Cypress Creek Water Quality Data Collection and Trends Analysis Report

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Table of Contents

1.0 Introduction 3
2.0 Analysis Purpose and Design 3
Purpose 3
Analysis Project Design 4
3.0 Evaluations 6
Overview 6
Ambient Data 6
Water Quality Constituents 0
Monitoring in Cypress Creek 1
Sufficiency of Data 2
Monitoring Results 2
Constituent Trends 3
Relationship to Flow 4
Ambient Analysis Summary 5
DMR Data 6
Indicator Bacteria (E. coli) 7
Dissolved Oxygen 10
Total Suspended Solids 11
Ammonia Nitrogen 13
CBOD5 15
Overview of results 17
Sanitary Sewer Overflows 18
SSO Summary 21
4.0 Outcomes and Implications 21
Appendix A – Monitoring Site Data 23

1.0 Introduction

To support the development of a watershed protection plan (WPP) for Cypress Creek, H-GAC conducted a series of water quality analyses. The purpose of this effort was to better understand water quality trends and variability that impact the ability of these waterways to meet state water quality standards and the water quality goals of local stakeholders.

This document will discuss the:

- Analysis design and purpose for these analyses;
- Data sources evaluated, including:
  - current and historical ambient water quality sampling data;
  - discharge monitoring reports (DMR) from wastewater treatment facilities (WWTFs)
  - sanitary sewer overflow (SSO) reports; and
- The outcome and implications of the analyses.

2.0 Analysis Purpose and Design

Purpose

The primary impetus for the WPP development project for the waterways of the Cypress Creek watershed is the water quality impairments and/or concerns listed for this segment and its tributaries[1]. The primary water quality issues identified as being of interest to this project are fecal waste and related pathogens (as evidenced by elevated levels of fecal indicator bacteria) and depressed dissolved oxygen (DO) (in part evidenced by elevated levels of nutrients – nitrogen and phosphorus compounds – and other precursors). Additional concerns raised by project stakeholders include introduction of sediment from development, mining operations, and other sources in the watershed. The indicators for these challenges are the constituents of concern for this analysis effort.

[1] The source for impairment or concern status is the 2016 Texas Integrated Report of Surface Water Quality, which describes the assessment process and results for these segments. The State of Texas assesses its waterways every two years, based on seven years of data. These assessments form the basis by which segments (defined portions of waterways) and their tributaries are classified as having impairments (inability to meet a state water quality standard for which a numerical or other specific limit exists) or concerns (levels of constituents which exceed screening levels or other criteria, but for which numerical or specific limits do not exist). The existence of an impairment is usually the primary driver for developing watershed-based plans for affected segments. More information on the2016 assessments can be accessed at https://www.tceq.texas.gov/waterquality/assessment/305_303.html. The current 2018 Integrated Report was approved subsequent to the completion of the analyses for this report. Future updates of this report will refernce the 2018 report.

Analysis Project Design

Identifying the desired answers and uses of the data evaluations is the first step in developing an analysis project design. The following answers and uses were identified as being necessary for informing stakeholders and their subsequent project decisions:

- General understanding
  - Is there sufficient data to describe water quality conditions in the watershed?
  - What is the extent of the problem?
  - Is the problem spatially variable (i.e. do some areas have worse water quality than others?)
  - Are the issues seasonally variable?
- Specific Sources
  - Are permitted dischargers[2] meeting their permit limits?
  - Are there significant SSOs in the watershed?
    - If so, where are they located, and what is causing them?
- Model inputs[3]
  - Flow and bacteria data for load duration curves (LDCs)

H-GAC and TCEQ developed the water quality data acquisition and evaluation approach reflected in this document to satisfy these information and modeling input needs. Additional information about the data quality objectives, concerns, and methodologies used in these analyses can be found in the Cypress Creek Modeling Quality Assurance Project Plan (QAPP)[4]. The general design for this evaluation project is:

1) Acquisition:
   a. Acquire at least five years[5] of quality-assured ambient water quality data[6] from the state's Surface Water Quality Monitoring Information System (SWQMIS) database for all monitoring stations active in the project watersheds.
   b. Acquire at least five years of DMRs from all WWTFs in the watershed.
   c. Acquire at least five years of SSO reports from all WWTFs in the watershed.
2) Evaluation
   a. Ambient data
      i. Determine if sufficient data exists for each station
      ii. Identify the historical trends for constituents of concern, by each station

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[2] For the purpose of this document, the permitted dischargers referred to are WWTFs operating under Texas Pollutant Discharge Elimination System (TPDES) water quality permits, whose discharges are evaluated through DMRs, and whose unintended releases are evaluated via SSO reports.

[3] The focus of this document is the general understanding of water quality in the watershed and specific potential pollutant sources that may shape modeling efforts. Model inputs are discussed in greater depth in the modeling documents available at www.cypresspartnership.com

[4] This document is available for review at www.cypresspartnership.com

[5] Updated during year two of the project to include all available data from the project period itself.

[6] The constituents for these acquisition tasks are summarized in Table 1.

iii. Identify any seasonal trends, by constituent
iv. Evaluate the relative character of water quality between stations
v. Update evaluations subsequent to the development of the WPP.

b. DMRs
   i. Evaluate the constituents of concern for compliance with WWTF permit limits
   ii. Evaluate the general level of compliance for WWTFs
   iii. Evaluate the seasonality of exceedances
   iv. Evaluate the relationship between plant size and exceedance
   v. Update evaluations subsequent to the development of the WPP.

c. SSOs
   i. Evaluate the number of SSOs by segment
   ii. Evaluate the volume of SSOs by segment
   iii. Evaluate the causes of SSOs by segment
   iv. Update evaluations subsequent to the development of the WPP.

Table 1 - Constituents of concern by evaluation task

Constituent of Concern	Ambient	DMR	SSO
E. coli (bacteria)	X	X	
DO (grab)	X	X	
Temperature	X		
pH	X		
Chlorophyll-a	X		
Nitrate+Nitrite	X		
Nitrate	X		
Flow (grab)	X		
Ammonia Nitrogen (NH3-N)	X	X	
Total Phosphorus	X		
TSS	X	X	
CBOD5		X	
Cause (SSO)			X
Number/Volume (SSO)			X

3.0 Evaluations

Overview

The initial evaluations were completed in September 2019 using the data available in SWQMIS (ambient) and the latest revisions to TCEQ databases (DMR and SSO) at that time. Statistical analyses were conducted in Statistical Analysis Software (SAS), and spatial evaluations were evaluated using Geographical Information Systems (GIS, specifically ArcGIS 10.6.). The outcomes of the evaluations were evaluated by project staff to translate the outputs into actionable implications for the WPP and characterization efforts. The full data and evaluation worksheets for these efforts are available on request but are not included in this report for sake of brevity. The information presented below is a summary of outcomes that have relevance for the project.

Ambient Data

Ambient water quality data are collected at over 400 sites in the 13-county Houston-Galveston region by H-GAC, local partners, and the TCEQ as part of the Clean Rivers Program (CRP)[7]. In general, most monitoring stations are sampled by CRP partners on a quarterly frequency for a suite of field, bacteriological, and conventional parameters[8]. Waterways are inherently dynamic systems, and water quality at any given time can vary greatly dependent on conditions at the time[9]. However, a history of samples provides a more representative view of the range of conditions that may be present in that waterway. Ambient data is important for characterizing waterways because it represents a range of conditions and has a historical aspect that allows for the identification of trends over time. The final determination of the regulatory status of each segment is based primarily on these ambient data. The goals and decisions for the WPP(s) are established in part due to the regulatory status, and therefore ambient data is an important source of information for informing stakeholder decisions. The current monitoring stations in Cypress Creek are shown in Figure 1 and described in Table 2.

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[7] More information about this state-wide water quality monitoring program can be found at https://www.tceq.texas.gov/waterquality/clean-rivers.

[8] More information about the specific monitoring and programmatic details of the local CRP can be found at http://www.h-gac.com/community/water/rivers/.

[9] For this report, 24-hour DO data is discussed in this section. In terms of technical terminology under CRP, 24-hour DO sampling is not considered "ambient" data, but rather, "biased sampling" because it is often collected during certain seasonal timeframes. Due to the nature of the 24-hour data for this project, and the basic categorization of this report, it is discussed as ambient data.

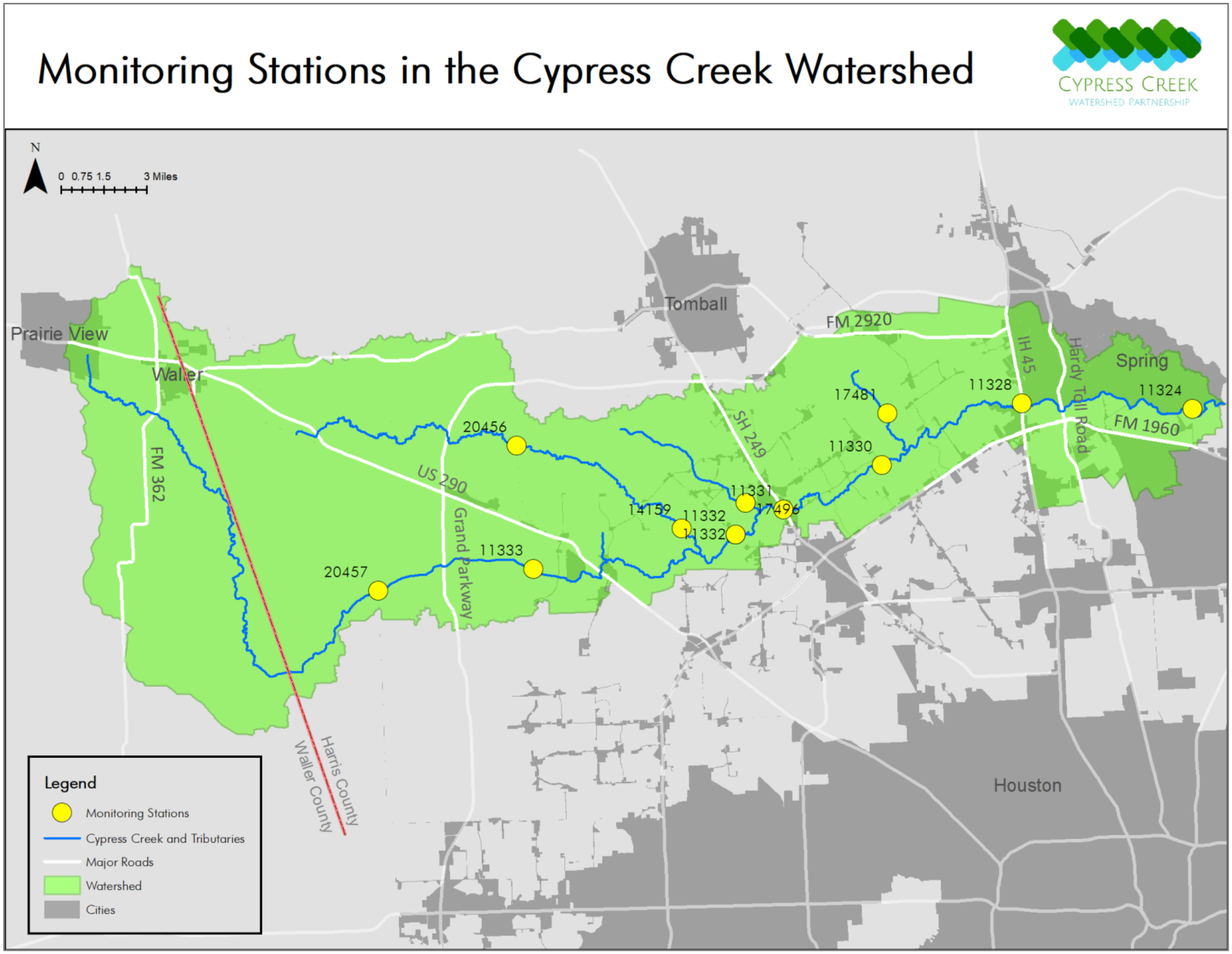

Figure 1 - Monitoring Stations in the Cypress Creek Watershed

Table 2 - Monitoring station locations

Station ID	Site Location
11324	Cypress Creek at Cypresswood Drive Bridge
11330	Cypress Creek at Steubner-Airline Road in Houston
11331	Cypress Creek at SH249
11332	Cypress Creek at Grant Road Near Cypress
11333	Cypress Creek at House-Hahl Road Near Cypress
14159	Little Cypress Creek at Kluge Road in Houston
17481	Spring Gully at Spring Creek Oaks Drive in Tomball
17496	Faulkey Gully of Cypress Creek at Lakewood Forest Drive
20456	Little Cypress Creek at Mueschke Road
20457	Cypress Creek at Katy Hockley Road
11328	Cypress Creek Bridge on IH 45

Water Quality Constituents

Routine ambient water quality monitoring under the CRP includes sampling for a suite of conventional, bacteriological, and field parameters. For this evaluation, a subset of those parameters most closely related to the goals of the WPP and characterization studies has been selected for in-depth analysis. The constituents reviewed are:

- *Escherichia coli (E. coli)* – a bacterial indicator of the presence of fecal wastes, and an indicator of the safety of waterways for human recreation.
- *DO, grab* – an indicator of the ability of the waterway to support aquatic life.
- *Temperature* – an indicator of a waterway's ability to hold oxygen, and a means for correlating other indicators to conditions in the waterways.
- *pH* – an indicator of the acidity or basicness of water, which may affect aquatic life and other uses.
- *Chlorophyll-a* – an indicator of aquatic plant productivity and action, which can indicate areas in which algal blooms or elevated nutrient levels are present, and thus potentially depressed DO.
- *Nitrate+Nitrite* – a measure of nitrogenous compounds and indicator of nutrient levels (and thus potential DO impacts).
- *Ammonia (NH3-N)* – a measure of specific nitrogenous compound that can impact aquatic life and is an indicator of nutrient levels and potentially of improperly treated sewage effluent.
- *Flow,grab* – a measure of water volume over time.
- *Total Phosphorus* – an indicator of nutrient levels, especially in relation to potential for algal blooms and depressed DO in elevated levels.
- *Total Suspended Solids (TSS)* - a measure of the number of suspended particles in water that indicates the potential of light infiltration in the water column and the presence of particulate matter on which bacteria may seek shelter.

The data this effort reviewed included 780 sampling events between 2009-2018. This time period is intended to show a broader historic data review. This report will be updated prior to the end of the WPP development project to include data acquired during the project term, and to provide a short-term view of the most current trends. The primary questions these evaluations sought to answer relate to: 1) the sufficiency of the data to characterize conditions; 2) the spatial component of variations in water quality conditions; 3) the extent of water quality issues; and 4) trends in water quality conditions, including any observable seasonal patterns[10]. The assessment was completed on the segment level, with attention to any unclassified tributaries which may be experiencing issues not common in the entire segment watershed. Full analysis of all the constituents for all stations is included as graphs in Appendix A[11].

Monitoring in Cypress Creek

Cypress Creek is the most southerly of the three primary tributary segments in the West Fork San Jacinto River (West Fork) watershed, draining some rural (but rapidly developing) areas of the Katy Prairie in its western extent, and developed areas along most of its central reach before its junction with Spring Creek and the West Fork just upstream of the confluence of the system with Lake Houston. Additional growth is expected to push west into this watershed in the coming decades. The waterway is a popular recreation area, and a great deal of community focus has been placed on its riparian corridor, including an active greenway.

The segment is heavily monitored, with 11 monitoring stations (Table 2 and Figure 1); seven on the main body, one on Faulkey Gully (1009C), one on Spring Gully (1009D), and two on Little Cypress Creek (1009E). The data for all stations is representative of ten years' worth of sampling and is sufficient to describe the conditions during the study period. Based on the 2016 integrated Report of Surface Water Quality elements of this segment have a series of water quality impairments and concerns (Table 3).

Table 3 - 2016 Integrated Report Status of Cypress Creek waterways

Constituent of Concern	**Waterbodies affected (by assessment unit)**
E. Coli – Impairment	1009_01, 1009_02, 1009_03, 1009_04, 1009C_01, 1009D_01, 1009E_01
DO (grab, screening level) – Concern	1009_01, 1009E_01
Nitrate (screening level) – Concern	1009_01, 1009_02, 1009_03, 1009_04, 1009C_01, 1009D_01, 1009E_01
Total Phosphorus (screening level) – Concern	1009_01, 1009_02, 1009_03, 1009_04, 1009C_01, 1009D_01, 1009E_01
Ammonia (screening level) – Concern	1009D_01
Habitat – Concern	1009_02
Chlorophyll-a (screening level) – Concern	1009_04

[10] Throughout this ambient water evaluation, statistical significance is defined as a p-value of 0.0545 or less. Any significance not based on this statistical review (e.g. seasonal trends, qualitative comments) will be specifically described as not being related to this significance threshold. The quantitative analysis for the ambient conditions was conducted using SAS.

[11] Statistical analysis in the graphs of Appendix B are based on a LOESS curve rather than a straight regression curve to better indicate change in trend over time for disparate stations.

As indicated in Table 3, all the assessment units of the segments in the system are impaired for fecal indicator bacteria and have concerns for total phosphorus and nitrate. Other constituents of concern are more sporadic.

Sufficiency of Data

Table 4 indicates the number of samples taken at each of the monitoring stations during the period assessed. The number of samples is sufficient enough to represent trends in water quality during this period, as even the station with the least number of samples averaged approximately four samples a year over the ten-year period.

Table 4 - Number of Sampling Events by Station

Segment	Station	Segment Name	Sampling Events	Earliest Event	Latest Event	Segment Name
1009	11324	Cypress Creek	39	03/04/2009	12/19/2018	Cypress Creek
1009	11328	Cypress Creek	63	01/15/2009	11/27/2018	Cypress Creek
1009	11330	Cypress Creek	89	01/15/2009	11/26/2018	Cypress Creek
1009	11331	Cypress Creek	87	02/18/2009	11/26/2018	Cypress Creek
1009	11332	Cypress Creek	98	01/15/2009	11/26/2018	Cypress Creek
1009	11333	Cypress Creek	89	01/15/2009	11/26/2018	Cypress Creek
1009	20457	Cypress Creek	35	04/01/2009	10/02/2018	Cypress Creek
1009C	17496	Faulkey Gully	89	01/15/2009	11/26/2018	Faulkey Gully
1009D	17481	Spring Gully	87	01/15/2009	11/26/2018	Spring Gully
1009E	14159	Little Cypress Creek	88	01/15/2009	11/26/2018	Little Cypress Creek
1009E	20456	Little Cypress Creek	40	04/01/2009	10/02/2018	Little Cypress Creek

Monitoring Results

Table 5 indicates the summary of monitoring results over the time range of the data, by station. The results generally reflect the status of the segments on the TCEQ Integrated Report, although it should be noted the time ranges of the data (2009-2018 for this report's evaluations, versus 2008-2014 for the Integrated Report) do not fully overlap. The results represent a geomean of all data from the time period. Specific results and additional detail for each station are included in Appendix A. Results shaded in red indicate a result that is not meeting a criteria or screening level, while green shading represent results that are in compliance with criteria/better than the screening level. Lack of shading indicates the data is not being compared to criteria/screening levels.

Table 5 - Monitoring Results by Segment (Geomean of data, 2009-2018)

Segment	Criteria	Units	Results by Segment			
			1009	**1009C**	**1009D**	**1009E**
Temperature	NA	Degrees Celsius	21.09	22.48	23.02	21.07
DO (grab)	Various[12]	mg/L	7.22	8.86	8.13	6.42
pH	9 (high)/6.5(low)	NA	7.74	7.99	8.12	7.63
TSS	NA	mg/L	29.42	14.98	13.05	18.21
Ammonia (NH3-N)	0.33	mg/L	0.10	0.09	0.14	0.10
Nitrate+Nitrite	NA	mg/L	0.99	NA	NA	0.25
Total Phosphorus	0.69	mg/L	1.23	2.17	1.91	1.02
E. coli	126.00	CFU/100mL	377.07	272.39	256.50	193.33
Chlorophyll-a	14.10	mg/L	9.53	NA	NA	NA
Nitrate	1.95	mg/L	3.47	7.15	5.81	3.80
Nitrite	NA	mg/L	0.07	NA	NA	0.12

As indicated in Table 5, *E. coli,* nitrate, and phosphorus levels are generally above the standard throughout the watershed (additional information on variability can be seen in Appendix A charts for each station). While pH levels are appropriate on a long-term average, results in Appendix A and the TCEQ Integrated Report assessments indicate pH may be problematic in some locations during some conditions.

Constituent Trends

Table 6 indicates the constituents in Segment 1009 and its unclassified tributaries for which there are statistically significant trends. The full data for all constituents for all stations can be found in Appendix A. Some trends, especially for the main channel of Cypress Creek, are not consistent across the whole segment, though the issues related to the constituents of primary concern (particularly *E. coli*) are relatively consistent.

[12] The grab screening level and minimums for DO are 5 and 3, respectively, for all segments except 1009C, Faulkey Gully, whose screening level and minimum are 2 and 1.5. Due to variability in DO throughout the day, a geomean in excess of the minimum or screening level should not be taken to mean that DO is consistently good throughout a daily cycle.

While there are numerous water quality issues for Cypress and its tributaries, the main channel and many of the unclassified tributaries show improvement on nutrients and/or DO and general stability on *E. coli* (although levels generally remain in excess of the standard). Table 6 indicates the status of trends by segment. Constituents in red indicate a negative trend (e.g., increasing *E. coli* or decreasing DO), and green indicates a positive trend. Constituents in gray indicate neutral perceived impact of the trend. Constituents whose trends were not statistically significant (based on a p value threshold of 0.0545) are not included in the table. While *E. coli* samples were often higher than the standard, they were relatively stable across the data time series so they do not appear in Table 6. Prior analyses[13] indicated that *E. coli* results in the period of time between 2012-2018 were increasing in segment 1009 in earlier years but were more stable in later years. The constituents were also evaluated for seasonality, although only temperature and DO showed observable seasonal patterns.

Table 6 - Water Quality Trends by Segment

Segment	Parameter	Trend	Number of Samples
1009	Flow	Increasing	266
1009	Nitrate-N	Decreasing	405
1009	Total Phosphorus	Decreasing	479
1009	TSS	Increasing	480
1009	pH	Decreasing	500
1009C	Total Phosphorus	Decreasing	89
1009D	Ammonia-N	Decreasing	86
1009D	DO (grab)	Increasing	85
1009D	TSS	Decreasing	87
1009E	Flow	Increasing	36
1009E	Nitrate+Nitrite	Increasing	38
1009E	Nitrate-N	Decreasing	90
1009E	Total Phosphorus	Decreasing	127
1009E	TSS	Increasing	128

Relationship to Flow

As part of the ambient data analyses, staff considered the relationship of constituent levels to flow conditions. Further work on the relationship between flow, bacteria, and DO was completed as part of LDC model development[14]. In general, Cypress Creek saw fairly consistent nonpoint source indications, as bacteria concentrations increased with flow fairly regularly throughout the stations of the waterway.

[13] Water quality data for Cypress Creek was assessed for 2012-2017 and 2015-2018 as part of the development of a Characterization Report under a previous Clean Water Act 319(h) concluded in early 2019.
[14] Please refer to the Cypress Creek Modeling Report available on www.cypresspartnership.com.

Ambient Analysis Summary

The Cypress Creek watershed exhibits water quality challenges and trends that reflect a watershed in developmental transition.

Bacteria remains an issue throughout the watershed, although recent years have seen *E. coli* levels stabilize in some areas.

Despite trends toward generally better water quality, nutrients remain a challenge in Segment 1009, suburban and exurban development being likely prominent sources as legacy agricultural activity diminishes.

Elevated TSS levels do not seem directly related to effluent flows (see DMR data analysis in the following pages), though wastewater is likely a component. Additional review may be needed to understand the potential sources of TSS. It is likely that disturbance by development, unstable areas of the channels, and other sources may be a source of TSS issues.

While water quality issues persist in these waterways since the 2016 assessment, they are not extraordinary in extent such that voluntary intervention through watershed-based plans would be fruitless. Targeted assessment and application of best management practices could be expected to reduce or remove impairments and concerns in these watersheds.

Figure 2 - Prairie Grasses, Paul Rushing Park

DMR Data

Discharges from wastewater treatment plants are regulated by water quality permits from the TCEQ which require stringent limits for effluent quality. In general, wastewater treatment plants in the Houston region are able to meet their permits with few excursions. However, because human waste has an appreciable pathogenic potential[15], identifying trends in permit exceedances for indicator bacteria by WWTFs is important in understanding overall impacts to waterways. Additionally, effluent (especially if improperly treated) can be a source of nutrient precursors to depressed DO. Discharges from WWTFs are monitored on a regular basis (with a frequency dependent on plant size and other factors). The data from these required sampling events is submitted to (and compiled by) the TCEQ as DMRs. As with any self-reported data, there is an expectation that some degree of uncertainty or variation from conditions may occur, but these DMRs are the most comprehensive data available for evaluating WWTFs in the watershed.

For this project, staff evaluated five parameters common to most WWTF permits, as reported in the last five years (2014-2019[16]) of DMRs available from TCEQ. Some parameters are themselves constituents of concern, while the others are indicators of the presence or potential presence of untreated/improperly treated waste[17]:

- Indicator bacteria (*E. coli)* – this common gut bacteria indicates the presence of untreated fecal waste and related pathogens which can impact human health.
- TSS – this measure of the number of suspended particles in water indicates the efficiency of the WWTF process, and the potential of effluent to impact sedimentation and light transmission in the waterway. Excessive particles in the water quality can foster bacteria survival, among other impacts.
- NH3-N – this nitrogenous compound is specifically harmful to aquatic systems, can impact human health in high concentrations, contributes to algal blooms and low DO, and can indicate the efficiency of wastewater treatment processes.
- DO, grab samples – this indicator directly characterizes the ability of the effluent to support aquatic life, and indicates the potential presence of nutrients and other oxygen-demanding substances (and thus the efficiency of treatment processes).
- CBOD5 – This indicator, which measures the depletion of oxygen over time by biological processes, indicates the efficiency of treatment.

[15] While the project considers many sources of fecal bacteria, recent research has indicated that human waste has a significantly higher risk of causing sickness in humans as compared to animal sources. Additional information about one research project illustrating this concept can be reviewed at http://oaktrust.library.tamu.edu/handle/1969.1/158640?show=full. (Gitter, 2017).

[16] 2019 data was not complete at the time of the analysis but was considered along with the previous 5 years.

