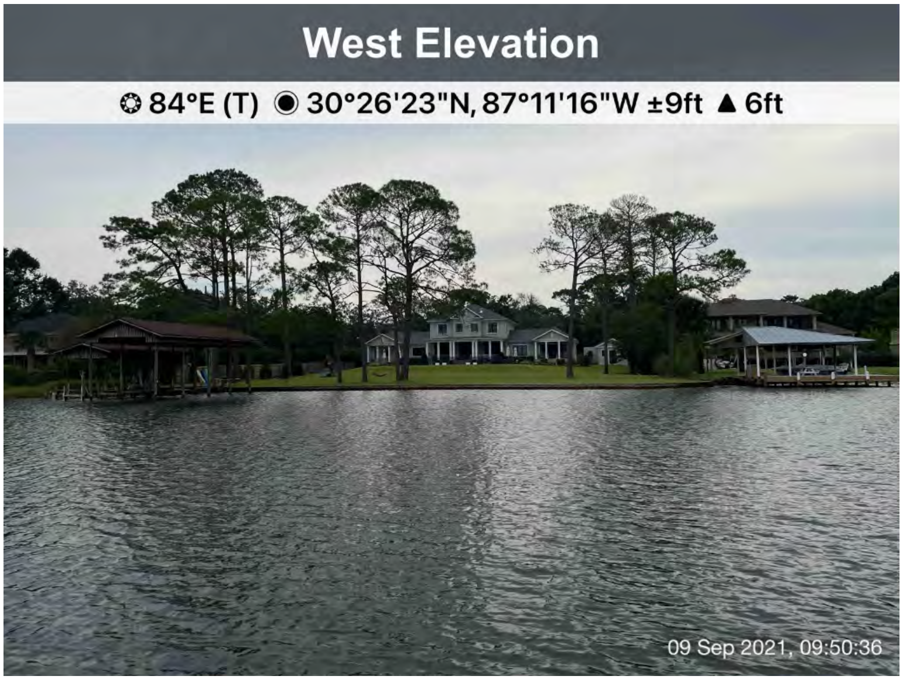
Photograph #26. West shoreline of the Bayou at the east terminus of E Mallory Street between Bayview Park and Osceola Blvd. House located at 1700 Osceola Blvd (White House) is located only a few feet of the mean high-water line. This appears to be purpose built especially considering the small boat garage specifically oriented to take advantage of its position along the shoreline. Initial thoughts would suggest close proximity of the home to the mean high-water line would indicate shoreline erosion but in our opinion this structure may have been constructed before city setbacks from the mean high-water line were required.



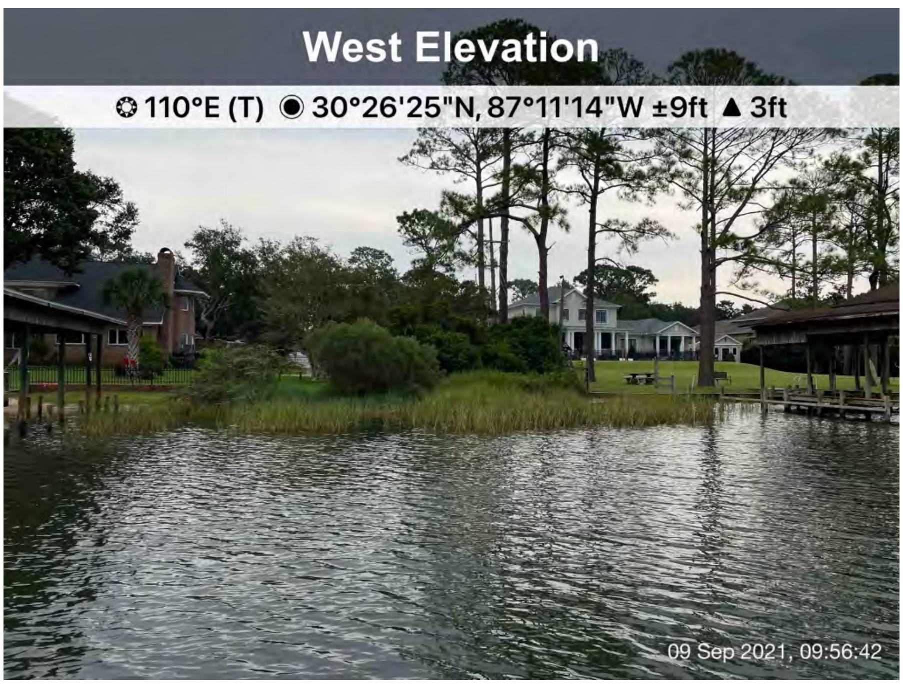
Photograph #27. Taken in the center of the Bayou looking southeast at the east shoreline of the Bayou.



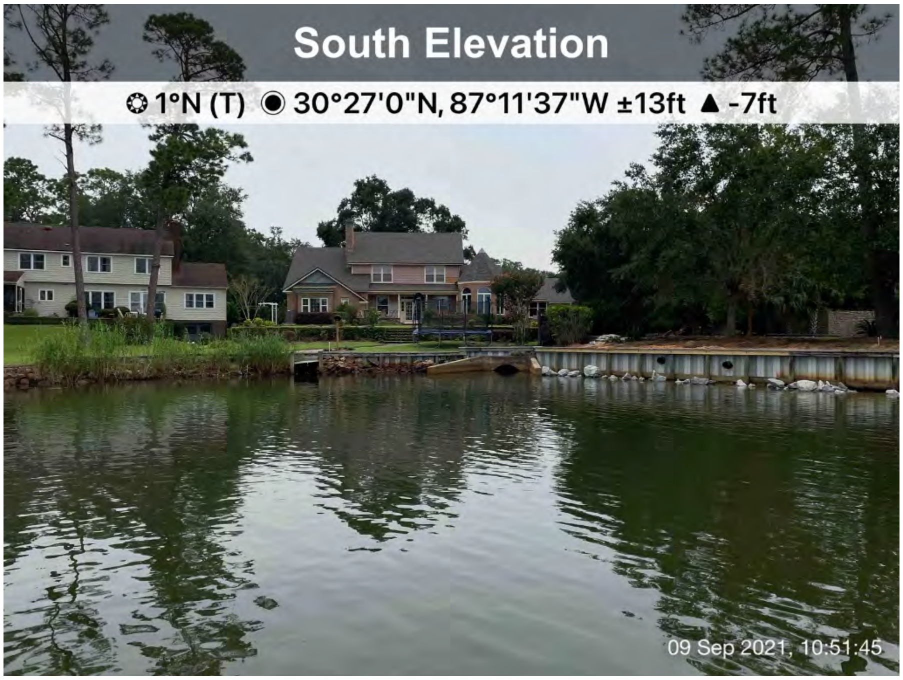
Photograph #28. Taken in the center of the Bayou looking southeast at the east shoreline of the Bayou.



Photograph #29. East shoreline of the Bayou just south of Hyde Park outfall. Shoreline represents one type of shoreline stabilization (i.e. manicured lawn that terminates to a vertical wall).



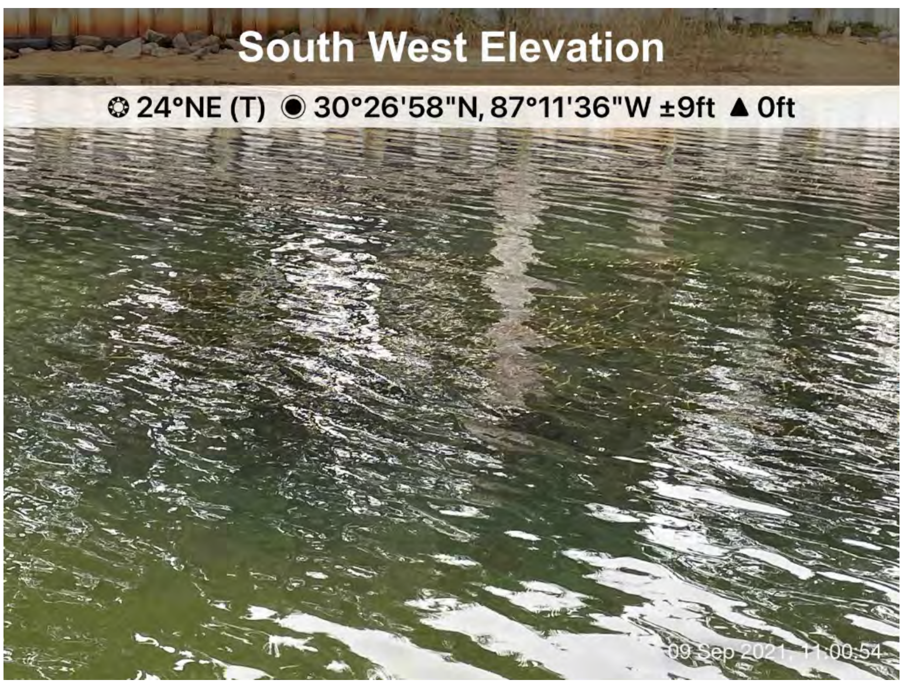
Photograph #30. Hyde Park outfall location. Emergent wetland vegetation consisting primarily of salt marsh cordgrass along the wateward edge of outfall.



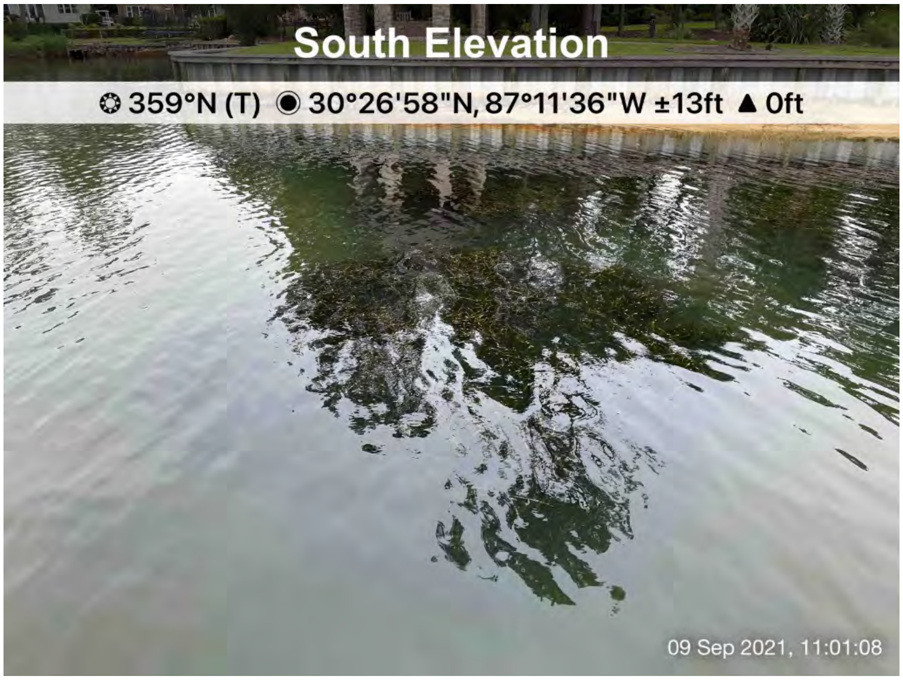
Photograph #31. Seville Street outfall location. There is a large sediment plume at this location which appears to be sediments that have accumulated from the outfall. Depths at this location are less than 2-ft. The bottom is dominated by coarse sands with thin layer of leaf pack. Dense bands of wild celery located along the entire shoreline but devoid in the area of the sediment plume which is centrally located in the small embayment.

Photograph #32. 1941 Seville Drive just northwest of outfall.

Photograph #33. 2000 Villafane Drive. Large estate home located just southeast of Seville Street outfall. This property is armored by vertical wall faced with quarried limestone. Dense band of submersed aquatic vegetation (wild celery) along the entire waterfront.



Photograph #34. Wild celery located along the waterfront of 2000 Villafane Drive.



Photograph #35. Wild celery located along the waterfront of 2000 Villafane Drive.

Photograph #36. Wild celery located along the waterfront of 2000 Villafane Drive.

Photograph #37. 691 Tennyson place. Emergent vegetation begins to transition to species less tolerant to saltwater including arrowhead (Sagittaria lancifolia), spider lily (Crinum Americanum), sawgrass (Cladium jamaicense). Aquatic hardwood trees also present including sweetbay magnolia (Magnolia virginiana) and bald cypress (Taxodium distichum).

Photograph #38. 695 Tennyson Place. East shoreline of Bayou dominated by broad band of emergent and submersed aquatic vegetation. Emergent vegetation consists of arrowhead, spider lily, and sawgrass. Submersed vegetation is dominated by wild celery.

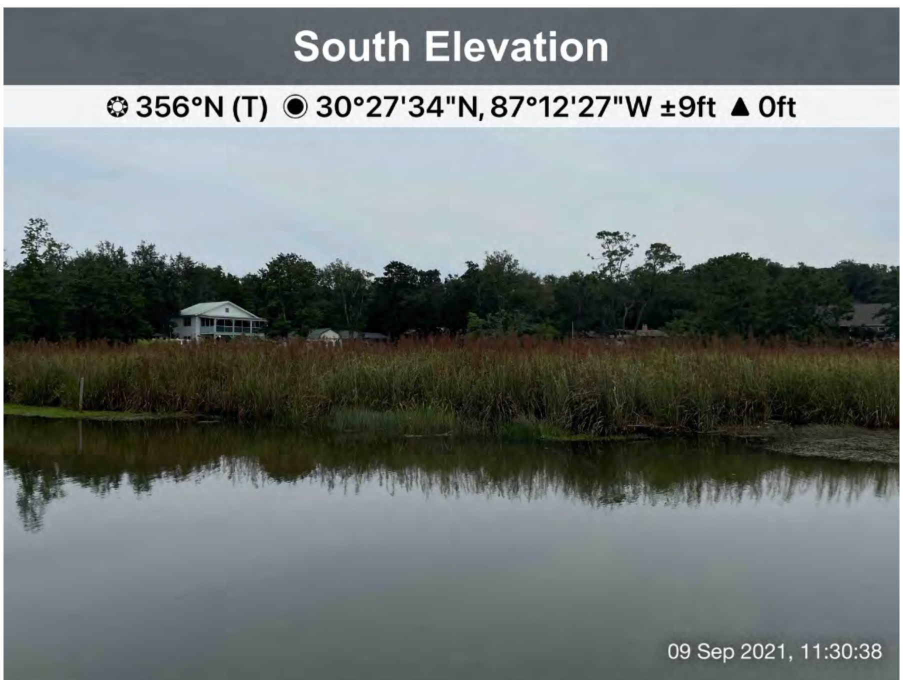
Photograph #39. 731 Tanglewood Drive. East shoreline of Bayou. Shoreline hardened with wooden wall faced with concrete rubble.

Photograph #40. 875 Tanglewood Drive. East shoreline of the Bayou. Manicured lawn to broad band of emergent wetland vegetation consisting of needle rush and arrowhead. Broad band of dense submersed vegetation consisting of wild celery just waterward of the emergent vegetation persisting to depths of -3-ft.

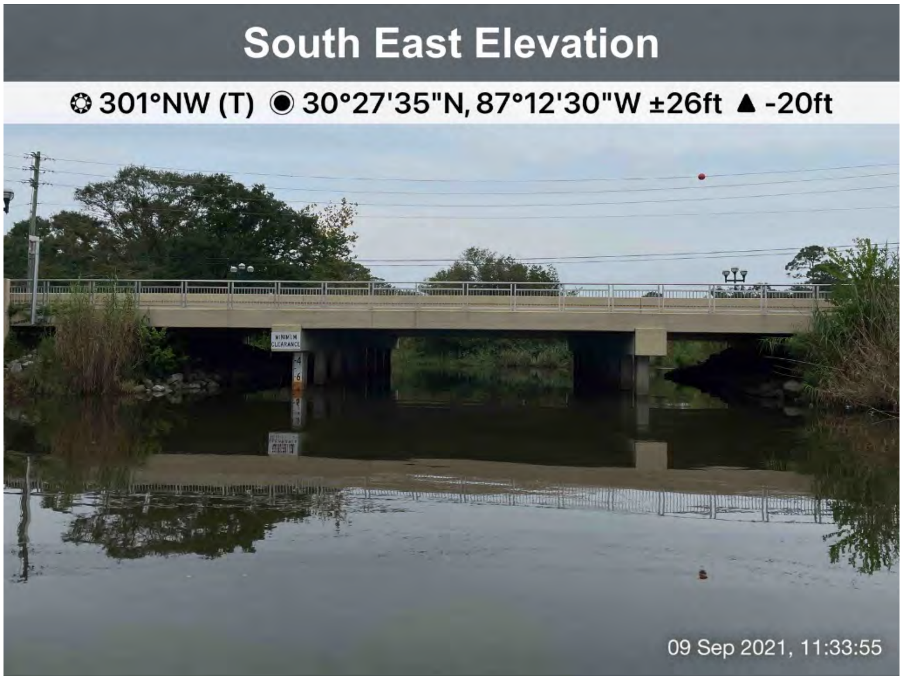
Photograph #41. Fruiting wild celery along the waterfront of 875 Tanglewood Drive.

Photograph #42. Waterfront of 4150 Menendez Drive. West shoreline of the Bayou. Emergent vegetation at this location dominated by common reed.

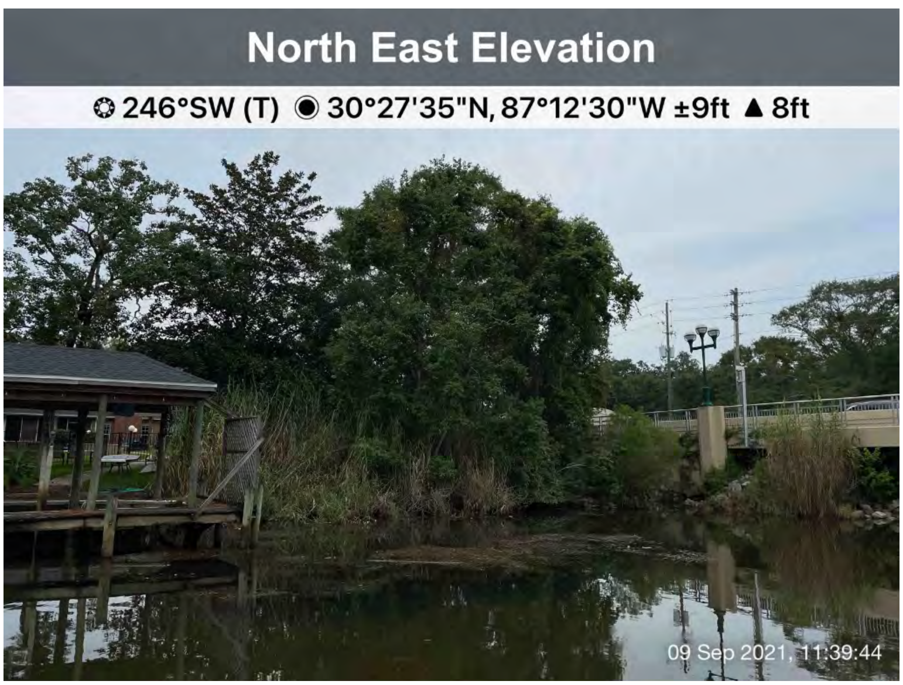
Photograph #43. Taken just east of 4150 Menendez Drive looking north at 12th Ave bridge.



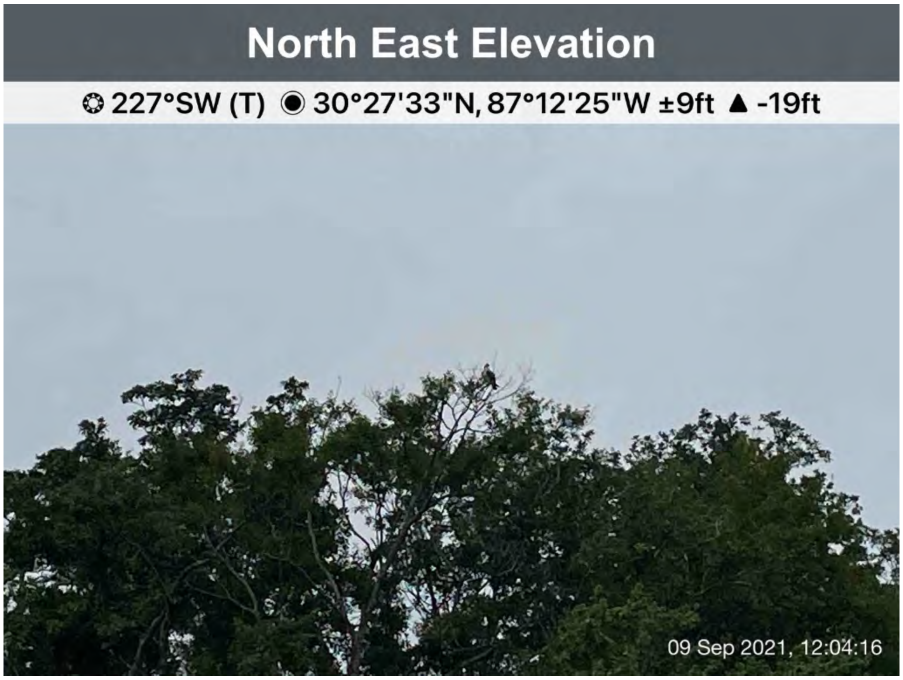
Photograph #44. Taken just east of 4150 Menendez Drive looking north east at broad tidal flat largely comprised of sawgrass.



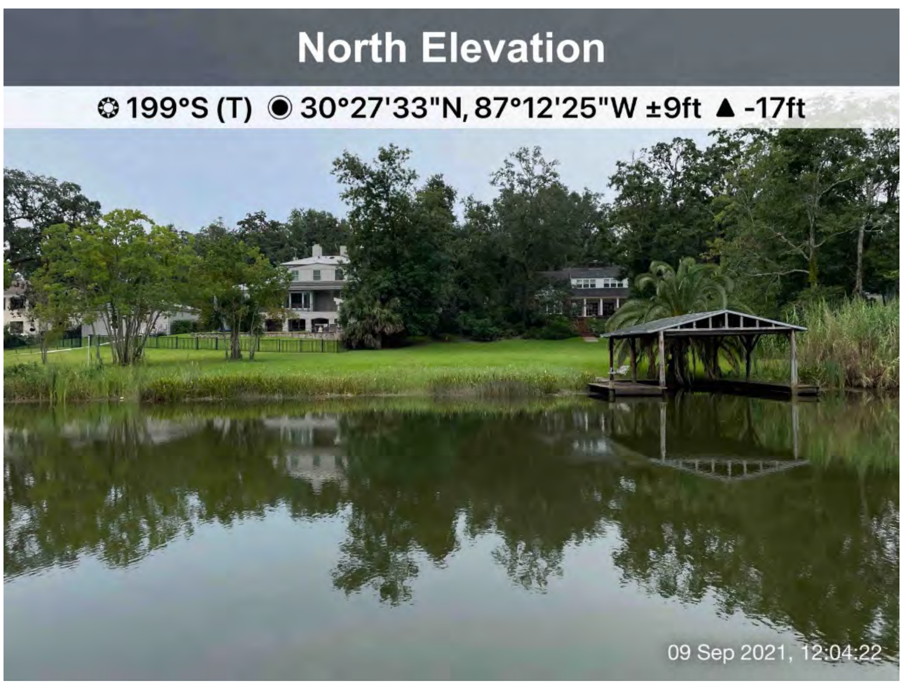
Photograph #45. 12th Ave bridge.



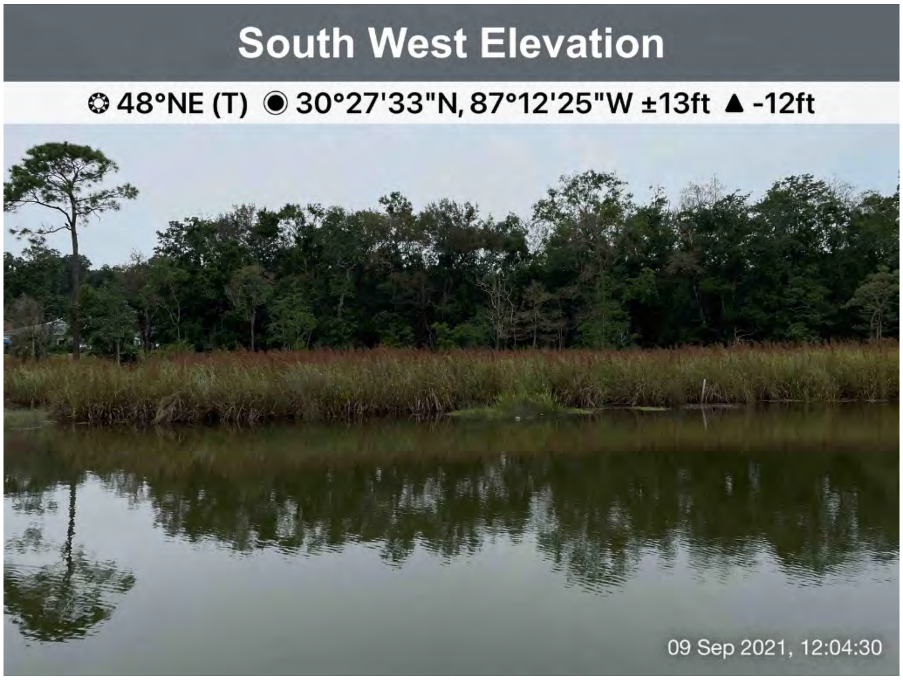
Photograph #46. Southwest corner of 12th Ave bridge abutment. Shoreline is dominated by common reed with a broad band of submersed vegetation (wild celery) located just waterward of the mean high water line and extending to depths of -3-ft.



Photograph #47. Osprey just south of 12th Ave bridge.

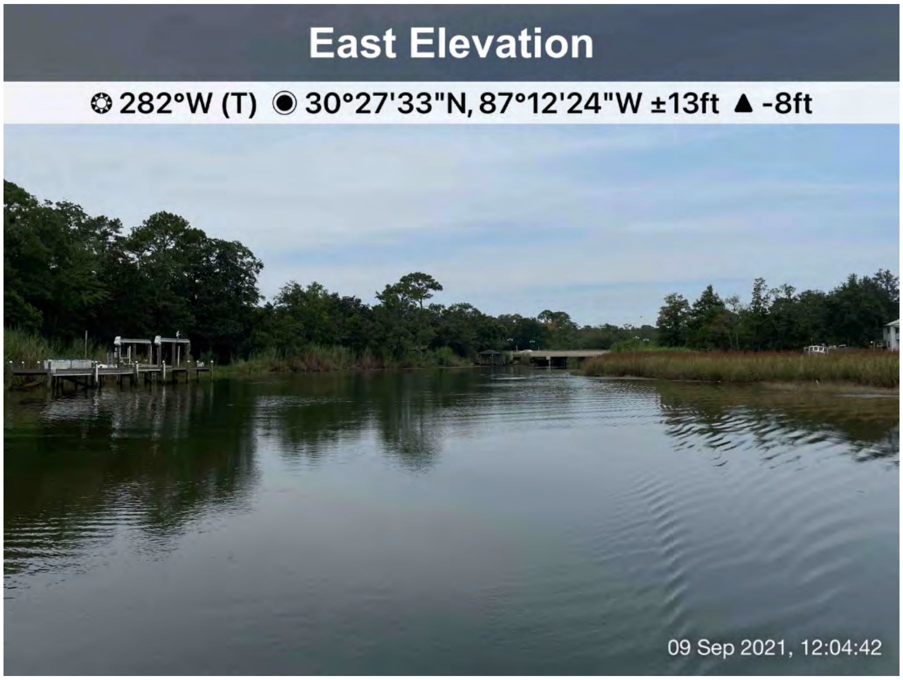


Photograph #48. 4130 Menendez Street. West shoreline of Bayou. Manicured lawn to emergent wetland vegetation.



Photograph #49. East shoreline of the Bayou just east of 4120 Menendez Drive. Large area of emergent wetland vegetation consisting primarily of sawgrass at this location.

Photograph #50. Taken in the center of the Bayou just north of 4120 Menendez looking south.



Photograph #51. Taken in the center of the Bayou just north of 4120 Menendez looking northwest towards 12th Ave.

Photograph #52. Gamarra Road outfall located along the west shoreline of the Bayou.

Photograph #53. 681 Tennyson Place. East shoreline of the Bayou. Common example of typical shoreline stabilization method for single family residence along the bayou. Vertical sheet pile wall with no rip rap.

Photograph #54. 234 Severin Drive. West shoreline of the Bayou. Large dense band of emergent wetland vegetation between the manicured lawn and the mean high-water line.

Photograph #55. 104 Severin Drive just north of E34th Street outfall along west shoreline of Bayou.

Photograph #56. Dock structure at 104 Severin Drive. Boathouse with enclosed walls generally not allowed by regulatory agencies with purview.

Photograph #57. E 34th Street outfall. West shoreline of Bayou.

Photograph #58. Menendez drive outfall located along west shoreline of Bayou.

Photograph #59. Area proximal to Menendez street outfall dominated by wild taro (Colocasia esculenta).

Photograph #60. 3420 North 18th Ave. Shoreline armored with vertical wall faced with quarried limestone. Broad area of submersed vegetation consisting of wild celery waterward of the existing rip rap to depths of -4-ft.

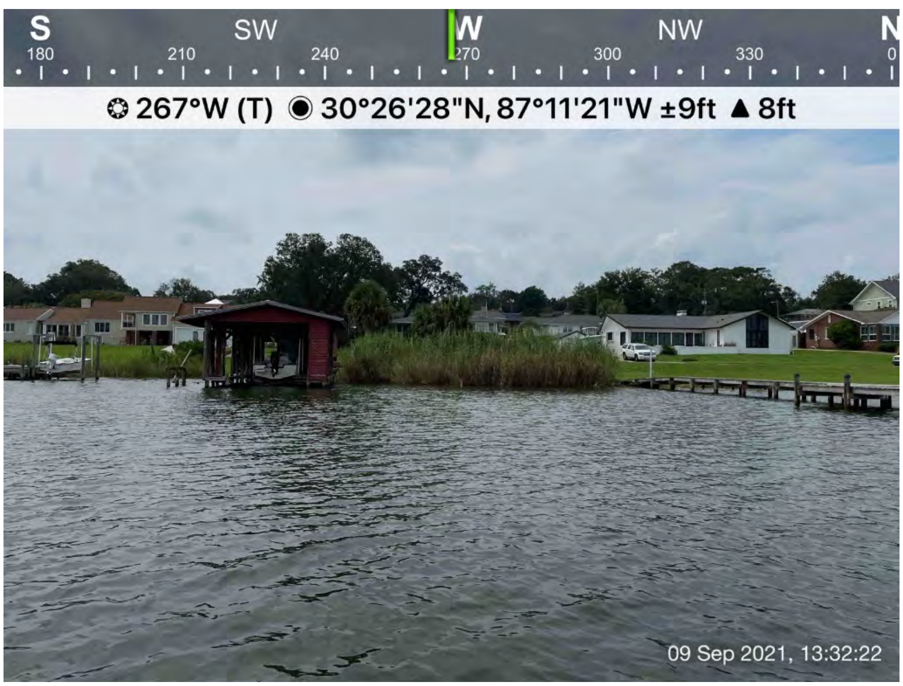
Photograph #61. 371 Woodbine Drive. East shoreline of the Bayou. Two shoreline stabilization techniques including vertical wall with no rip rap (left) and rip rap revetment (right). Submerged lands proximal to the shoreline comprised of submersed aquatic vegetation consisting of wild celery.

Photograph #62. 3012 Blackshear Ave. West shoreline of Bayou. Example of ineffective BMPs during construction. No barrier in place to keep exposed sediments from eroding into the Bayou.

Photograph #63. 3000 Blackshear Ave. West shoreline of Bayou. Manicured lawn to the mean high-water line. Little to no emergent wetland vegetation and limited submersed vegetation.

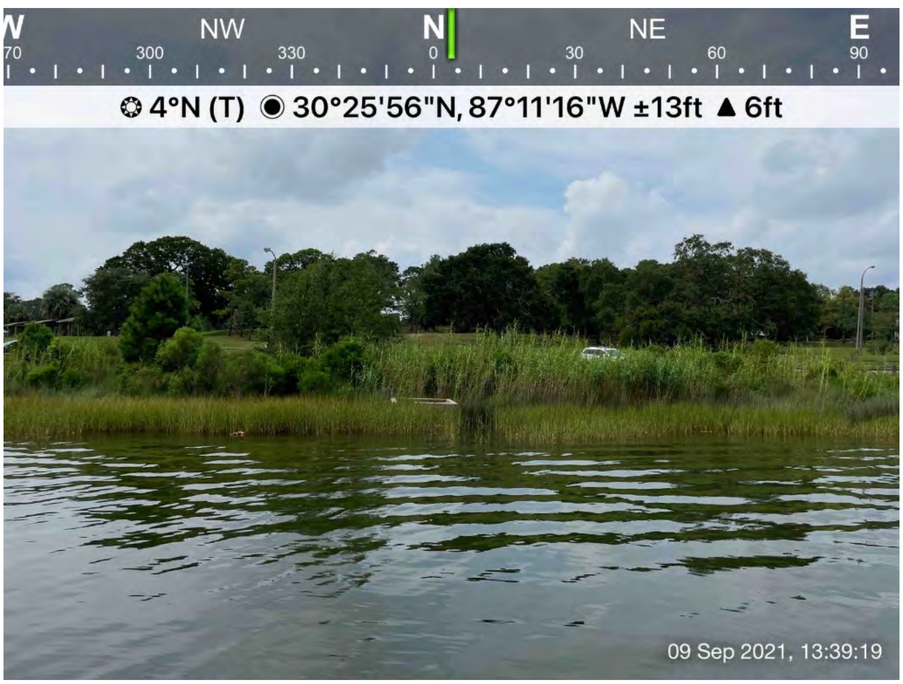
Photograph #64. Taken just south of Point Lakeview along west shoreline of Bayou. Manicured lawn to narrow band of emergent wetland vegetation at this location.

Photograph #65. 2600 Paradise Point Drive. West shoreline of Bayou. Open beach at this location. No emergent or submersed vegetation. Highly manipulated shoreline.

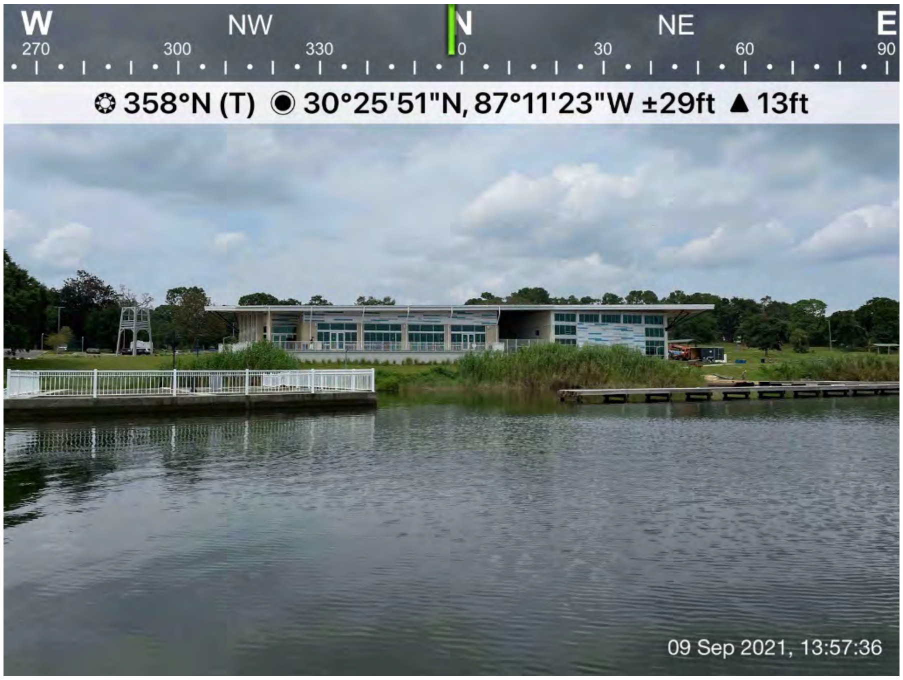


Photograph #66. 2304 Osceola Blvd. West shoreline of Bayou. This portion of the shoreline largely armored with except for a few areas with isolated patches of common reed.

Photograph #67. 2120 Whaley Ave. West shoreline of Bayou. Heavily armored shoreline consisting of stepped vinyl wall with Class II limestone rip rap.



Photograph #68. Outfall located at Malory Street parking lot along Bayview park.

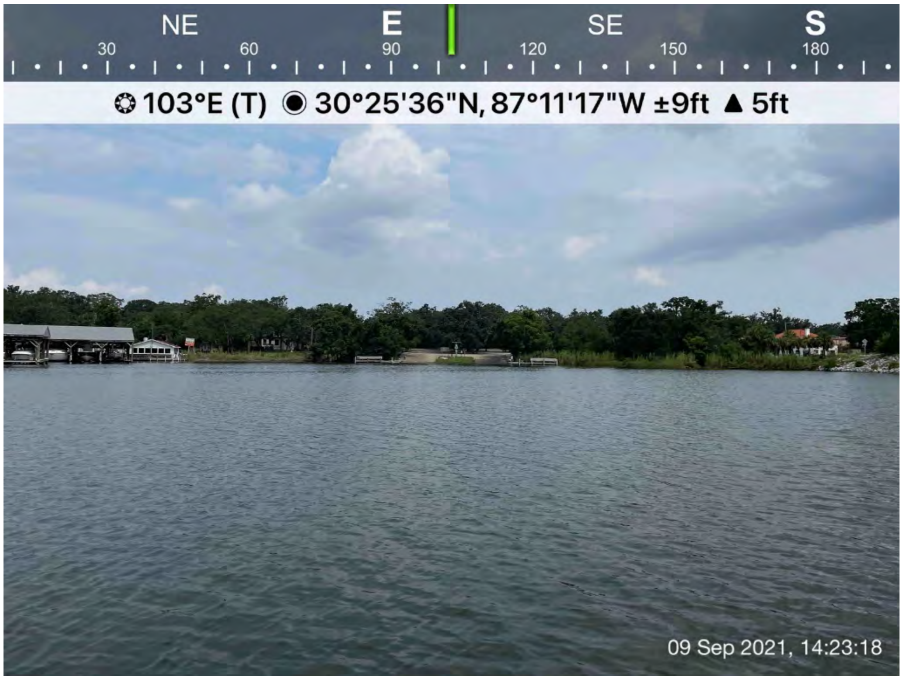


Photograph #69. Bayview park.

Photograph #70. E De Soto Street outfall location just north of Rooks Marina.

Photograph #71. Marina Oyster Barn.

Photograph #72. Marina Oyster Barn.



Photograph #73. Bayou Texar Boat ramp.

Photograph #74. Cervantes Street bridge.

Photograph #75. Cervantes street northwest bridge abutment.

Exhibit B

Calibration Certificate

Calibrated at Geotech's Florida service center
12165 Metro Parkway #25B
Fort Myers, FL 33966
(800) 304-5325 *Fax:* (239) 476-8893

YSI Pro DSS Calibration Certificate

Unit Number: 6046

Serial Number: 17K101134

Calibration Date 9/1/2021

Technician: Andy Jimenez

Installed Probes
- ☑ Conductivity
- ☑ PH/ORP
- ☑ DO
- ☑ TURB

- ☑ Display is clear, and free of damage
- ☑ Cable and accessories are free of damage
- ☑ Firmware version is up to date.

Display Battery 100 % **Pass**

Cable Flex Test: **Pass**

Cable Length	10M	pH/ORP Serial #	20M100273
Cable Lot #	18G101312	DO Probe Serial #	21B106180
Cond Probe Lot #	18G102746	Turb Probe Serial #	18J103579
Bath Temp	26.5 °C		
Meter Temp	26.3 °C		
Variance	-0.20	**Pass**	

Cond

Calibration	Reading		Buffer Lot #	Exp. Date	
1.413 mS	1.413 mS	**Pass**	OGK590	11/21	**Pass**

pH

Point Test	Calibration	Reading	mV	Slope		Buffer Lot #	Exp. Date	
2 Point	pH 7.00	pH 7.00	-6.2 mV			OGE815	5/22	**Pass**
	pH 10.01	pH 10.01	-179.3 mV	173.1	**Pass**	1GA961	1/23	**Pass**

ORP

Calibraition	Reading		Buffer Lot #	Exp. Date	
220 mV	220 mV	**Pass**	1GE739	2/22	**Pass**

Turbidity

Zero	Reading	Variance		Cal	Reading	Variance		Buffer Lot #	Exp. Date	
0 ntu	0 ntu	0 ntu	**Pass**	124 ntu	124 ntu	0.0%	**Pass**	20M	12/21	**Pass**

DO

Barometer	Calibration	Reading	Variance		Test Fluid
745 mmHg	98 %	98 %	0.0%	**Pass**	Water Saturated Air

Time:	Min.	Sec.	Reading		Nitrogen Lot #
	5	0	1 %	**Pass**	UA1066

Geotech Environmental Equipment, Inc. takes pride in ensuring this instrument is tested to function as specified by the manufacturer and was calibrated in accordance to manufacturer specifications. All calibration standards used are NIST traceable. With the provided lot numbers we can provide NIST documents on request. Call us at (800) 833-7958 and we will be glad to help.

Exhibit C

Sample Location Map

SHEET: 1 OF 1

D-TE: 09-10-21

DR- N BY: ZMJ

PROJECT NO.: 2018-703

Carpenter Creek/Bayou Texar Watershed Management Plan

Overall Map
Sample Locations

Notes

Exhibit D

Physical Water Quality Analysis Results

Sample #	Station Name	Latitude	Longitude	Measurement Date	Sample Time	Secchi Depth (m)	Total Depth (m)	Muck Depth (m)	Top/Mid/Bottom	WQ Depth (m)	Water Temp (°C)	DO (mg/L)	DO (%)	Salinity (ppt)	Conductivity (µS/cm)	pH	Turbidity (NTU)	Total Dissolved Solids	Notes
1	Mouth of Bayou	30.4185	-87.1924	9/9/2021	9:20 AM	N/A	2.82	NM	Top	0.30	N/A	7.49	98.5	8.50	14500	7.48	0.41	9700	Coarse sand, no muck
									Mid	1.41	N/A	4.94	69.0	10.70	18200	7.53	0.65	11820	
									Bottom	2.51	N/A	4.00	55.8	11.50	19700	7.50	0.56	12802	
2	Oyster Barn Marina - Near Shore East	30.4276	-87.1871	9/9/2021	2:06 PM	1.25	2.29	NM	Top	0.30	28.8	9.00	119.5	4.37	7941	7.76	0.73	5162	Coarse sand, no muck
									Mid	1.14	28.6	8.41	111.8	5.20	9330	7.67	0.56	6064	
									Bottom	1.98	29.0	5.81	79.1	8.56	14811	7.41	11.67	9627	
3	Oyster Barn Marina - Near Center	30.4272	-87.1885	9/9/2021	2:10 PM	1.31	3.07	>1.20	Top	0.30	28.8	9.08	120.3	4.17	7602	7.63	0.37	4941	Light grey muck, very fine
									Mid	1.54	29.2	4.86	67.3	10.79	18342	7.44	2.02	11922	
									Bottom	2.76	29.1	2.50	35.0	12.97	21711	7.36	25.81	14112	
4	Bayview Park North Dock - Near Shore West	30.4323	-87.1878	9/9/2021	1:44 PM	1.19	2.04	0.76	Top	0.30	28.7	9.20	121.7	4.03	7356	7.52	0.06	4781	Light grey muck, very fine
									Mid	1.02	29.6	4.30	58.7	6.97	12261	7.20	12.83	7969	
									Bottom	1.73	29.4	1.52	21.0	10.36	17666	7.11	29.06	11483	
5	Bayview Park North Dock - Near Center	30.4314	-87.1871	9/9/2021	1:49 PM	1.16	2.84	>1.82	Top	0.30	28.6	9.01	118.5	3.51	6465	7.40	0.17	4203	Light grey muck, very fine
									Mid	1.42	28.9	8.38	112.2	5.50	9834	7.66	0.54	6392	
									Bottom	2.53	29.2	3.71	51.4	11.25	19057	7.34	13.05	12387	
6	Hyde Park - Near Shore East	30.4404	-87.1874	9/9/2021	9:56 AM	0.99	1.83	0.39	Top	0.30	28.2	7.65	100.0	3.56	6518	6.97	0.75	4250	Grey muck, very fine
									Mid	0.92	29.1	7.65	100.0	5.27	9390	7.47	0.55	6120	
									Bottom	1.52	29.9	5.78	79.3	6.73	11874	7.30	8.82	7718	
7	Hyde Park - Offshore East	30.4402	-87.1878	9/9/2021	10:17 AM	1.09	2.13	>1.52	Top	0.30	29.2	8.46	113.4	4.69	8479	7.42	0.28	5511	Yogurt consistency grey muck, high % fines
									Mid	1.07	29.9	6.90	94.8	6.95	12230	7.38	1.47	7949	
									Bottom	1.82	30.1	5.33	73.5	7.34	12867	7.23	7.21	8364	
8	Hyde Park - Near Center	30.4401	-87.1883	9/9/2021	10:29 AM	1.19	2.40	>1.52	Top	0.30	29.3	8.41	113.2	5.17	9288	7.57	0.64	6037	Light grey muck, very fine
									Mid	1.20	29.9	6.29	86.7	7.73	13496	7.31	3.16	8772	
									Bottom	2.09	29.9	3.35	46.4	8.31	14439	7.13	27.72	9385	
9	Seville Dr Outfall - Near Shore East	30.4499	-87.1937	9/9/2021	10:45 AM	0.61	0.61	0	Top	0.10	29.3	5.54	74.2	4.17	7614	6.84	2.00	4949	Coarse sand, no muck
									Mid	0.31	29.8	4.33	58.7	4.84	8751	6.79	1.94	5688	
									Bottom	0.45	29.9	3.92	53.1	4.98	8974	6.79	1.89	5833	
10	Seville Dr Outfall - Offshore East	30.4495	-87.1939	9/9/2021	11:00 AM	1.09	1.58	0	Top	0.30	29.9	7.56	102.8	5.32	9553	7.15	1.32	6209	Coarse sand, no muck
									Mid	0.79	30.3	7.17	98.6	6.23	11056	7.23	1.66	7816	
									Bottom	1.27	30.3	6.95	95.6	6.43	11386	7.29	3.41	7401	
11	Seville Dr Outfall - Near Center	30.4488	-87.1941	9/9/2021	11:12 AM	1.09	2.13	>1.83	Top	0.30	29.9	8.24	111.7	4.66	8437	7.22	0.23	5484	Grey yoghurt consistency muck
									Mid	1.07	30.0	6.38	87.4	6.56	11594	7.10	1.77	7536	
									Bottom	1.82	29.9	5.02	69.2	7.52	13154	7.08	6.91	8550	
12	1950 E Texar - Near Shore West	30.4510	-87.2020	9/9/2021	1:15 PM	0.73	1.00	0.61	Top	0.30	29.8	5.57	75.1	4.23	7709	6.75	2.45	5011	Dense leaf pack, light grey muck with strong sulphide odor
									Mid	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
									Bottom	0.69	30.2	5.90	80.8	5.53	9903	6.78	3.64	6437	
13	1950 E Texar - Near Center	30.4518	-87.2008	9/9/2021	1:22 PM	0.91	1.83	>1.83	Top	0.30	29.3	8.23	109.7	3.66	6725	6.94	0.71	4371	Light grey muck, very fine
									Mid	0.92	30.2	8.21	112.5	5.85	10441	7.20	0.90	6787	
									Bottom	1.52	30.2	6.94	95.4	6.58	11633	7.07	1.84	7562	
14	E 34th Outfall - Near Shore West	30.4538	-87.2028	9/9/2021	12:50 PM	0.85	1.28	0.98	Top	0.30	29.6	8.22	110.9	4.73	8554	6.92	1.05	5560	Light grey muck, very fine with strong sulphide smell
									Mid	0.64	30.2	7.48	102.5	6.03	10730	6.91	8.36	6974	
									Bottom	0.97	30.2	7.25	99.4	6.06	10778	6.94	8.09	7005	
15	E 34th Outfall - Near Center	30.4539	-87.2025	9/9/2021	12:38 PM	0.85	1.98	>1.83	Top	0.30	29.7	8.40	113.6	4.80	8670	7.04	0.74	5635	3" layer of coarse sediment on top of light grey muck
									Mid	0.99	30.1	6.87	94.3	6.40	11344	6.96	135.30	7374	
									Bottom	1.67	30.1	6.23	85.5	6.61	11682	6.94	6.35	7593	
16	Gamarra Rd Outfall - Near Shore West	30.4557	-87.1686	9/9/2021	12:14 PM	0.94	1.22	1.58	Top	0.30	28.7	7.57	100.3	4.36	7915	6.67	2.64	5145	Grey muck with sulphide odor
									Mid	0.61	29.6	7.57	102.2	5.14	9247	6.70	6.52	6011	
									Bottom	0.91	29.8	7.69	104.5	5.52	9885	6.79	10.85	6425	
17	Gamarra Rd Outfall - Near Center	30.4558	-87.2042	9/9/2021	12:25 PM	0.76	1.52	>1.83	Top	0.30	29.3	8.20	110.3	4.95	8915	6.89	1.67	5795	Heavy leaf pack, grey muck with sulphide odor
									Mid	0.76	29.9	7.10	97.2	6.178	10957	6.86	2.21	7122	
									Bottom	1.21	29.9	6.52	89.1	6.29	11151	6.85	2.56	7248	
18	765 Tanglewood Drive - Near Center	30.4577	-87.2049	9/9/2021	12:00 PM	0.91	1.52	>1.83	Top	0.30	29.0	7.27	96.2	4.46	8096	6.60	2.37	5263	Leaf pack, light grey muck with sulphide odor
									Mid	0.76	29.8	7.01	95.4	5.60	10017	6.64	4.46	6511	
									Bottom	1.21	29.8	6.98	95.0	5.57	9971	6.68	6.68	6481	
19	4204 N 12th Ave - Near Center	30.4602	-87.2076	9/9/2021	11:46 AM	1.00	1.28	1.40	Top	0.30	27.0	5.77	73.4	2.65	4955	6.14	3.64	3221	Light tan muck with high organic contents
									Mid	0.64	28.6	5.72	75.8	4.52	8192	6.34	5.47	5325	
									Bottom	0.97	28.4	3.51	46.2	4.32	7844	5.48	4.68	5099	
20	12th Ave Bridge - Near Center	30.4599	-87.2084	9/9/2021	11:31 AM	1.03	1.03	0	Top	0.30	24.3	6.55	78.3	0.21	434	6.56	0.32	282	Coarse sand, no muck
									Mid	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
									Bottom	0.72	28.1	5.77	75.6	4.18	7608	6.39	6.84	4945	

Exhibit E

Sediment Characterization Results

Station Name	Latitude	Longitude	Depth to Top of Muck (ft)	Hard Bottom Depth (ft)	Muck Depth (ft)	Sediment Notes
Mouth of Bayou	30.4185	-87.1924	9.25	9.25	0.0	Coarse sand, no muck
Oyster Barn Marina - Near Shore East	30.4276	-87.1871	7.5	7.5	0.0	Coarse sand, no muck
Oyster Barn Marina - Near Center	30.4272	-87.1885	10.1	>14.1	>4.0	Light grey muck, very fine
Bayview Park North Dock - Near Shore West	30.4323	-87.1878	6.7	9.2	2.5	Light grey muck, very fine
Bayview Park North Dock - Near Center	30.4314	-87.1871	9.3	>15.3	>6.0	Light grey muck, very fine
Hyde Park - Near Shore East	30.4404	-87.1874	6.0	7.3	1.3	Grey muck, very fine
Hyde Park - Offshore East	30.4402	-87.1878	7.0	>12.0	>5.0	Yogurt consistency grey muck, high % fines
Hyde Park - Near Center	30.4401	-87.1883	8.0	>13.0	>5.0	Light grey muck, very fine
Seville Dr Outfall - Near Shore East	30.4499	-87.1937	2.0	2.0	0.0	Coarse sand, no muck
Seville Dr Outfall - Offshore East	30.4495	-87.1939	5.2	5.2	0.0	Coarse sand, no muck
Seville Dr Outfall - Near Center	30.4488	-87.1941	7.0	>13.0	>6.0	Grey yogurt consistency muck
1950 E Texar - Near Shore West	30.4510	-87.2020	3.3	5.3	2.0	Dense leaf pack, light grey muck with strong hydrogen sulfide odor
1950 E Texar - Near Center	30.4518	-87.2008	6.0	>12.0	>6.0	Light grey muck, very fine
E 34th Outfall - Near Shore West	30.4538	-87.2028	4.2	7.4	3.2	Light grey muck, very fine with strong sulphide smell
E 34th Outfall - Near Center	30.4539	-87.2025	6.5	>12.5	>6.0	3" layer of coarse sediment on top of light grey muck
Gamarra Rd Outfall - Near Shore West	30.4557	-87.1686	4.0	9.2	5.2	Grey muck with hydrogen sulfide odor
Gamarra Rd Outfall - Near Center	30.4558	-87.2042	5.0	>11.0	>6.0	Heavy leaf pack, grey muck with hydrogen sulfide odor
765 Tanglewood Drive - Near Center	30.4577	-87.2049	5.0	>11.0	>6.0	Leaf pack, light grey muck with hydrogen sulphide odor
4204 N 12th Ave - Near Center	30.4602	-87.2076	4.2	8.8	4.6	Light tan muck with high organic contents
12th Ave Bridge - Near Center	30.4599	-87.2084	3.4	3.4	0	Coarse sand, no muck

VOLUME 3B APPENDIX A

MONITORING PROGRAM REVIEW AND GAP ANALYSIS

Appendix A - MONITORING PROGRAM REVIEW AND GAP ANALYSIS

Appendix A – Monitoring Program Gap Analysis and Geospatial Assessment

To supplement the monitoring program review in the report, details on the period of the record reviewed, data gap identification method and geospatial assessment are included below.

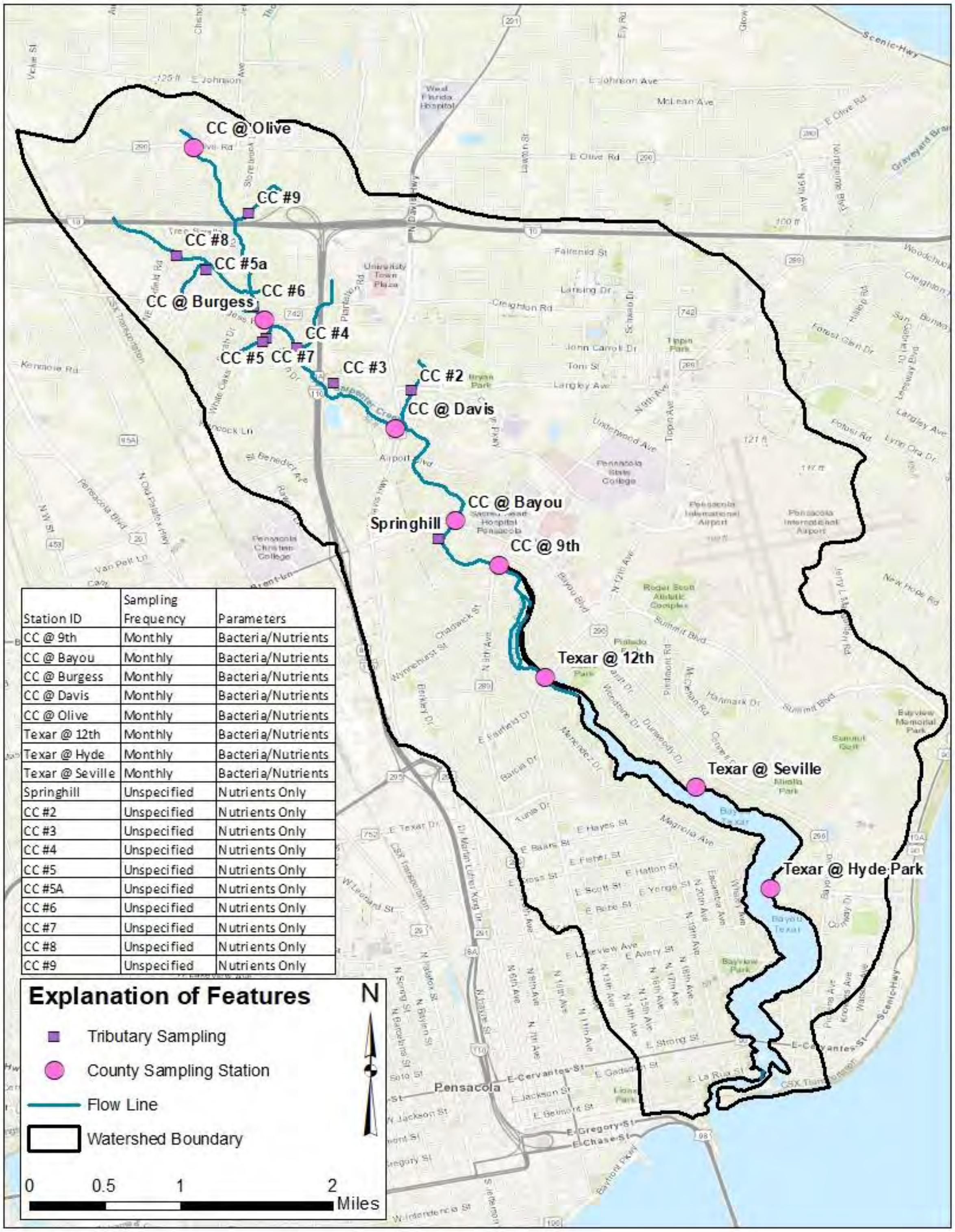
1. Existing Monitoring Program Review and Identification of Potential Data Gaps

Discussion of the monitoring program is limited to existing County stations and new data that were not included in the previous Monitoring Program review conducted by Wood in 2020. The period of record (POR) for data that are representative of the current monitoring program is June 2020- Present, however, it should be noted that the County only provided Wood with monitoring data through April 2021, so the review was limited to that POR. The existing monitoring program was reviewed to identify any additional temporal or water quality parameter monitoring gaps. The period of record plots produced for each monitoring station can be found in **Appendix B2**.

The County currently collects monthly samples from five stations within the Carpenter Creek WBID and three stations within the Bayou Texar WBID **(Figure A.1**). In June of 2020, Escambia County began collecting additional surface water quality parameters under their existing monitoring program, on a monthly frequency (**Table A-1)**. In March of 2021, the County picked up nine additional tributary stations for nutrient monitoring (Chl-a, NOx, TKN, TN, TP, and TSS).

A review of the existing County monitoring efforts identified several temporal data gaps in addition to an inconsistent collection of water quality parameters, which are discussed below.

Figure A.1: Existing stations within the Escambia County water quality monitoring network



Station ID	Sampling Frequency	Parameters
CC @ 9th	Monthly	Bacteria/Nutrients
CC @ Bayou	Monthly	Bacteria/Nutrients
CC @ Burgess	Monthly	Bacteria/Nutrients
CC @ Davis	Monthly	Bacteria/Nutrients
CC @ Olive	Monthly	Bacteria/Nutrients
Texar @ 12th	Monthly	Bacteria/Nutrients
Texar @ Hyde	Monthly	Bacteria/Nutrients
Texar @ Seville	Monthly	Bacteria/Nutrients
Springhill	Unspecified	Nutrients Only
CC #2	Unspecified	Nutrients Only
CC #3	Unspecified	Nutrients Only
CC #4	Unspecified	Nutrients Only
CC #5	Unspecified	Nutrients Only
CC #5A	Unspecified	Nutrients Only
CC #6	Unspecified	Nutrients Only
CC #7	Unspecified	Nutrients Only
CC #8	Unspecified	Nutrients Only
CC #9	Unspecified	Nutrients Only

Table A-1: Surface water quality parameters sampled at mainstem County stations

Parameter
Fecal indicators (*Enterococci* and *E. coli*)
Chlorophyll-a
Chloride
Calcium
Magnesium
Bromide
Alkalinity
Ammonia (N)
Nitrate+Nitrite (N)
Total Kjeldahl Nitrogen
Total Nitrogen*
Orthophosphate
Total Phosphorus
Total Organic Carbon
Sulfate
True Color
Total Suspended Solids

Bolded values represent additional parameters added to the sampling program starting in June of 2020.

1.1. Carpenter Creek (WBID 676) Main Stem and Bayou Texar (WBID 738) Stations

Stations identified in **Figure A.1** as "County Sampling Station" are sampled monthly under the current monitoring program. Data were not collected in September of 2020 due to Hurricane Sally. However, two sampling events took place in October 2020 (Oct.7 and Oct. 27) to fill in the data gap from the prior month. The County gave Wood approval to assign data from October 7, 2020, as "September 2020" data.

All parameters listed in **Table A-1** were collected at each station between June 2020 and October 2020. However, only bacterial water quality parameters were collected in November and December 2020, resulting in a temporal gap in nutrient monitoring.

No data were provided for January or February of 2021. Limited nutrient data were collected in conjunction with the tributary sampling events in March and April of 2021, however, these data are limited to stations within the Carpenter Creek WBID.

1.2. Tributary Stations

Stations identified in **Figure A.1** as "Tributary Sampling" are sampled at an unspecified frequency by the County. These stations were added in March of 2021 and are only sampled for nutrient parameters at this time. Five of the stations were sampled in March 2021, while the remaining four stations were sampled in April 2021. Station CC#5 was sampled during both events.

1.3. Data Gaps

Table A-2 provides a summary of the data gaps identified during the review of the existing monitoring program.

Table A-2: Data Gaps Identified Under the Current Monitoring Program

Station ID	Sampling Frequency	Parameters	POR Reviewed	Temporal Data Gap	Water Quality Parameter Data Gap
CC @ 9th	Monthly	Bacteria/Nutrients	June 2020 - April 2021	Nov 2020 - Feb 2021	Nutrients and Bacteria
CC @ Bayou	Monthly	Bacteria/Nutrients	June 2020 - April 2021	Nov 2020 - Feb 2021	Nutrients and Bacteria
CC @ Burgess	Monthly	Bacteria/Nutrients	June 2020 - April 2021	Nov 2020 - Feb 2021	Nutrients and Bacteria
CC @ Davis	Monthly	Bacteria/Nutrients	June 2020 - April 2021	Nov 2020 - Feb 2021	Nutrients and Bacteria
CC @ Olive	Monthly	Bacteria/Nutrients	June 2020 - April 2021	Nov 2020 - Feb 2021	Nutrients and Bacteria
Texar @ 12th	Monthly	Bacteria/Nutrients	June 2020 - April 2021	Nov 2020 - April 2021	Nutrients and Bacteria
Texar @ Hyde	Monthly	Bacteria/Nutrients	June 2020 - April 2021	Nov 2020 - April 2021	Nutrients and Bacteria
Texar @ Seville	Monthly	Bacteria/Nutrients	June 2020 - April 2021	Nov 2020 - April 2021	Nutrients and Bacteria
Springhill	Unspecified	Nutrients Only	June 2020 - April 2021	June 2020 - February 2021	Bacteria
CC #2	Unspecified	Nutrients Only	June 2020 - April 2021	June 2020 - February 2021	Bacteria
CC #3	Unspecified	Nutrients Only	June 2020 - April 2021	June 2020 - February 2021	Bacteria
CC #4	Unspecified	Nutrients Only	June 2020 - April 2021	June 2020 - February 2021	Bacteria
CC #5	Unspecified	Nutrients Only	June 2020 - April 2021	June 2020 - February 2021	Bacteria
CC #5A	Unspecified	Nutrients Only	June 2020 - April 2021	June 2020 - February 2021	Bacteria
CC #6	Unspecified	Nutrients Only	June 2020 - April 2021	June 2020 - February 2021	Bacteria
CC #7	Unspecified	Nutrients Only	June 2020 - April 2021	June 2020 - February 2021	Bacteria
CC #8	Unspecified	Nutrients Only	June 2020 - April 2021	June 2020 - February 2021	Bacteria
CC #9	Unspecified	Nutrients Only	June 2020 - April 2021	June 2020 - February 2021	Bacteria

2. Geospatial Assessment Based on Pollutant Loading

Areas of high nutrient loading, discovered during the pollutant load analysis, were compared to average nutrient concentrations seen at existing water quality stations to examine if the current monitoring network distribution captures areas of concern. Water quality data collected between June 2020 and June 2021 were used to calculate average nutrient concentrations for both TN and TP. Due to temporal data gaps, this period of record (POR) was selected so that all stations in the monitoring network were represented.

2.1. Total Nitrogen

The highest average TN concentrations were seen at CC #5 and CC @9th. It should be noted that there is only one data point for TN at CC #5, and it is unclear if this value is representative of normal conditions at this station. Although there is a spatial gap between station placement along Bayou Texar, there are no "hot spots" for TN loading that would require additional station placement. The spatial distribution of the existing monitoring stations is well dispersed throughout the watershed and appears to capture water quality in areas of high estimated TN loading.

2.2. Total Phosphorous

The highest average TP concentrations were seen at Texar @ Hyde and Springhill. It should be noted that there is only one data point for TP at Springhill, and it is unclear if this value is representative of normal conditions at this station. Although there is a spatial gap between station placement along Bayou Texar, there are no “hot spots” for TP loading that would require additional station placement. The spatial distribution of the existing monitoring stations is well dispersed throughout the watershed and appears to capture water quality in areas of high estimated TP loading.

Figure A.2: Estimated TN "Hot Spots" and Average TN concentrations within the watershed

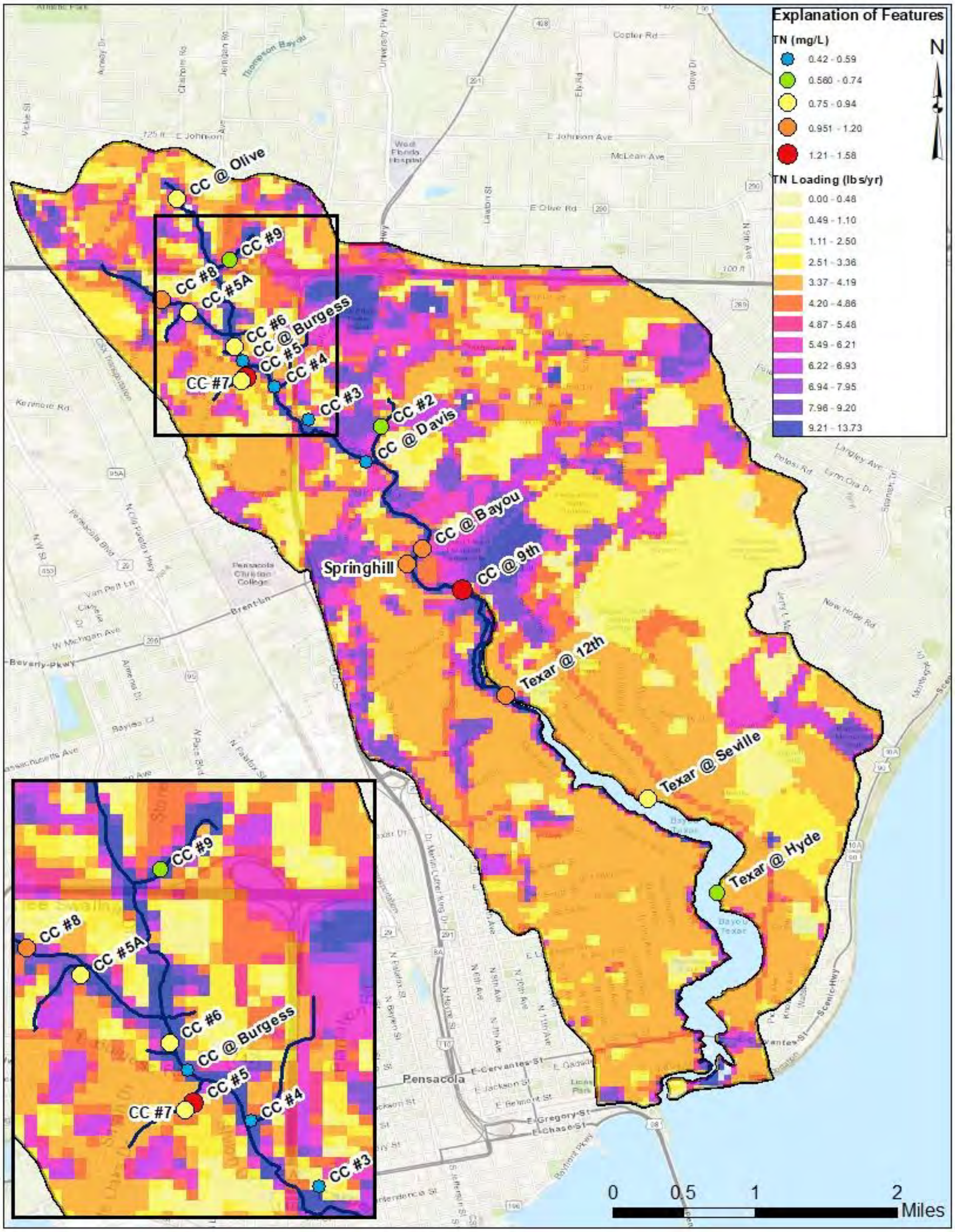
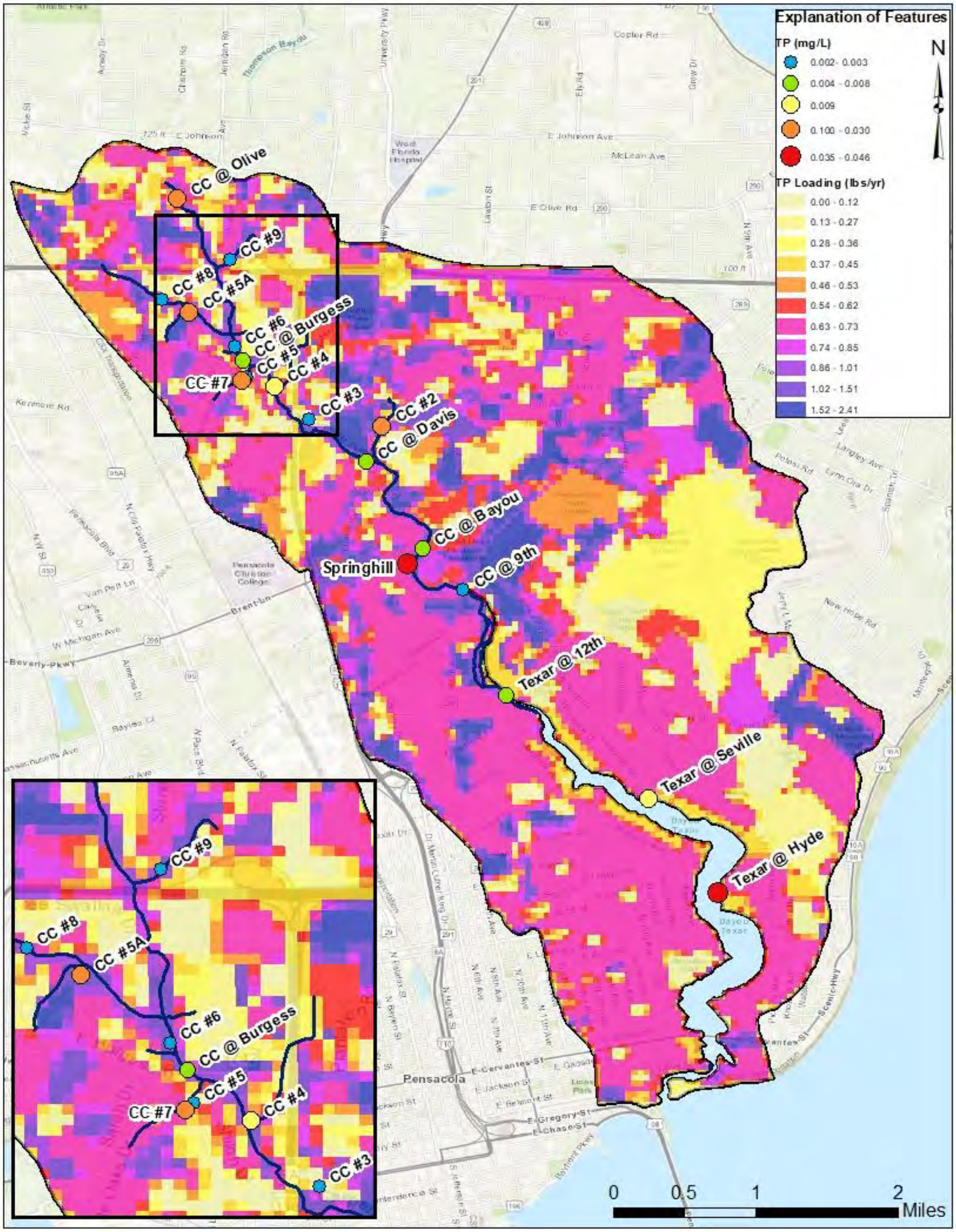


Figure A.3: Estimated TP "Hot Spots" and Average TP concentrations within the watershed



VOLUME 3B APPENDIX B

STATISTICAL ANALYSIS METHODOLOGIES, RESULTS, FIGURES AND TABLES

Appendix B1 - STATISTICAL ANALYSIS METHODOLOGIES AND RESULTS

wood.

Appendix B1 - Data Compilation and Statistical Methods

To supplement the condensed methods provided in the report, details on the data compilation, statistical methods used for the trend analysis, and exploratory correlation analysis are provided below.

1. Data Compilation

1.1. Hydrologic Data

1.1.1 Flow

Hydrologic data for Carpenter Creek and Bayou Texar were downloaded from the United States Geological Survey (USGS) National Water Information System (NWIS). Only two sites were located within the study area: Carpenter Creek at Pensacola, FLA (#02376079) and Carpenter Creek Nr Pensacola, FLA (#02376077). These data were not used, as they ended in 1977 and 1993, respectively.

1.1.2 Precipitation

Daily summary precipitation data for Pensacola Regional Airport (#USW00013899) were downloaded from the National Ocean and Atmospheric Administration (NOAA) Climate Data Online portal. Data were then checked to confirm that no gaps existed in the dataset. Thereafter rolling sums of 7-day antecedent rainfall were calculated for the period of record.

1.2. Water Quality Data

1.2.1 Groundwater Quality Data

Groundwater data for Carpenter Creek and Bayou Texar were downloaded from the United States Geological Survey (USGS) National Water Information System (NWIS). These data were not used, as they ended in 1989.

1.2.2 Surface Water Quality Data

The primary source of water quality data used in the analysis was the Florida Department of Environmental Protection (FDEP) Impaired Water Rule (IWR) Database, Run 60. Raw data for Carpenter Creek (Waterbody ID [WBID] 676) and Bayou Texar (WBID 748) were exported from the IWR Microsoft Access database. To have the most recent water quality data for these two WBIDs, additional data were retrieved from the FDEP's Watershed Information Network (WIN) using the online WIN Advanced View and Extraction System (WAVES).

The County provided three additional datasets that were included in this analysis. One dataset was from an intensive weekly sampling project focused on fecal coliform, *E. coli,* and field parameters conducted between May and July 2014. The second dataset from the County contained monthly bacteria, nutrient, and field parameter results from January 2020 to December 2020. The County also provided nutrient data collected between March and April 2021 that was part of a special Carpenter Creek tributary sampling event.

Crossover tables were developed for all parameters and stations within these four datasets. Duplicate data points, data from LakeWatch (per the County's request), and data with fatal qualifiers (A, B, F, G, H, K, L, N, O, Q, T, V, Y) were removed from the dataset. Data that were below method detection limits (MDL) were adjusted to one-half the MDL and daily averages were calculated if multiple samples for the same parameter were collected from the same station on the same day. Additionally, sample stations were aggregated if they were less than 500 feet apart. Time series were then plotted to determine which stations had sufficient periods of record to conduct additional correlational and trend analyses.

The following parameters were assessed:

- *Total Nitrogen (TN)*
- *Total Phosphorus (TP)*
- *Temperature*
- *Color*

- *Chlorophyll-a (Chl-a)*
- *Fecal Coliform*
- *Enterococci*
- *Total Suspended Solids (TSS)*
- *Specific conductance*
- *Dissolved Oxygen (DO)*
- *E. coli*
- *pH*
- *Aluminum*
- *Magnesium*
- *Orthophosphate (Ortho-P)*
- *Iron*
- *Calcium*
- *Nitrate-Nitrite (NOx)*

2. Data Analyses

2.2 Impairment Analysis

An informal impairment analysis was conducted on the compiled surface water dataset. Impairment assessments of nutrient-related parameters included Chl-a, TN, and TP while bacteriological-related parameters included *E. coli* (in Carpenter Creek) or *Enterococci* (in Bayou Texar).

Carpenter Creek (WBID 676) is subject to the Panhandle West freshwater stream Numeric Nutrient Criteria (NNC; 20 ug/L Chl-a, 0.67 mg/L TN, and 0.06 mg/L TP) expressed as annual geometric means (AGM), not to be exceeded more than once in a 3-year period. It is also subject to the freshwater *E. coli* criterion of 410 Colony Forming Units (CFU)/100 mL, not to be exceeded in 10% of samples during a 30-day period and/or a monthly geometric mean of 126 CFU, never to be exceeded.

Bayou Texar (WBID 738) is a tidally influenced area that fluctuates between predominately marine and predominately freshwaters during typical climatic and hydrologic conditions. Therefore, nutrient and nutrient response criteria do not apply, and only a Chl-a criterion of 11 ug/L expressed as an AGM, not to be exceeded more than once in a 3-year period, is applicable. However, as part of this informal impairment analysis, Bayou Texar results were assessed against the criteria from the downstream Estuary Nutrient Region (Upper Pensacola Bay) of 0.77 mg/L TN and 0.084 mg/L TP, not to be exceeded in more than 10% of measurements. The waterbody is subject to the marine *Enterococci* criterion of 130 Colony Forming Units (CFU)/100 mL, not to be exceeded in 10% of samples during a 30-day period and/or a monthly geometric mean of 35 CFU, never to be exceeded.

To show potential impairments, AGMs were calculated for all parameters with criteria based on AGMs then plotted. The annual percent exceedances were calculated for all parameters with criteria based on percent exceedances.

2.2 Trend Analysis

To identify potential trends in water quality, the non-parametric seasonal Mann-Kendall tests with the Theil-Sen's Slope, Tau test statistic, and a probability value for the trends were calculated. These tests were performed on the following water quality parameters: TN, nitrate + nitrite (NOx), TP, Chl-a, Dissolved oxygen (DO), and either *E. coli* (in Carpenter Creek) or *Enterococci* (in Bayou Texar). Seasonal trend analyses were conducted at both the waterbody and station scales. At the water body scale, quarterly data between 2010 and 2020 were used. At the station scale, two analyses were performed. At stations with sufficient data, trends were calculated using quarterly data between 2017 and 2020. This period was selected because the greatest number of stations had data between those years. Additionally, two Carpenter Creek stations (CC @ 9th and CC @ Davis) and two Bayou Texar stations (Texar @ 12th and Texar @ Bayview) had longer periods of record and were selected for trend analysis using quarterly data between 2010 and 2020.

Quarterly data were calculated by computing the median value when multiple observations of a water quality parameter were available for a given quarter. When no observations were available for a given quarter, data were not imputed or interpolated, because interpolation would risk artificially decreasing p-values reported by the Mann-Kendall tests and unnecessarily biasing Theil-Sen slope results.

For each water quality parameter at each station, the autocorrelation function (ACF) was first applied to screen for serial correlation before application of a Seasonal Mann-Kendall (SMK) trend test (Marchetto, 2021). If a significant ($p<0.05$) autocorrelation was detected for a given parameter the dataset underwent a "prewhitening" procedure and was then analyzed with the Mann-Kendall trend test (Bronaugh and Werner, 2013). Each Mann-Kendall test estimated a tau parameter whose sign (positive or negative) indicates the direction of the trend (increasing or decreasing) and a p-value. When Mann-Kendall results detected a statistically significant monotonic trend ($p<0.05$), the Theil-Sen estimator was applied to fit a linear trend and estimate its slope. The Theil-Sen slope provides an estimate of the rate at which the parameter linearly increased or decreased. The slope of the trend line is computed as the median of all slopes between all pairs of points. As a non-parametric, median-based regression method, the Theil-Sen estimator makes no assumption about the underlying distribution of the data and is robust to outliers.

2.3 Exploratory Correlation Analysis

Non-parametric correlation analysis (Spearman Correlation) was used to explore the relationships between water quality conditions throughout the Carpenter Creek and Bayou Texar watersheds. The analysis is considered exploratory, because correlation does not necessarily imply causation, however, a lack of correlation does not necessarily imply a lack of causation.

In addition to water quality variables, precipitation was also included in the analysis (using the cumulative 7-day antecedent rainfall). A lack of recent flow data in the watershed precluded the inclusion of flow in the correlation analysis.

Similar to the trend analysis, correlation analyses were performed at both the waterbody and individual station scales. Monthly median values for each waterbody were calculated for data collected from 2010 to 2020. Additionally, daily median values for each station were calculated for data collected from 2017 to 2020. Due to differences in sampling frequencies for nutrients and bacteria, correlations were run separately for these two groups of parameters when data were available. The Florida Department of Health (FDOH) frequently samples Texar @ Bayview for Enterococci, however, no other water quality parameters are collected during these sampling events. Although these results were not used in correlation analysis using daily medians, they were incorporated into the data set when calculating monthly medians at the WBID scale.

Correlation analyses were also performed comparing water quality parameters between Carpenter Creek and Bayou Texar. Two correlation matrices were calculated using the monthly median data from 2010-2020. Correlations were conducted twice: once without Chl-a and with Chl-a as it had a shorter time series, which limited the POR used.

3. Results

3.1 Station Grouping and Data Availability

3.1.1 Hydrologic Data

Flow data from the USGS was limited to observations recorded between 1959 and 1993. The highest frequency of flow data collection occurred at site # 2376079 between 1976 and 1977. Flow data availability is summarized in **Table B2-1**. The lack of recent flow data within Carpenter Creek or Bayou Texar precluded its use in this assessment.

Precipitation data from the station at Pensacola Regional Airport (USW0013899) were available from 1948 to 2021. A rolling sum of seven-day antecedent rainfall totals was calculated from 2009 to 2020. These data were used in the correlation analysis. The daily and seven-day rolling sum precipitation data are presented in **Figure B2.1**.

3.1.2 Groundwater Quality Data
Groundwater quality datasets from Carpenter Creek and Bayou Texar from the USGS were limited to data collected between 1959 and 1989 with most samples collected in the 1970s and 1980s. Groundwater quality data availability is summarized in **Table B2-2**.

3.1.3 Surface Water Quality Data
Surface water quality data from Carpenter Creek and Bayou Texar include data from as early as 1970 with the field parameters, nutrients, and bacteria recording the most samples (**Figure B2.2**). The parameters with the fewest samples include aluminum, alkalinity, calcium, iron, magnesium, and orthophosphate.

Prior to 2011, fecal coliform was sampled in both water bodies. A change in criteria meant that fecal coliform criteria was replaced by *E. coli* in Carpenter Creek and *Enterococci* in Bayou Texar. For some sampling events, both fecal coliform and its replacement (*E. coli* or *Enterococci*) were collected simultaneously. Results from these concurrent bacterial sampling events are presented in **Figure B2.3**. Results in Carpenter Creek come from 2014 and 2016 and show a higher R^2 between the variables, indicating a tighter correlation, even though it is a smaller dataset. The larger dataset from Bayou Texar comes from 2000-2011, has a lower $R^{2,}$ and is based entirely on data collected from the Texar @ Bayview station, the location of the FDOH beach monitoring station.

A total of eight aggregate water quality stations based on current sampling regimes and proximity were identified within Carpenter Creek while seven aggregate stations were identified within Bayou Texar (**Table B2-3**). Period of record plots for parameters of interest was then plotted, which revealed that only five stations in Carpenter Creek and five Stations in Bayou Texar provided periods of record sufficient for correlational and/or trend analyses (**Figure B2.4**). Any data not from these 10 stations were then reclassified as "Other" for further analysis.

3.2 Impairment Assessment
The informal impairment assessment is shown in **Figure Set B2.9**. Annual geometric means (AGM) were calculated and plotted for Chl-a, TN, and TP in Carpenter Creek (**Figure Set B2.9**). Chl-a AGMs never approach the criterion of 20 µg/L, however, one individual sample from CC @ Olive had a Chl-a of 33 µg/L. TN at Carpenter Creek has consistently exceeded the criterion of 0.67 mg/L, including every year since 2016 while TP has not exceeded the criterion of 0.6 mg/L with individual samples or by AGM. TN concentrations at CC @ 9th are consistently above the criterion while concentrations at CC @ Davis are consistently below. More than 10% of *E. coli* samples exceeded 410 CFU/100 mL in every year that data was available (**Table B2-4**) with CC @ Davis exceeding the criterion in 70% of samples from 2010 to the Present (**Table B2-5**).

Chl-a AGMs were calculated and plotted for Bayou Texar (**Figure Set B2-10**). Although the Chl-a AGMs never approach the criteria (11 µg/L), individual samples above this value were observed at Texar @ Seville, Texar @ Hyde, and Texar off DeSoto. More than 10% of samples exceeded the criteria for TN and Enterococci criteria every year between 2010 and 2020 (**Table B2-6**). Ninety-two percent of TN samples at Texar @ 12th and Texar @ Seville exceeded the criteria while 48 percent of *Enterococci* samples at Texar @ 12th exceeded the criteria (**Table B2-7**).

3.3 Trend Results
Within the area of study, eight stations and two WBIDs provided sufficient data for trend analysis for at least one of the parameters of interest using data between 2017-2020. Additionally, four stations and the two WBIDs provided sufficient data for trend analysis for at least one parameter using data from 2010-2020. All trend analysis results, both at the station and WBID scales, are presented in **Table B2-8**.

TN at CC @ 9th was the only parameter/station combination with a significant trend using data from 2017 to 2020. However, six significant trends were detected within the four stations that had sufficient data to analyze trends using

data from 2010 to 2020. Interestingly, although TN showed a significant increasing trend between 2017 and 2020 (*tau* = 0.61, p = 0.05), it occurs within a larger significant decreasing trend in TN seen at CC @ 9th from 2010 to 2020 (*tau* = -0.25, p = 0.04). Additional decreasing trends observed at CC @ 9th between 2010 and 2020 include dissolved oxygen (*tau* = -0.30, $p < 0.01$) and nitrate-nitrite (*tau* = -0.33, $p < 0.01$). Texar @ 12th also had a significant decreasing trend in nitrate-nitrite (*tau* = -0.32, $p < 0.01$) whereas there was a statistically significant (although minor in magnitude) increasing trend in nitrate-nitrite at CC @ Davis (*tau* = 0.01, $p < 0.01$).
All data within the WBIDs were combined to look at trends at the waterbody scale. No significant trends were detected using data from 2017 to 2020. However, two significant trends were detected in each WBID using data from 2010 to 2020. In Carpenter Creek (WBID 676) decreasing trends were observed in total phosphorous (*tau* = -0.25, p = 0.03) and dissolved oxygen (*tau* = -0.27, p = 0.03). In Bayou Texar (WBID 738) decreasing trends were observed in nitrate-nitrite (*tau* = -0.38, $p < 0.01$) and dissolved oxygen (*tau* = -0.28, p = 0.03).

3.4 Correlation Results

Twenty correlation results are presented in **Figure Set B2.11**. Positive correlations are indicated by blue shading while negative correlations are indicated by red shading. Correlations that were not statistically significant ($p > 0.05$) are covered by an 'X'.

Comparing monthly medians from 2010 to 2020 between Carpenter Creek and Bayou Texar (**Figures B2.11a and B2.11b**) shows positive correlations between TKN and Temperature, which were both negatively correlated with DO. Interestingly TN and Chl-a appear to be negatively correlated in Carpenter Creek while TP and Chl-a are positively correlated in Bayou Texar (**Figures B2.11c-f**). Given the number of other variables that are correlated with precipitation (sum of a 7-day antecedent value) in Carpenter Creek (**Figures B2.11g-l**) as compared to Bayou Texar (**Figures B2.11m-t**), it is possible that rainfall plays a more important role within the Creek than the Bayou. TN at CC @ 9th, which is the highest within the WBID, appears to be negatively correlated with TP, TSS, and turbidity. *E. coli* is generally positively correlated with precipitation, turbidity, and temperature.

References

Bronaugh, D., and Werner, A., 2013. zyp: Zhang þ Yue–Pilon trends package. http://cran.r-project.org/package=zyp.
Marchetto, A. 2021. Mann-Kendal Test, Seasonal and Regional Kendall Tests. http://cran.r-project.org/package=rkt.

Appendix B2 - STATISTICAL ANALYSIS FIGURES AND TABLES

Appendix B2 – Supplemental Figures and Tables

This appendix provides supplemental information for the main body of the report. This includes figures and tables.

Figures

Figure B2.1: Daily (blue) and 7-day rolling (black) precipitation data from Pensacola Regional Airport (Station # USW00013899) between 2009 and 2021.

