Watershed Characterization Report
Lower Rio Grande/Río Bravo Water Quality Initiative

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and

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Executive Summary

The Rio Grande/Río Bravo is an important transboundary water resource for both the US and Mexico. In recent years, this iconic river has become seriously threatened by the border region's growing population and rapid industrialization. In addition to water availability issues, several persistent water quality problems threaten to limit the beneficial uses of the river. Among the most common water quality problems faced by the Rio Grande/Río Bravo are elevated levels of fecal indicator bacteria and higher salinity due to increasing levels of total dissolved solids.

Recognizing that water quality problems in the Rio Grande/Río Bravo were beginning to impair the uses of the river, the federal governments of the United States and Mexico agreed to collaborate on a binational pilot project to study these problems in the portion of the river between Falcon Dam and the Gulf of Mexico, a section of the river where beneficial uses are being severely affected. The pilot project, named the Lower Rio Grande/Río Bravo Water Quality Initiative (LRGWQI), was formally authorized under the US-Mexico Water Treaty of 1944 and was initiated in September 2013. The information and data analysis contained in this report resulted in large part from the collaborative effort of the researchers involved in the LRGWQI project.

Among the technical tasks described in the Terms of Reference for the LRGWQI was the characterization of the Lower Rio Grande/Río Bravo watershed. In completing this task, LRGWQI researchers compiled and analyzed data and information on meteorology, land use/land cover, geology, topography, hydrology, soils, biology, demography and historical water quality from sources on both sides of the river. LRGWQI researchers used geospatial analysis methods to identify sources of pollutants to the river and to estimate actual and potential loadings of constituents of concern from point and nonpoint sources. Additionally, LRGWQI researchers analyzed existing historical water quality data to explore relationships between observed parameters and to examine water quality trends in time. The information and analyses presented in this report identify sources of contamination on both sides of the river and highlight the need for additional wastewater infrastructure, especially in existing urban areas and rapidly urbanizing areas of the watershed.

It is logical to conclude that the outlook for water quality in the Lower Rio Grande/Río Bravo is dependent on sustained binational efforts to reduce pollutant loadings to the river. Included in these efforts should be the continued maintenance of existing wastewater collection and treatment systems, as well as the construction of new wastewater infrastructure to mitigate the effects of a growing population and a thriving industrial sector. Important to the success of these efforts is improved binational cooperation in water quality monitoring and watershed planning.

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List of Acronyms and Abbreviations

ASAE	American Society of Agricultural Engineers
BECC	Border Environmental Cooperation Commission
BEHI	Border Environmental Health Initiative
BOD	biochemical oxygen demand
BPUB	Brownsville Public Utilities Board
°C	degrees Celsius
$CBOD_5$	five-day carbonaceous biochemical oxygen demand
CEAT	Comisión Estatal del Agua de Tamaulipas
CFU	colony forming unit
CILA	Comisión Internacional de Límites y Agua
CONAGUA	Comisión Nacional del Agua
cm	centimeter
L/s	liters per second
g	gram
GIS	geographic information system
hr	hour
IBWC	International Boundary and Water Commission
INEGI	Instituto Nacional de Estadistica, Geografia, e Informatica
Kg	kilogram
Km	Kilometer
L	liter
LRG	Lower Rio Grande
LRG/RB	Lower Rio Grande/Río Bravo
LRGWQI	Lower Rio Grande/ Río Bravo Water Quality Initiative
LULC	land use and land cover
m	meter
ml	milliliter
mg	milligram
MPN	most probable number
MRLC	Multi Resolution Land Characteristics
NH_3-N	ammonia nitrogen
NMSU	New Mexico State University
NLCD	National Land Cover Dataset
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
OSSF	on-site sewerage facility
pH	inverse logarithm of hydrogen ion concentration
PTAR	planta tratadora de aguas residuales
PUB	Public Utility Board
RSI	River Systems Institute
SEDUMA	Secretaría de Desarrollo Urbano y Medio Ambiente de Tamaulipas
SSURGO	Soil Survey of the US - Regional Geographic Online Database
SUD	Special Utility District
SWQMIS	Surface Water Quality Monitoring Information System
TAC	Texas Administrative Code

TCEQ	Texas Commission on Environmental Quality
TDS	total dissolved solids
TGLO	Texas General Land Office
TP	total phosphorus
TPDES	Texas Pollutant Discharge Elimination System
TPWD	Texas Parks and Wildlife Department
TRC	Technology Research Corporation
TSS	total suspended solids
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey

Watershed Characterization Report: Lower Rio Grande/Rio Bravo Water Quality Initiative

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1.0 Introduction

The Rio Grande defines over half of the international border between the US and Mexico. In its 3051 kilometer journey from the southern Rocky Mountains of the US to the Gulf of Mexico, the Rio Grande, known in Mexico as the Río Bravo, provides a vital life line to approximately 5.5 million people living in the Texas-Mexico Border Region (TCEQ, 2016).

The fifth longest river in the US and among the top twenty longest rivers in the world, the Rio Grande/Río Bravo has a watershed that covers an area of approximately 924,300 km^2 (IBWC, 2016). The river begins in the portion of the Rocky Mountains known as the San Juan Mountains, which are located in the southern portion of the US state of Colorado. The river flows south through central New Mexico, and then flows southeast as it becomes the southernmost portion of the interstate boundary between the US states of New Mexico and Texas and then the international border between Mexico and the U.S. before it reaches the Gulf of Mexico (Figure 1-1). Flow in the upper portions of the river is sustained primarily by snowmelt from the Rocky Mountains while inflows from the Pecos River and Devils River in the US and the Río Conchos in Mexico provide over two thirds of the water flowing in the river between Texas and Mexico.

In addition to supplying drinking water to more than 5.5 million people, the Rio Grande supplies enough water to irrigate approximately 2 million acres of agricultural land (IBWC, 2016) and is also the principle water source for a large number of multinational industrial facilities, known as Maquiladoras, which are located along the Texas-Mexico border.

In the US, due to the river’s interstate nature, the Rio Grande Compact of 1938 was put into place to allocate water use and regulate interstate water sharing between the U.S. states of Colorado, New Mexico, and Texas (NMSU, 2016). In 1944, the US and Mexico signed the “Utilization of Waters of the Colorado and Tijuana Rivers and of the Rio Grande,” also known as the US-Mexico Water Treaty of 1944, which allocates water in the three transboundary rivers between the two countries (IBWC 2016a) and, in 1948, the Pecos River Compact was created between New Mexico and Texas to apportion the water of the Pecos and to develop water-saving construction initiatives on the Pecos River (NMSU 2016a).

Figure 1-1. Rio Grande/Río Bravo (RG/RB) Watershed and Study Area

In recent years, the Rio Grande has become seriously threatened by the border regions' growing population and rapid industrialization (IBWC, 2016). In addition to water availability issues related, in part, to increasingly frequent drought conditions, several persistent water quality problems threaten to limit the beneficial uses of the river. Among the most common water quality problems faced by the Rio Grande/Río Bravo are elevated levels of fecal indicator bacteria and higher salinity due to increasing levels of total dissolved solids (TCEQ, 2014).

Recognizing that water quality problems in the Rio Grande/Río Bravo were beginning to impair the uses of the river on both sides of the border, the federal governments of the United States and Mexico agreed to authorize a binational pilot project to study these problems in a portion of the river where beneficial uses were being affected. The pilot project would form the basis for binational cooperation between the two countries to address transboundary water quality issues and serve as a model for addressing binational water quality issues elsewhere in the Rio Grande/Río Bravo. To this end, the federal governments of the United States and Mexico, as well as the state governments of Texas and the Mexican state of Tamaulipas, entered into an agreement to develop a binational water quality restoration and protection plan for the Lower Rio Grande/Río Bravo downstream of Falcon Reservoir. The agreement, named the Lower Rio Grande/Río Bravo Water Quality Initiative (LRGWQI), was formally authorized under the US-Mexico Water Treaty of 1944, and was initiated by an official Exchange of Letters signed between the two countries in September 2013 (Appendix A).

The data, analysis and information contained in this report resulted in large part from the collaborative effort of the researchers involved in the LRGWQI project.

1.1 Background

The specific objectives of the LRGWQI are further described in the Terms of Reference agreed to by the U.S. and Mexican Sections of the International Boundary and Water Commission (IBWC and CILA, respectively). These include the following:

- Address current and future water quality issues of the Lower Rio Grande/Río Bravo
- Implement management procedures and programs that enable affected parties to manage wastewater discharges and improve water quality conditions
- Evaluate current wastewater discharge infrastructure and management strategies for the potential for improving the quality of effluent discharges into the Lower Rio Grande/Río Bravo
- Evaluate new mechanisms and strategies for system operations that could improve ambient water quality and address border sanitation concerns

- Improve salinity management for return flows into the Lower Lower Rio Grande/Río Bravo
- Based on the results of the evaluations carried out, implement programs and projects to meet these objectives as appropriate, and result in measurable and sustainable improvements in the ambient water quality of the Lower Rio Grande/Río Bravo

The data compilation and analysis included in this report are part of the preliminary technical efforts initiated to address the objectives specified in the Terms of Reference for the LRGWQI project. A copy of the Terms of Reference of the LRGWQI project is included in Appendix B of this report.

1.2 Study Area

The Lower Rio Grande/Río Bravo (LRG/RB) is the 450 km stretch of the LRG/RB that begins just downstream of the dam on Falcon International Reservoir and ends in the Gulf of Mexico (Figure 1-2). This portion of the river creates the southern boundary of three U.S. counties in the state of Texas (Starr, Hidalgo, and Cameron) and the northern boundary of eight Mexican municipios in the state of Tamaulipas (Mier, Miguel Alemán, Camargo, Gustavo Díaz Ordaz, Reynosa, Río Bravo, Valle Hermoso, and Matamoros). In Texas, the region surrounding this portion of the river is commonly known as the Lower Rio Grande Valley or just the “Valley.” Several major “sister cities” are located in the Lower Rio Grande Valley (i.e., urban areas located directly across the river or in close proximity across the international boundary from each other), including Reynosa-McAllen and Matamoros-Brownsville. Several other smaller sister cities are also located in the upper portions of the LRG/RB and include Camargo-Rio Grande City, and Miguel Alemán-Roma (Figure 1-3).

1.3 Problem Definition

From the perspective of the US participants in the LRGWQI, the pollutants of concern to be addressed by the initiative were the ones listed in the 2012 Texas Integrated Report of Surface Water Quality (TCEQ, 2012). The report is a biennial analysis of surface water quality monitoring conducted by the TCEQ in water bodies throughout the State of Texas. The surface water quality segments designated in the Texas Surface Water Quality Standards (30 TAC Chapter 307) for LRG/RB are Segments 2302 (Rio Grande Below Falcon Reservoir) and 2301 (Rio Grande Tidal).

Figures 1-2 and 1-3 show the TCEQ-designated segments of LRG/RB and their associated transboundary watershed. Table 1-1 shows the water quality impairment and concerns which appear on the 2012 Texas Integrated Report of Surface Water Quality for Segment 2302 Segment 2301. It is important to note that, while dissolved oxygen, ammonia and nutrients are concerns in the Lower Rio Grande, the only actual impairment listed for either segment of the river is fecal indicator bacteria in Segment 2302.

Mexican interest in participating the LRGWQI is also linked to the results of Mexican water quality monitoring and to plans, by the Comisión Nacional del Agua (CONAGUA), to conduct a special study, known as a Declaratoria de Clasificación, on the LRG/RB.

