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Water Quality: Watershed Characterization Report for the East and West Forks of Double Bayou

Deliverable: Final Report

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Table of Contents

Watershed Characterization **5**

Baseline Data Set 5

Gap Analysis 5

Data Collection 6

Analysis of Models 9

Watershed Outreach 10

Public Participation Plan, Phase I 10

Next Steps 17

Summary of Data **17**

Temperature and Precipitation 17

Database and Spatial Analysis for Database Stations 20

Sampling Stations 20

Wastewater Treatment Update 24

Septic Tanks 24

Wastewater Treatment Plants and Facilities 25

Criteria 28

Water Quality Data 30

Dissolved Oxygen 30

Tidal Data and Water Levels 38

Bacteria 42

Nutrients and Chlorophyll-a 52

pH, Chloride, Sulfate and Total Dissolved Solids 66

Summary 71

Appendices

Appendix A. Additional Parameter Analysis 74

Appendix B: Stakeholder and Outreach 90

List of Figures

Figure 1. Double Bayou Watershed and Sampling Stations 6
Figure 2. Channel Depth Profile for Double Bayou (at USGS sampling stations site) 9
Figure 3. High-Resolution aerial imagery of dam/weir possible location 16
Figure 4. Double Bayou Level IV Ecoregions 18
Figure 5. Monthly average Max and Min Temperature during sampling periods at Anahuac station 410235, data provided by NCDC 19
Figure 6. Monthly versus average precipitation for Anahuac NCDC station 410235 20
Figure 7. LiDAR and DEM for station designation 21
Figure 8. East Fork versus West Fork station designations 22
Figure 9. Stations in the Double Bayou Watershed 23
Figure 10. On-site septic treatment systems in the Double Bayou Watershed 24
Figure 11. 24-hour Dissolved Oxygen Minimum, Maximum and Average Results 31
Figure 12. Spatial Analysis of Double Bayou 24-hour Dissolved Oxygen Minimum Exceedances 32
Figure 13 Temporal DO patterns during the sampling periods 33
Figure 14. Temporal Water Temperature patterns during the sampling periods 34
Figure 15. 24-hour Water Temperature Measurements All Stations 34
Figure 16. Linear Regression for dissolved oxygen and water temperature 35
Figure 17. Dissolved Oxygen in Double Bayou Watershed 35
Figure 18. Dissolved Oxygen in Double Bayou Watershed – Past Studies Non-estuarine Station Results 36
Figure 19. Dissolved Oxygen in Double Bayou Watershed – Past Studies Estuarine Station Results 37
Figure 20. 24-hour Salinity in Double Bayou 38
Figure 21. TBCD sensors in the Double Bayou Watershed. 39
Figure 22. Fall - TBCD Eagle Ferry Water Level and Precipitation in Double Bayou 40
Figure 23. Spring - TBCD Eagle Ferry Water Level and Precipitation in Double Bayou 41
Figure 24. Fall - TBCD Jenkins Weir Water Level and Precipitation in Double Bayou 41
Figure 25. Spring - TBCD Fairview Water Level and Precipitation in Double Bayou 42
Figure 26. Bacteria Sampling Results 43
Figure 27. Spatial Analysis of Double Bayou Bacteria Exceedances 44
Figure 28. Double Bayou Watershed Pathogens 45
Figure 29. Pathogens in Double Bayou Watershed – Past Studies Non-Estuarine Station Results 46
Figure 30. Pathogens in Double Bayou Watershed – Past Studies Estuarine Station Results 47
Figure 31. West Fork Double Bayou Enterococci 48
Figure 32. East Fork Double Bayou Enterococci 48
Figure 33. Estuary Stations Double Bayou watershed Enterococci 49
Figure 34. West Fork Double Bayou Fecal Coliform 49
Figure 35. East Fork Double Bayou Fecal Coliform 50
Figure 36. Estuary Stations Double Bayou Watershed Fecal Coliform 50
Figure 37. West Fork Double Bayou *E. coli* 51
Figure 38. East Fork Double Bayou *E. Coli* 51
Figure 39. Chlorophyll-a in Double Bayou Watershed 52

Figure 40. Spatial Analysis of Double Bayou Chlorophyll-a Exceedances 53
Figure 41. Chlorophyll-a in West Fork Double Bayou..... 54
Figure 42. Chlorophyll-a in East Fork Double Bayou..... 55
Figure 43. Estuary Stations Double Bayou Watershed Chlorophyll-a 55
Figure 44. Chlorophyll-a in Double Bayou Watershed – Past Studies Non-Estuarine Station Results..... 56
Figure 45. Chlorophyll-a in Double Bayou Watershed – Past Studies Estuarine Station Results 57
Figure 46. Nitrite in Double Bayou Watershed during sampling periods 58
Figure 47. Orthophosphate in Double Bayou Watershed during the sampling periods 59
Figure 48. Phosphorus in Double Bayou Watershed during the sampling periods 59
Figure 49. Ammonia in Double Bayou Watershed during the sampling periods..... 60
Figure 50. Spatial representation of ammonia in Double Bayou Watershed during the sampling periods..... 61
Figure 51. Nitrite in Double Bayou Watershed 62
Figure 52. Orthophosphate in Double Bayou Watershed 63
Figure 53. Phosphorus in Double Bayou Watershed..... 63
Figure 54. Ammonia in Double Bayou Watershed..... 64
Figure 55. Ammonia in Double Bayou Watershed – Past Studies Non-estuarine Station Results 65
Figure 56. Ammonia in Double Bayou Watershed – Past Studies Estuarine Station Results..... 66
Figure 57. Temporal pH patterns during the sampling period..... 67
Figure 58. Total Dissolved Solids for Double Bayou Watershed during sampling periods..... 68
Figure 59. Chloride in Double Bayou Watershed during the sampling periods..... 68
Figure 60. Sulfate in Double Bayou Watershed during sampling periods 69
Figure 61. Total Dissolved Solids for Double Bayou Watershed..... 69
Figure 62. Chloride in Double Bayou Watershed..... 70
Figure 63. Sulfate in Double Bayou Watershed 70
Figure 64. Linear Regression Analysis for Lab Sampling Parameters from Fall and Spring sampling..... 72

List of Tables

Table 1. Permit violations for wastewater constituents from the Oak Island wastewater treatment plant (October 2006 – June 2011). Bold values exceed the effluent limit required by the permit. 25
Table 2. Permit violations for wastewater constituents from the Anahuac wastewater treatment plant (October 2006 – June 2011). Bold values denote an exceedance of the effluent limit required by the permit. 26
Table 3. Permit violations for wastewater constituents from the Gulf West Facility (Landfill) Wastewater Facility (October 2006 – June 2011). Bold values denote an exceedance of the effluent limit required by the permit. 27
Table 4. TCEQ screening levels for criteria-classified sampling parameters and 85th percentile results 29
Table 5. Sampling Period Exceedances for Double Bayou 71

Watershed Characterization

Beginning in August 2009, GTRI started a watershed characterization process for the Double Bayou Watershed situated in the easter portion of the Lower Galveston Bay watershed (the Trinity-San Jacinto Estuary) on the Upper Texas Gulf Coast. GTRI, along with partners USGS Water Resources and Shead Conservation Solutions, performed a variety of tasks to accomplish the watershed characterization including: establishing baseline data set, analyzing the baseline data set to identifying gaps, developing and implementing a data monitoring plan, sampling and collecting data during fall of 2010 and spring of 2011, analyzing the data, conducting an analysis of models best situated for the watershed, and conducting watershed outreach including personal interviews with stakeholders, hosting an Open House and developing a public participation plan. Detailed discussions for each of these steps were developed as deliverables for the process; highlights will be discussed here, as well as overall data analysis, conclusions and recommendations.

Baseline Data Set

The rural nature of the Double Bayou watershed and relatively recent 303(d) listing (since 2004) of the West Fork of Double Bayou have set the stage for a somewhat limited collection of data when compared to more populous watersheds on the eastern shore of Galveston Bay. Land use is mainly pasture for cattle, with some agriculture, mostly in the form of rice farming. Oil and gas wells are scattered through the area. The area has an extensive network of irrigation canals as well as some channelized waterways that greatly alter the natural drainage pattern. Due to the small human population present in the watershed, it has only been featured in a handful of studies, and as a result has a very small initial baseline data set. Quantitative historic water flow data are unavailable. Details for each of the study sets are discussed in the Double Bayou Baseline Data Set report submitted previously under this contract; in summary, TCEQ's SWQM (Surface Water Quality Monitoring) data set has the biggest source of water quality data available for the area, but it is still limited in scope. Figures depicting the population and land use developed for the Double Bayou Baseline Data Set report are displayed in Appendix A. Additional Parameter Analysis.

Gap Analysis

The Gap Analysis (project deliverable submitted to the TCEQ Project Representative) found that spatial representation of sampling data in the watershed was heavily biased towards the estuarine and tidal portions of the area. The most frequently sampled constituents from the baseline data set were dissolved oxygen, water temperature, and pH. Bacteria were sampled on and off over the years but the temporal coverage had some gaps. The northern part of the East Fork of Double Bayou was not represented in the baseline data set. The Data Monitoring Plan was developed to focus on better spatial and temporal coverage (in terms of more frequent sampling) than was reflected in the historical data set.

Data Collection

Data collection by the USGS occurred at four sampling stations in the Double Bayou watershed (see Figure 1), West Fork Upper (WFU 554), West Fork Lower (WFL 558), East Fork Upper (EFU 546) and East Fork Lower (EFL 548). The sampling schedule included two to three visits by the USGS at each station during the sampling period for 24-hour in situ monitoring results. For lab parameter constituents, each station was sampled a total of five times during the sampling period, along with additional samples on some days for field blanks and replicates.

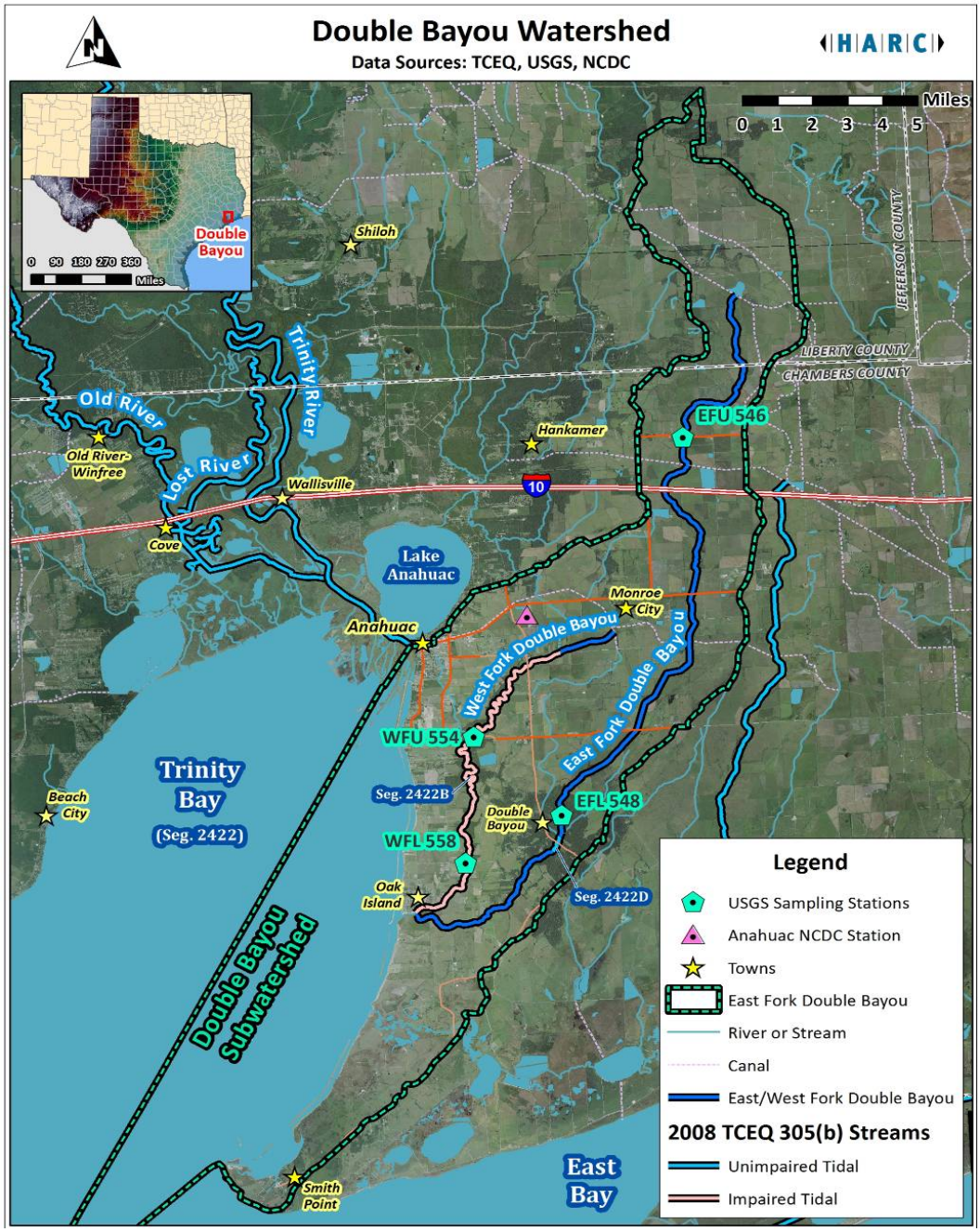


Figure 1. Double Bayou Watershed and Sampling Stations

The 24-hour in situ monitoring events included results for water temperature (degrees Celsius), specific conductivity (µS/cm), pH (standard units), turbidity (NTU) and dissolved oxygen concentration (mg/L). Most sampling events were extended to include a 48-hour sample period. Sampling dates and time events are listed below.

- WFU 554 and EFU 546
    - 8/25/10 11:45 – 8/26/10 13:30
    - 9/27/10 12:00 – 9/29/10 11:45
    - 10/26/10 13:00 – 10/28/10 12:45
    - 11/16/10 13:30 – 11/18/10 12:45
    - 3/8/11 12:00 – 3/10/11 11:45
    - 4/5/11 12:00 – 4/7/11 11:45
    - 5/10/11 11:45 – 5/12/11 11:15

- WFL 558 and EFL 548
    - 9/14/10 12:30 – 9/16/10 11:00
    - 10/12/10 13:30 – 10/14/10 13:15
    - 11/2/10 13:00 – 12/4/10 5:45
    - 3/22/11 13:00 – 3/24/11 12:45
    - 4/26/11 13:30 – 4/28/11 13:15

Lab parameter samples were collected on days on which 24-hour monitors were deployed or picked up, alternating between the upper and lower stations (see list of lab parameter sample dates and times below). Lab analytical results included a series of median water quality values recorded during lab samples collection such as discharge measured in conjunction with sample (cubic feet per second), water temperature (degrees Celsius), specific conductance (µS/cm), pH (standard units), dissolved oxygen concentration (mg/L) and turbidity (FNU). The lab parameters include results for (listed as Storet, Parameter):

- 70300 Residue on evaporation, dried at 180 degrees Celsius, water, filtered, (milligrams per liter)
- 00940 Chloride, Water, filtered (milligrams per liter)
- 00945 Sulfate, water, filtered (milligrams per liter)
- 00610 Ammonia, water, filtered (milligrams per liter as nitrogen)
- 00631 Nitrite plus nitrate, water, filtered (milligrams per liter as nitrogen)
- 00615 Nitrite, water, filtered (milligrams per liter as nitrogen)
- 00671 Orthophosphate, water, filtered (milligrams per liter)
- 00665 Phosphorus, water, filtered (milligrams per liter)
- 00600 Nitrogen, water, filtered (milligrams per liter)
- 39632 Atrazine, water, filtered, recoverable, Eliza method (micrograms per liter)
- 70953 Chlorophyll-a, phytoplankton, chromatographic-flourometric method (micrograms per liter)
- 32213 Pheophytin-a, phytoplankton (micrograms per liter)
- 00310 Biochemical oxygen demand, water, unfiltered, 5 days at 20 degrees Celsius (milligrams per liter)

- 00307 Carbonaceous biochemical oxygen demand, water, unfiltered, 5 days at 20 degrees Celsius (milligrams per liter)
- 31699 Escherichia coli, Colilert Quantitray method, water (most probable number per 100 milliliters)
- 31616 Fecal coliform, (colonies-forming unit per 100 milliliters)
- 31610 Total coliform, Colilert Quantitray method, water (most probable number per 100 milliliter)
- 31701 Enterococci, water (most probable number per 100 milliliters)

Data field blanks and replicates were included as part of the sampling procedures for QA/QC. Summary graphs for all constituents for the 24-hour in situ sampling results and lab parameter sampling results are shown in the Double Initial Data Analysis and Double Secondary Data Analysis reports. Certain constituents are discussed at length in the Water Quality section of this report, including the sampling data results from the current study as well as baseline data results. Additional parameter results not included in the discussion can be found in Appendix A. Additional Parameter Analysis.

Sampling at all four stations also included cross-channel depth measurements. Using the measurements from the stations taken in March 2011 and comparing to sounding data, a simple Channel Depth Profile map was created (Figure 2).

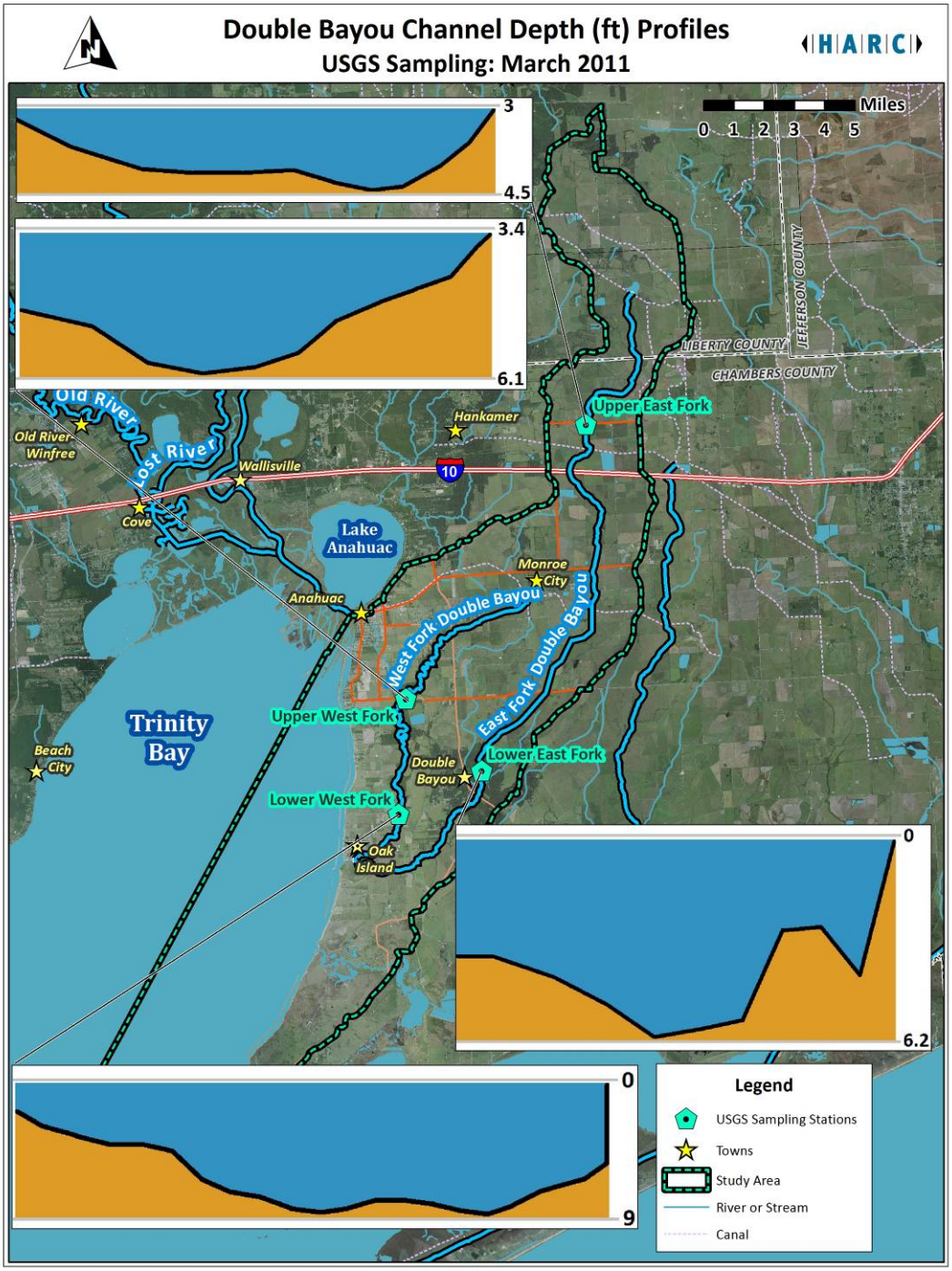


Figure 2. Channel Depth Profile for Double Bayou (at USGS sampling stations site)

Analysis of Models

The Double Bayou Analysis of Models report discussed a variety of models used regionally in watersheds that included one or several characteristics similar to Double Bayou. The analysis recommended that (a) more than one model should be employed, (b) SELECT will be

recommended for loading, particularly if bacteria (shown to be a problem pollutant) are of concern to the stakeholders, (c) SWAT, for other types of pollutants, or HSPF, for specific water flow, will be recommended for watershed modeling and (d) the final decision regarding model(s) chosen should depend on the stakeholders and their concerns. While the choice of a model is important, one should remember that models are tools and the best model is one that is scientifically rigorous, appropriate to the watershed, and responsive to stakeholder concerns.

Watershed Outreach

Shead Conservation Solutions developed a Phase I Public Participation Plan that identified six major tasks for outreach during the watershed characterization: (a) identify stakeholders , (b) coordinate development of presentation materials, (c) conduct stakeholder interviews, (d) host an Open House, (e) develop a final report and (f) develop a Phase II Public Participation Plan. The initial list of stakeholders included candidates from Chambers County, City of Anahuac, Liberty County, Local Agencies (TBCD & CLCND), Federal & State Agencies, Nongovernmental Organizations, Landowners, Oak Island Community, and Smith Point Community. Shead and GTRI worked together to develop a fact sheet for distribution to the stakeholders and map exhibits to be used during interviews and the Open House. GTRI presented a poster on the Double Bayou project at the Restore America's Estuaries National Conference held on November 15-17, 2010 in Galveston, Texas. The poster highlighted the Double Bayou watershed and presented some of the initial DO results from the early sampling events.

Public Participation Plan, Phase I[1]

The Phase I plan described six tasks to be performed during the project entitled, Water Quality: Watershed Characterization Report for the East and West Forks of Double Bayou ("Characterization Study"):

1. Identify Stakeholders
2. Coordinate Development of Presentation Materials
3. Conduct Stakeholder Interviews
4. Host an Open House
5. Prepare a Final Report
6. Develop a Phase II Public Participation Plan

The accomplishments of the first four tasks are described in the following sections. This document constitutes the Final Report. The Phase II plan is a separate document.

Stakeholder Identification

The Public Participation Plan, Phase I was designed to take information to: (a) those who might have authority/responsibility for planning and/or implementation of watershed improvements; (b) those who might have expertise to assist with planning and/or implementation; (c) those who

[1] The "Public Participation Plan Phase I" Section of this Final Report Deliverable was written and contributed by Shead Conservation solutions

might be directly affected by planning and/or implementation activities; and (d) those who might be opinion leaders in the community.

A preliminary list of stakeholder categories was developed and submitted in December 2009. (see Appendix B: Stakeholder and Outreach) Individuals were assigned to the categories and prioritized over the course of 2010, in consultation with local sources, and then supplemented and prioritized again during the course of the interviews in 2011. The list of stakeholders for the first and second round of interviews is also included in Appendix B: Stakeholder and Outreach.

Development of Presentation Materials

Presentation / outreach materials were coordinated with GTRI staff, which provided essential input and editing to written documents, and design and production in the case of the maps.

(a) The first item was a double-sided introductory fact sheet about the characterization project, plus a watershed planning glossary and list of EPA's 9 Elements of Watershed Protection Plans (WPPs) – to serve as a reference for stakeholders after the initial interviews. Copies of the documents were provided in labeled file folders for each interviewee.

(b) The presentation of water quality results was developed by GTRI staff to show, in a simple, graphic fashion on maps, whether or not exceedances of standards or screening levels had been found in each of the reaches associated with the four sampling sites. One map was developed for each of three parameters: indicator bacteria, dissolved oxygen, or chlorophyll-a. A copy of each map was also included in the file folders provided for interviewees.

(c) The third material was a PowerPoint presentation summarizing the topics of: watersheds, water quality standards, watershed planning, elements of the current study, results from the first round of data collection and analysis in Fall 2010, and next steps. This PowerPoint was shown at each interview.

(d) New maps were developed for the second round of interviews, with an initial set showing just the results from the second round of sampling. However, these were later modified to consolidate the results from both rounds of sampling – most interviewees having less interest in the intricacies of the sampling regimen than the "bottom line" results of whether the water bodies showed impairment. Copies of these maps were provided to interviewees.

(e) The PowerPoint was similarly updated for the second interview round, with results from both rounds of sampling. Examples of riparian area health and impairment (as opposed to water quality impairment) within the Double Bayou watershed were shown. The purpose of these slides was to begin providing watershed education for a topic that had been identified as being little understood during the first interview round.

(f) A tri-fold brochure was developed for distribution at outreach tables at GatorFest and the Rice Festival. It was tweaked slightly for the Open House (i.e., the listing of the Open House event and date were removed).

(g) A flyer promoting the Open House was developed and posted in local facilities.

(h) A press release promoting the Open House was developed and distributed to local media (see list in Appendix B: Stakeholder and Outreach.

(i) An ad for the Open House was developed and purchased for placement in *The Progress* the week of the Open House.

Examples of the presentation materials are included in Appendix B: Stakeholder and Outreach

Summary of Results

As with so many other community and/or environmental activities and initiatives, developing local stakeholder interest is a key element of success. Taking the message to potential stakeholders – when and where they might normally be/meet – is often more effective, especially in early stages, than a broad call for a public meeting. With that in mind, stakeholders were approached in most cases where they work or at meetings of public bodies on which they serve.

Round One Interviews. The purposes of the first round of interviews were to: (a) inform key stakeholders and opinion leaders of the Characterization Study; (b) provide them with key monitoring results from the first cycle of monitoring in Fall 2010; and (c) collect their first-hand knowledge of the watershed and their reactions to the study and first results. A total of 11 interviews of 22 people were conducted in April 2011.

Stakeholders shared their knowledge of both existing land uses and changes over time. Key points of interest:

- A concern about how agricultural inputs would be controlled was shared by many of the stakeholders.
- In addition to the common agricultural land uses of rice farming and cattle grazing, there are 2-3 crawfish farms in the watershed.
- Surface water in the East Fork turns black after a rainfall.
- The City of Anahuac's wastewater treatment plant was undergoing repairs to the air distribution system.
- Lack of drainage is an issue.
- Trinity Bay Conservation District (TBCD) staff felt that the post-Ike clearing was very beneficial, and their board is very supportive of spraying to control vegetation along/in the bayous.
- The Jenkins farm has water rights (27,500 ac-ft) from Trinity River Authority , with water delivery by Lower Neches Valley Authority (LNVA), and also has an offsite impoundment of 175 acres.
- The trailer park upstream of FM 1663 discharges their effluent by sprinklers.
- More divided interests and smaller tracts may be increasing the animal loading in some areas.
- AgriLife Extension reported that some kind of bacteria had been applied to ponds to use up nutrients and thus reduce algae growth.
- Natural Resource Conservation Service reported that Houactinite had been applied on 1,000-1,500 acres, and had some concern about heavy metals from that use.
- The upper watershed in Liberty County has not been riced in 10-15 years.
- The East Fork has experienced hydrologic changes in the past, which may be affected its DO problems.
- Water from Double Bayou is carried by Trinity Bay currents toward Smith Point and the oyster reefs there.

Round Two Interviews. The purposes of the second round of interviews were to: (a) inform key stakeholders and opinion leaders of monitoring results from the full Characterization Study – Fall 2010 and Spring 2011; (b) let them know about the potential upcoming project to develop a Watershed Protection Plan; and (c) solicit any reactions to the results and/or plan. A total of 13 interviews were conducted with 28 people in August-October 2011.

Stakeholders shared their knowledge of specific points of interest, including:

- Many were especially interested about the voluntary nature of a Watershed Protection Plan.
- Several like the idea of addressing the situation before it becomes worse and before a "hammer" might be applied.
- Several believe the West Fork's bacteria problems are related to the City of Anahuac's wastewater treatment plant (or sewer plant as it's often called).
- The only reported fish kill this summer on public waters was in June.
- Problems in the East Fork may be related to the channelization done for flood control – changing the natural hydrology.
- A second dam on the East Fork below Sykes Road stays open now, because the water rights are not in use.
- There are a lot of water supply and wastewater issues between the City of Anahuac and the Trinity Bay Conservation District.
- A perception exists that the water quality is okay for fish because people see lots of fish in the waters of the bayous.

Other Outreach Events

At the recommendation of AgriLife staff, a table space was obtained at GatorFest (September 17-18, 2011) and the Rice Festival (September 30-October 1, 2011). The table was shared with the Chambers Recovery Team, so that one person did not have to be there all the time for either group. The student intern for this project also helped staff the table at the Rice Festival.

Sharing the table also provided an opportunity to evaluate the origin of visitors to the Education Tents at the two festivals. ChaRT's focus was on nature tourism, and they were interested in visitors from outside the area, in contrast to the focus for this project. Thus, visitors were first asked whether they were from the local area. If so, the Double Bayou project was presented to them and they were invited to participate (by signing up for more information or attending the Open House). If not, the ChaRT volunteer discussed ChaRT's nature tourism project with the visitor.

It turned out that most of the visitors to the Education Tent at GatorFest were not local, but that more were local at the Education Tent for the Rice Festival. Locals did express interest, but were not always willing to share contact information. About ten names and addresses were collected during the two events. A large map of the watershed study area was created for the events, along with smaller maps showing the results for pathogens, dissolved oxygen, and chlorophyll-a. A tri-fold brochure was also prepared and distributed to interested folks. (see Appendix B: Stakeholder and Outreach for these items.)

Open House
The Open House was held on Thursday, October 13, 2011 from 4:00 p.m. to 7:00 p.m., at the Anahuac Branch of the Chambers County Public Library. A press release about the event was sent to the following media: *The Progress*, Anahuac; *Baytown Sun*, Baytown; *Hometown Press*, Winnie; KSHN Radio, Liberty; *Beaumont Enterprise*, Beaumont; *Liberty Gazette*, Liberty; and *Liberty Vindicator*, Liberty. The Open House was covered on the front page of *The Progress* on October 5, 2011 and an ad was purchased and placed in the October 12 edition of *The Progress*. (see Appendix B: Stakeholder and Outreach)

E- mails were also sent to a local Chambers County distribution list maintained by Shead Conservation Solutions, and a flyer was developed and posted at Anahuac City Hall, Bi-Rite Super Market, Chambers County Courthouse, Chambers County Public Library , Hill's Grocery, Nopalito's , Oak Island Market, Sherman Home Center, U.S. Post Office , and Wilcox Drugs (as well as included in the e-mail). All flyer locations were in Anahuac, with the exception of the Oak Island Market.

Large (21" x 29") maps were developed and posted at the Open House, in addition to the watershed study area boundary: results of the data collection and analysis for dissolved oxygen, pathogens, and chlorophyll-a. The updated brochure was also made available. The Open House was staffed by Shead Conservation Solutions and GTRI staffers. Although it had been expected that stakeholders would generally come at different times throughout the posted time period, most attendees showed by 4:00 or shortly after. Consequently, instead of mostly individual conversations, a brief overview of the project and results were presented by Linda Shead and Stephanie Glenn, followed by some individual conversations. A total of 19 people signed in during the event, ranging from elected officials to ranchers to homeowners and federal and state agency representatives (see Appendix B: Stakeholder and Outreach).

Discussion
A broad distribution of stakeholders and opinion leaders was identified and interviewed for this phase of the Double Bayou project. Shead Conservation Solutions' established network within Chambers County helped facilitate this effort. That network was augmented by recommendations from the group of initial interviewees.
The following items represent common themes of perceptions and concerns identified during the interviews and Open House:

- A perception exists among participants that the water quality in the forks of Double Bayou is okay for fish, because people see lots of fish in the waters of the bayous.
- Most stakeholders were especially glad to learn that a Watershed Protection Plan is voluntary, but some remain concerned about whether this is really the case.
- Several don't think contact recreation needs to be considered because of the alligator risk and other factors.
- Many liked the idea of addressing the situation before it becomes worse and before a "hammer" might be applied.
- Several believe the West Fork's bacteria problems are related to the City of Anahuac's wastewater treatment plant (or sewer plant, as it's often called).

- Agricultural producers and their representatives are sensitive to being blamed for water quality problems.

Continued contact and information sharing and demonstrating that a WPP is about all sources and all stakeholders and all voluntary – all of these will be essential for successful planning.

Lessons Learned

~ Scheduling of interviews or events in a rural area must take into consideration the calendar of farming and ranching activities. This was not a surprise due to previous projects of Shead Conservation Solutions, but still presented a challenge with the contract timeline and availability of data results, and will continue to need to be considered as early as possible to allow for scheduling accommodations.

~ As is currently planned, it will be very important to begin the next phase of the Double Bayou watershed project with an assessment of participant's level of understanding of the issues and the processes available to assess them. Although it had been thought that assessment was too early for this phase, it still might have been helpful to develop a questionnaire that would document: (a) the perceptions that participants had of the water quality in the bayous prior to the interviews, and (b) the level of understanding and/or support for continuing with development of a WPP after the interviews. Anecdotally, the answer to (a) would probably be fairly mixed – some thinking it's quite fine given the fish that they see, and others having noted that it turns black at times and there are fish kills. Anecdotally for (b), most everyone ended up supportive of developing a WPP as a good alternative, but some still have concerns about what it will "require" them to do – that's both on the agricultural side and the public utility side.

~ Using existing contacts to reach new ones was reasonably successful and will need to be continued to broaden the circle of informed / involved agricultural producers.

~ A presence at local festivals can be a way to increase awareness of the initiative, but consideration needs to be given to the festival audience. The experience gained at GatorFest and the Rice Festival this year indicates that GatorFest is not a useful venue for the project, but that the Rice Festival has more potential. Also, having more visual draw and some sort of giveaway would make it more effective at attracting visitor involvement with the table

~ Additional effort will be needed to involve the oyster industry at Smith Point, who would be affected by bacteria impairments from Double Bayou, but do not yet see this issue or the benefits of involvement. They have been understandably overwhelmed in recovering from the damages from Hurricane Ike, and now in dealing with the severe drought and its impacts on the oyster fishery.