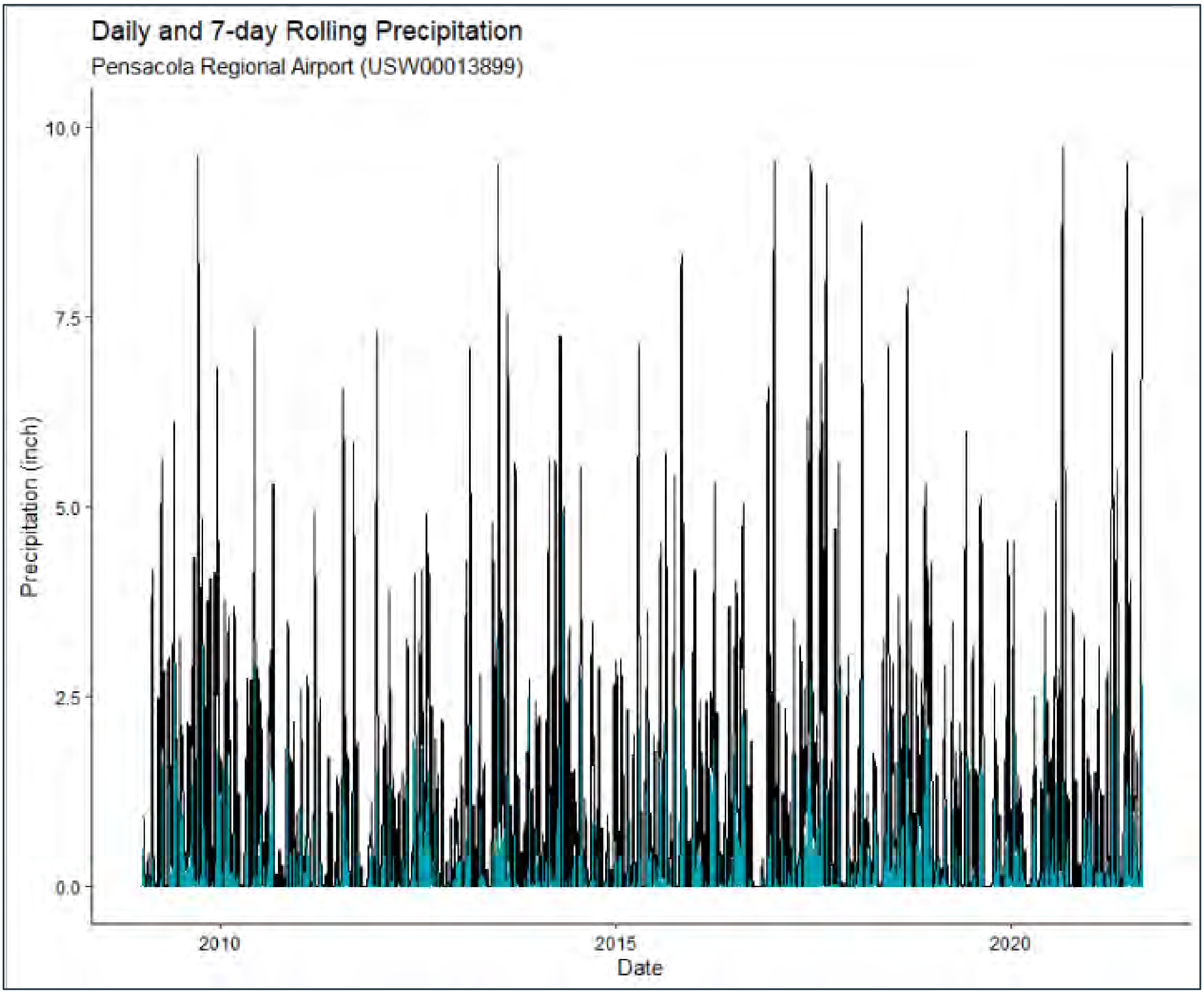


Figure B2.2: Period of record plots of Carpenter Creek (wbid 676) and Bayou Texar (wbid 738) showing sampling frequency from 1970 to the Present.

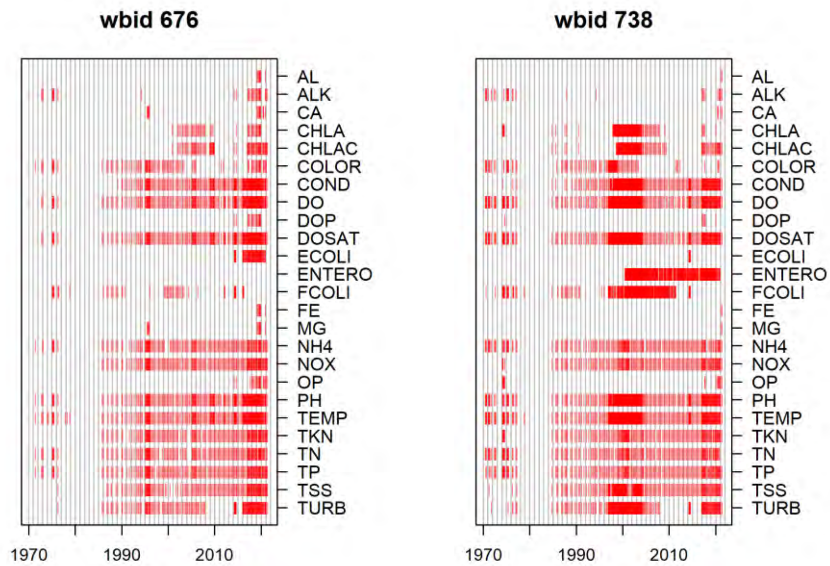
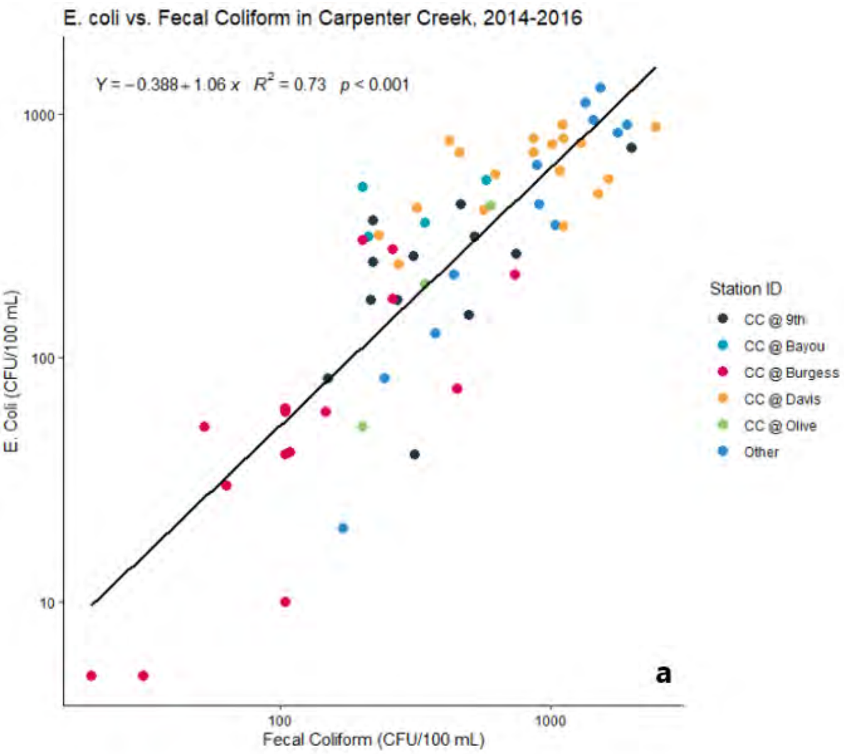


Figure B2.3: Scatter plots of concurrent samples of (a) fecal coliform and *E. coli* in Carpenter Creek (b) fecal coliform and *Enterococci* in Bayou Texar.



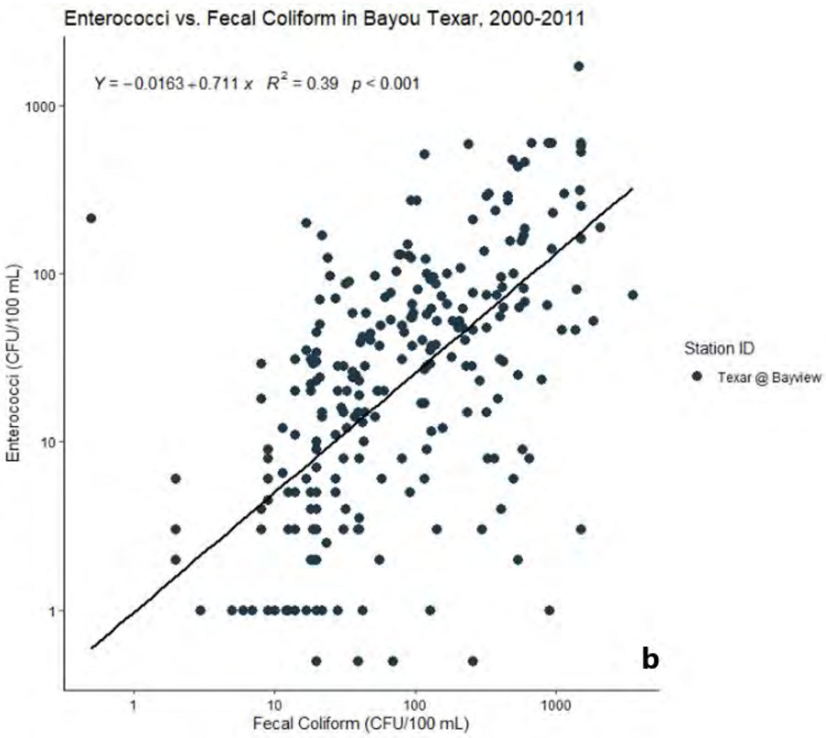


Figure B2.4: Sampling frequency by parameters for the 10 stations with the most robust datasets between 2010 and the Present.

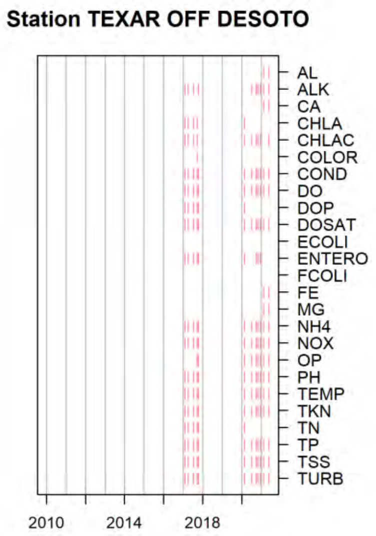
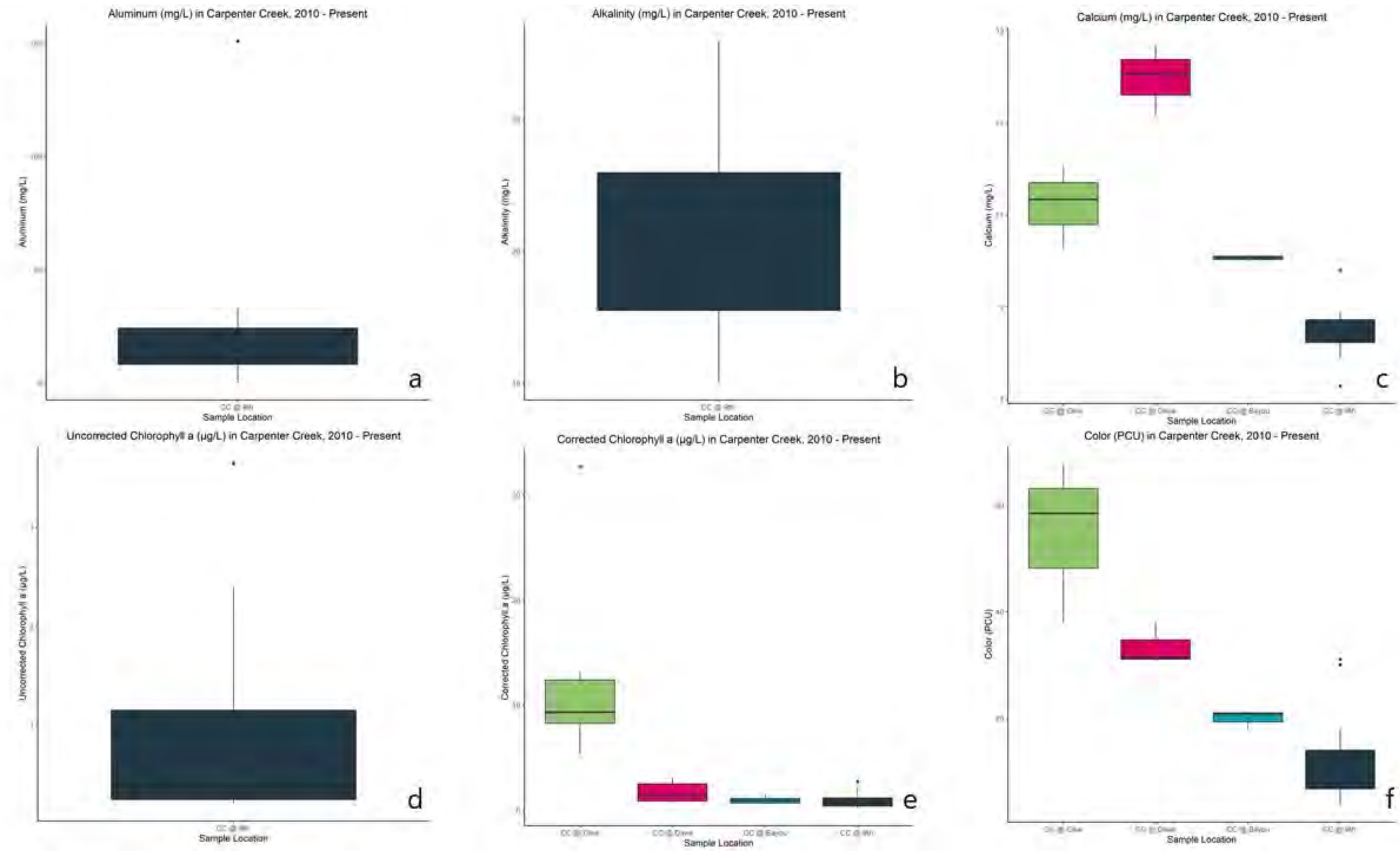
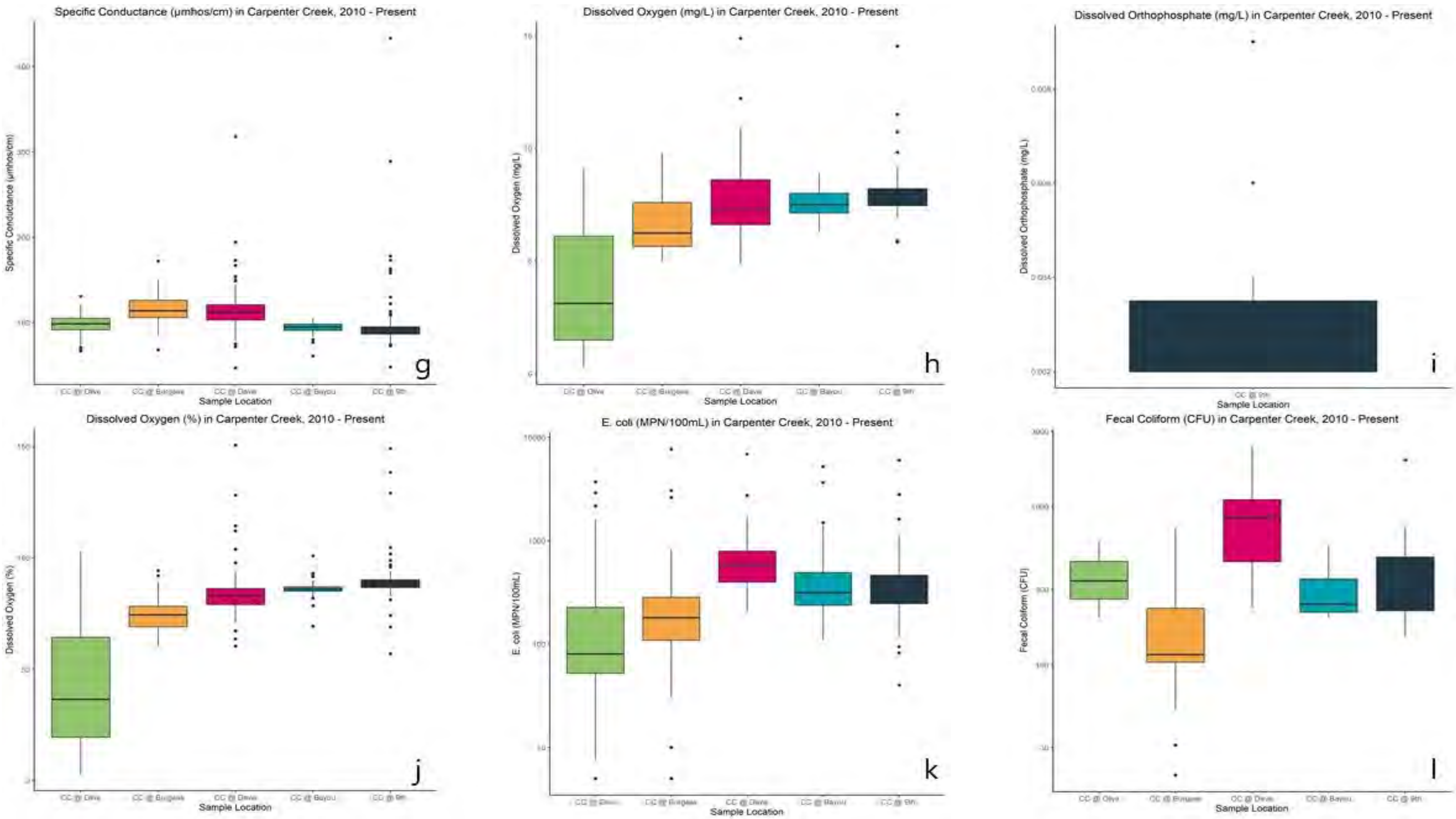
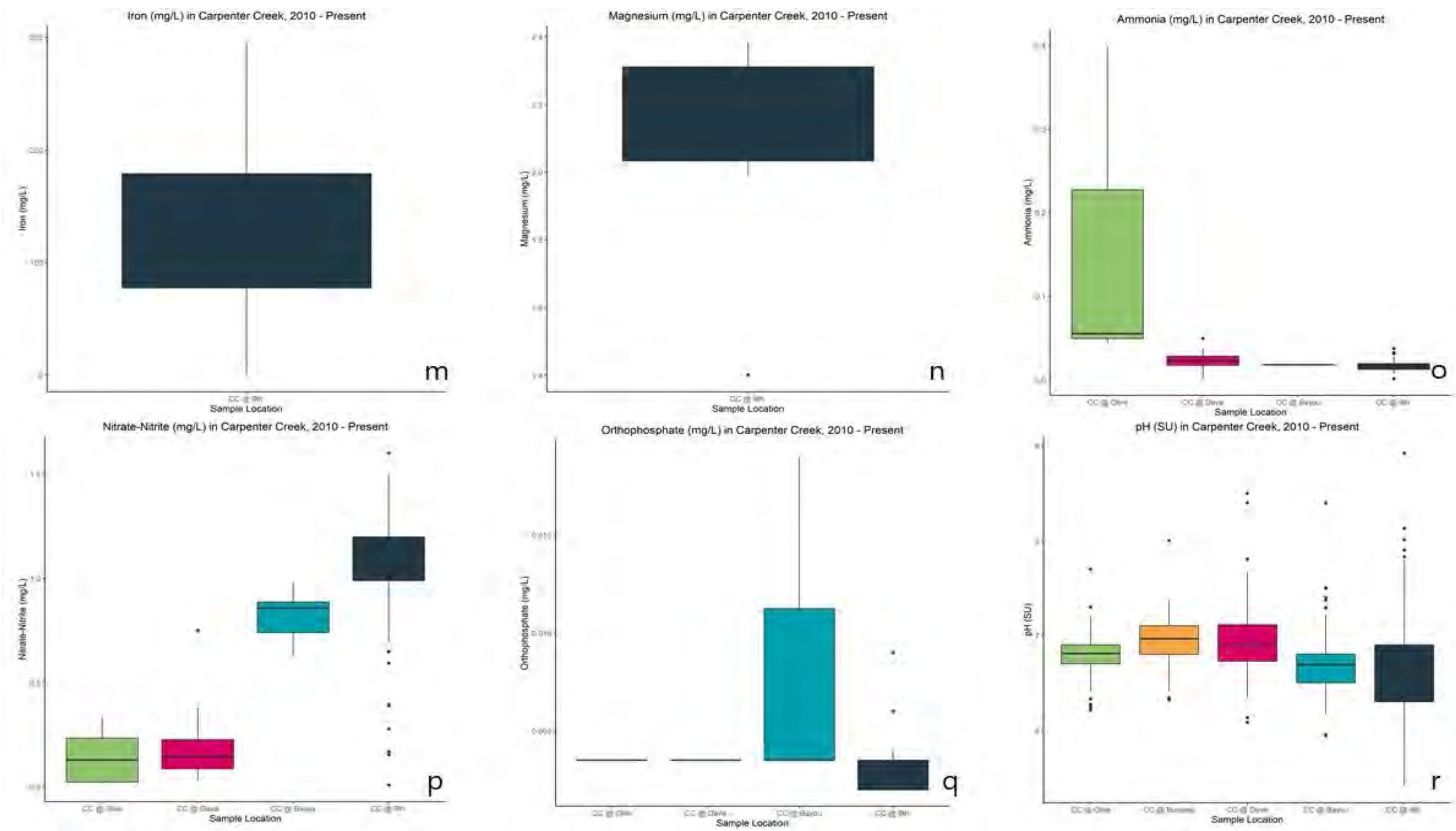
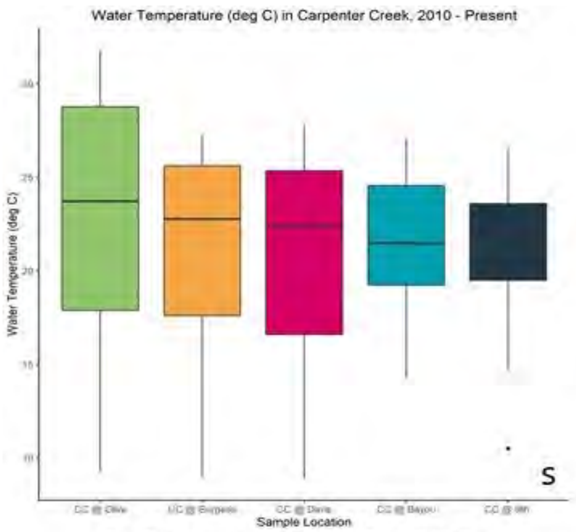

Station TEXAR OFF DESOTO
AL
ALK
CA
CHLA
CHLAC
COLOR
COND
DO
DOP
DOSAT
ECOLI
ENTERO
FCOLI
FE
MG
NH4
NOX
OP
PH
TEMP
TKN
TN
TP
TSS
TURB
2010
2014
2018

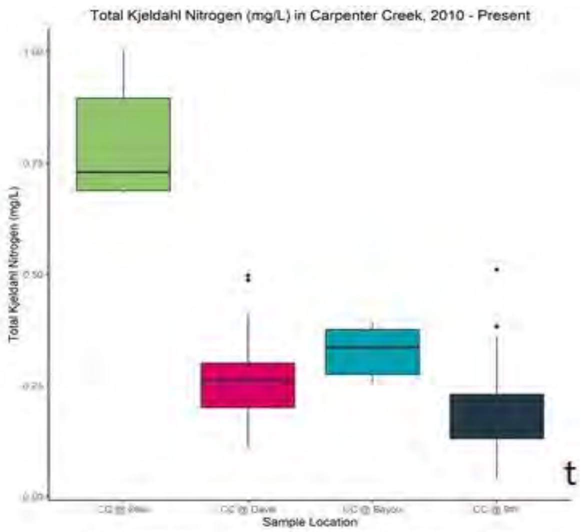
Figure Set B2.5: a-x. Box plots of Carpenter Creek (WBID 676) using data from 2010-Present.

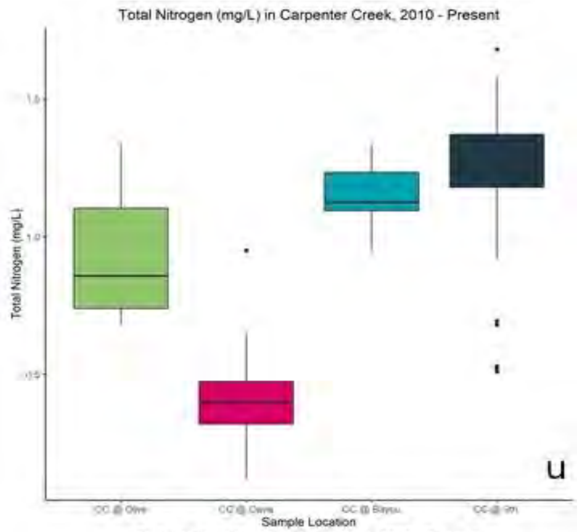


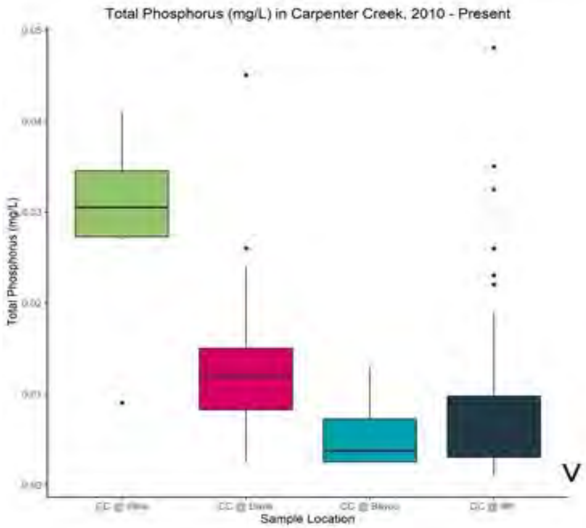

Specific Conductance (µmhos/cm) in Carpenter Creek, 2010 - Present
Specific Conductance (µmhos/cm)
Sample Location
g
Dissolved Oxygen (mg/L) in Carpenter Creek, 2010 - Present
Dissolved Oxygen (mg/L)
Sample Location
h
Dissolved Orthophosphate (mg/L) in Carpenter Creek, 2010 - Present
Dissolved Orthophosphate (mg/L)
Sample Location
i
Dissolved Oxygen (%) in Carpenter Creek, 2010 - Present
Dissolved Oxygen (%)
Sample Location
j
E. coli (MPN/100mL) in Carpenter Creek, 2010 - Present
E. coli (MPN/100mL)
Sample Location
k
Fecal Coliform (CFU) in Carpenter Creek, 2010 - Present
Fecal Coliform (CFU)
Sample Location
l

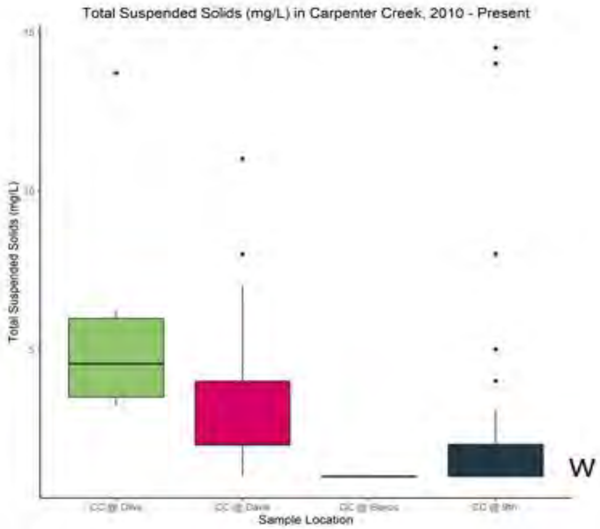

Iron (mg/L) in Carpenter Creek, 2010 - Present
Iron (mg/L)
Sample Location
m
Magnesium (mg/L) in Carpenter Creek, 2010 - Present
Magnesium (mg/L)
Sample Location
n
Ammonia (mg/L) in Carpenter Creek, 2010 - Present
Ammonia (mg/L)
Sample Location
o
Nitrate-Nitrite (mg/L) in Carpenter Creek, 2010 - Present
Nitrate-Nitrite (mg/L)
Sample Location
p
Orthophosphate (mg/L) in Carpenter Creek, 2010 - Present
Orthophosphate (mg/L)
Sample Location
q
pH (SU) in Carpenter Creek, 2010 - Present
pH (SU)
Sample Location
r


Water Temperature (deg C) in Carpenter Creek, 2010 - Present
Water Temperature (deg C)
Sample Location
s


Total Kjeldahl Nitrogen (mg/L) in Carpenter Creek, 2010 - Present
Total Kjeldahl Nitrogen (mg/L)
Sample Location
t


Total Nitrogen (mg/L) in Carpenter Creek, 2010 - Present
Total Nitrogen (mg/L)
Sample Location
u


Total Phosphorus (mg/L) in Carpenter Creek, 2010 - Present
Total Phosphorus (mg/L)
Sample Location
v


Total Suspended Solids (mg/L) in Carpenter Creek, 2010 - Present
Total Suspended Solids (mg/L)
Sample Location
w

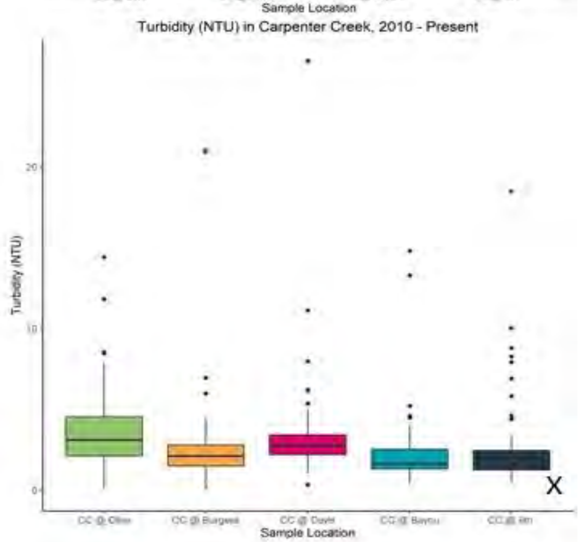
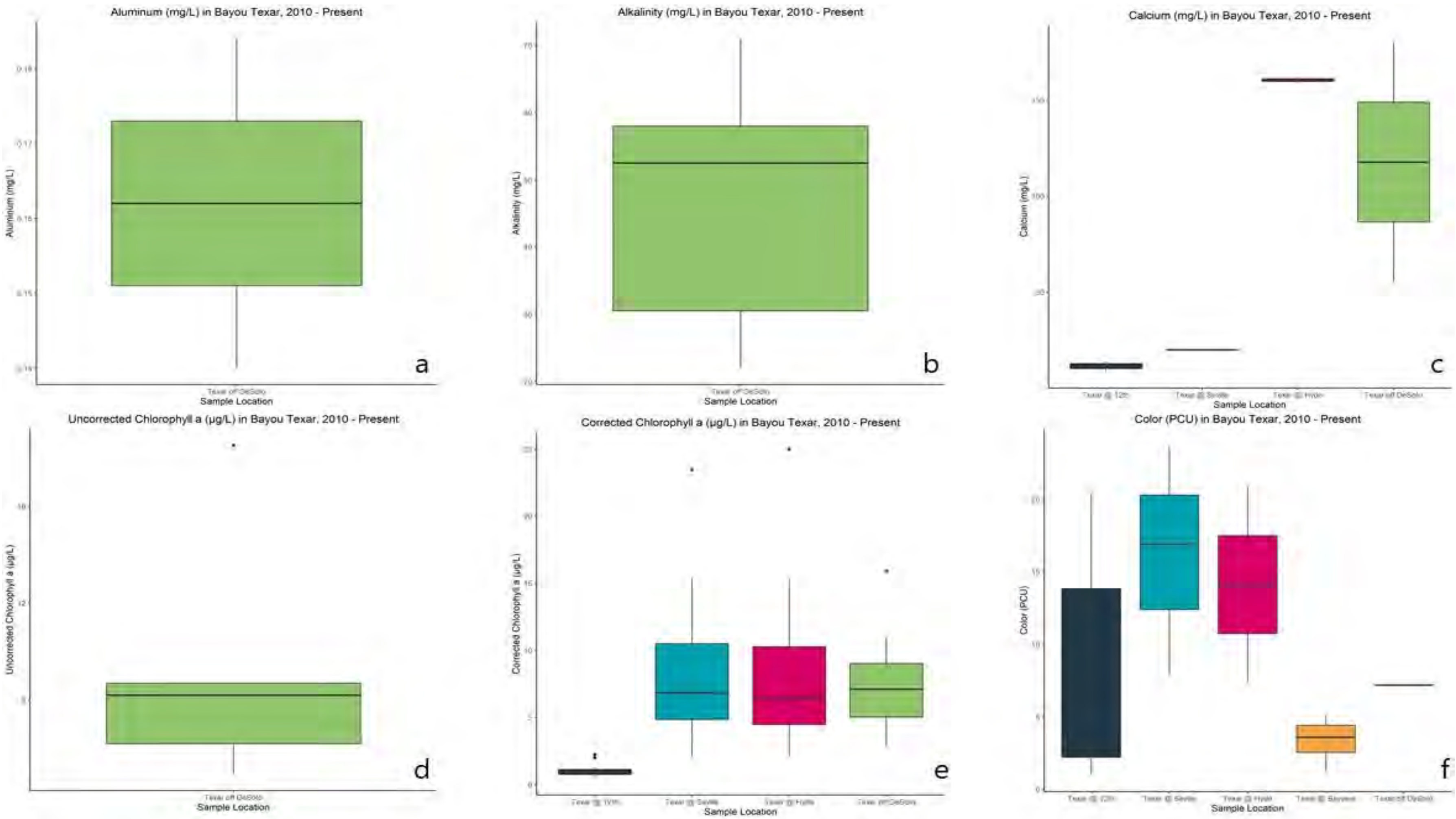
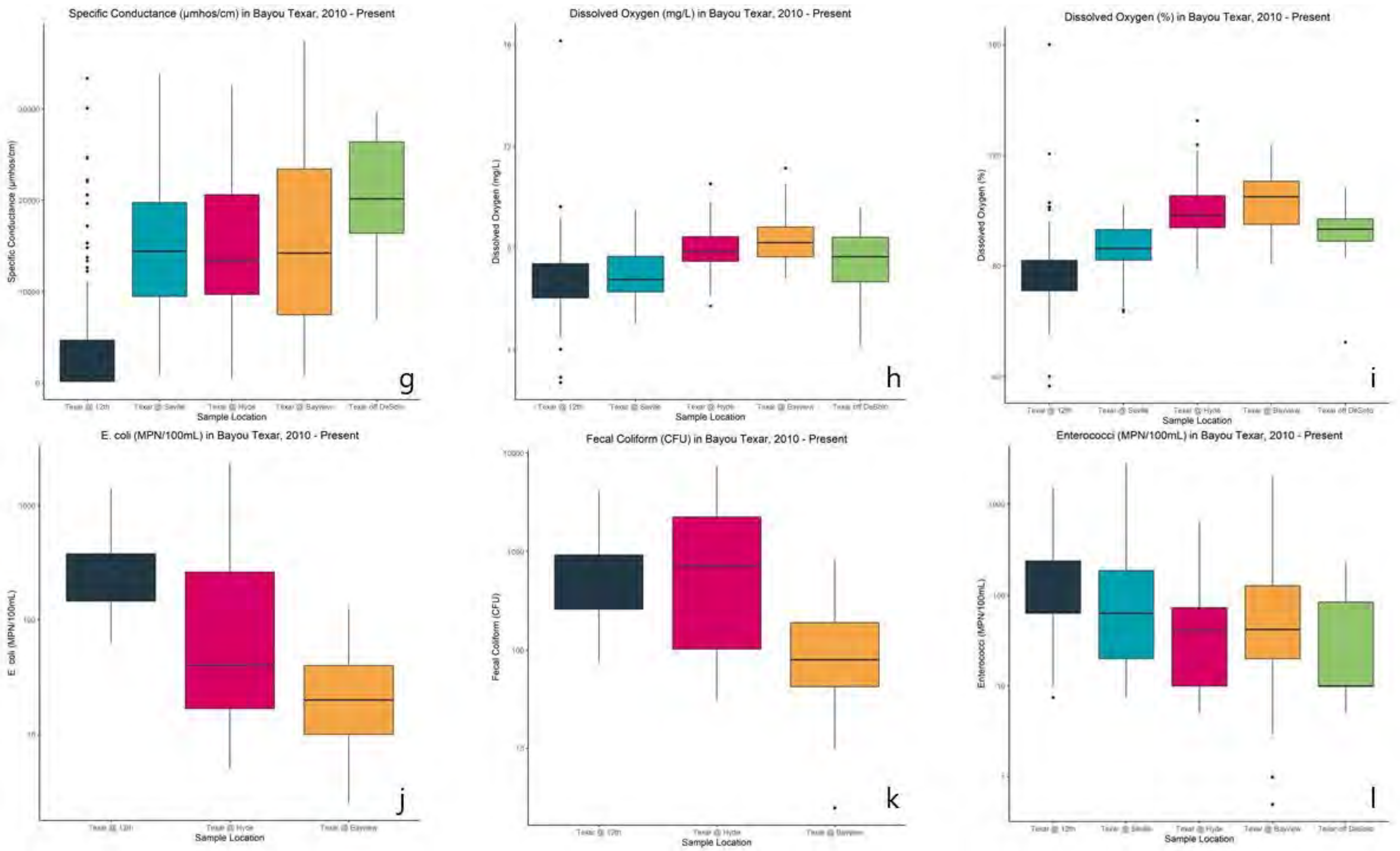
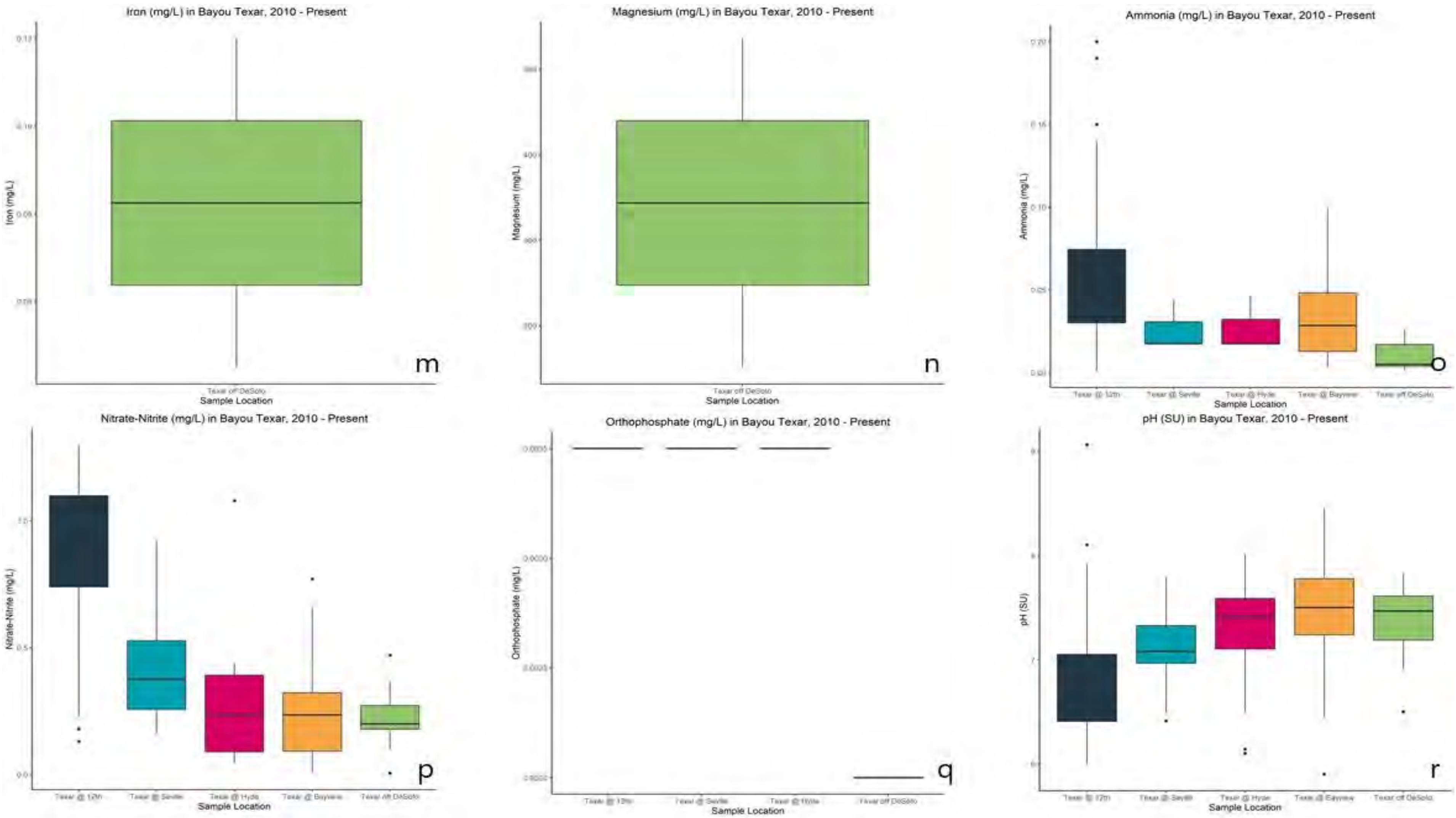

Turbidity (NTU) in Carpenter Creek, 2010 - Present
Turbidity (NTU)
Sample Location
x

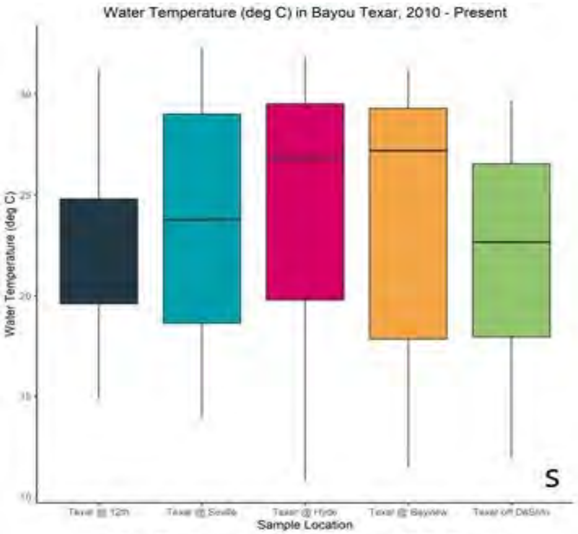
Figure Set B2.6: a-x. Box plots of Bayou Texar (WBID 738) using data from 2010-Present.

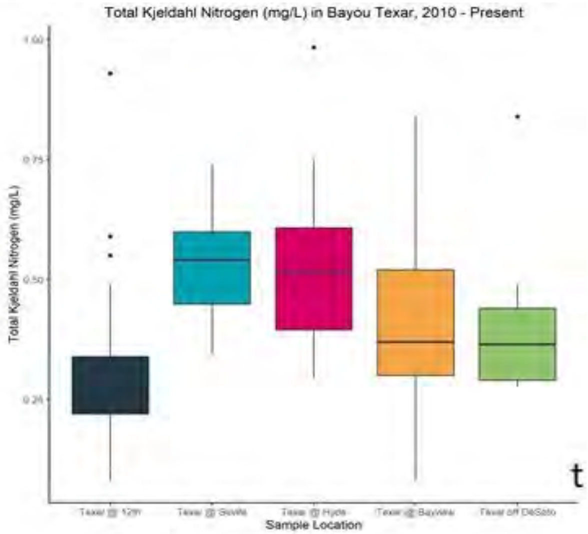


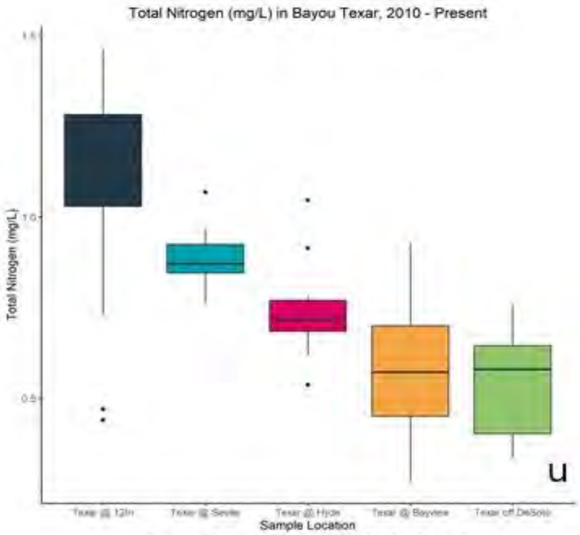

Specific Conductance (µmhos/cm) in Bayou Texar, 2010 - Present
Specific Conductance (µmhos/cm)
Sample Location
g
Dissolved Oxygen (mg/L) in Bayou Texar, 2010 - Present
Dissolved Oxygen (mg/L)
Sample Location
h
Dissolved Oxygen (%) in Bayou Texar, 2010 - Present
Dissolved Oxygen (%)
Sample Location
i
E. coli (MPN/100mL) in Bayou Texar, 2010 - Present
E. coli (MPN/100mL)
Sample Location
j
Fecal Coliform (CFU) in Bayou Texar, 2010 - Present
Fecal Coliform (CFU)
Sample Location
k
Enterococci (MPN/100mL) in Bayou Texar, 2010 - Present
Enterococci (MPN/100mL)
Sample Location
l

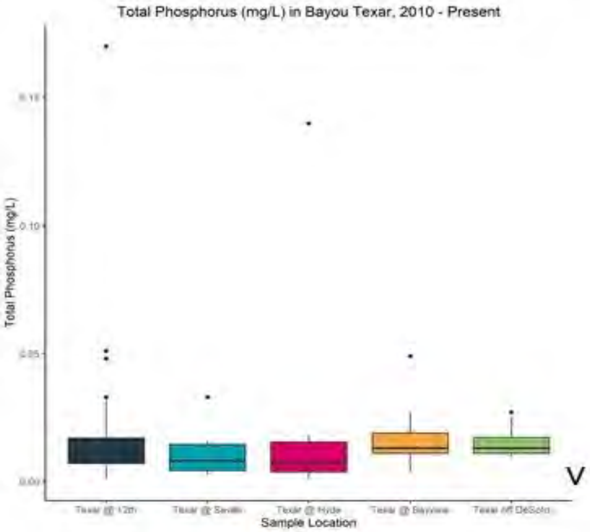


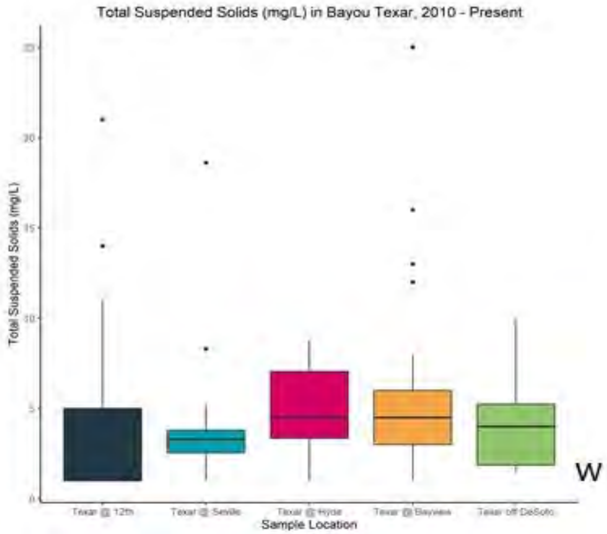
Iron (mg/L) in Bayou Texar, 2010 - Present
Iron (mg/L)
Texar off DeSoto
Sample Location
m
Magnesium (mg/L) in Bayou Texar, 2010 - Present
Magnesium (mg/L)
Texar off DeSoto
Sample Location
n
Ammonia (mg/L) in Bayou Texar, 2010 - Present
Ammonia (mg/L)
Sample Location
o
Nitrate-Nitrite (mg/L) in Bayou Texar, 2010 - Present
Nitrate-Nitrite (mg/L)
Sample Location
p
Orthophosphate (mg/L) in Bayou Texar, 2010 - Present
Orthophosphate (mg/L)
Sample Location
q
pH (SU) in Bayou Texar, 2010 - Present
pH (SU)
Sample Location
r


Water Temperature (deg C) in Bayou Texar, 2010 - Present
Water Temperature (deg C)
Sample Location
Texar @ 12th
Texar @ Seville
Texar @ Hyde
Texar @ Bayview
Texar off DeSoto
s


Total Kjeldahl Nitrogen (mg/L) in Bayou Texar, 2010 - Present
Total Kjeldahl Nitrogen (mg/L)
Sample Location
Texar @ 12th
Texar @ Seville
Texar @ Hyde
Texar @ Bayview
Texar off DeSoto
t


Total Nitrogen (mg/L) in Bayou Texar, 2010 - Present
Total Nitrogen (mg/L)
Sample Location
Texar @ 12th
Texar @ Seville
Texar @ Hyde
Texar @ Bayview
Texar off DeSoto
u


Total Phosphorus (mg/L) in Bayou Texar, 2010 - Present
Total Phosphorus (mg/L)
Sample Location
Texar @ 12th
Texar @ Seville
Texar @ Hyde
Texar @ Bayview
Texar off DeSoto
v


Total Suspended Solids (mg/L) in Bayou Texar, 2010 - Present
Total Suspended Solids (mg/L)
Sample Location
Texar @ 12th
Texar @ Seville
Texar @ Hyde
Texar @ Bayview
Texar off DeSoto
w

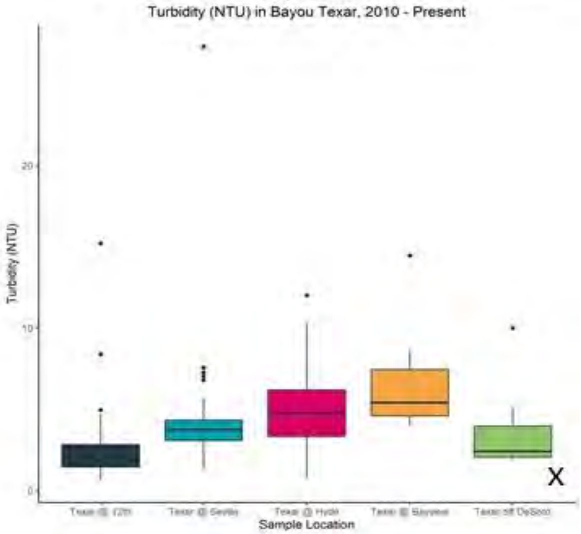
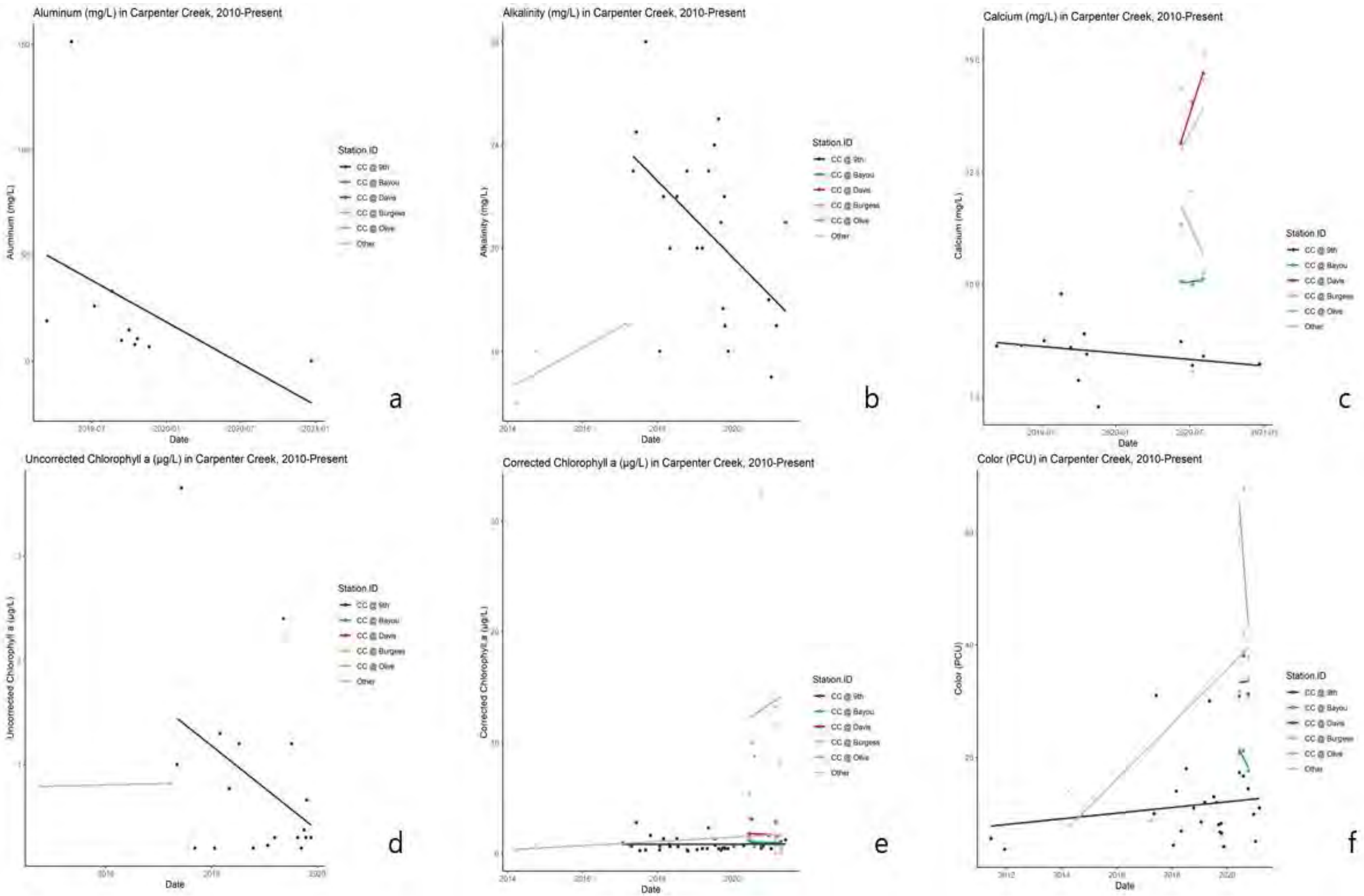
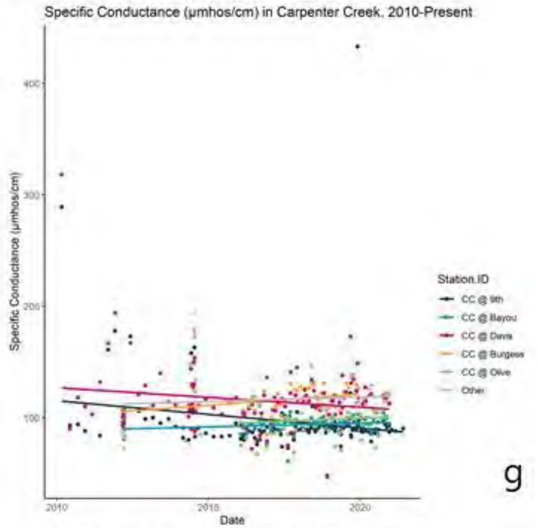
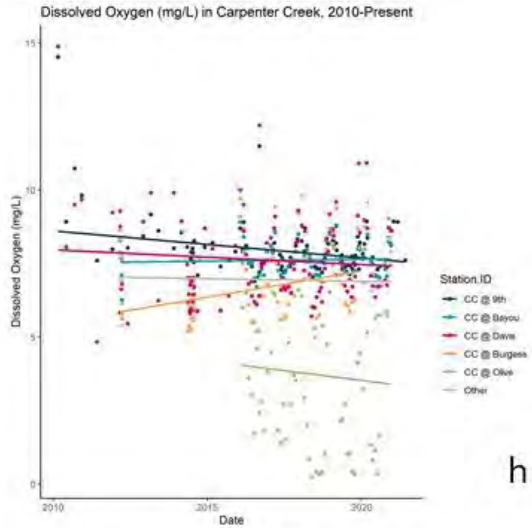
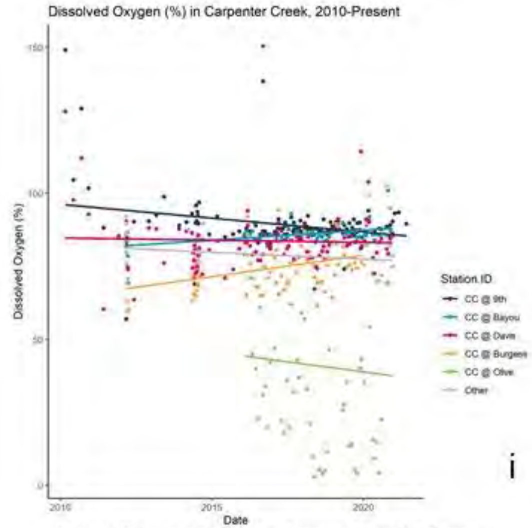

Turbidity (NTU) in Bayou Texar, 2010 - Present
Turbidity (NTU)
Sample Location
Texar @ 12th
Texar @ Seville
Texar @ Hyde
Texar @ Bayview
Texar off DeSoto
x

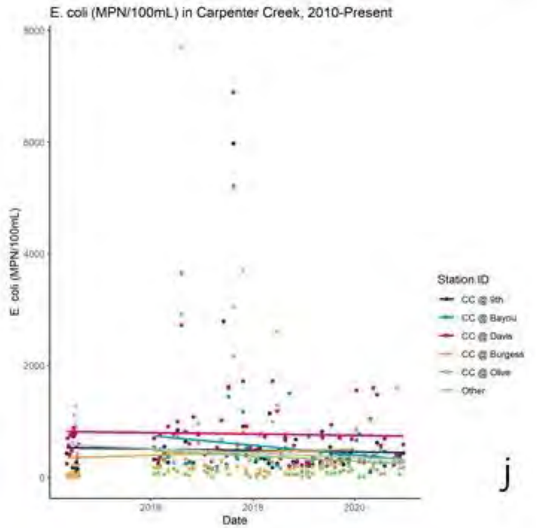
Figure Set B2.7: a-x. Time series of Carpenter Creek (WBID 676) using data from 2010-Present.

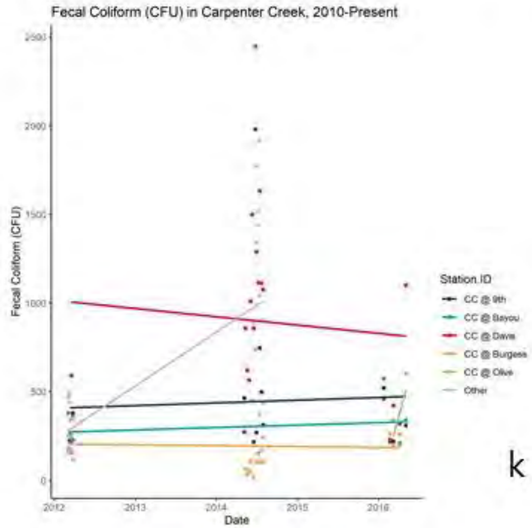


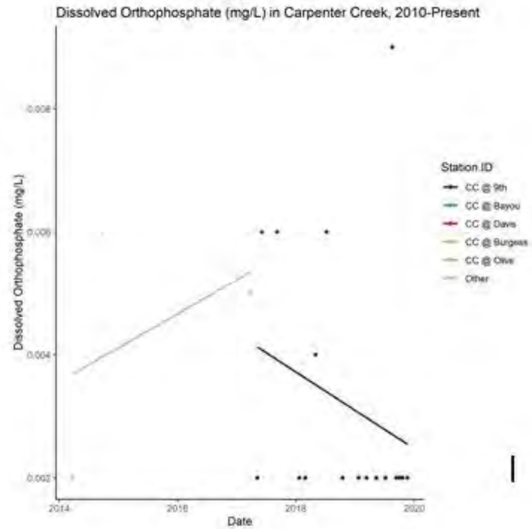

Specific Conductance (μmhos/cm) in Carpenter Creek, 2010-Present
Specific Conductance (μmhos/cm)
Date
Station.ID
CC @ 9th
CC @ Bayou
CC @ Davis
CC @ Burgess
CC @ Olive
Other
g

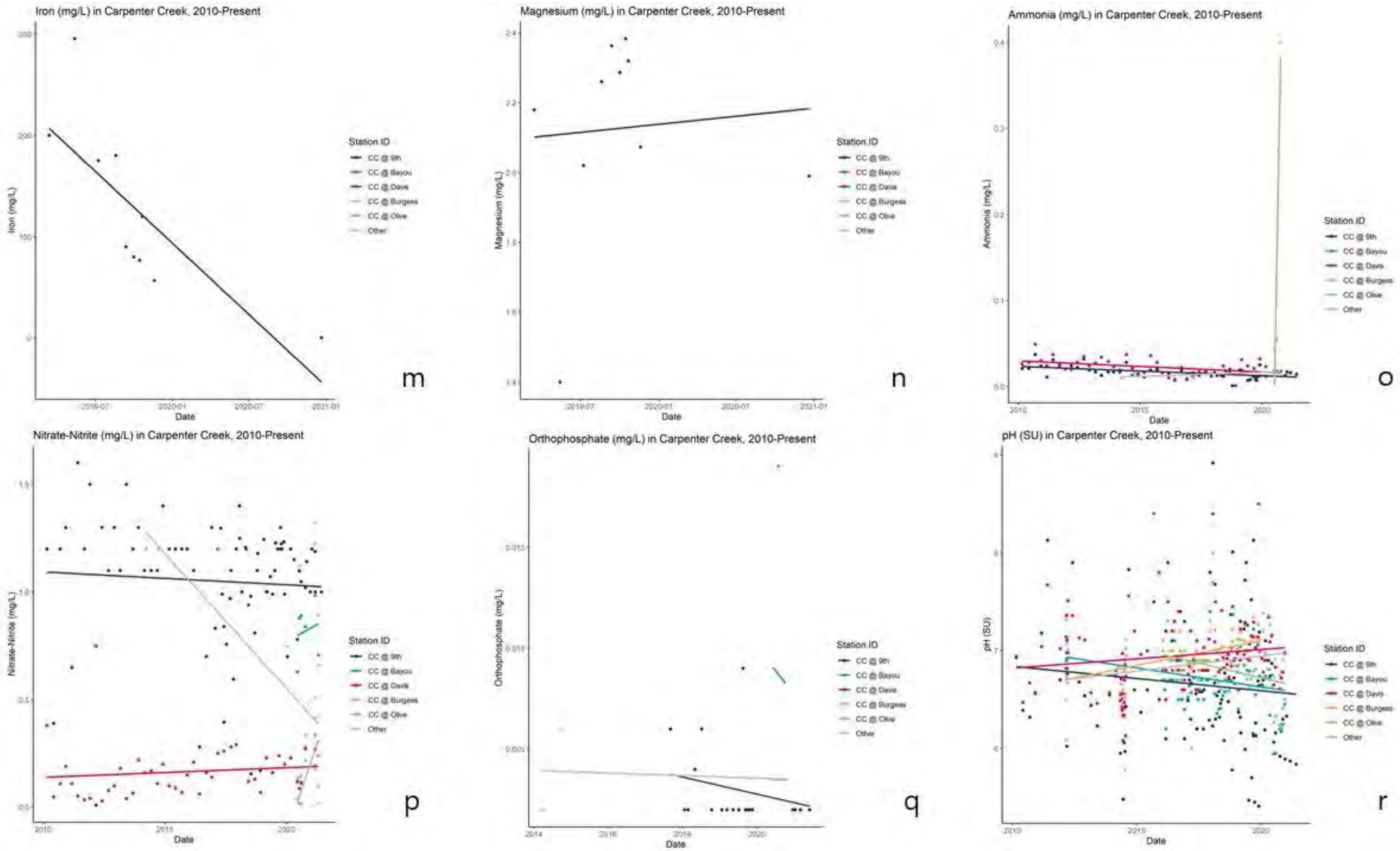

Dissolved Oxygen (mg/L) in Carpenter Creek, 2010-Present
Dissolved Oxygen (mg/L)
Date
Station.ID
CC @ 9th
CC @ Bayou
CC @ Davis
CC @ Burgess
CC @ Olive
Other
h

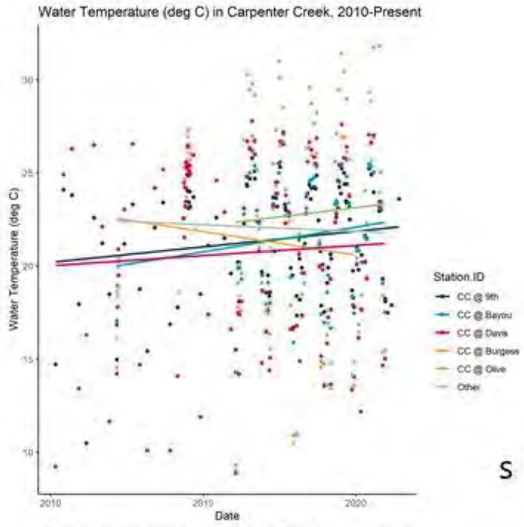

Dissolved Oxygen (%) in Carpenter Creek, 2010-Present
Dissolved Oxygen (%)
Date
Station.ID
CC @ 9th
CC @ Bayou
CC @ Davis
CC @ Burgess
CC @ Olive
Other
i

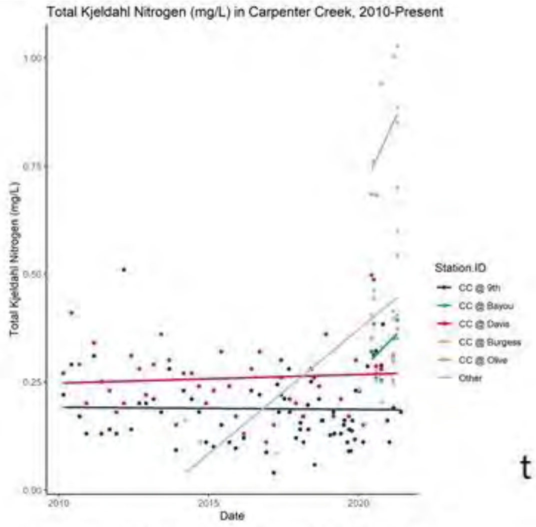

E. coli (MPN/100mL) in Carpenter Creek, 2010-Present
E. coli (MPN/100mL)
Date
Station.ID
CC @ 9th
CC @ Bayou
CC @ Davis
CC @ Burgess
CC @ Olive
Other
j

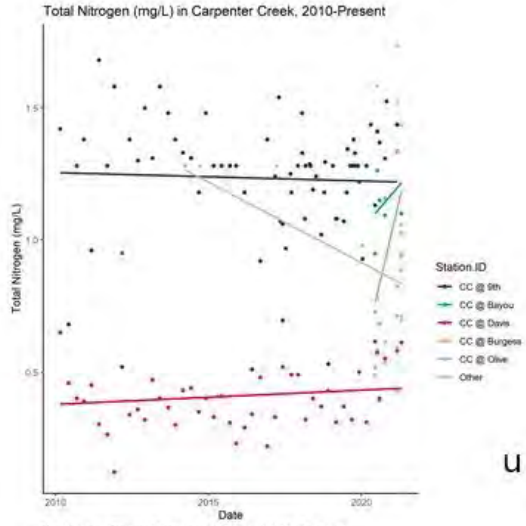

Fecal Coliform (CFU) in Carpenter Creek, 2010-Present
Fecal Coliform (CFU)
Date
Station.ID
CC @ 9th
CC @ Bayou
CC @ Davis
CC @ Burgess
CC @ Olive
Other
k

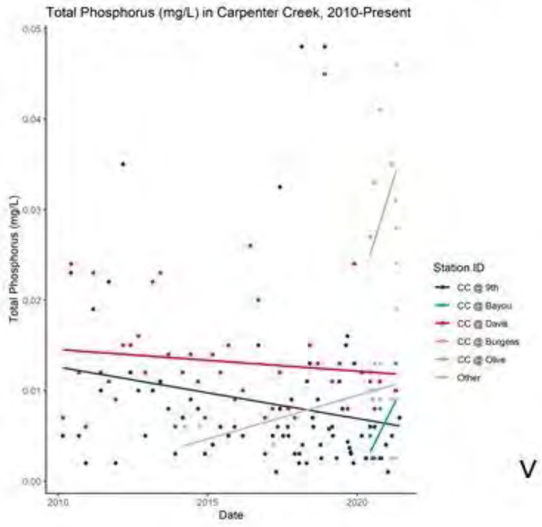

Dissolved Orthophosphate (mg/L) in Carpenter Creek, 2010-Present
Dissolved Orthophosphate (mg/L)
Date
Station.ID
CC @ 9th
CC @ Bayou
CC @ Davis
CC @ Burgess
CC @ Olive
Other
l

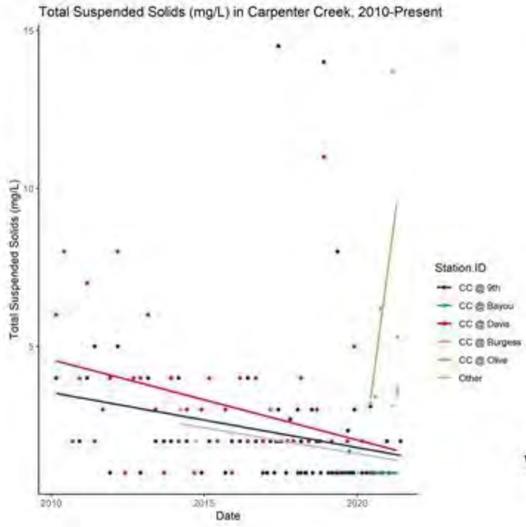

Iron (mg/L) in Carpenter Creek, 2010-Present
Iron (mg/L)
Date
Station ID
CC @ 9th
CC @ Bayou
CC @ Davis
CC @ Burgess
CC @ Olive
Other
m
Magnesium (mg/L) in Carpenter Creek, 2010-Present
Magnesium (mg/L)
Date
Station ID
CC @ 9th
CC @ Bayou
CC @ Davis
CC @ Burgess
CC @ Olive
Other
n
Ammonia (mg/L) in Carpenter Creek, 2010-Present
Ammonia (mg/L)
Date
Station ID
CC @ 9th
CC @ Bayou
CC @ Davis
CC @ Burgess
CC @ Olive
Other
o
Nitrate-Nitrite (mg/L) in Carpenter Creek, 2010-Present
Nitrate-Nitrite (mg/L)
Date
Station ID
CC @ 9th
CC @ Bayou
CC @ Davis
CC @ Burgess
CC @ Olive
Other
p
Orthophosphate (mg/L) in Carpenter Creek, 2010-Present
Orthophosphate (mg/L)
Date
Station ID
CC @ 9th
CC @ Bayou
CC @ Davis
CC @ Burgess
CC @ Olive
Other
q
pH (SU) in Carpenter Creek, 2010-Present
pH (SU)
Date
Station ID
CC @ 9th
CC @ Bayou
CC @ Davis
CC @ Burgess
CC @ Olive
Other
r


Water Temperature (deg C) in Carpenter Creek, 2010-Present
Water Temperature (deg C)
Date
Station.ID
CC @ 9th
CC @ Bayou
CC @ Davis
CC @ Burgess
CC @ Olive
Other
s


Total Kjeldahl Nitrogen (mg/L) in Carpenter Creek, 2010-Present
Total Kjeldahl Nitrogen (mg/L)
Date
Station.ID
CC @ 9th
CC @ Bayou
CC @ Davis
CC @ Burgess
CC @ Olive
Other
t


Total Nitrogen (mg/L) in Carpenter Creek, 2010-Present
Total Nitrogen (mg/L)
Date
Station.ID
CC @ 9th
CC @ Bayou
CC @ Davis
CC @ Burgess
CC @ Olive
Other
u


Total Phosphorus (mg/L) in Carpenter Creek, 2010-Present
Total Phosphorus (mg/L)
Date
Station.ID
CC @ 9th
CC @ Bayou
CC @ Davis
CC @ Burgess
CC @ Olive
Other
v


Total Suspended Solids (mg/L) in Carpenter Creek, 2010-Present
Total Suspended Solids (mg/L)
Date
Station.ID
CC @ 9th
CC @ Bayou
CC @ Davis
CC @ Burgess
CC @ Olive
Other
w

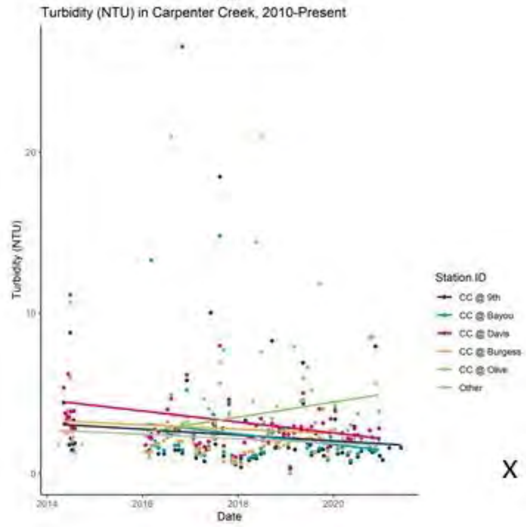
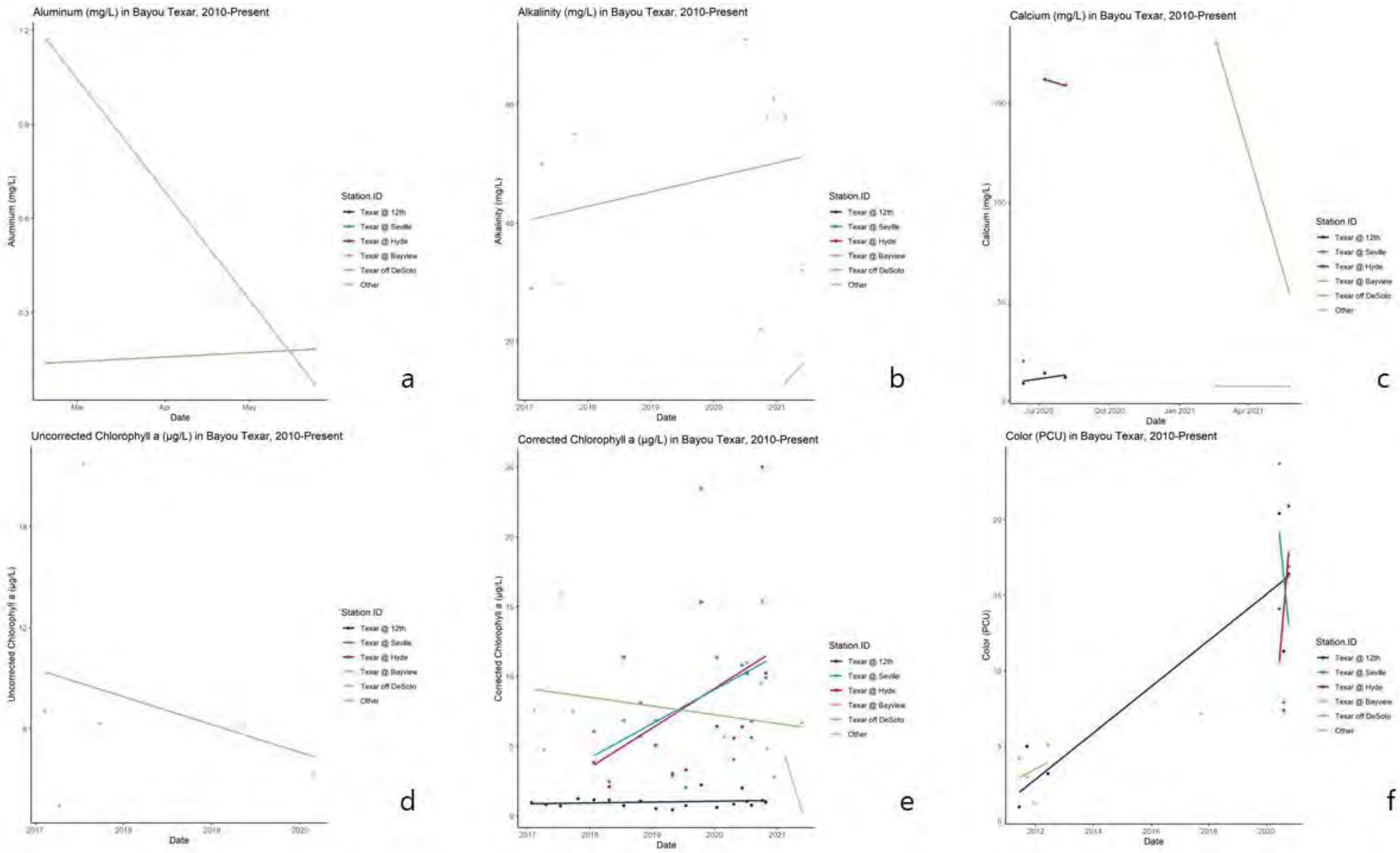
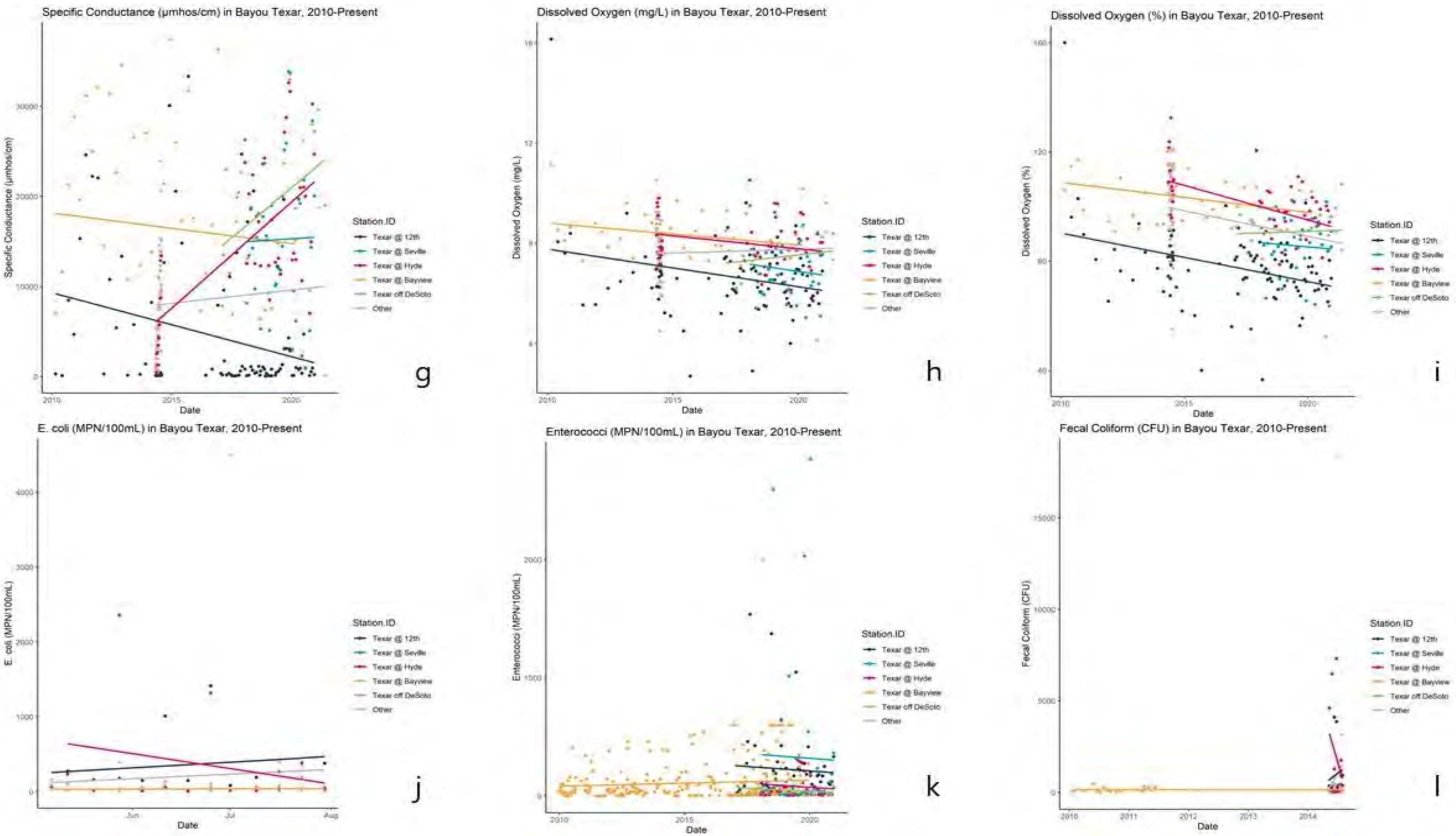
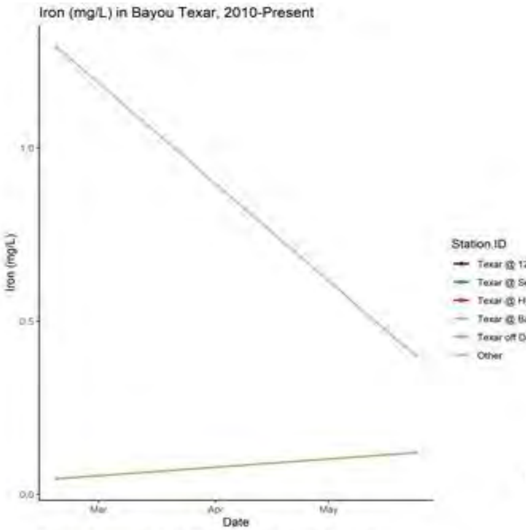

Turbidity (NTU) in Carpenter Creek, 2010-Present
Turbidity (NTU)
Date
Station.ID
CC @ 9th
CC @ Bayou
CC @ Davis
CC @ Burgess
CC @ Olive
Other
x

Figure Set B2.8: a-x. Time series of Bayou Texar (WBID 738) using data from 2010-Present.