[17] In consideration of the nutrient loading capacity of the plants, it should be noted that many nutrient parameters are not standard permit limits, and thus may not be tested. Based on review of correlations between nutrient parameters and flow for many stations the analyses did show a likelihood of plants as nutrient loading sources for non-permit limit parameters, particularly in effluent-dominated streams.

The parameter evaluations were based on the regulatory permit limits specific to each plant, and consider the number of exceedances by each plant, in each year, in each segment, and as a percentage of the total samples.

Indicator Bacteria (E. coli)

E. coli is an indicator bacterium widely common to the guts of warm-blooded animals. While many strains of *E. coli* are not themselves problematic, they are closely related to the presence of fecal waste, and therefore, to the host of pathogens present in wastes. The water quality standard for ambient conditions is 126 colony-forming units per 100ml of water (for the geomean of samples) and 399 cfu/100ml (for single grab samples), and these standards are generally applied as a permit condition for wastewater as well[18]. Evaluations for compliance with the permit limits were compared between segments, between plants, between years, between category (average or maximum values), and by season. Ninety-one plants reported bacteria results for these segments in the data timeframe evaluated. The outcomes are summarized in Tables 7 through 11.

Table 7 - E. coli Exceedance Statistics

Parameter	Number of Plants	Percentage of Plants
Plants in DMR	95	100%
Plants report bacteria	91	96%
Less than 1% violations	63	69%[19]
1% to 5% violations	21	23%
5% to 10% violations	6	7%
10% to 25% violations	0	0%
Greater than 25% violations[20]	1	1%
Exceedances of geomean	11	12%
Exceedances of single grab	34	37%

As indicated in Table 7, the greater majority of plants have less than 1% of their samples in violation[21]. However, roughly a third of all plants (27) have between 1 to 10% of their samples in violation, although the greater majority of this range is under 5%. The plants were generally more able to meet the

[18] Several plants in the watershed have more stringent limits (e.g., 63 CFU/100mL) depending on site-specific conditions, or participation in TMDL projects like the Houston-area Bacteria Implementation Group (BIG). For all analyses, the actual limit for each plant was used in comparison with its plant-specific results. The range of limits applied to the average and maximum conditions ranges from 63 to 399 cfu/100ml.

[19] The percentages in this column, starting with this cell, refer to the percentage of plants who report bacteria data who fall into this category, rather than the percentage of all plants.

[20] The single outlier here is a plant with few records during the time period, which may be due to incomplete data.

[21] The data in Table 7 indicates all violations, whether they be for the geomean or single grab sample criteria.

geomean standard than the single grab standard indicating that conditions may have a high degree of variability, but the small size of the pool of exceedances limits meaningful extrapolation from this data.

Table 8 - E. coli Exceedances by Season

Exceedance by Season by segment				
	Spring (Months 3-5)	Summer (6-8)	Fall (9-11)	Winter (12-2)
Total exceedances	31	24	22	27
Geomean exceedances	3	7	0	7
Single grab exceedances	28	17	22	20

As Table 8 indicates, there is not a strong relationship between season and violations, especially given the relatively small number of violations overall.

Table 9 - E. coli Exceedances by Year and Criteria

Exceedances by year, total							
	2014	2015	2016	2017	2018	2019	Total
Total Exceedances	19	12	18	24	19	12	104
Exceedances of Geomean	7 (41%)[22]	1 (6%)	2 (12%)	3 (17%)	2 (12%)	2 (12%)	17
Exceedances of Single Grab	12 (14%)	11 (12%)	16 (18%)	21 (24%)	17 (20%)	10 (12%)	87

Table 9 shows that there is not a strong trend in exceedances from year to year, either in consideration of total exceedances, or in either the geomean or single grab criteria. Mirroring the data in Table 8, the greater majority of exceedances are due to the single grab criteria, which may indicate more variable conditions in plant effluent.

Table 10 represents exceedances related to plant age. There is a relatively equal distribution of plants in the watershed (although age data was not available for 24 of the plants). Exceedances skew slightly toward older plants for total exceedances and exceedances of the single grab criteria, and there is not a strong enough relationship to age to comment on geomean exceedances.

Table 11 demonstrates the distribution of plants and exceedances by size. Mid-size (1-5 million gallons per day (MGD)) plants had the most violations of the single grab criteria and total violations, but the smallest plants had the most violations of the geomean criteria, albeit from a very small data set.

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[22] The percentages in parentheses represent the percent of all exceedances in this category represented by this year.

Table 10 - E. coli Exceedances by Plant Age

Distribution of plants by age[23]			
Age	Number of plants	Percent of all plants	
Before 1980	21	31%	
1980-2000	24	35%	
2000-2020	22	32%	
Exceedances by plant age			
Plant age	Number of exceedances (total)	Number of exceedances (geomean)	Number of exceedances (single grab)
Before 1980	31 (45%[24])	6 (37%)	25 (47%)
1980-2000	22 (32%)	7 (44%)	15 (28%)
2000-2020	16 (23%)	3 (19%)	13 (25%)

Table 11 - E. coli Exceedances by Plant Size

Distribution of plants by size (permitted flow in million gallons a day)			
Size	Number of plants	Percentage of plants	
0>0.5 MGD	43	47%	
0.5-1 MGD	26	29%	
1-5MGD	21	23%	
5-10 MGD	1	1%	
> 10 MGD	0	0%	
Exceedances by plant size			
Plant Size	Number of exceedances (total)	Number of exceedances (geomean)	Number of exceedances (single grab)
0>0.5 MGD	31 (30%[25])	12 (71%)	19 (22%)
0.5-1 MGD	21 (21%)	0 (0%)	21 (24%)
1-5MGD	49 (49%)	5 (29%)	44 (51%)
5-10 MGD	3 (3%)	0 (0%)	3 (3%)
>10 MGD	0 (0%)	0 (0%)	0 (0%)

In general, the results indicated that a very small number of exceedances were noted (104 out of 4,769 records), and only three plants had 5-10% of their samples show up as violations. Maximum values were

[23] 24 plants did not have data on original permit date available and are not considered in this table.
[24] Percentages in parentheses represent the percentage of total exceedances, represented by this age category. The numbers represent only exceedances from those plants which had permit age data.
[25] Percentages in parentheses represent the percentage of total exceedances, represented by this size category.

more commonly exceeded than average/geomean limits, indicating there is likely some variability in conditions. Seasonality was not generally an issue. Plant size was not a statistically significant indicator of potential to exceed limits[26] but mid-size plants had greater issue with the single sample criteria, and smaller plants the geomean. This may be in part due to relative frequency of monitoring, wherein large plants monitor more frequently and have more data to include in a geomean calculation, or it may be due to operational differences between larger manned plants and smaller unmanned plants. While WWTFs may be appreciable contributions under certain conditions, in localized areas, the DMR analysis indicates that they are not likely a significant driver of segment bacteria impairments due to the comparatively few exceedances. However, due to the relatively higher risk of pathogens from human waste, and proximity to developed areas, WWTF exceedances are likely still a point of concern for stakeholders.

Dissolved Oxygen

DO levels in WWTF effluent help indicate the efficiency of treatment processes. DO is generally more stable in effluent than it can be in ambient conditions because it is less subject to natural processes and variation in insolation. DO is measured in mg/L, and the permit limits with which results are compared vary based on the receiving water body and other factors. Unlike other contaminants, DO limits are based on a minimum, rather than maximum level, and represent a grab sample as opposed to a 24-hour monitoring event. Generally, permit limits for the data reviewed ranged between 4-6 mg/l. Evaluations for compliance with the permit limits were for all records, between years, and by season. Ninety-one plants reported DO results for these segments during this period. The outcomes are summarized in Tables 12-14.

Table 12 - DO Monitoring Statistics, 2014-2019

Category	Number	Percentage of samples
Plants in DMR dataset	94	100%
Plants report DO	91	97%
Total Records	5410	100%
Total Exceedances	19	0.4%

Table 13 - DO Exceedances by Year

Exceedances by year							
	2014	2015	2016	2017	2018	2019	Total
Exceedances	2	3	5	6	3	0	19

[26] As indicated previously, self-reported data obscures underlying uncertainties about variability in conditions. This is exacerbated when comparing manned, larger facilities who are more likely to sample more frequently, and smaller facilities who sample less frequently and are generally unmanned. These results should not be taken to have statistical significance.

Table 14 - DO Violations by Season

Violations by season by segment					
	Spring (Months 3-5)	Summer (Months 6-8)	Fall (9-11)	Winter (12-2)	Total
Exceedances	4	6	5	4	19

As with the *E. coli* data, there were very few violations of DO limits (19 total violations for 5,410 records.) There were no statistically significant seasonal components for the evaluated data. Based on these data and analyses, it is unlikely WWTFs are having any appreciable impact from DO levels in effluent, even before the dilution of these small volumes (relative to the larger volumes of the waterways) is considered. However, because these samples are DO grab samples, the potential variability of DO should be considered. Unlike a natural waterway, DO in plant effluent should see less daily cycling and therefore the grabs should be more representative than DO grabs in ambient conditions. The 19 violations represented 14 plants, indicating that there were no appreciable patterns of repetitive violations at single facilities.

Total Suspended Solids

TSS is generally an indication of wastewater treatment efficiency in removing solids. Substantial TSS levels in effluent can contribute to fostering bacterial regrowth as bacteria uses suspended particles as a protected growth medium. It can also decrease insolation in the water column and lead to deposition of particles on the substrate, etc. However, it can also be useful as an indicator that inefficient treatment may have led to other waste products (nutrients, etc.) being elevated in effluent.

Permit limits for TSS include a concentration based (average) limit (in mg/l) and a total weight-based limit (in weight/day). Both average and maximum monitored results exist for most plants. Evaluations for compliance with the permit limits were compared for all plants, between years, for both concentration and total volume, by season, and between category (average or maximum values). Ninety-four plants reported TSS results for these segments during this period. The outcomes are summarized in Tables 15-17.

Table 15 - Monitoring Statistics for TSS, 2014-2019

Category	Number	% of samples
Plants in DMR dataset	94	100%
Plants reporting TSS	94	100%
Total Records	16,732	100%
Total Exceedances	163	1.0%
Total Exceedances, Average	112	
Total Exceedances, Maximum	51	
Total Exceedances, Concentration Average (mg/L)	97	
Total Exceedances, Concentration Maximum (mg/L)	51	
Exceedances, Weight Average (kg/d)	15	
Exceedances Weight Maximum (kg/d)	0	

Table 16 - TSS Exceedances by Year

Category	Total	2014	2015	2016	2017	2018	2019
Weight/Day	15	2	1	7	0	1	4
Average	15	2	1	7	0	1	4
Maximum	0	0	0	0	0	0	0
Concentration	148	19	12	29	23	48	17
Average	97	12	9	16	17	34	9
Maximum	51	7	3	13	6	14	8
Total	163	21	13	36	23	49	21
Average	112	14	10	23	17	35	13
Maximum	51	7	3	13	6	14	8

Table 17 - TSS Exceedances by Season

Category	Winter (Months 12-2)	Spring (Months 3-5)	Summer (Months 6-8)	Fall (Months 9-11)
Weight/Day	5	7	2	1
Average	5	7	2	1
Maximum	0	0	0	0
Concentration	50	45	30	23
Average	33	30	18	16
Maximum	17	15	12	7
Total	55	52	32	24
Average	38	37	20	17
Maximum	17	15	12	7

Corresponding to other parameters, TSS violations were rare, making up less than one percent of the total sample records. There were no clear differences by year, although winter and spring months had greater exceedances of both concentration and weight-based limits. In general, TSS results indicate WWTFs are operating within their permit limits with little issue and that TSS inputs from WWTFs are not likely a chronic issue of importance for the waterways. However, it is likely that they are of concern to stakeholders on a localized basis and may be indicative of opportunities for WWTF improvement. Unlike other constituents, however, the exceedances occurred at a relatively smaller number of facilities. Thirty WWTFs accounted for the 163 exceedances, with three of the facilities accounting for 70 exceedances. This indicates that there may be localized issues for TSS regardless of the overall result.

Ammonia Nitrogen

NH3-N is a nitrogenous compound that can be toxic in concentration to people and aquatic wildlife and can also contribute to the deleterious impacts of elevated nutrient loadings. Additionally, excessive NH3-N levels in effluent indicate inefficient wastewater treatment and may correlate to the presence of improperly treated sewage.

Like TSS, permit limits for NH3-N include a concentration based (average) limit (in mg/l) and a total weight-based limit (in weight/day). Both average and maximum permit limit values exist for most plants. Evaluations for compliance with the permit limits were compared between plants, between years, between seasons, and between category (average or maximum values). Ninety-one plants reported NH3-N results for these segments during the original analysis period. The outcomes are summarized in Tables 18 through 20.

Table 18 - Ammonia Exceedances, 2014-2019

Category	Number	% of samples
Plants in DMR dataset	94	100%
Plants reporting TSS	91	97%
Total Records	16732	100%
Total Exceedances	177	1.0%
Total Exceedances, Average	107	
Total Exceedances, Maximum	70	
Total Exceedances, Concentration Average (mg/L)	93	
Total Exceedances, Concentration Maximum (mg/L)	70	
Exceedances, Weight Average (kg/d)	14	
Exceedances, Weight Maximum (kg/d)	0	

Table 19 - Ammonia Exceedances by Year

Category	Total	2014	2015	2016	2017	2018	2019
Weight/Day	14	0	1	6	3	3	1
Average	14	0	1	6	3	3	1
Maximum	0	0	0	0	0	0	0
Concentration	163	16	22	29	44	46	6
Average	93	5	14	21	24	26	3
Maximum	70	11	8	8	20	20	3
Total	177	16	23	35	47	49	7
Average	107	5	15	27	27	29	4
Maximum	70	11	8	8	20	20	3

Table 20 - Ammonia Exceedances by Season

Category	Winter (Months 12-2)	Spring (Months 3-5)	Summer (Months 6-8)	Fall (Months 9-11)
Weight/Day	4	4	2	4
Average	4	4	2	4
Maximum	0	0	0	0
Concentration	39	42	43	39
Average	25	24	23	21
Maximum	14	18	20	18
Total	43	46	45	43
Average	29	28	25	25
Maximum	14	18	20	18

Corresponding to other parameters, Ammonia violations were rare, making up roughly one percent of the total sample records. The yearly rate of exceedance is generally increasing as time passes (with 2019 being an outlier due to incomplete data). There was little if any seasonality to the exceedances. In general, ammonia results indicate WWTFs are operating within their permit limits with little issue and that ammonia inputs from WWTFs are not likely a chronic issue of importance for the waterways. However, it is likely that they are of concern to stakeholders on a localized basis, and may be indicative of opportunities for WWTF improvement. Like TSS, the exceedances occurred at a relatively smaller number of facilities. 42 WWTFs accounted for the 177 exceedances, with four of the facilities accounting for 60 of those exceedances. This indicates that there may be localized issues for ammonia regardless of the overall result.

CBOD5

CBOD5 is not a pollutant itself, but is an indicator of biological oxygen demand, and thus potentially the presence of improperly treated effluent in a sample.

Like TSS and NH3-N, permit limits for CBOD5 include a concentration based (average) limit (in mg/l) and a total weight-based limit (in weight/day). For this evaluation, records for both were considered because of the nature of the test. Both average and maximum permit limit values exist for concentration limits for most plants. Evaluations for compliance with the permit limits were compared between plants, between seasons, between years, and between category (average or maximum values). Ninety-one plants reported CBOD5 results for these segments during this period. The outcomes of these analyses are summarized in Tables 21 through 23.

Table 21 - CBOD5 Exceedances, 2014-2019

Category	Number	% of samples
Plants in DMR dataset	94	100%
Plants reporting TSS	91	97%
Total Records	16,223	100%
Total Exceedances	43	0.3%
Total Exceedances, Average	26	
Total Exceedances, Maximum	17	
Total Exceedances, Concentration Average (mg/L)	93	
Total Exceedances, Concentration Maximum (mg/L)	70	
Exceedances, Weight Average (kg/d)	14	
Exceedances, Weight Maximum (kg/d)	0	

Table 22 - CBOD5 Exceedances by Year

Category	Total	2014	2015	2016	2017	2018	2019
Weight/Day	3	0	0	1	1	0	1
Average	3	0	0	1	1	0	1
Maximum	0	0	0	0	0	0	0
Concentration	40	8	3	3	7	17	2
Average	23	3	2	2	5	10	1
Maximum	17	5	1	1	2	7	1
Total	43	8	3	4	8	17	3
Average	26	3	2	3	6	10	2
Maximum	17	5	1	1	2	7	1

Table 23 - CBOD5 Exceedances by Season

Category	Winter (Months 12-2)	Spring (Months 3-5)	Summer (Months 6-8)	Fall (Months 9-11)
Weight/Day	0	2	0	1
Average	0	2	0	1
Maximum	0	0	0	0
Concentration	6	14	13	7
Average	4	7	6	6
Maximum	2	7	7	1
Total	6	16	13	8
Average	4	9	6	7
Maximum	2	7	7	1

Corresponding to other parameters, CBOD5 violations were rare, making up less than one percent of the total sample records. The yearly rate of exceedance was variable but not clearly trending. Spring and summer months saw more exceedances. However, for both considerations, the number of exceedances is so small as to limit the applicability of any trends. In general, CBOD5 results indicate WWTFs are operating within their permit limits with little issue and that inputs that would be demonstrated by CBOD5 from WWTFs are not likely a chronic issue of importance for the waterways. However, it is likely that they are of concern to stakeholders on a localized basis and may be indicative of opportunities for WWTF improvement. The exceedances occurred at a relatively smaller number of facilities, but few had more than a few exceedances. One plant accounted for almost half (19) of all exceedances. This indicates that there may be localized issues for ammonia regardless of the overall result.

Overview of results

While there were exceedances for the evaluated constituents, the majority of plants met their permit limits the majority of the time without significant issue in both the original and updated analyses. Even allowing for variability in effluent conditions not reflected in the DMR results, it is unlikely that WWTFs are an appreciable source of contamination in the watershed on a chronic, wide-ranging scale. Bacteria source modeling[27] supports this evaluation, indicating that for *E. coli* specifically, WWTFs are projected to account for a fairly minor amount of overall load. However, the potential for localized inputs may be underrepresented by the overall impact of WWTFs for the watershed.

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[27] Please refer to the Cypress Creek Modeling Report, available at www.cypresspartnership.com

However, in interpreting these results, it should be noted that while WWTFs may not be the largest source of bacteria, they are likely one of the human fecal waste sources, and therefore have an inherently higher pathogenic potential than other sources. Additionally, unlike other source of natural and diffuse fecal waste in the watersheds, WWTF effluent has both regulatory controls and voluntary measures by which improperly treated wastewater may be addressed. Given the nature of WWTF effluent as a human pollutant, and our direct ability to influence its character, WWTF bacteria should be considered as a potential focus for some best management practices. While other constituents (e.g. nutrients) are not necessarily any more harmful than other sources in the watershed, the principle of direct control of effluent applies to their consideration as well. This is exacerbated for nutrients given the lack of permit limits for some nutrient parameters, and the likelihood that WWTFs may be appreciable nutrient loading sources in effluent dominated streams.

Sanitary Sewer Overflows

Unlike treated WWTF effluent, SSOs represent a high, if episodic risk, because they can have concentrations of bacteria several orders of magnitude higher than treated effluent. Untreated sewage can contain large volumes of raw fecal matter, making it a significant health risk where SSOs are sizeable and/or chronic issues. The causes of SSOs vary from human error to infiltration of rainwater into sewer pipes. Data used for these analyses is self-reported and may vary in quality. Even in the best of circumstances, the ability to accurately gauge SSO volumes or even occurrences in the field is limited by several factors. Actual SSO volumes and incidences are generally expected to be greater than reported due to these fundamental challenges. SSO causes were broken into four broad categories with several subcategories each, to reflect the breakdown in the TCEQ SSO database. It should be noted, however, that this categorization depends on the accuracy of the data reported by the utilities. Additionally, while a single cause is typically listed on the SSO report, many SSOs are caused by a combination of factors[28].

This study considered five years of TCEQ SSO violation data for 2014-2018[29]. There were 187 SSO records from 48 plants considered for the watershed area. Of those 48 plants, 11 plants had more than five SSOs, and of those 11 plants, two plants had 10 or more SSOs. However, number of SSOs did not correspond well to volume of SSOs. Only three plants had a cumulative SSO volume greater than 50,000 gallons, and only two of those plants had a number of SSOs greater than five (but still less than 10). Tables 24 and 25 reflect the breakdown of SSOs by year and cause, for number (Table 24) and volume (Table 25).

As shown in Table 24, the number of SSOs by year has been fairly stable, except for 2017. While not all the increase that year can be linked to Hurricane Harvey, a sizeable portion (approximately 25% of the

[28] e.g., fats, oils, and grease collecting in lift station motors can cause overflows in high rain events when excess water is in a system. The event may be listed as lift station failure, but FOG and inflow and infiltration of rainwater were also causative elements.

[29] When the report was compiled, the 2018 dataset was not accurate and complete for the Houston region. Statistics for 2018 should be viewed in this light. H-GAC and TCEQ are working to address this data issue and will update this report when it is complete.

total SSOs for 2017) and likely many of the SSOs reported subsequently may have been impacted by the hurricane. While that outlier is an important consideration as to the impact of weather events on SSO frequency in a watershed with frequent flooding events, it should not be taken as an indicator of a normal year. Outside of 2017, there was not a strong trend in number of SSOs.

In terms of cause by number, the general category of weather-related issues accounted for 22.5%, malfunctions and operational issues accounted for 42.2%, blockages accounted for 23.5%, and 11.8% were listed as unknown causes.

Table 24 - SSOs by Cause and Year (Number)

SSOs by Year and Cause (Number)						
Cause	**2014**	**2015**	**2016**	**2017**	**2018**	**Total**
Weather	**0**	**3**	**10**	**24**	**5**	**42**
Rain / Inflow / Infiltration	*0*	*3*	*10*	*6*	*5*	*24*
Hurricane	*0*	*0*	*0*	*18*	*0*	*18*
Malfunctions	**9**	**15**	**15**	**33**	**7**	**79**
WWTP Operation or Equipment Malfunction	*3*	*1*	*5*	*10*	*2*	21
Power Failure	*1*	*0*	*3*	*2*	*0*	6
Lift Station Failure	*4*	*10*	*4*	*7*	*5*	30
Collection System Structural Failure	*1*	*4*	*2*	*14*	*0*	21
Human Error	*0*	*0*	*1*	*0*	*0*	1
Blockages	**7**	**14**	**4**	**15**	**4**	**44**
Blockage in Collection System-Other Cause	*2*	*6*	*1*	*0*	*1*	10
Blockage in Collection System Due To Fats/Grease	*3*	*8*	*2*	*11*	*2*	26
Blockage Due To Roots/Rags/Debris	*2*	*0*	*1*	*4*	*1*	8
Unknown Cause	***3***	***0***	***6***	***7***	***6***	**22**
Total	**19**	**32**	**35**	**79**	**22**	**187**

While the number of SSOs indicates the frequency with which sewage systems have events, and thus the chronicity of the load from those plants, the volume of SSOs indicates the extent of the impact they have (i.e. a small plant with 100 small SSOs may produce a more chronic, but smaller discharge than a large plant with a single SSO of a much larger volume). As Table 25 indicates, the examination of SSOs by cause and year for volume is somewhat similar, in that 2017 was an exceptional year. However, outside of 2017, the volume and numbers from Table 24 did not track proportionately, indicating that number and volume of SSO do not necessarily have a direct relationship in the data.

Malfunctions, as a broad category, remains the primary volumetric source of SSOs, accounting for 57.5% of all SSOs. Weather-related events are next at 29.0%, followed by blockages at 9.4%, with an unknown portion making up 4.1% of volume. The breakdown of source over the entire watershed should not be taken as an accurate cause profile for individual areas in the watershed but reflects the general challenges to the area's wastewater infrastructure.

Table 26 summarizes the consideration of seasonal impacts on SSOs. While spring SSOs were predominant, followed by fall, the limited number of SSOs over the period and the number of extraordinary high flow events (including Hurricane Harvey in 2017), provide reasons to limit extrapolation of these results to suggest a strong seasonal trend.

Table 25 - SSOs by Year and Cause (Volume)

SSOs by Year and Cause (Volume)						
Cause	**2014**	**2015**	**2016**	**2017**	**2018**	**Total**
Weather	**0**	**8,750**	**36,512**	**152,918**	**19,345**	**217,525**
Rain / Inflow / Infiltration	0	8,750	36,512	150,000	19,345	**214,607**
Hurricane	0	0	0	2,918	0	**2,918**
Malfunctions	**23,475**	**79,970**	**150,158**	**165,096**	**13,570**	**432,269**
WWTP Operation or Equipment Malfunction	700	2,500	8,925	24,502	3,300	**39,927**
Power Failure	5,000	0	135,404	2,364	0	**142,768**
Lift Station Failure	17,750	15,370	5,224	3,030	10,270	**51,644**
Collection System Structural Failure	25	62,100	105	135,200	0	**197,430**
Human Error	0	0	500	0	0	**500**
Blockages	**3,220**	**19,512**	**1,198**	**42,815**	**3,477**	**70,222**
Blockage in Collection System-Other Cause	1,650	9,180	705	0	1,500	**13,035**
Blockage in Collection System Due To Fats/Grease	970	10,332	393	32,665	477	**44,837**
Blockage Due To Roots/Rags/Debris	600	0	100	10,150	1,500	**12,350**
Unknown Cause	**604**	**0**	**26,537**	**3,303**	**503**	**30,947**
Total	**27,299**	**108,232**	**214,405**	**364,132**	**36,895**	**750,962**

Table 26 - Seasonality of SSO occurrence

Seasonality of SSOs		
Season	**Number**	**Volume**
Winter	51	101,797
Spring	47	309,430
Summer	51	118,716
Fall	38	221,019
Total	187	750,962

The total volume by year varied greatly, representing the often-episodic nature of SSOs. Volume by year for each segment also varied greatly, and not always in relationship to other segments (e.g. in 2012 SSOs in segment 1008 went up sharply, and down sharply in segment 1009). This suggests that commonly experienced causes (precipitation levels, etc.) may not be a primary driver for SSOs.

While preliminary modeling indicates SSOs in general are not likely an appreciable chronic source of bacteria (and other products from the waste stream) but may be impactful on a local, episodic basis.

