Water Quality Data Analysis Summary Report for the Spring Creek Watershed

May 2020

This document was prepared by the Houston-Galveston Area Council (H-GAC) for the stakeholders of the Spring Creek Watershed Partnership. It was prepared in cooperation with the Texas Commission on Environmental Quality (TCEQ) and the United States Environmental Protection Agency (EPA).

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List of Acronyms

AU	Assessment Unit
CBOD5	5-Day Carbonaceous Biological Oxygen Demand
CFS	Cubic Feet Per Second
CFU	Colony Forming Units
CRP	Clean Rivers Program
DMR	Discharge Monitoring Report
DO	Dissolved Oxygen
EPA	United States Environmental Protection Agency
IR	Texas Integrated Report of Surface Water Quality
H-GAC	Houston-Galveston Area Council
MGD	Millions of Gallons Per Day
mg/L	Milligrams Per Liter
mL	Milliliters
SAS	Statistical Analysis Software
SSO	Sanitary Sewer Overflow
SWQMIS	Surface Water Quality Monitoring Information System
TCEQ	Texas Commission on Environmental Quality
TPDES	Texas Pollutant Discharge Elimination System
TSS	Total Suspended Solids
WPP	Watershed Protection Plan
WWTF	Wastewater Treatment Facility

SECTION 1: INTRODUCTION

The watershed area of Spring Creek includes portions of Grimes, Harris, Montgomery, and Waller Counties. Approximately 440 square miles of land are drained by a network of tributaries into the main stem of Spring Creek before ultimately discharging into the West Fork San Jacinto River and Lake Houston (**Figure 1**). Land cover in the eastern third of the watershed is heavily developed with more development expected to extend westward into land currently covered by pasture, grass, forest and shrubs. 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.

In order to understand the status of surface water quality in the Spring Creek Watershed, the Houston-Galveston Area Council (H-GAC) has analyzed monitoring and report data from the past decade and summarized the results of these analyses herein. This assessment will serve as a baseline for water quality trends and variability in the watershed which will help to illustrate where improvements can be made in order to meet state water quality standards. Such information will be critical for the development of a Watershed Protection Plan (WPP) which will outline the specific goals and action strategies set forth by local stakeholders to achieve water quality improvements.

This document will include:

- A summary of the design and purpose of each analysis,
- A description of the data sources considered for each analysis which include ambient water quality monitoring data, discharge monitoring report (DMR) data from wastewater treatment facilities (WWTFs), and reports of sanitary sewer overflows (SSOs) collected in the past decade, and
- An overview of the implications of the results of the analyses.

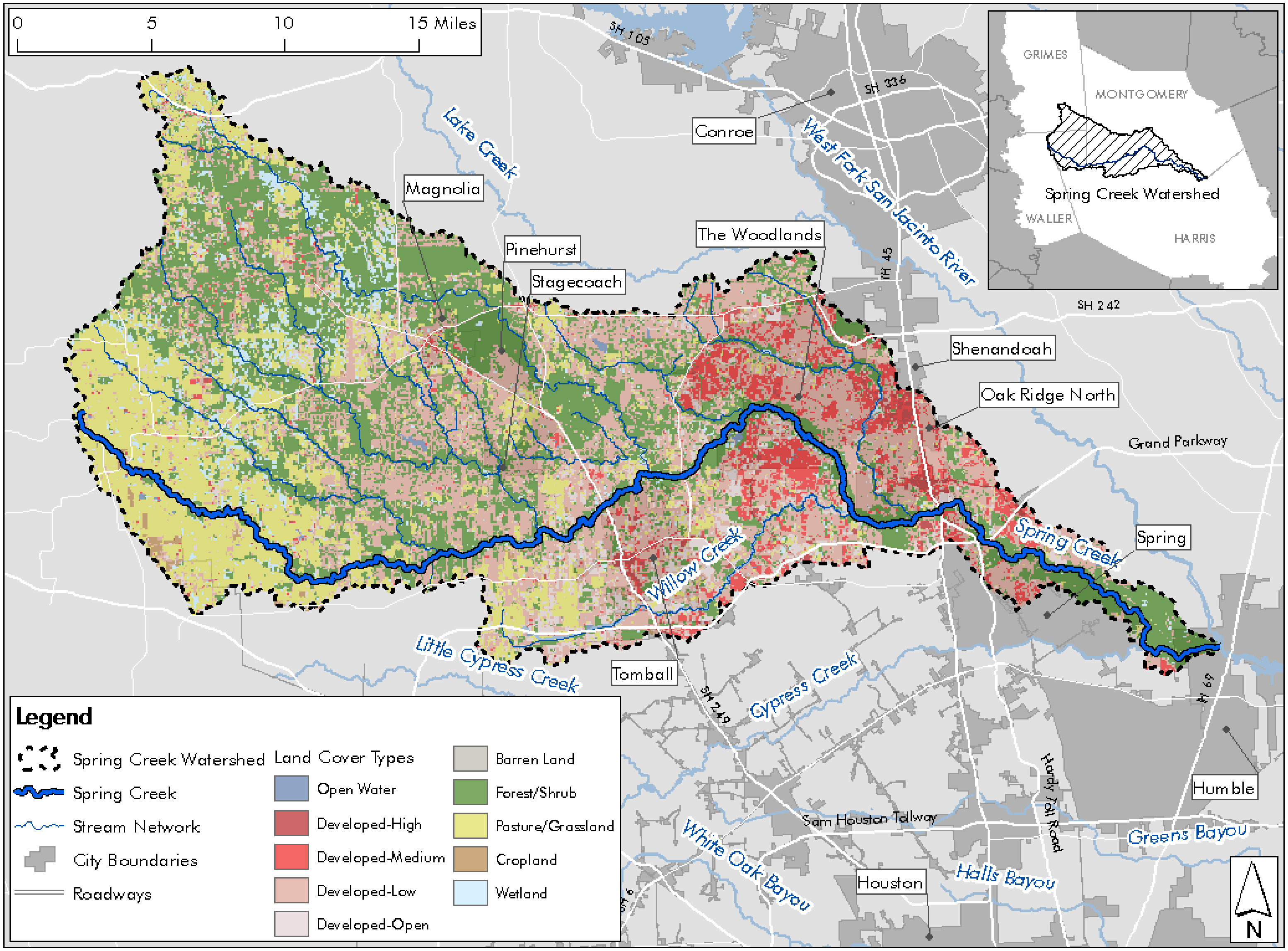


Figure 1. *The Spring Creek Watershed, Land Cover and Regional Context*

Section 2: Analysis Purpose and Design

2.1 Purpose

Based on findings from the 2018 Texas Integrated Report of Surface Water Quality (IR)[1] produced by the Texas Commission on Environmental Quality (TCEQ), multiple stream segments throughout the Spring Creek Watershed are listed as impaired for contact recreation. This is due to the frequent exceedance of state water quality standards for fecal indicator bacteria, *Escherichia coli* (*E. coli*). Additionally, low levels of dissolved oxygen (DO) and high levels of nutrients and other constituents were noted in the 2018 IR as concerns for other surface water uses.

2.2 Project Design

In order to adequately describe the current condition of surface water quality in stream segments throughout the Spring Creek Watershed, the following analyses were designed to address the needs outlined below.

- General Understanding
    - Determine whether there is sufficient data to describe water quality in the watershed.
    - Describe the extent of the challenges impacting water quality in the watershed.
    - Visualize whether water quality is spatially variable, and if so, identify focus areas.
    - Identify any seasonal variability in the water quality data.
- Source Identification
    - Analyze discharge monitoring report data from Texas Pollutant Discharge Elimination System (TPDES) permitted WWTFs to verify whether their discharges are in compliance with permit limits.
    - Quantify the frequency, distribution and causes of SSOs in the watershed.
- Model Development[2]
    - Assess stream flow and water quality data for future use in load duration curve analysis.

To answer these requirements data were acquired and evaluated according to the standards below.

- Data Acquisition
    - Data from monitoring stations throughout the watershed area will be retrieved from the Surface Water Quality Monitoring Information System (SWQMIS) to characterize ambient conditions.
    - At least five years of data from DMRs and SSO reports from within the watershed will be used to characterize wastewater quality.
- Data Evaluation
    - Ambient (SWQMIS) Data

[1] The State of Texas assesses its waterways every two years, based on seven year sets of SQMIS 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.

[2] The data evaluated in this report will be used to develop models to estimate potential pollutant source loads contributing to impairments in the watershed. These models and their implications will be discussed further in a summary report to be developed by August 2020. Additional information about the data quality objectives, concerns, and methodologies used in these analyses can be found in the Spring Creek Modeling Quality Assurance Project Plan available for review at http://springcreekpartnership.com.

        - Determine if sufficient data exists for each station.
        - Identify the historical trends for constituents of concern, by each station.
        - Identify any seasonal trends, by constituent.
        - Evaluate the relative character of water quality between stations.
        - Update evaluations prior to the development of the WPP.
    - DMR Data
        - Evaluate the constituents of concern for compliance with WWTF permit limits and the general level of compliance for WWTFs.
        - Evaluate whether there is any seasonal variance of exceedances.
        - Evaluate any relationship between plant size and exceedance.
        - Update evaluations prior to the development of the WPP.
    - SSO Report Data
        - Evaluate the frequency, volume and causes of SSOs by stream segment.
        - Update evaluations prior to the development of the WPP.

Table 1. *Data Sources for Constituents of Concern*

Constituent of Concern	SWQMIS Data	DMR Data	SSO Data
E. coli	X	X	
DO, grab	X	X	
Temperature	X		
pH	X		
Chlorophyll-a	X		
Nitrate-Nitrite	X		
Nitrate	X		
Instantaneous Flow	X		
Ammonia Nitrogen	X	X	
Total Phosphorous	X		
Total Suspended Solids (TSS)	X	X	
Biological Oxygen Demand		X	
SSO Cause			X
SSO Frequency/Volume			X

SECTION 3: EVALUATIONS

3.1 Overview

Analyses conducted for this report began in the spring of 2020 using the latest available data from the SWQMIS, DMR, and SSO databases. Statistical Analysis Software (SAS) was used to generate statistical results and the spatial analysis platform ArcGIS v10.6 was used to evaluate geographical trends and variations in the data. The results of all analyses conducted for this report were reviewed by project staff, and outcomes pertinent to the development of a WPP were selected for the focus of discussion in this document. The full data and evaluation worksheets for these efforts are available on request but are not included in this report for sake of brevity.

3.2 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). In general, most monitoring stations are sampled by CRP partners on a quarterly frequency for a suite of field, bacteriological, and conventional parameters. Waterways are inherently dynamic systems, and water quality at any given time can vary greatly dependent on conditions at the time. 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 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 the Spring Creek Watershed are shown in **Figure 2** and described in **Table 2**.

Data collected by CRP partners and incorporated into the SWQMIS include a number of parameters characterizing conventional, bacteriological and other field conditions of surface water at each site. For the purposes of this report, specifically pertaining to the informed development of a WPP for the Spring Creek Watershed, a subset of the SWQMIS dataset for stations throughout the watershed area was selected. The parameters focused on in this analysis include:

- *E. coli* – bacteria common in the intestines of all warm blooded animals used as an indicator of the presence of fecal wastes. Due to this relationship, it may also be used as a proxy indicator of the safety of waterways for human recreation as fecal waste can be a vector for human pathogens. The state water quality geomean standard for *E. coli* concentrations is 126 colony forming units per 100 milliliters (CFU/100 mL) and the single sample standard is 399 CFU/100 mL.
- DO, grab and 24-hour measurements – 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 and Nitrite – a measure of nitrogenous compounds and indicator of nutrient levels (and thus potential DO impacts).
- Ammonia Nitrogen – 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.
- Instantaneous Flow – 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.
- 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.

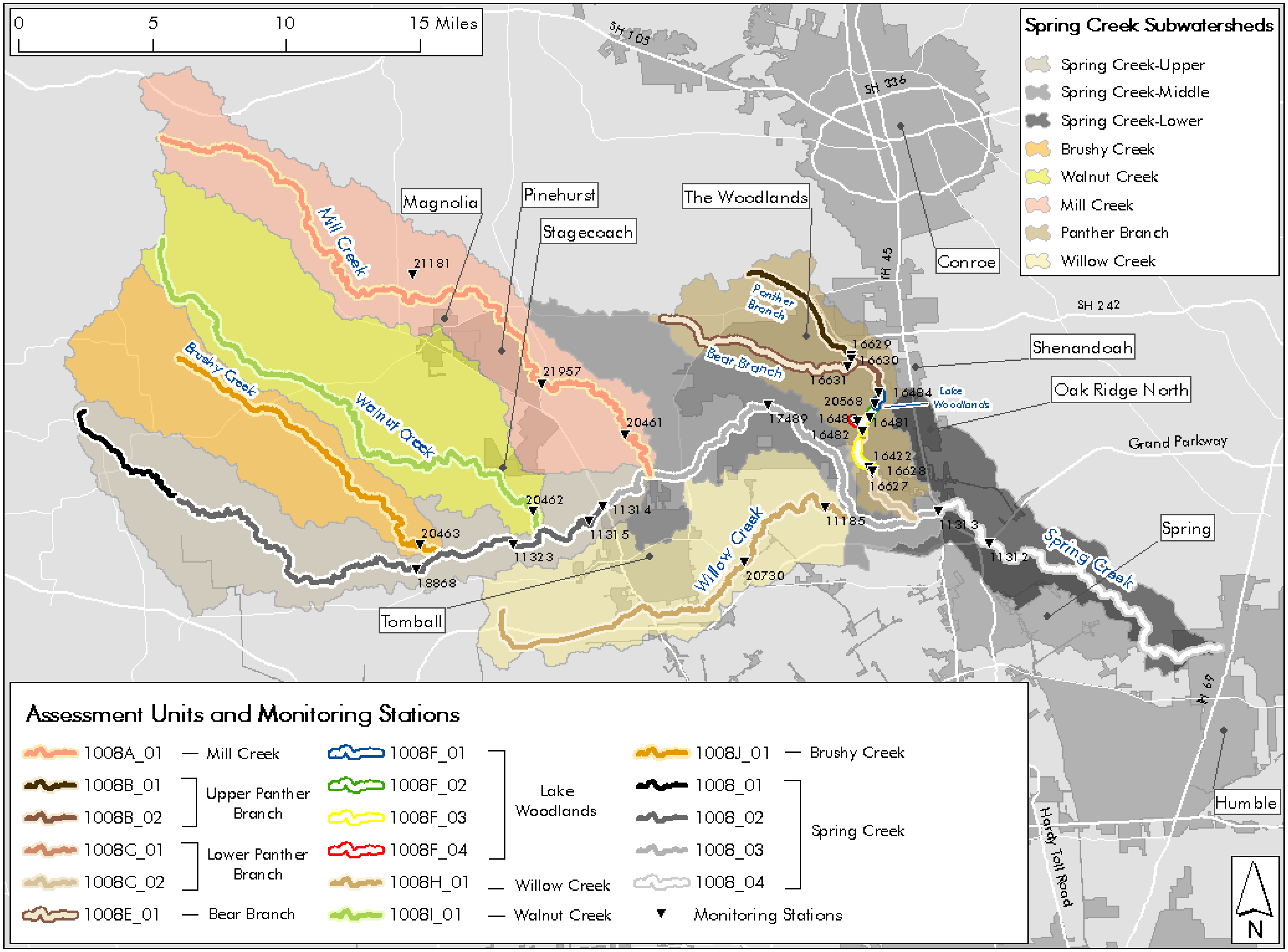


Figure 2. Monitoring Sites and Assessment Units in the Spring Creek Watershed

Table 2. Monitoring Stations, Locations, Sampling Frequency, and Period of Record

Station Number	Stream Segment	Assessment Unit	Sampling Events	Earliest Event	Latest Event
11312	Spring Creek	1008_04	93	1/8/2009	4/29/2019
11313	Spring Creek	1008_03	76	1/21/2009	5/15/2019
11314	Spring Creek	1008_02	83	2/18/2009	4/29/2019
11315	Spring Creek	1008_02	11	8/18/2015	6/9/2017
11323	Spring Creek	1008_02	96	1/8/2009	4/29/2019
17489	Spring Creek	1008_03	93	1/8/2009	4/29/2019
18868	Spring Creek	1008_02	46	4/1/2009	4/16/2019
20461	Mill Creek	1008A_01	34	4/1/2009	10/4/2016
21957	Mill Creek	1008A_01	11	3/14/2017	4/9/2019
21181	Mill Creek	1008A_01	1	8/23/2012	8/23/2012
16629	Upper Panther Branch	1008B_02	99	1/15/2009	9/13/2017
16630	Upper Panther Branch	1008B_01	99	1/15/2009	9/13/2017
16422	Lower Panther Branch	1008C_01	30	10/15/2014	9/13/2017
16627	Lower Panther Branch	1008C_02	98	1/15/2009	9/13/2017
16628	Lower Panther Branch	1008C_02	69	1/15/2009	9/10/2014
16631	Bear Branch	1008E_01	98	1/15/2009	9/13/2017
16481	Lake Woodlands	1008F_04	98	1/15/2009	9/13/2017
16482	Lake Woodlands	1008F_03	97	1/15/2009	9/13/2017
16483	Lake Woodlands	1008F_02	99	1/15/2009	9/13/2017
16484	Lake Woodlands	1008F_01	100	1/15/2009	9/13/2017
20568	Lake Woodlands	1008F_01	84	1/7/2009	8/26/2010
11185	Willow Creek	1008H_01	90	1/8/2009	2/5/2019
20730	Willow Creek	1008H_01	87	10/8/2009	4/29/2019
20462	Walnut Creek	1008I_01	39	4/1/2009	4/9/2019
20463	Brushy Creek	1008J_01	39	4/1/2009	4/9/2019

Monitoring in Spring Creek

Between 2009 and 2019, 1,770 samples were collected from the stations listed in **Table 2**. The main segment, Spring Creek (1008), is represented by 7 of 25 total sites throughout the watershed. Sample site density is highest in and around the township of The Woodlands on the tributaries Panther Branch (1008B and 1008C), Bear Branch (1008E), and the reservoir Lake Woodlands (1008F). The remaining 7 sites are distributed among the tributaries Mill Creek (1008A), Willow Creek (1008H), Walnut Creek (1008I), and Brushy Creek (1008J). This dataset captures historic trends in the most recent decade and will be updated in advance of the completion of the WPP to reflect data collected during the project term. A full analysis of each constituent for stations with sufficient data will be represented as a series of graphs in **Appendix A: Monitoring Site Data**[3].

[3] 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

Sub-sections of each stream segment classified as assessment units (AUs) are the basic unit of analysis for the IRs produced by TCEQ. The 2018 IR deemed several AUs in the Spring Creek Watershed impaired for recreation use due to high levels of fecal indicator bacteria (*E. coli*). These AUs and others within the watershed were also flagged as concerns for aquatic life and general use due to high nutrient levels and depressed oxygen. A more detailed summary of the results of the 2018 IR for AUs in the Spring Creek watershed are referenced in **Table 3** below.

Table 3. *2018 IR Status of Spring Creek Waterways*

	Impairments			
Segment	**AU(s)**	**Parameter**	**Use**	**Category**
Spring Creek, 1008	02, 03, 04	*E. coli*	Recreation	4a (all)
Lower Panther Branch,1008C	01, 02	*E. coli*	Recreation	4a (all)
Willow Creek, 1008H	01	*E. coli*	Recreation	4a
Walnut Creek, 1008I	01	*E. coli*	Recreation	5a
Brushy Creek, 1008J	01	*E. coli*	Recreation	5a
	Concerns			
Segment	**AU(s)**	**Parameter**	**Use**	**Level of Concern**
Spring Creek, 1008	02	Fish Community	Aquatic Life	CN
Spring Creek, 1008	03, 04	Nitrate	General	CS (all)
Spring Creek, 1008	03, 04	Total Phosphorus	General	CS (all)
Upper Panther Branch, 1008B	01	Cadmium	Aquatic Life	CN
Upper Panther Branch, 1008B	01	Nitrate	General	CS
Upper Panther Branch, 1008B	01	Total Phosphorus	General	CS
Lower Panther Branch, 1008C	01, 02	Nitrate	General	CS (all)
Lower Panther Branch, 1008C	01, 02	Total Phosphorus	General	CS (all)
Lower Panther Branch, 1008C	02	Depressed DO	Aquatic Life	CS
Lake Woodlands, 1008F	01	Depressed DO	Aquatic Life	CS
Willow Creek, 1008H	01	Nitrate	General	CS
Willow Creek, 1008H	01	Total Phosphorus	General	CS
Walnut Creek, 1008I	01	Depressed DO	Aquatic Life	CS
Brushy Creek, 1008J	01	Depressed DO	Aquatic Life	CS

conducted using SAS. Statistical analysis in the graphs of Appendix A are based on a LOESS curve rather than a straight regression curve to better indicate change in trend over time for disparate stations.

Sufficiency of Data

Above, **Table 2** details the frequency of sampling events for each station in the Spring Creek Watershed as well as establishing the period of record for each site.

Spring Creek (Segment 1008) is well represented by six of its seven monitoring stations with a minimum average of 4.6 sampling events per year of study. Of note, Station 11315 was only monitored for a two year period between 2015 and 2017.

Looking at monitoring data on the tributaries collected since 2009, an important note should be made about Mill Creek (Segment 1008A). Station 20461 was sampled an average of 4.9 times per year, however, it was discontinued as a sampling site in 2016 after determining its proximity to a reservoir was negatively impacting surface water quality (especially DO) measurements. Sampling for Mill Creek has since been conducted upstream at Station 21957 starting in 2017. Station 21181 appears to have been sampled only once. Combined data from Stations 20461 and 21957 will be observed in this analysis in order to characterize ambient conditions in Mill Creek with the caveat that these data may be skewed by the influence of a nearby reservoir.

On Lower Panther Branch (1008C), an abbreviated dataset occurs at station 16422 with its first sampling date recorded in 2014. This site is spatially similar to station 16628 which was discontinued in 2014, and therefore represents a continuation of data to the present for that location.

Station 20568 on Lake Woodlands (1008F) shows a high frequency of sampling events but was only sampled between 2009 and 2010.

All other tributary sites have continuous periods of record and sample frequency averages greater than 4. In the second year of this project, updated data will be analyzed in a subsequent report to reflect more current conditions.

Monitoring Results

A summary of ambient data represented as the geomean of each parameter for its period of record is shown in **Table 4** below. These results are comparable to that of the 2018 IR, though not identical due to the use of overlapping datasets. Where the 2018 IR examined surface water data collected from 2009-2016, this analysis extends the dataset to cover 2009-2019 where possible. Results shaded in red indicate geomeans that exceed criteria or screening levels, while green shading represents results that are in compliance with criteria or better than the screening level. Lack of shading indicates the data is not being compared to criteria or screening levels.

Table 4. *Monitoring Results by Segment, 2009-2019 Geomean*

Parameter	Criteria	Unit	Geomean Results by Segment								
			1008	**1008A**	**1008B**	**1008C**	**1008E**	**1008F**	**1008H**	**1008I**	**1008J**
Temperature	NA	Degrees Celsius	19.52	21.77	21.77	21.67	21.01	22.27	20.72	19.30	18.79
DO, grab	Various	mg/L	6.88	6.26	6.26	6.38	6.39	8.51	7.73	6.04	5.52
DO, 24 Hour, Minimum	Various	mg/L	6.03							5.01	5.27
DO, 24 Hour, Maximum	Various	mg/L	7.57							7.13	6.29
DO, 24 Hour, Average	Various	mg/L	6.79							6.18	5.83
pH	9 (high) 6.5(low)	NA	7.44	7.40	7.40	7.71	7.49	8.45	7.62	7.34	7.05
TSS	NA	mg/L	16.51	8.42	8.42	18.61	17.09	18.09	11.48	17.55	9.77
Ammonia Nitrogen	0.33	mg/L	0.06	0.14	0.14	0.14	0.12	0.11	0.11	0.10	0.12
Nitrate and Nitrite	NA	mg/L	0.22	2.22	2.22	2.45	0.38	1.23		0.23	0.09
Total Phosphorus	0.69	mg/L	0.24	0.73	0.73	1.08	0.27	0.87	1.65	0.21	0.15
E. coli	126	CFU/ 100mL	228.41	73.35	73.35	150.85	146.56	42.37	207.05	201.73	232.58
Chlorophyll-a	14.1	mg/L	1.89					16.31			
Nitrate	1.95	mg/L	0.64	1.94	1.94	2.27	0.31	1.07	6.09		
Nitrite	NA	mg/L	0.04								

Trends

By examining all parameters collected from surface water samples in the Spring Creek Watershed and how measurements for those parameters have changed over time, trends in the data were determined. Statistically significant ($p < 0.0545$) trends observed in these analyses are summarized in **Table 5** below. Cells shaded in green represent trends that support good water quality such as decreasing fecal indicator bacteria levels and increasing dissolved oxygen. Red shading indicates trends that could be negatively impacting water quality such as increasing nutrient levels and decreasing dissolved oxygen. Parameter trends highlighted in gray are predicted to be of neutral impact to water quality. Results for parameters with stable trends over time are not represented in **Table 5**, however, graphs depicting the results of those assessments can be found in **Appendix A: Monitoring Site Data**. Consequently, parameter measurements that exceeded water quality standards but remained consistently high throughout the study period (such as *E. coli*) may not be captured by the summary.

Table 5. Water Quality Trends by Segment

Segment	Parameter	Trend	Start Date	End Date	N
Spring Creek, 1008	DO, grab	Increasing	01/08/2009	05/15/2019	470
Spring Creek, 1008	Nitrate and Nitrite	Increasing	04/01/2009	04/16/2019	52
Spring Creek, 1008	Total Phosphorus	Decreasing	01/08/2009	05/15/2019	461
Mill Creek, 1008A	DO, 24-hour Maximum	Increasing	10/11/2013	10/02/2018	10
Mill Creek, 1008A	DO, 24-hour Mean	Increasing	10/11/2013	10/02/2018	10
Mill Creek, 1008A	DO, 24-hour Minimum	Increasing	10/11/2013	10/02/2018	10
Mill Creek, 1008A	DO, grab	Increasing	04/01/2009	04/09/2019	43
Mill Creek, 1008A	Instantaneous Flow	Increasing	02/09/2012	04/09/2019	33
Mill Creek, 1008A	Nitrate and Nitrite	Decreasing	04/01/2009	04/09/2019	43
Upper Panther Branch, 1008B	Ammonia-N	Increasing	01/15/2009	07/18/2017	66
Upper Panther Branch, 1008B	DO, grab	Increasing	01/15/2009	09/13/2017	198
Upper Panther Branch, 1008B	Temperature	Increasing	01/15/2009	09/13/2017	198
Lower Panther Branch, 1008B	Ammonia Nitrogen	Increasing	01/15/2009	07/18/2017	66
Bear Branch, 1008E	Ammonia Nitrogen	Increasing	01/15/2009	07/18/2017	33
Bear Branch, 1008E	DO, grab	Increasing	01/15/2009	09/13/2017	98
Bear Branch, 1008E	Instantaneous Flow	Increasing	09/29/2009	09/13/2017	84
Bear Branch, 1008E	Temperature	Increasing	01/15/2009	09/13/2017	98
Bear Branch, 1008E	Total Phosphorus	Increasing	01/15/2009	07/18/2017	33
Lake Woodlands, 1008F	Ammonia Nitrogen	Increasing	01/15/2009	07/18/2017	132
Lake Woodlands, 1008F	*E. coli*	Decreasing	01/15/2009	07/18/2017	132
Lake Woodlands, 1008F	TSS	Decreasing	01/15/2009	07/18/2017	128
Willow Creek, 1008H	*E. coli*	Increasing	01/08/2009	04/29/2019	177
Willow Creek, 1008H	pH	Decreasing	01/08/2009	04/29/2019	175
Brushy Creek, 1008J	DO, grab	Increasing	04/01/2009	04/09/2019	37
Brushy Creek, 1008J	pH	Increasing	04/01/2009	04/09/2019	39

Relationship to Flow

Parameter measurements and their relationships to flow conditions were considered in this analysis. Further work on the relationship between flow, bacteria, and DO was completed as part of LDC model development[4]. According to the results of the LDC models, surface water in the Spring Creek Watershed is

[4] The Spring Creek Modeling Report is currently being developed and will be made available at http://springcreekpartnership.com.

likely impacted by nonpoint source pollution. This is indicated by fecal indicator bacteria concentrations that are observed to increase with flow magnitude.

Ambient Analysis Summary

Of the ambient water quality parameters observed, geomean values for fecal indicator bacteria levels measured between 2009 and 2019 exceeded state water quality standards most frequently. Of the segments with geomeans that exceeded criteria, Willow Creek (1008H) showed an increasing trend in *E. coli* over time. Only Mill Creek (1008A), Upper Panther Branch (1008B) and Lake Woodlands (1008F) showed geomean values for *E. coli* within criteria levels. In fact, *E. coli* levels in Lake Woodlands have followed a significant decreasing trend over time.

Nutrients also seem to pose a challenge to water quality in the Spring Creek Watershed. Total phosphorous geomeans exceeded screening levels on Panther Branch (1008B and 1008C), Lake Woodlands (1008F) and Willow Creek (1008). Nitrate nitrogen geomeans were also found to be above screening levels on the lower portion of Panther Branch (1008C) and Willow Creek (1008H). Spatially, these exceedances occur in the eastern third of the watershed where developed areas are most prevalent.

Low levels of DO are a concern noted in the 2018 IR that are not necessarily captured in this analysis. This is most likely due to the overlap of datasets observed—The 2018 IR observed data collected from 2009-2016 whereas this analysis uses 2009-2019 as the study period.

Targeted assessment and application of best management practices could be expected to reduce or remove impairments and concerns in these watersheds.

3.3 DMR Data

Discharges from wastewater treatment plants are regulated by water quality permits from TCEQ which require stringent limits for effluent quality. Generally, wastewater treatment plants in the Houston region are able to meet their permits. However, because human waste has an appreciable pathogenic potential, 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) 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 or improperly treated waste:

- Indicator bacteria (*E. coli*) – bacteria common in the intestines of all warm blooded animals used as an indicator of the presence of fecal wastes. Due to this relationship, it may also be used as a proxy indicator of the safety of waterways for human recreation as fecal waste can be a vector for human pathogens.
- 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.

- Ammonia Nitrogen – 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).
- 5-Day Carbonaceous Biological Oxygen Demand (CBOD5) – This indicator, which measures the depletion of oxygen over time by biological processes, indicates the efficiency of treatment.

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

As with surface water sampled throughout the watershed to gage ambient conditions, discharge from WWTFs is assessed for compliance with state water quality standards. In the case of *E. coli*, the permitted geomean standard for bacteria concentrations is 126 CFU/100 mL whereas the grab sample standard is 399 CFU/100 mL. For this analysis, compliance with permit limits for bacteria were compared across segments, plant types, years, and seasons. Data from the 61 plants represented by DMRs in the Spring Creek Watershed are summarized in the tables below.

In **Table 6**, it is clear that of the plants reporting violations of bacteria criteria, the majority are in exceedance less 1% of the time. Following these, plants reporting samples exceeding the criteria between 1% and 5% of the time comprise the bulk of the remainder. Approximately 14.7% of all WWTFs reported values exceeding the standard greater than 5% of the time. The disparity between the number of samples exceeding the geomean standard compared to samples exceeding the grab standard could indicate high variability in the data. Higher rates of exceedance from leading to localized impacts from specific sites may be overshadowed by the broad scope of this analysis.

Table 6. E. coli *Exceedance Statistics, 2014-2019*

Parameter	Number of Plants	Percent of Plants	Percent of Reports
Plants in DMR	61		
Plants Reporting Bacteria	61		
Total Records	6,082		
Less than 1% Violations[5]	32	52.5%	
1% to 5% Violations	20	32.8%	
5% to 10% Violations	6	9.8%	
10% to 25% Violations	3	4.9%	
Greater than 25% Violations	0	0.0%	
Exceedances of Geomean	24		0.4%
Exceedances of Single Grab	88		1.4%
Total Exceedances	112		1.8%

Below in **Table 7** and **Table 8**

Table 8, no clear trends were observed in either geomean or single grab criteria exceedance or the total number of exceedances observed annually and seasonally. However, single sample criteria exceedance happens more frequently than geomean exceedance annually and seasonally which further supports the assumption that variability in the dataset is high.

Table 7. E. coli *Exceedances by Year*

	Exceedances by Year						
	2014	**2015**	**2016**	**2017**	**2018**	**2019**	**Total**
By Geomean	8	2	8	4	1	1	24
By Grab	14	16	18	17	8	15	88
Total Exceedances	22	18	26	21	9	16	112

Table 8. E. coli *Exceedances by Season*

	Exceedances by Season				
	Spring (Months 3-5)	Summer (Months 6-8)	Fall (Months 9-11)	Winter (Months 12-2)	Total
By Geomean	3	8	9	4	24
By Grab	24	28	19	17	88
Total Exceedances	27	36	28	21	112

[5] 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.

Plants evaluated for bacteria criteria exceedance compared to age of initial permit issuance are represented in **Table 9** below. Based on these results, a relationship between plant age and bacteria exceedance is not clear. Further, it should be noted that this analysis does not reflect any improvements made to older plants between their initial permit date and the present day that may have led to better management of effluent water quality.

Table 9. *E.* coli *Exceedances by Plant Age*

Distribution of Plants by Age			
Age	Number of Plants	Percent of All Plants	
Before 1980	15	24.6%	
1980-2000	19	31.1%	
2000-2020	27	44.3%	
Exceedances by Plant Age			
Age	Number of Exceedances (Total)	Number of Exceedances (Geomean)	Number of Exceedances (Single Grab)
Before 1980	30	3	27
1980-2000	32	11	21
2000-2020	58	10	48

In **Table 10** and **Figure 3** below, plants of different sizes were analyzed for *E. coli* criteria exceedance. Plants are sized according to permitted output in millions of gallons per day (MGD). According to the results, 60.7% of total reported exceedances occurred at smaller plants discharging between 0.5-1.0 MGD. These small-to-mid size plants also had the most violations of both geomean standard of any size category.

Table 10. *E.* coli *Exceedances by Plant Size*

Distribution of Plants by Size (Permitted Flow in MGD)			
Size	Number of Plants	Percent of Plants	
0>0.5 MGD	41	67.2%	
0.5-1 MGD	10	16.4%	
1-5MGD	8	13.1%	
5-10 MGD	2	3.3%	
> 10 MGD	0	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	28	8	20
0.5-1 MGD	37	15	22
1-5MGD	8	1	7
5-10 MGD	24	0	24
>10 MGD	15	0	15

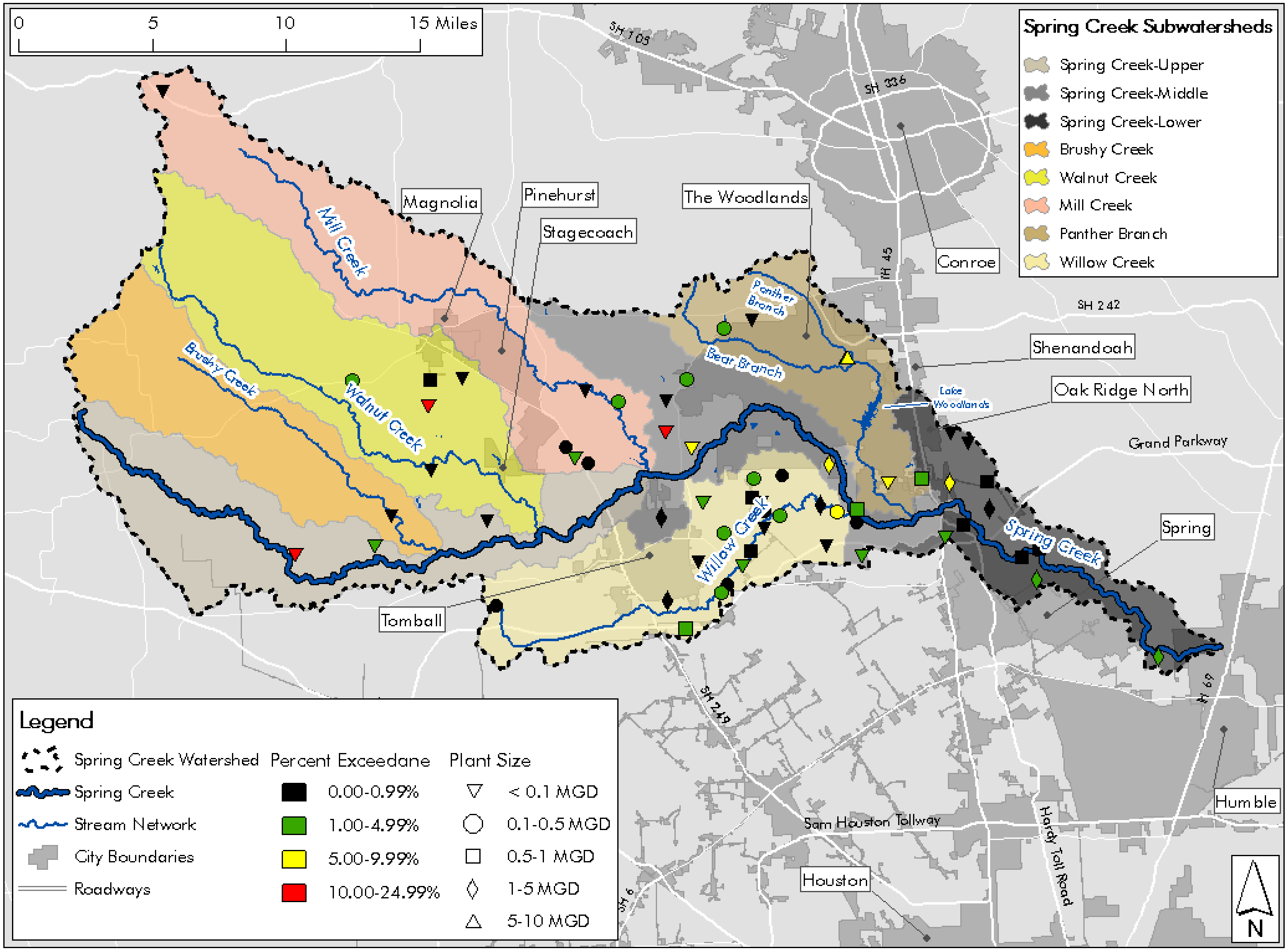


***Figure 3.** Percent* E. coli *Standard Exceedance and Plant Size, 2014-2019*

Spatially, the three plants reporting exceedances of *E. coli* standards in excess of 10% of the total values reported are distributed several miles apart from each other in the less developed area west of The Woodlands Township (**Figure 3**). All three plants are permitted for the smallest amount of flows, <0.1 MGD. More size variation is seen in plants reporting between 5 and 10% of their report values in exceedance of the standard, however, they are all spatially similar in that they occur most frequently on the more developed eastern side of the watershed. Plants reporting less than 5% of their total report values for E. coli in exceedance of the standard are diverse in size and distribution throughout the watershed.