In addition to the water quality impairment and concerns included in Table 1-1, the US and Mexican LRGWQI Partners agreed to investigate sources of salinity in the river upstream of the Gulf of Mexico's tidal influence on the river (i.e., upstream of TCEQ Segment 2301).

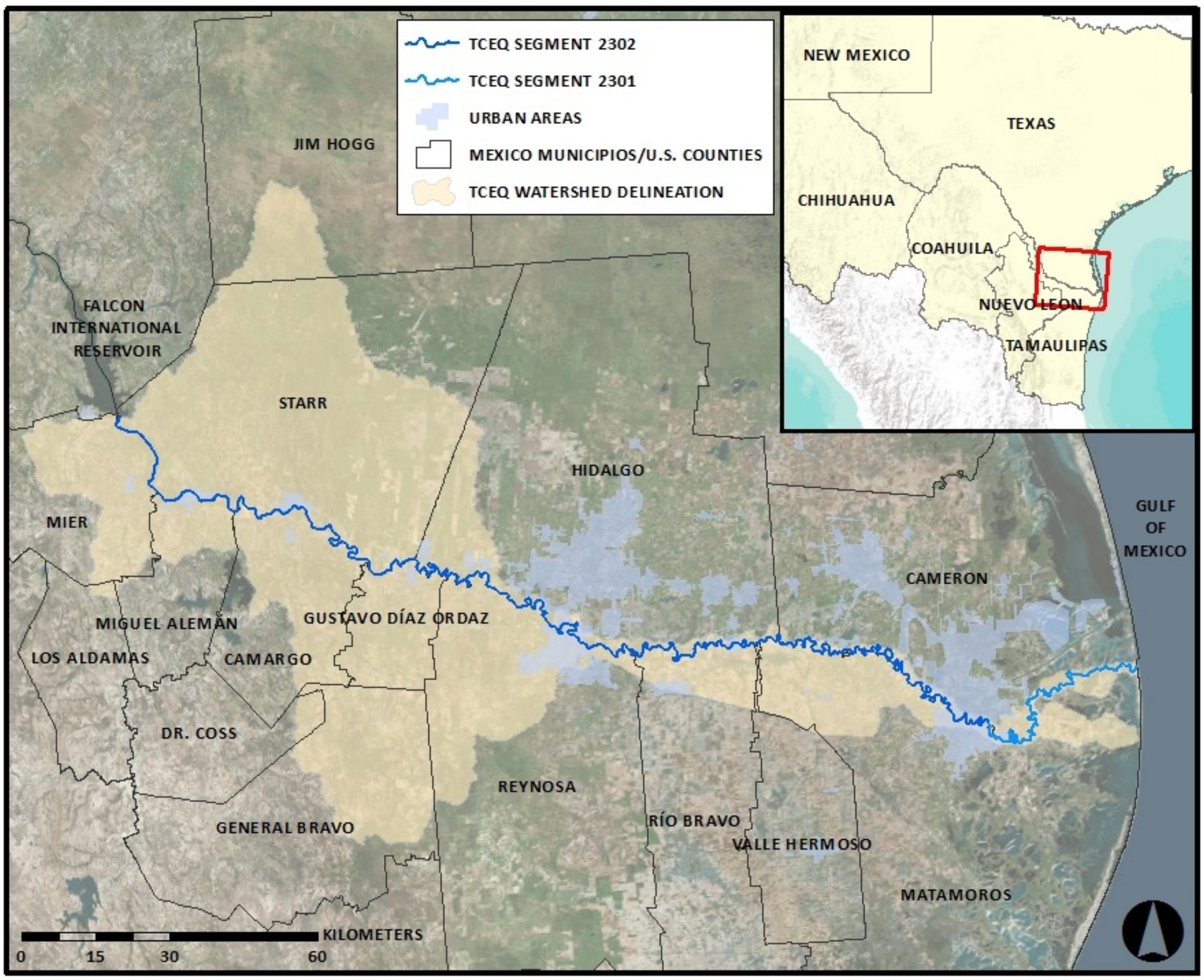


Figure 1-2. The Lower Rio Grande/Rio Bravo (LRG/RB) and Its Surrounding Watershed

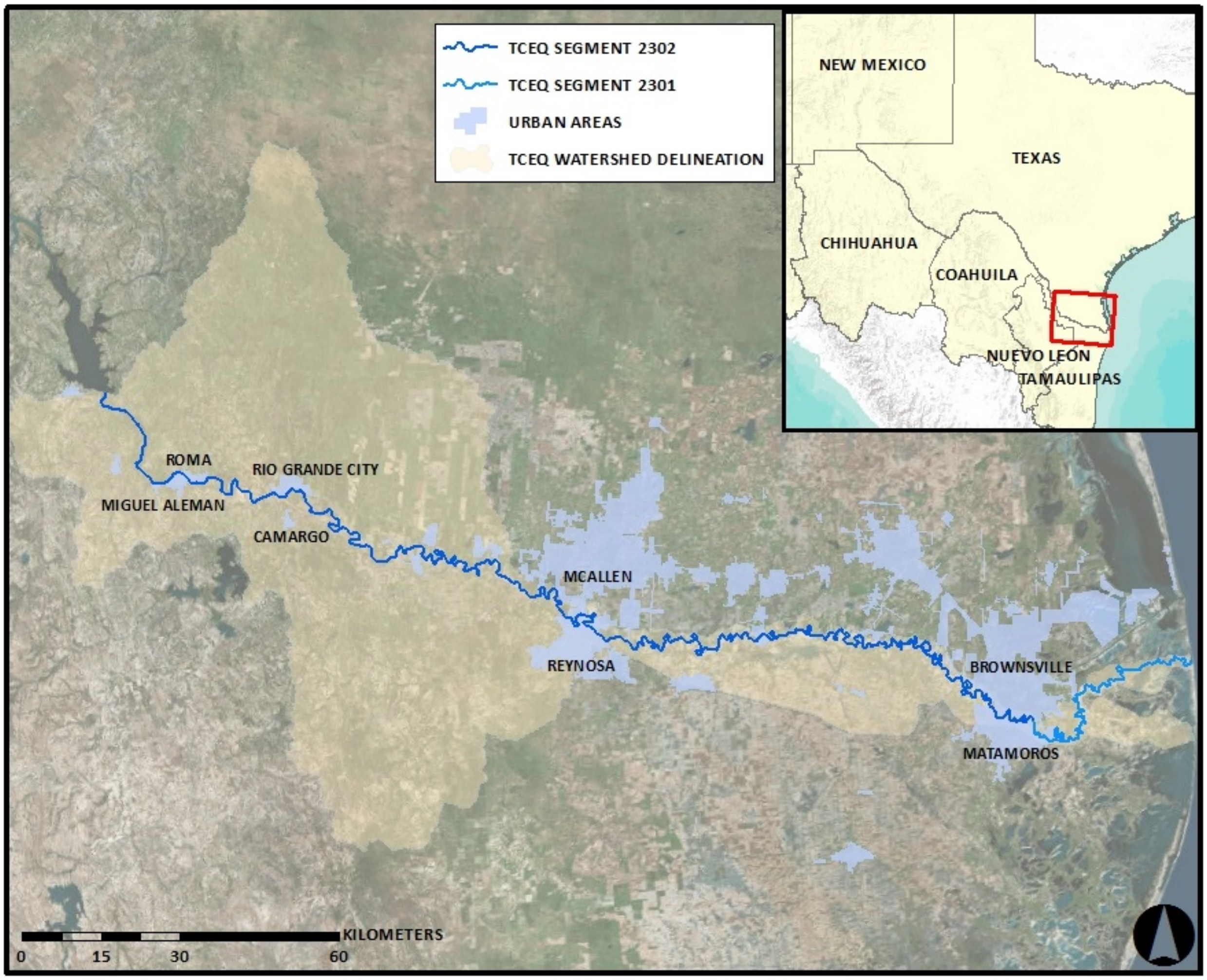


Figure 1-3. Major "Sister" Cities in the LRG/RB "Valley"

Table 1-1. Water Quality Impairment and Concerns Listed in the 2012 Texas Integrated Report of Surface Water Quality for Lower Rio Grande

Segment Number	Segment Description	Impairment	Year Listed	Concerns
2302	Rio Grande Below Falcon Reservoir	Bacteria	1996	Ammonia Nutrients Low Dissolved Oxygen
2301	Rio Grande Tidal	NA	NA	Bacteria Nutrients

2.0 Previous Work

The LRG/RB and its tributaries have been monitored and studied for many years by binational, national, and state agencies and academic institutions. A number of these efforts have included the characterization of potential pollutant sources in the watershed, including wastewater outfalls and nonpoint sources of pollution. LRGWQI researchers gathered data and information from a number of these reports, other published reports and from other data sources. Important information on wastewater treatment infrastructure was also collected and compiled from project certification documents used by infrastructure funding organizations, such as the Border Environmental Cooperation Commission (BECC). Much of this information is available on internet web sites in the form of accessible data sets and/or published reports.

Among the data and reports compiled and reviewed as part of the LRGWQI were analyses of historical and synoptic water quality data collected by the IBWC, CONAGUA, TCEQ and the Instituto Tecnológico y de Estudios Superiores de Monterrey. Below is a brief description of six important data compilation and analyses efforts, which helped inform the characterization of the LRG/RB watershed presented in this report.

2.1 US Agency for International Development (USAID, 2009)

In 2009, under contract with Abt Associates Inc. for USAID, the Instituto Tecnológico y de Estudios Superiores de Monterrey completed the report titled "Evaluación de la Calidad del Agua del Bajo Río Bravo con Enfoque en Su Saneamiento y Protección de Fuentes de Abastecimiento." The report summarized the result of synoptic water quality monitoring efforts conducted on the LRG/RB and a number of its tributaries in Tamaulipas and Nuevo Leon in 2009. Additionally, the study assessed the state of water and wastewater infrastructure and its impact on water quality in the river.

The report concluded that there were, at the time of the report, discharges to the LRG/RB that affected its water quality and that, given the river's use as a drinking water supply, the discharges represented a serious health problem.

2.2 River Systems Institute (RSI) – Texas State University (2010, 2010a)

In 2010, Texas State University's River Systems Institute (RSI) completed a "Historical Data Review and Analysis of Selected Segments of the Rio Grande: Analysis of Bacterial Water Quality and Associated Parameters" (RSI, 2010) and a "Bacteria Load Analysis Report of Selected Segments of the Rio Grande" (RSI, 2010a). Both studies were commissioned by the TCEQ and examined water quality monitoring data collected under the TCEQ's Surface Water Quality Monitoring and Clean Rivers programs from 2002 to 2008. The studies also investigated potential loadings of fecal indicator bacteria (fecal coliform and *E. coli*) to the river.

The RSI reports segregated the results of their data analyses into four sections, each section associated with lotic (non-reservoir) portions of the river. One of the portions of the river detailed in these reports was the RG/RB below Falcon Reservoir (TCEQ Segment 2302). In addition to confirming bacteria impairments listed by the TCEQ in the LRG/RB near Anzalduas Dam, the McAllen/Reynosa area, and near Ranch Viejo in the Brownsville/Matamoros area, the reports found high levels of indicator bacteria in a portion of the river located near Rio Grande City.

The reports highlighted an apparent geographic association between areas of high population density and population growth and high bacteria levels in the river. The report also analyzed bacteria levels with respect to precipitation, concluding that high bacteria levels occurred in the river during episodes of both high precipitation and during dry weather periods.