SSO Summary

SSOs are always a concern in watersheds with bacterial impairment and vulnerability to nutrient loading. Their concentrations of untreated human waste pose a disproportionately high risk to human health during recreation, and their episodic nature can make them an acute risk while they are ongoing. In terms of chronic loading, SSOs volumes in the project area are generally too small on an average basis to move conditions in the waterways in general. For comparison, a single plant of small to moderate size may have a discharge of 3 MGD, while the sum of all SSOs in the project area for a year is less than 3 million gallons. The SSOs are far greater in concentration, but their relatively minor volumes negate them to some degree as a primary source in average conditions.

However, given their pathogenic potential, inherently close proximity to urban populations, and the principle of focusing on those sources within our control, SSOs should remain as a consideration for best management practices (BMPs) in the watersheds. A specific point of interest for this data in Cypress Creek is the impact and potential future implications for increasing high flow events, which can easily overwhelm even well-functioning sanitary collections systems.

4.0 Outcomes and Implications

The review of water quality data for the Cypress Creek watershed provided a better understanding of the character of water quality issues in these systems and will inform subsequent stakeholder decisions. The primary questions answered were in regard to the sufficiency of the data, the extent and severity of water quality trends, seasonality of water quality issues, and the potential impact of wastewater effluent and SSOs.

In general, the review concluded that data was sufficient for all analyses, other than the lack of complete SSO data for 2018.

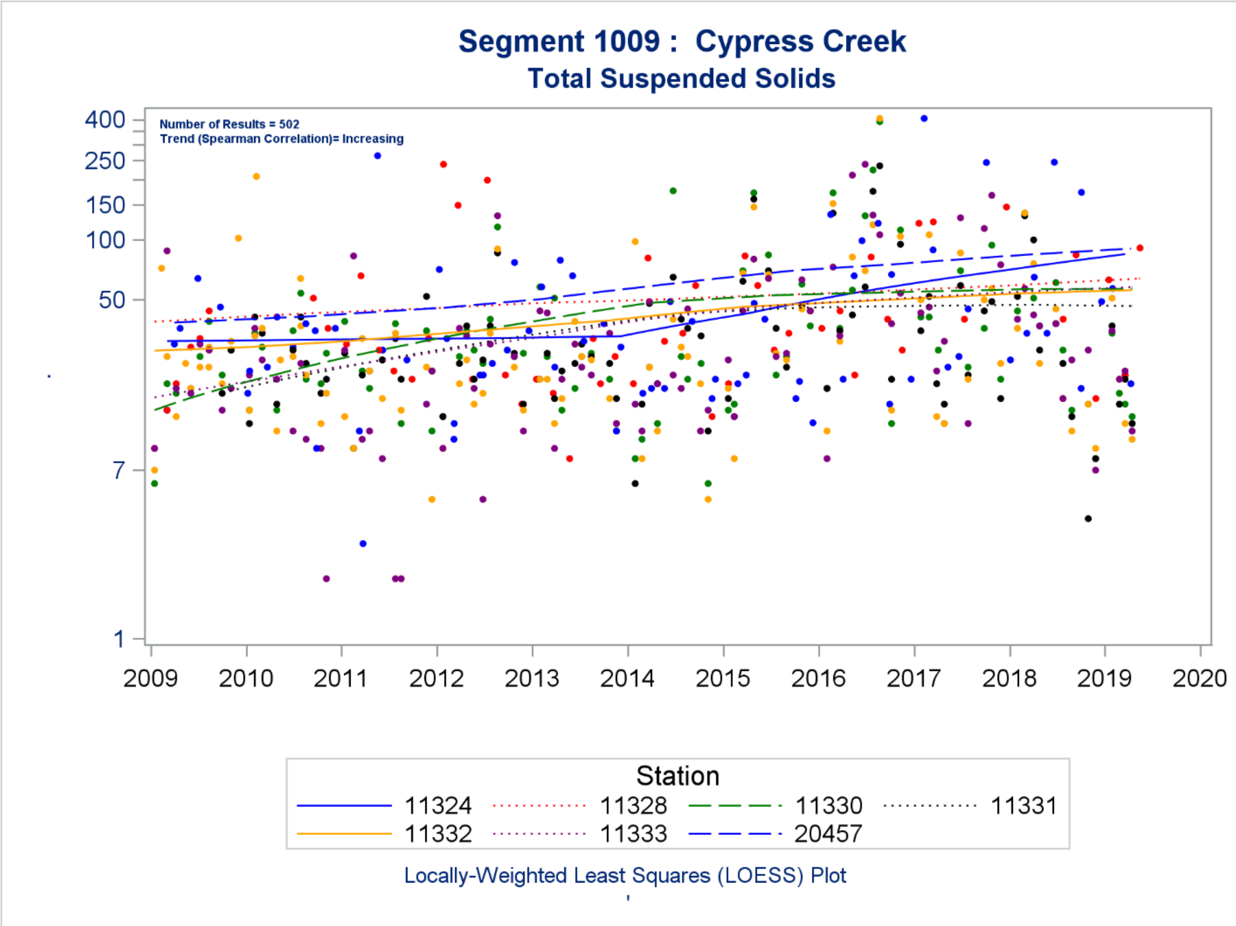
As discussed in the individual analyses, the water quality issues facing this watershed are widespread in extent. Trends are mixed, with some positive trends toward stability in *E. coli*, but increasing levels of some other constituents. Compared to modeling results and future growth projections, it is likely that increased development in the watershed will dramatically alter the balance of pollutant sources and change the hydrologic processes and time frames by which pollutants reach the waterways in precipitation events.

Permitted wastewater effluent was generally of good quality and unlikely to be a widespread water quality issue except in limited scales and timeframes. The exception to this is the likelihood that nutrients without permit limits are source loads from plants, especially in effluent-dominated streams. SSOs were present in all areas of the watershed, in numbers that were not appreciable but also not negligible. There were few statistically significant relationships between exceedance of water quality standards and WWTF permit limits, or incidences of SSOs, and seasonal change other than expected relationships evident in DO levels in ambient conditions.

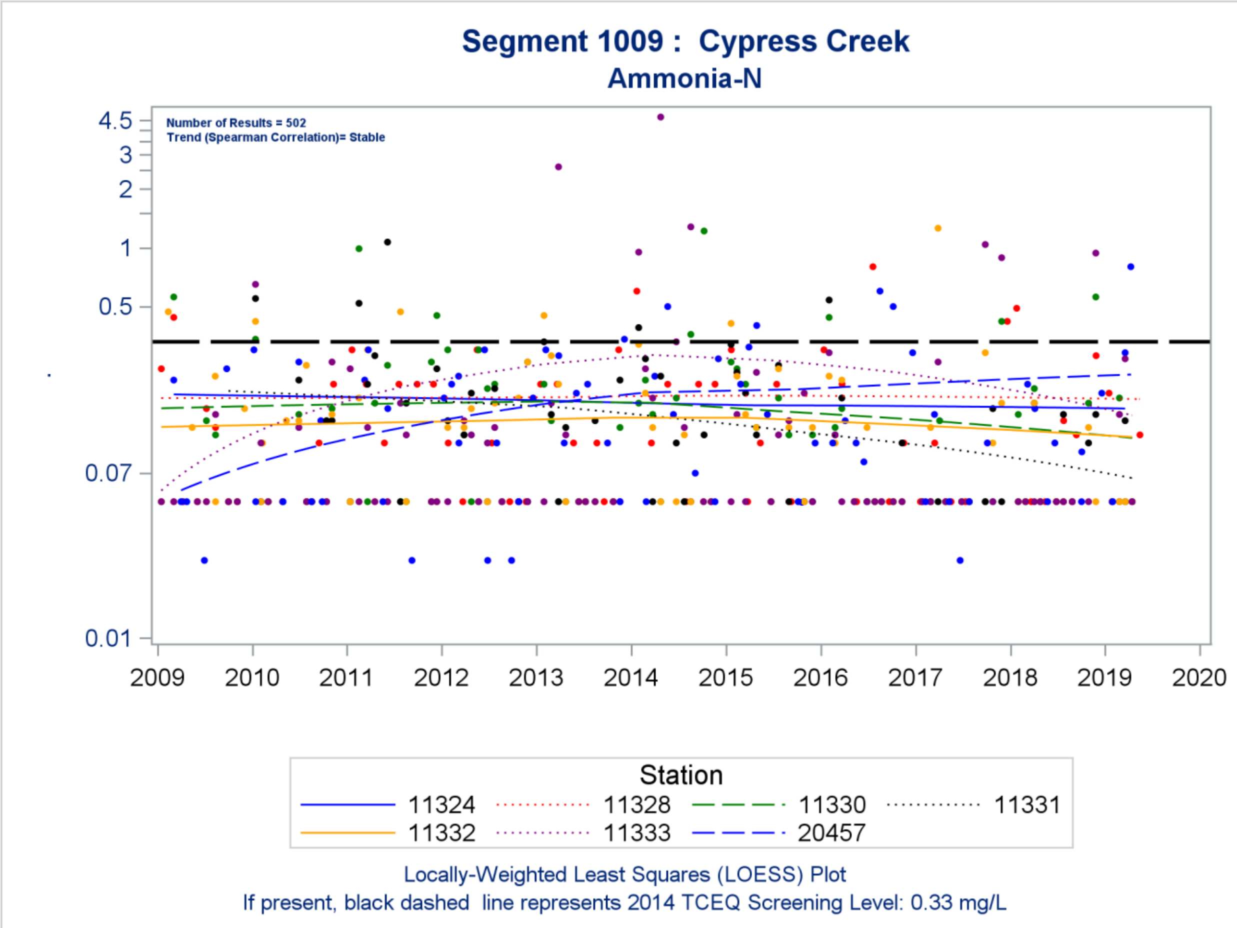
Overall, water quality in these watersheds faces many challenges, but is within the range which may be successfully addressed through best management practices under a watershed-based plan. With continued growth of the Houston region continuing to push west into the watershed, the implication for future water quality is likely negative without intervention. Subsequent efforts should be made to identify causes and sources of the primary constituent of concern (indicator bacteria), and to characterize nutrient sources further to identify areas within the project watersheds most vulnerable to pollutant loadings and/or best suited for BMP siting.

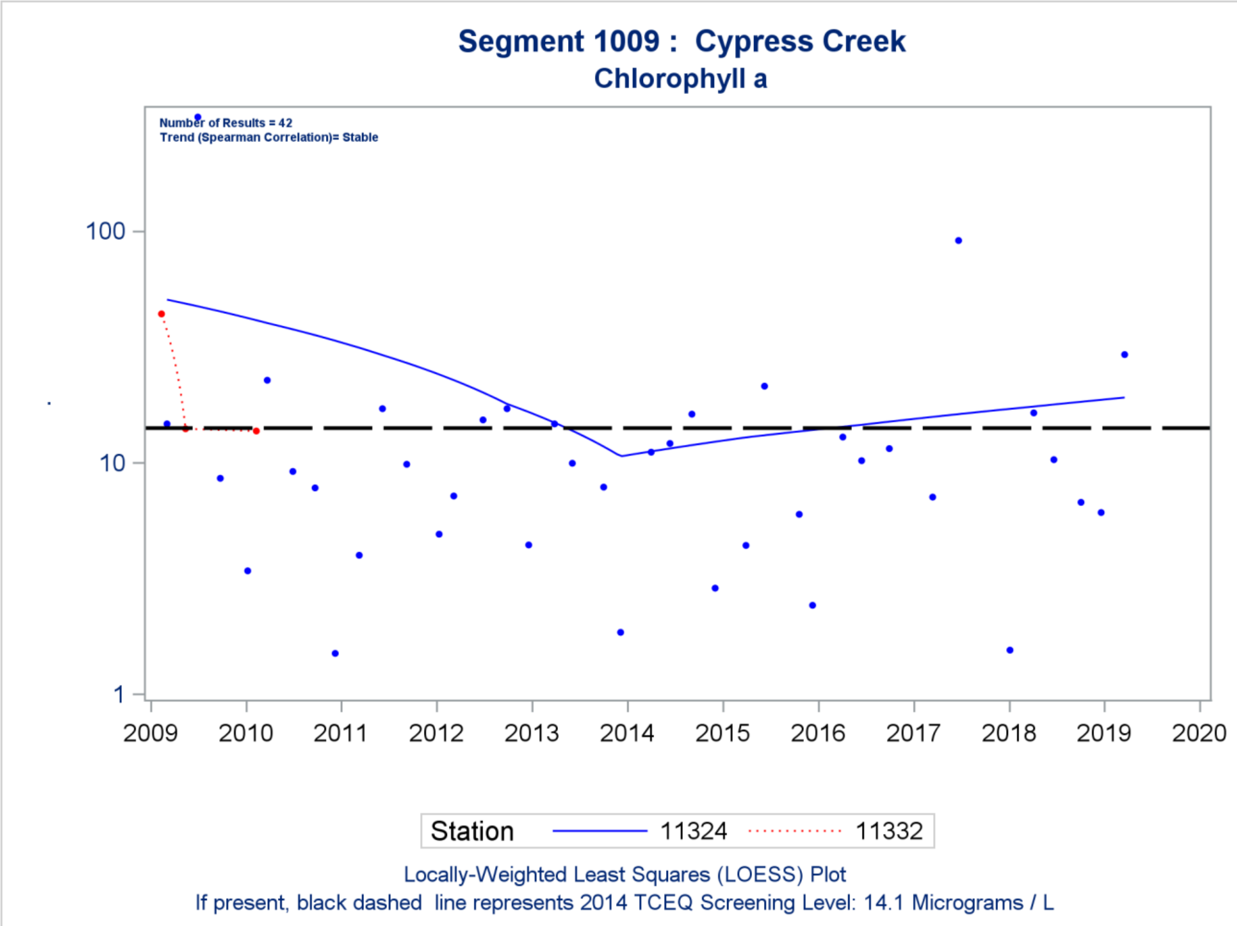
Appendix A – Monitoring Site Data

The following charts represent the results, by segment and station, for all constituents evaluated. The period of data for the effort is 2009-2018, although data for each station may vary as indicated in the charts.

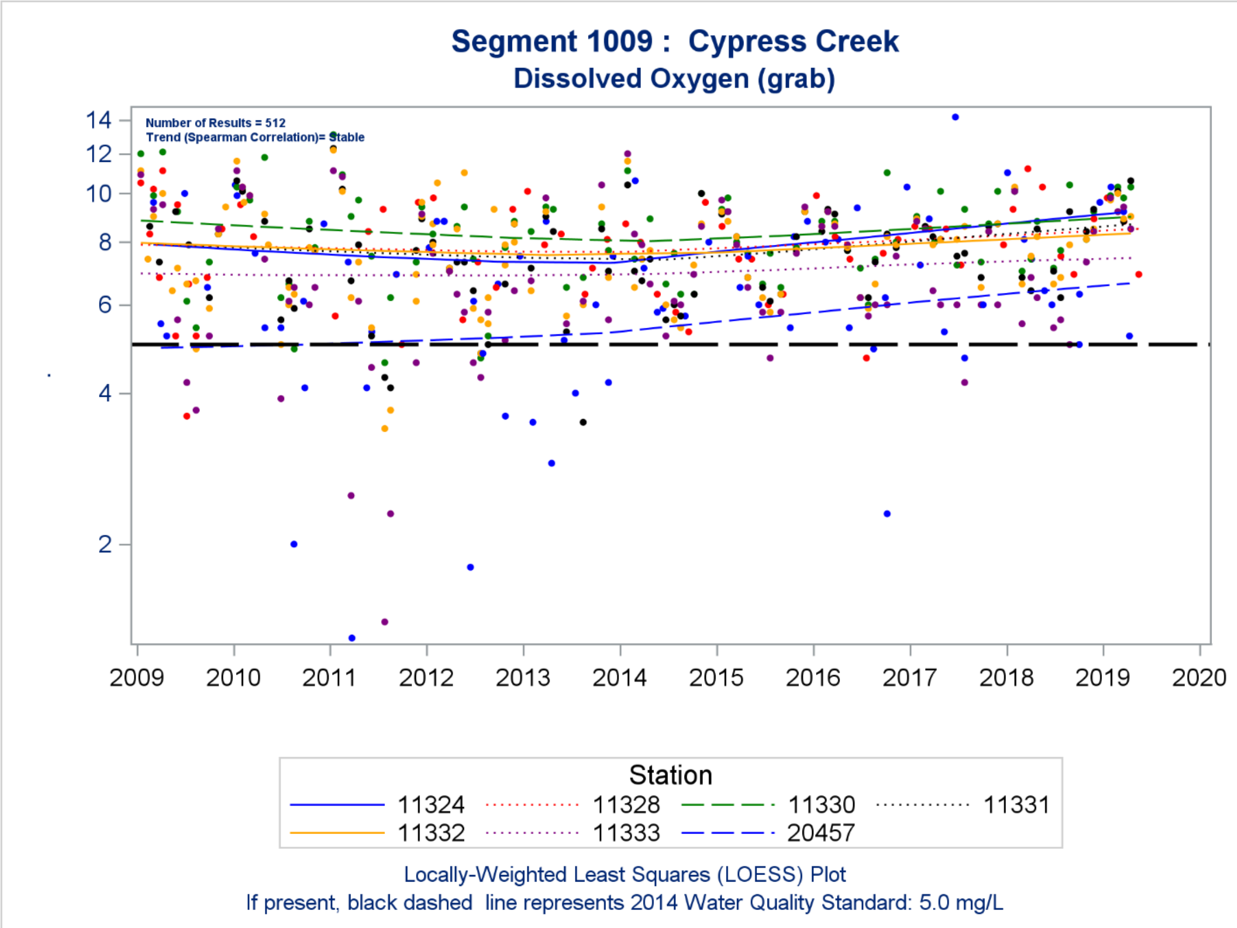


Segment 1009 : Cypress Creek
Total Suspended Solids
Number of Results = 502
Trend (Spearman Correlation)= Increasing
400
250
150
100
50
7
1
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
11324
11328
11330
11331
11332
11333
20457
Locally-Weighted Least Squares (LOESS) Plot

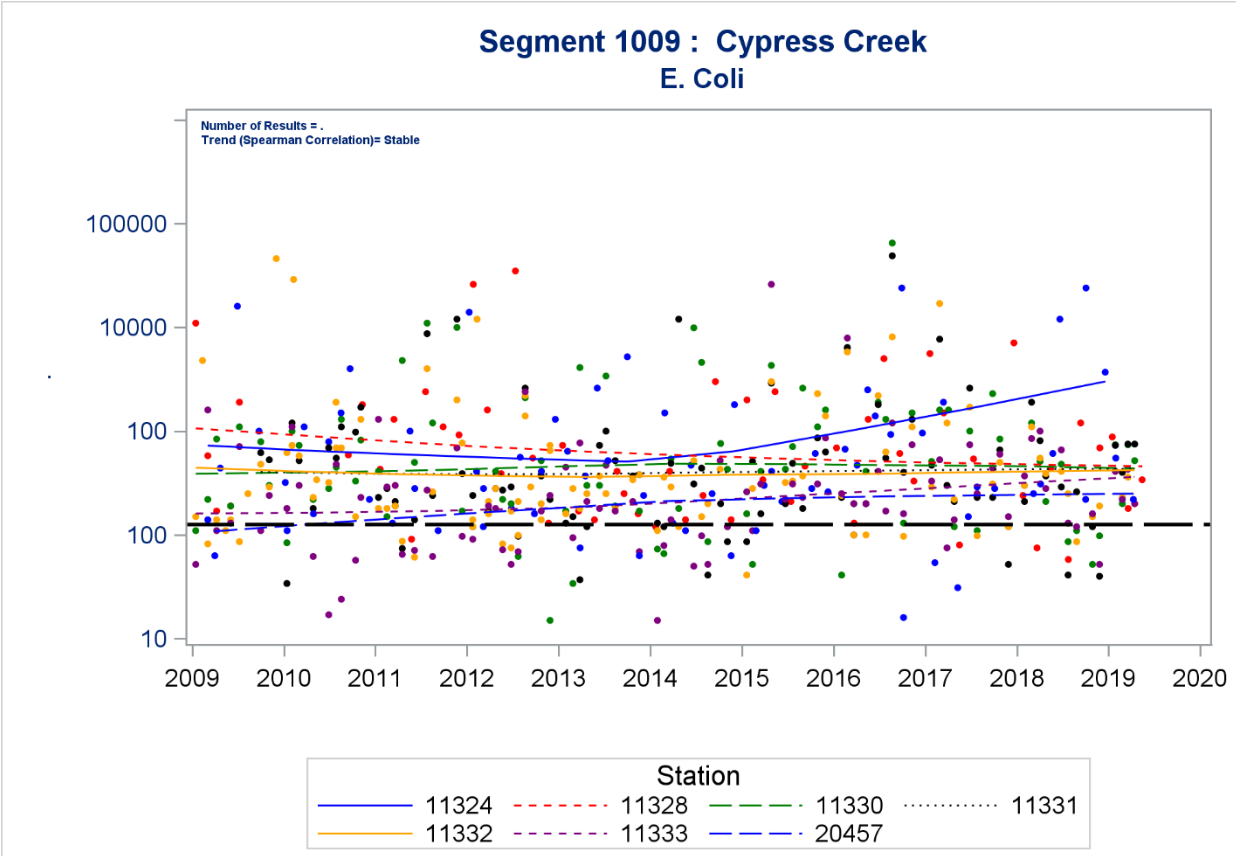

Segment 1009 : Cypress Creek
Ammonia-N
Number of Results = 502
Trend (Spearman Correlation)= Stable
4.5
3
2
1
0.5
0.07
0.01
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
11324
11328
11330
11331
11332
11333
20457
Locally-Weighted Least Squares (LOESS) Plot
If present, black dashed line represents 2014 TCEQ Screening Level: 0.33 mg/L



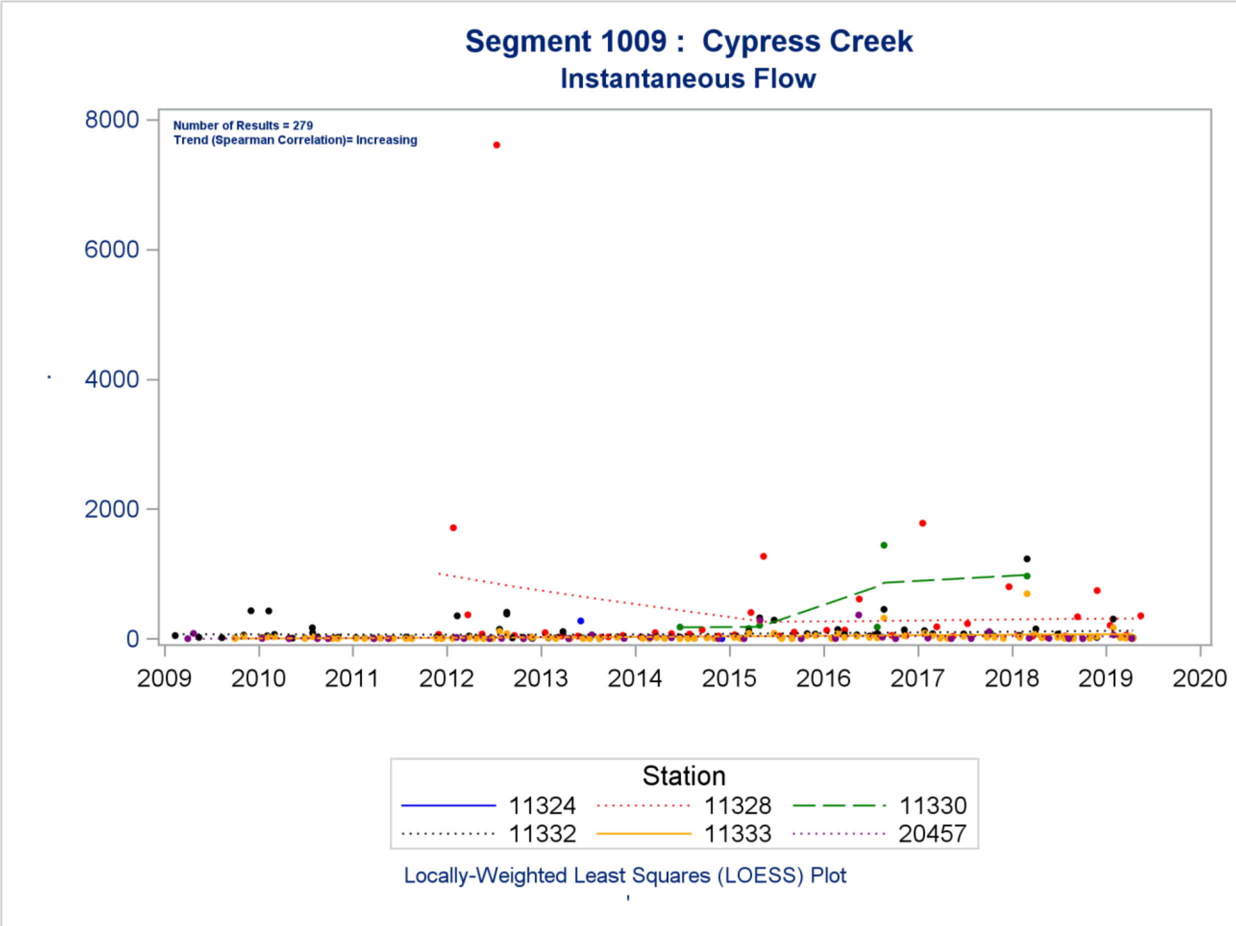
Segment 1009 : Cypress Creek
Chlorophyll a
Number of Results = 42
Trend (Spearman Correlation)= Stable
100
10
1
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
11324
11332
Locally-Weighted Least Squares (LOESS) Plot
If present, black dashed line represents 2014 TCEQ Screening Level: 14.1 Micrograms / L