Overall, the results of the analyses of DMR *E. coli* data indicated that the total number of exceedances reported was small relative to the total number of DMR reports submitted for the period of 2014-2019 (120 out of 6,082 records). Further, only 9 plants out of 61 exceeded the bacteria standard in >5% of their samples. Maximum grab values were more commonly exceeded than geomean limits which suggests high variability in the data. Seasonality was not observed to be significant in shaping trends in bacteria concentrations. Evaluations of plant size relative to number of exceedances revealed that small plants (<0.5 MGD) reported the most violations of any size category for both the geomean and single sample standards. 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 milligrams per liter (mg/L), and the permit limits can 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. 61 plants reported DO results during this period. The outcomes are summarized in the tables below.

Table 11 summarizes the overall statistics of DO data reported by WWTFs in the Spring Creek Watershed. Very few (20 of 4,082 total reports) samples fell below the minimum standard.

Table 11. *DO Exceedance Statistics, 2014-2019*

Category	Number	Percent of Records
Plants in DMR Dataset	61	
Plants Reporting DO	61	
Total Records	4,082	
Total Exceedances	20	0.5%

After arranging the data temporally, no annual or seasonal trends were observed in the reported data (**Table 12** and **Table 13**). However, in light of the low occurrence of exceedance relative to the overall dataset, determining trends from these values may not accurately represent DO dynamics in the Spring Creek Watershed.

Table 12. DO Exceedances by Year

	Exceedances by Year						
	2014	2015	2016	2017	2018	2019	Total
Exceedances	6	2	2	2	5	3	20

Table 13. DO Exceedances by Season

	Exceedances by Season				
	Spring (Months 3-5)	Summer (Months 6-8)	Fall (Months 9-11)	Winter (Months 12-2)	Total
Exceedances	6	6	3	5	20

Due to the findings of this analysis, it is unlikely that low DO levels in the waterways of the Spring Creek Watershed are being driven by WWTF effluent. As with the results of the bacteria analysis, it is important to note that periodic impacts to DO levels may occur on a localized level, but may not be well represented in this broad analysis. While the impacts of WWTFs on DO levels may not be a chronic or widespread issue in the watershed, an analysis of DO values reported in DMRs is still a critical component of this project especially as it pertains to identifying localized impacts.

TSS

To determine the efficiency of wastewater treatment in removing solids, TSS is evaluated. Bacteria use suspended particles as a protected growth medium and can therefore occur in greater concentrations when TSS is high. Additionally, TSS can 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 per day. Both average and maximum monitored results exist for most plants. Evaluations for compliance with concentration and total weight permit limits were made for the overall dataset and for annual and seasonal data. These results are summarized in the tables below.

The summary of reports made for TSS measurements and the number of exceedances of the concentration and weight standards are presented in **Table 14** below. Compared to the total number of reports submitted between 2014 and 2019, the total frequency of exceedance is very small (less than 2%).

Table 14. TSS Exceedance Statistics, 2014-2019

Category	Number	Percent of Records
Plants in DMR Dataset	61	
Plants Reporting TSS	61	
Total Records	8,090	
Exceedances of Concentration	88	1.1%
Exceedances of Weight	38	0.5%
Total Exceedances	126	1.6%

Viewing the data annually as represented in **Table 15**, there does not seem to be any significant pattern to either concentration, weight or combined total violations.

Table 15. TSS Exceedance by Year

	Exceedances by Year						
	2014	2015	2016	2017	2018	2019	Total
Concentration	11	8	11	14	23	21	88
Weight	2	2	4	9	15	6	38
Total	13	10	15	23	38	27	126

Table 16 shows TSS report data in exceedance of standards organized seasonally. Of the four seasons, samples exceeding the concentration and weight standards seem to be most prevalent during the winter months.

Table 16. TSS Exceedance by Season

	Exceedances by Season				
	Spring (Months 3-5)	Summer (Months 6-8)	Fall (Months 9-11)	Winter (Months 12-2)	Total
Concentration	21	19	17	31	88
Weight	7	11	6	14	38
Total	28	30	23	45	126

Though periodic, local impacts may not be captured by these results, water quality throughout the Spring Creek Watershed is unlikely to be impacted by TSS from WWTFs at the watershed level. Seasonal analysis showed that samples exceeding the concentration and weight standards occurred with the highest frequency in winter months, but the overall percentage of samples exceeding the standards compared to the total number of reports was negligibly small. Despite this, observing TSS in WWTF effluent is still worth considering when moving forward with best management practices for water quality. As mentioned previously, TSS is often correlated with nutrient and bacteria levels, and can be tracked as a measure of WWTF improvement.

Ammonia Nitrogen

Ammonia nitrogen is a component that indicates negative impacts to water quality due to nutrient loading. Further, it can be toxic to humans and wildlife. Deficiencies in wastewater treatment that lead to improperly treated sewage entering waterways can be indicated by elevated levels of ammonia nitrogen.

Similar to TSS, concentration and weight measurements are used to assess compliance of ammonia nitrogen levels with permit limits. In **Table 17** below, the results of samples reported to be in exceedance of the standard as reported between 2014 and 2019 are summarized. As with many other constituents examined here, ammonia nitrogen violations were infrequent and occurred in only 2.4% of the observed records.

Table 17. *Ammonia Nitrogen Exceedance Statistics, 2014-2019*

Category	Number	Percent of Records
Plants in DMR Dataset	61	
Plants Reporting Ammonia Nitrogen	61	
Total Records	8,092	
Exceedances of Concentration	129	1.6%
Exceedances of Weight	65	0.8%
Total Exceedances	194	2.4%

In **Table 18** below, number of ammonia nitrogen exceedances per year are represented for measurements of both concentration and weight. No trend was observed in the annual data.

Table 18. *Ammonia Nitrogen Exceedance by Year*

	Exceedances by Year						
	2014	2015	2016	2017	2018	2019	Total
Concentration	22	13	28	29	18	19	129
Weight	5	6	17	16	14	7	65
Total	27	19	45	45	32	26	194

When observed seasonally as in **Table 19**, exceedances of concentration and weight standards for ammonia nitrogen do seem to occur more frequently in the spring and especially the summer months.

Table 19. *Ammonia Nitrogen Exceedance by Season*

	Exceedances by Season				
	Spring (Months 3-5)	Summer (Months 6-8)	Fall (Months 9-11)	Winter (Months 12-2)	Total
Concentration	38	39	27	25	129
Weight	18	22	13	12	65
Total	56	61	40	37	194

The results of the analyses of ammonia nitrogen reported by Spring Creek Watershed WWTFs between 2014 and 2019 show that exceedances do not follow any annual pattern but are more common in spring and summer months with summer capturing the highest frequency of concentration and weight violations.

However, the total number of exceedances reported for ammonia nitrogen comprise less than 3% of the total reported values. This indicates that WWTFs are generally operating within permit limits and that ammonia inputs from WWTFs are not likely a chronic issue of importance for Spring Creek waterways. Periodic, localized impacts may not be as apparent when using a broad scope analysis. Ammonia nitrogen may still have use as an indicator of WWTF efficiency much in the same way as TSS and will therefore continue to be considered for best management practices in the watershed.

Biological Oxygen Demand

CBOD5 measures the depletion of oxygen over time by biological processes, and indicates the efficiency of treatment. It is not a pollutant itself, but is informative of the water quality of effluent from WWTFs. In **Table 20** below, the exceedances of concentration and weight standards for CBOD5 in relation to the total number of reported values are summarized. Of all the DMR constituents examined, CBOD5 exceedance is the rarest. Of the 8,164 report values examined, only 28 exceeded either the concentration or weight standard making up only 0.3% of the dataset.

Table 20. *CBOD5 Exceedance Statistics, 2014-2019*

Category	Number	Percent of Records
Plants in DMR Dataset	61	
Plants Reporting Ammonia Nitrogen	61	
Total Records	8,164	
Exceedances of Concentration	17	0.2%
Exceedances of Weight	11	0.1%
Total Exceedances	28	0.3%

Table 21 examines annual CBOD5 exceedances. No clear trend in CBOD5 exceedance values occurs in the observed data, but it should be noted that determining a trend from exceedance values occurring at such low frequencies might be misrepresentative of the overall dataset.

Table 21. *CBOD5 Exceedance by Year*

	Exceedances by Year						
	2014	2015	2016	2017	2018	2019	Total
Concentration	2	2	0	5	4	4	17
Weight	1	1	0	3	5	1	11
Total	3	3	0	8	9	5	28

From the seasonal observations of CBOD5 exceedance frequency shown in **Table 22**, there does seem to be a higher occurrence of exceedance in winter months. However, it bears repeating that as a subset of 8,164 total report values, the 16 exceedances of CBOD5 observed in winter months between 2014 and 2019 may not constitute a representative trend.

Table 22. CBOD5 Exceedance by Season

	Exceedances by Season				
	Spring (Months 3-5)	Summer (Months 6-8)	Fall (Months 9-11)	Winter (Months 12-2)	Total
Concentration	2	3	2	10	17
Weight	1	3	1	6	11
Total	3	6	3	16	28

CBOD5 exceedances were relatively rare in this DMR dataset compared to the other observed parameters. No annual pattern was observed and though exceedances were most frequent seasonally in the winter, the small number of exceedances limits the applicability of any trends. From this analysis, it can be assumed that WWTFs are not likely a chronic source of poor CBOD5 values in the waterways of the Spring Creek Watershed. As with previous analyses however, it should be noted that determining periodic and localized impacts may require further investigation.

Overview of Results

Exceedances for all constituents compared to their permit standards were uncovered by this analysis. However, plants in the Spring Creek Watershed were largely found to be in compliance with their permit limits for the majority of the period of study. It is unlikely that WWTFs are an appreciable source of contamination in the watershed on a chronic, wide-ranging scale. However, this broad analysis may underrepresent localized impacts of WWTF outfalls. For example, a spatial examination of individual plant locations and their respective sizes and exceedances of bacteria standards yielded results indicating high percentages of exceedance from small plants west of the most developed parts of the watershed. This spatial analysis also revealed plants of various sized reporting exceedances between 5 and 10% of their total records were located on the more developed eastern half of the watershed.

WWTFs may not be the largest source of bacteria, but effluent from these facilities has an inherently higher pathogenic potential than other sources due to the treatment of human waste. Additionally, unlike other sources 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.

3.4 SSOs

Though SSOs occur episodically, they represent a high-risk vector for bacteria contamination 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. Known causes of SSOs 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.

This study considered five years of TCEQ SSO violation data for 2014-2019. There were 131 SSO records from 26 plants considered for the watershed area. Of those 26 plants, 11 plants had ≥5 SSOs, and of those 11 plants, 5 plants had ≥10 SSOs. However, number of SSOs did not correspond well to volume of SSOs. Only 4 plants had a cumulative SSO volume greater than 50,000 gallons, and only one of those plants had a number of SSOs >5. Below, tables and figures reflect the breakdown of SSOs by year and cause, for number and volume, respectively.

As shown in **Table 23** and **Figure 4**, there was not a strong trend in number of SSOs over time. In terms of cause by number, the general category of weather-related issues accounted for 23.7% of the overall total, malfunctions and operational issues accounted for 35.9%, blockages accounted for 29.8%, and 10.7% were listed as unknown causes.

Table 23. *Number of Annual SSO Events*

CAUSE	2014	2015	2016	2017	2018	2019
Weather	**1**	**0**	**8**	**7**	**9**	**6**
Rain / Inflow / Infiltration	1		8	1	9	6
Hurricane				6		
Malfunctions	**5**	**5**	**10**	**6**	**13**	**8**
WWTF Operation or Equipment Malfunction	2		4	1	5	1
Power Failure	1	1	1	2	1	
Lift Station Failure	2	1	3	1	3	3
Collection System Structural Failure		3	1	2	4	4
Human Error			1			
Blockages	**6**	**9**	**5**	**1**	**10**	**8**
Blockage in Collection System-Other Cause	3	5	2	1	6	2
Blockage in Collection System Due to Fats/Grease	1	3	3		3	4
Blockage Due to Roots/Rags/Debris	2	1			1	2
Unknown Cause	**0**	**2**	**3**	**1**	**5**	**3**
Total	**12**	**16**	**26**	**15**	**37**	**25**

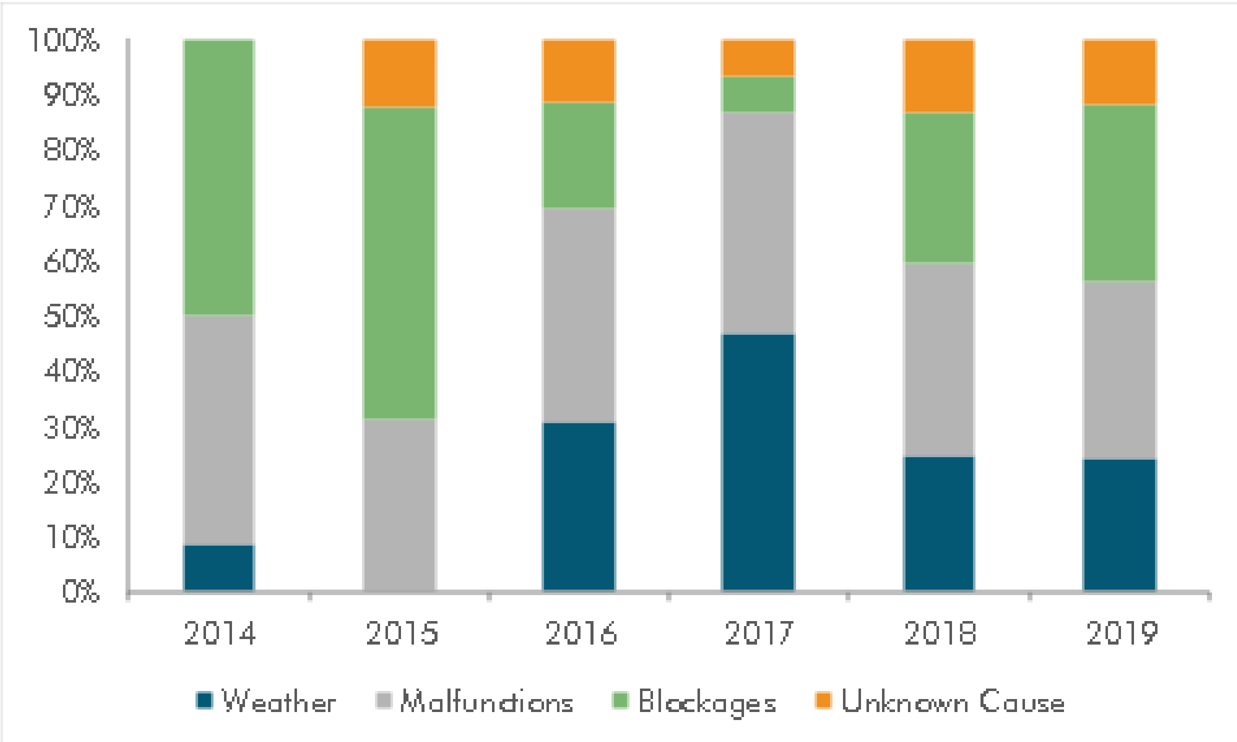


Figure 4. *Percent Total Annual SSO Events*

While numbering SSO events informs how frequently these overflows impact the watershed, volume of overflow is an indicator of the magnitude of impact. The results summarized in **Table 24** and **Figure 5** indicate that as with number of events, there was no real temporal trend in volume of events. Of note, though 2017 had the second lowest total overflow volume reported over the five years of study, over 80% of the overflow volume was associated with a hurricane event (Hurricane Harvey). Apart from that isolated event and a high volume of overflows caused by blockages in 2015, malfunctions were the most common cause of high volume overflows throughout the study period.

Of the total volume of overflows reported from 2014-2019, malfunctions were responsible for 46.2%. Blockages comprised 21.9% of the overall volume, weather contributed 16.5% and unknown causes led to the remaining 15.3%. These overall contributions are important to consider in a general sense for estimating impacts to the watershed area.

Table 24. Annual SSO Events by Volume (in Gallons)

CAUSE	2014	2015	2016	2017	2018	2019
Weather	**500**	**0**	**44,300**	**58,700**	**12,301**	**10,294**
Rain / Inflow / Infiltration	500		44,300	300	12,301	10,294
Hurricane				58,400		
Malfunctions	**31,010**	**19,300**	**87,748**	**11,090.5**	**150,374**	**52,723**
WWTF Operation or Equipment Malfunction	26,000		2,050	0.5	724	10,000
Power Failure	3,000	300	2,500	10,000	2,500	
Lift Station Failure	2,010	1,500	62,300	100	53,850	35,023
Collection System Structural Failure		17,500	500	990	93,300	7,700
Human Error			20,398			
Blockages	**20,750**	**50,000**	**4,880**	**2,400**	**80,350**	**8,915**
Blockage in Collection System-Other Cause	17,000	23,500	3,395	2,400	22,100	5,980
Blockage in Collection System Due to Fats/Grease	1,950	25,500	1,485		8,250	1,915
Blockage Due to Roots/Rags/Debris	1,800	1,000			50,000	1,020
Unknown Cause	**0**	**1,970**	**77,060**	**100**	**925**	**36,500**
Total	**52,260**	**71,270**	**213,988**	**72,290.5**	**243,950**	**108,432**

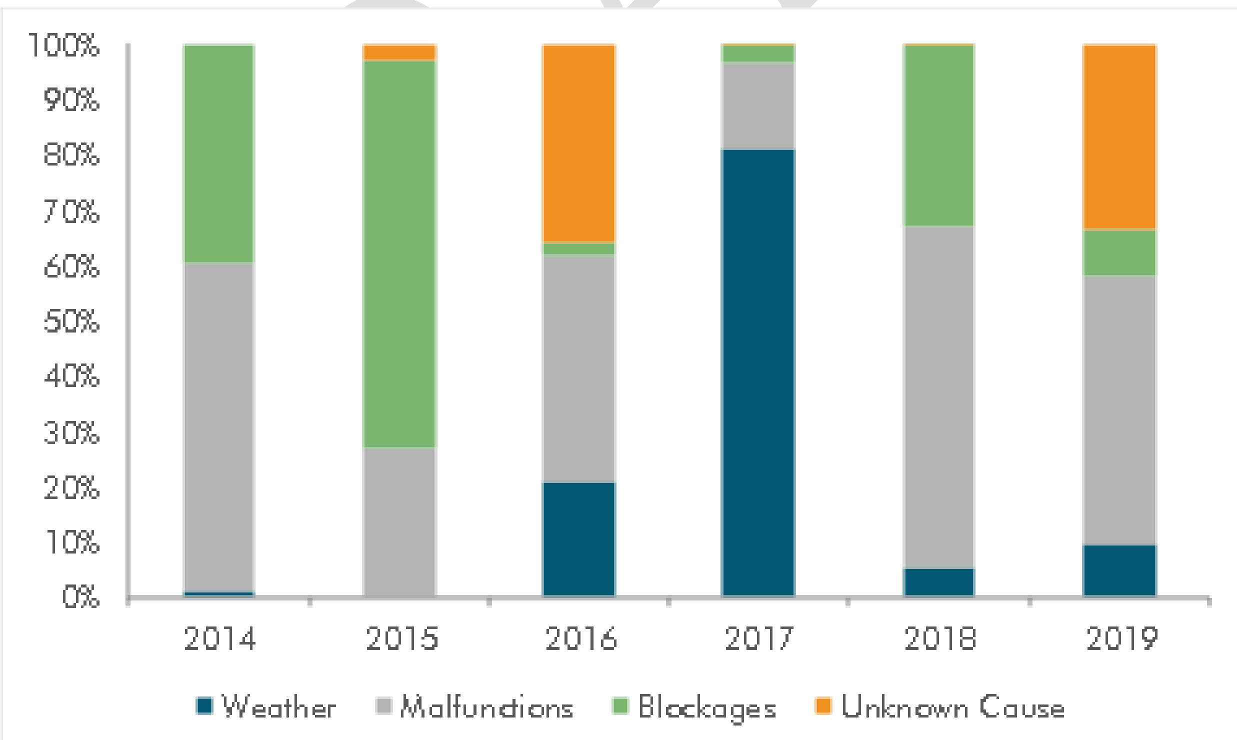


Figure 5. *Percent Total Annual SSO Volume*

One further consideration to make from the SSO report data is whether the frequency or volume of events showed any seasonal trend. In **Table 25** below, the data do not support any clear seasonal pattern in the data.

Table 25. *Seasonal SSO Frequency and Volume (in Gallons)*

Season	Number	Volume
Winter (Months 12-2)	20	139,605.0
Spring (Months 3-5)	38	329,974.0
Summer (Months 6-8)	47	169,158.0
Fall (Months 9-11)	26	123,453.5
Total	**131**	**762,190.5**

SSO Summary

Of the 26 plants that reported SSOs between 2014 and 2019, 11 had ≥5 SSOs—5 of those had ≥10. The number of occurrences was not necessarily indicative of overflow volume. Only one of the 4 plants reporting a cumulative SSO volume greater than 50,000 gallons had >5 SSOs. There was not a strong annual or seasonal trend in number or volume of SSOs. In terms of general cause, malfunctions and operational issues accounted for the highest number of events and overflow volume respective to the other general categories of weather, blockages, and unknown causes.

While this data is useful, it should be noted that it is also self-reported and may vary in quality. Overflow volumes and numbers of events may be greater than the values recorded in the report data. In addition, causes may be overgeneralized due to multiple factors ultimately resulting in SSOs.

In watersheds where bacteria and nutrient loading are of particular concern, the impacts of SSOs are important to understand due to their concentrations of untreated human waste. These events pose a high risk to human health especially due to their proximity to urban populations. Further, despite their episodic occurrences, SSOs can be extreme loading sources in the sense of volume introduced in a short time frame. Though SSOs do not have the same potential to have chronic impacts on waterways as effluent from high volume WWTFs, for the aforementioned reasons, it is still critical to consider SSO management among the best management practices selected to improve water quality in the Spring Creek Watershed.

SECTION 4: OUTCOMES AND IMPLICATIONS

This initial analysis of ambient, DMR and SSO report data is foundational for understanding and characterizing water quality concerns in the Spring Creek Watershed. Findings from this report can be used to inform stakeholders as they work toward the development of a WPP.

Data meeting the criteria for sufficiency were used to determine what constituents of water quality are of greatest concern and the extent to which their impacts have been observed throughout the area waterways. As indicated in the 2018 IR results for this watershed, an analysis of the SWQMIS dataset identified high levels of the fecal indicator bacteria *E. coli* as the most pervasive impact to water quality. Further, elevated nutrient (nitrate nitrogen and total phosphorous) levels observed in the highly developed eastern third of the watershed present challenges to water quality. Depressed DO levels were also highlighted in several segments in the 2018 IR, but comparable results were not captured in this analysis. This is most likely due to the incomplete overlap of datasets observed for each report with the analysis described herein including more recent data where increasing trends in DO have been observed.

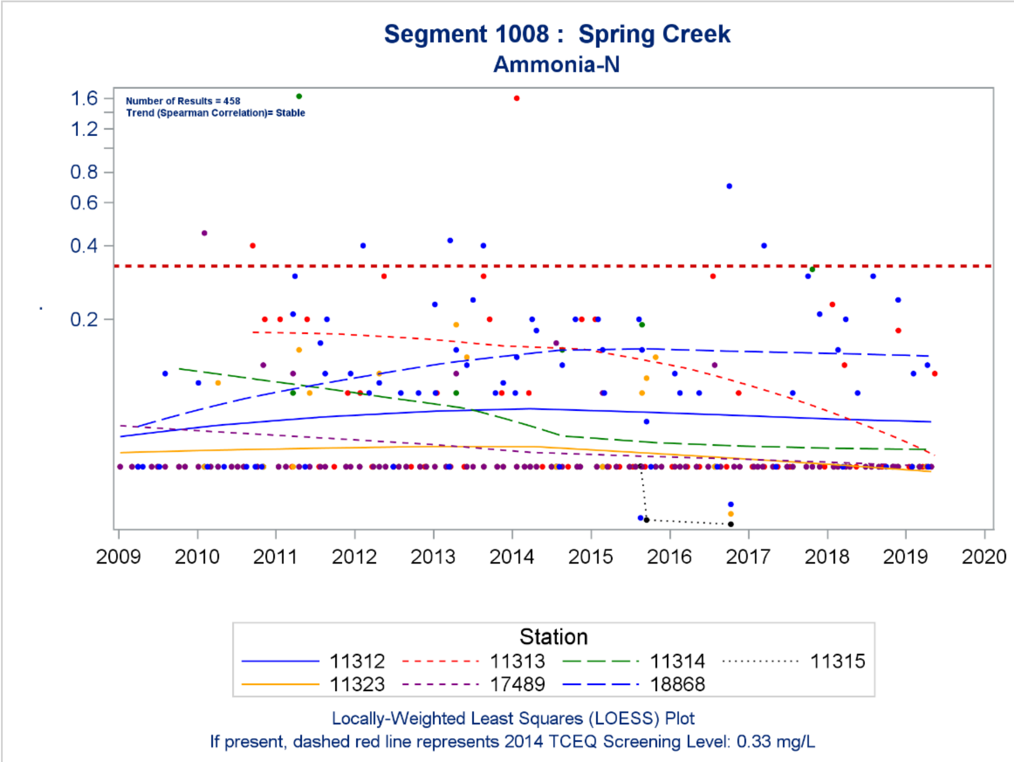
Permitted wastewater effluent was unlikely to be a widespread or chronic water quality issue but requires further investigation on limited spatial scales and timeframes. However, understanding these discharges is still critical to the development of this project as WWTFs without permit limits for certain nutrients act as source loads—particularly in effluent-dominated streams. Further, as treatment facilities for human waste, improper treatment indicators identified in DMR analyses can have greater implications for risk to human health.

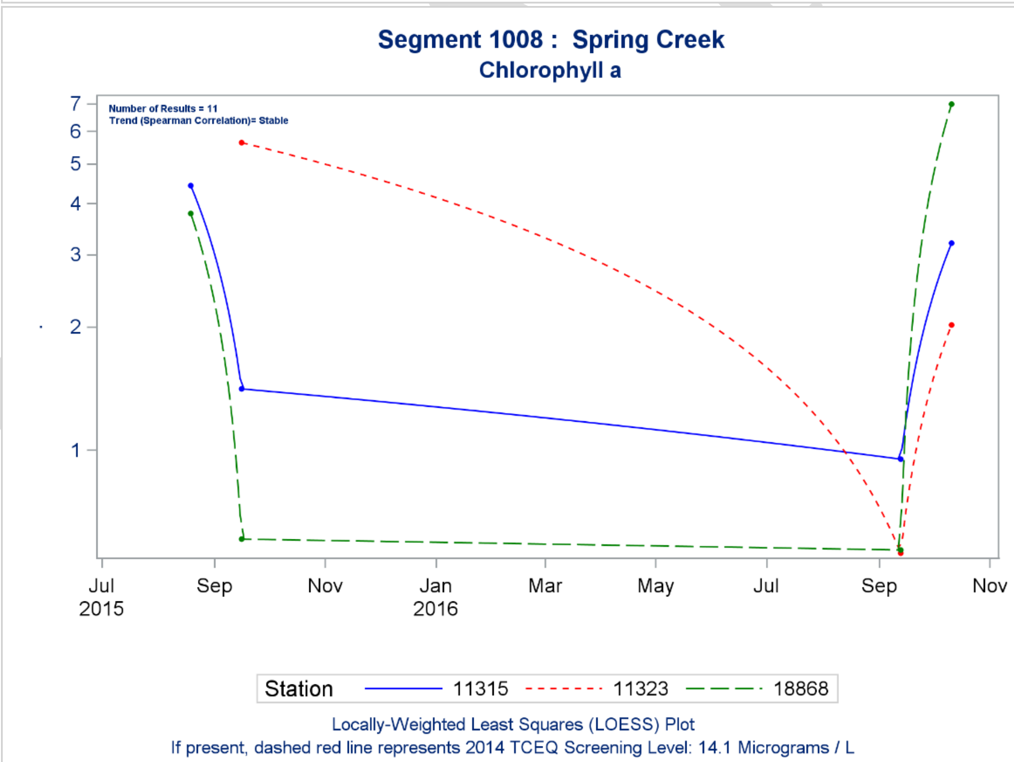
An analysis of SSO reports from the Spring Creek Watershed indicated that 42.3% of reporting plants experienced 5 or more SSO events between 2014 and 2019. Plants reporting 10 or more events throughout the study period accounted for 19.2% of the data. Number of events did not correspond to magnitude of overflow volume, however. For both number of SSO events and volume of overflow, malfunctions were among the most common for the general cause categories. However, it is important to note that while only one cause is usually listed on the report, multiple compounding factors can lead to SSOs. Ultimately, causes listed in SSO reports are prone to a degree of subjectivity as opposed to more quantitative measurements. While the episodic overflow volumes reported during these events are relatively small compared to the scale of effluent produced by WWTFs, SSO inputs are of particular concern due to the untreated nature of the sewage associated with them and the subsequent risk to human health.

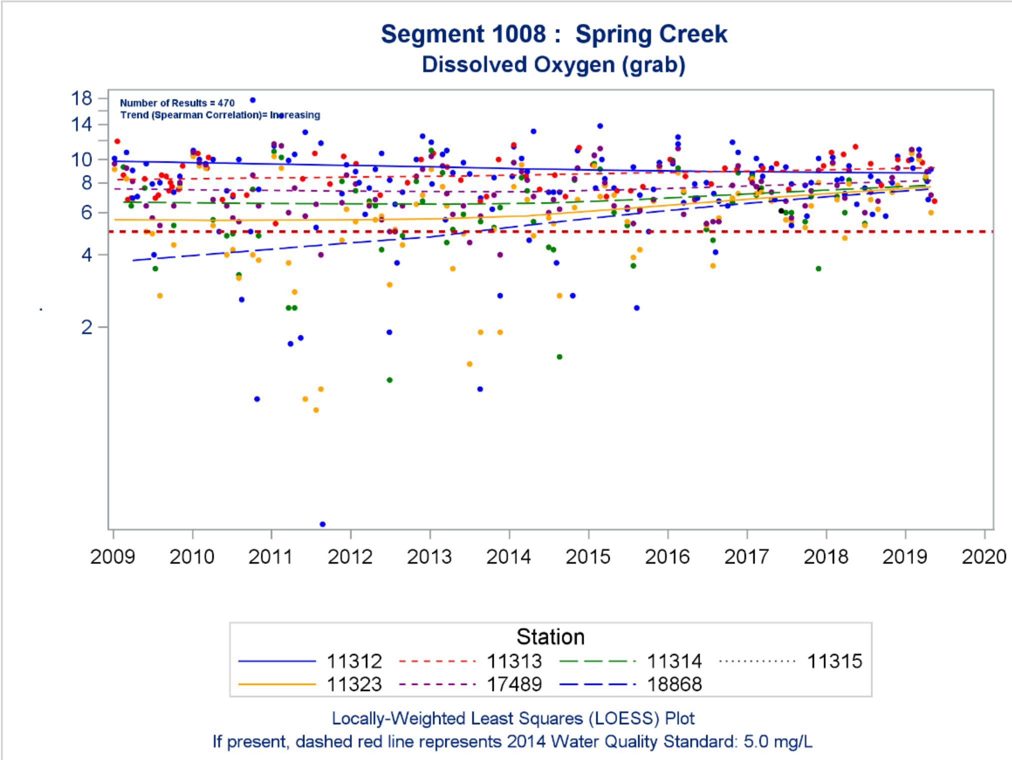
As future growth projections indicate that increased development in the watershed is likely, the balance of pollutant sources and current hydrologic processes could be altered significantly in the coming years. These changes could result in further water quality impacts without intervention. Subsequent 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 the implementation of management strategies.

APPENDIX A: MONITORING SITE DATA

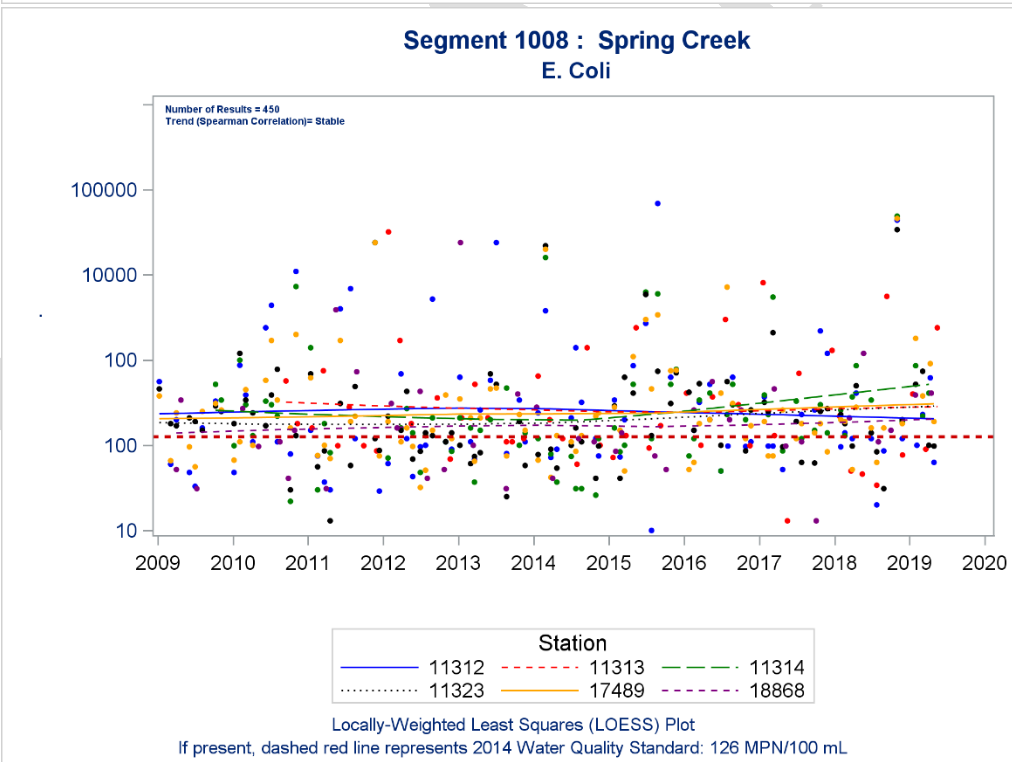
The following charts represent the results, by segment and station, for all constituents evaluated. The period of observation is 2009-2019, although data for each station may vary as indicated in the charts. The quantitative analysis for the ambient conditions was conducted using SAS. Statistical analyses are based on a LOESS curve rather than a straight regression curve to better indicate change in trend over time for disparate stations.