2.3 IBWC Reports (2011, 2013 and 2014)

In 2011, the IBWC completed a special study designed to investigate the sources of indicator bacteria in the LRG/RB near Brownsville, Texas. The study included synoptic monitoring of indicator bacteria in the river and in a number of ditches and outfalls flowing into the river in the area near the cities of Brownsville and Matamoros. The results of the study, summarized in a report titled "Bacteria Characterization in Segment 2302_01 of the Rio Grande near Brownsville, Texas," showed that fecal indicator bacteria in the LRG/RB had fallen significantly between 2008 and 2011. The report stated that the likely reason for the reduction in bacteria was the completion of a new large capacity wastewater treatment facility in Matamoros, Tamaulipas. The report did, however, note a "spike" in bacteria concentrations in May of 2010 and it identified a number of non-permitted outfalls that appeared to contribute flow to the river at steady state conditions.

In 2013, the IBWC published a "Rio Grande Basin Summary Report," which summarized and presented water quality monitoring data collected by the IBWC and its partners in the international portion of the Rio Grande Basin. The IBWC produces Basin Summary Reports approximately every five years under a state-federal water quality monitoring partnership program known as the Clean Rivers Program. The reports present water quality data trends and other information about portions of the river monitored under the program, including the LRG/RB.

The IBWC's 2013 Rio Grande Basin Summary Report confirmed fecal indicator bacteria impairments in the upper portion of the LRG/RB downstream of Falcon Dam and in the lower portion of the river near Brownsville. The report also presented trend analyses indicating increasing trends in *E. coli* in the river near Rio Grande City, increasing salinity in the river downstream of McAllen/Reynosa and decreasing dissolved oxygen in the tidally influenced portion of the river near its confluence with the Gulf of Mexico.

In December of 2013, under contract with the IBWC, the engineering and environmental consulting firm, TRC, conducted a synoptic survey of the LRG/RB to identify and characterize potential discharge and diversion points affecting selected reaches of the LRG/RB. As part of the study, TRC sampled three reaches of the LRG/RB, including an 11.75 Km stretch of the river near Rio Grande City, Texas, a 41.7 Km stretch of the LRG/RB near Reynosa, Tamaulipas, and a 12.9 Km stretch of the LRG/RB near Progreso, Texas. The results of the study were summarized in a 2014 report titled "Synoptic Survey Report of Selected Areas in the Lower Rio Grande."

In addition to identifying 79 potential diversion and/or discharge points during the survey, analytical results of water samples collected by TRC at five discharge points flowing into the river showed elevated levels of indicator bacteria, biochemical oxygen demand and ammonia nitrogen. The synoptic survey of discharge points was conducted during dry weather conditions, which suggested a steady state nonpoint source contribution of these pollutants to the river.

3.0 Watershed Description

The maps in Figures 1-2 and 1-3 show the extent of the LRG/RB watershed as delineated by the LRGWQI. The total transboundary watershed area is approximately 7316 Km^2. Although the upper portion of the LRG/RB watershed is defined by Falcon Dam, the headwaters of the two largest tributaries, the Río Alamo and the Río San Juan, are located in the mountains of the northern Mexican states of Nuevo Leon and Coahuila, respectively. Therefore, even with the northern boundary of the watershed set at Falcon Dam, the natural watershed of the LRG/RB actually extends deep into the interior of Mexico (Figure 1-1). However, both the Río Alamo and the Río San Juan are impounded by dams located within 20 Km of the LRG/RB. The resulting reservoirs, Las Blancas on the Río Alamo and Marte R. Gomez on the Río San Juan, which provide a reliable source of fresh water to the northern portion of the Mexican state of Tamaulipas, also provide a convenient western limit of the LRG/RB's watershed.

The resulting transboundary watershed is an area with similar areal extent on both sides of the LRG/RB, 4032 km^2 on the US side and 3285 km^2 on the Mexican side. Flow and water quality monitoring conducted at historical flow gage stations located directly downstream of the three dams provides background flow and water quality information for the headwaters of the LRG/RB and for its two major tributaries.

3.1 Climate and Meteorology

The LRG/RB watershed is located in a subtropical region of North America with hot, usually humid, summers and mild winters (Parcher, 2010). Annual average high temperature in the watershed is 34.17^oC, the highest average temperatures typically occur in the month of August. Average annual low temperatures range from 7.78^oC near Rio Grande City to 10.61^oC near Brownsville (NOAA, 2016). Occasional artic and pacific cold fronts bring short-term freezing temperatures to the watershed.

The climate in the LRG/RB watershed is classified as semi-arid to arid. Annual average rainfall ranges from 410.4 mm in the upper portion of the watershed near Falcon Reservoir to 649.7 mm near Brownsville (NOAA, 2016).

3.1.1 Precipitation

Average annual precipitation varies significantly from one portion of the LRG/RB watershed to the other, increasing by approximately 40% from the headwaters near Falcon Dam to mouth of the river near Brownsville/Matamoros (Figure 3-1). Tropical storms and hurricanes in the Gulf of Mexico and the Mexican Pacific Coast strongly influence yearly rainfall and climate patterns in the LRG/RB watershed (Parcher, 2010). The hurricane season lasts from June 1, until November 30. During this season, storms can generate extreme amounts of precipitation in short periods of time, sometimes causing severe flooding in the watershed.

Figure 3-2 shows average annual rainfall totals measured in the Rio Grande Valley of south Texas. Despite an average annual rainfall exceeding 600 mm, the LRG/RB watershed is subject to prolonged periods of drought.

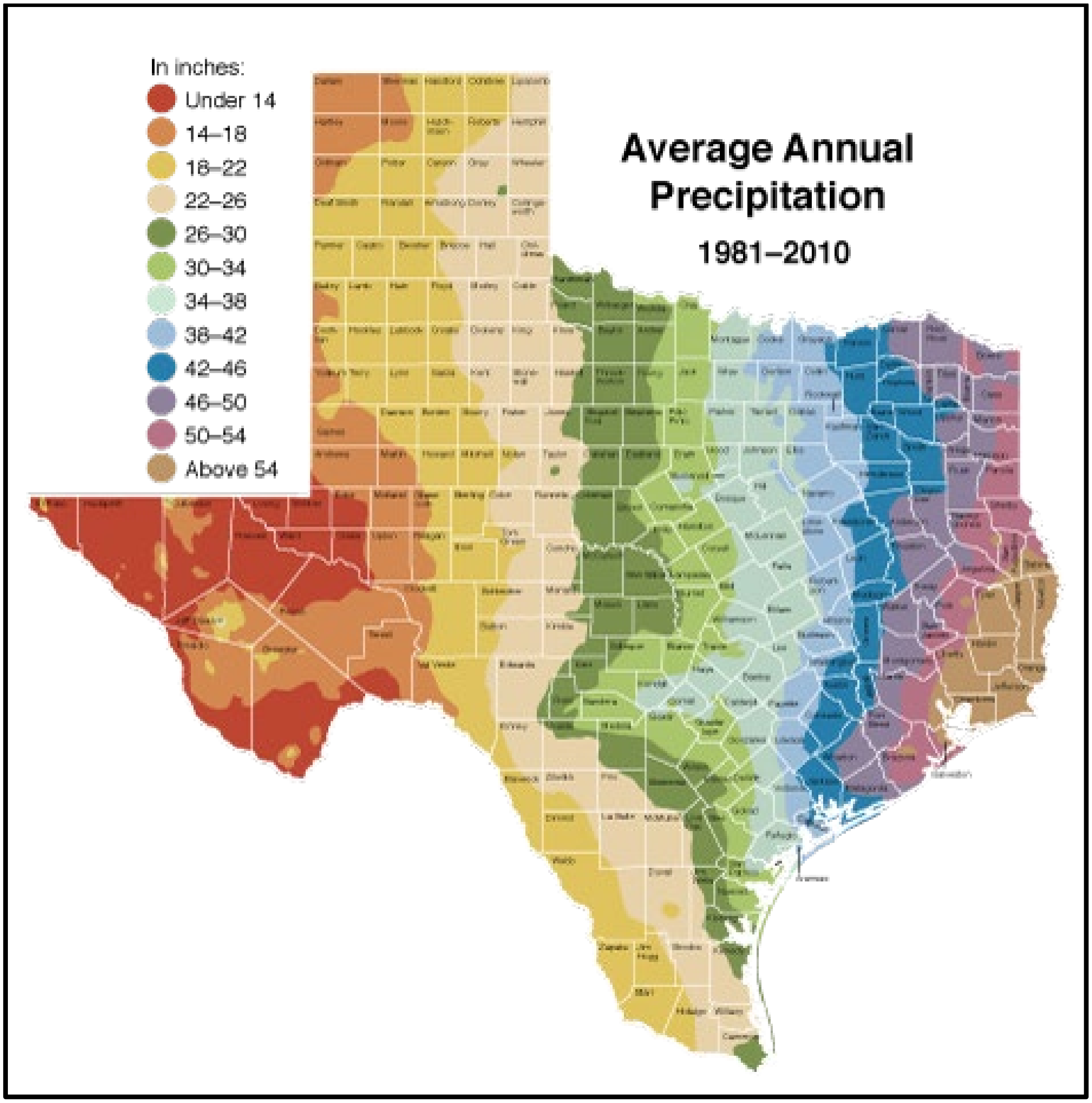


Figure 3-1. Average Annual Precipitation in the State of Texas1981-2010. Source: Texas Historical Association – TexasAlmanac.com.

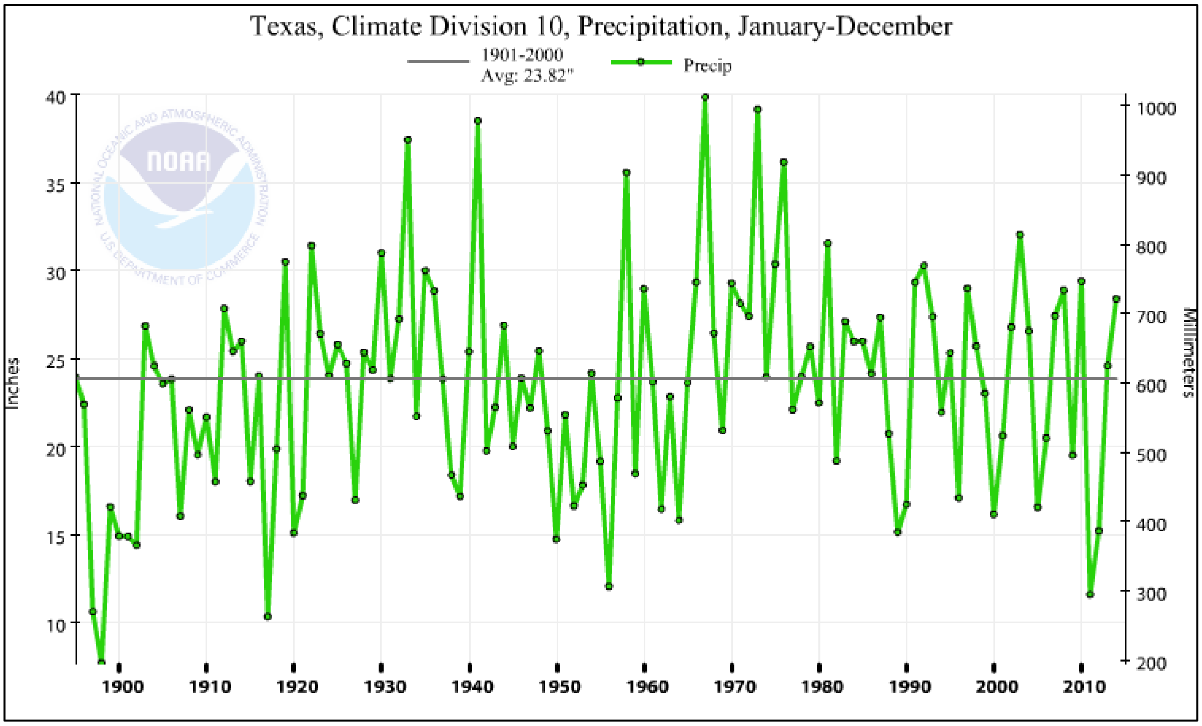


Figure 3-2. Average Annual Rainfall in the Rio Grande Valley, South Texas

The Texas Water Development Board defines drought conditions as those in which evapotranspiration rates are higher than precipitation rates causing overall water loss in a region. Decreases in rainfall and/or increases in temperature can cause this to occur leading to lower levels in the reservoirs and in river channels (Parcher, 2010). The Palmer Drought Severity Index (PDSI) is a measure of drought that has a scale from -6.0 (extremely dry) to +6.0 (extremely moist) with zero being "normal" moisture for the area. On this scale, the Rio Grande Valley has an annual average of 0.5 below the normal (Figure 3-3). This means that, on average, the area has experienced more dry periods than wet periods and has typically been below normal moisture conditions since 1895. Since 1994, a serious drought in the region has caused major economic loss on both sides of the border due to water shortages. Besides economic loss, water shortages can impair biodiversity and damage the ecological health of a watershed.