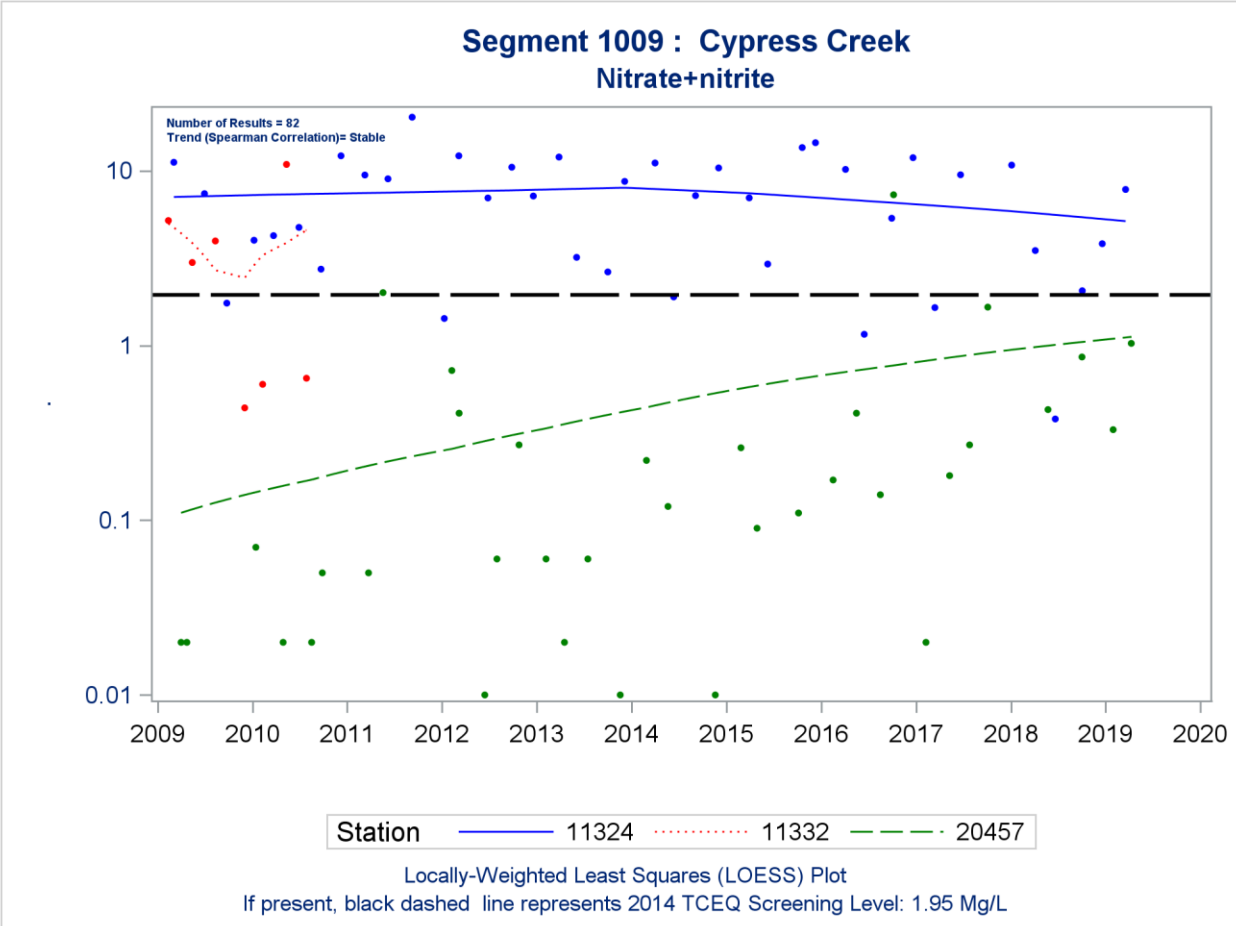


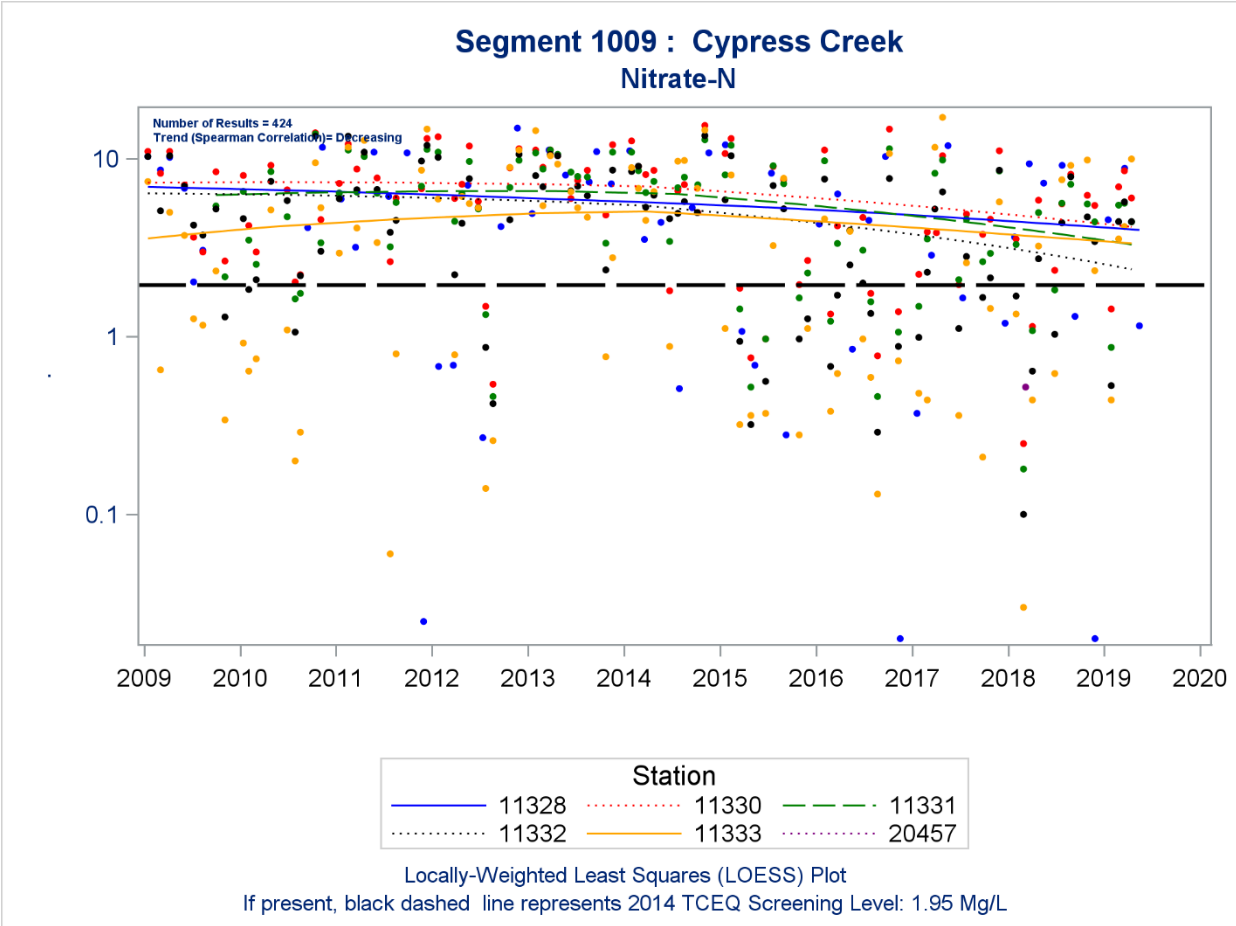
Segment 1009 : Cypress Creek
Dissolved Oxygen (grab)
Number of Results = 512
Trend (Spearman Correlation)= Stable
14
12
10
8
6
4
2
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
11324
11328
11330
11331
11332
11333
20457
Locally-Weighted Least Squares (LOESS) Plot
If present, black dashed line represents 2014 Water Quality Standard: 5.0 mg/L

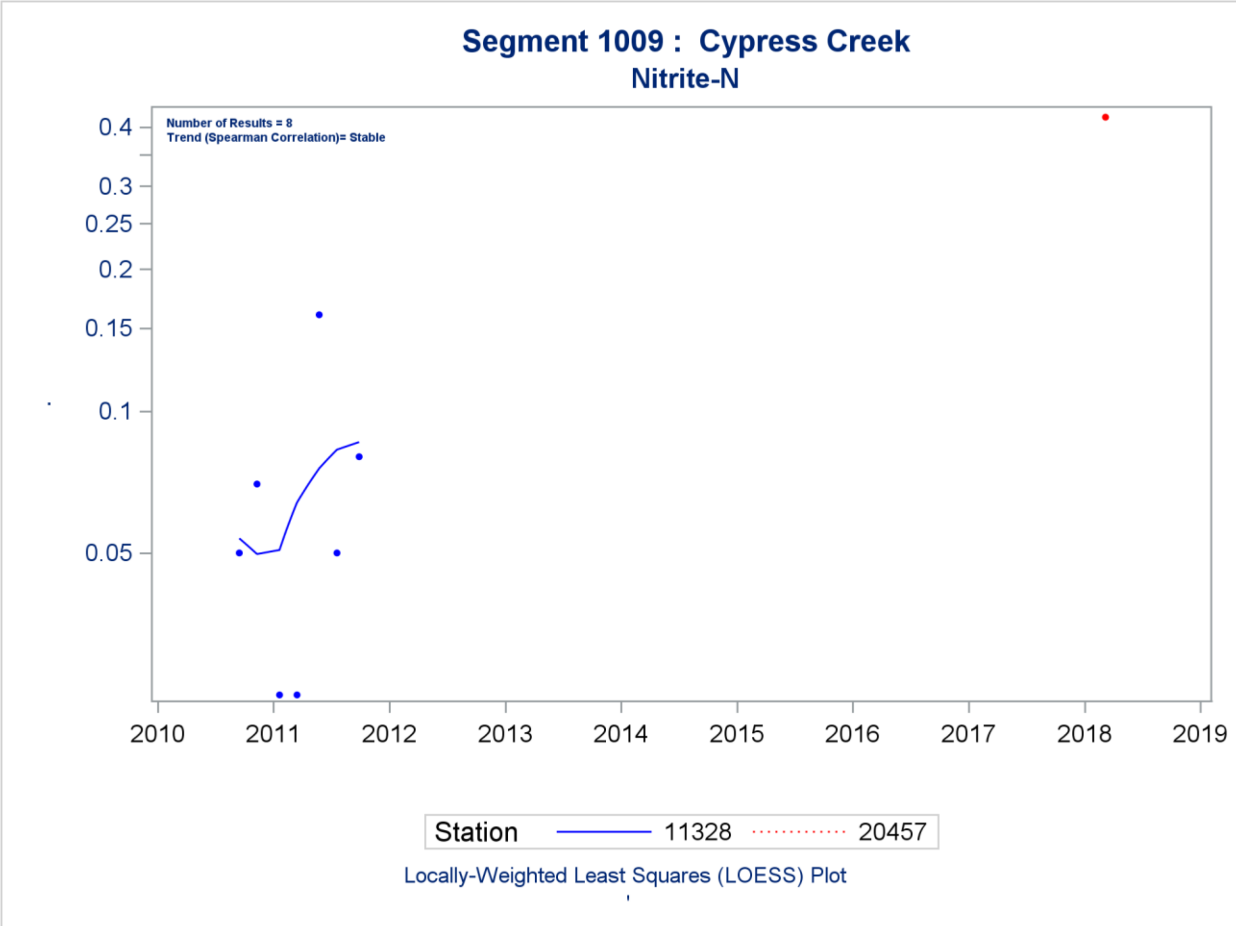


Locally-Weighted Least Squares (LOESS) Plot
If present, black dashed line represents 2014 Water Quality Standard: 126 MPN/100 mL

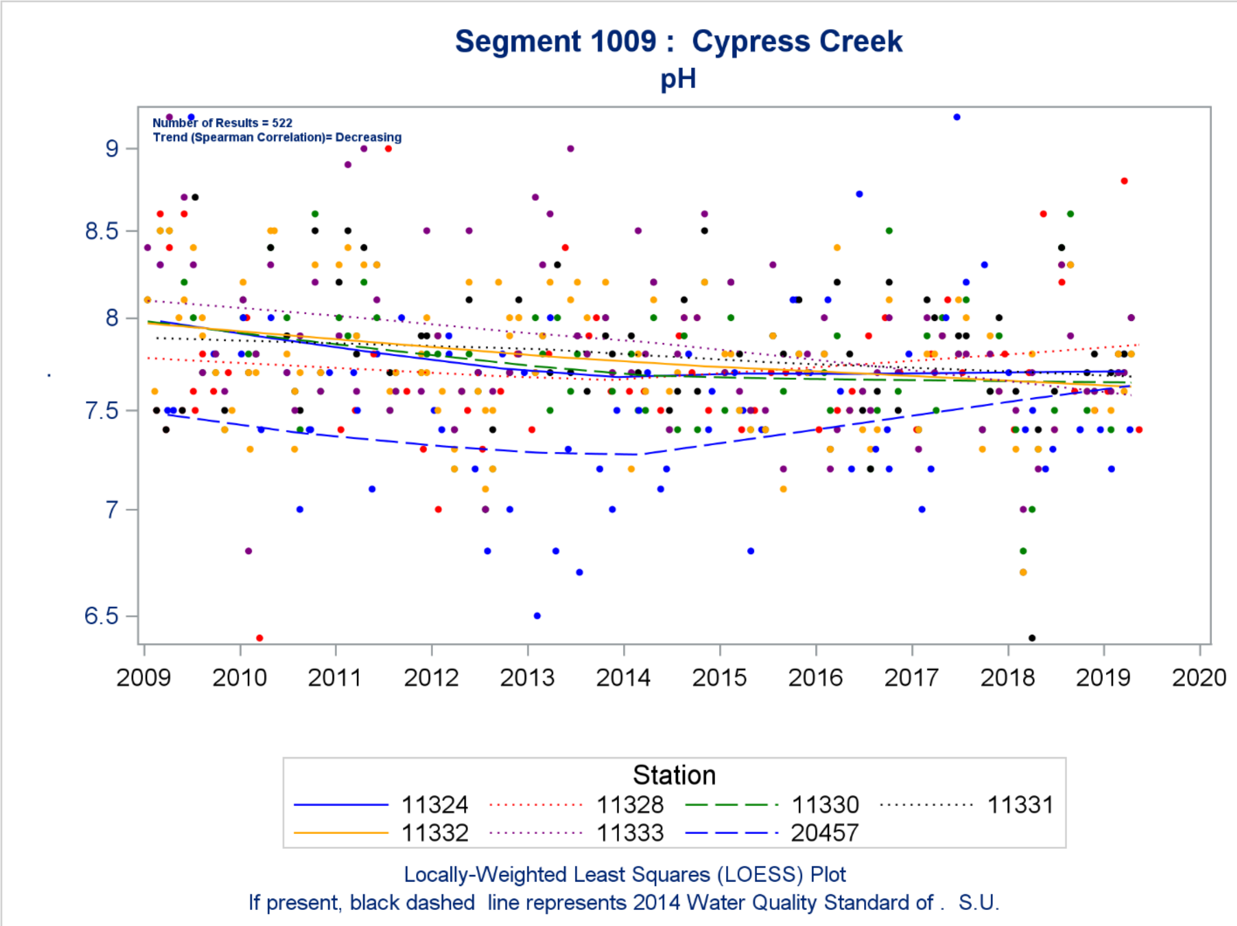

Segment 1009 : Cypress Creek
Instantaneous Flow
Number of Results = 279
Trend (Spearman Correlation)= Increasing
8000
6000
4000
2000
0
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
11324
11328
11330
11332
11333
20457
Locally-Weighted Least Squares (LOESS) Plot

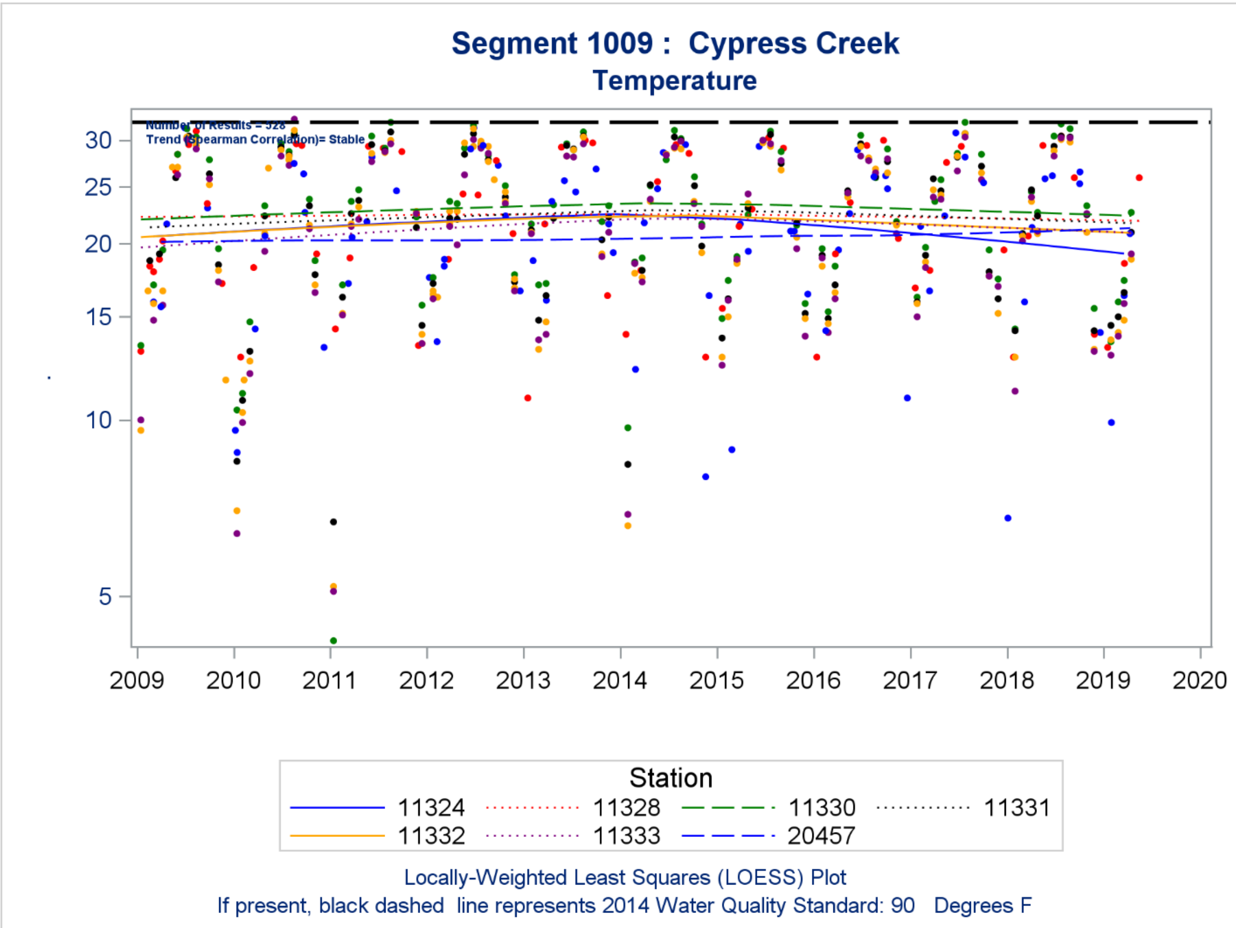

Segment 1009 : Cypress Creek
Nitrate+nitrite
Number of Results = 82
Trend (Spearman Correlation)= Stable
10
1
0.1
0.01
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
11324
11332
20457
Locally-Weighted Least Squares (LOESS) Plot
If present, black dashed line represents 2014 TCEQ Screening Level: 1.95 Mg/L


Segment 1009 : Cypress Creek
Nitrate-N
Number of Results = 424
Trend (Spearman Correlation)= Decreasing
10
1
0.1
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
11328
11330
11331
11332
11333
20457
Locally-Weighted Least Squares (LOESS) Plot
If present, black dashed line represents 2014 TCEQ Screening Level: 1.95 Mg/L

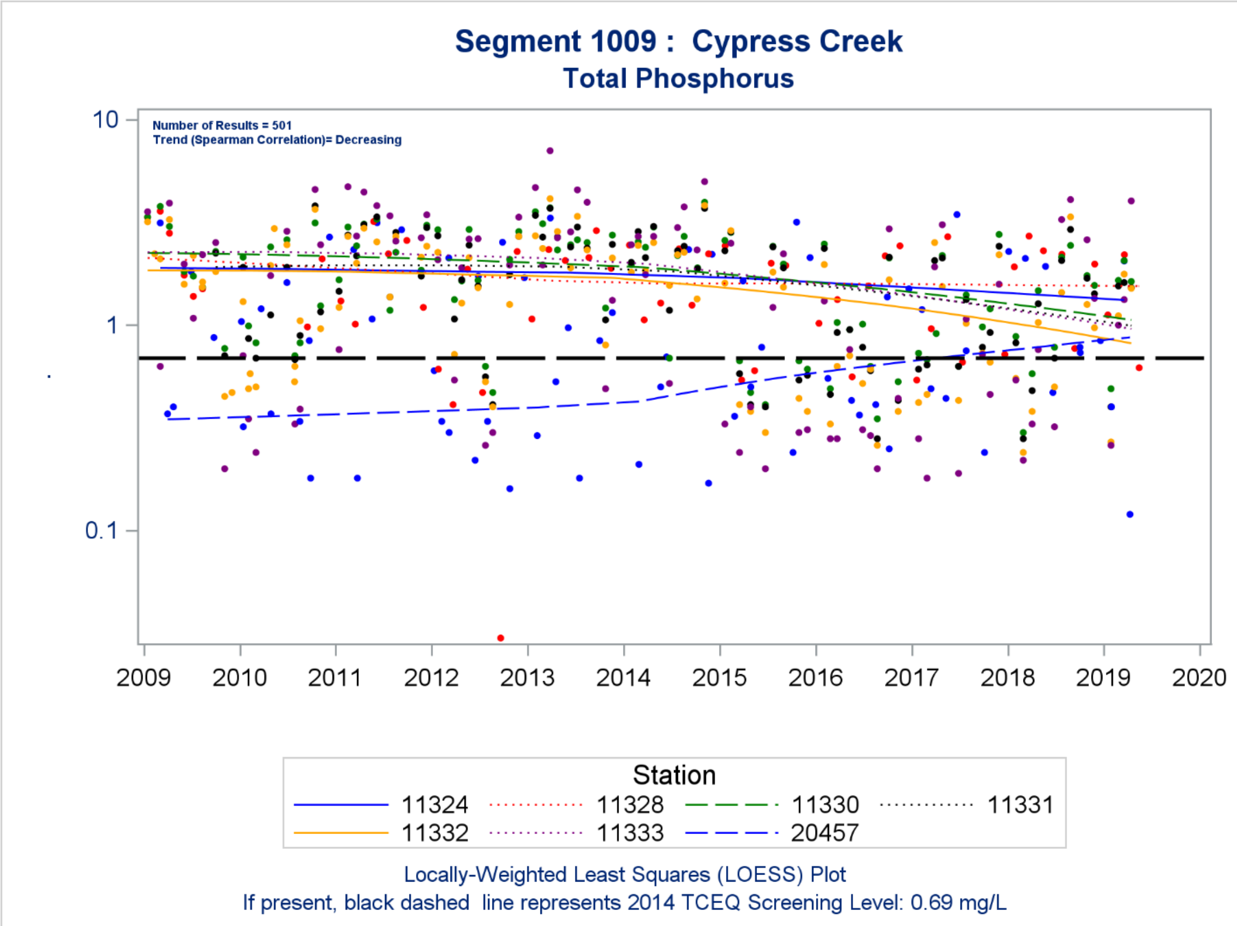


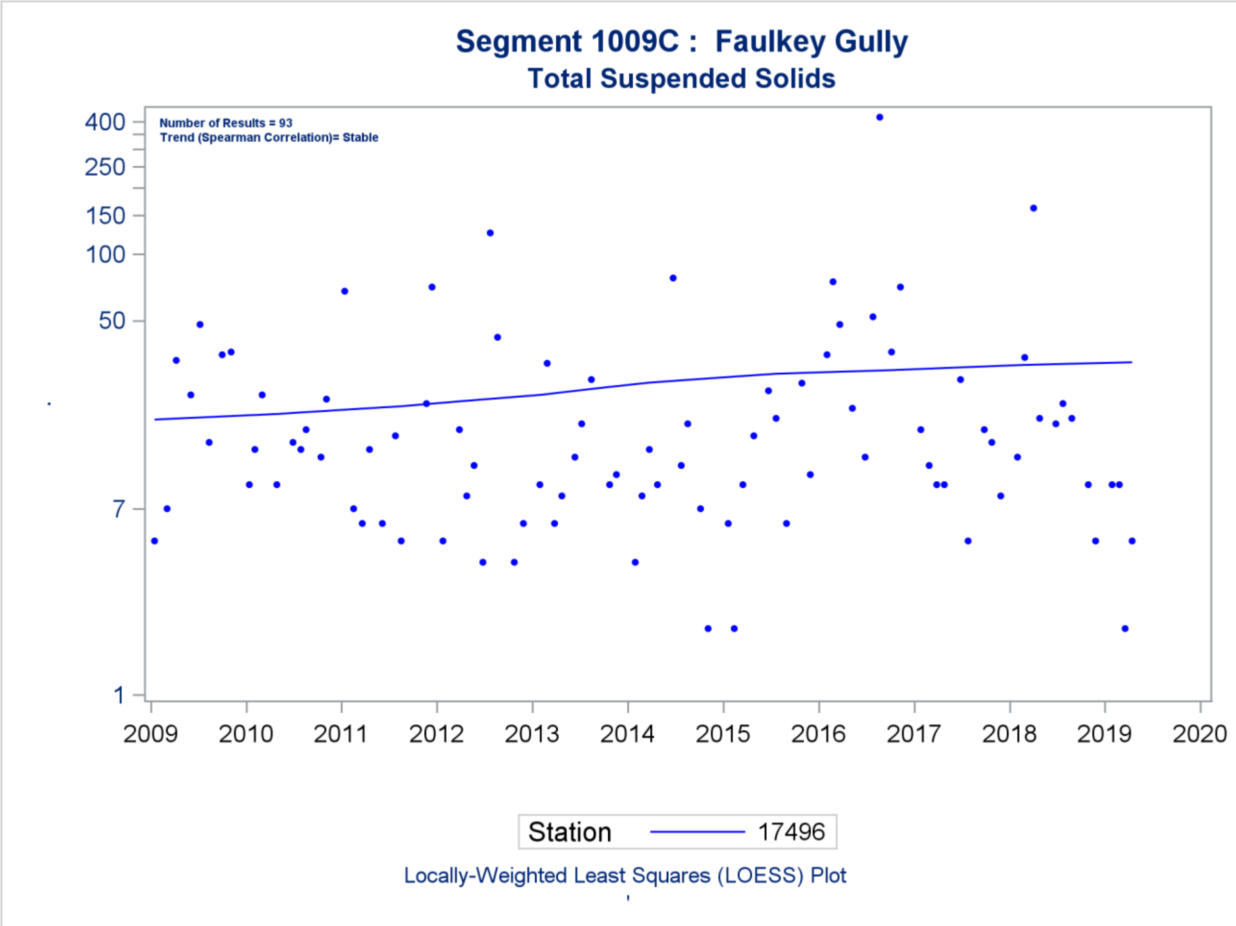
Segment 1009 : Cypress Creek
Nitrite-N
Number of Results = 8
Trend (Spearman Correlation)= Stable
0.4
0.3
0.25
0.2
0.15
0.1
0.05
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
Station
11328
20457
Locally-Weighted Least Squares (LOESS) Plot


Segment 1009 : Cypress Creek
pH
Number of Results = 522
Trend (Spearman Correlation)= Decreasing
9
8.5
8
7.5
7
6.5
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
11324
11328
11330
11331
11332
11333
20457
Locally-Weighted Least Squares (LOESS) Plot
If present, black dashed line represents 2014 Water Quality Standard of . S.U.