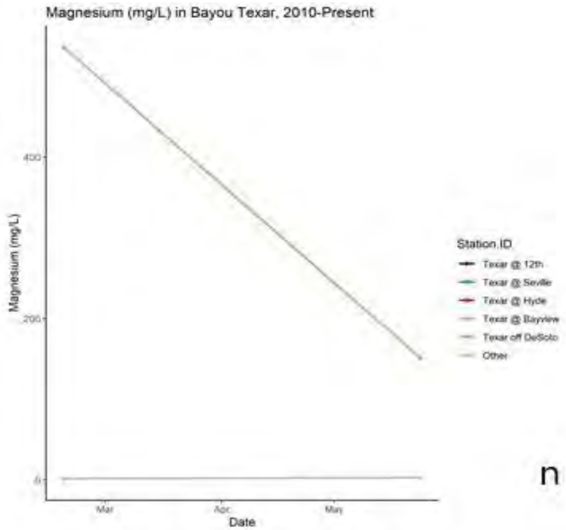




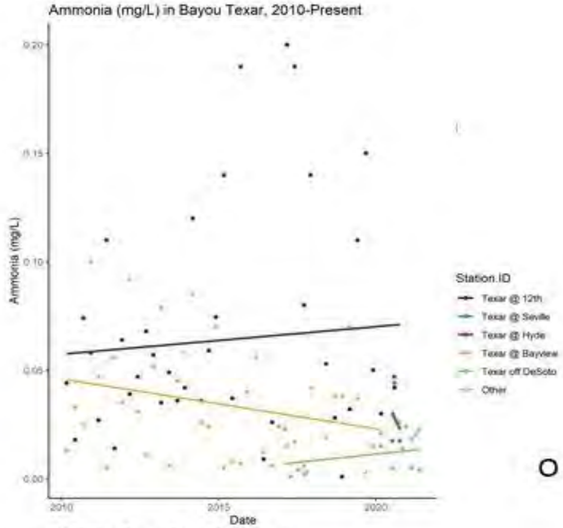
Specific Conductance (µmhos/cm) in Bayou Texar, 2010-Present
Specific Conductance (µmhos/cm)
Date
g
Dissolved Oxygen (mg/L) in Bayou Texar, 2010-Present
Dissolved Oxygen (mg/L)
Date
h
Dissolved Oxygen (%) in Bayou Texar, 2010-Present
Dissolved Oxygen (%)
Date
i
E. coli (MPN/100mL) in Bayou Texar, 2010-Present
E. coli (MPN/100mL)
Date
j
Enterococci (MPN/100mL) in Bayou Texar, 2010-Present
Enterococci (MPN/100mL)
Date
k
Fecal Coliform (CFU) in Bayou Texar, 2010-Present
Fecal Coliform (CFU)
Date
l
Station.ID
Texar @ 12th
Texar @ Seville
Texar @ Hyde
Texar @ Bayview
Texar off DeSoto
Other


Iron (mg/L) in Bayou Texar, 2010-Present
Iron (mg/L)
Date
Mar
Apr
May
Station.ID
Texar @ 12th
Texar @ Seville
Texar @ Hyde
Texar @ Bayview
Texar off DeSoto
Other

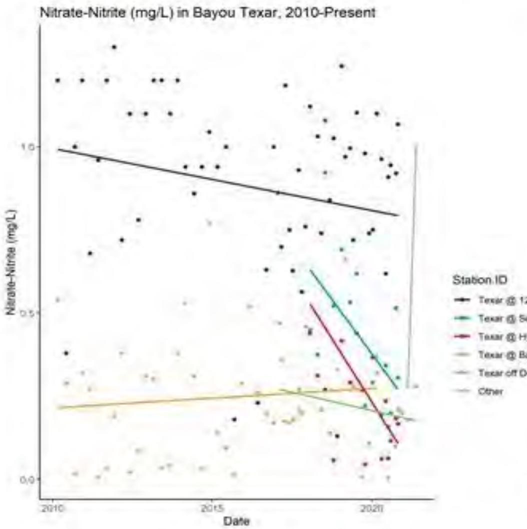
m


Magnesium (mg/L) in Bayou Texar, 2010-Present
Magnesium (mg/L)
Date
Mar
Apr
May
Station.ID
Texar @ 12th
Texar @ Seville
Texar @ Hyde
Texar @ Bayview
Texar off DeSoto
Other

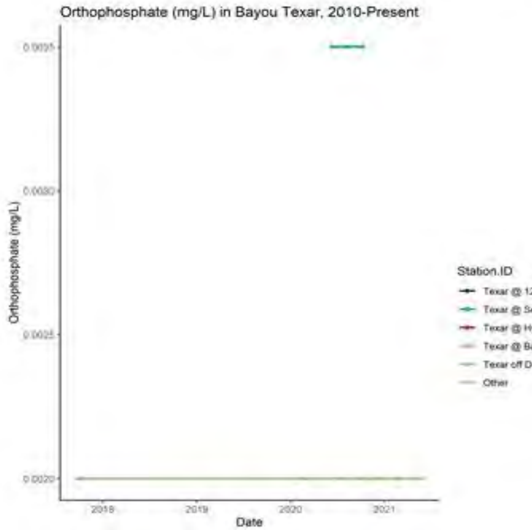
n


Ammonia (mg/L) in Bayou Texar, 2010-Present
Ammonia (mg/L)
Date
Station.ID
Texar @ 12th
Texar @ Seville
Texar @ Hyde
Texar @ Bayview
Texar off DeSoto
Other

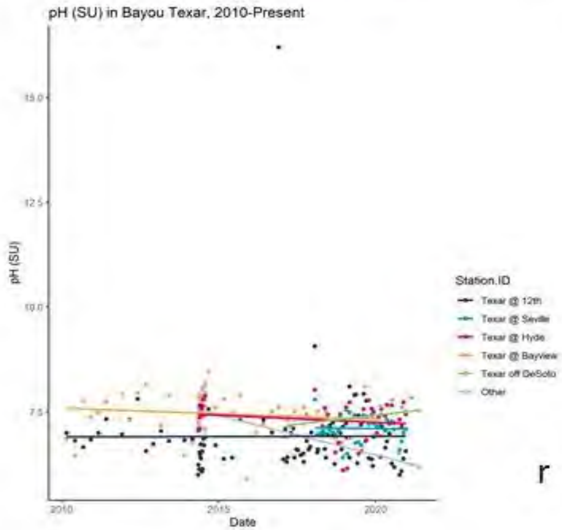
o


Nitrate-Nitrite (mg/L) in Bayou Texar, 2010-Present
Nitrate-Nitrite (mg/L)
Date
Station.ID
Texar @ 12th
Texar @ Seville
Texar @ Hyde
Texar @ Bayview
Texar off DeSoto
Other

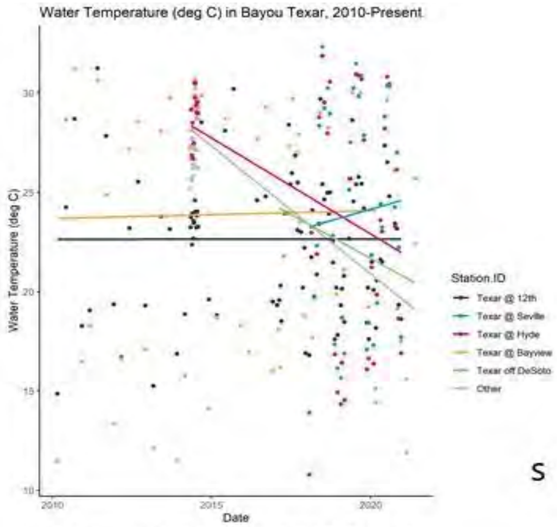
p

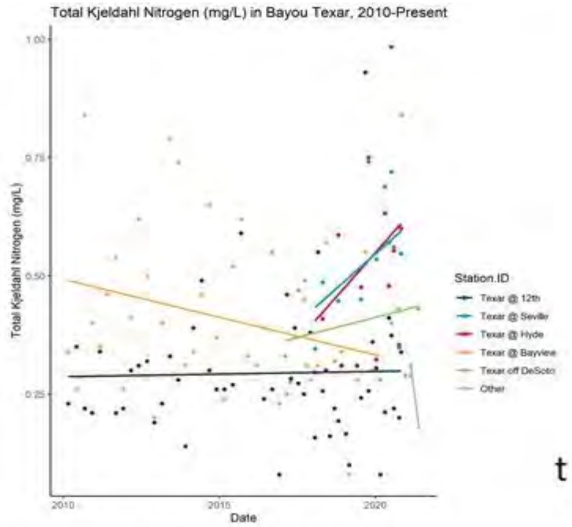

Orthophosphate (mg/L) in Bayou Texar, 2010-Present
Orthophosphate (mg/L)
Date
Station.ID
Texar @ 12th
Texar @ Seville
Texar @ Hyde
Texar @ Bayview
Texar off DeSoto
Other

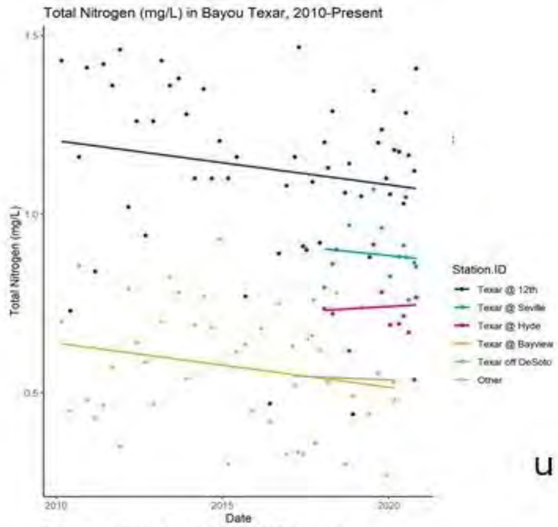
q

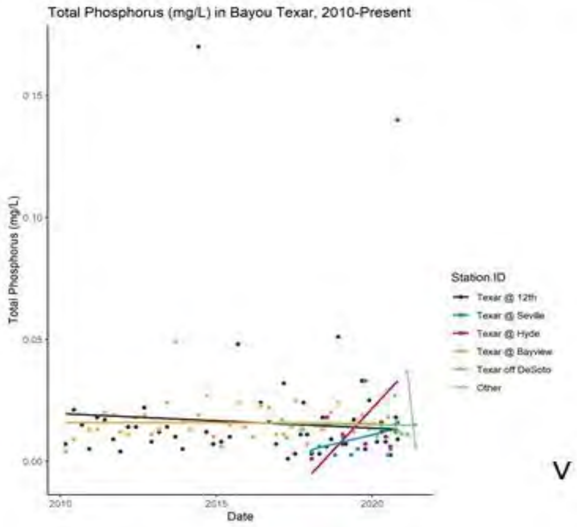

pH (SU) in Bayou Texar, 2010-Present
pH (SU)
Date
Station.ID
Texar @ 12th
Texar @ Seville
Texar @ Hyde
Texar @ Bayview
Texar off DeSoto
Other

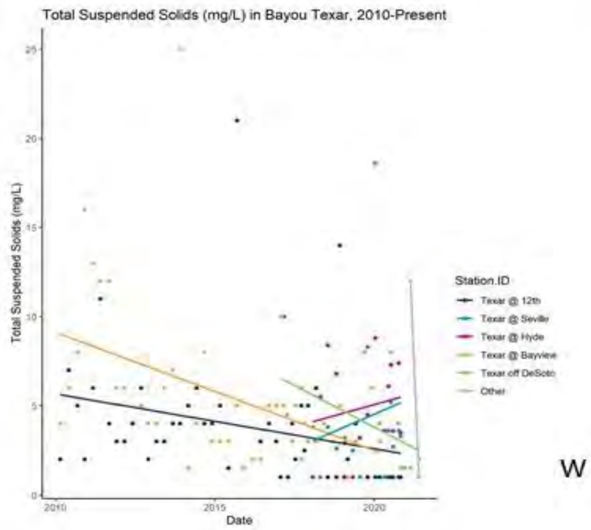
r


Water Temperature (deg C) in Bayou Texar, 2010-Present
Water Temperature (deg C)
Date
Station.ID
Texar @ 12th
Texar @ Seville
Texar @ Hyde
Texar @ Bayview
Texar off DeSoto
Other
s


Total Kjeldahl Nitrogen (mg/L) in Bayou Texar, 2010-Present
Total Kjeldahl Nitrogen (mg/L)
Date
Station.ID
Texar @ 12th
Texar @ Seville
Texar @ Hyde
Texar @ Bayview
Texar off DeSoto
Other
t


Total Nitrogen (mg/L) in Bayou Texar, 2010-Present
Total Nitrogen (mg/L)
Date
Station.ID
Texar @ 12th
Texar @ Seville
Texar @ Hyde
Texar @ Bayview
Texar off DeSoto
Other
u


Total Phosphorus (mg/L) in Bayou Texar, 2010-Present
Total Phosphorus (mg/L)
Date
Station.ID
Texar @ 12th
Texar @ Seville
Texar @ Hyde
Texar @ Bayview
Texar off DeSoto
Other
v


Total Suspended Solids (mg/L) in Bayou Texar, 2010-Present
Total Suspended Solids (mg/L)
Date
Station.ID
Texar @ 12th
Texar @ Seville
Texar @ Hyde
Texar @ Bayview
Texar off DeSoto
Other
w

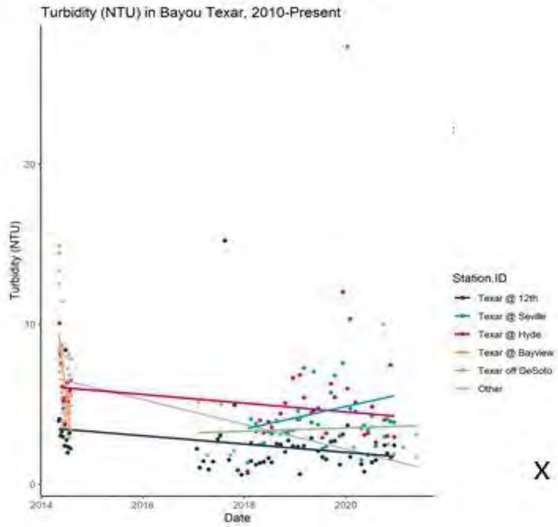
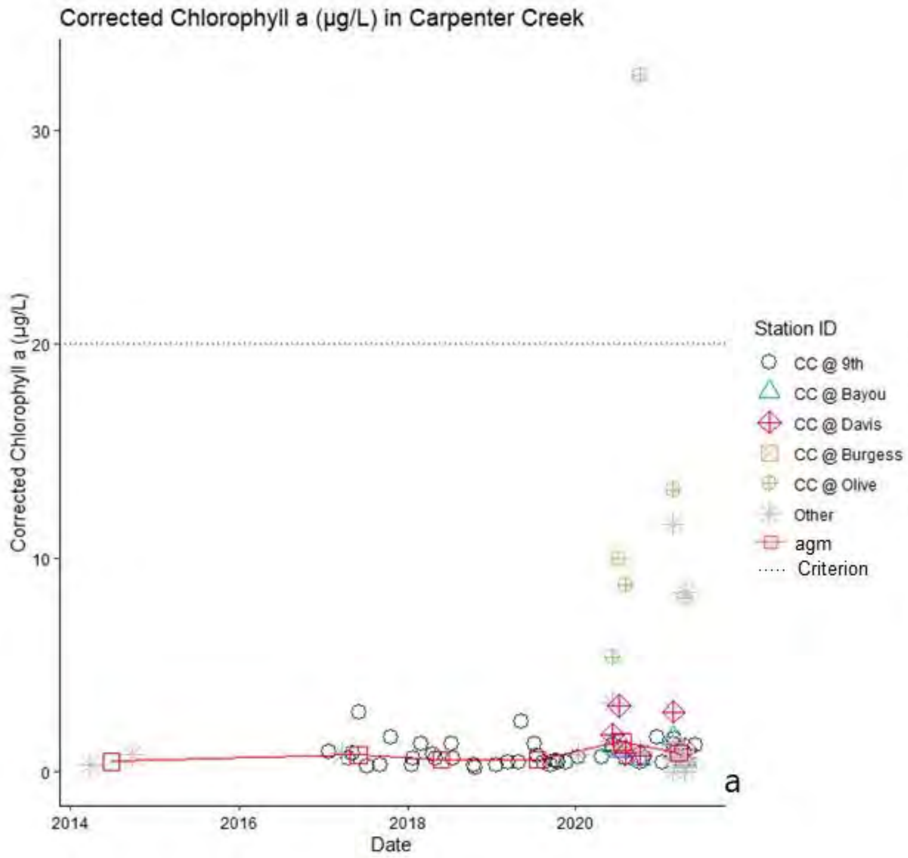
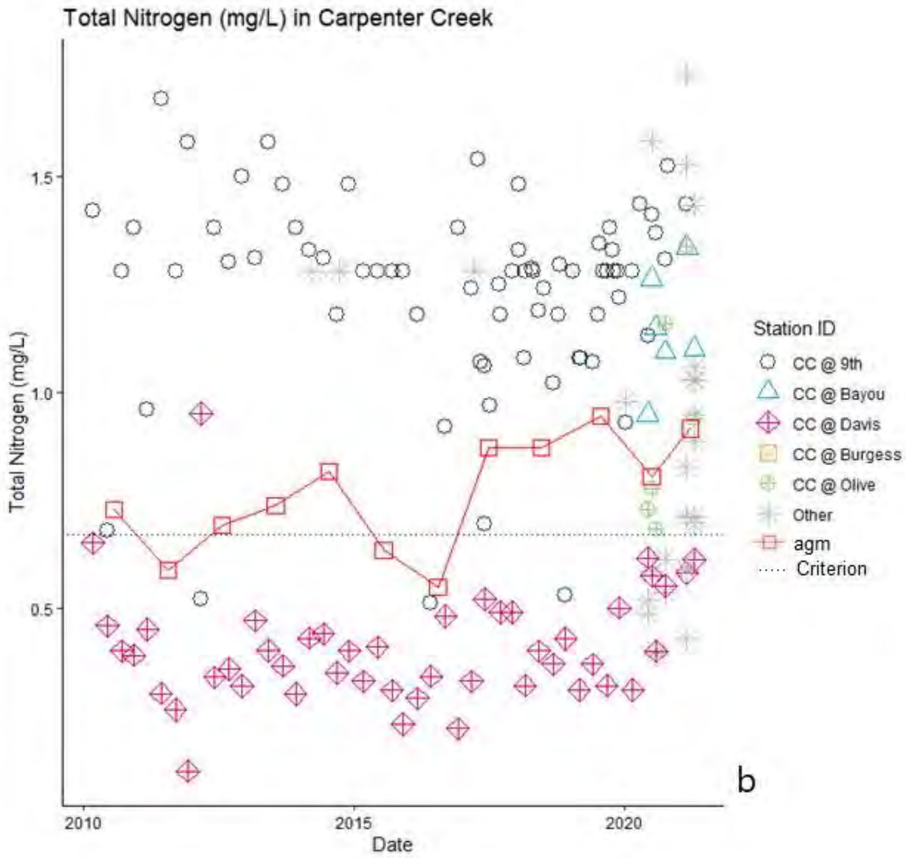
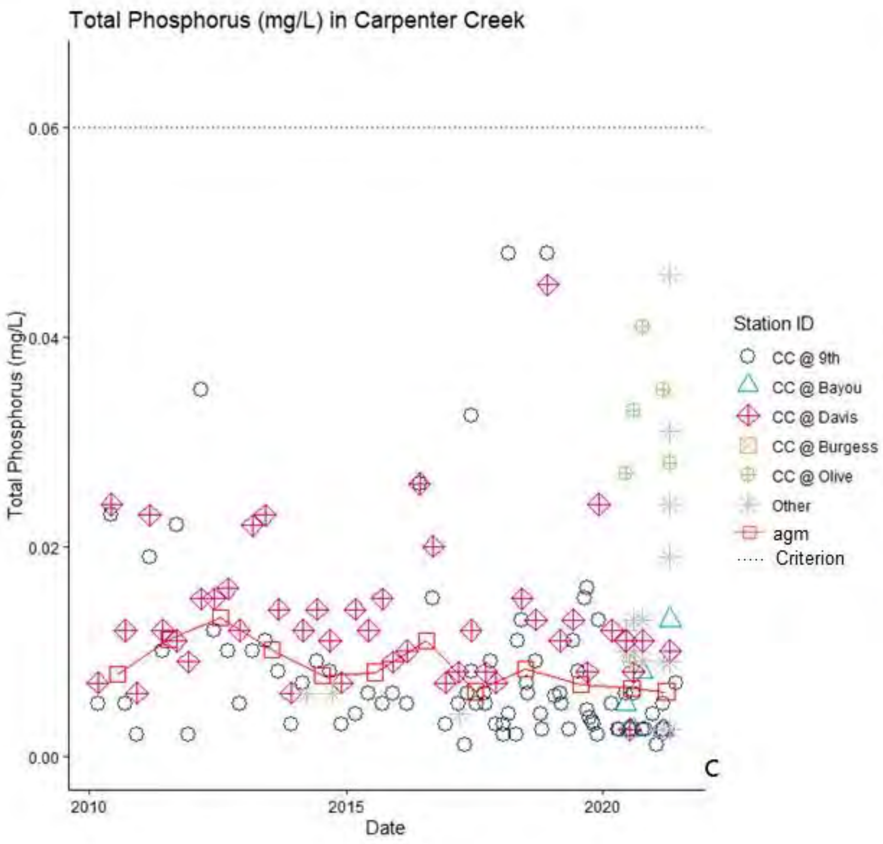

Turbidity (NTU) in Bayou Texar, 2010-Present
Turbidity (NTU)
Date
Station.ID
Texar @ 12th
Texar @ Seville
Texar @ Hyde
Texar @ Bayview
Texar off DeSoto
Other
x

Figure Set B2.9: a-d. Time series and annual geometric means (AGMs) of Carpenter Creek compared to the water quality criteria.






Total Phosphorus (mg/L) in Carpenter Creek
0.06
0.04
0.02
0.00
Total Phosphorus (mg/L)
2010
2015
2020
Date
Station ID
CC @ 9th
CC @ Bayou
CC @ Davis
CC @ Burgess
CC @ Olive
Other
agm
Criterion
c

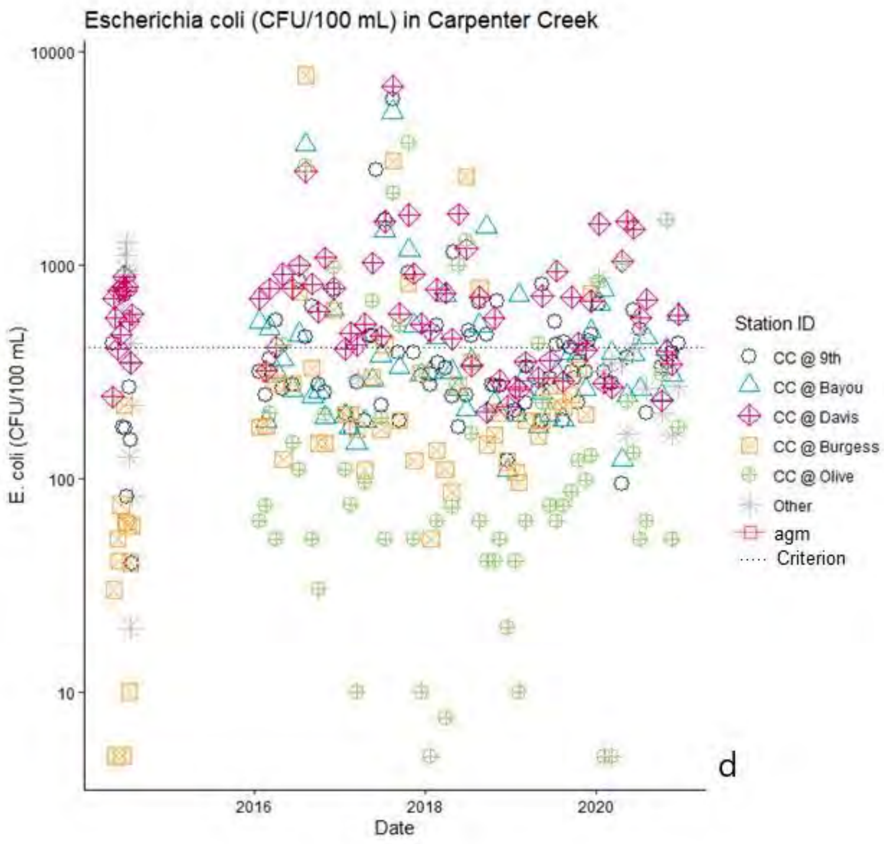
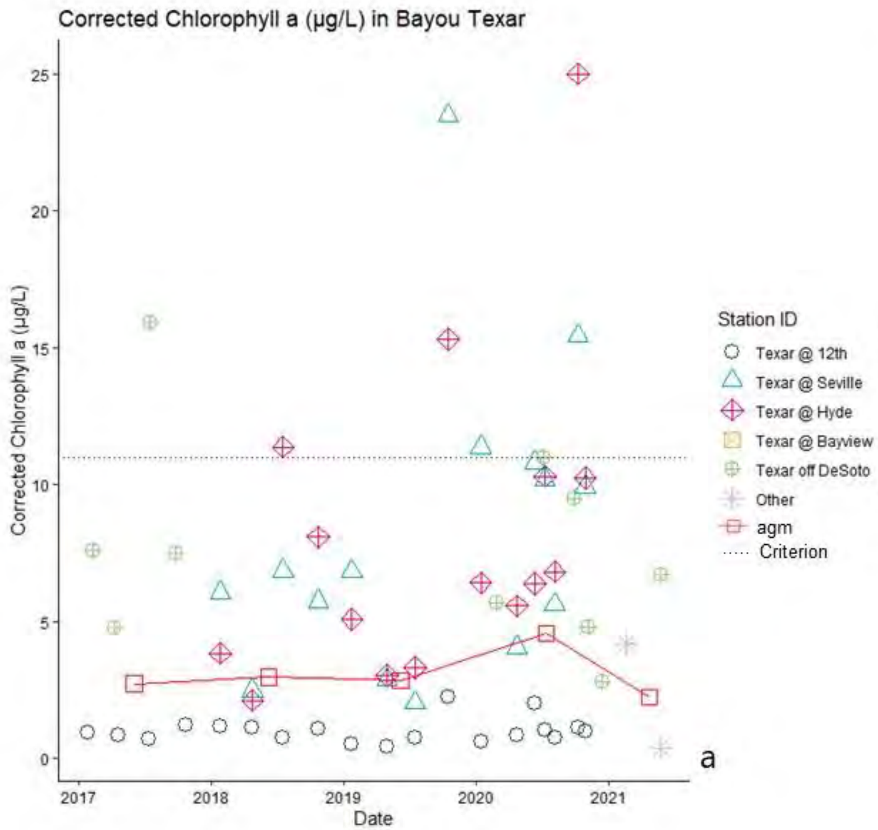
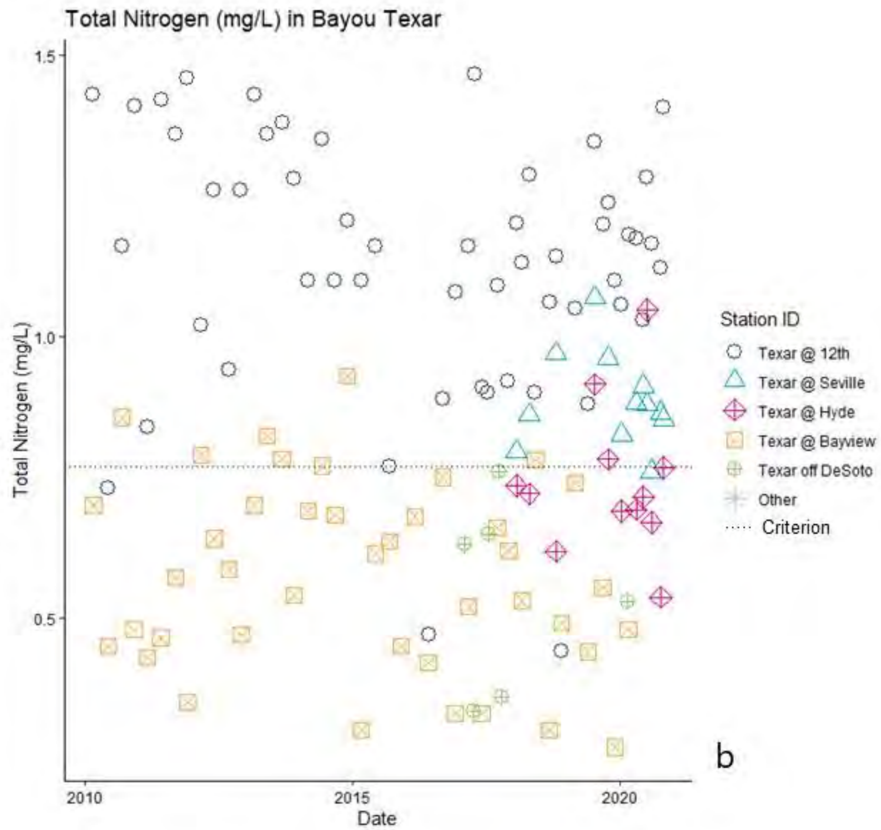
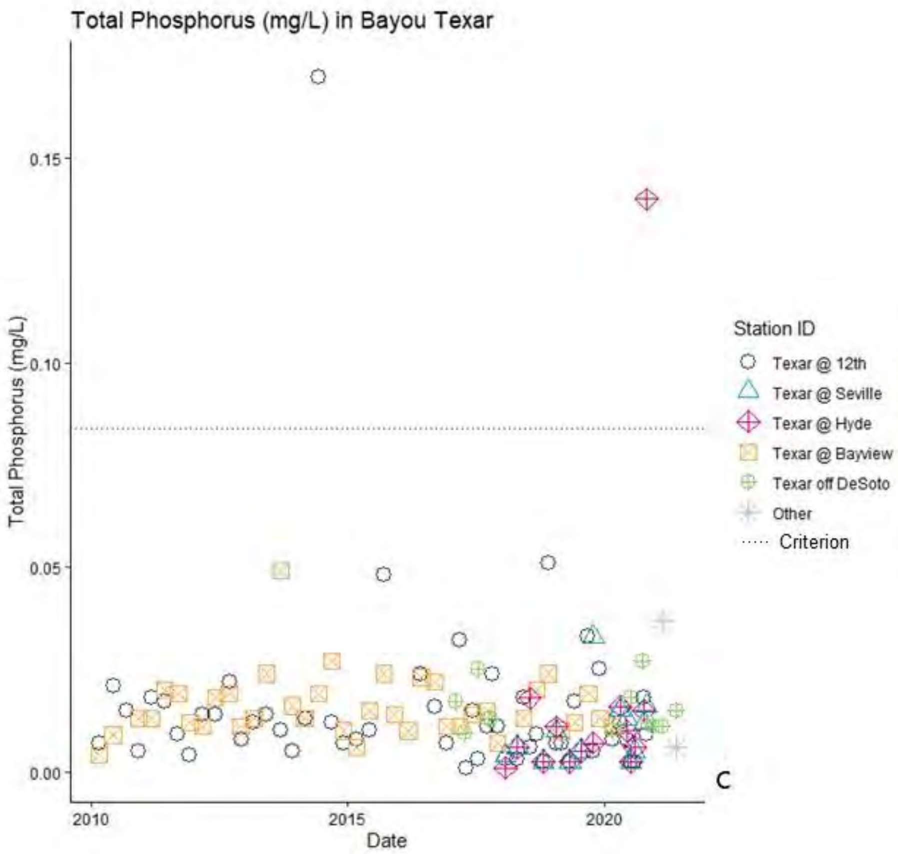

Escherichia coli (CFU/100 mL) in Carpenter Creek
10000
1000
100
10
E. coli (CFU/100 mL)
2016
2018
2020
Date
Station ID
CC @ 9th
CC @ Bayou
CC @ Davis
CC @ Burgess
CC @ Olive
Other
agm
Criterion
d

Figure Set B2.10: a-d. Time series and annual geometric means (AGMs) of Carpenter Creek compared to the water quality criteria.






Total Phosphorus (mg/L) in Bayou Texar
Total Phosphorus (mg/L)
0.00
0.05
0.10
0.15
2010
2015
2020
Date
c
Station ID
Texar @ 12th
Texar @ Seville
Texar @ Hyde
Texar @ Bayview
Texar off DeSoto
Other
Criterion

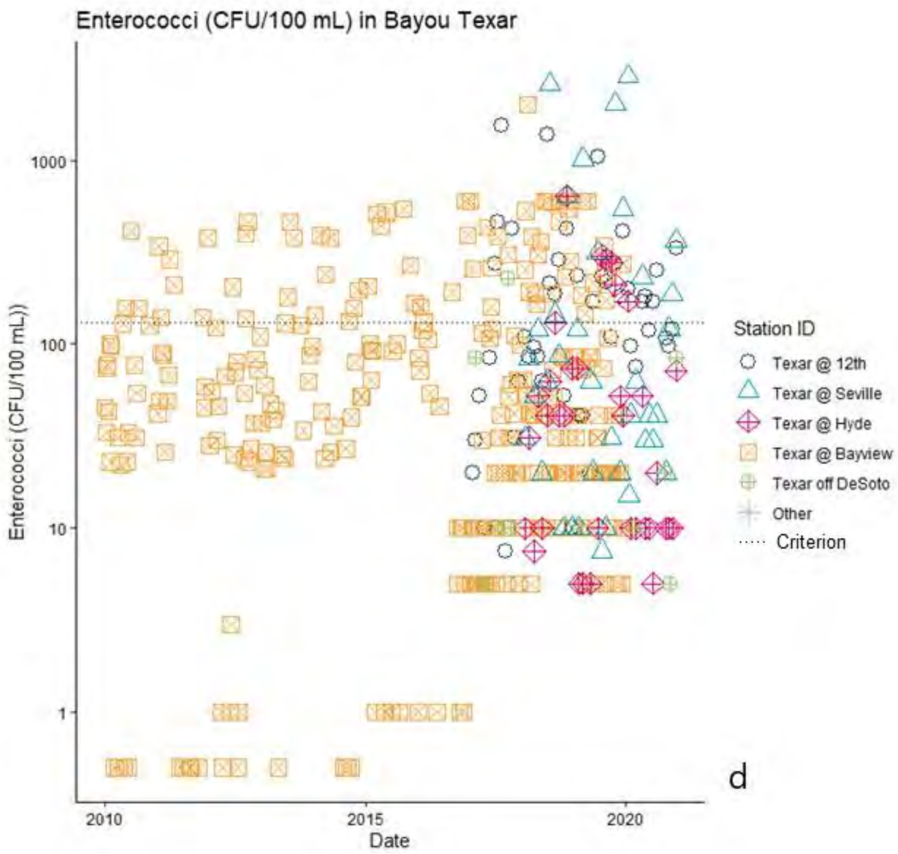
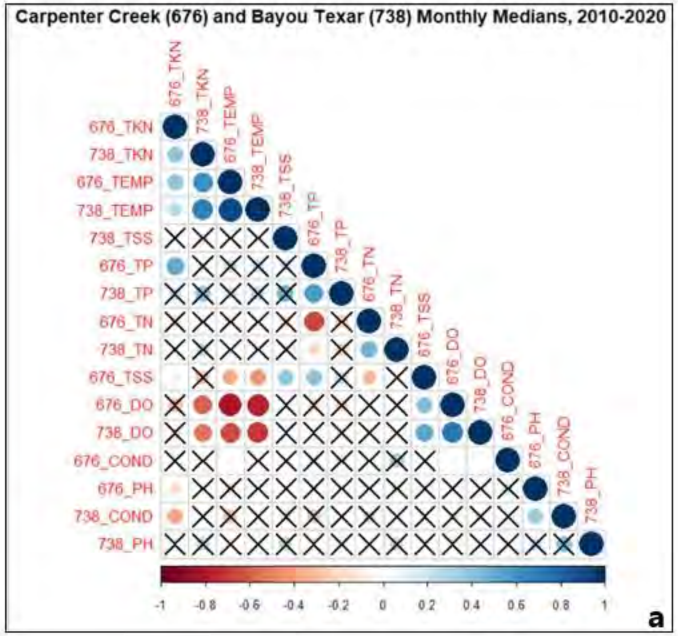
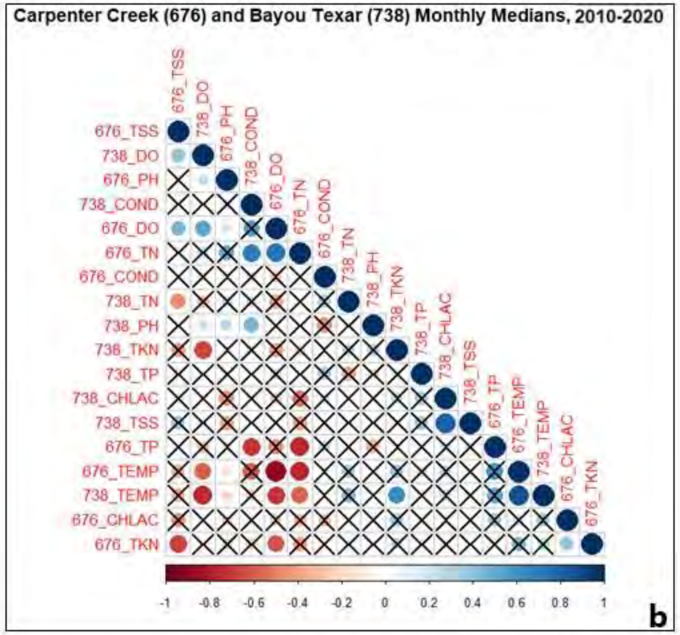

Enterococci (CFU/100 mL) in Bayou Texar
Enterococci (CFU/100 mL))
1
10
100
1000
2010
2015
2020
Date
d
Station ID
Texar @ 12th
Texar @ Seville
Texar @ Hyde
Texar @ Bayview
Texar off DeSoto
Other
Criterion

Figure Set B2.11: a-t. Correlation matrices of wbid and station data from Carpenter Creek (wbid 676) and Bayou Texar (wbid 738)

Monthly medians, wbids combined (2010-2020)





n = 46

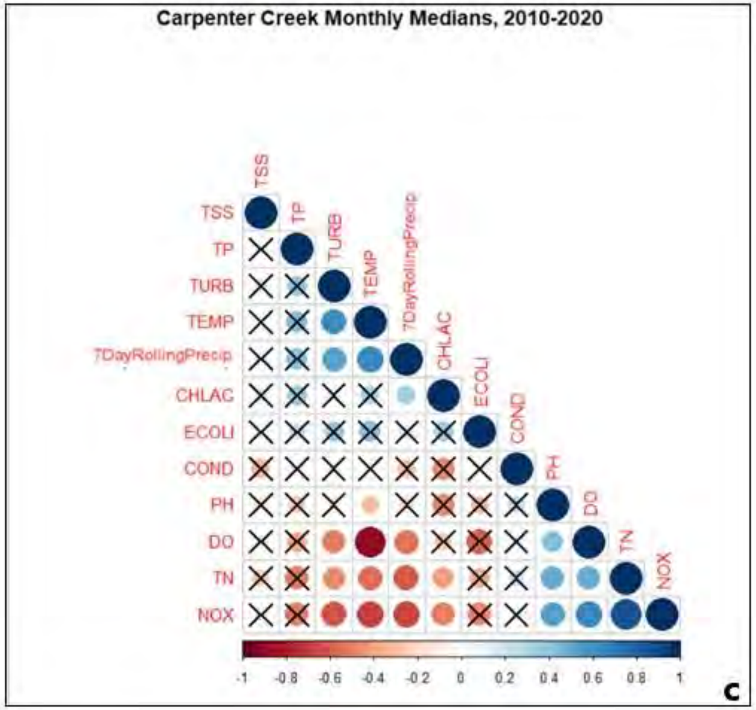
Nutrients, without Chl-a

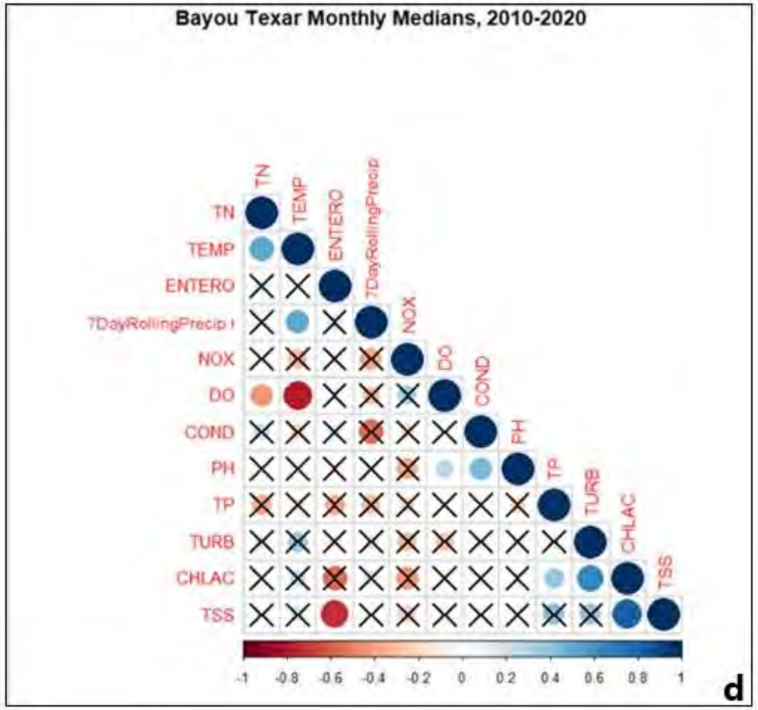
Note:
CHLAC – Corrected Chlorophyll-a | COND – Specific Conductance
DO – Dissolved Oxygen | ECOLI – E. coli | ENTERO – Enterococci | PH = pH
TEMP – Temperature | TURB – Turbidity | TKN – Total Kjeldahl Nitrogen
TN – Total Nitrogen | TP – Total Phosphorus | TSS – Total Suspended Solids
7dayrollingprecip – 7-Day rolling antecedent precipitation

n = 14

Nutrients, with Chl-a

Monthly medians by wbid (2010-2020)





n = 23

All Parameters

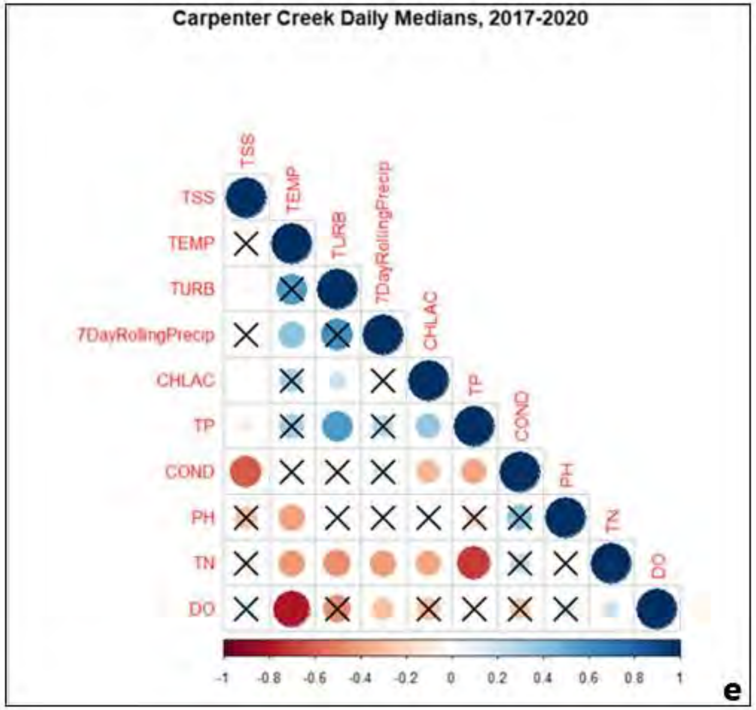
Note:
CHLAC – Corrected Chlorophyll-a | COND – Specific Conductance
DO – Dissolved Oxygen | ECOLI – E. coli | ENTERO – Enterococci | PH = pH
TEMP – Temperature | TURB – Turbidity | TKN – Total Kjeldahl Nitrogen
TN – Total Nitrogen | TP – Total Phosphorus | TSS – Total Suspended Solids
7dayrollingprecip – 7-Day rolling antecedent precipitation

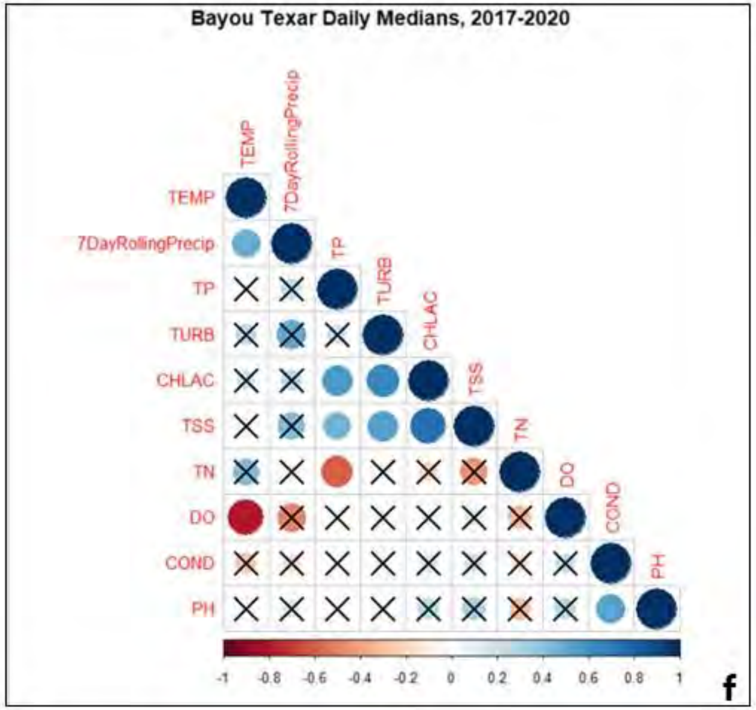
n = 15

All Parameters

wood.

Daily medians by wbid (2017-2020)





n = 29

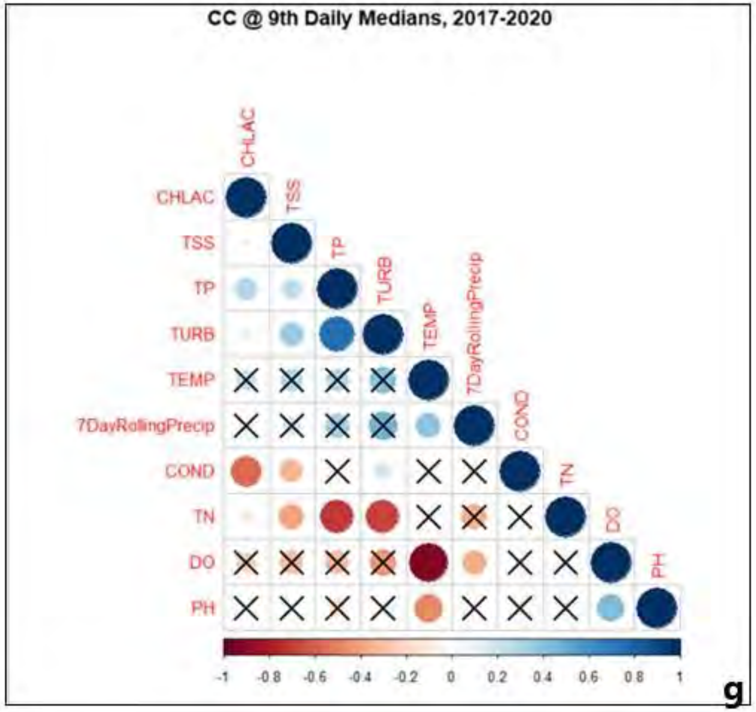
Nutrients

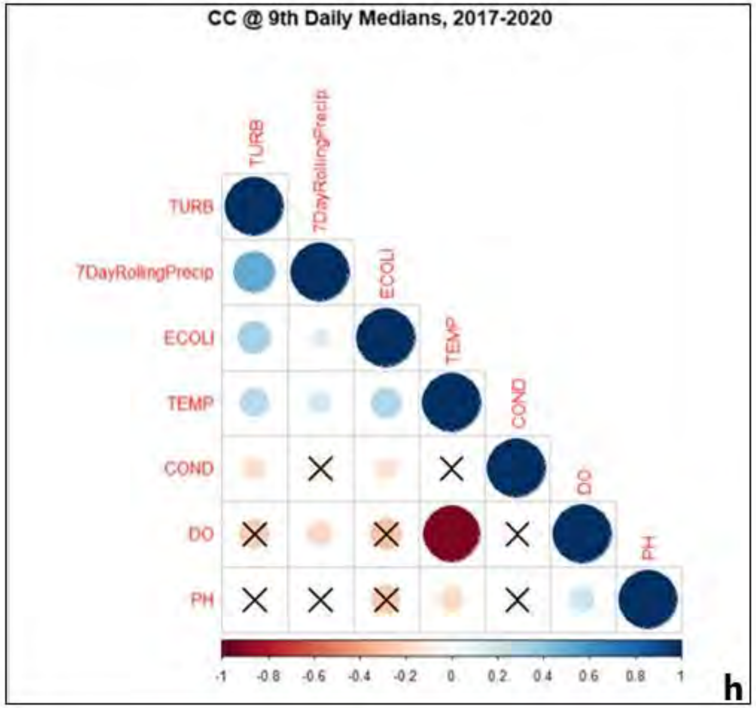
Note:
CHLAC – Corrected Chlorophyll-a | COND – Specific Conductance
DO – Dissolved Oxygen | ECOLI – E. coli | ENTERO – Enterococci | PH = pH
TEMP – Temperature | TURB – Turbidity | TKN – Total Kjeldahl Nitrogen
TN – Total Nitrogen | TP – Total Phosphorus | TSS – Total Suspended Solids
7dayrollingprecip – 7-Day rolling antecedent precipitation

n = 18

Nutrients

Daily medians, CC @ 9th (2017-2020)





n = 28

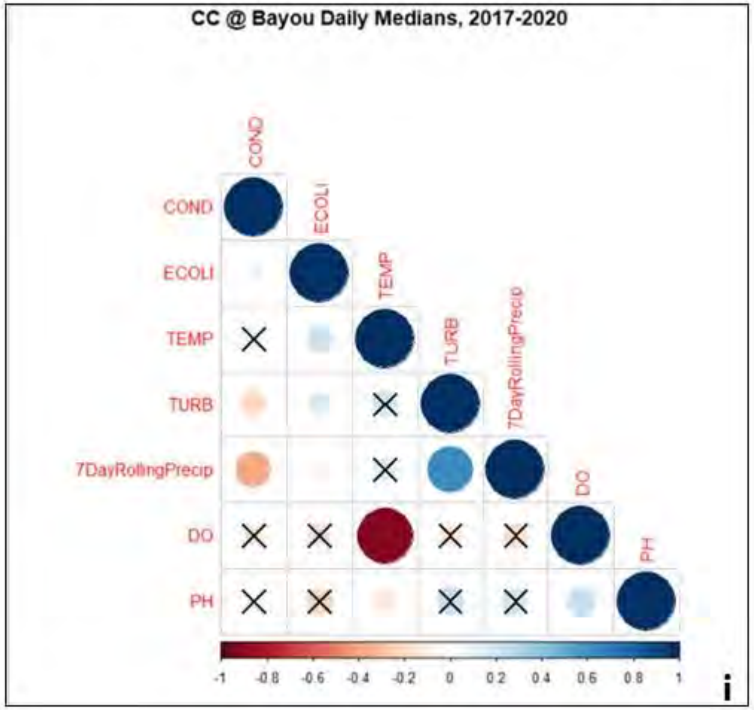
Nutrients

Note:
CHLAC – Corrected Chlorophyll-a | COND – Specific Conductance
DO – Dissolved Oxygen | ECOLI – E. coli | ENTERO – Enterococci | PH = pH
TEMP – Temperature | TURB – Turbidity | TKN – Total Kjeldahl Nitrogen
TN – Total Nitrogen | TP – Total Phosphorus | TSS – Total Suspended Solids
7dayrollingprecip – 7-Day rolling antecedent precipitation

n = 62

Bacteria

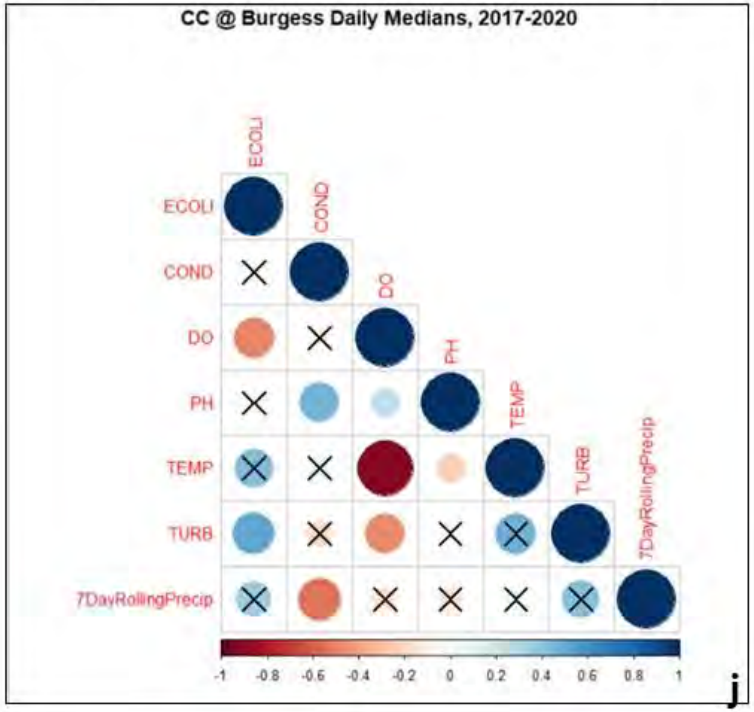
Daily medians, CC @ Bayou (2017-2020)



n = 48

Bacteria

Daily medians, CC @ Burgess (2017-2020)

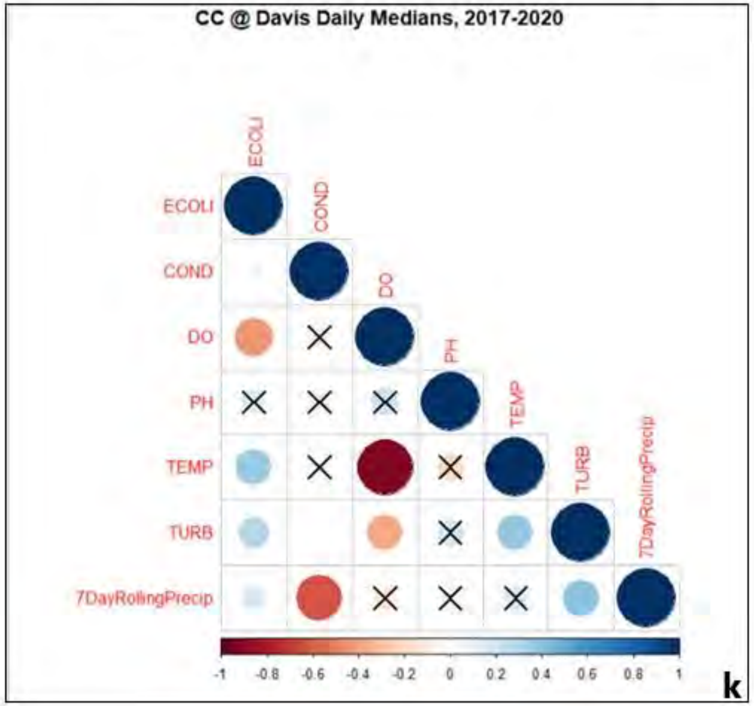


n = 36

Bacteria

Note:
CHLAC – Corrected Chlorophyll-a | COND – Specific Conductance
DO – Dissolved Oxygen | ECOLI – E. coli | ENTERO – Enterococci | PH = pH
TEMP – Temperature | TURB – Turbidity | TKN – Total Kjeldahl Nitrogen
TN – Total Nitrogen | TP – Total Phosphorus | TSS – Total Suspended Solids
7dayrollingprecip – 7-Day rolling antecedent precipitation

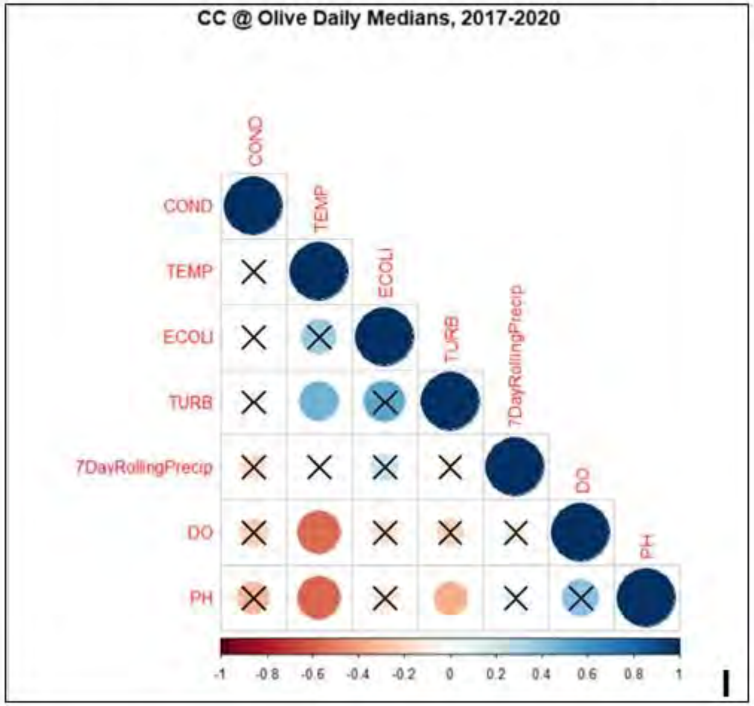
Daily medians, CC @ Davis (2017-2020)



n = 48

Bacteria

Daily medians, CC @ Olive (2017-2020)

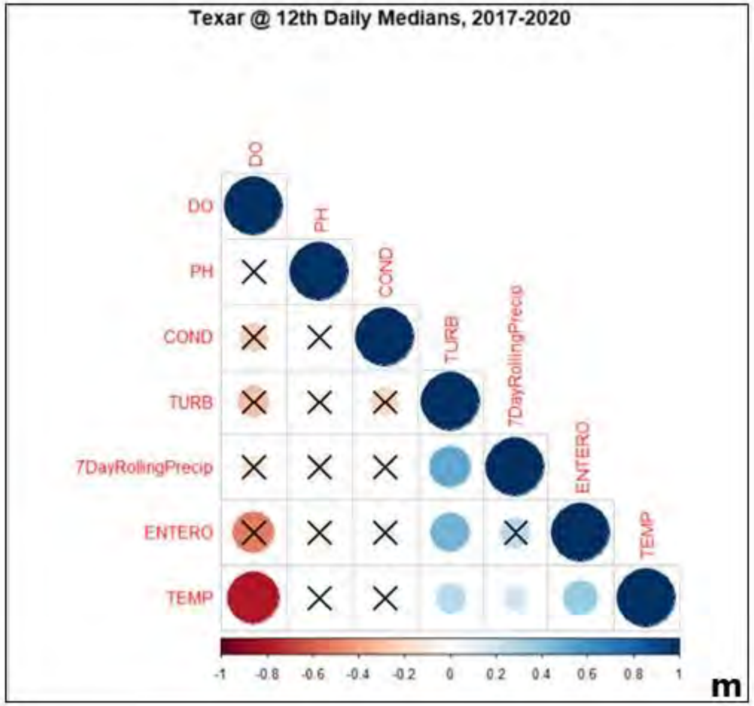


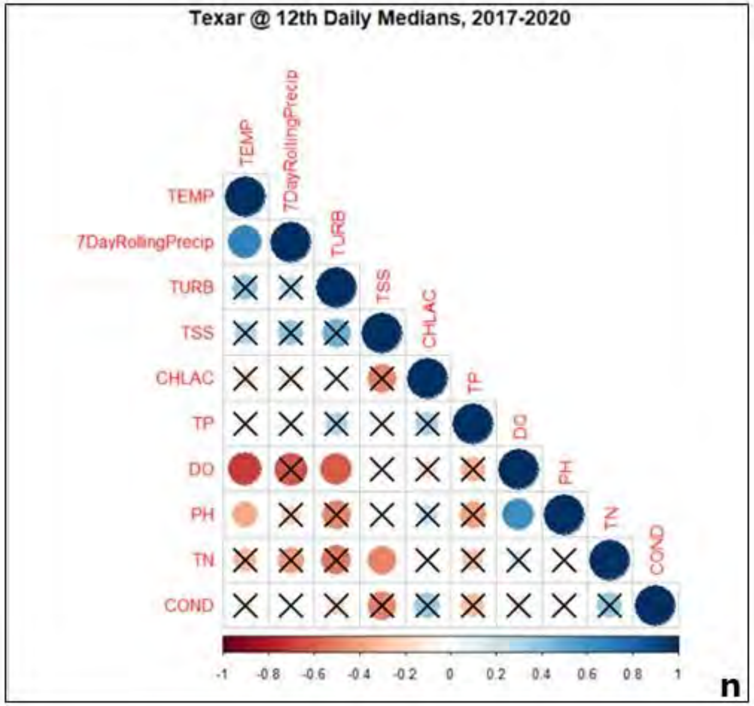
n = 46

Bacteria

Note:
CHLAC – Corrected Chlorophyll-a | COND – Specific Conductance
DO – Dissolved Oxygen | ECOLI – E. coli | ENTERO – Enterococci | PH = pH
TEMP – Temperature | TURB – Turbidity | TKN – Total Kjeldahl Nitrogen
TN – Total Nitrogen | TP – Total Phosphorus | TSS – Total Suspended Solids
7dayrollingprecip – 7-Day rolling antecedent precipitation

Daily medians, Texar @ 12th (2017-2020)





n = 48

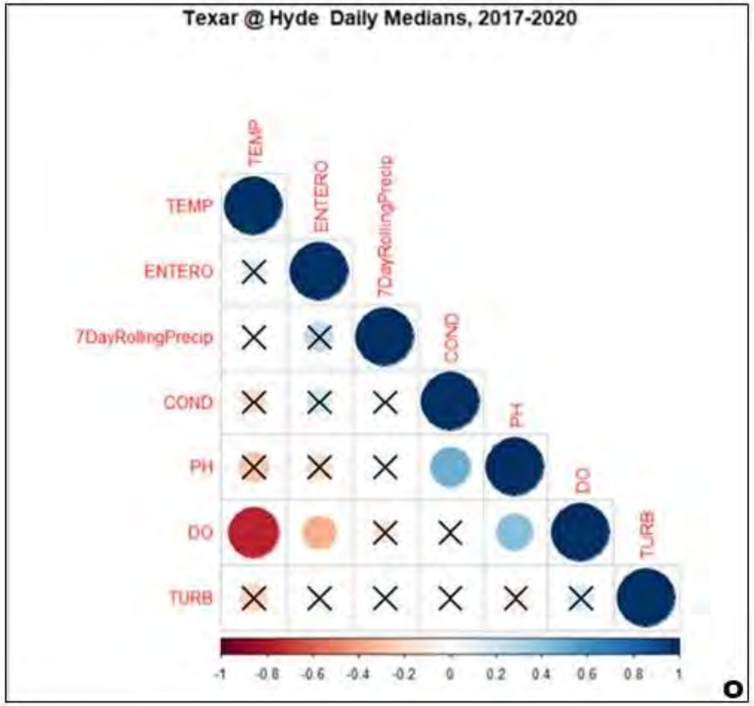
Bacteria

Note:
CHLAC – Corrected Chlorophyll-a | COND – Specific Conductance
DO – Dissolved Oxygen | ECOLI – E. coli | ENTERO – Enterococci | PH = pH
TEMP – Temperature | TURB – Turbidity | TKN – Total Kjeldahl Nitrogen
TN – Total Nitrogen | TP – Total Phosphorus | TSS – Total Suspended Solids
7dayrollingprecip – 7-Day rolling antecedent precipitation

n = 12

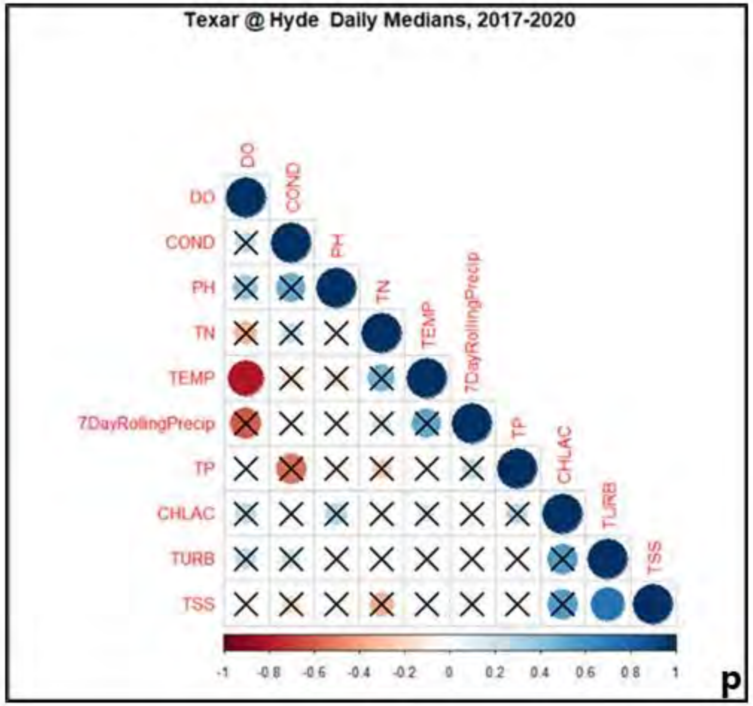
Nutrients

Daily medians, Texar @ Hyde (2017-2020)



n = 34

Bacteria

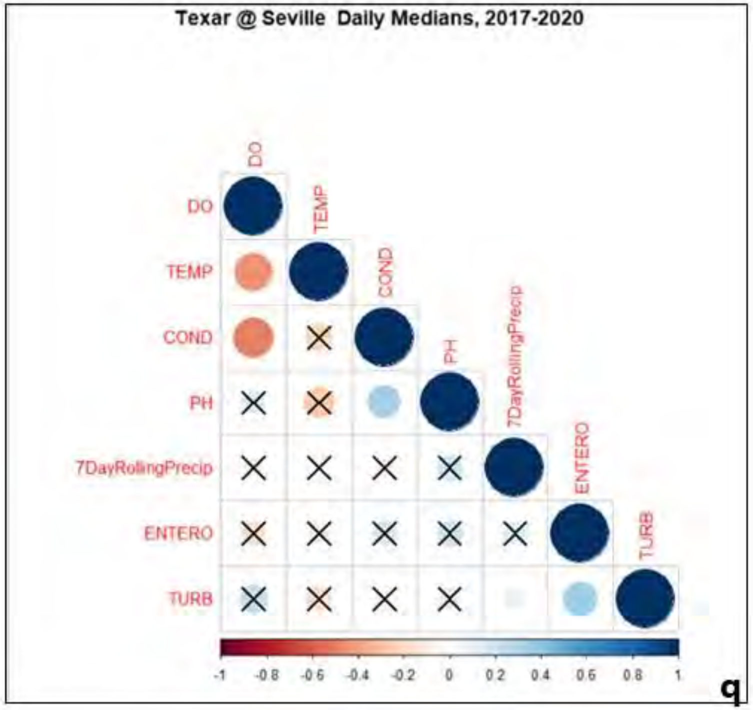


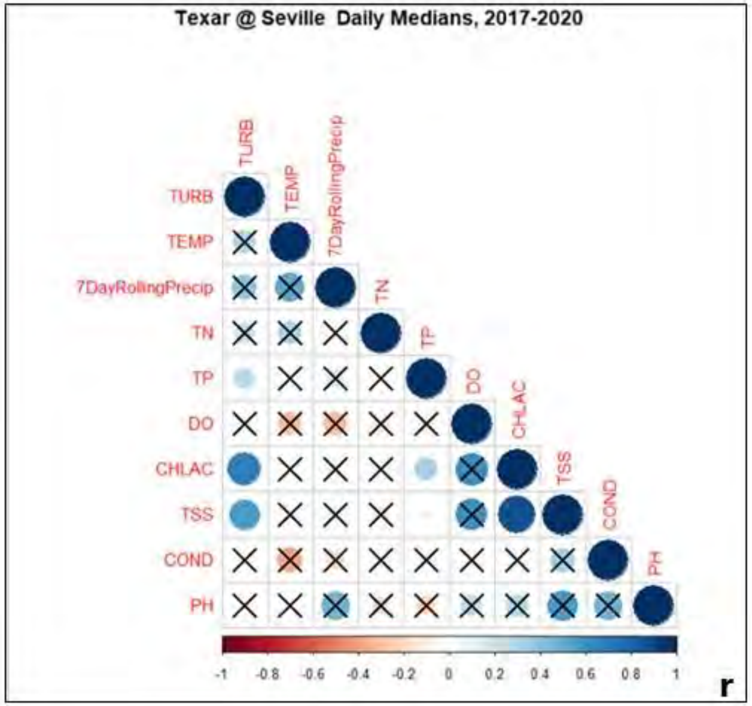
n = 11

Nutrients

Note:
CHLAC – Corrected Chlorophyll-a | COND – Specific Conductance
DO – Dissolved Oxygen | ECOLI – E. coli | ENTERO – Enterococci | PH = pH
TEMP – Temperature | TURB – Turbidity | TKN – Total Kjeldahl Nitrogen
TN – Total Nitrogen | TP – Total Phosphorus | TSS – Total Suspended Solids
7dayrollingprecip – 7-Day rolling antecedent precipitation

Daily medians, Texar @ Seville (2017-2020)





n = 36

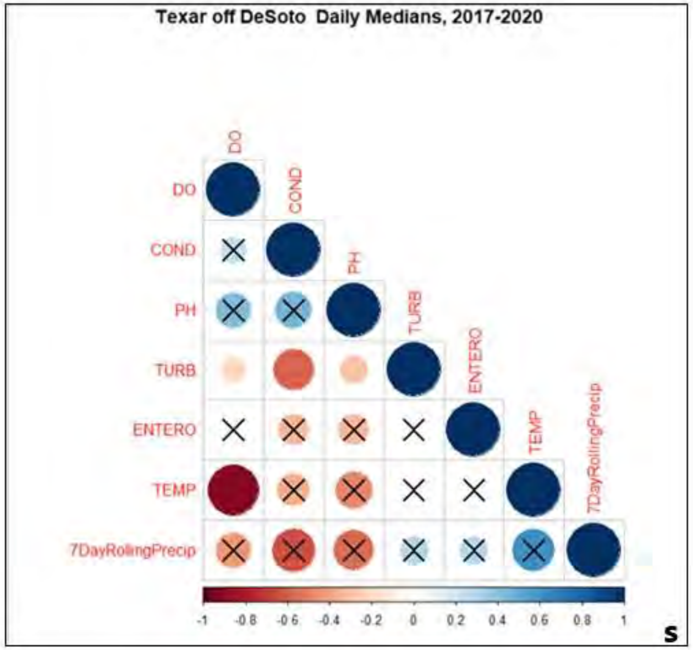
Bacteria

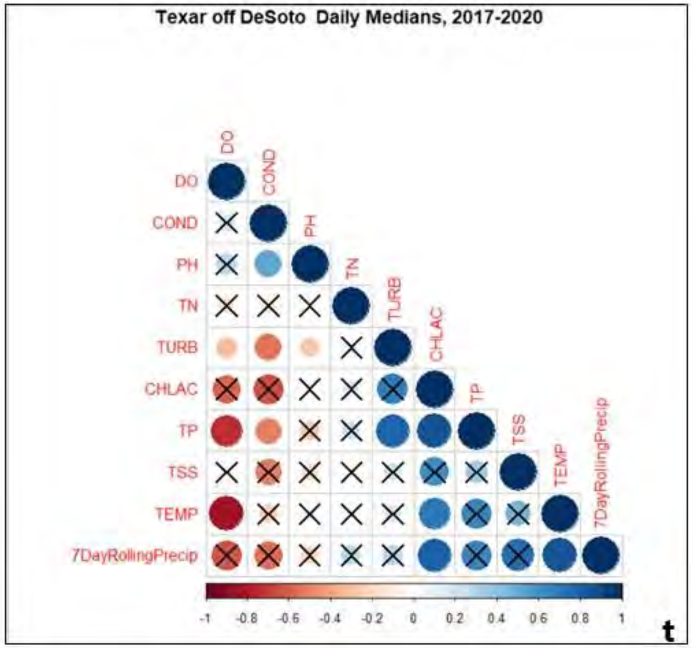
Note:
CHLAC – Corrected Chlorophyll-a | COND – Specific Conductance
DO – Dissolved Oxygen | ECOLI – E. coli | ENTERO – Enterococci | PH = pH
TEMP – Temperature | TURB – Turbidity | TKN – Total Kjeldahl Nitrogen
TN – Total Nitrogen | TP – Total Phosphorus | TSS – Total Suspended Solids
7dayrollingprecip – 7-Day rolling antecedent precipitation

n = 11

Nutrients

Daily medians, Texar off DeSoto (2017-2020)





n = 9

Bacteria

Note:
CHLAC – Corrected Chlorophyll-a | COND – Specific Conductance
DO – Dissolved Oxygen | ECOLI – E. coli | ENTERO – Enterococci | PH = pH
TEMP – Temperature | TURB – Turbidity | TKN – Total Kjeldahl Nitrogen
TN – Total Nitrogen | TP – Total Phosphorus | TSS – Total Suspended Solids
7dayrollingprecip – 7-Day rolling antecedent precipitation

n = 9

Nutrients

Tables

Table B2-1: Summary of surface water flow data availability within Carpenter Creek and Bayou Texar.

Surface Water Sites				
USGS SW Site No.	USGS SW Site Name	Start Date	End Date	Count
2376077	CARPENTER CREEK NR PENSACOLA, FLA.	10/29/1959	8/26/1993	26
2376079	CARPENTER CREEK AT PENSACOLA, FLA.	01/2/1976	5/12/1977	239

Table B2-2: Summary of groundwater quality data availability within Carpenter Creek and Bayou Texar watersheds from the USGS.

GW Sites				
USGS GW Site No.	USGS GW Site Name	Start Date	End Date	Count
302541087114502	THIA-17TH&GONZALEZ	12/1/1970	8/26/1989	200
302541087114501	TH1-17TH&GONZALEZ ST	12/1/1970	1/13/1987	188
302646087122701	PENSACOLA 12TH AVE. WELL	4/1/1971	4/1/1971	1
302713087124501	ALVIN VOSS-10TH AVE	1/1/1947	1/1/1947	1
302943087133802	WELL NR BRENT	2/7/1972	2/1/1972	1
302943087133801	L. SPILLERS PLANTATN. RD	12/14/1971	12/14/1971	1
302555087122701	WELL 2 NR PENSACOLA, FL	No Data		

Table B2-3: Summary of surface water station aggregations within Carpenter Creek and Bayou Texar.

Final Aggregated Station Name	Original Station Name	Alias	Sampling Agency	WBID	Start Date	End Date	Data Source	Latitude	Longitude
CC @ Target	21FLPNS 33020149	Carpenter Creeks blw Target Stormwater	DEP NW District	676	3/5/2012	3/26/2012	IWR	30.4672222	-87.2104167
CC @ Target	21FLPNS G4NW024 4	Carpenter Creek below Target Stormwater (also, 33020149)	DEP NW District	676	3/25/2014	3/22/2017	IWR	30.46723911	-87.21033539
CC @ Target	G4NW024 4	Carpenter Creek below Target Stormwater Pond	DEP NW District	676	3/25/2014	9/25/2014	WIN	30.46724473	-87.21034024
CC @ 9th	21FLESC CARPENT ERCR10	CARPENTERCR10, Carpenter Creek @ 9th Ave.	ESCAMBIA COUNTY	676	1/25/2016	12/11/2019	IWR	30.47117974	-87.21321808
CC @ 9th	CARPENT ERCR10	Carpenter Cr 10 (9th), 33020048 (CC@9th), CC@9th	ESCAMBIA COUNTY	676	1/14/2020	6/3/2021	County	30.47117974	-87.21321808
CC @ 9th	FD CC @ 9th	33020048 (CC@9th) FD	ESCAMBIA COUNTY	676	1/14/2020	7/8/2020	County	30.47117974	-87.21321808
CC @ 9th	CARPENT ERCR10	Carpenter Creek @ 9th Ave.	ESCAMBIA COUNTY	676	1/25/2016	12/11/2019	WIN	30.47118536	-87.21322292
CC @ 9th	21FLPNS 33020048	CARPENTERS CR 9TH AVE BRIDGE, 21FLPNS 33020148	DEP NW District	676	6/5/2006	3/26/2012	IWR	30.4712008	-87.2133389
CC @ 9th	21FLBFA 33020048	CARPENTERS CREEK AT 9TH AVE	BREAM FISHERMAN ASSOCIATION	676	3/5/1989	3/1/2020	IWR	30.471222	-87.213333
CC @ 9th	33020048	CARPENTERS CREEK AT 9TH AVE	BREAM FISHERMAN ASSOCIATION	676	12/3/2017	3/1/2020	WIN	30.47122762	-87.21333785

Final Aggregated Station Name	Original Station Name	Alias	Sampling Agency	WBID	Start Date	End Date	Data Source	Latitude	Longitude
CC @ 9th	Texar-09	Carpenter's Creek @ Ninth Avenue	ESCAMBIA COUNTY	738	5/7/2014	7/30/2014	2014 Storm Event	30.47118	-87.213218
CC @ 9th	21FLPNS G4NW0415	Carpenters Creek upstream of 9th Avenue	DEP NW District	676	4/19/2017	12/2/2019	IWR	30.47142	-87.214
CC @ 9th	G4NW0415	Carpenter Creek upstream of 9th Avenue	DEP NW District	676	9/6/2017	12/2/2019	WIN	30.47142562	-87.21400485
CC @ Bayou	21FLPNS 33020228	Carpenters Creek @ Miller's Ale House	DEP NW District	676	3/5/2012	3/26/2012	IWR	30.47528	-87.21744
CC @ Bayou	21FLPNS 33020058	Carpenters Creek at Brent Lane	DEP NW District	676	3/5/2012	3/26/2012	IWR	30.4752805	-87.2174444
CC @ Bayou	33020058 (Brent)	CC@ Bayou Blvd, Carpenter Cr 20 (Bayou)	ESCAMBIA COUNTY	676	1/14/2020	6/10/2020	County	30.4752805	-87.2174444
CC @ Bayou	CARPENTERCR20 (Bayou)	33020058 (Brent), CC@ Bayou Blvd	ESCAMBIA COUNTY	676	6/10/2020	4/20/2021	County	30.4752805	-87.2174444
CC @ Bayou	21FLESC CARPENTERCR20	CARPENTERCR20, Carpenter Creek @ Bayou Blvd.	ESCAMBIA COUNTY	676	1/25/2016	12/11/2019	IWR	30.47540299	-87.217294
CC @ Bayou	CARPENTERCR20	Carpenter Creek @ Bayou Blvd.	ESCAMBIA COUNTY	676	1/25/2016	12/11/2019	WIN	30.47540861	-87.21729885
CC @ Airport	21FLPNS 33020051	Carpenters Creeek at Airport Blvd	DEP NW District	676	3/5/2012	3/26/2012	IWR	30.480675	-87.2213

Final Aggregated Station Name	Original Station Name	Alias	Sampling Agency	WBID	Start Date	End Date	Data Source	Latitude	Longitude
CC @ Davis	21FLWQSPESC030US	Escambia-Carpenters Creek-1-1 (WBID 676)	FDEP Water Quality Standards and Special projects	676	4/15/2005	12/12/2005	IWR	30.48386	-87.221398
CC @ Davis	2376077		USGS		10/29/1959	8/26/1993	USGS	30.4841458	-87.2225736
CC @ Davis	21FLPNS 33020050	Carpenters Creeek at Davis Hwy	DEP NW District	676	3/5/2012	3/26/2012	IWR	30.4841458	-87.2225736
CC @ Davis	21FLPNS 33020049	CARPENTERS CR DAVIS HIGHWAY BR	DEP NW District	676	6/5/2006	12/9/2009	IWR	30.4841518	-87.2225535
CC @ Davis	21FLESC CARPENTERCR30	CARPENTERCR30, Carpenter Creek @ Davis HWY (SR291)	ESCAMBIA COUNTY	676	1/25/2016	12/11/2019	IWR	30.48418066	-87.22301925
CC @ Davis	33020050 (Davis)	Carpenter Cr 30 (Davis)	ESCAMBIA COUNTY	676	1/14/2020	6/10/2020	County	30.48418066	-87.22301925
CC @ Davis	CARPENTERCR30	Carpenter Cr 30 (Davis), 33020050 (Davis), CC@Davis	ESCAMBIA COUNTY	676	6/10/2020	4/20/2021	County	30.48418066	-87.22301925
CC @ Davis	CARPENTERCR30	Carpenter Creek @ Davis HWY (SR291)	ESCAMBIA COUNTY	676	1/25/2016	12/11/2019	WIN	30.48418628	-87.2230241
CC @ Davis	21FLBFA 33020049	CARPENTERS CREEK AT DAVIS HWY	BREAM FISHERMAN ASSOCIATION	676	3/5/1989	3/1/2020	IWR	30.484278	-87.222583
CC @ Davis	33020049	CARPENTERS CREEK AT DAVIS HWY	BREAM FISHERMAN ASSOCIATION	676	12/3/2017	3/1/2020	WIN	30.48428362	-87.22258785
CC @ Davis	Texar-06	Carpenter's Creek @ Davis Highway	ESCAMBIA COUNTY	676	5/7/2014	5/7/2014	2014 Storm Event	30.484193	-87.222558
CC @ Burgess	21FLPNS 33020053	Carpenters Creek at Burgess Road	DEP NW District	676	6/5/2006	3/26/2012	IWR	30.4940583	-87.2350888

Final Aggregated Station Name	Original Station Name	Alias	Sampling Agency	WBID	Start Date	End Date	Data Source	Latitude	Longitude
CC @ Burgess	21FLA 33020053	CARPENTERS CREEK	DEP NE District	676	6/28/1971	10/30/1987	IWR	30.4942	-87.2347
CC @ Burgess	Texar-07	Carpenter's Creek @ Burgess Road	ESCAMBIA COUNTY	676	7/16/2014	7/30/2014	2014 Storm Event	30.494239	-87.235335
CC @ Burgess	21FLESC CARPENT ERCR40	CARPENTERCR40, Carpenter Creek @ Burgess Rd. (SR742)	ESCAMBIA COUNTY	676	1/25/2016	12/11/2019	IWR	30.49447863	-87.2355557
CC @ Burgess	33020053 (Burgess)	CC @ Burgess (CARPENTERCR40)	ESCAMBIA COUNTY	676	1/14/2020	6/10/2020	County	30.49447863	-87.2355557
CC @ Burgess	CARPENT ERCR40 (Burgess)	33020053 (Burgess), CC@Burgess	ESCAMBIA COUNTY	676	6/10/2020	4/20/2021	County	30.49447863	-87.2355557
CC @ Burgess	CARPENT ERCR40	Carpenter Creek @ Burgess Rd. (SR742)	ESCAMBIA COUNTY	676	1/25/2016	12/11/2019	WIN	30.49448425	-87.23556056
CC @ Oakfield	21FLPNS 33020054	CARPENTERS CREEK NEAR OAKFIELD R	DEP NW District	676	3/5/2012	3/5/2012	IWR	30.5	-87.244444
CC @ Oakfield	21FLA 33020054	CARPENTERS CREEK NEAR OAKFIELD R	DEP NE District	676	6/28/1971	10/30/1987	IWR	30.5	-87.2444
CC @ Olive	21FLESC CARPENT ERCR50	CARPENTERCR50, Carpenter Creek @ Olive Rd. (SR290)	ESCAMBIA COUNTY	676	1/25/2016	12/11/2019	IWR	30.51092346	-87.2422332
CC @ Olive	33020057 (Olive)	CARPENTERCR50 (Olive)	ESCAMBIA COUNTY	676	1/14/2020	6/10/2020	County	30.51092346	-87.2422332
CC @ Olive	CARPENT ERCR50 (Olive)	CC @ Olive	ESCAMBIA COUNTY	676	6/10/2020	4/20/2021	County	30.51092346	-87.2422332

Final Aggregated Station Name	Original Station Name	Alias	Sampling Agency	WBID	Start Date	End Date	Data Source	Latitude	Longitude
CC @ Olive	CARPENT ERCR50	Carpenter Creek @ Olive Rd. (SR290)	ESCAMBIA COUNTY	676	1/25/2016	12/11/2019	WIN	30.51092909	-87.24223806
CC @ Olive	21FLA 33020057	CARPENTERS CR OLIVE RD	DEP NE District	676	2/12/1973	3/5/1989	IWR	30.511	-87.2421
CC @ Olive	21FLPNS 33020057	CARPENTERS CR OLIVE RD	DEP NW District	676	6/5/2006	6/5/2006	IWR	30.5109722	-87.2420833
Texar @ Cervantes	21FLPNS 3302HBT7	lower Bayou Texar TMDL wbid 738-7	DEP NW District	738	3/1/2004	3/1/2004	IWR	30.4249167	-87.1875833
Texar @ Cervantes	21FLA 33020HA2	BAYOU TEXAR 100 FT S CERVANTES S	DEP NE District	738	8/19/1987	8/4/1992	IWR	30.4222	-87.1889
Texar @ Cervantes	21FLA 3302HB11	BAYOU TEXAR AT CERVANTES STREET	DEP NE District	738	7/6/1970	9/4/1985	IWR	30.425	-87.1875
Texar @ Cervantes	Texar-02	Bayou Texar @ Cervantes Bridge Boat Ramp	ESCAMBIA COUNTY	738	5/7/2014	7/30/2014	2014 Storm Event	30.426582	-87.186626
Texar off DeSoto	21FLPNS G4NW040 2	G4NW0402	DEP NW District	738	2/9/2017	2/27/2020	IWR	30.4276	-87.18931
Texar off DeSoto	G4NW040 2	Bayou Texar 200 Meters above Hwy 90 Bridge	DEP NW District	738	9/25/2017	12/14/2020	WIN	30.42760561	-87.18931484
Texar @ Bayview	21FLBFA 3302HC11	BAYVIEW PARK PIER BAYOU TEXAR	BREAM FISHERMAN ASSOCIATION	738	3/5/1989	3/1/2020	IWR	30.4311447	-87.19014176
Texar @ Bayview	Texar-03	Bayou Texar @ Bayview Park	ESCAMBIA COUNTY	738	5/7/2014	7/30/2014	2014 Storm Event	30.432787	-87.187626

Final Aggregated Station Name	Original Station Name	Alias	Sampling Agency	WBID	Start Date	End Date	Data Source	Latitude	Longitude
Texar @ Bayview	21FLPNS 3302HC11	BAYVIEW PARK PIER, BAYOU TEXAR	DEP NW District	738	12/30/1996	4/6/2004	IWR	30.4312179	-87.1905895
Texar @ Bayview	21FLDOH ESCAMBIA 317	Bayou Texar	DOH	738	7/31/2000	12/16/2019	IWR	30.432251	-87.188685
Texar @ Hyde	Texar-04	Bayou Texar @ Hyde Park Road	ESCAMBIA COUNTY	738	5/7/2014	7/30/2014	2014 Storm Event	30.440361	-87.187294
Texar @ Hyde	21FLA 3302HD20	BAYOU TEXAR AT HYDE PARK ROAD	DEP NE District	738	2/17/1970	11/3/1978	IWR	30.4403	-87.1875
Texar @ Hyde	21FLESC TEXARBAY OU30	TEXARBAYOU30	ESCAMBIA COUNTY	738	1/25/2018	12/11/2019	IWR	30.44038436	-87.18731761
Texar @ Hyde	TEXARBAY OU30 (Hyde Park)	Bayou texar @ Hyde Park (TEXARBAYOU30), 3302HED20, Hyde Park	ESCAMBIA COUNTY	738	12/16/2020	12/16/2020	County	30.44038998	-87.18732245
Texar @ Hyde	TEXARBAY OU30	Bayou Texar @ End of Hyde Park Rd.	ESCAMBIA COUNTY	738	1/25/2018	12/11/2019	WIN	30.44038998	-87.18732245
Texar @ Paradise	21FLA 33020HD7	BAYOU TEXAR OFF PARADISE POINT	DEP NE District	738	9/16/1970	4/28/1977	IWR	30.4458	-87.1875
Texar @ Seville	21FLA 3302HE17	BAYOU TEXAR MID BAY ARPT STM DRA	DEP NE District	738	7/6/1970	4/1/1971	IWR	30.45	-87.1944
Texar @ Seville	21FLESC TEXARBAY OU40	TEXARBAYOU40	ESCAMBIA COUNTY	738	1/25/2018	12/11/2019	IWR	30.44999999	-87.194444

Final Aggregated Station Name	Original Station Name	Alias	Sampling Agency	WBID	Start Date	End Date	Data Source	Latitude	Longitude
Texar @ Seville	TEXARBAY OU40 (Seville)	Bayou texar @ Seville, Texar@Seville, 3302HE12, Seville Dr	ESCAMBIA COUNTY	738	12/16/2020	12/16/2020	County	30.44999999	-87.194444
Texar @ Seville	TEXARBAY OU40	Bayou Texar @ 1961 Seville Dr.	ESCAMBIA COUNTY	738	1/25/2018	12/11/2019	WIN	30.45000561	-87.19444884
Texar @ 12th	21FLBFA 33020HF1	BAYOU TEXAR AT 12TH AVE BRIDGE	BREAM FISHERMAN ASSOCIATION	738	3/5/1989	3/1/2020	IWR	30.460028	-87.20875
Texar @ 12th	33020HF1	BAYOU TEXAR AT 12TH AVE BRIDGE	BREAM FISHERMAN ASSOCIATION	738	12/3/2017	3/1/2020	WIN	30.46003362	-87.20875485
Texar @ 12th	21FLESC TEXARBAY OU50	TEXARBAYOU50	ESCAMBIA COUNTY	738	1/24/2017	12/11/2019	IWR	30.46048599	-87.208825
Texar @ 12th	TEXARBAY OU50 (12th)	Bayou Texar @ 12th Ave, Texar @ 12th, 33020HF5 (CC@12th)	ESCAMBIA COUNTY	738	12/16/2020	12/16/2020	County	30.46048599	-87.208825
Texar @ 12th	TEXARBAY OU50	Bayou Texar @ 12th Ave.	ESCAMBIA COUNTY	738	1/24/2017	12/11/2019	WIN	30.46049161	-87.20882985
Texar @ 12th	21FLA 33020HF5	BAYOU TEXAR 100 FT S OF 12TH AVE	DEP NE District	738	8/19/1987	8/19/1987	IWR	30.4611	-87.2083
Texar @ 12th	21FLA 33020HF1	BAYOU TEXAR AT 12TH AVE BRIDGE	DEP NE District	738	7/6/1970	4/5/1992	IWR	30.4625	-87.2097
Texar @ 12th	Texar-05	Bayou Texar @ 12th Avenue	ESCAMBIA COUNTY	738	6/18/2014	6/25/2014	2014 Storm Event	30.460028	-87.20875
CC#2	@ Langley		ESCAMBIA COUNTY	676	4/20/21	4/20/21	2021 Tributary	30.487851	-87.221522

Final Aggregated Station Name	Original Station Name	Alias	Sampling Agency	WBID	Start Date	End Date	Data Source	Latitude	Longitude
CC#5	@ Shiloh Drive		ESCAMBIA COUNTY	676	3/1/21	3/1/21	2021 Tributary	30.492784	-87.235297
CC#5a	SW Corner Ditch Shiloh and Gettysburg		ESCAMBIA COUNTY	676	3/1/21	3/1/21	2021 Tributary	30.499341	-87.241037
CC#8	Siskin		ESCAMBIA COUNTY	676	3/1/21	4/20/21	2021 Tributary	30.500724	-87.24383
Springhill	5170 Springhill		ESCAMBIA COUNTY	676	4/20/21	4/20/21	2021 Tributary	30.473781	-87.218863
CC#7	Beauclerc Apts		ESCAMBIA COUNTY	676	4/20/21	4/20/21	2021 Tributary	30.492438	-87.235673
CC#3	Village Oaks		ESCAMBIA COUNTY	676	3/1/21	3/1/21	2021 Tributary	30.488556	-87.228856
CC#4	Born Drive		ESCAMBIA COUNTY	676	4/20/21	4/20/21	2021 Tributary	30.491872	-87.23234
CC#6	380 E Burgess Rd		ESCAMBIA COUNTY	676	4/20/21	4/20/21	2021 Tributary	30.495886	-87.236495
CC#9	Heirloom		ESCAMBIA COUNTY	676	3/1/21	3/1/21	2021 Tributary	30.504732	-87.236962

Table B2-4: Summary of Chl-a, TN, TP, and *E. coli* data and exceedances in Carpenter Creek.

Year	Chl-a (AGM)	Chl-a (count)	TN (AGM)	TN (count)	TP (AGM)	TP (count)	E. coli (count)	E. coli (exceedances)	Percent E. coli Exceedance
2010	ID	0	**0.73**	4	0.008	4	0	ID	ID
2011	ID	0	0.59	4	0.011	4	0	ID	ID
2012	ID	0	**0.69**	4	0.013	4	0	ID	ID
2013	ID	0	**0.74**	4	0.010	4	0	ID	ID
2014	0.46	2	**0.82**	6	0.008	6	45	19	**42**
2015	ID	0	0.63	4	0.008	4	0	ID	ID
2016	ID	0	0.55	4	0.011	4	60	26	**43**
2017	0.76	8	**0.87**	10	0.006	11	64	28	**44**
2018	0.54	9	**0.87**	12	0.008	13	66	23	**35**
2019	0.53	12	**0.94**	14	0.007	14	68	15	**22**
2020	1.38	8	**0.80**	8	0.006	9	60	20	**33**
2021	0.86	5	**0.92**	2	0.006	5	0	ID	ID

Table B2-5: Exceedances of *E. coli* criterion by the station from 2010 to Present in Carpenter Creek.

Station.ID	E. coli (count)	E. coli (exceedances)	Percent E. coli Exceedance
CC @ 9th	85	30	**35**
CC @ Bayou	60	19	**32**
CC @ Burgess	60	9	**15**
CC @ Davis	73	51	**70**
CC @ Olive	60	13	**22**
Other	25	9	**36**

Table B2-6: Summary of Chl-a, TN, TP, and *E. coli* data and exceedances in Bayou Texar.

Year	Chl-a (AGM)	Chl-a (count)	Total TN (count)	TN (exceedances)	Percent TN Exceedance	Total TP (count)	TP (exceedance)	Percent TP Exceedance	Total Enterococci (count)	Enterococci (exceedances)	Percent Enterococci Exceedance
2010	ID	0	8	4	**50**	7	0	0	24	3	**13**
2011	ID	0	8	4	**50**	8	0	0	20	6	**30**
2012	ID	0	8	5	**63**	8	0	0	27	4	**15**
2013	ID	0	8	6	**75**	8	0	0	20	3	**15**
2014	ID	0	8	5	**63**	8	1	**13**	19	7	**37**
2015	ID	0	7	2	**29**	7	0	0	18	7	**39**
2016	ID	0	7	2	**29**	7	0	0	20	5	**25**
2017	2.7	8	15	6	**40**	16	0	0	65	12	**18**
2018	3.0	4	17	10	**59**	17	0	0	86	30	**35**
2019	2.9	4	14	10	**71**	19	0	0	86	25	**29**
2020	4.6	12	24	15	**63**	28	1	4	41	11	**27**
2021	2.3	2	0	ID	ID	4	0	0	0	ID	ID

Table B2-7: Exceedances of *E. coli*, TN, and TP criterion by the station from 2010 to Present in Bayou Texar.

Station.ID	TN (count)	Total TN (exceedances)	Percent TN Exceedance	Total TP (count)	Total TP Exceedances	Percent TP Exceedance	Total Enterococci (count)	Total Enterococci (exceedances)	Percent Enterococci Exceedance
Texar @ 12th	53	49	**92**	55	1	2	48	23	**48**
Texar @ Bayview	41	6	**15**	39	0	0	297	71	**24**
Texar @ Hyde	12	3	**25**	15	1	7	35	7	**20**
Texar @ Seville	12	11	**92**	14	0	0	37	11	**30**
Texar off DeSoto	6	0	0	12	0	0	9	1	**11**

Table B2-8: Summary Mann-Kendall Trend Test results from individual stations and WBIDs using quarterly data.

ID – Insufficient data to perform analysis. * - Analysis was performed on prewhitened data.

Station or WBID	Time Period	Parameter	Sen's Slope	Tau	p-value	Trend
CC @ 9th	2017-2020	Total Nitrogen	**0.07**	**0.61**	**0.05**	**Significant Increasing Trend**
		Total Phosphorus	-0.01	-0.55	0.08	No Significant Trend
		Chlorophyll a (corrected)	0.14	0.22	0.56	No Significant Trend
		E. coli	-48.67	-0.33	0.33	No Significant Trend
		Nitrate-Nitrite	0.04	0.22	0.56	No Significant Trend
		Dissolved Oxygen*	0.05	0.04	0.88	No Significant Trend
CC @ Bayou	2017-2020	Total Nitrogen	ID	ID	ID	ID
		Total Phosphorus	ID	ID	ID	ID
		Chlorophyll a (corrected)	ID	ID	ID	ID
		E. coli	-50	-0.55	0.08	No Significant Trend
		Nitrate-Nitrite	ID	ID	ID	ID
		Dissolved Oxygen*	0.02	0.02	0.96	No significant Trend
CC @ Burgess	2017-2020	Total Nitrogen	ID	ID	ID	ID
		Total Phosphorus	ID	ID	ID	ID
		Chlorophyll a (corrected)	ID	ID	ID	ID
		E. coli	ID	ID	ID	ID
		Nitrate-Nitrite	ID	ID	ID	ID
		Dissolved Oxygen*	0.92	0.2	0.47	No significant Trend
CC @ Davis	2017-2020	Total Nitrogen	-0.01	-0.125	0.73	No Significant Trend
		Total Phosphorus	-0.01	-0.28	0.42	No Significant Trend
		Chlorophyll a (corrected)	ID	ID	ID	ID
		E. coli	-68.5	-0.17	0.61	No Significant Trend
		Nitrate-Nitrite	-0.03	-0.44	0.17	No Significant Trend
		Dissolved Oxygen*	0.10	0.03	0.89	No Significant Trend
CC @ Olive	2017-2020	Total Nitrogen	ID	ID	ID	ID

Station or WBID	Time Period	Parameter	Sen's Slope	Tau	p-value	Trend
		Total Phosphorus	ID	ID	ID	ID
		Chlorophyll a (corrected)	ID	ID	ID	ID
		E. coli	-2	-0.08	0.87	No Significant Trend
		Nitrate-Nitrite	ID	ID	ID	ID
		Dissolved Oxygen*	0.37	0.02	0.96	No Significant Trend
Texar @ 12th	2017-2020	Total Nitrogen	0.04	0.17	0.61	No Significant Trend
		Total Phosphorus	-0.01	0	1	No Significant Trend
		Chlorophyll a (corrected)	0.03	0.17	0.61	No Significant Trend
		Enterococci	5.25	0.29	0.30	No Significant Trend
		Nitrate-Nitrite*	0.14	0.17	0.39	No Significant Trend
		Dissolved Oxygen*	-0.90	-0.23	0.22	No Significant Trend
Texar @ Bayview	2017-2020	Total Nitrogen	-0.01	0.00	1.00	No Significant Trend
		Total Phosphorus	ID	ID	ID	ID
		Chlorophyll a (corrected)	ID	ID	ID	ID
		Enterococci	ID	ID	ID	ID
		Nitrate-Nitrite*	-0.01	-0.11	0.72	No Significant Trend
		Dissolved Oxygen	0.475	0.33	0.734	No Significant Trend
CC @ 9th	2010-2020	Total Nitrogen	**-0.02**	**-0.25**	**0.04**	**Significant Decreasing Trend**
		Total Phosphorus	-0.01	-0.22	0.06	No Significant Trend
		Chlorophyll a (corrected)	ID	ID	ID	ID
		E. coli	ID	ID	ID	ID
		Nitrate-Nitrite	**-0.07**	**-0.33**	**<0.01**	**Significant Decreasing Trend**
		Dissolved Oxygen	**-0.03**	**-0.30**	**<0.01**	**Significant Decreasing Trend**
CC @ Davis	2010-2020	Total Nitrogen	0.01	0.06	0.61	No Significant Trend
		Total Phosphorus	-0.01	-0.12	0.31	No Significant Trend
		Chlorophyll a (corrected)	ID	ID	ID	ID
		E. coli	ID	ID	ID	ID
		Nitrate-Nitrite	**0.01**	**0.01**	**0.01**	**Significant Increasing Trend**

Station or WBID	Time Period	Parameter	Sen's Slope	Tau	p-value	Trend
		Dissolved Oxygen	-0.04	-0.09	0.51	No Significant Trend
Texar @ 12th	2010-2020	Total Nitrogen	-0.02	-0.20	0.10	No Significant Trend
		Total Phosphorus	-0.01	-0.09	0.50	No Significant Trend
		Chlorophyll a (corrected)	ID	ID	ID	ID
		Enterococci	ID	ID	ID	ID
		Nitrate-Nitrite	**-0.03**	**-0.32**	**<0.01**	**Significant Decreasing Trend**
		Dissolved Oxygen	-0.13	-0.24	0.07	No Significant Trend
Texar @ Bayview	2010-2020	Total Nitrogen	-0.01	-0.19	0.12	No Significant Trend
		Total Phosphorus*	-0.01	-0.01	0.62	No Significant Trend
		Chlorophyll a (corrected)	ID	ID	ID	ID
		Enterococci	-0.61	-0.61	0.65	No Significant Trend
		Nitrate-Nitrite*	0.05	0.07	0.53	No Significant Trend
		Dissolved Oxygen	**-0.08**	**-0.27**	**<0.05**	**Significant Decreasing Trend**
Carpenter Creek (WBID 676)	2017-2020	Total Nitrogen	-0.09	-0.25	0.40	No Significant Trend
		Total Phosphorus	0.01	0.08	0.86	No Significant Trend
		Chlorophyll a (corrected)	0.11	0.25	0.40	No Significant Trend
		E. coli	-1.5	-0.04	1.0	No Significant Trend
		Nitrate-Nitrite	-0.09	-0.33	0.23	No Significant Trend
		Dissolved Oxygen*	-0.10	-0.07	0.75	No Significant Trend
Bayou Texar (WBID 738)	2017-2020	Total Nitrogen	0.09	0.42	0.13	No Significant Trend
		Total Phosphorus	-0.01	-0.04	1.0	No Significant Trend
		Chlorophyll a (corrected)	0.71	0.5	0.06	No Significant Trend
		Enterococci	-1.5	-0.04	1.0	No Significant Trend
		Nitrate-Nitrite	-0.07	-0.42	0.13	No Significant Trend
		Dissolved Oxygen*	-0.28	-0.08	0.69	No Significant Trend
Carpenter Creek (WBID 676)	2010-2020	Total Nitrogen	0.02	0.15	0.21	No Significant Trend
		Total Phosphorus	**-0.01**	**-0.25**	**0.03**	**Significant Decreasing Trend**
		Chlorophyll a (corrected)	0.05	0.31	0.21	No Significant Trend

Station or WBID	Time Period	Parameter	Sen's Slope	Tau	p-value	Trend
		E. coli*	210	0.19	0.26	No Significant Trend
		Nitrate-Nitrite*	0.20	0.09	0.39	No Significant Trend
		Dissolved Oxygen	**-0.09**	**-0.27**	**0.03**	**Significant Decreasing Trend**
Bayou Texar (WBID 738)	2010-2020	Total Nitrogen*	-0.14	-0.13	0.22	No Significant Trend
		Total Phosphorus	-0.01	-0.15	0.21	No Significant Trend
		Chlorophyll a (corrected)	0.71	0.5	0.06	No Significant Trend
		Enterococci	1.48	0.02	1	No Significant Trend
		Nitrate-Nitrite	**-0.03**	**-0.38**	**<0.01**	**Significant Decreasing Trend**
		Dissolved Oxygen	**-0.07**	**-0.28**	**0.03**	**Significant Decreasing Trend**

VOLUME 3B APPENDIX C

POLLUTANT LOAD ANALYSIS TABLES

Appendix C - POLLUTANT LOAD ANALYSIS TABLES

Table C-1: Published runoff coefficients (c) for meteorological zone 1 based on Non-DCIA CN and percent DCIA.