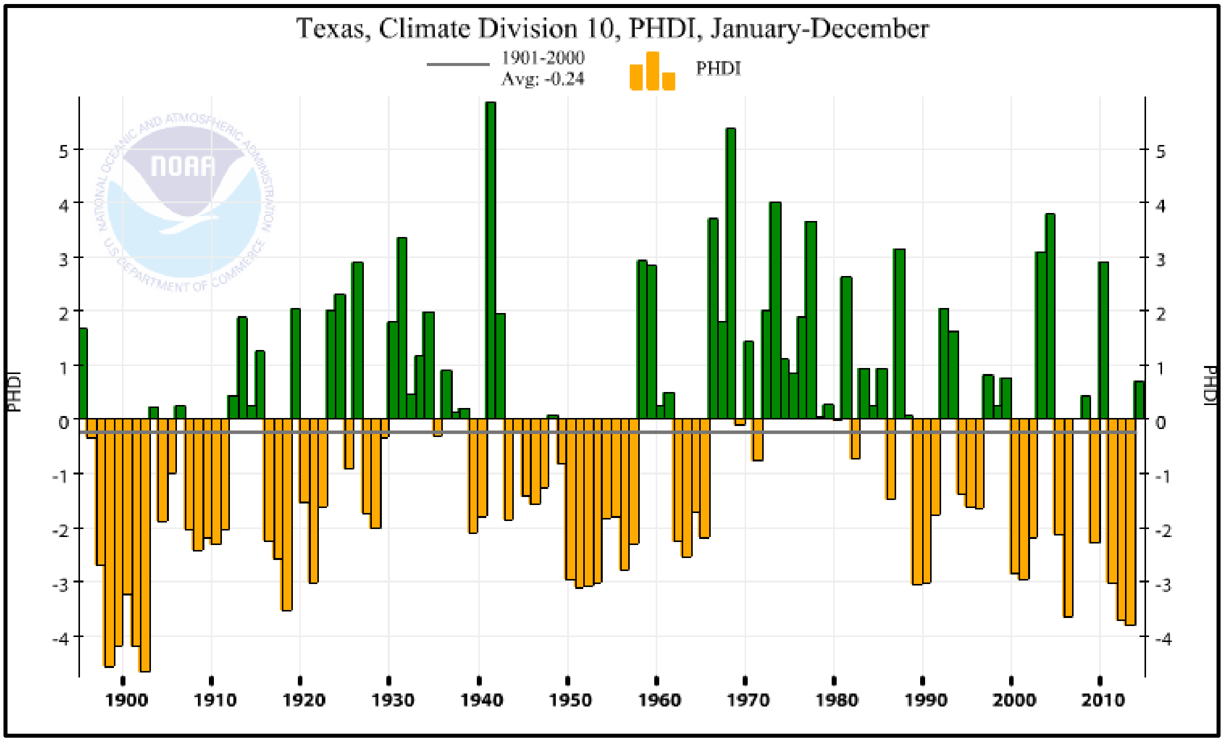


Figure 3-3. Palmer Hydrologic Drought Index (PDHI) for a Portion of the Texas Lower Rio Grande Valley (i.e., Hidalgo and Cameron Counties). Source: National Climatic Data Center (2007).

3.2 Land use and Land Cover

Figure 3-4 shows land use and land cover in the LRG/RB watershed. The seamless binational land cover dataset displayed in Figure 3-4 was developed jointly by the US Geological Survey (USGS) and Mexico's Instituto Nacional de Estadistica, Geografia, e Informatica (INEGI) as part of the Border Health Intitiative (USGS, 2015). This binational land cover dataset combines the US' Multi-Resolution Land Characteristics Consortium (MRLC) land use/land cover classification scheme (a modified Anderson level I and II at a scale of 1:100,000) with INEGI's Uso de Suelo y Vegetacion Serie III classification (1:250,000). The resulting land use/land cover (LULC) classes are consistent across the international border and consist of eight different LULC classifications: developed, agriculture, forest, shrub, water, barren, grass/pasture, and wetland. The source of the data are Landsat 5 and 7 images taken in 2001.

Overall, 4.72 percent of the LRG/RB watershed is classified as developed or built-up urban land and 24.29 percent is used for agriculture (Table 3-1). Approximately 35 percent of the watershed is pasture, hay, or grasslands and 33 percent is shrub or scrublands. Wetlands comprise only 2 percent of the total watershed area.

Tables 3-2 and 3-3 provide country-specific detail regarding land use and cover in the LRG/RB watershed.

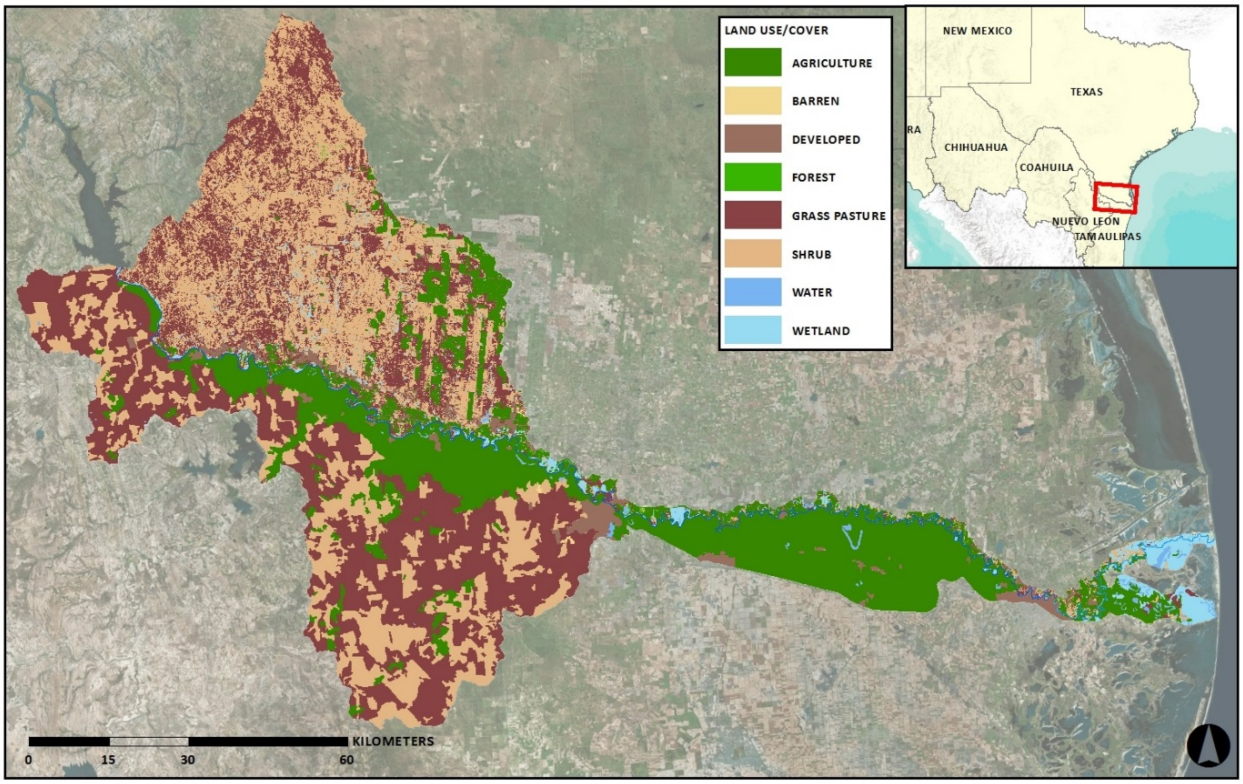


Figure 3-4. Land Use and Land Cover in the LRG/RB Watershed

Table 3-1. Land Use/land Cover in the LRG/RB Watershed

Land Cover Category†	Area (Km²)	Percent LRG/RB Watershed Total
Agriculture	1,776.88	24.29%
Barren Land	14.26	0.19%
Developed/Urban	345.07	4.72%
Forrest	16.05	0.22%
Pasture Hay/Grasslands	2,548.82	34.84%
Shrub/Scrub	2,418.43	33.05%
Wetlands	156.26	2.14%
Water	40.68	0.56%
Total	7,316.45	100.00%

Table 3-2. Land Use/Land Cover in the Mexican Portion of the LRG/RB Watershed

Land Cover Category	Area (Km^2)	Percent LRG/RB Watershed MX Side	Percent LRG/RB Watershed Total
Agriculture	1,344.01	33.34%	18.37%
Barren Land	2.82	0.07%	0.04%
Developed/Urban	106.28	2.64%	1.45%
Forrest	0.03	<0.001%	<0.001%
Pasture Hay/Grasslands	1,572.77	39.01%	21.50%
Shrub/Scrub	945.43	23.45%	12.92%
Wetlands	37.40	0.93%	0.51%
Water	22.94	0.57%	0.31%
Total	4,031.67	100.00%	55.10%

Table 3-3. Land Use/Land Cover in the US Portion of the LRG/RB Watershed

Land Cover Category	Area (Km^2)	Percent LRG/RB Watershed US Side	Percent LRG/RB Watershed Total
Agriculture	432.88	13.18%	5.92%
Barren Land	11.44	0.35%	0.16%
Developed/Urban	238.79	7.27%	3.26%
Forrest	16.05	0.49%	0.22%
Pasture Hay/Grasslands	976.05	29.71%	13.34%
Shrub/Scrub	1,473.00	44.84%	20.13%
Wetlands	118.87	3.62%	1.62%
Water	17.74	0.54%	0.24%
Total	3,284.81	100.00%	44.90%

3.3 Geology, Topography, and Soils

The geology, topography and soils in a river's watershed influence the physical and ecological properties of the river. Below is a summary of the geology, topography and soils of the LRG/RB watershed.

3.3.1 Geology

The LRG/RB watershed is located in the western Gulf of Mexico coastal plain at the base of outcropping tertiary geologic units of the Goliad, Catahoula, Frio and Vicksburg formations, which are composed mainly of Miocene sandstones and clays. In the northern and western portions of the watershed coarser fluvial sedimentary formations of the Eocene Jackson and Wilcox groups are found, along with Oligocene conglomerates (Figure 3-5). Quaternary alluvial sediments and terrace/floodplain deposits dominate the riparian areas surrounding the river and its tributaries.