Next Steps

The project team decided to go ahead last fall with a 319 NPS application to develop a WPP for Double Bayou, even before the water quality results could be known. The reason for the decision was to avoid incurring a long gap in stakeholder involvement between funded projects, should the new results indicate the benefit of watershed protection activities. We have been fortunate to be selected for funding for that WPP project, with a contract expected in early

November. The next steps will then be implementation of the Public Participation Plan, Phase II.[2]

Next Steps - Sampling Note

Interviews with residents of the Double Bayou area indicated the possibility that a dam or weir was located on East Fork Double Bayou on the Jenkins property, located north of Interstate-10 and south of FM 1663. High-resolution aerial imagery was used to verify these accounts; the location and aerial view of the dam/weir is displayed in Figure 3. Further investigation as to the location and to ascertain if the object is a dam or weir and possible changes to flow patterns will be part of the analysis for the next data monitoring plan; if flow patterns are greatly altered, current sampling station locations may need to be moved to better represent the bayou.

Figure 3. High-Resolution aerial imagery of dam/weir possible location

[2] This section ends the "Public Participation Plan Phase I" Section of this Final Report Deliverable that was written and contributed by Shead Conservation solutions

Next Steps

As mentioned in the Stakeholder and Summary discussion sections, next steps will include taking what we learned from the Double Bayou Watershed Characterization project and applying it towards a Double Bayou Watershed Protection Plan (WPP). Deliverables from the Double Bayou Watershed Characterization study include an established baseline data set, data monitoring plans to use as straw men for developing the next data monitoring plan, an initial collection of data samples from the Fall of 2010 and Spring of 2011, data analysis for the data samples conducted during this study as well as the baseline data set, a recommendation of models best situated for the watershed, and the beginnings of watershed outreach including personal interviews with stakeholders, hosting a successful Open House and developing a public participation plan. The data sampling and initial analysis suggest that ammonia, dissolved oxygen, bacteria and chlorophyll-a are emerging as possible constituents of concern. Future data monitoring plans should prioritize these constituents. Lack of flow data negated certain methods of analysis, such as developing loading curves. Future data monitoring plans should focus on collecting quantitative flow data. Continued contact for stakeholder resources will be essential for moving forward with a Double Bayou WPP. The elements of the Double Bayou Watershed Characterization Study will prove invaluable as the first steps to completing a successful WPP. Initial funding seeking efforts have proven successful; currently contract negotiations are underway with the Texas State and Soil Water Conservation Board to continue the WPP process in Double Bayou.

Summary of Data

Temperature and Precipitation

The Double Bayou watershed lies mainly in the Northern Humid Gulf Coast Prairies ecoreiong, with some small parts in the Texas-Louisiana Coastal Marshes (see Figure 4). Annual precipitation for the Northern Humid Gulf Coast Prairies ecoregion varies from 37 inches in the southwest portion to 58 inches in the northeast, with a summer maximum. Annual precipitation for the Texas-Louisiana Coastal Marshes ecoregion varies from 48 to 54 inches in Texas and up to 60 inches in Louisiana. Both ecoregions are noted for their more wet and humid climates.

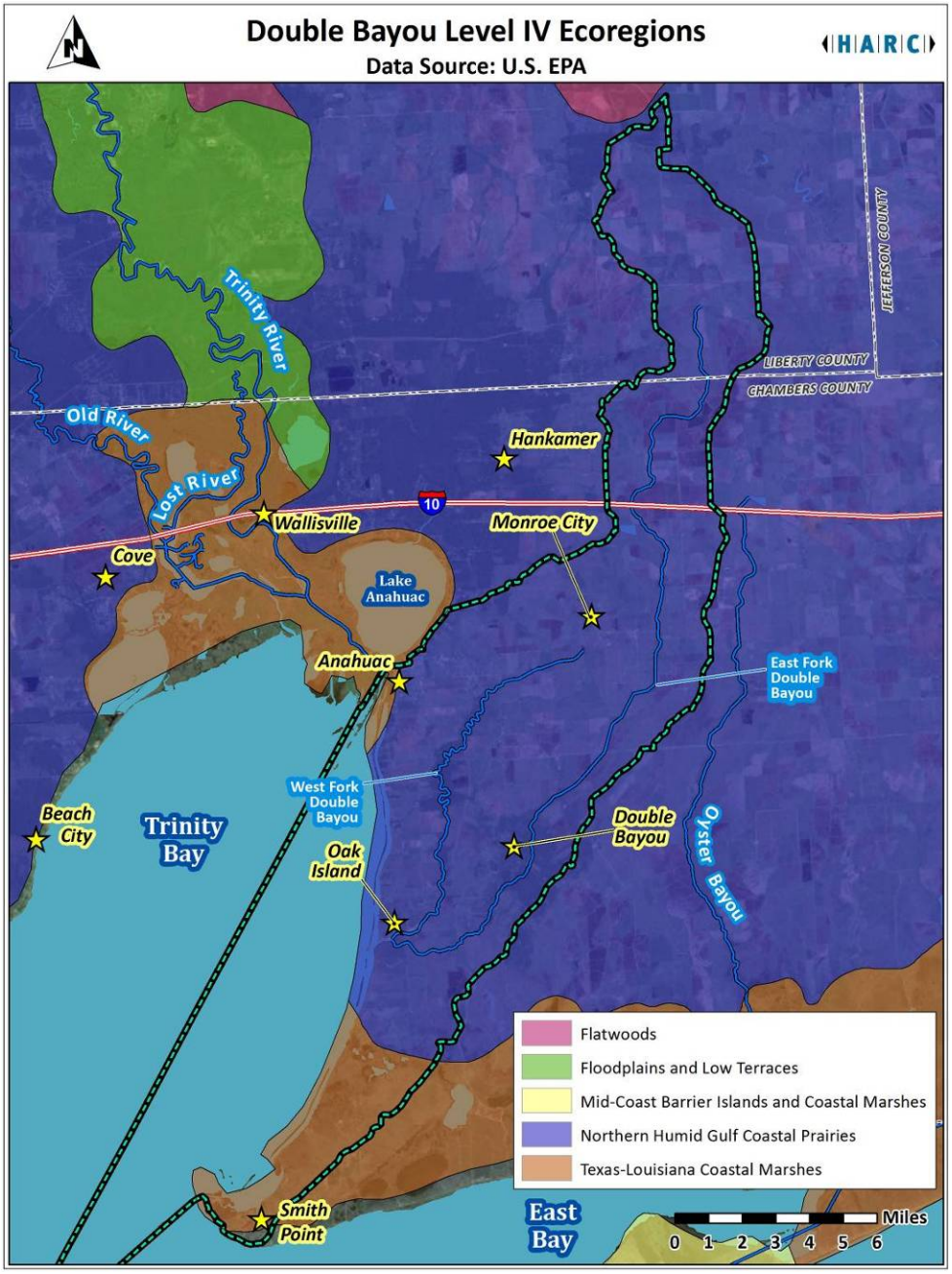


Figure 4. Double Bayou Level IV Ecoregions

Temperature and precipitation data sets during the sampling period were obtained from the National Climatic Data Center's (NCDC) Anahuac station, Cooperative ID 410235, elevation 7.3 meters above sea level, located in Chambers County (Figure 5). The monthly average maximum and minimum temperature analysis showed that the sampling periods during the 2010 and 2011 years were within the average range when compared to all samples averaged daily for 1909-2010 (Figure 6).

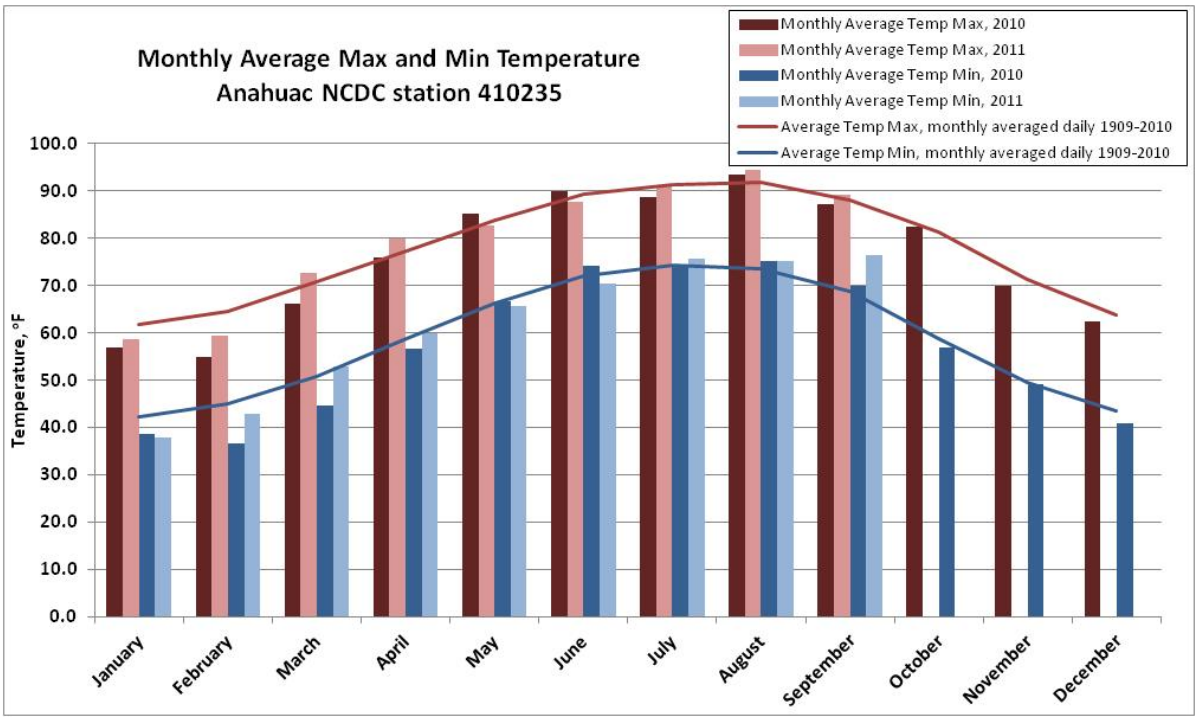


Figure 5. Monthly average Max and Min Temperature during sampling periods at Anahuac station 410235, data provided by NCDC

The precipitation sum for the sampling periods of August 2010 – November 2010 and March 2011-May 2011 were below average except for September and November 2010 (see Figure 6). Note that Texas is currently suffering from significant drought and precipitation state wide is far less than normal.

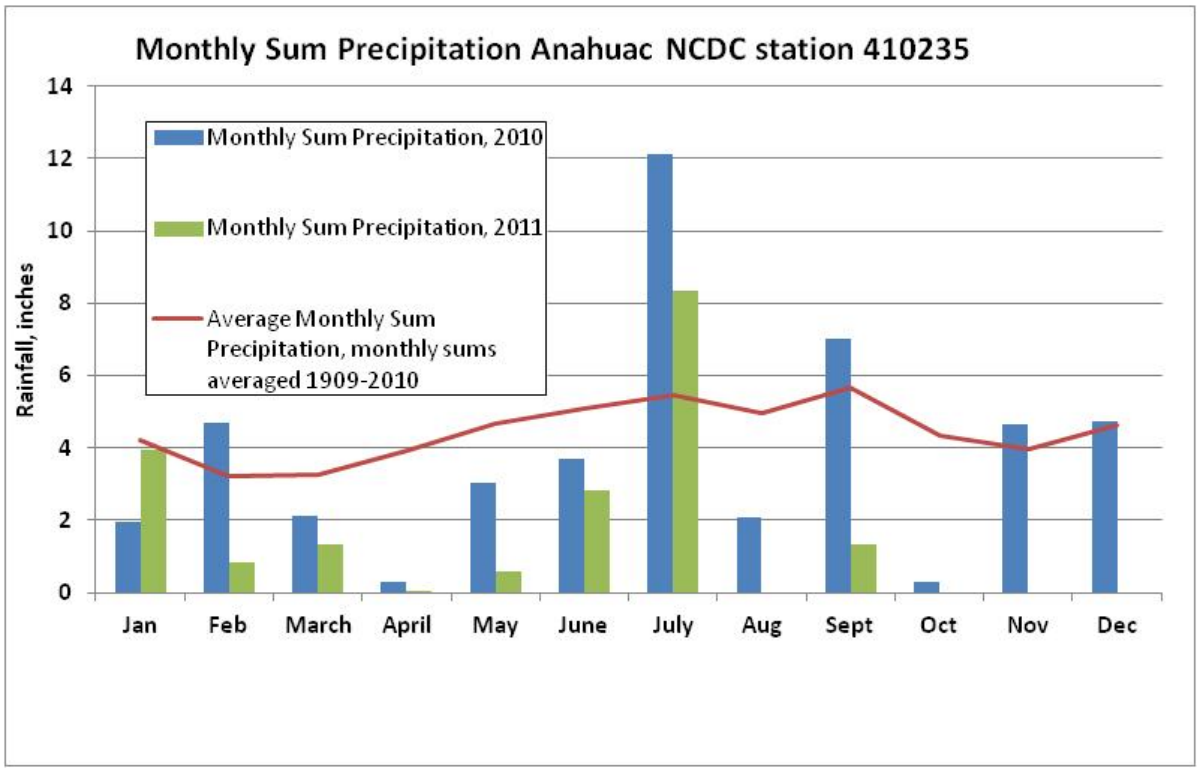


Figure 6. Monthly versus average precipitation for Anahuac NCDC station 410235

Database and Spatial Analysis for Database Stations

Sampling Stations

GTRI developed a database for Double Bayou including all sampling data compiled to date for the project and the baseline data set. Included in the database are the TCEQ Surface Water Quality Monitoring (SWQM) data (to date), The Department of State Health Services (DSHS) data, the older USGS data set from a previous study and the current USGS sampling data. The database includes all metadata from each dataset, as well as new metadata detailing which study set the data are from, the associated Quality Assurance procedures, a column noting if the station is Tidal, Non-Tidal or Estuary based and a subset for East or West Fork based.

When assembling the database of monitoring stations, it was necessary to assign a Tidal vs. Non-Tidal vs. Estuary designation for each station. Estuary designations were assigned to all stations located within Galveston Bay, as defined via aerial imagery. Tidal vs. Non-Tidal designations were assigned using the TCEQ SWQM stations, which have a tidal vs. non-tidal designation for each of their stations. The stations were overlaid on a high-resolution Light Detection and Ranging (LiDAR) derived Digital Elevation Model (DEM), as displayed in Figure 7. The elevation dataset was grouped into 32 distinct classes, and the elevation class where the SWQM stations switched from Tidal to Non-Tidal was identified. Any station located at or above this elevation class was designated as Non-Tidal.

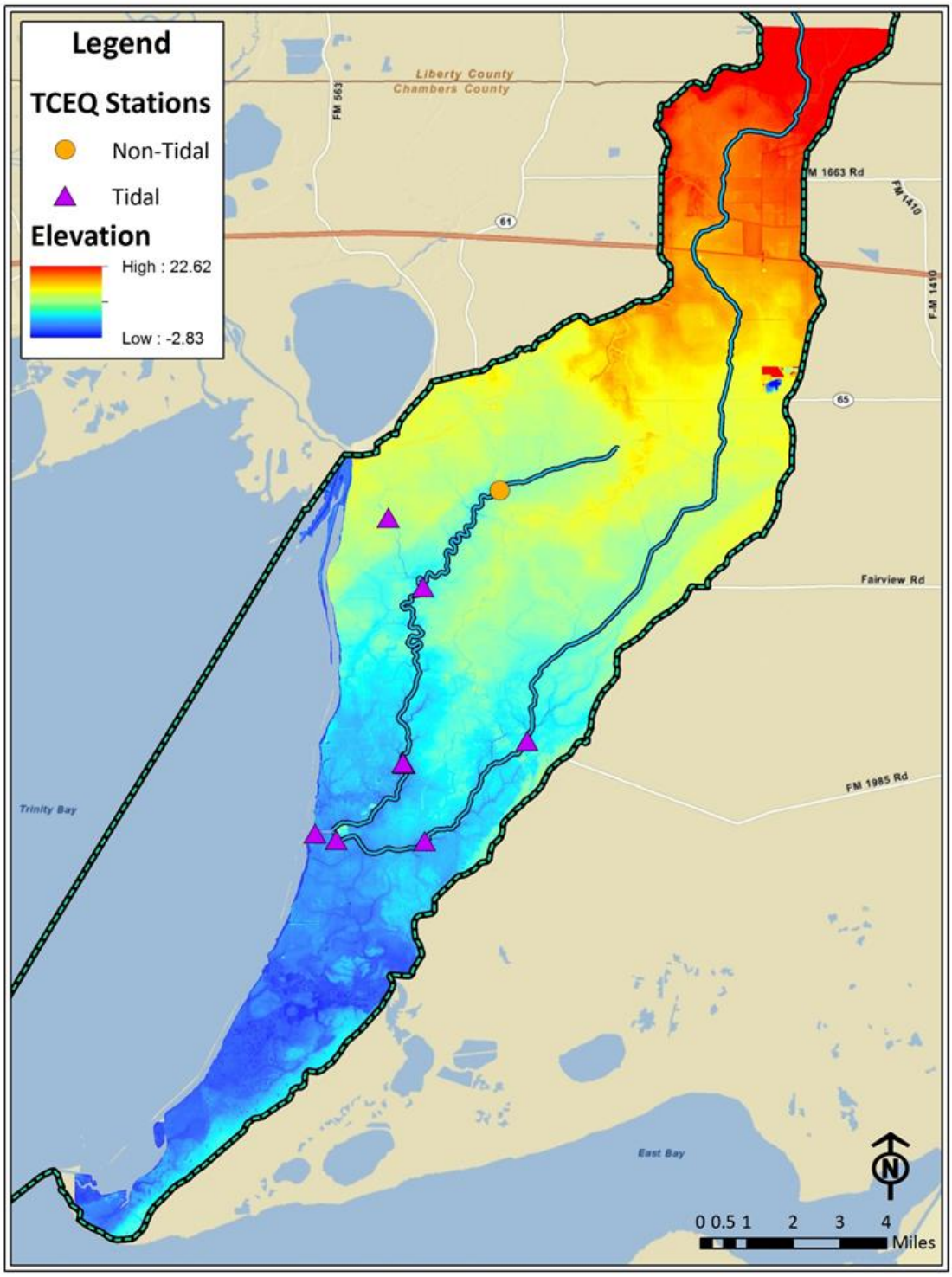


Figure 7. LiDAR and DEM for station designation

An East Fork versus West Fork designation was also needed for the stations database. The LiDAR DEM was again used to make this determination. A dividing line between the two drainages was manually delineated, and is displayed in Figure 8. Stations on each side of the

line were assigned to the appropriate fork. This same dividing line was used to assign septic systems to each fork.

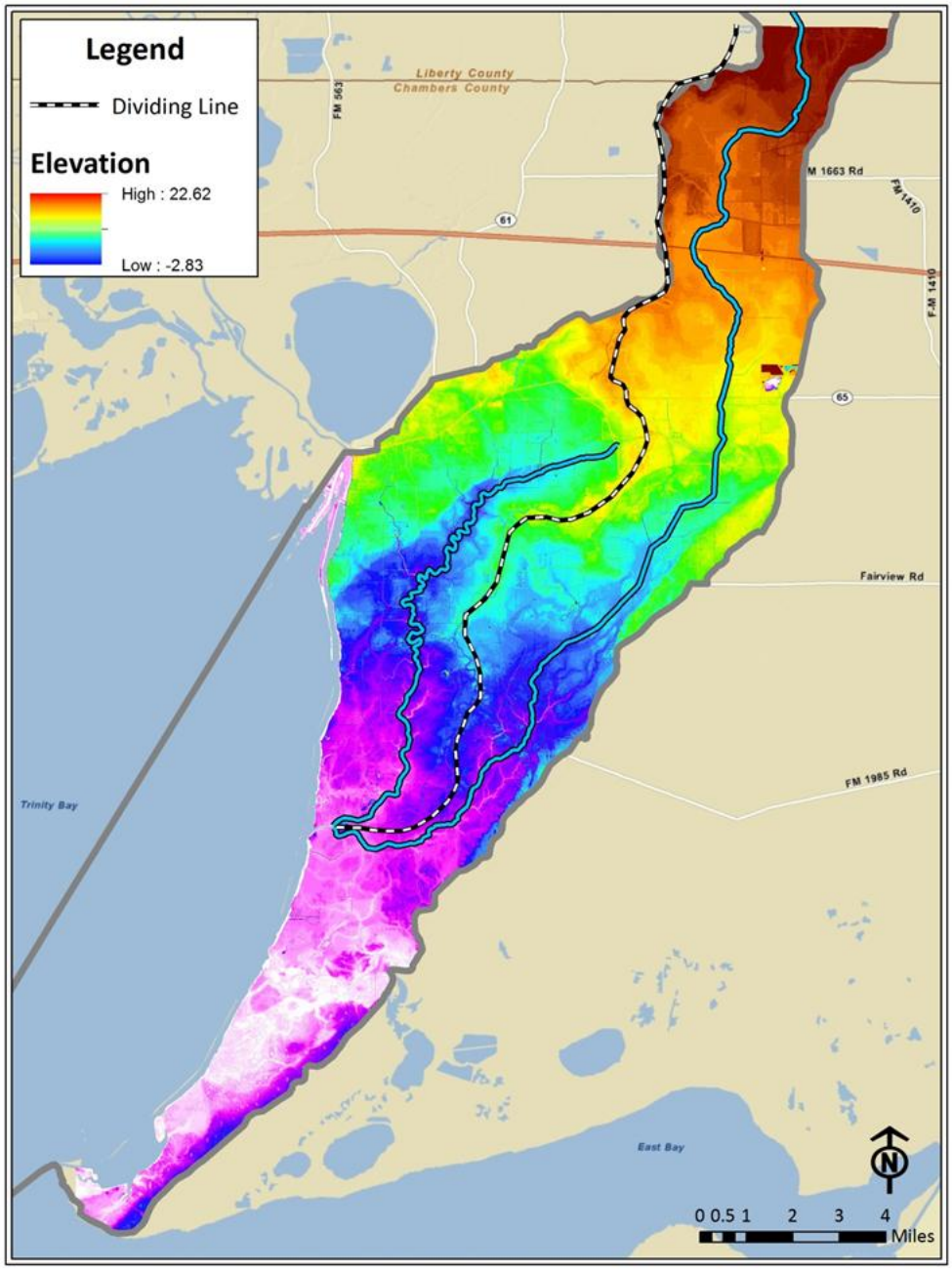


Figure 8. East Fork versus West Fork station designations

Data from all the stations included in the database will be used in this discussion for analysis. All stations included from the database are displayed in Figure 9. The following designations will be used: TCEQ Non-Tidal, TCEQ Tidal, TCEQ Estuary, USGS Non-Tidal (indicating stations and data from our current sampling regime), USGS Tidal (indicating stations and data

from our current sampling regime), USGS Older Studies (indicating data from previous studies), and DSHS (Department of State Health Services stations).

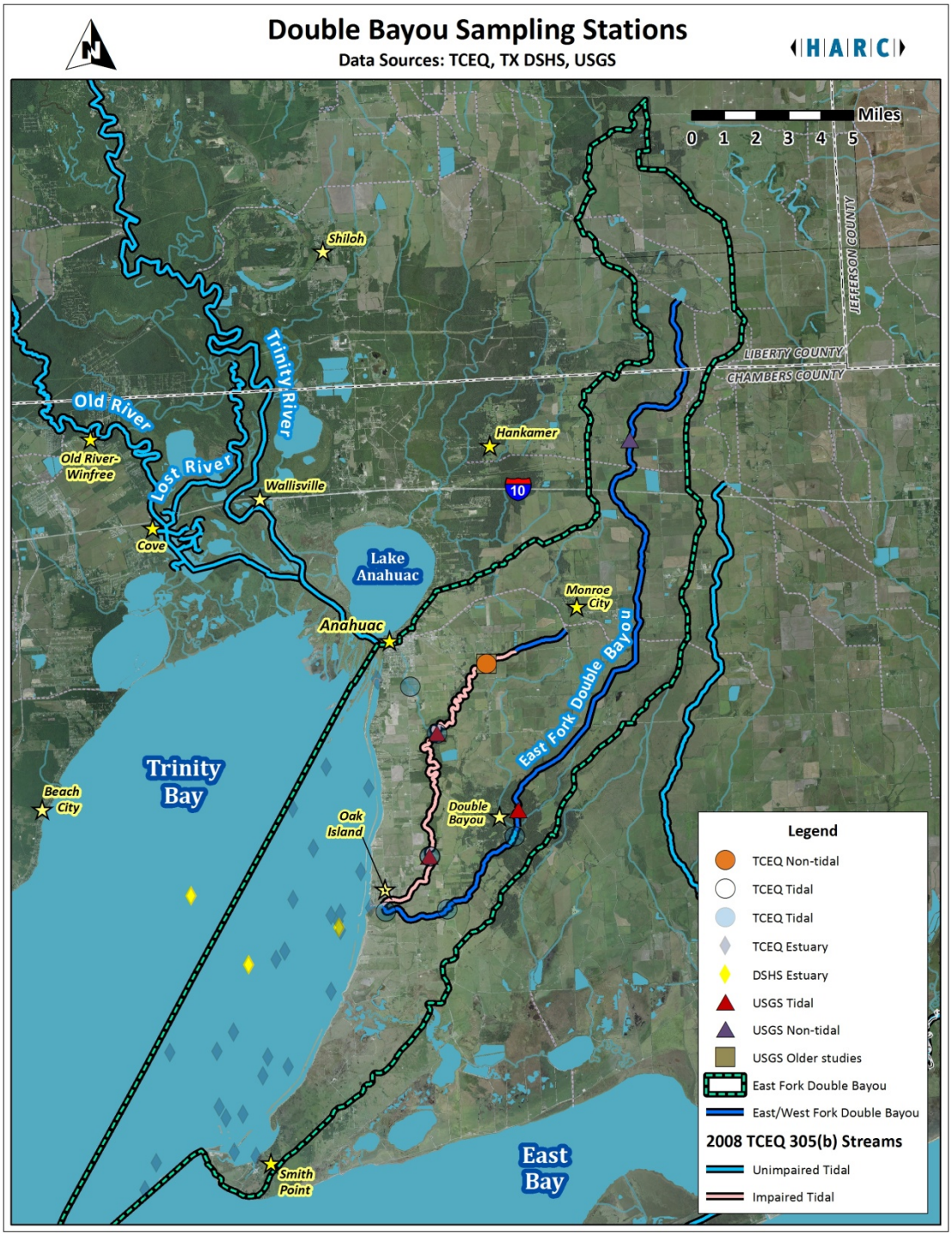


Figure 9. Stations in the Double Bayou Watershed

Wastewater Treatment Update

Septic Tanks

On-site treatment systems (OSSS, septic systems and similar decentralized systems) are recognized as a possible source of bacteria and dissolved oxygen impairments in the Double Bayou watershed. There are currently 52 permitted OSSS systems in the Double Bayou Watershed (Figure 10). Using the draining designations discussed in context with Figures 8 and 9, drainage into East or West Fork was determined for each registered OSSS. The majority of the OSSS permits lie along the West Fork drainage system.

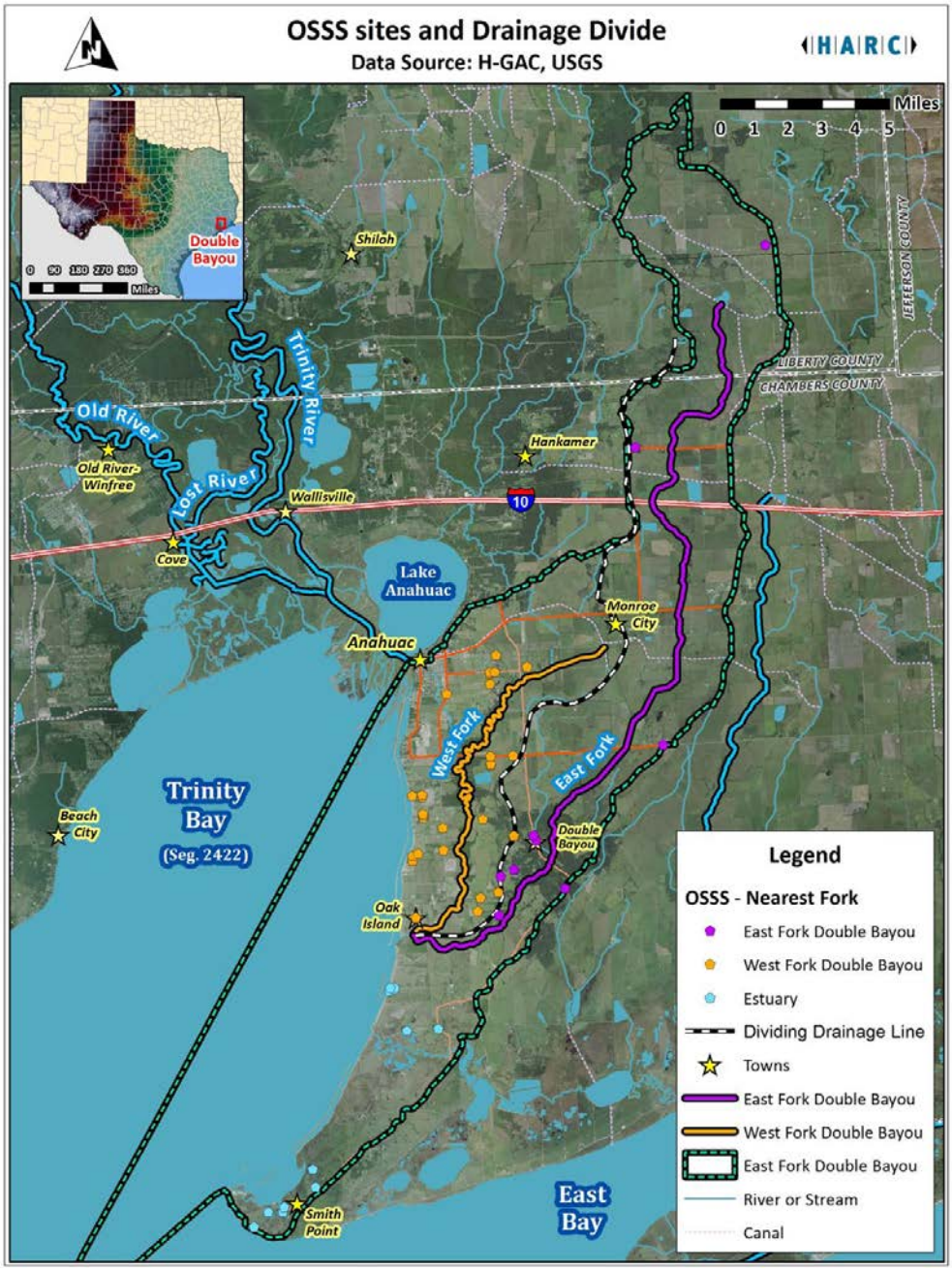


Figure 10. On-site septic treatment systems in the Double Bayou Watershed

Wastewater Treatment Plants and Facilities

Two municipal WWTP's are located in the Double Bayou watershed as well as two wastewater treatment facilities (WWTF's; e.g. municipal landfills). The two WWTP's and two WWTF's operate under National Pollutant Discharge Elimination System (NPDES) individual permits. Discussion details about the WWTP's are in the Double Bayou Gap Analysis report; this section will update the table from that report with the latest non-compliance data. Permit compliance data for the WWTP's were obtained from the USEPA Enforcement and Compliance History Online (ECHO) database.[3]

The first WWTP is located near the community of Oak Island in the lower portion of the Double Bayou watershed. The Oak Island WWTP lies near TCEQ station 14552. According to the ECHO database, in the year 2000 there were 171 households located in a three mile radius of the WWTP. The date of last inspection is reported as October 1997. While there are no notices of permit violations on record for the WWTP, there are two incidences of permit exceedance for 5-day Biological Oxygen Demand (BOD_5) and flow (see Table 1).

This WWTP had no new effluent violations. Between July 2008 and June 2011, 6 of 12 quarters were in regulatory non-compliance with a total of 16 reporting violations during that period.

Table 1. Permit violations for wastewater constituents from the Oak Island wastewater treatment plant (October 2006 – June 2011). Bold values exceed the effluent limit required by the permit.

		CONC IN EFFLUENT	**EFFLUENT LIMIT**	**CONC IN EFFLUENT**	**EFFLUENT LIMIT**
CONSTITUENT	**DATE**	30 DAY AVG (mg/L)	30 DAY AVG (mg/L)	Million Gallons per Day (MGD)	MGD
Biological Oxygen Demand, 5-Day (BOD_5)					
	6/30/09	**26.7**	20.0	-	-
Flow, in conduit or thru treatment plant (MGD)					
	11/30/07	-	-	**0.468**	0.1

The second WWTP is located just south of Anahuac. The effluent from the Anahuac WWTP flows into the Anahuac Ditch which connects to the West Fork of Double Bayou. The confluence of the Anahuac Ditch and Double Bayou is located above TCEQ sampling station 18361. According to the ECHO database, in the year 2000 there were 1,128 households located in a three mile radius of the WWTP. This facility has been inspected 4 times in the last 5 years with the most recent inspection in February 2011. This facility has received three informal notices of permit violation since 2004 (December 2004, January 2007, and December 2007). There are a number of incidences of permit exceedance for ammonia, chlorine, and BOD5 (see Table 2) with many instances of significant non-compliance for ammonia.

[3] Permit compliance data were obtained via the USEPA Enforcement and Compliance History Online (ECHO) database http://www.epa-echo.gov/echo/compliance_report_water_icp.html.

Table 2. Permit violations for wastewater constituents from the Anahuac wastewater treatment plant (October 2006 – June 2011). Bold values denote an exceedance of the effluent limit required by the permit.