NDCIA	Percent DCIA																				
CN	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
30	0.006	0.048	0.090	0.132	0.175	0.217	0.259	0.301	0.343	0.386	0.428	0.470	0.512	0.554	0.596	0.639	0.681	0.723	0.765	0.807	0.849
35	0.009	0.051	0.093	0.135	0.177	0.219	0.261	0.303	0.345	0.387	0.429	0.471	0.513	0.555	0.597	0.639	0.681	0.723	0.765	0.807	0.849
40	0.014	0.056	0.098	0.139	0.181	0.223	0.265	0.307	0.348	0.390	0.432	0.474	0.515	0.557	0.599	0.641	0.682	0.724	0.766	0.808	0.849
45	0.020	0.062	0.103	0.145	0.186	0.228	0.269	0.311	0.352	0.394	0.435	0.476	0.518	0.559	0.601	0.642	0.684	0.725	0.767	0.808	0.849
50	0.029	0.070	0.111	0.152	0.193	0.234	0.275	0.316	0.357	0.398	0.439	0.480	0.521	0.562	0.603	0.644	0.685	0.726	0.767	0.808	0.849
55	0.039	0.079	0.120	0.161	0.201	0.242	0.282	0.323	0.363	0.404	0.444	0.485	0.525	0.566	0.606	0.647	0.687	0.728	0.768	0.809	0.849
60	0.052	0.092	0.132	0.172	0.212	0.252	0.291	0.331	0.371	0.411	0.451	0.491	0.531	0.570	0.610	0.650	0.690	0.730	0.770	0.810	0.849
65	0.069	0.108	0.147	0.186	0.225	0.264	0.303	0.342	0.381	0.420	0.459	0.498	0.537	0.576	0.615	0.654	0.693	0.732	0.771	0.810	0.849
70	0.092	0.130	0.167	0.205	0.243	0.281	0.319	0.357	0.395	0.433	0.471	0.508	0.546	0.584	0.622	0.660	0.698	0.736	0.774	0.812	0.849
75	0.121	0.158	0.194	0.230	0.267	0.303	0.340	0.376	0.412	0.449	0.485	0.522	0.558	0.595	0.631	0.667	0.704	0.740	0.777	0.813	0.849
80	0.162	0.196	0.230	0.265	0.299	0.334	0.368	0.402	0.437	0.471	0.506	0.540	0.574	0.609	0.643	0.678	0.712	0.746	0.781	0.815	0.849
85	0.220	0.252	0.283	0.315	0.346	0.378	0.409	0.441	0.472	0.503	0.535	0.566	0.598	0.629	0.661	0.692	0.724	0.755	0.787	0.818	0.849
90	0.312	0.339	0.366	0.393	0.419	0.446	0.473	0.500	0.527	0.554	0.581	0.608	0.634	0.661	0.688	0.715	0.742	0.769	0.796	0.823	0.849
95	0.478	0.496	0.515	0.533	0.552	0.571	0.589	0.608	0.626	0.645	0.664	0.682	0.701	0.719	0.738	0.757	0.775	0.794	0.812	0.831	0.849
98	0.656	0.666	0.676	0.685	0.695	0.705	0.714	0.724	0.734	0.743	0.753	0.763	0.772	0.782	0.792	0.801	0.811	0.821	0.830	0.840	0.849

Source: Stormwater Quality Applicant's Handbook, Design Requirements for stormwater Treatment Systems in Florida, March 2010 Draft.

wood.

Table C-2: Summary of curve numbers based on land use and soil group.

FLUCCS	GENERALIZED LAND USE DESCRIPTION	HYDROLOGIC SOILS GROUP						DCIA
		A	B	B/D	C	D	W	
1100	Residential-Low Density	39	61	61	74	80	99.8	20
1200	Residential-Med Density	39	61	61	74	80	99.8	25
1300	Residential-High Density	39	61	61	74	80	99.8	50
1400	Commercial	39	61	61	74	80	99.8	85
1500	Industrial	39	61	61	74	80	99.8	72
1600	Extractive	39	61	61	74	80	99.8	0
1700	Institutional	39	61	61	74	80	99.8	65
1800	Recreational	39	61	80	74	80	99.8	10
1900	Open Land	39	61	80	74	80	99.8	0
2100	Cropland and Pastureland	39	61	80	74	80	99.8	0
2200	Tree Crops - Citrus	32	58	79	72	79	99.8	10
2300	Feeding Operations	32	58	79	72	79	99.8	10
2400	Nurseries and Vineyards	67	78	89	85	89	99.8	5
2500	Specialty Farms	67	78	89	85	89	99.8	5
2600	Other Open Lands - Rural	39	61	80	74	80	99.8	0
3100	Herbaceous Rangeland	39	61	80	74	80	99.8	0
3200	Shrub and Brush Rangeland	30	48	73	65	73	99.8	0
3300	Mixed Rangeland	30	48	73	65	73	99.8	0
4100	Upland Coniferous Forest	32	58	79	72	79	99.8	0
4200	Upland Hardwood Forests	32	58	79	72	79	99.8	0

Table C-2: Continued
Summary of curve numbers based on land use and soil group.

FLUCCS	GENERALIZED LAND USE DESCRIPTION	HYDROLOGIC SOILS GROUP						DCIA
		A	B	B/D	C	D	W	
4300	MIXED HARDWOOD FORESTS	32	58	79	72	79	99.8	0
4400	TREE PLANTATIONS	32	58	79	72	79	99.8	0
5000	WATER	99.8	99.8	99.8	99.8	99.8	99.8	100
5100	STREAMS AND WATERWAYS	99.8	99.8	99.8	99.8	99.8	99.8	100
5200	LAKES	99.8	99.8	99.8	99.8	99.8	99.8	100
5300	RESERVOIRS	99.8	99.8	99.8	99.8	99.8	99.8	100
6100	WETLAND HARDWOOD FORESTS	99.8	99.8	99.8	99.8	99.8	99.8	100
6200	WETLAND CONIFEROUS FORESTS	99.8	99.8	99.8	99.8	99.8	99.8	100
6300	WETLAND FORESTED MIXED	98	98	98	98	98	99.8	100
6400	VEGETATED NON-FORESTED WETLANDS	98	98	98	98	98	99.8	100
7400	MINING	39	61	80	74	80	99.8	0
8100	TRANSPORTATION / UTILITIES	83	89	89	92	93	99.8	25
8200	COMMUNICATIONS	83	89	89	92	93	99.8	25
8300	UTILITIES	83	89	89	92	93	99.8	25

Table C-3: Summary of literature-based runoff characterization for general land use categories in Florida.

LAND USE CATEGORY	TYPICAL RUNOFF CONCENTRATION (MG/L)						
	TN	TP	BOD	TSS	Cu	Pb	Zn
Low-Density Residential[1]	1.5	0.18	4.7	23	0.008[4]	0.002[4]	0.031[4]
Single-Family	1.85	0.31	7.9	37.5	0.016	0.004	0.062
Multi-Family	1.91	0.48	11.3	77.8	0.009	0.006	0.086
Low-Intensity Commercial	0.93	0.16	7.7	57.5	0.018	0.005	0.094
High-Intensity Commercial	2.48	0.23	11.3	69.7	0.015	--	0.16
Light Industrial	1.14	0.23	7.6	60	0.003	0.002	0.057
Highway	1.37	0.17	5.2	37.3	0.032	0.011	0.126
Pasture	2.48	0.7	5.1	94.3	--	--	--
Citrus	2.31	0.16	2.55	15.5	0.003	0.001	0.012
Row Crops	2.47	0.51	--	19.8	0.022	0.004	0.03
General Agriculture[2]	2.42	0.46	3.8	43.2	0.013	0.003	0.021
Undeveloped / Rangeland / Forest	1.15	0.055	1.4	8.4	--	--	--
Mining / Extractive	1.18	0.15	7.6[3]	60.0[3]	0.003[3]	0.002[3]	0.057[3]
Wetland	1.01	0.09	2.63	11.2	0.001	0.001	0.006
Open Water / Lake	1.6	0.067	1.6	3.1		0.025[5]	0.028

1. Average of single-family and undeveloped loading rates.
2. Mean of pasture, citrus, and row crop land uses.
3. Runoff concentrations assumed equal to industrial values for these parameters.
4. Value assumed to be equal to 50% of single-family concentration.
5. Runoff concentrations assumed equal to wetland values for these parameters.

Notes: This table is a replica of Table 4-17 in the Final Report of "Evaluation of Current Stormwater Design Criteria within the state of Florida" prepared for the Florida Department of Environmental Protection (June 2007). Prepared by Environmental Research & Design, Inc. Harvey H. Harper, Ph.D., P.E. & David M. Baker, P.E. Total N, and Total P EMC values are from Table 3.4 in March 2010 Draft Department of Environmental Protection and Water Management Districts Environmental Resource Permit Stormwater Quality Applicant's Handbook Design Requirements for Stormwater Treatment Systems in Florida. Wetland and Open Water/Lake EMC values are from Table 7 of the Final Report of "Evaluation of Alternative Stormwater Regulations for Southwest Florida". (Revised Sept 08, 2003) Submitted to Water Enhancement & Restoration Coalition, Inc. Prepared by Environmental Research & Design, Inc. Harvey H. Harper, Ph.D., P.E. & David M. Baker, P.E.

VOLUME 3B APPENDIX D

QUALITY BAYOU TEXAR ASSESSMENT

Appendix D - QUALITY BAYOU TEXAR ASSESSMENT

WETLAND SCIENCES INCORPORATED

September 10, 2021

Crissy Mehle
Water Resources Manager
4400 Bayou Boulevard, Suite 31A,
Pensacola, FL 32503

Re: *Qualitative Assessment of Bayou Texar*
Carpenter Creek Watershed Management Plan
WSI Reference #2018-703

Dear Mrs. Mehle,

This letter report shall summarize Wetland Sciences, Inc. qualitative assessment of Bayou Texar in support of the Carpenter Creek Watershed Management Plan. This work was aimed at satisfying task item 3.2 of the agreed scope of work.

Field work was undertaken on Thursday, September 9, 2021. Our efforts were originally scheduled for the week of August 30th but were postponed due to inclement weather from Hurricane Ida which made landfall on August 28 and affected local conditions during the week of August 30th.

The weather during the sampling effort was ideal. Max temperature was 87 degrees with light north winds at 3 mph. High tide was 1:50 AM and 3:42 PM. Low tide was 8:13 AM and 7:33 PM. Tidal amplitude was 1.0-ft.

Our efforts included general qualitative observations of shoreline conditions, collection of several water quality parameters, and physical characterization of submersed sediments within the Bayou.

General qualitative observations of shoreline conditions are summarized in the attached site photographic essay (Exhibit A). Included with this essay is a map key that identifies the location of each photograph. The condition of the shoreline for a variety of locations within the Bayou are summarized. Key observations include:

- The shoreline between Cervantes Street bridge and the mouth of the Bayou is largely free from anthropogenic impacts except for existing dock structures that line the west shoreline. Both the east and west shorelines contain broad bands of emergent wetland vegetation dominated by salt marsh cord grass (*Spartina alterniflora*), black needle rush (*Juncus roemerianus*), and salt grass (*Distichlis spicata*). The submerged lands between the waterward edge of emergent wetland vegetation and the edge of the dredged channel was largely dominated by dense coverage of wild celery (*Vallisneria americana*).
- The shoreline between the Cervantes Street bridge and Gamarra Road is highly manipulated. There are a variety of modifications to the shoreline in this area including vertical seawalls, vertical seawalls faced with rock, rock revetments, manicured lawns that terminate at the mean high water, and shorelines graded to resemble an open beach.
- From Gamarra road north to the bridge at North 12th Avenue the shorelines are comprised largely of broad low littoral zones dominated by dense coverage of sawgrass (*Cladium jamaicense*).

Submerged lands from the waterward edge of the emergent vegetation to depths of -4-ft. were dominated by dense meadows of wild celery.

Again, each of the observed conditions are detailed in the attached site photographic essay.

Physical measurements of water quality parameters including temperature, dissolved oxygen, salinity, conductivity, pH, turbidity, and total dissolved solids were gathered using a YSI ProDSS (digital sampling system) multiparameter instrument. Calibration certificate for this instrument is included in **Exhibit B**. The location of each sample site is depicted in the map appended as **Exhibit C**. Results of the monitoring efforts are appended as **Exhibit D**.

Finally, WSI attempted to characterize submerged sediments within the Bayou. Sediment samples were collected at each location depicted in **Exhibit C**. Physical measurements were made from a 19-ft. recreational watercraft by probing the bottom of the bayou with a 29 mm diameter (1.13-inch) diameter, 16-ft. aluminum range pole with a convex steel cap covering the terminal end. Each section of the range pole was graduated in 0.1-foot increments. At each sample location, the depth of water over sediment was carefully measured to the nearest 0.1 foot using the probe. The probe was then forced downward through the sediment until refusal. A second measurement was taken at depth. The difference between the two measurements was then calculated to determine the thickness of unconsolidated fine-grain sediment. The results of this effort are appended as **Exhibit E**.

Most of the submerged lands of Bayou Texar are covered by a layer of fine-grained sediments. WSI identified fine grain sediment deposits greater than 6-ft. in depth along the central portions of the Bayou from the 12th Ave bridge to Cervantes Street bridge. From the open waters of the Bayou to the shoreline there was an obvious gradient of decreasing fine-grain sediment thickness except for the area between Gamarra Road and the 12th Ave bridge.

This concludes our findings. If you have questions, please do not hesitate to call.

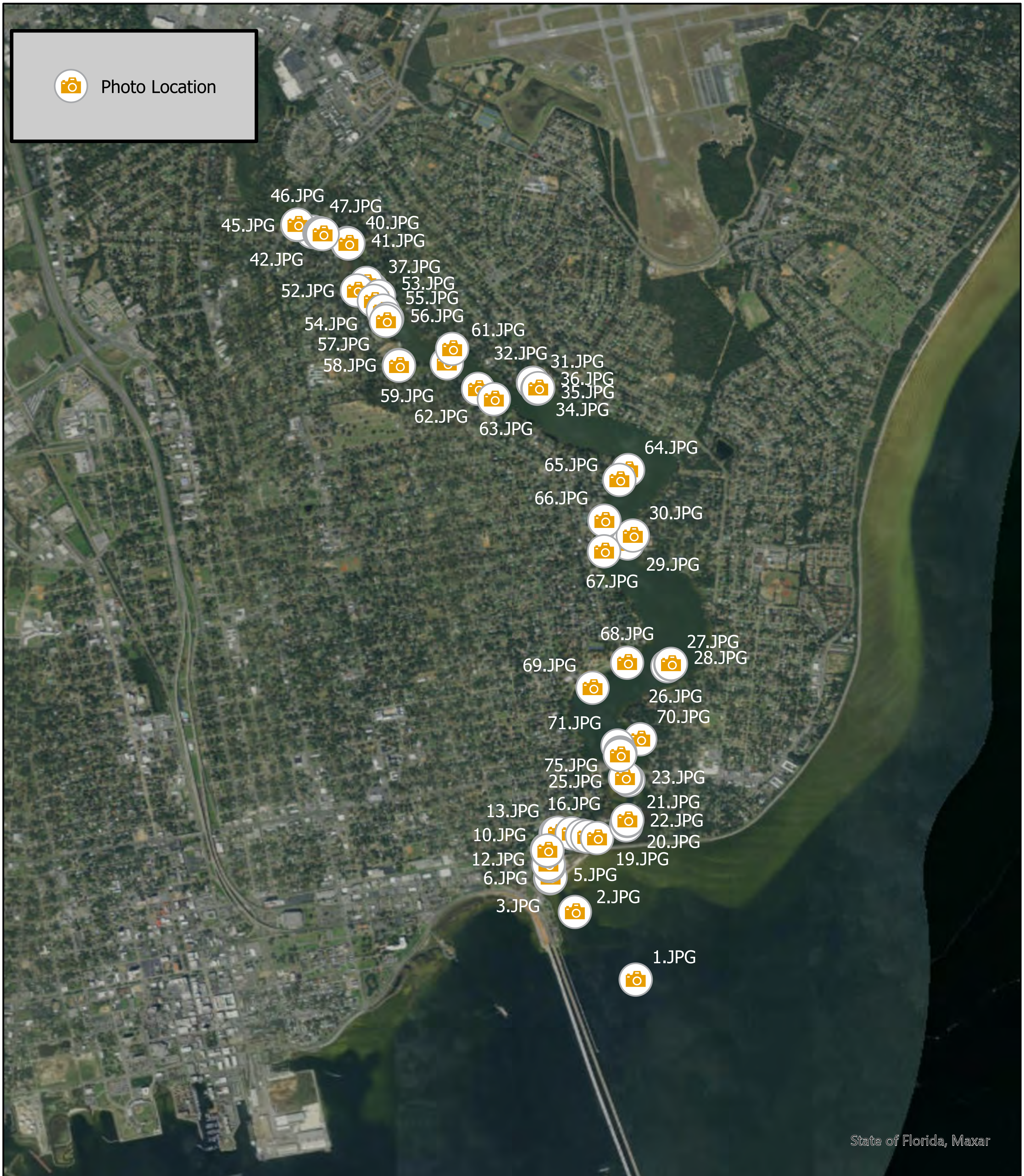
Sincerely,
WETLAND SCIENCES, INC.

Keith Johnson
Environmental Scientist

3308 Gulf Beach Highway | Pensacola, Florida 32507 | 850.453.4700 | keith@wetlandsciences.com

Exhibit A

Site Photographic Essay



WETLAND SCIENCES INCORPORATED

All data within this map are supplied as is, without warranty. This product has not been prepared for legal, engineering, or survey purposes. Users of this information should review or consult the primary data sources to ascertain the usability of the information.

Photo Location Map

Carpenter Creek/Bayou Texar Watershed Management Plan

0 0.2 0.41 0.82 1.23 1.64 Miles

Data Source: WSI
Imagery Source: ESRI

Coordinate System: NAD 1983 FL State Plane North

N W E S

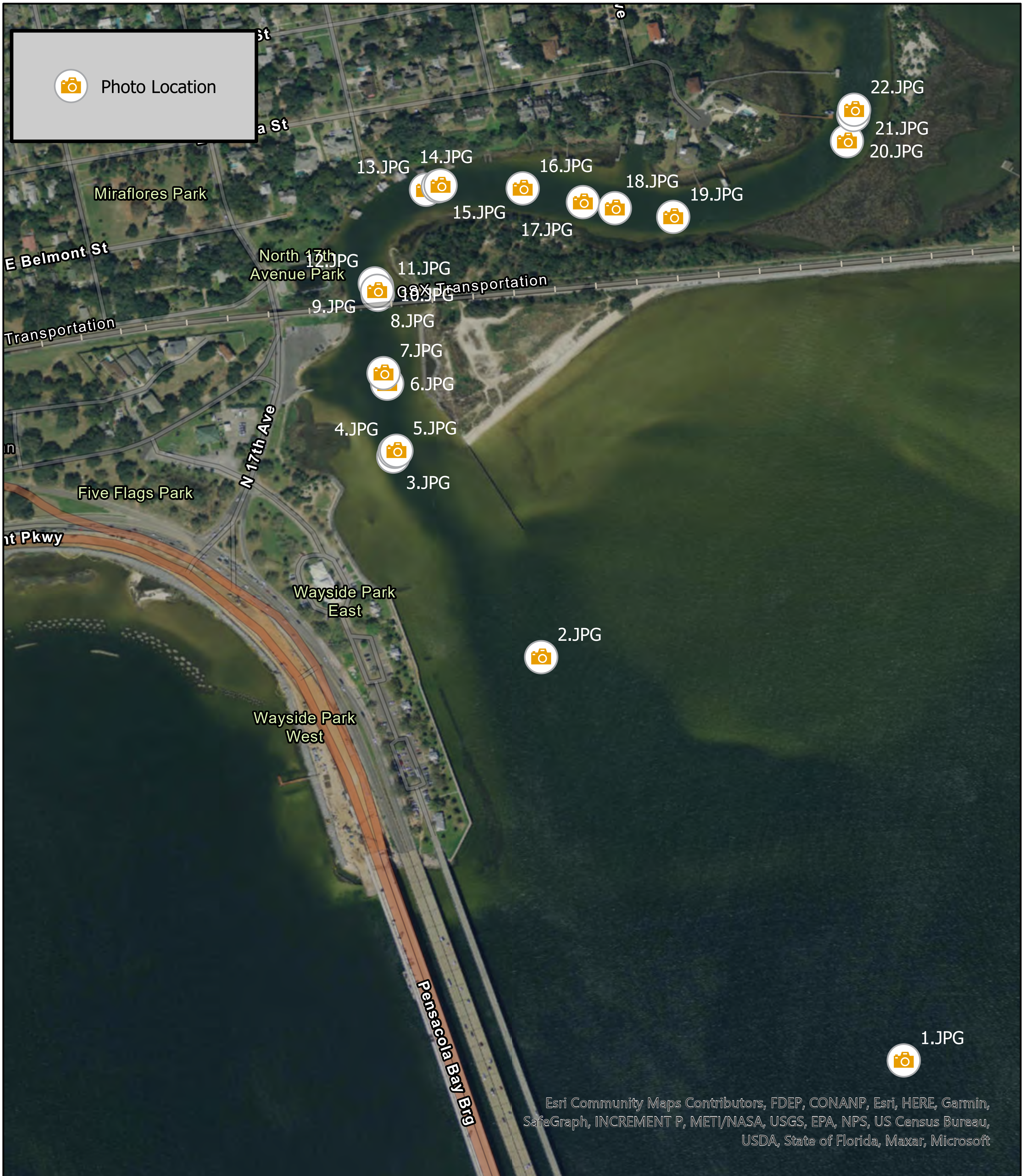


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Photo Location Map

Carpenter Creek/Bayou Texar Watershed Management Plan

0 0.03 0.07 0.14 0.21 0.28 Miles

Data Source: WSI
Imagery Source: ESRI

N W E S

Coordinate System: NAD 1983 FL State Plane North

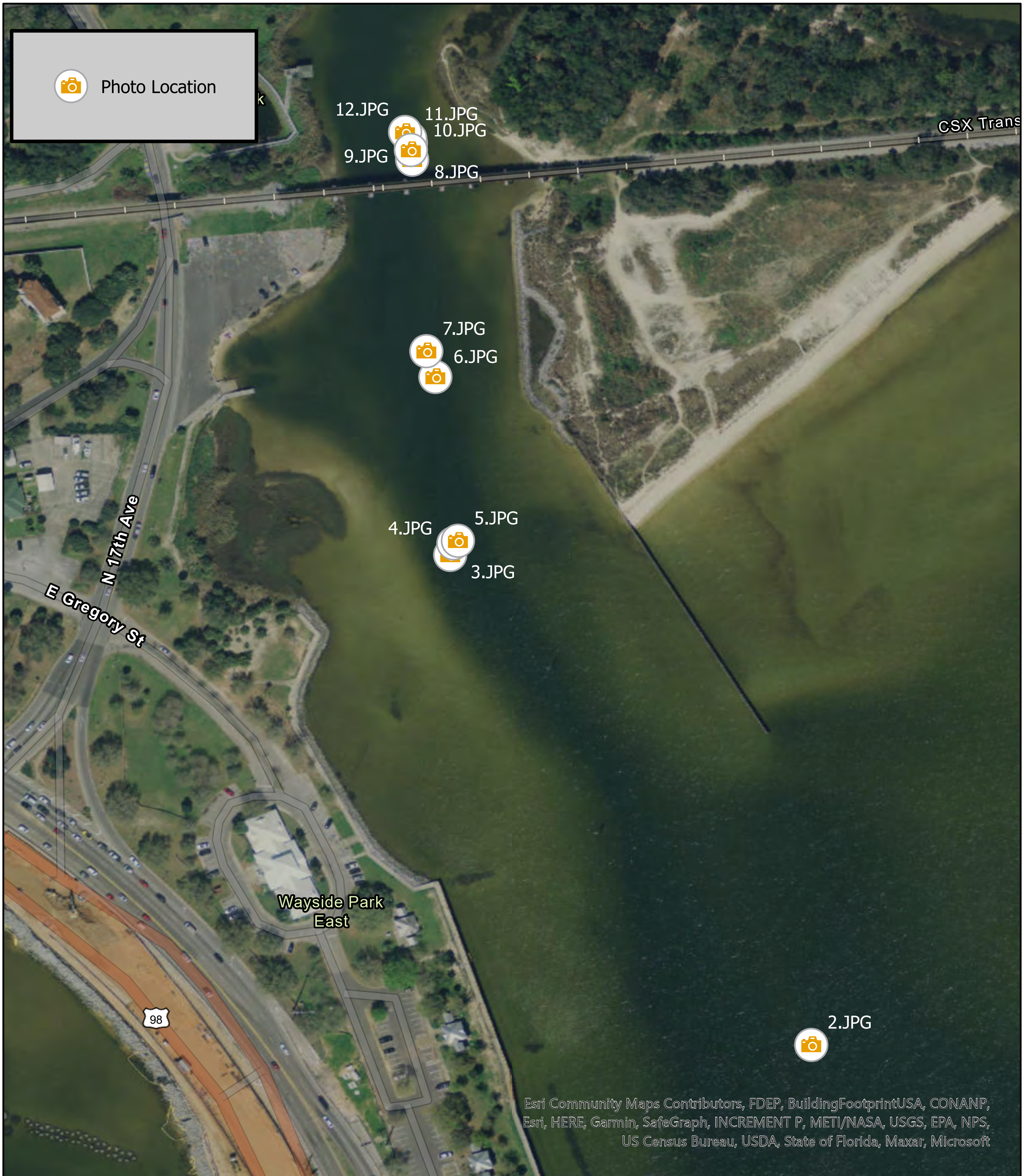

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Photo Location Map

Carpenter Creek/Bayou Texar Watershed Management Plan

0 0.01 0.03 0.06 0.08 0.11 Miles

Data Source:
WSI
Imagery Source:
ESRI

Coordinate System:
NAD 1983 FL
State Plane North

N W E S

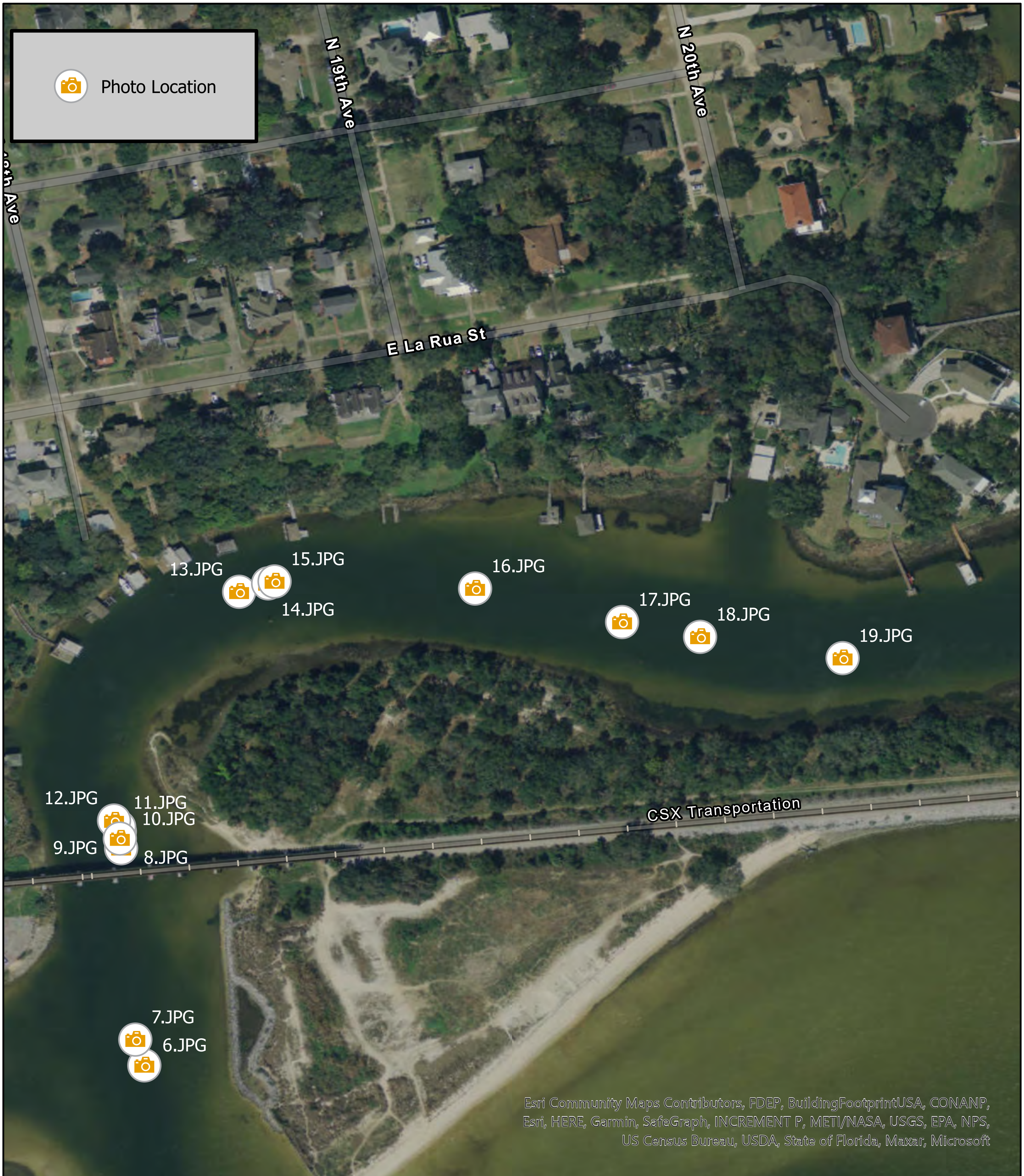

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Photo Location Map

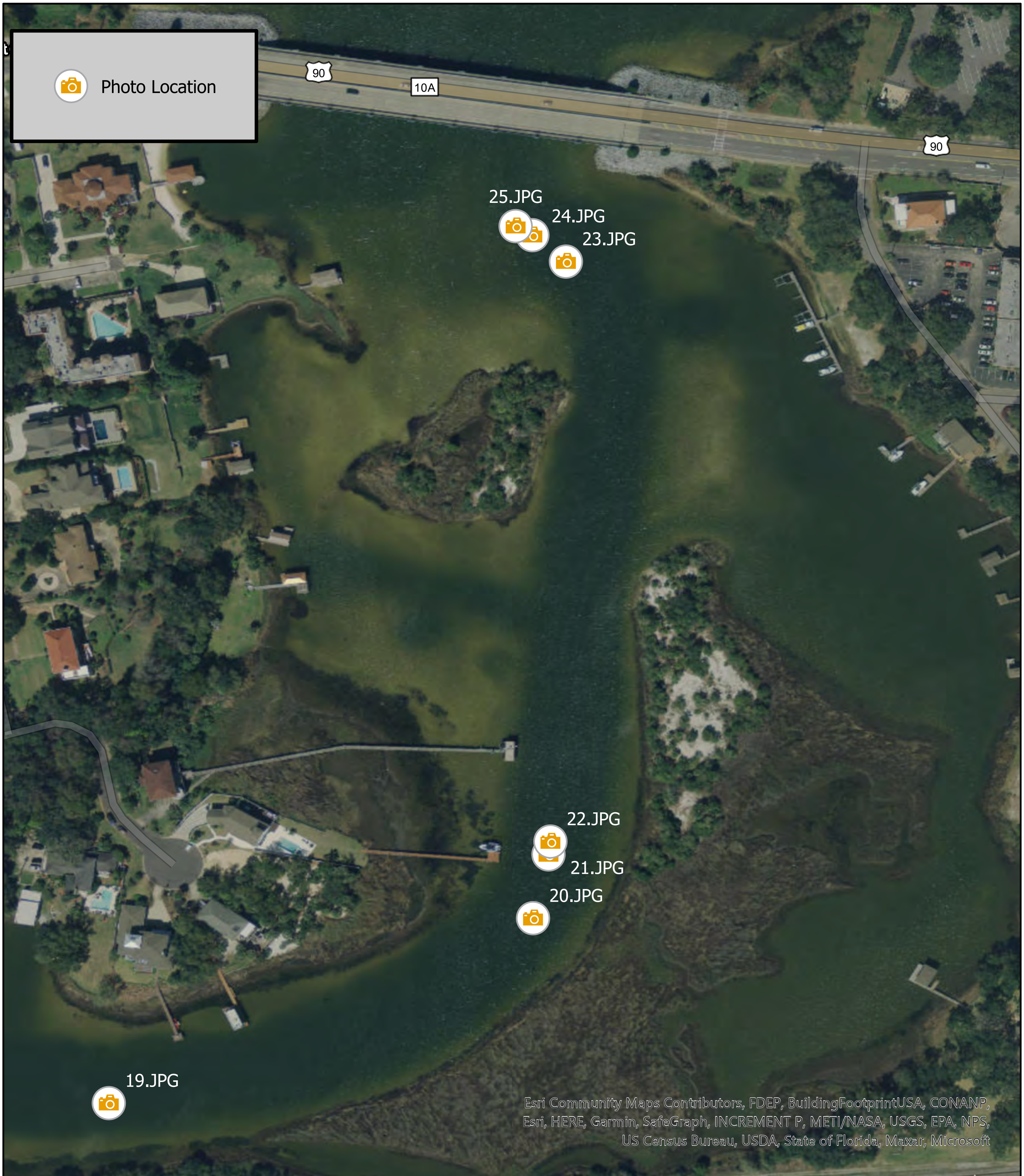
Carpenter Creek/Bayou Texar Watershed Management Plan

0 0.01 0.03 0.06 0.08 0.11 Miles

Data Source: WSI
Imagery Source: ESRI

Coordinate System: NAD 1983 FL State Plane North

N W E S



WETLAND SCIENCES INCORPORATED

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Photo Location Map

Carpenter Creek/Bayou Texar Watershed Management Plan

0 0.01 0.03 0.06 0.08 0.11 Miles

Data Source: WSI
Imagery Source: ESRI

Coordinate System: NAD 1983 FL State Plane North

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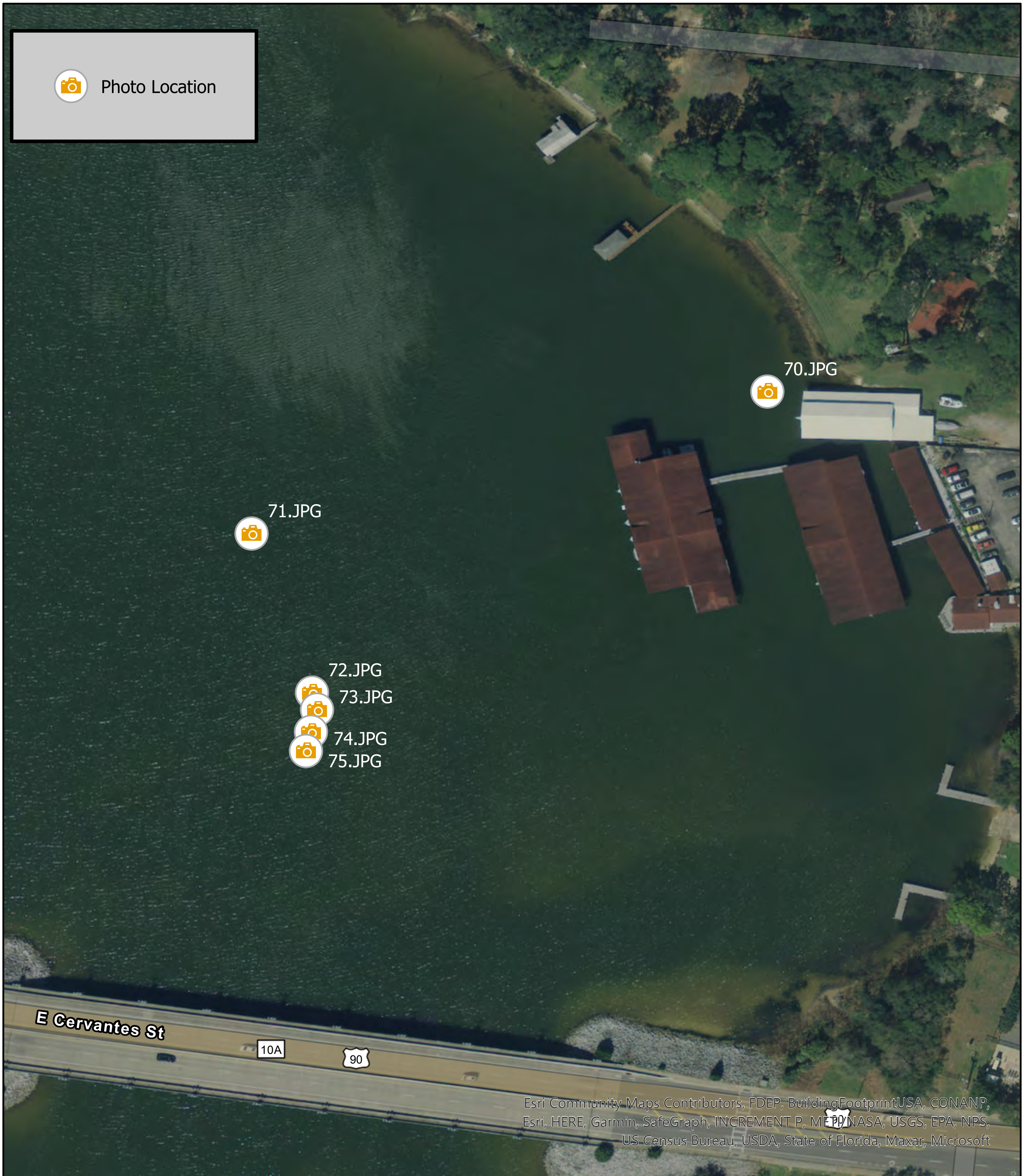

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Photo Location Map

Carpenter Creek/Bayou Texar Watershed Management Plan

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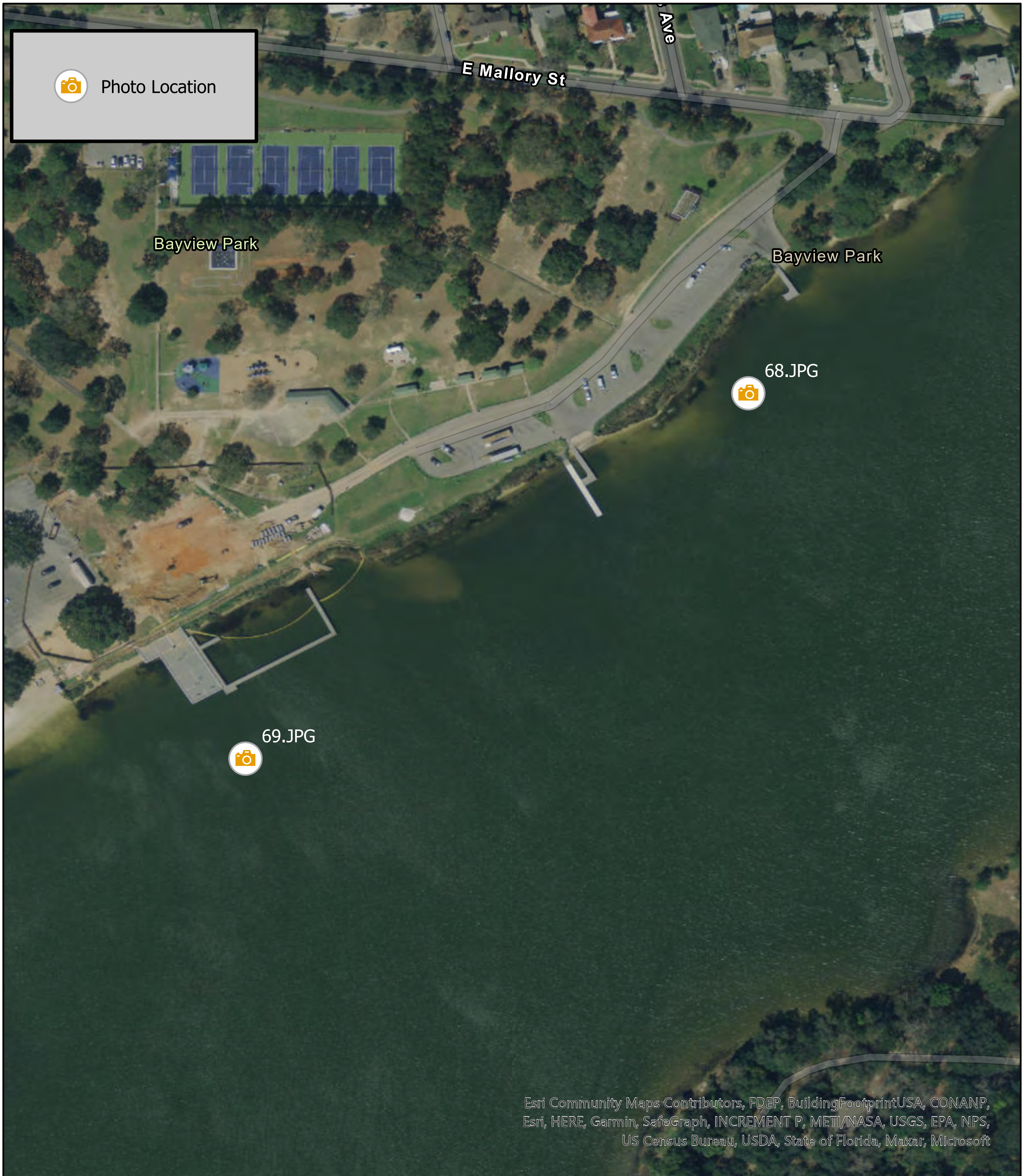

WETLAND SCIENCES INCORPORATED

Photo Location Map

Carpenter Creek/Bayou Texar Watershed Management Plan

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Coordinate System: NAD 1983 FL State Plane North

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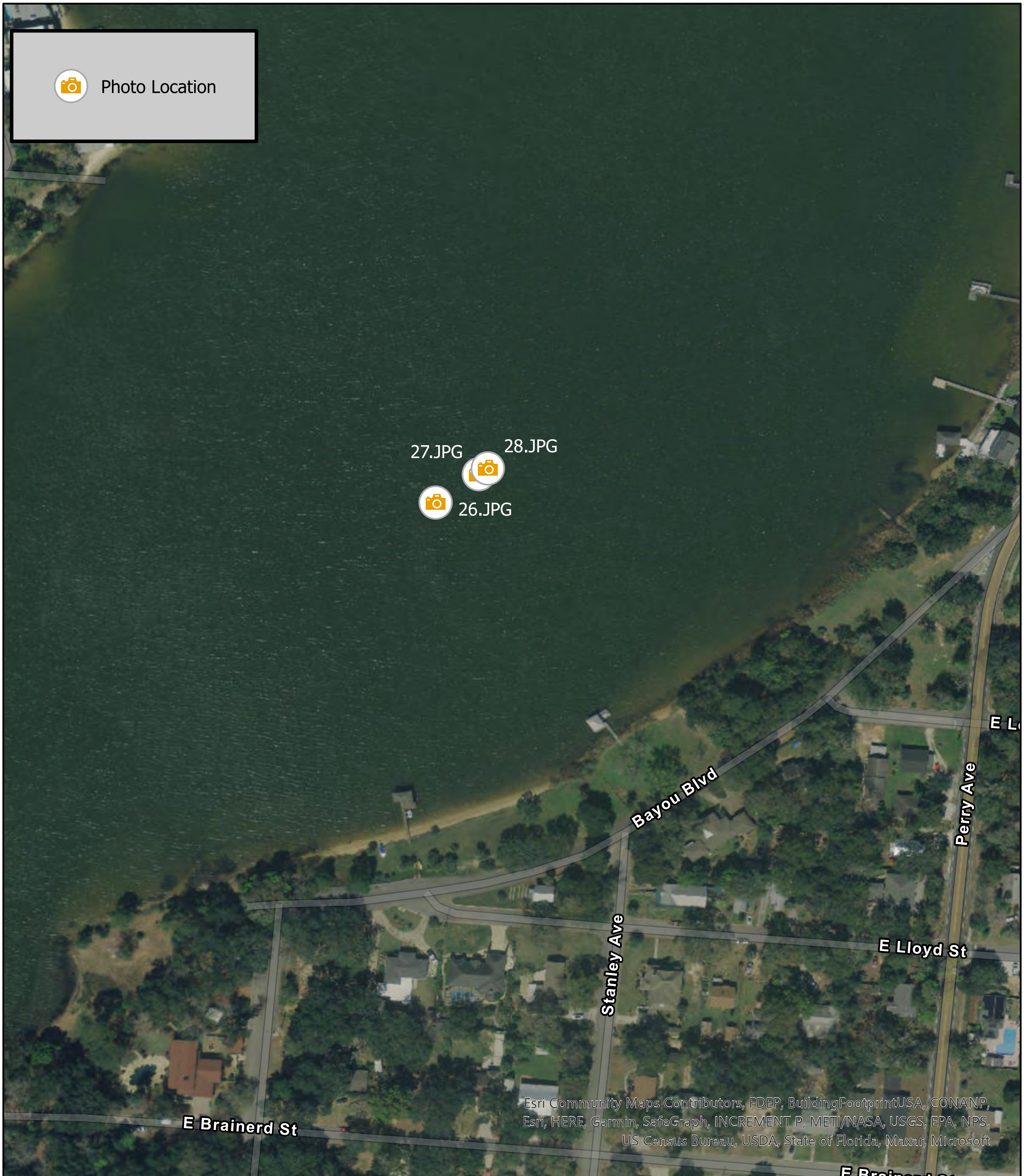

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Photo Location Map

Carpenter Creek/Bayou Texar Watershed Management Plan

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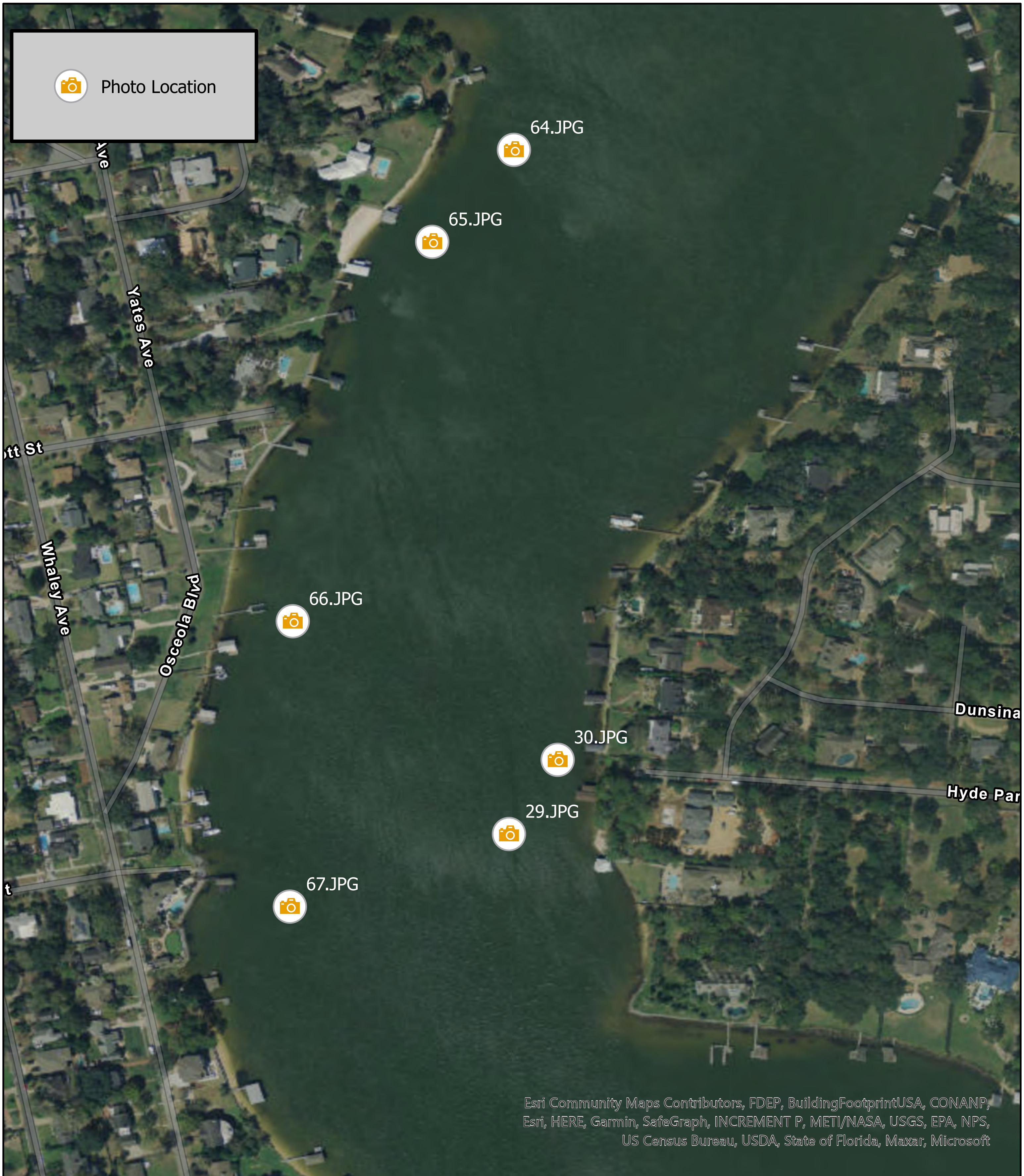

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Photo Location Map

Carpenter Creek/Bayou Texar Watershed Management Plan

0 0.02 0.04 0.09 0.13 0.18 Miles

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WSI
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ESRI

Coordinate System:
NAD 1983 FL
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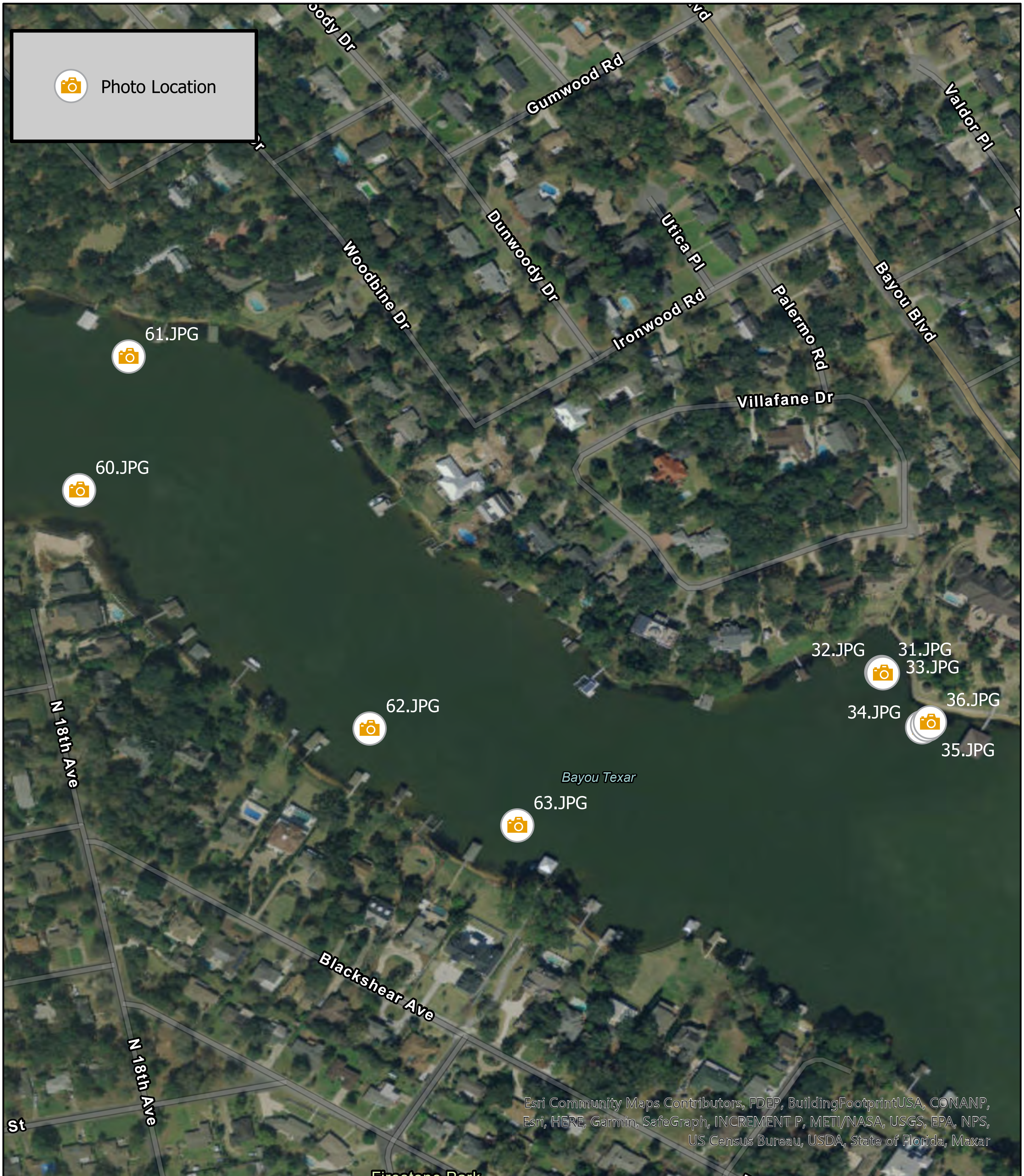

WETLAND SCIENCES INCORPORATED

Photo Location Map

Carpenter Creek/Bayou Texar Watershed Management Plan

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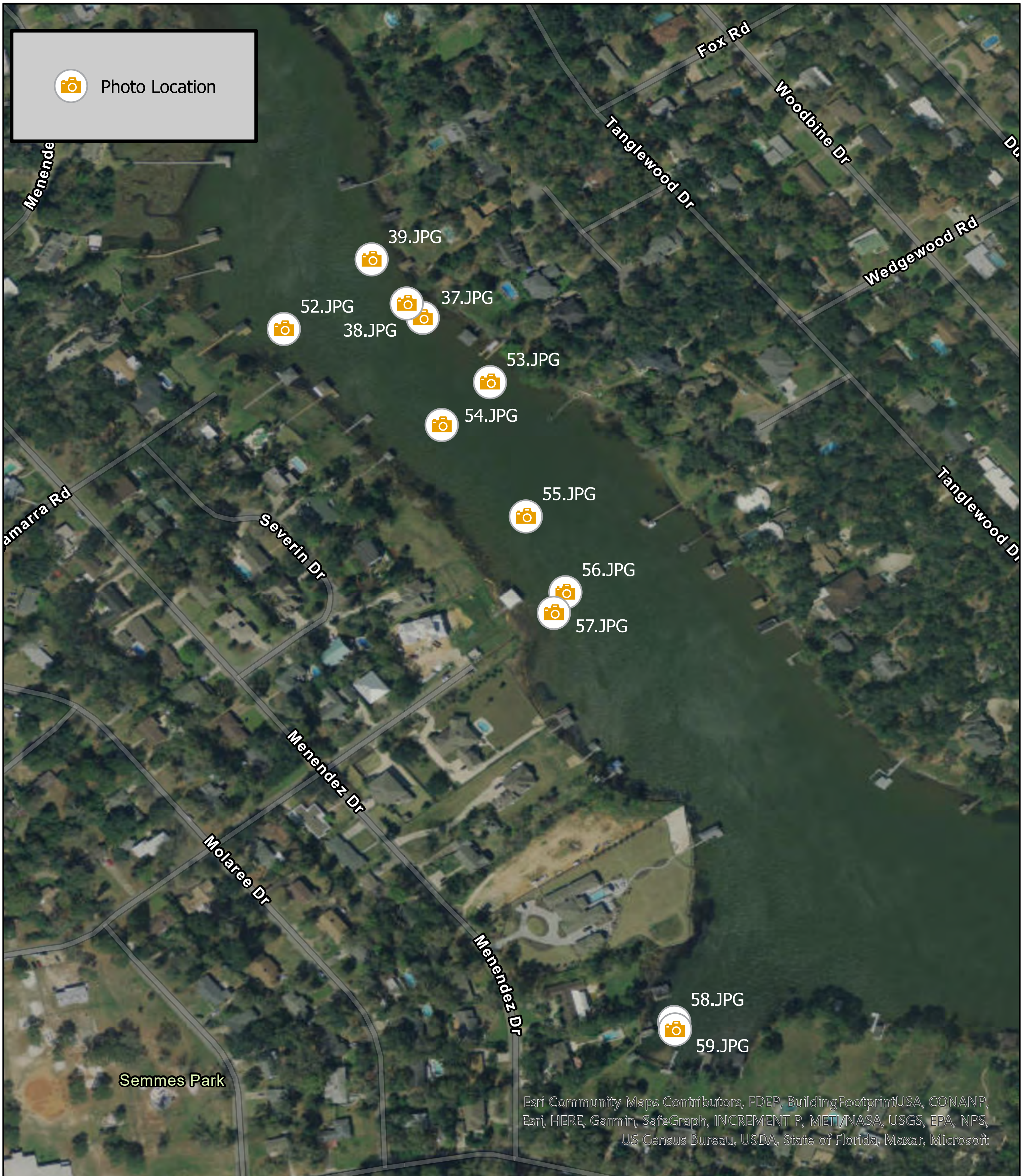

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Photo Location Map

Carpenter Creek/Bayou Texar Watershed Management Plan

Data Source: WSI
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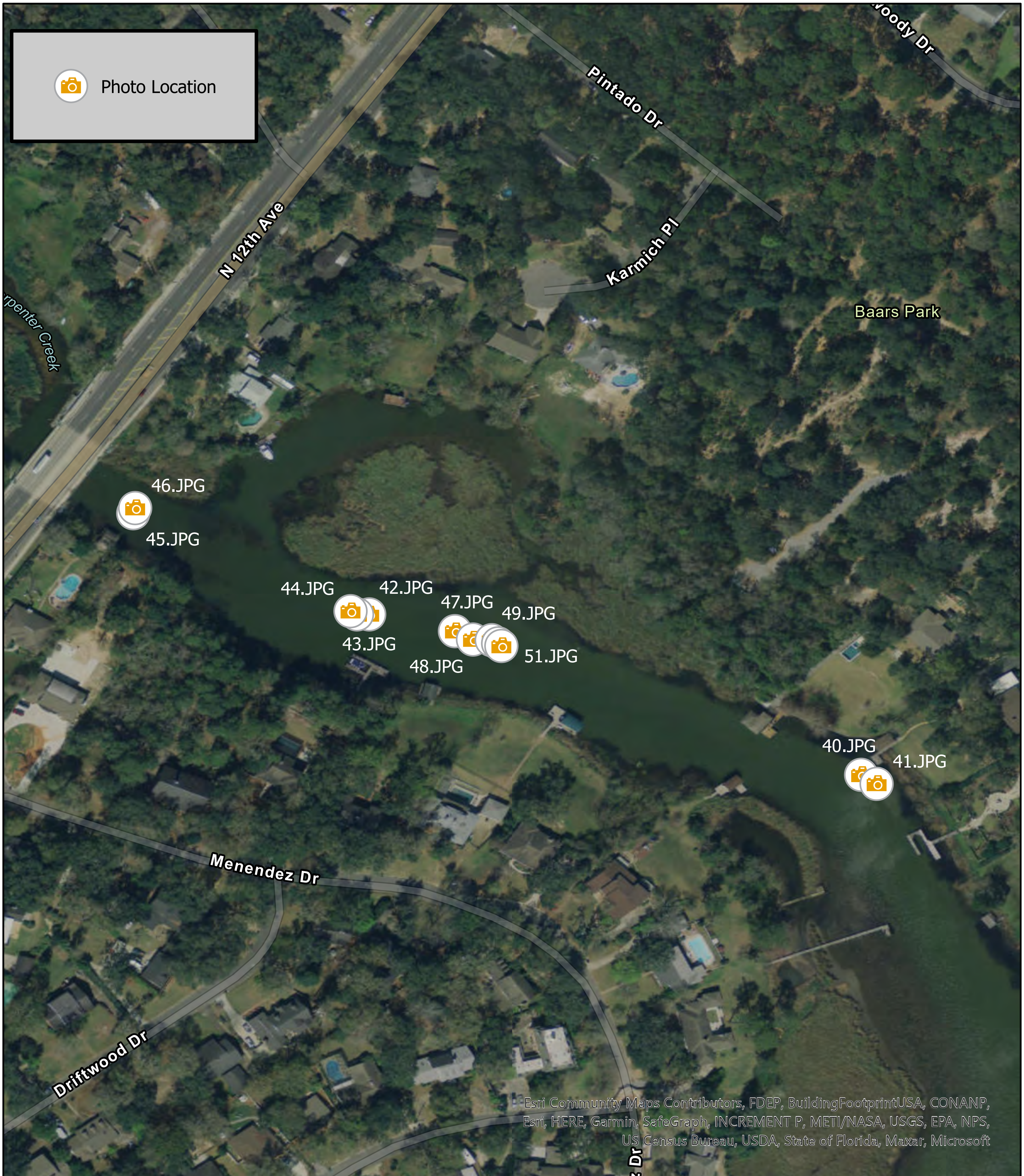

WETLAND SCIENCES INCORPORATED

Photo Location Map

Carpenter Creek/Bayou Texar Watershed Management Plan

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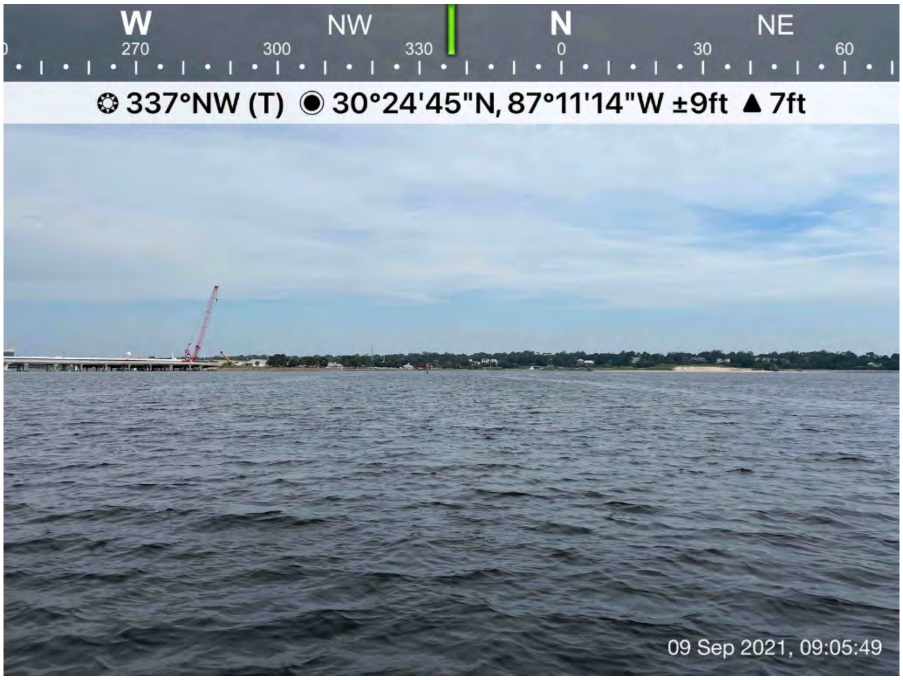
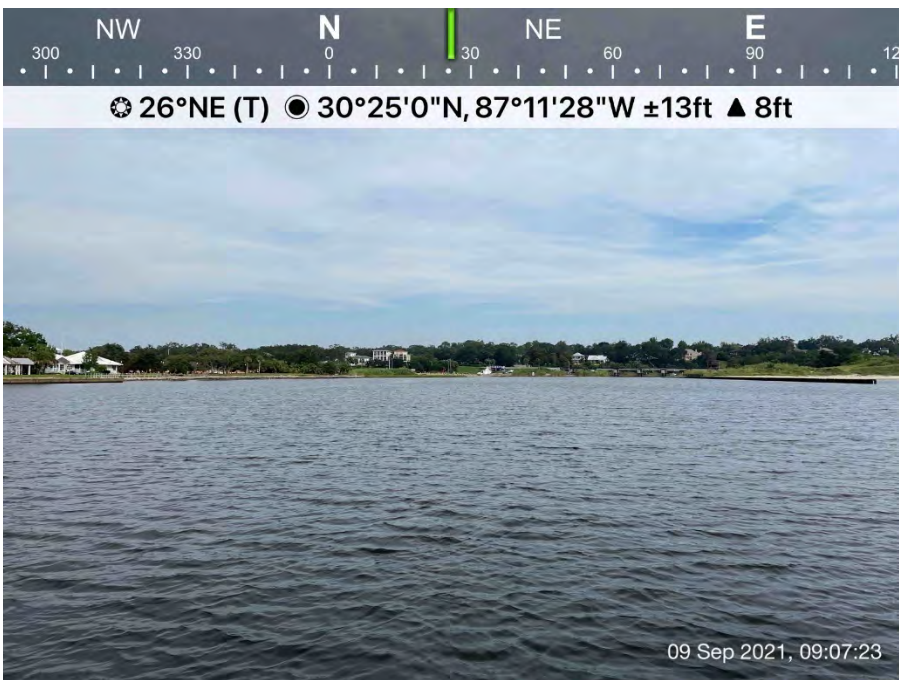
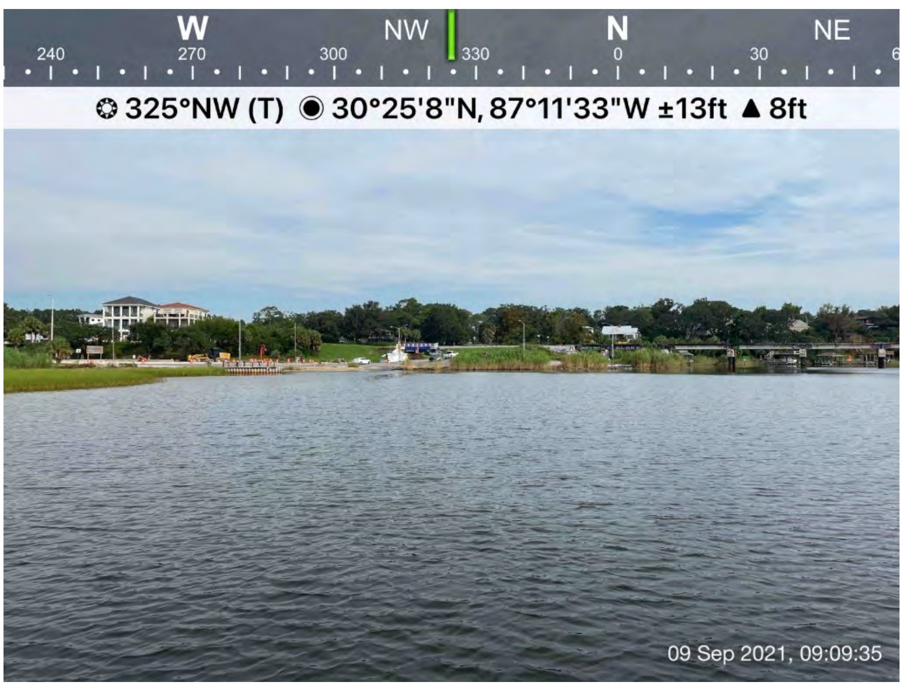


Photograph #1. Photograph taken in Pensacola Bay just south of the entrance to Bayou Texar.

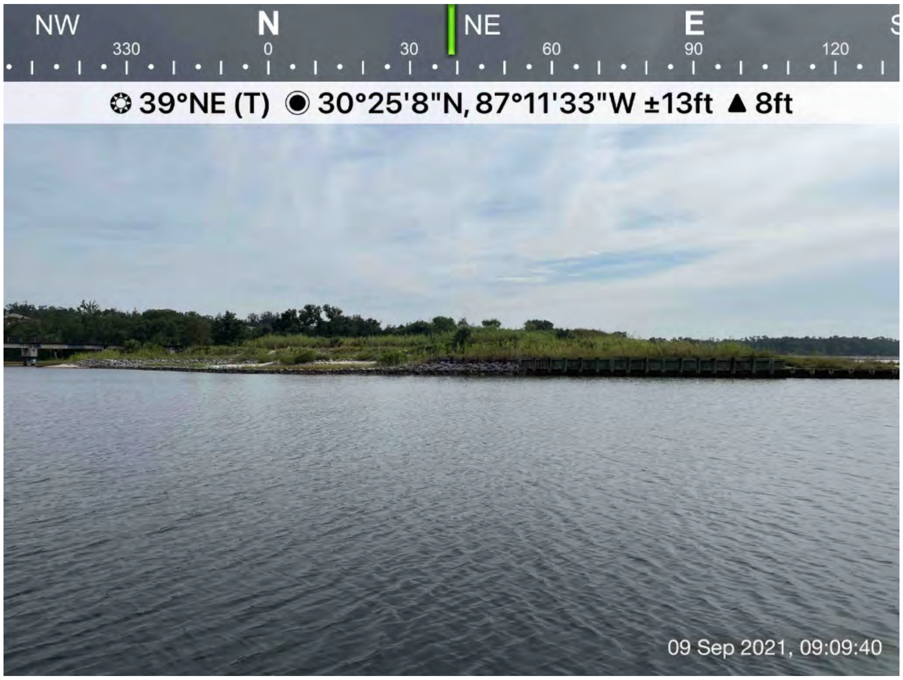


Photograph #2. Mouth of Bayou Texar at Pensacola Bay.

Photograph #3. Area of broad emergent aquatic vegetation located along the west side of the mouth of Bayou Texar. This area is dominated by salt marsh cordgrass (Spartina alterniflora) and common reed (Phragmites australis).

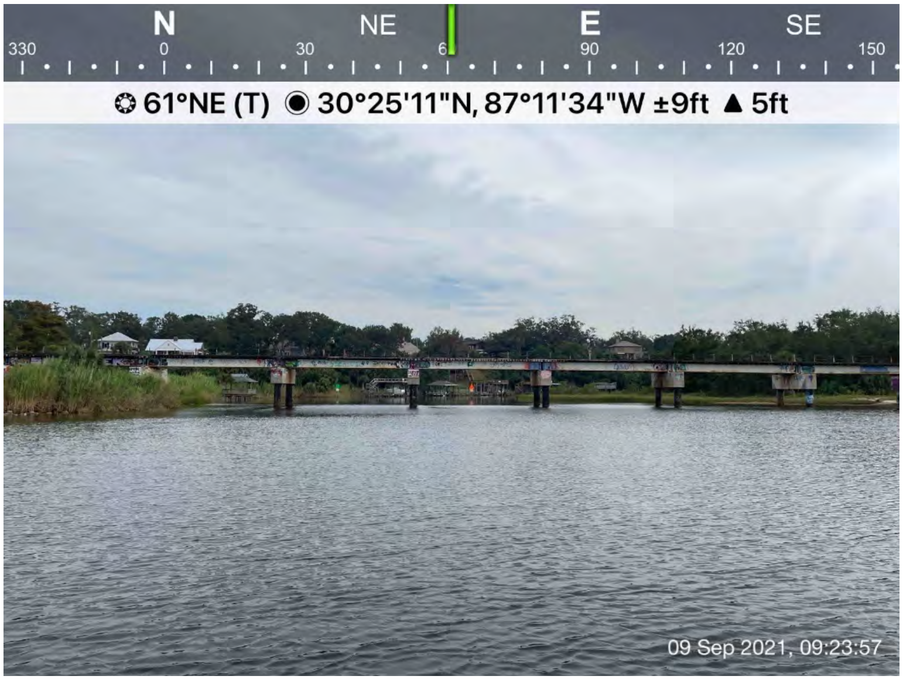


Photograph #4. 17th Ave boat ramp. There is a broad shallow shelf south of the boat ramp that is occupied by salt marsh cordgrass (Spartina alterniflora) and common reed (Phragmites australis). The shoreline north of the boat ramp is occupied by dense populations of common reed (Phragmites australis).

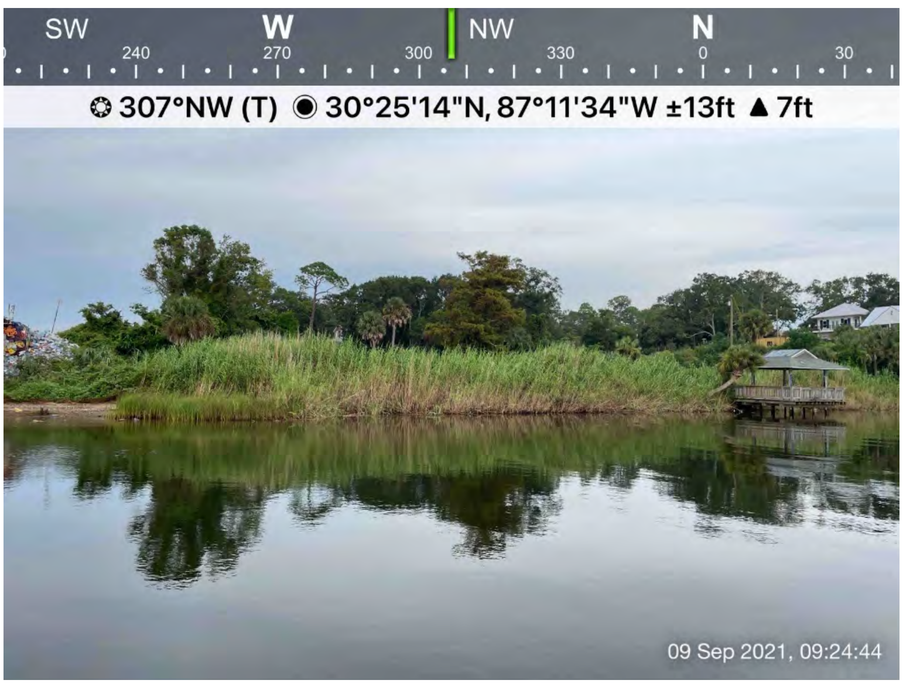


Photograph #5. Eastern shoreline along the mouth of Bayou Texar. This portion of the shoreline is armored with a mixed of vertical wooden retaining wall and limestone rip rap. Areas landward of the armored shoreline are occupied by common reed and salt grass (Distichlis spicata).

Photograph #6. Condition of east shoreline along the mouth of Bayou Texar just south of the railroad bridge. Shoreline armored with quarried limestone. Upland areas landward of the armored shoreline used as a dredge disposal site so native plant communities are altered.



Photograph #7. Railroad bridge that crosses the mouth of Bayou Texar. Structure is supported by steel piles with concrete pile caps.



Photograph #8. Taken just north of the railroad bridge looking northwest along the west shoreline of the Bayou. Shoreline dominated by dense coverage of common reed subtended by salt marsh cordgrass especially along the deeper margins of the littoral zone.

Photograph #9. Taken just north of the railroad bridge looking north at the marked navigation channel that exist between the mouth of the Bayou and the Cervantes Street bridge. There is a significant bluff along the west shoreline between 1720 E Belmont and east toward the terminus of La Rua Landing. Shoreline is largely occupied by broad, dense band of common reed. The bluff is comprised of a mature canopy of live oaks (Quercus virginiana), cabbage palm (Sabal palmetto).

Photograph #10. East shoreline of Bayou texar just between E La Rua Street and the railroad tracks. This area contains a broad shallow littoral zone mostly dominated by salt marsh cordgrass. Submersed aquatic vegetation

(SAVs) located waterward of the emergent vegetation to depths of -3-ft. SAVs primarily dominated by wild celery (Vallisneria americana) subtended by widgeon grass (Ruppia maritima).

Photograph #11. Northeast corner of the railroad track abutment. Littoral zones north of the railroad track largely dominated saltmarsh cordgrass. Xeric hardwood community landward of the emergent wetland community. Shoreline extremely stable and no signs of erosion.

Photograph #12. Northwest corner of the railroad bridge abutment. Shoreline dominate by common reed with limited isolated patches of salt marsh cord grass. Shoreline extremely stable with only disturbance the result of pedestrian access.

Photograph #13. Navigational aids including channel markers and no mooring signs along the entire channel between the railroad bridge and Cervantes Street Bridge. This is east shoreline of the Bayou which has not been affected by land disturbance activities associated with historical residential development. Shoreline dominated by broad shelf of salt marsh cord grass and wild celery. Upland coastal strand/xeric upland hardwood forest landward of the emergent wetland community.

Photograph #14. Submersed reef located along the waterfront of 1817 E La Rua Street along the west shoreline of the Bayou. The reef is obviously purpose built and deployed by the homeowner. It is marked by a sign "danger reef".

Photograph #15. Close up of submersed reef located along the waterfront of 1817 E La Rua Street.

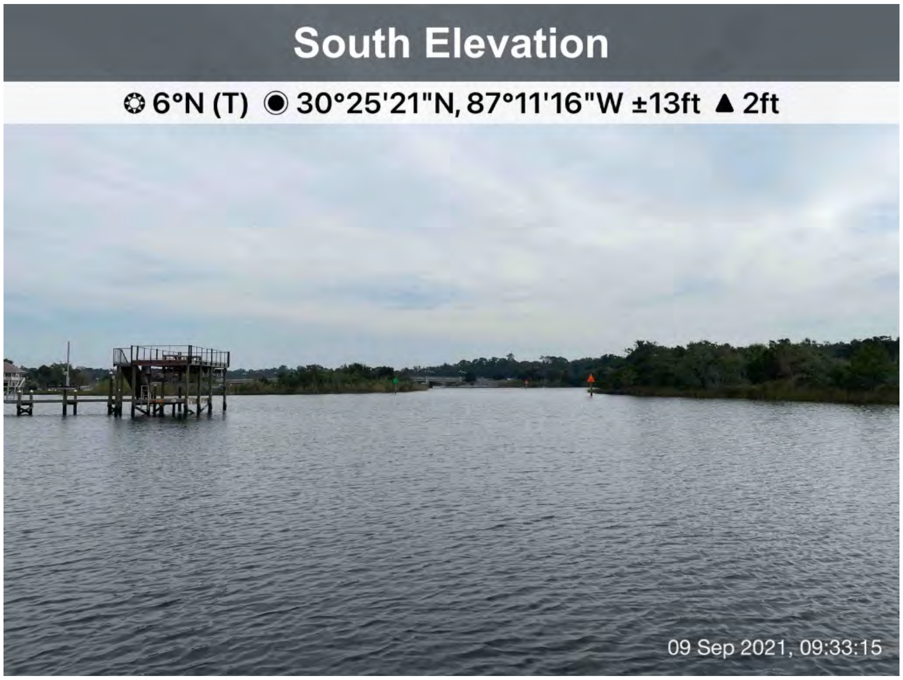
Photograph #16. View of east shoreline

Photograph #17. East shoreline of the Bayou just south of the east terminus of La Rua landing. It's at this location in the bayou where black needle rush (*Juncus romerianus*) begins to dominate the emergent wetland community. Needle rush becomes prevalent just north of Marker 6A (left of picture).

Photograph 18. West shoreline of the Bayou at 1919 E La Rua Street. It's at this location that the bluff subsides and tapers to the east. Manicured lawns terminate at a broad band of emergent and submersed vegetation. Emergent vegetation is dominated by common reed (landward side) and saltmarsh cord grass (waterward side). Submersed vegetation is dominated by wild celery.

Photograph #19. West shoreline of Bayou at 400 La Rua Landing. Single family lots are elevated a few feet above the mean high water line. Manicured lawns end at broad band of emergent and submersed vegetation consisting of salt marsh cord grass and wild celery.

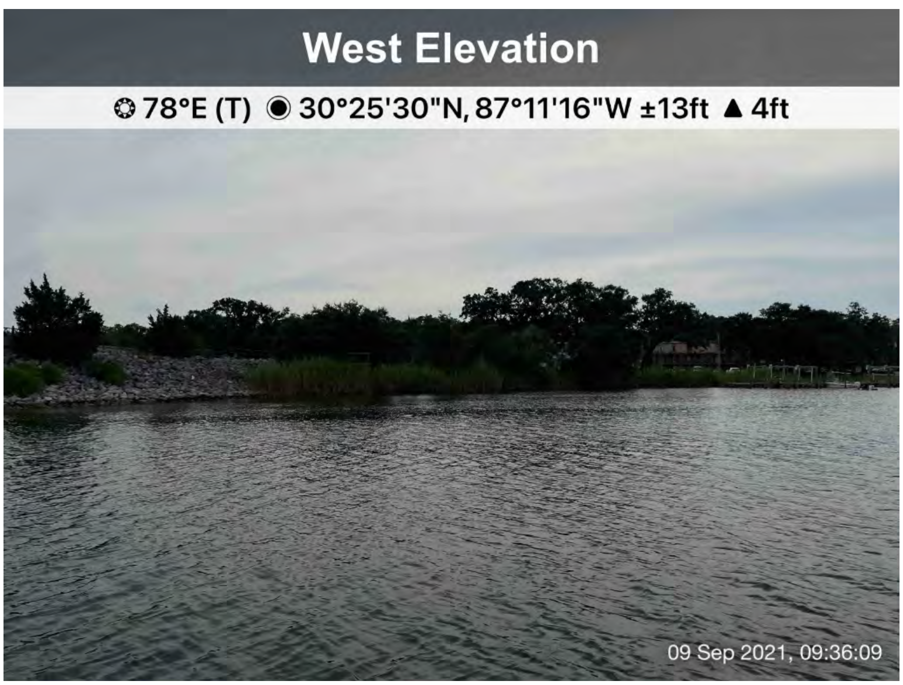
Photograph #20. Tidal flat located between the east shoreline and the center channel of the bayou. This area is dominated by black needle rush subtended by salt marsh cordgrass (along waterward edge). This broad band of vegetation is surrounding by dense meadow of submersed vegetation consisting of wild celery.



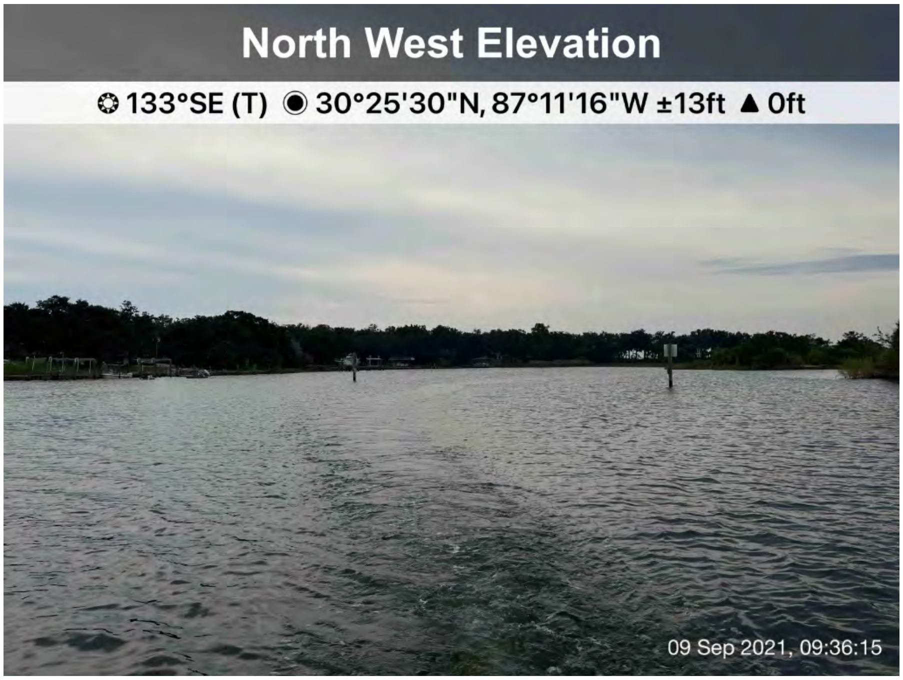
Photograph #21. Taken just east of 406 La Rua Landing looking north toward Cervantes street bridge.

Photograph #22. West shoreline of the bayou at 406 and 408 La Rua Landing. Broad band of emergent wetland vegetation dominated by salt marsh cord grass between the residential structures and the mean high-water line. There is a broad band of submersed band of wild celery between the mean high-water line and the channel. Boardwalk's accessing the riparian waterfront are elevated 5-ft. above grade to comply with dock construction guidelines over marsh.

Photograph #23. West shoreline of Bayou at 2008 E Gadsen Street at the southwest corner of the Cervantes Street bridge abutment. Shoreline of this property altered and resembles open sand beach. The manicured lawn of this property terminates at the open beach. No emergent or submersed vegetation at this location.

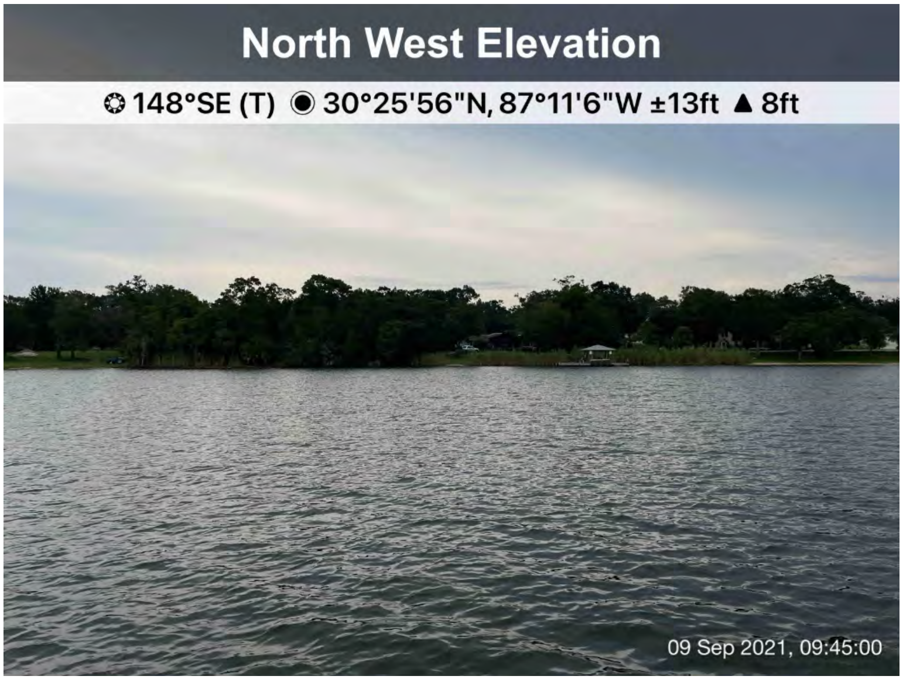


Photograph #24. West shoreline of the bayou at the northwest corner of the Cervantes Street bridge abutment. Abutment is armored by quarried limestone. Broad, dense band of common reed located just north of the bridge abutment along the west shoreline of the property.