3.3.2 Topography

The southern and eastern portions of the LRG/RB watershed lie in the ecological region classified by the USEPA as the Lower Rio Grande Alluvial Plain, while the northwestern parts lie in the Texas-Tamaulipan Thorn Scrub region. The terrain is generally level and low in most of the watershed. The elevation of the watershed varies from sea level at the Gulf Coast to approximately 300 meters (m) above mean sea level at its highest extent, with an average slope of only 40 cm/km, or 0.04% (Figure 3-6).

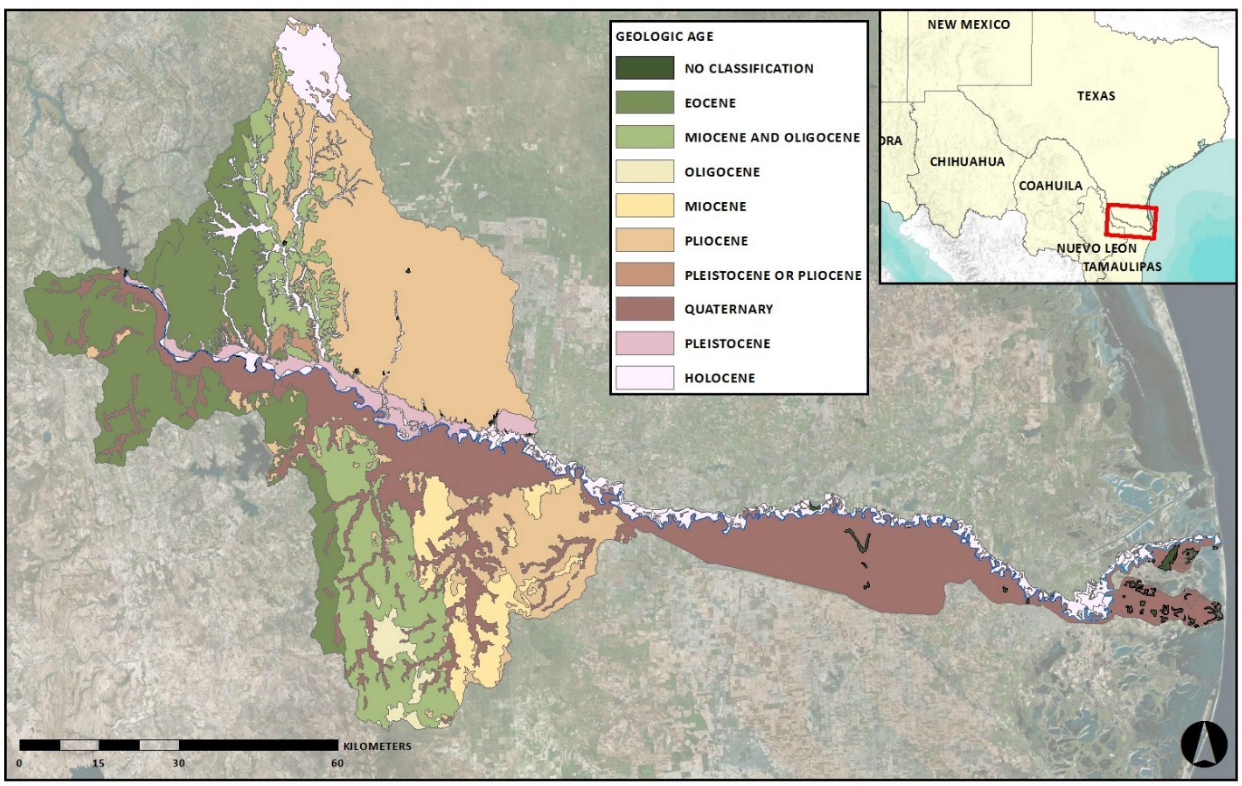


Figure 3-5. Geologic Rock Formations in the LRG/RB Watershed

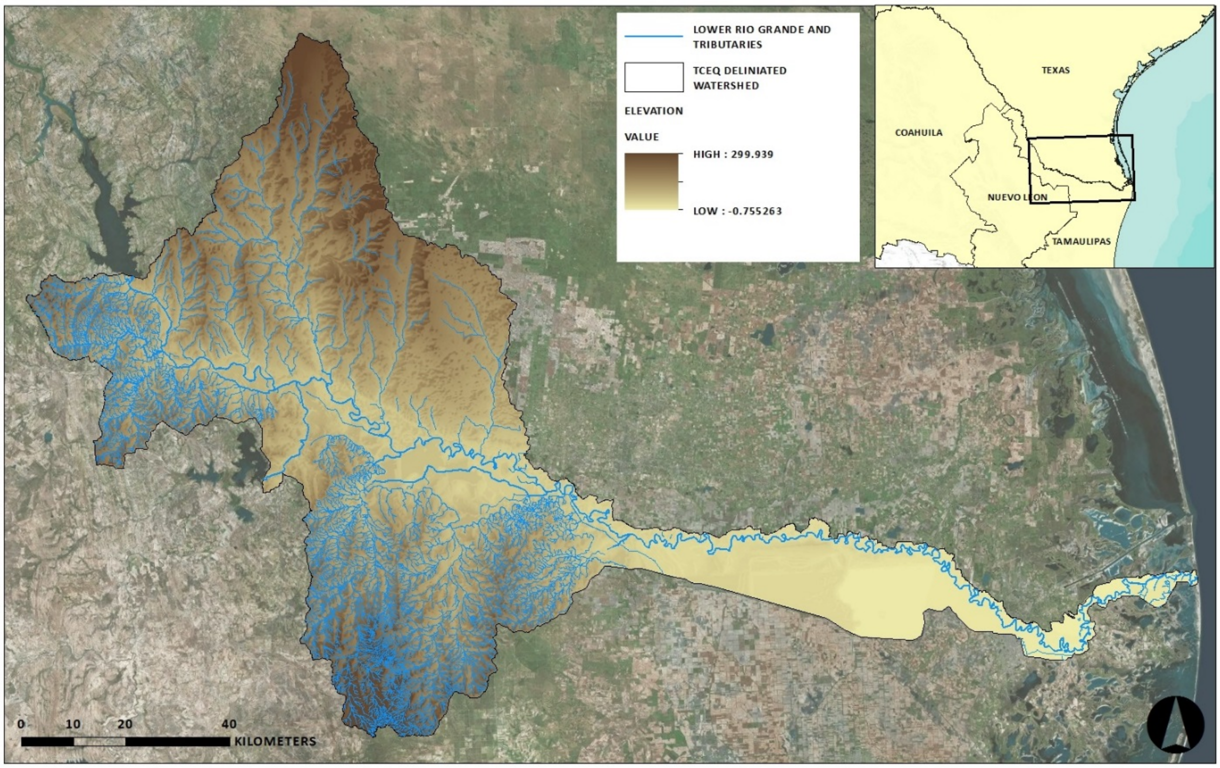


Figure 3-6. Topography and Hydrology in the LRG/RB Watershed

3.3.3 Soils

Like the binational data layers presented in Figures 3-4 through 3-6, the transboundary soils layer shown in Figure 3-7 was produced by the Border Environmental Health Initiative (BEHI) project and combines the USDA's SSURGO dataset (USDA, 2004) with data from INEGI's Edafologia - Perfiles de Suelo (INEGI, 1970). The resulting dataset combines the soil classification systems of the two data sources to produce a seamless binational soils layer extending across the LRG/RB watershed.

Soils in the LRG/RB watershed are primarily fine-textured and well drained. Aridisol and entisol soil types dominate the northern and western portions of the watershed, while vertisols are prominent in the southern and eastern portions of the watershed. Limited leaching in aridisol soil types often results in one or more subsurface soil horizons in which suspended or dissolved minerals have been deposited, including silicate clays, sodium, calcium carbonate, gypsum or other soluble salts. Accumulation of salts on the surface can result in soil salinization. Vertisol soil types in the southern portion of the watershed can have high water holding capacity, and very slow water permeability. Together with the low and level topography, these soil properties give rise to scattered marshes and wetlands in the coastal portion of the LRG/RB watershed.

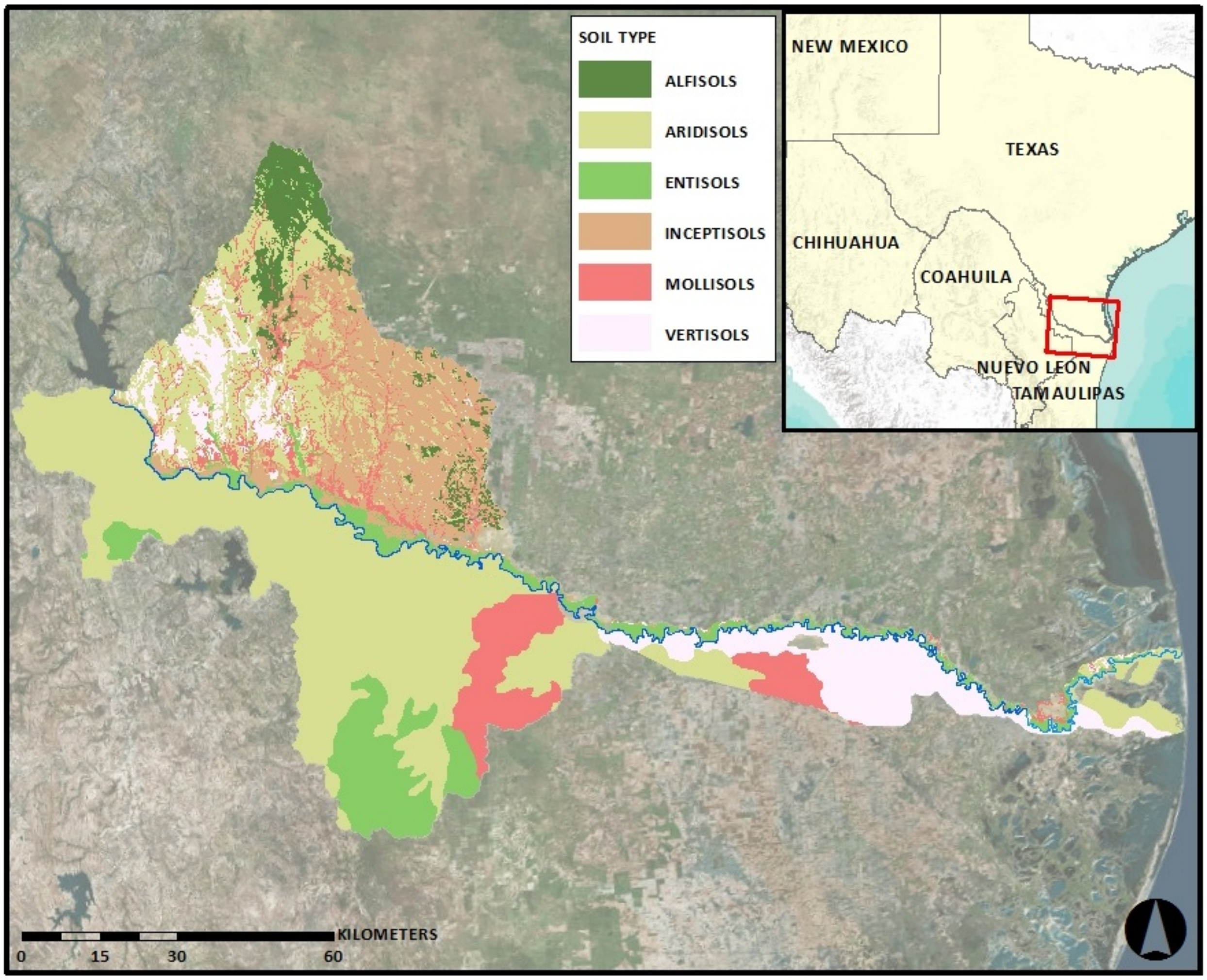


Figure 3-7. Soil Types in the LRG/RB Watershed

3.4 Hydrology

The mainly fluvial hydrology of the LRG/RB is characterized by its coastal-deltaic nature. For most of its length, the LRG/RB fluvial system meanders through large areas of relatively flat land, with a mean change in elevation of approximately 40 meters over a distance of 100 Km (Figure 3-6). As is the case with most large rivers approaching terminal grade, the coastal plain of the LRG/RB forms a natural web of distributary channels and oxbow lakes, which intensify in number and size as the riparian areas of the river enter the deltaic plain. Many of these channels and lakes, known locally as "resacas," are used for conveyance of water from the river for municipal and agricultural use.