Segment 1008 : Spring Creek
Ammonia-N
Number of Results = 458
Trend (Spearman Correlation)= Stable
1.6
1.2
0.8
0.6
0.4
0.2
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
11312
11313
11314
11315
11323
17489
18868
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 TCEQ Screening Level: 0.33 mg/L

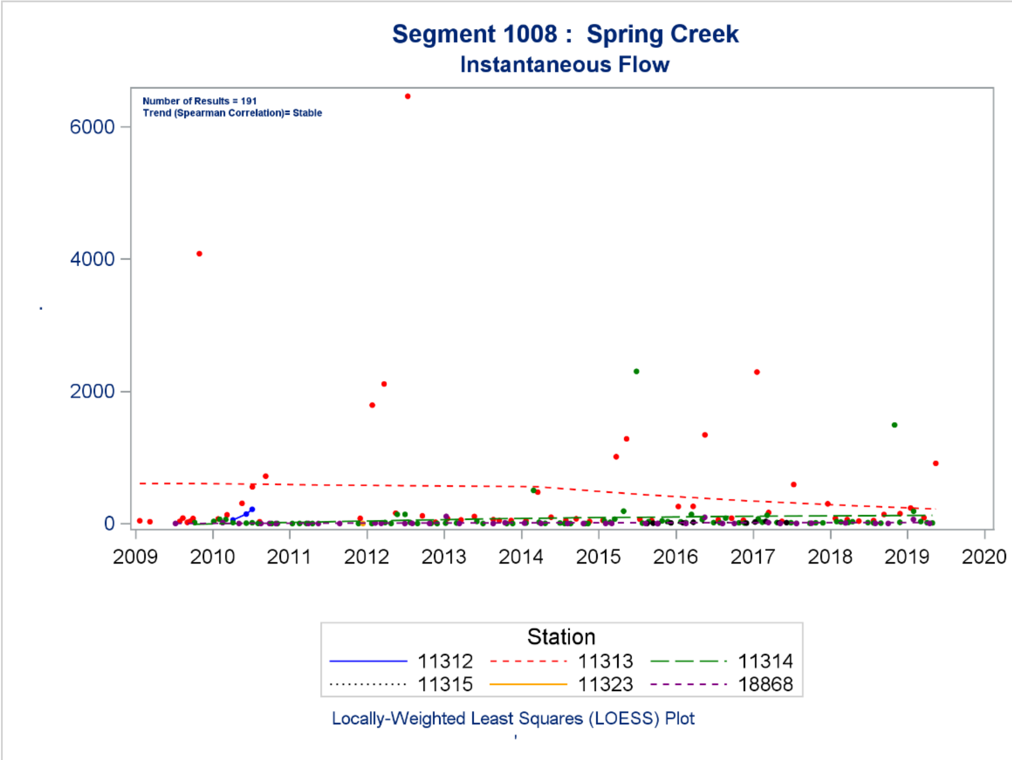

Segment 1008 : Spring Creek
Chlorophyll a
Number of Results = 11
Trend (Spearman Correlation)= Stable
7
6
5
4
3
2
1
Jul 2015
Sep
Nov
Jan 2016
Mar
May
Jul
Sep
Nov
Station
11315
11323
18868
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 TCEQ Screening Level: 14.1 Micrograms / L

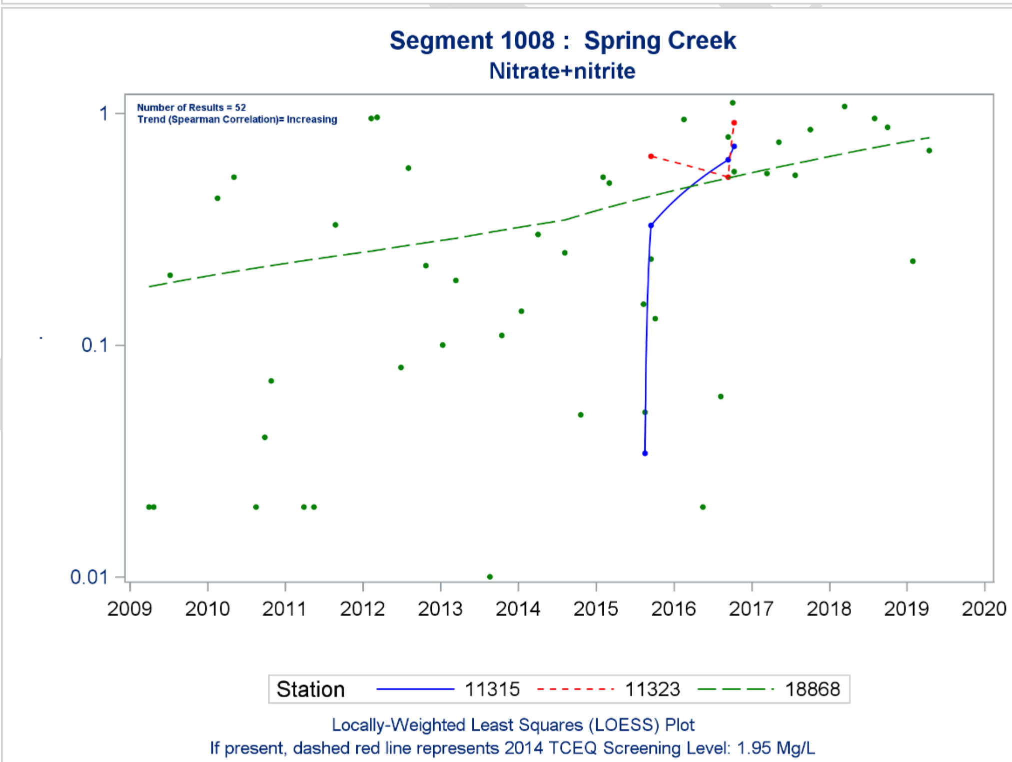


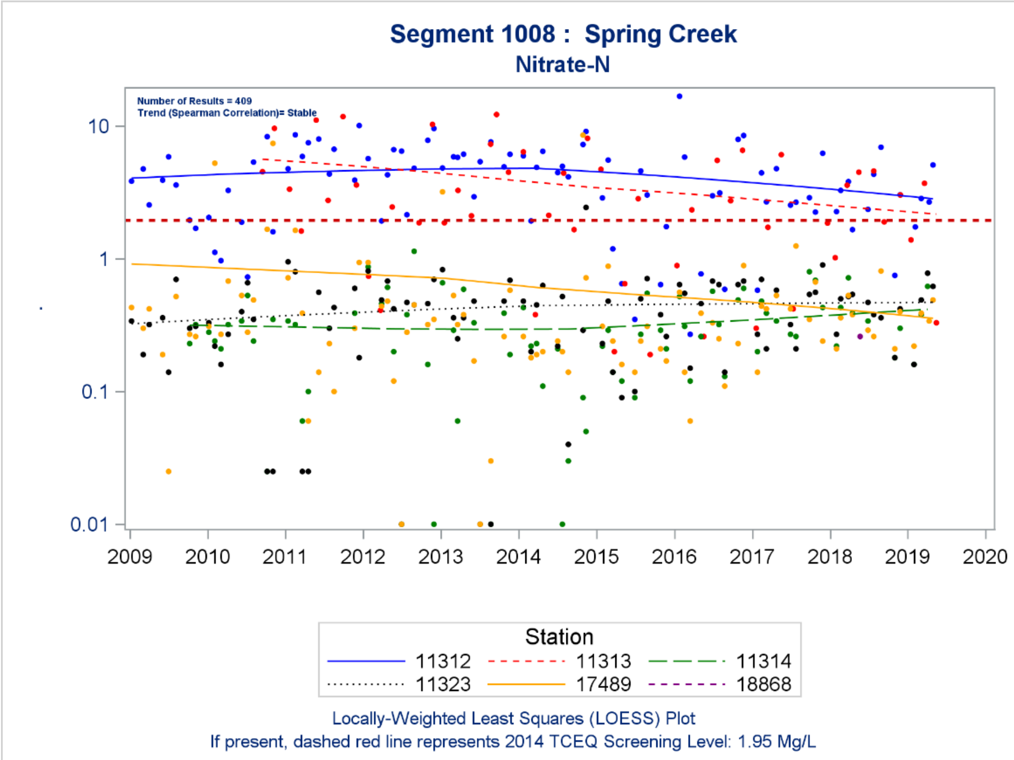
Segment 1008 : Spring Creek
Dissolved Oxygen (grab)
Number of Results = 470
Trend (Spearman Correlation)= Increasing
18
14
10
8
6
4
2
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
11312
11313
11314
11315
11323
17489
18868
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 Water Quality Standard: 5.0 mg/L

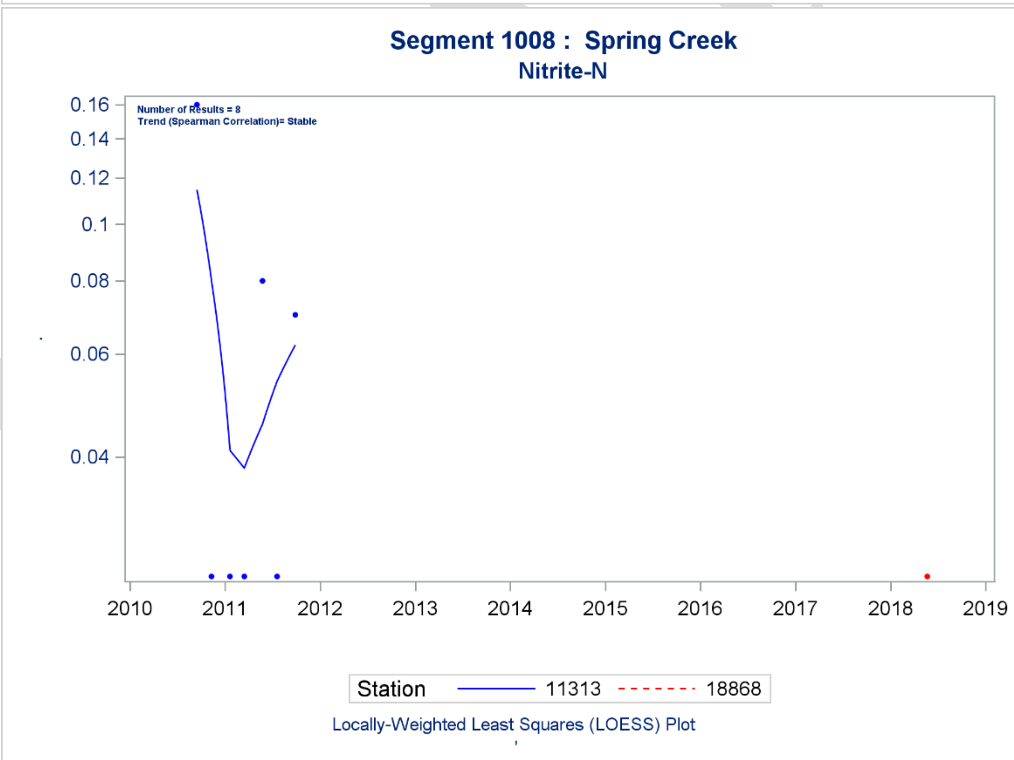


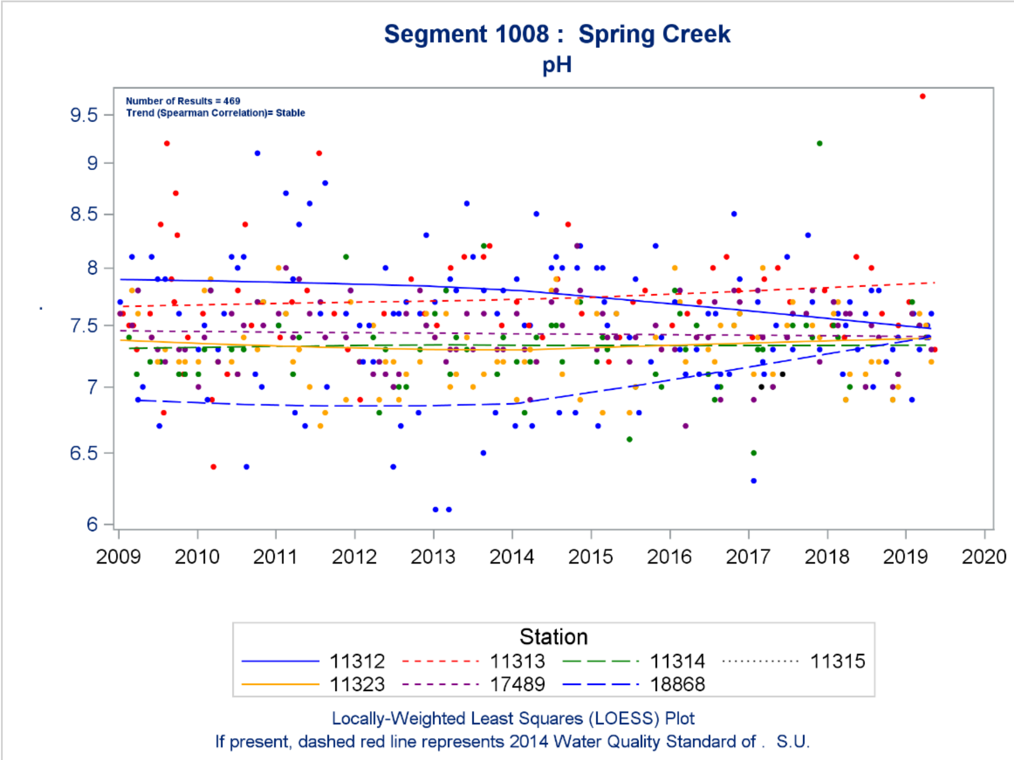
Segment 1008 : Spring Creek
E. Coli
Number of Results = 450
Trend (Spearman Correlation)= Stable
100000
10000
100
100
10
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
11312
11313
11314
11323
17489
18868
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 Water Quality Standard: 126 MPN/100 mL

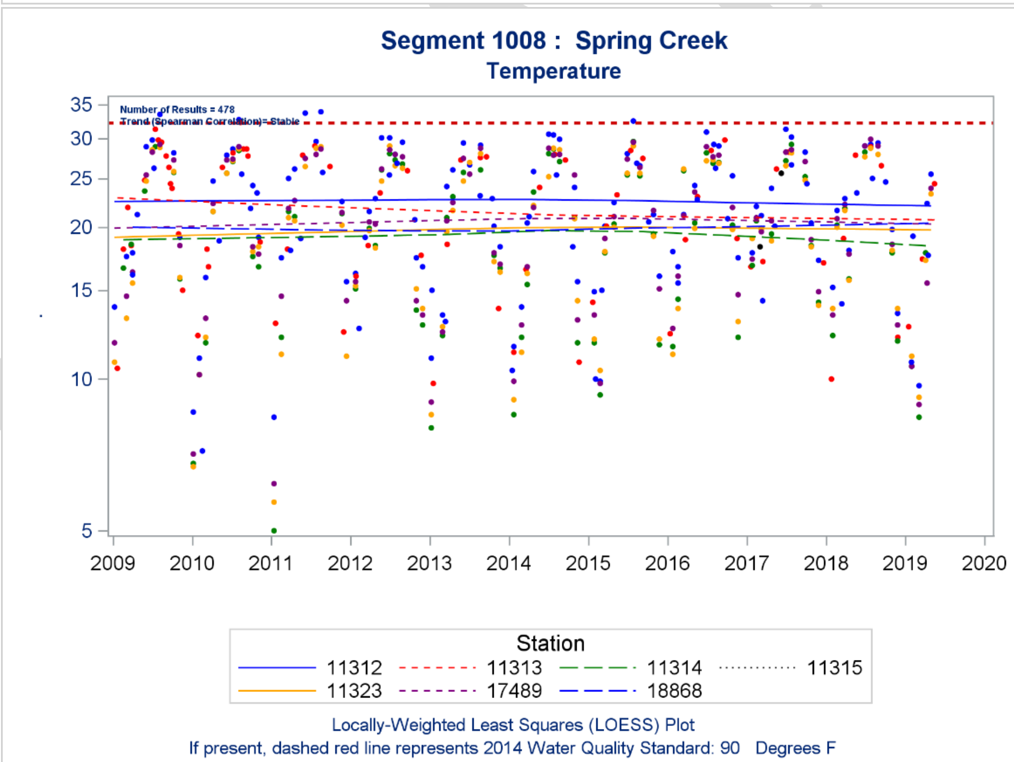

Segment 1008 : Spring Creek
Instantaneous Flow
Number of Results = 191
Trend (Spearman Correlation)= Stable
6000
4000
2000
0
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
11312
11313
11314
11315
11323
18868
Locally-Weighted Least Squares (LOESS) Plot

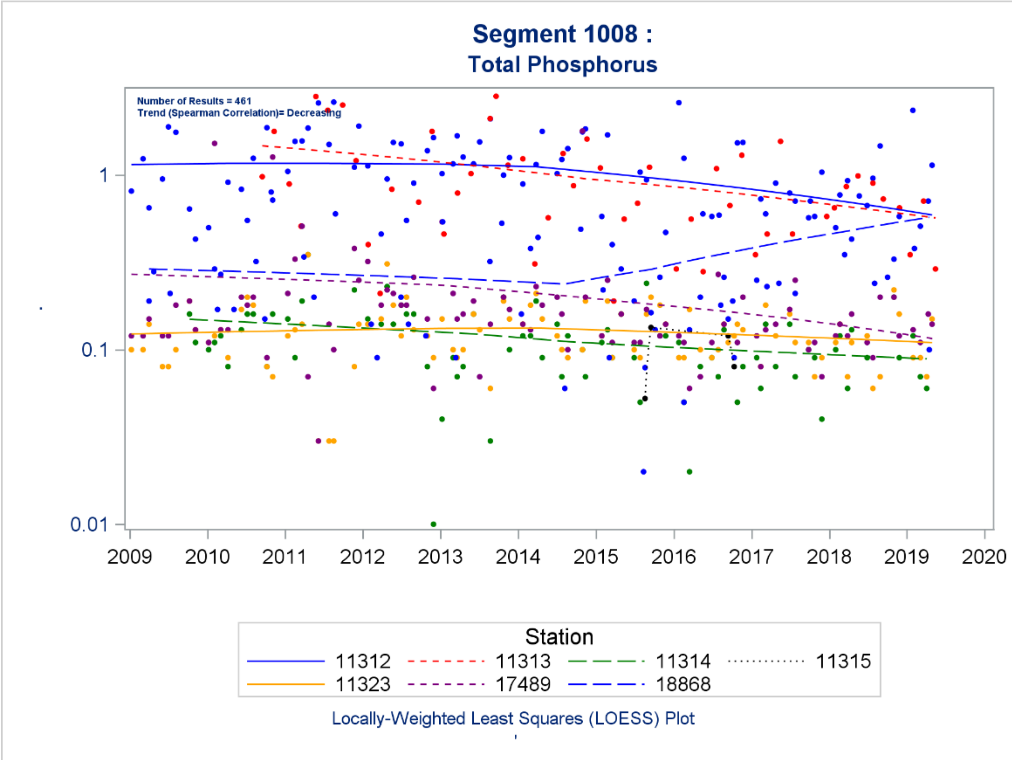

Segment 1008 : Spring Creek
Nitrate+nitrite
Number of Results = 52
Trend (Spearman Correlation)= Increasing
1
0.1
0.01
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
11315
11323
18868
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 TCEQ Screening Level: 1.95 Mg/L

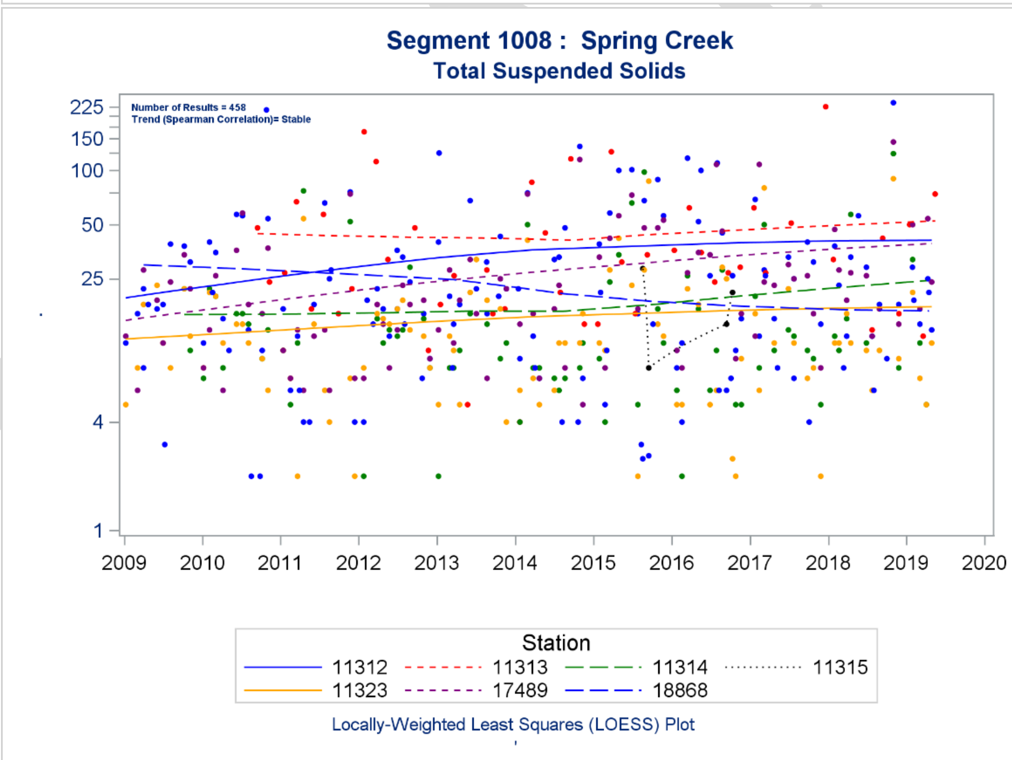

Segment 1008 : Spring Creek
Nitrate-N
Number of Results = 409
Trend (Spearman Correlation)= Stable
10
1
0.1
0.01
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
11312
11313
11314
11323
17489
18868
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 TCEQ Screening Level: 1.95 Mg/L

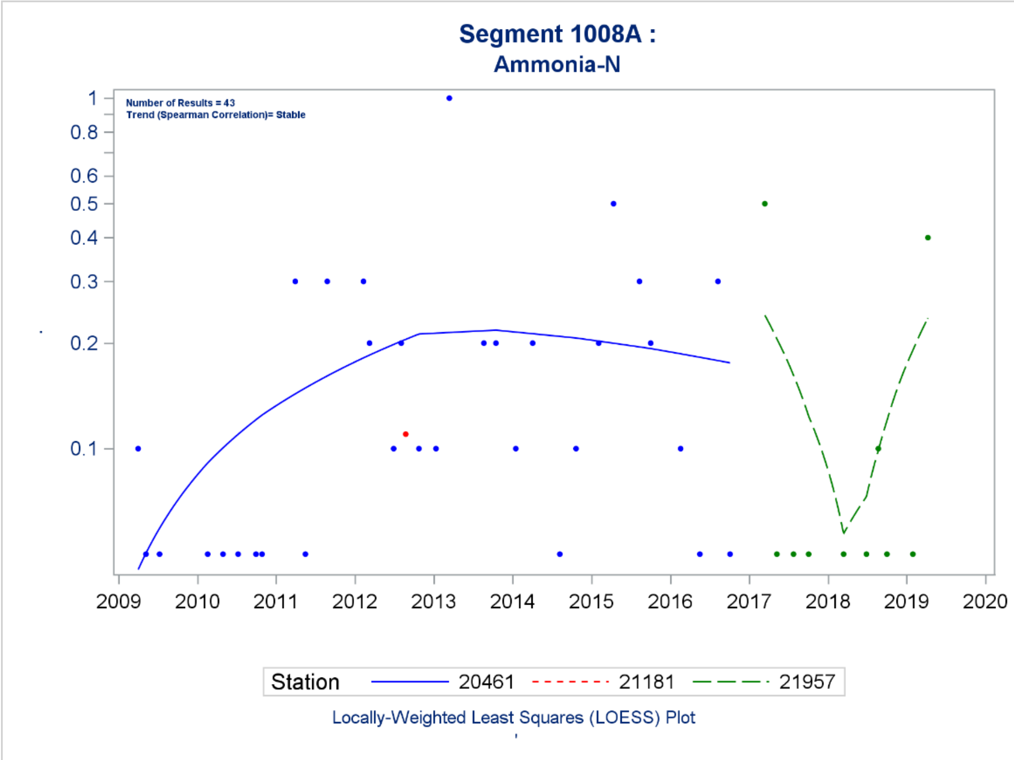

Segment 1008 : Spring Creek
Nitrite-N
Number of Results = 8
Trend (Spearman Correlation)= Stable
0.16
0.14
0.12
0.1
0.08
0.06
0.04
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
Station
11313
18868
Locally-Weighted Least Squares (LOESS) Plot

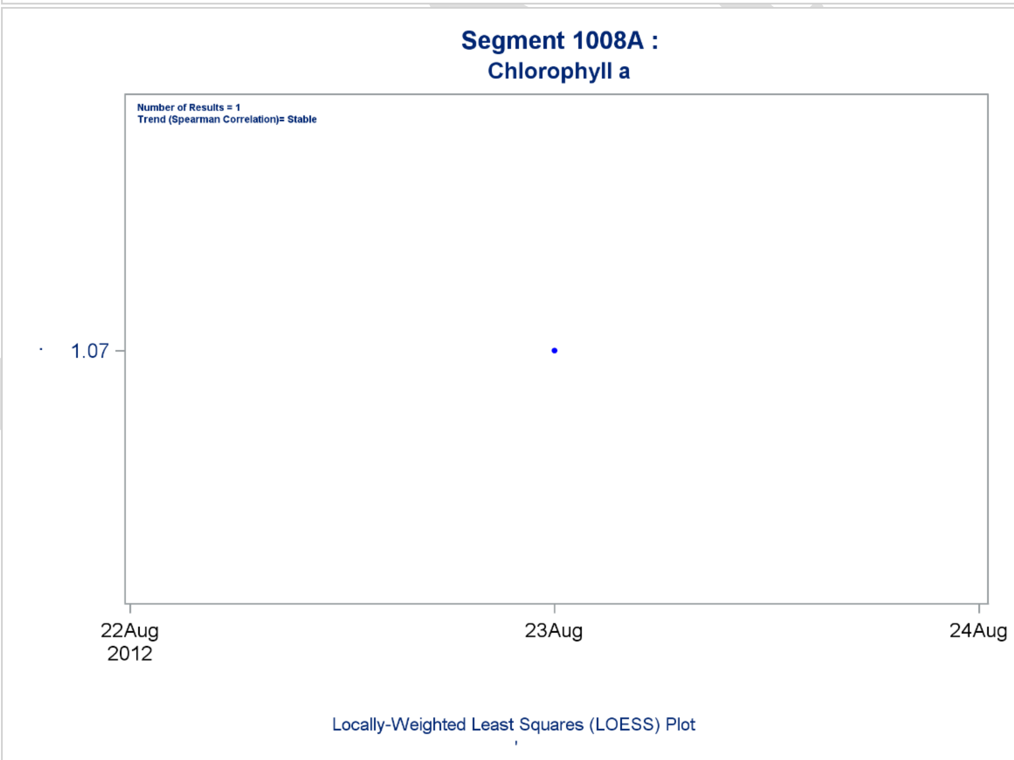

Segment 1008 : Spring Creek
pH
Number of Results = 469
Trend (Spearman Correlation)= Stable
9.5
9
8.5
8
7.5
7
6.5
6
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
11312
11313
11314
11315
11323
17489
18868
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 Water Quality Standard of . S.U.

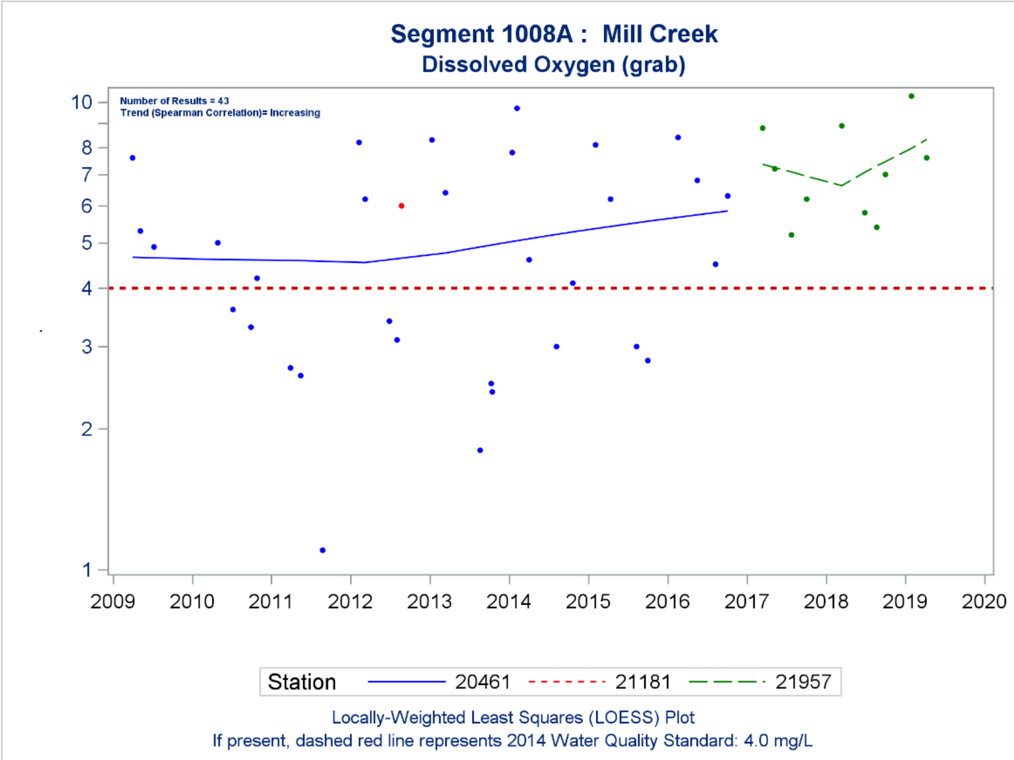

Segment 1008 : Spring Creek
Temperature
Number of Results = 478
Trend (Spearman Correlation)= Stable
35
30
25
20
15
10
5
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
11312
11313
11314
11315
11323
17489
18868
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 Water Quality Standard: 90 Degrees F

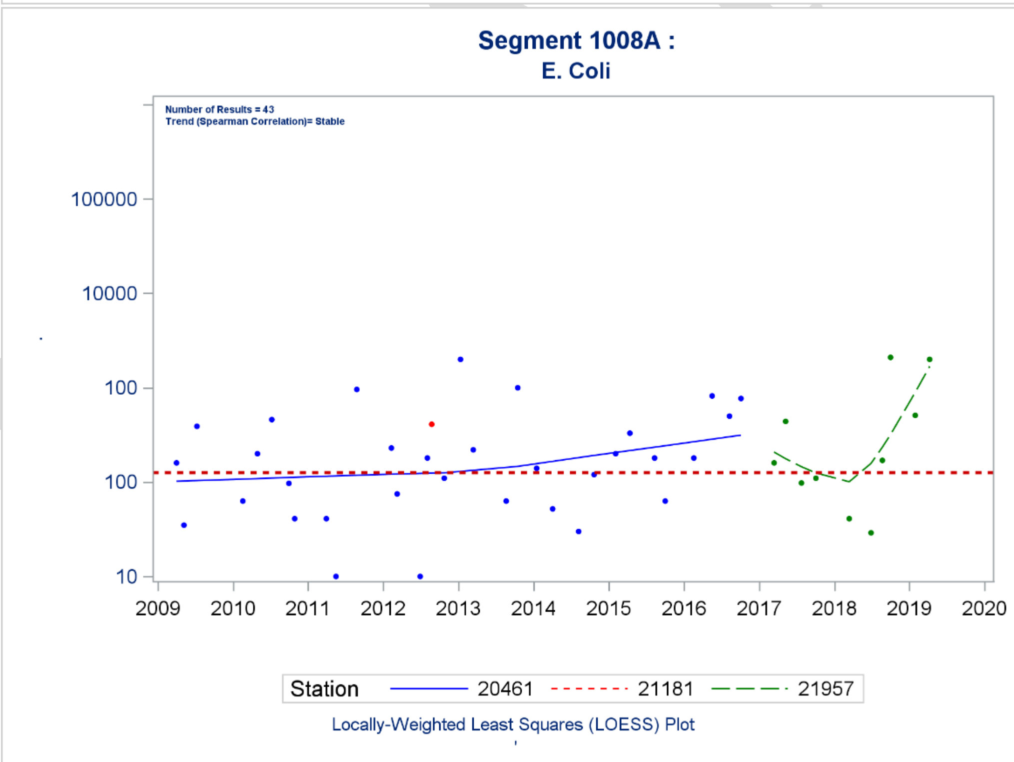

Segment 1008 :
Total Phosphorus
Number of Results = 461
Trend (Spearman Correlation)= Decreasing
1
0.1
0.01
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
11312
11313
11314
11315
11323
17489
18868
Locally-Weighted Least Squares (LOESS) Plot

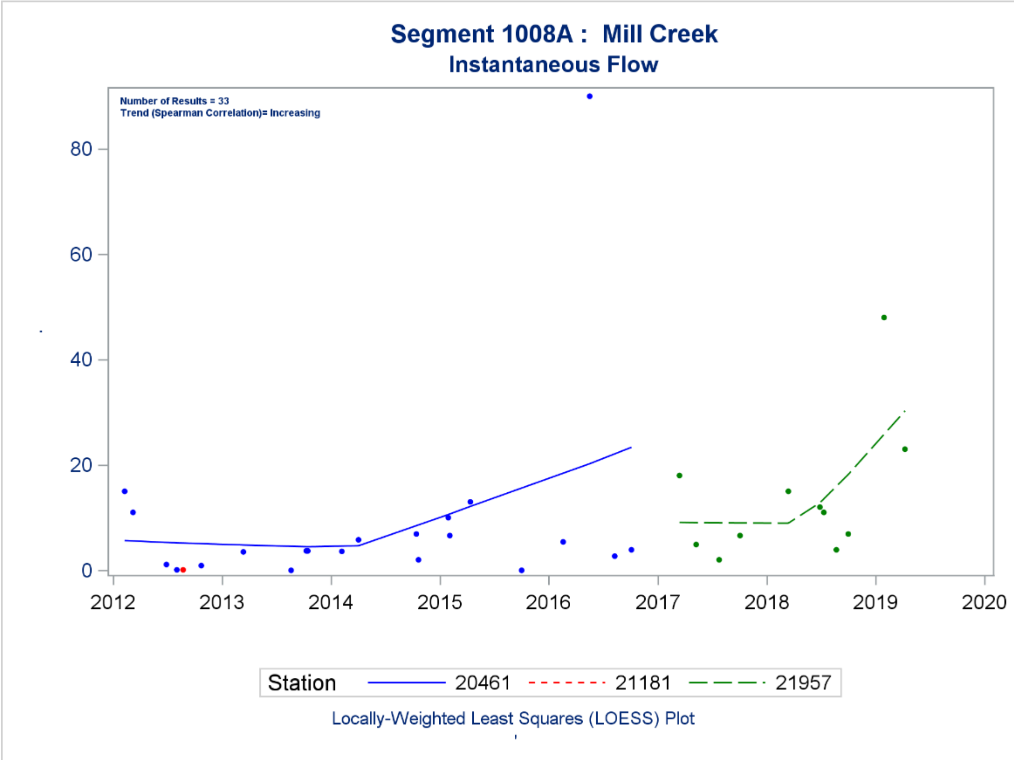

Segment 1008 : Spring Creek
Total Suspended Solids
Number of Results = 458
Trend (Spearman Correlation)= Stable
225
150
100
50
25
4
1
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
11312
11313
11314
11315
11323
17489
18868
Locally-Weighted Least Squares (LOESS) Plot


Segment 1008A :
Ammonia-N
Number of Results = 43
Trend (Spearman Correlation)= Stable
1
0.8
0.6
0.5
0.4
0.3
0.2
0.1
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
20461
21181
21957
Locally-Weighted Least Squares (LOESS) Plot

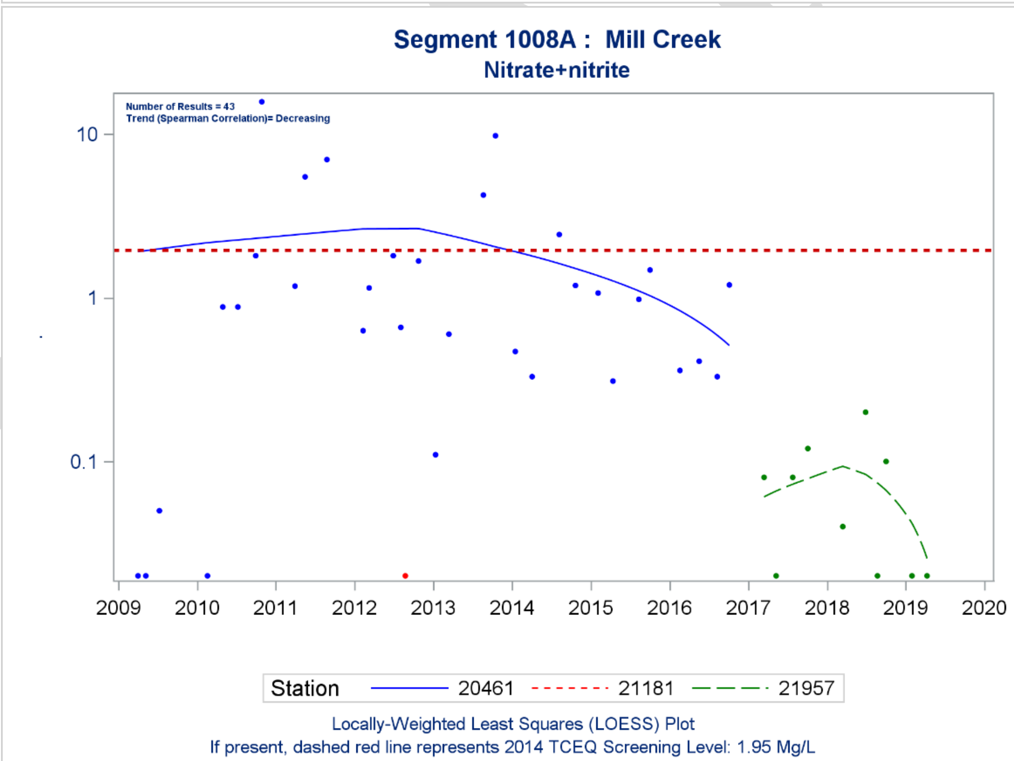

Segment 1008A :
Chlorophyll a
Number of Results = 1
Trend (Spearman Correlation)= Stable
1.07
22Aug
2012
23Aug
24Aug
Locally-Weighted Least Squares (LOESS) Plot


Segment 1008A : Mill Creek
Dissolved Oxygen (grab)
Number of Results = 43
Trend (Spearman Correlation)= Increasing
10
8
7
6
5
4
3
2
1
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
20461
21181
21957
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 Water Quality Standard: 4.0 mg/L

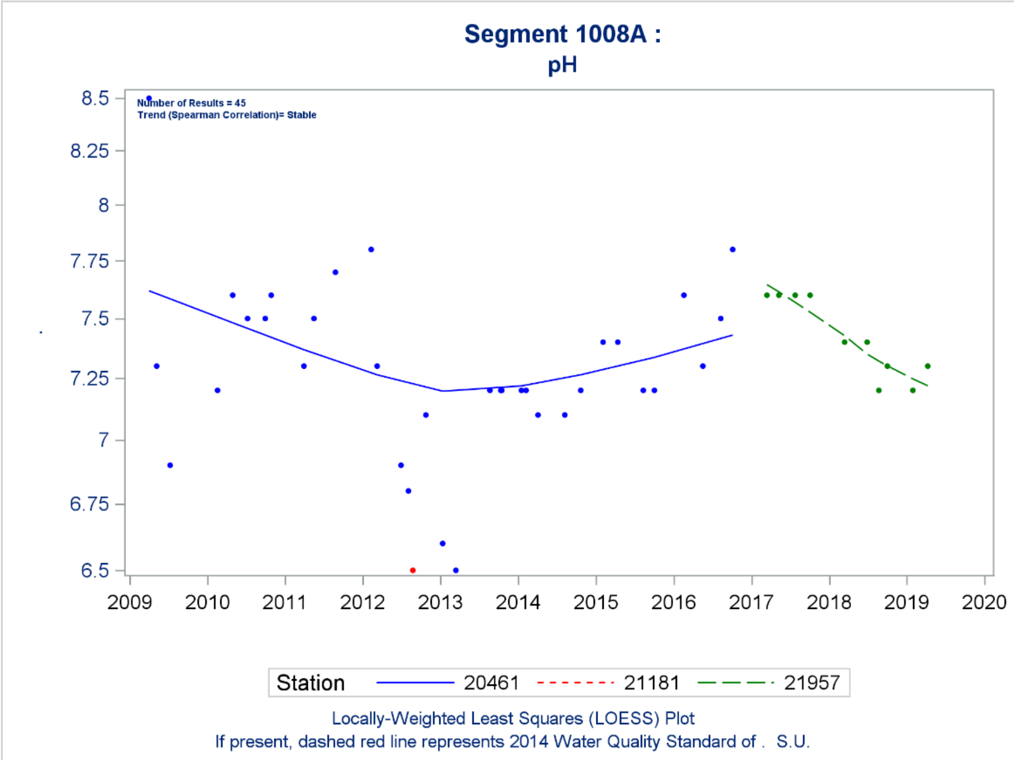

Segment 1008A :
E. Coli
Number of Results = 43
Trend (Spearman Correlation)= Stable
100000
10000
100
100
10
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
20461
21181
21957
Locally-Weighted Least Squares (LOESS) Plot