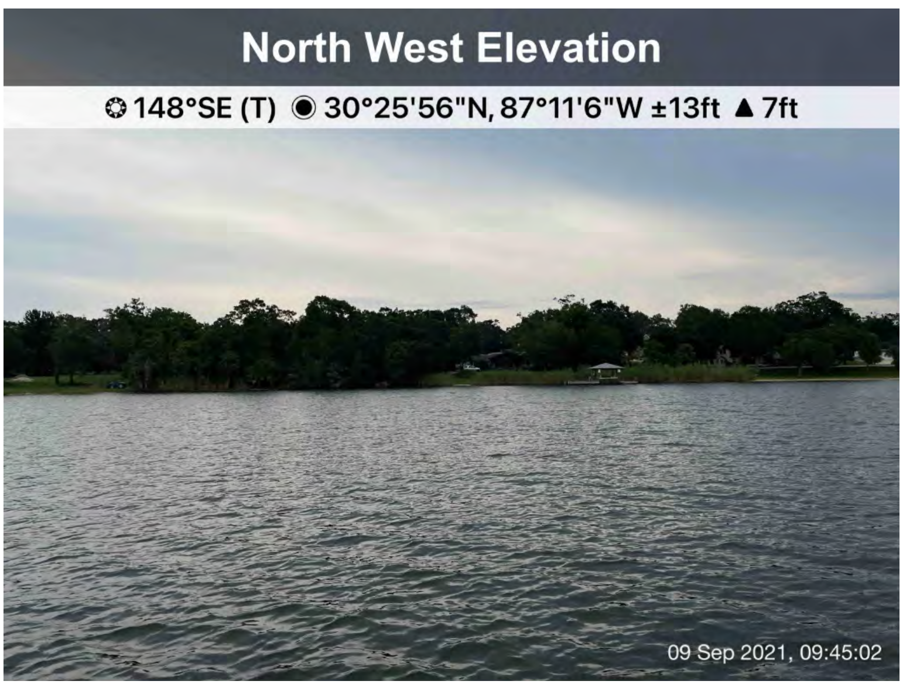


Photograph #25. Taken just south of the Cervantes Street bridge looking south along the center channel of the Bayou.

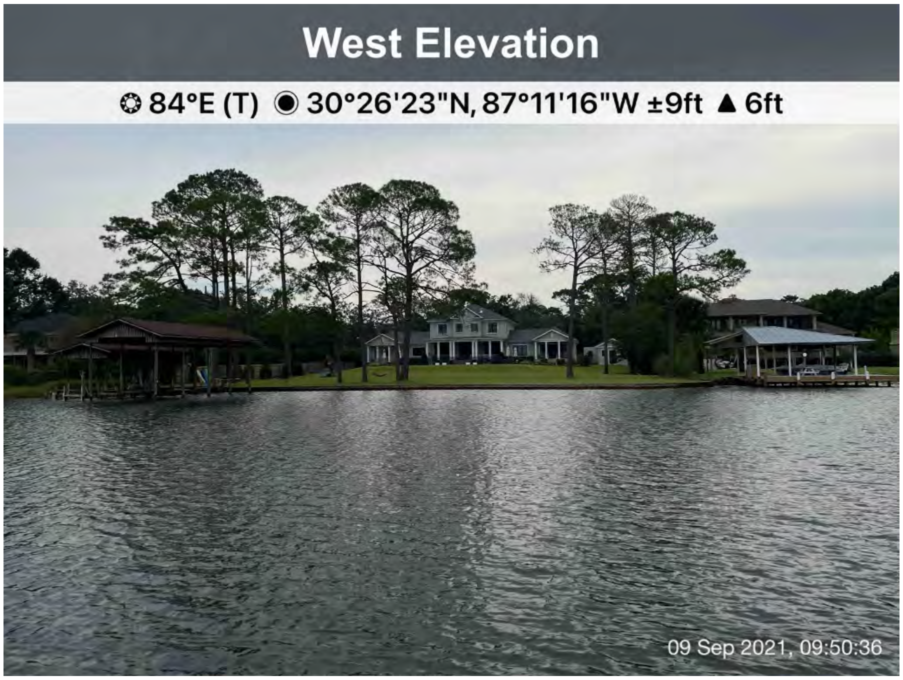
Photograph #26. West shoreline of the Bayou at the east terminus of E Mallory Street between Bayview Park and Osceola Blvd. House located at 1700 Osceola Blvd (White House) is located only a few feet of the mean high-water line. This appears to be purpose built especially considering the small boat garage specifically oriented to take advantage of its position along the shoreline. Initial thoughts would suggest close proximity of the home to the mean high-water line would indicate shoreline erosion but in our opinion this structure may have been constructed before city setbacks from the mean high-water line were required.



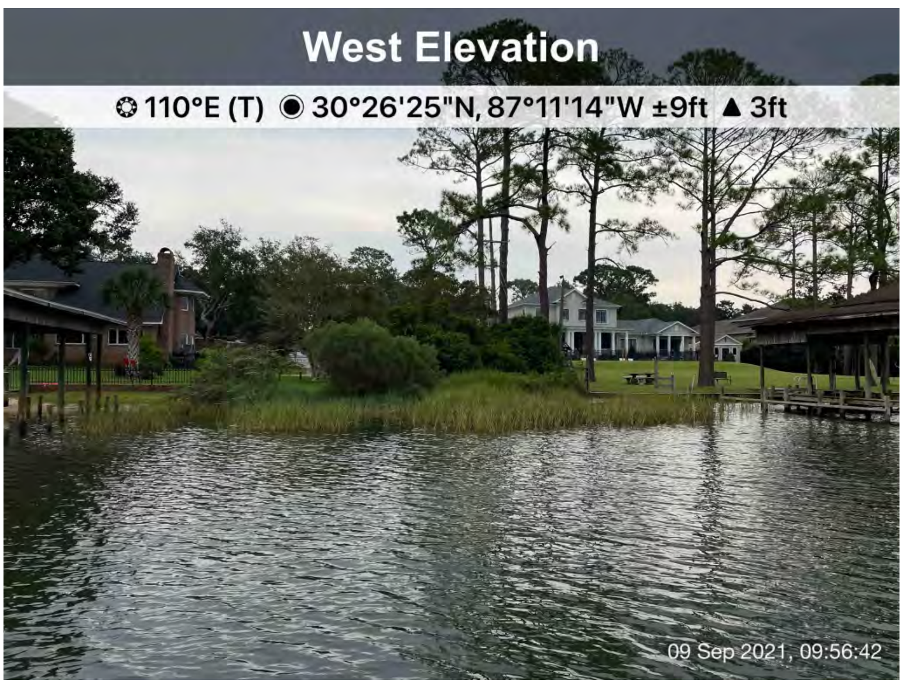
Photograph #27. Taken in the center of the Bayou looking southeast at the east shoreline of the Bayou.



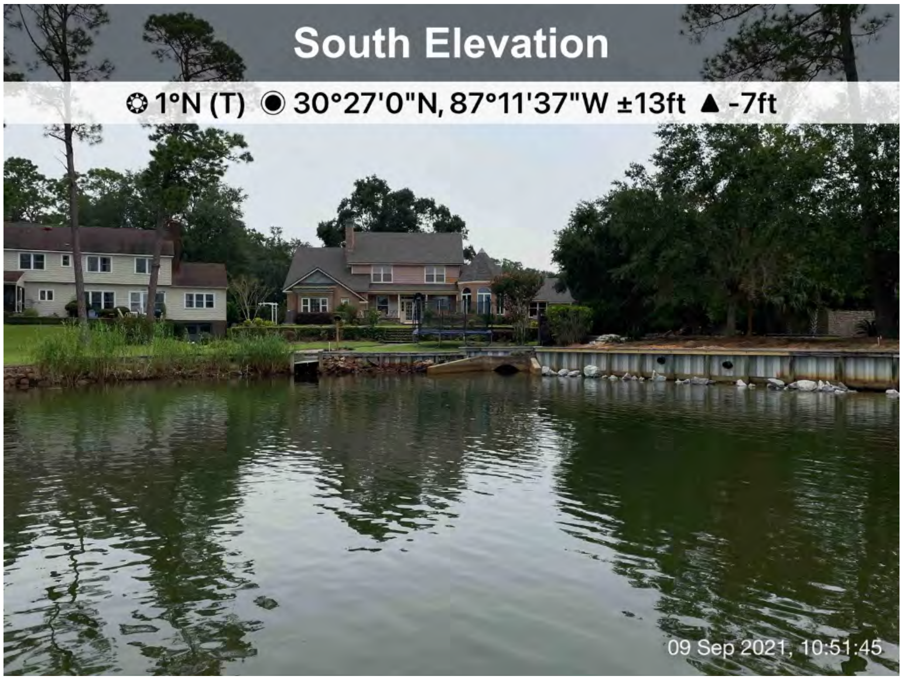
Photograph #28. Taken in the center of the Bayou looking southeast at the east shoreline of the Bayou.



Photograph #29. East shoreline of the Bayou just south of Hyde Park outfall. Shoreline represents one type of shoreline stabilization (i.e. manicured lawn that terminates to a vertical wall).



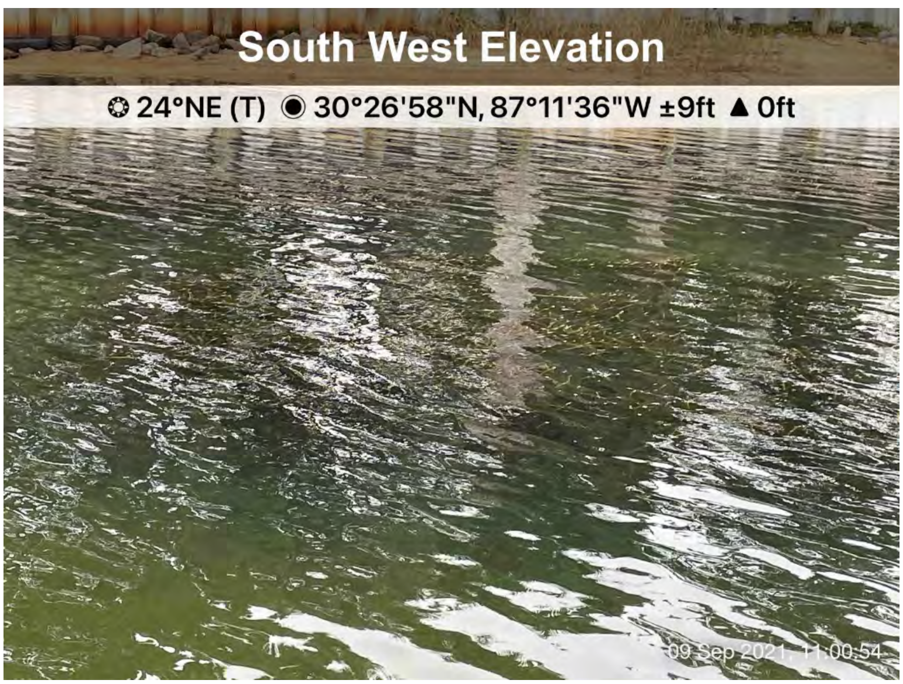
Photograph #30. Hyde Park outfall location. Emergent wetland vegetation consisting primarily of salt marsh cordgrass along the wateward edge of outfall.



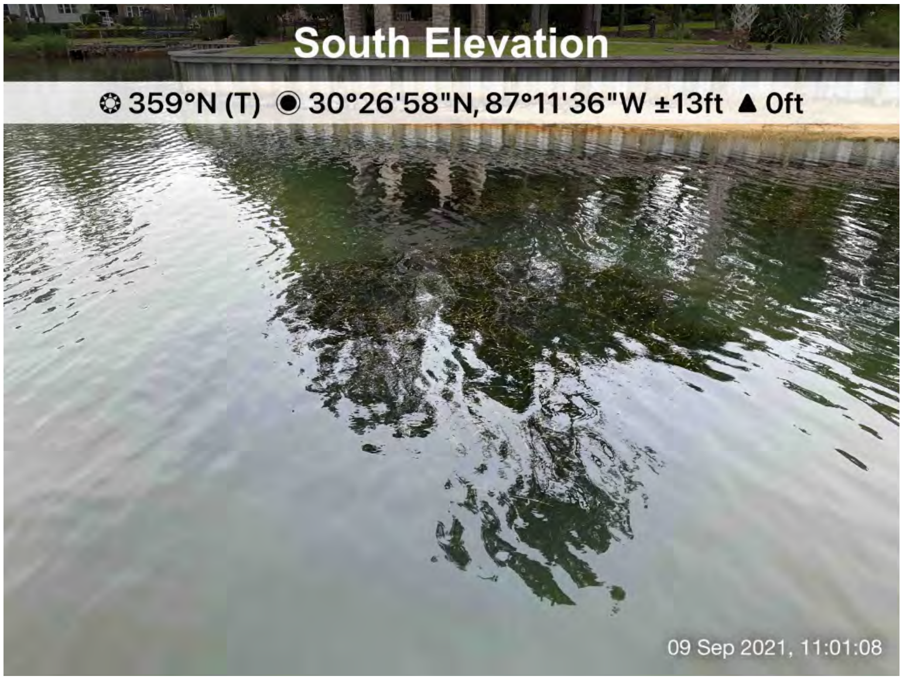
Photograph #31. Seville Street outfall location. There is a large sediment plume at this location which appears to be sediments that have accumulated from the outfall. Depths at this location are less than 2-ft. The bottom is dominated by coarse sands with thin layer of leaf pack. Dense bands of wild celery located along the entire shoreline but devoid in the area of the sediment plume which is centrally located in the small embayment.

Photograph #32. 1941 Seville Drive just northwest of outfall.

Photograph #33. 2000 Villafane Drive. Large estate home located just southeast of Seville Street outfall. This property is armored by vertical wall faced with quarried limestone. Dense band of submersed aquatic vegetation (wild celery) along the entire waterfront.



Photograph #34. Wild celery located along the waterfront of 2000 Villafane Drive.



Photograph #35. Wild celery located along the waterfront of 2000 Villafane Drive.

Photograph #36. Wild celery located along the waterfront of 2000 Villafane Drive.

Photograph #37. 691 Tennyson place. Emergent vegetation begins to transition to species less tolerant to saltwater including arrowhead (Sagittaria lancifolia), spider lily (Crinum Americanum), sawgrass (Cladium jamaicense). Aquatic hardwood trees also present including sweetbay magnolia (Magnolia virginiana) and bald cypress (Taxodium distichum).

Photograph #38. 695 Tennyson Place. East shoreline of Bayou dominated by broad band of emergent and submersed aquatic vegetation. Emergent vegetation consists of arrowhead, spider lily, and sawgrass. Submersed vegetation is dominated by wild celery.

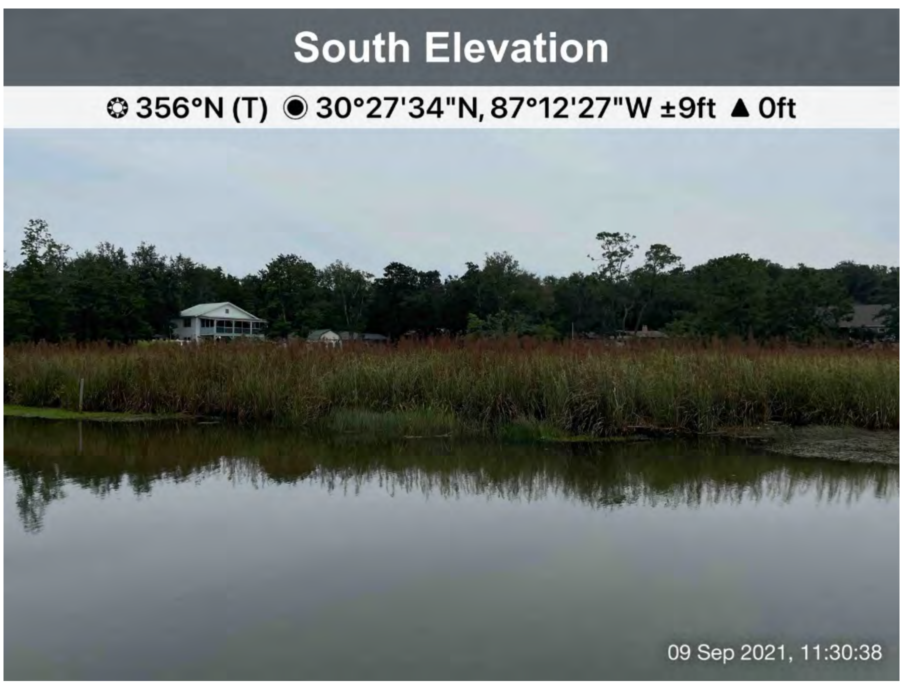
Photograph #39. 731 Tanglewood Drive. East shoreline of Bayou. Shoreline hardened with wooden wall faced with concrete rubble.

Photograph #40. 875 Tanglewood Drive. East shoreline of the Bayou. Manicured lawn to broad band of emergent wetland vegetation consisting of needle rush and arrowhead. Broad band of dense submersed vegetation consisting of wild celery just waterward of the emergent vegetation persisting to depths of -3-ft.

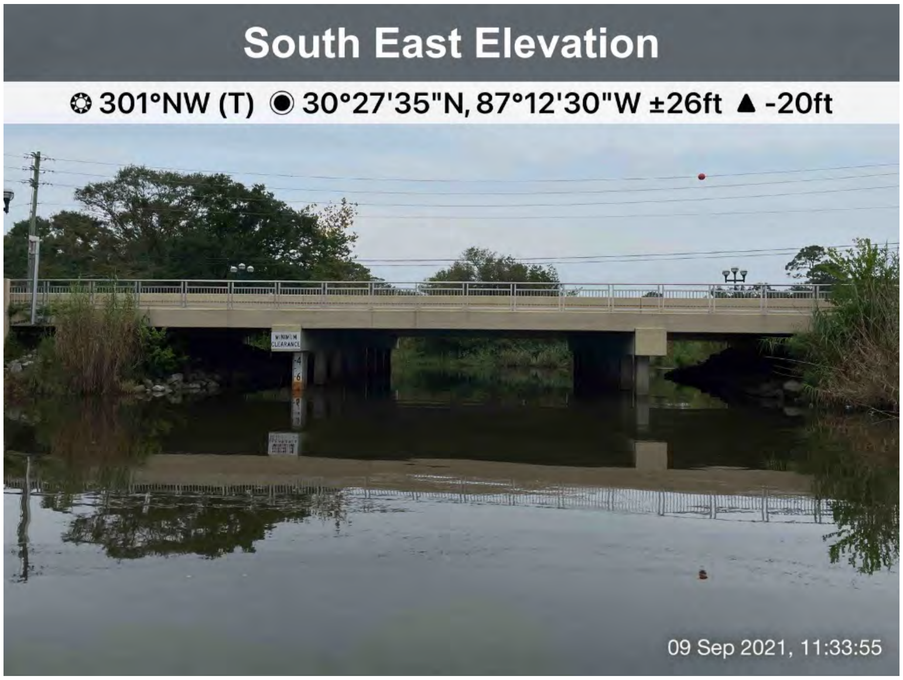
Photograph #41. Fruiting wild celery along the waterfront of 875 Tanglewood Drive.

Photograph #42. Waterfront of 4150 Menendez Drive. West shoreline of the Bayou. Emergent vegetation at this location dominated by common reed.

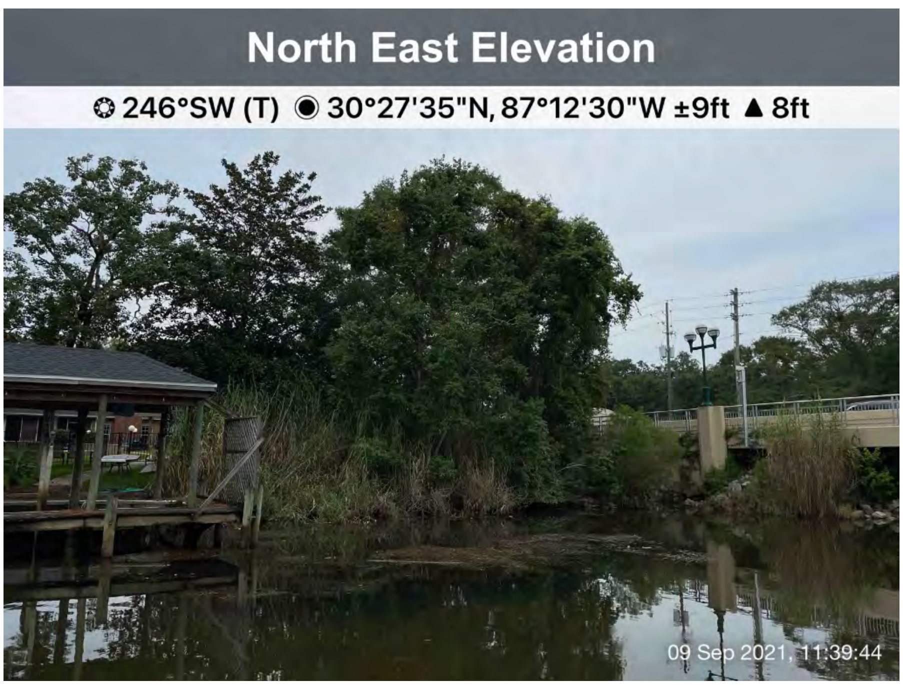
Photograph #43. Taken just east of 4150 Menendez Drive looking north at 12th Ave bridge.



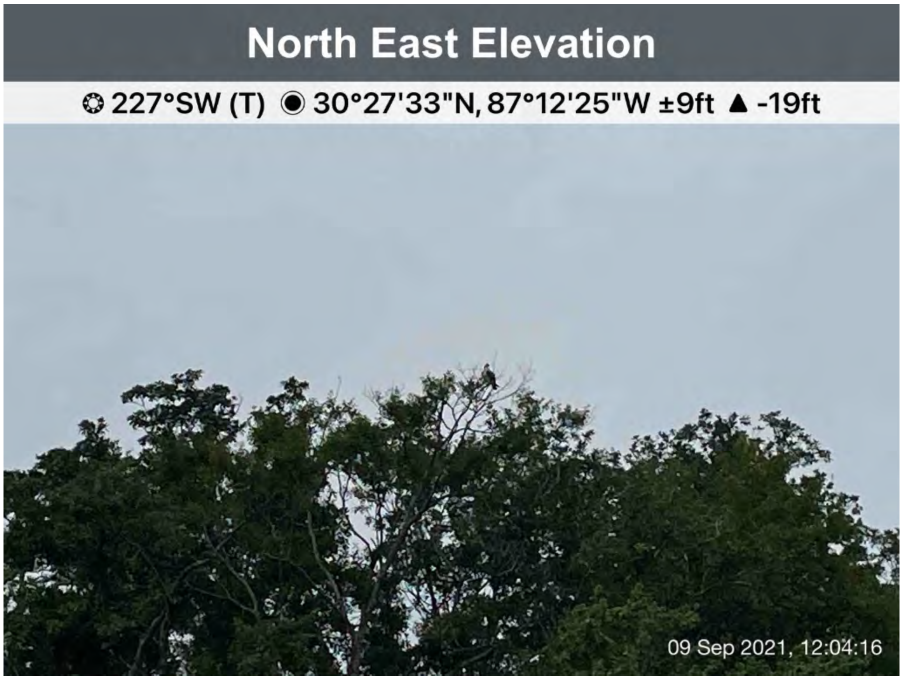
Photograph #44. Taken just east of 4150 Menendez Drive looking north east at broad tidal flat largely comprised of sawgrass.



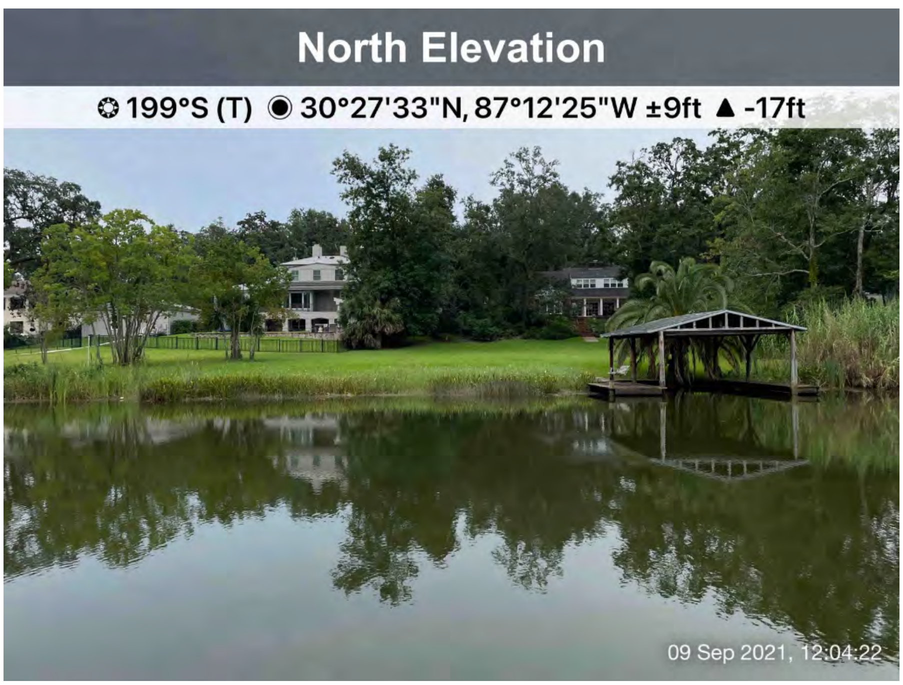
Photograph #45. 12th Ave bridge.



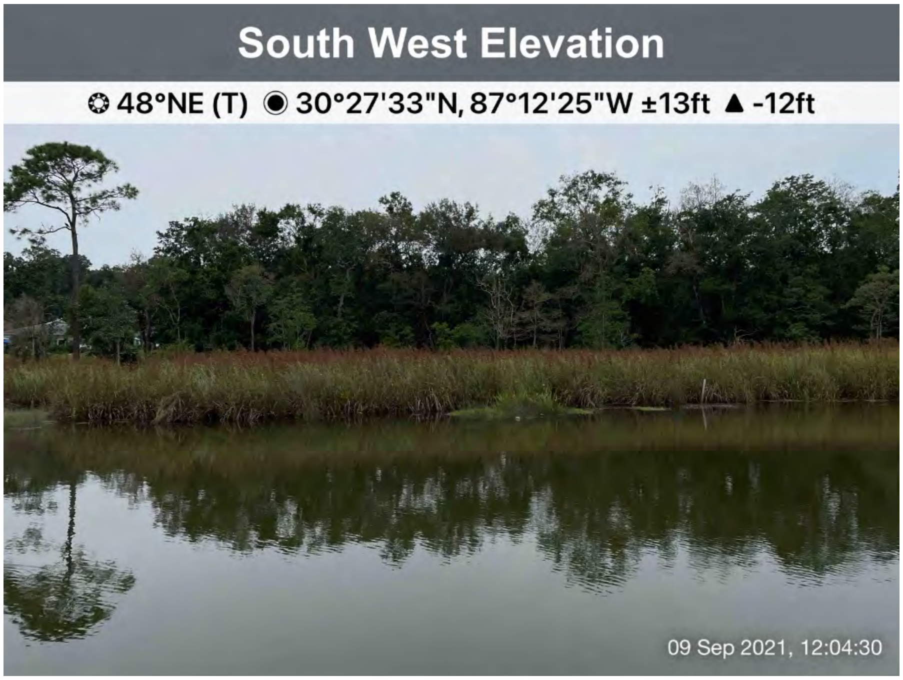
Photograph #46. Southwest corner of 12th Ave bridge abutment. Shoreline is dominated by common reed with a broad band of submersed vegetation (wild celery) located just waterward of the mean high water line and extending to depths of -3-ft.



Photograph #47. Osprey just south of 12th Ave bridge.

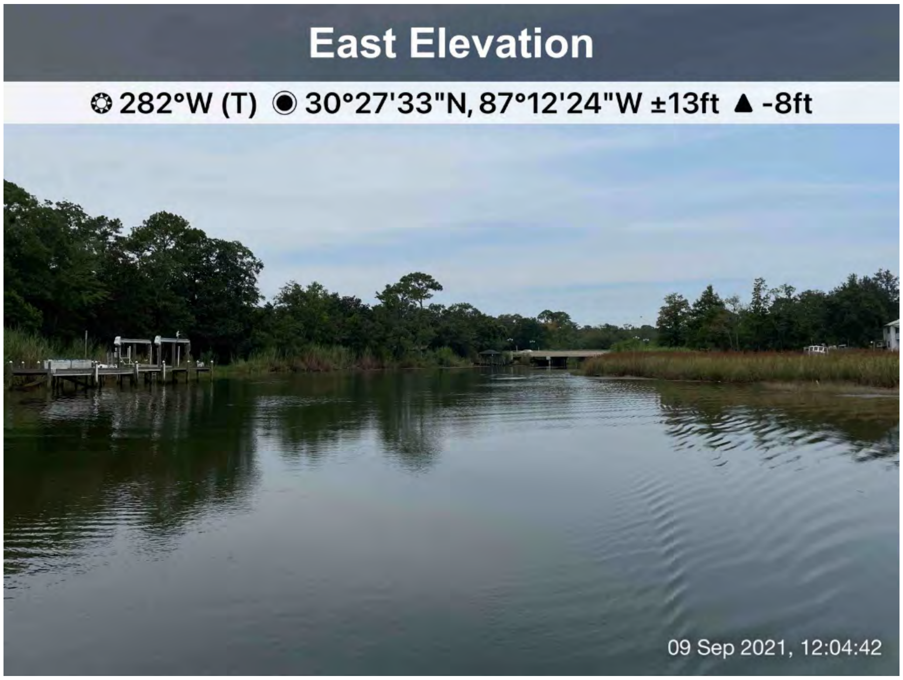


Photograph #48. 4130 Menendez Street. West shoreline of Bayou. Manicured lawn to emergent wetland vegetation.



Photograph #49. East shoreline of the Bayou just east of 4120 Menendez Drive. Large area of emergent wetland vegetation consisting primarily of sawgrass at this location.

Photograph #50. Taken in the center of the Bayou just north of 4120 Menendez looking south.



Photograph #51. Taken in the center of the Bayou just north of 4120 Menendez looking northwest towards 12th Ave.

Photograph #52. Gamarra Road outfall located along the west shoreline of the Bayou.

Photograph #53. 681 Tennyson Place. East shoreline of the Bayou. Common example of typical shoreline stabilization method for single family residence along the bayou. Vertical sheet pile wall with no rip rap.

Photograph #54. 234 Severin Drive. West shoreline of the Bayou. Large dense band of emergent wetland vegetation between the manicured lawn and the mean high-water line.

Photograph #55. 104 Severin Drive just north of E34th Street outfall along west shoreline of Bayou.

Photograph #56. Dock structure at 104 Severin Drive. Boathouse with enclosed walls generally not allowed by regulatory agencies with purview.

Photograph #57. E 34th Street outfall. West shoreline of Bayou.

Photograph #58. Menendez drive outfall located along west shoreline of Bayou.

Photograph #59. Area proximal to Menendez street outfall dominated by wild taro (Colocasia esculenta).

Photograph #60. 3420 North 18th Ave. Shoreline armored with vertical wall faced with quarried limestone. Broad area of submersed vegetation consisting of wild celery waterward of the existing rip rap to depths of -4-ft.

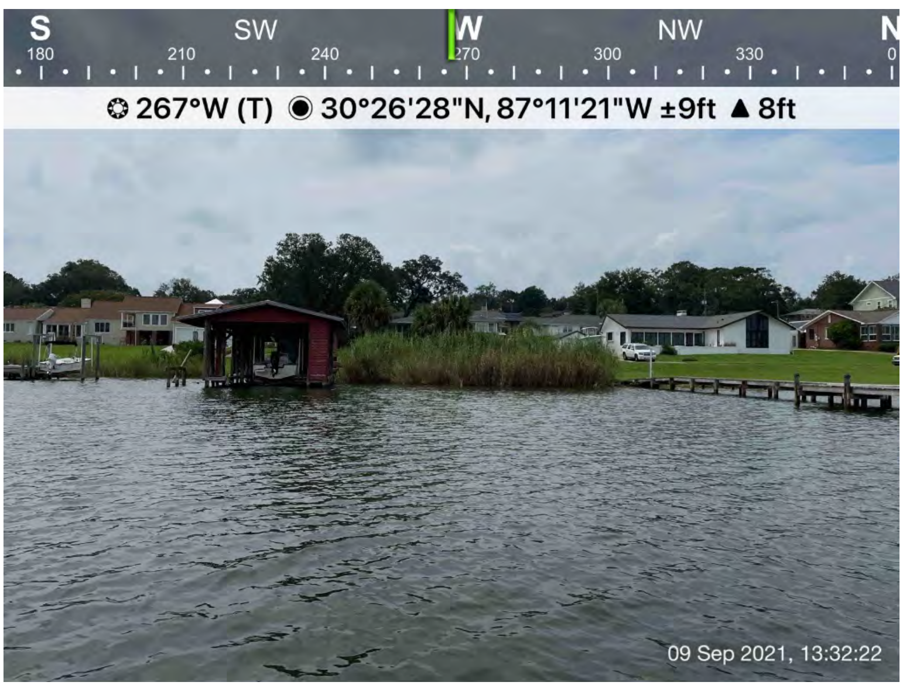
Photograph #61. 371 Woodbine Drive. East shoreline of the Bayou. Two shoreline stabilization techniques including vertical wall with no rip rap (left) and rip rap revetment (right). Submerged lands proximal to the shoreline comprised of submersed aquatic vegetation consisting of wild celery.

Photograph #62. 3012 Blackshear Ave. West shoreline of Bayou. Example of ineffective BMPs during construction. No barrier in place to keep exposed sediments from eroding into the Bayou.

Photograph #63. 3000 Blackshear Ave. West shoreline of Bayou. Manicured lawn to the mean high-water line. Little to no emergent wetland vegetation and limited submersed vegetation.

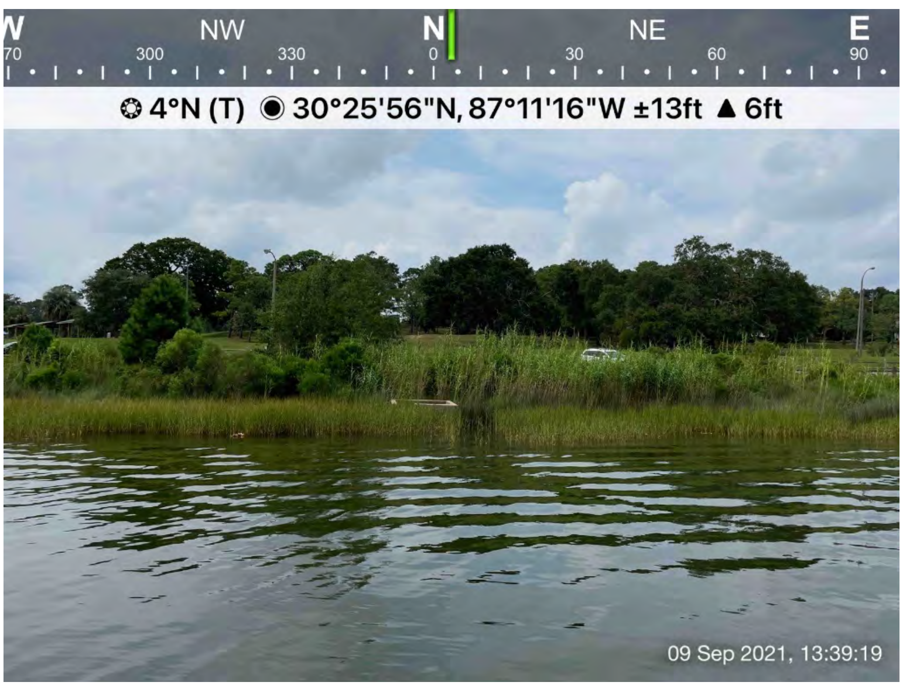
Photograph #64. Taken just south of Point Lakeview along west shoreline of Bayou. Manicured lawn to narrow band of emergent wetland vegetation at this location.

Photograph #65. 2600 Paradise Point Drive. West shoreline of Bayou. Open beach at this location. No emergent or submersed vegetation. Highly manipulated shoreline.

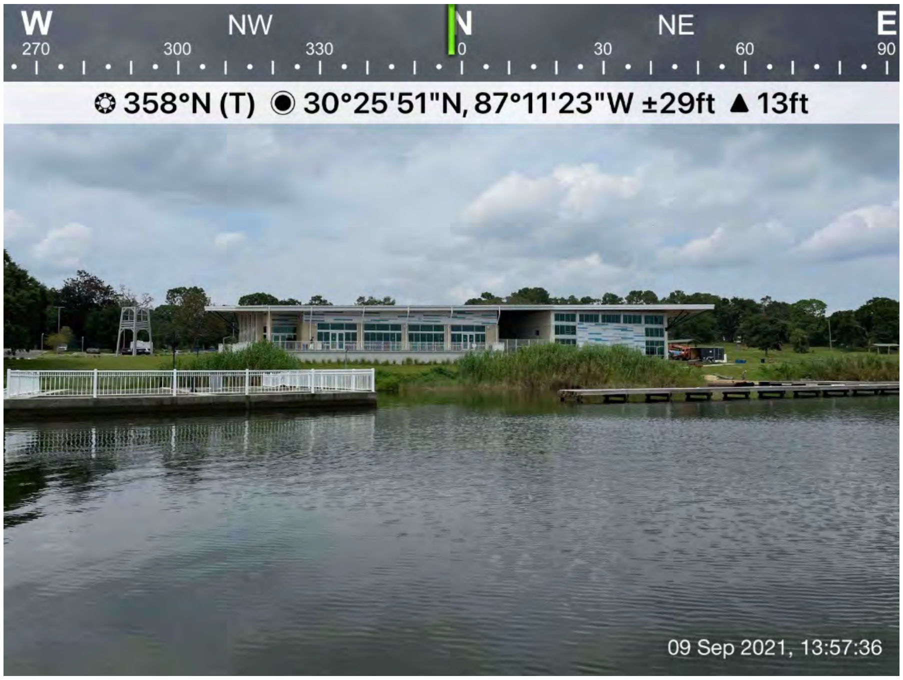


Photograph #66. 2304 Osceola Blvd. West shoreline of Bayou. This portion of the shoreline largely armored with except for a few areas with isolated patches of common reed.

Photograph #67. 2120 Whaley Ave. West shoreline of Bayou. Heavily armored shoreline consisting of stepped vinyl wall with Class II limestone rip rap.



Photograph #68. Outfall located at Malory Street parking lot along Bayview park.

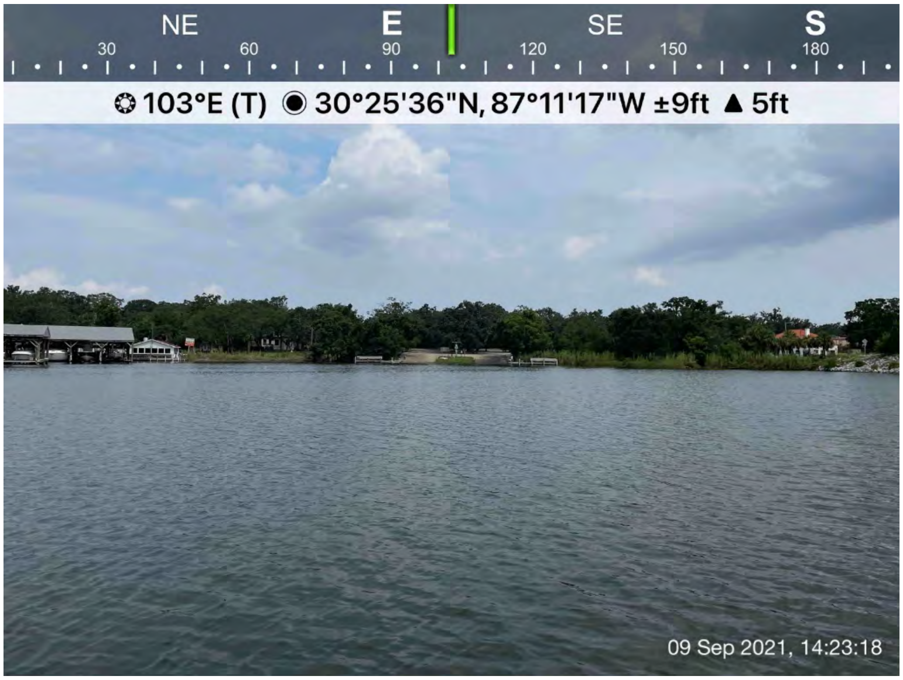


Photograph #69. Bayview park.

Photograph #70. E De Soto Street outfall location just north of Rooks Marina.

Photograph #71. Marina Oyster Barn.

Photograph #72. Marina Oyster Barn.



Photograph #73. Bayou Texar Boat ramp.

Photograph #74. Cervantes Street bridge.

Photograph #75. Cervantes street northwest bridge abutment.

Exhibit B

Calibration Certificate

Calibrated at Geotech's Florida service center
12165 Metro Parkway #25B
Fort Myers, FL 33966
(800) 304-5325 *Fax:* (239) 476-8893

YSI Pro DSS Calibration Certificate

Unit Number: 6046
Serial Number: 17K101134

Calibration Date 9/1/2021
Technician: Andy Jimenez

Installed Probes
- ☑ Conductivity
- ☑ PH/ORP
- ☑ DO
- ☑ TURB

- ☑ Display is clear, and free of damage
- ☑ Cable and accessories are free of damage
- ☑ Firmware version is up to date.

Display Battery 100 % **Pass**
Cable Flex Test: **Pass**

Cable Length	10M	pH/ORP Serial #	20M100273
Cable Lot #	18G101312	DO Probe Serial #	21B106180
Cond Probe Lot #	18G102746	Turb Probe Serial #	18J103579
Bath Temp	26.5 °C		
Meter Temp	26.3 °C		
Variance	-0.20	**Pass**	

Cond

Calibration	Reading		Buffer Lot #	Exp. Date	
1.413 mS	1.413 mS	**Pass**	OGK590	11/21	**Pass**

pH

Point Test	Calibration	Reading	mV	Slope		Buffer Lot #	Exp. Date	
2 Point	pH 7.00	pH 7.00	-6.2 mV			OGE815	5/22	**Pass**
	pH 10.01	pH 10.01	-179.3 mV	173.1	**Pass**	1GA961	1/23	**Pass**

ORP

Calibraition	Reading		Buffer Lot #	Exp. Date	
220 mV	220 mV	**Pass**	1GE739	2/22	**Pass**

Turbidity

Zero	Reading	Variance		Cal	Reading	Variance		Buffer Lot #	Exp. Date	
0 ntu	0 ntu	0 ntu	**Pass**	124 ntu	124 ntu	0.0%	**Pass**	20M	12/21	**Pass**

DO

Barometer	Calibration	Reading	Variance		Test Fluid
745 mmHg	98 %	98 %	0.0%	**Pass**	Water Saturated Air

Time:	Min.	Sec.	Reading		Nitrogen Lot #
	5	0	1 %	**Pass**	UA1066

Geotech Environmental Equipment, Inc. takes pride in ensuring this instrument is tested to function as specified by the manufacturer and was calibrated in accordance to manufacturer specifications. All calibration standards used are NIST traceable. With the provided lot numbers we can provide NIST documents on request. Call us at (800) 833-7958 and we will be glad to help.

Exhibit C

Sample Location Map

SHEET:	1 OF 1
DATE:	09-10-21
DRAWN BY:	ZMJ
PROJECT NO.:	2018-703

Carpenter Creek/Bayou Texar Watershed Management Plan

Overall Map
Sample Locations

Notes

Exhibit D

Physical Water Quality Analysis Results

Sample #	Station Name	Latitude	Longitude	Measurement Date	Sample Time	Secchi Depth (m)	Total Depth (m)	Muck Depth (m)	Top/Mid/Bottom	WQ Depth (m)	Water Temp (°C)	DO (mg/L)	DO (%)	Salinity (ppt)	Conductivity (µS/cm)	pH	Turbidity (NTU)	Total Dissolved Solids	Notes
1	Mouth of Bayou	30.4185	-87.1924	9/9/2021	9:20 AM	N/A	2.82	NM	Top	0.30	N/A	7.49	98.5	8.50	14500	7.48	0.41	9700	Coarse sand, no muck
									Mid	1.41	N/A	4.94	69.0	10.70	18200	7.53	0.65	11820	
									Bottom	2.51	N/A	4.00	55.8	11.50	19700	7.50	0.56	12802	
2	Oyster Barn Marina - Near Shore East	30.4276	-87.1871	9/9/2021	2:06 PM	1.25	2.29	NM	Top	0.30	28.8	9.00	119.5	4.37	7941	7.76	0.73	5162	Coarse sand, no muck
									Mid	1.14	28.6	8.41	111.8	5.20	9330	7.67	0.56	6064	
									Bottom	1.98	29.0	5.81	79.1	8.56	14811	7.41	11.67	9627	
3	Oyster Barn Marina - Near Center	30.4272	-87.1885	9/9/2021	2:10 PM	1.31	3.07	>1.20	Top	0.30	28.8	9.08	120.3	4.17	7602	7.63	0.37	4941	Light grey muck, very fine
									Mid	1.54	29.2	4.86	67.3	10.79	18342	7.44	2.02	11922	
									Bottom	2.76	29.1	2.50	35.0	12.97	21711	7.36	25.81	14112	
4	Bayview Park North Dock - Near Shore West	30.4323	-87.1878	9/9/2021	1:44 PM	1.19	2.04	0.76	Top	0.30	28.7	9.20	121.7	4.03	7356	7.52	0.06	4781	Light grey muck, very fine
									Mid	1.02	29.6	4.30	58.7	6.97	12261	7.20	12.83	7969	
									Bottom	1.73	29.4	1.52	21.0	10.36	17666	7.11	29.06	11483	
5	Bayview Park North Dock - Near Center	30.4314	-87.1871	9/9/2021	1:49 PM	1.16	2.84	>1.82	Top	0.30	28.6	9.01	118.5	3.51	6465	7.40	0.17	4203	Light grey muck, very fine
									Mid	1.42	28.9	8.38	112.2	5.50	9834	7.66	0.54	6392	
									Bottom	2.53	29.2	3.71	51.4	11.25	19057	7.34	13.05	12387	
6	Hyde Park - Near Shore East	30.4404	-87.1874	9/9/2021	9:56 AM	0.99	1.83	0.39	Top	0.30	28.2	7.65	100.0	3.56	6518	6.97	0.75	4250	Grey muck, very fine
									Mid	0.92	29.1	7.65	100.0	5.27	9390	7.47	0.55	6120	
									Bottom	1.52	29.9	5.78	79.3	6.73	11874	7.30	8.82	7718	
7	Hyde Park - Offshore East	30.4402	-87.1878	9/9/2021	10:17 AM	1.09	2.13	>1.52	Top	0.30	29.2	8.46	113.4	4.69	8479	7.42	0.28	5511	Yogurt consistency grey muck, high % fines
									Mid	1.07	29.9	6.90	94.8	6.95	12230	7.38	1.47	7949	
									Bottom	1.82	30.1	5.33	73.5	7.34	12867	7.23	7.21	8364	
8	Hyde Park - Near Center	30.4401	-87.1883	9/9/2021	10:29 AM	1.19	2.40	>1.52	Top	0.30	29.3	8.41	113.2	5.17	9288	7.57	0.64	6037	Light grey muck, very fine
									Mid	1.20	29.9	6.29	86.7	7.73	13496	7.31	3.16	8772	
									Bottom	2.09	29.9	3.35	46.4	8.31	14439	7.13	27.72	9385	
9	Seville Dr Outfall - Near Shore East	30.4499	-87.1937	9/9/2021	10:45 AM	0.61	0.61	0	Top	0.10	29.3	5.54	74.2	4.17	7614	6.84	2.00	4949	Coarse sand, no muck
									Mid	0.31	29.8	4.33	58.7	4.84	8751	6.79	1.94	5688	
									Bottom	0.45	29.9	3.92	53.1	4.98	8974	6.79	1.89	5833	
10	Seville Dr Outfall - Offshore East	30.4495	-87.1939	9/9/2021	11:00 AM	1.09	1.58	0	Top	0.30	29.9	7.56	102.8	5.32	9553	7.15	1.32	6209	Coarse sand, no muck
									Mid	0.79	30.3	7.17	98.6	6.23	11056	7.23	1.66	7816	
									Bottom	1.27	30.3	6.95	95.6	6.43	11386	7.29	3.41	7401	
11	Seville Dr Outfall - Near Center	30.4488	-87.1941	9/9/2021	11:12 AM	1.09	2.13	>1.83	Top	0.30	29.9	8.24	111.7	4.66	8437	7.22	0.23	5484	Grey yoghurt consistency muck
									Mid	1.07	30.0	6.38	87.4	6.56	11594	7.10	1.77	7536	
									Bottom	1.82	29.9	5.02	69.2	7.52	13154	7.08	6.91	8550	
12	1950 E Texar - Near Shore West	30.4510	-87.2020	9/9/2021	1:15 PM	0.73	1.00	0.61	Top	0.30	29.8	5.57	75.1	4.23	7709	6.75	2.45	5011	Dense leaf pack, light grey muck with strong sulphide odor
									Mid	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
									Bottom	0.69	30.2	5.90	80.8	5.53	9903	6.78	3.64	6437	
13	1950 E Texar - Near Center	30.4518	-87.2008	9/9/2021	1:22 PM	0.91	1.83	>1.83	Top	0.30	29.3	8.23	109.7	3.66	6725	6.94	0.71	4371	Light grey muck, very fine
									Mid	0.92	30.2	8.21	112.5	5.85	10441	7.20	0.90	6787	
									Bottom	1.52	30.2	6.94	95.4	6.58	11633	7.07	1.84	7562	
14	E 34th Outfall - Near Shore West	30.4538	-87.2028	9/9/2021	12:50 PM	0.85	1.28	0.98	Top	0.30	29.6	8.22	110.9	4.73	8554	6.92	1.05	5560	Light grey muck, very fine with strong sulphide smell
									Mid	0.64	30.2	7.48	102.5	6.03	10730	6.91	8.36	6974	
									Bottom	0.97	30.2	7.25	99.4	6.06	10778	6.94	8.09	7005	
15	E 34th Outfall - Near Center	30.4539	-87.2025	9/9/2021	12:38 PM	0.85	1.98	>1.83	Top	0.30	29.7	8.40	113.6	4.80	8670	7.04	0.74	5635	3" layer of coarse sediment on top of light grey muck
									Mid	0.99	30.1	6.87	94.3	6.40	11344	6.96	135.30	7374	
									Bottom	1.67	30.1	6.23	85.5	6.61	11682	6.94	6.35	7593	
16	Gamarra Rd Outfall - Near Shore West	30.4557	-87.1686	9/9/2021	12:14 PM	0.94	1.22	1.58	Top	0.30	28.7	7.57	100.3	4.36	7915	6.67	2.64	5145	Grey muck with sulphide odor
									Mid	0.61	29.6	7.57	102.2	5.14	9247	6.70	6.52	6011	
									Bottom	0.91	29.8	7.69	104.5	5.52	9885	6.79	10.85	6425	
17	Gamarra Rd Outfall - Near Center	30.4558	-87.2042	9/9/2021	12:25 PM	0.76	1.52	>1.83	Top	0.30	29.3	8.20	110.3	4.95	8915	6.89	1.67	5795	Heavy leaf pack, grey muck with sulphide odor
									Mid	0.76	29.9	7.10	97.2	6.178	10957	6.86	2.21	7122	
									Bottom	1.21	29.9	6.52	89.1	6.29	11151	6.85	2.56	7248	
18	765 Tanglewood Drive - Near Center	30.4577	-87.2049	9/9/2021	12:00 PM	0.91	1.52	>1.83	Top	0.30	29.0	7.27	96.2	4.46	8096	6.60	2.37	5263	Leaf pack, light grey muck with sulphide odor
									Mid	0.76	29.8	7.01	95.4	5.60	10017	6.64	4.46	6511	
									Bottom	1.21	29.8	6.98	95.0	5.57	9971	6.68	6.68	6481	
19	4204 N 12th Ave - Near Center	30.4602	-87.2076	9/9/2021	11:46 AM	1.00	1.28	1.40	Top	0.30	27.0	5.77	73.4	2.65	4955	6.14	3.64	3221	Light tan muck with high organic contents
									Mid	0.64	28.6	5.72	75.8	4.52	8192	6.34	5.47	5325	
									Bottom	0.97	28.4	3.51	46.2	4.32	7844	5.48	4.68	5099	
20	12th Ave Bridge - Near Center	30.4599	-87.2084	9/9/2021	11:31 AM	1.03	1.03	0	Top	0.30	24.3	6.55	78.3	0.21	434	6.56	0.32	282	Coarse sand, no muck
									Mid	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
									Bottom	0.72	28.1	5.77	75.6	4.18	7608	6.39	6.84	4945	

Exhibit E

Sediment Characterization Results

Station Name	Latitude	Longitude	Depth to Top of Muck (ft)	Hard Bottom Depth (ft)	Muck Depth (ft)	Sediment Notes
Mouth of Bayou	30.4185	-87.1924	9.25	9.25	0.0	Coarse sand, no muck
Oyster Barn Marina - Near Shore East	30.4276	-87.1871	7.5	7.5	0.0	Coarse sand, no muck
Oyster Barn Marina - Near Center	30.4272	-87.1885	10.1	>14.1	>4.0	Light grey muck, very fine
Bayview Park North Dock - Near Shore West	30.4323	-87.1878	6.7	9.2	2.5	Light grey muck, very fine
Bayview Park North Dock - Near Center	30.4314	-87.1871	9.3	>15.3	>6.0	Light grey muck, very fine
Hyde Park - Near Shore East	30.4404	-87.1874	6.0	7.3	1.3	Grey muck, very fine
Hyde Park - Offshore East	30.4402	-87.1878	7.0	>12.0	>5.0	Yogurt consistency grey muck, high % fines
Hyde Park - Near Center	30.4401	-87.1883	8.0	>13.0	>5.0	Light grey muck, very fine
Seville Dr Outfall - Near Shore East	30.4499	-87.1937	2.0	2.0	0.0	Coarse sand, no muck
Seville Dr Outfall - Offshore East	30.4495	-87.1939	5.2	5.2	0.0	Coarse sand, no muck
Seville Dr Outfall - Near Center	30.4488	-87.1941	7.0	>13.0	>6.0	Grey yogurt consistency muck
1950 E Texar - Near Shore West	30.4510	-87.2020	3.3	5.3	2.0	Dense leaf pack, light grey muck with strong hydrogen sulfide odor
1950 E Texar - Near Center	30.4518	-87.2008	6.0	>12.0	>6.0	Light grey muck, very fine
E 34th Outfall - Near Shore West	30.4538	-87.2028	4.2	7.4	3.2	Light grey muck, very fine with strong sulphide smell
E 34th Outfall - Near Center	30.4539	-87.2025	6.5	>12.5	>6.0	3" layer of coarse sediment on top of light grey muck
Gamarra Rd Outfall - Near Shore West	30.4557	-87.1686	4.0	9.2	5.2	Grey muck with hydrogen sulfide odor
Gamarra Rd Outfall - Near Center	30.4558	-87.2042	5.0	>11.0	>6.0	Heavy leaf pack, grey muck with hydrogen sulfide odor
765 Tanglewood Drive - Near Center	30.4577	-87.2049	5.0	>11.0	>6.0	Leaf pack, light grey muck with hydrogen sulphide odor
4204 N 12th Ave - Near Center	30.4602	-87.2076	4.2	8.8	4.6	Light tan muck with high organic contents
12th Ave Bridge - Near Center	30.4599	-87.2084	3.4	3.4	0	Coarse sand, no muck

VOLUME 3C

STREAM ASSESSMENT GUIDANCE MANUAL AND SUMMARY REPORT

Escambia County
Water Quality & Land Management Division
3363 West Park Place
Pensacola, FL 32505

August 2022
Wood Project No.: 600643

Carpenter Creek & Bayou Texar Watershed Management Plan

Task 3.3.6 & 3.3.7
Stream Assessment Guidance Manual and Summary Report

Escambia County PD 17-18.086, PO #191526

CARPENTER CREEK & BAYOU TEXAR WATERSHED MANAGEMENT PLAN

TASK 3.3.6 & 3.3.7
STREAM ASSESSMENT REPORT AND GUIDANCE MANUAL

Prepared for

Escambia County
Water Quality & Land Management Division
3363 West Park Place
Pensacola, FL 32505

Escambia County PD 17-18.086, PO #191526

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Wood Project No. 600643

August 2022

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1. INTRODUCTION

Escambia County (County) contracted Wood Environment & Infrastructure Solutions, Inc. (Wood) to develop a comprehensive watershed management plan (WMP) for the Carpenter Creek and Bayou Texar watershed to address legacy impairments, develop best management practices (BMPs), and identify future site-specific projects and activities through stakeholder engagement and best available science.

The Carpenter Creek and Bayou Texar WMP provides a roadmap for identifying, addressing, and recommending actions to help manage water quantity, improve water quality and ecosystem functions, expand public access and recreational opportunities, and build more equitable and resilient communities. The WMP efforts have included a Watershed Evaluation Report (**Task 2**), hydrologic and hydraulic modeling and sea level rise evaluation (**Task 3.1**), water quality analysis and pollutant load modeling (**Task 3.2**), and stream assessments (**Task 3.3**) in addition to various site visits and meetings with the County and public (**Task 1** and **Task 7**). In **Task 4**, the results from previous tasks were combined to provide watershed management projects and recommendations.

Stream restoration and management are essential for the biophysical integrity of Carpenter Creek, its tributaries, Bayou Texar and the adjacent communities. This report summarizes the stream assessment efforts completed in **Task 3.3.1** (channel system classification), **Task 3.3.2** (categorical channel improvements), **Task 3.3.3** (unit cost and life cycle cost assessment), **Task 3.3.4** (management system and decision matrix), and **Task 3.3.5** (open channel system GIS map) and presents guidance for implementation of proposed projects. This document will serve as a guidance manual for channel restoration and management (**Task 3.3.6**) and a summary of stream assessment efforts under the Carpenter Creek and Bayou Texar WMP (**Task 3.3.7**).

2. CHANNEL SYSTEM CLASSIFICATION

The objective of **Task 3.3.1** was to develop a watershed-specific stream typology that can be used to understand and categorize the Carpenter Creek drainage network along with the varying issues that impact it. The stream typology was developed by synthesizing an array of existing data, historic information and local knowledge, data collected in the field, and desktop analyses. The following section summarizes the efforts of **Task 3.3.1**, and additional details are provided in the previously submitted **Task 3.3.1** report **(Attachment A**).

2.1 Methodology

2.1.1 Field Reconnaissance and Biophysical Data

Initial site visits with the County were conducted in February 2020. Based on the initial field reconnaissance and preliminary geospatial analysis, 12 stream reaches were selected for collection of detailed biophysical field data (8 sites for full reach assessment, and 4 sites for visual assessment). Biophysical field data collection was conducted in November 2020.

The Bank Assessment for Non-point Source Consequences of Sediment (BANCS) method was utilized at 8 sites to measure field variables (e.g., bankfull height, bank angle, root density, bank materials) and used empirical relationships to derive bank unit erosion rates (Rosgen 2014). Applying erosion rates to the heights and lengths of the creek banks provided an estimate for sediment yield in each reach. An adaptation of the NRCS Stream Visual Assessment Protocol (SVAP) was used to assign biological condition scores to each reach by assessing channel alteration, hydromodification, riparian buffer vegetation, bank stability, water appearance, nutrient enrichment, barriers to fish movement, instream fish cover, pool structure, invertebrate habitat, and tree canopy closure (NRCS 1998).

Detailed cross-section survey data (with a relative datum) was collected at 7 sites (3, 4, 5, 6, 8, 43, and 64) to compare channel morphology to that of stable regional norms and determine how bankfull channel dimensions expand down valley. Regional empirical curves developed by Metcalf et al. (2009) and reviewed by Wood (AMEC 2013) provided regionally appropriate and expected cross-sectional geometries that could be compared to the measured existing cross-sectional data in RiverMorph 5.2 software. These comparisons were explored to estimate departures of the existing reaches from stable conditions.

Sediment samples were taken at point bars to determine the percent of gravel embedded in the sand (by weight) with the ultimate goal of determining potential to restore gravel features on the streambed.

2.1.2 Watershed and Valley Variables from Geospatial Data

ESRI ArcGIS 10.4 and 10.8 software was used to evaluate selected variables helpful for interpreting existing stream conditions and for extrapolating the results of the studied reaches to unexplored reaches with similar drainage area characteristics. Watershed and valley variables such as drainage area, valley slope, drainage density, and development percentage were estimated using County LiDAR, land use, soil type, and aerial imagery. The geospatial data was explored for evidence of hydromodification tipping points and departures from stable stream grades. Historic aerial imagery from 1940-2020 were compiled and examined to identify broad trends in land use history and drainage system modification likely to impact stream stability and biophysical integrity.

2.2 Results

2.2.1 Data Synthesis and Mapping

The recorded, temporal, and geospatial data were examined and synthesized to derive a biophysical stream typology for the Carpenter Creek drainage network. The typology primarily considered degrees and kinds of departures from stable conditions and how they relate to current and legacy human stressors. Stream reaches with similar watershed, valley, floodplain, and in-channel variables were grouped in Functional Process Zones (FPZ) (Thorp et al., 2008). The FPZs allow convenient mapping of geomorphically and biophysically similar reaches and are useful for visualization and planning purposes.

Gradient color codes were also developed to show the relative stability of each reach, with green indicating sites that are near equilibrium and currently stable, yellow indicating altered low-lying upland drainage features that contribute to downstream disequilibrium, orange indicating unstable stream channels vulnerable to continued erosion and/or sedimentation, and red indicating sites with ongoing channel erosion and valley hillslope failures. The red sites pose the greatest systematic threat to existing infrastructure and have the highest sediment yields. **Figure 2.1** shows the FPZ and color codes for each reach of Carpenter Creek.

2.2.2 Hydrophysiographic Disruption

In developing a watershed-specific stream typology, impacts of developing landscapes and emerging climate trends on the fluvial geomorphology and stability of the drainage network were observed. Throughout the watershed, development and directly connected impervious area (DCIA) lead to higher and more frequent flood pulses, and these historically seepage-dominated streams are receiving more greatly peaked runoff than they would naturally. Channelized/incised reaches disconnected from their floodplains are attempting to rebuild floodplains at lower elevations, which causes scour and bank failures, and delivers high sediment yields downstream. The hydraulic alteration of the watershed along with increasing frequency and intensity of storms inhibit the stream and riparian forests' ability to recover between events. It was observed that the ratio of floodplain width to bankfull width in stable reaches (and regionally) was around 7, while that ratio was around 4 for the excessively eroding reaches. Additionally, it was noted that many of the severely unstable reaches were located adjacent to existing traditional stormwater ponds. These observations show that overall approach to restoration and stabilization of Carpenter Creek should seek to establish wider (more regionally appropriate) floodplains and to curb the flood pulses associated with urban hydrologic modification, using a blended approach of watershed, floodplain, and stream channel treatments.

Table 2.1 briefly describes the 10 identified FPZs in the Carpenter Creek watershed and summarizes potential management options to either prevent harmful impacts to stable reaches or to alleviate existing impacts and issues in unstable reaches. More detailed descriptions of the FPZs and their specific reaches within the Carpenter Creek drainage network are provided in the **Task 3.3.1** report **(Attachment A)**.

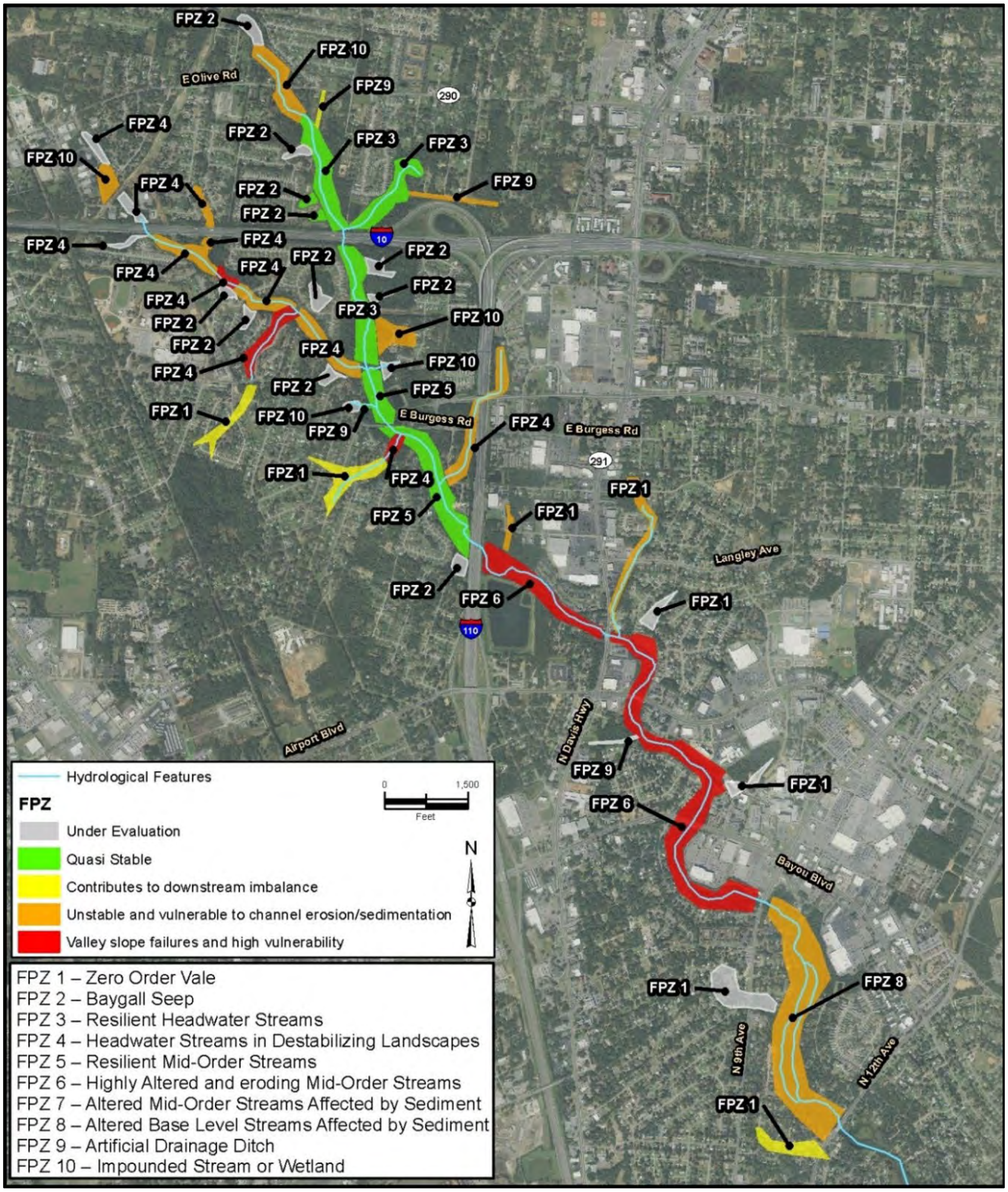
Table 2.1 – Hierarchical Classification of Functional Process Zones

FPZ	Title	Description	Management Options
1	Zero Order Vale	Dry valleys that concentrate, deliver, and infiltrate storm flow to stream channels. All zero order vales in watershed converted to residential development.	Hydromodification reversal focused on groundwater infiltration.
2	Baygall Seep	Upgradient features that intersect the water table, are perennially wet, and may maintain shallow, anabranching channels. Some have been impounded, but 10 forested seeps remain in the watershed. These wetlands are highly vulnerable to erosion and headcutting from artificially increased, concentrated runoff or entrenchment of downstream reaches.	Avoid discharging concentrated stormwater to these areas, but if necessary, utilize diffusers that mimic groundwater exfiltration and pretreat with BAM.
3	Resilient Headwater Streams	First order streams with drainage areas from 0.1-2 sq mi. Small, well-defined sandy channels meandering through densely canopied, boggy hardwood wetland forests. Some reaches historically occupied and maintained by beavers. These sites currently stable, but near tipping points in development thresholds.	Require protective development and stormwater management ordinances. Beaver management where appropriate.
4	Headwater Streams in Destabilizing Landscapes	Same stream type as FPZ 3, but in more heavily developed landscapes. They are systematically unstable, incised, eroding, and exporting substantial sediment downstream.	Watershed and waterbody restoration
5	Resilient Mid-Order Streams	Stable streams with drainage areas from 2.5-35 q mi. Deep channels with varied habitat, pools, sandy bottoms and gravel armoring that meander through dense hardwood bottomlands that receive substantial baseflow and exhibit alluvial floodplain features. One confirmed reach remaining in watershed but threatened by new development.	Require protective development and LID stormwater management ordinances.
6	Highly Altered and Eroding Mid-Order Streams	Same stream type as FPZ 5 but highly altered by channelization, hydromodification, and development. Exhibit substantial erosion and valley hillslope failures and subsequent sedimentation.	Require substantial watershed and valley retrofits.
7	Altered Mid-Order Streams Affected by Sediment	Not currently present in watershed but would apply to mid-order - reaches that were being smothered by sediment from unstable upstream reaches.	Require watershed restoration, drainage network stabilization, and waterbody restoration. Phase upstream restorations to avoid smothering restored FPZ-7 reaches.
8	Altered Baselevel Streams Affected by Sediment	Reaches at the outlet of a drainage network (just upstream of Bayou Texar). Broad channels with deep pools meandering through a wide bottomland forest floodplain that also receives substantial baseflow. Existing channel altered by ditching (and historically by beavers) and lacking deep pools as result of straightening and upstream sediment yields. Will likely transition to tidal creek as sea level rises.	Require watershed restoration, drainage network stabilization, and waterbody restoration. Plan morphology and habitats that will provide stable transition to increased tidal influence.

FPZ	Title	Description	Management Options
9	Artificial Drainage Ditch	Ditches dug for development drainage or conveyance from stormwater ponds to creek. Several are eroding, but some have naturalized and are stable.	Natural channel design retrofit for unstable ditches.
10	Impounded Stream or Wetland	Former seeps or tributaries that have been blocked to impound water. Many unmaintained and vulnerable to failure.	Partially or completely remove high risk cross valley dam or weir.

Note: LID = low impact development (green engineering). BAM = biologically activated media.

Figure 2.1 – Functional Process Zone (FPZ) Locations and Channel Stability



3. CATEGORICAL CHANNEL IMPROVEMENTS

3.1 Channel Stability and Discontinuity Issues

The common issues impacting the reaches within the Carpenter Creek drainage network are summarized in the following sections. More detailed descriptions are provided in the **Task 3.3.2** report (**Attachment B**).

3.1.1 Loss of Grade Control

The grade of a stream is the long-term average longitudinal valley slope, and regional ranges of stable grades vary with drainage area and streambed substrates. Stressors such as deforestation, upstream erosion, excessive runoff, bridge hydraulics, and channel dredging and straightening can destabilize the grade, or produce acute, unsustainable changes in valley slope. Knickpoints are small erosional cascades with steep drops and plunge pools and are diagnostic of a loss of grade control. As the stream seeks a more regionally appropriate valley slope, the knickpoint will migrate upstream (known as headcutting) and destabilize valley side slopes as the bed erosion attempts to flatten the valley's longitudinal slope. Arresting knickpoints and controlling grade are high priorities in restoration efforts.

3.1.2 Channel Erosion, Migration, and Floodplain Widening

There are intrinsic regional relationships between bankfull channel width, floodplain width, and drainage area size. When stressors such as intensified runoff, channel incision and disconnection from floodplains, and climatic shifts in frequency and intensity of floods are present, the system compensates for an inadequate floodplain by eroding the bankfull channel's streambank and increasing channel meander rates to grade a wider floodplain. This eroding bankfull channel migrates across the valley bottom and erodes the valley hillslopes until a wide enough floodplain is achieved in equilibrium with the greater fluvial forces of the aforementioned stressors. This process of floodplain widening in response to hydromodification destroys adjacent forests and threatens nearby infrastructure. Flood channel widening can be caused by loss of grade control, excessive sedimentation, or localized erosion from poorly dissipated stormwater outfalls or bridge structures. Forested and densely vegetated banks are resistant to erosion, but if stressors persist, forested banks can collapse in a series of seemingly sudden and catastrophic episodes. These processes can unfold for decades, while consistently disrupting biological functions during this period of channel evolution. Once the floodplain dimension fits the watershed and climactic conditions, then the streambank and bottomland forest can be very stable, and the trees can become a stabilizing influence on the channel meander. Forest resiliency and floodplain dimension are intrinsically linked.

Florida channels meander through their floodplain within a regionally appropriate "meander belt width". Channel migration rates are slow and nearly imperceptible in healthy Florida streams. If the valley hillslopes artificially confine the floodplain and encroach into the meander belt width, the channel migration will eventually scour into the hillslopes and cause slope failures. Floodplain confinement can be caused by development directly encroaching into the floodplain or by hydromodification and climatic changes that render the existing floodplain width inadequate for changing conditions.

Valley slope failures can also be caused by concentrated groundwater flow that weakens the internal shear strength of slopes and/or saps sediment through the embankment causing it to collapse. Groundwater sapping can readily occur on steep and high valley side slopes with water ponded above them.

3.1.3 Bridge Hydraulics

Many bridges and culvert crossings create sudden expansions and contractions in flow which destabilize stream grade, create eddies that erode banks, disrupt continuity of sediment transport and fish passage, and often constrict flow, creating backwater effects and raising upstream water levels. Bridges can be redesigned for stream continuity and addressing existing instabilities upstream and downstream of bridge crossings can help to alleviate erosion, sedimentation, and instability of the system.

3.1.4 Sediment Loads

A degree of balanced erosion and sedimentation is natural in streams and provides sediment necessary for instream and downstream habitats, but excess erosion and sedimentation can smother downstream habitats and cause channel shallowing and widening. The biophysical and sediment data collected in Carpenter Creek reaches as part of **Task 3.3.1** was compared to natural, stable streams in the region (**Table 3.1**). The existing sediment yield estimates a long-term central tendency but does not predict catastrophic floods or rare conditions (Rosgen et al., 2019). It should be noted that the methodology used to estimate sediment yield has not been calibrated to North Florida, and load estimates provided are for comparative purposes.

The sediment yields of the unstable reaches of Carpenter Creek are 4 to 37 times greater than natural regional rates, which indicates urgency in preventative measures to protect stable reaches and regarding the stabilization and restoration of highly unstable reaches.

Table 3.1 – Carpenter Creek Bank Erosion Rate Estimations and Comparison

Site	BEHI	NBS	Bank Erosion Rate (ft/yr)	Bank Height (ft)	Existing Sediment Yield per LF of Bank (Cubic Feet/yr/LF)	Typical Stable Sediment Yield per LF of Bank (Cubic Feet/yr/LF)	Yield Ratio	Erosion Status
3	High	High	0.58	7.2	4.17	0.26	16	Highly Unstable
4	High	High	0.58	8.0	4.60	0.29	16	Highly Unstable
5	Very High	Extreme	1.32	8.0	10.57	0.29	37	Extremely Unstable
6	Moderate	High	0.42	2.1	0.88	0.07	12	Highly Unstable
8	Very low	Moderate	0.07	1.5	0.11	0.05	2	Stable
43	Low	Very low	0.02	1.0	0.02	0.03	0.5	Stable
64	High	High	0.58	1.5	0.87	0.05	16	Highly Unstable
35	Moderate	Low	0.15	3.7	0.56	0.13	4	Moderately Unstable

Notes: BEHI = Bank Erosion Hazard Index, NBS = near bank stress (Rosgen, 2009).
Typical bank erosion rate is indicated as 0.04 ft/yr based on Low/Low NBS/BEHI.
Yield Ratio = existing yield divided by typical stable yield. Is the multiplier of the normal sediment load.

3.2 Stream Stabilization and Channel Treatment Options

The following sections summarize a suite of treatment options available for addressing stability and discontinuity issues. More thorough descriptions of each treatment type are included in the **Task 3.3.2** report (**Attachment B**). The treatment options include channel restoration and stabilization with natural and inert materials as well as watershed-level stormwater treatments and forest management. These treatments can be applied along entire reaches or as small-scale improvements on select bends or confined areas.

3.2.1 Restoration/Stabilization Priorities

Stream restoration/stabilization are effective practices for addressing many stream corridor stability and discontinuity issues. Doll et al. (2003) describe Priority 1, 2, 3, and 4 options for restoration/stabilization of incised and unstable channels based on distinct differences in site conditions and approaches to floodplain restoration (**Figure 3.1**). Priorities 1 and 2 utilize natural channel design to create self-maintaining, self-organizing systems with appropriately dimensioned bankfull channels and re-establish connection to adequate floodplains. Priority 1 restoration brings the bankfull channel up to the historic floodplain level, while Priority 2 restoration creates a new floodplain at the level of the existing channel. Priority 1 and 2 restorations provide the most resilient energy dissipation, flood relief, habitat, recreation, and water quality benefits.

Where existing infrastructure or other site conditions limit available space, Priority 1 or 2 natural channel designs may not be feasible. Priority 3 stabilization establishes floodplain benches at the existing bankfull level and creates a multi-stage channel. The floodplain is often under-dimensioned, so the bankfull channel may not be able to meander, and imported rock or soil bioengineering may be used to inhibit channel widening and add resilience to valley hillslopes. Priority 4 stabilization, or stabilize in place (SIP), stabilizes the existing banks and hillslopes without repatterning or changing channel geometries, and does not include reconnection to floodplains. Stabilization can be achieved with hard armoring, soil bioengineering techniques, or a combination of the two.

Figure 3.1 – Priority 1, 2, and 3 Stream Restoration and Stabilization

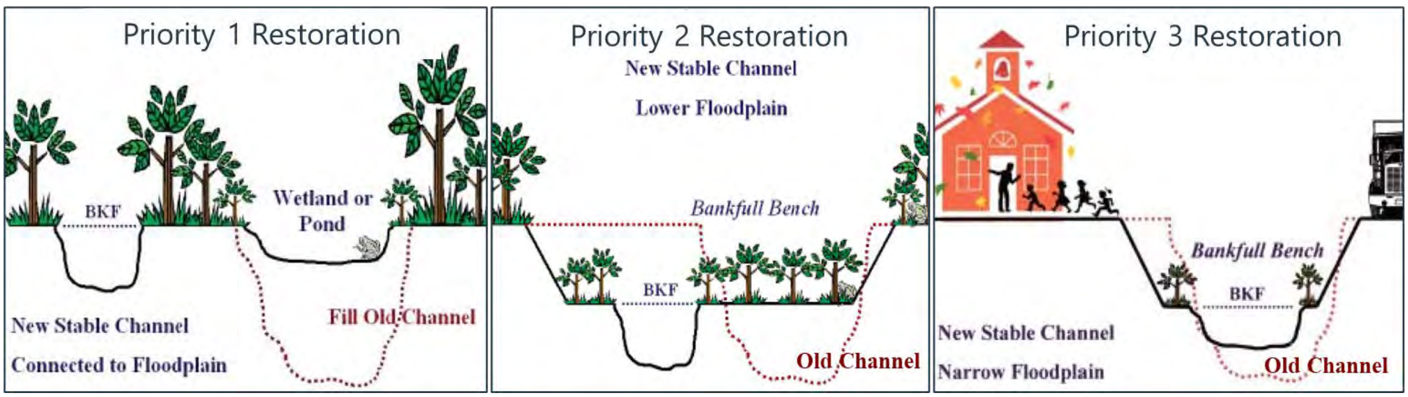


Image adapted from Doll et al. (2003).

3.2.2 Green Stream Restoration/Stabilization Infrastructure

Priority 1 and 2 restorations with natural channel design are examples of "green" stream restoration infrastructure that mimic natural processes, provide multiple environmental benefits and sustainability, and present a natural aesthetic. Natural channel design utilizes natural materials where additional protection or structures are needed. Rosgen cross-vanes are a type of large woody debris places in straight channel reaches to induce pools, Rosgen J-hooks are woody debris placed at outer banks to direct flow toward the middle of the channel and prevent bend scour, and Rosgen toe wood is an array of logs and root wads used to armor the channel toe instead of using rock or riprap (which is not often naturally found in Florida streams). Wing deflectors made of wood or coir logs with backfill and plantings mimic tight bends and induce scour pools that provide valuable habitat diversity in otherwise straight stream reaches.

Priority 3 and 4 stabilizations can be achieved with green infrastructure as well through the use of vegetation reinforced soil slopes (VRSS), which utilize layers of soil, geofabric, and live plants to stabilize steep banks and valley hillslopes (up to 0.5:1 horizontal: vertical slopes and up to 60 ft high). Where additional scour protection is needed, the toe of the slope may be armored with rock/riprap. Because stabilization is achieved with rooting vegetation, VRSS provides ecological, aesthetic, and water quality benefits in addition to erosion control.

In natural conditions, floodplains of Northwest Florida streams are almost always forested. Roots, branches, leaf packs, and fallen woody debris are vital for maintaining stability, habitat, water quality, and resilience in the channels and floodplains of these stream systems. Effective and resilient channel restoration and management includes forest management that focuses on maintaining and restoring regionally appropriate forest structure and community composition while adjusting for hydrologic changes from urbanization. Hydraulic and hydrologic modeling data can help determine which species and structures will be appropriate and resilient at different reaches within the drainage network.

In reaches historically populated by beavers but that do not currently have sufficient in-stream woody debris, beaver dam analog structures can be installed to dissipate energy and improve grade control, stability, sediment storage, fish habitat, and water quality. The arrangements of live stakes, logs, and sticks mimic abandoned beaver dams and attract beavers to enhance and maintain them.

Green engineering methods provide excellent carbon sources for pollutant reduction, dissipate energy and reduce downstream harm, create abundant terrestrial and aquatic habitat supporting fish and wildlife, improve property values, offer recreational opportunities, and strengthen over time,

3.2.3 Gray Stream Stabilization Infrastructure

Gray infrastructure describes inert structures associated with more traditional engineering methods and materials, such as trapezoidal channels or lining with concrete, steel, plastic, and imported rock. While gray methods address erosion and slope stability, they do not provide as many environmental or social benefits as green engineering methods and can sometimes displace excessive forces to downstream areas. Green engineering methods are generally recommended, but where confinements limit green options, gray methods may be required and can produce a blended result.

Gray slope stabilization infrastructure such as is typically used in Priority 3 or 4 stabilizations to armor banks and valley hillslopes against scour can help to prevent gravity failures. Gray slope stabilization types include riprap (slopes composed of rock or rubble), articulated concrete block (interconnected blocks that overlay soil slopes and often have openings for small vegetation), gabion baskets (metal cages filled with rocks or concrete that protect banks from erosion), or bulkheads (poured concrete or steel sheet piles acting as retaining walls or "seawalls"). Marine mattresses (horizontal versions of gabion baskets designed to protect the channel bed from scour) are another traditional gray engineering method used to prevent scour in channels.

Newbury riffles are hydraulic structures designed to mimic rock riffles and raise bankfull water level to reconnect incised bankfull channel flows to the floodplain. They can provide grade control, trap sediment, and allow seasonal fish passage (Newbury et al. 2011). Because Carpenter Creek (and Florida streams in general) have sandy beds, Newbury riffles need to be carefully designed and their use limited to areas generating substantial fluvial forces across large elevation changes (such as drops that create supercritical flow conditions).

Gray treatments are robust systems that are well-understood by a wide array of engineers and construction contractors, degrade over time, and require periodic maintenance and replacement.

3.2.4 Hydromodification and Stormwater Treatments

Hydromodification of the watershed intensifies runoff and flood pulses through increases in impervious surfaces, short-circuiting overland and channel flow, and reduced interception, floodplain retention, and groundwater infiltration. Part of an effective, holistic, resilient stream restoration and channel management plan is to address hydromodification issues at the watershed level.

Where possible, low impact development (LID) and green stormwater infrastructure (GSI) methods should be used for new developments and to retrofit existing developments. LID/GSI stormwater infrastructure mimics natural hydrology, "slowing down, spreading out, and soaking in" stormwater by disconnecting impervious surfaces, utilizing more pervious surfaces, lengthening flow paths, providing storage that includes groundwater infiltration, and utilizing vegetation for interception and evapotranspiration are all core concepts of LID/GSI designs. Widespread implementation of LID/GSI can restore more natural watershed functions and flow paths and curb flood pulses that cause scour and bank failures in urban streams. They also provide more water quality, habitat, aesthetic, and social benefits than traditional stormwater infrastructure.

The connections of stormwater infrastructure to stream corridors are also important factors to consider for preventing channel scour and instability. Spreader swales, stilling basins, aprons, or other structures to dissipate energy at an outfall can lessen the impact on the receiving channel. Where stormwater flow slopes are high (approximately 2%-8%), regenerative stormwater conveyance (RSWC) configurations can be used to dissipate energy into the receiving channel and can provide water quality treatment of baseflow. RSWC structures are designed with log and rock steps and pools similar to those found in mountain streams, but with Wood's Florida-specific RSWC design approach and native forest plantings, they can provide habitat, fish passage, and a natural aesthetic.

Development codes and incentive programs can help accomplish widespread implementation of LID/GSI throughout the watershed. More detailed descriptions of stormwater management and retrofit options along with conceptual designs for select stormwater project locations in the Carpenter Creek watershed are provided in the **Task 4** Watershed Recommendations report.

3.3 Categorical Carpenter Creek Treatment Options

Table 3.2 summarizes the primary channel stability and discontinuity issues in the Carpenter Creek FPZ categories and presents the potential treatment options that would be appropriate for each issue.

Table 3.2 – Treatment Options for FPZ Types

FPZ	Issues	Potential Treatment Options
FPZ 1	Impervious surfaces	Hydromodification (LID stormwater retrofits, DCIA energy dissipation, Development Codes)
FPZ 2	Vulnerable to development impacts	Preventative watershed hydromodification (LID stormwater retrofits, DCIA energy dissipation, Development Codes)
FPZ 3	Vulnerable to development impacts	Preventative watershed hydromodification (LID stormwater retrofits, DCIA energy dissipation, Development Codes), forest and beaver management
FPZ 4	Urban Runoff	Watershed hydromodification (LID stormwater retrofits, DCIA energy dissipation, Development Codes), forest and beaver management
	Scour/Incision	Natural Channel Design (Priority 1 & 2), Two-stage channel (Priority 3), VRSS, Gray SIP, Newbury Riffle, Regenerative stormwater conveyance
FPZ 5	Vulnerable to development impacts	Preventative watershed hydromodification (LID stormwater retrofits, DCIA energy dissipation, Development Codes, regenerative stormwater conveyance), forest and beaver management
FPZ 6	Scour/Incision	Natural Channel Design (Priority 1 & 2), Two-stage channel (Priority 3), VRSS, Gray SIP, Newbury Riffle, Regenerative stormwater conveyance
	Floodplain Disconnection	Natural Channel Design (Priority 1 & 2), Two-stage channel (Priority 3)
	Urban Runoff and Development Impacts	Watershed hydromodification (LID stormwater retrofits, DCIA energy dissipation, Development Codes, Regenerative stormwater conveyance), forest and beaver management
	Lack of Bends	Natural Channel Design (Priority 1)
FPZ 8	Lack of Bends	Natural Channel Design (Priority 1)
	Sediment Smothering	Natural Channel Design (Priority 1), Upstream restoration/stabilization
	Future Tidal Conditions	Natural Channel Design (Priority 1 & 2), Two-stage channel (Priority 3) adaptable to future conditions
FPZ 9	Scour/Incision	Natural Channel Design (Priority 2), Two-stage channel (Priority 3), VRSS, Gray SIP

FPZ	Issues	Potential Treatment Options
	Floodplain Disconnection	Natural Channel Design (Priority 2), Two-stage channel (Priority 3)
FPZ 10	Impoundment	Natural Channel Design (Priority 1 & 2), Two-stage channel (Priority 3), VRSS, Gray SIP, Wetland Restoration

Note: Gray SIP = Gray engineering stabilization in place (includes, riprap, articulated concrete block, gabions, marine mattresses, and bulkheads/retaining walls).

3.4 Sediment and Water Quality Load Reduction Potential

The observed unstable stream reaches of Carpenter Creek occur in FPZ 4 (Headwater Streams in Destabilizing Landscapes) , FPZ 6 (Highly Altered and Eroding Mid-Order Streams), and FPZ 8 (Altered Baselevel Streams Affected by Sediment). These unstable reaches transport substantially more sediment than stable reaches, as shown in **Table 3.1**. **Table 3.3** presents the excess sediment yields in unstable stream reaches of Carpenter Creek by FPZ derived from comparisons of estimated existing sediment yield values to regionally stable sediment yield values. These values represent an estimated upper limit to sediment load reduction (per year, per linear mile of stream) from stabilization with Priority 2 restoration.

In addition to sediment load reduction, stream restoration (natural channel design) also generally provides nitrogen removal. Following the Chesapeake Bay Total Maximum Daily Load (TMDL) protocol methodology, Wood estimated total nitrogen (TN) load reduction via three different mechanisms including erosion reduction resulting from the stabilization of banks (Protocol 1 - P1), reduction from hyporheic[1] exchange during baseflow (Protocol 2 - P2), and floodplain exchange from floodplain reconnection (Protocol - P3). The potential for TN removal varies by the size of the stream and watershed, and **Table 3.4** shows the approximate potential annual TN load removal (per mile of stream restoration) for unstable reaches in FPZ 4, FPZ 6, and FPZ 8. There are approximately 2 miles of stream in FPZ 4, 2 miles in FPZ 6, and one mile in FPZ 8; if all 5 miles of stream within unstable reaches were to receive Priority 1 or Priority 2 stream restoration, it could provide TN load reductions up to approximately 4,500 lb/yr (depending on existing water quality conditions). While sediment and biophysical data required for load reduction calculation was not collected at ditches (FPZ 9) or impounded streams (FPZ 10), restoration/stabilization in these FPZs could provide additional water quality improvement.

Stream restoration with natural channel design also reduces total phosphorus (TP) and total suspended solids (TSS), but currently, methodologies for estimating TP and TSS removal typically vary by project. The reduction in TP and TSS is typically associated with prevented or reduced erosion and sediment transport, and therefore will depend on the existing sediment loads and phosphorus content and fractionation within the soils and sediments of each restored stream segment.

Table 3.3 – Excess Sediment Yield of Unstable Carpenter Creek Functional Process Zones (FPZ)

FPZ Category	FPZ 4	FPZ 6	FPZ 8
Excess Sediment Yield (TPY/LM)	208	1,227	109

TPY/LM = Tons per year per linear mile of stream.

[1] Hyporheic flow is that which moves through porous media in the streambed and streambanks.