		CONC IN EFFLUENT	EFFLUENT LIMIT	CONC IN EFFLUENT	EFFLUENT LIMIT
CONSTITUENT	**DATE**	MAX, Grab Sample (mg/L)	MAX, Grab Sample (mg/L)	30 DAY AVG (mg/L)	30 DAY AVG (mg/L)
Nitrogen, Ammonia Total (as N)					
	5/31/11	**32.0**		**4.8**	
	4/30/11	**16.5**		**11.3**	
	3/31/11	**46.4**		**25.8**	
	2/28/11	**11.5**		**9.3**	
	1/31/11	7.5		**4.7**	
	12/31/10	**22.8**		**9.5**	
	11/30/10	**24**		**12.8**	
	10/31/10	**21.6**		**10.8**	
	9/30/10	**14.0**		**6.7**	
	4/30/10	**16.0**		**7.3**	
	3/31/10	**12.6**		**6.4**	
	8/31/09	1.7		**3.4**	
	7/31/09	8.5		**3.5**	
	6/30/09	**14.0**	≤10.0	**9.5**	≤3.0
	5/31/09	**24.0**		**15.1**	
	3/31/09	6.5		**3.7**	
	2/28/09	7.6		**5.1**	
	11/30/08	9.8		**5.9**	
	10/31/08	9.0		**5.8**	
	3/31/08	**14.6**		**8.4**	
	1/31/08	**14.2**		**4.1**	
	12/31/07	7.6		**3.5**	
	3/31/07	6.4		**4.1**	
	2/28/07	8.5		**5.0**	
	1/31/07	**12.8**		**6.5**	
	12/31/06	**20.0**		**15.0**	
	11/30/06	**14.6**		**3.6**	
Dissolved Oxygen					
	5/31/11	**0.2**	≥4.0	-	
Chlorine, Total Residual					
	1/31/11	**4.71**		-	
	11/30/10	**0.0**		-	
	8/31/10	**4.02**		-	
	7/31/10	**4.05**		-	
	1/31/10	**4.0**	≥1.0 ≤4.0	-	-
	9/30/09	**6.0**		-	
	3/31/09	**4.0**		-	
	11/30/08	**4.1**		-	
	6/30/08	**4.6**		-	

	3/31/08	**4.9**		-	
	2/29/08	**4.7**		-	
	1/31/08	**4.0**		-	
	11/30/07	**4.4**		-	
	10/31/07	**4.2**		-	
	8/31/07	**7.7**		-	
	7/31/07	**5.2**		-	
	6/30/07	**4.4**		-	
	4/30/07	**4.7**		-	
	3/31/07	**5.2**		-	
	2/28/07	**4.2**		-	
	1/31/07	**4.0**		-	
	12/31/06	**4.4**		-	
Biological Oxygen Demand, 5-Day (BOD_5)					
	5/31/2009	**28.8**	25.0	9.7	10.0
	12/31/2006	**41.1**		**12.4**	

The Smith Point wastewater treatment facility (WWTF) is located near Smith Point in the lower Double Bayou watershed near the intersection of FM 562 and Hawkins Camp Road. According to the USEPA ECHO database, there are a no of incidences of permit exceedance. It is considered a minor facility with an average throughput of <0.1 MGD. As such, this facility has never been inspected under its NPDES permit. It has failed to comply with reporting requirements 4 times in the last 3 years.

The Allied Waste Gulf West WWTF is a municipal landfill that is located northwest of Monroe City. According to the ECHO database, in the year 2000 there were 145 households located in a three mile radius of the WWTP. This facility is considered a minor facility, thus there are no NPDES inspections on record. However, the facility's NPDES permit has been in violation 5 of the last 12 quarters, with 11 effluent exceedances for aluminum, total organic carbon, and Chemical Oxygen Demand (COD) (see Table 3) and many more instances of reporting violations. This facility has undergone 16 inspections under the Resource Conservation and Recovery Act (RCRA) and in the last 5 years, has incurred 3 informal (April & August 2009, March 2010) and 1 formal enforcement action (November 2006) with a penalty of $2,928. The RCRA permit has been in violation 12 of the last 12 quarters for permit exceedances and reporting violations.

Table 3. Permit violations for wastewater constituents from the Gulf West Facility (Landfill) Wastewater Facility (October 2006 – June 2011). Bold values denote an exceedance of the effluent limit required by the permit.

		CONC IN EFFLUENT	**EFFLUENT LIMIT**	**CONC IN EFFLUENT**	**EFFLUENT LIMIT**
CONSTITUENT	**DATE**	MAX, Grab Sample (mg/L)	MAX, Grab Sample (mg/L)	30 DAY AVG (mg/L)	30 DAY AVG (mg/L)
Aluminum, total (as Al)					
Discharge point 001	1/31/11	**8.62**	1.77		
Discharge point 001	8/31/2009	**8.00**			

Discharge point 001	4/30/2009	**12.00**			-
Discharge point 001	7/31/2008	**3.89**		-	
Discharge point 003	11/30/2008	**3.46**		-	
Discharge point 003	11/30/2007	**3.46**		-	
Carbon, total organic (TOC)					
Discharge point 001	1/31/2008	-	-	**60**	55
Discharge point 003	4/30/2008	-		**67**	
Chemical Oxygen Demand (COD)					
Discharge point 001	1/31/2008	-	-	**192**	150
Discharge point 001	12/31/2007	-		**178**	
Discharge point 003	1/31/2008	-		**262**	

Criteria

In order to measure stream water quality, a set of comparison values for data points must be established. TCEQ has developed screening levels for a variety of surface water quality parameters in the State. TCEQ surface water quality criteria and screening levels used for the water parameters sampled for the Double Bayou Watershed Characterization are listed in Table 4. [4] State surface water quality criteria or screening levels do not exist for some parameters. Drinking water standards have been established by the EPA, but often these standards are more stringent than the criteria established for surface waters designated for contact recreation or aquatic life use, and are not appropriate for use in the Double Bayou Characterization. In order to create comparison values for these data, 85th percentile calculations were developed using TCEQ surface water quality data collected from 22 water quality stations located in Trinity Bay watersheds east of the San Jacinto River up to the western boundary of Double Bayou. Stations used for the 85th percentile calculations are shown in Appendix A. Additional Parameter Analysis. Not all sampling parameters used for this watershed characterization had enough data to develop 85th percentile calculations. Some parameters with established screening criteria were included in the 85th percentile calculation as a point of interest. The time period for data used in the 85th percentile calculation included 2000-2009, comprising 1,068 spring records and 1,175 fall records. Results are shown in Table 4[5].

[4] 2010 Guidance for Assessing and Reporting Surface Water Quality in Texas (August 25,2010), In Compliance with Sections 305(b) and 303(d) of the Federal Clean Water Act prepared by Surface Water Quality Monitoring Program Monitoring and Assessment Section Water Quality Planning Division, TCEQ

[5] Based on TCEQ HGAC SWQM Data, selected storets based on USGS samples, from tributary stations in GBEP segmentation (segments C6, TR, T, E only) --represents East Lower Galveston Bay Watershed, collected from 2000-2009 (10 years), 85th percentile calculated for field "Value2" (values identified as < multiplied by 0.5)

Table 4. TCEQ screening levels for criteria-classified sampling parameters and 85th percentile results

Storet Code	Parameter	Parameter Unit	85th percentile Fall	85 percentile Spring	Tidal TCEQ Screening levels	Non-Tidal TCEQ Screening levels	Estuary TCEQ Screening levels	Bacteria Screening Level Geometric Mean	Bacteria Screening Level Single Sample	DO Screening Level Tidal 24 hour average (unclassified waterbody)	DO Screening Level Non Tidal 24 hour average (unclassified waterbody)	DO Screening Level Estuary 24 hour average (unclassified waterbody)	DO Screening Level Tidal, Non Tidal and Estuary 24 hour Minimum (unclassified waterbody)
94	Specific conductance (µS/cm)	µS/cm	15934	11105									
70300	Residue on evaporation, water, filtered, (milligrams per liter)	milligrams per liter	13730	9168									
940	Chloride, Water, filtered (milligrams per	milligrams per liter	6789	1237.8									
945	Sulfate, water, filtered (mg/L)	milligrams per liter	987.4	358.6									
10	Water temperature	°C	28.6	25.25									
300	Dissolved oxygen concentration (mg/L)	milligrams per liter	8.11	9.28						4	5	4	3
400	pH (standard units)	(standard units)	8	8.1									
665	Phosphorus, water, filtered (mg/L)	milligrams per liter	0.31	0.24	0.66	0.69	0.21						
671	Orthophosphate, water, filtered (mg/L)	milligrams per liter	0.17	0.19	0.46	0.37	0.19						
610	Ammonia, water, filtered (mg/L as nitrogen)	milligrams per liter as nitrogen	0.05	0.12	0.46	0.33	0.1						
615	Nitrite, water, filtered (mg/L as nitrogen)	milligrams per liter as nitrogen	0.05	0.03	1.1	1.95	0.17						
39632	Atrazine, water, filtered, recoverable, Eliza method (micrograms per liter)	micrograms per liter			3	3	3						
31616	Fecal coliform, (colonies-forming unit per 100 milliliters)	colonies-forming unit per 100 milliliters						200	400				
31699	Escherichia coli, Colilert Quantitray method, water (most probable number per 100	most probable number per 100 milliliters						126	394				
31701	Enterococcus, water, (most probable number per 100 milliliters)	most probable number per 100 milliliters						35	89				

Water Quality Data

Dissolved Oxygen

Dissolved Oxygen (DO) results from the 24-hour monitoring events for Fall 2010 and Spring 2011 are shown in Figure 11. As discussed in the Double Bayou Data Gap Analysis, Double Bayou West Fork is listed on the 303(d) impaired waters list with a designation for DO. The DO minimum criterion for the station used to designate the listing on West Fork is 3.0 mg/L (samples for DO need to be above the criterion); the DO average (4.0 mg/L criteria for tidal and 5.0 mg/L for freshwater unclassified) is used to assess a concern[6]. During the Fall and Spring sampling periods, five of seven sampling days at EFU 546 and two of seven sampling days at WFU 554 did not meet the average criteria for DO. Two of seven sampling days at EFU 546, two of seven sampling days at WFU 554 and one of five sampling days at EFL 548 did not meet the minimum criteria for DO during the sampling period (Figure 12). The WFU 554 station had the highest percent exceedances (36% Fall) for minimum criteria followed by EFU 546 (14% Fall, 22% Spring) and then by EFL 548 (8% Spring). WFU 554 Spring, EFL 548 Fall and WFL 558 Fall and Spring had no minimum exceedances during the sampling period.

[6] From dialogue on December 17, 2009 with Christine Kolbe, Aquatic Scientist at the TCEQ Surface Water Quality Monitoring Program, Austin, Texas and 2010 Guidance for Assessing and Reporting Surface Water Quality in Texas (August 25,2010), In Compliance with Sections 305(b) and 303(d) of the Federal Clean Water Act prepared by Surface Water Quality Monitoring Program Monitoring and Assessment Section Water Quality Planning Division, TCEQ

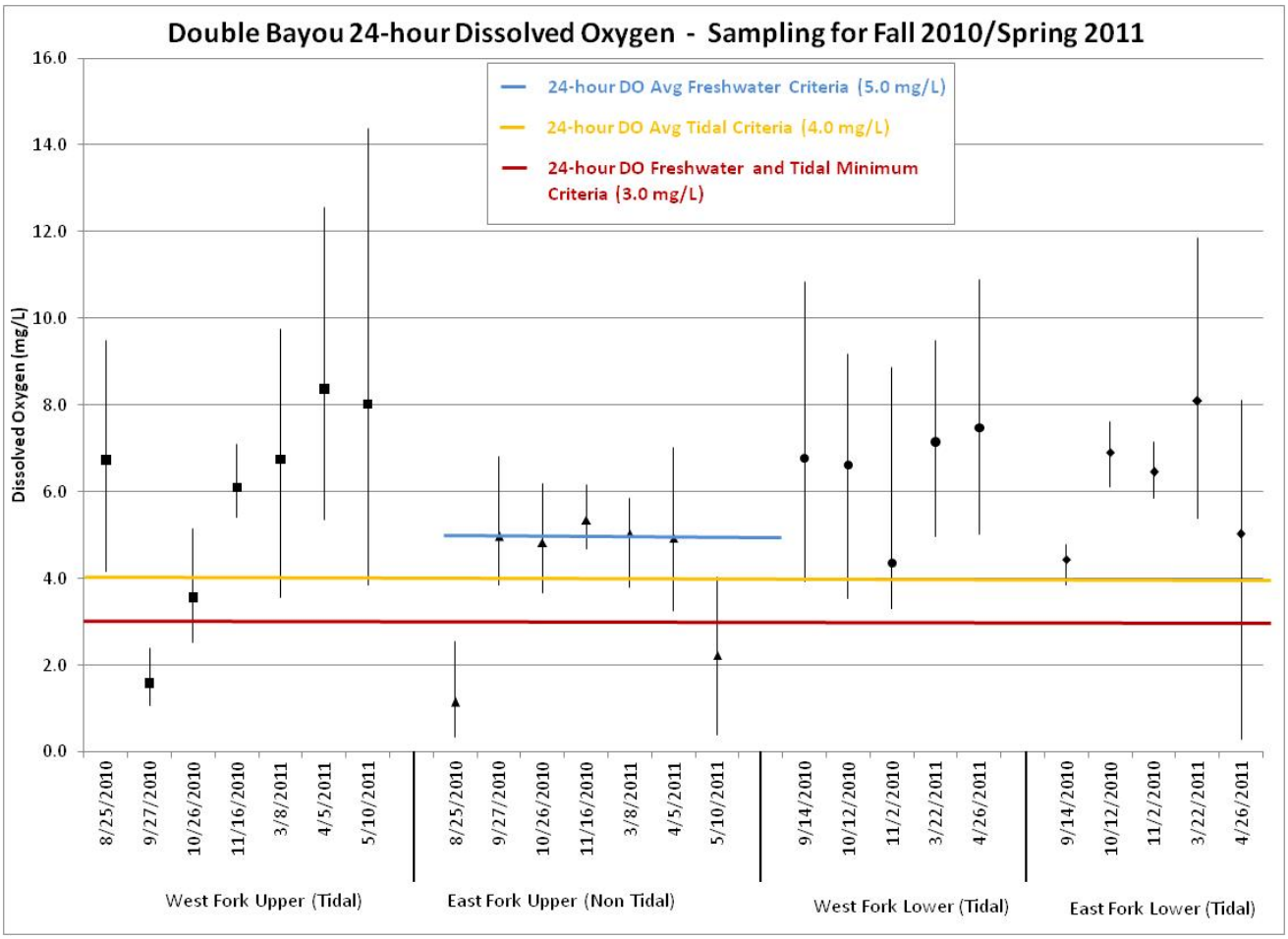
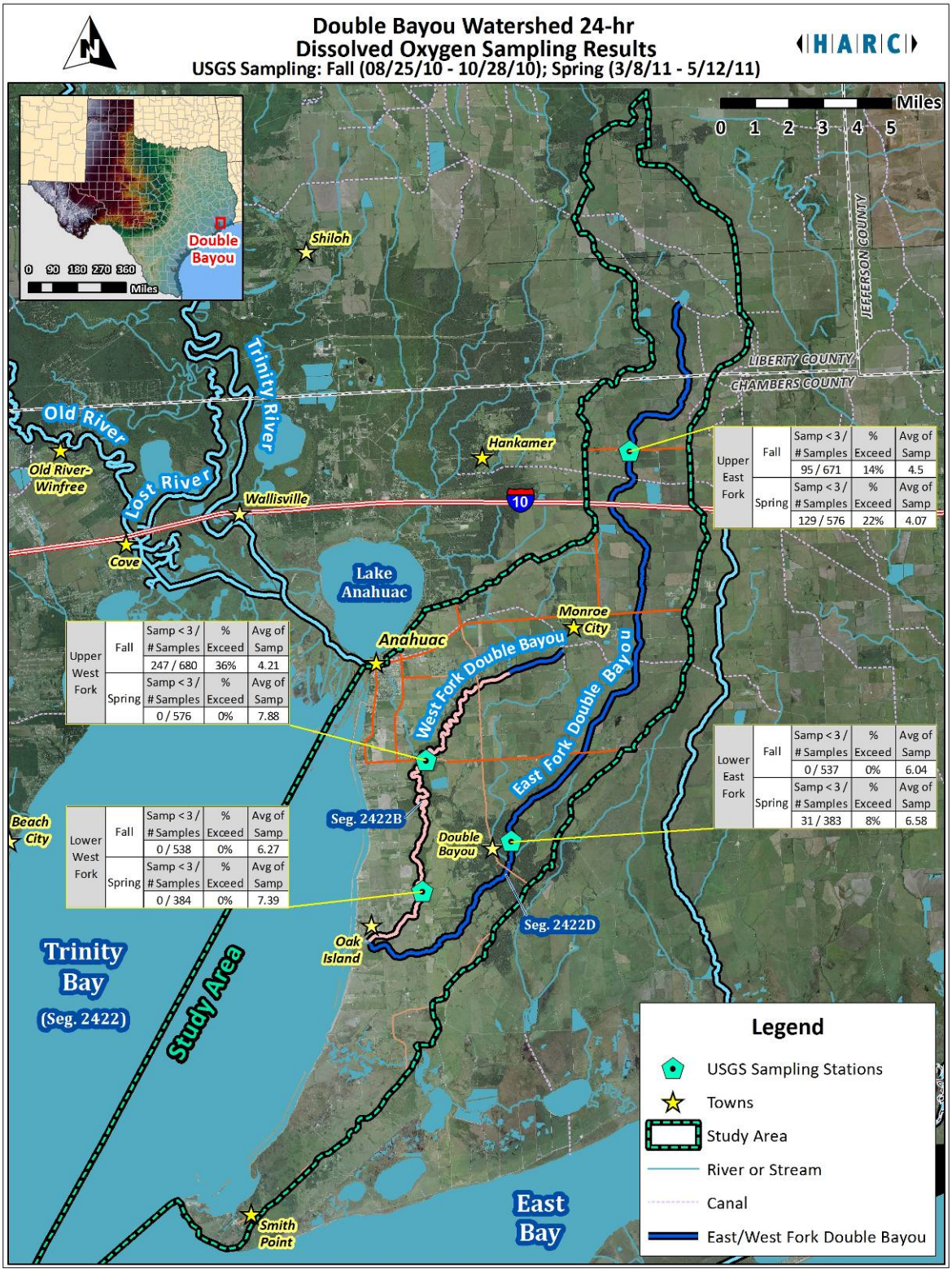


Figure 11. 24-hour Dissolved Oxygen Minimum, Maximum and Average Results



		Samp < 3 / # Samples	% Exceed	Avg of Samp
Upper East Fork	Fall	95 / 671	14%	4.5
	Spring	129 / 576	22%	4.07

		Samp < 3 / # Samples	% Exceed	Avg of Samp
Upper West Fork	Fall	247 / 680	36%	4.21
	Spring	0 / 576	0%	7.88

		Samp < 3 / # Samples	% Exceed	Avg of Samp
Lower East Fork	Fall	0 / 537	0%	6.04
	Spring	31 / 383	8%	6.58

		Samp < 3 / # Samples	% Exceed	Avg of Samp
Lower West Fork	Fall	0 / 538	0%	6.27
	Spring	0 / 384	0%	7.39

Figure 12. Spatial Analysis of Double Bayou 24-hour Dissolved Oxygen Minimum Exceedances

As discussed in the Initial and Secondary Data Analysis reports, temporal patterns during the 24-hour sampling time frame follow the typical DO pattern, with DO levels lower in the morning (Figure 13). Dissolved Oxygen correlation to Water Temperature using linear regression was analyzed. The typical relationship of increasing water temperatures versus declining dissolved oxygen did not necessarily hold true for our samples when compared by station. As discussed, this could be the result of the stronger mixing that would occur in the tidal stations. It could also be a function of the fact that water temperature during the sampling period was not extremely variable. Water temperatures remained fairly steady throughout all of the sampling periods (Figure 14). Figure 15 displays the Average, Maximum and Minimum Water Temperatures during the sampling period. As noted, temperatures were fairly steady with five degrees as the highest variability. As expected, temperatures decreased during the time period of fall sampling and increased during the time period of spring sampling. For more extensive analysis comparing the water temperature baseline data set with the sampling data with specific breakouts for East Fork, West Fork and Estuarine, see Appendix A. Additional Parameter Analysis.

Long-term trend regression analysis does show a correlation of colder water holding more dissolved oxygen (Figure 16). Figure 17 shows the baseline data set for DO with the current study sampling data (the lab sampling parameter rather than the 24-hour study).For more extensive analysis comparing the dissolved oxygen baseline data set with the sampling data with specific breakouts for East Fork, West Fork and Estuarine, see Appendix A. Additional Parameter Analysis. Figures 18 and 19 display the spatial results for the baseline data for dissolved oxygen in the Double Bayou watershed (does not include the current sampling results). Estuarine results are generally consistently above the minimum criteria, but both East and West Forks have samples across the years that are under the minimum criteria, with more recent years having more numerous exceedances (Figure 18).

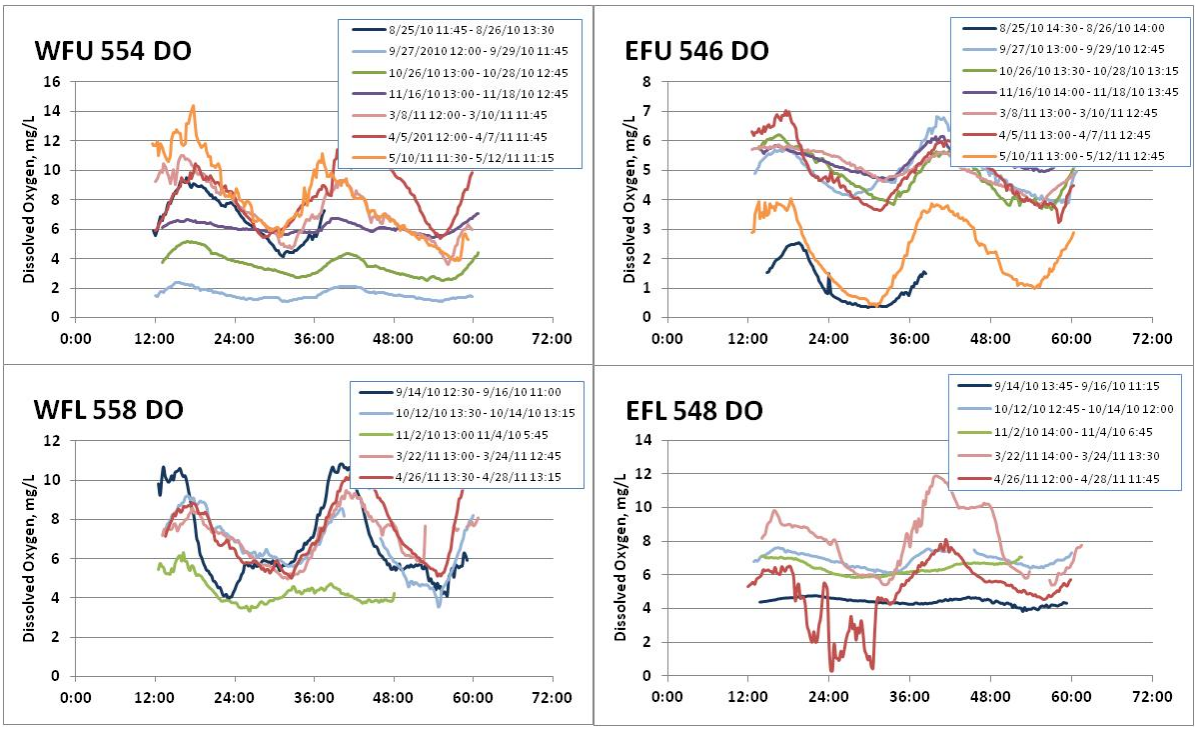


Figure 13 Temporal DO patterns during the sampling periods

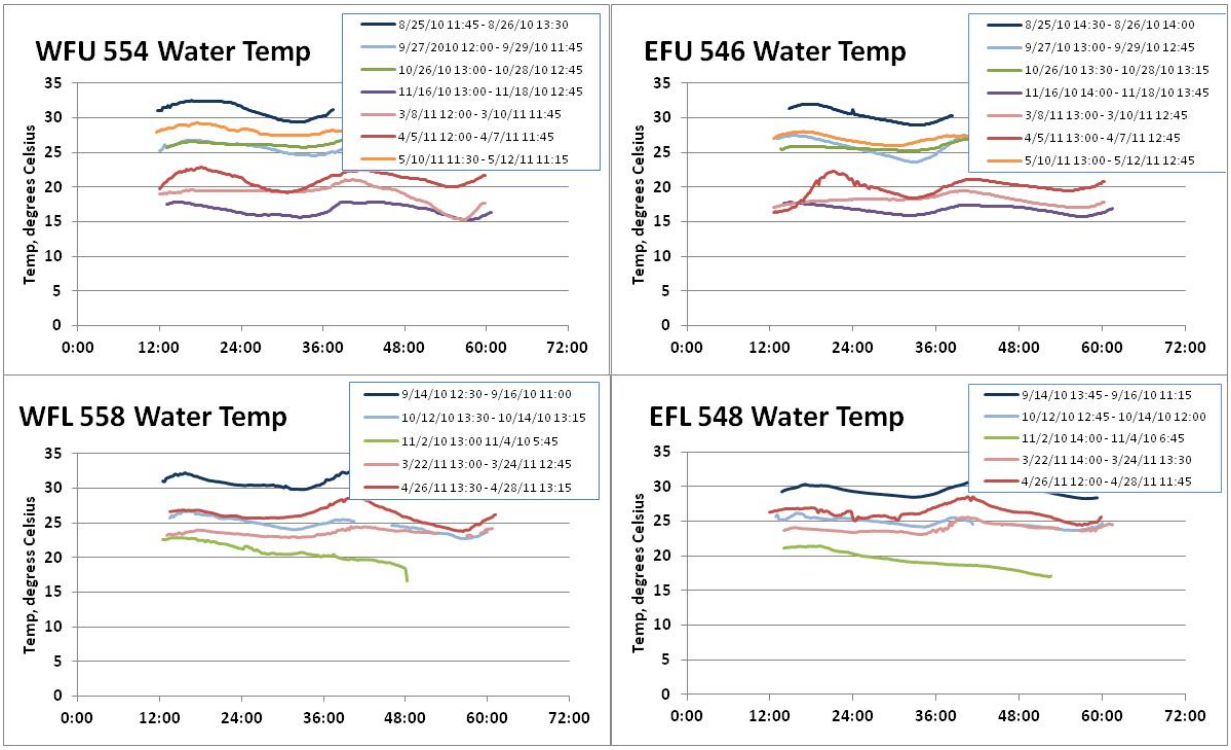


Figure 14. Temporal Water Temperature patterns during the sampling periods

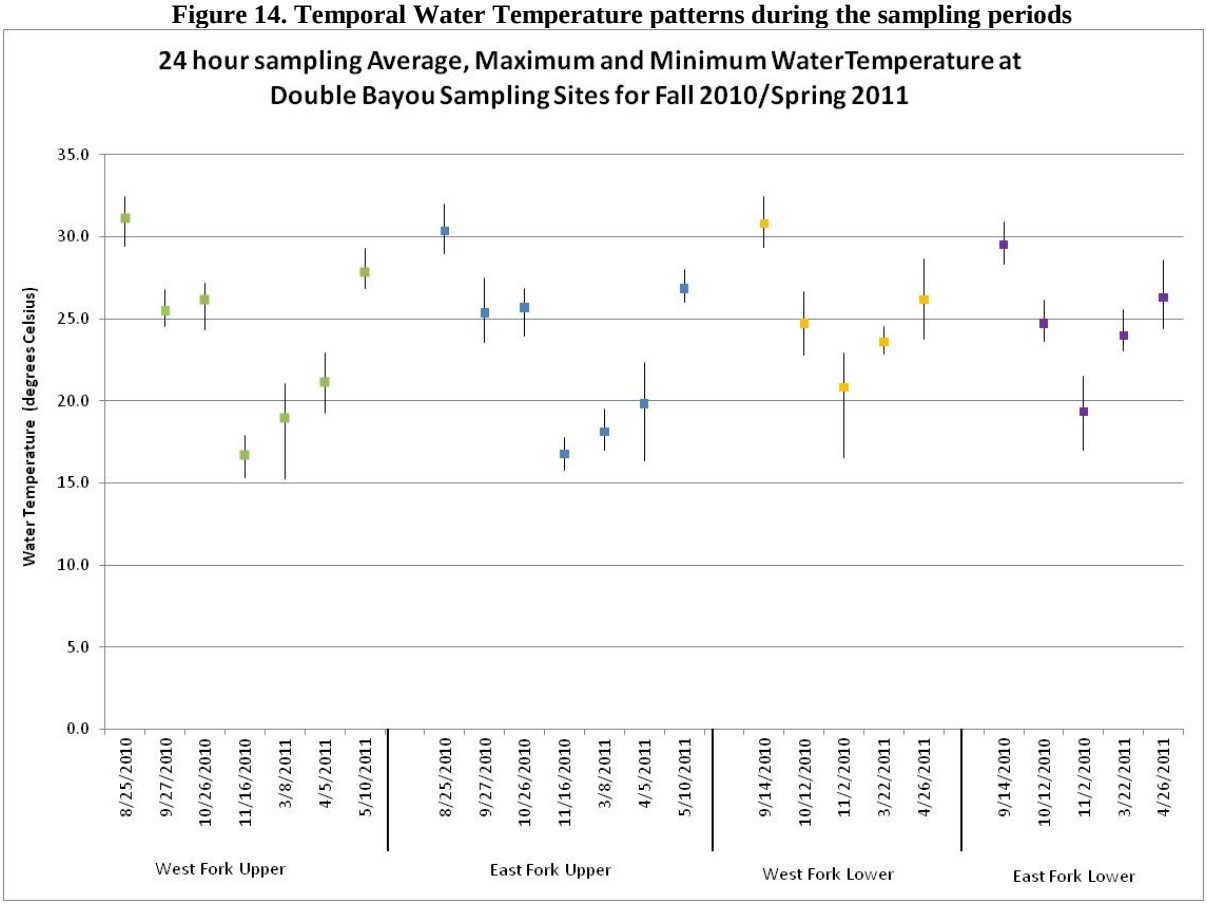


Figure 15. 24-hour Water Temperature Measurements All Stations

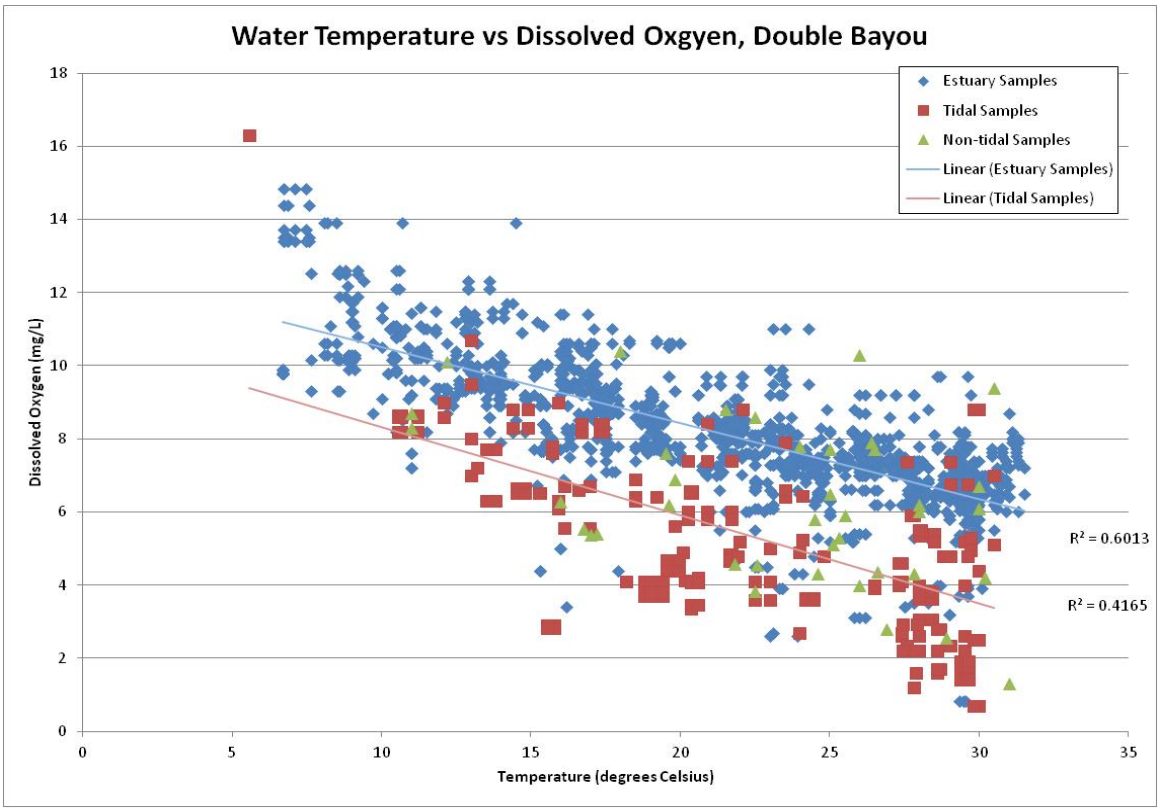


Figure 16. Linear Regression for dissolved oxygen and water temperature

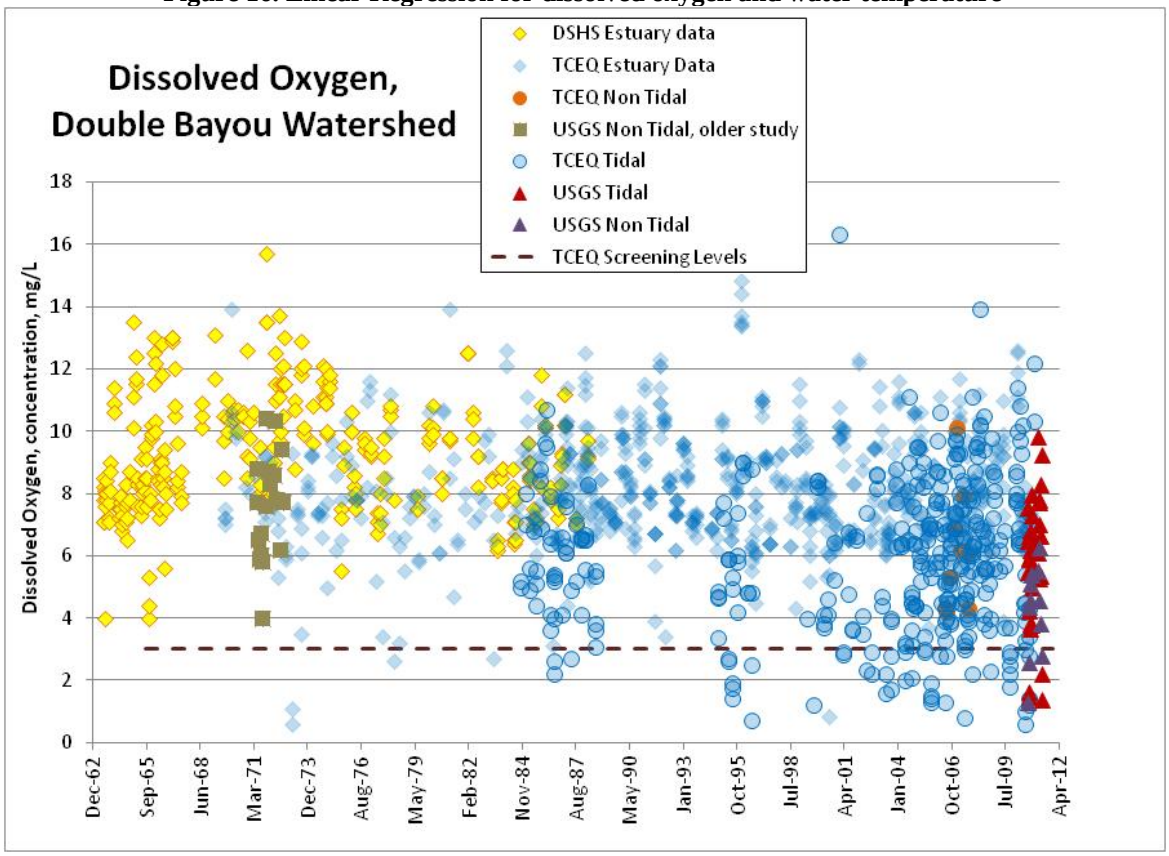


Figure 17. Dissolved Oxygen in Double Bayou Watershed

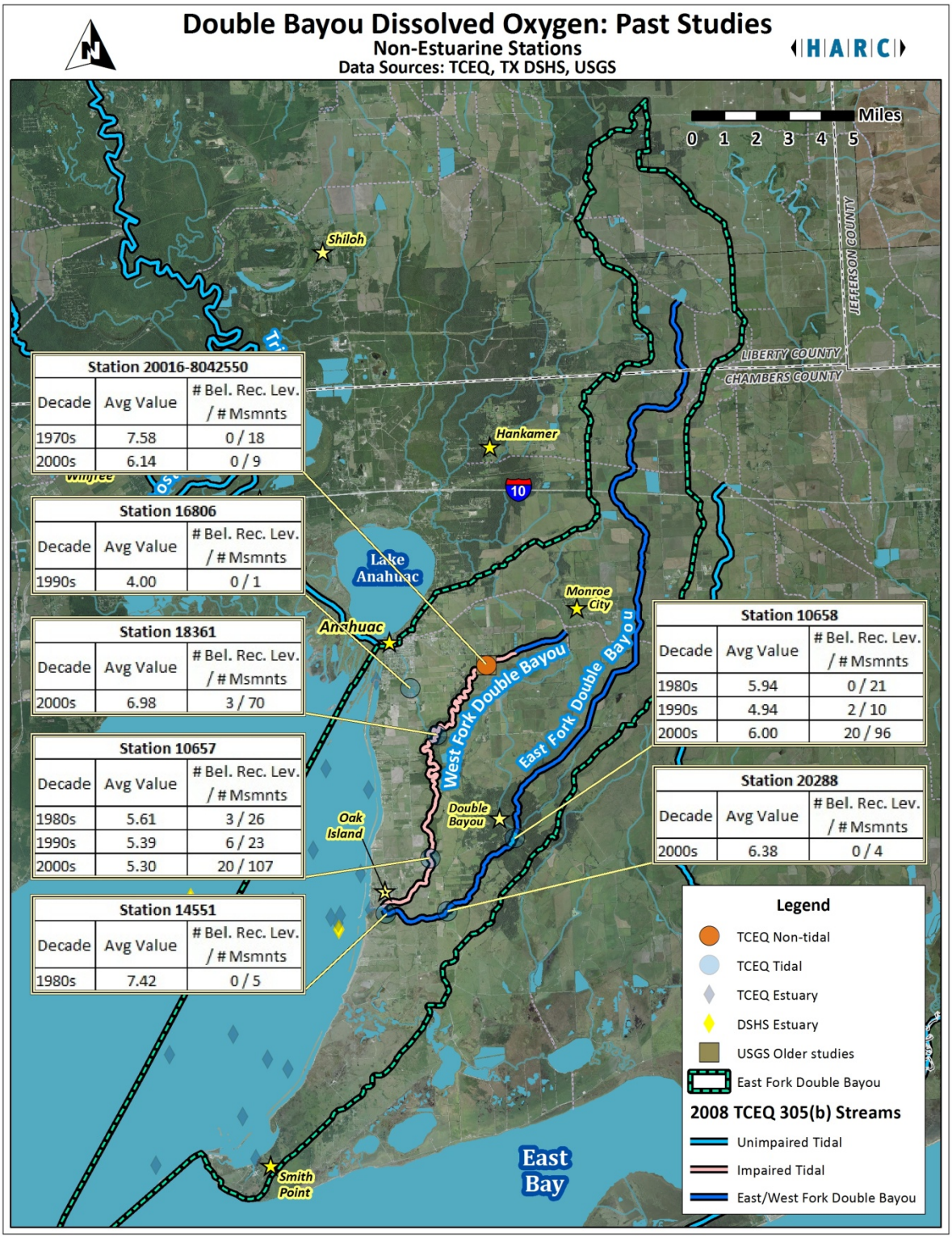


Figure 18. Dissolved Oxygen in Double Bayou Watershed – Past Studies Non-estuarine Station Results