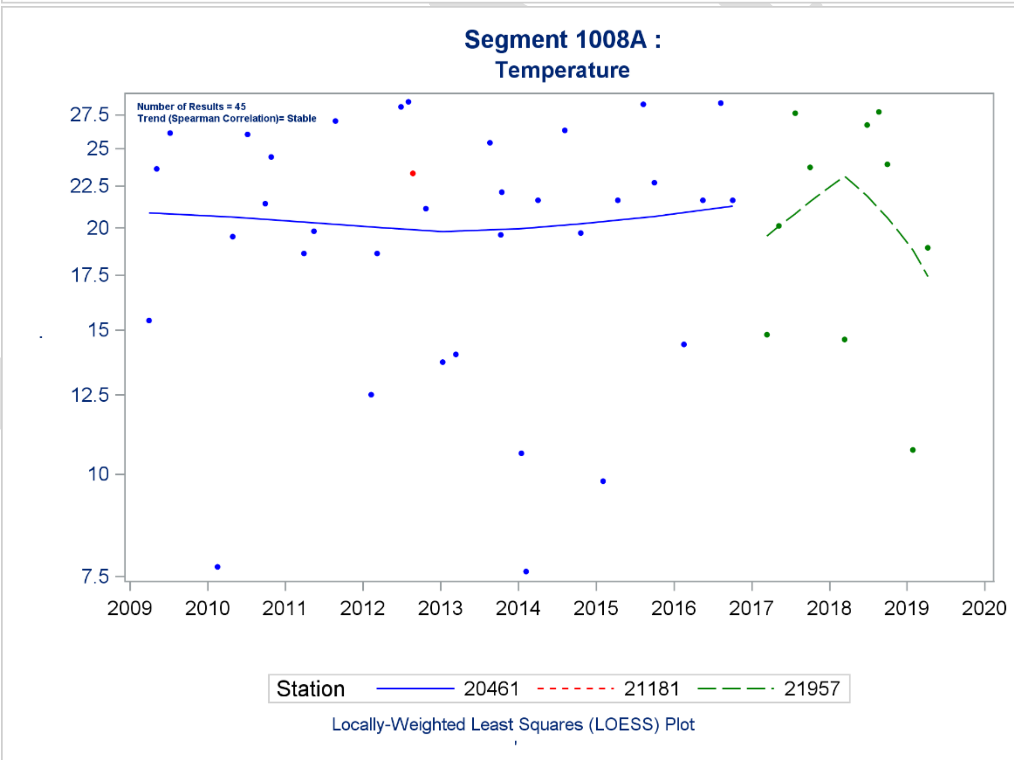


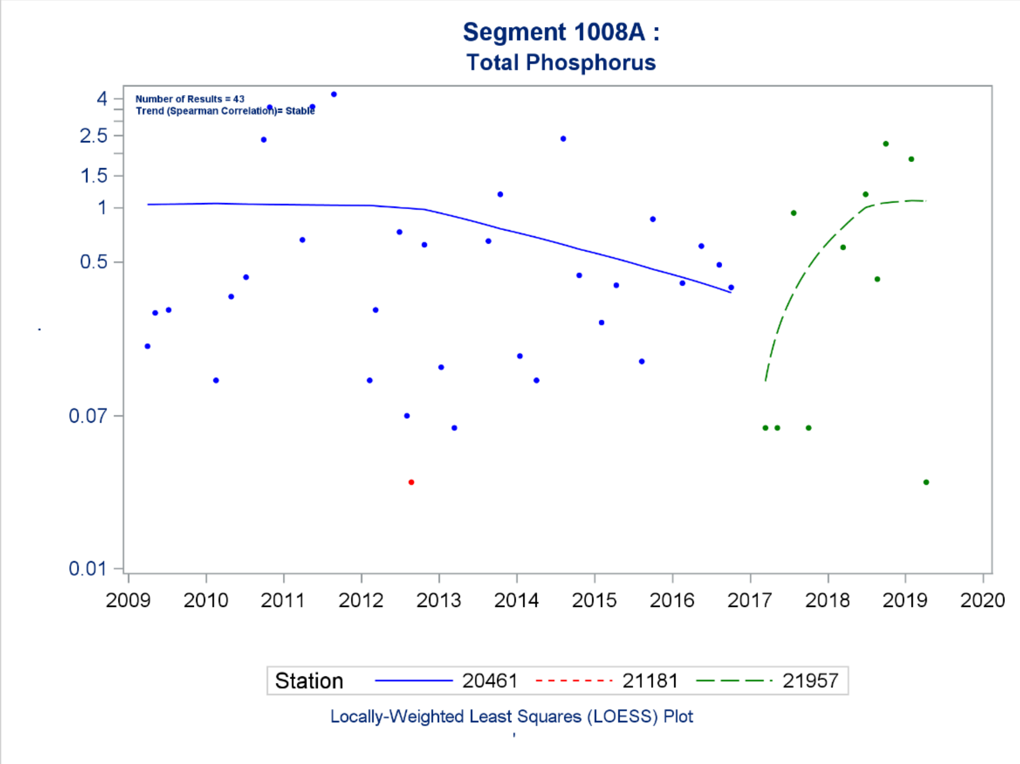
Segment 1008A : Mill Creek
Instantaneous Flow
Number of Results = 33
Trend (Spearman Correlation)= Increasing
80
60
40
20
0
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
20461
21181
21957
Locally-Weighted Least Squares (LOESS) Plot

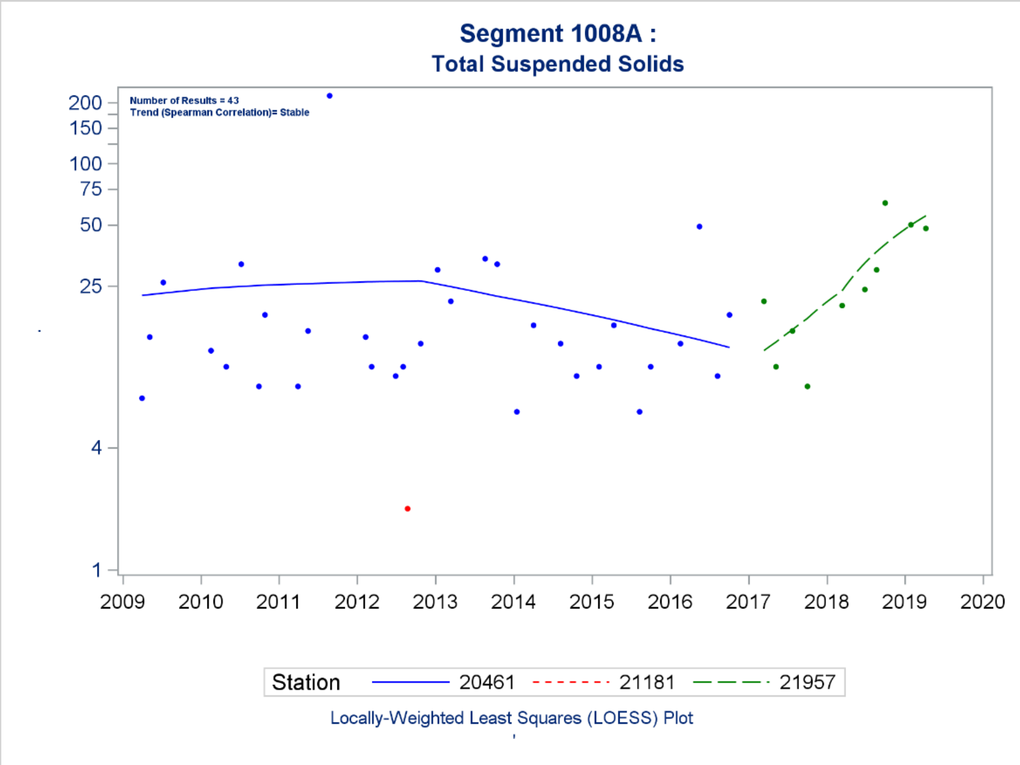


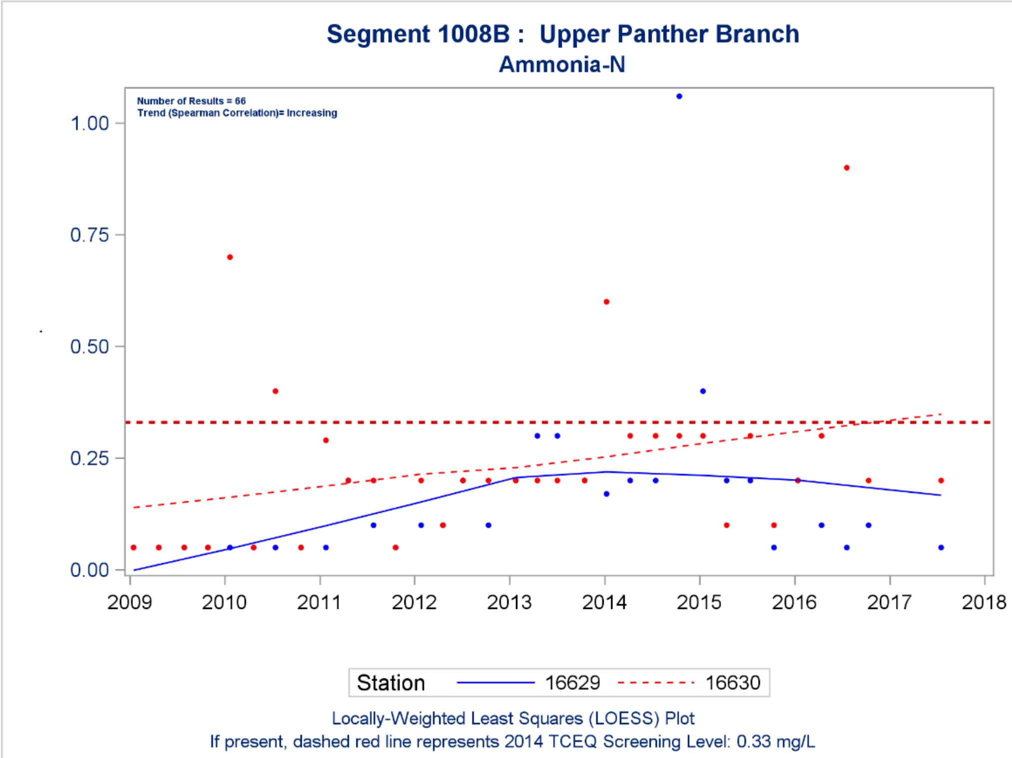
Segment 1008A : Mill Creek
Nitrate+nitrite
Number of Results = 43
Trend (Spearman Correlation)= Decreasing
10
1
0.1
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
20461
21181
21957
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 TCEQ Screening Level: 1.95 Mg/L

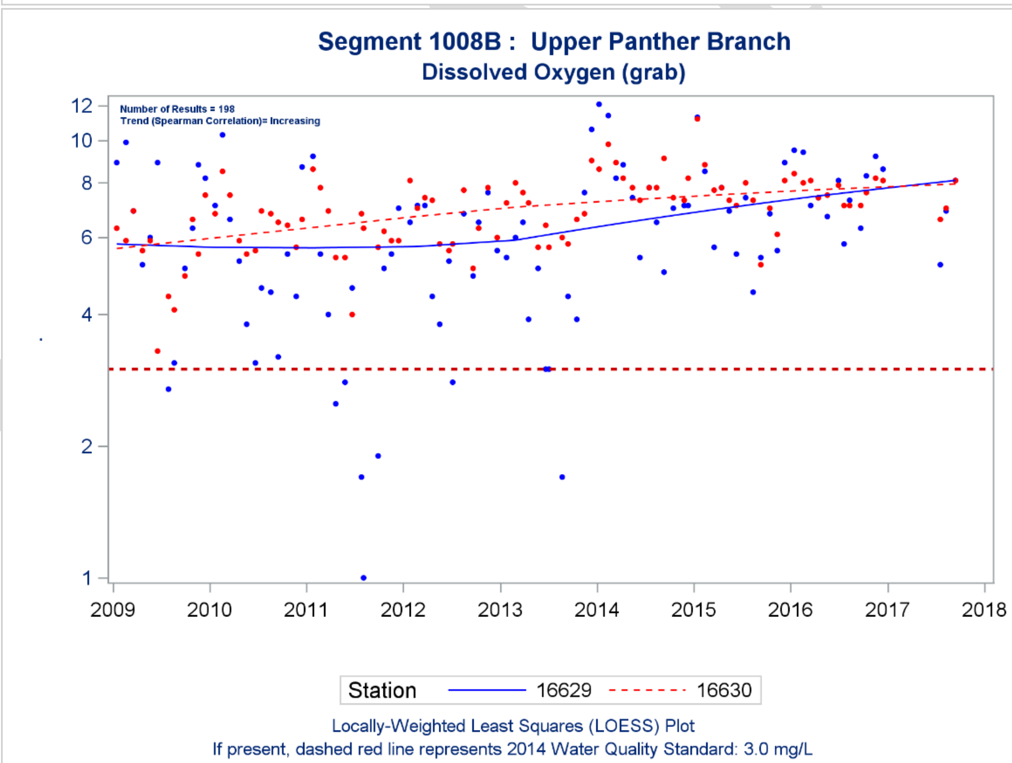

Segment 1008A :
pH
Number of Results = 45
Trend (Spearman Correlation)= Stable
8.5
8.25
8
7.75
7.5
7.25
7
6.75
6.5
2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020
Station 20461 21181 21957
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 Water Quality Standard of . S.U.

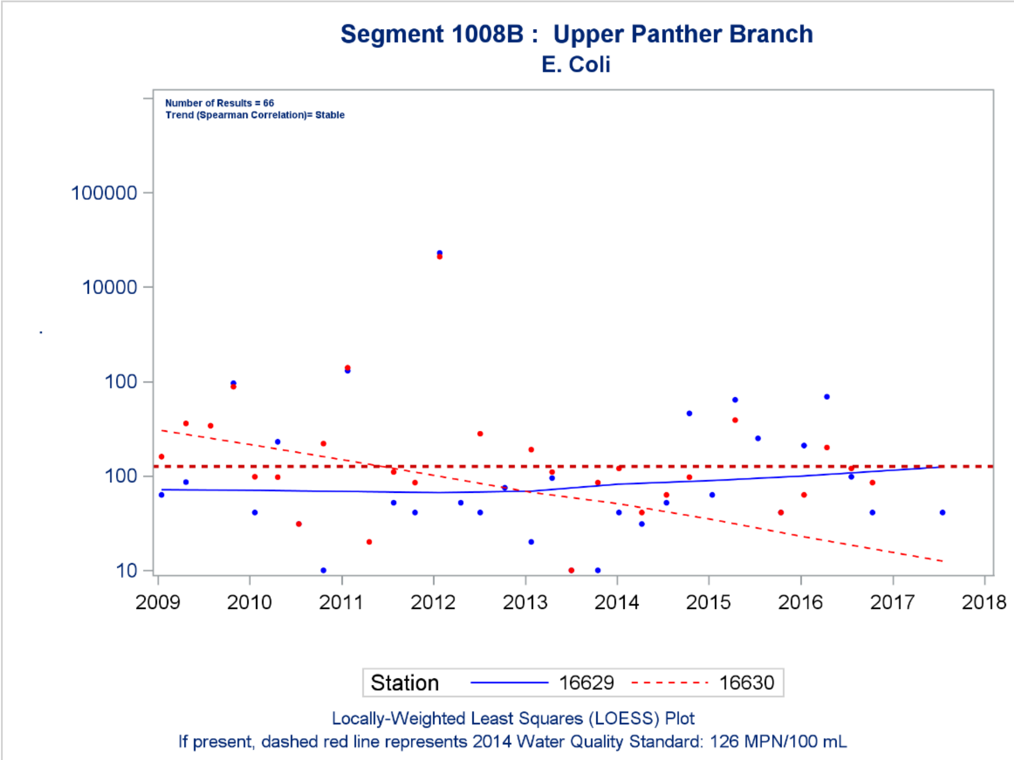

Segment 1008A :
Temperature
Number of Results = 45
Trend (Spearman Correlation)= Stable
27.5
25
22.5
20
17.5
15
12.5
10
7.5
2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020
Station 20461 21181 21957
Locally-Weighted Least Squares (LOESS) Plot

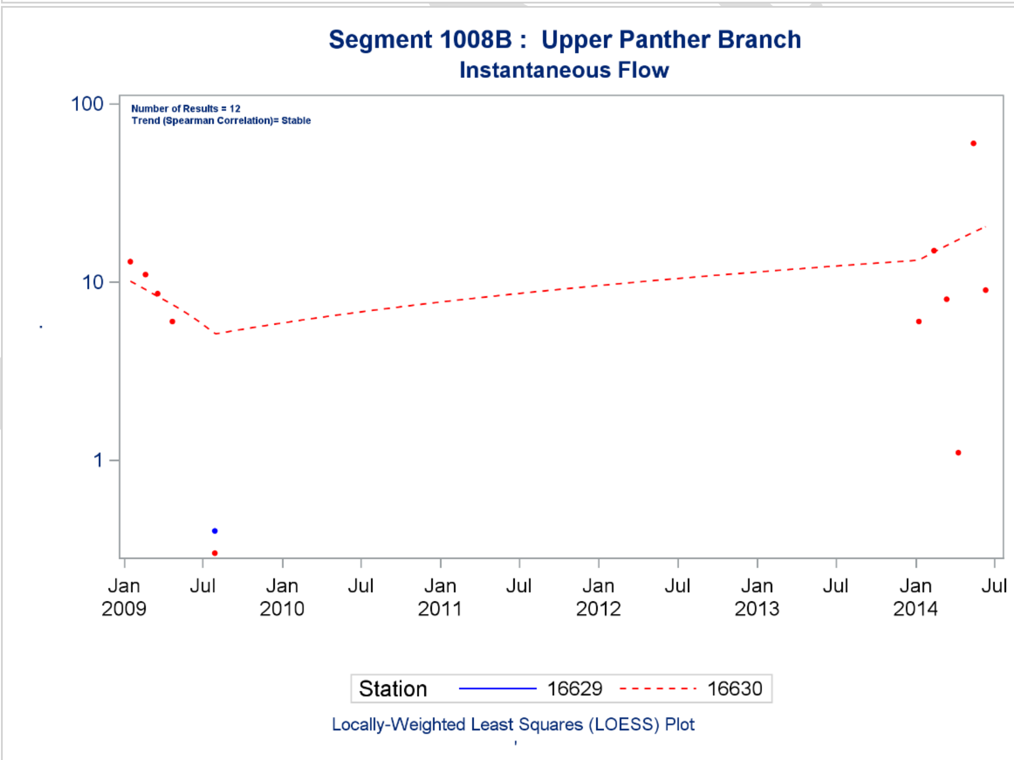

Segment 1008A :
Total Phosphorus
Number of Results = 43
Trend (Spearman Correlation)= Stable
4
2.5
1.5
1
0.5
0.07
0.01
2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020
Station 20461 21181 21957
Locally-Weighted Least Squares (LOESS) Plot

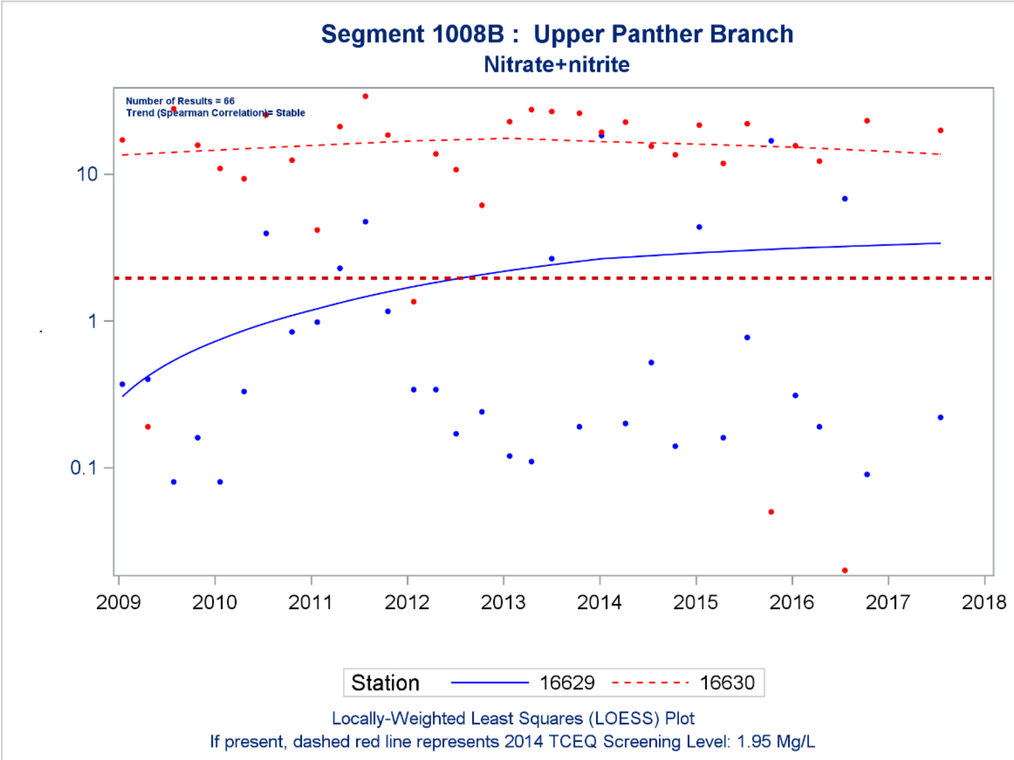

Segment 1008A :
Total Suspended Solids
Number of Results = 43
Trend (Spearman Correlation)= Stable
200
150
100
75
50
25
4
1
2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020
Station 20461 21181 21957
Locally-Weighted Least Squares (LOESS) Plot

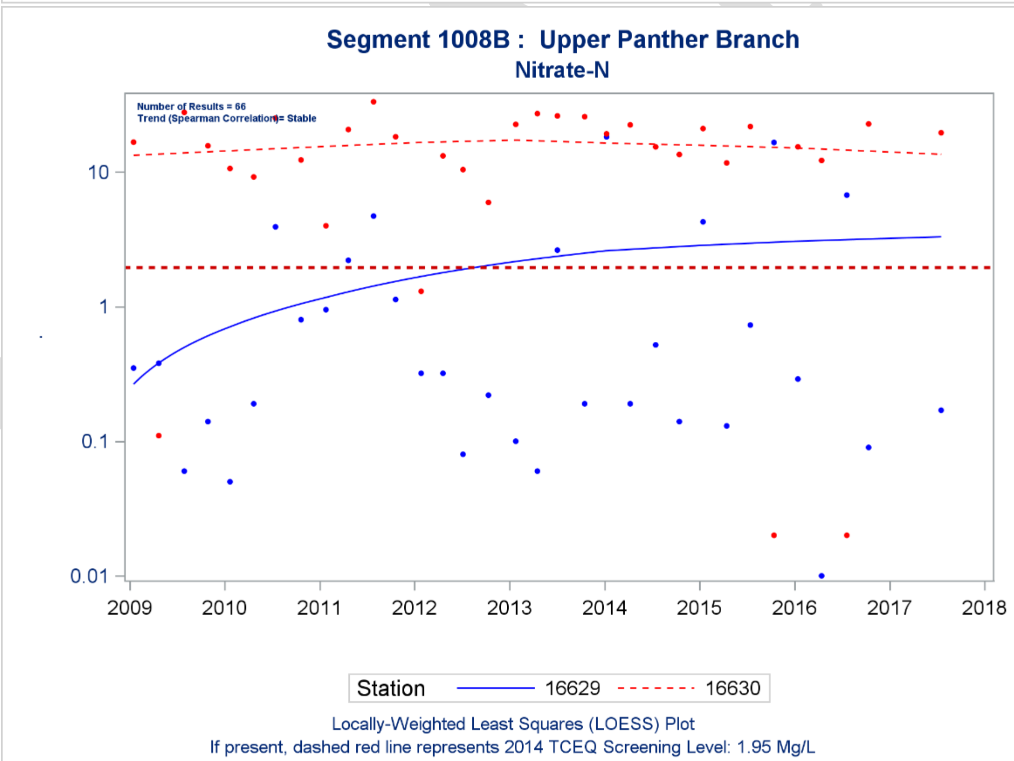

Segment 1008B : Upper Panther Branch
Ammonia-N
Number of Results = 66
Trend (Spearman Correlation)= Increasing
1.00
0.75
0.50
0.25
0.00
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Station
16629
16630
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 TCEQ Screening Level: 0.33 mg/L

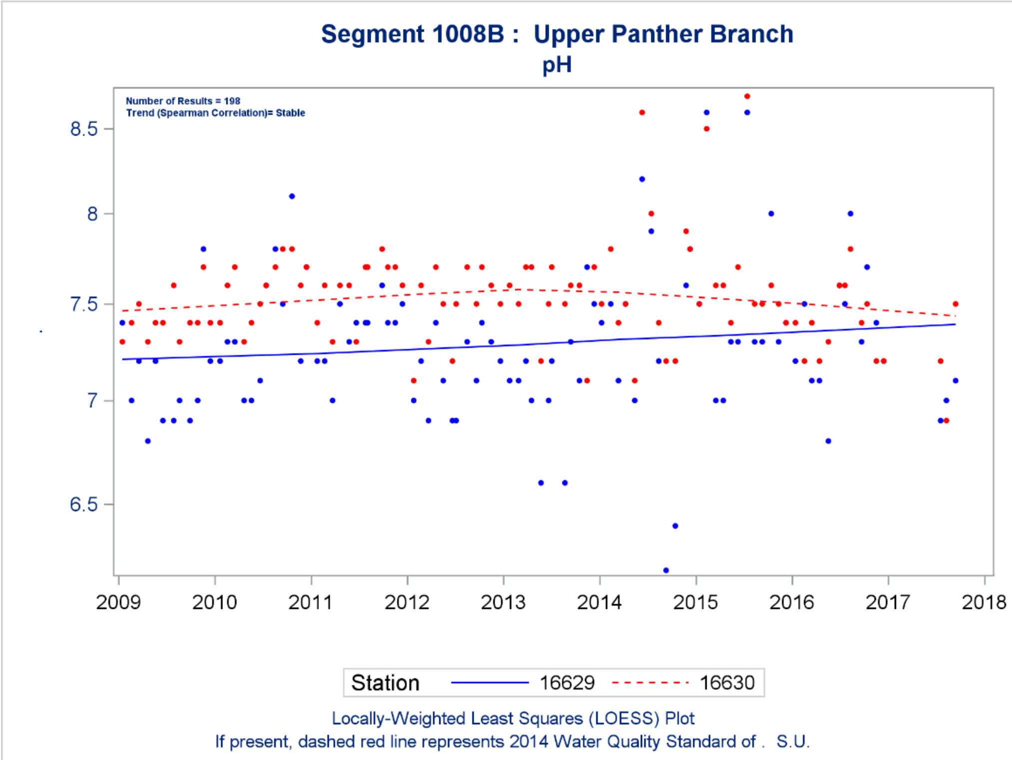

Segment 1008B : Upper Panther Branch
Dissolved Oxygen (grab)
Number of Results = 198
Trend (Spearman Correlation)= Increasing
12
10
8
6
4
2
1
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Station
16629
16630
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 Water Quality Standard: 3.0 mg/L

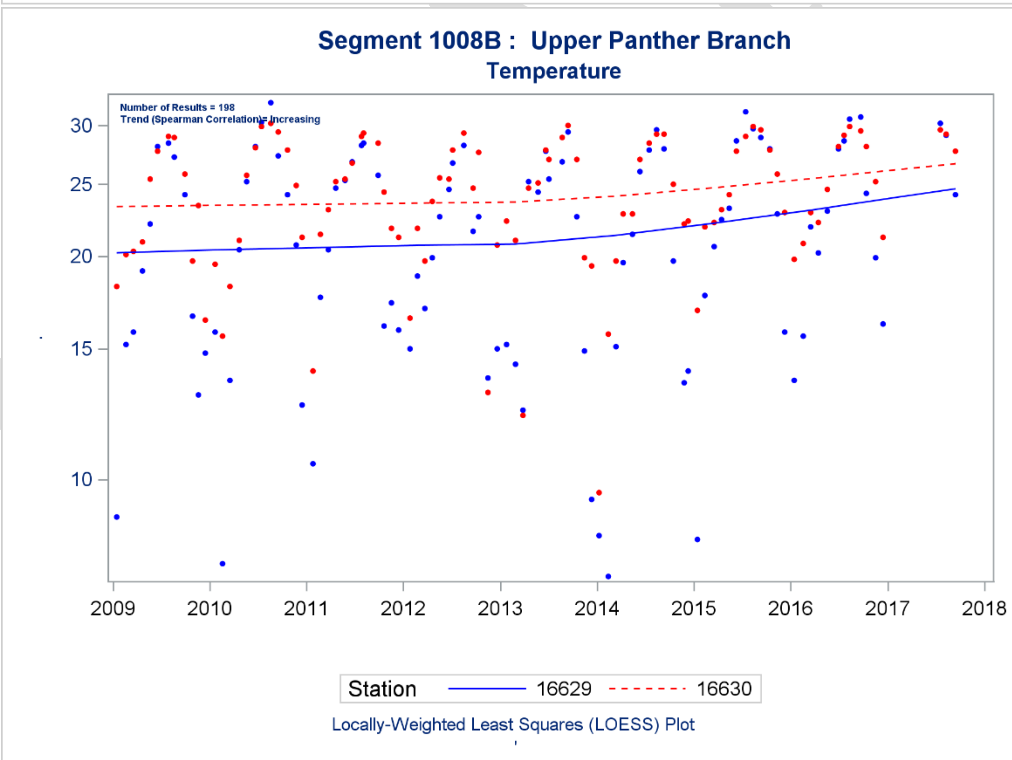

Segment 1008B : Upper Panther Branch
E. Coli
Number of Results = 66
Trend (Spearman Correlation)= Stable
100000
10000
100
100
10
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Station
16629
16630
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 Water Quality Standard: 126 MPN/100 mL

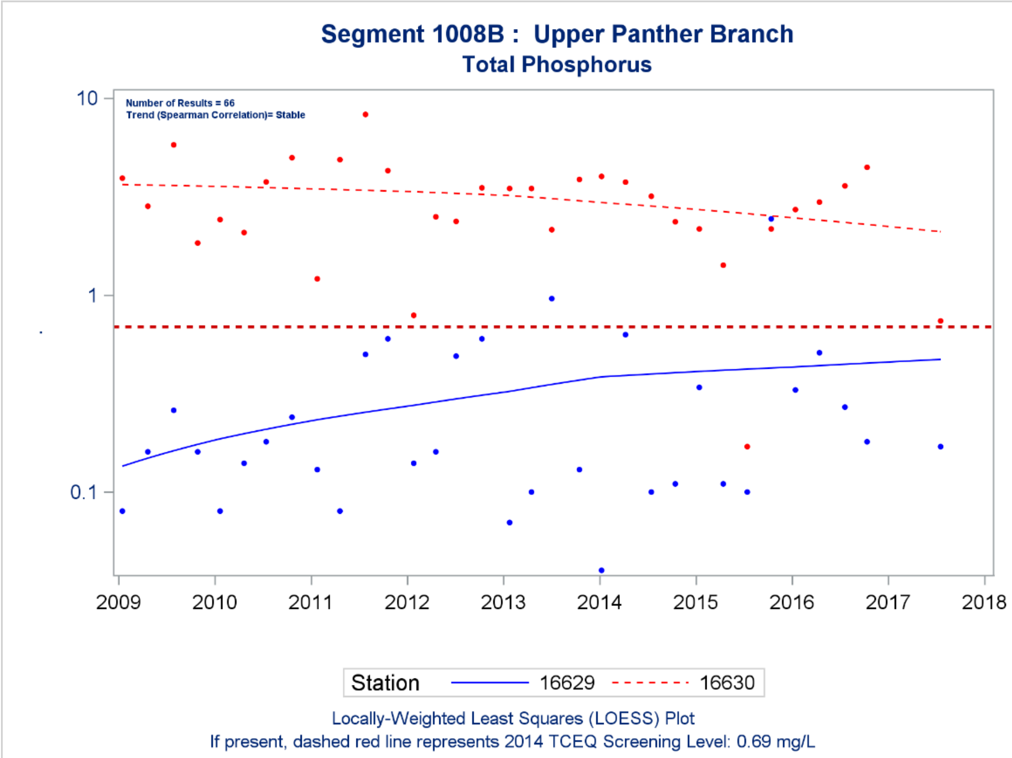

Segment 1008B : Upper Panther Branch
Instantaneous Flow
Number of Results = 12
Trend (Spearman Correlation)= Stable
100
10
1
Jan 2009
Jul
Jan 2010
Jul
Jan 2011
Jul
Jan 2012
Jul
Jan 2013
Jul
Jan 2014
Jul
Station
16629
16630
Locally-Weighted Least Squares (LOESS) Plot

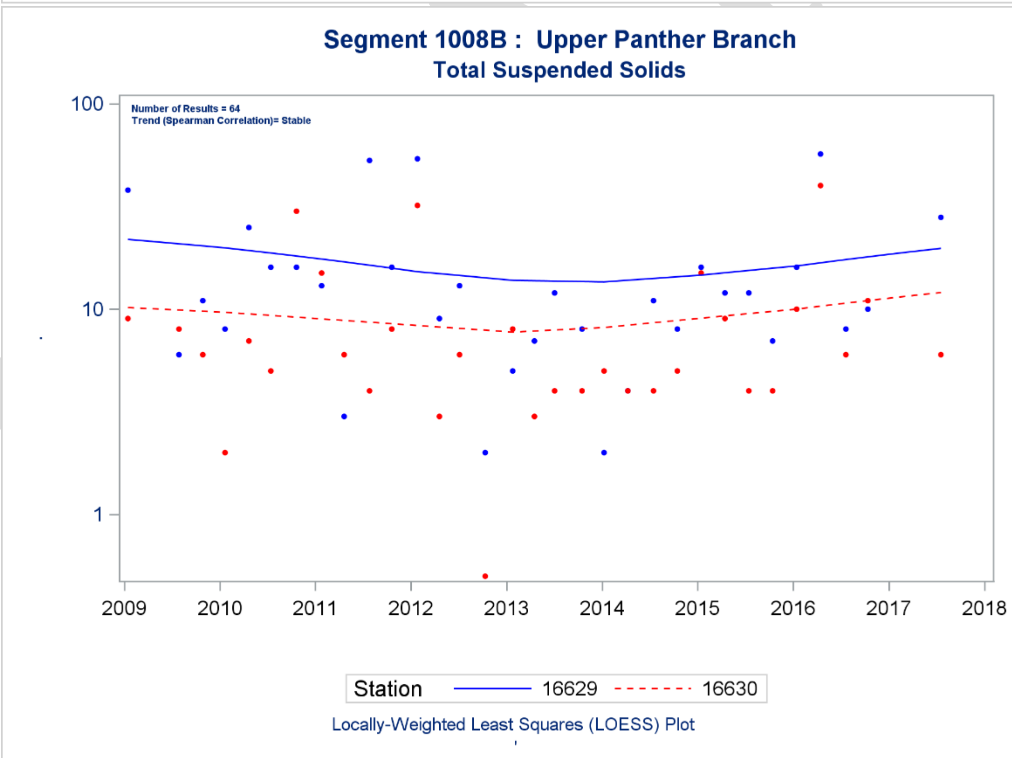

Segment 1008B : Upper Panther Branch
Nitrate+nitrite
Number of Results = 66
Trend (Spearman Correlation)= Stable
10
1
0.1
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Station
16629
16630
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 TCEQ Screening Level: 1.95 Mg/L

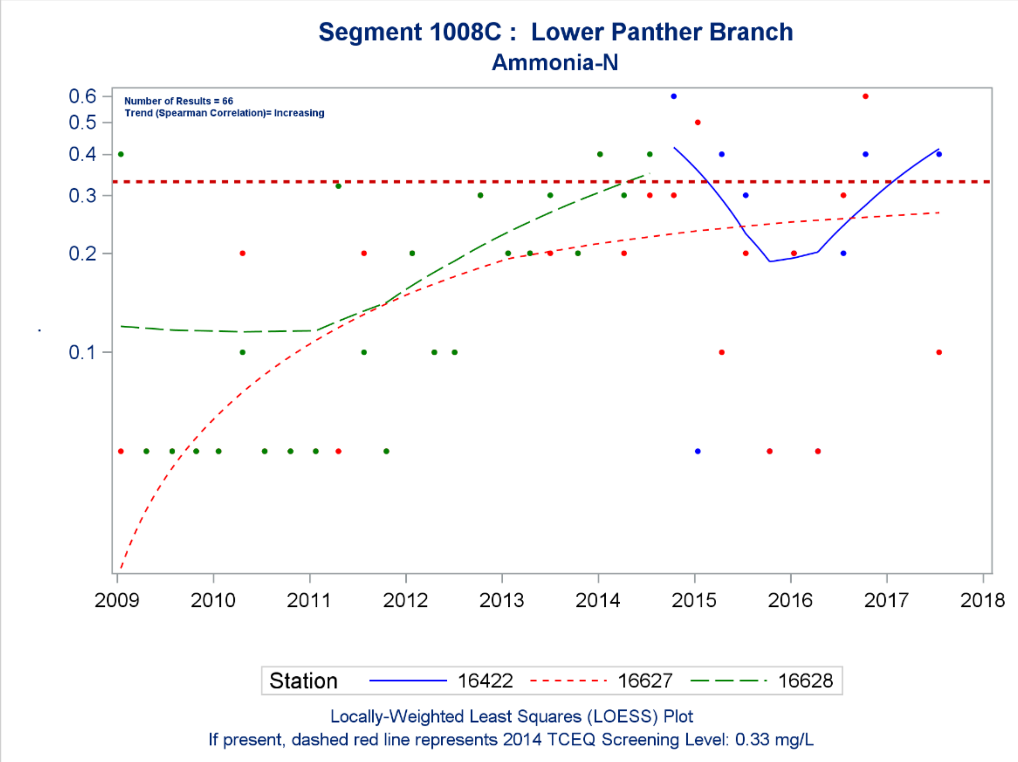

Segment 1008B : Upper Panther Branch
Nitrate-N
Number of Results = 66
Trend (Spearman Correlation)= Stable
10
1
0.1
0.01
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Station
16629
16630
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 TCEQ Screening Level: 1.95 Mg/L

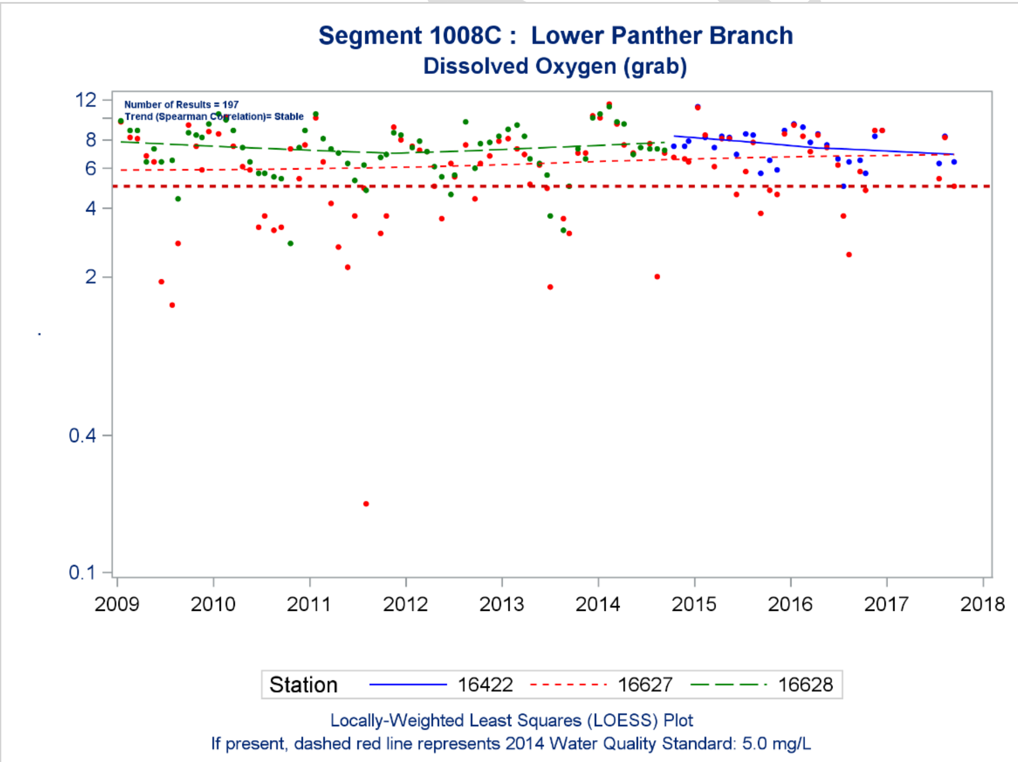

Segment 1008B : Upper Panther Branch
pH
Number of Results = 198
Trend (Spearman Correlation)= Stable
8.5
8
7.5
7
6.5
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Station
16629
16630
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 Water Quality Standard of . S.U.