Table 3.4 – TN Removal Potential for Stream Restoration in Unstable Functional Process Zones (FPZ)

Potential Nitrogen Load Reduction (lb TN/yr/mi)				
FPZ Category	**P1-Erosion**	**P2-Hyporheic**	**P3-Floodplain**	**Total**
FPZ 4	125	404	44	**573**
FPZ 6	736	663	107	**1,506**
FPZ 8	66	208	57	**331**

4. UNIT COST AND LIFE-CYCLE COST ESTIMATES

4.1 Cost Benefit Analysis Approach

The following section summarizes the cost-benefit analysis (CBA) described in the previously submitted **Task 3.3.3** report (**Attachment C**). A triple bottom line (TBL) approach was used to account for the combined financial, environmental, and social dimensions of each assessed retrofit type. The TBL was quantified and monetized by estimating the net present value (NPV) of each retrofit category and alternatives were evaluated in terms of their investment worthiness in U.S. Dollars. The criteria used for this study were:

- Only monetize line items with primary and proximal value to the residents of Escambia County.
- Select only line items with credible and available monetization values.
- Select line items most likely to provide significant economic benefits or costs related to the proposed activities.
- Do not use line items that collectively incorporate redundant costs or benefits.

A subset of line items relevant for assessing multi-purpose channel improvements for the benefit of the people and environment of Escambia County were included in the CBA with a primary purpose of enabling the channel systems to become more self-sustaining, prevent erosion and slope failure, improve bottomland forests, and contribute to maintenance and repair costs. Line items include retrofit costs, or all costs and fees related to the design and implementation of the treatment; avoided operation and maintenance (O&M), which includes various types of channel maintenance such as mowing and dredging; wetland habitat, an estimated value based on wetland mitigation credits; stream habitat, an intrinsic value based on economic data from mature stream mitigation projects outside of Florida; water quality, which is estimated based on traditional BMP costs to achieve similar load reductions; property values, an assessment of property value increases expected over 20 years as a result of restoration; and flood avoidance, a value based on a cost-effective analysis (CEA) model to account for the reduction in various damages such as buildings, automobiles, and displacement.

The selected treatments fall into two broad categories based on the dominant materials used and their associated benefits: green and gray infrastructure. Gray infrastructure uses civil engineering technology to stabilize channels by the installation of inert materials such as riprap, concrete, steel, and plastic, while green infrastructure uses ecological engineering technology to variably integrate native vegetation, soil and rock stratigraphy, and natural channel patterns and dimensions to create largely self-sustaining drainage systems that are multifunctional. The gray and green treatment approaches that were selected for CBA include stream restoration, valley stabilization, soil bioengineering bank stabilization, riprap channel lining, gabion bank stabilization, and articulated concrete block (ACB) stabilization.

To meet the overall project goal of providing CBA for channel improvement recommendations, unit costs for select treatments were assigned and the quantities were defined over the assigned life cycle of the project. A detailed explanation of each treatment including a full breakdown of costs and net benefits can be found in the **Task 3.3.3** report (**Attachment C**).

4.2 Cost Benefit Analysis Results

Tables 4.1 and **4.2** provide the estimated costs and benefits for each monetized line item and range of values for each treatment, and the triple bottom line is summarized in rank order for the mean values with ranges depicted in **Table 4.3**.

The best-case returns were overall positive for the following scenarios:

- Stream restoration in all three drainage positions
- Priority 3 and 4 VRSS in mid-order FPZ-6
- Riprap and articulated concrete block at mid-order FPZ-6

Average values were overall positive for the following scenarios:

- Stream restoration in all three landscape positions
- Priority 3 VRSS for mid-order FPZ-6

Worst case scenarios provide net positive returns for:

- Headwater and baselevel stream restoration positions

Table 4.1 – Estimated Costs and Benefits for Stream Restoration & Green Infrastructure Stabilization

Treatment Type	Stream Restoration			VRSS (Priority 3)			VRSS (Priority 4)		
Item	**Headwater**	**Mid-Order**	**Baselevel**	**Headwater**	**Mid-Order**	**Baselevel**	**Headwater**	**Mid-Order**	**Baselevel**
Retrofit Cost	($1,464,100)	($6,091,500)	($1,458,900)	Not Assessed	($6,989,000)	Not Assessed	Not Assessed	($5,416,000)	Not Assessed
Avoided O&M	$189,900	$201,400	$188,700		$201,400			$201,400	
Wetland Habitat	$125,000	$367,800	$108,000		$146,500			$74,800	
Stream Habitat	$4,173,000	$4,173,000	$4,173,000		$3,210,000			$459,200	
Water Quality	$3,072,300	$8,073,900	$1,773,600		$4,327,400			$3,946,900	
Property Value	$205,700	$517,000	$517,700		$206,800			$206,800	
Flood Avoidance	$50,000	$50,000	$50,000		$50,000			$0	
Overall	**$6,351,800**	**$7,291,600**	**$5,352,100**		**$1,153,100**			**($526,900)**	

Note: Values represent mean estimates of 20-yr net present value (NPV) per linear mile of restoration/stabilization.

Table 4.2 – Estimated Costs and Benefits for Gray Infrastructure Stabilization

Treatment Type	Riprap			Gabions			Articulated Concrete Block		
Item	**Headwater**	**Mid-Order**	**Baselevel**	**Headwater**	**Mid-Order**	**Baselevel**	**Headwater**	**Mid-Order**	**Baselevel**
Retrofit Cost	($3,862,700)	($9,290,400)	Not Assessed	($2,739,500)	($6,232,000)	Not Assessed	($2,037,100)	($4,609,900)	Not Assessed
Avoided O&M	$189,900	$201,400		$189,900	$201,400		$189,900	$201,400	
Wetland Habitat	$0	$0		$0	$0		$0	$0	
Stream Habitat	$0	$0		$0	$0		$0	$0	
Water Quality	$670,000	$3,946,900		$670,000	$3,946,900		$670,000	$3,946,900	
Property Value	$0	$0		$0	$0		$0	$0	
Flood Avoidance	$0			$0			$0	$0	
Overall	**($3,002,800)**	**($5,142,100)**		**($1,879,600)**	**($2,083,700)**		**($1,177,200)**	**($461,600)**	

Note: Values represent mean estimates of 20-yr net present value (NPV) per linear mile of stabilization.

Table 4.3 – Ranges of Triple Bottom Line Net Present Value for each Scenario

Retrofit Scenario	Position	Mean NPV	NPV Range	
			Worst Case	Best Case
Stream Restoration	Mid-Order FPZ-6	$ 7,291,600	$ (1,510,900)	$ 13,815,160
Stream Restoration	Headwater FPZ-4	$ 6,351,800	$ 1,876,770	$ 9,831,930
Stream Restoration	Baselevel FPZ-8	$ 5,352,100	$ 1,225,080	$ 8,530,760
VRSS - Priority 3	Mid-Order FPZ-6	$ 1,153,100	$ (5,143,050)	$ 5,927,430
VRSS - Priority 4	Mid-Order FPZ-6	$ (526,900)	$ (4,699,650)	$ 2,564,630
Articulated Block	Mid-Order FPZ-6	$ (461,600)	$ (3,918,720)	$ 2,165,860
Articulated Block	Headwater FPZ-4	$ (1,177,200)	$ (2,218,280)	$ (308,100)
Gabion	Headwater FPZ-4	$ (1,879,600)	$ (3,131,400)	$ (799,780)
Gabion	Mid-Order FPZ-6	$ (2,083,700)	$ (6,027,450)	$ 1,030,390
Riprap	Headwater FPZ-4	$ (3,002,800)	$ (4,591,560)	$ (1,586,020)
Riprap	Mid-Order FPZ-6	$ (5,142,100)	$ (10,003,370)	$ (1,110,490)

The top positive total TBL NPV scenarios for average conditions are mid-order stream restoration, headwater stream restoration, baselevel stream restoration, and Priority 3 VRSS, while the bottom 5 are mid-order riprap, headwater riprap, mid-order gabion, headwater gabion, and headwater articulated block. The majority of the best-case scenarios exhibit positive TBL, except headwater riprap, gabions, and articulated block; and mid-order riprap. Stream restoration at headwater and baselevel positions resulted in positive TBL despite their worst-case scenario ranking.

Gray infrastructure approaches provided very little to no environmental or social benefits needed to compensate for the requisite capital investment and O&M costs suggesting this type of infrastructure should be used where neither stream restoration nor soil bioengineering is applicable. Green infrastructure approaches provided significant environmental and social benefits in all three drainage networks positions (headwater, mid-order, and baselevel) and are expected to provide significant net positive returns. The only form of green infrastructure that did not exhibit a positive TBL was Priority 4 VRSS due to the approach's similarity to gray infrastructure and lack of added stream habitat.

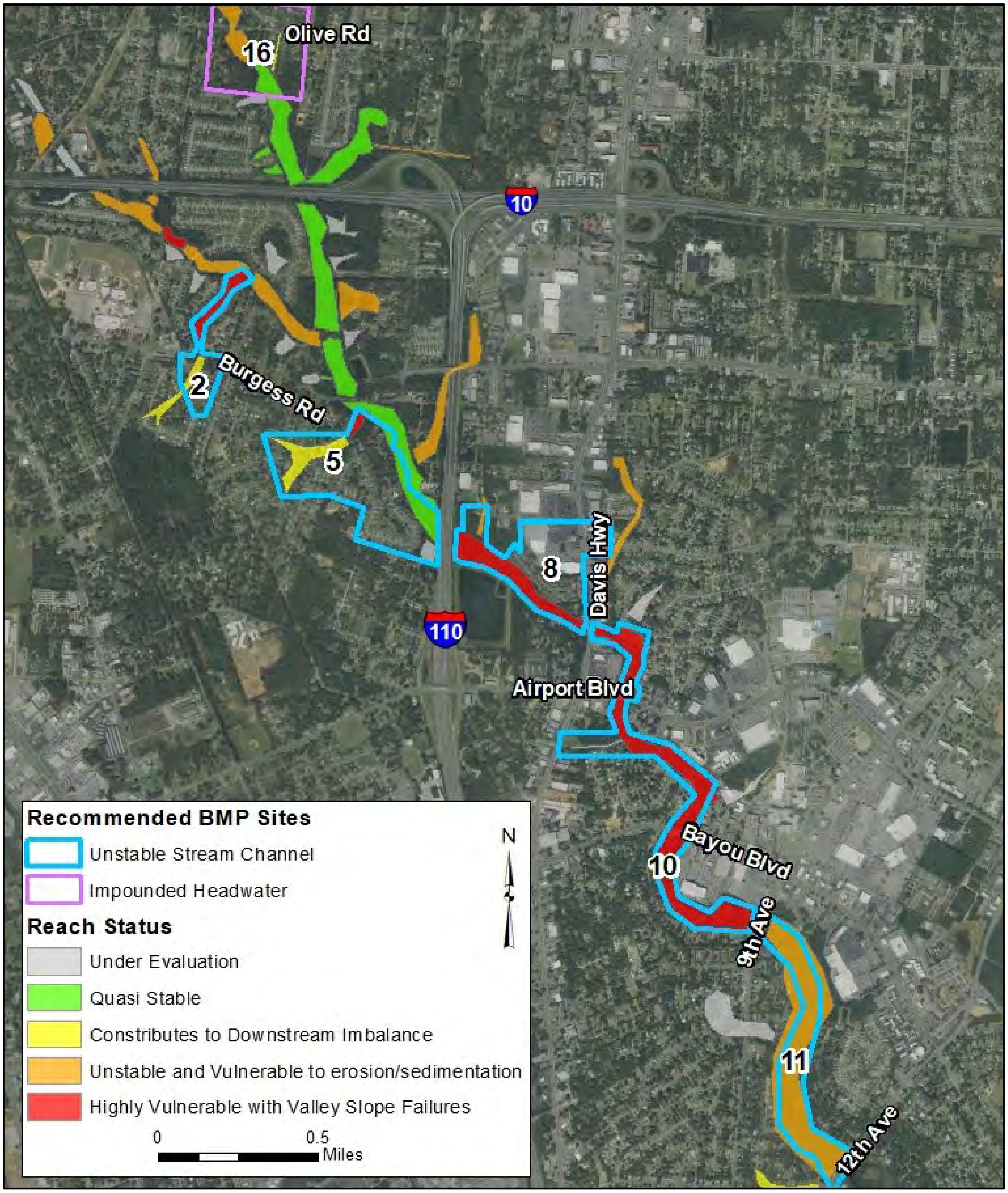
5. CHANNEL MANAGEMENT SYSTEM

5.1 Channel Management Site Selection

In development of the **Task 4** Watershed Recommendations Report, the channel system classifications and mapping, categorical improvement assessment, and cost-benefit analysis presented in previous sections were considered along with results of hydrologic & hydraulic (H&H) and water quality modeling efforts, existing and potential recreational and public access opportunities, and feedback from meetings with the County and the public to develop recommendations for channel and watershed improvement projects. Project recommendations were organized by numbered sites, and concept plans were developed for each site.

Based on the data analysis in **Task 3.3.1**, stream reaches in FPZ 4, FPZ 6, and FPZ 8 exhibited the highest channel instability and erosion. Further evaluation of the data showed that select reaches within the unstable FPZs had the highest potential for continued erosion and bank failure and/or most pronounced impacts from sediment smothering. These reaches were included in the project sites recommended as candidates for stream channel restoration and are shown in **Figure 5.1**.

Figure 5.1 – Recommended Stream Restoration Sites



The headwater FPZ 4 reaches at Site 2 (Headwaters near Burgess Road) and Site 5 (The Creek at Shiloh Drive) were selected because of their high bank stress, unstable sediment yields, and need for grade control. While Site 2 was the more impaired tributary, and Site 5 was in the beginning stages of unstable response to hydromodification, without timely intervention, Site 5 could degrade to similar conditions to those of Site 2, generating highly unstable sediment yields.

The mid-order FPZ 6 reaches at Site 8 (The Creek at Sterling Hills) and Site 10 (The Creek from Davis Highway to 9th Ave) were selected because of their high bank stresses and highly unstable erosion and sediment yields. Site 10 exhibited the highest bank erosion hazard index scores, near bank stress, and sediment yields. Within Site 10, the stream reach between Davis Highway and Airport Boulevard had sediment yields almost 40 times higher than stable conditions and exhibited extremely unstable conditions (as demonstrated by extreme bank failures that damaged properties).

The baselevel FPZ 8 reach at Site 11 (The Creek from 9th Ave to 12th Ave) was selected because of its moderately unstable bank conditions, but primarily because of the high degree of habitat smothering by upstream sediment deposition and artificial channel straightening.

Site 16 (Olive Rd Headwaters) included an impounded headwater/wetland historically maintained by beavers. While stream restoration was not recommended for Site 16, beaver dam analogues were recommended as part of a suite of stormwater management projects and practices. It should be noted that the site areas include stormwater and water quality best management practices (BMP) in addition to channel restoration and stabilization areas. Further details regarding site selection are presented in the **Task 4** Watershed Recommendations Report.

5.2 Recommended Channel Restoration and Management

5.2.1 FPZ 4 Channel Restoration and Management

Priority 2 stream restoration with natural channel design (NCD) was recommended for the headwater tributary at Site 2 and Site 5 (**Figure 5.2**). Providing a sufficiently wide (at least 65 ft for Site 2, 40 ft for Site 5) alluvial bottomland forest floodplain at the grade of the existing channel and repatterning a regionally appropriate stream channel controls stream grade, reduces bank stress and erosion, and creates a stream corridor more resilient to urban flood pulses. Additional BMPs were recommended to help manage and reverse watershed hydromodification. These included retrofitting stormwater ponds and outfalls with spreader swales to reduce localized channel scour, baffle box retrofits to provide water quality treatment, and implementation of neighborhood-wide LID programs. It should be noted that the conceptual design for Site 5 was presented as Priority 2 restoration, however, if watershed BMPs are effectively implemented throughout the drainage area, it is possible that channel incision and headcutting could be avoided, and Priority 1 restoration could be possible.

5.2.2 FPZ 6 Channel Restoration and Management

The reach of Carpenter Creek in Site 8 had three zones with varying levels of stress and accessibility. In the upstream section near I-110, the channel was not incised/entrenched, but mostly impacted by sediment deposition. Priority 1 restoration with addition of beaver dam analogue (BDA) structures could be used to repattern the stream channel and improve habitat and water quality (**Figure 5.3**). The middle zone was entrenched from ditching and heavy erosion and actively headcutting. Priority 2 restoration could be used in the middle zone to control grade, reduce erosion and bank failures, repattern a natural stream channel, and provide a sufficient bottomland forest floodplain (100 ft wide). The most downstream section was ditched, has eroding banks, and appears to embay water levels during low flow conditions. While Priority 2 restoration would be beneficial, properties and buildings tightly confine the stream, with a series of homes overhanging the banks on stilts. Additional proposed watershed BMPs included directing existing untreated outfalls to a wet detention pond that discharges through a broad weir and utilizing continuous monitoring and adaptive control (CMAC) in existing ponds to manage and reduce peak runoff rates.

Site 10 contains the most severely eroding reaches of Carpenter Creek and is the most essential (and ambitious) proposed channel management project. Priority 2 stream restoration is recommended for the entire length of ditched and incised stream from Davis Hwy to 9th Ave; it would provide a sufficiently wide bottomland forested floodplain (80-390 ft), provide grade control, and stabilize valley hillslopes to protect existing forests from slope failure (**Figure 5.4**). Highway crossings split Site 10 into three distinct sections that could be constructed in phases – upstream reach from Davis Hwy to Airport Blvd (the most severely eroding of the three), middle reach from Airport Blvd to Bayou Blvd, and downstream reach from Bayou Blvd to 9th Ave. The channel slope will need to be altered in the upstream section to avoid a steep, unstable drop near Davis Hwy, but ICPR modeling showed no adverse flooding impacts from the changing grades. The valley hillslopes in Site 10 can be constructed with geofabric-reinforced groundwater drains to reduce sapping erosion from adjacent perched dry ponds, and any stormwater outfalls that intersect the project can be replaced/retrofit with energy dissipation structures that prevent localized channel scour. Additional watershed BMPs included LID retrofits of adjacent parking lots with large directly connected impervious areas, baffle boxes and spreader swales at outfalls, and neighborhood-wide LID and bioswale programs.

5.2.3 FPZ 8 Channel Restoration and Management

The reach of Carpenter Creek in FPZ 8 was divided into two parallel ditched channels through a 30-acre bottomland swamp. The western branch does not appear to have continuous open channel flow. Priority 1 restoration is recommended on the eastern branch to reconstruct bends that will provide pool morphology and fish habitat (**Figure 5.4**). Because the stream grade can still access its intact, sufficiently wide bottomland floodplain, bend addition and construction can be performed with minimal clearing and grading. Fish rearing areas can be excavated in the lower part of the floodplain that is developing as a delta.

Figure 5.2 – Conceptual Stream Restoration at Site 2 (Left) and Site 5 (Right)

Figure 5.3 – Conceptual Stream Restoration at Site 8

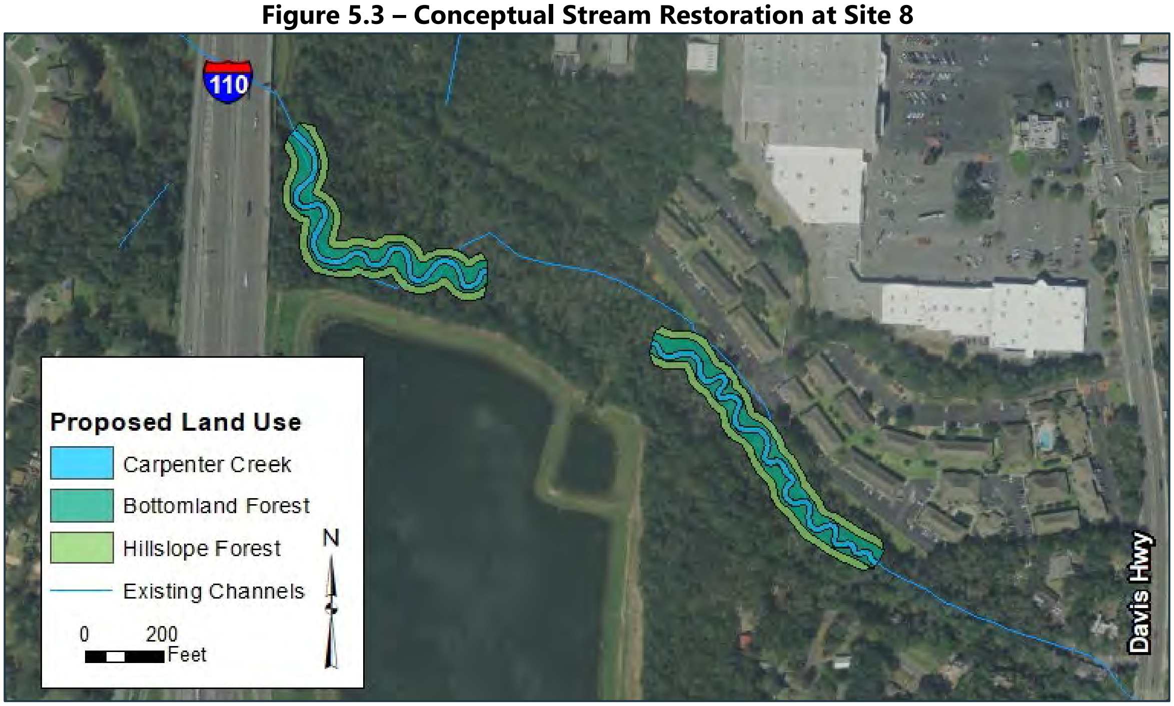
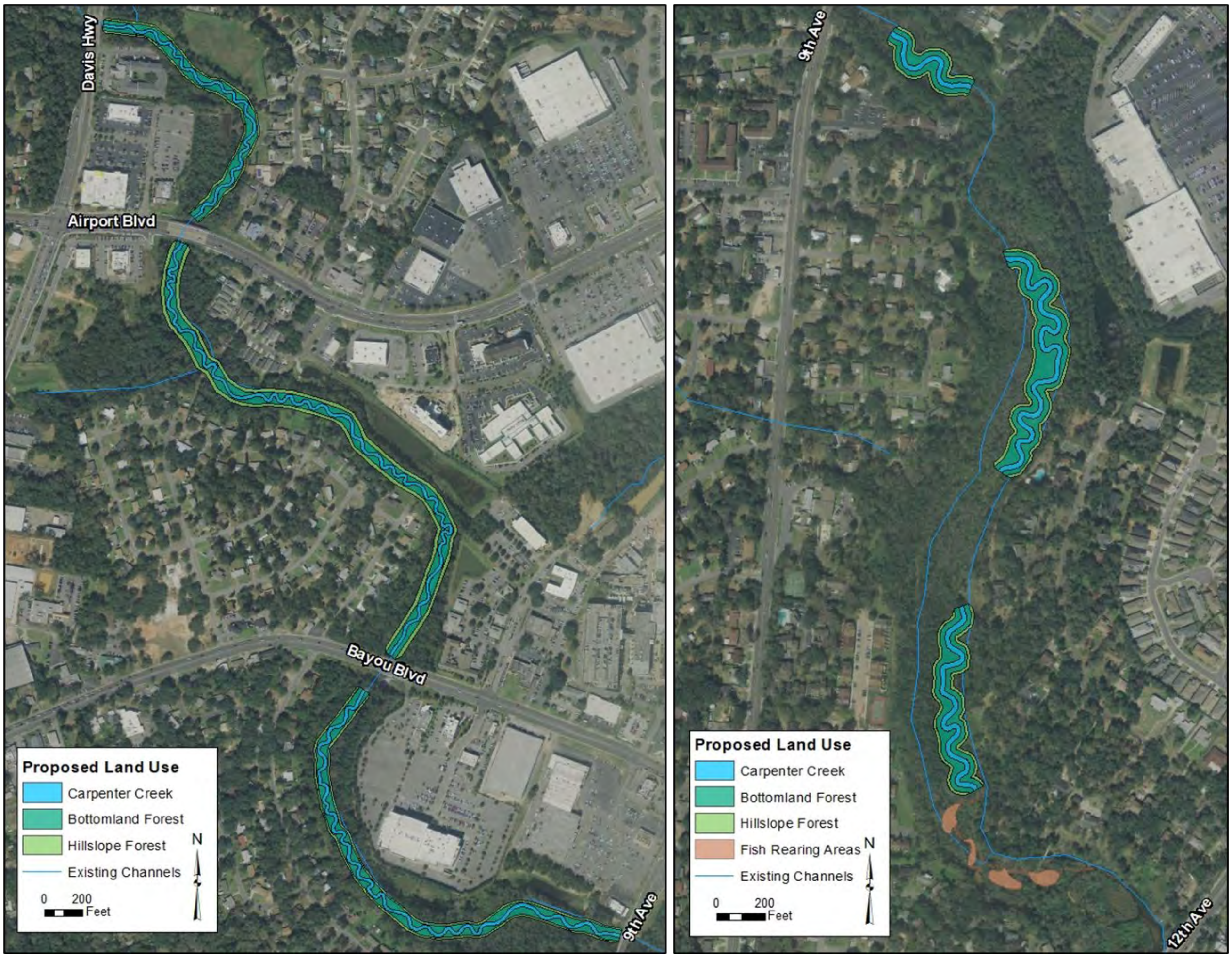


Figure 5.4 – Conceptual Stream Restoration at Site 10 (Left) and Site 11 (Right)



5.3 Channel Restoration and Management Summary

Table 5.1 summarizes the channel proposed channel restoration and additional watershed management BMPs presented in the previous section. **Table 5.2** summarizes the estimated costs, load removals, miles of stream restoration, and acres of wetland restoration associated with the proposed channel restoration and management projects. In **Task 4**, all proposed stream and watershed projects were ranked according to a project scoring matrix that valued improvements in water quality and quantity, protection/restoration of habitat, recreational opportunities, contribution to community resiliency, constructability, permitability, land acquisition, and cost vs. benefit. The channel restoration and management projects presented in previous sections all ranked in the top 5 (out of 15), with Site 10 and Site 2 tied for the top ranking. Further details about proposed designs, cost benefit analysis, and project ranking are provided in the **Task 4** Watershed Recommendations Report.

Table 5.1 – Proposed Channel Restoration and Management

Site ID	Name	FPZ	Channel Restoration Type	Additional Management Efforts
2	Headwaters near Burgess Road	4	Priority 2 NCD.	Pond with spreader swale, baffle box with BAM, curb & gutter program.
5	The Creek at Shiloh Drive	4	Priority 2 NCD (Priority 1 if hydromodification reversed).	Retrofit pond with BAM, spreader swale on outfall, bioswale program.
8	The Creek at Sterling Hills	6	Priority 1 & 2 NCD & BDA.	Existing pond CMAC, treatment pond with overland weir.
10	The Creek from Davis Highway to 9th Ave	6	Priority 2 NCD with groundwater drains in hillslopes.	LID retrofits of adjacent parking lots, LID and bioswale programs, baffle boxes and spreader swales at outfalls.
11	The Creek from 9th Ave to 12th Ave	8	Priority 1 NCD bend addition, fish rearing areas, tidal creek adaptation.	Restoration of upstream reaches and LID programs to limit sediment smothering.
16	Olive Rd Headwaters	10		Detention ponds with BAM, terraced bioretention ditches, BDA to replace historic beaver dams.

Note: NCD = natural channel design. BDA = beaver dam analogues. BAM = bioactive media. CMAC = Continuous Monitoring & Adaptive Control. LID = low impact development.

Table 5.2 – Proposed Channel Management System Potential Beneficial Impacts

			Project Objectives				Benefits			
Site ID	Site Names	Cost	Water Quantity	Fish & Wildlife Habitat	Public Access & Recreation	Community Resiliency	TN (lbs/yr) Removed	Sediment (Tons/yr) Removed	Stream (mi) Restored	Wetland (Ac) Restored
2	Headwaters Near Burgess Rd	$1,913,561	√	√	√	√	167	130	0.3	2.3
5	The Creek at Shiloh Dr	$432,033	√	√	-	√	55	45	0.1	0.5
8	The Creek at Sterling Hills	$3,084,245	√	√	√	√	444	90	0.3	3.8
10	The Creek from Davis Hwy to 9th Ave	$14,800,341	√	√	√	√	1,954	2,000	1.3	14.6
11	The Creek from 9th to 12th Ave	$1,297,594	√	√	√	√	137	45	0.4	6.3
16	Olive Rd Headwaters	$2,115,750	√	√	√	√	207	4.1	-	-

6. CHANNEL RESTORATION GUIDANCE

Ideally, all 5 of the top-ranked stream restoration projects recommended in Task 4 along the creek would be designed, permitted, and constructed concurrently as a single mega-project. A comprehensive do-it-all-at-once implementation would typically take at least 3 years from commencement of design to completion of construction – most likely 4 years for a project of this scope and scale. However, due to availability of funding and other factors this may not be feasible. Phased implementation of these projects requires careful consideration of bank stability, sediment transport, watershed changes, and position within the drainage network.

6.1 Prioritization and Phasing

There are two main factors that determine the ideal phasing of restoring reaches. First, upstream reaches should typically be restored before downstream reaches because excessive erosion from unmitigated upstream reaches would smother restoration efforts in downstream reaches. However, the degree of instability and erosion are also key prioritization factors, and sometimes the lower reaches can be designed to pass high sediment yields from upstream. In the proposed restoration reaches, Sites 2, 5, and 8 are all upstream of Sites 10A (from Davis Hwy to Airport Blvd), 10B (from Airport Blvd to Bayou Blvd), 10C (from Bayou Blvd to 9th Ave), and 11. However, Sites 10A, 10B, and 10C are the most unstable and have the most severe erosion rates and potential for damaging surrounding properties.

Currently, the most severe erosion in the drainage network causing the most severe damage to built infrastructure and upland forests is occurring at Site 10, specifically in Site 10A. This is the most critical stream reach to restore, as it has the greatest potential to impact adjacent properties through bluff failure, downstream reaches through sediment smothering, and upstream reaches through headcutting. It is highly recommended that restoration of Site 10A be pursued as the first project should phasing be required. Stream restoration projects of this scale generally take approximately 3 years to complete, from the beginning of engineering design, through permitting, and to the end of construction. If funding and land access are not secured, then projects can be delayed further until resolution. In the 3 or more years it takes to complete Site 10A restoration, monitoring, planning, design, and permitting activities can simultaneously occur at other reaches.

According to the data collected for this project, Sites 10B and 10C have the highest sediment yield rates in the mainstem of Carpenter Creek, after Site 10A, and would be recommended as the second and third phases of restoration. Site 8 has the next highest sediment yield (and is upstream of Site 11), so it would be recommended as the fourth phase of restoration. Site 11 has the lowest sediment yield and is the furthest downstream, so it would be recommended as the 5th phase of restoration. The tributary Sites 2 and 5 are shorter, smaller headwater reaches and could be restored in parallel with the mainstem, possibly through other funding mechanisms or programs. According to the existing data, Site 2 is more critically unstable that Site 5, so it would be recommended as the first tributary reach to be restored. If conditions remain consistent with the existing data collected, this sequence would be the most effective for restoring the most unstable reaches of Carpenter Creek. However, conditions may change subsequent to this assessment as the system is dynamic and one of the key stressors is large storms.

6.2 Stream Monitoring Program

If construction of each Site is in a series where more than one year will pass from completion of one site to the next (or last), then it is recommended that a stream monitoring program be implemented as the beginning stages of Site 10A restoration are underway. Stream monitoring would include erosion studies consisting of bank pins and scour chains, cross-section surveys, and regular site assessments at fixed locations within each proposed restoration reach. Bank pins are weatherproofed steel rods driven horizontally into the stream banks, initially flush with the surface of the bank. Cross sections are surveyed (typically in relative datum) to capture the geometry of the bank. The site is revisited regularly, and the length of the exposed rod along with the change in area of the surveyed cross sections are used to measure the erosion of the banks.

Scour chains are installed in the riffle bed of the stream at the repeat cross section site to measure the depth of bed scour or deposition (Rosgen 2014). The chain is buried vertically into the bed substrate so that the top of the chain is flush with the bed surface. If scour occurs, the chain will be exposed and lay on the bed. If deposition occurs after scour, the chain will lay horizontally, but be buried. If only deposition occurs, the chain will be buried, but still vertical. The depths to the chain are recorded, and if the rate of scour and deposition are relatively equal, the bed of the stream is stable. If the deposition rate is higher, the stream is aggrading; if the scour rate is higher, the stream is incising.

Regular stream monitoring at fixed locations within each proposed restoration reach will provide data needed to adapt the phasing strategy to potential changes in the drainage network. If Site 8 starts to show sediment yield rates greater than 5x the natural baseline, its sediment will smother restoration completed in Site 10B or 10C, and thus, Site 8 restoration should be completed before Site 10B or 10C.

Currently, Site 2 is more severely eroding than Site 5, but if LID and watershed management initiatives change the drainage area characteristics, that may not be the case after several years. If Site 5 shows evidence of rapid headcutting and more severe erosion and sediment yield, then Site 5 should be prioritized before Site 2.

It should be noted that stream sediment monitoring data combined with sediment nutrient and water quality data collected prior to and after restoration could be used to receive load reduction credits for water quality regulation requirements (e.g., total maximum daily load-TMDL). If the County wishes to pursue calculations of nutrient load reductions resulting from stream restoration efforts, a complementary sediment and water quality sampling plan could be developed.

6.3 Channel Restoration Guidance Summary

Figure 6.1 shows a guide for stream restoration project phasing, beginning with implementation of Site 10A and stream monitoring at the mainstem creek sites (8, 10B, 10C, and 11) and tributary sites (2 and 5). The original sequence is based on current conditions but is intended to be adaptive as informed by the results of the monitoring data. It should be noted that the tributary site monitoring and restoration can be performed in parallel with mainstem restoration and monitoring, and the timeframe can begin as early as real estate matters are settled and funding sources are identified. An estimated phasing schedule for the mainstem creek restoration projects is shown in **Table 6.1**. This schedule assumes that each mid-order and baselevel reach restoration project would take about 3 years from the beginning of design to the end of construction and that the subsequent project could start design when the previous project is in the last year of construction. **Table 6.2** shows an option to compress the schedule by designing the first 5 project reaches in parallel, then phasing the construction of each reach.

The tributary reach restoration projects are not shown in **Table 6.1 or 6.2**, as their timeline is not dependent on mainstem construction activities. Because the tributary sites are smaller headwater creeks, the estimated range for project completion is 2-3 years.

In summary, the 5 main projects could be completed from design through construction in about 4 years if funded as a single mega-project. If both design and construction are phased in series across 5 project areas, then the total timeline would be closer to 11 years for completion. An intermediate approach would be to commission comprehensive design and permitting for all 5 areas, followed by construction of each of 5 areas in series. That scenario would require approximately 7 years complete. Erosion will progress and more damage will occur over time, so Wood recommends taking the shortest possible path that funding and logistics allow.

Figure 6.1 – Channel Restoration Implementation Phasing Guide

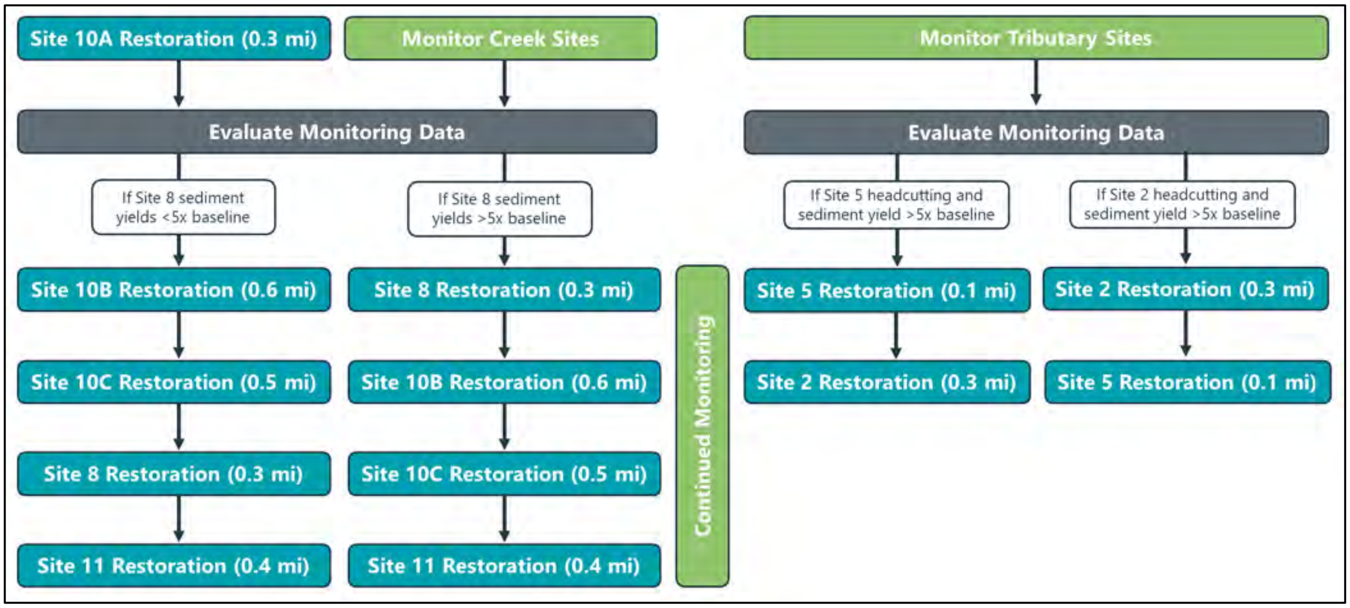


Table 6.1 – Approximate Long-term Mainstem Channel Restoration Phasing Schedule

1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						

Table 6.2 – Approximate Compressed Design and Construction Phasing Schedule

1						
2						
3						
4		Construction				
5			Construction			
6				Construction		
7					Construction	

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VOLUME 3C ATTACHMENT A

CHANNEL SYSTEM

CLASSIFICATION REPORT

Attachment A

Task 3.3.1 Report

CARPENTER CREEK & BAYOU TEXAR WATERSHED MANAGEMNT PLAN

TASK 3.3.1
STREAM ASSESSMENT CHANNEL SYSTEM CLASSIFICATION

Prepared for

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April 2021

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1. INTRODUCTION

The purposes of this technical report are to document a work progress milestone, enable County review and comments on findings to date, and take the first steps in drafting a Stream Restoration guidance for Carpenter Creek and its tributaries. That first step involves descriptions of the streams in the watershed based on their key geomorphic processes, geography, physical integrity, and resiliency. These variables are essential to understand prior to conceiving potential remedies. The concept is to develop a watershed-specific stream typology that can be used as a shorthand or means for understanding the issues as they vary along the drainage network.

Ultimately that understanding will be used to conceive and categorize effective time-critical and long-term management and restoration strategies and techniques across the watershed. The typology maps stream types based on current conditions in the watershed, but because it also ties watershed stressors to in-valley outcomes, it can be used to predict and map outcomes under hypothetical future conditions in the watershed. Preliminary, illustrative suggestions for protective and restorative measures are previewed in this report as the stream types are described. Final recommendations are to be fully developed during the next series of sub-tasks.

2. METHODOLOGY

2.1 Initial Reconnaissance

Site visits were conducted in areas of interest based on County experience with problem areas; suggestions by local consultant Keith Johnson of Wetland Sciences, Inc.; areas of interest to the interested public; review of existing reports and maps; and review of aerial photographs. More than 20 sites were observed over 3 days during February 2020. Observations covered the run of the creek system from its headwaters to the Bayou and at various areas of stormwater and recreational interest within the watershed. The technical working group and public meetings were conducted to solicit information regarding creek history and issues in the watershed. This suite of initial activities provided valuable information for developing our subsequent more detailed field assessments.

2.2 Stream Morphology and Field Diagnosis

Biophysical data and diagnostic observations were collected from 12 stream reaches over a 5-day period in November 2020 (**Figure 1**). Study reaches were selected to assure samples encompassed the range of variability along the drainage network. Another 8 reaches were visually examined without data collection to narrow breakpoint locations for mapping potential stream types. Creek conditions and bridge structures were also examined at 10 road crossings within the watershed. The information collected at the crossings was not part of the stream classification but will factor into a special category of treatment recommendations in subsequent deliverables.

Biophysical data was collected to diagnose departures from stable stream pattern and dimension, specifically concerning grade control (vertical stability) and bank erosion (lateral stability). Stability analysis was aided by direct observations and subsequent data synthesis of stream planform, valley confinement, forest/vegetation condition and density, channel blockages (including debris dams and beaver activity), sediment depositional features, knickpoints (migrating headcuts), maximum channel depths, bankfull channel width, alluvial valley width (active floodplain), terracing, and cross-section shape (thalweg depth and bankfull width).

Bank erosion rate was explored using the 'Bank Assessment for Non-point source Consequences of Sediment' (BANCS) method at 8 sites (Rosgen 2014) (sites shown as Reach Assessment in **Figure 1**). This approach develops a bank erosion hazard index (BEHI) score based on observed ranges in ratio of bank height to bankfull height, root density, root depth, bank angle, surface protection, bank materials, and sediment stratification. The BEHI numeric score is categorized with an adjective rating of Very Low, Low, Moderate, High, Very High, and Extreme. BANCS also provides means for scoring the near bank stress (NBS). NBS Methods 1 and 5 were used as applicable. Method 1 interprets NBS in association with the presence of transverse bars and Method 5 predicts it based on ratio of the maximum near bank depth to bankfull mean depth. NBS adjective ratings include the same categories from Very Low to Extreme as for BEHI. The adjective scores are then applied to a nomograph giving a comparative estimate of average annual bank erosion rates in inches per year. The rates can be multiplied by the height and length of the affected bank to calculate the reach's sediment yield. These yields do not factor in the stream classification directly but will be used as part of the ranking criteria and for recommending treatments.

Biological conditions were assessed using an adaptation of the NRCS Stream Visual Assessment Protocol (SVAP) (NRCS 1998). SVAP provides index scores for channel alteration, selected aspects of hydromodification, riparian buffer vegetation, bank stability, water appearance, nutrient enrichment, barriers to fish movement, instream fish cover, pool structure, invertebrate habitat, and tree canopy closure. Some of this information overlaps with more robust geomorphic and water quality assessments, but the SVAP data related to pool structure, fish cover, canopy closure, and invertebrate habitat provide valuable stand-alone information for assessing instream biodiversity potential. Overall SVAP scores range from 1 to 10 with the following nominal categories: >9.0 Excellent, 7.5-9.0 Good, 6.1-7.4 Fair, <6 Poor. The SVAP is not intended to predict biological expression, but it can be used as a general indicator of its uppermost potential under existing conditions.

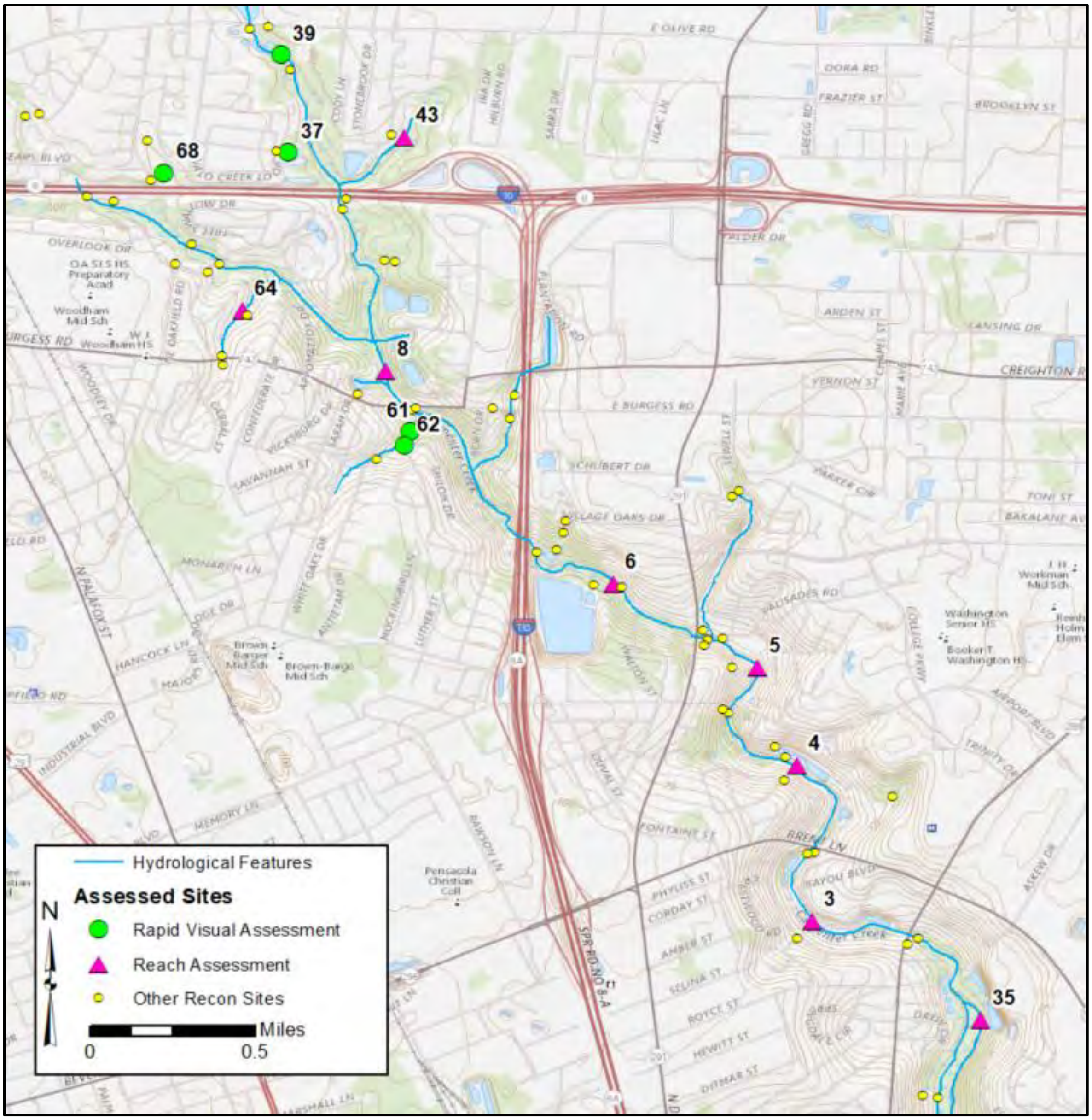
Detailed cross-section survey data was collected at 7 sites (3, 4, 5, 6, 8, 43, and 64) to compare channel morphology to that of stable regional norms and determine how bankfull channel dimensions expand downvalley. Regional norms are defined by regressions relating channel dimension to the drainage area size. Metcalf et al. (2009) provides these 'regional curves' for the northwest Florida hydrophysiographic region. Dr. Kiefer reviewed these curves and almost all of the stable sites used in their derivation in 2011-2013 as part of a statewide stream morphology and nutrient stress study for FDEP (AMEC 2013), finding them to be developed from stable groundwater-dominated streams that are most common in the panhandle. These conditions would have applied well to the pre-development conditions in the Carpenter Creek watershed. Based on Wood's previous studies in the hydrophysiographic region including the Florida panhandle and southeastern Alabama, 2 to 3 natural channel types are expected in the watershed – seepage ravines, headwater baseflow channels, and mid-order closed canopy channels – and perhaps some sapping gullies induced by extensive late 19th century and early 20th-century clear-cutting. Existing conditions can be benchmarked against these expectations. Cross-section data was explored in RiverMorph 5.2 software which displays and calculates bankfull channel dimensions useful for diagnosing departures from a stable condition.

Substrate conditions were examined at the same sites as those surveyed by taking sediment samples on point bars and separating the sand and finer materials from any gravel present. The main purpose of doing this is to determine the potential for attempting to restore gravel features on the streambed. The wet weight of the bulk sample was taken prior to sieving and then the material retained as pebble and gravel in the sieve was separately weighed. This information was used to determine the percent gravel embedded within the sand by weight. The dominant sand size was determined by comparing sampled grains to those attached to a Unified Soil Classification System geotechnical gage.

The size of the two largest particles sampled in the bar materials was also recorded. On the downstream-most site in the study, streambed dunes were noted and the dune crests and spacings were measured. The presence of human litter and urban debris was also noted throughout the study area.

The data collected during these stream assessments will be provided to the County in tabular form (Microsoft Excel), and photos from the assessment sites are provided in **Appendix B**.

Figure 1 – Field Reconnaissance and Stream Assessment Sites



2.3 Watershed and Valley Variables from GIS Data

ESRI ArcGIS 10.4 software was used to evaluate selected variables helpful for interpreting existing stream conditions and for extrapolating the results of the studied reaches to unexplored reaches with similar drainage area characteristics. The County DEM was used to delineate the drainage area of each study site. Existing land use layers from 2016 were updated where 2020 aerials indicated obvious development expansions. Other layers were used as available without modification.

Variables extracted from the best available GIS information for each stream study reach included drainage area size, valley slope, percent cover by developed versus undeveloped land use (according to Florida Land Use and Cover Classification System-FLUCCS), upstream and downstream elevations of each reach, soil types and hydrologic soil group, linear miles of roads, open channel drainage density, and public park space acres. Undeveloped land use and road density were examined for evidence of harmful development thresholds associated with systematic channel instability.

This information is useful for identifying potential causes of erosion derived from drainage area modifications; screening land use patterns warranting more granular examination of potential treatment variables (e.g., directly connected impervious area); and identifying particular stream reaches especially vulnerable to continued development. For this report, the data was primarily explored for evidence of coarse tipping points into systematic erosion driven by drainage area hydromodification and to identify creek areas with existing or future vulnerability. The relationships between valley slope and drainage area were also examined for any extensive departures from stable grades along the drainage network.

2.4 Historic Aerial Photos

Aerial photographs spanning 8 decades were compiled and rectified in GIS software to visually examine broad trends in land use history and any apparent drainage system modifications likely to affect stream stability and biology. These included coverage from 1940, 1951, 1958, 1961, 1965, 1970, 1973, 1981, 1989, 1995, 1999, 2000, 2004, 2010, 2013, 2019, and 2020. The aerials were qualitatively interpreted for trends in development, road building, channel dredging, and deforestation likely to adversely affect the biophysical integrity or trajectory of streams at various positions along the drainage network.

2.5 Synthesis and Map Color Codes

The suite of recorded, temporal, and geospatial data was examined for each study site to derive a biophysical typology for the streams of the Carpenter Creek watershed. This classification is based on a riverine ecosystem synthesis of the instream and overbank habitats and stability of those features dependent on how fluvial geomorphic form and processes vary along the drainage network. Primary considerations centered on what kinds of departures in vertical and lateral stability occur in relation to human stressors known to affect stream corridor equilibrium in developed landscapes. Stream reaches exhibiting similar characteristics of watershed, valley, floodplain, and in-channel variables are referred to as Functional Process Zones (FPZ) (Thorp et al 2008). FPZs are effectively the stream types delineated in map form. FPZs are process-based and often exhibit abrupt transitions along the valley, making a convenient and useful mapping and planning tool. For Carpenter Creek, direct and indirect legacy effects of human alterations were considered in FPZ derivation. A a summary of FPZ types and potential management strategies is provided in **Table 1** and discussed in detail in the following section.

There can be positional variability among sites within some of the FPZs regarding their vulnerability and history of instability. For that reason, Wood developed 4 stability categories and mapped the reaches with a color modifier reflecting the erosional status and vulnerability of each reach (**Appendix A**). The FPZ assigned to each reach can be used to interpret the basic biophysical conditions of the site, and the color-coding enables enhanced understanding of the severity and continued vulnerability of each reach to erosion and sedimentation at disequilibrium.

- Green sites are close to equilibrium and are the most stable, but this should not be interpreted as an indication of genuine resiliency in the face of additional development.
- Yellow sites are altered drainage features that contribute to downstream disequilibrium. This designation was reserved for areas that are not technically streams. Most yellow areas occur in fully developed landscapes. In a broad perspective, more than 80% of the Carpenter Creek watershed could have been assigned a yellow color and any unstable stream adversely affects those downvalley, but the concept was to restrict such designations to 'zero order streams.' These are special areas exhibiting stream valley morphology, but that actually are low-lying uplands lacking stream hydrology. These were delineated because they may represent areas of useful foci for green-engineering stormwater management system retrofits at the transition from terrestrial to fluvial environments.
- Orange sites have unstable stream channels that are vulnerable to continued erosion and/or sedimentation. The most severe disequilibrium occurs within the channel and/or on its banks.
- Red sites have a combination of ongoing channel erosion and valley hillslope failures. Red sites are those that pose the greatest systematic jeopardy to existing infrastructure and developed property. Existing forests within these valleys are inexorably being overwhelmed by erosion as the system tries to rectify an under-dimensioned flood zone.

Table 1 – Hierarchical Classification of Functional Process Zones

FPZ	Descriptive Title	Management
1	Zero Order Vale	Almost have been converted, varying in potential for hydromodification reversals
2	Baygall Seep	Vulnerable to headcut dewatering from entrenched confluence
3	Resilient Headwater Streams	Require protective development and stormwater management ordinances
4	Headwater Streams in Destabilizing Landscapes	Require watershed and waterbody restoration
5	Resilient Mid-Order Streams	Require protective development and stormwater management ordinances
6	Highly Altered and Eroding Mid-Order Streams	Require substantial watershed and valley retrofits
7	Altered Mid-Order Streams Affected by Sediment	Require watershed restoration, drainage network stabilization, and waterbody restoration
8	Altered Baselevel Streams Affected by Sediment	Require watershed restoration, drainage network stabilization, and waterbody restoration
9	Artificial Drainage Ditch	Some are erosive and act like a pipe, while others have naturalized and are stable
10	Impounded Stream or Wetland	Cross valley dam or weir

3. RESULTS

3.1 Hydrophysiographic Disruption – the Urban Stream Syndrome

The stream classification was developed in exploration of the specific effects of the developed landscape and emerging climate trends on the fluvial geomorphology and stability of the drainage network. Wood looked for field evidence of problems related to common and rare storms, and their potential synergic disruptions to an equilibrium condition. Distributed low impact development (LID) and green infrastructure (GI) treatments are often required for disrupting the short flow paths in urban stream syndrome and preventing harmful erosion and pollution that destroys the biophysical integrity of natural stream corridors (Walsh et al. 2005). These can be part of a layered solution involving treatment trains before and after gutter collection. Conventional wet and dry detention ponds, while they have other benefits, do not appear to be serving as stand-alone solutions to prevent stream erosion downstream of intense development. In fact, most of the substantially eroding stream segments in the watershed are adjacent to large dry ponds.

Specific mechanisms and stream sensitivities to urban stream syndrome vary by Hydrophysiographic region and some emerging remedies are more portable than others (Booth et al. 2016). Layered solutions that address routine runoff events and very large flood pulses are likely to be required for Carpenter Creek. The need to better address flood pulses was evidenced by creek types that were artificially incised in the 1960's attempting to carve new floodplains at lower elevations, while at the same time they are passing extraordinarily high sediment yields delivered from accelerated upstream erosion.

To put that process into perspective, the comparatively stable stream corridors in the watershed have active floodplains that average 11.2 times wider than their bankfull channel widths (W_{FPL}/W_{BKF}). None of the laterally stable channels had W_{FPL}/W_{BKF} ratios less than 7. This provides a sense of the regional requirements for flood prone width under insufficiently treated runoff regimes in the developed Carpenter Creek watershed. Conversely, the excessively eroding corridors are currently averaging W_{FPL}/W_{BKF} ratios of 4.4, and these corridors will continue to erode. The pace of advancing erosion is not linear or incremental and is harder to quantify. Existing forests resist change and failures rapidly unfold at locations in chaotic fashion over time. Vulnerable corridors are identified, but specific erosions will unfold in a non-uniform manner within those corridors – eventually destroying and rebuilding them over a period of some decades. However, the unpredictability of the timing of specific damage areas warrants a sense of urgency.

The overall drainage system is intrinsically sensitive to the effects of directly connected impervious area (DCIA) because the creek corridors originally evolved as baseflow streams fed by long flow paths through the surficial aquifer. Equilibrium conditions that developed over millennia were in sync with seepage delivery layered by occasional flood pulses. These paths and runoff volumes have been fundamentally altered over a matter of decades from the effects of pavement. Standard and customary stormwater treatments have been implemented, but these have not been enough to prevent systematic erosion. Short circuiting runoff to the channel system via curb-and-gutter and sending it to ponds designed to dewater in 72-hour time frames located adjacent to the valley hillslope does not sufficiently re-extend the flow path for success.

The streams of the Carpenter Creek watershed almost undoubtedly receive moderate erosive flows far more frequently than they did under their predeveloped conditions. This can be viewed as a 'press disturbance', one that occurs so frequently that it acts as an almost constant stress. Press disturbances weaken systems and can make them more vulnerable to the effects of pulsed disturbances. Pulsed disturbances are comparatively uncommon and can range in frequency from seasonal floods to rare catastrophic extremes. Abstraction and infiltration treatments prior to runoff reaching curb and gutter seem warranted as a means for reducing the somewhat pervasive press disturbances of the watershed. Such extensions more closely mimic the drainage paths of the region's biophysically stable and naturally productive systems, enabling them to ultimately deliver improved sediment and pollutant loads to the Bayou versus the existing short-circuited and eroding status.

Another apparent factor relates to tropical storm intensification and frequencies under a changing climate. Highly damaging windstorms dumping immense volumes of rainfall have occurred frequently during the 2000's. Forests holding stream corridors together usually have many years, if not decades, to recover between such events and the plant assemblages in such positions are adapted to such pulsed disturbances reaching a long-term equilibrium morphology along and across the valley. However, it seems likely that the recent series of such storms has compromised the recovery of the forests especially at channel and slope breaks. Pulsed disturbance vulnerabilities can be addressed by giving the stream what it needs, a larger active forested floodplain that can better dissipate the energy of these pulses and recover more quickly as a result. Such investments can be made in ways that improve the fishery and recreation potential of these corridors. Regional stormwater detention and diversion systems could also be part of the solution, but available land is limited. The specific and logical treatments are the subject of ongoing tasks, but for now this background is an important factor in the derivation of the stream classification.

3.2 FPZ 1 – Zero Order Vale

Streams are characteristically ordered based on their progressive downstream positions along the drainage network, with headwater creeks typically referred to as 1st Order streams. Major rivers are high-order systems and creeks at intermediate drainage positions are referred to as mid-order streams.

Zero order streams occupy dry valleys that are not universally recognized as streams because they have low water tables, often lack a channel at the valley bottom, and are more terrestrial than fluvial in function. They rarely flow but can draw runoff during large or intense storm events delivering it to streams with well-developed channels and greater flow permanency at lower elevations.

Several areas in the Carpenter Creek watershed have valley formations with side slopes and longitudinal profiles akin to those of stream valleys, but do not support a stream channel with aquatic or wetland flora and fauna. These areas are so dry that all of them are currently occupied by residential development. None of them appear to have been wet bottomlands in historic aerials prior to development. However, they seem likely to have once served as important natural infiltration galleries for concentrated runoff during intense rainfall events.

At least six developed Zero Order Vales occur upstream of unstable portions of Carpenter Creek or its headwater tributaries. One of those was a heavily eroded ravine in the 1940's, while the rest appear to occupy historically stable ground. These areas would probably have appeared as native grassy swales with scattered open pine canopies prior to land use conversion. Three more developed Zero Order Vales outfall directly to Bayou Texar.

Since most are now partially encumbered by impervious surfaces (especially roads, rooftops, and driveways), this suggests that they may represent valuable positions for retrofitting green stormwater infiltration systems as part of a treatment train aimed at diverting or returning runoff from impervious surfaces to infiltrate to the groundwater flow in a more natural manner.

3.3 FPZ 2 – Baygall Seeps

These systems also occupy upper drainage positions that are typically upgradient of most headwater streams but unlike FPZ 1 systems, Baygall Seeps intersect the water table and are perennially wet from groundwater seepage. In some cases, the groundwater flow is sufficiently voluminous to carve and maintain shallow open channels, often anastomosing into multiple anabranches (what some people refer to as 'braided streams'[1]). The little channels wind through dense hardwood forests of trees, shrubs, and shade-loving groundcover comprised of species thriving under perennial saturation and organic soils. In some cases, these seeps occupy recovered gullies. Their amphitheater-like shape and steady gentle flow make them tempting targets for impoundment, and some have been converted.

At least 10 baygall seeps remain in the watershed, many with excellent and stable forest conditions. Baygall seeps deliver low energy, low sediment, low nutrient, low pH water with dissolved carbon to the creek's baseflow, and these deliveries should be maintained. These sites are highly regulated wetlands that are vulnerable to intense artificial runoff erosion and their junctions can be susceptible to headcut gully formation commencing near their confluences with downstream floodplains. They are not good candidates as receiving waters for concentrated stormwater treatment outfalls. If discharging to these wetlands is required, it is best to consider using diffusers to mimic groundwater exfiltration and pretreatment with biologically activated media (BAM).

3.4 FPZ 3 – Resilient Headwater Streams

These systems gather nearly-perennial to perennial water from first order drainage areas of approximately 0.1 to about 2 square miles. They consist of small, but well-defined sandy channels, typically less than 12 feet wide and shallower than 2 feet deep, meandering through densely canopied hardwood wetland forests with substantial shrub thickets. The wetlands are fed by groundwater seepage and are variably boggy with organic soils. The bottomlands generally lack extensive alluvial features with most sediment transport being confined to the streambed and channel margins. Tree roots can readily and fully span the sediments beneath the stream channel, adding significant resiliency and long lag times before succumbing to excess forces delivered by urban runoff.

Beavers sometimes occupy these streams, creating lots of small jams that induce the channels to find multiple low-flow pathways and that create small organic steps. This stream type is very stable and is as near-to-natural as streams get in this watershed. It is possible beavers add to the resiliency of these sites in developed watersheds, acting as agents to patch incipient headcuts to which they would almost certainly be drawn to fill as they begin to erode from the effects of urban hydromodification. Perhaps notably, all 3 sites categorized as FPZ 3 not only exhibit wide native forest bottomlands, but also have some of the largest patches of terrestrial forest buffers along those bottomlands among all the streams of the watershed. These conditions provide the best separation from development and are favorable for beavers.

As discussed under FPZ 4 in the next section, the FPZ 3 sites all occur near tipping points in development thresholds associated with the erosion occurring in FPZ 4 streams. FPZ 3 sites are worth conserving in their present form and their continued resiliency is perched near the edge of vulnerability to erosion associated with increased development and roadbuilding.

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[1] 'Braided stream' is commonly used as a pseudonym for anabranching systems with multiple interconnected channels crossing the valley floor. When used by fluvial geomorphologists, the term means something more specific to include only those systems that form under very high natural sediment loads in high-energy mountain valleys and glacial outwash areas. They are inapplicable to Florida.

At least one of these sites is so close to the tipping point it is possible that absent beavers it would have already crossed into erosive regimes. Beavers may be enabling better forest recovery between erosive events and forest-damaging mega-storms. Beaver management is an important consideration for this stream type. Future development infill or expansion should be permitted only with LID approaches to stormwater management, should account for storm intensification, and include modern green stormwater retrofits in existing neighborhoods as warranted.

3.5 FPZ 4 – Headwater Streams in Destabilizing Landscapes

These sites are similar in natural origin and drainage network positions to FPZ 3 and would otherwise belong to the same stream type, except they are now systematically unstable. Urban runoff creates loss of grade control by scouring soil out from under the root masses of the bottomland forest. Channel incision unfolds and subsequent bank erosion occurs as the incision steepens and weakens the streambanks. So, once the channels incise, they enter fluvial geomorphic feedback loops that accelerate and expand erosive conditions. These systems may export more than 40 times the sediment of FPZ 3 streams to downstream waters.

They also have reduced capacity for processing nutrient pollution, are more likely to present barriers to upstream fish passage, offer less fish habitat cover types, and have reduced macroinvertebrate habitat substrates.

Comparisons of the watershed conditions of FPZ 3 and 4 streams are particularly instructive for informing potential tipping points of development effects from the landscape. For example, the stable streams studied had less than 80% developed land (barren, transportation/communication/utilities, urban and built up) and at least 20% undeveloped FLUCCS areas (upland forests, water, wetlands, and rangeland). The eroding headwater streams all fell beyond those thresholds.

As mentioned, the FPZ 3 sites are close to the upper untreated development thresholds currently at 77% and 68% developed land uses. If they cross a tipping point and start to erode, they will rapidly transform to FPZ 4 stream types with increased sediment yield, decreased nutrient retention, and decreased biological potential. FPZ 4 sites could be restored in some cases by retrofitting their contributing areas with green stormwater infrastructure (GSI) to re-establish truncated groundwater flow paths. Migrating knickpoints could be concurrently halted and dissipated using beaver dam analogues (BDA) and facilitating beaver activity as feasible.

3.6 FPZ 5 – Resilient Mid-Order Streams

Prior to development, this stable and beautiful stream type would have dominated most of the length of Carpenter Creek. These creeks are efficient at sediment transport, exhibit low erosion rates, and maintain relatively deep channels with excellent pool depth and a wide variety of instream habitats. These systems typically drain basins ranging from 2.5 to 35 square miles in the region – fully encompassing the largest drainage area available in the Carpenter Creek watershed to the Bayou. These channels meander through dense hardwood bottomlands with copious baseflow and periodic flood pulses powerful enough to form alluvial features in the floodplain, especially within the meander belt. The floodplain dissipates high energy flood pulses through chutes and small backswamp depressions. The bankfull channels are typically 15 to 40 feet wide and have predominantly sandy bottoms with some gravel armoring in high velocity patches and fine silty organics in slackwater areas and along the channel margins. Pools can reach several feet deep at bankfull flow in undeveloped landscapes.

The best remaining example of this stream type occurs between the confluence of Carpenter Creek with its western branch and Burgess Road. It is in a remote location and is probably seldom seen by the public. It is in overall excellent biological condition, but with some evidence of nutrient pollution. It is close to a 'State Park quality' stream condition. Because the sole confirmed reach of this creek type occurs only at the upper position of the drainage network where there is enough flow pickup for this kind of stream to occur, its channel width is at the small end of the range (about 14 feet). Similar watershed and valley conditions occur between Burgess Road and I-110 downstream of the observed reach, and that area is tentatively assigned as FPZ 5 pending further confirmation. Shortly after crossing I-110 downvalley, the system no longer retains its stability and becomes FPZ 6.

The confirmed stable reach occurs at watershed conditions very close to land use tipping points associated with erosion. It currently has a built environment at 79% vs an 80% threshold, and road density is at 14 vs a 14.5 mile/square mile threshold. This is particularly concerning because a new development cleared one of the largest remaining forests south of I-10 during 2019 and 2020. This development is located immediately upstream of this FPZ. The unfolding development may place this currently uncommon reach in jeopardy as the development seems to utilize only conventional stormwater treatment, includes very wide paved roads and cul-de-sacs, and has a wet detention stormwater overflow that passes flow to an unforested powerline ROW on a long steep valley hillslope draining west to Carpenter Creek. There are usually lag times between when the intensity of watershed development crosses erosive tipping points and causes the breakdown of geomorphic integrity, so there may be time to retrofit with LID treatments that mimic the hydrology of the previously all-forested condition before the new erosive trajectory begins.

3.7 FPZ 6 - Highly Altered and Eroding Mid-Order Streams

Prior to development, these reaches would have fallen within the same broad category of natural channel type as those described for FPZ 5, except they are now more greatly and systematically eroding. Two segments are characterized as FPZ-6; the upper FPZ 6 area occurs between I-110 and N Davis Highway, and the lower FPZ 6 area runs from Davis Highway to 9th Avenue. One significant differentiator between these two reaches is that the lower reach was dredged and deepened sometime between 1961 and 1965. Another is that the native valley width was historically narrower in the downstream run.

Upper FPZ 6

The upper reach appears to be a rapidly evolving transition between the more stable headwater region of the watershed upstream of I-110 and the highly destabilized lower watershed downstream of Davis Highway. This reach is highly variable and its possible that it could be divided into up to four sub-reaches varying in their alteration history and in intensity of erosion and sedimentation:

- Sub-Reach A. Based on observations made from the I-110 bridge, there may be a short semi-stable area east of the highway where the channel temporarily retains decent integrity in a run that is currently largely unexplored. However, during our initial recon visit we saw that the floodplain is truncated by an old bermed stormwater pond positioned within the bottomland and this is expected to diminish the beneficial effects of what would otherwise be a very wide and resilient forested valley bottom there.
- Sub-Reach B. During the field study our team verified the presence of a sub-reach that has lost grade control, with ongoing channel entrenchment and migrating headcuts at least 5 feet below the original stream bottom. This area is immediately downstream of the potential Sub-Reach A area, and its headcutting poses a threat to the stability of upstream reaches as the knickpoints continue to migrate upvalley. This sub-reach runs roughly parallel to the extent of the northern berm of large

FDOT pond. The pond is a former borrow pit, south of the native creek corridor, reclaimed as a stormwater management system. Its drainage outlet has cut a small non-perennial headwater channel through the Carpenter Creek bottomlands which is currently unstable but appears to be approaching a stable pattern.

- Sub-Reach C. The sediment being scoured from Sub-Reach B is chaotically deposited on Sub-Reach C immediately downstream. The channel in this reach is simultaneously eroding and being smothered by upstream yield. Hurricane Sally dumped an average of 6" of fresh sand over a base of stiff bottomland clay across most of the floodplain in Sub-Reach C. This area runs parallel to a long frontage of apartment complex parking that sits atop the northern valley hillslope – tightly pressed upon the floodplain margin. Portions of the lot are above a steep slope subject to erosion. That lot generates copious stormwater runoff and litter yields to the creek and its floodplain. Litter debris consisted of tires, construction materials, shopping carts, garbage, and plastic floatables. The instream habitat lacks normal pools, which are alternately smothered by sediment or excessively scoured. Lateral instability is high, and the channel lacks normal bend geometry either from a history of ditching (no direct evidence observed) or avulsions (channel erosion that cuts off the bends).
- Sub-Reach D. The valley narrows downstream approaching Davis Highway where it is sandwiched between light commercial development along the north slope and older residential development across the south slope. The creek appears to be backwatered along much of this stretch. The south development consists of single-family residences, some of which are on stilts encroaching into the floodplain. This reach may have been dredged and straightened prior to the 1960's or suffered from a major loss of grade control based on aerial evidence. It was not dredged concurrently with the areas downstream of Davis Highway as evidenced in a 1965 aerial. One local resident from the southern frontage met with us while we were examining this reach from the Davis Highway bridge and stated the system has experienced diminished fish, turtle, and bird use; that the water is often stagnant and putrid; that flood waters rise higher than before; and that his opinion is that riprap placed upstream and underneath the bridge is contributing to these conditions.

Lower FPZ 6

The second and lower segment of the FPZ 6 stream type occurs from Davis Highway to 9th Ave. It is a long confined and artificially entrenched valley that was deepened sometime between 1961 and 1965. Although this valley was naturally deeply dissected between 40 to 50 high bluffs above the bottomlands it was likely stable in that configuration after a few millennia of channel evolution. The 1960's dredging and erosion divorced the channel from its native forested floodplain, focusing erosive forces to destabilize its banks more effectively. The site has lost its normal resiliency against large floods. The creek currently lacks a sufficient floodplain for energy dissipation and is attempting to build one. The related episodic erosion extends beyond the channel margins, causing slope failures affecting houses and infrastructure. The average annual unit bank erosion rate from this reach is expected to be about 75 times greater than that of a stable native channel in the same position. Because the banks are so high, the unit sediment yield from this reach averages about 600 times that of a stable headwater stream of equivalent length.

Slope repairs to date have been reactive and relied on inert materials without reforestation. While currently at local scale, more extensive similar repairs run the risk of displacing flood forces downstream with cumulative effect. Much of the eastern frontage of the valley slope is bordered by immense commercial parking lots without distributed runoff treatment. The amount of virtually contiguous impervious surface of those lots approaches 250 acres. Treatment was retrofit as large dry ponds between those lots and the eroding floodplain. The western slope and bluffs are occupied mostly by single family residential, and some commercial enterprise.

The remaining forests in this corridor consist of closed canopies of hardwood wetland and upland species depending on elevation, with some pines and cabbage palms. The ground is generally traversable during low flow conditions. The understory is variably occupied by dense shrub layers and generally sparse ground cover. The forests occupy a combination of natural ground, spoil piles from the 1960's dredging, and eroding channel slopes. Four highways cross the lower FPZ 6 system. In downvalley order these are Davis Hwy, Airport Blvd, Bayou Blvd, and 9th Avenue. These offer convenient divisions for discussing some of the variability along this 7,100 foot long valley:

- Davis Hwy to Airport Blvd. This area has experienced focused, dramatic bluff erosion in two locations along the north slope, both being repaired with concrete flexmat and boulder toe protection. Ongoing erosion is destroying a parking lot at an assisted living facility just downstream of Davis Hwy on the south slope. Two large dry ponds were constructed in former upland forest buffers flanking both sides of the valley, fronting about 1/4th of the segment length. The remaining forested slope sits comparatively high above the dredged channel and is vulnerable to erosion. It is inexorably being diminished by catastrophic erosion over time. Sediment transport is high through the channel and pools are largely eradicated. Very little fish or macroinvertebrate habitat occurs. Small amounts of gravel are buried within thick sand bed loads. The bankfull channel cross-section area has evolved within the regional range for a watershed this size, but it is shaped wider and shallower than typical cross sections, which is consistent with its high local and upstream sediment yields. This high width to depth (w/d) ratio increases near bank stress, accelerating bank erosion. The channel is straightened, again diminishing its ability to dissipate energy which further accelerates erosive forces, while simultaneously failing to maintain normal amounts of habitat heterogeneity associated with stream bends. This reach would normally provide excellent game fish and aquatic fauna habitat but does not sustain those benefits today. Litter is moderate with floatables dominant. Algal growth in light gaps implies poor water quality. This reach presents perhaps the single most challenging run to stabilize and restore along the entire drainage network – and among the most pressing in need.
- Airport Blvd to Bayou Blvd. This area's northern valley slope is flanked by multi-family residential properties, a very long dry pond servicing a large commercial parking lot complex, and a wet pond/commercial complex. The southern flank consists mostly of single-family residential properties and the creek's upper forest zone is part of their backyards. Several residents have cleared the forest and the creek is poorly buffered. Fish habitat, especially pools, is suppressed by sedimentation. The stream banks of this entrenched straightened channel are eroding, and deforestation is unfolding. The system appears to have sufficient floodplain width to invoke a Priority 2 natural channel design[2], but this would require cooperation of private property owners to grant easements to expand the bottomland into portions of their property. The result would be a more fishable and navigable (via kayak or canoe) run with a sustainable and developing forest.
- Bayou Blvd to 9th Ave. This reach has similar within-valley conditions to that above. Its eastern flank is bordered entirely by a large parking lot and a dry pond that services its runoff. The western and

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[2] Priority 1 restoration reverses the effects of entrenchment by raising the lost grade and reflooding the abandoned wetlands at their pre-development elevations. Priority 2 restoration maintains channel grade at existing elevation and excavates a new properly dimensioned floodplain at a stable elevation – restoring the energy dissipation and hydraulic habitat benefits of the floodplain. In this case, the work would also involve re-meandering the bankfull channel. Priority 3 restoration expands the eroding surfaces of the channel, either by laying back the side slopes or adding multiple stages. It is not fairly stream restoration because it is not self-organizing and sustaining like Priority 1 or 2 approaches. Priority 4 stabilizes the banks or slopes in place using either inert surfaces or soil bioengineering approaches. The work completed in the reach downstream of Davis Hwy is Priority 4 stabilization.

southern flank is bordered entirely by single family residences. Residents report beaver activity including construction of cross-channel dams that blow out after storms. Birdlife is enjoyed by some residents we spoke with during our site assessment here. Fallen trees have induced some instream habitat heterogeneity, including small jet pools that have exposed small gravel veneers. However, the surface sediments are dominated by sand that subsumes the small, embedded volume of gravel present in the system. This site also has high potential for Priority 2 natural channel design restoration that would create better fish and wildlife habitat and a more resilient and less erosive flood conveyance. It should be mentioned that such improvements to either of these latter runs should be made concurrently with, or subsequent to, upstream sediment reduction treatments, otherwise the work may be overwhelmed by sedimentation and the ecological and recreational benefits erased. Areas restored using Priority 2 restoration may improve flood capacity of the system, subject to verification by modeling.

3.8 FPZ 7 - Altered Mid-Order Streams Affected by Sediment

This is a placeholder category that has not been observed in the watershed. It may occur if certain partial restoration measures are implemented or could be an intermediate state of some segments during a long-term comprehensive restoration program. It is an area with a sufficiently dissipative floodplain and a relatively stable bankfull channel that has reduced instream habitat due to sediment smothering.

3.9 FPZ 8 – Altered Baselevel Streams Affected by Sediment

'Baselevel' is a term applied to the elevation of land or water at the outlet of a drainage network or portion of that network. The baselevel of Carpenter Creek is the prevailing water elevations and sediment fan in upper Bayou Texar. As sea level rises, so does that baselevel. Baselevel is an important concept in fluvial geomorphology because it can have a substantial effect on upstream channel condition and upstream yields can affect aspects of baselevel.

This stream type occurs upstream of the Bayou between 9th and 12th Avenues. Its bottomland swamp is above baselevel today, ranging from floodplain elevations of 9 to less than 3 feet, but it will be increasingly subsumed by sea level rise and increased tidal amplitude over the next few decades. At some point the system will likely flip toward a tidal creek condition, transitioning from an upper tidal swamp to a tide marsh. Any present investment in channel restoration should account for this potential, as feasible.

The existing bottomland forest is in generally excellent condition with good native diversity in the forest. Understory consists of a variety of shrubs at highly variable densities and shade adapted groundcover favoring highly saturated soil conditions, including extensive patches of ferns and golden club (*Orontium aquaticum*). The high water table has enabled thick accumulations of soft muck supporting bay trees and other hardwood species adapted to such growing media. It is difficult to traverse in places with quickmud conditions. It is, however, a beautiful example of this kind of bottomland forest – a local ecological gem.

The floodplain is broad, and two channels were dug along its eastern and western margins the same time that FPZ 6 was dredged. The western channel appeared to be smaller than the eastern branch, which has captured most of the flow over time. It is possible beavers have blocked sections of the western branch and/or that it has at least partially filled with sediment. The role of beavers was inferred from seeing beaver signs on the western floodplain margins and by the presence of more than waist-deep muck in in open water pockets reticulated throughout the western forest floodplain that made the swamp impassable from that side. The presence of beavers and lack of a well-defined channel should be confirmed by local residents whose property borders the western slope, or by drone. The available LiDAR topography failed to discern the western channel if it still occurs, and that DEM barely and sporadically captures the well-defined eastern channel. The eastern channel's sandy bottom can be glimpsed through the canopy on recent aerial photos, but no such features are visible on the western branch.

The eastern branch is free flowing with a sandy streambed and has well-defined forested streambanks. The right channel bank facing downstream consists of the spoil cast during channel dredging. It is fully forested. The main channel runs close to the eastern valley hillslope and is fairly easy to access from that direction. The eastern hillslope is bordered by box stores and single-family residents on large lots. The channel bed is dominated by sand, with sporadic protrusion pools creating thin veneers of gravel under fallen logs in the stream. The channel is unnaturally straight and supports high enough velocities to sustain dune bedforms. The streambanks are relatively low and stable. They are buttressed by large sediment accumulations delivered from upstream sources, and when bankfull flow is exceeded it can spillover the floodplain which dissipates the energy of the flood pulse.

The channel is about 25 to 30 feet wide and is 3 to 4 feet deep at bankfull flow. It flows with copious cool and clear baseflow. Deep pools that would naturally occur and support excellent game fish habitat are lacking due to the high upstream sediment yields and straight channel planform. Pools could be induced by creating meander patterns, installing large woody material arrays, and reducing upstream sediment yields. These same implementations could induce better rearing habitat for juvenile freshwater phases of estuarine and marine fishes as well as native sunfish like bass. As sea level rises, the site will become more estuarine. It would be prudent to determine if there is an overlap in the range of channel pattern and dimension suitable for the hydrology of today that could also be stable under increased tidal influence. This section of the creek could be enhanced to provide better aquatic habitat and to provide an excellent kayaking and fishing experience. It has a history among locals as a swimming hole, even as recently as a few years ago (as evidenced by an abandoned dock just upstream of the research site), but sedimentation has diminished its recreational capacity.

3.10 FPZ 9 – Artificial Drainage Ditch

Because the watershed generally provides excellent internal soil drainage, few terrestrial drainage ditches were dug. Some have naturalized and require little or any ecological improvement, while others are actively eroding or pass untreated pollutants downstream. The known ditches have been color coded accordingly. Although at least 2 of the ditches were dug to provide development drainage, most are short drains downstream of impoundments or stormwater ponds. The two eroding or vulnerable ditches have sufficient adjacent undeveloped land to enable Priority 2 natural channel design as a means to improve their drainage capacity, stability, ecology, and water quality capacity. Landowner permission is likely required.

3.11 FPZ 10 – Impounded Stream or Wetland

At least 5 such features occur in the watershed. These range from blockages across former Baygall Seeps and small tributaries. Some double as embankment roads. Many of these were constructed before regulation, and it is unlikely they are based on robust designs. Berm maintenance may be limited to non-existent. Some such impoundments have failed in the watershed in recent years, including one in the headwaters during Hurricane Sally. These failures release sediments downstream, and in some cases, may represent safety concerns. These areas are prime candidates for restoration should they be acquired.

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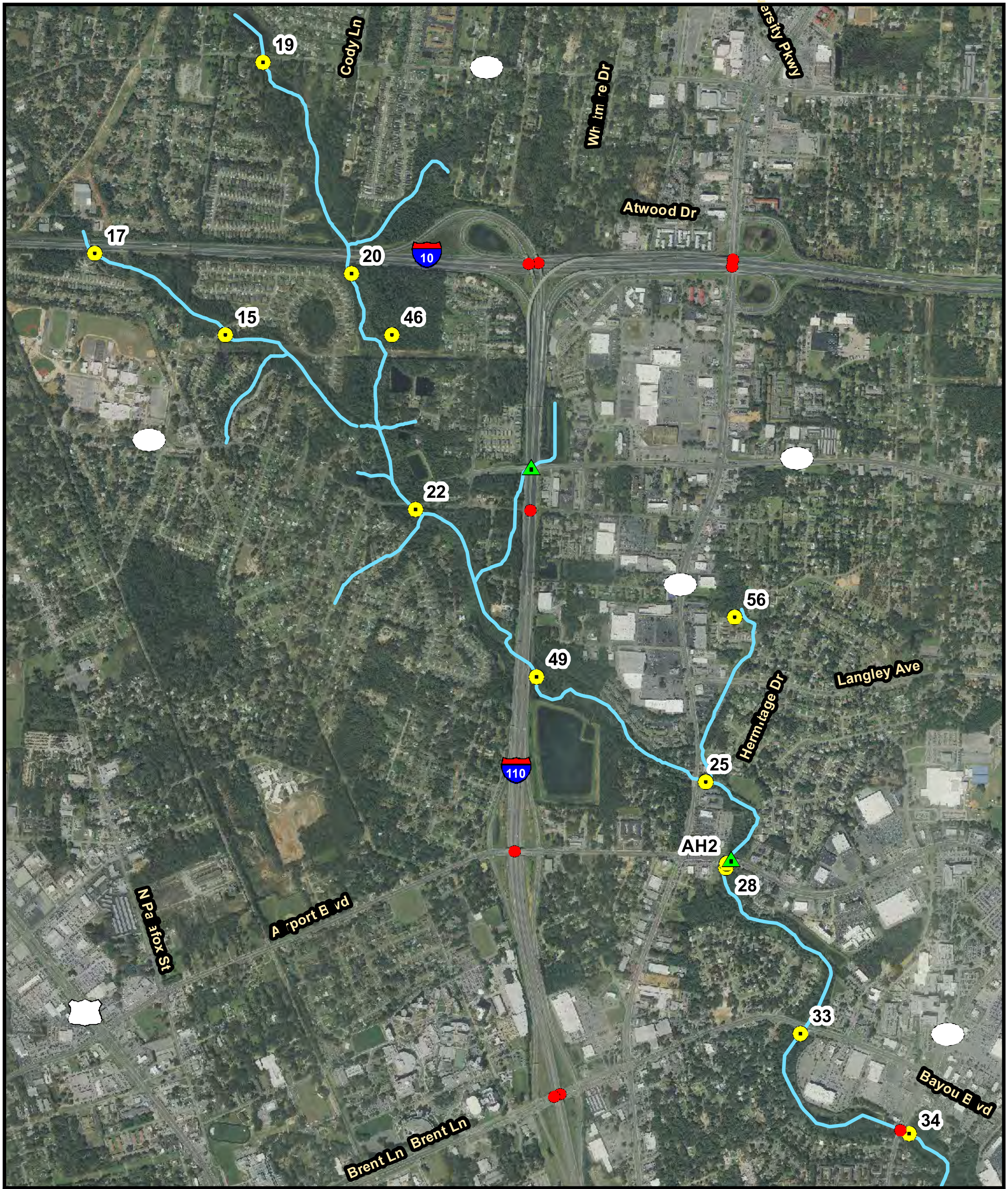
APPENDIX A
Maps



Notes:

1- Project No.: 600643

2- Data Source - Wood, ESRI, NHD, County

3- This map is intended to be used for planning purposes only. It is not a survey.

Date: 04/15/2021
Revised:AB
Checked By:JK

Explanation of Features

N

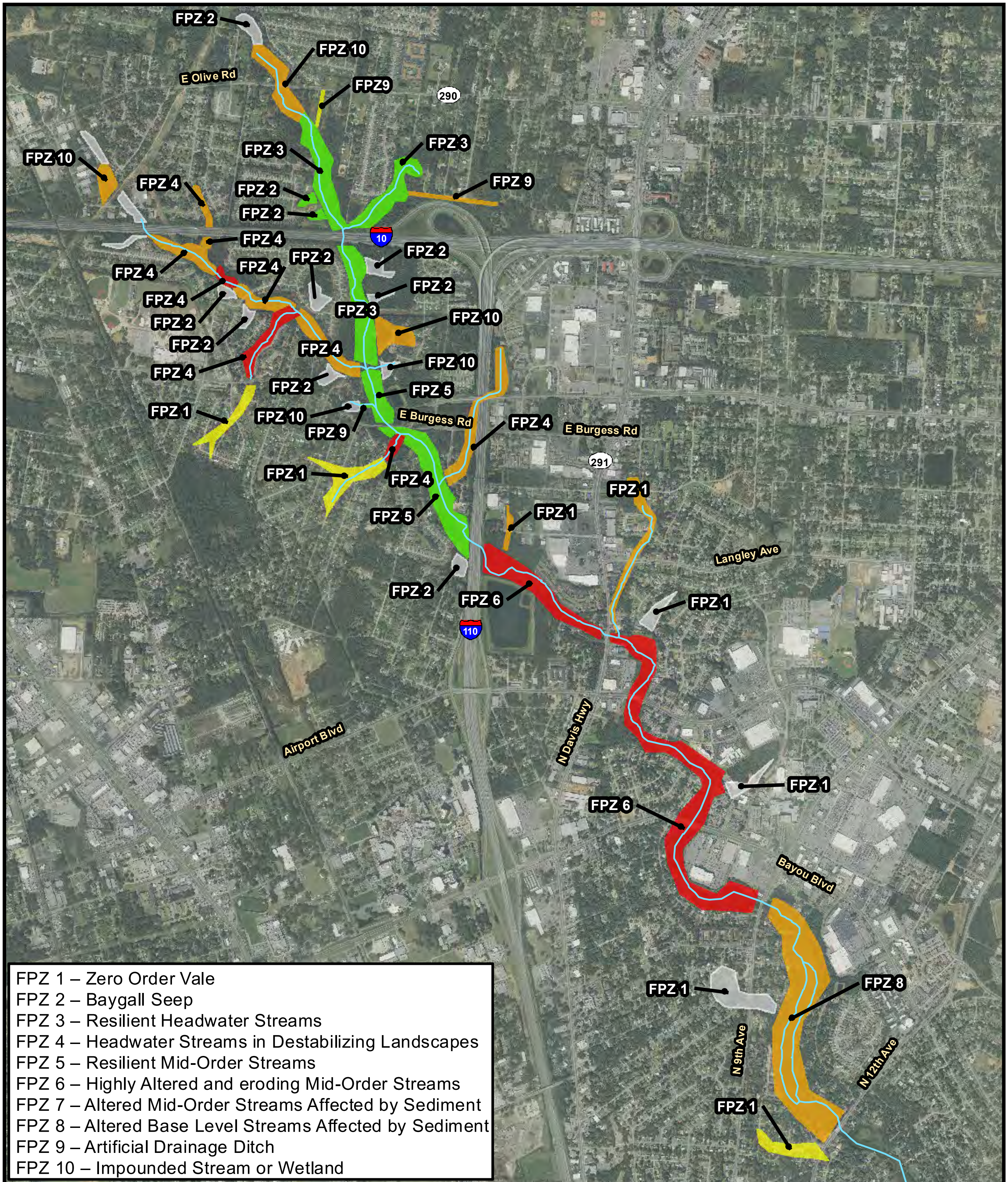
- Bridge
- Culvert
- Site
- Hydrological Features

0 1,500
Feet

wood.

Bridge Crossing Locations
Carpenters Creek
Escambia County, Florida

Path: V:\600643_Carpenter_Creek_Bayou_Texar_WMP\MXD\Report\8x11P_Bridge_culverts_sites.mxd



Notes:

1- Project No.: 600643

2- Data Source - Wood, ESRI, NHD, County

3- This map is intended to be used for planning purposes only. It is not a survey.

Date: 04/15/2021
Revised:AB
Checked By:JK

Explanation of Features

N

Hydrological Features

FPZ

- Under Evaluation
- Quasi Stable
- Contributes to downstream imbalance
- Unstable and vulnerable to channel erosion/sedimentation
- Valley slope failures and high vulnerability

0 1,500
Feet

wood.

FPZ Locations
Carpenters Creek
Escambia County, Florida

Path: V:\600643_Carpenter_Creek_Bayou_Texar_WMP\MXD\Report\8x11P_FPZ_sites.mxd

APPENDIX B
Site Photos

Photograph #1: Site 56 (FPZ 1)
Steep sided ravine

Photograph #2: Site 56 (FPZ 1)
Vegetated ravine slopes abutting residential development

Photograph #3: Site 56 (FPZ 1)

Photograph #4: Site 56 (FPZ 1)

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VOLUME 3C ATTACHMENT B

STREAM ASSESSMENT CATEGORICAL IMPROVEMENTS REPORT

Attachment B
Task 3.3.2 Report

wood.

CARPENTER CREEK & BAYOU TEXAR WATERSHED MANAGEMNT PLAN

TASK 3.3.2
STREAM ASSESSMENT CATEGORICAL IMPROVEMENTS

Prepared for

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This technical memo builds on the previous **Task 3.3.1** Stream Classification, delving into the treatment options available to create a more stable and resilient drainage network in balance with the hydraulic and sediment loads of the watershed. The desired outcome is to implement treatments along the network over time, resulting in reduced erosion, flood hazard reduction, better water quality in the creek and bayou, and a natural balance of sediment transport through the system. When implemented at sufficient scope and scale, these treatments can meet goals to conserve and improve aquatic and terrestrial ecology, improve recreation potential and value, and create a more flood resilient system.