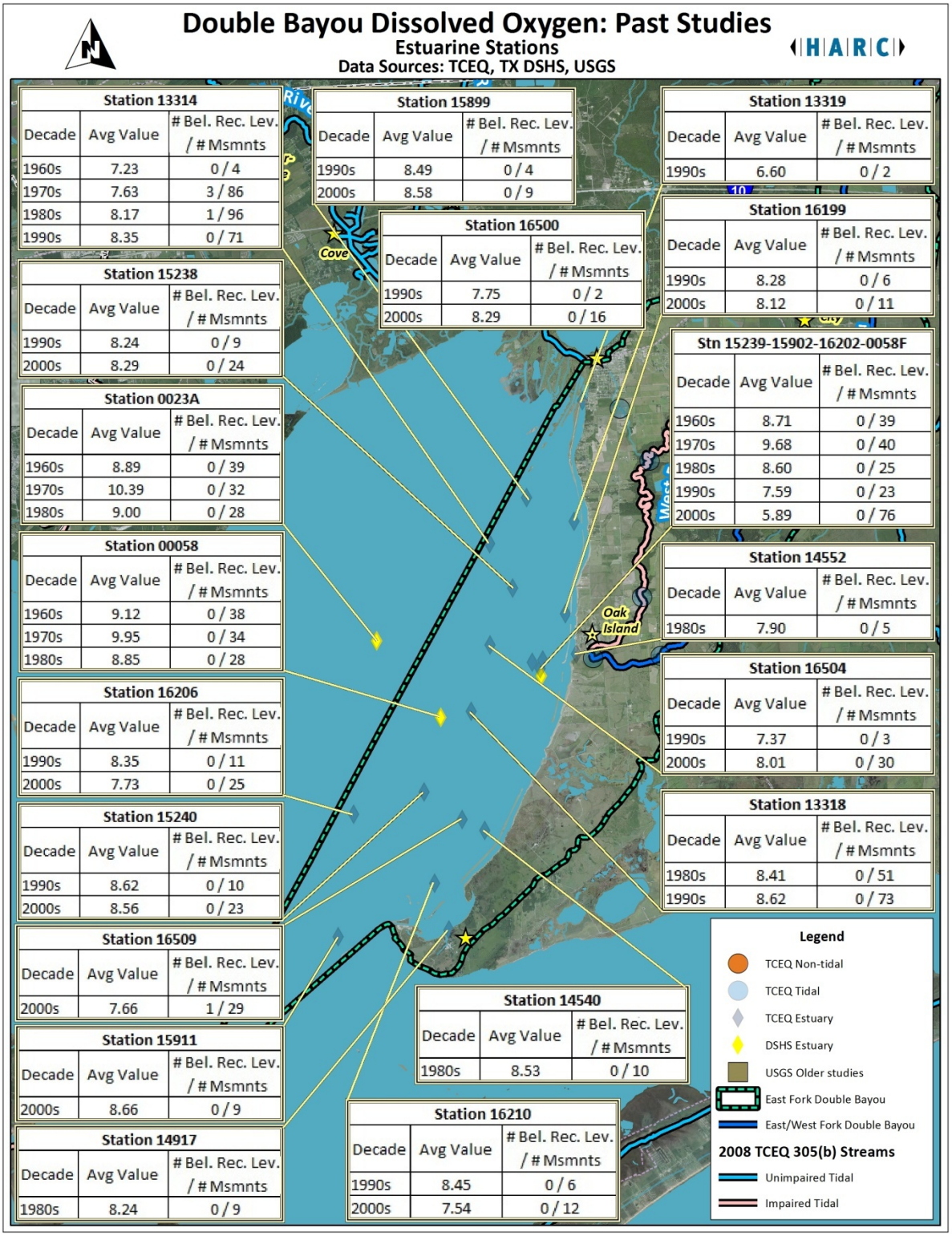


Figure 19. Dissolved Oxygen in Double Bayou Watershed – Past Studies Estuarine Station Results

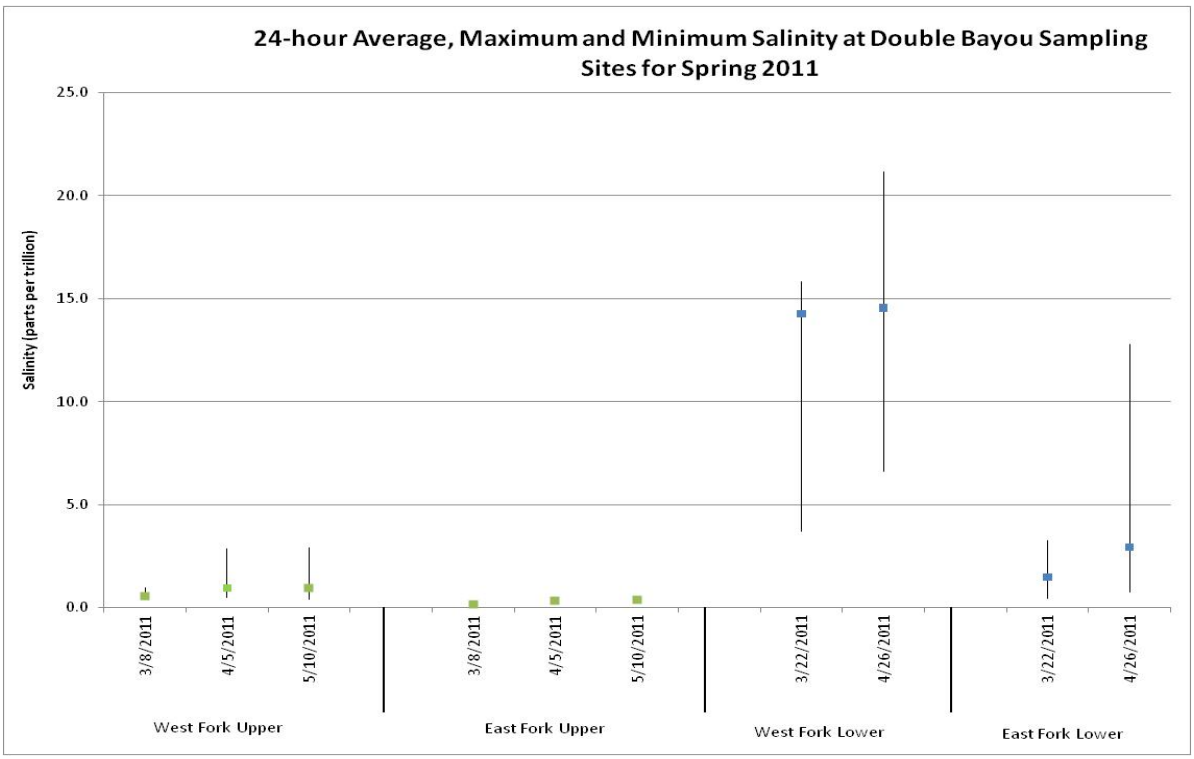


Figure 20. 24-hour Salinity in Double Bayou

Figure 20 displays the 24-hour sampling Average, Maximum and Minimum Salinity results for Spring 2011. WFL 558 had the highest salinity averages and maximums, and EFU 546 had the lowest, which is to be expected as a tidal versus non-tidal station. The next section discusses in more depth mixing and tidal effects.

Tidal Data and Water Levels

As discussed in the Initial Data Analysis report, bayou level and precipitation data sets from the TBCD were analyzed with tidal data in order to assess how the bayous respond to precipitation. The TBCD has several sensors in the study area that measure precipitation and bayou water levels. Note that the water level sensors are relative to themselves; i.e., the 0 foot level is not sea level, but rather where that sensor was placed in the water – all measurements will be relative to this level. Figure 21 displays the location of the TBCD sensors in the watershed.

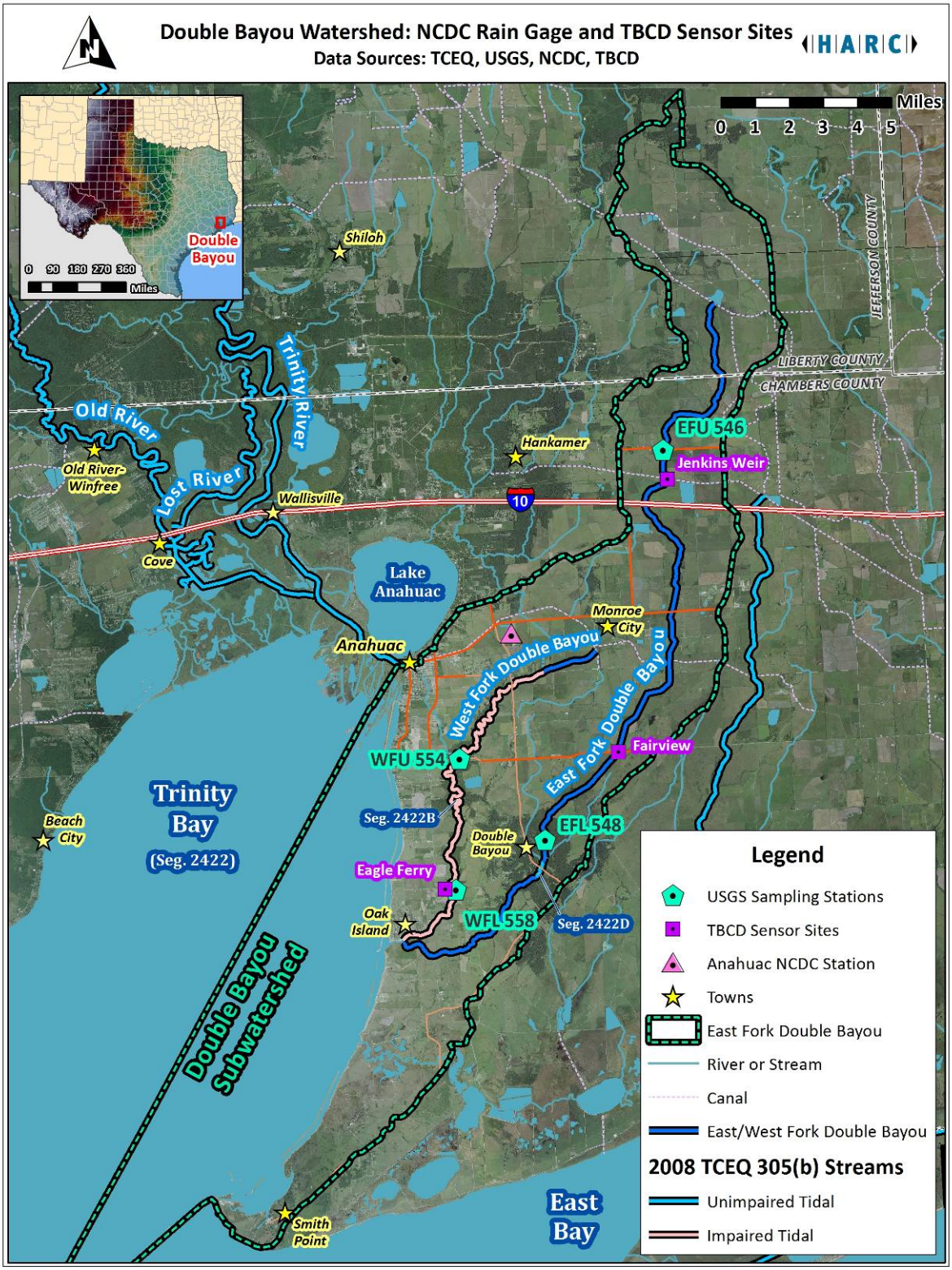


Figure 21. TBCD sensors in the Double Bayou Watershed.

Jenkins Weir is the most northern TBCD sensor in the study area, and very close to the EFU 546 sampling station. Eagle Ferry is located right by the WFL 558 sampling station, and the most southern TBCD sensor in the study area.

Figures 22 and 24 (from the Initial Data Analysis report, shown for comparison) display water levels, cumulative precipitation and tidal activity during a two week rainy period from 8/26/2010 to 9/13/2010 for Eagle Ferry, Fairview Road, and Jenkins Weir. As mentioned previously, the fall sampling period did not have a significant rain event, but there was some rain in the beginning, so the time period of 3/1/2011 to 3/21/2011 was chosen for analysis.

Eagle Ferry, Figures 22 and 23, the station closest to our Tidal WFL 558 station, shows significant tidal influence on the measured water level. Water levels in the bayou follow the temporal tidal pattern. It is interesting to note that while the figures clearly show the tidal influence on the ebb and flow of the water levels at Eagle Ferry, it should be noted that precipitation does have an effect on overall level of water – Figure 23 shows water levels topping at around 1.5-2.5 feet with hardly any precipitation input; Figure 22, though, shows that during a significant input the highs of the water levels go up to approximately 4 feet.

Jenkins Weir, Figures 24 and 25, the station closest to our Non-Tidal EFU 546 station, appears to be dominated by precipitation. As stated previously, these patterns are expected for tidally designated stream segments, but it is discussed and presented here to note that mixing at each of these stations will be different, with differing water columns as a result.

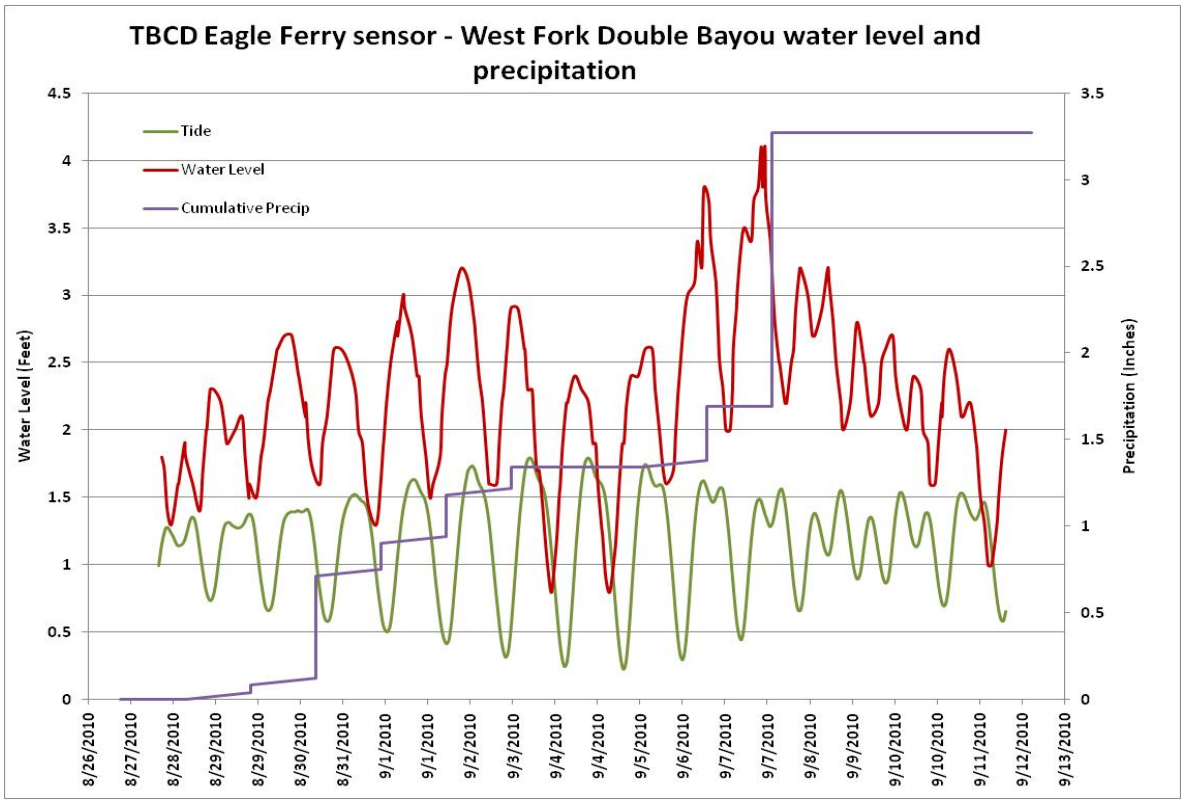


Figure 22. Fall - TBCD Eagle Ferry Water Level and Precipitation in Double Bayou

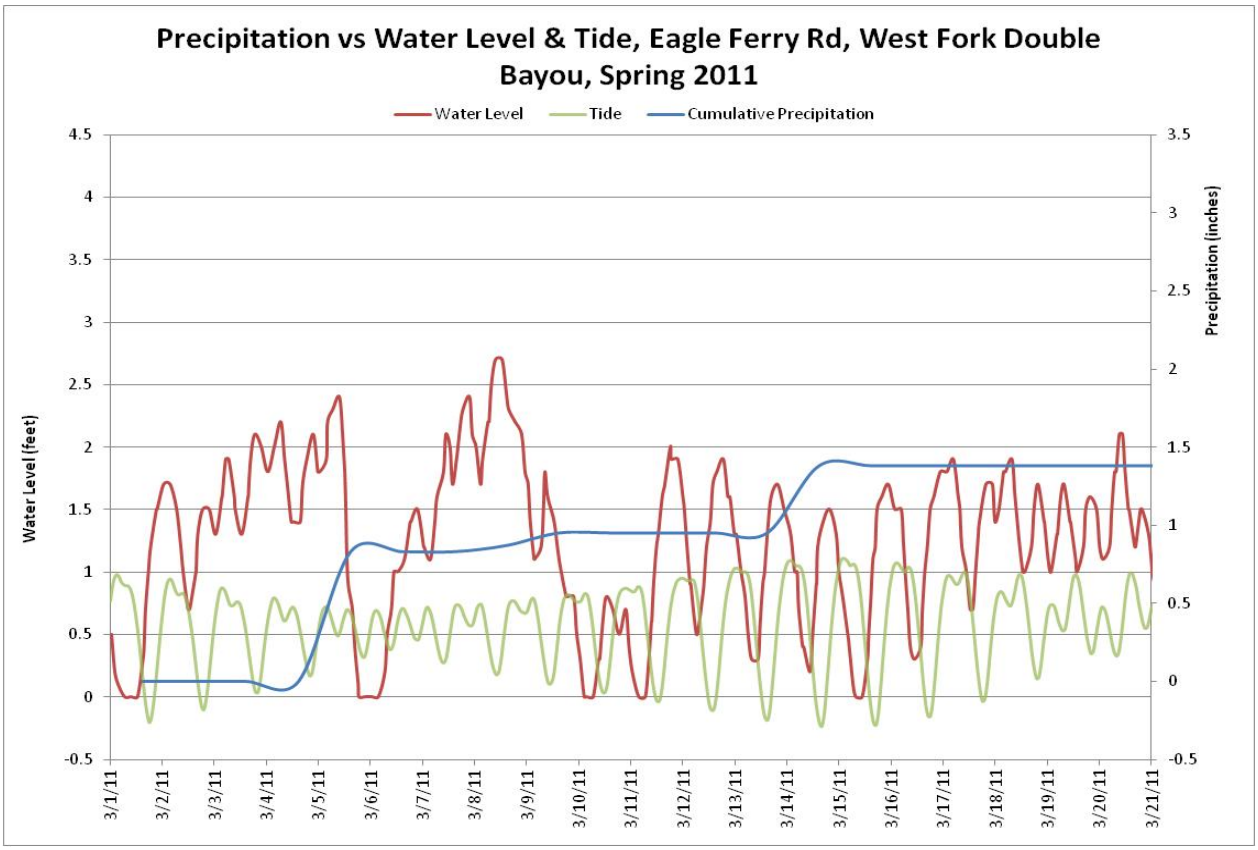


Figure 23. Spring - TBCD Eagle Ferry Water Level and Precipitation in Double Bayou

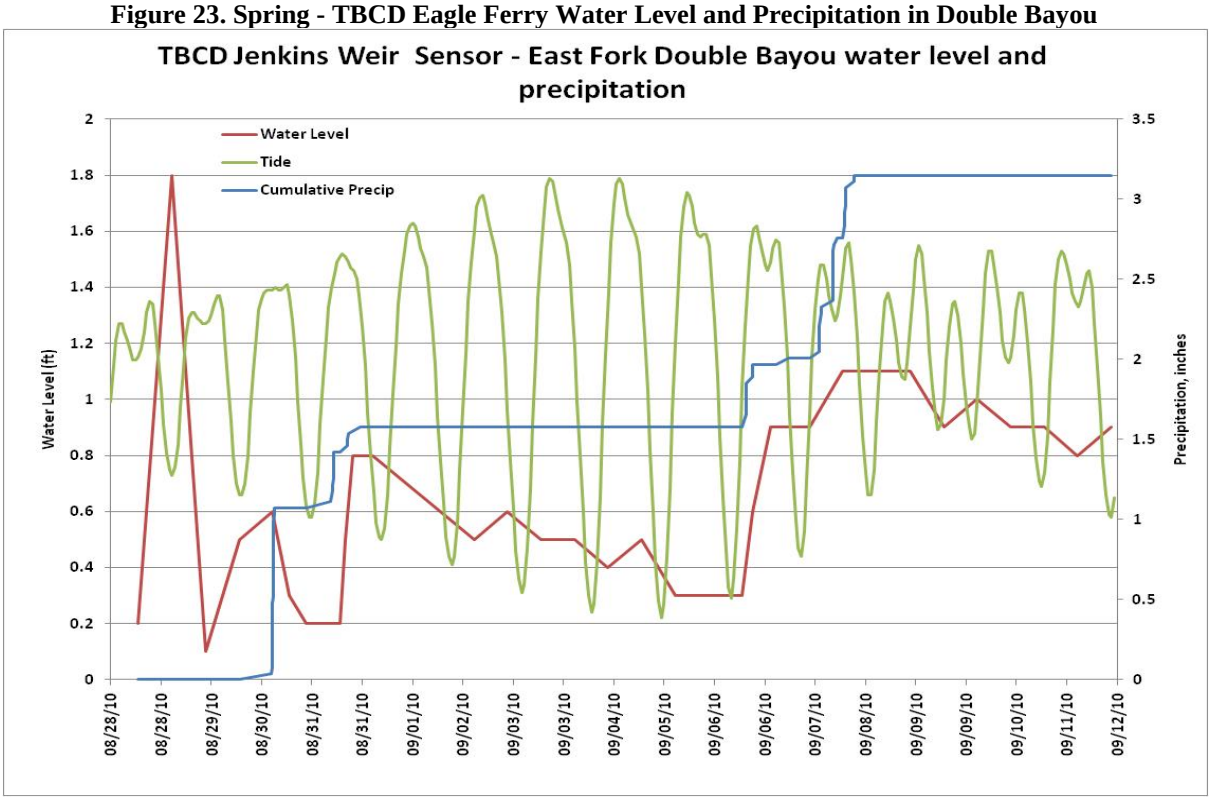


Figure 24. Fall - TBCD Jenkins Weir Water Level and Precipitation in Double Bayou

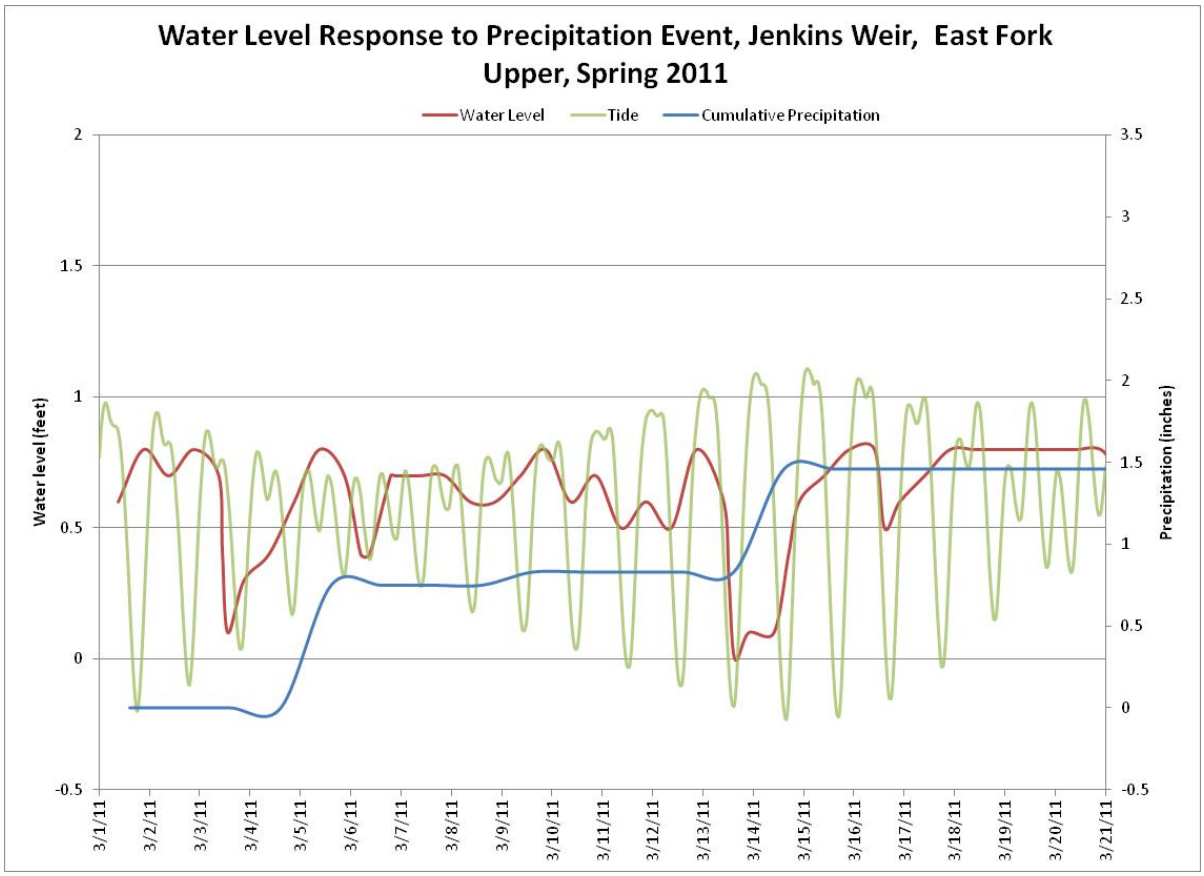


Figure 25. Spring - TBCD Fairview Water Level and Precipitation in Double Bayou

Bacteria

Figure 26 displays results for the pathogen screening. Storet 31699, *Escherichia coli*, Colilert Quantitray method, water (most probable number per 100 milliliters), Storet 31616, Fecal coliform, (colonies-forming unit per 100 milliliters), and Storet 331701 Enterococci, water (most probable number per 100 milliliters), have a TCEQ screening level of 394, 400 and 89 colonies/mL, respectively. The highest exceedance levels were measured in the Spring at EFL 548 and WFL 558 and in the Fall at WFU 554 and WFL 558 stations.

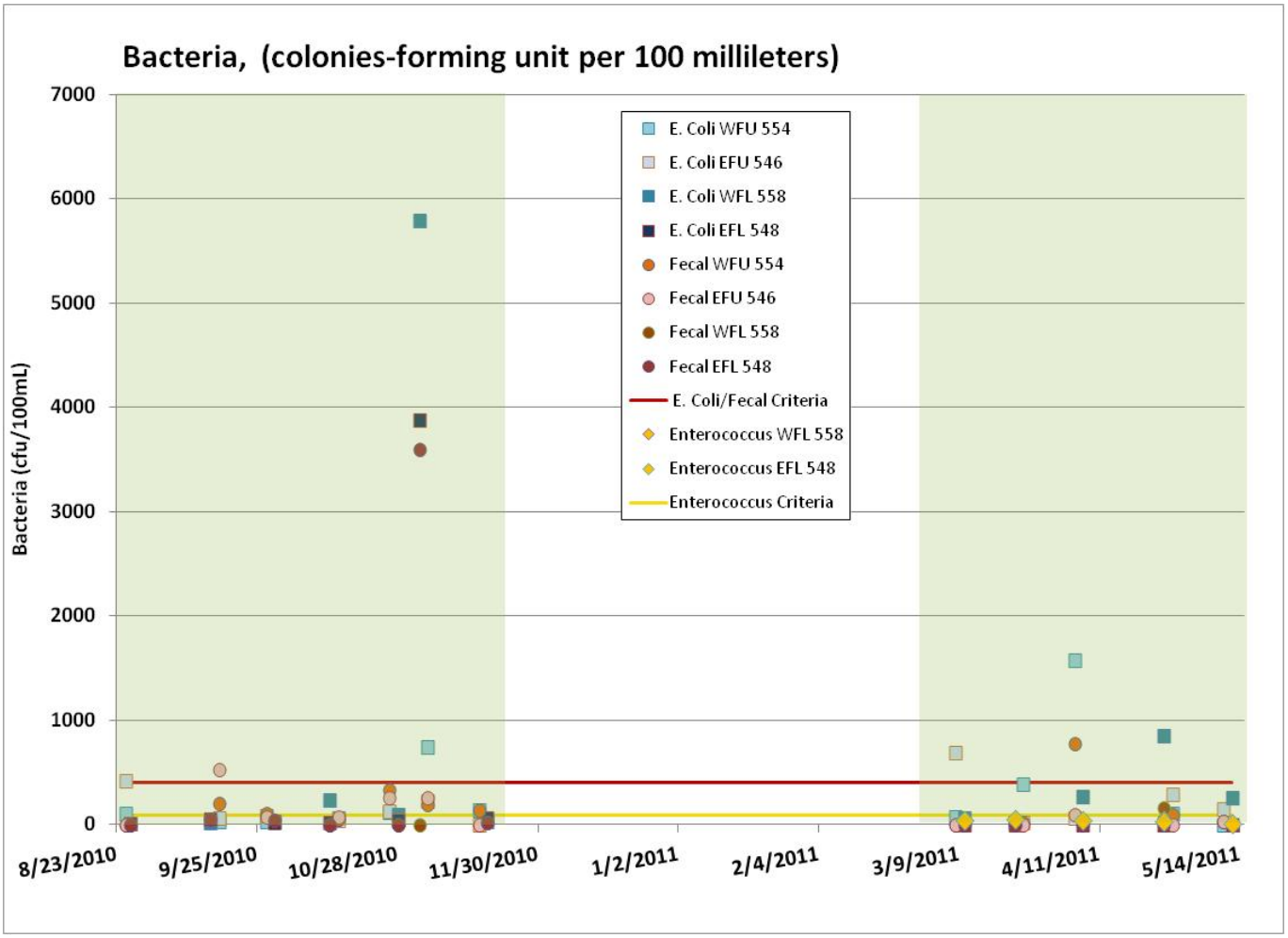


Figure 26. Bacteria Sampling Results

For bacteria, 20% of West Fork Upper samples exceeded the criteria limit during both sampling periods (combined). East Fork Upper exhibited 17% exceedance, West Fork Lower 13%, and East Fork Lower 13% exceedance (see Figure 27 for spatial distribution).