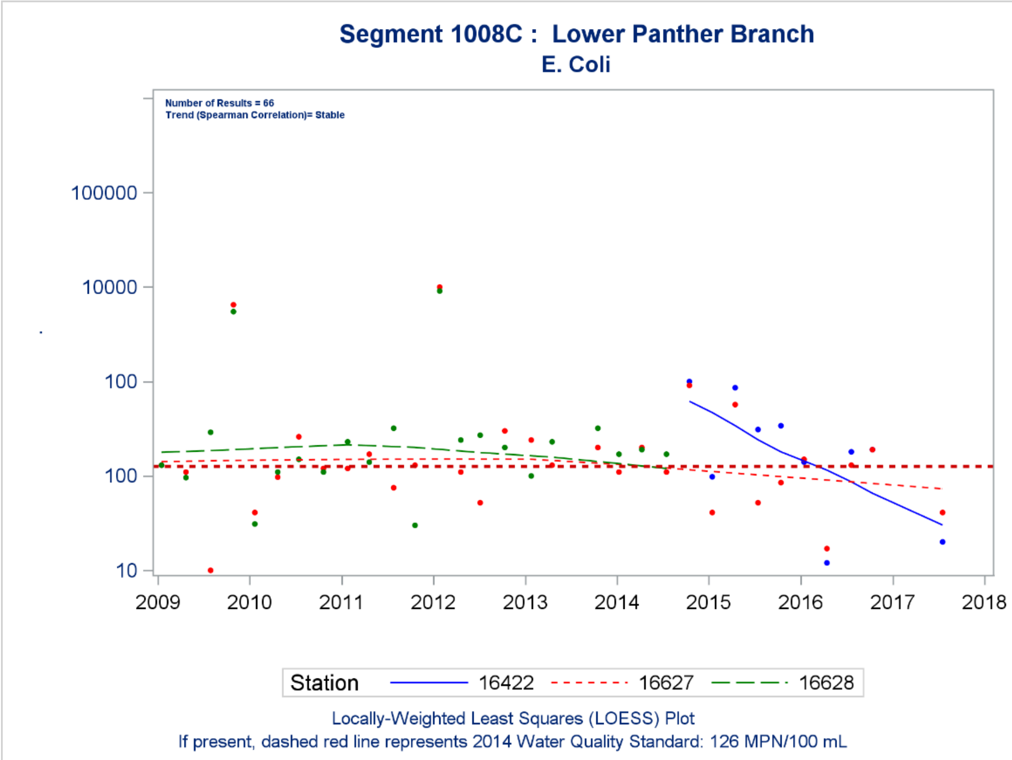

Segment 1008B : Upper Panther Branch
Temperature
Number of Results = 198
Trend (Spearman Correlation)= Increasing
30
25
20
15
10
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Station
16629
16630
Locally-Weighted Least Squares (LOESS) Plot


Segment 1008B : Upper Panther Branch
Total Phosphorus
Number of Results = 66
Trend (Spearman Correlation)= Stable
10
1
0.1
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Station
16629
16630
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 TCEQ Screening Level: 0.69 mg/L

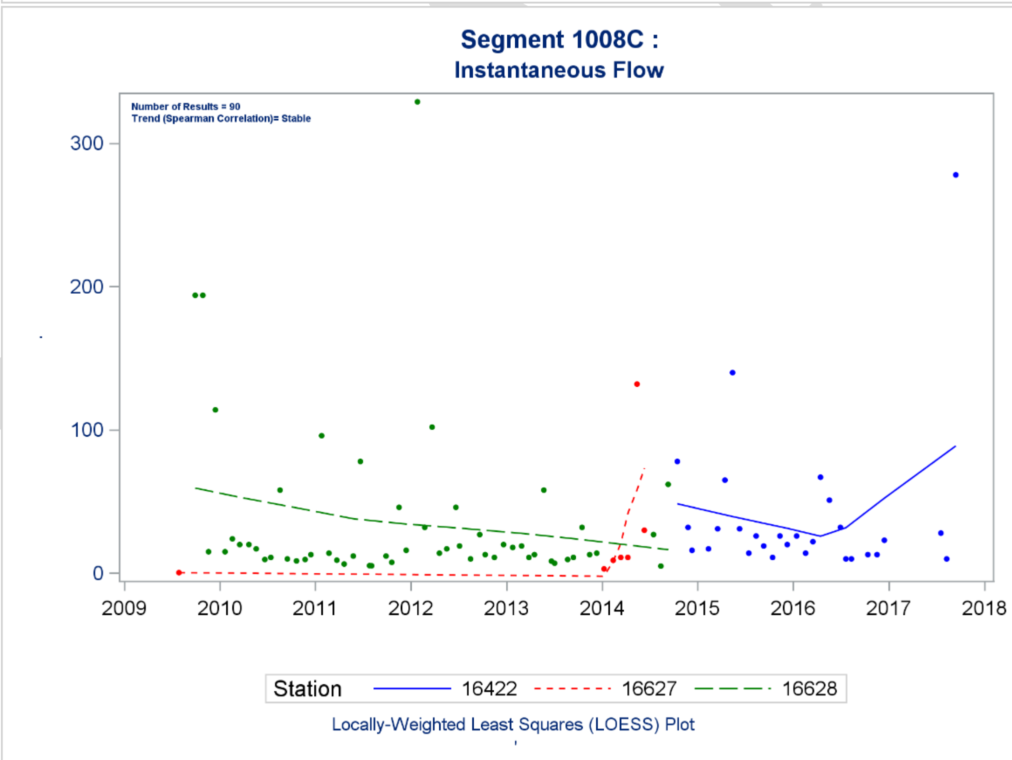

Segment 1008B : Upper Panther Branch
Total Suspended Solids
Number of Results = 64
Trend (Spearman Correlation)= Stable
100
10
1
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Station
16629
16630
Locally-Weighted Least Squares (LOESS) Plot


Segment 1008C : Lower Panther Branch
Ammonia-N
Number of Results = 66
Trend (Spearman Correlation)= Increasing
0.6
0.5
0.4
0.3
0.2
0.1
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Station
16422
16627
16628
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 TCEQ Screening Level: 0.33 mg/L

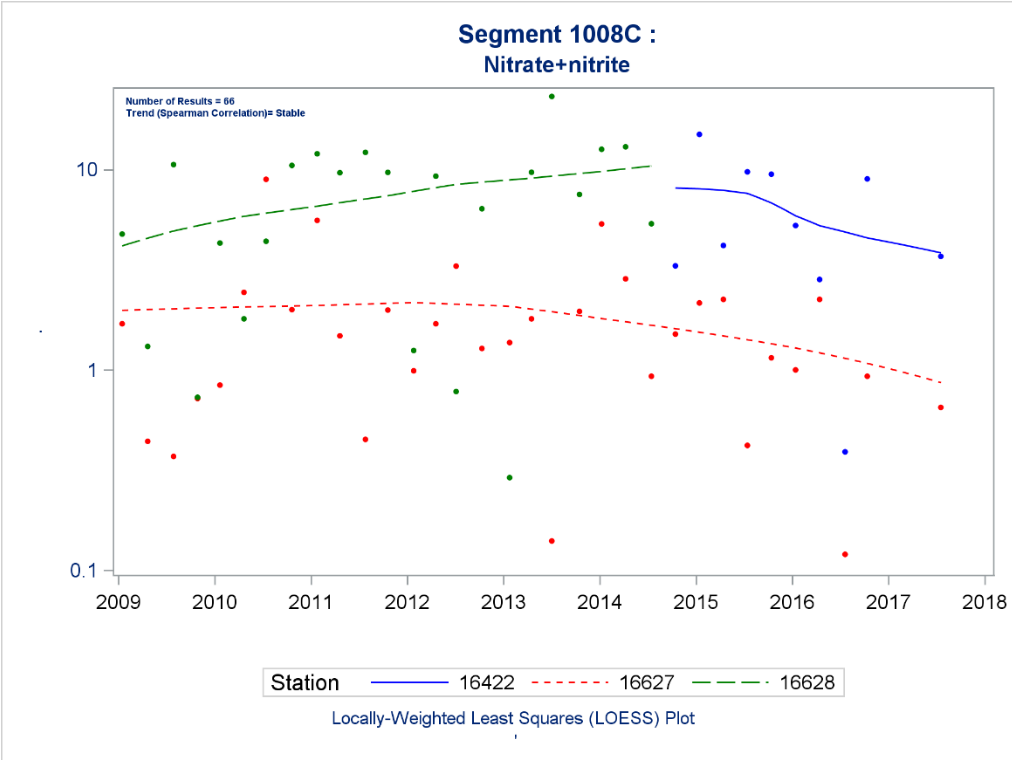

Segment 1008C : Lower Panther Branch
Dissolved Oxygen (grab)
Number of Results = 197
Trend (Spearman Correlation)= Stable
12
8
6
4
2
0.4
0.1
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Station
16422
16627
16628
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 Water Quality Standard: 5.0 mg/L

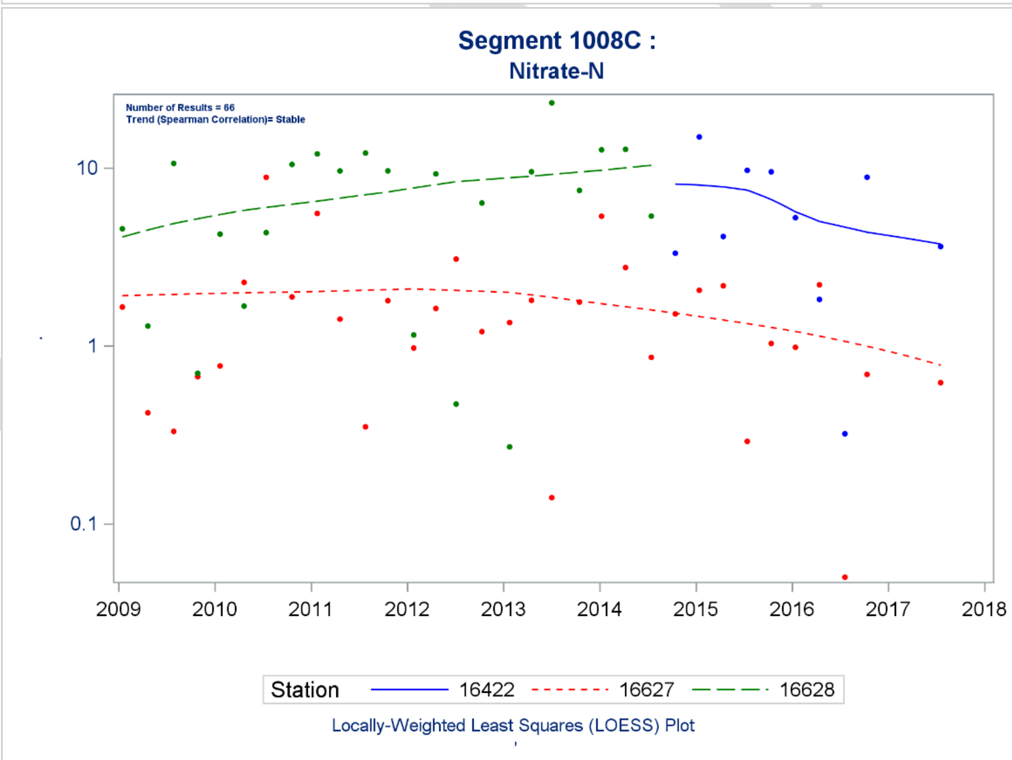


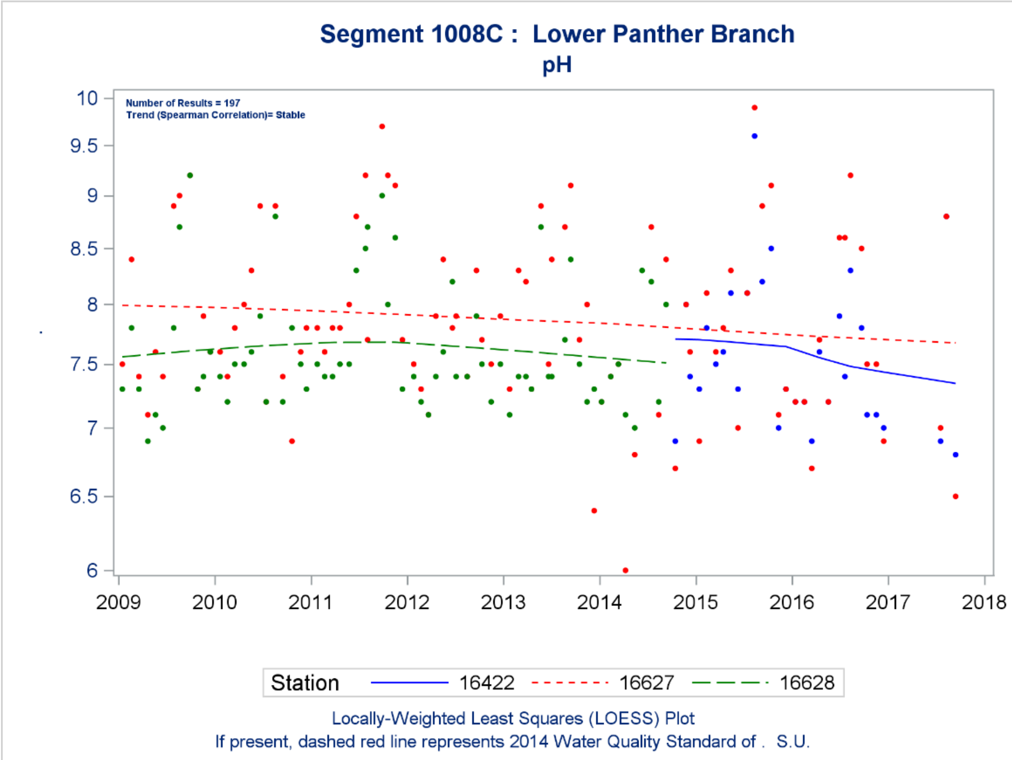
Segment 1008C : Lower Panther Branch
E. Coli
Number of Results = 66
Trend (Spearman Correlation)= Stable
100000
10000
100
100
10
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Station 16422 16627 16628
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 Water Quality Standard: 126 MPN/100 mL

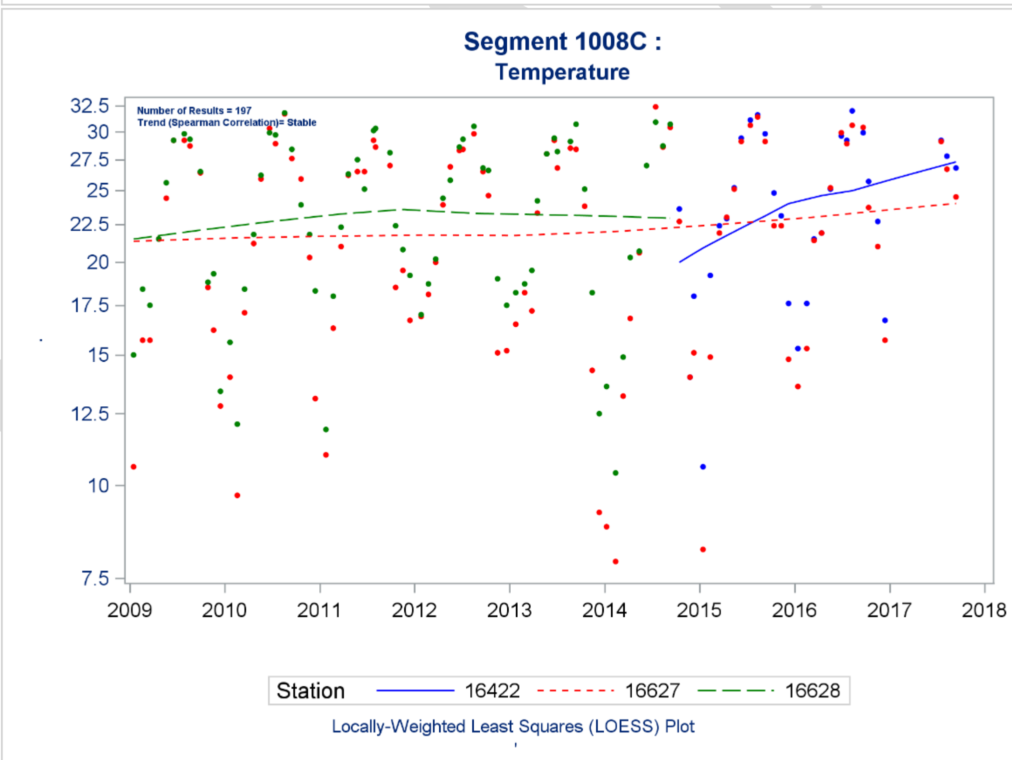


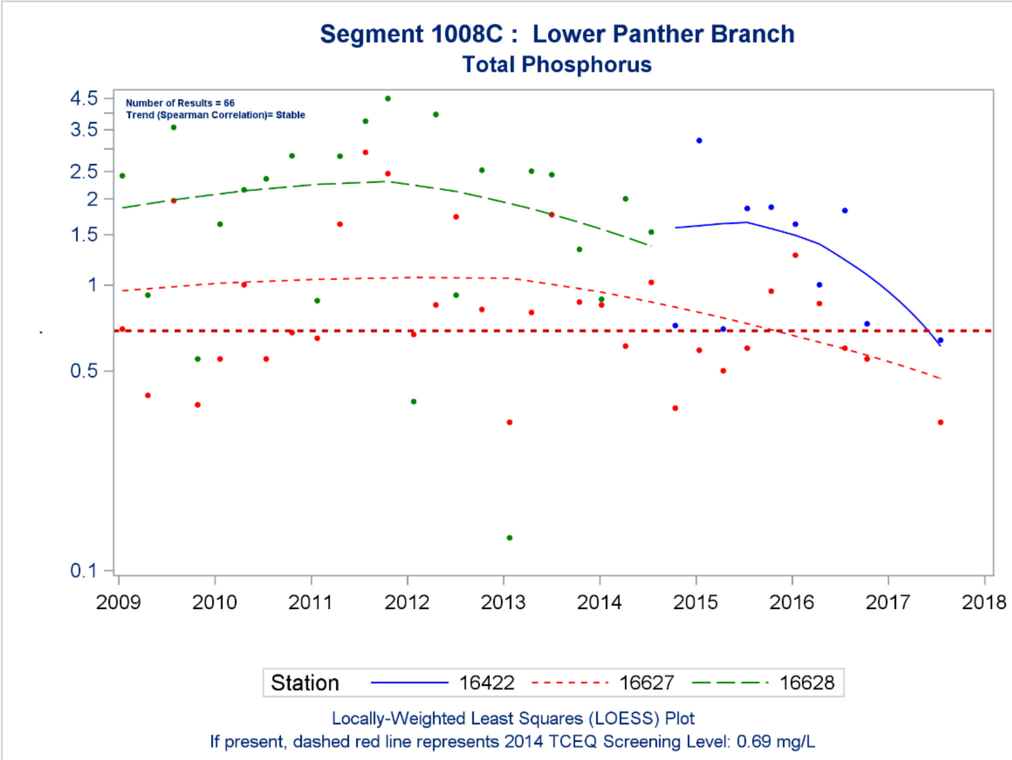
Segment 1008C :
Instantaneous Flow
Number of Results = 90
Trend (Spearman Correlation)= Stable
300
200
100
0
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Station 16422 16627 16628
Locally-Weighted Least Squares (LOESS) Plot

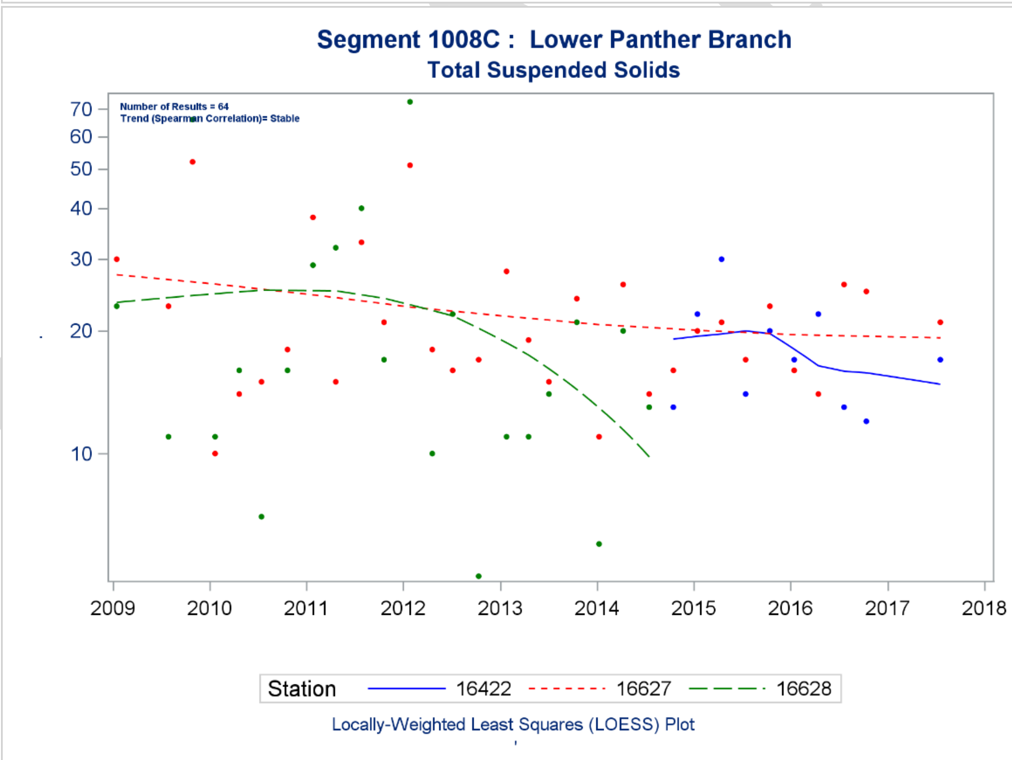

Segment 1008C :
Nitrate+nitrite
Number of Results = 66
Trend (Spearman Correlation)= Stable
10
1
0.1
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Station
16422
16627
16628
Locally-Weighted Least Squares (LOESS) Plot

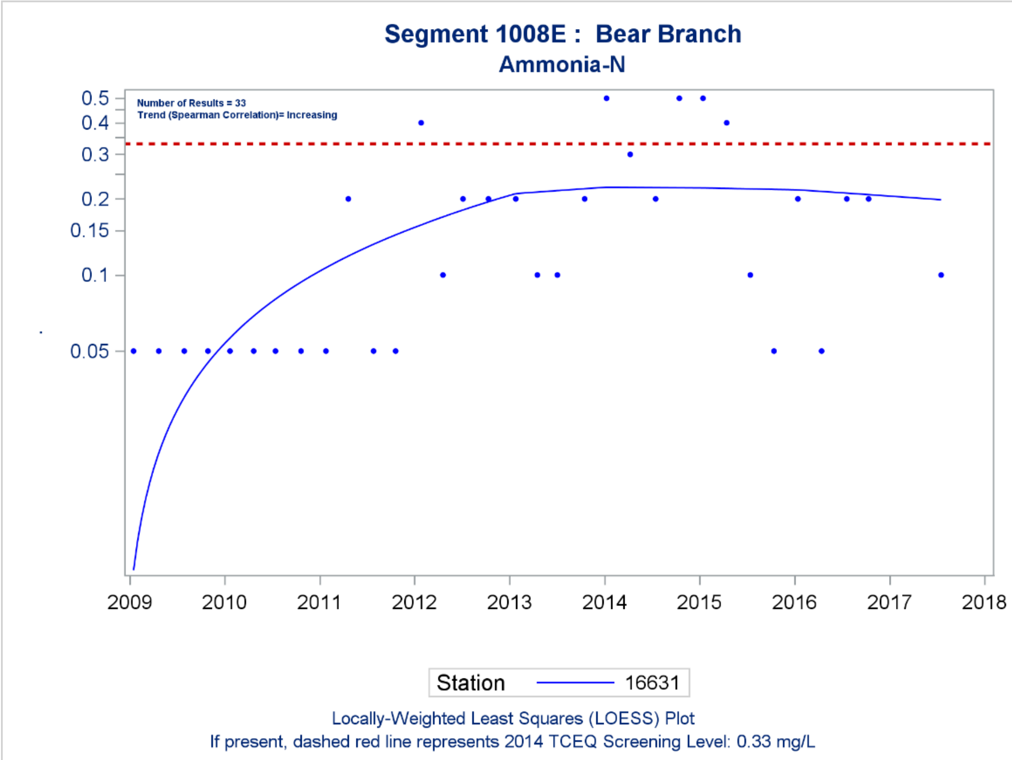

Segment 1008C :
Nitrate-N
Number of Results = 66
Trend (Spearman Correlation)= Stable
10
1
0.1
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Station
16422
16627
16628
Locally-Weighted Least Squares (LOESS) Plot

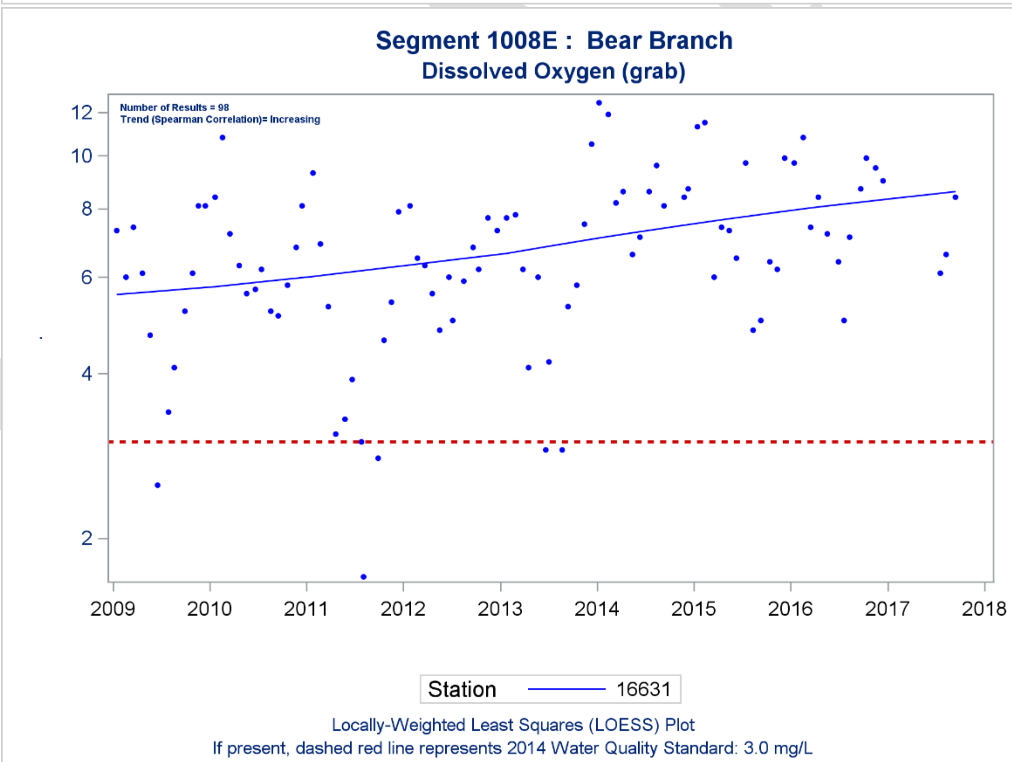

Segment 1008C : Lower Panther Branch
pH
Number of Results = 197
Trend (Spearman Correlation)= Stable
10
9.5
9
8.5
8
7.5
7
6.5
6
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Station
16422
16627
16628
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 Water Quality Standard of . S.U.


Segment 1008C :
Temperature
Number of Results = 197
Trend (Spearman Correlation)= Stable
32.5
30
27.5
25
22.5
20
17.5
15
12.5
10
7.5
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Station
16422
16627
16628
Locally-Weighted Least Squares (LOESS) Plot

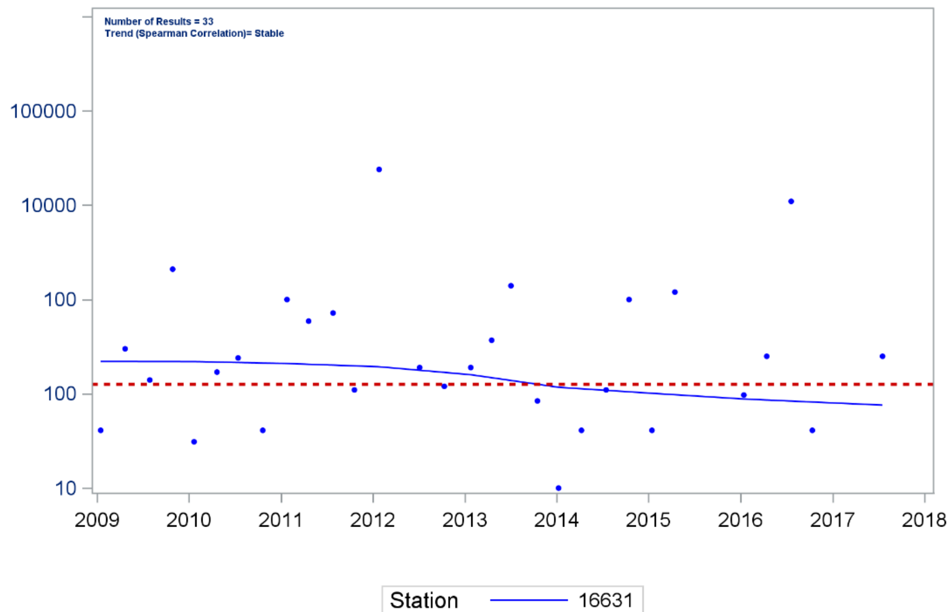

Segment 1008C : Lower Panther Branch
Total Phosphorus
Number of Results = 66
Trend (Spearman Correlation)= Stable
4.5
3.5
2.5
2
1.5
1
0.5
0.1
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Station
16422
16627
16628
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 TCEQ Screening Level: 0.69 mg/L


Segment 1008C : Lower Panther Branch
Total Suspended Solids
Number of Results = 64
Trend (Spearman Correlation)= Stable
70
60
50
40
30
20
10
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Station
16422
16627
16628
Locally-Weighted Least Squares (LOESS) Plot


Segment 1008E : Bear Branch
Ammonia-N
Number of Results = 33
Trend (Spearman Correlation)= Increasing
0.5
0.4
0.3
0.2
0.15
0.1
0.05
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Station
16631
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 TCEQ Screening Level: 0.33 mg/L

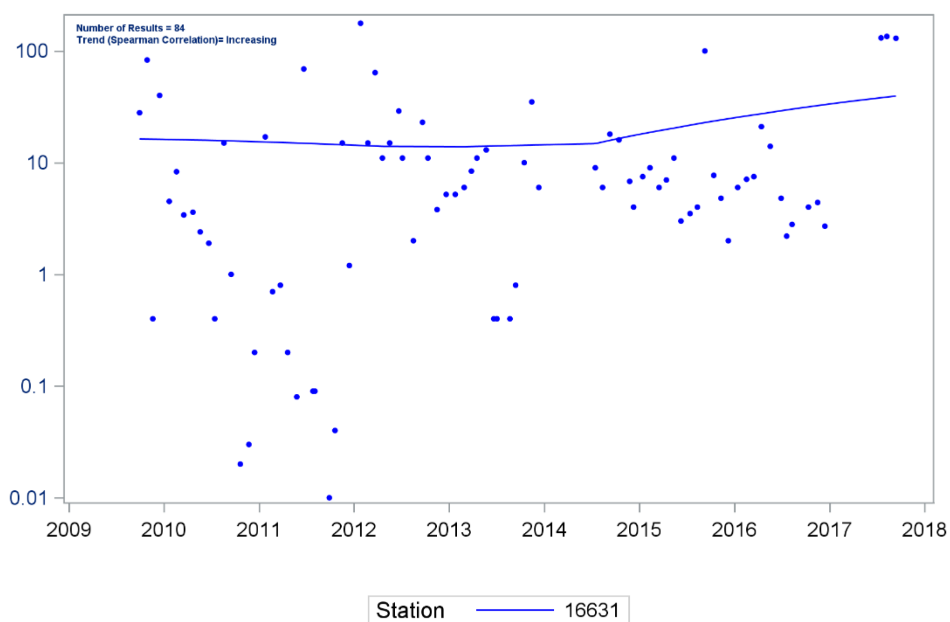

Segment 1008E : Bear Branch
Dissolved Oxygen (grab)
Number of Results = 98
Trend (Spearman Correlation)= Increasing
12
10
8
6
4
2
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Station
16631
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 Water Quality Standard: 3.0 mg/L

Segment 1008E : Bear Branch
E. Coli

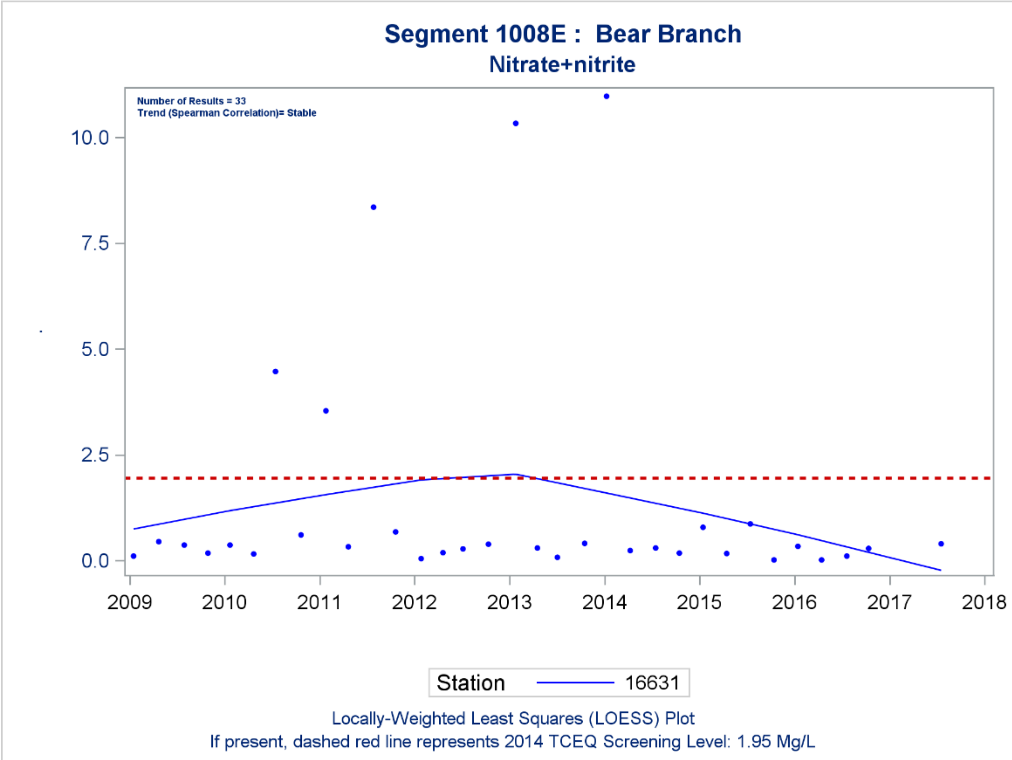


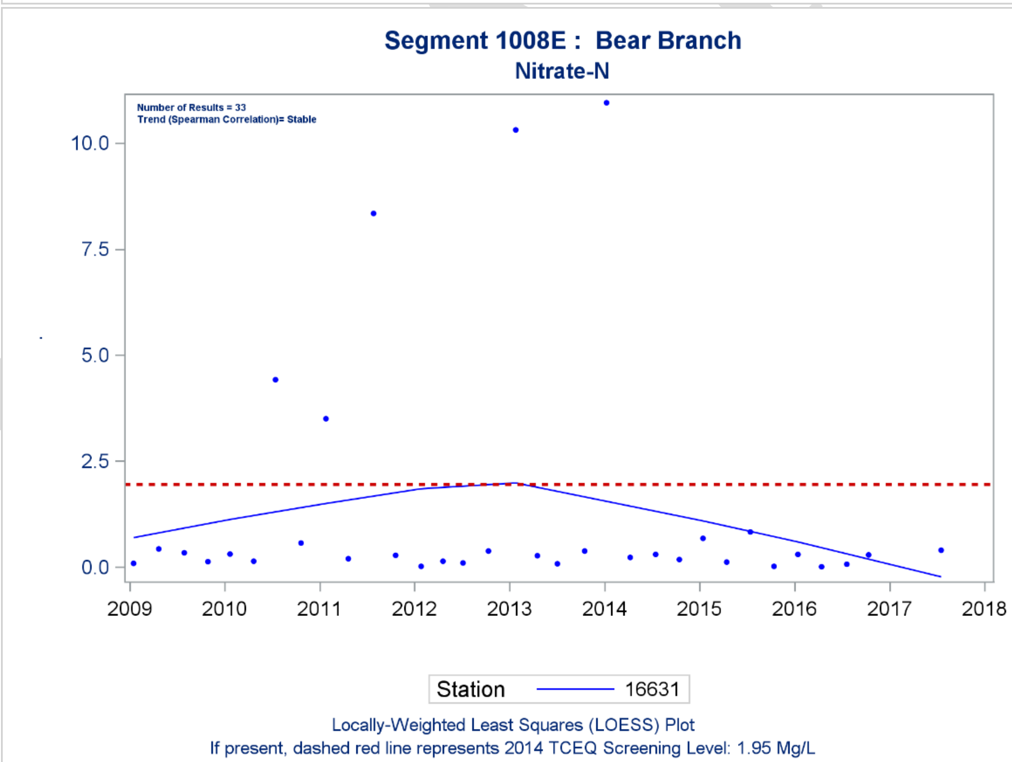
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 Water Quality Standard: 126 MPN/100 mL