Perennial contributions to flow in the LRG/RB are rare, with the only measureable natural tributary inflows coming from the Río Alamo and the Río San Juan. In recent years, the natural flow from these two tributaries has diminished due to the relatively recent impoundments of these two contributing rivers into the Las Blancas and Marte R. Gomez reservoirs, respectively, and an increase in agricultural water use from these reservoirs. Flow contributions to the LRG/RB, from base flow, are likely, although the exact amount of these base flow contributions has not been well studied. The LRG/RB also receives seasonal flow contributions from several large drains which carry return flows from irrigated agricultural land primarily on the Mexican side of the watershed.

The final 79 Km stretch of the river, prior to its confluence with the Gulf of Mexico, is influenced by tidal forcing and becomes increasingly brackish in a downstream direction. The flow of seawater upstream is dependent on tidal conditions as well as on the flow conditions of the river. Often in this portion of the river, the water column becomes highly stratified with fresh to brackish water near the surface flowing over strongly saline water at the bottom of the river. The upstream extent of tidal influence is artificially halted near the eastern edge of the Matamoros-Brownsville urban area by a concrete block weir used, among other things, to increase the depth of the river on the fresh water side. The El Jardín weir, as it is known, is the site of the last major irrigation district pump on the US side.

3.5 Biology

The LRG/RB watershed is home to a diverse array of wildlife including nearly 700 species of vertebrates and 1,200 plant species (Schmandt, et al. 2002). Vegetation cover in the LRG/RB watershed is dominated by native Tamaulipan Brushland, characterized by dense, thorny vegetation with a high degree of biological diversity (Parcher, 2010). Sugar Hackberry is the most common tree species found throughout the watershed except where mesquite is dominant near the coast and near Falcon Reservoir (Lonard and Judd, 2002). The riparian areas along the banks of the LRG/RB host tall, lush vegetation that provides important nesting and feeding habitats for local birds and animal life (Parcher, 2010; Lonard and Judd, 2002). The tidal portion of the LRG/RB is dominated by tropical vegetation, such as Mexican Palmettos. At the mouth of the river, the vegetation is similar to the barrier islands along Laguna Madre to the north and to the south, which have shrub-like plants and grasses with no trees present.

According to Schmandt, et al. 2002, urban and agricultural development in the region has had an adverse effect on the natural environment and led to a considerable loss in biodiversity. The LRG/RB watershed has been identified as an area where wildlife habitat is rapidly vanishing and in immediate need of protection (Lonard and Judd, 2002). It is a critical habitat for many animal species, some of which are listed as threatened or endangered by the US Fish and Wildlife Service. Of the vertebrate species living in the watershed, more than 86 of them are listed as endangered, threatened, or are considered candidates for immediate action (Schmandt, et al., 2002). The diminished woody brushland habitat in this region is of specific concern to the biologists because it is the hunting and breeding ground for the endangered ocelot (Figure 3-8). The ocelot's numbers in the US have dwindled down to 50 individuals, largely due to habitat destruction, the single greatest threat they face. It is estimated that since the 1900's, 99% of native brush in the LRG/RB riparian zone has been destroyed (Jahrsdoerfer and Leslie, 1988).

Figure 3-8. The Endangered Ocelot Species, *Leopardus pardalis*; Native to South Texas and Central and South America. Source: TPWD 2003.

Migrating waterfowl and songbird populations have also declined due to habitat loss. However, since the 1980's, USFWS has been working to create a wildlife corridor by restoring patches of native riparian habitat and purchasing land to connect those land areas (USFWS, 2016). The USFWS Wildlife corridor program has helped preserve much of the existing native riparian environment in the LRG/RB watershed and the effort will continue to decrease habitat fragmentation and to increase the range of native habitat in the watershed, providing a refuge to species with declining populations.

Improving the natural habitat in a river's watershed also benefits water quality in the river. Improvements in the quality of riparian vegetation have been shown to decrease erosion along river banks and improve the pollutant assimilative capacity of the water body. Rivers with healthy riparian areas often have higher levels of dissolved oxygen and less suspended sediment loads.

As riparian zones can be an indicator of river health, so too can the state of fish communities. In the LRG/RB, the number of native fish has declined by 70% in the last two decades (Lacewell, et al., 2010). Freshwater fish species have migrated further upstream and have been replaced in the mouth of the Rio Grande by estuarine and marine species. This migration correlates with decreasing river flow, increases in nutrient concentrations, competition with non-native species for resources, and increasing salinity (Schmandt, et al., 2002). These changes have ultimately resulted in fewer and less diverse aquatic fauna.

Non-native and invasive species have also become a common problem in the region. Many invasive species were added to the ecosystem intentionally, such as saltcedar to reduce erosion and several fish species for game fishing (Lacewell, et al., 2010). These non-native species compete with the native ones for space and resources and, when left unattended, can overtake and damage an ecosystem. Not only do invasive species jeopardize the functioning of natural ecosystems, they can also cause serious economic damage (Rauschuber, 2002). In the LRG/RB, the giant read (*Arundo donax*) and saltcedar (*Tamarix aphylla*) aggravate water availability problems by consuming an amount of water equivalent to about 11% of all irrigation water diverted by US irrigation districts in the watershed (Lacewell, et al., 2010). Invasive water plants, such as water hyacinth (*Eichhornia crassipes*) and hydrilla (*Hydrilla verticillada*), clog waterways and interfere with the movement of water for drainage and irrigation, ultimately affecting agricultural activities in the area.

3.6 Demography

The following section is intended to provide a brief demographic profile of the LRG/RB watershed. Demographic information compiled for this report was obtained from the 2010 Decennial Census of the United States, conducted by the US Census Bureau (US Census, 2010), and the 2010 Censo de Poblacion y Vivienda, conducted by INEGI (INEGI, 2010). More detailed population information is included in Section 4.2.1 of this report.

Despite the fact that rural areas predominate in the LRG/RB watershed, the majority of the approximately 2.5 million people living in the region live within urban areas in the 4 Texas border counties and the 11 Tamaulipas municipios included in the watershed (Figure 3-9).

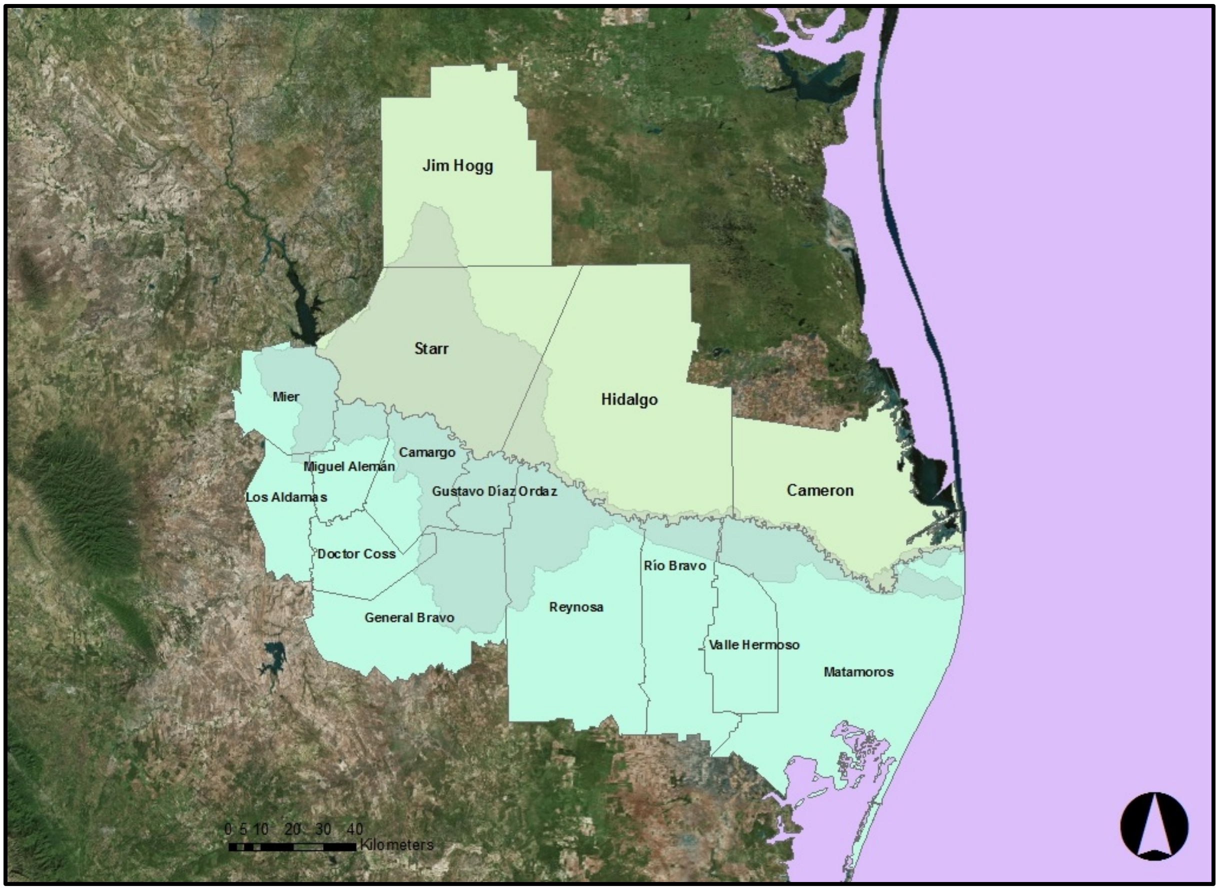


Figure 3-9. Portions of US Counties and Mexican Municipios included within the LRG/RB Watershed.

The total population for the 4 counties on the U.S. side of the watershed was 1,203,123 in 2010 and the total population for the 11 municipios included on the Mexican side of the watershed was 1,341,998, indicating an almost even split in the overall transboundary watershed population between the US and Mexico. It should be noted that although only a small fraction of Cameron and Hidalgo county residents live within the LRG/RB watershed, the service areas of public utilities that provide drinking water to county residents extend well north of the watershed boundary and the majority of the residents in these counties depend on the LRG/RB for drinking water.

Comparisons between U.S. and Mexican census data are difficult to make because the two countries collect different demographic data. The following sections provide separate descriptions of the demographic information collected in each country.