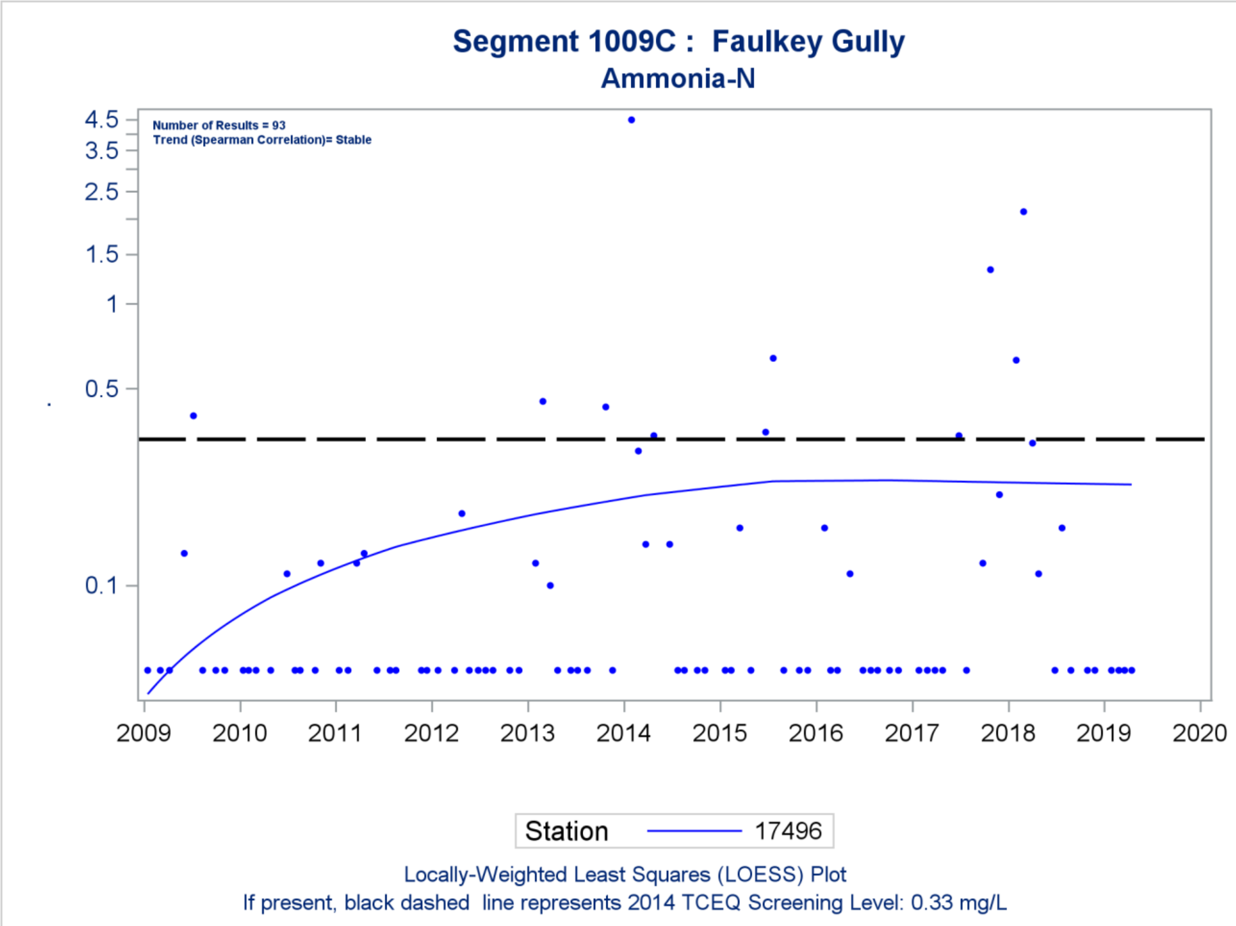


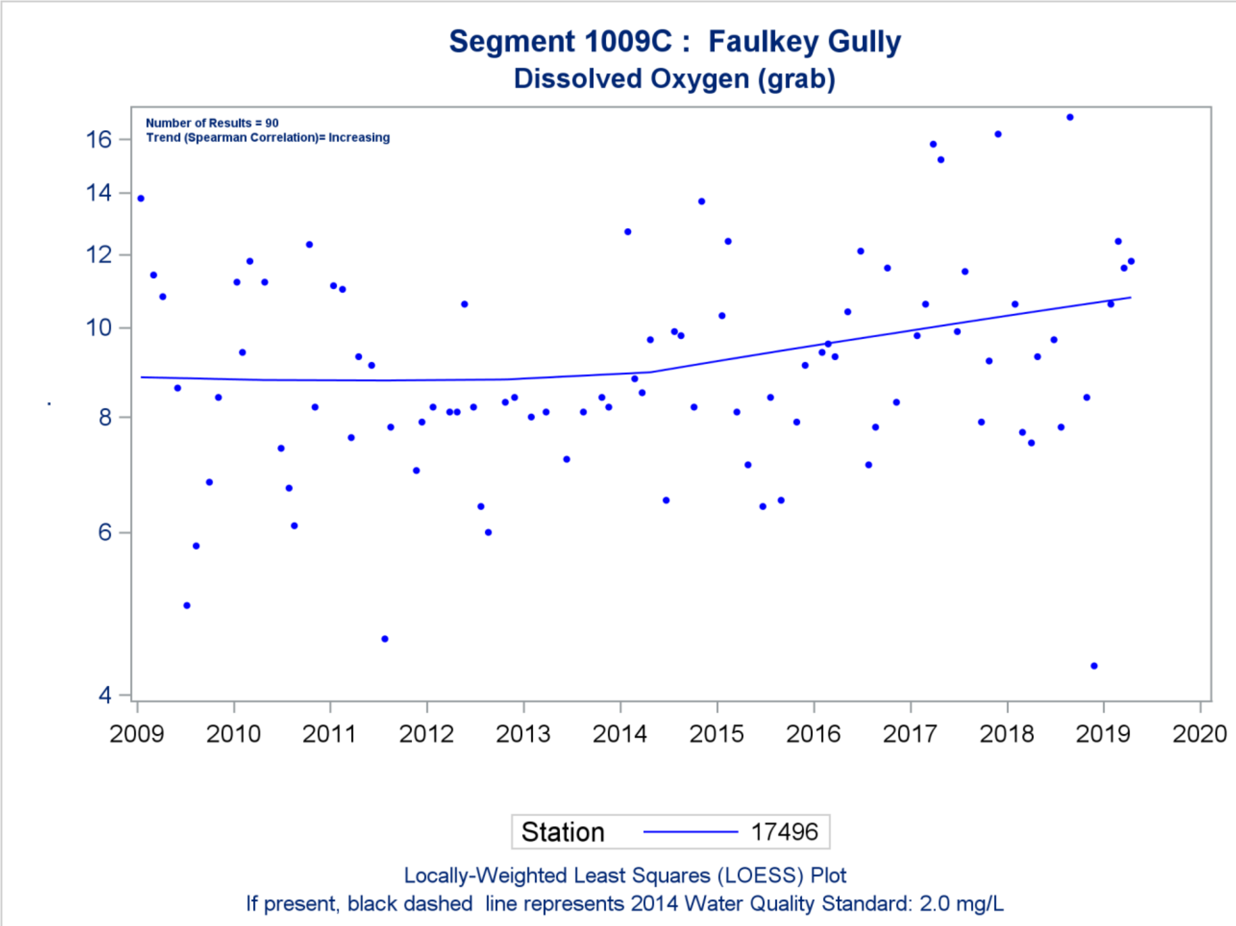
Segment 1009 : Cypress Creek
Temperature
Number of Results = 528
Trend (Spearman Correlation)= Stable
30
25
20
15
10
5
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
11324
11328
11330
11331
11332
11333
20457
Locally-Weighted Least Squares (LOESS) Plot
If present, black dashed line represents 2014 Water Quality Standard: 90 Degrees F

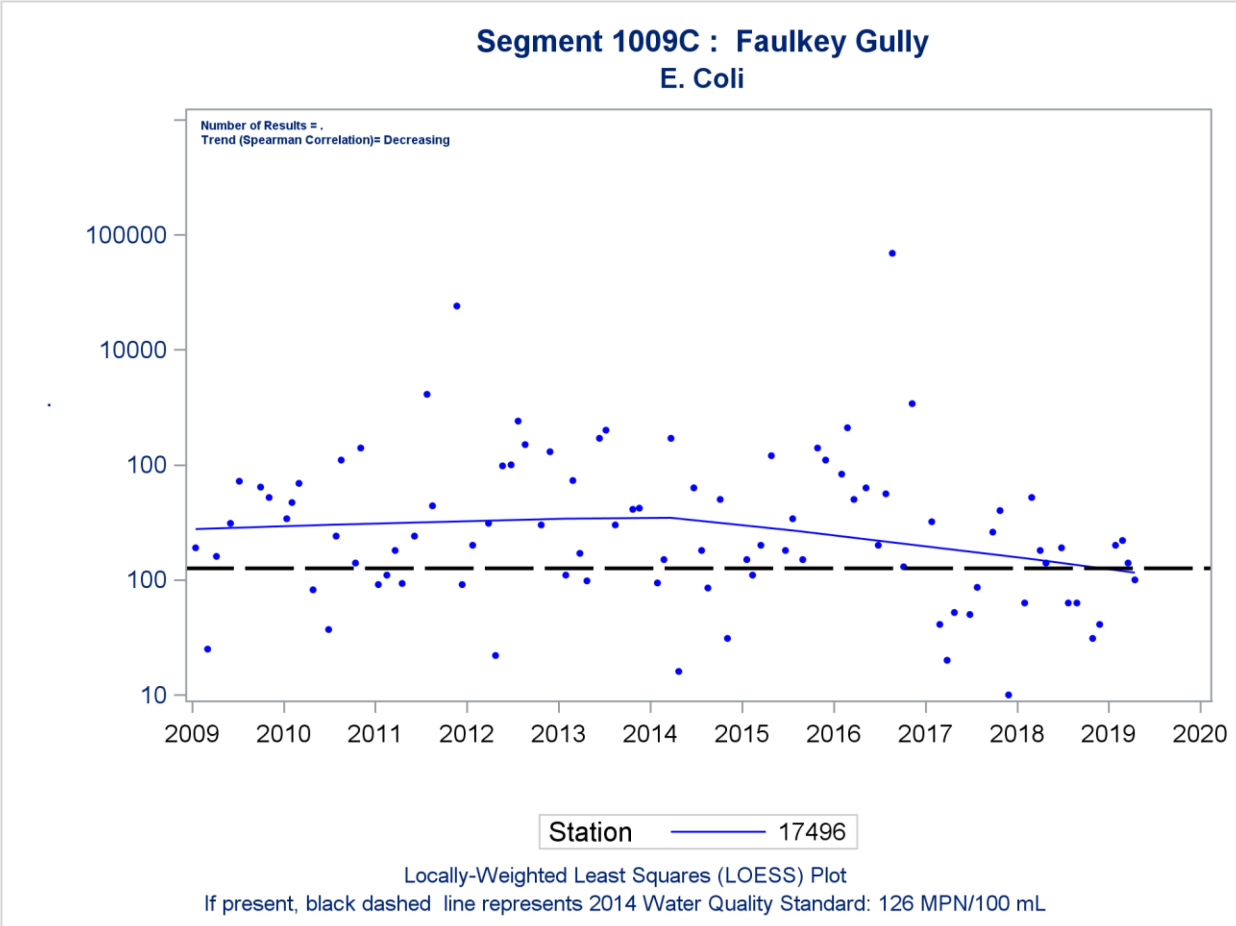

Segment 1009 : Cypress Creek
Total Phosphorus
Number of Results = 501
Trend (Spearman Correlation)= Decreasing
10
1
0.1
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
11324
11328
11330
11331
11332
11333
20457
Locally-Weighted Least Squares (LOESS) Plot
If present, black dashed line represents 2014 TCEQ Screening Level: 0.69 mg/L

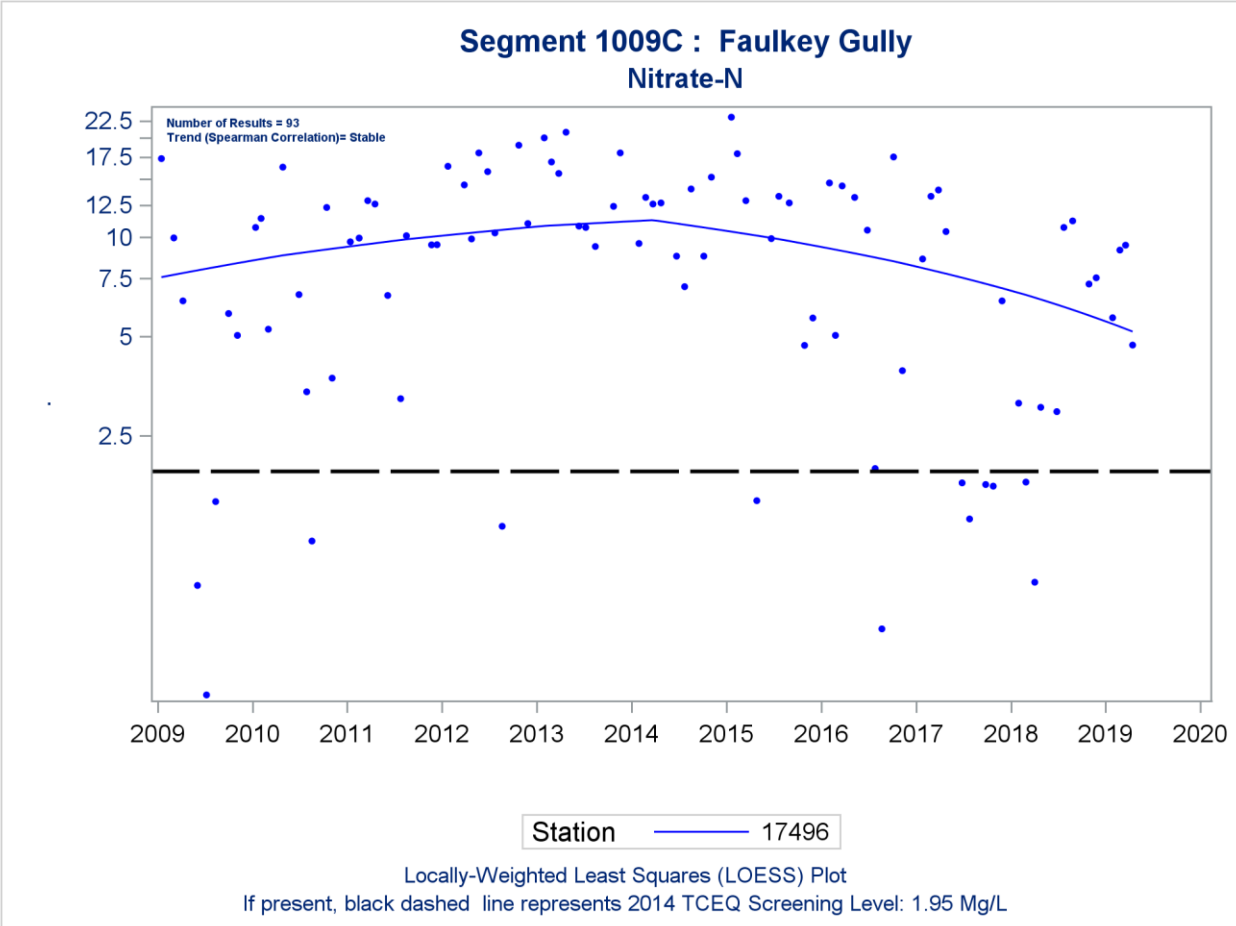


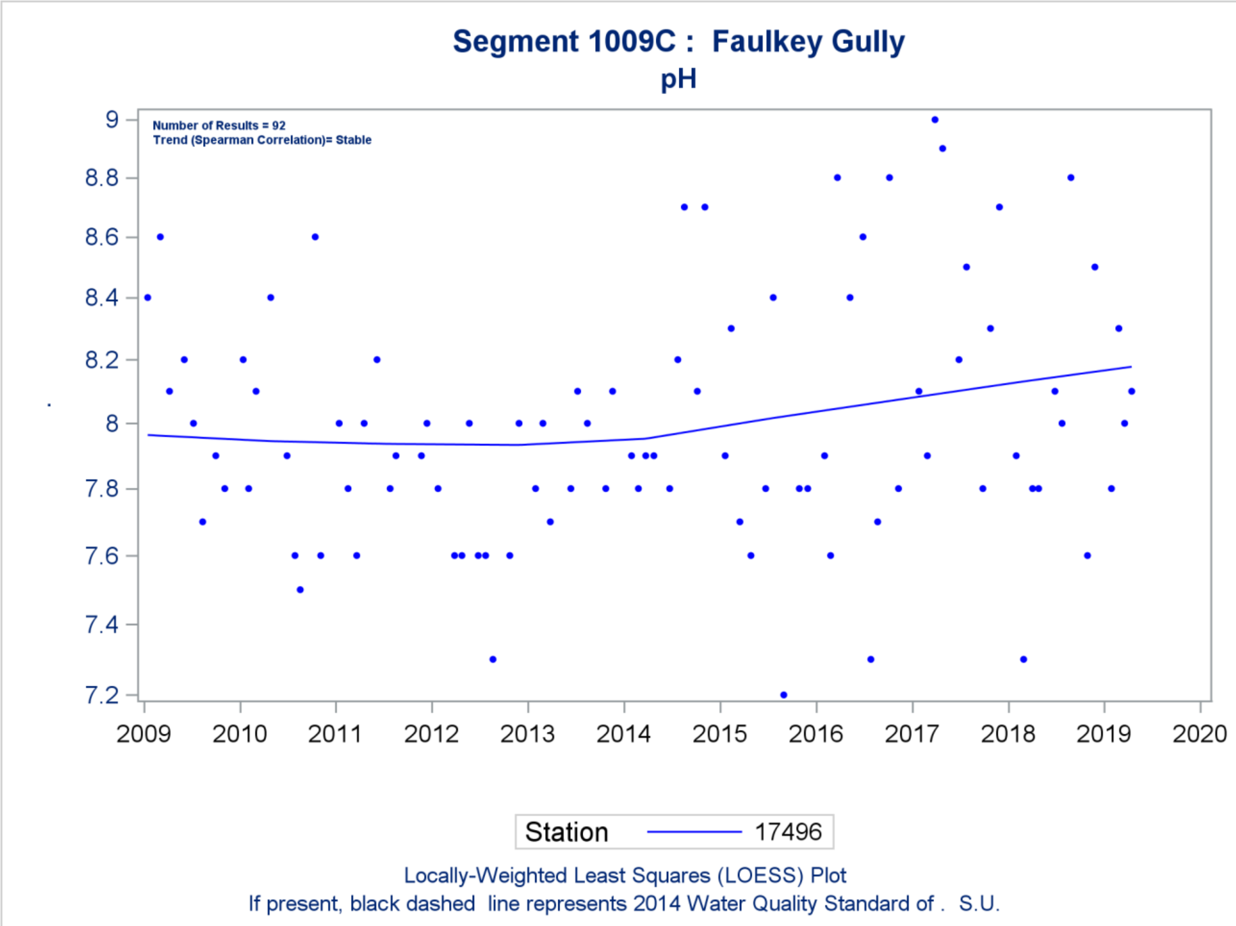
Segment 1009C : Faulkey Gully
Total Suspended Solids
Number of Results = 93
Trend (Spearman Correlation)= Stable
400
250
150
100
50
7
1
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
17496
Locally-Weighted Least Squares (LOESS) Plot


Segment 1009C : Faulkey Gully
Ammonia-N
Number of Results = 93
Trend (Spearman Correlation)= Stable
4.5
3.5
2.5
1.5
1
0.5
0.1
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
17496
Locally-Weighted Least Squares (LOESS) Plot
If present, black dashed line represents 2014 TCEQ Screening Level: 0.33 mg/L

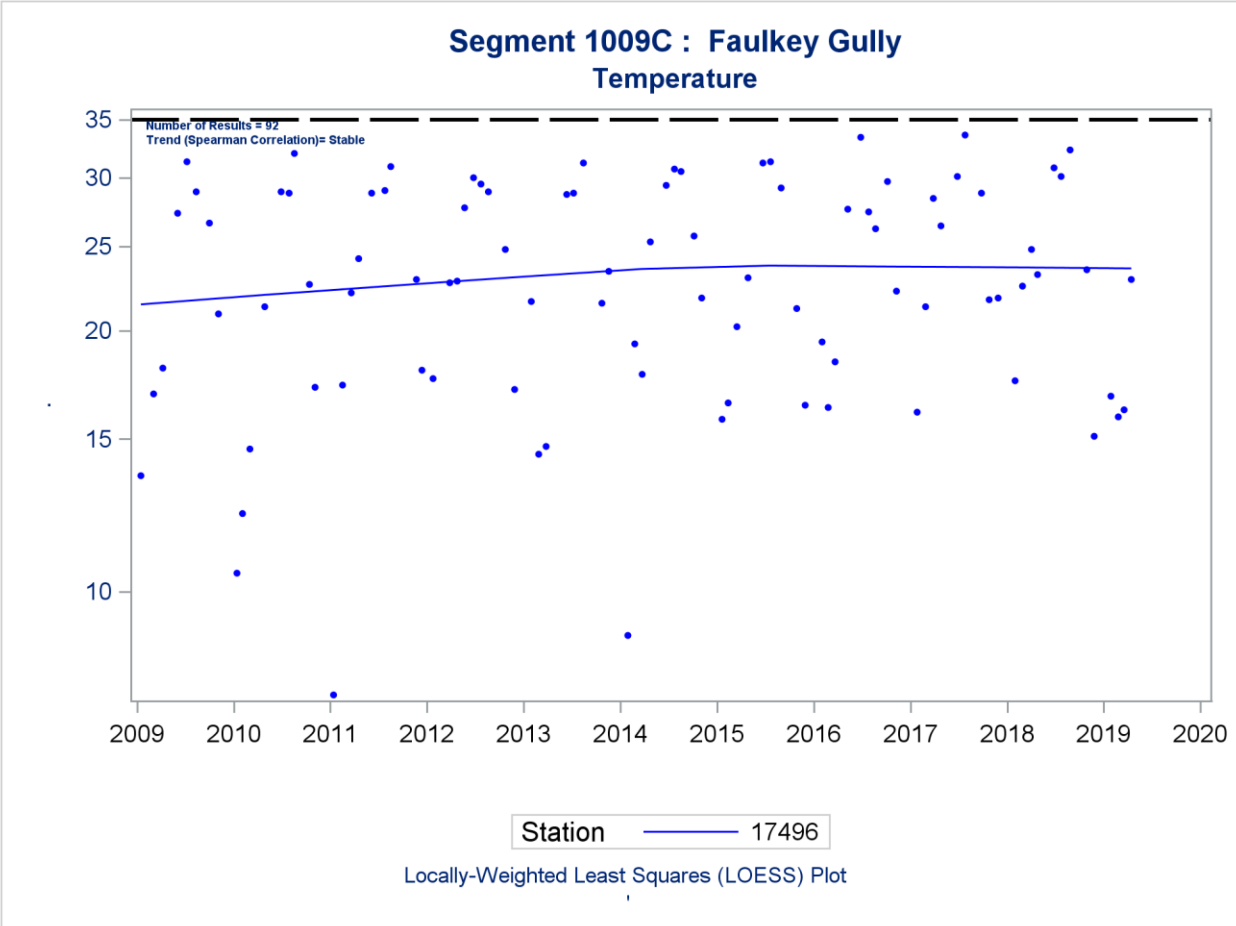

Segment 1009C : Faulkey Gully
Dissolved Oxygen (grab)
Number of Results = 90
Trend (Spearman Correlation)= Increasing
16
14
12
10
8
6
4
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
17496
Locally-Weighted Least Squares (LOESS) Plot
If present, black dashed line represents 2014 Water Quality Standard: 2.0 mg/L


Segment 1009C : Faulkey Gully
E. Coli
Number of Results = .
Trend (Spearman Correlation)= Decreasing
100000
10000
100
100
10
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
17496
Locally-Weighted Least Squares (LOESS) Plot
If present, black dashed line represents 2014 Water Quality Standard: 126 MPN/100 mL