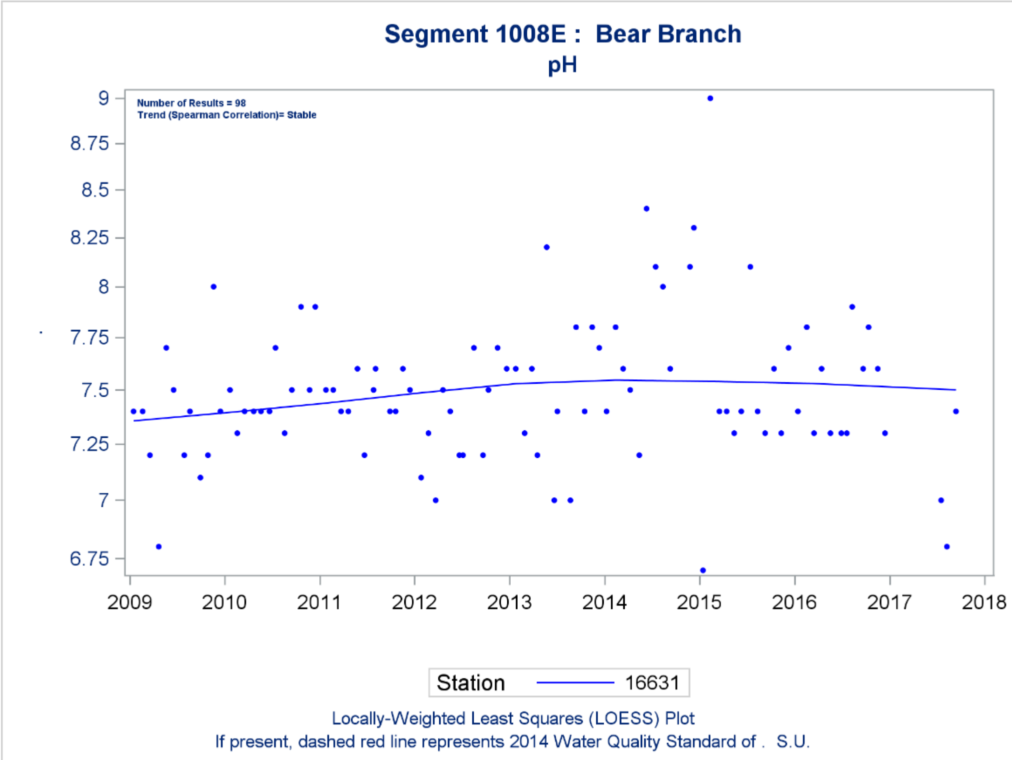
Segment 1008E : Bear Branch
Instantaneous Flow



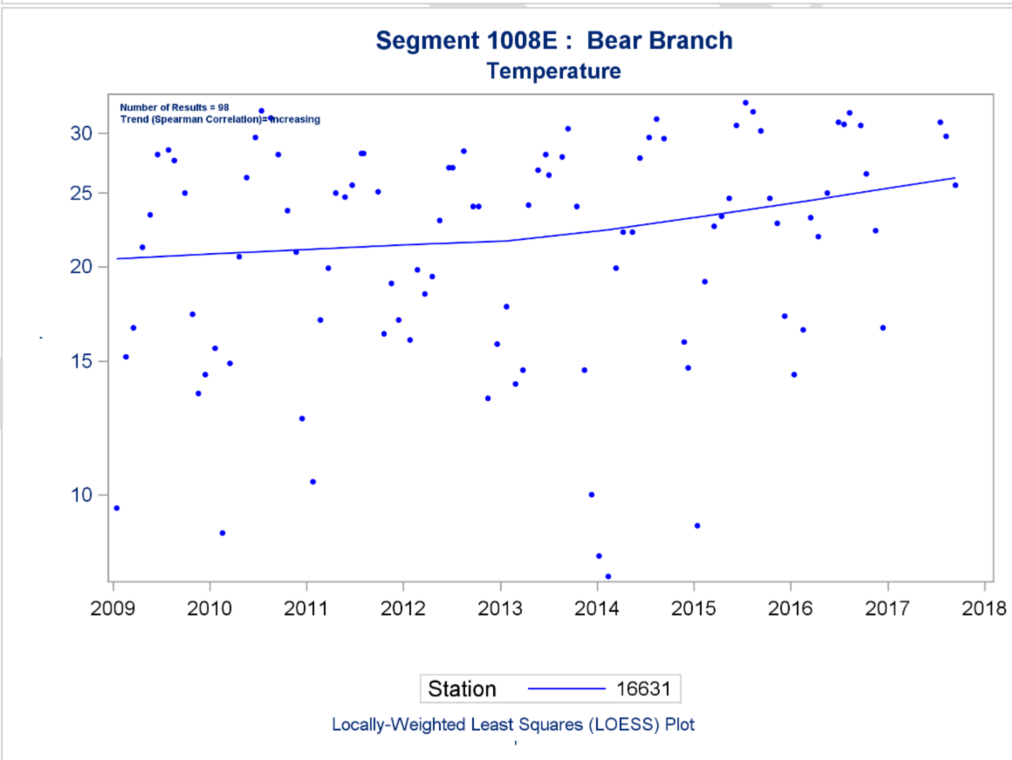
Locally-Weighted Least Squares (LOESS) Plot


Segment 1008E : Bear Branch
Nitrate+nitrite
Number of Results = 33
Trend (Spearman Correlation)= Stable
10.0
7.5
5.0
2.5
0.0
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Station
16631
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 TCEQ Screening Level: 1.95 Mg/L

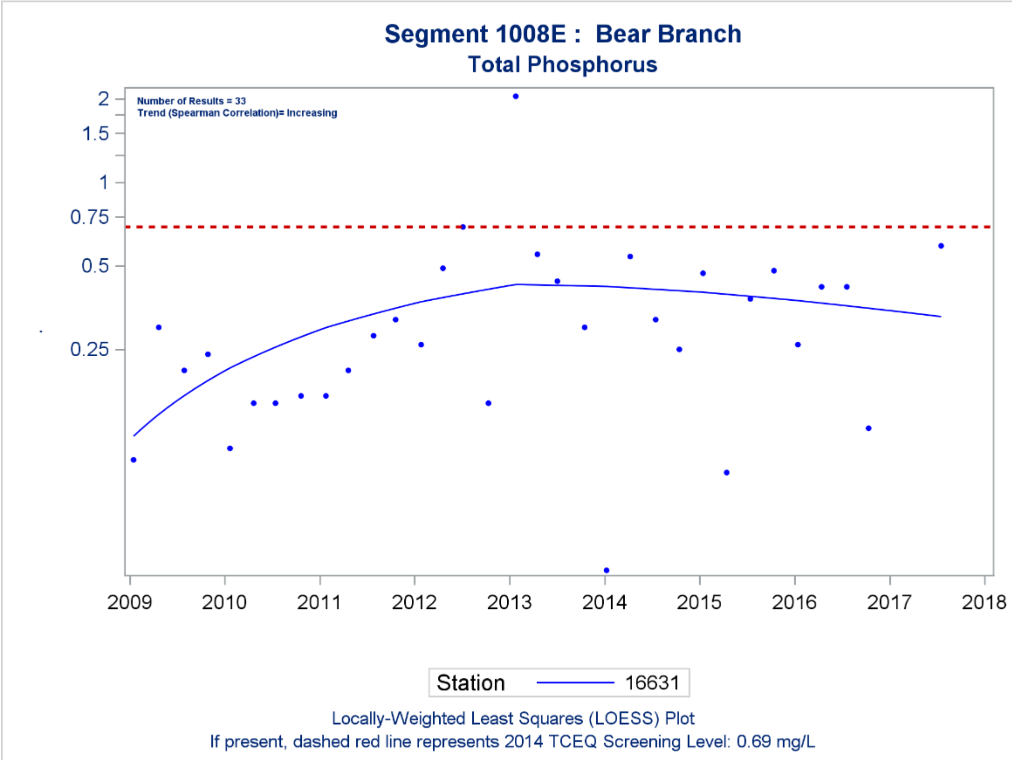

Segment 1008E : Bear Branch
Nitrate-N
Number of Results = 33
Trend (Spearman Correlation)= Stable
10.0
7.5
5.0
2.5
0.0
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Station
16631
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 TCEQ Screening Level: 1.95 Mg/L

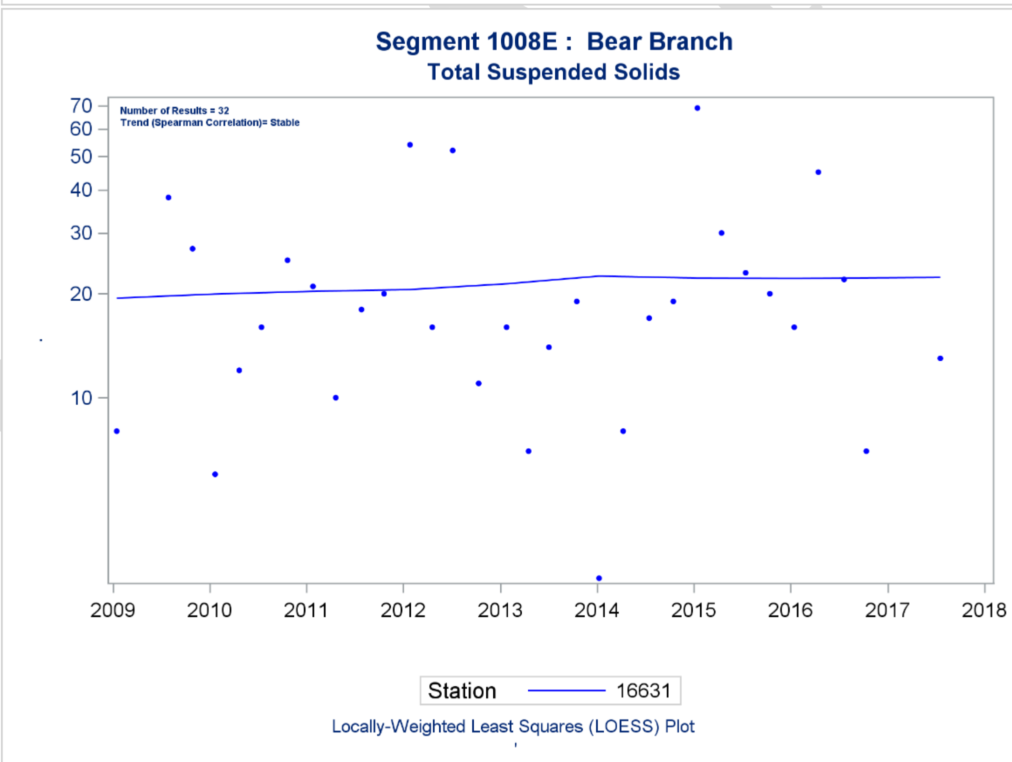


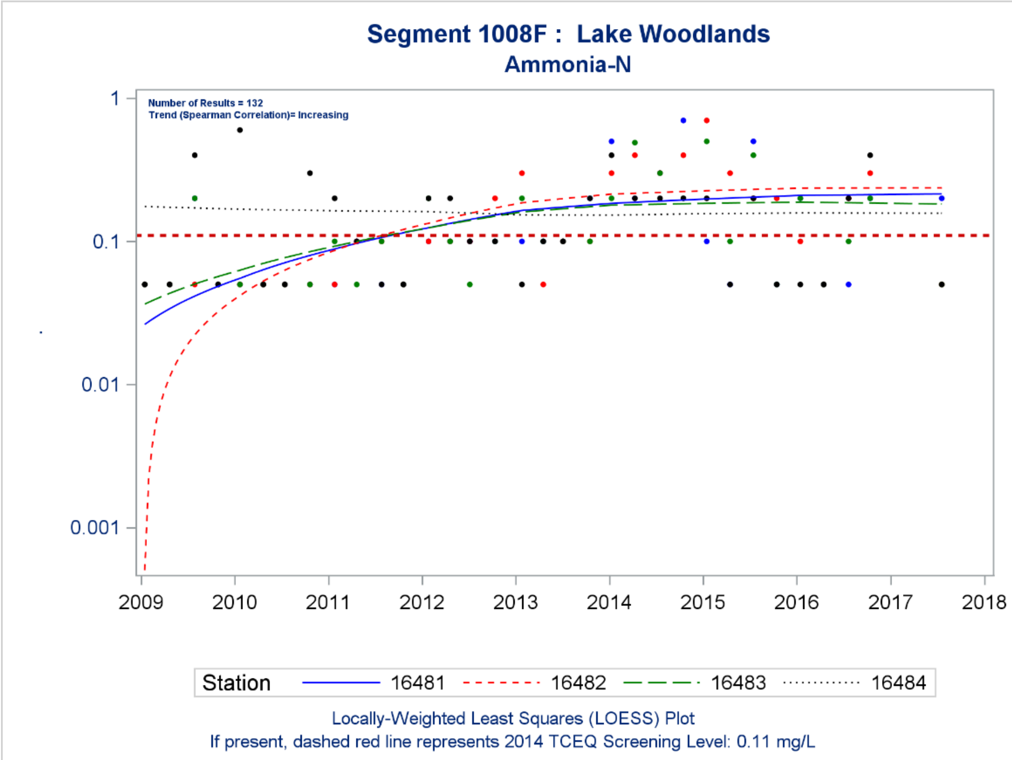
Segment 1008E : Bear Branch
pH
Number of Results = 98
Trend (Spearman Correlation)= Stable
9
8.75
8.5
8.25
8
7.75
7.5
7.25
7
6.75
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Station
16631
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 Water Quality Standard of . S.U.



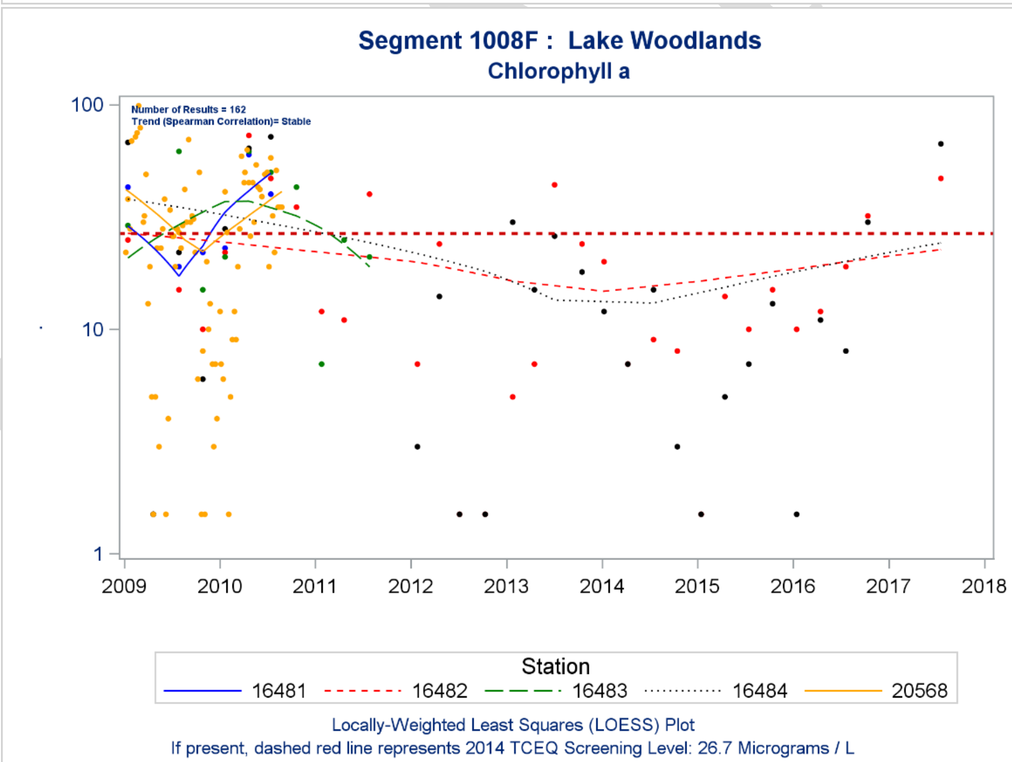
Segment 1008E : Bear Branch
Temperature
Number of Results = 98
Trend (Spearman Correlation)=Increasing
30
25
20
15
10
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Station
16631
Locally-Weighted Least Squares (LOESS) Plot


Segment 1008E : Bear Branch
Total Phosphorus
Number of Results = 33
Trend (Spearman Correlation)= Increasing
2
1.5
1
0.75
0.5
0.25
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Station
16631
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 TCEQ Screening Level: 0.69 mg/L

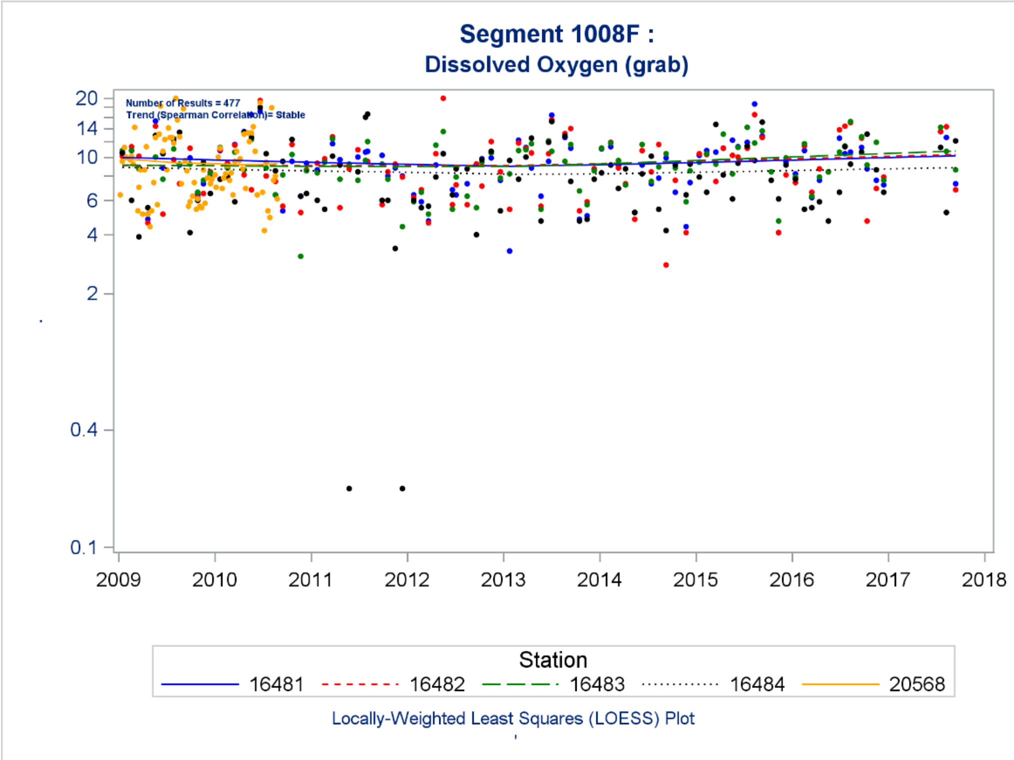

Segment 1008E : Bear Branch
Total Suspended Solids
Number of Results = 32
Trend (Spearman Correlation)= Stable
70
60
50
40
30
20
10
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Station
16631
Locally-Weighted Least Squares (LOESS) Plot



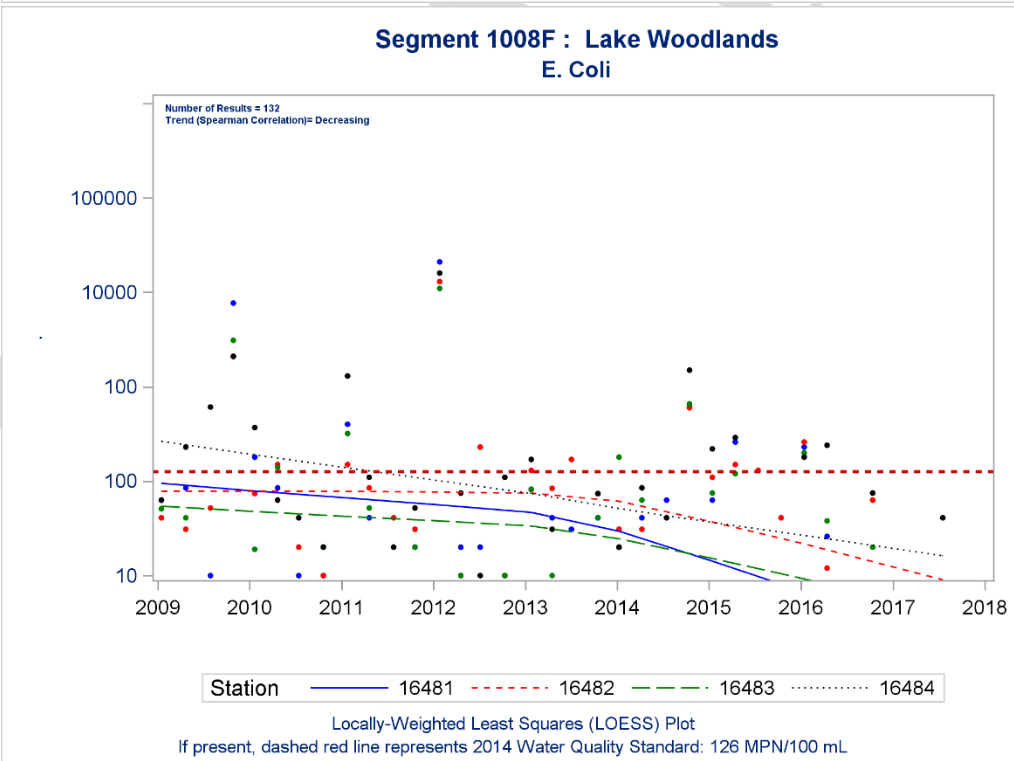
Segment 1008F : Lake Woodlands
Ammonia-N
Number of Results = 132
Trend (Spearman Correlation)= Increasing
1
0.1
0.01
0.001
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Station
16481
16482
16483
16484
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 TCEQ Screening Level: 0.11 mg/L



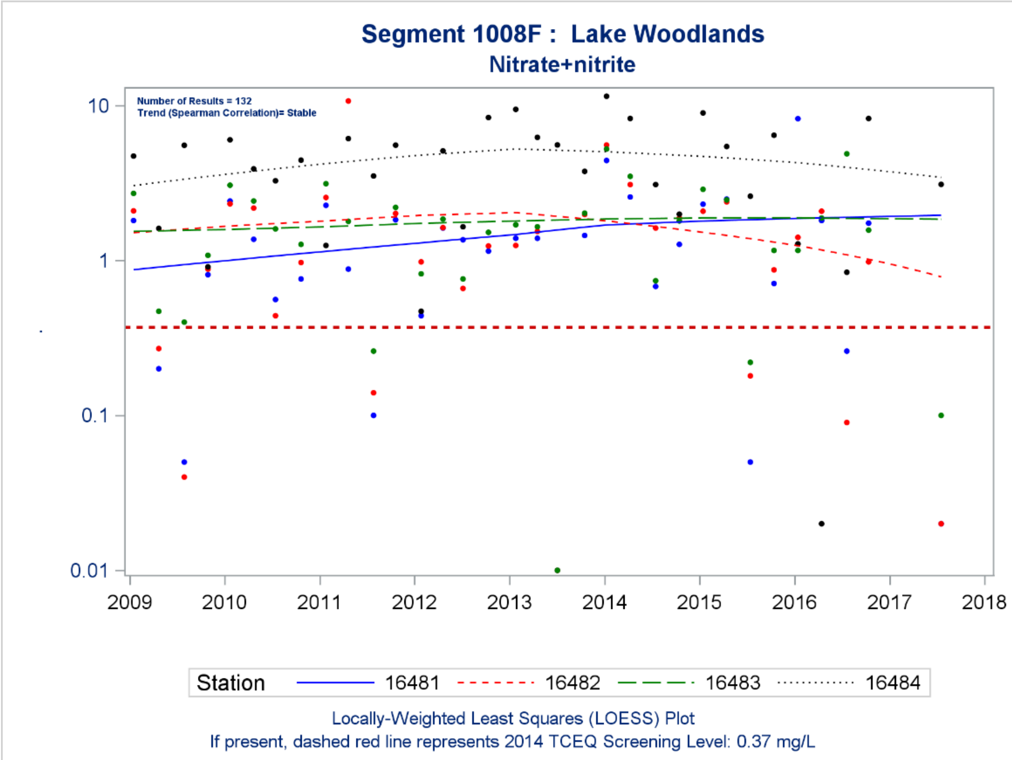
Segment 1008F : Lake Woodlands
Chlorophyll a
Number of Results = 162
Trend (Spearman Correlation)= Stable
100
10
1
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Station
16481
16482
16483
16484
20568
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 TCEQ Screening Level: 26.7 Micrograms / L



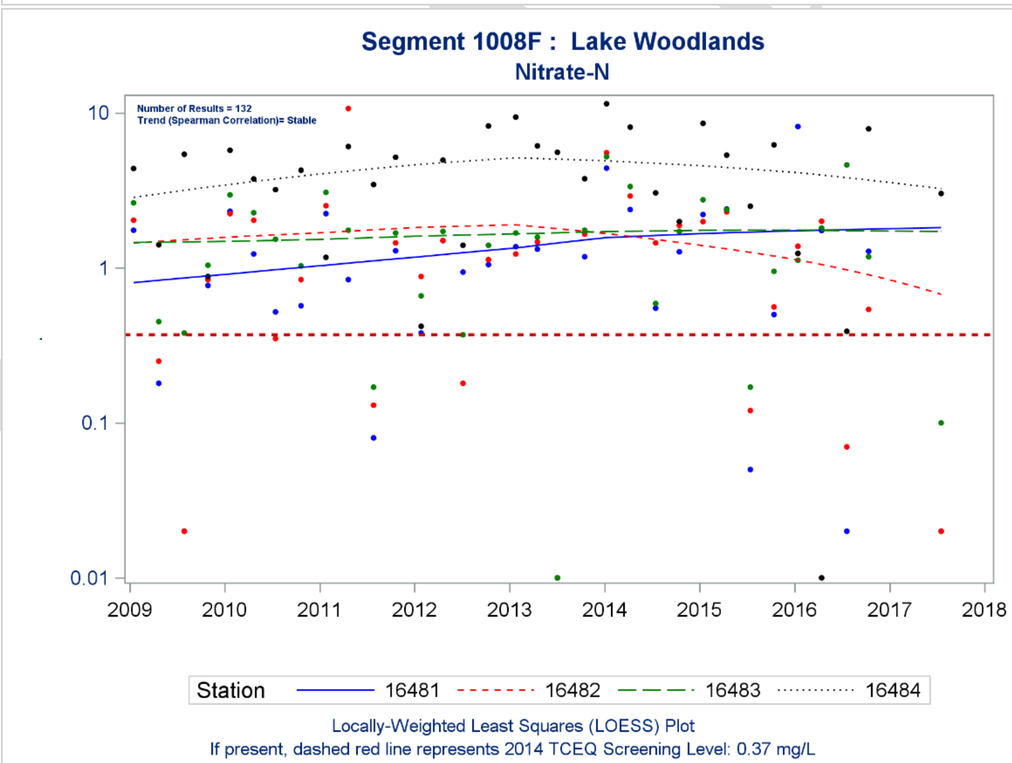
Segment 1008F :
Dissolved Oxygen (grab)
Number of Results = 477
Trend (Spearman Correlation)= Stable
20
14
10
6
4
2
0.4
0.1
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Station
16481
16482
16483
16484
20568
Locally-Weighted Least Squares (LOESS) Plot



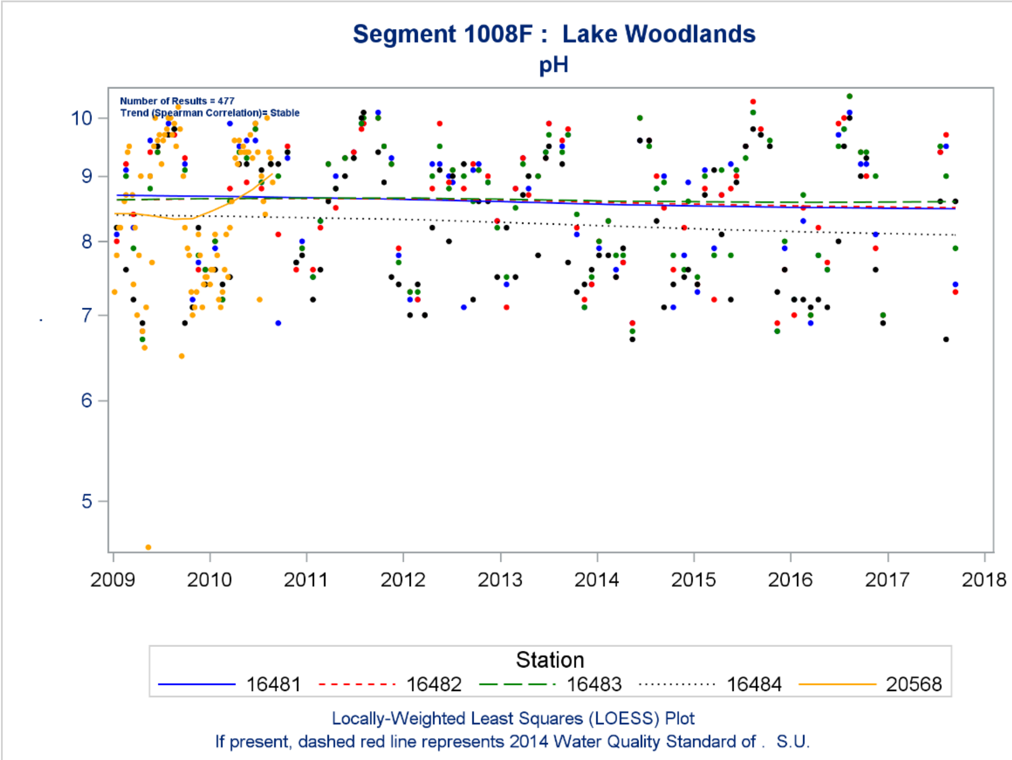
Segment 1008F : Lake Woodlands
E. Coli
Number of Results = 132
Trend (Spearman Correlation)= Decreasing
100000
10000
100
100
10
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Station
16481
16482
16483
16484
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 Water Quality Standard: 126 MPN/100 mL

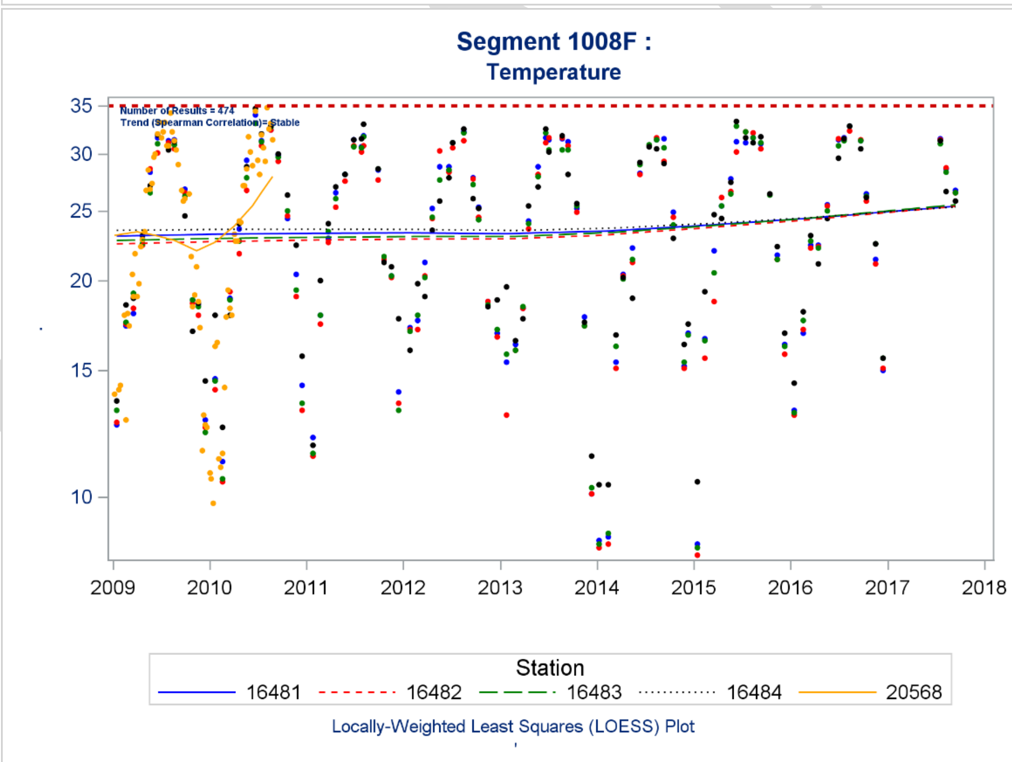


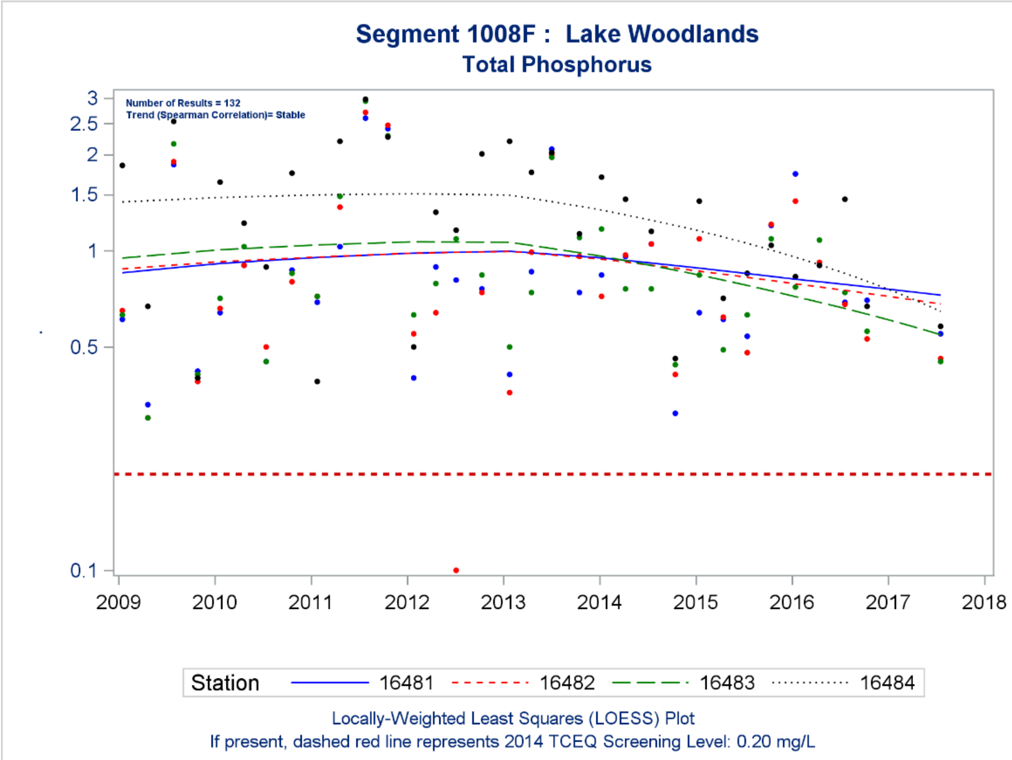
Segment 1008F : Lake Woodlands
Nitrate+nitrite
Number of Results = 132
Trend (Spearman Correlation)= Stable
10
1
0.1
0.01
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Station
16481
16482
16483
16484
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 TCEQ Screening Level: 0.37 mg/L