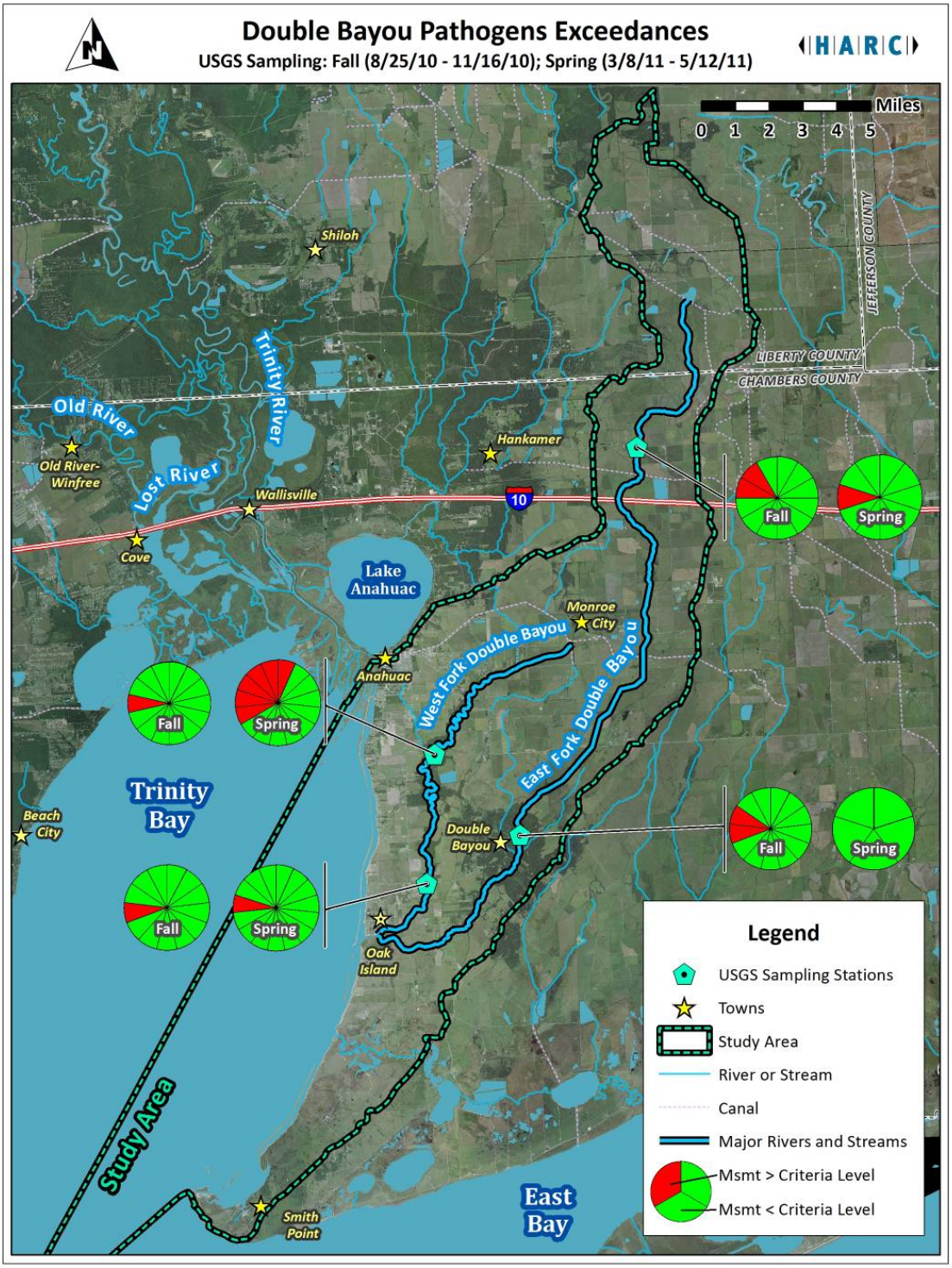


Figure 27. Spatial Analysis of Double Bayou Bacteria Exceedances

Figure 28 displays the pathogens data for all of the Double Bayou watershed including the baseline data set and current study sampling results. Figures 29 and 30 display the spatial results for the baseline data for pathogens in the Double Bayou watershed (does not include the current sampling results). Figure 29 shows non-estuarine bacteria exceedances in the 1970's, 1980's, and 2000's (it should be noted that during the 1990's minimal bacteria sampling was done in the area). Estuarine results (Figure 30) show minimal exceedances throughout the years.

Figures 31-38 display the pathogens data for all of the Double Bayou watershed for Fecal coliform, *E. Coli* and Enterococci. Figures are shown by pathogen, then by East Fork, West Fork or Estuary. West Fork and East Fork show Enterococci levels over the screening criteria. Double Bayou estuary stations also show Enterococci levels over the screening criteria, although far fewer and not the magnitude as displayed in the bayous. West Fork and East Fork also show Fecal Coliform samples over the screening criteria. West Fork has many more samples over the screening level, but there is also more data available for West Fork. Estuary stations show a minor number of samples over the criteria, and those are mostly concentrated around 1972-1995. West Fork and East Fork both have *E. Coli* samples well over the screening criteria. There were not enough data for estuarine *E. Coli* analyses. Fecal Coliform data have the most historic representation for Double Analysis pathogen testing, with data extending back to the 1960's.

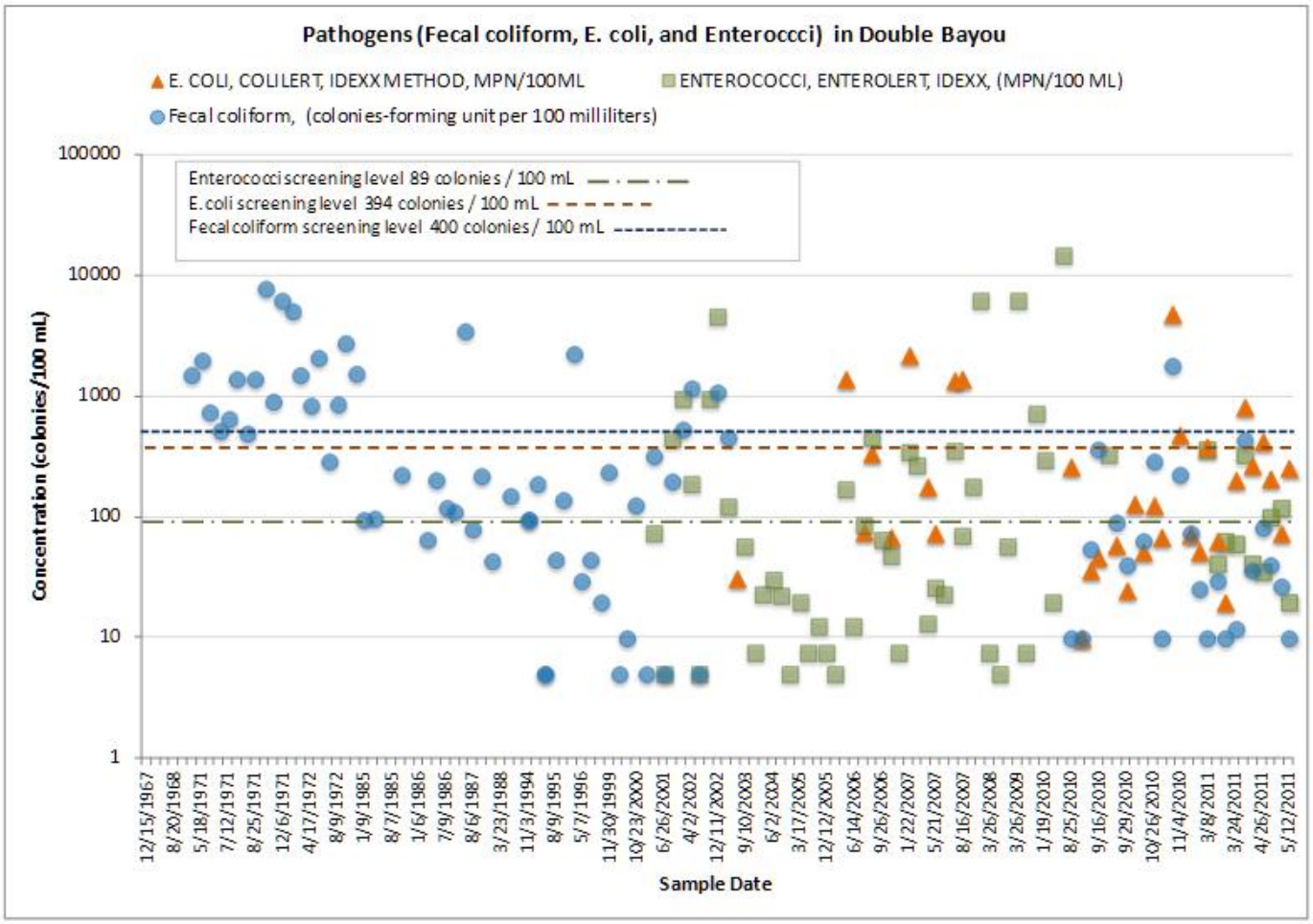


Figure 28. Double Bayou Watershed Pathogens

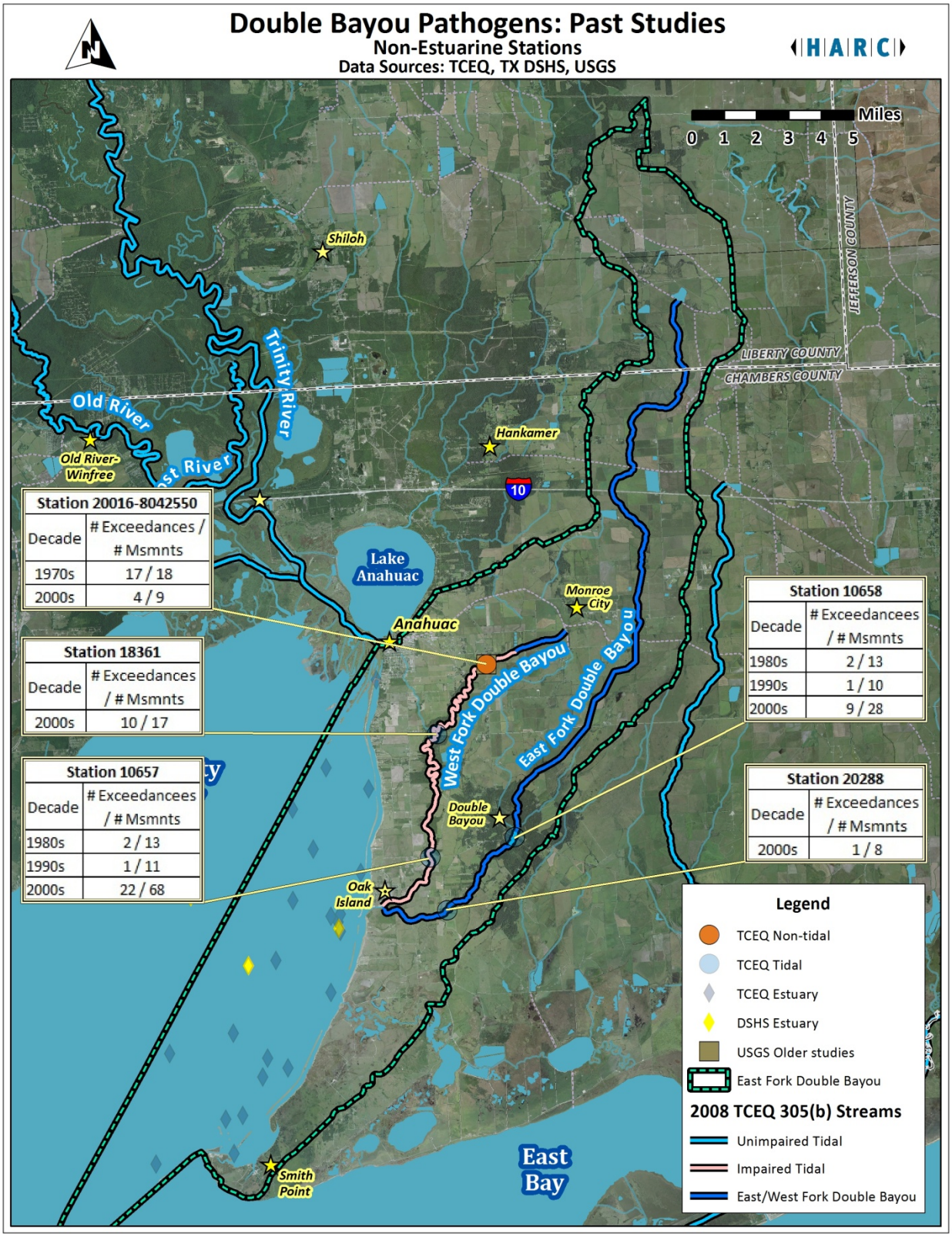


Figure 29. Pathogens in Double Bayou Watershed – Past Studies Non-Estuarine Station Results

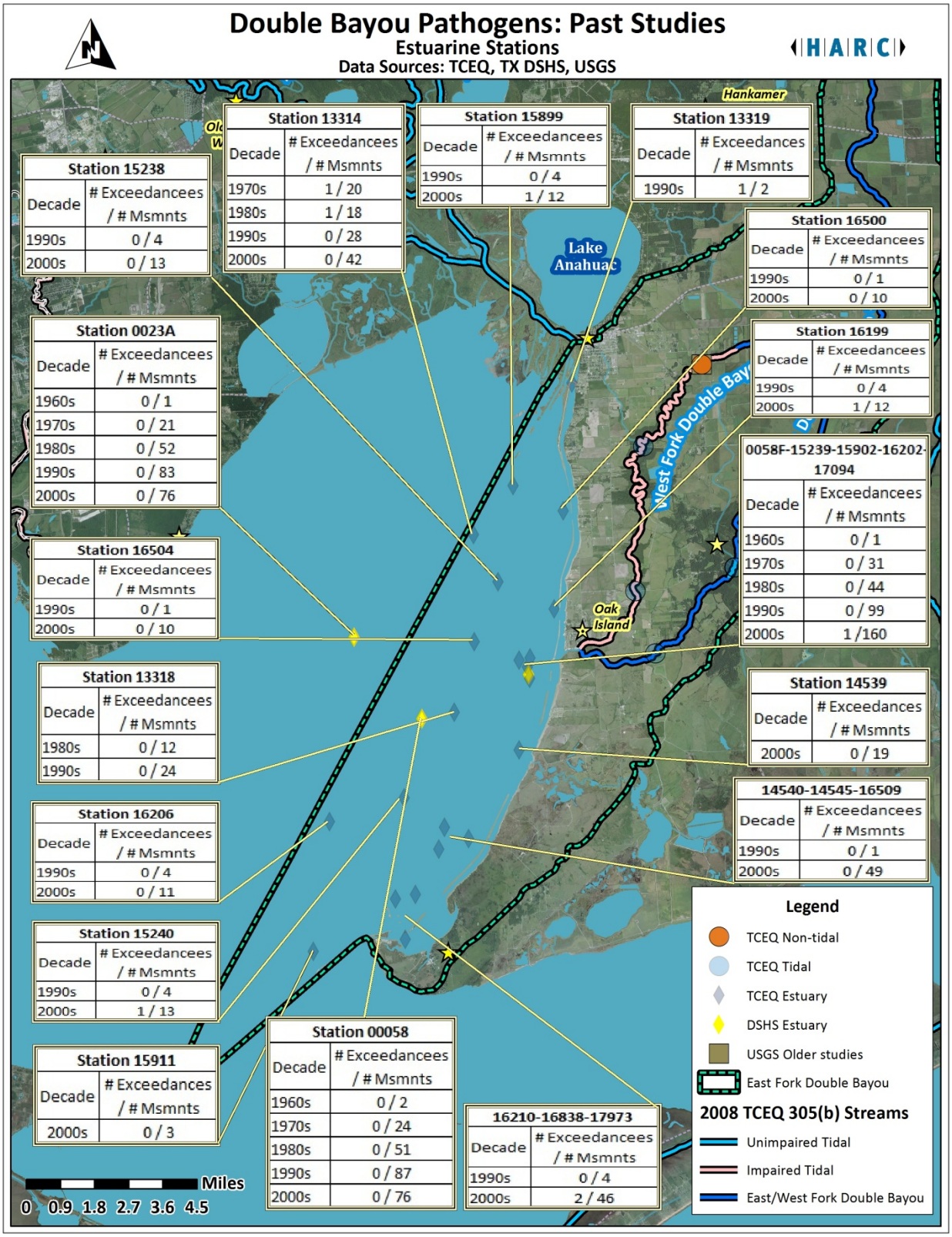


Figure 30. Pathogens in Double Bayou Watershed – Past Studies Estuarine Station Results