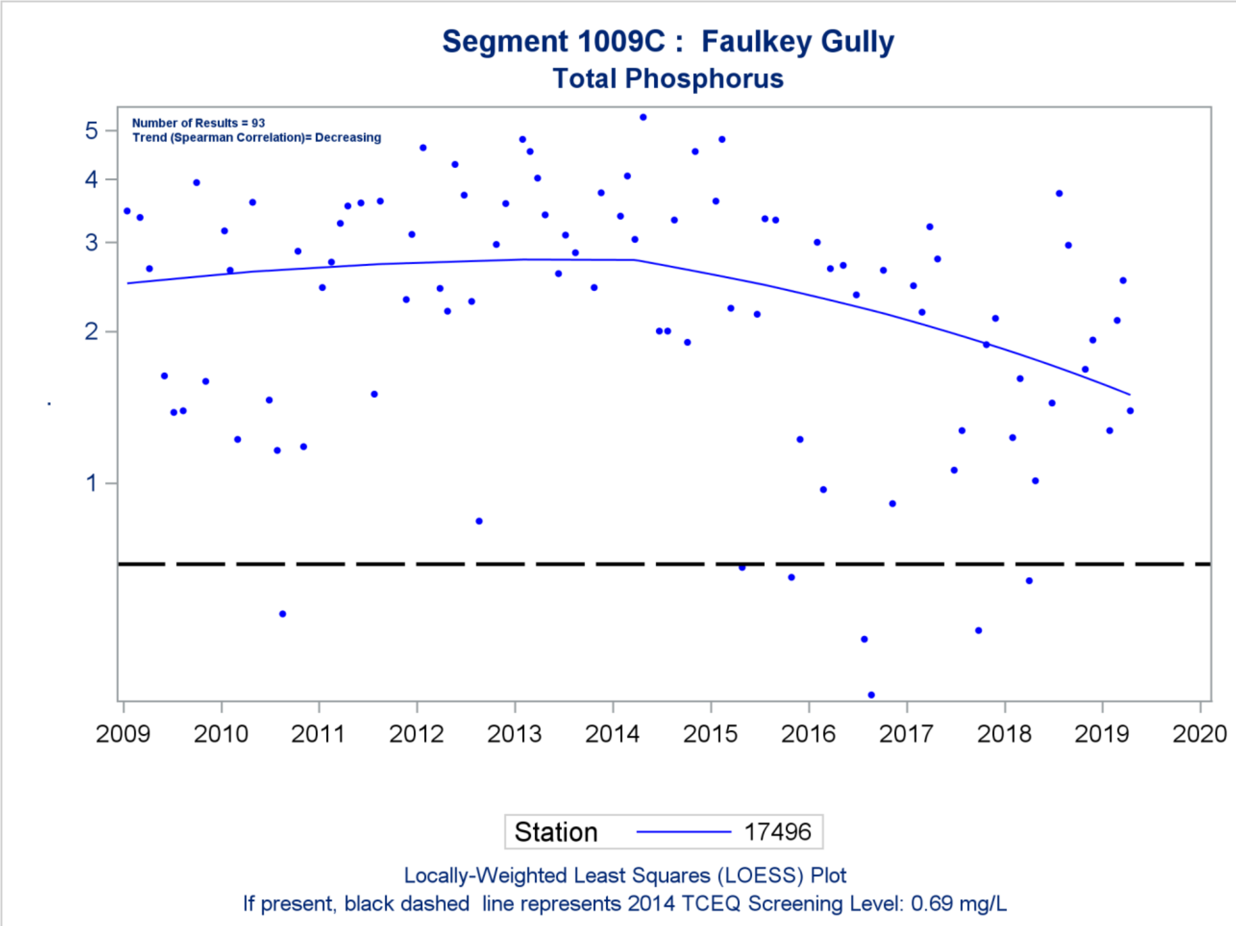

Segment 1009C : Faulkey Gully
Nitrate-N
Number of Results = 93
Trend (Spearman Correlation)= Stable
22.5
17.5
12.5
10
7.5
5
2.5
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
17496
Locally-Weighted Least Squares (LOESS) Plot
If present, black dashed line represents 2014 TCEQ Screening Level: 1.95 Mg/L



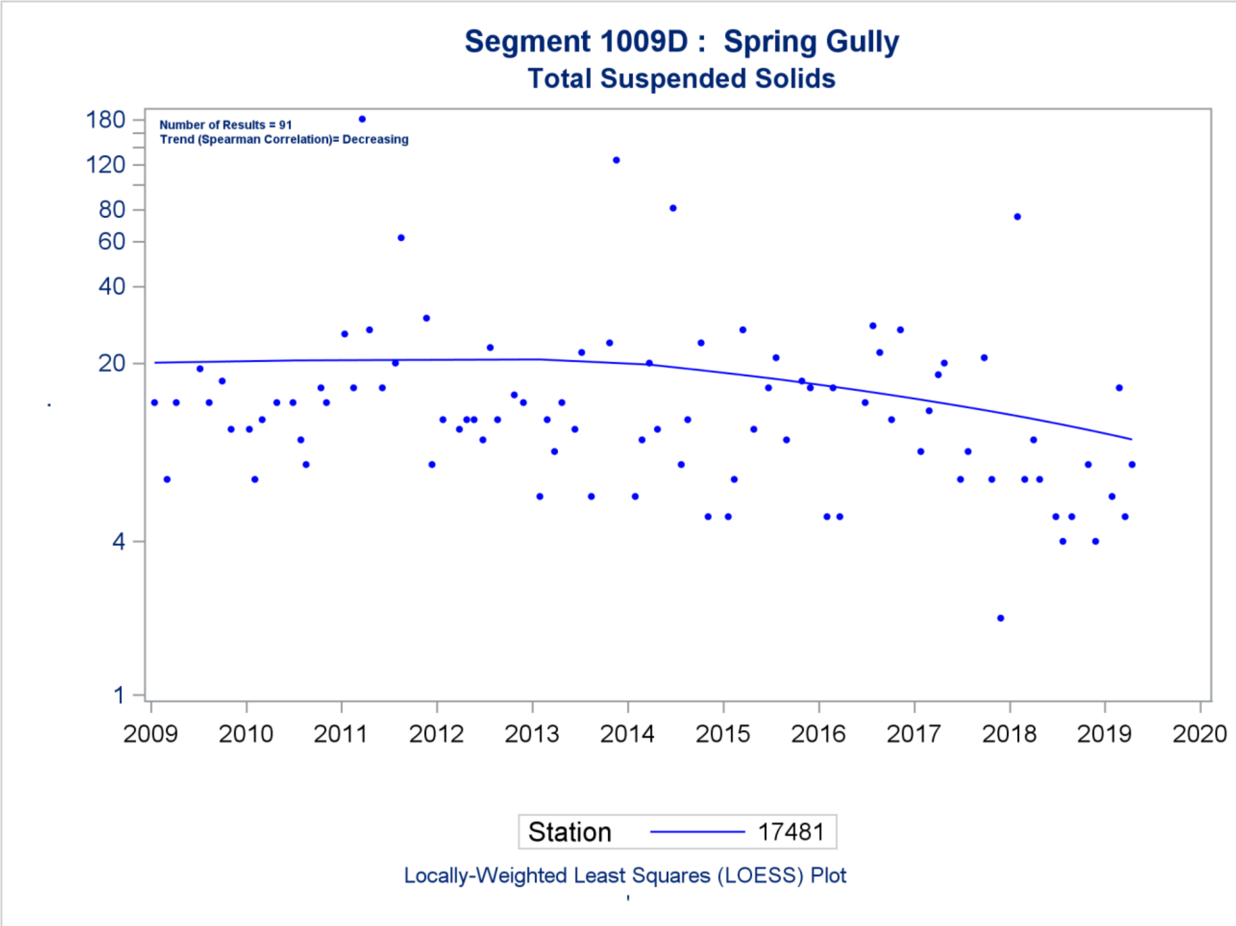
Segment 1009C : Faulkey Gully
pH
Number of Results = 92
Trend (Spearman Correlation)= Stable
9
8.8
8.6
8.4
8.2
8
7.8
7.6
7.4
7.2
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
17496
Locally-Weighted Least Squares (LOESS) Plot
If present, black dashed line represents 2014 Water Quality Standard of . S.U.

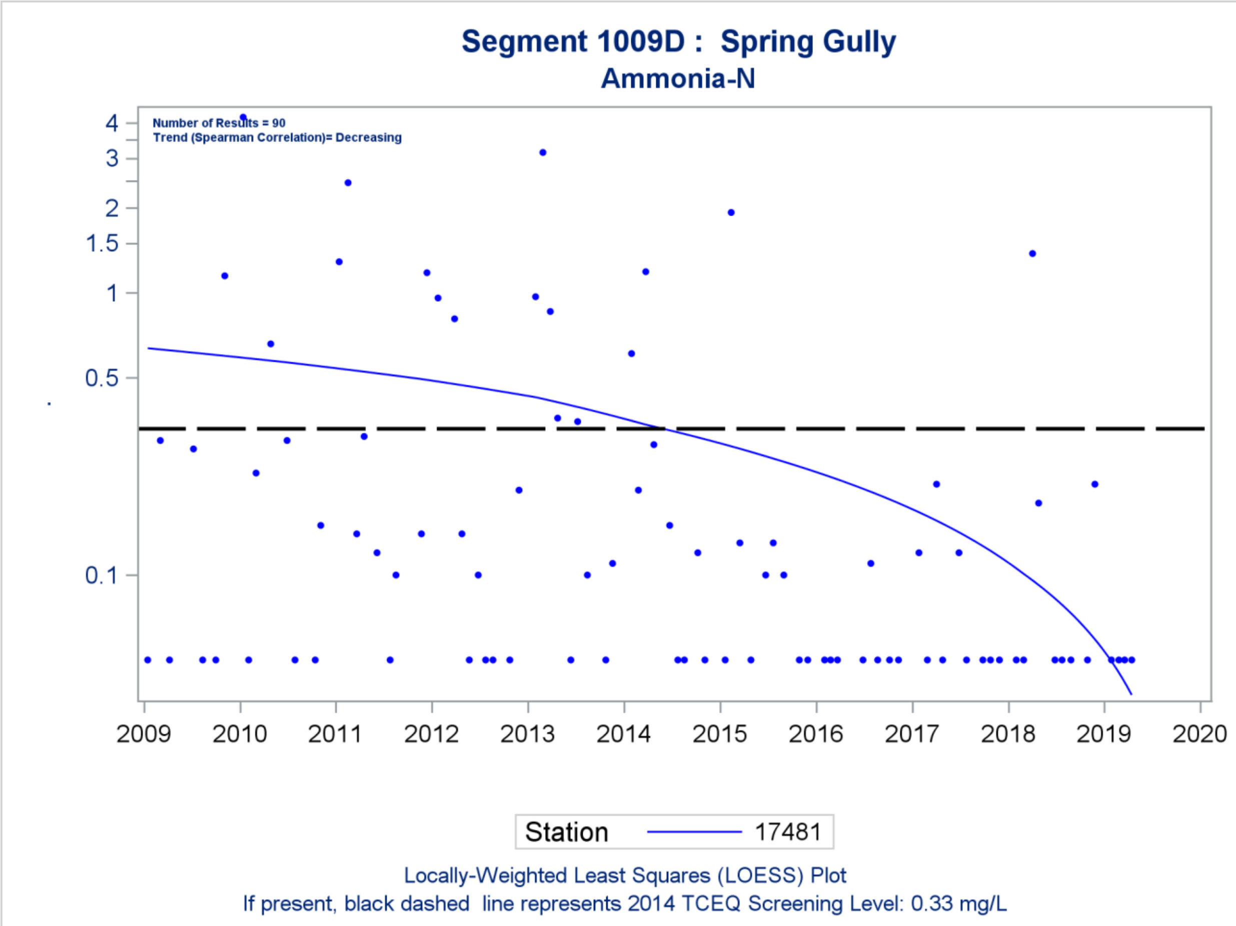


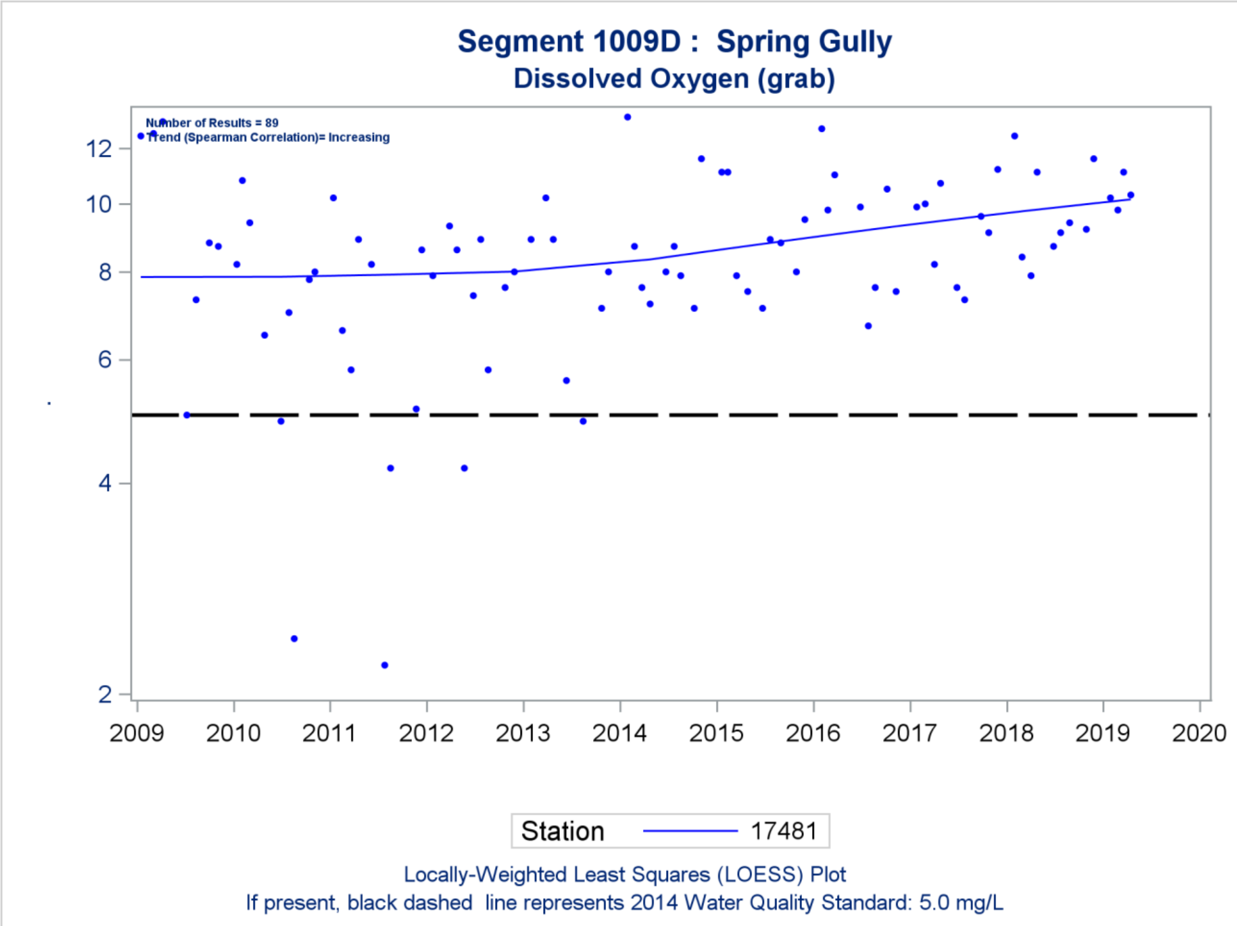
Segment 1009C : Faulkey Gully
Temperature
Number of Results = 92
Trend (Spearman Correlation)= Stable
35
30
25
20
15
10
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
17496
Locally-Weighted Least Squares (LOESS) Plot

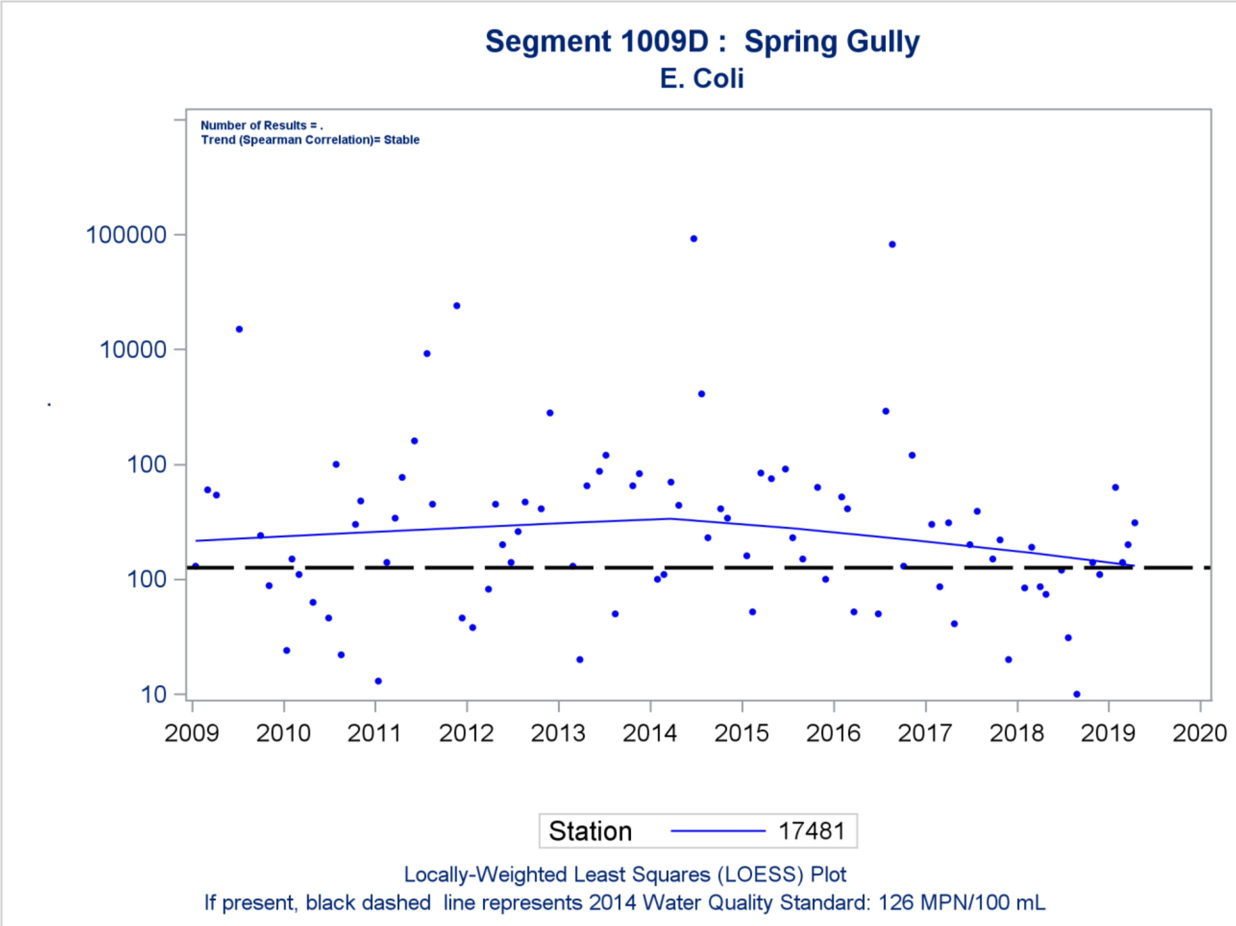


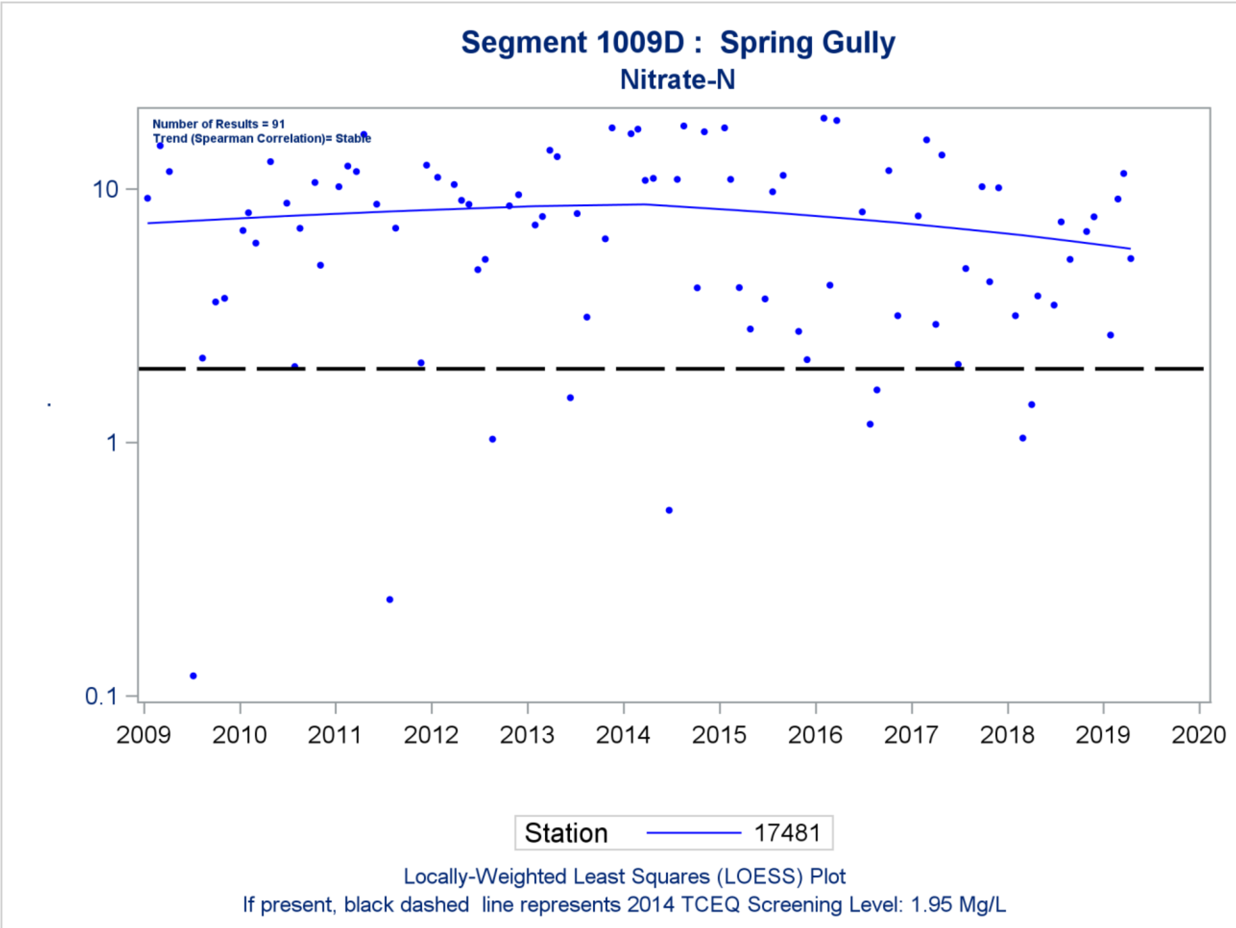
Segment 1009C : Faulkey Gully
Total Phosphorus
Number of Results = 93
Trend (Spearman Correlation)= Decreasing
5
4
3
2
1
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
17496
Locally-Weighted Least Squares (LOESS) Plot
If present, black dashed line represents 2014 TCEQ Screening Level: 0.69 mg/L

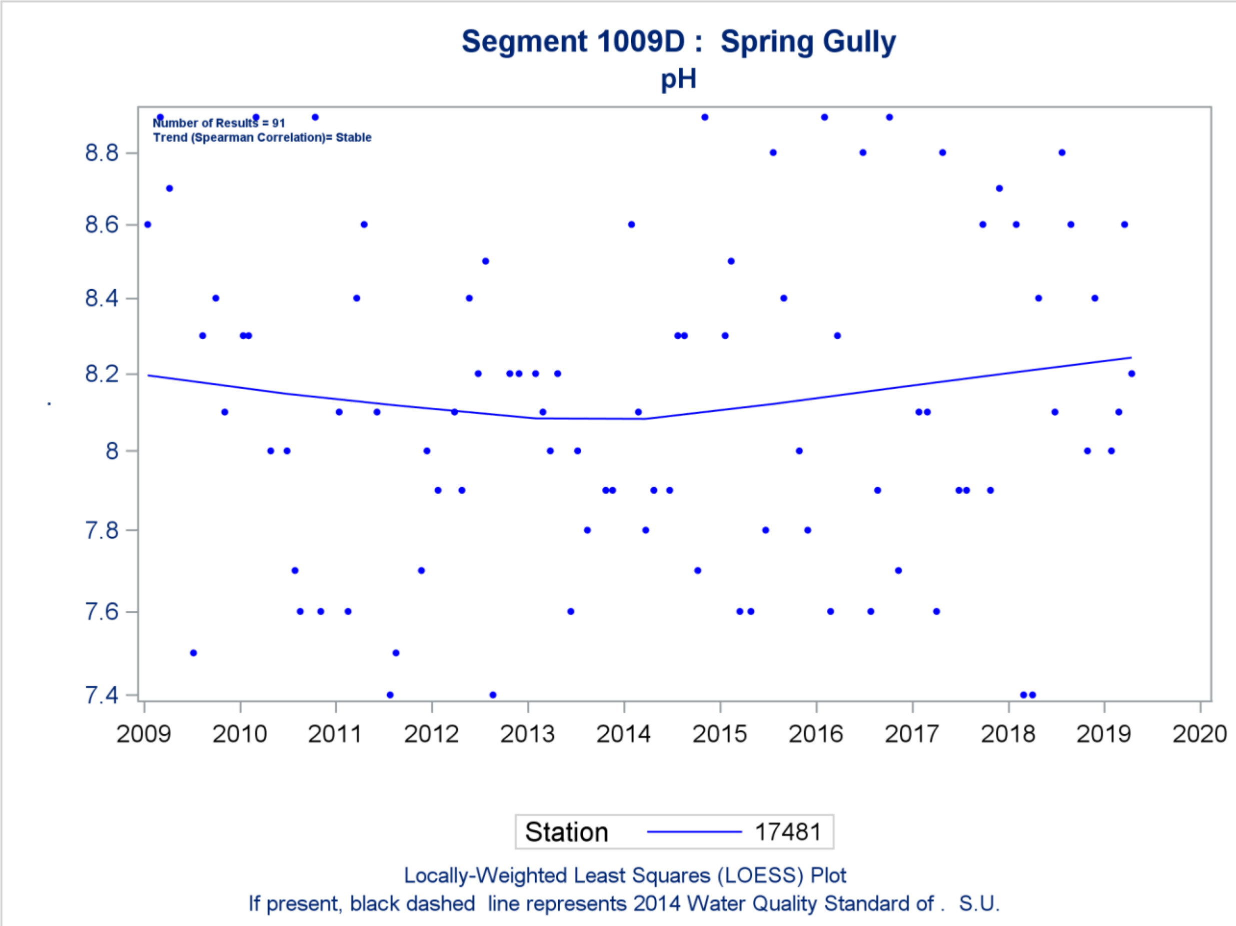

Segment 1009D : Spring Gully
Total Suspended Solids
Number of Results = 91
Trend (Spearman Correlation)= Decreasing
180
120
80
60
40
20
4
1
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
17481
Locally-Weighted Least Squares (LOESS) Plot