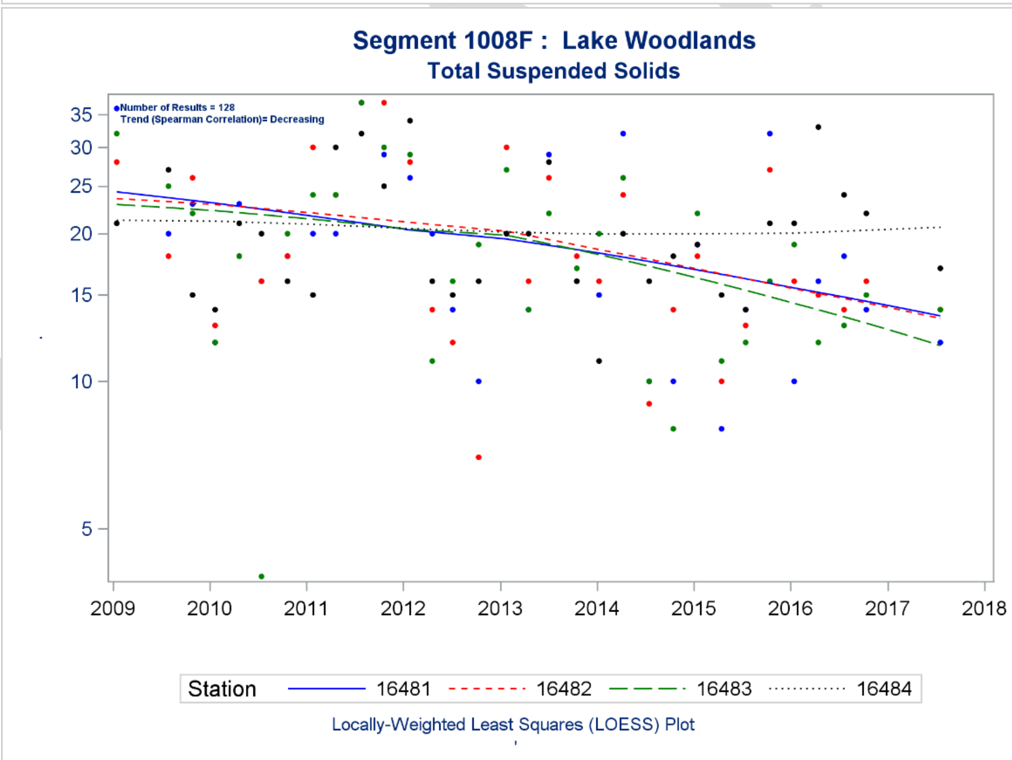


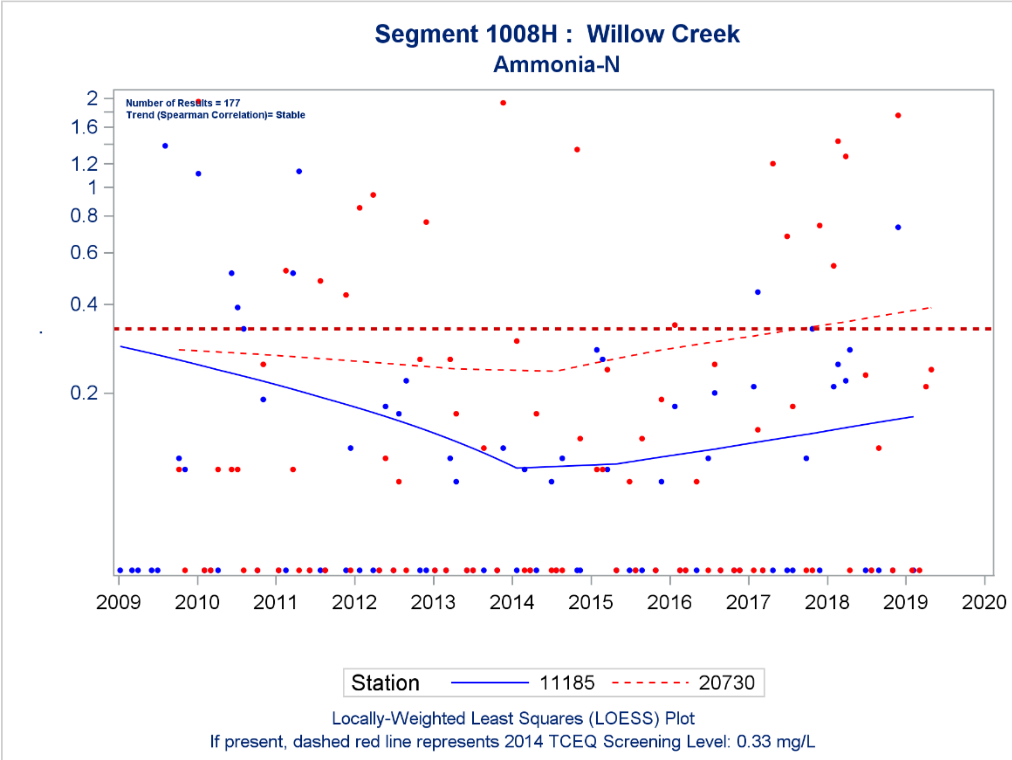
Segment 1008F : Lake Woodlands
Nitrate-N
Number of Results = 132
Trend (Spearman Correlation)= Stable
10
1
0.1
0.01
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Station
16481
16482
16483
16484
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 TCEQ Screening Level: 0.37 mg/L

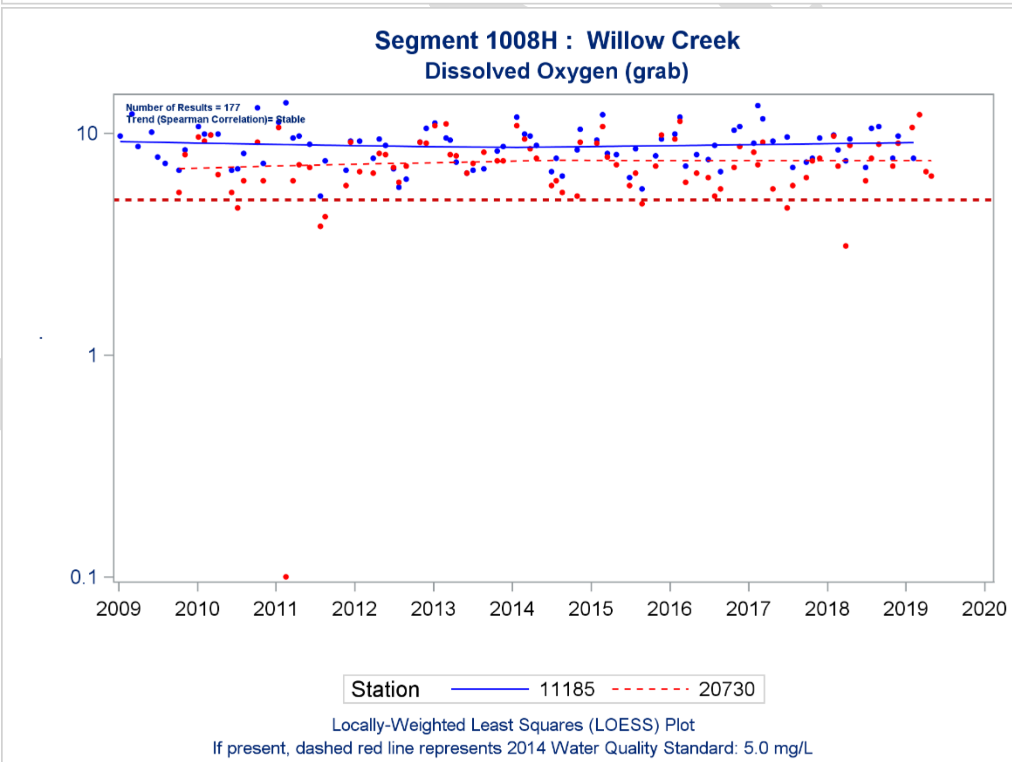

Segment 1008F : Lake Woodlands
pH
Number of Results = 477
Trend (Spearman Correlation)= Stable
10
9
8
7
6
5
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Station
16481
16482
16483
16484
20568
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 Water Quality Standard of . S.U.

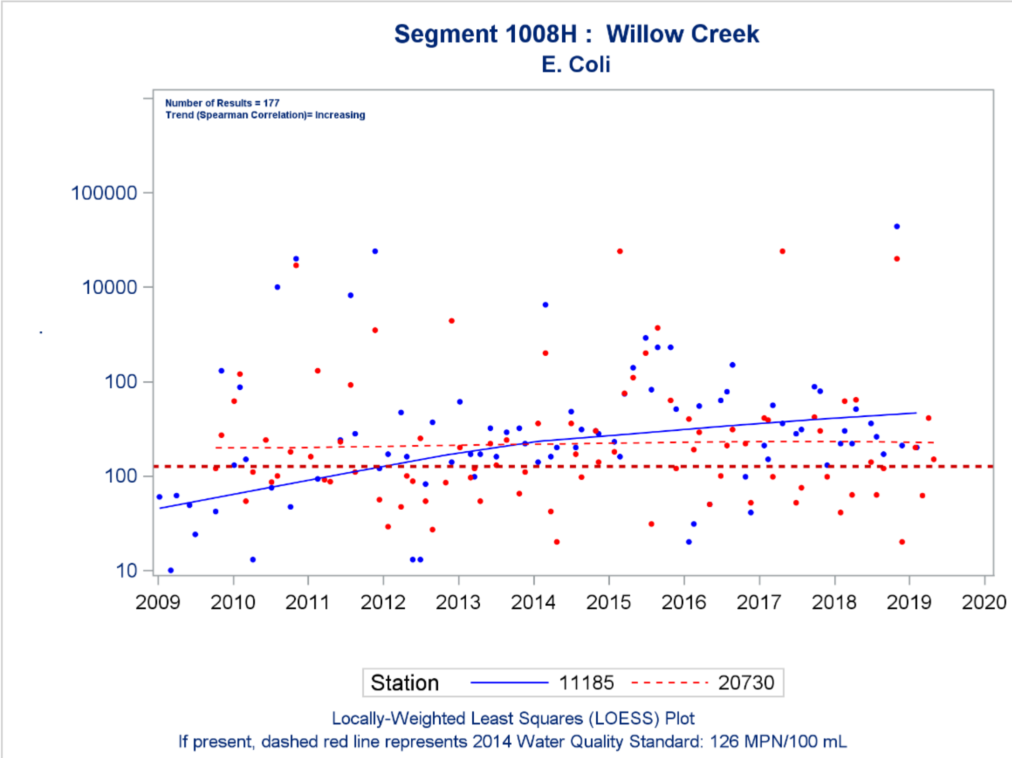

Segment 1008F :
Temperature
Number of Results = 474
Trend (Spearman Correlation)= Stable
35
30
25
20
15
10
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Station
16481
16482
16483
16484
20568
Locally-Weighted Least Squares (LOESS) Plot

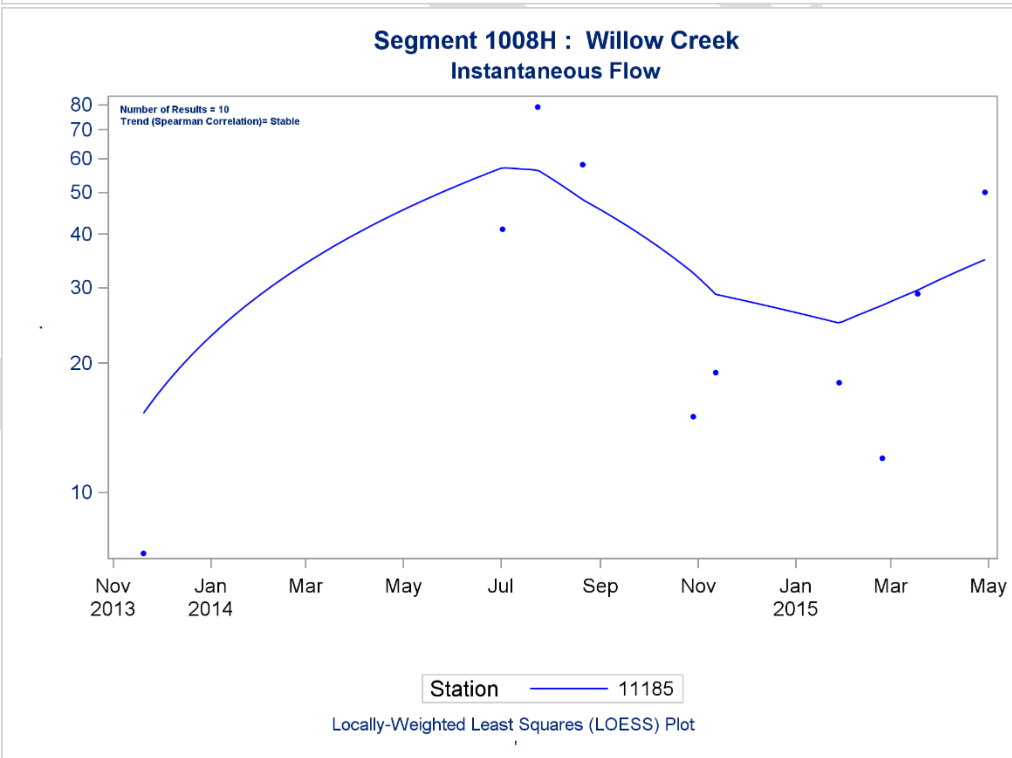

Segment 1008F : Lake Woodlands
Total Phosphorus
Number of Results = 132
Trend (Spearman Correlation)= Stable
3
2.5
2
1.5
1
0.5
0.1
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Station 16481 16482 16483 16484
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 TCEQ Screening Level: 0.20 mg/L

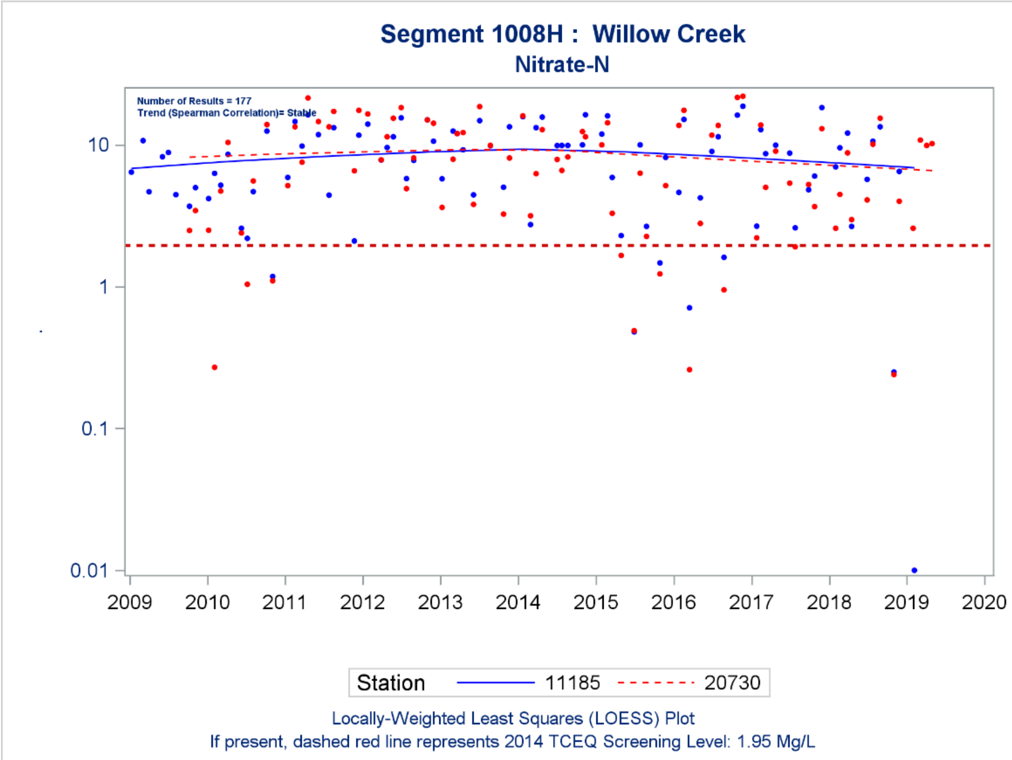

Segment 1008F : Lake Woodlands
Total Suspended Solids
Number of Results = 128
Trend (Spearman Correlation)= Decreasing
35
30
25
20
15
10
5
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Station 16481 16482 16483 16484
Locally-Weighted Least Squares (LOESS) Plot

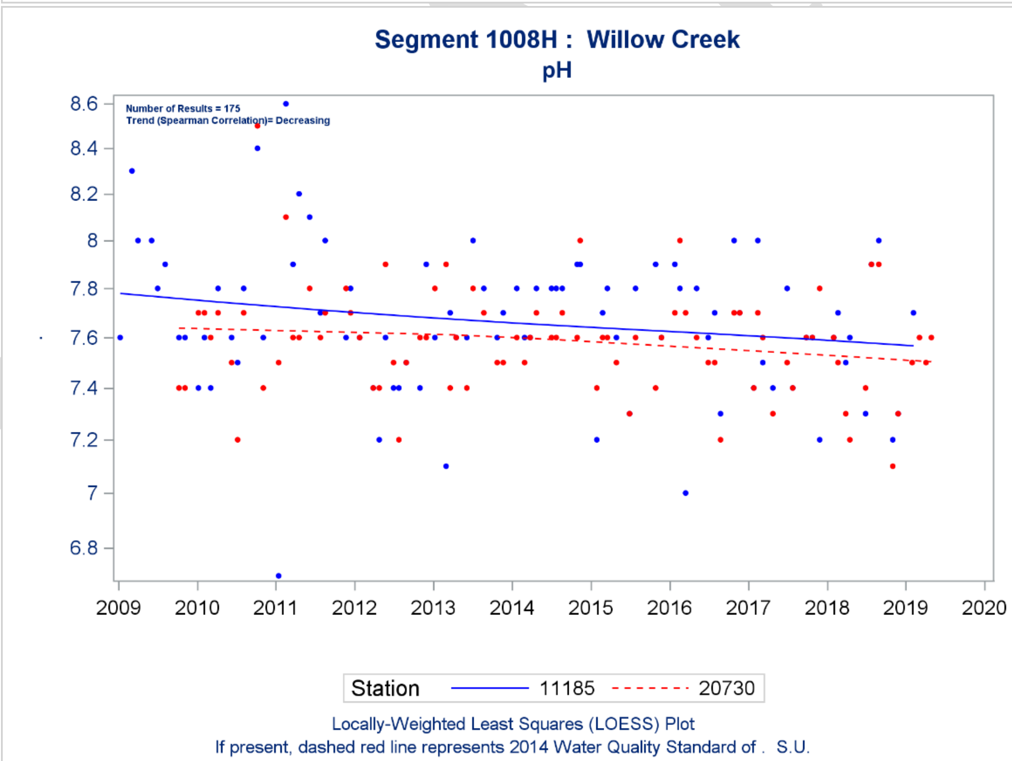

Segment 1008H : Willow Creek
Ammonia-N
Number of Results = 177
Trend (Spearman Correlation)= Stable
2
1.6
1.2
1
0.8
0.6
0.4
0.2
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
11185
20730
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 TCEQ Screening Level: 0.33 mg/L

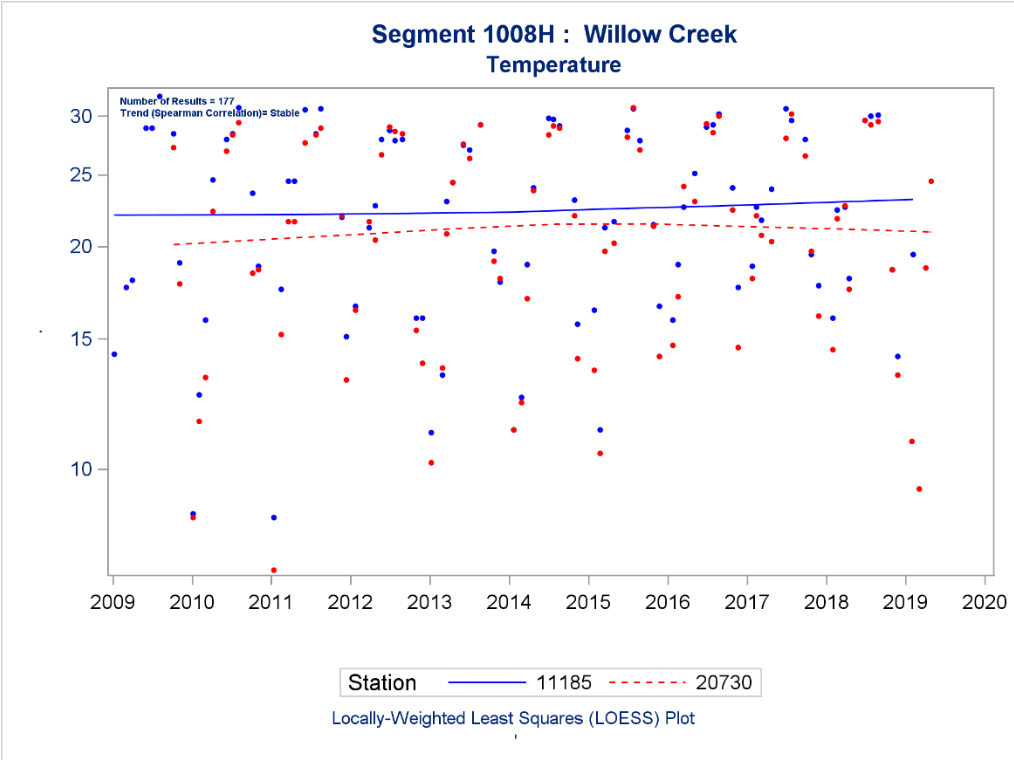

Segment 1008H : Willow Creek
Dissolved Oxygen (grab)
Number of Results = 177
Trend (Spearman Correlation)= Stable
10
1
0.1
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
11185
20730
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 Water Quality Standard: 5.0 mg/L


Segment 1008H : Willow Creek
E. Coli
Number of Results = 177
Trend (Spearman Correlation)= Increasing
100000
10000
100
100
10
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
11185
20730
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 Water Quality Standard: 126 MPN/100 mL

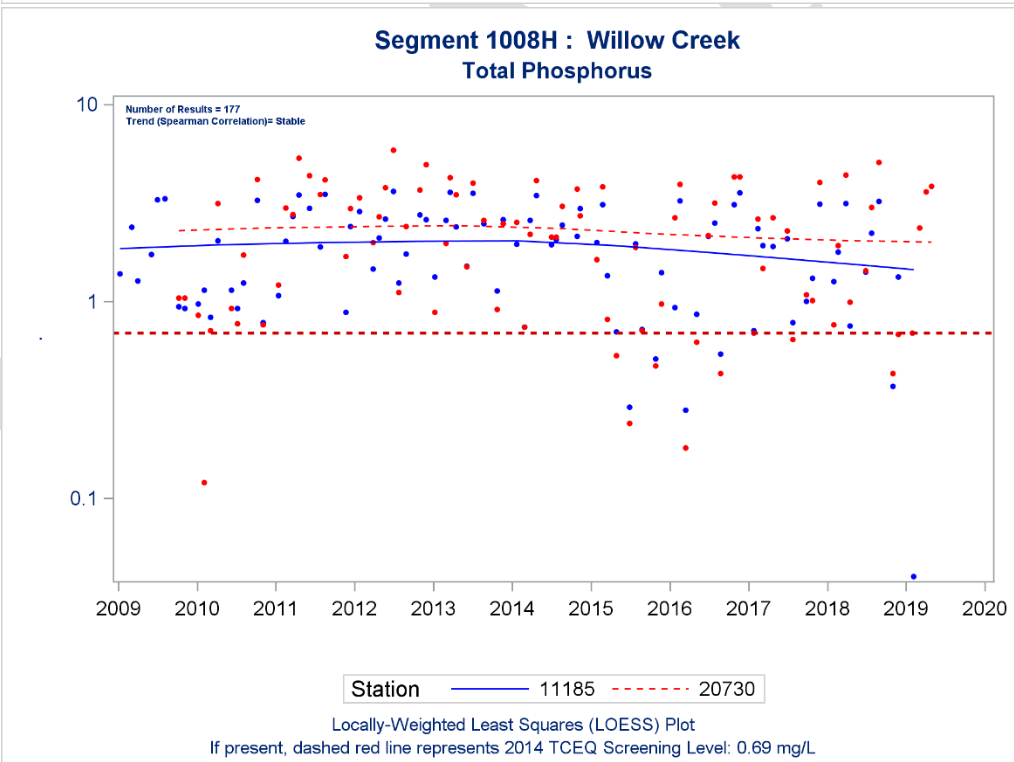

Segment 1008H : Willow Creek
Instantaneous Flow
Number of Results = 10
Trend (Spearman Correlation)= Stable
80
70
60
50
40
30
20
10
Nov 2013
Jan 2014
Mar
May
Jul
Sep
Nov
Jan 2015
Mar
May
Station
11185
Locally-Weighted Least Squares (LOESS) Plot


Segment 1008H : Willow Creek
Nitrate-N
Number of Results = 177
Trend (Spearman Correlation)= Stable
10
1
0.1
0.01
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
11185
20730
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 TCEQ Screening Level: 1.95 Mg/L

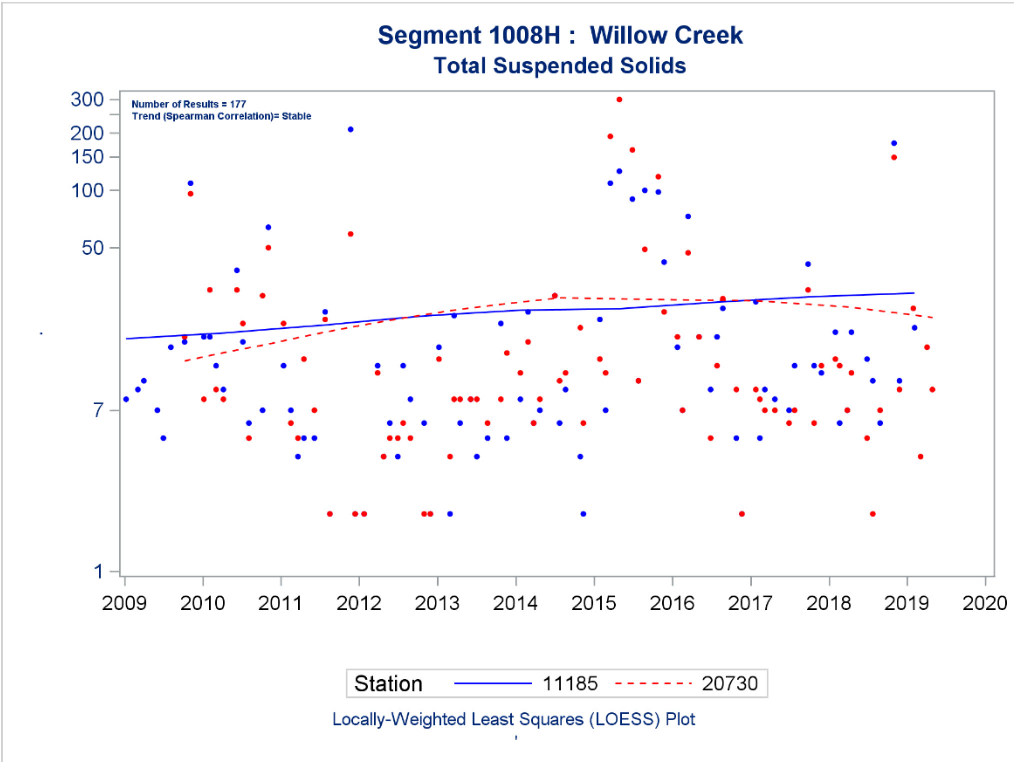

Segment 1008H : Willow Creek
pH
Number of Results = 175
Trend (Spearman Correlation)= Decreasing
8.6
8.4
8.2
8
7.8
7.6
7.4
7.2
7
6.8
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
11185
20730
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 Water Quality Standard of . S.U.

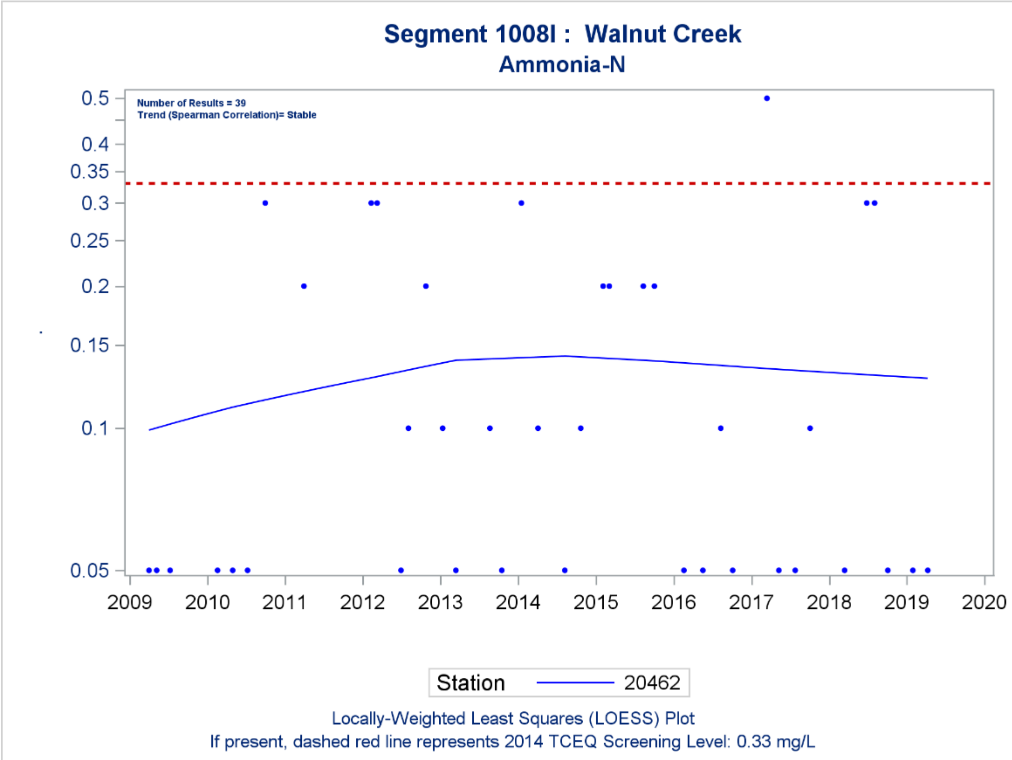


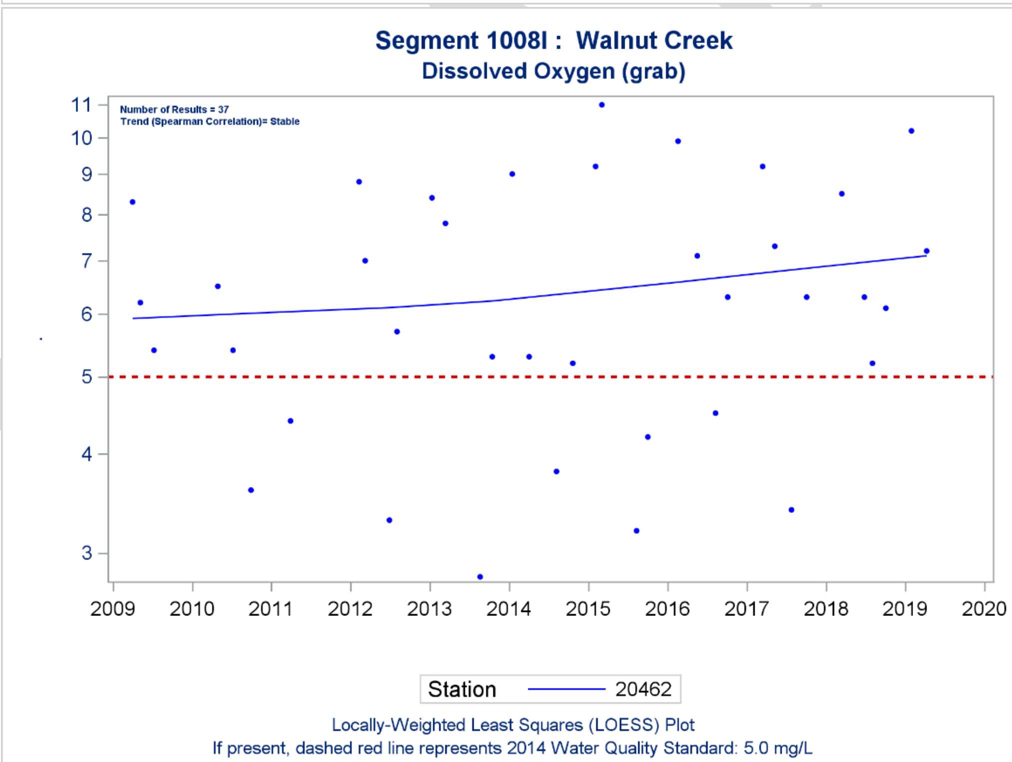
Segment 1008H : Willow Creek
Temperature
Number of Results = 177
Trend (Spearman Correlation)= Stable
30
25
20
15
10
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station 11185 20730
Locally-Weighted Least Squares (LOESS) Plot

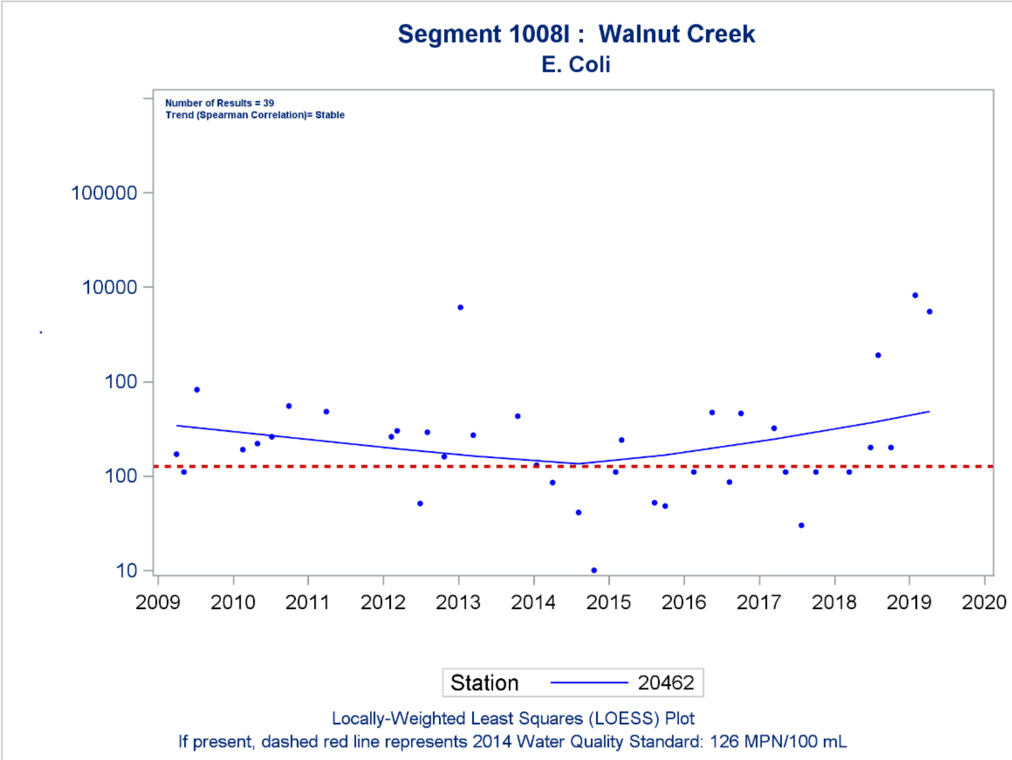


Segment 1008H : Willow Creek
Total Phosphorus
Number of Results = 177
Trend (Spearman Correlation)= Stable
10
1
0.1
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station 11185 20730
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 TCEQ Screening Level: 0.69 mg/L

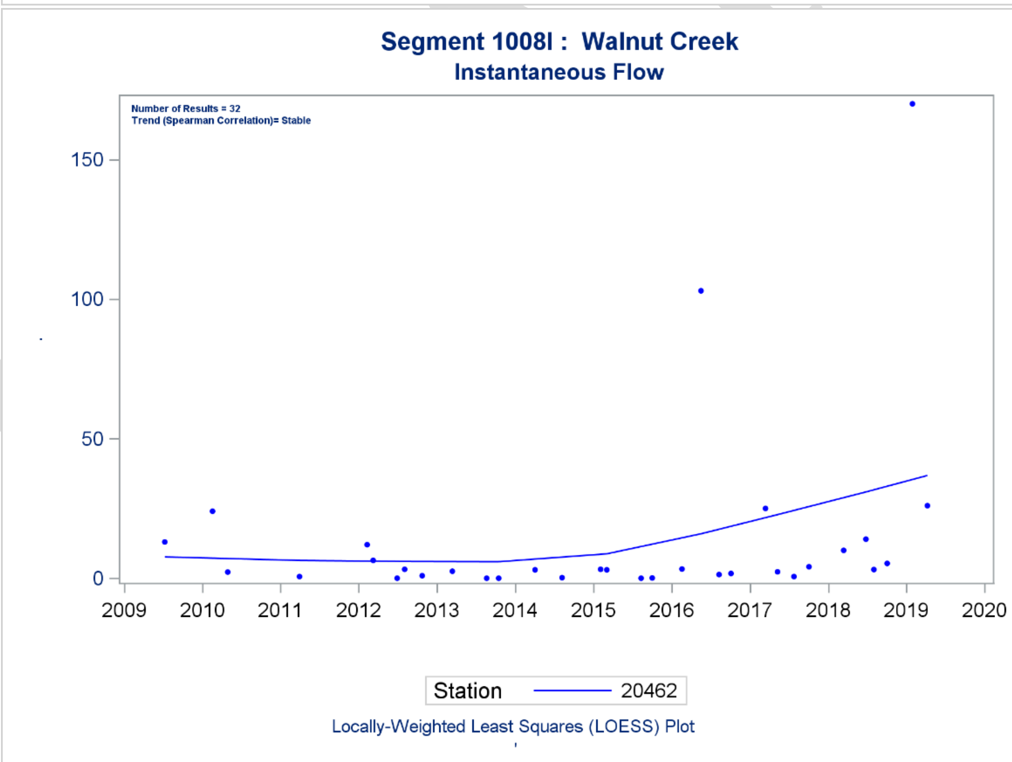

Segment 1008H : Willow Creek
Total Suspended Solids
Number of Results = 177
Trend (Spearman Correlation)= Stable
300
200
150
100
50
7
1
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
11185
20730
Locally-Weighted Least Squares (LOESS) Plot


Segment 1008I : Walnut Creek
Ammonia-N
Number of Results = 39
Trend (Spearman Correlation)= Stable
0.5
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station 20462
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 TCEQ Screening Level: 0.33 mg/L