US Demographics

Geographically, the LRG/RB watershed includes portions of Starr and Jim Hogg Counties, which contain small, mainly rural populations. The small portion of Jim Hogg County included in the watershed is particularly sparsely populated, with less than 50 resdients estimated to live in that portion of the LRG/RB watershed. A significant portion of western Hidalgo County, also composed mainly of rural areas, but containing a number of urban and suburban residentential areas near the river, is also included in the LRG/RB watershed. Narrow strips of land at the southern boundaries of Hidalgo and Cameron Counties complete the delineation of the LRG/RB watershed on the US side. Table 3-4 shows the percentage of each US county included in the LRG/RB watershed.

Table 3-4. Areas of US Counties within the LRG/RB Watershed

US County Name	Total Area (Km^2)	Area within the LRG/RB Watershed (Km^2)	Percent of Area within the LRG/RB Watershed
Jim Hogg	2959.652	265.103	8.96
Starr	3154.853	2455.275	77.83
Hidalgo	4128.736	431.5523	10.45
Cameron	2463.922	154.989	6.29

Cameron, Hidalgo, Starr and Jim Hogg counties share many common characteristics, but also exhibit some demographic differences. Between 2000 and 2010, the total population of Cameron, Hidalgo, Starr and Jim Hogg counties increased by 29.2 percent from 978,369 to 1,264,091 (US Census Bureau, 2010). Hidalgo County is the most populated county in the US portion of the LRG/RB watershed with 774,769 inhabitants (in 2010), which amounts to 61.3 percent of the four-county population. Starr County, the US County with the most land area in the watershed, contributes only 4.8 percent of the four-county population. Hidalgo County is the fastest growing county in the US portion of the LRG/RB watershed. Between 2000 and 2010, Hidalgo County's population increased by 36.1 percent, whereas population growth in Jim Hogg County over the same period increased by only 1.78 percent (US Census Bureau, 2010).

The population of all four US counties in the LRG/RB watershed is predominantly hispanic, ranging from 88.1 percent in Cameron County to 95.8 percent for Starr County (US Census Bureau, 2010). The population is young, with the median age for each county well below the national average of 37.2. Hidalgo County's median age is 28.3 and one third of the population of Cameron, Hidalgo, and Starr Counties are under the age of 18. The region is considered economically depressed, with half of all residents under 18 years of age living below the US annual income poverty level threshold of $22,050. The median annual income in the four counties ranges from $22,418 for Starr County to $30,760 for Cameron County (US Census Bureau, 2010).

In addition to total population and population growth, the demographic differences between the US counties in the LRG/RB watershed relate also to population density. Hidalgo County's population is not only 13 times greater than Starr County, 70 percent of people in Hidalgo County live in cities or towns, whereas in Starr County that figure is just over 40 percent. The population of Cameron County is also composed mainly of urban residents. In 2010 Cameron County had the greatest population density of the four counties with 75% of the population in living in urban areas. Residents living in the Brownsville and Harlingen areas make up the greatest portion of the urban population in Cameron County. In Hidalgo County, the largest population centers are clustered around the cities of McAllen, Edinburg, Mission, and Pharr. In Starr County, most of the urban population lives in the Roma and Rio Grande City urban areas.

Despite living in an economically depressed area of the country, over two thirds of US LRG/RB watershed residents live in owner-occupied homes. However, an unusually high number of households in the four county area lack basic water and sewer services. Many of these households are located in unincorporated suburban areas known as "colonias." The Texas Secretary of State lists 942 Colonias in Hidalgo County, 257 in Starr County and 195 in Cameron County, amounting to approximately 52 percent of all recognized borderland colonias in Texas. Additional information about wastewater infrastructure and wastewater produced by colonia residents is included in Section 4.2.1 of this report.

Mexican Demographics

Mexico's Municipios are political subdivisions roughly equivalent to US counties. These sub-state political subdivisions encompass urban and rural communities known as localides. Portions of eleven municipios located along the US/Mexico Border Region are within the LRG/RB watershed and are subdivisions of the Mexican states of Tamaulipas and Nuevo León, including Mier, Los Aldamas, Miguel Alemán, Camargo, Doctor Coss, General Bravo, Gustavo Díaz Ordaz, Reynosa, Río Bravo, Valle Hermoso and Matamoros (Table 3-5).

Table 3-5. Portions of Mexican Municipios within the LRG/RB Watershed

Municipio Name	Total Area (Km^2)	Area within the LRG/RB Watershed (Km^2)	Percent of Area within the LRG/RB Watershed
Mier	932.924	546.075	58.53
Los Aldamas	695.7065	16.43297	2.36
Miguel Aleman	634.6336	190.9839	30.09
Camargo	932.7429	571.9506	61.32
Doctor Coss	712.467	40.82493	5.73
General Bravo	1906.30	712.4675	37.37
Gustavo Diaz Ordaz	429.199	429.199	100.00
Reynosa	3139.97	891.0035	28.38
Rio Bravo	1571.70	236.969	15.08
Valle Hermoso	899.43	10.87112	1.21
Matamoros	4658.486	708.9242	15.22

Major population centers on the Mexican side of the RG/RB watershed include Matamoros, Río Bravo, Reynosa, Gustavo Díaz Ordaz, Camargo, Miguel Alemán and Mier. The total population for these cities in 2010 was 1,341,998. Reynosa, with a population of 608,891, accounts for 45 percent of this total, while Matamoros, at 489,193, comprises 36 percent (INEGI, 2010). The least populated municipios, Gustavo Díaz Ordaz, Camargo, Miguel Alemán, and Mier, together comprise only 4.7 percent of total population in the watershed.

As with the watershed population living north of the LRG/RB, the population of all 11 watershed municipios is predominantly hispanic. The median age in the watershed municipios is 27, which is slightly higher than the 25.8 estimated for the rest of the country. This region of Mexico is considered economically prosperous by Mexican national standards, with an average annual per capita income of 62,400 Mex$, more than 1.5 times the national average of 37,752 Mex$.

INEGI's private dwelling data shows that the two most populated municipios, Reynosa and Matamoros, have the lowest percentages of population with piped water, electricity, and sewage collection and treatment. For example, the number of people in Reynosa without access to a public sewer service is estimated to be 12.5 percent of inhabitants, or 81,478. In Reynosa, as many as 15 percent of private dwellings do not have a water utility connection, 12.5 percent do not have electricity and 12.6 percent do not flush to an indoor toilet connected to a sewer system. In actual numbers, an estimated 21,440 homes of Reynosa's 170,171 private dwellings do not have access to a sewer system. Additional information about wastewater infrastructure and wastewater produced by Mexican watershed residents is included in Section 4.2.1 of this report.

4.0 Sources of Pollutants in Surface Water

Sources of pollutants that affect surface water quality are commonly classified in accordance with the mechanisms by which the pollutants are generated and transported. Environmental scientists and regulators generally classify surface water pollutant sources as either point sources or nonpoint sources.

Point sources of surface water pollution emanate from distinct, well defined geographic locations or "points," such as pipes or other conduits that discharge directly into a receiving water body. These sources can include outfalls of untreated wastewater and outfalls of municipal and industrial wastewater treatment facilities. Most point source discharges are regulated or otherwise controlled using specific discharge criteria designed to minimize their impact to receiving water bodies.

Nonpoint sources of pollution are the result of processes that accumulate and concentrate pollutants from larger geographic areas. The resulting "diffuse" pollution can enter a receiving water body at multiple locations or may flow into a water body through sheet flow or through shallow groundwater base flow. The most common natural process associated with nonpoint source pollution is rainfall runoff, however some nonpoint sources, known as steady state nonpoint sources, can affect surface water bodies under dry weather conditions. Steady state nonpoint sources include pollutant sources such as leaking sewer pipes, malfunctioning septic systems, irrigation return flows or direct deposition of untreated waste into receiving water bodies (e.g., bacteria from direct defecation into surface waters). The phased nature of the LRGWQI limits the first phase of the initiative to the analysis of water quality in the Lower Rio Grande/Río Bravo under steady state conditions, hence the Terms of Reference for the LRGWQI limit the study of pollutant sources in the LRG/RB watershed to point sources and steady state nonpoint sources.

4.1 Point Sources

A binational investigation of point sources in the LRG/RB watershed, conducted as part of the LRGWQI project, identified a total of 19 wastewater outfalls discharging directly to the river or to a tributary of the LRG/RB (Figure 4-1). Ten of these outfalls are located on the US side of the river and the other 9 outfalls are located on the Mexican side.

Fourteen of the point source outfalls located in the LRG/RB watershed are associated with municipal wastewater treatment facilities; 3 of the outfalls are discharges of untreated wastewater attributable to faulty sanitary sewer infrastructure; 1 outfall is a discharge of filter backwash water from the City of Roma's drinking water treatment facility and 1 outfall is an intermittent discharge of power plant cooling water from the Brownsville Public Utilities' (BPUB's) Silas Ray Power Plant (Table 4-1).

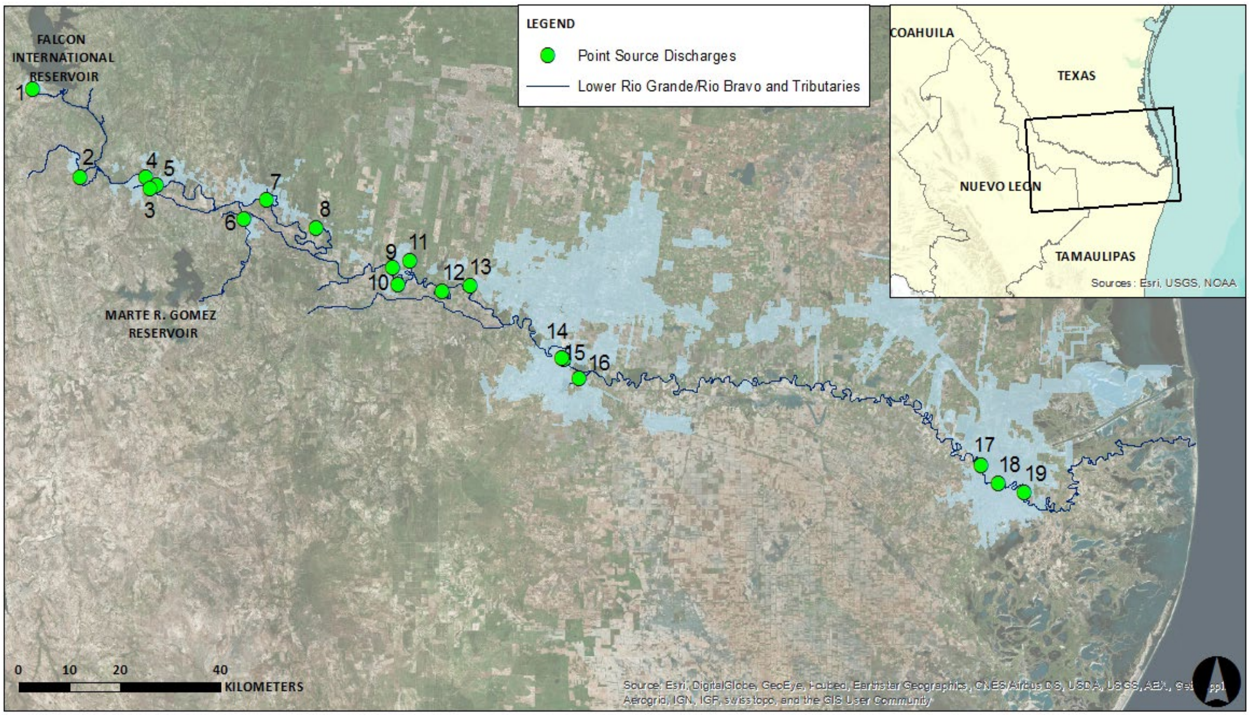


Figure 4-1. Point Source Discharges to the Lower Rio Grande/Río Bravo

Most of the point source discharges to the LRG/RB are relatively small (less than 100 L/s), however 2 facilities in the watershed (Ciudad Reynosa PTAR 1 and BPUB's Southside Wastewater Treatment Facility) are designed to produce effluent flows exceeding 500 L/s each.