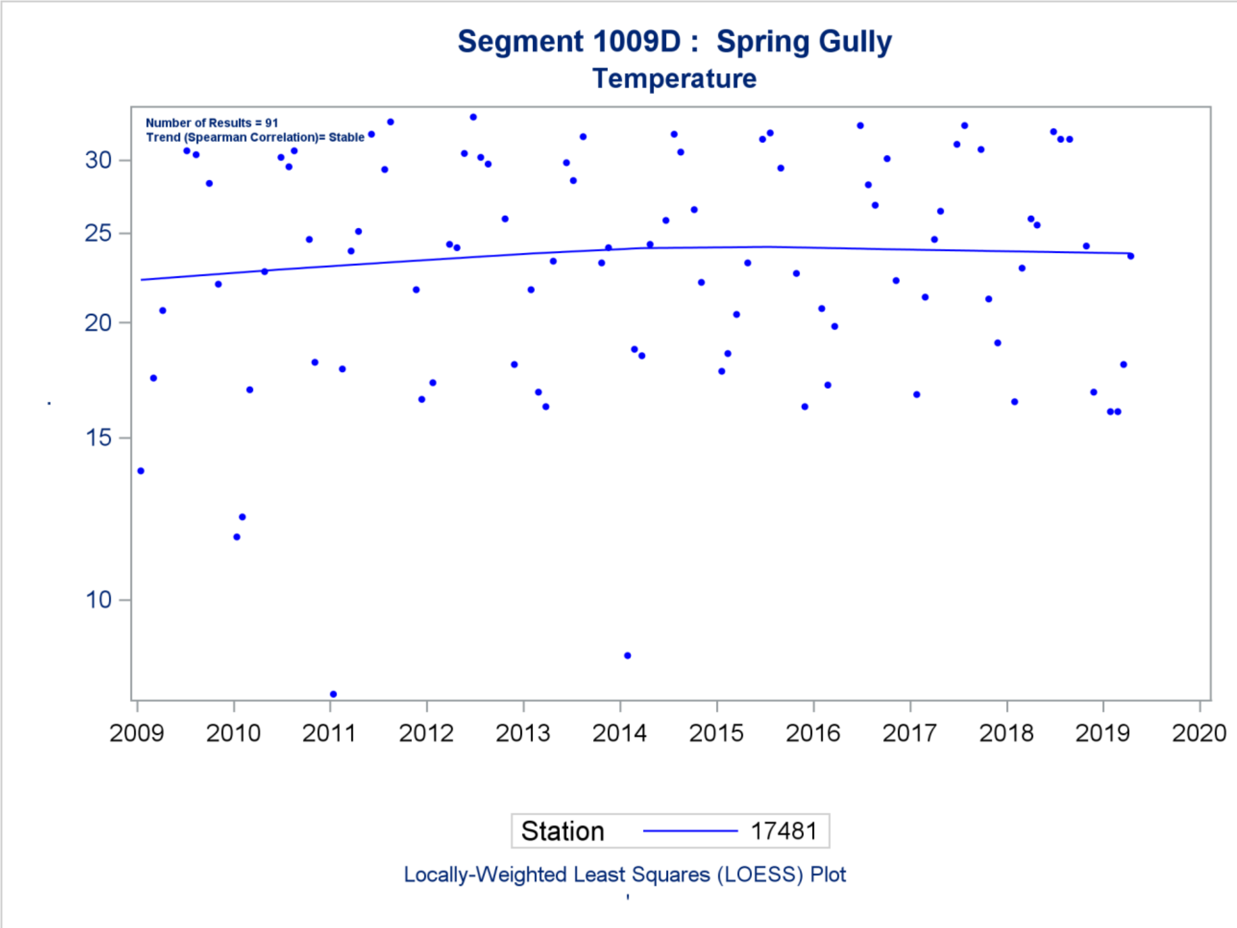

Segment 1009D : Spring Gully
Ammonia-N
Number of Results = 90
Trend (Spearman Correlation)= Decreasing
4
3
2
1.5
1
0.5
0.1
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
17481
Locally-Weighted Least Squares (LOESS) Plot
If present, black dashed line represents 2014 TCEQ Screening Level: 0.33 mg/L

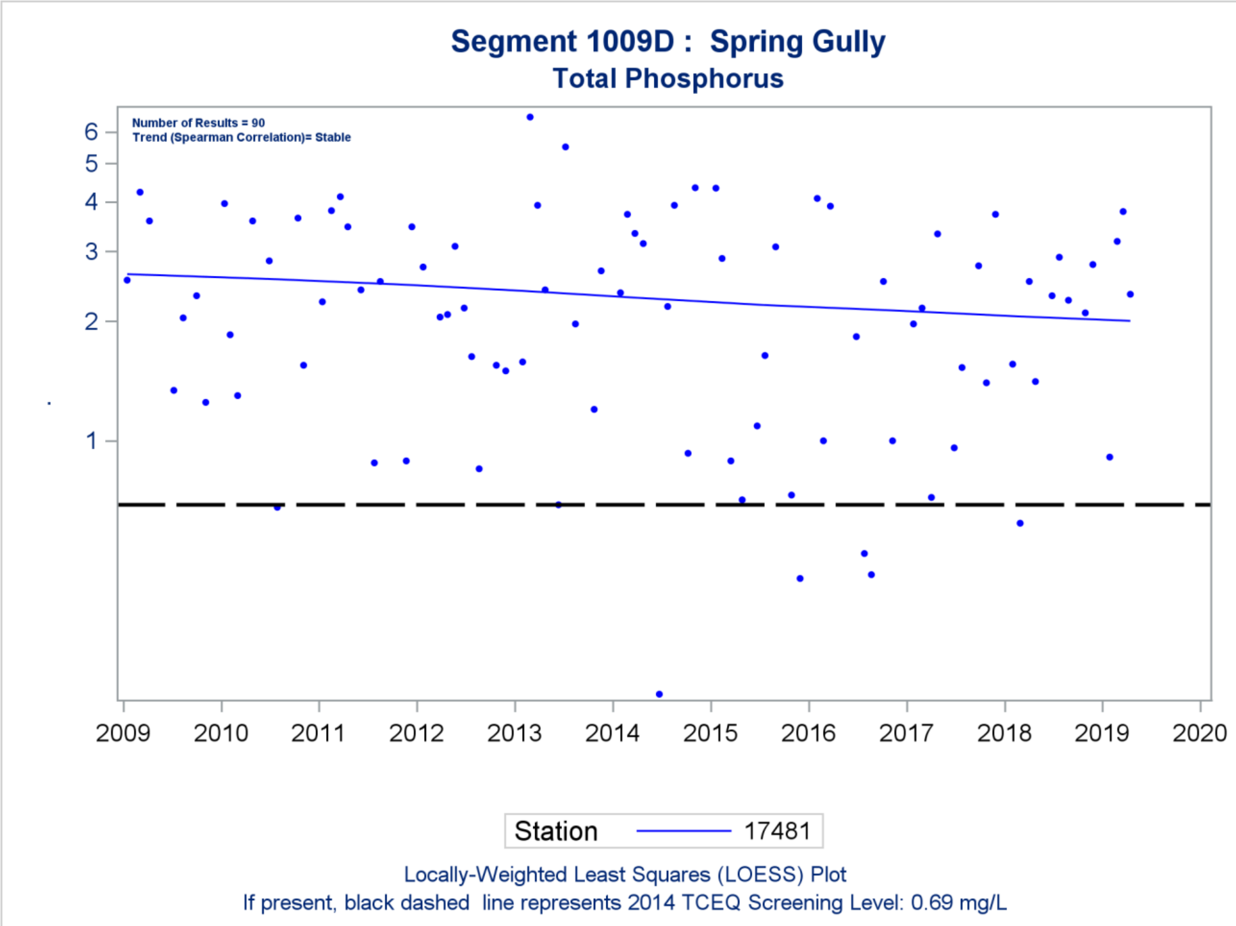

Segment 1009D : Spring Gully
Dissolved Oxygen (grab)
Number of Results = 89
Trend (Spearman Correlation)= Increasing
12
10
8
6
4
2
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
17481
Locally-Weighted Least Squares (LOESS) Plot
If present, black dashed line represents 2014 Water Quality Standard: 5.0 mg/L

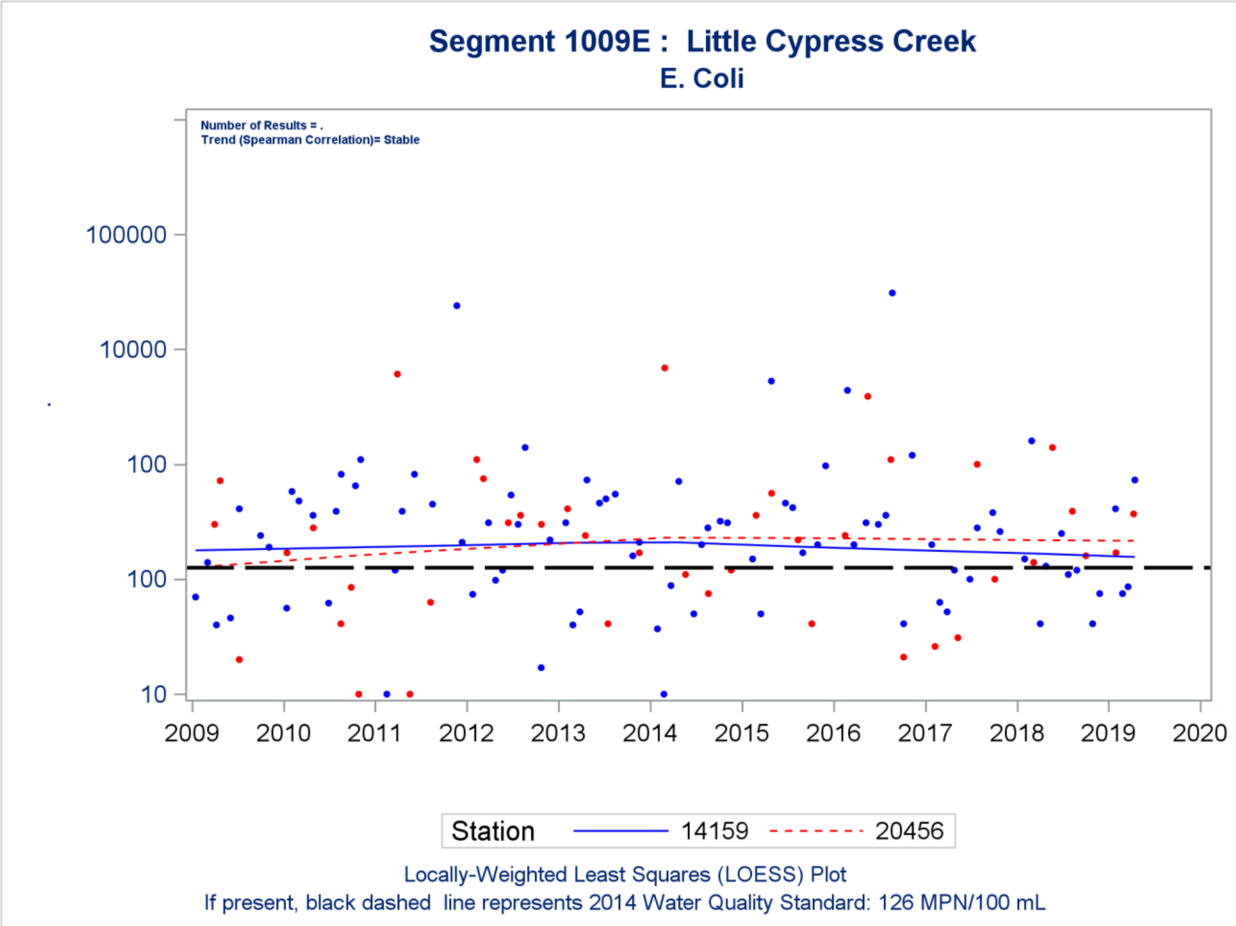

Segment 1009D : Spring Gully
E. Coli
Number of Results = .
Trend (Spearman Correlation)= Stable
100000
10000
100
100
10
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
17481
Locally-Weighted Least Squares (LOESS) Plot
If present, black dashed line represents 2014 Water Quality Standard: 126 MPN/100 mL

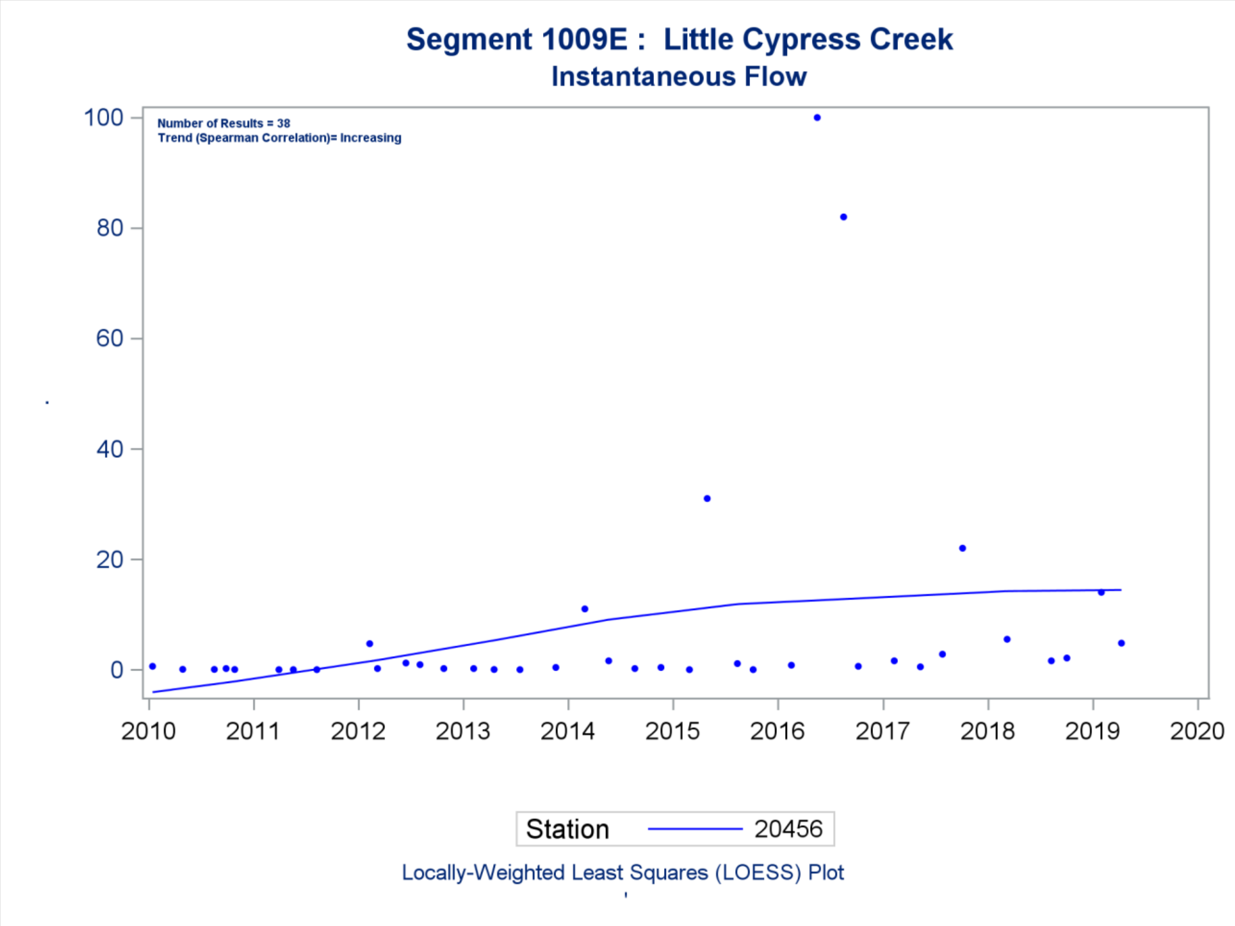

Segment 1009D : Spring Gully
Nitrate-N
Number of Results = 91
Trend (Spearman Correlation)= Stable
10
1
0.1
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
17481
Locally-Weighted Least Squares (LOESS) Plot
If present, black dashed line represents 2014 TCEQ Screening Level: 1.95 Mg/L

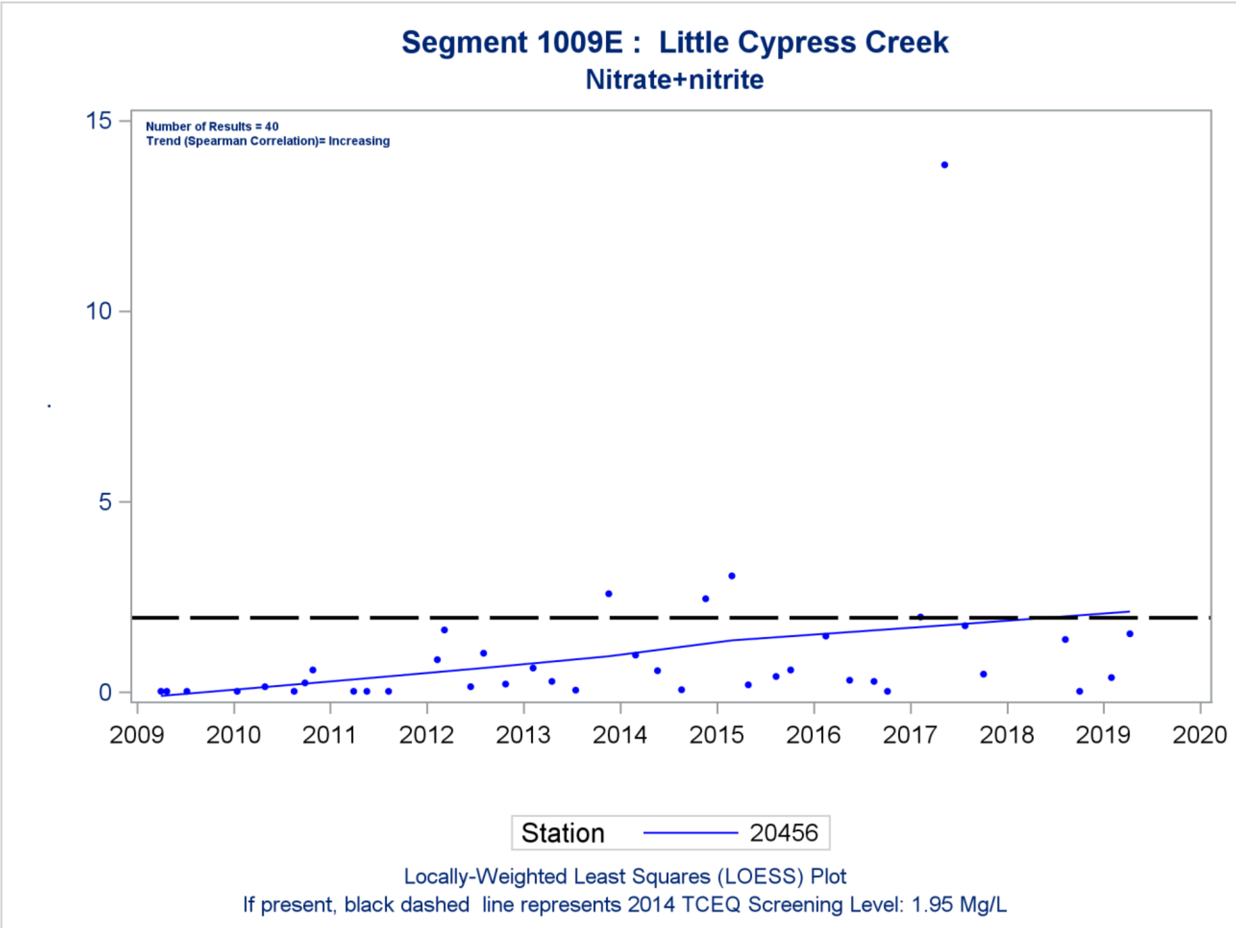

Segment 1009D : Spring Gully
pH
Number of Results = 91
Trend (Spearman Correlation)= Stable
8.8
8.6
8.4
8.2
8
7.8
7.6
7.4
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
17481
Locally-Weighted Least Squares (LOESS) Plot
If present, black dashed line represents 2014 Water Quality Standard of . S.U.


Segment 1009D : Spring Gully
Temperature
Number of Results = 91
Trend (Spearman Correlation)= Stable
30
25
20
15
10
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
17481
Locally-Weighted Least Squares (LOESS) Plot

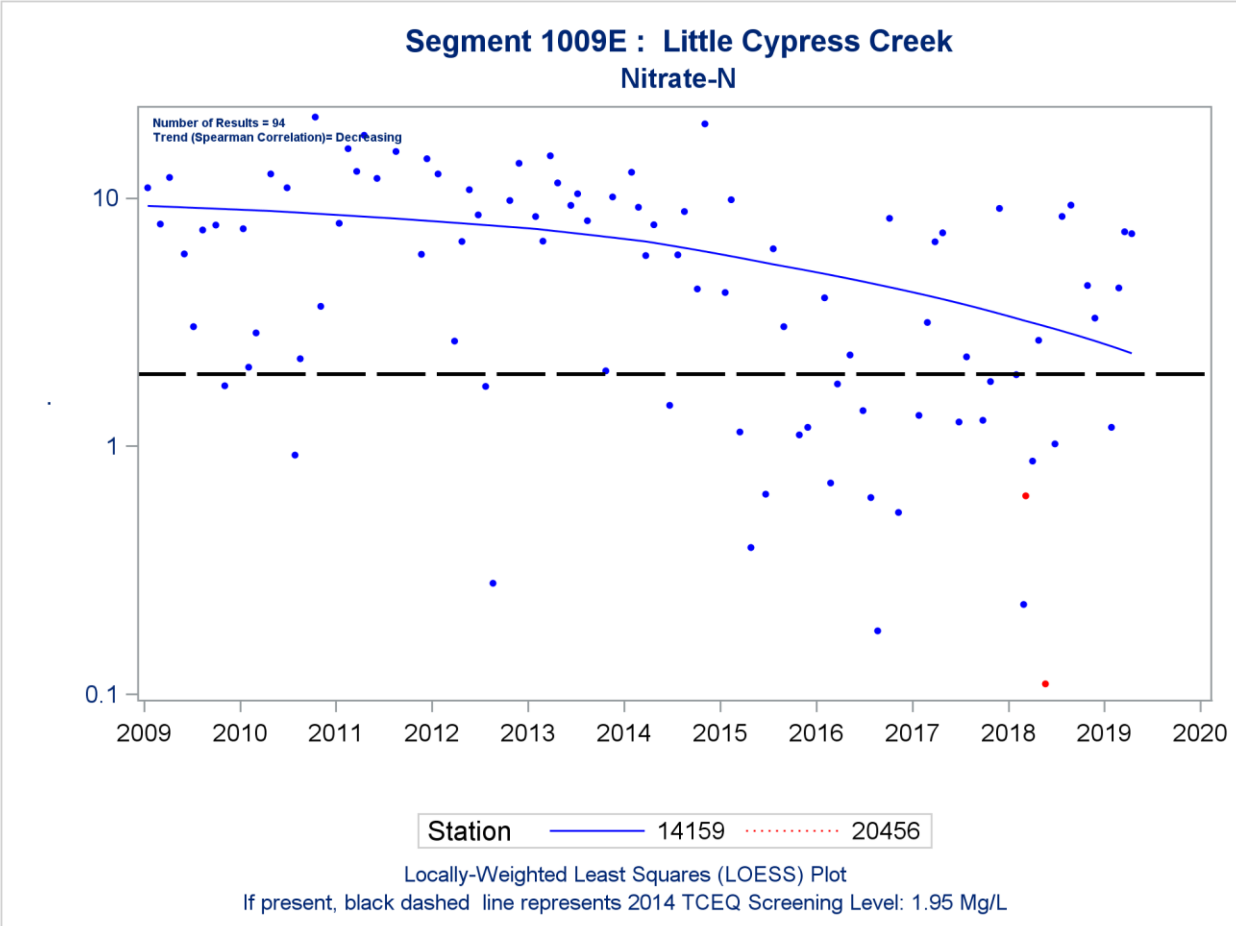

Segment 1009D : Spring Gully
Total Phosphorus
Number of Results = 90
Trend (Spearman Correlation)= Stable
6
5
4
3
2
1
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
17481
Locally-Weighted Least Squares (LOESS) Plot
If present, black dashed line represents 2014 TCEQ Screening Level: 0.69 mg/L


Segment 1009E : Little Cypress Creek
E. Coli
Number of Results = .
Trend (Spearman Correlation)= Stable
100000
10000
100
100
10
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
14159
20456
Locally-Weighted Least Squares (LOESS) Plot
If present, black dashed line represents 2014 Water Quality Standard: 126 MPN/100 mL

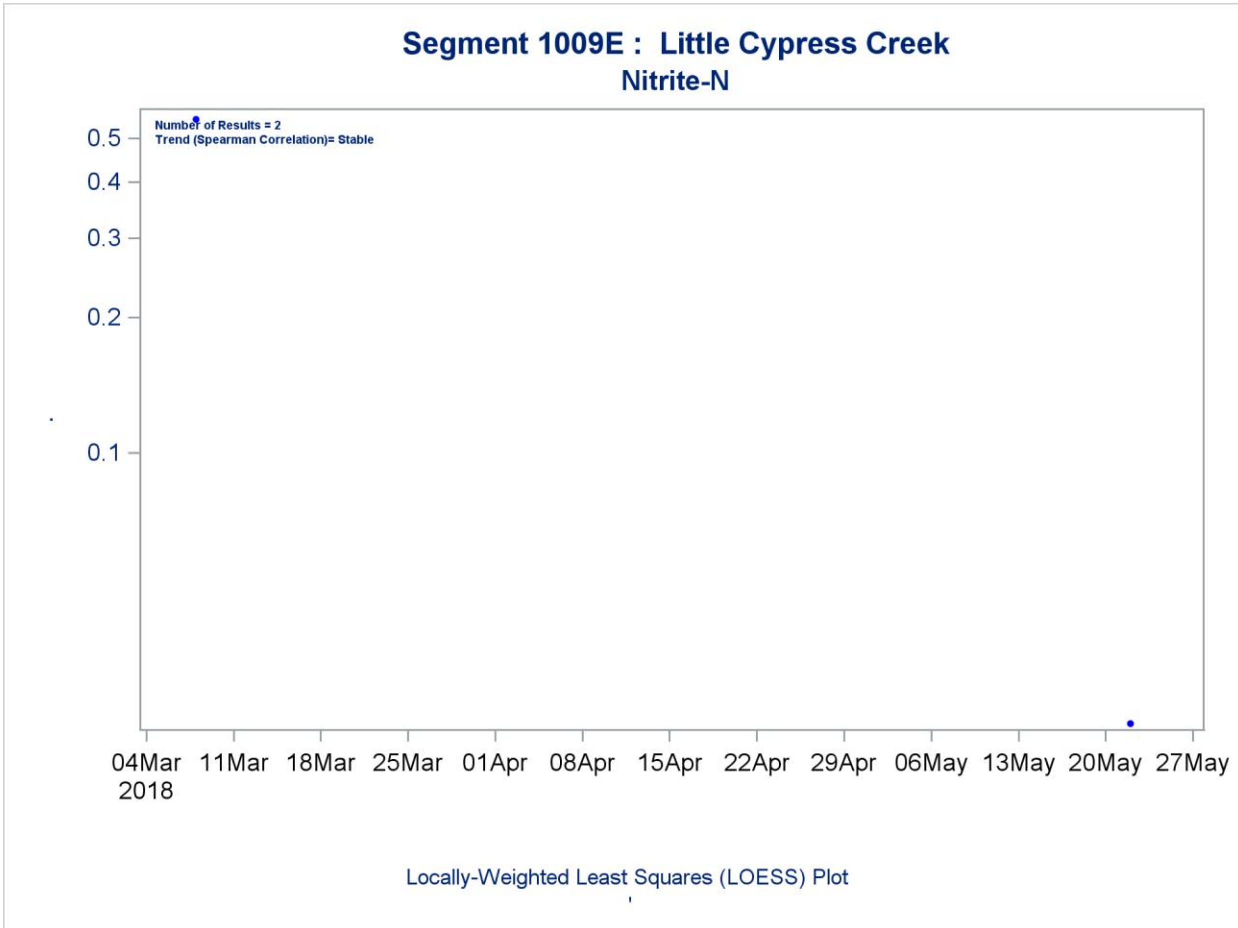

Segment 1009E : Little Cypress Creek
Instantaneous Flow
Number of Results = 38
Trend (Spearman Correlation)= Increasing
100
80
60
40
20
0
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
20456
Locally-Weighted Least Squares (LOESS) Plot