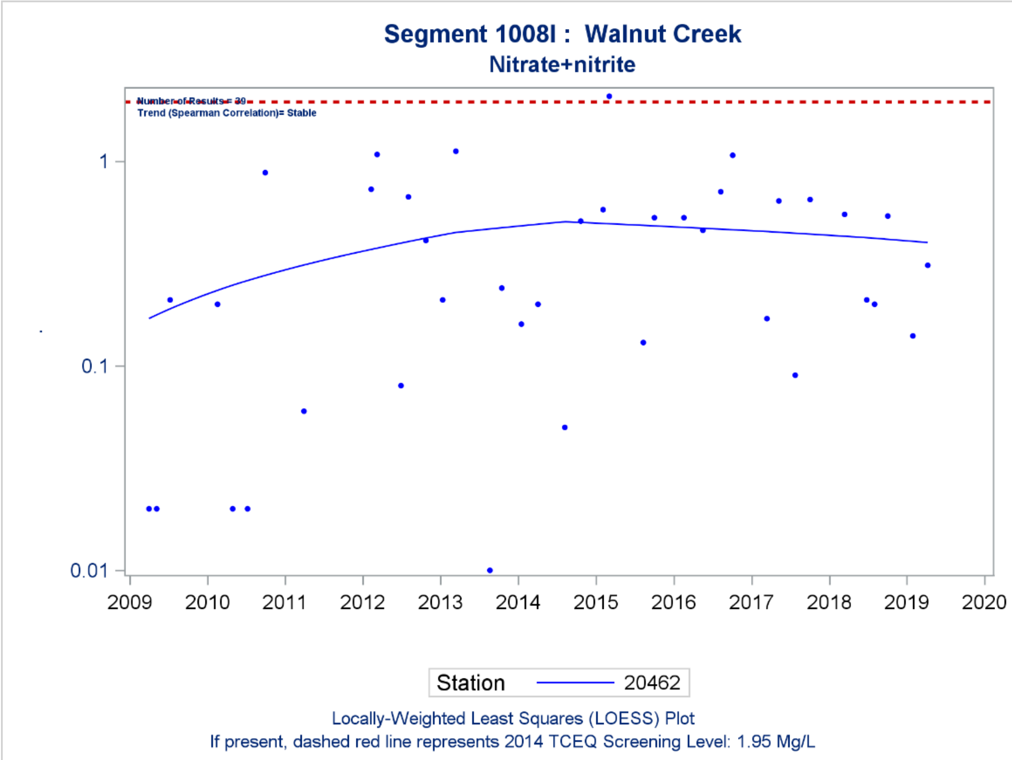

Segment 1008I : Walnut Creek
Dissolved Oxygen (grab)
Number of Results = 37
Trend (Spearman Correlation)= Stable
11
10
9
8
7
6
5
4
3
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station 20462
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 Water Quality Standard: 5.0 mg/L

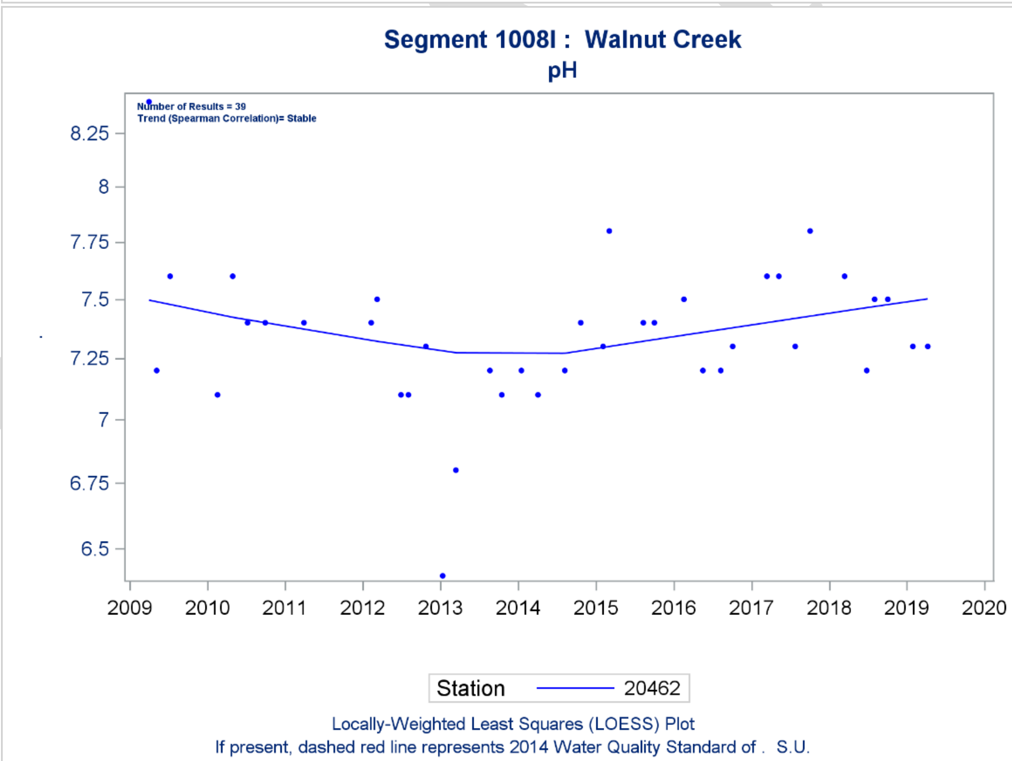


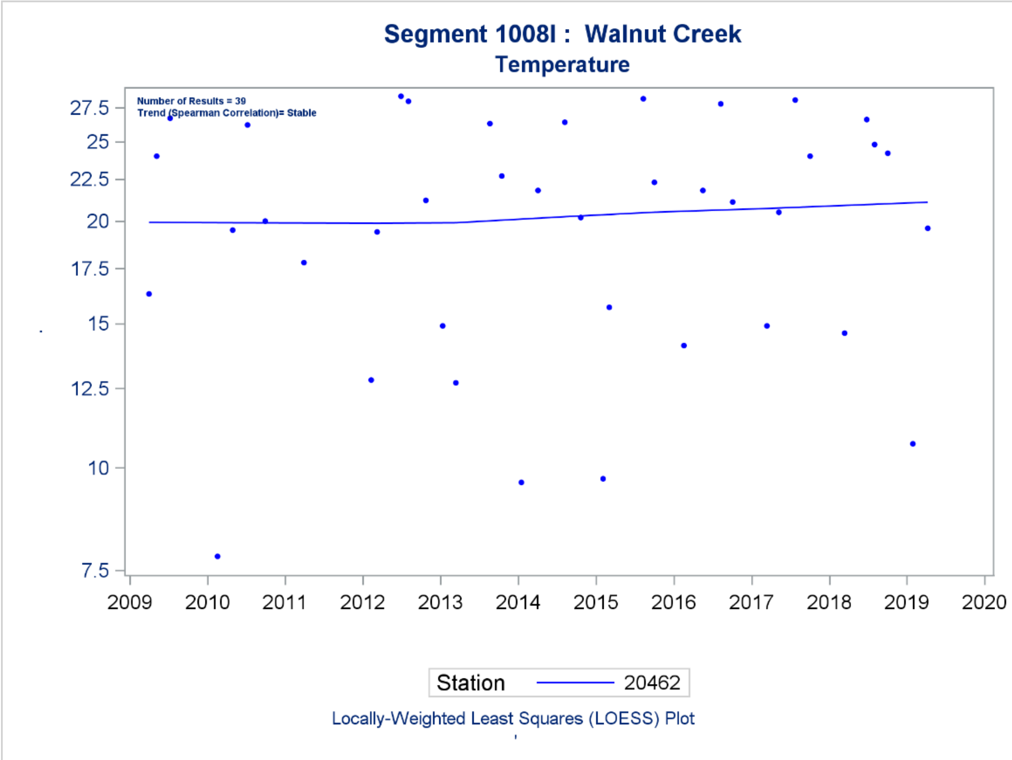
Segment 1008I : Walnut Creek
E. Coli
Number of Results = 39
Trend (Spearman Correlation)= Stable
100000
10000
100
100
10
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
20462
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 Water Quality Standard: 126 MPN/100 mL

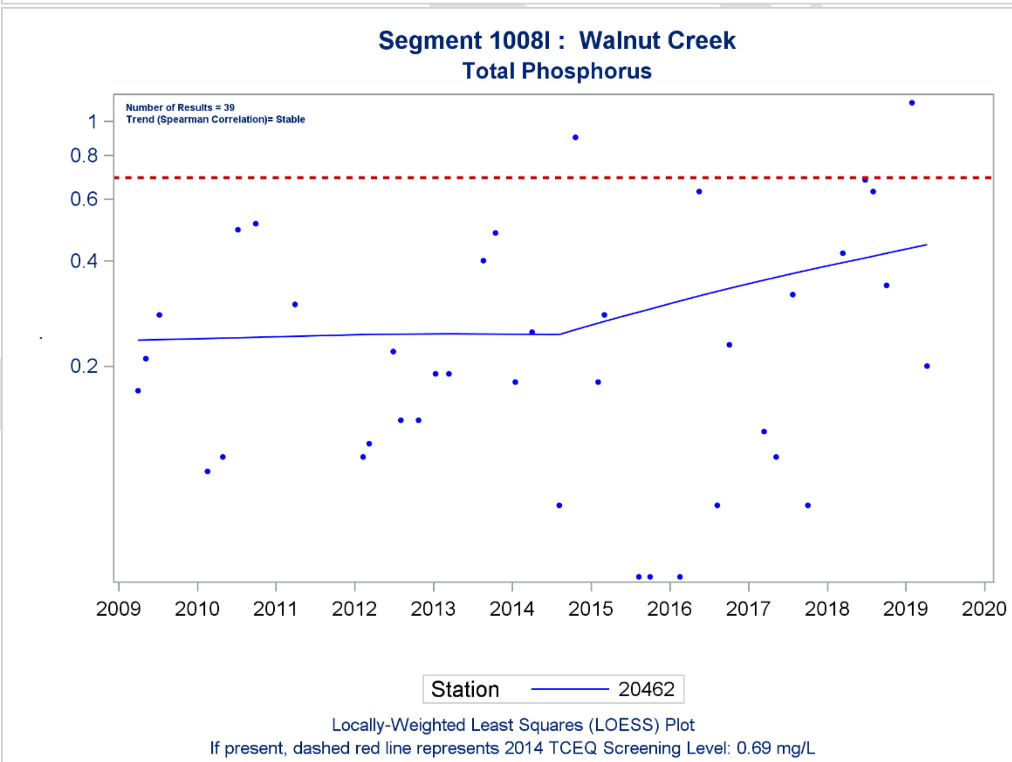


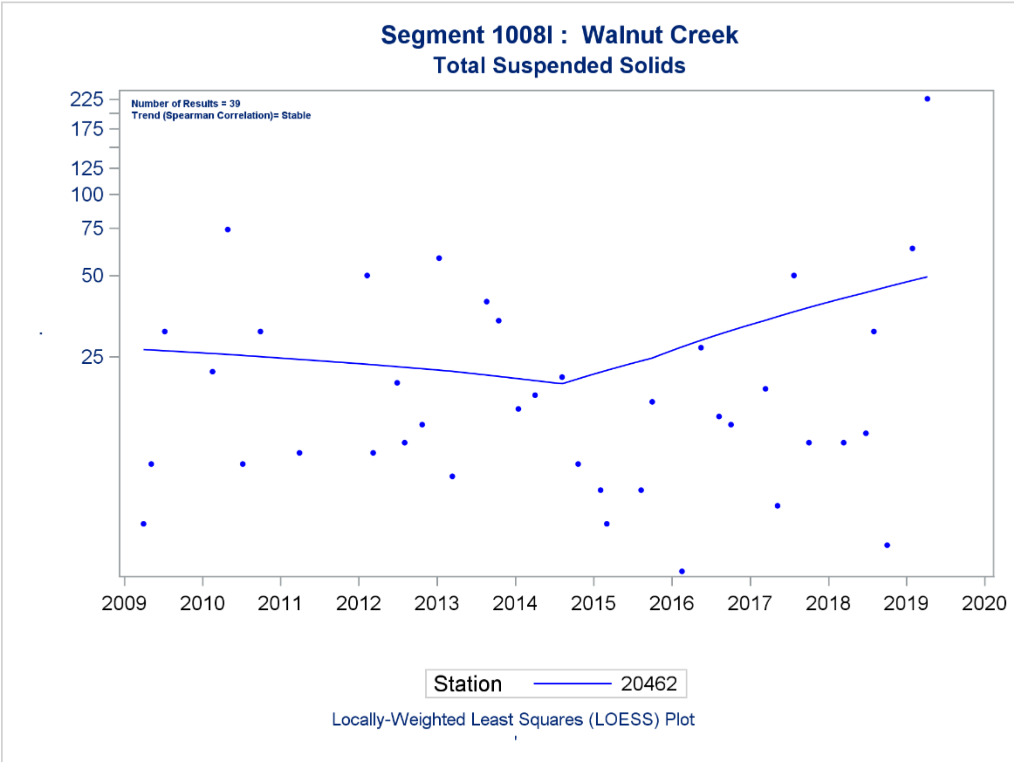
Segment 1008I : Walnut Creek
Instantaneous Flow
Number of Results = 32
Trend (Spearman Correlation)= Stable
150
100
50
0
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
20462
Locally-Weighted Least Squares (LOESS) Plot


Segment 1008I : Walnut Creek
Nitrate+nitrite
Number of Results = 39
Trend (Spearman Correlation)= Stable
1
0.1
0.01
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
20462
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 TCEQ Screening Level: 1.95 Mg/L

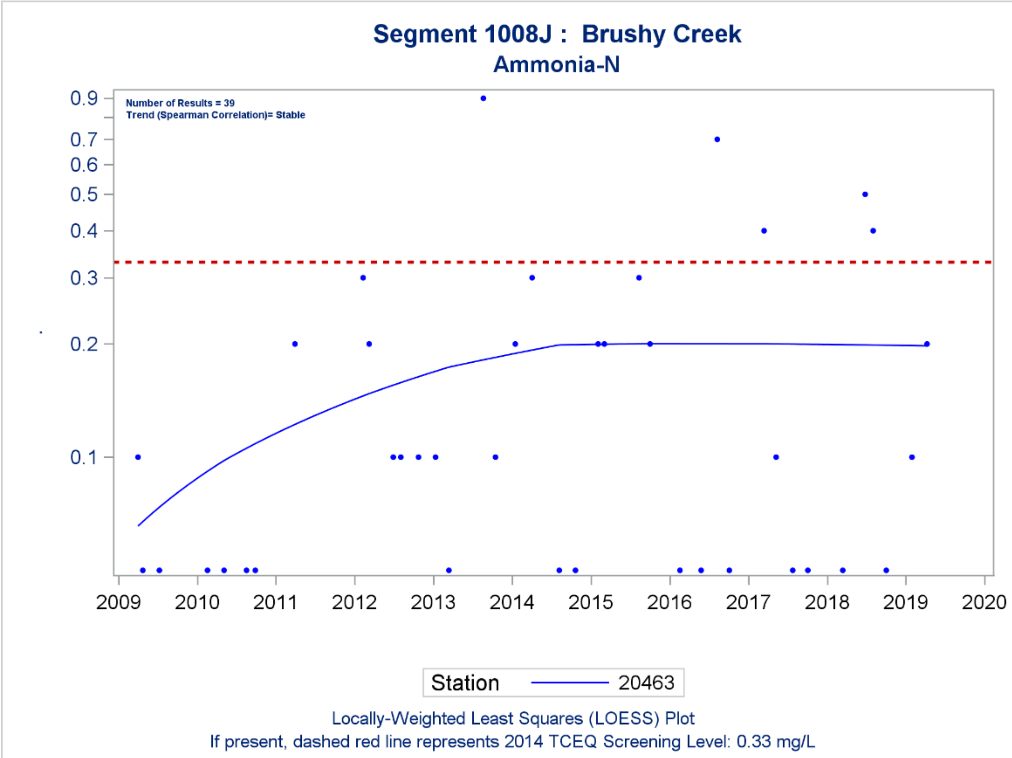

Segment 1008I : Walnut Creek
pH
Number of Results = 39
Trend (Spearman Correlation)= Stable
8.25
8
7.75
7.5
7.25
7
6.75
6.5
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
20462
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 Water Quality Standard of . S.U.

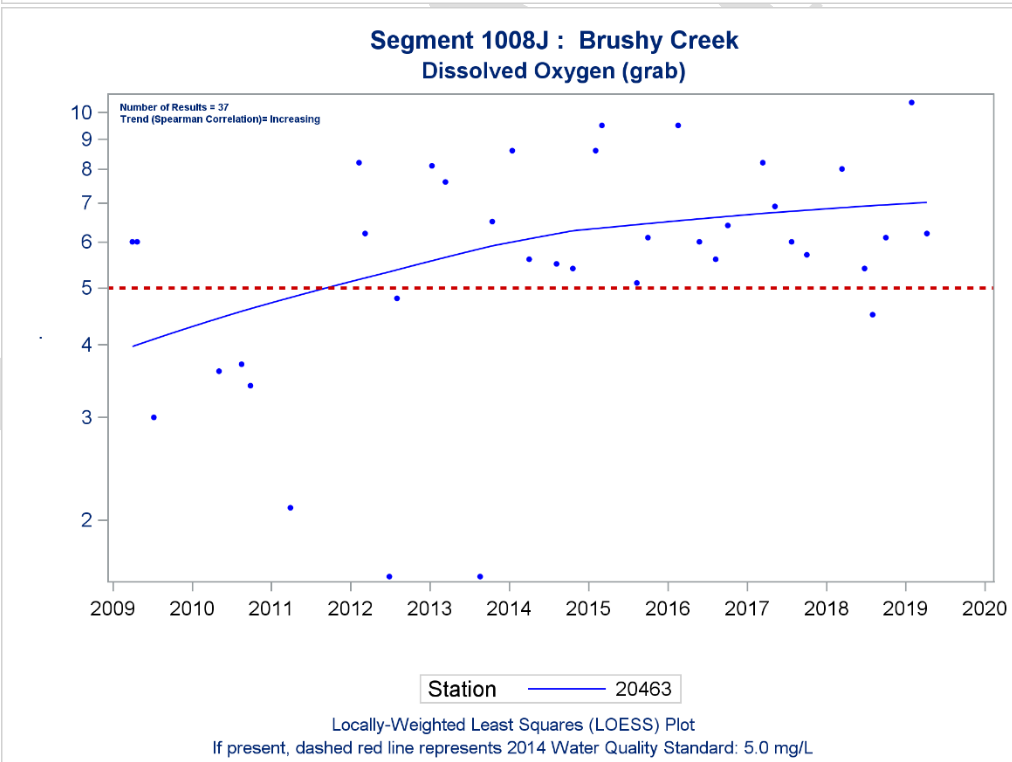

Segment 1008I : Walnut Creek
Temperature
Number of Results = 39
Trend (Spearman Correlation)= Stable
27.5
25
22.5
20
17.5
15
12.5
10
7.5
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
20462
Locally-Weighted Least Squares (LOESS) Plot

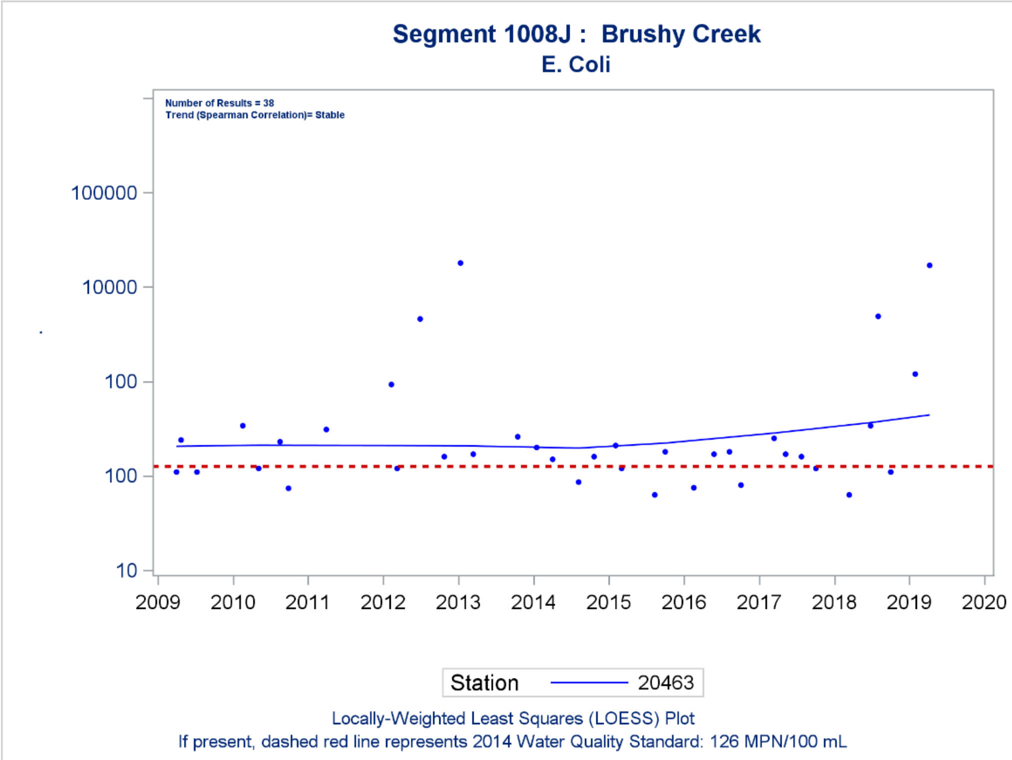

Segment 1008I : Walnut Creek
Total Phosphorus
Number of Results = 39
Trend (Spearman Correlation)= Stable
1
0.8
0.6
0.4
0.2
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
20462
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 TCEQ Screening Level: 0.69 mg/L

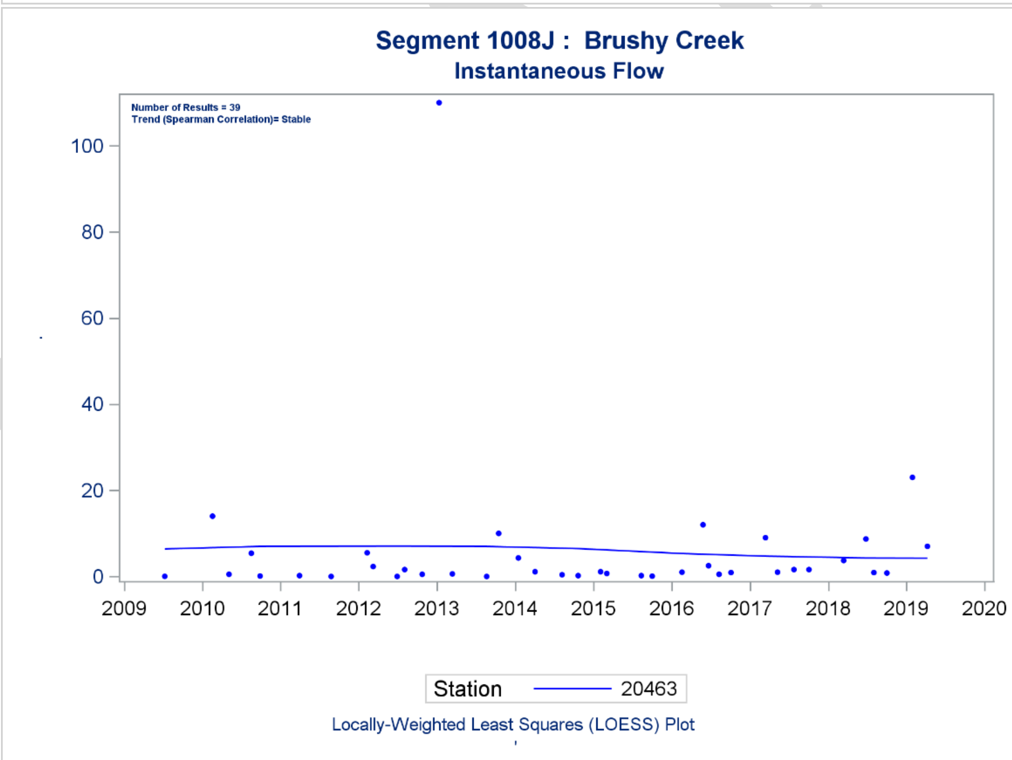


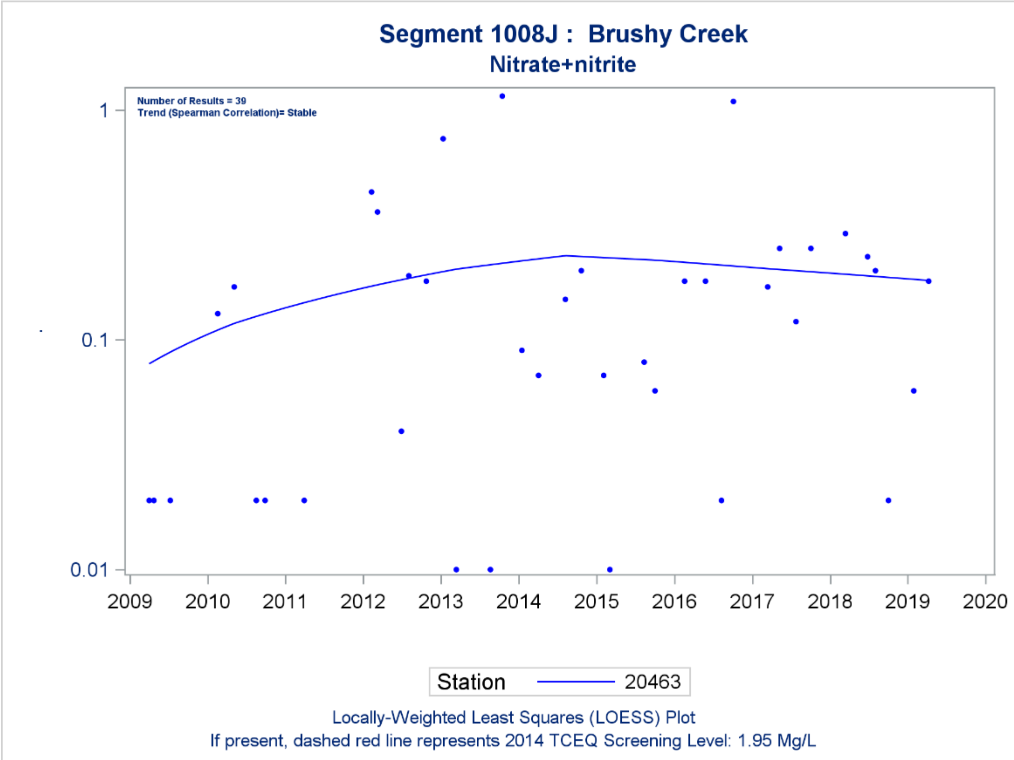
Segment 1008I : Walnut Creek
Total Suspended Solids
Number of Results = 39
Trend (Spearman Correlation)= Stable
225
175
125
100
75
50
25
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
20462
Locally-Weighted Least Squares (LOESS) Plot


Segment 1008J : Brushy Creek
Ammonia-N
Number of Results = 39
Trend (Spearman Correlation)= Stable
0.9
0.7
0.6
0.5
0.4
0.3
0.2
0.1
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station 20463
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 TCEQ Screening Level: 0.33 mg/L

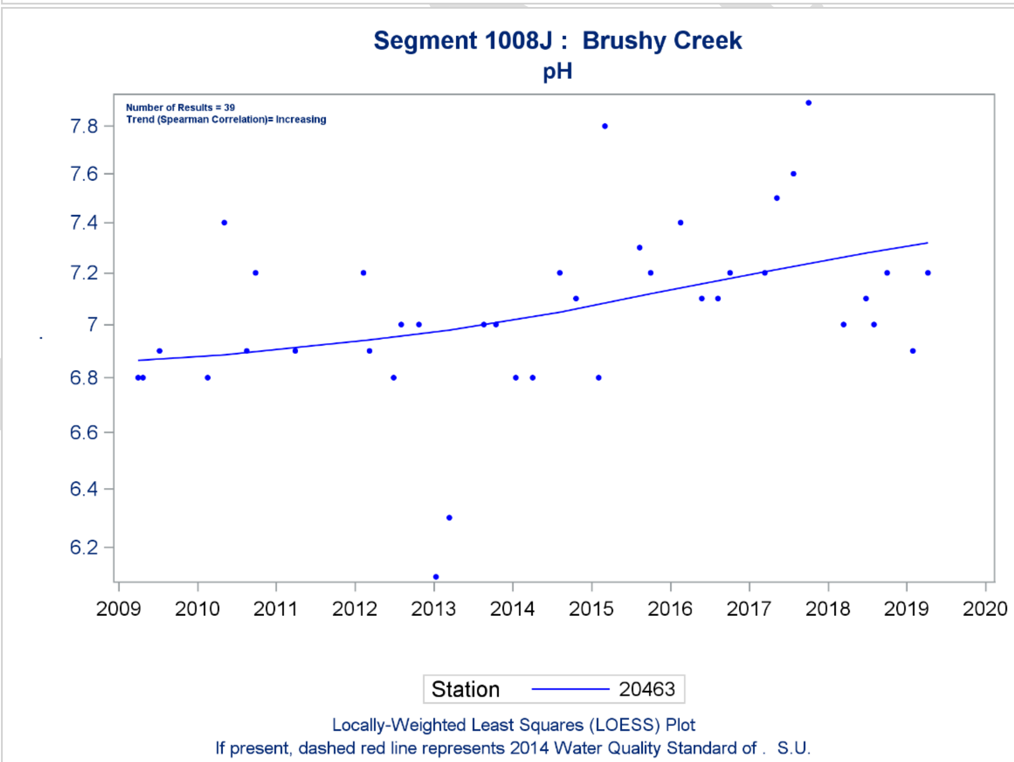

Segment 1008J : Brushy Creek
Dissolved Oxygen (grab)
Number of Results = 37
Trend (Spearman Correlation)= Increasing
10
9
8
7
6
5
4
3
2
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station 20463
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 Water Quality Standard: 5.0 mg/L


Segment 1008J : Brushy Creek
E. Coli
Number of Results = 38
Trend (Spearman Correlation)= Stable
100000
10000
100
100
10
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station 20463
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 Water Quality Standard: 126 MPN/100 mL

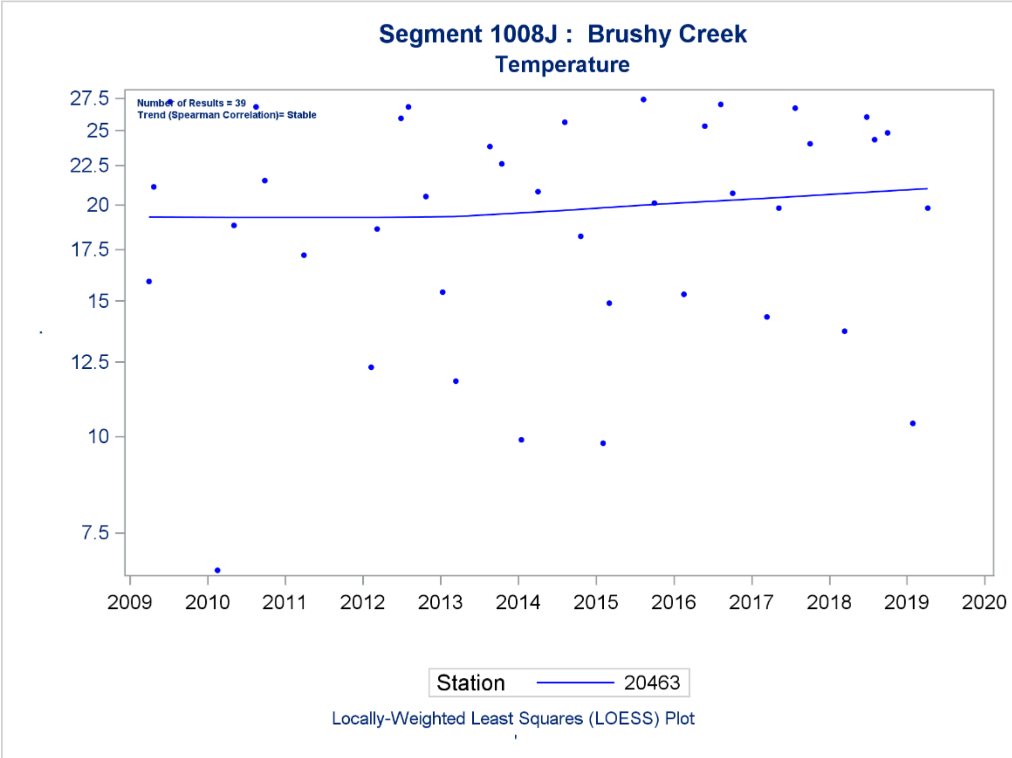

Segment 1008J : Brushy Creek
Instantaneous Flow
Number of Results = 39
Trend (Spearman Correlation)= Stable
100
80
60
40
20
0
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station 20463
Locally-Weighted Least Squares (LOESS) Plot



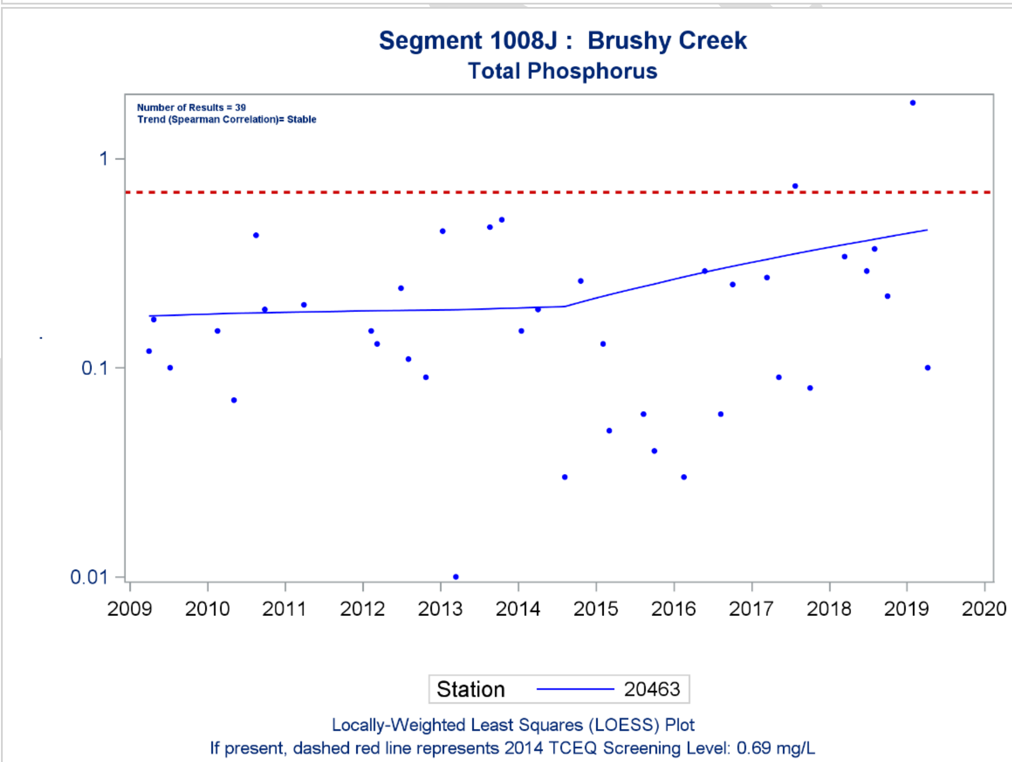
Segment 1008J : Brushy Creek
Nitrate+nitrite
Number of Results = 39
Trend (Spearman Correlation)= Stable
1
0.1
0.01
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
20463
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 TCEQ Screening Level: 1.95 Mg/L



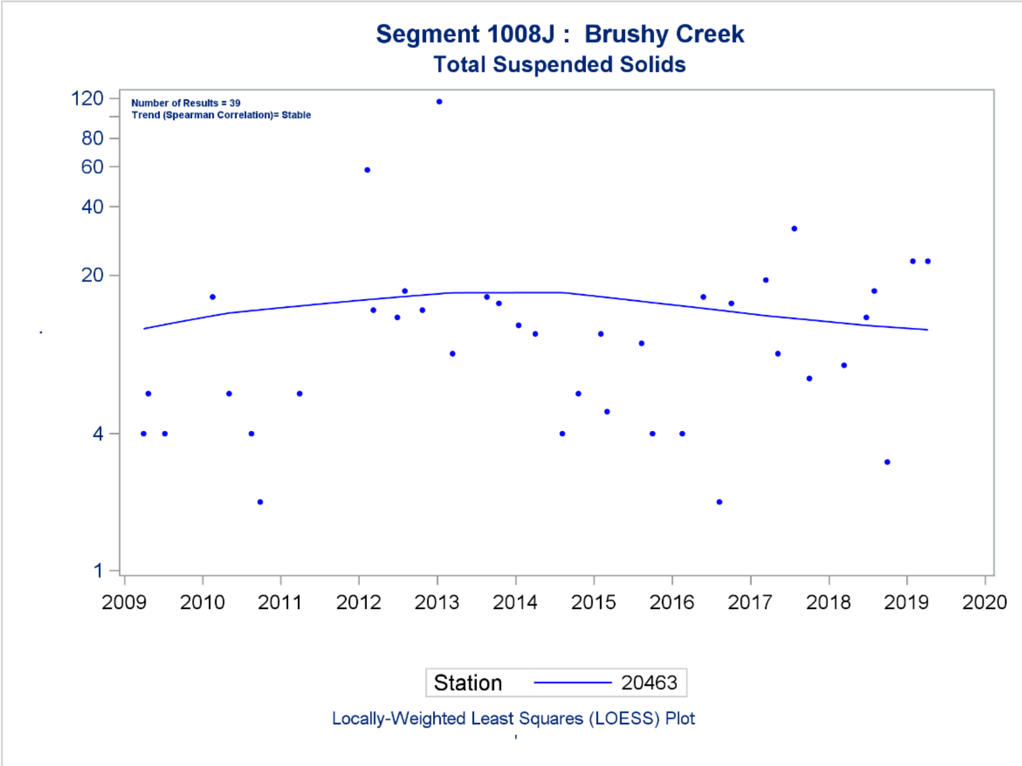
Segment 1008J : Brushy Creek
pH
Number of Results = 39
Trend (Spearman Correlation)= Increasing
7.8
7.6
7.4
7.2
7
6.8
6.6
6.4
6.2
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
20463
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 Water Quality Standard of . S.U.



Segment 1008J : Brushy Creek
Temperature
Number of Results = 39
Trend (Spearman Correlation)= Stable
27.5
25
22.5
20
17.5
15
12.5
10
7.5
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
20463
Locally-Weighted Least Squares (LOESS) Plot



Segment 1008J : Brushy Creek
Total Phosphorus
Number of Results = 39
Trend (Spearman Correlation)= Stable
1
0.1
0.01
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
20463
Locally-Weighted Least Squares (LOESS) Plot
If present, dashed red line represents 2014 TCEQ Screening Level: 0.69 mg/L



Segment 1008J : Brushy Creek
Total Suspended Solids
Number of Results = 39
Trend (Spearman Correlation)= Stable
120
80
60
40
20
4
1
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Station
20463
Locally-Weighted Least Squares (LOESS) Plot