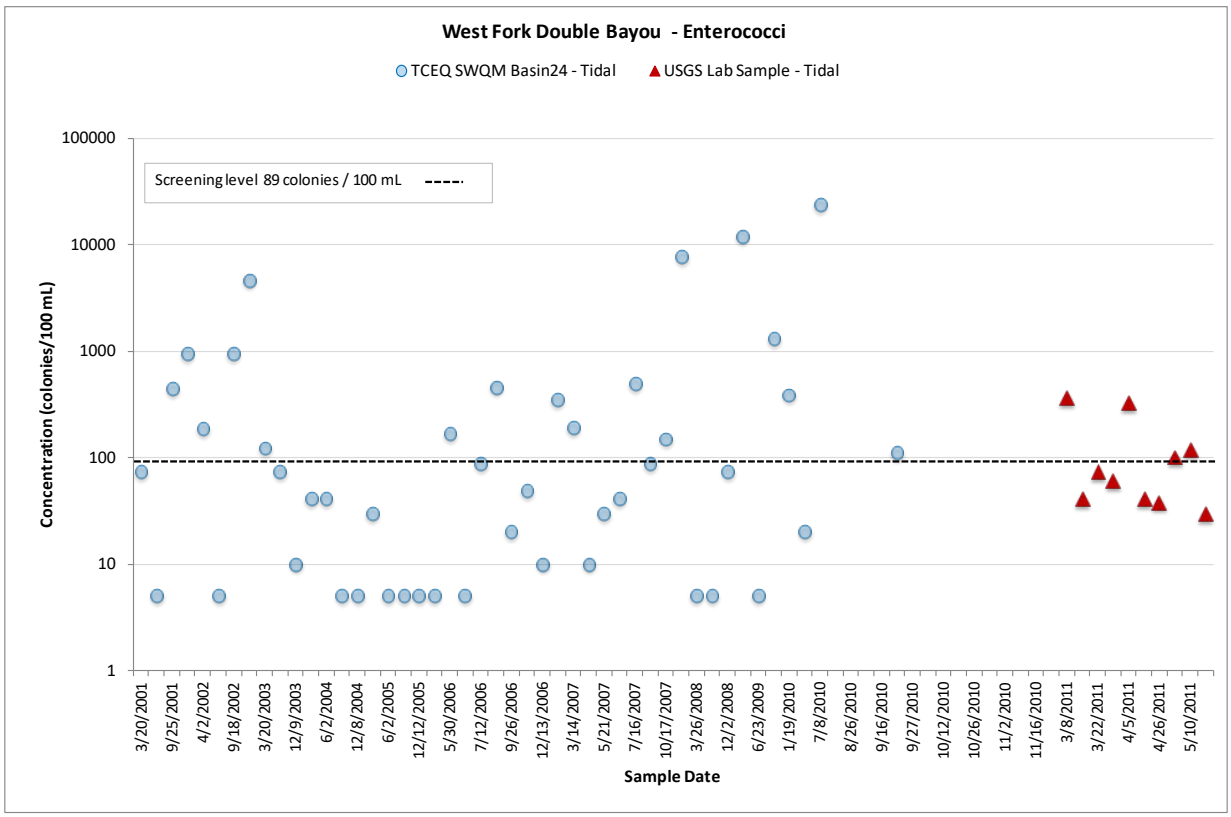


Figure 31. West Fork Double Bayou Enterococci

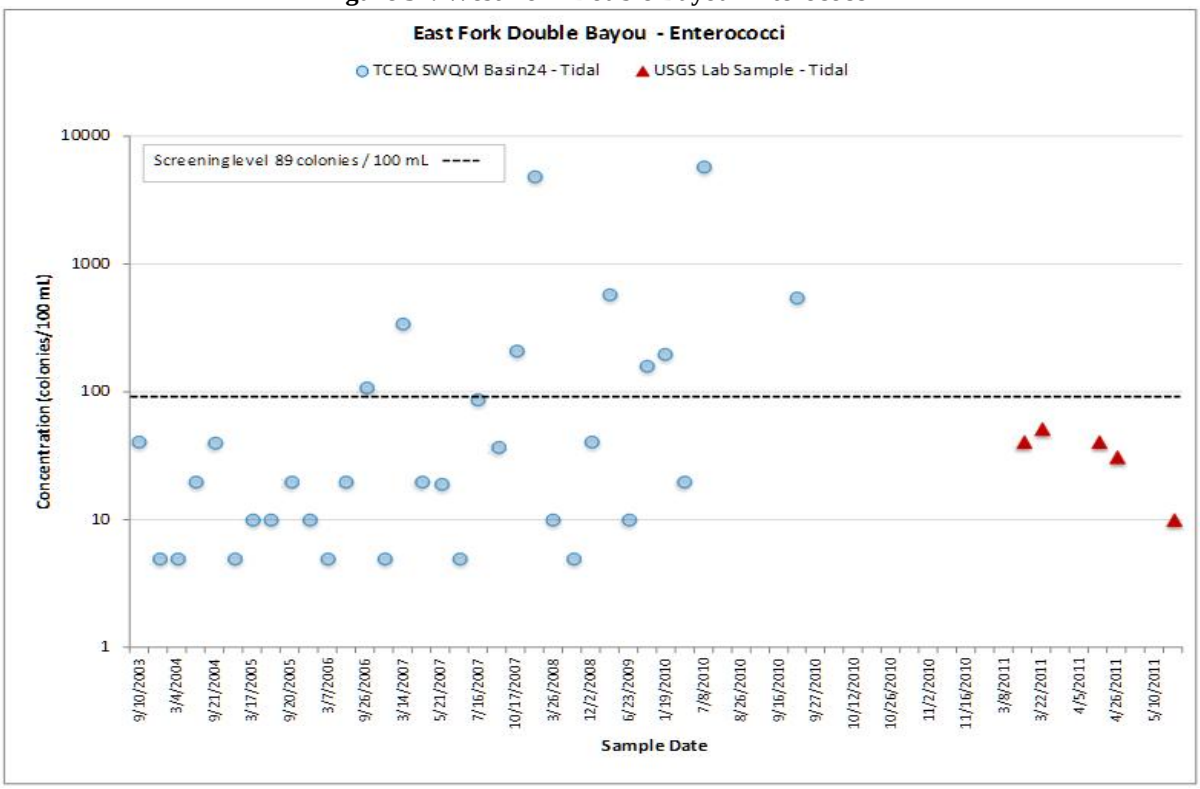


Figure 32. East Fork Double Bayou Enterococci

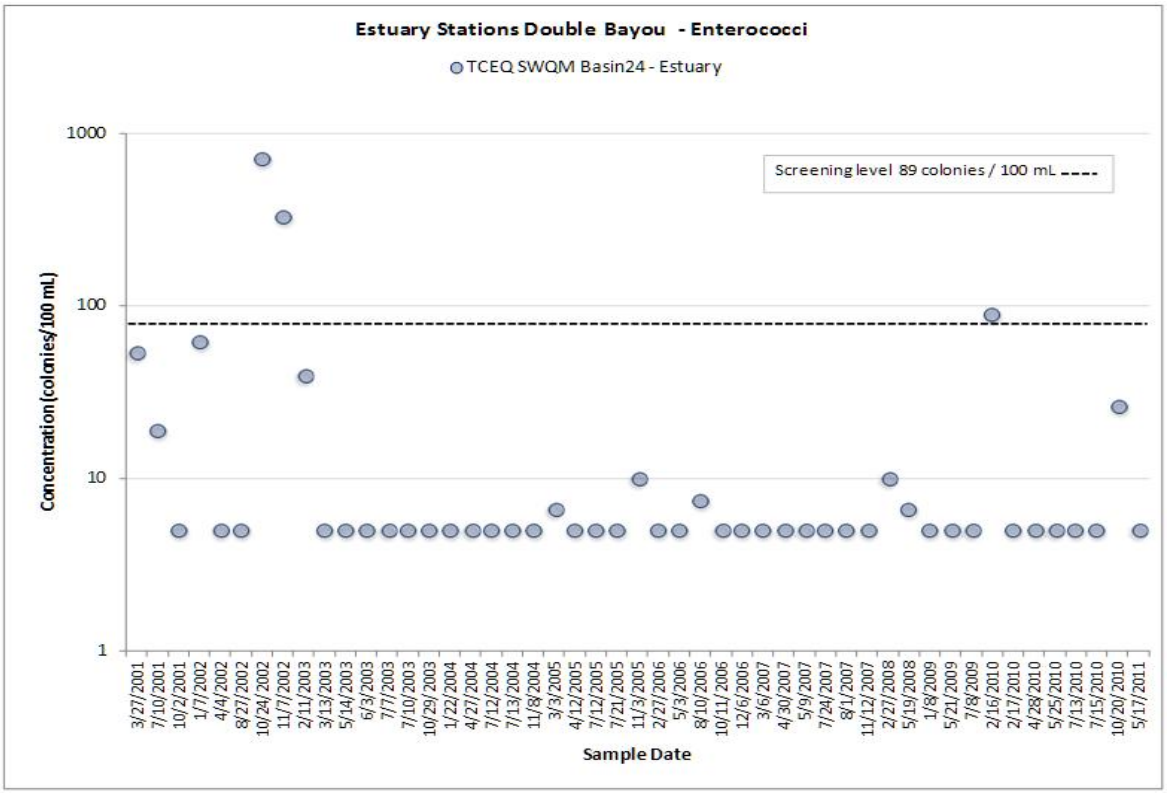


Figure 33. Estuary Stations Double Bayou watershed Enterococci

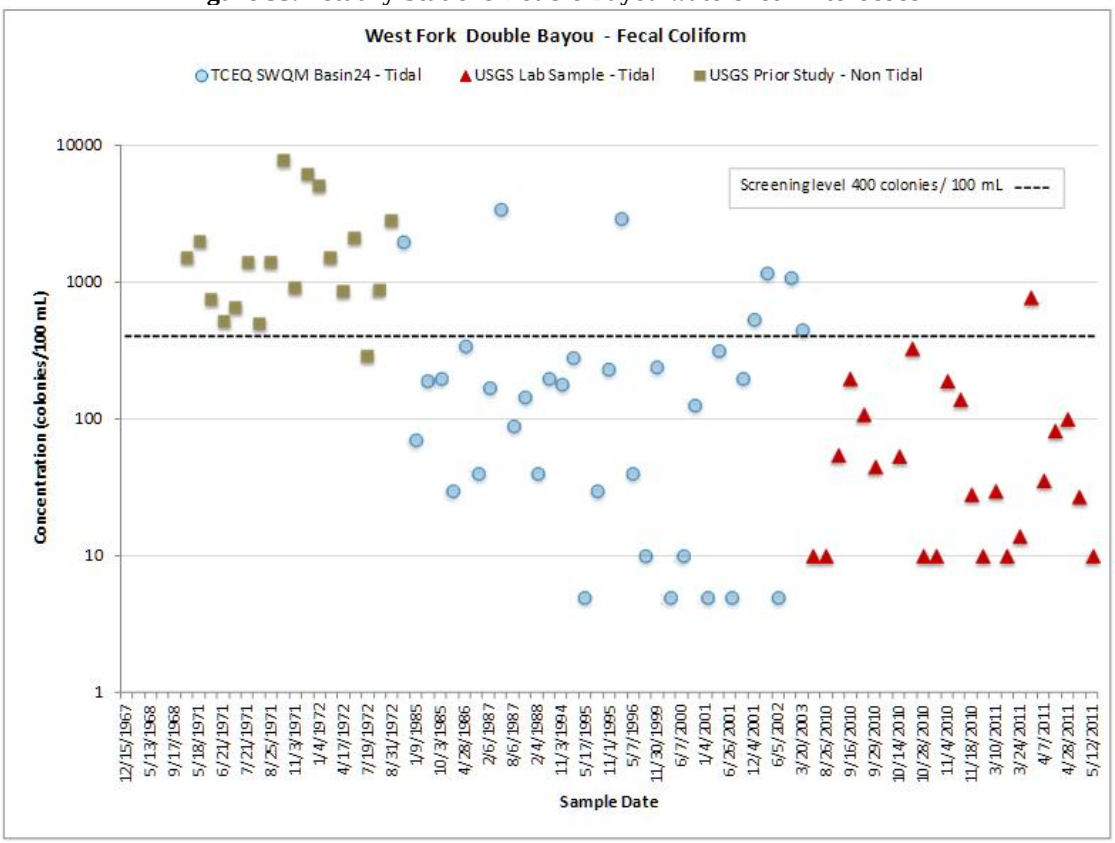


Figure 34. West Fork Double Bayou Fecal Coliform

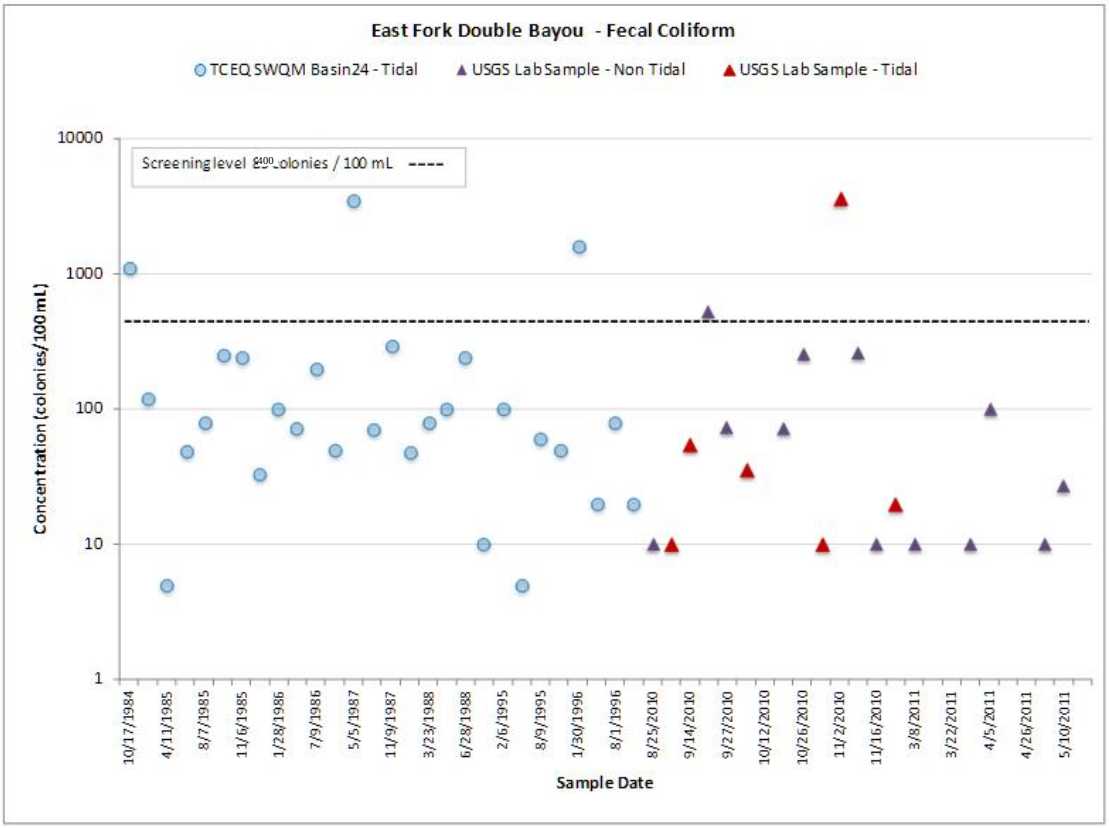


Figure 35. East Fork Double Bayou Fecal Coliform

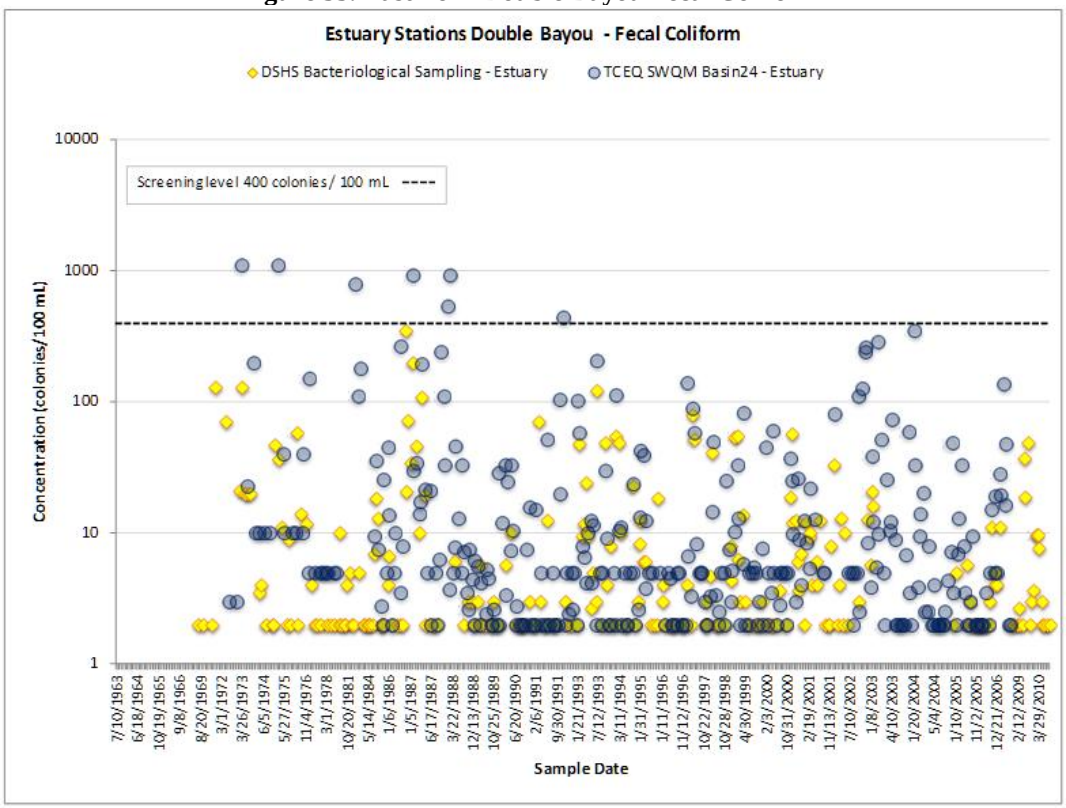


Figure 36. Estuary Stations Double Bayou Watershed Fecal Coliform

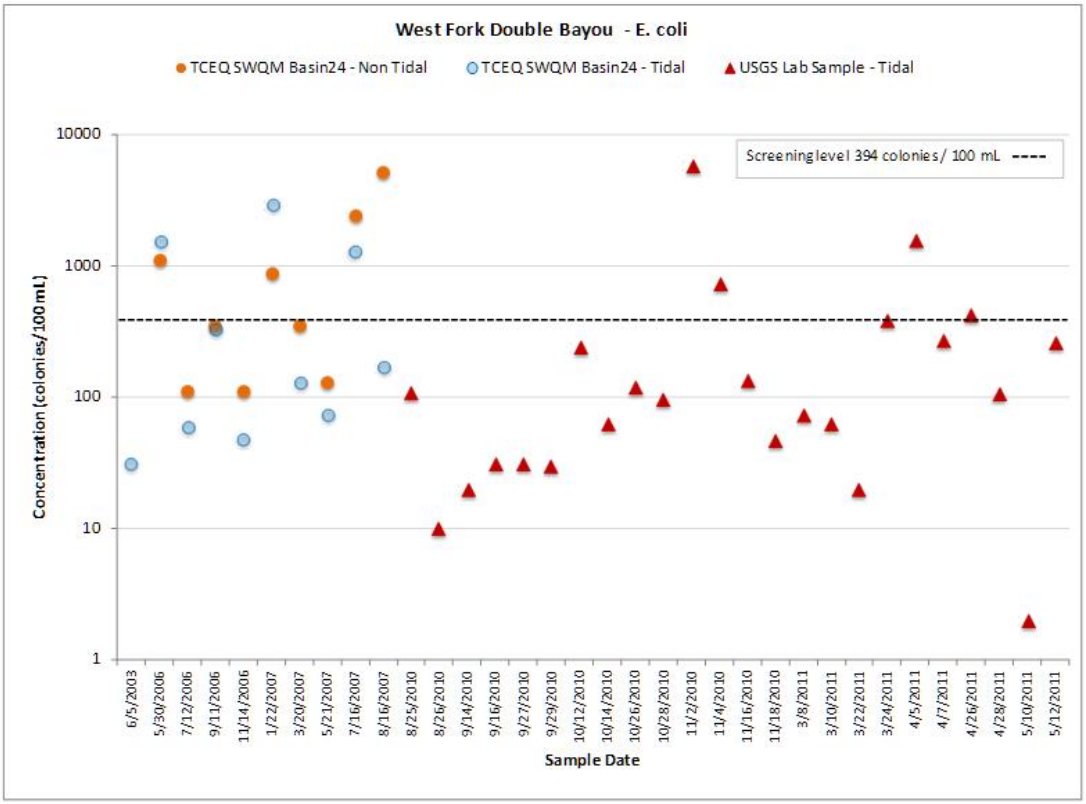


Figure 37. West Fork Double Bayou *E. coli*

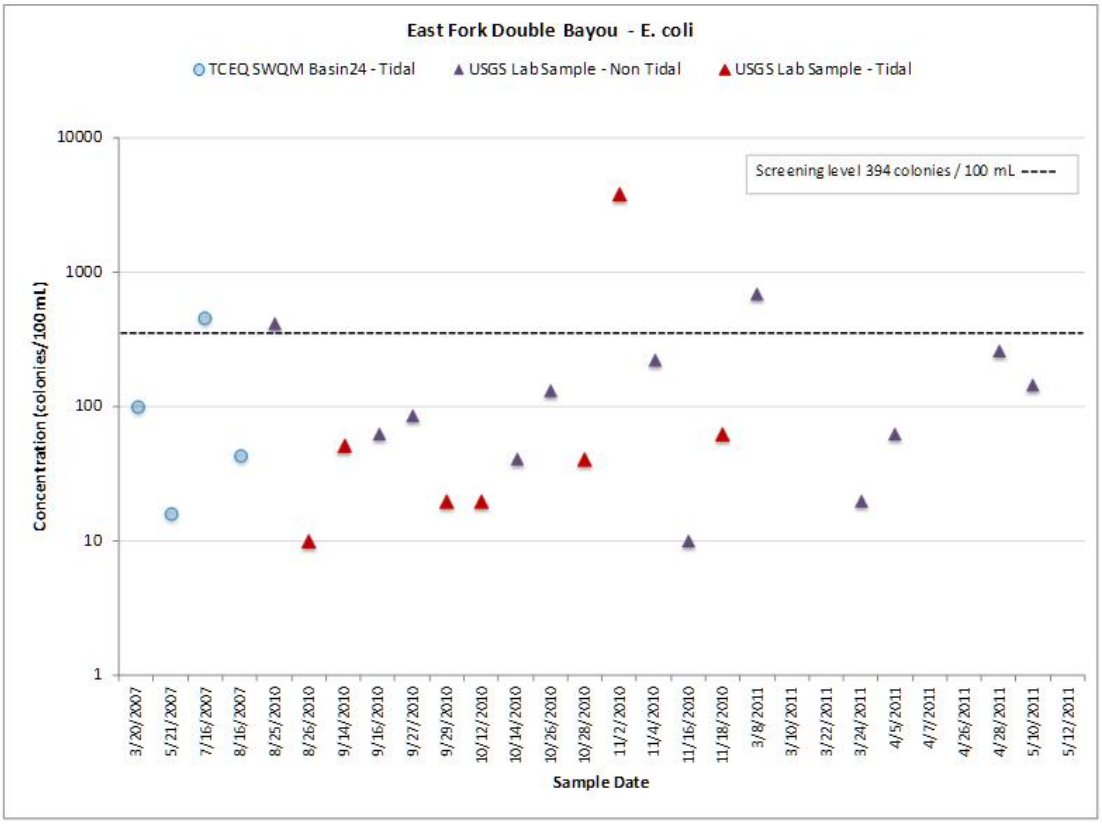


Figure 38. East Fork Double Bayou *E. Coli*

Nutrients and Chlorophyll-a

Chlorophyll-a samples showed exceedances over criteria levels for all sampling stations in the Fall and WFL 558 in the Spring (Figures 39 and 40). High levels of chlorophyll-a can indicate elevated concentrations of phytoplankton, (which may indicate an algal bloom and increased levels of nutrients). Nutrients remained under the screening levels during this sampling period.

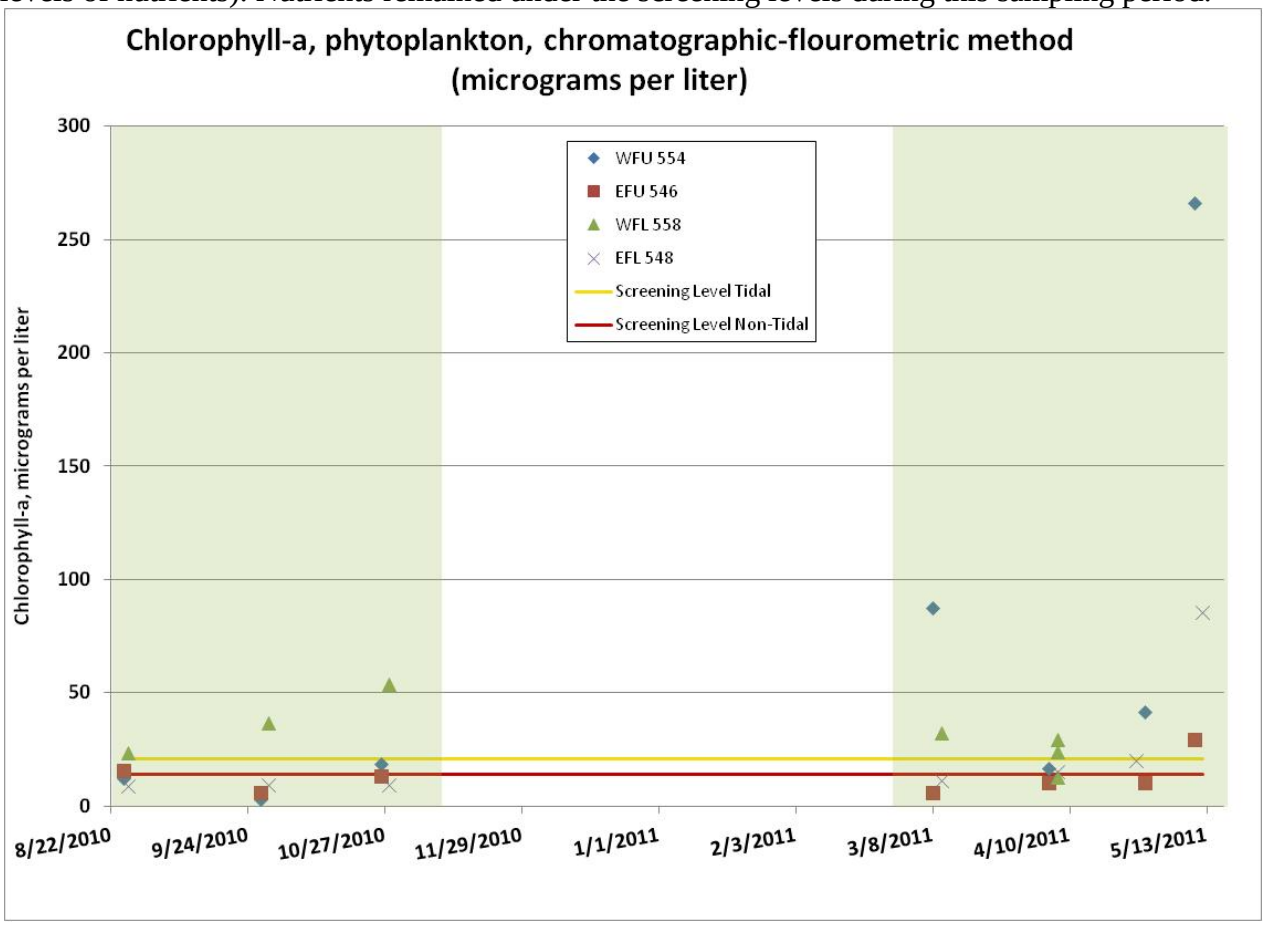
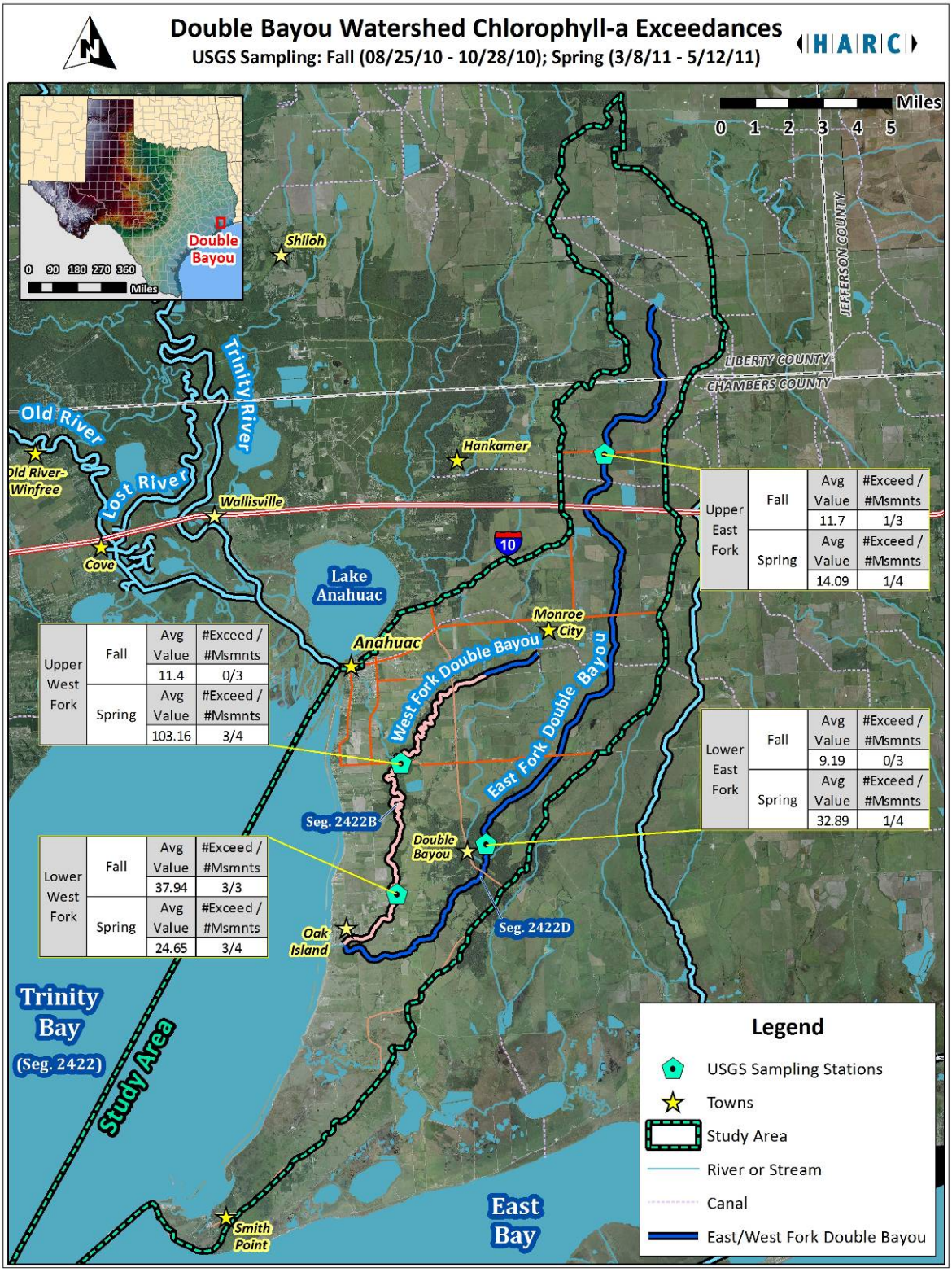


Figure 39. Chlorophyll-a in Double Bayou Watershed



Upper East Fork	Avg Value	#Exceed / #Msmnts
Fall	11.7	1/3
Spring	14.09	1/4

Upper West Fork	Avg Value	#Exceed / #Msmnts
Fall	11.4	0/3
Spring	103.16	3/4

Lower East Fork	Avg Value	#Exceed / #Msmnts
Fall	9.19	0/3
Spring	32.89	1/4

Lower West Fork	Avg Value	#Exceed / #Msmnts
Fall	37.94	3/3
Spring	24.65	3/4

Figure 40. Spatial Analysis of Double Bayou Chlorophyll-a Exceedances

The West Fork Double Bayou chlorophyll-a historical data set compared with the sampling data showed that the tidal portions of West Fork have consistently had samples over the screening criteria (Figure 41). The magnitude of one sample in particular from the sampling data is much higher than samples from the baseline data set; this could be due to a lack of precipitation – a similarly high sample on the same day was noted at East Fork Double Bayou (Figure 42) – the historic drought could be responsible for perturbation to the typical ecosystem to produce atypical results. Figure 43 show the historical data set for estuary stations in Double Bayou watershed. Higher magnitude samples seemed to be more problematic in the 1972-1978 time period. Results over the screening levels are pretty consistent for the 2000's. Figures 44 and 45 display the spatial results for the baseline data for chlorophyll-a in the Double Bayou watershed (does not include the current sampling results).

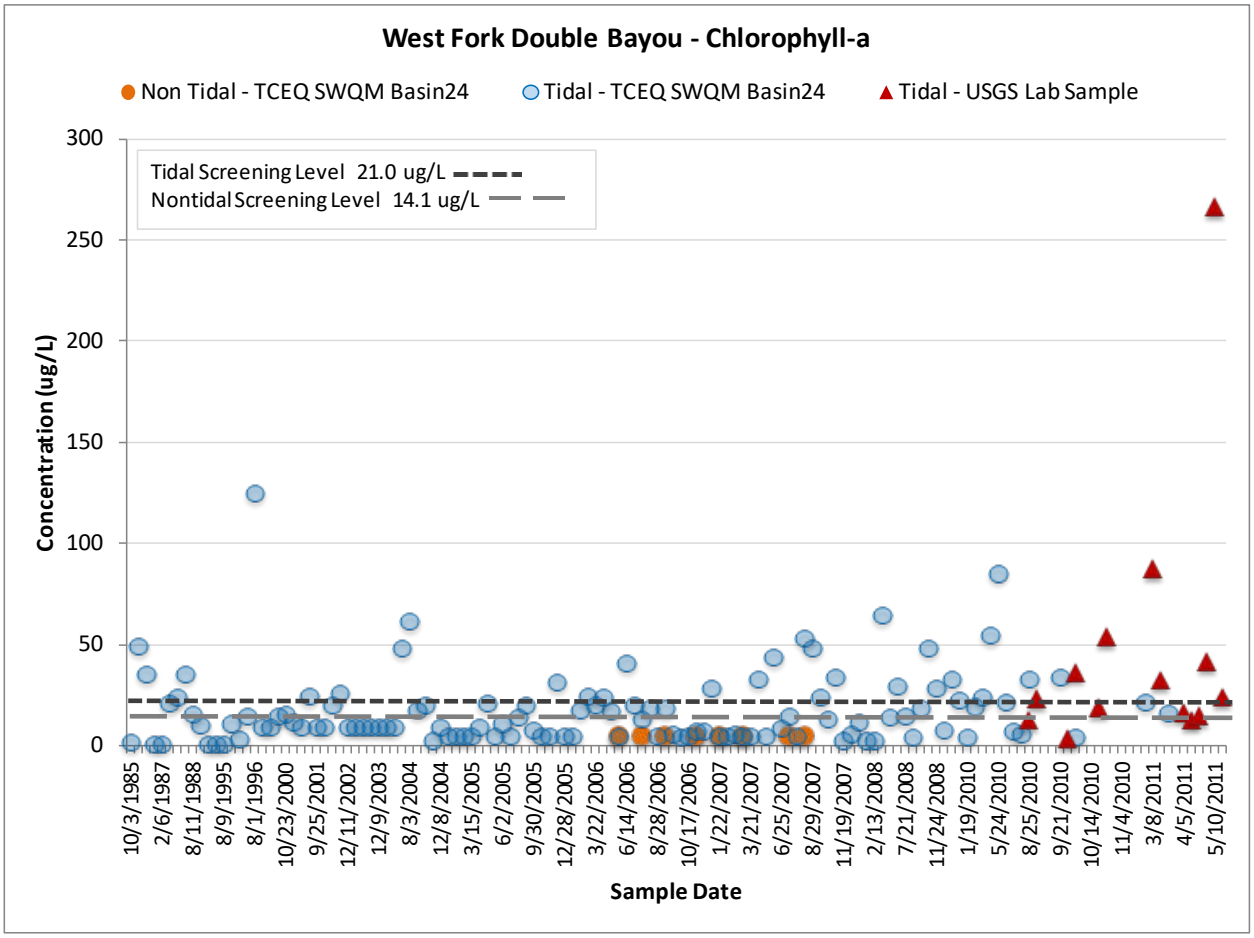


Figure 41. Chlorophyll-a in West Fork Double Bayou

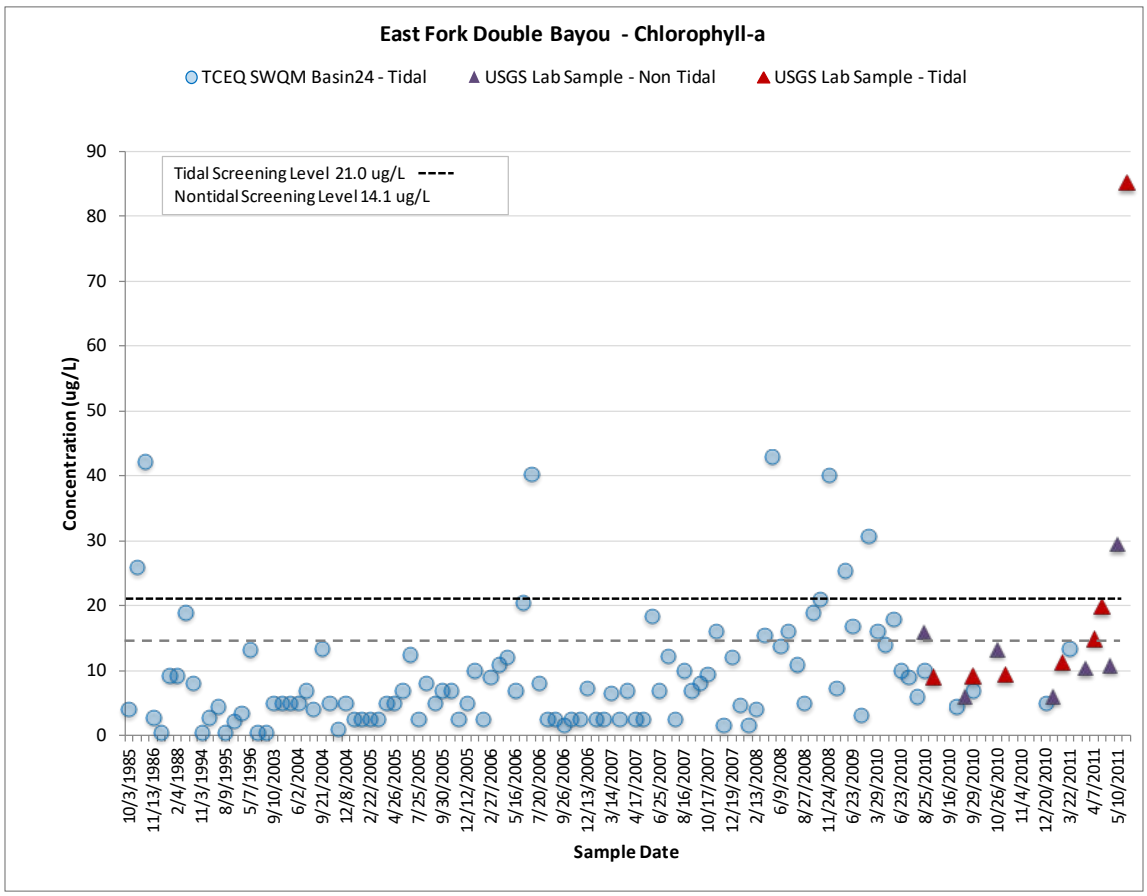


Figure 42. Chlorophyll-a in East Fork Double Bayou

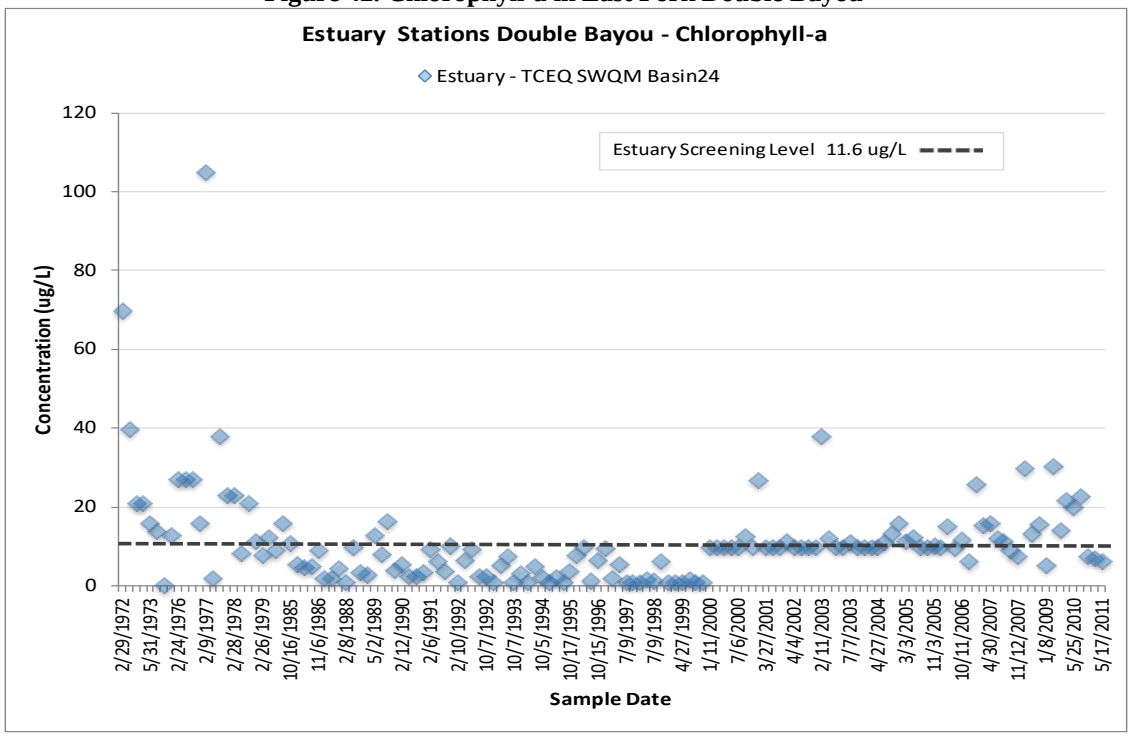


Figure 43. Estuary Stations Double Bayou Watershed Chlorophyll-a

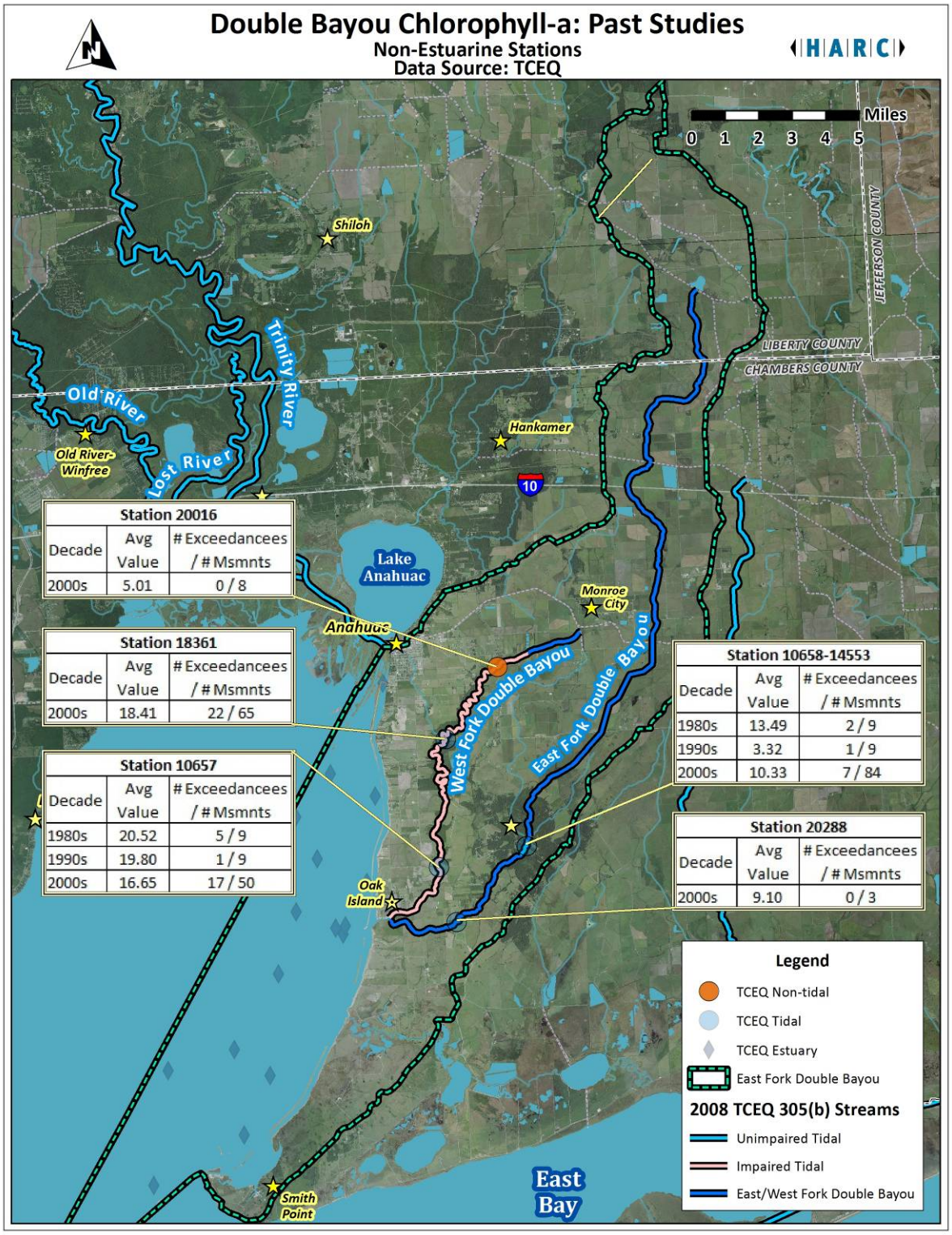


Figure 44. Chlorophyll-a in Double Bayou Watershed – Past Studies Non-Estuarine Station Results

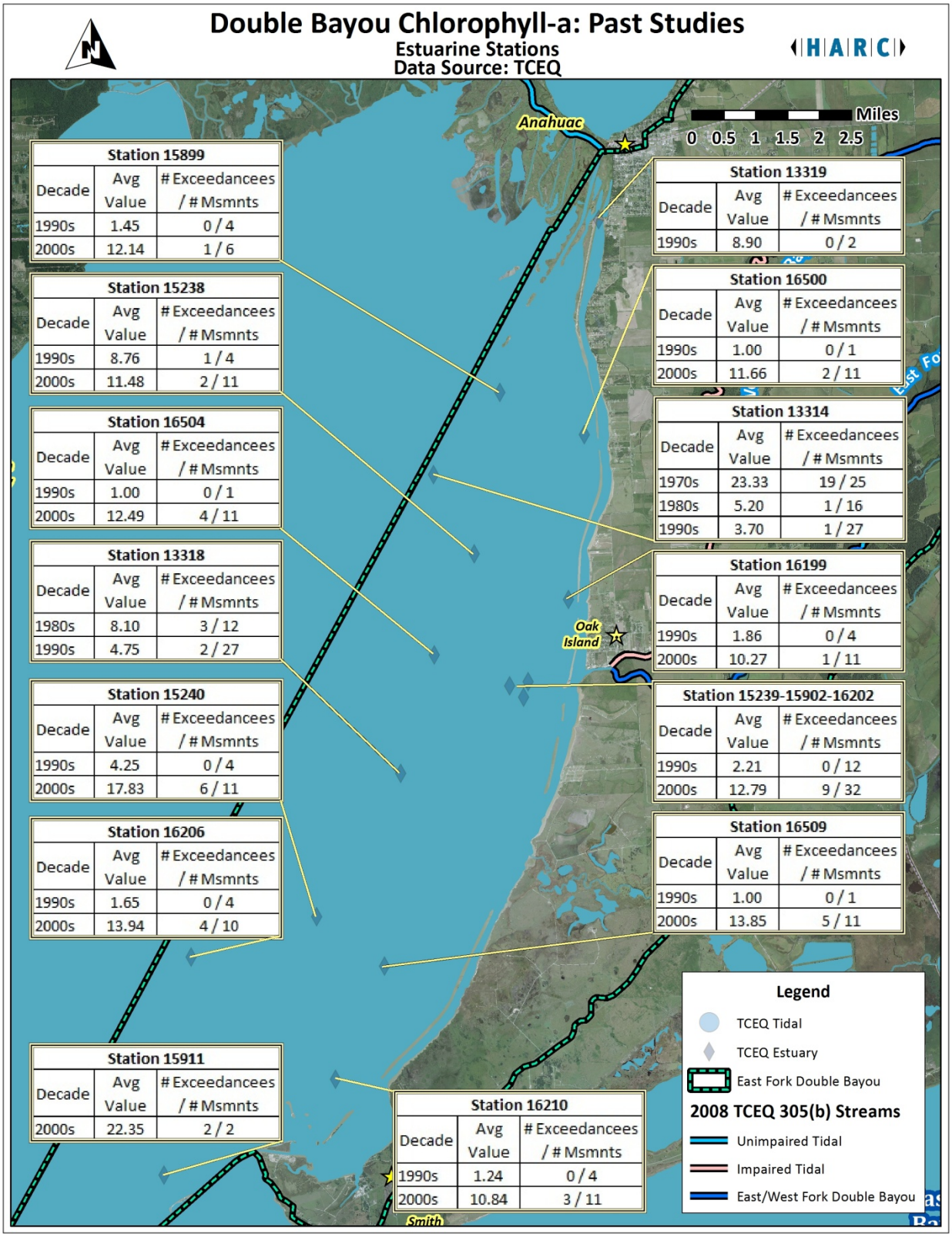


Figure 45. Chlorophyll-a in Double Bayou Watershed – Past Studies Estuarine Station Results

Nitrite, Orthophosphate and Phosphorus samples all showed levels below the screening levels for both sampling seasons; phosphorus samples were much higher in the Spring at WFU 554 (Figures 46-48).