This memo describes the treatments that will, in subsequent deliverables, be combined into a watershed management plan; it covers the building blocks along with additional background regarding how departures from a stable stream condition can be treated.

2. CHANNEL STABILITY & DISCONTINUITY ISSUES

2.1 Loss of Grade Control

Stable streams maintain a long-term average longitudinal slope down the valley, referred to as the grade. The range of stable grades are a regional condition that varies locally with drainage area size and streambed substrates. Grade can be destabilized by deforestation, upstream erosion, excessive runoff, bridge hydraulics, channel dredging, and channel straightening among other stressors.

A stable grade is not inert; Carpenter Creek's sand and gravel are naturally in nearly constant motion. A stable stream may locally adjust its grade in response to individual storms, but the long-term trend is that the bed slope fluctuates around a central tendency rather than trending steeper or more gradual over time. A loss of grade control means the valley floor or streambed is changing its slope as a trend. It is fundamentally unstable and is seeking an alternative slope. Loss of grade control is a loss of foundation and is thus considered the most severe kind of erosion problem.

A key field diagnostic of grade control loss is the knickpoint. Knickpoints are small erosional cascades on the channel where the water is plunging over some resistant material in the streambed. This creates a plunge pool, or a scour hole, immediately downstream. It looks like a small waterfall and can be a few inches to more than several feet high. The eroding surface migrates upstream once it overcomes the local resistant layer, and thus is said to be 'head-cutting.' Sometimes the knickpoint is called a headcut for that reason. Florida headcuts are typically detained (but not arrested) by root systems or clay layers in the streambed.[1] An 'arrested headcut' occurs when the knickpoint is rendered inert, and is no longer migrating. Arresting a knickpoint is difficult because knickpoints headcut in waves over time, which can alter the grade upstream and downstream of the present headcut(s). It is common to see knickpoints in various stages of

[1] In native NW FL sapping ravines, we often see natural 'root-steps' that have superficial resemblance to knickpoints. These are stable and desirable features that occur in a narrow window of valley and watershed conditions that are uncommon in the Carpenter Creek watershed. If present, they will be in selected Baygall systems here. Another confounding presentation involves beaver dams and jams. Look for tooth marks and other beaver signs in the vicinity of a series of low woody debris and root cascades.

development along an actively regrading streambed. New ones can pop up anywhere along such valleys after every storm. Treating the headcut at its current position addresses the local symptom, not the systemic cause.

Absent grade control, any bank stability treatments upstream of the actively migrating headcut will not be sustained – they will eventually be undermined by the loss of streambed grade. Most in-stream habitat amendments downstream of active headcuts will be buried by excessive sedimentation. Grade control is a primary priority treatment when indicated.

2.2 Channel Widening

Streambank erosion usually indicates an unfolding process of channel enlargement, especially widening. There's an intrinsic regional relationship between the bankfull channel width and drainage area size. For this reason, we can diagnose channel size departures using regressions of channel dimension versus drainage area, referred to as 'regional curves.' Metcalf et al (2009) developed regional curves that apply to our study area.

Urban hydromodification often unleashes erosion on the streambank, but this is usually more of an indication of inadequate floodplain width rather than too small of a bankfull channel. The system is trying to build a wider floodplain at a lower elevation than the existing one in response to combinations of 3 main stressors: 1) intensified runoff from impervious surfaces, 2) an incised bankfull channel that no longer spills over onto its floodplain, and 3) climate change increasing the frequency of large floods. Consequently, it erodes the streambank to get the floodplain it needs. A migrating streambank is simply the path to a larger floodplain. Once adequate floodplain width and elevation are achieved, then the streambank stops excessively eroding and the bankfull channel dimension returns to its regional norm. This takes many decades to achieve equilibrium; destroying aquatic habitat, surrounding forests, and infrastructure in process.

Loss of grade control is often a precursor to channel widening, as it undermines the foundation of the streambank. Local hydraulic effects from poorly dissipated stormwater outfalls or bridges can also generate bank widening. Excessive sedimentation, which shallows the stream and puts greater stress on the banks forcing a larger width-to-depth ratio to maintain its total cross-section area also generates bank widening. So it is important to diagnose whether bank erosion derives from local or systemic stressors to recommend sustainable and resilient countermeasures.

Bank erosion is normally resisted by woody root systems in natural Florida streams. Stable channel pattern and dimension result from the long-term interactions of this vegetation with fluvial forces and sediment yield delivered from upstream sources. Florida's long growing season and abundant rainfall enable powerful forest root structures to develop and sustain. Natural valleys and watersheds deliver comparatively low sediment yields and fluvial force, enabling the forest to exert considerable biological influence over the alluvial controls. This results in channel patterns that are not strictly alluvial in derivation and has design ramifications regarding the portability of methods assuming alluvial control. Removing or weakening the streambank and floodplain forest generally unleashes bank erosion. Conversely, forested banks, once established, are highly resistant to erosion. They are so resistant that they can mask the effects of long-term excessive stresses giving a false appearance of a stable regime when it is just a matter of time before the forest fails and the banks collapse.

Lag effects in fluvial geomorphic adjustment like this are common. Excessive bank erosion is often not a steady process year-over-year but occurs in leaps and bounds with sometimes long steady intercessions occurring between seemingly sudden and catastrophic events. The threshold effects for streambank erosion were present all along, just the timing of the erosion is uncertain. This exact timeline of stressor threshold exceedance, forest resistance leading to lagged expression, and the sudden appearance of patches of catastrophic erosion are unfolding in FPZ-6 between Davis Highway and 9th Avenue. Much of the erosion we see along the Carpenter Creek drainage network is just a matter of the timing of excessive forces finally overcoming the forest's resistance.

2.3 Floodplain Widening/Valley Slope Failure

Channel migration dictates floodplain dimension. As the channel bends migrate, they grade the floodplain width, inexorably renewing its surfaces over time. This unfolds very slowly in Florida. So slowly it is hardly perceptible when walking a stable floodplain and channel over a period of some years. Channel migration occupies a meander belt – this is the "wiggle room" the stream requires. The stable meander belt width depends on watershed size and runoff characteristics. If the meander belt is too narrow, bend migration and streambank erosion accelerate.

If the valley hillslopes overly confine the floodplain, the meander will encroach into the bluff causing large slope failures. This kind of bluff erosion is occurring between Davis Highway and 9th Ave. The urban landscape and climate change have rendered its pre-development floodplain width inadequate and, in that area, the confining valley slopes are now in the way. When the valley side slopes are widely spaced and greatly subsume the growing meander belt, the system is deemed unconfined and is not subject to this kind of slope failure.

Hillslope failures in the region can also be induced by groundwater sapping. This occurs in areas with high relief and strong groundwater flow that the soil lithology directs through easily transported sand layers near the base of the slope. The concentrated groundwater flow pipes the sand to a receiving water body and the material above the void collapses. Many of the gully ravines in Northwest Florida and along the east shore of Mobile Bay in Alabama formed in this manner. This form of erosion may be a contributing factor on some valley hillslopes along Carpenter Creek.

2.4 Bridge Hydraulics

Bridges were historically not designed to assure the biophysical integrity of the streams they cross. In some cases, standard and customary bridge design disrupts the continuity of upstream fish passage and retards continuity of sediment transport, especially at culvert crossings. Crossings can also create sudden flow contractions and expansions that erode stream beds (attacking grade) and create eddies and near bank stress that collapses streambanks. Bridges can also constrict flow, raising water levels upstream during low and high flows. Fortunately, advanced bridge design – referred to as passage continuity construction (PCC) – addresses these legacy effects and is often a critical appurtenant aspect of stream restoration necessary to unlock the full potential of the restoration benefits.

3. STREAM STABILIZATION PRIORITY OPTIONS

Stream restoration and stabilization practices of artificially incised and actively eroding channels are categorized based on whether the bankfull channel and active floodplain can be repatterned to become self-sustaining, and whether the existing flood line is to be raised or reduced to achieve the available resiliency. Floodplain pattern and dimension are critical variables for stable Florida stream corridors, and they take on added dimensions under the effects of urban stream syndrome. Doll et al. (2003) describe Priority 1, 2, 3, and 4 options for stream restoration/stabilization, offering a valuable perspective because they account for distinct differences in approach to floodplain restoration. These options describe remedies for stabilizing eroding channels that have incised over time, but in some cases areas, downstream of the incision are not entrenched. Wood provides a corollary option for this case as well.

Priorities 1 and 2 attempts to create self-organizing systems with full access to stable floodplain elevations and dimensions. They are rather genuinely deemed ecosystem restoration options because the systems are self-sustaining and strengthen over time. However, there is not always sufficient room, budget, or time to conduct these options in the entirety of the urban core. Priorities 3 and 4 represent channel improvements that can have ecological benefits but that are designed to resist the available forces and material loads rather than harness and adjust to them.

Figure 3.1 – Incised and Eroding Channel Section

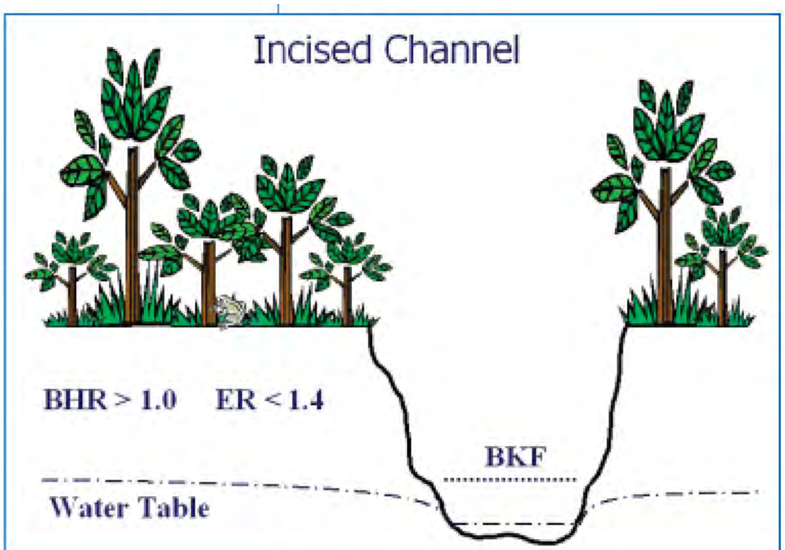


Image Credit: Doll et al. (2003). BHR – bank height ratio. ER- entrenchment. BKF – incised bankfull flow level.

3.1 Priority 1 Restoration – Bring the Waterline Up to the Historic Floodplain

Where channels are incised and not able to access their existing floodplains, Priority 1-ENT (entrenched) restoration aims to raise the bankfull flow back up to reconnect with its floodplain and often to rehydrate historic wetlands. This can be accomplished by filling or reconstructing the channel, but also through less intensive means including the addition of weirs, bends or other structures that raise the bankfull flow elevation enough to reconnect to existing intact floodplains.

Connection to floodplains helps to dissipate energy and facilitates infiltration to groundwater, aiding in slope stabilization, reduction of peak storm flows, and water quality improvement. It should be noted that Priority 1 restoration often results in higher elevations of flood stages or a widening of the existing degraded wetland/floodplain footprint, so it may not be an appropriate restoration method in stream corridors that are closely bordered by development.

Figure 3.2 – Priority 1 Restoration Section

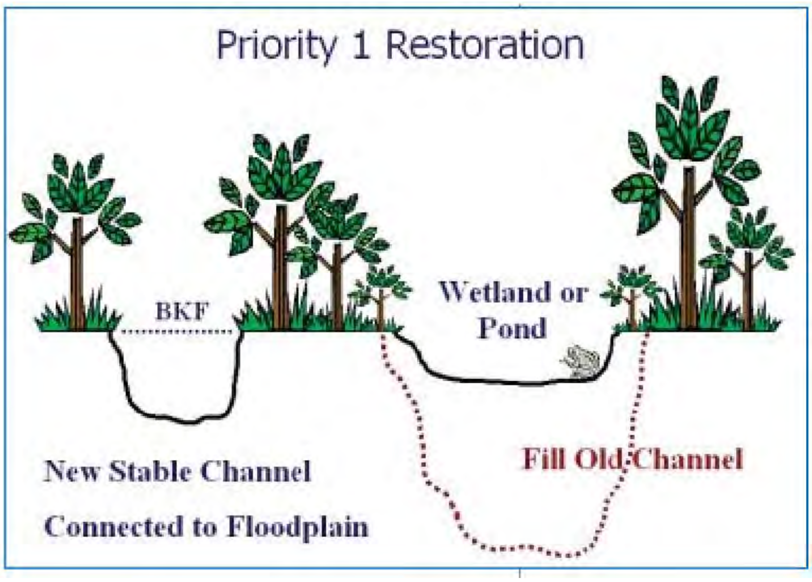


Image Credit: Doll et al. (2003). BKF – restored bankfull flow level.

In some cases, the stream is not excessively incised and still has access to its floodplain but has been straightened in ways that compromise its biological integrity. The Priority 1-STR (straightened) option then involves retrofitting natural bend patterns without a need to raise the prevailing waterline. In both Priority 1 options, the result is the restoration of a historic floodplain and a meandering open channel coursing through it, with routine water exchange between them.

3.2 Priority 2 Restoration – Bring a New Floodplain Down to the Existing Waterline

For incised or ditched channels that cannot access their floodplains, but that need to retain their existing bed elevation due to various land use and grade constraints, Priority 2 restoration aims to create a new floodplain, brought down to a lower, accessible elevation. This type of restoration is typically accomplished through construction or repatterning of a stream with a bankfull channel meandering through a floodplain and maintaining riffles and pools. Priority 2 restoration projects can be constructed adjacent to or within the existing undeveloped property. Priority 2 restoration often adds flood storage volume, in addition to the benefits provided by floodplain access, and can reduce flood elevations. It essentially produces the fluvial system that would evolve on its own over time, short-circuiting decades of erosion and ecological disruptions and eliminating the need to produce ad-hoc responses to eruptions of catastrophic erosion events that are hard to predict in time and location. It is typically the most intensive and costly form of restoration but usually returns ample benefits on investment.

Figure 3.3 – Priority 2 Restoration Section

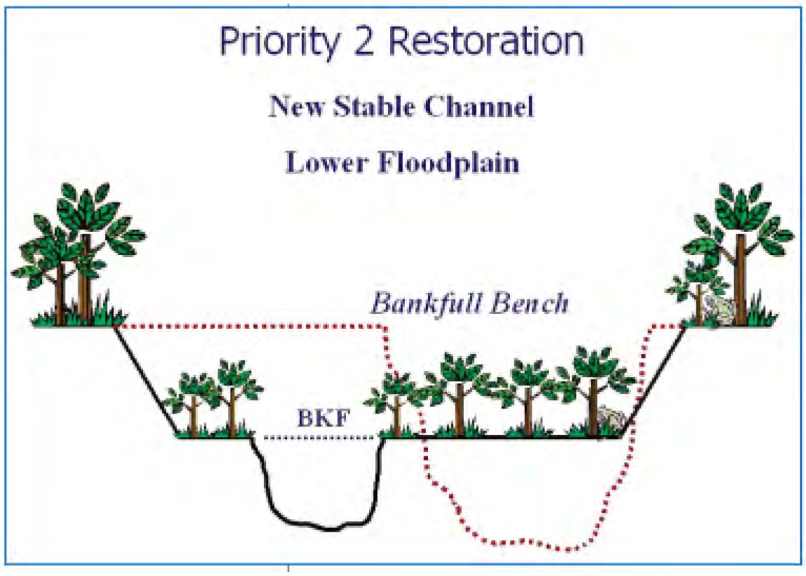


Image Credit: Doll et al. (2003). BKF – bankfull flow with new floodplain access.

3.3 Priority 3 Stabilization – Bench the Floodplain

This option creates a multi-stage channel by creating a wider flood bench at the existing bankfull flow elevation. This reduces shear stress and mitigates erosion but does not necessarily create the same resilience as Priority 1 or 2 options in sand-bed streams because the floodplain remains under-dimensioned. To compensate for this, designers often add imported rock on the streambanks to suppress the natural tendency toward bend migration or retard channel widening. Rock is also typically imported to the streambed for grade control. Imported rock is sometimes added in an adaptive fashion in response to serial failures of this method in sandy valleys. Two approaches to Priority 3 stabilization can be considered.

Priority 3-B patterns the valley in accordance with a Rosgen B stream type. The Rosgen natural channel design approach requires a stable reference reach in the same hydrophysiographic region as the project site. B-streams can provide a ready urban solution where rocky streambeds and step-pool streams with rapids and cascades are native. It also can work well in gravel-dominated streams. However, it is not a self-organizing and highly resilient approach in sandy urban Florida stream corridors. Where we have encountered stable Rosgen B streams in natural Florida landscapes they have been seepage ravines lacking the powerful flood pulses delivered by urban runoff.

Figure 3.4 – Priority 3 Stabilization Section

Image Credit: Doll et al. (2003).

Priority 3-MS (multistage) retains a straight main channel and flanks it with flood terraces(s) at multiple elevations to improve sediment transport and reduce erosive forces. These are 'level-of-service' designs based on hydraulic calculations, also referred to as tractive force design (NRCS 2007). In effect, they provide a more resilient ditch than that of the classic trapezoidal channel (e.g. single-stage channel).

Priority 3 options are typically only considered when there is insufficient lateral room to create Priority 1 or 2 solutions. Priority 3 enlarges the existing floodplain allowing it to dissipate energy and trap sediment, but in a manner that is not self-organizing over the long term. It provides a more complex, bigger, and more beneficial ditch versus historic approach. Priority 3 solutions are often required over short channel segments that otherwise support Priority 1 or 2 restoration.

3.4 Priority 4 Stabilization – Stabilize-in-Place

Priority 4 stabilization, often referred to as stabilization in place (SIP), involves stabilization of existing banks without repatterning or changing channel dimensions. Various methods can be used to stabilize the banks, including vertical bulkheads, armoring with materials such as riprap or gabion baskets, or slope stabilization with soil bioengineering techniques. While Priority 4 stabilization does not offer flood control, recharge, or water quality benefits associated with connection to a floodplain, it can reduce erosion, sediment transport, and slope failure where the treatments are installed. It can also displace energy and intensify downstream erosion. Some soil bioengineering techniques provide countermeasures to downstream energy displacement. Priority 4 stabilization is expensive, provides comparatively limited environmental value, and is typically reserved for areas where development or infrastructure has encroached into the floodplain or along a failing valley hillslope and the other Priorities are not supported by site conditions.

4. CHANNEL TREATMENT TYPES

Using an art analogy, the Stream Restoration Priority Options relate to the available medium (e.g. canvas, marble, or film) and the Treatment Types are the tools of production (brushes, paint, chisel, and lens). Stream restoration in this watershed will necessarily be a vibrant mixed-media production.

The channel treatments are not all mutually exclusive, and all of those listed are likely to contribute portions of an integrated solution to match the scope, scale, and position of the problems and achieve watershed goals and objectives. The primary emphasis of this memo is on work within the valley, but mention is necessarily made also of addressing the adverse effects of hydromodification with stormwater management retrofits aimed specifically at erosion problems caused by urban hydromodification. The need to treat the waterbody and the watershed is clearly indicated.

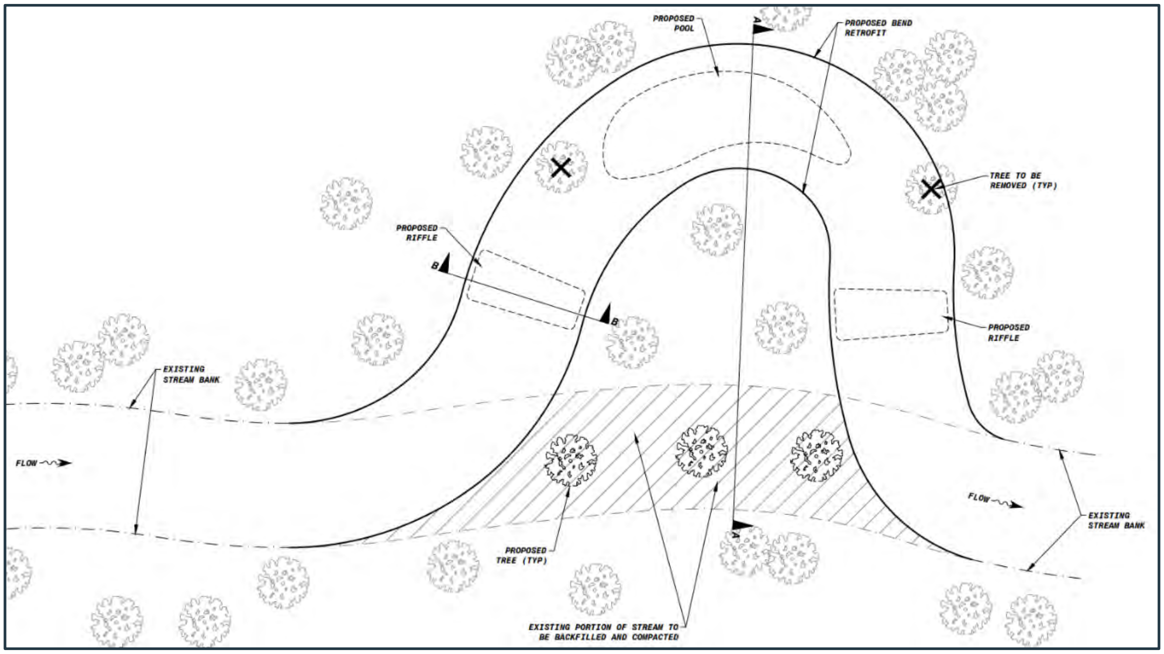
4.1 Green Stream Restoration Infrastructure

Green stream restoration infrastructure generally provides a natural aesthetic, utilizes natural materials, mimics natural processes, provides multiple environmental benefits, and is designed to be sustainable. Three green engineering methods that can be applied to channel and stream stabilization include natural channel design, vegetation reinforces soil slopes (VRSS), and various applications of woody debris.

Natural Channel Design (Priority 1, 2, or sometimes 3)

Natural channel design aims to restore the dimension, pattern, and profile of a disturbed creek system by mimicking regionally appropriate stable stream corridors, focusing primarily on physical stability and biological function, rather than returning them to a pre-development, pristine state. Natural channel design can be implemented in Priority 1-3 restoration, as described in **Section 3**. Natural channel design projects range from reconstructing entire ditched sections of streams to small-scale improvements such as retrofitting select bends (**Figure 4.1**). Through creation or reconnection of floodplains and inclusion of natural stream features such as meanders, pools, and riffles, natural channel design offers a wide variety of benefits including erosion control and bank stabilization, improved flood protection, improved aquatic and terrestrial habitat, and fish passage, improved water quality, reduced maintenance needs, and both recreational and economic opportunities. Applying natural channel design as a treatment for unstable reaches of Carpenter Creek could also provide many of these additional hydrologic, environmental, and social benefits.

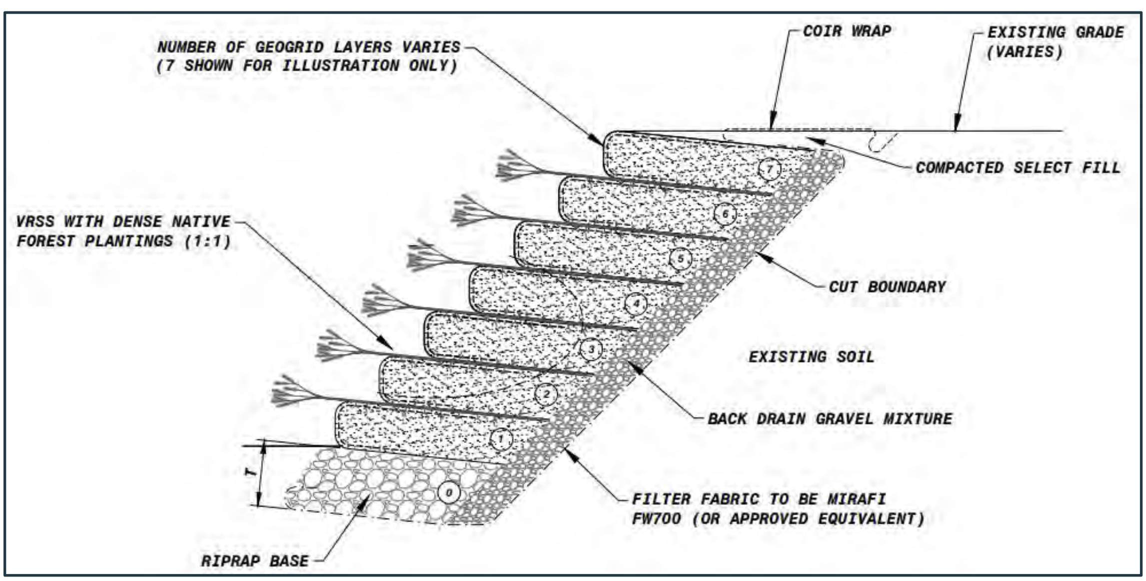
Figure 4.1 – Bend Retrofit Example



Vegetation Reinforced Soil Slope (Priority 2, 3, and 4)

Vegetation reinforced soil slope (VRSS) is a soil bioengineering technique that utilizes natural, vegetative materials to stabilize steep banks with slopes up to 0.5:1 (horizontal: vertical) and banks up to 60 ft high. VRSS utilizes layers of soil wrapped in geofabric with living, rootable vegetation planted between each layer so that the root system will bind the layers together over time. If needed, toe protection can also be added to prevent scour. In addition to bank stabilization, VRSS offers ecological, water quality, and aesthetic benefits and is highly adaptable to many different settings and shapes.

Figure 4.2 – Vegetation Reinforced Soil Slope (VRSS)



Rosgen Cross-Vanes, J-hooks, and Toe Wood (Priority 1 and 2)

Rosgen Cross-Vanes is a type of large woody debris (LWD) that are placed on straight reaches to induce pools and direct flow toward the center of the channel, away from the banks, and to relieve erosive stresses on the banks. Rosgen J-Hooks can be placed at the outer bank of a bend to similarly direct flow toward the center of the channel and away from the banks. Rosgen toe wood is a cantilevered array of cross-stacked logs and root wads that are used to armor the channel toe and provide a foundation along the outer bank of bends. These can be used in place of riprap toe protection where hydrologic conditions allow (typically perennial streams that preserve wood from decay). In addition to bank stabilization and protection from scouring by energy dissipation, woody debris such as that used in toe wood provides fish habitat and is not subject to particle erosion, so it is often preferable to riprap (where conditions are appropriate).

Figure 4.3 – Rosgen Toe Wood

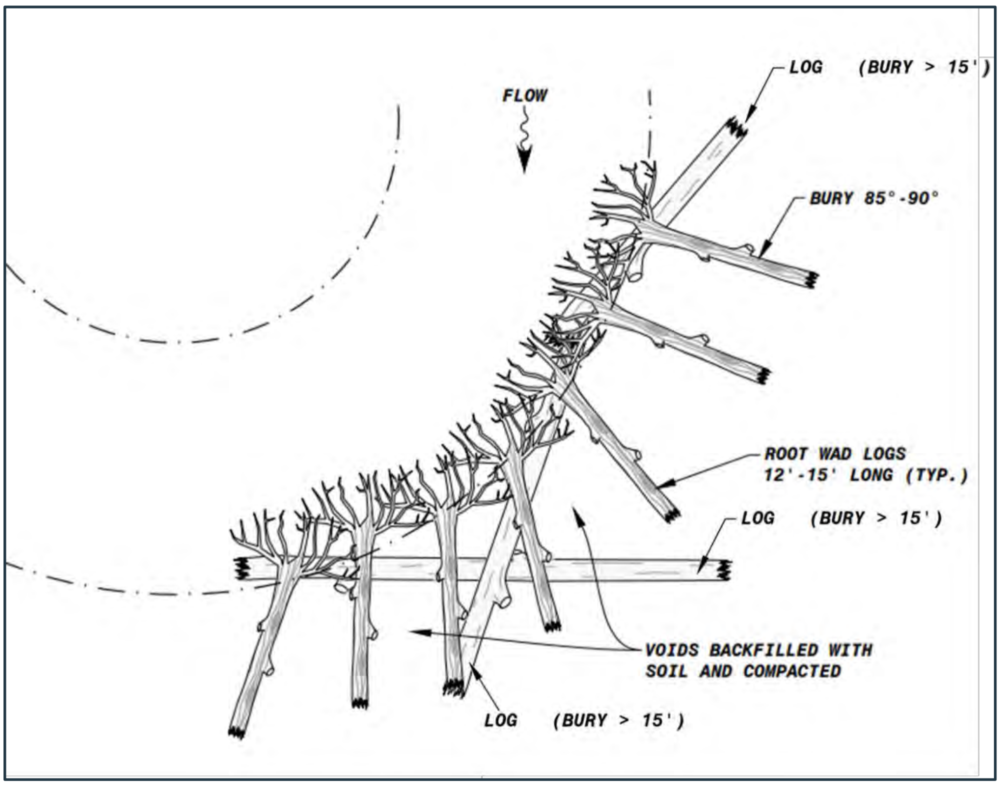
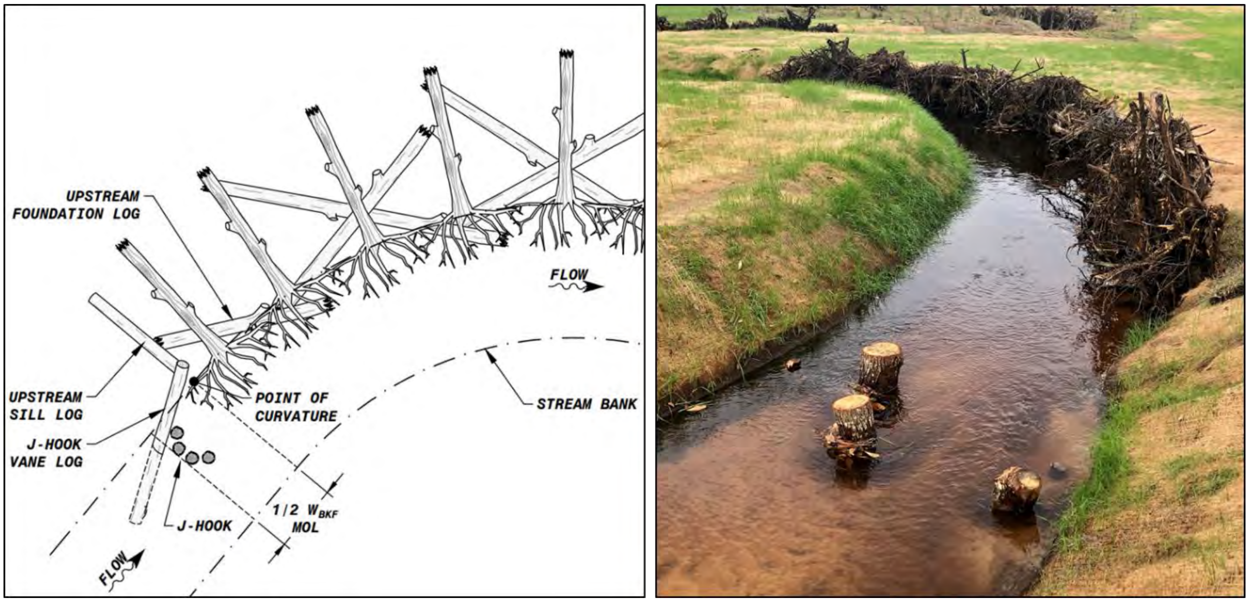


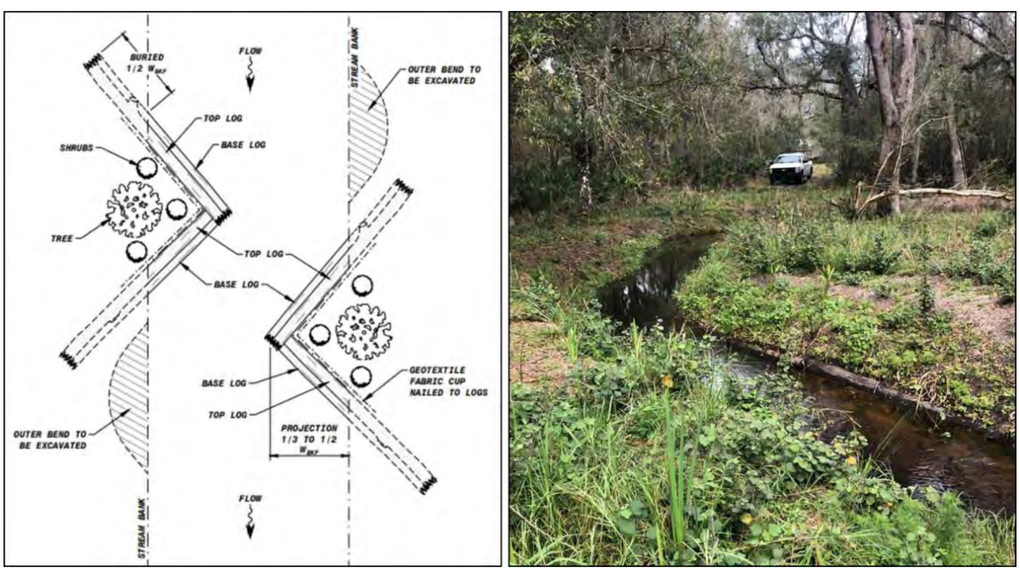
Figure 4.4 – Rosgen J-Hooks



Wing Deflectors

Wing deflectors are triangular projections from an existing stream bank (sequenced in pairs) that form tight bends creating hydraulic habitat diversity in the form of projection scour pools and overhanging banks. These tight bends mimic bends in natural Florida headwater streams that formed around well-established tree roots. Wing deflectors are typically constructed with stacked timbers or coir logs, backed with geofabric, filled with soil, and planted with trees, shrubs, and other native vegetation.

Figure 4.5 – Wing Deflectors



4.2 Gray Infrastructure

Gray infrastructure describes inert structures used for channel stabilization that are associated with more traditional engineering methods and materials, such as trapezoidal channels or lining with concrete and rock. While gray infrastructure methods address erosion and stability issues, they provide few additional environmental or social benefits and can degrade over time. It is generally recommended that green infrastructure methods be considered first, and that gray infrastructure methods be considered only if required by site and project conditions. Due to constraints and confinements (such as bridges or existing structures), gray engineering techniques may be required in discrete sections and are often blended with green infrastructure techniques in channel restoration projects (e.g., utilizing bulkheads in a stream section without sufficient width for natural channel and floodplain dimensions or utilizing riprap near bridge sections).

Riprap (Priority 3 or 4)

Riprap is a stabilization material composed of rock (limestone, granite, concrete rubble) and used to armor shorelines, streambanks, and channels against scour and erosion. Riprap armoring is often used to stabilize the channel in place (Priority 4) by armoring most or all of the banks but can also be used more discretely as toe protection or within certain natural channel design features. For most Priority 4 applications, VRSS could be used in place of riprap.

Figure 4.6 – Riprap Channel Protection and Riffle Around Aerial Pipeline

(Edwards Bottomlands)

Articulated Concrete Block (Priority 4)

Articulated concrete blocks (ACB) are composed of interconnected, interlocking blocks that overlay the bank slopes and protect the underlying soils from erosion and are used in Priority 4 stabilization in place. Open-cell varieties allow for vegetation to grow through the holes and provide some aesthetic and habitat benefits. ACB systems provide erosion and scour protection, but do not inherently stabilize the underlying slopes.

Figure 4.7 – Open Cell Articulated Concrete Block Integrated into a VRSS Foundation

Gabions and Marine Mattresses (Priority 3 or 4)

Gabions or gabion baskets are cages or boxes filled with rocks or concrete that can be used to stabilize stream banks and slopes against erosion. The cages prevent the rocks from washing away during high flow events, but they have limited energy dissipation capabilities, and the build-up of silt and gravel within the voids reduces their design lifetime. VRSS can typically provide similar erosion control and better energy dissipation than gabions (along with additional habitat, water quality, and social benefits). Reno or marine mattresses are a horizontal version of gabions that line the channel to protect the bed as well as the banks. They are permeable and can sometimes allow for vegetation growth in the open spaces, but similar to gabions, their strength depends on their reinforcement and mesh material that breaks down over time.

Figure 4.8 – Gabion Baskets (Left) and Marine Mattresses (Right)

Photo Credit: http://gabion1.co.uk/river-bank-protection (left). https://www.gabionbasketsbox.com (right).

Bulkheads or Retaining Walls (Priority 4)

Bulkheads or retaining walls (often called seawalls) are vertical structures typically composed of poured concrete or steel sheet piles to hold the banks in place. Bulkheads stabilize the channel and can be used in laterally confined areas where sloped banks may not be feasible. However, bulkheads require rigorous geotechnical assessments, groundwater management design, and routine inspections for condition or failure. Bulkheads typically offer little to no energy dissipation or other habitat, water quality, or social benefits.

Newbury Riffle (Priority 1, 2, 3 or 4)

Hydraulic structures designed as rock riffles are effective at raising bankfull water levels to restore floodplain/channel water exchanges in incised streams, provide grade control at actively head cutting reaches, trap sediments, and simultaneously allow for continuous (or seasonal) upstream fish passage (Newbury et al. 2011). Newbury Riffles are engineered structures with ecological and stream stability benefits. They can be implemented on sand bed streams with care in design. Newberry Riffles are a level-of-service design dependant on the hydraulics of the design storm, transport resistance of the rock sizes used, and the ability of the adjacent floodplain to dissipate energy and accommodate abutment protections.

This treatment is restricted to local scale areas generating significant fluvial force across large elevation changes. This is especially true for those drops in grade that generate super-critical flow[2] during flood events. Potential use of Newbury Riffle is downstream of selected bridges where plunge pools or mass wasting occurs across significant hydraulic gradients. A good example is downstream of Davis Highway where a hydraulic jump occurred during Hurricane Sally and massive valley slope erosion has been occurring. Another conceivable location would be at large knickpoints at tributary junctions.

Figure 4.9 – Newbury Riffle

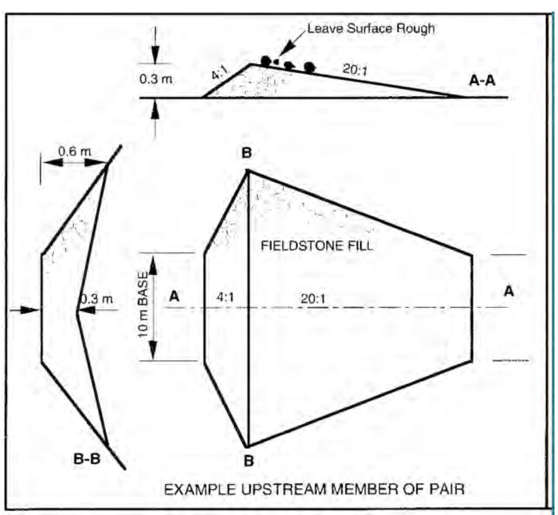


Image Credit: Newbury & Gaboury (1994)

[2] Super-critical flow is not normal for Florida streams and it creates jumps and waves that act like an auger or motorgrader on the streambed and banks. Newbury riffles are one of a very small number of available treatments specifically designed to pass supercritical flow.

4.3 Hydromodification Treatments

Hydromodification is the root cause of urban stream erosion. This derives from the intensified runoff of impervious surfaces, compounded by increased storm frequency-intensity-duration effects of climate change. One of the great values of planning at watershed scale is the potential for integrating stormwater management systems with stream restoration. The stormwater management systems listed below treat water before it reaches the stream channel. Most of the treatments are deemed 'green infrastructure' because they mimic and restore natural water balance and flow processes to the watershed. Green infrastructure provides a wide array of public and environmental benefits throughout the watershed and in its drainage network (EFC 2017). So, although this memo focuses on stream restoration and stormwater management systems, and watershed treatments are to be more fully described elsewhere in the plan, it is imperative to mention stormwater runoff treatments that can create significant resiliency within the drainage network in the context of its stream restoration benefits.

Detention Ponds

Wet and dry detention ponds are standard and customary stormwater treatments designed to address a subset of hydromodification effects and water quality improvements. They typically treat runoff collected by streets and gutter. Treatment after curb-and-gutter of urban runoff alone seldom prevents stream erosion. In some conditions, detention hydraulics can actually increase the cumulative duration of erosive threshold events. While detention ponds are a valuable tool in the overall kit, they are best viewed as only part of an integrated runoff management solution.

Low Impact Development (LID) and Green Stormwater Infrastructure (GSI) Retrofits

The distinction between LID/GSI approaches to stormwater management versus detention ponds include the point and distribution of treatments; what kinds of rainfall events and antecedent conditions they positively affect; and their effects on the biophysical integrity of stream corridors. The first notable difference is one of position. In general, LID/GSI options treat runoff prior to stormwater reaching the gutter, while detention ponds treat it after. LID/GSI treatments either divert, intercept, or infiltrate rainfall and runoff to lengthen its flow path and suppress volumes reaching the creek. They replace primary soil and vegetation functions affecting rainfall interception and infiltration that are artificially converted to runoff events by impervious surfaces. If implemented at a sufficient scale, they can restore watershed runoff functions to mimic key aspects of natural flow paths and peak flows that normally carve and maintain the open channel and its aquatic habitat features.

A valuable way to view these treatments from a stream integrity perspective is that LID/GIS treatments affect what happens to the first 2 inches of rainfall. These events are characteristically those that urban runoff converts from groundwater to surface water inflow and have the greatest cumulative effect on the hydrobiology and biodiversity of streams. They are not properly addressed by detention ponds. In urban settings absent distributed treatment, these rainfall events switch from providing steady groundwater flow to receiving streams and instead become runoff events that put benthic organisms into a drift and contribute to bank erosion.

Another notable distinction of LID/GSI treatments is they are generally small-scale treatments with large-scale distributions around the watershed. The density and locations of these treatments can be used to delay the runoff response to manage sub-basins for threshold effects or to even restore hydrology akin to that of a native forest. LID/GSI can be used to protect streams in good condition or to restore a better hydrologic balance to those already eroding.

Reversing hydromodification, when achievable, takes time to implement and thorough collaboration with private and public property owners. Even at threshold cumulative effect, it often cannot reverse damaging instability trends in the stream corridor. In other words, curing hydromodification does not necessarily reverse the wound, but does make it a lot easier to heal it and can be an essential component to improving the resiliency and biological outcomes of the stream restoration activities. Streams that are already eroding, especially those which have lost grade control or have become incised or substantially divorced from their active floodplains will attempt to build a new floodplain irrespective of hydromodification reversals. The severity and pace of this may be reduced, and the water quality and biological outcomes for the restored stream will be far better than those absent addressing hydromodification.

Streams that are near a tipping point of development threshold can be greatly protected by prioritizing rapid LID/GSI retrofits in their drainage areas. This is preventative medicine. Some headwater portions of the watershed will benefit from this, immensely and urgently.

<u>Development Codes</u>

Some jurisdictions require new infill development to meet stream protection goals using LID/GSI. Others take it one step further and require new development to provide mitigation (either in-kind or via a mitigation fund) that creates a net stream benefit.

4.4 Passing the Stormwater Baton

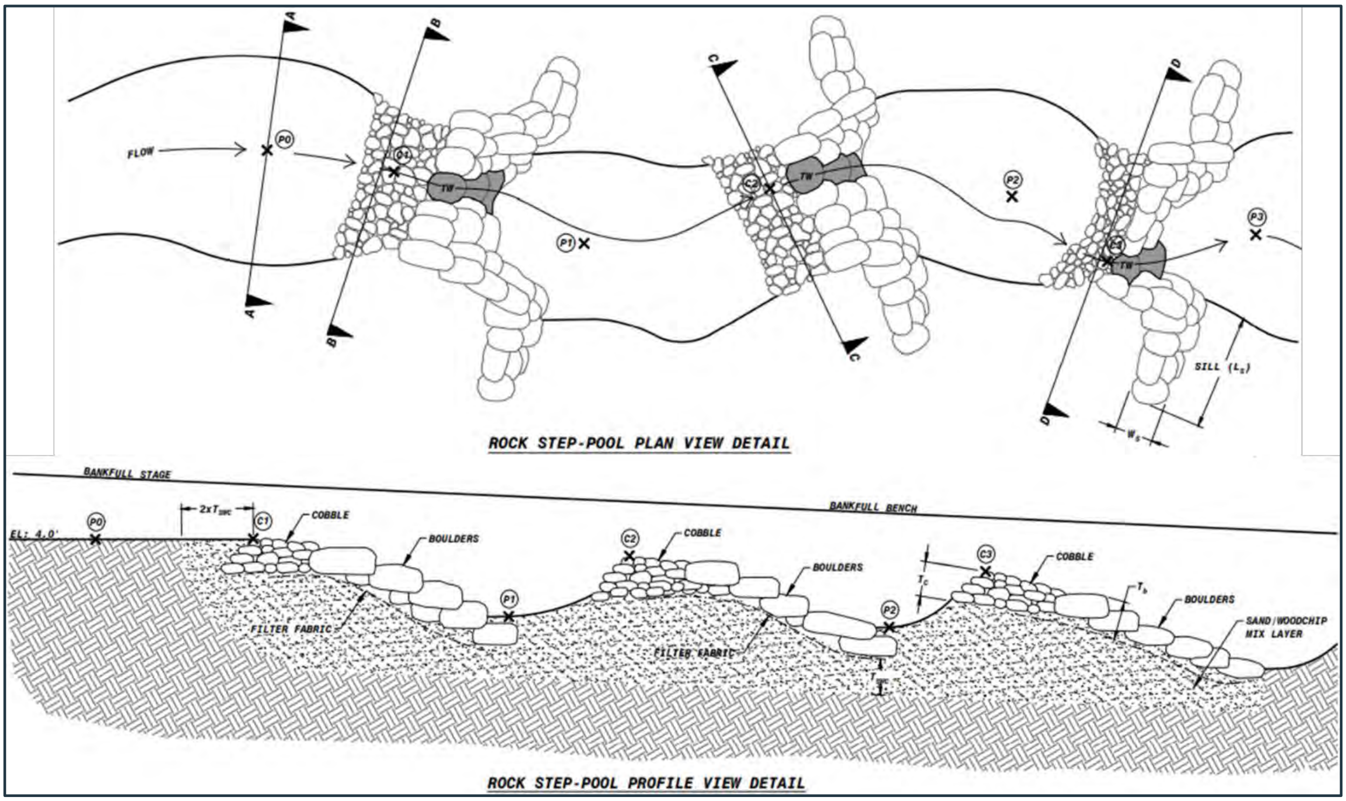
The stormwater drainage into Carpenter Creek is often passed at confluences from the stormwater management system to the floodplain with inadequate energy dissipation, which causes local scale erosion. This is like a relay racer throwing the baton to the ground rather than seamlessly handing it off. The resulting erosion adds up in cumulative effect. There are numerous means for providing outlet energy dissipation, but most are intended to protect the foundation of the pipe outlet or street end and simply displace the high-velocity discharge further downgradient eroding floodplain or streambank soils. Alternatives that contemplate this handoff into the floodplain are required.

<u>Regenerative Stormwater Conveyance (a type of Priority 3)</u>

Where stormwater flow crosses slopes on the order of 2% to 8%, a type of step-pool stream configuration referred to as a Regenerative Stormwater Conveyance (RSWC) can be installed that dissipates runoff energy and treats the nutrient load of the baseflow and normal flow. This is a combined rock and log structure that appears similar to a mountain stream. Much of the low flow volume transports through the bed materials, which are outfitted with biologically active media (BAM). The BAM can consist of sawdust, Bold-n-Gold, or other sources of carbon to drive the microbial uptake of nutrients. The pools between the steps detain water, providing additional treatment a pipe would certainly lack during moderate flows. Most of the flow rides over the steps during flood conditions and modest amounts of treatment occur through the restored forest soils as the flood recedes.

RSWC is not wholly self-organizing in Florida conditions and is more properly viewed as engineering versus stream restoration. However, it does provide some fish habitat value, some tree canopy, and a more naturalistic aesthetic than the gray infrastructure alternatives. Wood has developed a Florida-specific RSWC design approach that integrates imported stone steps with native forest species to achieve stability.

Figure 4.10 – Florida Regenerative Stormwater Conveyance Plan and Profile View



4.5 Bottomland Forest Management

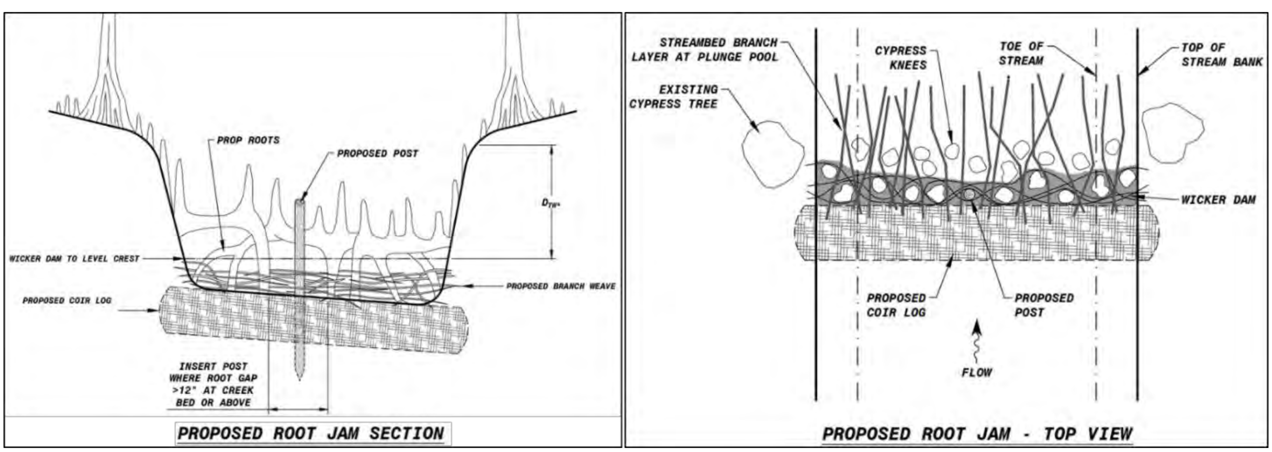
Floodplain pattern and dimension exert perhaps the most dominant aspect of control on stream corridor stability, and the floodplain is almost always naturally forested in northwest Florida. The live forests impart significant strength to soils that would otherwise be easily eroded by stream and flood flows. Tree falls and woody material loads into the stream channel create essential habitat substrates for aquatic macroinvertebrates and induce a wide variety of small pools and other hydraulic habitats of value to fish. The woody load slows the flow and dissipates energy overall, and the fine woody debris and leaves provide a major carbon source that is essential to stream metabolism and nutrient load reductions. A Northwest Florida stream absent a strong forest is unlikely to be a healthy creek.

This means that creek restoration is also an exercise in forest development and management. Forest species have to be selected based on their flood and force tolerances, and reproductive strategies. This means the community species composition and distribution differ across the floodplain with elevation relative to flood frequency and depths, with soil drainage properties associated with different alluvial surfaces in the floodplain, and proximity to swift currents along the channel margins. Differences occur down valley as well as the creek picks up more power. All of these factors can steadily adjust from urban hydromodification, and a range of stream types draining watersheds larger than those of an urban basin should be examined when considering urban restoration strategies because the urban hydrology delivers larger floods, more frequently than a rural watershed of the same size. So, upland development can inexorably alter the bottomland forest.

Forest structure (the variable density of groundcover, shrub, sub-canopy, and canopy layers in the forest) also varies somewhat among stream types. The structure of bottomland forests and stream morphology of the region occur in concert with beaver activity. The presence of beavers is generally stabilizing in effect – also contributing geodiversity and biodiversity to the system. Beavers are likely to be important agents of limited grade control repairs, nitrogen balance, fish habitat, and wetland hydrology. Thus, beaver management is part of the solution.

One form of stream restoration treatment is referred to as Beaver Dam Analog (BDA). BDA seeks to harness beavers as stream restoration agents by installing structures made from local logs, branches, and live stakes across the stream bed, woven in a fashion that appears like a natural abandoned beaver dam to a beaver. Beavers are drawn to these structures and enhance them and maintain them long term. BDA can dissipate energy, trap sediments, provide some grade control, improve fish habitat, and remove nutrients.

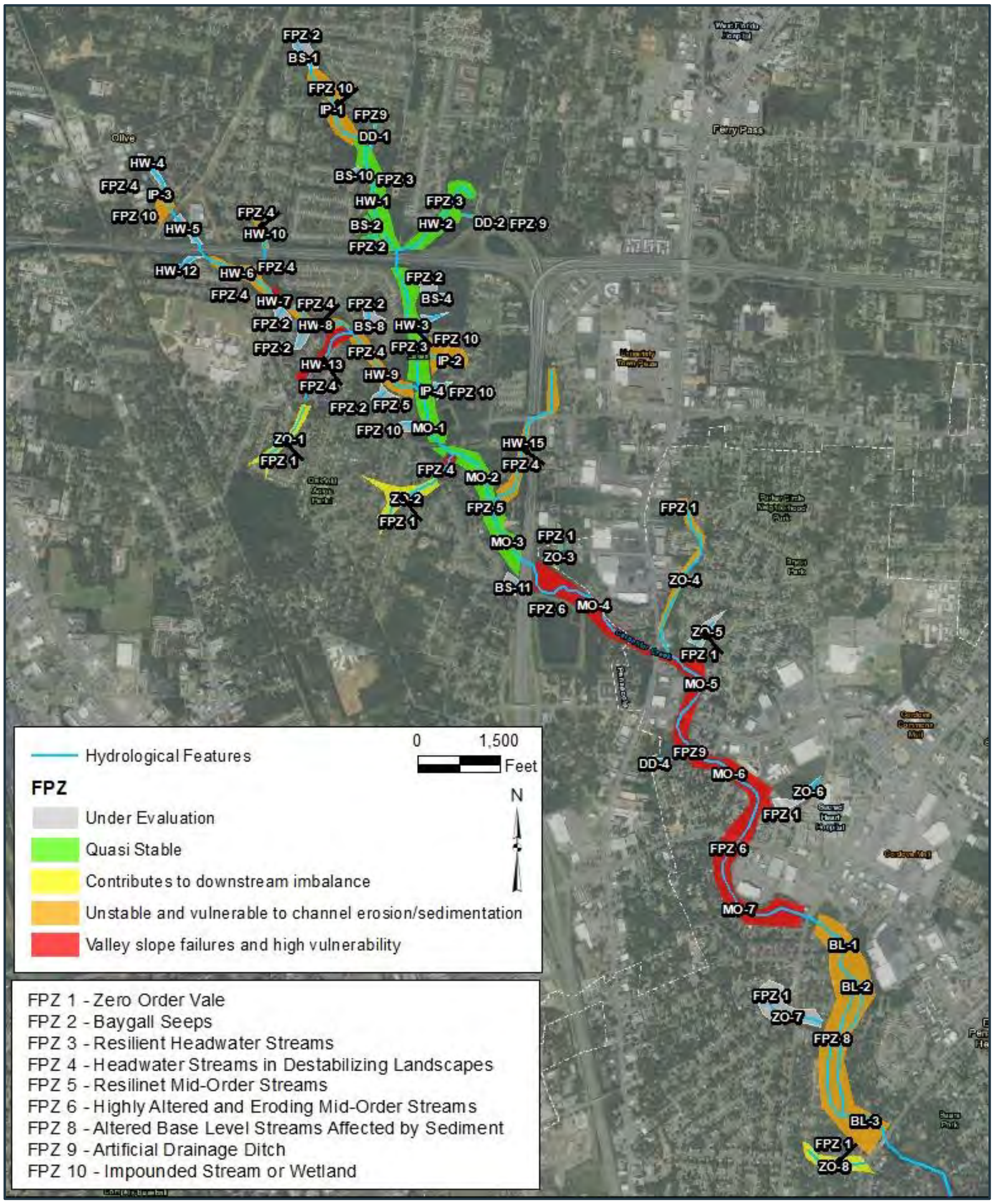
Figure 4.11 – Beaver Dam Analog (BDA)



5. CARPENTER CREEK STREAM TYPE TREATMENT APPLICABILITY

The gray and green infrastructure treatment types described above have varying applicability within the Carpenter Creek system. Each of the functional process zone (FPZ) stream types that were characterized in detail in the technical memorandum for **Task 3.3.1** exhibits common erosional or destabilizing issues. Each FPZ type along with its primary stability issues and potential stabilization treatment options are summarized in the following section. **Figure 5.1** shows each FPZ in Carpenter Creek, and **Table 5.1** summarizes the treatment options and benefits for each FPZ.

Figure 5.1 – Functional Process Zones (FPZ) and Bank Stability in Carpenter Creek



FPZ 1 – Zero Order Vale (ZO)

Zero order vales are dry valleys that can serve as collection and infiltration areas for runoff during large storm events. The FPZ1 areas within the watershed are currently developed, with high degrees of impervious surfaces, so the primary treatment option is to implement hydromodification measures, including LID/GSI stormwater retrofits, stormwater outlet energy dissipation, and nonstructural BMPs such as development codes.

FPZ 2 – Baygall Seeps (BS)

Baygall seeps are small channels fed and carved by seepage/groundwater, upgradient to headwater streams. Within this watershed, at least 10 baygall seeps exist in stable conditions but are vulnerable to development impacts, such as impoundment or receiving concentrated urban stormwater flow. The preserving function of these baygall seeps will require preventative hydromodification treatments within their contributing drainage areas, which include LID/GSI stormwater retrofits, stormwater outfall energy dissipation, and nonstructural BMPs such as development codes.

FPZ 3 – Resilient Headwater Streams (HW)

These headwater streams are small but well-defined with a drainage area around 0.1-2 square miles. These streams have wide native forest bottomlands and terrestrial forested buffers separating them from development. While FPZ 3 streams are stable, they are vulnerable to development impacts, so the primary preventative treatment option is to implement hydromodification treatments within their contributing drainage areas, which include LID/GSI stormwater retrofits, stormwater outfall energy dissipation, and nonstructural BMPs such as development codes. Forest and beaver management are also significant components.

FPZ 4 – Headwater Streams in Destabilizing Landscapes (HW)

These headwater streams are also small, but well-defined with a drainage area around 0.1-2 square miles but have largely urban watersheds instead of forested watersheds. The urban runoff creates scour, incision, and bank erosion, and FPZ 4 streams also have reduced nutrient attenuation potential, offer less aquatic habitat, and may limit fish passage. Treatment options for FPZ 4 streams include watershed hydromodification treatments (LID/GSI stormwater retrofits, DCIA energy dissipation, and regenerative stormwater conveyance), green infrastructure within the channel (Priority 1 or 2 natural channel design or VRSS), or gray infrastructure within the channel (riprap, ACB, gabion baskets/marine mattresses, bulkheads/retaining walls, and/or Newbury riffle). Forest and beaver management are also significant components.

FPZ 5 – Resilient Mid-Order Streams (MO)

Creeks that drain 2.5 to 35 square mile areas, receive ample baseflow, meander through forested bottomlands, and maintain stable, relatively deep channels with a variety of instream habitats. While the FPZ-5 reach in Carpenter Creek is currently stable and in good condition, its watershed and surrounding land use are reaching a potential tipping point. Further development will increase impervious surfaces and runoff and remove existing forested buffers, which may destabilize the creek. While FPZ 5 streams are seemingly stable, they are vulnerable to development impacts, so the primary preventative treatment option is to implement hydromodification treatments within their contributing drainage areas, which include LID/GSI stormwater retrofits, stormwater outfall energy dissipation, and nonstructural BMPs such as development codes. Forest and beaver management are also significant components.

FPZ 6 – Highly Altered and Eroding Mid-Order Streams (MO)

Prior to development, these mid-order streams would have been categorized as FPZ 5, but in their current state, they are great and actively eroding. Several destabilizing conditions and features were observed within the FPZ 6 reaches, including incision, scour, migrating headcuts, disconnection from floodplains, bank erosion from steep slopes and urban runoff, loss of forested buffer, and lack of bends. Treatment options for FPZ 6 streams include watershed hydromodification treatments, green infrastructure within the channel (Priority 1 or 2 natural channel design, VRSS), gray infrastructure within the channel, or repatterning the stream through the addition of bends. Forest and beaver management are also significant components.

FPZ 8 – Altered Base-level Streams Affected by Sediment

One stream reach of Carpenter Creek is classified in FPZ 8. This stream type flows through a diverse bottomland swamp with a broad floodplain (which possibly houses a parallel channel), but it is likely that as the sea level rises, it may become tidally influenced. The main channel has well-defined, stable stream banks, but is unnaturally straight and supports high velocities, and experiences sediment accumulation from upstream. It appears pools and in-stream habitat that should be present are smothered by the sediment loads. Repatterning the stream through the addition of bends (Priority 1) could be implemented to induce pools and reintroduce aquatic habitat. Various types of restoration, stabilization and watershed hydromodification in upstream reaches could serve to reduce the sediment load received by FPZ 8. Natural channel design that accommodates existing and future tidal conditions (hydrologic and ecological) could also be considered to make the reach resilient to sea-level rise changes. Forest and beaver management are also significant components.

FPZ 9 – Artificial Drainage Ditch

Artificial ditches, which are typically straight with steep bank slopes, do not mitigate flood pulses, are susceptible to erosion and bank failures and can contribute sediment loads to downstream reaches. Natural channel design (Priority 2) could potentially be implemented to improve drainage capacity, stability, ecology, and water quality in these ditches (if available right of way or landowner permissions permit). Depending on site conditions, Priority 3 restoration or stabilization in place (with VRSS or gray engineering materials) could also serve to stabilize the ditches and prevent erosion.

FPZ 10 – Impounded Stream or Wetland

FPZ 10 includes both wetlands and streams that have been impounded by berms or embankments, many of which have failed or are likely to fail. Failure releases sediments downstream and can pose safety hazards. Treatment options for FPZ 10 segments include stream restoration with natural channel design or stabilization in place (Priority 1-4) or wetland restoration. It should be noted that restoring these areas would likely require land acquisition.

Table 5.1 – Treatment Options for FPZ Types

FPZ	Issues	Potential Treatment Options
FPZ 1	Impervious surfaces	Hydromodification (LID stormwater retrofits, DCIA energy dissipation, Development Codes)
FPZ 2	Vulnerable to development impacts	Watershed Hydromodification (LID stormwater retrofits, DCIA energy dissipation, Development Codes)
FPZ 3	Vulnerable to development impacts	Watershed Hydromodification (LID stormwater retrofits, DCIA energy dissipation, Development Codes)
FPZ 4	Urban Runoff	Watershed Hydromodification (LID stormwater retrofits, DCIA energy dissipation, Development Codes)
	Scour/Incision	Natural Channel Design (Priority 1-3), VRSS, Gray SIP, Newbury Riffle, Regenerative Stormwater
FPZ 5	Vulnerable to development impacts	Watershed Hydromodification (LID stormwater retrofits, DCIA energy dissipation, Development Codes, Regenerative Stormwater)
FPZ 6	Scour/Incision	Natural Channel Design (Priority 1-3), VRSS, Gray SIP, Newbury Riffle, Regenerative Stormwater
	Floodplain Disconnection	Natural Channel Design (Priority 1-3)
	Urban Runoff and Development Impacts	Watershed Hydromodification (LID stormwater retrofits, DCIA energy dissipation, Development Codes, Regenerative Stormwater)
	Lack of Bends	Natural Channel Design (Priority 1)
FPZ 8	Lack of Bends	Natural Channel Design (Priority 1)
	Sediment Smothering	Natural Channel Design (Priority 1), Upstream restoration
	Future Tidal Conditions	Natural Channel Design (Priority1-3) adaptable to future conditions
FPZ 9	Scour/Incision	Natural Channel Design (Priority 2)
	Floodplain Disconnection	Natural Channel Design (Priority 2)
FPZ 10	Impoundment	Natural Channel Design (Priority 1-3), VRSS, Gray SIP, Wetland Restoration

Note: Gray SIP = Gray engineering stabilization in place (includes, riprap, articulated concrete block, gabions, marine mattresses, and bulkheads/retaining walls).

6. WATER QUALITY AND SEDIMENT LOAD REDUCTIONS

6.1 Water Quality Load Reductions

Stream restoration (natural channel design) generally provides nitrogen removal via three different mechanisms including erosion reduction resulting from the stabilization of banks (P1), reduction from hyporheic[3] exchange during baseflow (P2), and floodplain exchange from floodplain

[3] Hyporheic flow is that which moves through porous media in the streambed and streambanks.

reconnection (P3). Our total nitrogen (TN) removal analysis follows stream restoration protocols used for the Chesapeake Bay Total Maximum Daily Load (TMDL), which determined stream restoration to be among the lowest cost options for TN reduction in urban Virginia. The potential for TN removal varies by the size of the stream and watershed as shown in **Table 6.1**. Carpenter Creek has approximately 3.7 miles of headwater streams and 3.6 miles of mid-order streams that could benefit from stream restoration. If every mile of those streams were restored, the approximate potential TN load removal could be 5,500 lb per year (depending on existing water quality and stream conditions). This figure represents an upper limit, as the impacted stream reaches (in FPZs 4, 6, 8, 9, and 10) likely provide varying degrees of existing nutrient treatment, and it is unlikely that every mile of stream would receive natural channel design stabilization treatments.

Table 6.1 – TN Removal Potential in Restored Streams

TN Removed (lb TN/yr/mile)				
Stream Category	**P1-Erosion**	**P2-Hyporheic**	**P3-Floodplain**	**Total**
Headwater (<2 SM)	51	539	62	652
Mid-Order (2-20 SM)	51	742	79	872
Lowland (>20 SM)	51	1,011	103	1,165

Stream restoration with natural channel design also reduces total phosphorus (TP) and total suspended solids (TSS), but currently, methodologies for estimating TP and TSS removal typically vary by project. The reduction in TP and TSS is typically associated with prevented or reduced erosion and sediment transport, and therefore will depend on the existing sediment loads and phosphorus content and fractionation within the soils and sediments of each restored stream segment.

While natural channel design offers the most beneficial features (infiltration and plant uptake in natural floodplains, hyporheic exchange, aquatic vegetation, and erosion control) and the greatest potential for water quality improvement, alternative green infrastructure or combined green and gray infrastructure stabilization methods can also provide some water quality benefits. Generally, forested riparian buffers, wetland connection, vegetated banks, aquatic vegetation, and carbon sources within the stream (or stormwater infrastructure) can provide treatment and preventing erosion of nutrient-rich sediments can reduce nutrient loading to the stream. The degree to which each stabilization method provides water quality benefits will depend on the existing water quality inputs and the nutrient attenuation features included in the designs.

6.2 Sediment Load Reductions

Erosion in natural streams and their native watersheds yield sediments down valley. This provides source material for a variety of instream habitats such as riffles and point bars and ultimately provides sediment that is organized in bays and estuaries as deltas, bars, and barrier islands depending on scale and location. There is a natural balance, and too much yield disrupts ecology and recreation by smothering deeper habitats in the creek and bayou.

Rosgen (2009) developed the Bank and Nonpoint Source Consequences of Sediment (BANCS) method of sediment load prediction, which the U.S. EPA often accepts as a basis for determining contributions of excessive stream erosion when evaluating sediment TMDL loads. The BANCS method is a rapid visual and diagnostic approach requiring field observations and simple measurements of several variables in the channel to assign adjective ratings regarding the near bank shear stress (NBS) and bank hazard erosion index (BEHI). BEHI determines how vulnerable a bank is to erosion and NBS determines to what extent excessive forces are available to trigger that vulnerability. The method provides bank migration rates in units of ft/yr. That rate can be multiplied by bank height and bank length to generate an erosion volume or mass.

Wood conducted BANCS assessments at selected locations along the drainage network to learn more about the range of erosion rates prevalent among the stream types in the watershed. **Table 6.2** provides the field data. **Table 6.3** provides the load estimates from that data and compares those to what would reasonably be expected from a stable stream in a similar drainage area position and valley form. Natural stable streams in the region typically score from Very Low to Moderate ratings on NBS and BEHI. For hypothetical stable stream comparisons, we assigned a Low rating to both variables. We applied Rosgen's erosion rate nomograph for Sedimentary and/or Metamorphic Geology.

BANCS results estimate the annual average sediment load generated by the common flow conditions that normally conduct the most overall work creating the bankfull channel (Rosgen 2009). They should be viewed as the long-term average erosion rate for that bank condition, as opposed to a prediction of the precise amount of erosion that will occur in a given year. In Northwest Florida, the applicable flow conditions characteristically are equaled or exceeded several times a year (AMEC 2013). The method does not predict transient erosion rates from catastrophic, uncommon floods, very wet years, or drought years – it is intended as a central tendency (Rosgen et al. 2019). Measured wet year rates have large positional variability and can be even more extreme during mega-storms like the one in 2014 (McMillan et al. 2017). This is expected because erosion rarely occurs evenly along the bank and is temporally chaotic. The BANCS method has not been calibrated to Northwest Florida conditions and load estimates provided here are for comparative purposes only.

Table 6.2 – Carpenter Creek BANCS Data

Site	BEHI Adjective Rating	BEHI Total Score	Study Bank Height	Bankfull Height	BHR	*BEHI Category Scores*							NBS
						Study Bank Height/ Bankfull Height	Root Depth/ Bank Height	Weighted Root Density	Bank Angle	Surface Protection	Bank Material Adjustment	Stratification Adjustment	
3	High	35	7.24	2.14	3.4	10	0	3	8	5	10	--	High
4	High	33	8	2	4.0	10	3	1	3	6	10	--	High
5	Very High	42	8	2	4.0	10	1	2	9	10	10	--	Extreme
6	Moderate	25	2.1	1.4	1.5	6	10	3	9	2	0	5	High
8	Very low	6	1.45	1.45	1.0	1	0	0	3	2	0	--	Moderate
43	Low	16	0.97	0.97	1.0	1	0	0	5	0	10	--	Very low
64	High	36	1.52	0.7	2.2	8	0	5	3	10	10	--	High
35	Moderate	29	3.65	3.65	1.0	10	10	1	7	1	0	--	Low

BEHI - bank erosion hazard index. BHR - bank height ratio (low bank height/bankfull depth).

Table 6.3 – Carpenter Creek Bank Erosion Rates Estimations and Comparison

Site	BEHI	NBS	Bank Erosion Rate (ft/yr)	Bank Height (ft)	Existing Sediment Yield per LF of Bank (Cubic Feet/yr/LF)	Typical Stable Sediment Yield per LF of Bank (Cubic Feet/yr/LF)	Yield Ratio	Erosion Status
3	High	High	0.58	7.2	4.17	0.26	16	Highly Unstable
4	High	High	0.58	8.0	4.60	0.29	16	Highly Unstable
5	Very High	Extreme	1.32	8.0	10.57	0.29	37	Extremely Unstable
6	Moderate	High	0.42	2.1	0.88	0.07	12	Highly Unstable
8	Very low	Moderate	0.07	1.5	0.11	0.05	2	Stable
43	Low	Very low	0.02	1.0	0.02	0.03	0.5	Stable
64	High	High	0.58	1.5	0.87	0.05	16	Highly Unstable
35	Moderate	Low	0.15	3.7	0.56	0.13	4	Moderately Unstable

Notes: typical bank erosion rate is indicated as 0.04 ft/yr based on Low/Low NBS/BEHI.
Yield Ratio = existing yield divided by typical stable yield. Is the multiplier of the normal sediment load.

Estimated Carpenter Creek erosion is typically more than 10 times that of expected natural rates, with some areas approaching 40 times normal rates. Bank erosion estimated using the BANCS model for stable streams produce low yields, with migration rates of less than an inch per year. This is reasonable for Florida's tightly held forested streambanks. The high existing erosion rates indicate a failing forest. Once the forest is utterly overwhelmed and banks are rather entirely denuded, erosion rates will accelerate even more.

This legacy and trend indicate some urgency in solutions that prevent erosion in areas currently stable. That means addressing hydromodification with LID/GSI and considering the effects of forestry and beaver management. The greater prevalence of actively erosive conditions suggests that the existing combinations of hydrology, geomorphology, and forest cover are systematically unstable, requiring a variety of stream restoration and streambank stabilization measures to be assembled into a cohesive plan. Erosion rates are likely to worsen absent intervention. Existing forest cover near the streambank is effectively subject to long-term failure and downstream areas will continue to be smothered by sediment. Repatterning and reforesting the floodplain is indicated over long sections of the main channel of Carpenter Creek downstream of I-110. Numerous development and infrastructure encroachments, road crossings, and stormwater outlets require special consideration and careful abutment/confluence design to assure continuity of sediment transport and habitat connectivity along the valley. The problem has been decades in the making and will require phased solutions over perhaps many years. Funding prioritization and construction sequencing will take on a large dimension in the plan.

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VOLUME 3C ATTACHMENT C

CHANNEL UNIT COSTS AND TOTAL LIFE-CYCLE COST MODEL REPORT

Attachment C

Task 3.3.3 Report

STREAM RESTORATION
ESTIMATE UNIT COSTS AND DEVELOP TOTAL LIFE-CYCLE COST MODEL
TASK 3.3.3

Prepared for

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1.0 BACKGROUND AND OBJECTIVES

This document provides a cost-benefit analysis (CBA) for stream corridor restoration activities described in **Task 3.3.2**. A triple bottom line (TBL) approach was used to account for the combined financial, environmental, and social dimensions of each assessed retrofit type. The TBL is quantified and monetized by estimating the net present value (NPV) of each retrofit category. Thus, alternatives can be evaluated in terms of their investment worthiness and can also be compared in terms of a common unit, the U.S. Dollar. A tremendous amount of flexibility can be employed when assigning TBL line items. Inclusionary criteria used for this study are;

- Only monetize line items with primary and proximal value to the residents of Escambia County
- Select only line items with credible and available monetization values
- Select line items most likely to provide significant economic benefits or costs related to the proposed activities
- Do not use line items that collectively incorporate redundant costs or benefits

The idea is not to include every conceivable TBL item but to provide a sufficient subset of line items relevant for assessing multi-purpose channel improvements for the benefit of the people and environment of Escambia County. The economic referent group is the society of Escambia County, including its residents, businesses, and visitors. Some of the monetized variables have tradeable value for Escambia County government as a referent group. The largest and most tangible of these, 'Water Quality Improvement' is highlighted throughout the document. Some of the other economic variables could become tradeable for the County in the future, for example, 'Stream Habitat' for mitigation credits.

The primary purpose of restoration activities within the Carpenter Creek drainage network is to enable the channel systems to become more self-sustaining, preventing erosion and slope failure, which diminish aquatic ecology, reduce bottomland forests, and contribute to maintenance and repair costs. Investments that reduce the perennial maintenance and operation costs and that will concurrently improve downstream water quality, reduce sedimentation, improve fish habitat, and create recreational/aesthetic conditions for public benefit have been conceived and described. The design philosophy is to assess the economics of methods to stabilize the channels and adjacent slopes in the Carpenter Creek watershed. The methods vary from stabilization in place, to restoration of natural riparian corridors that do not compromise existing flood protection. The CBA of stream restoration is compared to common approaches to stabilizing channel banks using hard-armoring and soil-bioengineering treatments instead of grass.

To meet the overall project goal of providing CBA for channel improvement recommendations, unit costs for each treatment must be assigned. Then the quantities are determined over the assigned life-cycle of the project, taking into account the timing of expenditures and the time value of money. The document first describes the economics of several basic project benefits distributed among the three TBL dimensions; quantifies the costs of each of the selected treatment categories; and then provides the net cost-benefit balance of each treatment.

1.1 General Economic Variables

Some variables are common to all assessments to enable equitable comparisons among them. A 20-year life cycle was assigned as this is a standard period used to assess public works projects, and it enabled Wood to efficiently build upon the assessments of others using the same cycle. A 4% discount rate was used to account for the time value of money. This rate was selected because it was also used in the same studies Wood references that applied a 20-year life cycle. Values were monetized in annual time increments and assigned timelines consistent with a reasonable expectation for the cash flow of each line item. Each treatment was assumed to be constructed within the first year of the project, which is realistic for all the considered retrofits. All unit values obtained from pre-2018 sources were adjusted to 2018 equivalents using the U.S. Consumer Price Index (CPI).[1]

Each treatment was applied to one linear mile of channel. The TBL can thus be multiplied by the actual number of miles a project may contemplate obtaining a preliminary estimate of costs and benefits. Very large projects, perhaps on the order of 10 miles or more, are likely to result in more favorable economies of scale, while projects less than a mile long will have higher unit costs than those estimated here. Thus, the economic model illustrated in this document is suggested for individual projects ranging from 0.5 to 5 miles long.

1.2 Financial Benefits

Financial line items include the public costs to design, construct, and maintain the project over its life cycle. Those implementation costs vary significantly by treatment and are discussed separately by treatment. The avoided costs of existing infrastructure maintenance of the eroding creeks and infrastructure comprise potential benefits for all the conceived treatments, but the burden varies with storm events and is not easily predicted. Further, erosion leads to sediment accumulations in the Bayou Texar which eventually may warrant dredging.

1.2.1 Infrastructure and Conveyance

Stream restoration treatments were conceived to eliminate routine and periodic maintenance that the County and City conduct in the stream and appurtenant infrastructure including debris and sediment cleanouts and rebuilding the shoreline after episodes of periodic erosion. Typical costs for routine urban drainage system maintenance in southwest Florida are approximately $13,800 per mile per year, while contingency costs from hurricanes drive that annual average up to $51,000/mile (Wood 2019). Using the lower value, the Net Present Value (NPV) of this effort is $187,500 per mile for 20 years. Although this cost was submitted to be representative, it is based on a single study and therefore has uncertainty akin to that of a concept screening level cost estimate, warranting examination across a range of -30% to +50% per American Association of Cost Engineers Class 5 guidelines (AACE 2012). The high-end value was over-ridden and set using

[1] 2018 was used instead of more recent pricing which is unstable due to the economic effects of tariffs and the pandemic. TBL pricing is primarily for comparing alternatives.

the NPV derived from an average annual maintenance burden of $51,000. This variable is deemed tangible for County/Municipal government.

1.2.2 Sediment Trapping

Stabilized banks, a more natural sediment transport regime, and increased floodplain exchange are stream restoration benefits that would result in decreased sediment loads. Decreased sediment loads would save costs associated with dredging. Dredging costs associated with removing the sediments estimated to be generated by a one-mile stretch of channel were used to determine the benefit of streambank stabilization. Based on applying the Rosgen Bank Assessment of Nonpoint Source Consequences of Sediment (BANCS) procedure to existing and hypothetical stable conditions in the Carpenter Creek watershed, one mile of stream restoration could result in a net reduction of up to 1,227 tons per year per linear mile (TPY/LM) of sediment transport. That maximum reduction applies to Priority 2 Restoration conducted in the most severely eroding areas of the watershed (FPZ 6 located between Davis Highway and 9th Avenue). Substantial reductions are also available for FPZ 4 (208 TPY/LM) and FPZ 8 (109 TPY/LM). If dredging occurs every ten years at a cost of $30 per ton[2], the NPV of streambank erosion control would range from $1,200 to $13,900 depending on stream location. This variable is deemed tangible for County/Municipal government. It was summed with avoided maintenance costs in subsequent tabulations.

Some forms of hard-armoring may simply displace erosion from the treated area downstream or to the opposite streambank if left undisturbed by treatment. However, this benefit was credited for any retrofit that fully lined the banks even if it does displace energy.

1.3 Environmental Benefits

Potential environmental benefits include fish and wildlife habitat and water quality. Habitat values were assigned using market prices for wetland mitigation and stream mitigation. These costs are intended to be measures of the replacement value of these habitats, based on the market value society places on each habitat when required by regulation to purchase them. This does not necessarily mean these values are tradeable, although they could become so under the right circumstances. For now, they simply reflect the intrinsic value of these habitats to society and are not intended to represent tradable value for County/Municipal government.

Water quality benefits were assigned using an infrastructure avoidance cost for nitrogen removal projects. This approach credits the channel retrofit project with a certain amount of nitrogen removal and then values that removal based on what it would cost to remove it using terrestrial stormwater management treatments instead. The average cost-effectiveness ($/lb) of treating nitrogen by all common means in Florida was used to assign this value (FSA 2017). Nitrogen was selected because sampled total nitrogen (TN) concentrations in Carpenter Creek and Bayou Texar frequently exceed Numeric Nutrient Criteria (NNC), and nitrogen removal rates are reasonably quantifiable for all the treatments considered from existing information and/or simple calculations. This is a tangible value for County/Municipal government.

[2] Unit cost estimate via personal communication of former Wood dredging services lead Joe Wagner, 10/17/18

Environmental variables do not all apply to every treatment described in this document. For example, wetlands and streams are created as part of natural channel design projects but do not result from hard-armoring canals in-situ.

1.3.1 Wetland Benefits

Increased wetland acres and the many natural services they provide are a benefit of certain forms of channel restoration. To determine the wetland value per mile of restored channel, the costs associated with purchasing wetland mitigation credits were applied to these acreages and adjusted for a 0.7 UMAM.[3] Dual forested UMAM credit mitigation fees for western Florida wetland banks were used, which were $85,000 per credit for three such mitigation banks[4] (Mitigation Marketing, 2020). Wetland replacement values were assigned to year one of the project timelines. Under this model, the wetlands provide a permanent benefit that is fully credited upon their initiation with variable annual expenses discounted for routine establishment and maintenance costs. The acreage of wetlands affected, their functional lift from existing conditions, and their establishment and maintenance costs vary by treatment and site potential and are thus separately applied per treatment and FPZ.

This could be a tradable value for County government, subject to actual market and regulatory complexities affecting its feasibility for trade. Wood suggests assuming this to be a non-tradable value unless otherwise proven as such in actual project design and permitting. Instead, this monetization should simply be viewed as the intrinsic value of wetlands to society.

1.3.2 Stream Channel Benefits

Wood examined economic data from mature stream mitigation programs in both North Carolina and South Carolina to obtain intrinsic stream habitat values, as Florida does not have formal stream mitigation banks or programs. In North Carolina, the mitigation market is primarily driven by the Department of Mitigation Services (NCDMS) fee-in-lieu program. Under a fee-in-lieu program, the impacting entity pays a fee to the government to take responsibility for the mitigation. In the case of North Carolina, this fee is then used to pay private contractors to supply projects meeting state criteria. Mitigation is credited by linear foot (LF) of stream restored. The 2018 cost of a stream mitigation credit in North Carolina is $508, and credits are generated using the following ratios: restoration (1LF: 1 Credit), enhancement (2.5 LF: 1 Credit), and preservation (5 LF: 1 Credit).[5] Therefore, one mile of stream restoration in North Carolina is valued at $2,680,000.

In South Carolina, stream mitigation is priced at $150 to $175 per credit on the open market where the market is primarily driven by private mitigation banks and permittee responsible mitigation (PRM) projects[6]. In South Carolina, a linear foot of stream can generate anywhere from 0.775 credits (preservation) to 4.05 credits (Priority 1 or 2 restoration) depending on the quality of the

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[3] The Unified Mitigation Assessment Method (UMAM) assigns functional gain to wetlands based on a composite index of each of 3 major functions the mitigation wetland provides versus a fully functional system (water environment, community structure, and landscape ecology). A UMAM of 0.7 indicates a system that provides 70% of fully natural function, a value that is commonly achievable in heavily disturbed settings.

[4] Breakfast Point (Bay County), Devil's Swamp (Bay and Walton Counties), San Pedro Bay (Taylor County),

[5] https://deq.nc.gov/about/divisions/mitigation-services/dms-customers/fee-schedules

[6] Personal communication, Wood South Carolina stream restoration expert William Rector, 10/8/18.

existing stream and the level of work required to protect/restore the resource. For Priority 2 restoration, one mile of high-quality stream restoration in South Carolina would cost approximately $3,740,000 at a price of $175/credit for 4.05 credits per foot.

The average value for stream mitigation prices in the Carolinas is $3,210,000 per mile stream creation. The amount of stream creation potential varies by valley and watershed conditions for the Carpenter Creek watershed, but for each mile of valley about 1.3 miles of stream channel can be created because of channel meanders. Thus, a typical value is $4,173,000 per mile of valley restored.

Stream habitat could be a tradable value for County government, subject to future regulatory mechanisms necessary to open an in-kind stream mitigation market. Until that occurs, Wood suggests assuming this to be a non-tradable value. Instead, this monetization is viewed as the intrinsic value of stream habitat to society.

1.3.3 Water Quality Benefits[7]

Wood assessed the reduction of pounds of total nitrogen removed per year (lb TN/yr) that creek restoration would accomplish by three impact classes (detailed in **Task 3.3.1**) and by specific treatment categories (natural channel design, soil bioengineering, hard-armoring, detailed in **Task 3.3.2**). The impact classes include 1) FPZ 4 – Headwater Destabilized Creeks, 2) FPZ 6 – Highly Altered and Eroding Mid-Order Streams, and 3) FPZ 8 – Altered Baselevel Creeks Affected by Sediment. These categories are carried through much of this assessment. FPZ 4 sites are scattered mostly west of I-110. FPZ-6 sites are between Davis Highway and 9th Avenue, and FPZ 8 is between 9th Avenue and Bayou Texar. The benefit was assigned based on the average annualized NPV[8] of $268/lb for nitrogen removal in 20 projects across Florida (FSA 2017). These projects ranged in value from $9/lb for vegetation harvesting to $1,259/lb baffle boxes. The use of an average value makes sense given that multiple approaches are usually required to meet regulatory load reduction thresholds at watershed or MS4 scales. From this data, Wood applied an average benefit value of $268/lb.

Nitrogen reduction is a tradable variable for County government. Although beyond the scope of this study, other pollutant reductions potentially assignable to stream and wetland restoration such as total phosphorus, total suspended solids, trace metals, and bacterial contaminants could be considered as tradeable values on a site-specific basis.

1.4 Social Line Items

Social variables include property value increases, and potentially avoided residential damages related to flood reductions.

1.4.1 Property Value

Multiple economic studies from across the developed world support that residential property values characteristically increase with stream restoration due to natural aesthetics, water quality

[7] Nitrogen was used as a surrogate for stormwater pollutants. Only nitrogen removal was assessed.

[8] Capital and O&M costs were amortized for a 20-year annual period, at 4% interest.

improvements, and recreational opportunities (Nicolls and Crompton 2017). The uplift varies as a function of distance to the waterbody and the quality of the waterbody and can range from less than 1% to 26% of the total property value (American Rivers 2016). A study from California provided a more centric range, with 3% property value increases for projects to revegetate and stabilize streambanks and 11% increases for projects emphasizing fish habitat (Streiner and Loomis 1995). Thus, Wood varied the values to rise by restoration category to account for projects focused on increasing fishable and swimmable habitat as streams enlarge, as follows:

- Headwater streams receiving forest management and stream restoration-3%
- Mid-order streams receiving natural channel design-10%
- Baselevel streams receiving natural channel design-10%

To assess property value increases along a one-mile valley segment, Wood conducted an aerial interpretation and estimated there to be about 0 to 70 homes per mile in restorable areas, with a reasonably characteristic value of 55. Home value statistics indicated an average mid-tier value of $183,475 for homes in Pensacola.[9]

The presumed value increase was multiplied by the assigned number of homes and amortized annually for 20 years at 4% interest to calculate the NPV. The NPV of uplift can range from $0 to $873,000 per creek mile depending on the number of affected properties and the characteristics of the channel improvements. As an example, a 10% uplift for mid-order natural channel design (NCD) adds $18,347 of value per property. Fifty-five properties per mile provide a one-time gross value increase of $1,009,100. All owners would not realize this gain in year one, as it is only garnered after a sale, so the returns are assumed to occur evenly over a 20-year period, which results in an NPV of $685,700. If the County wished to calculate potential tax revenue increases, the property value uplift would be credited in year one, with the net annual gain in taxes generated from the lift established as a 20-year annuity. This is simply mentioned as a possibility but conducting that assessment in a reasonably robust manner is beyond the scope and purpose of this TBL economic assessment.

Projected property value increases based are not viewed as being tradeable at this time but could benefit specific property owners subsequent to the success of stream restoration projects in the watershed. This variable is simply intended to reflect a characteristic social benefit of stream restoration for now.

1.4.2 Flood Reductions

Priority 2 stream restoration has the ability to mitigate flooding impacts. To assess the value of one mile of creek restoration would have on residential flooding, Wood used a cost-effective analysis (CEA) template for residential flooding. This model can account for various components such as building damages, content damages, automobile damages, displacement costs, lost wages, road detour costs, and public works costs during different storm events (2-, 5-, 10-, 25-, and 100-year). Wood used a hypothetical value of 5% of total residential value per flood event ($12,700). Wood updated the template with a 4% interest rate over 20 years in order to match our other analyses. Based on this model, the value for flooding can be worth approximately $15,000

[9] Pensacola Home Value Index from Zillow.com 2021.

per structure over a 20-year period for severely flood-prone areas within the 25-year floodplain, which would equate to NPV of $300,000 along a one mile stretch of channel with 20 affected residences. Wood views this as an upper value for the purposes of this assessment. Because flooding impacts are site-specific, depending upon how flood-prone an area is and the actual values of the affected property, the flooding value offered by restoration could also be as little as $0, which appears to be more typical of most of the study area. As a base case, Wood calculated an intermediate value for 10 homes in the 100-year floodplain receiving Flood Plain Level of Service (FPLOS) improvement to be removed from the floodplain. This results in a reduction of $5,000 damages per dwelling over 20 years, for a total NPV of $50,000.

These benefits are quantified to frame a line item that can be a primary driver for stream restoration in some areas, but that varies considerably in its potential depending on site characteristics and the scope and scale of the remedy. For example, because FPLOS improvements are scale dependant they are unlikely to occur by restoring one mile of channel, unless it is in a headwater position. One mile is simply a way to unitize the CBA results among all line items. Further, FPLOS gains may or may not be achievable solely by working in the waterbody and may also require integration with road crossing culvert retrofits. Road crossing reconstruction is not part of this stream restoration cost model.

Such gains must be assessed on a case-by-case basis, preferably in concert with a sufficiently detailed watershed hydrology and hydraulics model, to determine actual FPLOS results. Detailed flood studies beyond the scope of this project are needed to make this value tangible and accurate on a site-specific basis. Some tradable aspects of flood reductions could emerge upon further study, but for now, this value is deemed rather inconsequential and non-tradable.

1.4.3 Recreation and Education Benefits

Some variables were contemplated for inclusion but are more amenable to auxiliary mention. For example, it is widely recognized that NCD is likely to improve recreational opportunity values; especially those related to birding, fishing, kayaking, and multimodal terrestrial trails. However, these benefits require public infrastructure investments and community acceptance of the locations of entry points and trails that require investments not covered by the scope of this stream restoration assessment. These implementations are viewed here as 'add-ons' to the restoration but can be essential drivers for public willingness to embrace expensive urban stream renewal projects. Although not integrated into this CBA TBL model, two examples of monetized recreational values are mentioned in the stream restoration benefits section of this report.