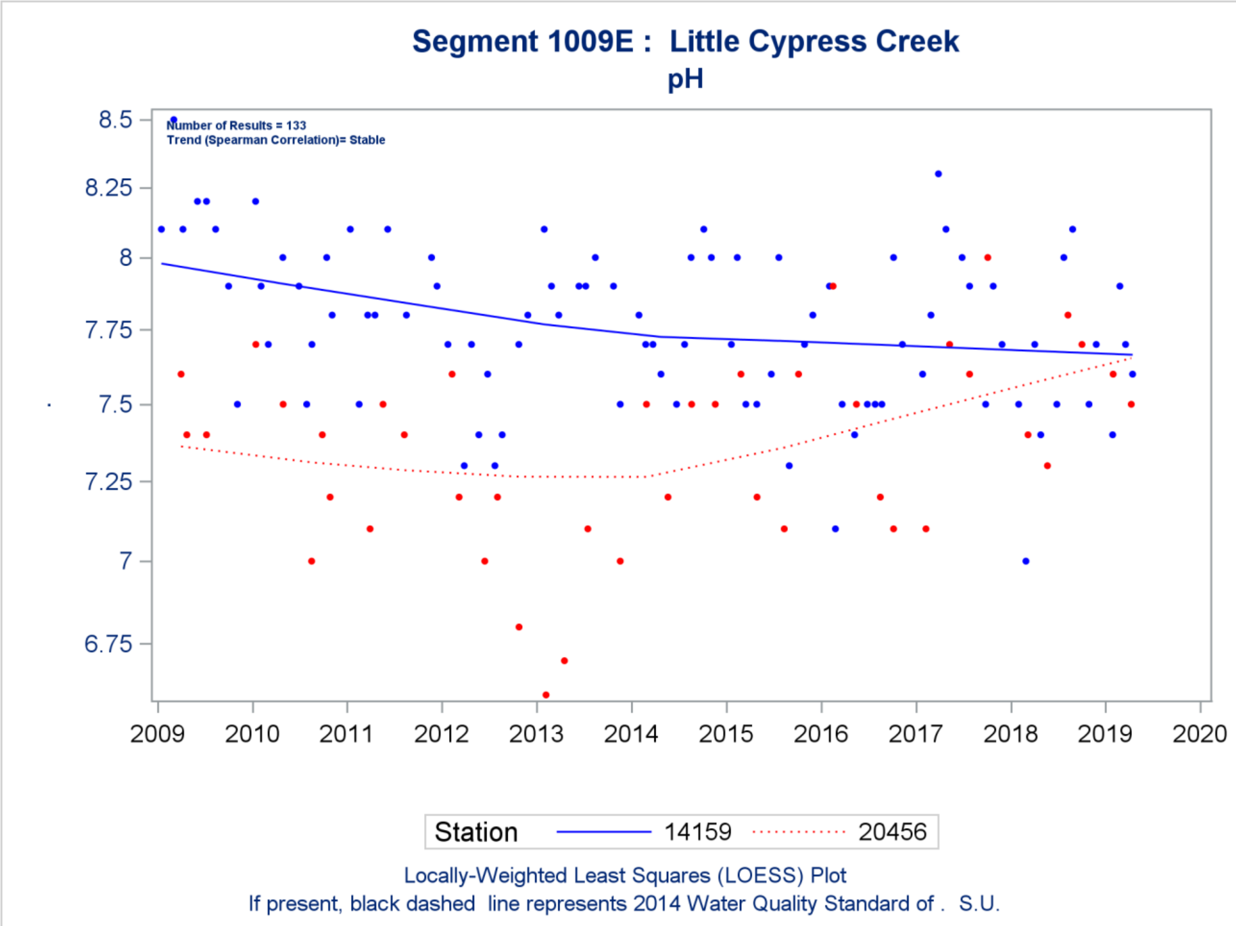


Segment 1009E : Little Cypress Creek
Nitrate+nitrite
Number of Results = 40
Trend (Spearman Correlation)= Increasing
15
10
5
0
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
20456
Locally-Weighted Least Squares (LOESS) Plot
If present, black dashed line represents 2014 TCEQ Screening Level: 1.95 Mg/L

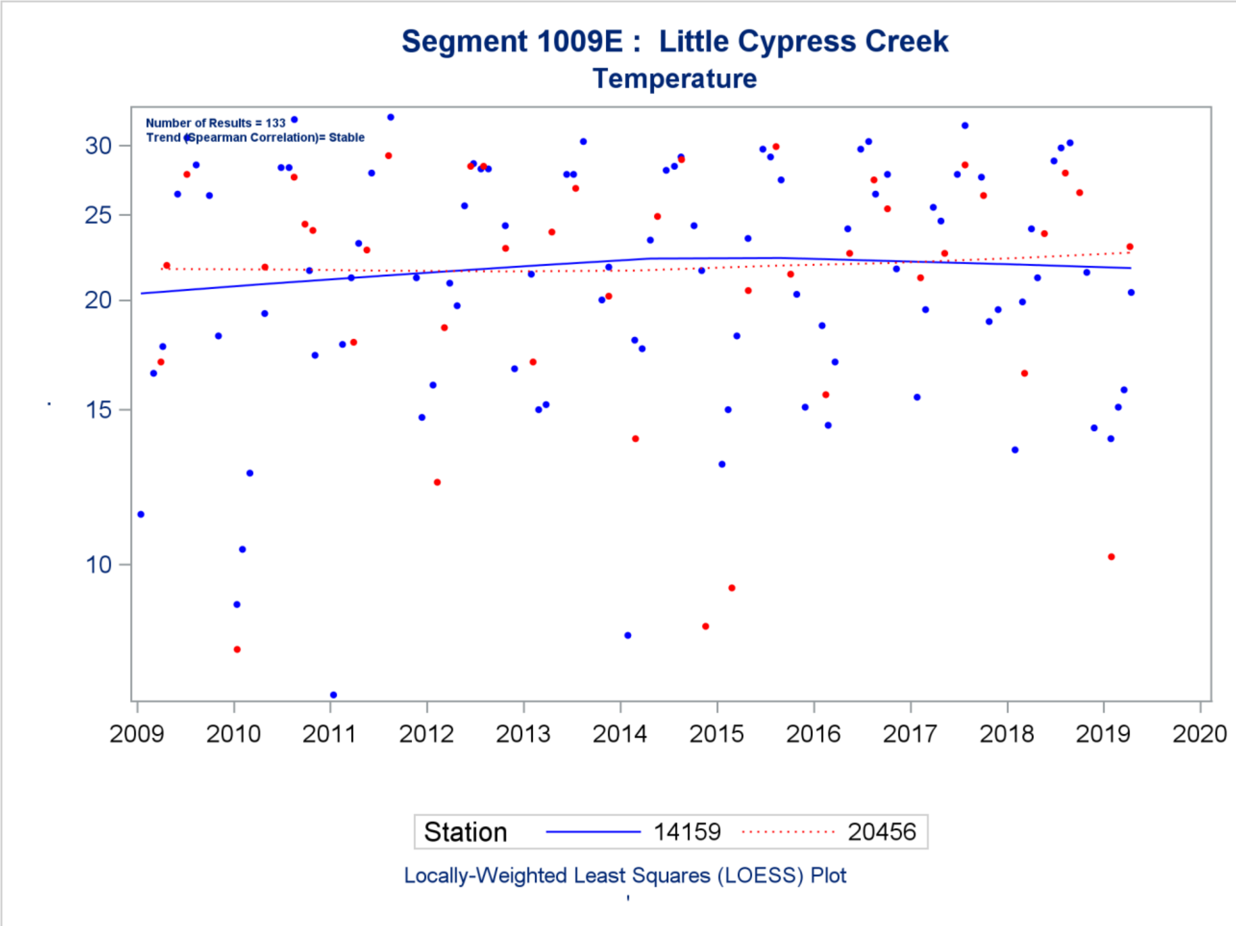


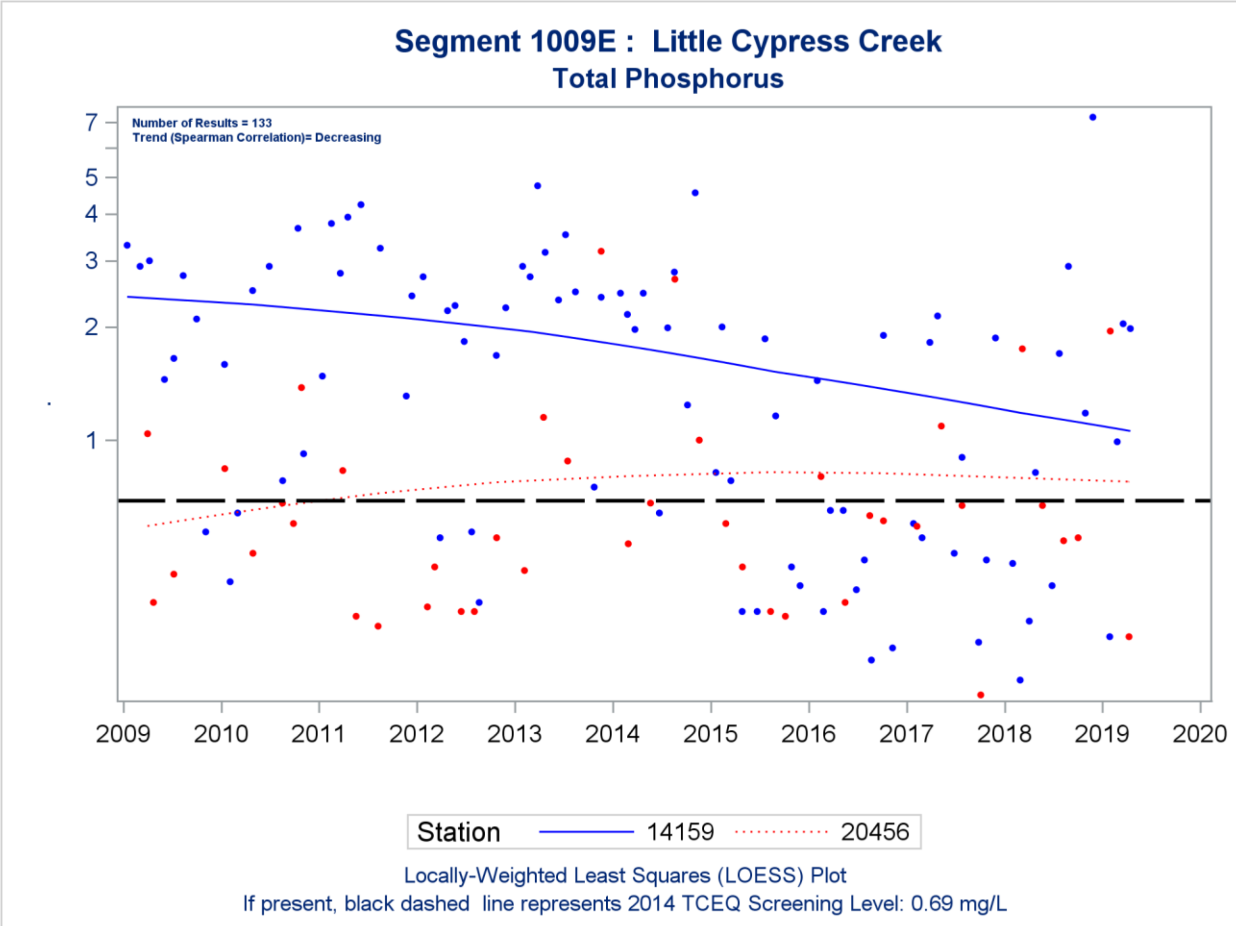
Segment 1009E : Little Cypress Creek
Nitrate-N
Number of Results = 94
Trend (Spearman Correlation)= Decreasing
10
1
0.1
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
14159
20456
Locally-Weighted Least Squares (LOESS) Plot
If present, black dashed line represents 2014 TCEQ Screening Level: 1.95 Mg/L

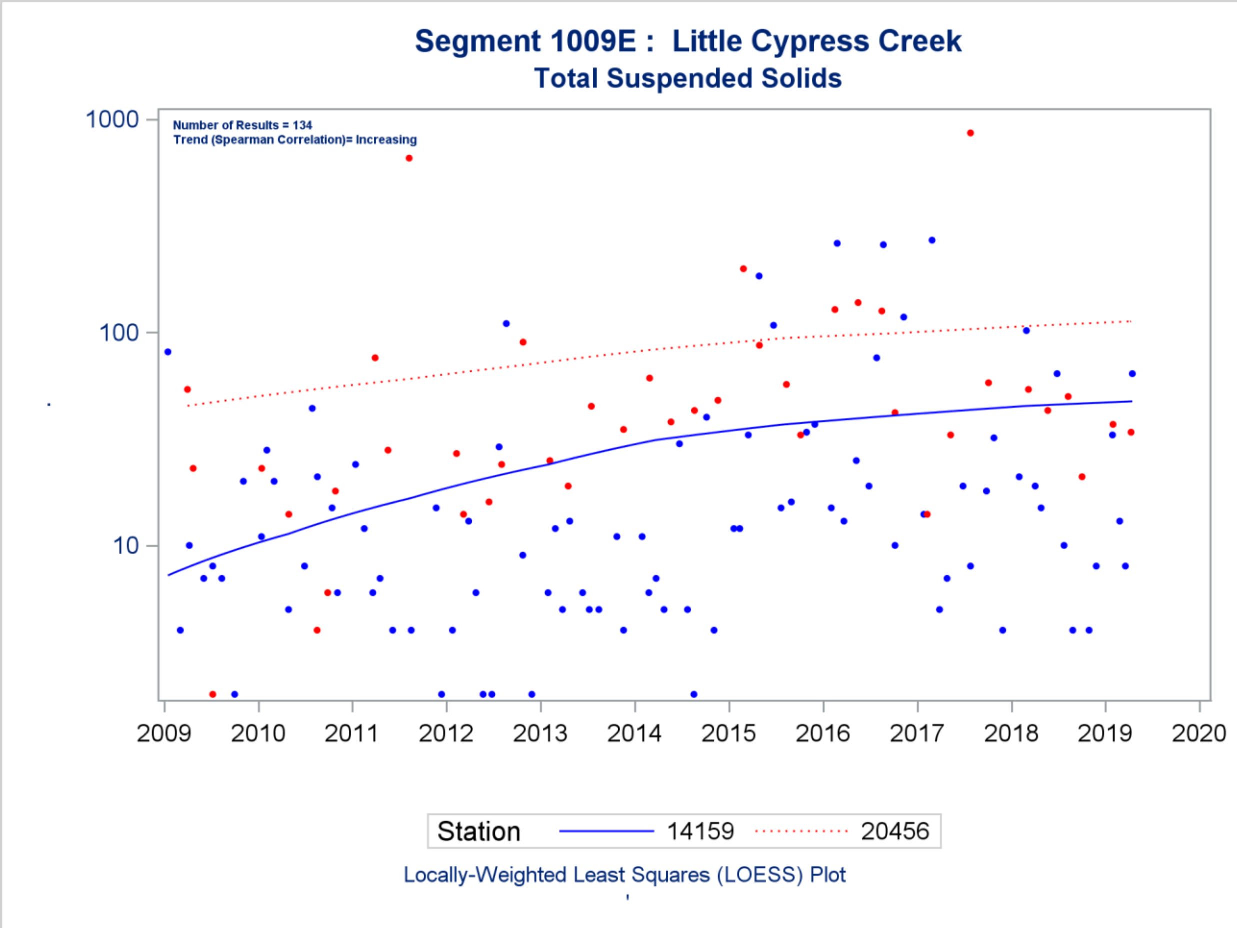

Segment 1009E : Little Cypress Creek
Nitrite-N
Number of Results = 2
Trend (Spearman Correlation)= Stable
0.5
0.4
0.3
0.2
0.1
04Mar 2018
11Mar
18Mar
25Mar
01Apr
08Apr
15Apr
22Apr
29Apr
06May
13May
20May
27May
Locally-Weighted Least Squares (LOESS) Plot



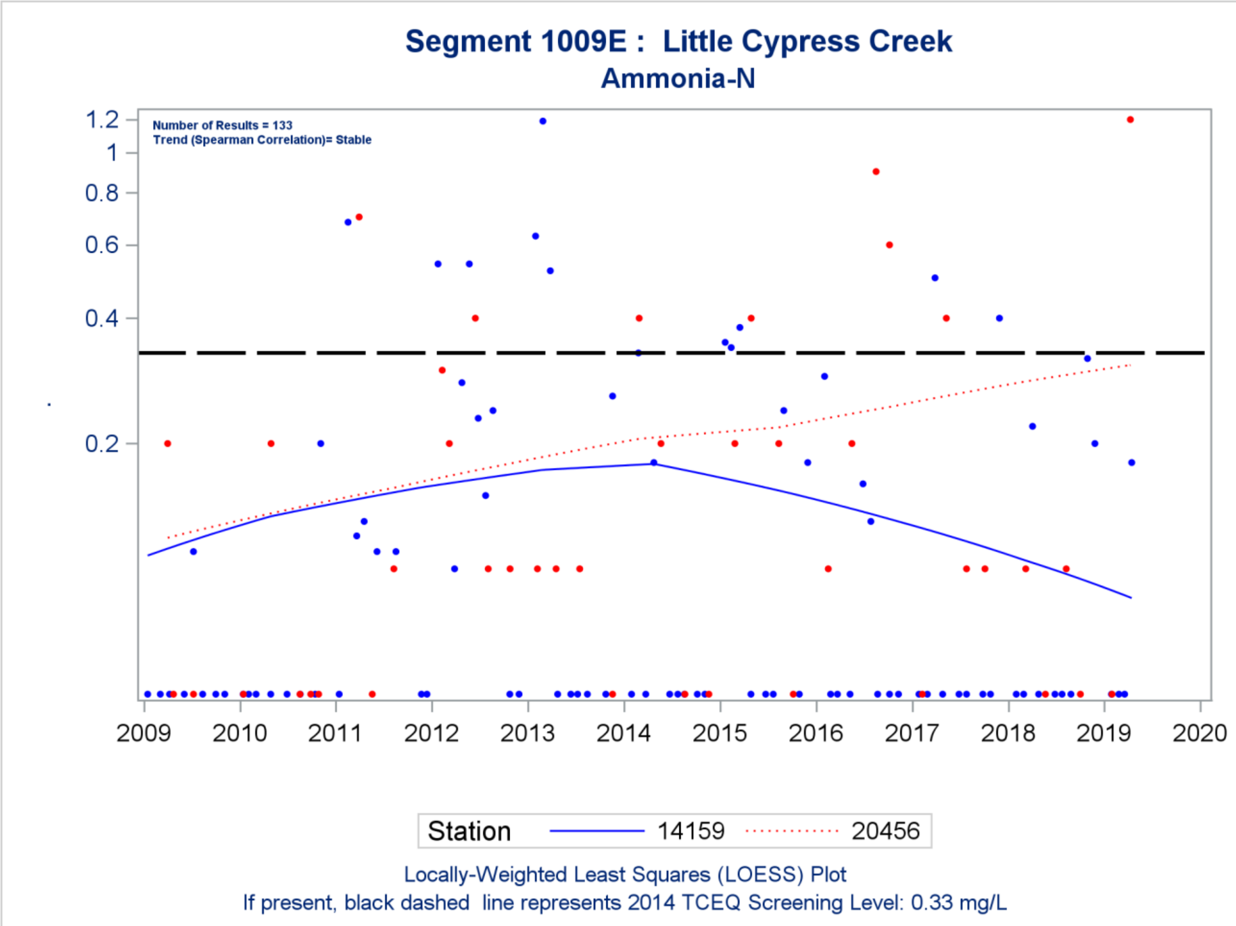
Segment 1009E : Little Cypress Creek
pH
Number of Results = 133
Trend (Spearman Correlation)= Stable
8.5
8.25
8
7.75
7.5
7.25
7
6.75
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
14159
20456
Locally-Weighted Least Squares (LOESS) Plot
If present, black dashed line represents 2014 Water Quality Standard of . S.U.

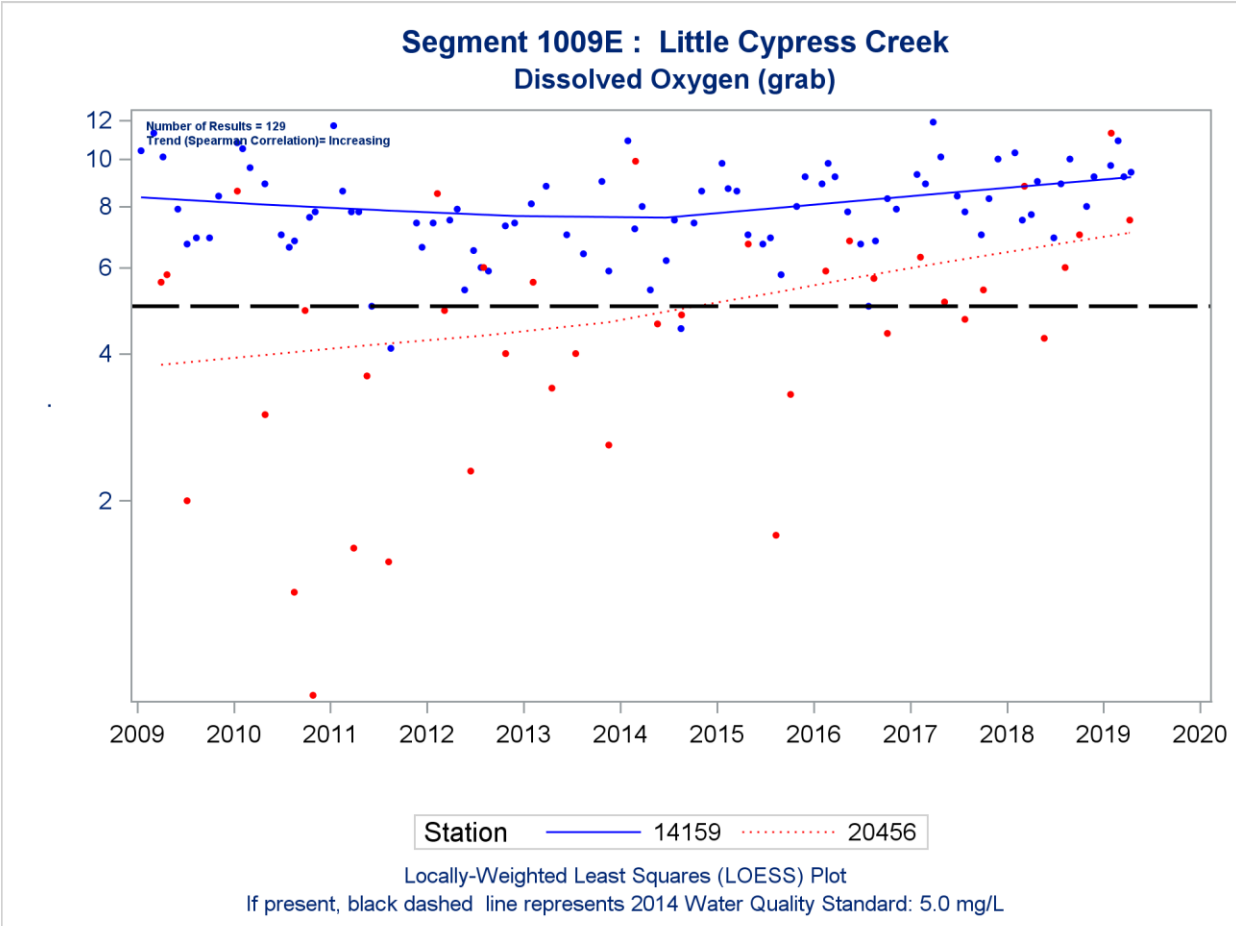

Segment 1009E : Little Cypress Creek
Temperature
Number of Results = 133
Trend (Spearman Correlation)= Stable
30
25
20
15
10
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
14159
20456
Locally-Weighted Least Squares (LOESS) Plot


Segment 1009E : Little Cypress Creek
Total Phosphorus
Number of Results = 133
Trend (Spearman Correlation)= Decreasing
7
5
4
3
2
1
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
14159
20456
Locally-Weighted Least Squares (LOESS) Plot
If present, black dashed line represents 2014 TCEQ Screening Level: 0.69 mg/L



Segment 1009E : Little Cypress Creek
Total Suspended Solids
Number of Results = 134
Trend (Spearman Correlation)= Increasing
1000
100
10
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
14159
20456
Locally-Weighted Least Squares (LOESS) Plot


Segment 1009E : Little Cypress Creek
Ammonia-N
Number of Results = 133
Trend (Spearman Correlation)= Stable
1.2
1
0.8
0.6
0.4
0.2
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
14159
20456
Locally-Weighted Least Squares (LOESS) Plot
If present, black dashed line represents 2014 TCEQ Screening Level: 0.33 mg/L


Segment 1009E : Little Cypress Creek
Dissolved Oxygen (grab)
Number of Results = 129
Trend (Spearman Correlation)= Increasing
12
10
8
6
4
2
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
14159
20456
Locally-Weighted Least Squares (LOESS) Plot
If present, black dashed line represents 2014 Water Quality Standard: 5.0 mg/L