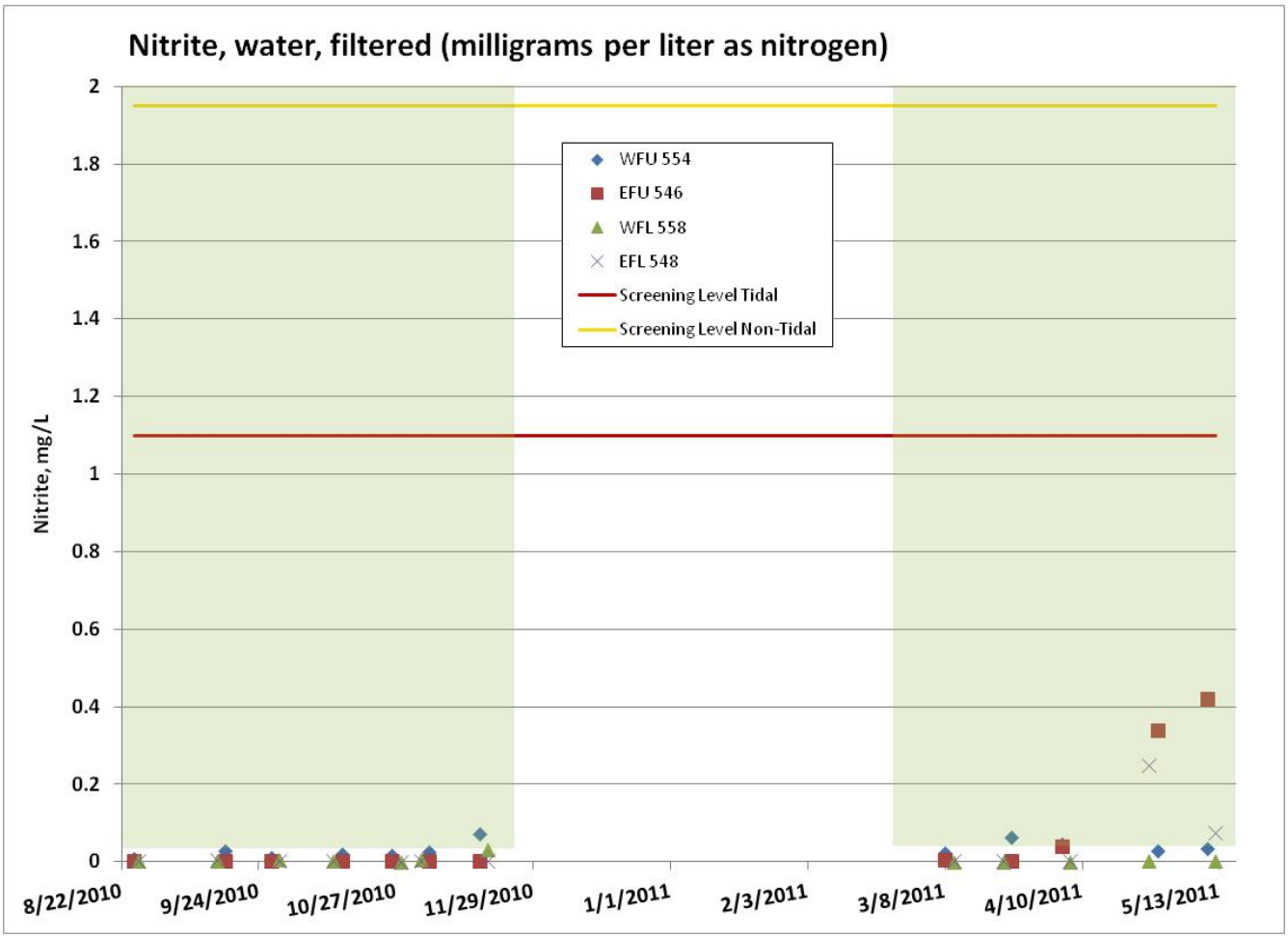


Figure 46. Nitrite in Double Bayou Watershed during sampling periods

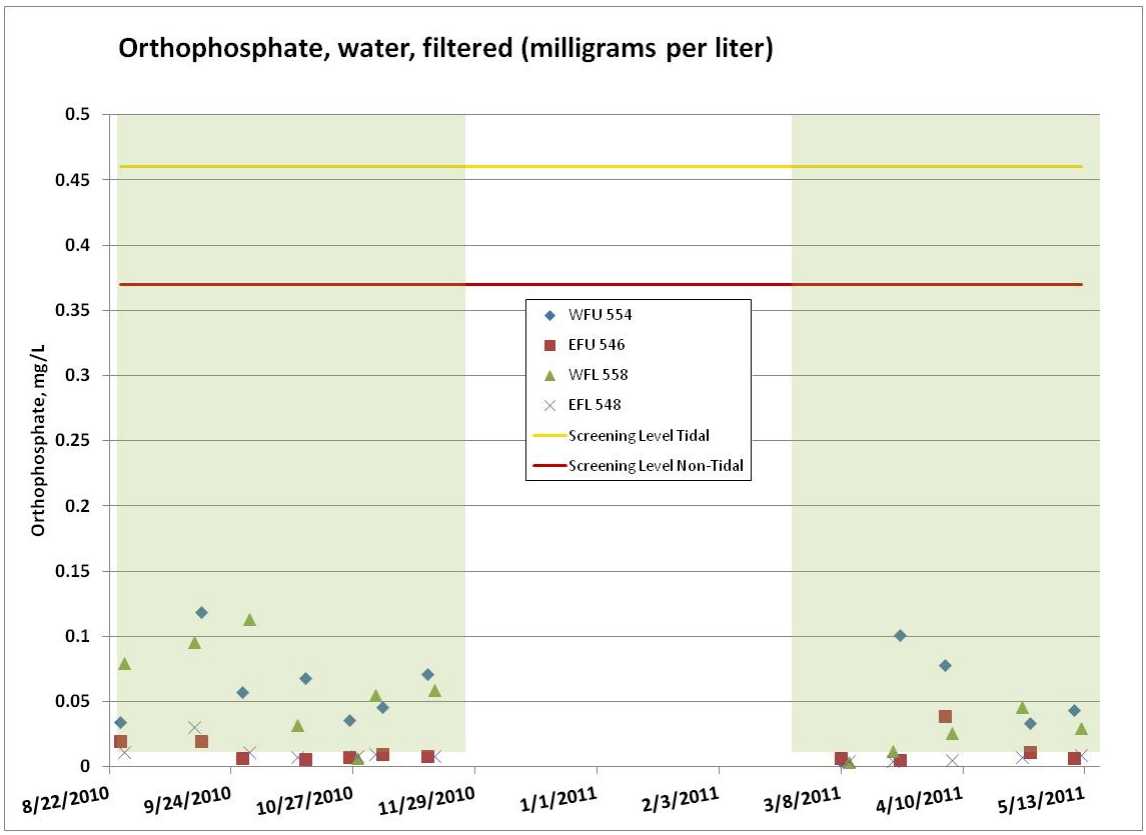


Figure 47. Orthophosphate in Double Bayou Watershed during the sampling periods

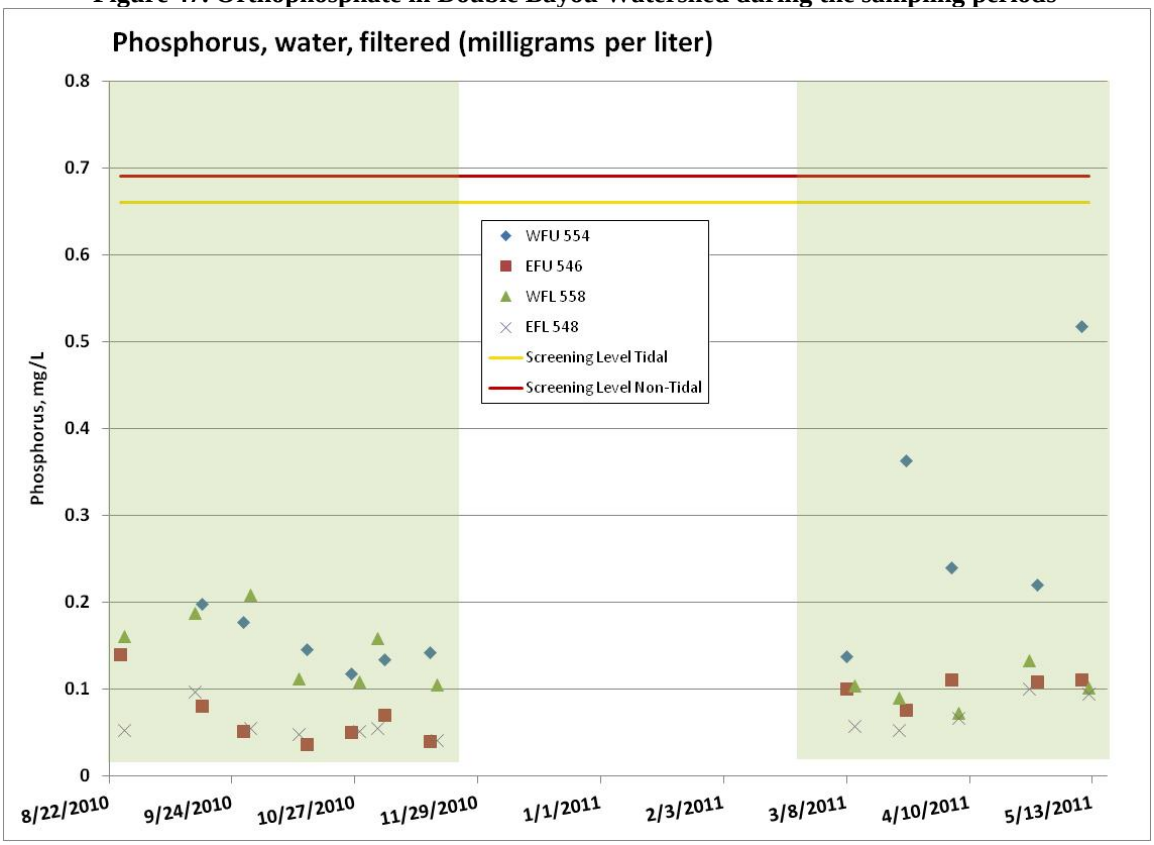


Figure 48. Phosphorus in Double Bayou Watershed during the sampling periods

Ammonia samples were much higher during the Spring sampling period (Figure 49), WFU 554, EFL 548 and EFU 546 all had samples over the screening levels; EFU 546 had a maximum sample of 2.67 mg/L. Figure 50 displays the results spatially; EFU 546 had the most exceedances (during the Spring sampling period) and WFU 554 had the next highest amount of exceedances (again, during the Spring sampling period).

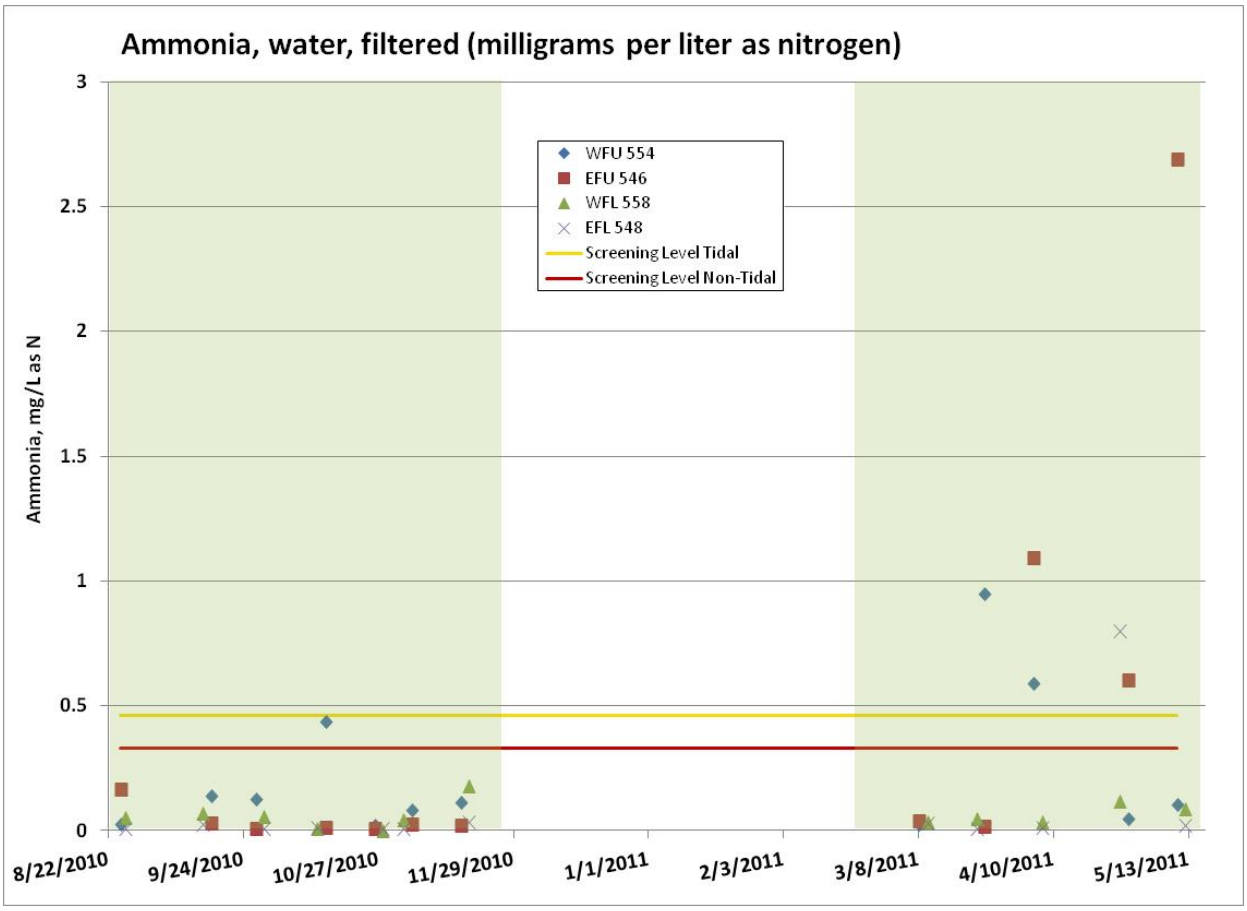


Figure 49. Ammonia in Double Bayou Watershed during the sampling periods

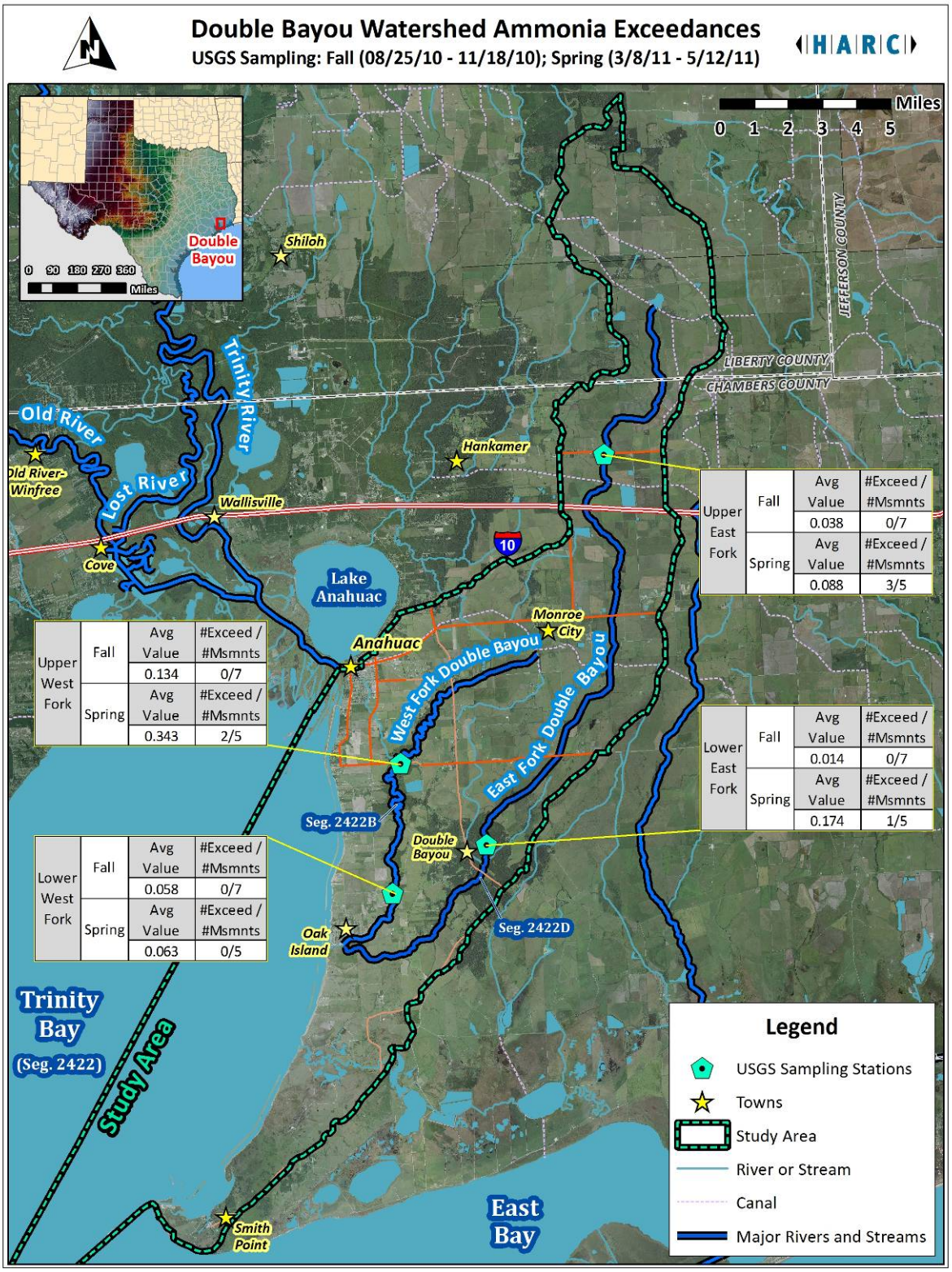


Figure 50. Spatial representation of ammonia in Double Bayou Watershed during the sampling periods

Nitrite, Orthophosphate, Phosphorus and Ammonia were analyzed for all existing data for the watershed (Figures 51-54). Phosphorus samples were much higher in the Spring at WFU 554, but levels have been higher in the past; TCEQ data reflect two instances in 2006 and 2007 where phosphorus samples exceeded the TCEQ Tidal screening level. USGS data from a previous study show an exceedance in 1972. Ammonia samples from the current study reflected some very high samples from both Tidal and Non-Tidal stations (both exceeding criteria limits). TCEQ and older USGS data also show some exceedances in the past, although the magnitude of exceedance is greater from the current study's data set. Effluent exceedances from the Anahuac WWTP show exceedance permit violations for ammonia consistently. This could exacerbate the ammonia in the bayou for West Fork, but it would not be considered a source for the East Fork stations. Figures 55 and 56 display the spatial results for the baseline data for ammonia in the Double Bayou watershed (does not include the current sampling results). Figure 55 displays a trend toward more exceedance and higher average values in the 80's and 90's than the 00's, with a more pervasive problem in the East Fork. Figure 56 shows that ammonia is not a pervasive problem in the estuarine stations. One station in particular, 13314, did seem to get numerous exceedances in the 70's and 80's, but the numbers were better in the 90's. Stations closer the shoreline showed some minor exceedances.

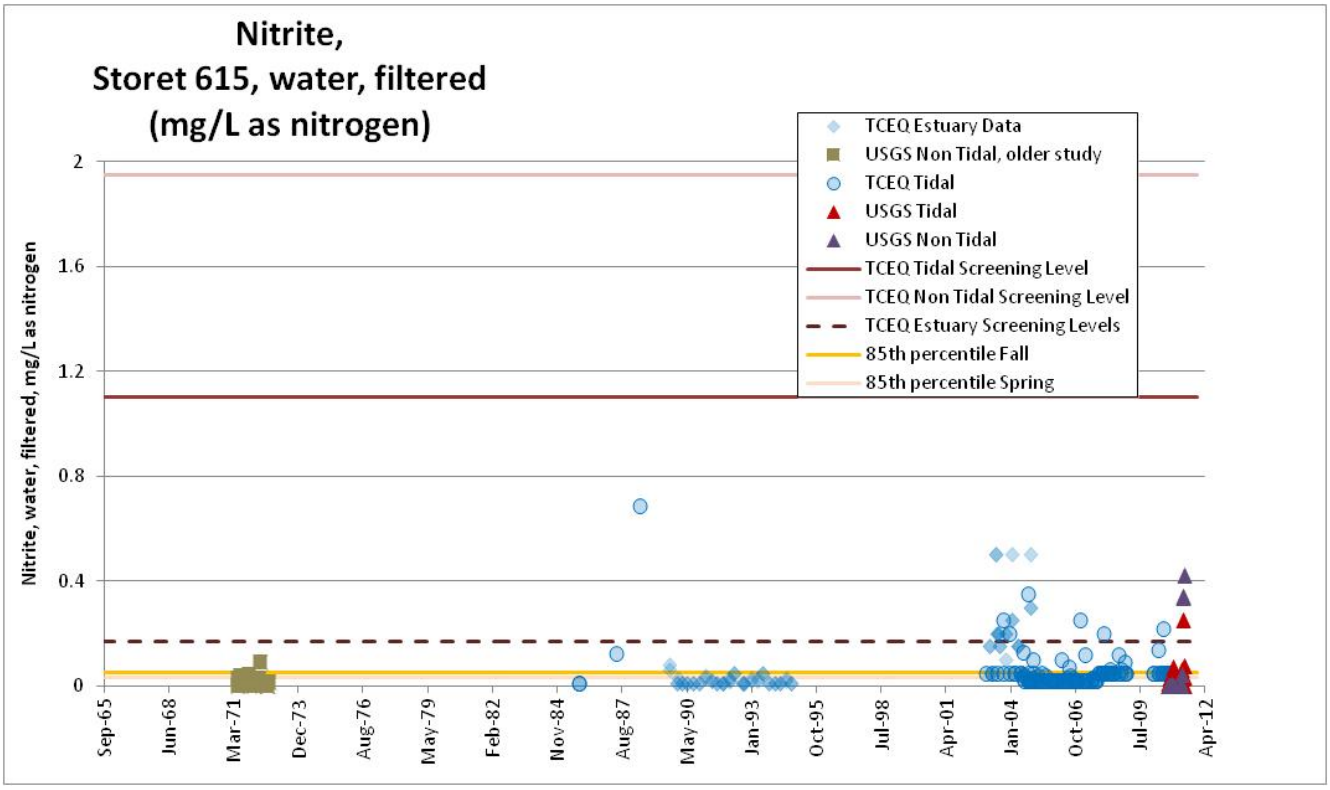


Figure 51. Nitrite in Double Bayou Watershed

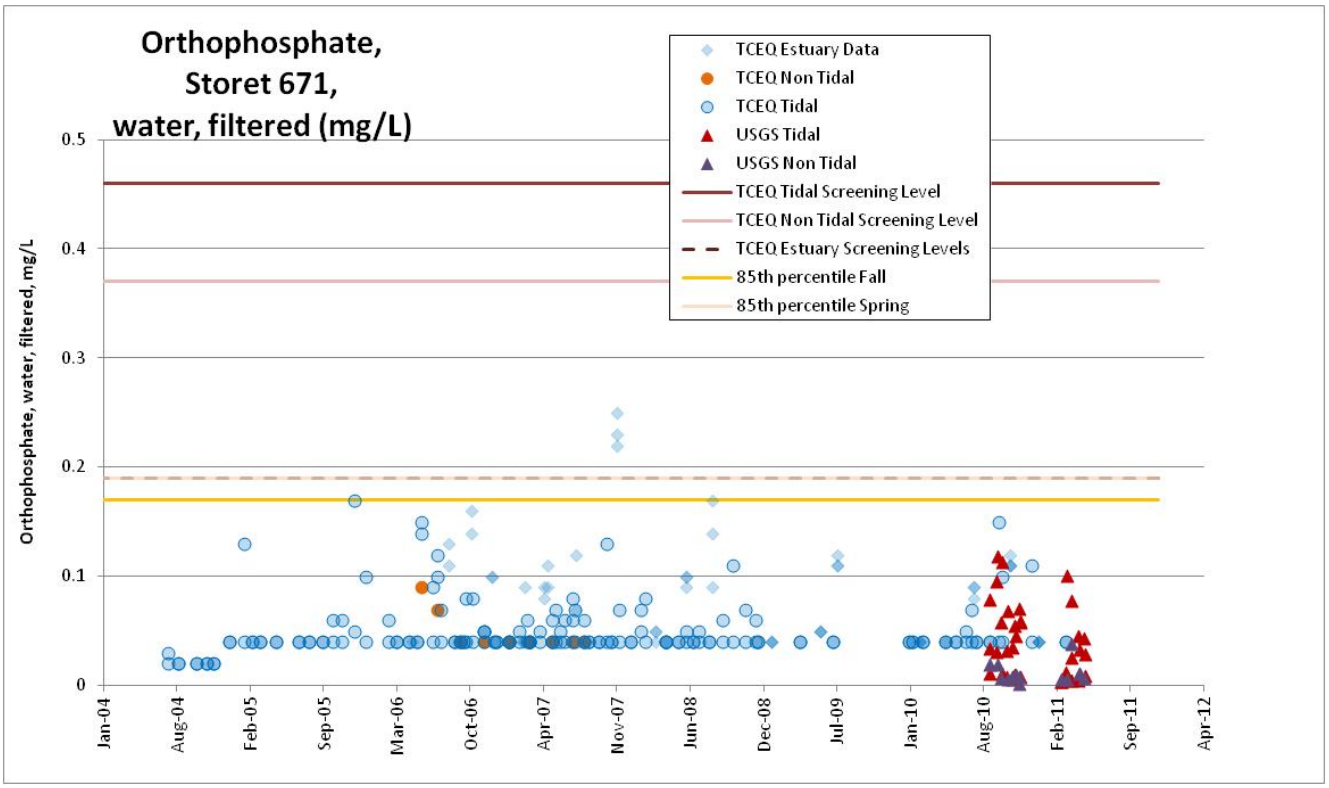


Figure 52. Orthophosphate in Double Bayou Watershed

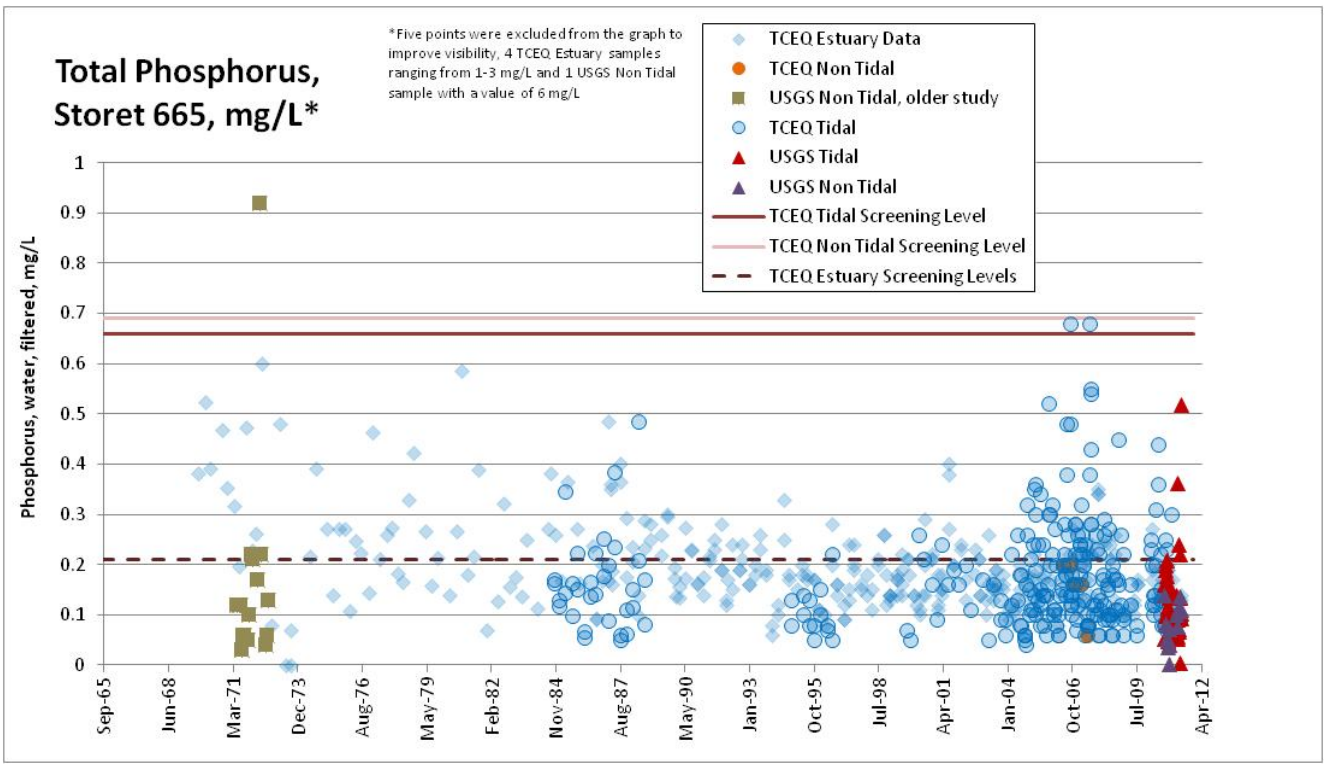


Figure 53. Phosphorus in Double Bayou Watershed

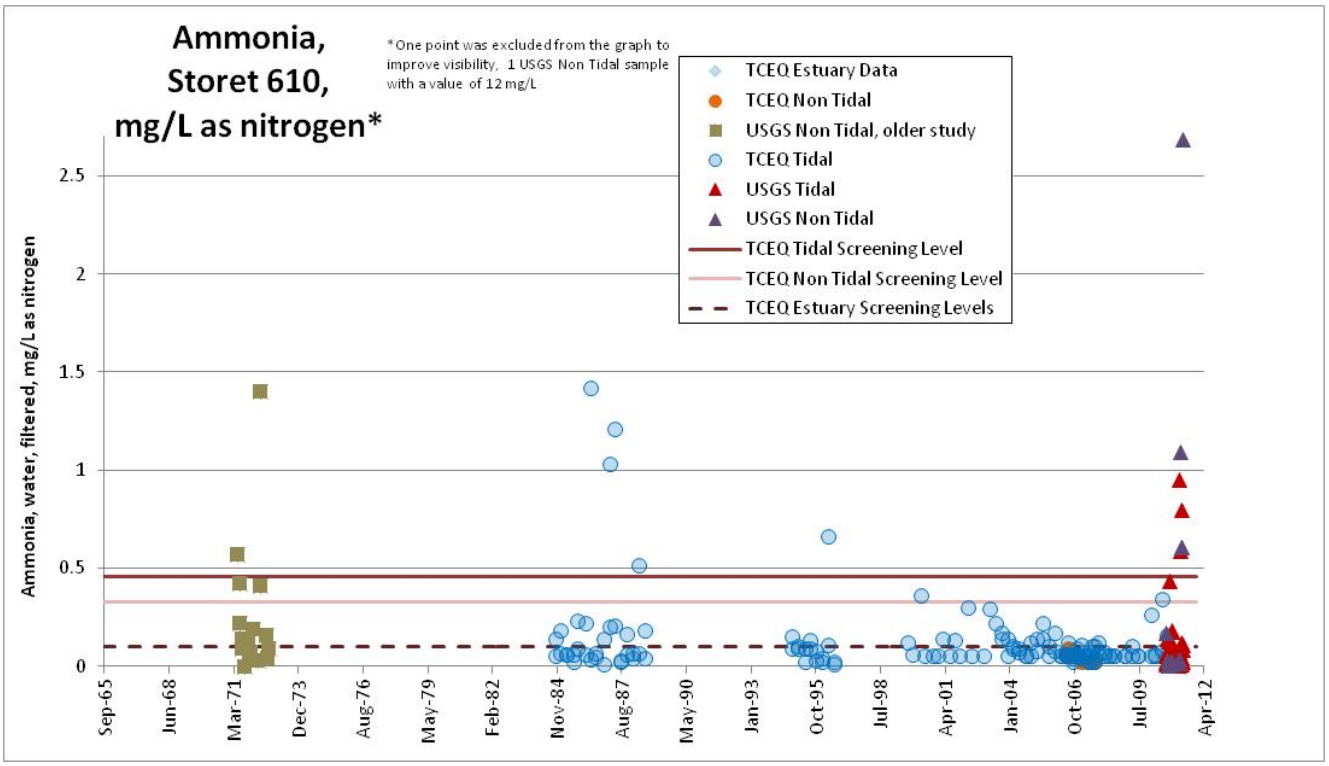


Figure 54. Ammonia in Double Bayou Watershed

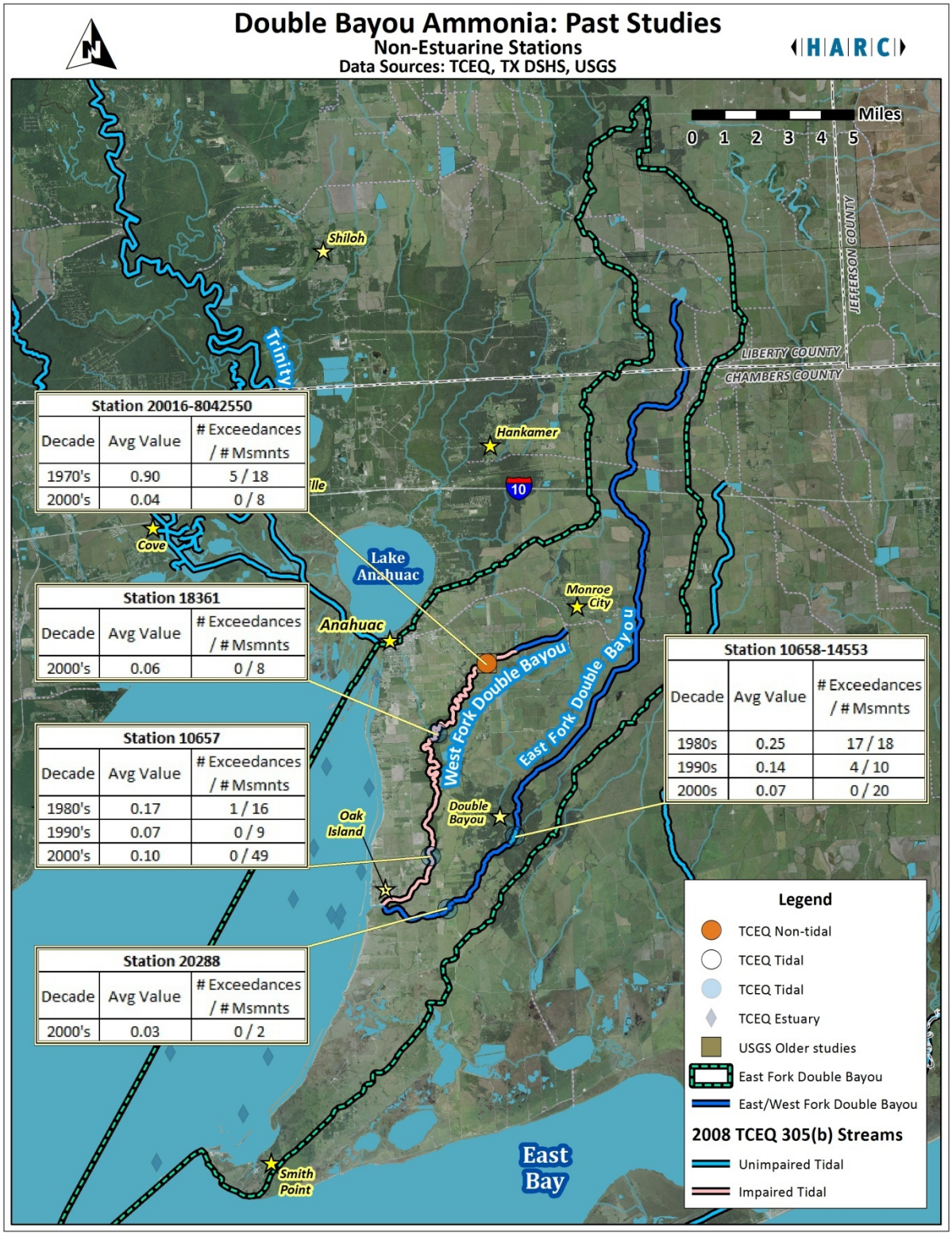


Figure 55. Ammonia in Double Bayou Watershed – Past Studies Non-estuarine Station Results

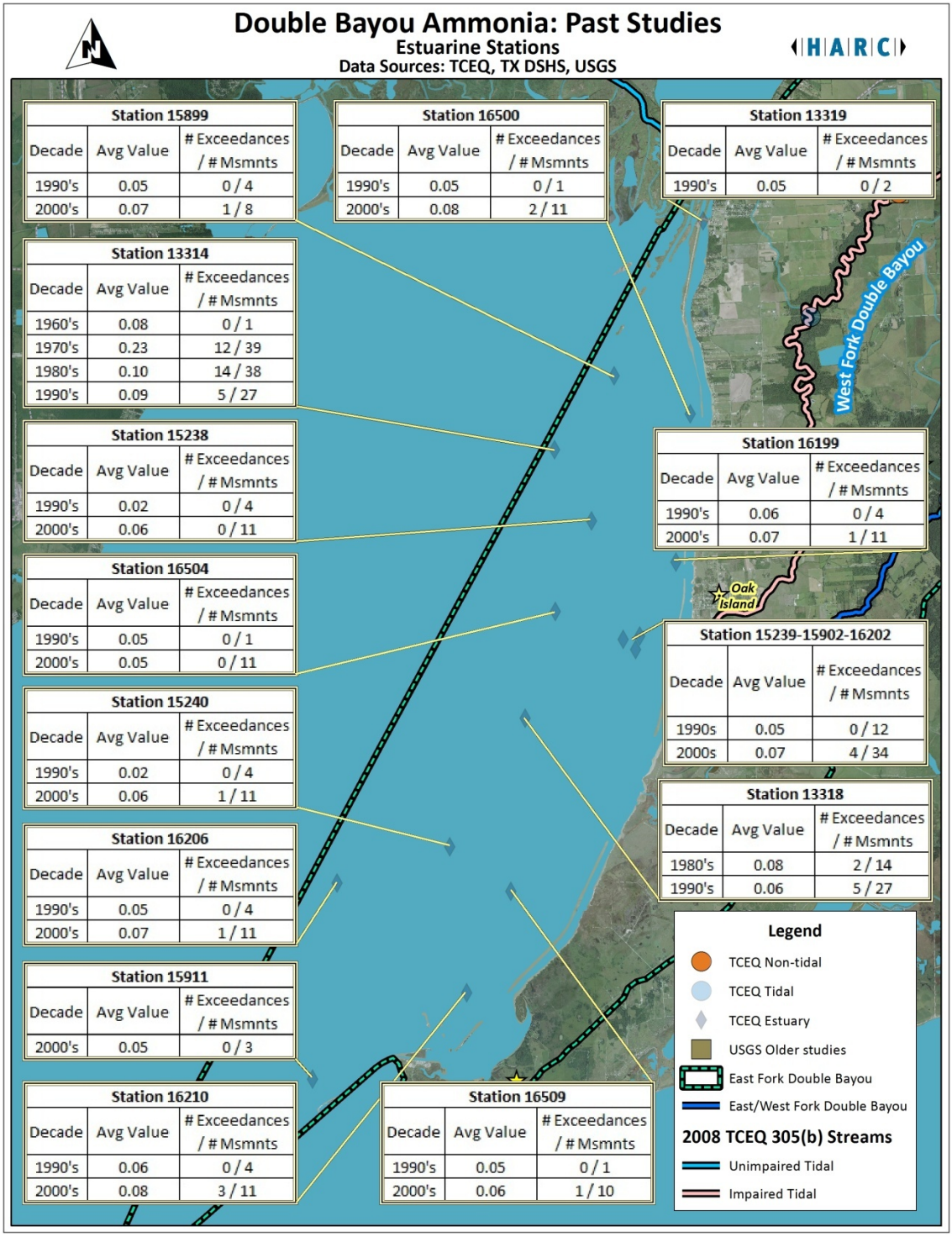


Figure 56. Ammonia in Double Bayou Watershed – Past Studies Estuarine Station Results

<u>pH, Chloride, Sulfate and Total Dissolved Solids</u>

There was not a great variation among the sampling stations for pH during the 24-hour sampling period for Fall and Spring (Figure 57). The range for all stations in Double Bayou during this sampling period was 6.4-8.7.