NCD and soil bioengineering treatments are also likely to boost educational opportunities. Benefits are usually calculated by applying a daily cost of education per child to the number of visits expected to be made to the site in lieu of classroom days. Visitation will vary significantly pending project proximity to schools, site accessibility for children, and the curriculum of the school; and an overall value will likely be small compared to other line items, so it was not quantified for this study.

2.0 STREAM RESTORATION COSTS

Three categories of restoration were assessed. This approach accounts for the fact that small headwater creeks offer different cost and benefit quantities versus larger systems downstream. Stream restoration design integrates the channel, its wetland floodplain, and adjacent hillslope. Major construction costs involve a temporary bypass system, valley and channel reconstruction, wetland establishment, and hillslope stabilization and afforestation. Other line items include engineering and survey and mobilization/demobilization, which Wood adds to the construction costs listed above as fixed costs per mile. A 10% contingency is added to the earthwork costs of baselevel streams (FPZ-8), 15% for eroding headwater creeks (FPZ-4), and 20% for streams in vulnerable settings (FPZ-6) to allow for channel repairs on an as-needed basis. All of the aforementioned line items form the base cost.

Most of the retrofits, but especially stream restoration, will variably require concurrent road crossing culvert retrofits, resolution of subterranean utility conflicts, and landowner agreements to be fully implemented. This cost model assumes such contingencies are either avoidable or necessary for reasons unrelated to the creek retrofits alone, without compromising overall project benefits. This assumption is based on Wood's work on recent detailed urban stream restoration project designs in Starke and Jacksonville, FL. Some costs are excluded from this assessment, most notably land acquisition, construction bonds, and permit fees.

2.1 Priority 1B and Priority 2 Stream Restoration

This cost includes re-patterning and re-dimensioning the existing cross-section to create a multi-stage natural channel system that is in equilibrium with its channel- and floodplain-forming flows from the existing watershed. The design approach taken follows guidance to make the floodplain as large as required to support a self-organizing channel system within an urban landscape. This provides for some degree of climate change resiliency.

This line item includes all major costs to implement stream restoration independent of wetland restoration costs including engineering, survey, initial seeding, temporary erosion controls, large woody debris habitat, and toe wood bank stabilization, riprap to protect infrastructure at high-stress areas, mobilization/demobilization, clearing and grubbing, earthwork, temporary erosion control blankets (rolled erosion control product – RECP), and valley hillslope stabilization using vegetation reinforced soil slopes (VRSS) as needed. It does not include wetland forest establishment and long-term maintenance, which are calculated separately below.

The maximum floodplain approach resulted in stream restoration costs of $(1,316,600), $(5,728,800), and $(1,458,900) per mile for FPZ-4 headwater, FPZ-6 mid-order, and FPZ-8 baselevel streams respectively. The large cost for FPZ-6 was driven mainly by a need to stabilize higher and steeper valley hillslopes in a tightly confined valley, and greater amounts of earthwork for the larger systems.

Costs are most highly sensitive to the unit cost of earthwork, and contractor bid pricing for this work can vary widely for identical tenders. Wood used FDOT's highest earthwork cost category, which is about 4x greater than the actual unit cost of earthwork of a recent similar project in Starke Florida to account for presumably longer haul distances and travel times to recipient sites in more developed extensively Escambia County, especially within Pensacola, versus those encountered in Starke.

2.2 Wetland & Valley Hillslope Afforestation and Maintenance

Headwater restoration would provide approximately 4.9 acres of wetland improvements per valley mile, mid-order channel restoration would provide an average of 11.8 acres per mile, and baselevel stream restoration would improve about 12.7 acres per mile. These acreages are based on, at minimum, improvements to wetland hydrology and long-term forest stability related directly to the effects of re-establishing the hydraulic reach of common overbank flow events. It relates to the portion of the floodplain reactivated by the restoration. Actual bottomlands may be larger and subsume these acreages in some settings. These riparian terrace forests adjacent to the restored alluvial floodplain also have substantial value, but that has not been credited absent knowledge of a commitment to preservation via conservation easement or a substantial buffer ordinance.

Two primary wetland cost scenarios are involved. Clearing of failing bottomlands and replacement by wetland creation is required for Priority 2 Restoration. These wetland construction costs include finish grading, initial planting, plant establishment, and long-term monitoring and maintenance. Wood derived the applicable unit costs from forested riparian wetland construction bids for our recent projects for the Suwannee River Water Management District (SRWMD), Southwest Florida Water Management District (SWFWMD), and Mosaic Company. The per-acre costs are $14,486 for implementation in year one, followed by $1,700 of monitoring and maintenance during forest establishment (years 2 through 10), and then $850/year thereafter through year 20. This gives NPV of ($30,740) per wetland acre. Thus the 20-year wetland NPV costs are ($147,500), and ($362,700) for headwater and mid-order, systems respectively.

The baselevel stream segment requires Priority 1B Restoration which entails retrofitting new bends along a straight ditch and selective breaches in the ditch spoil to improve water exchange between floodplain and creek. Line items are similar to those used in Priority 1 Restoration but scaled to reflect the more limited footprint of finished grading, planting, and forest management and monitoring required. The 20-year wetland NPV costs for baselevel restoration areas is ($44,700).

2.3 Total Costs for Stream Restoration

Under the maximum floodplain development scenario, total costs of this treatment are $(1,464,100), $(6,091,500), and $(1,458,900) for headwater, mid-order, and baselevel streams respectively.

3.0 STREAM RESTORATION NET BENEFITS

Stream restoration provides a variety of financial, environmental, and social benefits. Wood has assigned unit costs to these different variables, where possible, and then standardized them by applying the costs to a one-mile-long stretch of valley restoration. The subsections below describe the results of this application.

3.1 Financial

The major financial benefits are avoided routine maintenance and sediment removal costs. Channels requiring routine maintenance occur throughout the watershed, but it is unclear how much maintenance is conducted. The average cost savings NPV for avoided O&M (including cleanouts, patching erosion, and future Bayou dredge burden) are $189,900 (headwaters), $201,400 (mid-order), and $188,700 (baselevel).

3.2 Environmental

Wood assessed market values for wetland and stream habitat mitigation, and nitrogen removal as financial surrogates for the environmental benefits of stream restoration. The total environmental values assigned are $7,370,300, $12,614,700 and $6,054,600 for headwater, mid-order, and baselevel valleys. Irrespective of other benefits, the combined environmental benefits appear to amply justify stream restoration in the Carpenter Creek watershed as a worthwhile public investment. Some of the single environmental value line items alone provide such justification.

3.2.1 Wetland Habitat

The creek categories provide different amounts of wetland functional lift per restored mile, on average, as described under the stream restoration costs section. The Uniform Mitigation Assessment Method (UMAM) was categorized by stream restoration type in a generic way for this cost model. Site-specific variability will range. **Table 1** provides a summary of the applied existing versus proposed UMAM outcomes for water environment (hydrology and water quality), community structure, and landscape setting values.

Table 1 – UMAM Crediting Scenarios

FPZ	Water Environment		Community Structure		Landscape Setting		Net Unit Lift
	Existing	Proposed	Existing	Proposed	Existing	Proposed	
4 - Headwater	2	7	6	7	4	7	0.30
6 - Mid-Order	2	7	5	7	3	7	0.37
8 - Baselevel	6	7	6.5	7.5	6	7	0.10

The trajectory of forest conditions is considered in these scenarios. For example, some large portions of forests in actively eroding and regrading valleys are in good condition today, but they are essentially being consumed by ongoing destabilization. The future alluvially active reach of the creek it is trending toward thus sets the acreage limits this evaluation is applied to cover. That endpoint is what the restoration process accelerates in a controlled fashion.

The NPV benefit is $149,000, $363,700, and $389,500 for headwater, mid-order, and baselevel segments. Because the referent group is the public of Escambia County and City of Pensacola, the benefit is assigned at 100% during Year 1 of the project timeline. If the local governments decided to sell UMAM credits (or simply apply them to permitting requirements for County/Municipal wetland impacts), the cashflow would likely unfold over time and the NPV would be reduced when viewing the government as the referent group.

3.2.2 Stream Habitat

Stream habitat NPV benefits are $4,173,000, applied to Year 1. These benefits alone appear to justify overall investment in stream restoration for headwater and baselevel sites. The more earthwork intensive mod-order sites between Davis Highway and 9th Avenue are not net positive based solely on stream restoration valuation. However, a case could be made that mid-order streams in Carpenter Creek have the most pressing issues and thus offer the greatest priority for investment; despite the stream habitat being equally credited among all drainage positions, their instability affects downstream waterbodies. In fact, a previously unstated assumption of the benefits in this economic study is that upstream externalities have been sufficiently addressed to prevent their occurrence from disrupting the benefits of the local restoration. To reflect this, the FPZ-6 and FPZ-8 costs and benefits could be summed to get a better idea of the threshold of unit investment required and its unit payoff for stream habitat ($8,346,00 stream habitat value from $7,550,000 investment).

There is usually public perception favoring work in larger streams that support fishing and swimming. These larger waterbodies generally do offer greater aquatic biodiversity and larger bottomland forest than smaller creeks with less flow permanency, but for the purposes of this study, the fisheries value adjustment was assessed in relation to social benefits, specifically property value increases associated with fish habitat improvements.

The state of Florida or the USACE would have to re-interpret or start enforcing in-kind mitigation requirements for streams to establish a market for Florida stream mitigation. Thus, the values provided are conceptual, and should not be viewed as a source of tangible County/Municipal revenue. If such a market develops, revenue would likely be distributed over time.

3.2.3 Water Quality – Nitrogen Reduction

Wood calculated the reduction of pounds of total nitrogen removed per year (lb TN/yr) that stream corridor restoration would accomplish by the three-stream categories. Nitrogen was selected because it is a limiting nutrient for large Florida streams, lakes, and estuaries, and its stream restoration treatments are largely biologically mediated. Treatments may also reduce phosphorus, however phosphorus exhibits variable soil chemistry and geological sources in the Florida panhandle and is likely a non-limiting or co-limiting parameter in Carpenter Creek and Bayou Texar (which are impaired/likely impaired for TN, but not TP or chlorophyll-a).

Our analysis was adapted from stream restoration protocols used for the Chesapeake Bay TMDL, which determined stream restoration to be among the lowest cost options for TN reduction in Virginia.[10] Three nitrogen removal mechanisms that stream restoration provides were examined, including erosion reduction resulting from the stabilization of banks (P1), stream channel substrates (hyporheic) reduction during baseflow and bankfull flows (P2), and flow exchange from floodplain reconnection (P3) (Schueler and Stack 2014). In Florida’s sandbed streams much of the

[10] Stream restoration was also determined to be among the lowest cost options for total phosphorus (TP) and total suspended solids (TSS) reduction.

P2 reductions are expected to occur as part of an overall instream metabolism that extends beyond the hyporheic box below the streambed into the organic substrates and aquatic vegetation of the open channel and channel banks.

Erosion reductions were based on the net difference between estimates of sediment delivery from restored versus existing systems, estimated using the Rosgen BANCS method. This provides an average annual yield for years when the dominant transport mechanism occurs during bankfull discharges. Pritchett et al. (1959) reported a typical value of 0.06% nitrogen in Florida soils, which gives a yield of 1.2 lb TN per ton of sediment. Stream restoration reduces nitrogen loads 587 (FPZ-4), 1,541 (FPZ-6), and 350 (FPZ-8) lbs TN/yr/mile.

Large reductions are provided by denitrification of water fluxing through channel substrates and soil media contacting the channel margins, referred to as hyporheic exchange. This was assumed to occur most frequently within 5 lateral feet beyond the bankfull channel streambanks, and 2 feet below the streambed in sandy soils with a bulk density of 110 lb per cubic foot; which fall within acceptable ranges allowed for dimensioning the hyporheic box that is used for crediting TN reductions in Chesapeake Bay TMDLs. Reductions are approximated by using Chesapeake Bay freshwater stream denitrification rates of 1.06×10^{-4} lb TN/ton treatment media/day, as Florida rates are currently unknown. The amount of available treatment media for hyporheic exchange (e.g. hyporheic box) increases with stream size and accounts for TN reductions of 404, 663, and 208 lb/yr/mile for headwater, mid-order, and baselevel streams.

The Chesapeake Bay TMDL also assesses treatment provided by the wetland floodplain. Treatment efficiency depends on the rainfall depth required to access the floodplain (which indirectly accounts for frequency of treatment events) and the floodplain storage volume (which provides a gradient of treatment dependent on the relative size of the treatment volume over the wetland, relative to the area contributing runoff). Nomographs from Schueler and Stack (2014) relating these two variables to the percent of annual nitrogen removal were applied as a rough estimate because similar information is currently unavailable for Florida streams. Floodplain access rainfall depth was assumed to be 0.5 watershed inches and the floodplain storage volume was calculated to be less than 0.025 watershed inches for a mile of Carpenter Creek stream restoration using a 12" retention storage depth. This provides a very low storage volume estimate and a mid-level floodplain access rainfall volume on the Chesapeake nomographs, resulting in an estimated annual treatment efficiency of 1.5%. That efficiency was applied to annual TN loads derived from yields of 6 lb/ac as a characteristic value for the Carpenter Creek watershed (FDEP 2013). It should be noted that this TN load value is based on modeled loading estimates for the Jackson Creek, Jones Creek, and Bayou Chico TMDL in Pensacola, FL, but it may be updated upon completion of the water quality analyses in **Task 3.2**. The floodplain treatment is 44, 107, and 57 lbs/yr TN removed per mile of stream with a drainage density of 0.4 miles of stream restored per square mile of drainage area. In Wood's professional judgment, these efficiencies are likely to be understated for Florida waters, which naturally have greater overbank frequencies and total annual flood durations than the floodplains of mid-Atlantic and northeastern U.S. streams.

The total nitrogen estimated to be removed per linear mile of restoration is 587, 1,541, and 350 lb/yr for headwater, mid-order, and baselevel streams (**Table 2**). To place these calculations into some greater context, one mile of stream restoration treats 6%, 16%, and 4% of the total contributing load for headwater, mid-order, and baselevel systems respectively. These are unit values and treatment is likely to be cumulative as a function of the linear distance restored up to the limits of a region's sustainable drainage density.[11]

The Carpenter Creek basin's drainage density means, on average, a mile of creek services 2.5 square miles of watershed. So, if a maximum of 3.8 miles of stream restoration were conducted in systems cumulatively draining 9.5 square miles, and the restoration was distributed among 1.5 miles of headwater streams, 1.4 miles of mid-order streams, and 0.9 miles of baselevel streams; the overall treatment efficiency would be 9% (3,283 lbs removed from a basin yield of 36,480 lbs).

Table 2 - Estimated Nitrogen Reduction from Carpenter Creek Restoration

TN Removed (lb TN/yr/mile)				
Stream Category	**P1 - Erosion**	**P2 - Hyporheic**	**P3 - Floodplain**	**Total**
FPZ-4 Headwater	125	404	44	573
FPZ-6 Mid-Order	736	663	107	1506
FPZ-8 Baselevel	66	208	57	331

The NPV of stream restoration for TN removal is $3,072,300, $8,073,900, and $1,773,600 when amortized at NPV of $268/lb/year for 20 years; for a mile of headwater, mid-order, and baselevel stream restoration respectively. These benefits are all greater than the cost of stream restoration for their respective stream types.

Further, the hypothetical 3.8-mile restoration scenario mentioned earlier represents an NPV of $13 million for TN removal. The NPV stream restoration costs required to achieve that reduction would be $12 million. This suggests that when the scope of the solution matches that of the problem, the water quality benefits alone can readily justify large-scale stream restoration plans.

3.3 Social

Stream restoration characteristically improves residential property values and can also selectively improve flood resiliency. Both benefits can be monetized using available information but are expected to vary significantly on a case-by-case basis throughout the watershed.

3.3.1 Property Value Increase and Flood Damage Reduction

Wood estimates characteristic NPV property value increases at $205,700 for headwater streams and $517,000 for mid-order/baselevel streams. This is based on 55 residences being affected per linear mile. Each value can be scaled for a given site based on the proportion of properties actually bordering the channel.

Flood risk reduction values are likely to be small, at $50,000 on average, but can be quite substantial for flood-prone sites bordering the stream corridor; upwards of $300,000 for residential

[11] Drainage density is the linear distance stream channel per unit drainage area. Often expressed as miles/square mile.

developments along the channels. $50,000 was assigned uniformly to sites in all three drainage positions.

3.3.2 Recreation

As mentioned earlier this was not monetized on a cashflow basis because the potential recreational benefits typically require additional investments in access and linear architecture to unlock them. However, two recent economic studies of Florida stream restoration examined related benefits. In one fairly close to Pensacola, Autocase (2018) placed an immense $550,000 annual value on the enhanced ecosystem services derived from 2.0 miles of stream restoration in D'Olive Creek on the red drum, spotted trout, and blue crab fisheries of D'Olive Bay along the eastern shore of Mobile Bay. The NPV of these ecosystem services to fishing was calculated at $14.9 million. If a similar NPV was generated in Bayou Texar from roughly 3.8 miles of Carpenter Creek restoration, then the recreational fishery value alone justifies investment.

For a study in Jacksonville, Florida, Autocase (2019) placed the NPV recreational value of the proposed Emerald Trail and pocket park systems along the planned 2.8 miles of McCoys Creek restoration project at $3.5 million (amortized over a 50-year period at a 3% discount rate). The net present value derived from an expected 60,000 person visits per year.

3.3.3 Social Value Summary

The total social values are estimated at $255,700, $567,00, and $567,000 for progressively larger stream types per stream mile restored. These values are intrinsic to the stream restoration.

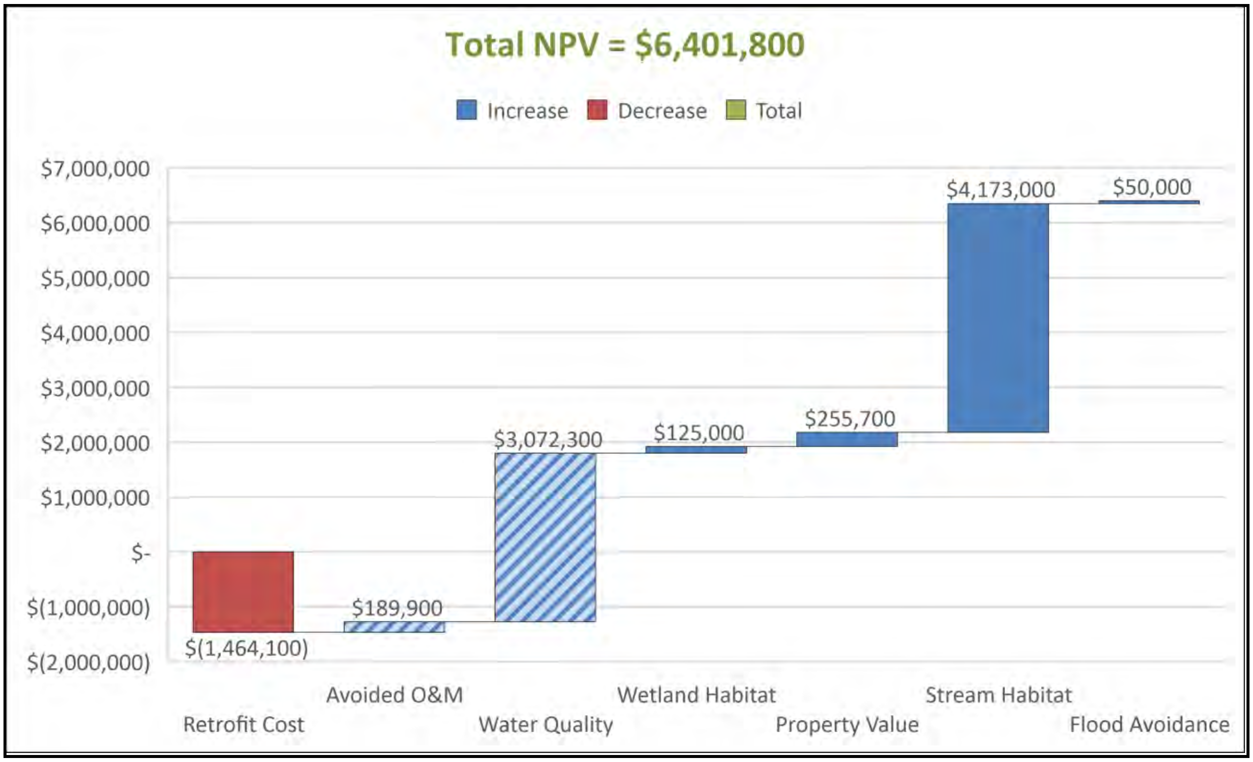
Even greater social value can be unlocked with integrated investments in recreational amenities like pocket parks, trails, and kayak ramps with thresholds of stream restoration at scales that create sought after resources. With such investments, an additional recreation value in excess of $500,000 per year is attainable, with a likely NPV of more than $15 million.

The economic benefits of stream restoration in the watershed greatly outweigh the costs as follows:

- Headwater FPZ-4: $7,865,900 benefit - $1,464,100 cost = NPV $6,401800. B/C ratio = 5.4.
- Mid-Order FPZ-6: $13,433,100 benefit - $6,091,500 cost = NPV $7,341,600. B/C ratio = 2.2.
- Baselevel Channels: $6,861,000 benefit - $1,458,900 cost = NPV $5,402,100. B/C ratio = 4.7.

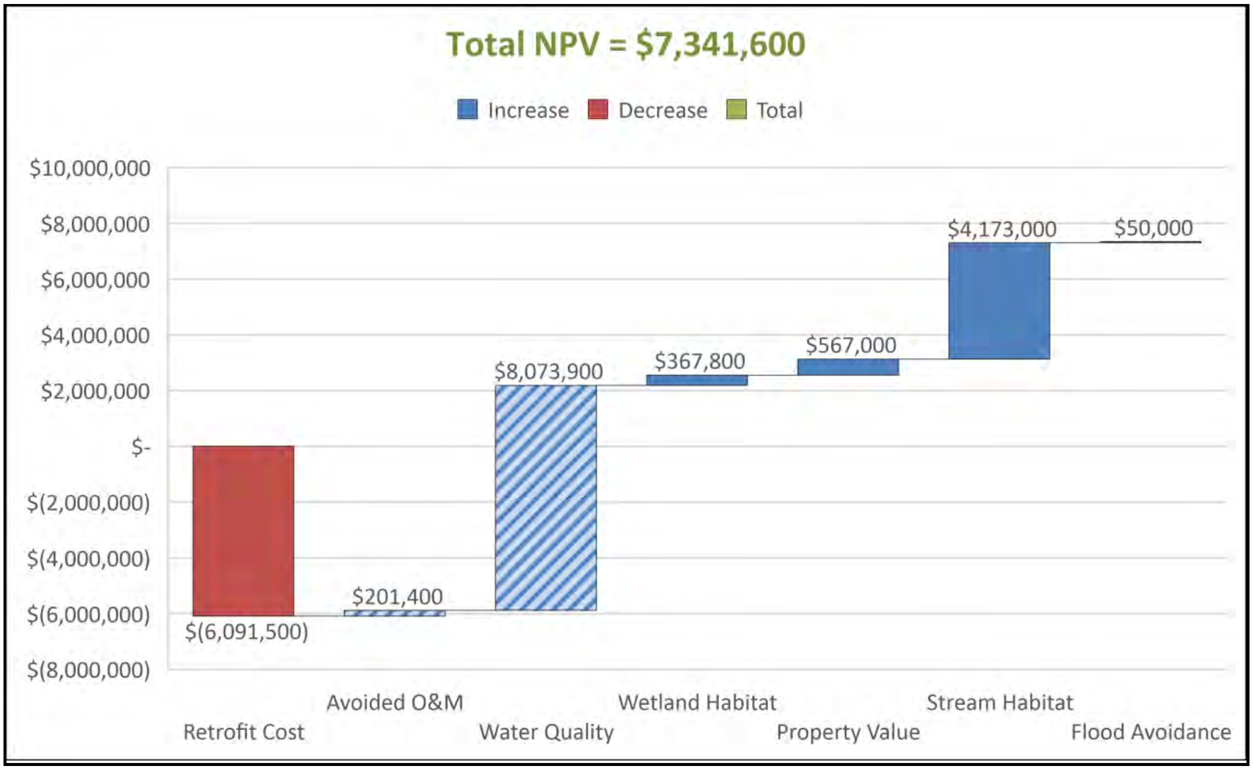
The major benefits are driven by environmental values, with less significant additions related to financial and social elements (**Figures 1** through **3**). While the Benefit/Cost ratio is greatest for headwater channels, it is more likely that the public will engage most heavily with the larger streams making them the most effective political drivers. This illustrates a key point for this report; that comparative economics should not be the sole variable in making public investment decisions. Also, despite its lower B/C ratio, work in FPZ-6 is a keystone consideration as it is required to unlock the restoration potential of downstream sections of the Creek and the Bayou affected by its massive erosion.

Figure 1 - Triple Bottom Line Results for FPZ-4 Headwater Stream Restoration



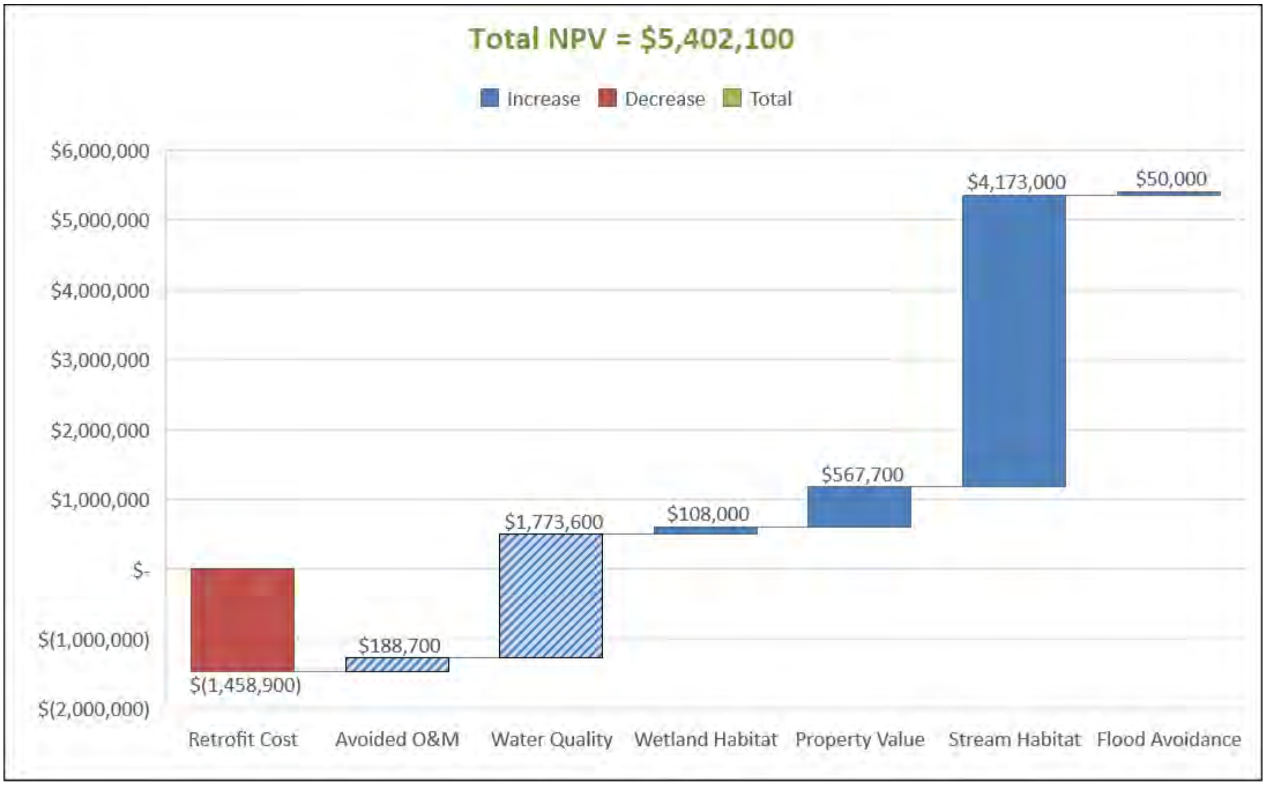
Light blue bars are tradable values for local government.

Figure 2 - Triple Bottom Line Results for FPZ-6 Mid-Order Stream Restoration



Light blue bars are tradable values for County government.

Figure 3 - Triple Bottom Line Results for FPZ-8 Baselevel Stream Restoration



Light blue bars are tradable values for County government.

4.0 VALLEY STABILIZATION

A variety of channel lining options can be deployed that would mitigate chronic streambank and valley slope erosion. Five approaches were explored to provide a range of values; including two soil bioengineering variations of vegetation reinforced soil slopes (VRSS), and three inert liners (gray infrastructure) consisting of riprap boulders, gabion baskets, and articulated concrete block. These approaches represent a range of Priority 3 and 4 stabilization solutions. The costs and benefits of these approaches are developed for comparison as alternatives to stream restoration and to each other.

All three gray infrastructure solutions were conceived as Priority 4 Stabilization, mitigating slope and bank failures with as little earthwork as possible. These are effectively stabilization-in-place alternatives and apply to areas lacking sufficient undeveloped valley width to implement other priorities.

Two VRSS configurations were assigned, one as a green alternative to gray Priority 4 solutions, and the other as a Priority 3 Stabilization. For the purposes of this study, Priority 3 solutions include a bankfull bench along the existing bankfull channel and a valley slope reduction above the bench between it and the developed slope crest. Priority 3 applies to areas with available lateral expansion between that of Priority 4 constraints and the greater dimensions required for naturalized Priority 1 or 2 floodplain and hillslope stability. VRSS is unlikely to apply to FPZ-4 or FPZ-8 as a stand-alone solution based on their morphology and types of erosion but may be a more common solution for consideration in FPZ-6. Therefore, it was only applied to the mid-order stream category used in this economic analysis.[12]

5.0 SOIL BIOENGINEERING BANK STABILIZATION COSTS

The combined slope severity and bank heights of the confined valley areas along Carpenter Creek (e.g. FPZ-6) typically would benefit from stabilization using Vegetation Reinforced Soil Slopes (VRSS), as opposed to simply planting trees on the failing slope. The VRSS provides an internally reinforced geogrid of biodegradable rolled erosion control product (RECP) as a temporary surrogate for long-term strength to be supplied by live woody root systems. Trees and shrubs are installed between the geogrid layers, and their roots sustainably bind the soil between each layer. The temporary fabrics provide time for the root systems to establish.

5.1 Construction and Long-Term Management

VRSS implementation costs include engineering, survey, temporary erosion controls, and mobilization/demobilization as fixed costs. Site-specific costs include clearing, earthwork, toe protection, and the VRSS geogrid and vegetation. Earthwork involves the sub grading of the bank for Priority 4 and also the development of a bankfull bench and slope removal for Priority 3 scenarios. The subgrade material is then blended with soil enhancements as part of re-building the bank as a VRSS. Toe protection typically is installed as a riprap layer at the base of the VRSS or the channel bench toe to the scour depth. VRSS is the only in-situ stabilization approach examined in this study that dissipates energy as opposed to displacing it. Therefore, no downstream energy dissipators or toe protection are required.

The capital costs for VRSS construction are $76.50 per square yard face (SYF[13]) based on installing coir fabric in 1-foot lifts, with 1-gallon woody plants installed on 2-foot spacings between lifts. A VRSS is essentially an afforestation project, with maintenance costs similar to those of forested wetland establishment. When that cashflow is unitized for VRSS square yard face, it amounts to $2.39 per SYF, bringing the total unit NPV to $78.89/SYF.

5.2 Overall Net Present Value

The sum of fixed, earthwork, stone toe, VRSS, and clearing costs results in NPV retrofit costs for VRSS of $(6,989,00), and ($5,416,000) for Priority 3 and Priority 4 segments in FPZ-6.

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[12] VRSS is also sometimes a component of stream restoration in confined urban valleys and was necessarily embedded as a capital expenditure within the cost model used for Priority 2 stream restoration in the FPZ-6 stream restoration scenario. In stream restoration, the VRSS is deemed an appurtenant treatment varying in need. In the section above we are highlighting VRSS as the dominant treatment, which Priority 4 easily fits conceptually. Priority 3 also invokes more substantial channel repatterning (absent a meander), but we are still referring to it as a 'VRSS treatment' as that will be the dominant visual feature from adjacent property.

[13] Square yard face is a unit of measure for the nominal surface area of the treated bank. The area is akin to draping a taught smooth sheet over the bank, without crenulations. It is calculated using bank angle, bank height, and bank length by trigonometry.

6.0 SOIL BIOENGINEERING BANK STABILIZATION NET BENEFITS

VRSS's provide a variety of financial, environmental, and social benefits. Wood has assigned unit costs to these different variables, where possible, and then standardized them by applying the costs to a one-mile-long stretch of valley restoration. The subsections below describe the results of this application.

6.1 Financial

The major financial benefits are avoided routine maintenance and sediment removal costs. The average cost savings are $187,500 for avoided O&M and $13,900 for avoided dredging costs, for a NPV savings of $201,400 per valley mile.

6.2 Environmental

Wood assessed market values for wetland habitat mitigation and nitrogen removal as financial surrogates for the environmental benefits of VRSS. VRSS alone does not provide stream channel restoration but can add buffer value in the case of Priority 4 approaches. When implemented as a Priority 3 stabilization, the VRSS coupled with aquatic habitat amendments adds instream habitat value at a reduced rate versus Priority 1 and 2 Restoration, but more than Priority 4 stabilization. Priority 3 VRSS as conceived for this model approximates outcomes received using a Rosgen B channel restoration approach. The total environmental values assigned are $7,863,900 and $4,480,900 for Priority 3 and Priority 4 VRSS approaches.

6.2.1 Wetland Habitat

The valleys provide different amounts of wetlands per restored mile, on average, by stream type as described under the stream restoration costs section. The lower layers of a VRSS and the bankfull bench can provide wetland enhancement as well, and Wood quantified this benefit assigning similar UMAM principals as those used for stream restoration. This resulted in average amounts of wetlands created at 2.4 and 4.7 acres per mile of restoration for the Priority 4 and Priority 3 scenarios at mid-order stream positions. The NPV benefit is $73,800 and $144,500 for these respectively. Because the referent group is the citizens of Escambia County/Pensacola, the benefit is assigned at 100% during Year 1 of the project timeline. If the local government decided to sell UMAM credits (or simply apply them to permitting requirements for wetland impacts), the cash flow would likely unfold over time and the NPV would be reduced when viewing the government as the referent group.

6.2.2 Stream Habitat

Stream habitat is not fully restored by these treatments but is enhanced as conceptualized for this model. Stream habitat was credited at 1.3x less than full restoration for Priority 3 VRSS, at $3,210,000. For Priority 4 VRSS stream restoration was credited mainly as a buffering and stabilization effect at $457,200, which is 14% of the Priority 3 level.

6.2.3 Water Quality – Nitrogen Reduction

The total nitrogen estimated to be removed per linear mile of valley restoration by implementing VRSS is related to the amount of floodplain wetland created and the reduced erosion of the streambanks. Hyporheic exchange is not credited as that results from natural channel restoration components not provided by VRSS.

The erosion stabilization reduction was credited similarly to stream restoration, based on observations that the clear majority of excess sedimentation is derived from bank erosion. For Priority 3 stabilization, the floodplain nitrogen restoration was also credited because that approach constructs a wetland bankfull bench.

Wood estimated TN reductions of 736 lb/yr and 807 lb/yr for Priority 4 and 3 systems treated with VRSS. The NPV of stream restoration for TN removal is $3,946,900 and $4,327,400 when amortized at NPV of $268/lb/year for 20 years; for a mile of Priority 4 and 3 valley stabilization respectively.

6.3 Social

Stream buffer restoration characteristically increases residential property values, especially in systems where it improves fisheries (American Rivers 2016). Wood, therefore, assigned 40% of the property value increases calculated for stream restoration to VRSS's constructed on mid-order streams, as these are the most likely to achieve direct fishing benefits and observable water quality improvements from having a stable native vegetation shoreline. Even if VRSS was indicated for headwater streams, they would not be credited because they are generally less fishable and observable. Wood estimates characteristic property value increases of $693,000 for both kinds of mid-order stream scenarios. This is based on 60 residences being affected per linear mile. Value can be scaled for a given site based on the proportion of properties bordering the stream valley.

Flood risk reduction values are not likely to occur from VRSS because the hydraulic capacity of the channel is not increased.

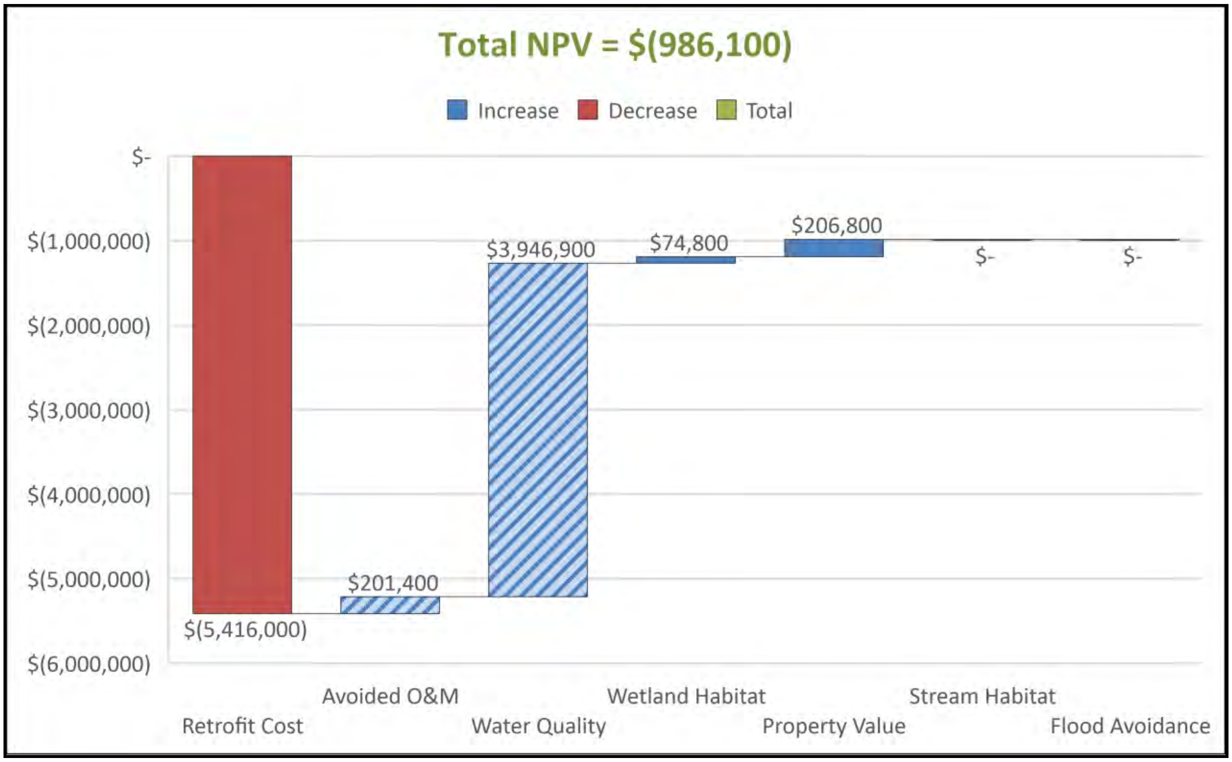
6.4 Overall NPV

The overall economic benefits of VRSS stabilization are positive when installed as a Priority 3 stream rehabilitation, but do not provide triple-bottom-line returns in excess of investment for the mid-order channel scenarios examined along Carpenter Creek:

- Priority 4: $4,429,900 benefit - $5,416,000 cost = NPV $(415,900). B/C ratio = 0.82.
- Priority 3: $8,142,100 benefit - $6,989,000 cost = NPV $1,153,100. B/C ratio = 1.16.

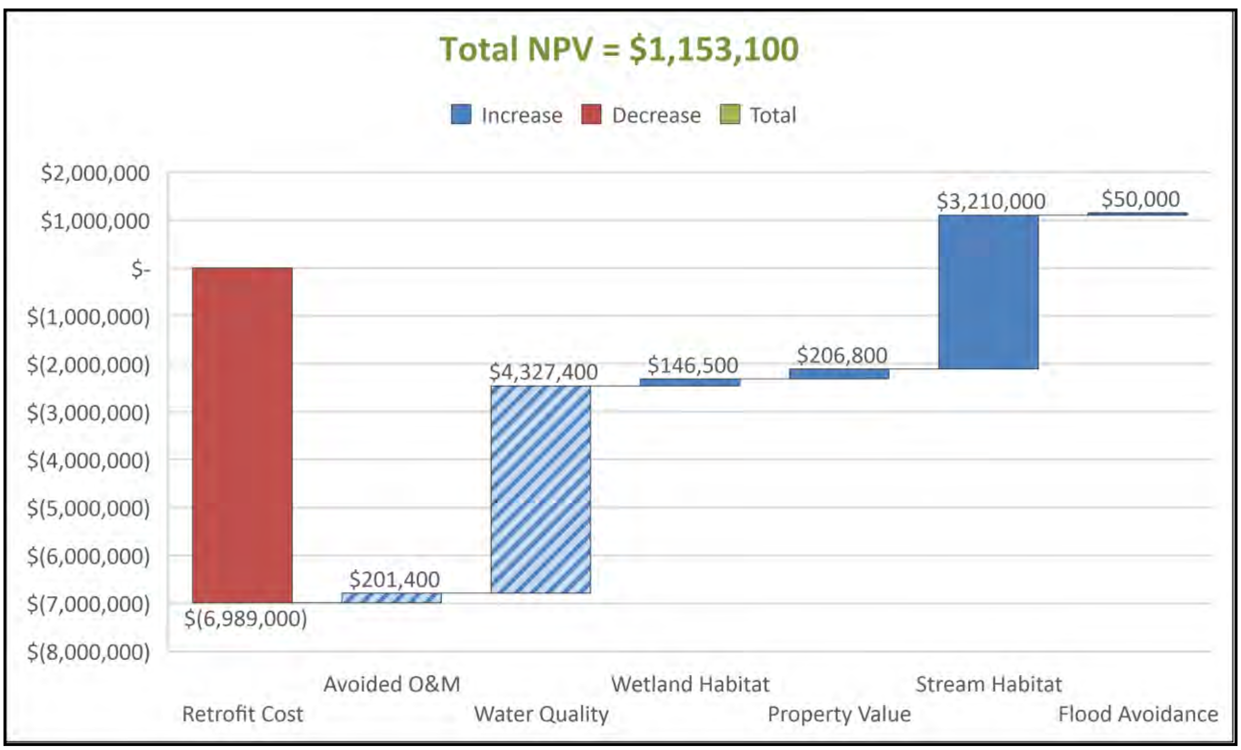
Large water quality benefits accrue for both scenarios, and Priority 3 adds significant stream habitat value (**Figures 4** and **5**).

Figure 4 - Triple Bottom Line Results for Priority 4 VRSS



Light blue bars are tradable values for County government.

Figure 5 - Triple Bottom Line Results for Priority 3 VRSS



Light blue bars are tradable values for County government.

7.0 RIPRAP CHANNEL LINING COSTS

Riprap is one of the most widely used channel bank stabilization treatments. It is deformable, thus accommodating of slowly changing bank morphology, and is easily repaired after large flow events. It must be established on a 2.5:1 side slope or more gradual for stability at the typical bank heights in the Carpenter Creek drainage network. This treatment is most likely to be considered in short sections of the valley requiring a Priority 4 approach, especially at sudden contractions and expansions near bridges and other cross-creek infrastructure.

7.1 Construction and Initial Establishment

Riprap implementation costs include engineering, survey, temporary erosion controls, and mob/demobilization as fixed costs. Site-specific costs include clearing, earthwork, edge and grade protection, and the riprap stone and underlying filter fabric. Earthwork involves the subgrading of the bank and export of net cut to achieve stable slopes. Riprap displaces fluvial forces. Therefore, energy dissipation and grade control are often required on otherwise untreated streambed downstream to prevent otherwise stable banks from being undermined.

The capital costs for riprap construction are $(3,826,700) and $(9,290,400) for headwater and mid-order systems respectively. Costs for baselevel systems were not assessed because this scenario is unlikely.

7.2 Long-Term Management

Storm events exceeding the level of service of the riprap design can require extensive bank repairs and recovery operations of the displaced stone. The extent of damage is highly variable and probabilistic. Wood sets the NPV of retrofit costs at 30% of initial earthwork construction.

8.0 RIPRAP CHANNEL LINING NET BENEFITS

Riprap provides a mix of financial and environmental benefits. Wood has assigned unit costs to these different variables, where possible, and then standardized them by applying the costs to a one-mile-long stretch of stabilization for comparative purposes. This unitization should not be interpreted that Wood is recommending 1-mile long riprap installations. On the contrary, these are likely to apply in smaller doses. This viewpoint also applies to the other gray alternatives described in this report. The subsections below describe the results of this application.

8.1 Financial

The major financial benefits are avoided routine maintenance and sediment removal costs. The cost savings result in NPV of $189,900 (FPZ-4) and $201,400 (FPZ-6) per treated mile.

8.2 Environmental

Riprap does not create wetland or stream habitat but does reduce nitrogen load associated with channel bank erosion.

The erosion stabilization reduction was credited similarly to that of Priority 4 VRSS. A case could be made to reduce this to account for the fact riprap traps very little upstream sediment load and actually may displace some load. However, because riprap is not being recommended for large scale implementation, discounting the erosion protection in that way would simply be splitting hairs.

8.3 Social

Riprap does not increase property values or avoid flood risk costs.

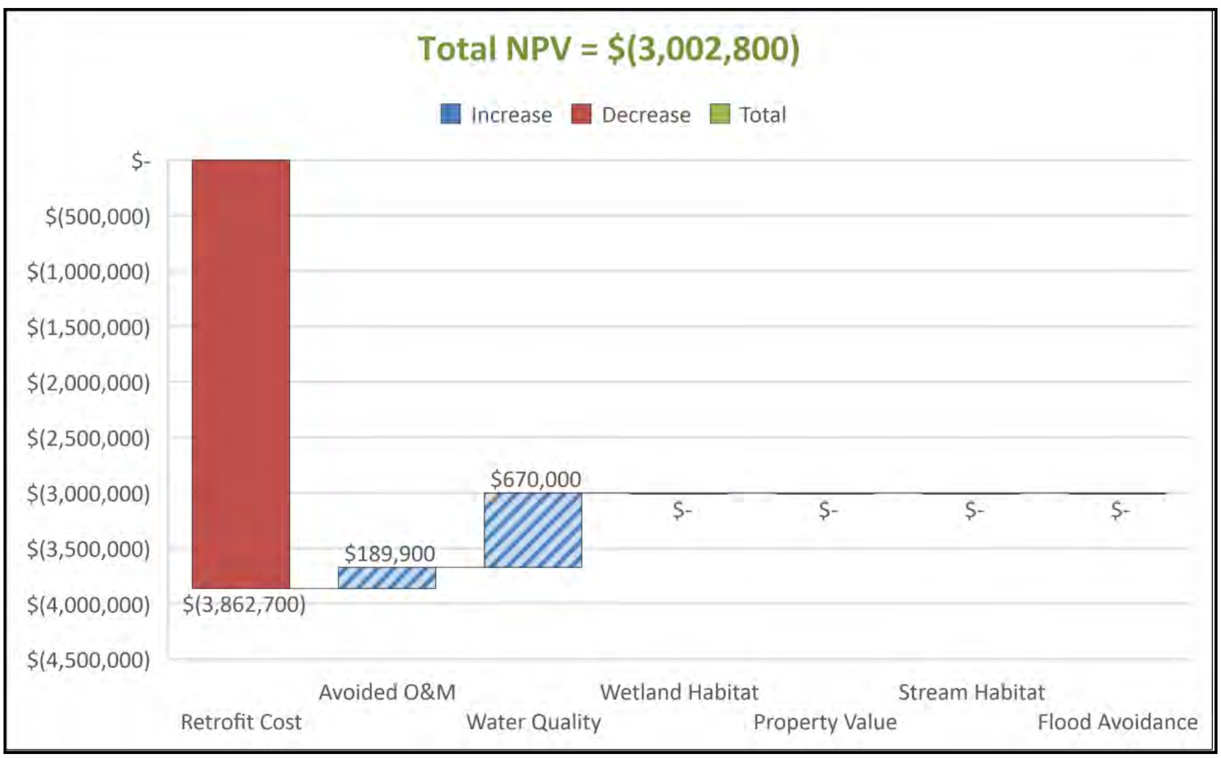
8.4 Overall NPV

The overall economic benefits of riprap stabilization in Carpenter Creek is negative, suggesting the do-nothing alternative is preferred for anything more than surgical applications of last resort:

- Headwater: $859,000 benefit - $3,862,700 cost = NPV $(3,002,800). B/C ratio = 0.22.
- Mid-Order: $4,148,300 benefit - $9,290,400 cost = NPV $(5,142,100). B/C ratio = 0.45.

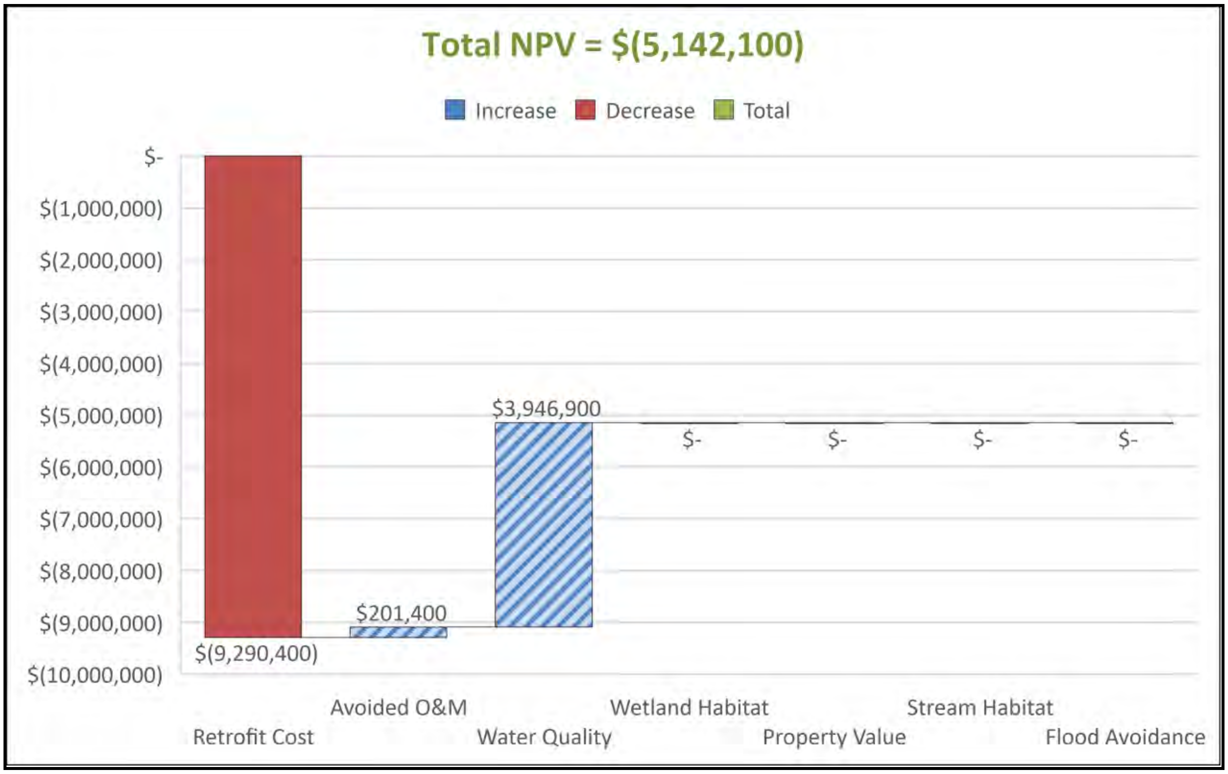
The largest benefit relates to the water quality benefits of erosion control, but this is dwarfed by the retrofit implementation costs (**Figures 6** and **7**). respectively.

Figure 6 - Triple Bottom Line Results for Headwater Riprap



Light blue bars are tradable values for County government.

Figure 7 - Triple Bottom Line Results for Mid-Order Riprap



Light blue bars are tradable values for County government.

9.0 GABION BANK STABILIZATION COSTS

Gabions are one of the most widely used bank stabilization treatments. Their wire baskets enable the use of much smaller rocks than riprap, with similar or better levels of performance. The drawback to gabions is the integrity of the system depends on the wire mesh, which degrades over time. Gabion systems can be widely applied to the typical bank conditions in the Carpenter Creek drainage system at steeper slopes, thus requiring less earthwork.

9.1 Construction and Initial Establishment

Gabion system implementation costs include engineering, survey, temporary erosion controls, and mob/demobilization as fixed costs. Site-specific costs include clearing, earthwork, toe protection, and the gabion baskets and underlying filter fabric. Earthwork involves the subgrading of the bank and export of net cut to achieve stable slopes. Gabions displace fluvial forces. Therefore, protection is required on untreated streambed downstream that has otherwise stable banks to prevent them from being undermined. Toe protection is also required to protect the gabion baskets from being undermined at their foundation.

The capital costs for gabion construction are $(2,739,500) and $(6,232,000) for headwater and mid-order systems.

9.2 Long-Term Management

Gabions have reportedly shorter than rated life spans in at least some urban Florida settings, requiring major retrofits roughly every 10 years.[14] Wood added 30% to the Year 1 earthwork costs to account for this additional cost.

10.0 GABION BANK STABILIZATION NET BENEFITS

Gabions provide a mix of financial and environmental benefits. Wood has assigned unit costs to these different variables, where possible, and then standardized them by applying the costs to a one-mile-long stretch of restoration. The subsections below describe the results of this application.

10.1 Financial

The major financial benefits are avoided routine maintenance and sediment removal costs. The cost savings result in NPV of $189,900 (FPZ-4, headwaters) and $201,400 (FPZ-6, mid-order) per treated mile.

10.2 Environmental

Gabions do not create wetland or stream habitat but do reduce nitrogen load associated with bank erosion.

The erosion stabilization reduction was credited similarly to that of Priority 4 VRSS. A case could be made to reduce this to account for the fact gabions trap very little upstream sediment load and actually may displace some load downstream. However, because gabions are not being recommended for large-scale implementation, discounting the erosion protection in that way is unnecessary. However, large-scale implementation of gabions or related solutions should account for this by reducing the benefit by approximately 15%.

10.3 Social

Gabions do not increase property values or avoid flood risk costs.

10.4 Overall NPV

The overall economic benefits of gabion stabilization in Carpenter Creek is negative, suggesting the treatment should be one of last resort in surgical applications to protect critical infrastructure where room is inadequate for more beneficial treatments:

- Headwater: $859,900 benefit - $2,739,500 cost = NPV $(1,879,600). B/C ratio = 0.31.
- Mid-Order: $4,148,300 benefit - $6,232,000 cost = NPV $(2,083,700). B/C ratio = 0.67.

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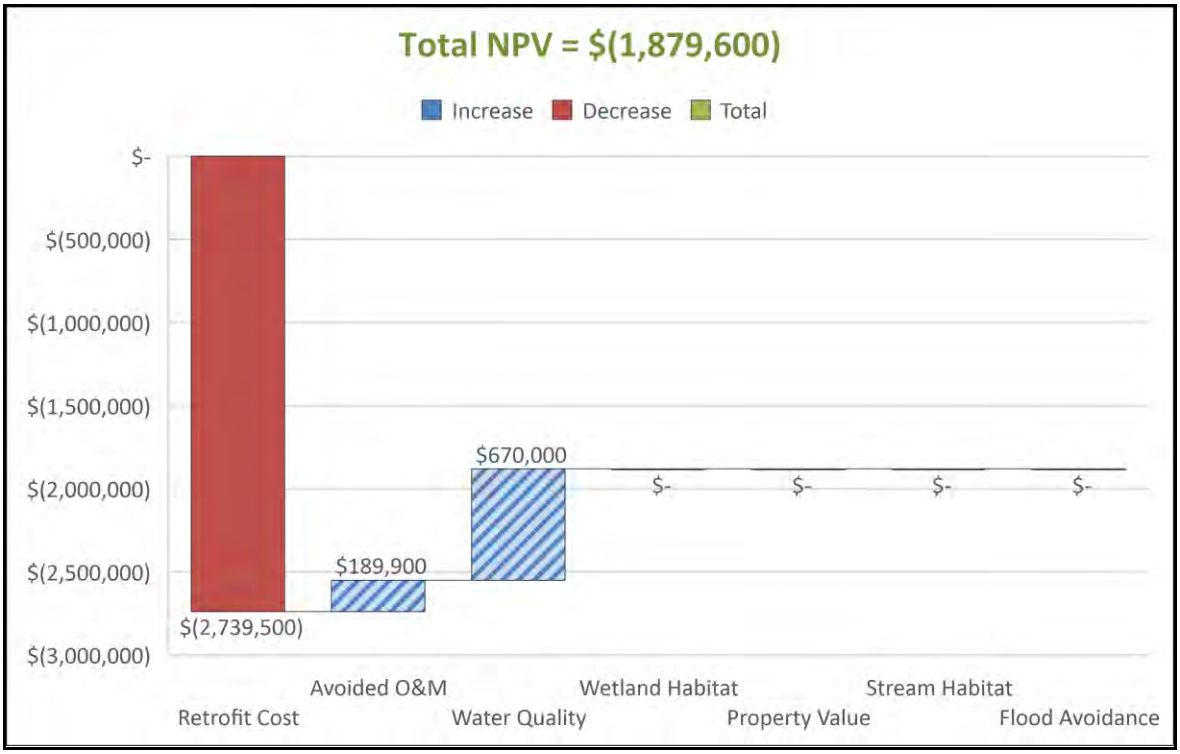
[14] Pinellas County, for example, once extensively relied upon gabion systems and currently seeks to diminish reliance on them for this reason.

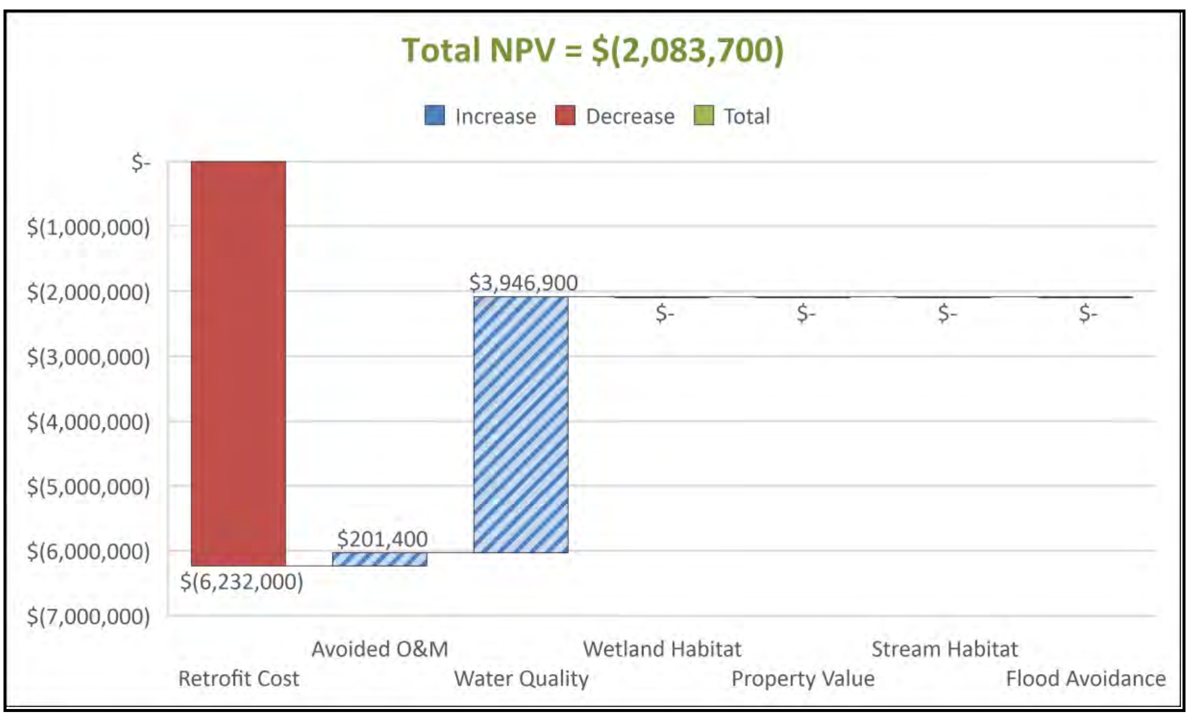
The largest benefit relates to avoided maintenance costs, but this is dwarfed by the retrofit implementation costs (**Figures 8** and **9**).

Figure 8 - Triple Bottom Line Results for Headwater Gabions



Light blue bars are tradable values for County government.

Figure 9 - Triple Bottom Line Results for Mid-Order Gabions



Light blue bars are tradable values for County government.

11.0 ARTICULATED CONCRETE BLOCK (ACB) STABILIZATION COSTS

ACBs were developed for use in a variety of in-situ bank and channel lining stabilization treatments, especially those with difficult installation sites. They are flexible and have low profiles that require less subgrading than other treatments. These systems can be widely applied to the typical bank conditions in the Carpenter Creek drainage system, although some sites may require special anchors when applied to banks steeper than 2:1.

11.1 Construction and Long-Term Management

ACB implementation costs include engineering, survey, temporary erosion controls, and mob/demobilization as fixed costs. Site-specific costs include clearing, earthwork, toe protection, and the ACB and underlying filter fabric. Earthwork involves the subgrading of the bank and export of net cut to achieve stable slopes but can be minimal compared to other treatments. ACB displaces fluvial forces. Therefore, toe protection is required and so is downstream energy dissipation.

The capital costs for ACB construction are $(2,037,100) and $(4,609,900) for headwater and mid-order areas respectively. Unlike other inert treatments contemplated in this study, unit costs are not similar for headwater and mid-order systems because the unit costs of the ACB increase substantially with thickness, and larger thicknesses were applied for the mid-order areas.

ACBs have low maintenance requirements. Thus, overall ACB costs are estimated at the construction and initial establishment values. It should be noted that ACB longevity varies by manufacturer and environmental conditions. A related product is articulating flexible concrete mats (FCM) with erosion control mesh backing. FCM is less expensive than ABM but is not as robust. For example, FCM was applied to valley slope erosion in two areas between Davis Hwy and Bayou Blvd and is showing signs of degradation within a few years of installation. Although sometimes promoted as a green solution, vegetation in ABM and FCM interstices is often poorly established and typically lacks long-term native diversity.

12.0 ACB STABILIZATION NET BENEFITS

ACB provides a mix of financial and environmental benefits. Wood has assigned unit costs to these different variables, where possible, and then standardized them by applying the costs to a one-mile-long stretch of restoration. The subsections below describe the results of this application.

12.1 Financial

The major financial benefits are avoided routine maintenance and sediment removal costs. The average cost savings are NPV $189,900 and $201,400 respectively for headwater and mid-order systems.

12.2 Environmental

ACB does not create wetland or stream habitat but can reduce nitrogen load associated with channel bank erosion.

The erosion stabilization reduction was credited in the same manner applied to riprap and gabions, with identical results.

12.3 Social

ACB does not increase property values or avoid flood risk costs.

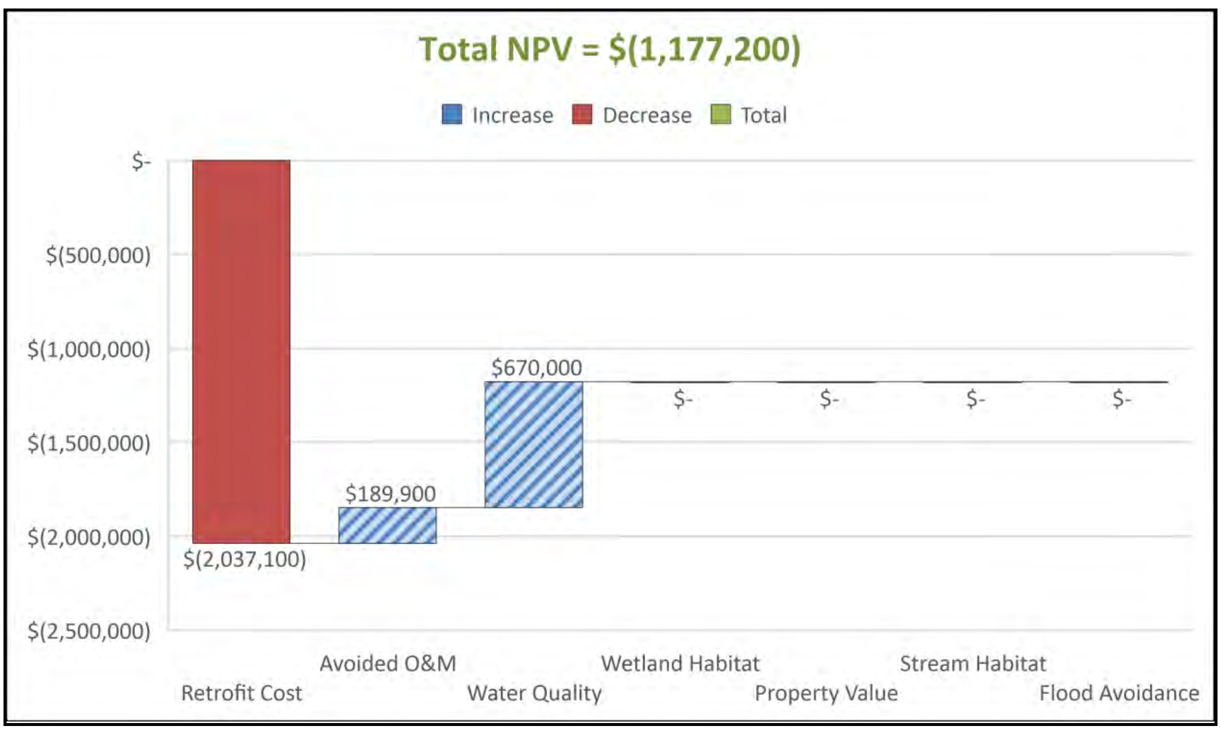
12.4 Overall NPV

The overall economic benefits of ACB shoreline stabilization in the Carpenter Creek watershed is negative, suggesting the do-nothing alternative is preferred:

- Headwater: $859,900 benefit - $2,037,100 cost = NPV $(1,177,200). B/C ratio = 0.42.
- Mid-Order: $4,148,300 benefit - $4,609,900 cost = NPV $(461,600). B/C ratio = 0.90.

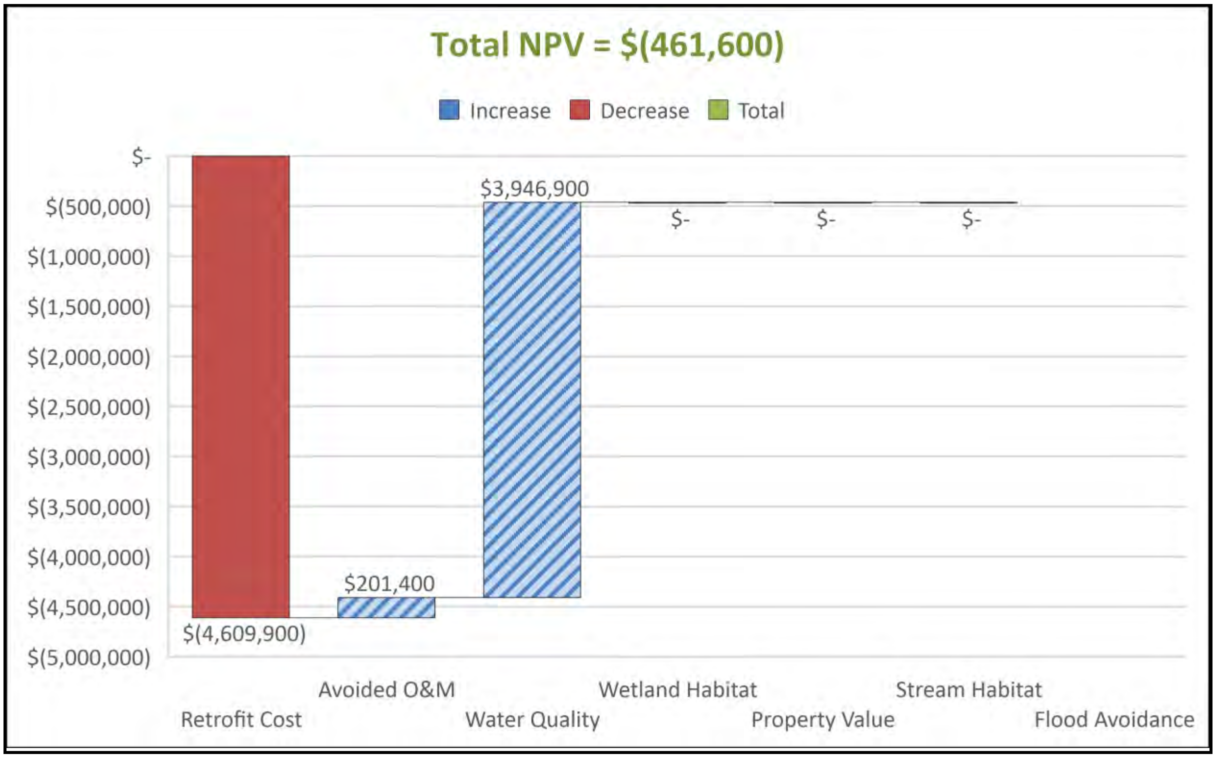
The largest benefit relates to improved water quality associated with reduced erosion, but this is dwarfed by the retrofit implementation costs in headwater positions and is sightly negative in mid-order positions (**Figures 10** and **11**).

Figure 10 - Triple Bottom Line Results for Headwater ACB



Light blue bars are tradable values for County government.

Figure 11 - Triple Bottom Line Results for Mid-Order ACB



Light blue bars are tradable values for County government.

13.0 COST BENEFIT SUMMARY

The triple-bottom-line (TBL) cost-benefit assessment (CBA) includes monetization of financial, environmental, and social dimensions of several proposed retrofit approaches aimed at substantially reducing the routine and perpetual erosion, habitat loss, and related hazards for the Carpenter Creek stream network. Each approach varies regarding implementation and management costs, and the types and amount of benefits provided. Treatments fall into two broad categories based on the dominant materials used and their associated benefits; green and gray infrastructure.

Gray infrastructure uses civil engineering technology to stabilize channels by the installation of inert materials such as riprap, concrete, steel, and plastic. Channel re-patterning or enlargement is minimized. Green infrastructure uses ecological engineering technology to variably integrate native vegetation, soil and rock stratigraphy, and natural channel patterns and dimensions to create largely self-sustaining drainage systems that are multifunctional. These treatments include bank stabilization using soil bioengineering techniques and creating multi-stage channels using natural channel design. Stream restoration, as defined for this assignment, synthesizes natural channel design and soil bioengineering. In reality, many green approaches are integrated with inert materials. For example, riprap is often used as a foundation for toe protection at the bottom of soil bioengineered streambanks.

The advantage of gray infrastructure is that it can be almost universally applied to drainage systems and that a wide array of engineers and contractors are available to design and construct related projects. The primary disadvantage is that it provides limited environmental benefits, and in some cases can accelerate or displace flow in ways causing new erosion downstream. Green approaches, in contrast, provide ample environmental and social benefits without downstream displacement of adverse impacts. However, green approaches typically require more real-estate to implement versus gray and thus can be more limited in their site-specific applicability.[15] Although there is an increasing emphasis to 'design with nature' for its multiple benefits, fewer engineers and contractors are currently experienced with green approaches versus gray.

Gray and green approaches also differ in their underlying design philosophy. Gray approaches provide resiliency by resisting nature and are typically designed with a particular level of service in mind. Once the level of service is exceeded, the system utterly or substantively fails. In contrast, green approaches provide resiliency using more of a bend-but-don't-break philosophy by accommodating or even harnessing natural forces in a corridor designated to biophysically adjust to pulsed, seasonal, and daily disturbances. This is how naturally stable undeveloped stream corridors function. They are ultimately self-organizing. Another important distinction is that gray structures degrade over time and green corridors strengthen as they mature. However, in an era of uncertain climate trajectories and in highly developed settings a layered approach using gray and green methods often makes the most sense. TBL economics provides one variable when considering the emphasis and priorities of layered solutions at watershed scale.

13.1 Triple Bottom Line

Tables 2 and **3** summarize the TBL CBA results, providing the calculated net present value (NPV) for green and gray infrastructure treatments for headwater, mid-order, and baselevel FPZs. Each TBL component is reported as a line item and summed for an overall project value. A positive number means the approach's benefits outweigh its costs for the public. The financial line incorporates the implementation and O&M costs of the retrofit.

This line item treats the avoided existing O&M and sediment management costs as a benefit and subtracts the retrofit implementation and O&M costs to provide the net present value (NPV) of the proposed approach.

None of the gray infrastructure choices provide environmental or social benefits sufficient to compensate for the requisite capital investment and O&M costs (**Table 3**). In other words, it makes no financial sense to systematically invest in these kinds of treatments to improve value for the citizens and visitors of Escambia County/Pensacola. However, it is important to recognize that this economic evaluation assesses systematic improvements occurring at a unit scale of a mile of valley length. Gray treatments are often implemented to armor valuable terrestrial infrastructure along the channel systems from erosion on a more surgical scale where needed, and in such cases, the

[15] Wood preliminarily assessed the available undeveloped corridor widths at selected areas throughout the watershed as part of Tasks 3.3.1 and 3.3.2 and observed ample opportunity widths for natural channel design solutions in many areas. An underlying assumption of the scenarios developed for this assessment is that fee simple land acquisition or fee easements are not required, and that restoration access and maintenance rights will be granted at no cost. In situations where this a poor assumption, the real estate costs can simply be unitized to those required for a mile of equivalent frontage and subtracted from the NPV TBM value because it is a Year 1 expense in the cashflow.

patches may certainly be warranted. Also, gray solutions may make sense along valuable infrastructure running parallel to or across valley margins that are too tightly constrained to allow green options. This will depend on the value of the structure and the risks involved.

Table 3 - Gray Infrastructure Triple-Bottom Line Summary

Riprap	Headwater	Mid-Order	Baselevel
Financial NPV	$ (3,672,800)	$ (9,089,000)	Not Assessed
Environmental NPV	$ 670,000	$ 3,946,900	
Social NPV	$ -	$ -	
Triple Bottom Line	**$ (3,002,800)**	**$ (5,142,100)**	

Gabions	Headwater	Mid-Order	Baselevel
Financial NPV	$ (2,549,600)	$ (6,030,600)	Not Assessed
Environmental NPV	$ 670,000	$ 3,946,900	
Social NPV	$ -	$ -	
Triple Bottom Line	**$ (1,879,600)**	**$ (2,083,700)**	

Articulated Block	Headwater	Mid-Order	Baselevel
Financial NPV	$ (1,847,200)	$ (4,408,500)	Not Assessed
Environmental NPV	$ 670,000	$ 3,946,900	
Social NPV	$ -	$ -	
Triple Bottom Line	**$ (1,177,200)**	**$ (461,600)**	

Green infrastructure provides substantial environmental and social benefits that outweigh the retrofit costs in some cases (**Table 4**). This includes positive NPV for stream restoration in all three drainage network positions. The environmental benefits drive the investment return of stream restoration more than the monetized social benefits. However, stream restoration provides a string foundation for social benefits related to fishing and other forms of recreation that can be unlocked by further investments in parks and access infrastructure beyond the scope of the stream restoration itself.

The only form of green infrastructure that did not exhibit a positive TBL was Priority 4 VRSS. That is due to the fact that Priority 4 VRSS is in effect simply a means to provide a gray infrastructure approach for stabilizing the valley form largely in-situ using a type of reforestation system in lieu of steel, plastic, concrete or imported stone. Priority 4 approaches do not add important stream habitat.

Table 4 - Green Infrastructure Triple-Bottom Line Summary

Stream Restoration	Headwater	Mid-Order	Baselevel
Financial NPV	$ (1,274,200)	$ (5,890,100)	$ (1,270,200)
Environmental NPV	$ 7,370,300	$ 12,614,700	$ 6,054,600
Social NPV	$ 255,700	$ 567,000	$ 567,700
Triple Bottom Line	**$ 6,351,800**	**$ 7,291,600**	**$ 5,352,100**

VRSS - Priority 3	Headwater	Mid-Order	Baselevel
Financial NPV	Not Assessed	$ (6,787,600)	Not Assessed
Environmental NPV		$ 7,683,900	
Social NPV		$ 256,800	
Triple Bottom Line		**$ 1,153,100**	

VRSS - Priority 4	Headwater	Mid-Order	Baselevel
Financial NPV	Not Assessed	$ (5,214,600)	Not Assessed
Environmental NPV		$ 4,480,900	
Social NPV		$ 206,800	
Triple Bottom Line		**$ (526,900)**	

However, the environmental and social benefits of every green approach outweigh those benefits versus gray approaches. As an example, VRSS is often a more environmentally friendly and sustainable treatment for bank stabilization compared to gabions or riprap. **Tables 3** and **4** illustrate that Priority 3 VRSS has superior financial, environmental, and social benefits versus gabion, riprap, and ACB stabilization; costing less to implement and providing greater overall benefits. So, where local scale bank stabilization is needed in areas physically suitable for VRSS, it should be strongly considered in lieu of inert alternatives. ACB and Priority 4 VRSS provide similar overall costs and benefits, and which is implemented depends on acceptance of non-forested versus forested conditions.

As a practical matter, VRSS likely requires a minimum scale for application that may be greater than that of riprap, but similar to face lengths deemed worthy of deploying gabions or ACB. For example, VRSS and gabions are less applicable as countermeasures against an existing small gully from concentrated overland flow paths across the valley slope than riprap which is much more flexible and immediate in its installation. Typically, VRSS would apply best to areas of toe scour combined with sheet erosion, or gravity failures of high embankments at least a few dozen feet long. For example, Wood applied an integrated VRSS/ACB system as part of a dam abutment erosion countermeasure about 100 feet long in an area requiring sufficient modularity to conserve several old-growth cypress trees with a high natural aesthetic on the Loxahatchee River. We would have probably treated a much smaller surface using riprap instead in a similar setting.

13.2 Range of Values

The costs and benefits reported so far are Wood's estimates of central tendency for each treatment and location category. These are likely to fall into cost estimate ranges akin to schematic design or conceptual studies with a categorical accuracy range of -20% to +30% for costs (AACE, 2012).[16] These ranges were used to explore worst- and best-case scenarios. The worst-case scenario assigned the maximum cost and minimum benefit for the ranges indicated, while the best-case scenario combined the lowest cost and greatest benefits.

Tables 5a and **5b** provide the breakdown for each monetized line item and range of values for each scenario, and the triple bottom line is summarized in rank order for the mean values with ranges depicted in **Table 6**.

The best-case returns were overall positive for the following scenarios:

- Stream restoration in all three drainage positions
- Priority 3 and 4 VRSS in mid-order FPZ-6
- Riprap and articulated concrete block at mid-order FPZ-6

Average values were overall positive for the following scenarios:

- Stream restoration in all three landscape positions
- Priority 3 VRSS for mid-order FPZ-6

Worst case scenarios provide net positive returns for:

- Headwater and baselevel stream restoration positions

[16] Because we assign costs with a negative sign and are monetizing net benefit, the range applied is -30% to +20% of the net benefits reported.

Table 5a - Scenario Value Ranges – Stream Restoration and VRSS

Stream Restoration	Headwater			Mid-Order			Baselevel		
Item	Mean	Worst Case	Best Case	Mean	Worst Case	Best Case	Mean	Worst Case	Best Case
Retrofit Cost	-$1,464,100	-$1,903,330	-$1,024,870	-$6,091,500	-$7,918,950	-$4,264,050	-$1,458,900	-$1,896,570	-$1,021,230
Avoided O&M	$189,900	$94,950	$708,000	$201,400	$100,700	$708,000	$188,700	$94,350	$708,000
Wetland Habitat	$125,000	$62,500	$162,500	$367,800	$183,900	$478,140	$108,000	$54,000	$140,400
Stream Habitat	$4,173,000	$2,086,500	$5,424,900	$4,173,000	$2,086,500	$5,424,900	$4,173,000	$2,086,500	$5,424,900
Water Quality	$3,072,300	$1,536,150	$3,993,990	$8,073,900	$4,036,950	$10,496,070	$1,773,600	$886,800	$2,305,680
Property Value	$205,700	$0	$267,410	$517,000	$0	$672,100	$517,700	$0	$673,010
Flood Avoidance	$50,000	$0	$300,000	$50,000	$0	$300,000	$50,000	$0	$300,000
Overall	$6,351,800	$1,876,770	$9,831,930	$7,291,600	-$1,510,900	$13,815,160	$5,352,100	$1,225,080	$8,530,760

VRSS (Priority 3)	Headwater			Mid-Order			Baselevel		
Item	Mean	Worst Case	Best Case	Mean	Worst Case	Best Case	Mean	Worst Case	Best Case
Retrofit Cost	$0	$0	$0	-$6,989,000	-$9,085,700	-$4,892,300	$0	$0	$0
Avoided O&M	$0	$0	$0	$201,400	$100,700	$261,820	$0	$0	$0
Wetland Habitat	$0	$0	$0	$146,500	$73,250	$190,450	$0	$0	$0
Stream Habitat	$0	$0	$0	$3,210,000	$1,605,000	$4,173,000	$0	$0	$0
Water Quality	$0	$0	$0	$4,327,400	$2,163,700	$5,625,620	$0	$0	$0
Property Value	$0	$0	$0	$206,800	$0	$268,840	$0	$0	$0
Flood Avoidance	$0	$0	$0	$50,000	$0	$300,000	$0	$0	$0
Overall	$0	$0	$0	$1,153,100	-$5,143,050	$5,927,430	$0	$0	$0

VRSS (Priority 4)	Headwater			Mid-Order			Baselevel		
Item	Mean	Worst Case	Best Case	Mean	Worst Case	Best Case	Mean	Worst Case	Best Case
Retrofit Cost	$0	$0	$0	-$5,416,000	-$7,040,800	-$3,791,200	$0	$0	$0
Avoided O&M	$0	$0	$0	$201,400	$100,700	$261,820	$0	$0	$0
Wetland Habitat	$0	$0	$0	$74,800	$37,400	$97,240	$0	$0	$0
Stream Habitat	$0	$0	$0	$459,200	$229,600	$596,960	$0	$0	$0
Water Quality	$0	$0	$0	$3,946,900	$1,973,450	$5,130,970	$0	$0	$0
Property Value	$0	$0	$0	$206,800	$0	$268,840	$0	$0	$0
Flood Avoidance	$0	$0	$0	$0	$0	$0	$0	$0	$0
Overall	$0	$0	$0	-$526,900	-$4,699,650	$2,564,630	$0	$0	$0

Table 5b - Scenario Value Ranges – Riprap, Gabions, and Articulated Concrete Block

Riprap	Headwater			Mid-Order			Baselevel		
Item	Mean	Worst Case	Best Case	Mean	Worst Case	Best Case	Mean	Worst Case	Best Case
Retrofit Cost	-$3,862,700	-$5,021,510	-$2,703,890	-$9,290,400	-$12,077,520	-$6,503,280			
Avoided O&M	$189,900	$94,950	$246,870	$201,400	$100,700	$261,820			
Wetland Habitat	$0	$0	$0	$0	$0	$0			
Stream Habitat	$0	$0	$0	$0	$0	$0			
Water Quality	$670,000	$335,000	$871,000	$3,946,900	$1,973,450	$5,130,970			
Property Value	$0	$0	$0	$0	$0	$0			
Flood Avoidance	$0	$0	$0		$0	$0			
Overall	-$3,002,800	-$4,591,560	-$1,586,020	-$5,142,100	-$10,003,370	-$1,110,490			

Gabions	Headwater			Mid-Order			Baselevel		
Item	Mean	Worst Case	Best Case	Mean	Worst Case	Best Case	Mean	Worst Case	Best Case
Retrofit Cost	-$2,739,500	-$3,561,350	-$1,917,650	-$6,232,000	-$8,101,600	-$4,362,400			
Avoided O&M	$189,900	$94,950	$246,870	$201,400	$100,700	$261,820			
Wetland Habitat	$0	$0	$0	$0	$0	$0			
Stream Habitat	$0	$0	$0	$0	$0	$0			
Water Quality	$670,000	$335,000	$871,000	$3,946,900	$1,973,450	$5,130,970			
Property Value	$0	$0	$0	$0	$0	$0			
Flood Avoidance	$0	$0	$0		$0	$0			
Overall	-$1,879,600	-$3,131,400	-$799,780	-$2,083,700	-$6,027,450	$1,030,390			

Articulated Concrete Block	Headwater			Mid-Order			Baselevel		
Item	Mean	Worst Case	Best Case	Mean	Worst Case	Best Case	Mean	Worst Case	Best Case
Retrofit Cost	-$2,037,100	-$2,648,230	-$1,425,970	-$4,609,900	-$5,992,870	-$3,226,930			
Avoided O&M	$189,900	$94,950	$246,870	$201,400	$100,700	$261,820			
Wetland Habitat	$0	$0	$0	$0	$0	$0			
Stream Habitat	$0	$0	$0	$0	$0	$0			
Water Quality	$670,000	$335,000	$871,000	$3,946,900	$1,973,450	$5,130,970			
Property Value	$0	$0	$0	$0	$0	$0			
Flood Avoidance	$0	$0	$0	$0	$0	$0			
Overall	-$1,177,200	-$2,218,280	-$308,100	-$461,600	-$3,918,720	$2,165,860			

Table 6 - TBL NPV for each Scenario with Ranges

Retrofit Scenario	Position	Mean NPV	NPV Range	
			Worst Case	Best Case
Stream Restoration	Mid-Order FPZ-6	$ 7,291,600	$ (1,510,900)	$ 13,815,160
Stream Restoration	Headwater FPZ-4	$ 6,351,800	$ 1,876,770	$ 9,831,930
Stream Restoration	Baselevel FPZ-8	$ 5,352,100	$ 1,225,080	$ 8,530,760
VRSS - Priority 3	Mid-Order FPZ-6	$ 1,153,100	$ (5,143,050)	$ 5,927,430
VRSS - Priority 4	Mid-Order FPZ-6	$ (526,900)	$ (4,699,650)	$ 2,564,630
Articulated Block	Mid-Order FPZ-6	$ (461,600)	$ (3,918,720)	$ 2,165,860
Articulated Block	Headwater FPZ-4	$ (1,177,200)	$ (2,218,280)	$ (308,100)
Gabion	Headwater FPZ-4	$ (1,879,600)	$ (3,131,400)	$ (799,780)
Gabion	Mid-Order FPZ-6	$ (2,083,700)	$ (6,027,450)	$ 1,030,390
Riprap	Headwater FPZ-4	$ (3,002,800)	$ (4,591,560)	$ (1,586,020)
Riprap	Mid-Order FPZ-6	$ (5,142,100)	$ (10,003,370)	$ (1,110,490)

The top positive total TBL NPV scenarios for average conditions are mid-order stream restoration headwater stream restoration, baselevel stream restoration, and Priority 3 VRSS in descending order (**Table 6**). The bottom 5, starting with the least valuable are mid-order riprap, headwater riprap, mid-order gabion, headwater gabion, and headwater articulated block.

Most of the best-case scenarios exhibit positive TBL, except headwater riprap, gabions, and ACB; and mid-order riprap. Only two worst-case scenarios resulted in positive TBL; stream restoration at headwater and baselevel positions.

This range of TBL results indicates that 10 of 12 stream restoration scenarios were positive, counting Priority 3 VRSS as Rosgen B channel restoration (83%). Only 3 of 21 Priority 4 scenarios were positive (14%). The TBL return on investment declines the more the approach departs from a naturally functioning condition. This suggests prioritization of stream restoration wherever it can be applied in areas requiring retrofits, with secondary emphasis on in-situ soil bioengineering techniques in situations where sufficient capital cannot be raised to support stream restoration or stream restoration is biophysically infeasible. Gray infrastructure should be relegated to patchwork where neither stream restoration nor soil bioengineering applies.

Irrespective of the TBL return on investment, the ability to raise or divert public capital may be limited and the general perception is that increased returns require greater capital investments. However, capital costs of the highest return retrofits, namely stream restoration, are generally lowest to intermediate between in-situ soil bioengineering and gray treatments (**Table 7**). In fact, headwater and baselevel stream restoration for Carpenter Creek is notably the least capital intensive, while providing significant net positive returns. Capital costs for all remedies in FPZ-6 are rather similar (except for riprap), with ACB being the least expensive but stream restoration offering the highest return ratio.

Table 7 - Capital Investment Sorted by Channel Position and Ranked by Mean Cost

Retrofit Scenario	Position	Mean Capital	Capital Range	
			Worst Case	Best Case
Stream Restoration	Baselevel FPZ-8	$ (1,458,900)	$ (1,896,570)	$ (1,021,230)
Stream Restoration	Headwater FPZ-4	$ (1,464,100)	$ (1,903,330)	$ (1,024,870)
Articulated Block	Headwater FPZ-4	$ (2,037,100)	$ (2,648,230)	$ (1,425,970)
Gabion	Headwater FPZ-4	$ (2,739,500)	$ (3,561,350)	$ (1,917,650)
Riprap	Headwater FPZ-4	$ (3,862,700)	$ (5,021,510)	$ (2,703,890)
Articulated Block	Mid-Order FPZ-6	$ (4,609,900)	$ (5,992,870)	$ (3,226,930)
VRSS - Priority 4	Mid-Order FPZ-6	$ (5,416,000)	$ (7,040,800)	$ (3,791,200)
Stream Restoration	Mid-Order FPZ-6	$ (6,091,500)	$ (7,918,950)	$ (4,264,050)
Gabion	Mid-Order FPZ-6	$ (6,232,000)	$ (8,101,600)	$ (4,362,400)
VRSS - Priority 3	Mid-Order FPZ-6	$ (6,989,000)	$ (9,085,700)	$ (4,892,300)
Riprap	Mid-Order FPZ-6	$ (9,290,400)	$ (12,077,520)	$ (6,503,280)

Regarding the challenges to public works funding, stream restoration is notable differentiator for several granting agencies versus inert retrofits for agencies co-funding solutions that benefit fisheries, stimulate local economies, mitigate flood hazards, and improve water quality. These include NFWF, NOAA, USEPA, FWC, and FEMA, among others.

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