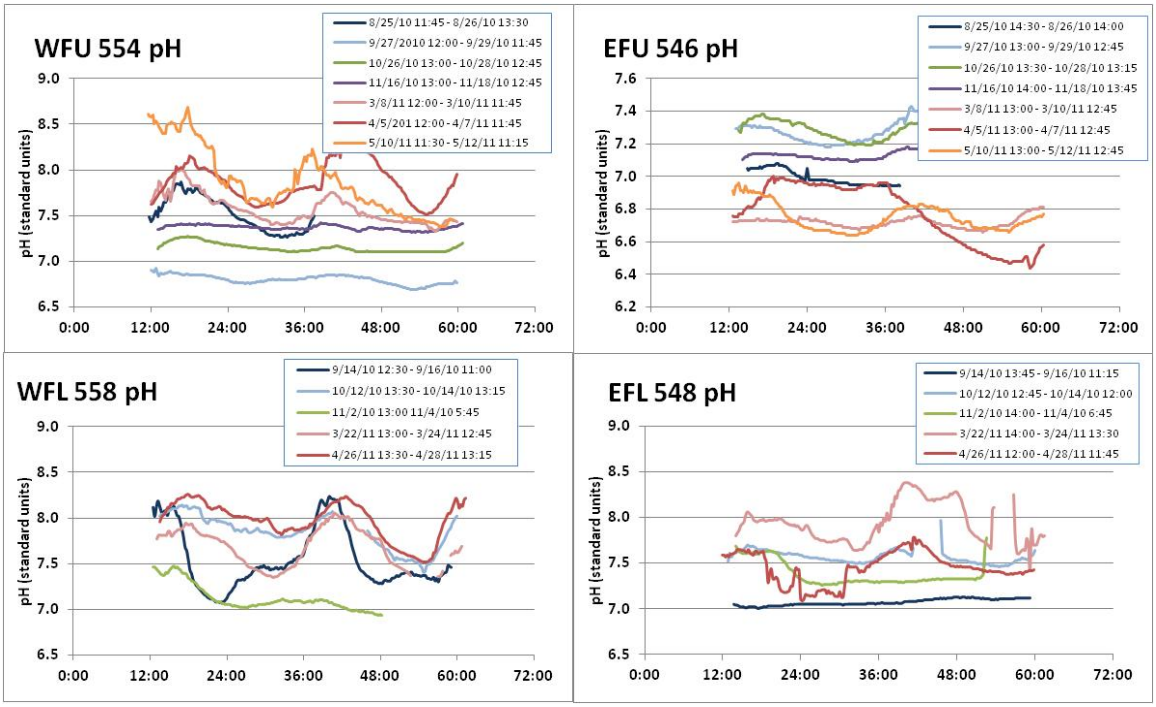


Figure 57. Temporal pH patterns during the sampling period

Total Dissolved Solids (TDS), measured as Residue on Evaporation was highest at WFL 558 during both seasons (Figure 58). Spring samples at WFL 558 were much higher than the fall samples. Chloride and Sulfate followed this same trend, with the highest measured samples at WFL 558 during both season and spring samples much higher at WFL 588 than the fall samples (Figures 59 and 60). 85th percentile calculations show a general trend in surrounding bayous for TDS, Chloride and Sulfate to be lower in the Spring. The sample levels are fairly consistent with the historic baseline data set for the watershed (Figures 61-63).

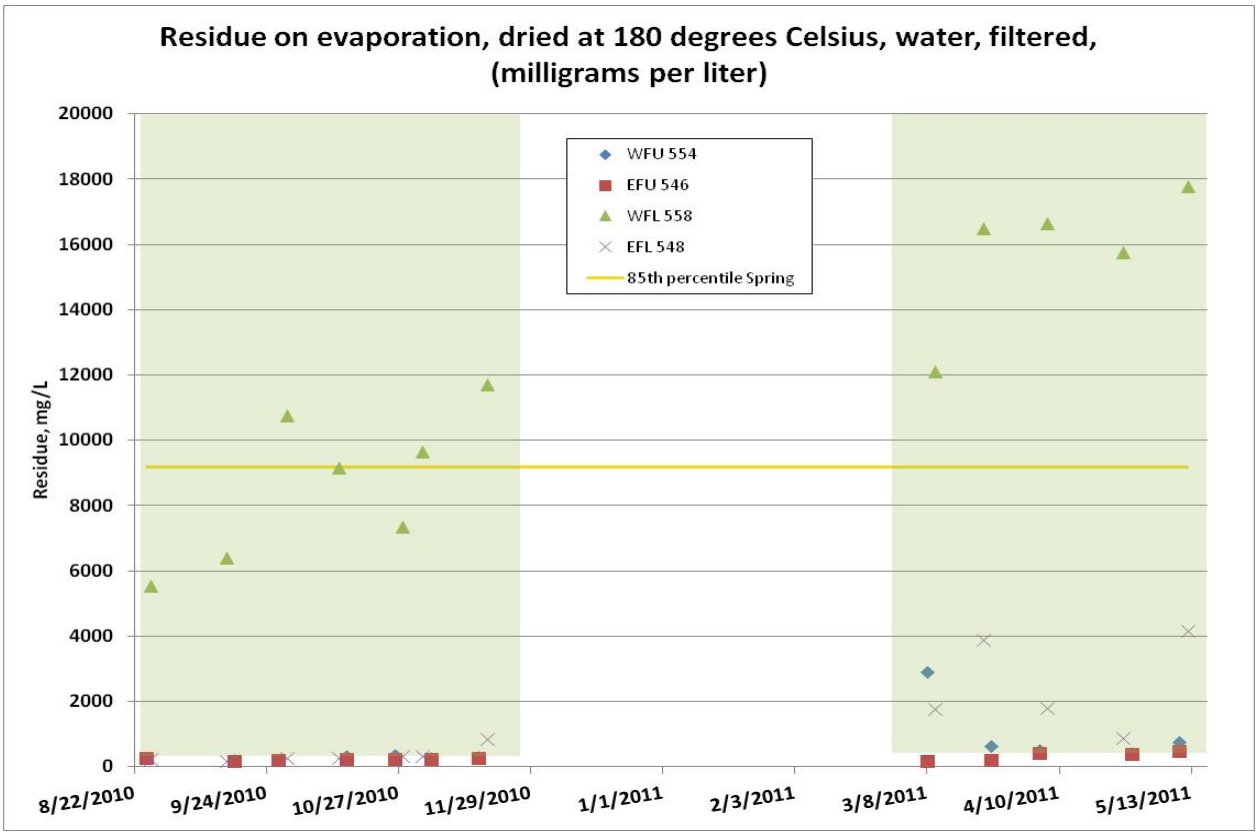


Figure 58. Total Dissolved Solids for Double Bayou Watershed during sampling periods

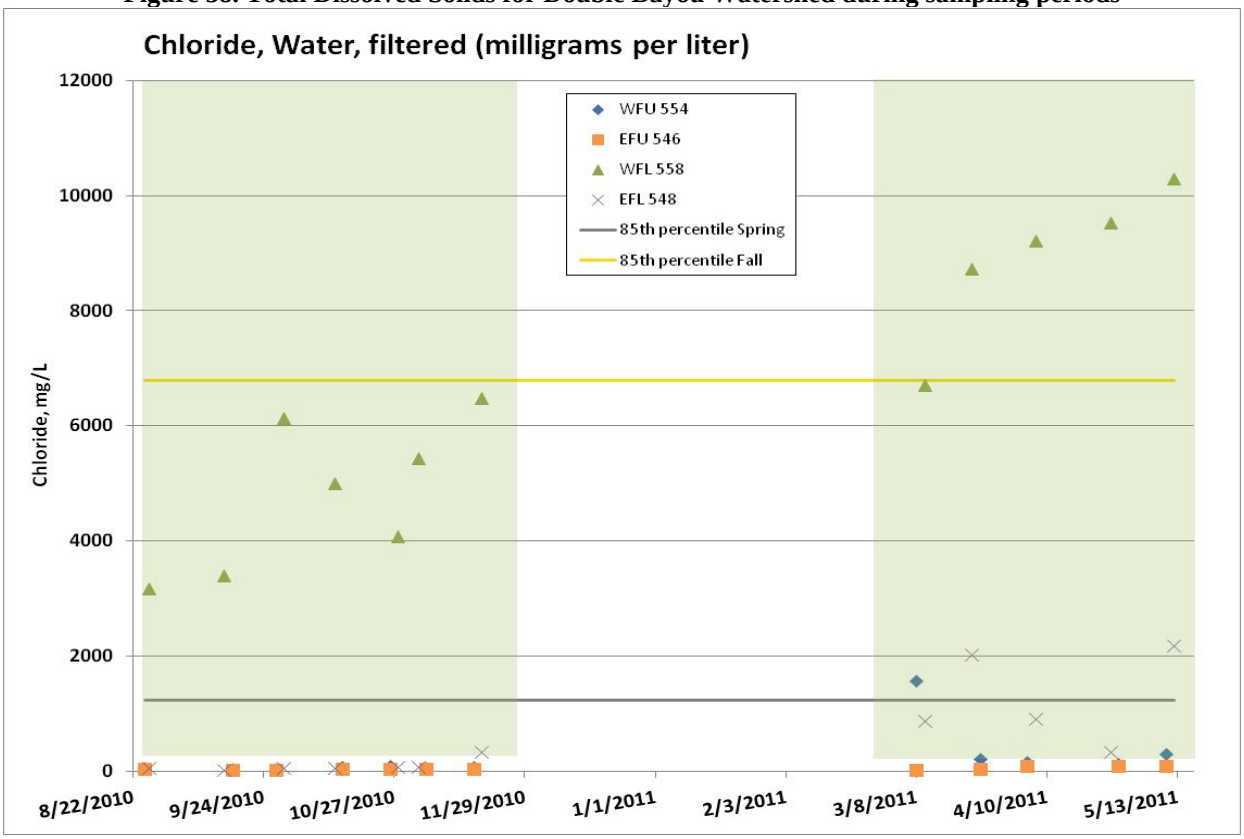


Figure 59. Chloride in Double Bayou Watershed during the sampling periods

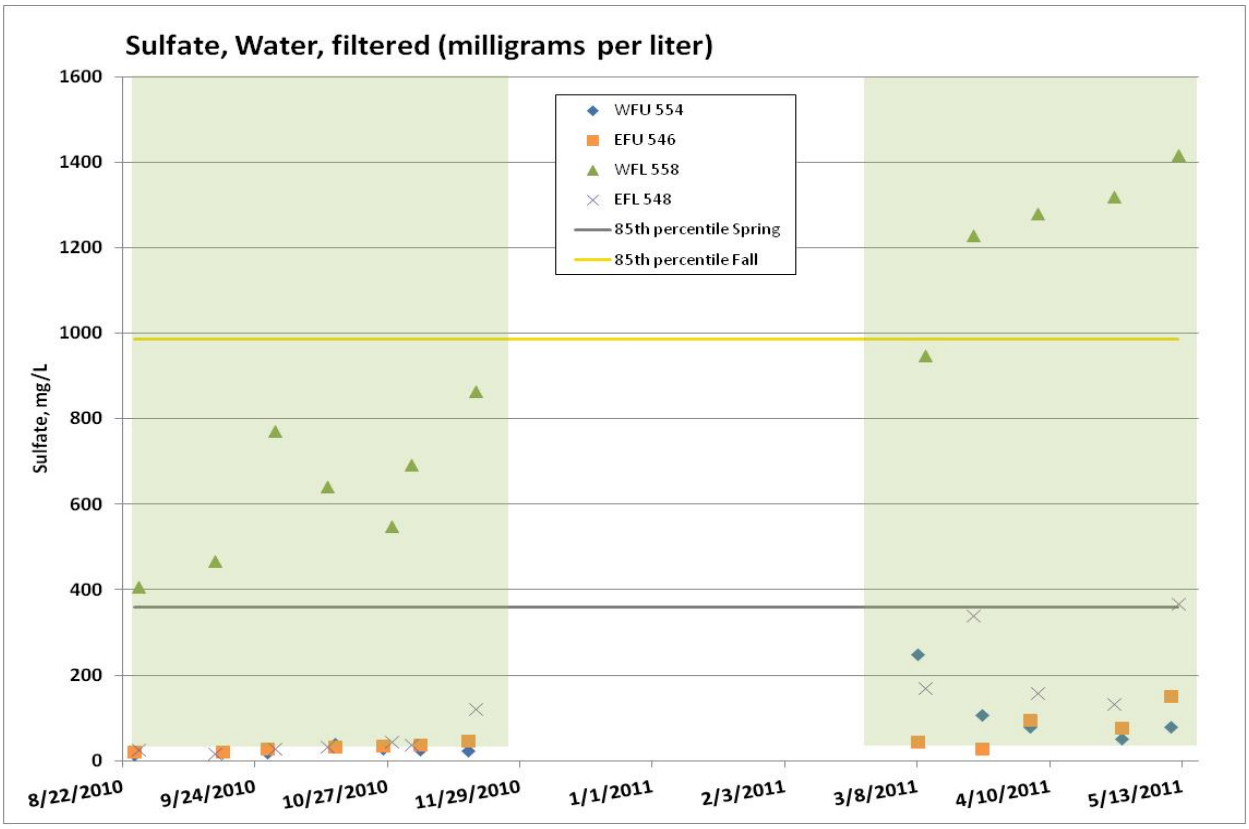


Figure 60. Sulfate in Double Bayou Watershed during sampling periods

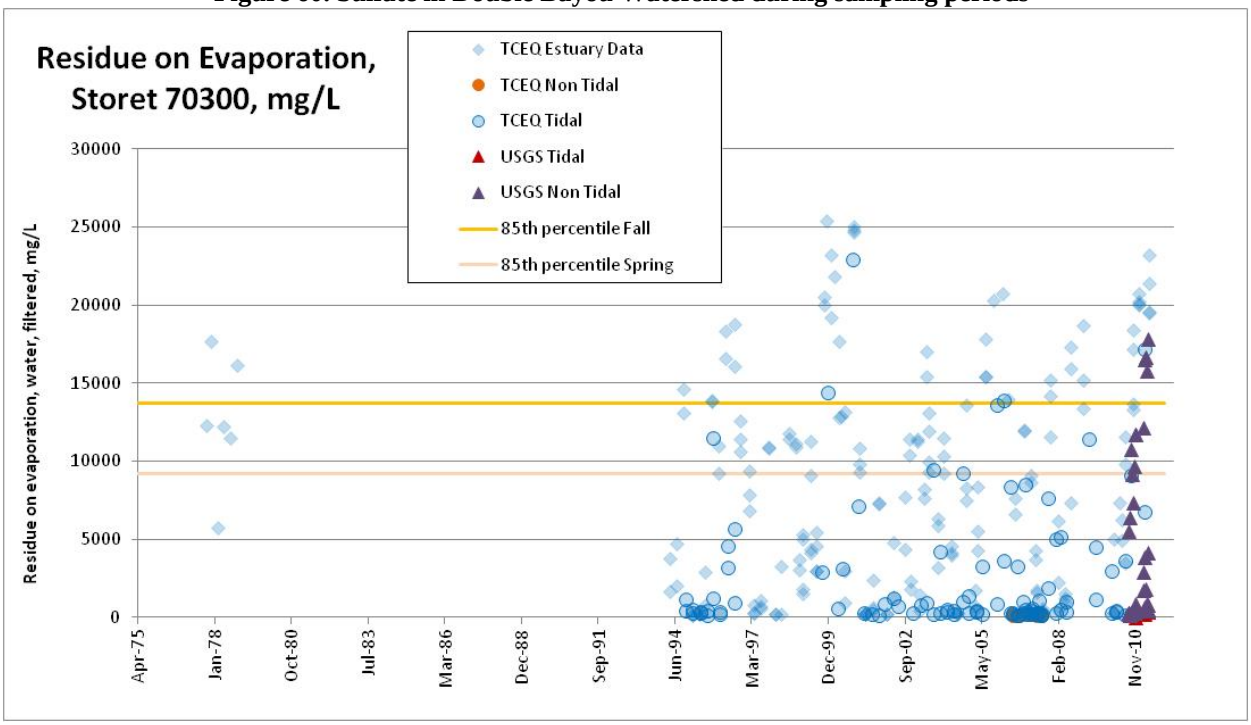


Figure 61. Total Dissolved Solids for Double Bayou Watershed

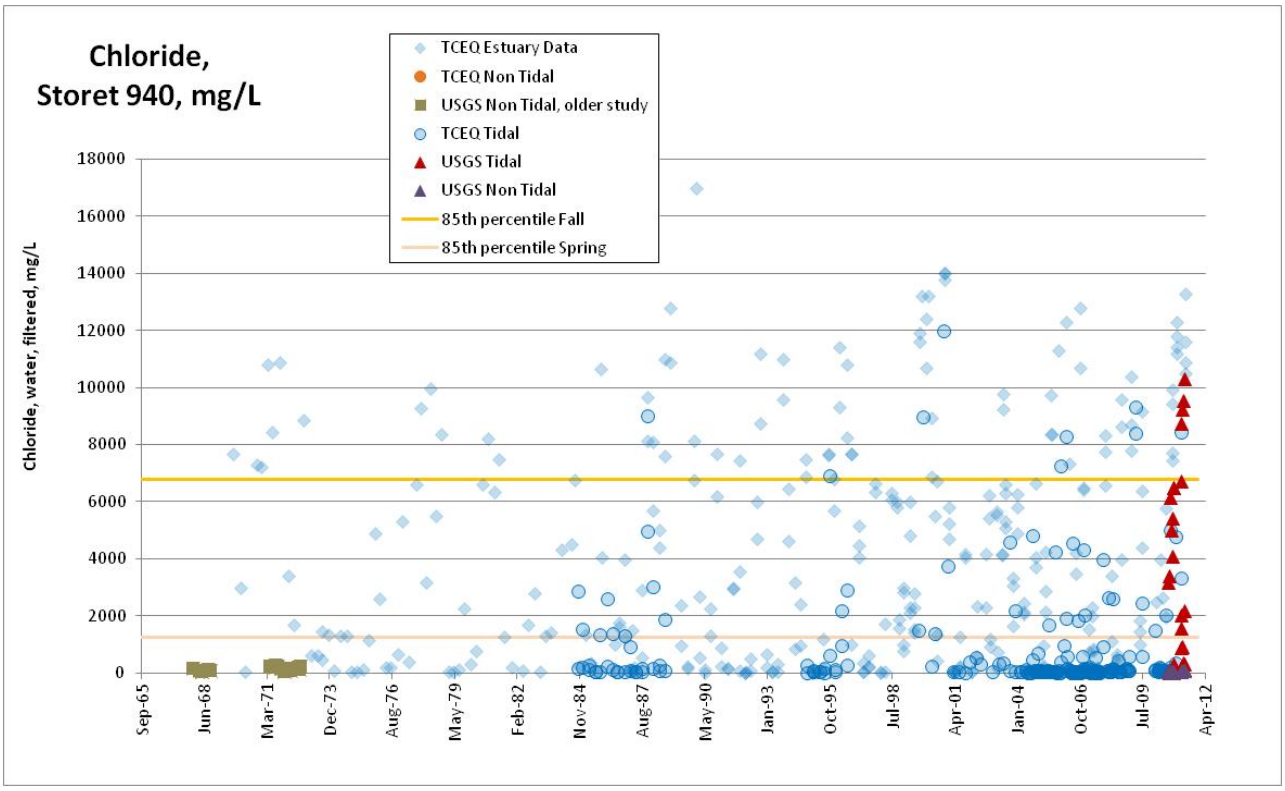


Figure 62. Chloride in Double Bayou Watershed

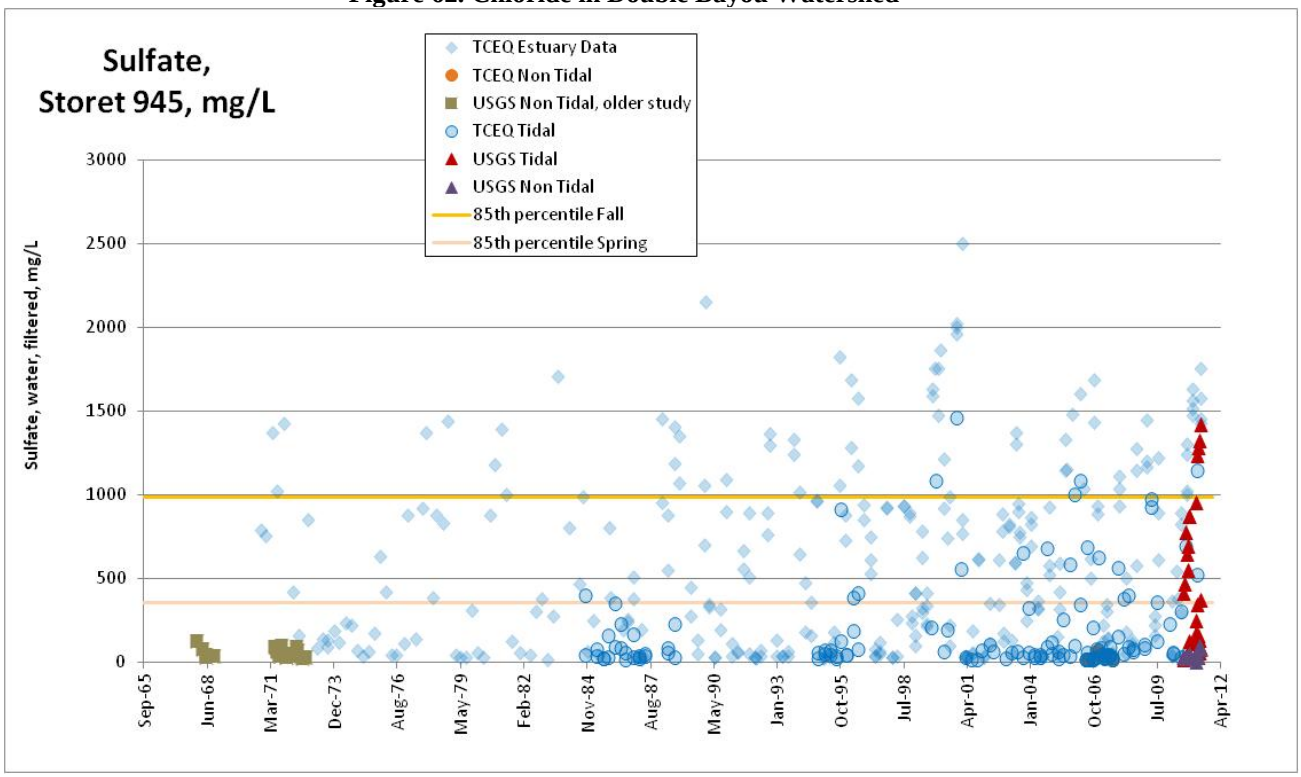


Figure 63. Sulfate in Double Bayou Watershed

Summary

Table 5 displays the parameters that had exceedances during the sampling periods and their corresponding sampling stations. Note that sulfates, chlorides and TDS were all extremely high at WFU 554 when compared with the Spring 85th percentile data.

Table 5. Sampling Period Exceedances for Double Bayou

Station	Station Type	Parameters with Screening Level Exceedances during sampling periods
WFU 554	Tidal	Bacteria, Dissolved Oxygen, Chlorophyll-a, Ammonia
WFL 558	Tidal	Bacteria, Chlorophyll-a
EFU 546	Non-Tidal	Bacteria, Dissolved Oxygen, Chlorophyll-a, Ammonia
EFL 548	Tidal	Bacteria, Dissolved Oxygen, Chlorophyll-a, Ammonia

Extremely low DO was a problem for all stations during the sampling periods except for WFL 558. EFU 546 had 24-hour sampling periods in both the Fall and Spring, and EFL 548 in the Spring, where sample minimums got down to less than 1.0 mg/L. Comparing historic DO sample data with the recent study sampling data shows low DO samples are consistent across time for both East Fork and West Fork, although this is the first study to have non-tidal DO samples results for East Fork.

Elevated bacteria levels were found at all stations during the sampling periods. Comparing historic data with the recent sampling data shows bacteria samples have consistently measured above screening levels in both bayous.

Elevated chlorophyll-a levels were found at all stations. Elevated ammonia levels were much higher in the Spring and found at WFU 554, EFU 546 and EFL 548. Ammonia in the bayous could be present due to increased bacteria concentrations, decay of plant or animal material; in addition, ammonia can also come from domestic or agricultural pollution, primarily from fertilizers, organic matter or fecal matter. Comparing current sampling data to the historic baseline data set showed that elevated ammonia has been a problem in the past.

TDS, Sulfate, and Chloride, have their highest measured values at WFL 558 for both Fall and Spring. Pheophytin-a (a breakdown product of chlorophyll-a), chlorophyll-a, Enterococci and *E. coli* have highest measured values at WFU 554 in the Fall. Pheophytin-a, chlorophyll-a and *E. coli* have highest measured values at WFL 558 in the Spring

Linear regression analysis for all lab parameters from the combined sampling periods displayed typical correlations (Figure 64). For example, TDS is highly correlated with Chloride and Sulfate, which are also highly correlated with each other. The Nitrogen, Ammonia, Nitrite and Nitrite plus Nitrate groups are highly correlated with each other. Fecal, *E. coli* and Enterococci are highly correlated with each other. Phosphorus did display a higher correlation with chlorophyll-a and Pheophytin-a, suggesting a relationship. Atrazine displayed a higher correlation with pH, DO, Turbidity and Fecal and Total Coliform. Atrazine levels were not very high during either of the sampling time periods. This could be due to the numerous amounts of

non-detects picked up for Atrazine during the sampling period. Constituent correlations with r^2 values higher than 0.30 are highlighted.

Figure 64. Linear Regression Analysis for Lab Sampling Parameters from Fall and Spring sampling

	Discharge	Water temp	Specific conductance	pH (standard units)	DO	Turbidity	Residue on evaporation, dried at 180	Chloride, Water, filtered (milligrams per	Sulfate, water, filtered (milligrams per	Ammonia, water, filtered (milligrams per	Nitrite plus nitrate, water, filtered (milligrams per	Nitrite, water, filtered (milligrams per	Orthophosphate, water, filtered (milligrams per	Phosphorus, water, filtered (milligrams per	Nitrogen, water, filtered (milligrams per	Atrazine, water, filtered, recoverable,	Chlorophyll-a, phytoplankton, chromatographic-	Pheophytin-a, phytoplankton (micrograms	Suspended sediment concentration (percent	Sand/fine separation	Biochemical oxygen demand,	Carbonaceous biochemical oxygen	Escherichia coli, Colifert Quantitray	Fecal coliform, (colonies- forming unit	Total coliform, Colifert Quantitray	Enterococcus, water, (most probable
Discharge		0.03	0.07	0.03	0.04	0.00	0.08	0.09	0.12	0.00	0.00	0.00	0.02	0.01	0.00	0.18	0.01	0.03	0.01	0.07	0.02	0.01	0.01	0.00	0.00	0.01
Water temp			0.00	0.03	0.11	0.10	0.00	0.00	0.00	0.00	0.01	0.00	0.04	0.04	0.00	0.00	0.01	0.00	0.02	0.01	0.04	0.03	0.03	0.01	0.01	0.18
Specific conductance				0.14	0.00	0.13	0.91	0.91	0.91	0.03	0.14	0.02	0.00	0.00	0.04	0.02	0.01	0.00	0.10	0.21	0.07	0.05	0.01	0.03	0.02	0.15
pH (standard					0.45	0.16	0.20	0.20	0.19	0.05	0.09	0.03	0.02	0.15	0.03	0.41	0.23	0.25	0.10	0.04	0.01	0.02	0.00	0.01	0.01	0.05
DO						0.00	0.03	0.02	0.02	0.02	0.03	0.05	0.00	0.05	0.03	0.46	0.12	0.19	0.00	0.05	0.00	0.06	0.00	0.01	0.04	0.17
Turbidity							0.15	0.15	0.14	0.00	0.00	0.00	0.03	0.01	0.00	0.46	0.00	0.00	0.53	0.15	0.10	0.01	0.00	0.00	0.00	0.03
Residue on evaporation								0.988	0.99	0.03	0.04	0.03	0.02	0.00	0.05	0.03	0.00	0.00	0.13	0.21	0.07	0.05	0.01	0.03	0.02	0.09
Chloride									0.99	0.03	0.05	0.04	0.02	0.00	0.05	0.03	0.00	0.00	0.13	0.20	0.07	0.05	0.01	0.02	0.02	0.09
Sulfate										0.01	0.03	0.02	0.01	0.00	0.04	0.04	0.00	0.00	0.13	0.22	0.06	0.05	0.01	0.03	0.03	0.09
Ammonia											0.80	0.65	0.01	0.03	0.62	0.00	0.00	0.00	0.04	0.03	0.05	0.00	0.00	0.01	0.05	0.01
Nitrite plus nitrate												0.71	0.00	0.01	0.82	0.00	0.00	0.00	0.01	0.02	0.04	0.00	0.01	0.01	0.00	0.09
Nitrite													0.01	0.01	0.82	0.00	0.00	0.00	0.00	0.05	0.01	0.00	0.00	0.01	0.00	0.00
Orthophosph														0.38	0.00	0.03	0.01	0.04	0.18	0.02	0.00	0.00	0.00	0.03	0.02	0.06
Phosphorus															0.05	0.01	0.65	0.66	0.10	0.00	0.12	0.15	0.01	0.03	0.07	0.07
Nitrogen																0.00	0.02	0.03	0.01	0.00	0.08	0.00	0.00	0.02	0.02	0.07
Atrazine																	0.04	0.08	0.21	0.03	0.02	0.08	0.18	0.69	0.54	
Chlorophyll-a																		0.68	0.09	0.01	0.13	0.21	0.01	0.04	0.00	0.03
Pheophytin-a																			0.05	0.00	0.18	0.18	0.10	0.02	0.04	0.30
Suspended sediment																				0.00	0.00	0.01	0.01	0.03	0.01	
Sand/fine																					0.02	0.06	0.02	0.03	0.01	
BOD																						0.62	0.00	0.00	0.02	0.05
CBOD																							0.01	0.00	0.01	0.00
E. coli																								0.89	0.50	0.17
Fecal coliform																									0.70	0.91
Total coliform																										0.36
Enterococcus																										

As mentioned in the Stakeholder discussion section, next steps will include taking what we learned from the watershed characterization and applying it towards a Double Bayou Watershed Protection Plan. Deliverables from the Double Bayou Watershed Characterization study include an established baseline data set, data monitoring plans to use as straw men for developing the next data monitoring plan, an initial collection of data samples from the Fall of 2010 and Spring of 2011, data analysis for the data samples conducted during this study as well as the baseline data set, a recommendation of models best situated for the watershed, and the beginnings of watershed outreach including personal interviews with stakeholders, hosting a successful Open House and developing a public participation plan. The data sampling and initial analysis suggest that ammonia, dissolved oxygen, bacteria and chlorophyll-a are emerging as possible constituents of concern. Future data monitoring plans should prioritize these constituents. Lack of flow data negated certain methods of analysis, such as developing loading curves. Future data monitoring plans should focus on collecting quantitative flow data. Continued contact for stakeholder resources will be essential for moving forward with a Double Bayou WPP. The elements of the Double Bayou Watershed Characterization Study will prove invaluable as the first steps to completing a successful WPP.