The majority of point source discharges to the LRG/RB, or to one of its tributaries, occur in the upper portion of the watershed (Figure 4-1). This is mainly due to the fact that wastewater from municipalities and several industrial plants located in the middle and lower portions of the watershed is treated and discharged into drains that flow away from the LRG/RB and thence to the US and Mexican portions of the Laguna Madre. This includes several municipal wastewater treatment facilities on the US side of the LRG/RB and a number of industrial discharges associated with manufacturing facilities, known as "maquiladoras," located mainly on the Mexican side of the river.

Table 4-1. Point Source Discharges to the LRG/RB

Map No.	Facility Name	Discharge Type	Design Flow (L/s)
1	Nueva Ciudad Guerrero (Imhoff Tank)	Treated Municipal Wastewater	12
2	Ciudad Mier	Treated Municipal Wastewater	20
3	Ciudad Miguel Aleman	Treated Municipal Wastewater	75
4	City of Roma 3	Drinking Water Treatment Facility Outfall (Treatment Filter Backwash)	20
5	City of Roma 2	Treated Municipal Wastewater	90
6	Ciudad Camargo	Treated Municipal Wastewater	30
7	City of Rio Grande City	Treated Municipal Wastewater	66
8	Union Water Supply Corporation	Treated Municipal Wastewater	34
9	AGUA Special Utility District	Treated Municipal Wastewater	61
10	Ciudad Gustavo Diaz Ordaz	Treated Municipal Wastewater	3
11	La Joya Independent School District	Treated Municipal Wastewater	0.5
12	City of La Joya	Drinking Water Treatment Facility Outfall (Filter Backwash)	64
13	City of Peñitas	Treated Municipal Wastewater	33
14	Descarga Municipal D2 Libramiento Luis Echeverria, Reynosa	Untreated Municipal Wastewater	NA*
15	Descarga Municipal D3 Libramiento Luis Echeverria (International Bridge), Reynosa	Untreated Municipal Wastewater	NA*
16	Ciudad Reynosa PTAR 1	Treated Municipal Wastewater	1000
17	Brownsville Public Utility Board	Power Plant Cooling Water	17
18	Descarga Municipal D4 Colonia El Jardín, Matamoros	Untreated Municipal Wastewater	NA*
19	Brownsville Public Utility Board	Treated Municipal Wastewater	561

* Not a wastewater treatment facility, therefore a design flow cannot be specified

4.1.1 US Point Source Discharges

Figure 4-2 shows the location of US point source discharges to the LRG/RB.

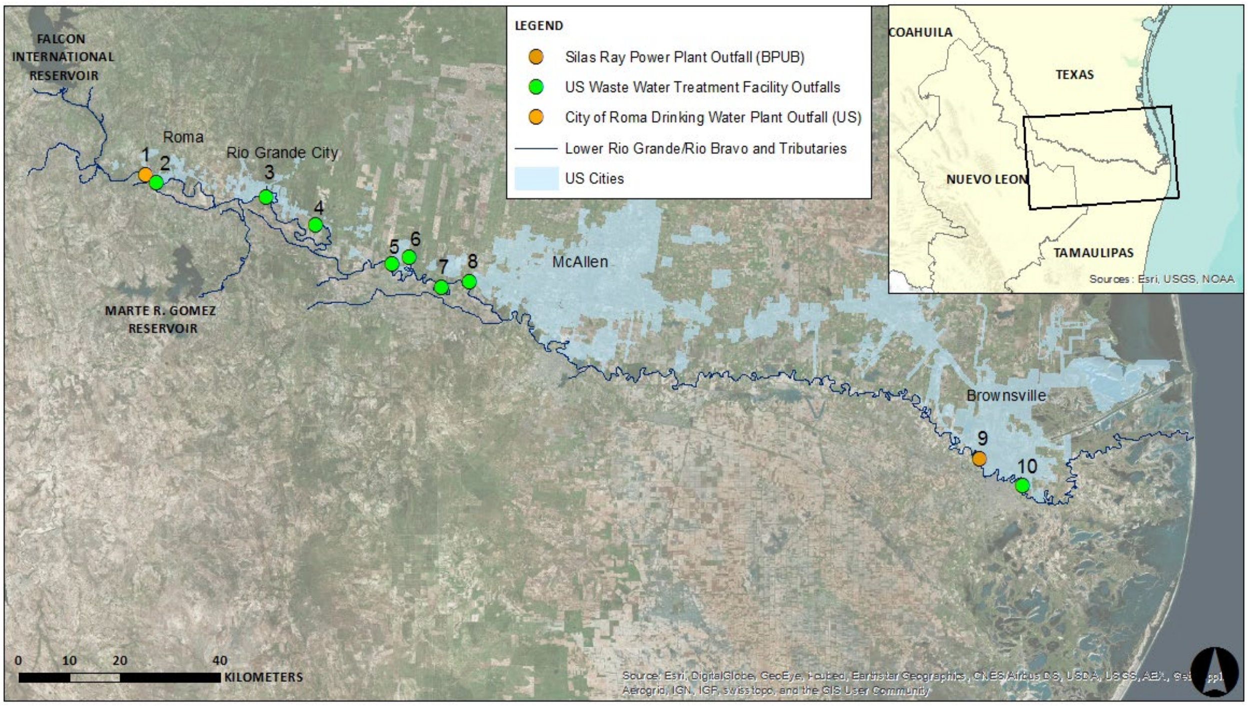


Figure 4-2. US Point Source Discharges to the Lower Rio Grande/Río Bravo

Eight of the 10 outfalls associated with these point source discharges are attributable to municipal wastewater treatment facilities located mainly in the upper portion of the watershed; one outfall discharges filter backwash water from the City of Roma's drinking water treatment facility and one outfall discharges cooling water from BPUB's Silas Ray Power Plant. Table 4-2 shows the effluent limits permitted under the Texas Pollutant Discharge Elimination System (TPDES) and National Pollutant Discharge Elimination System (NPDES) for each of the US point source discharges in the LRG/RB watershed.

Table 4-2 US Point Source Discharges to the Lower Rio Grande/Río Bravo and Permit Limits (daily averages)

Map Number	1	2	3	4	5	6	7	8	9	10
Facility Name	City of Roma3	City of Roma2	City of Rio Grande City	Union WSC	AGUA SUD	La Joya ISD	City of La Joya	City of Peñitas	Brownsville PUB	Brownsville PUB
Discharge Type	Municipal Wastewater	Municipal Wastewater	Municipal Wastewater	Municipal Wastewater	Municipal Wastewater	Municipal Wastewater	Municipal Wastewater	Municipal Wastewater	Industrial Wastewater	Municipal Wastewater
TPDES Permit Number	WQ11212003	WQ11212002	WQ10802001	WQ14313001	WQ14415001	WQ13523006	WQ12675001	WQ14884001	WQ03096000	WQ10397003
NPDES Permit Number	TX0119709	TX0117544	TX0068764	TX0124613	TX0125598	TX0124559	TX0127337	TX0131491	TX0105651	TX0055484
Flow (L/s)	19.7	87.6	65.7	33.9	61.3	0.6	64.4	32.9	17.1	560.8
Biochemical Oxygen Demand – 5 Day (mg/L)	-	20	20	10	10	20	20	20	-	10
Ammonia Nitrogen (mg/L)	-	-	-	3	3	-	3	-	-	3
Total Suspended Solids (mg/L)	-	20	20	15	15	20	20	20	-	3
Dissolved Oxygen (mg/L)	-	4	2	4	4	2	4	4	-	4
Temperature (°C)	-	-	-	-	-	-	-	-	115	-
pH Minimum	-	6	6	6	6	6	6	6	6	6
pH Maximum	-	9	9	9	9	9	9	9	9	9
E. Coli (CFU/100ml or MPN)	-	126	126	126	126	126	126	126	-	-
Enterococcus (CFU/100ml or MPN)	-	-	-	-	-	-	-	-	-	35
Sulfate (mg/L)	-	-	-	-	-	-	-	-	1893	-
Total Aluminum (mg/L)	-	-	-	-	-	-	-	-	0.78	-
Total Copper (mg/L)	-	-	-	-	-	-	-	-	0.11	-
Total Dissolved (mg/L)	-	-	-	-	-	-	-	-	4400	-
Free Available Chlorine (mg/L)	-	-	-	-	-	-	-	-	0.2	-

A brief description of each of the US point source discharger in the LRG/RB watershed is provided in the following sections.

1. **The City of Roma's Drinking Water Treatment Facility**

   Located less than 100 meters from the LRG/RB, the City of Roma's drinking water treatment facility provides potable water to approximately 30,945 residents living within Roma's city limits and surrounding area. The facility uses conventional treatment technology, which consists of coagulation, flocculation, sedimentation, and filtration. Discharge monitoring reports show this facility discharges a daily average of between 1.3 and 8.5 L/s of treatment filter backwash water to the river (minimum and maximum daily averages per month over the years 2000-2015) with an overall daily average discharge of 3.6 L/s.

The City of Roma's Drinking Water Treatment Facility

2. **The City of Roma's Wastewater Treatment Facility**

   Located approximately 2 kilometers southeast of the City of Roma's drinking water treatment facility and 568 meters from the LRG/RB, the City of Roma's wastewater treatment facility provides wastewater treatment services for approximately 10,088 residents living within Roma's city limits and an additional 4,582 living in the surrounding area. The facility uses an extended aeration oxidation ditch system process with activated sludge and chlorination. Discharge monitoring reports show this facility discharges a daily average of between 48.2 L/s and 363.6 L/s, with an overall daily average discharge of 157.4 L/s. The outfall for the City of Roma's wastewater treatment facility is located on the north bank of the LRG/RB, approximately 4 kilometers downstream from the city's drinking water treatment facility outfall.

The City of Roma's Wastewater Treatment Facility

3. The City of Rio Grande City's Wastewater Treatment Facility

The City of Rio Grande City's wastewater treatment facility is located approximately 105 meters from the LRG/RB. The facility provides wastewater treatment services to approximately 13,834 residents living within the city limits of Rio Grande City. Like the City of Roma, the City of Rio Grande City's wastewater treatment facility is an oxidation ditch system with activated sludge and chlorination. Discharge monitoring reports show this facility discharges a daily average flow of between 18.3 and 59.5 L/s, with an overall daily average discharge of 36.6 L/s.

The City of Rio Grande City's Wastewater Treatment Facility

4. Union Water Supply Corporation's Wastewater Treatment Facility

The Union Water Supply Corporation's wastewater treatment facility is located approximately 2.3 kilometers from the LRG/RB. The facility provides wastewater treatment services to approximately 5,913 residents living in the largely rural communities of Garciasville, La Casita and El Refugio and surrounding areas. The wastewater treatment facility is an oxidation ditch system with activated sludge and chlorination. Discharge monitoring reports show this facility discharges a daily average flow of treated effluent of between 3.0 and 14.5 L/s, with an overall daily average discharge of 7.7 L/s.

The Union Water Supply Corporation's Wastewater Treatment Facility

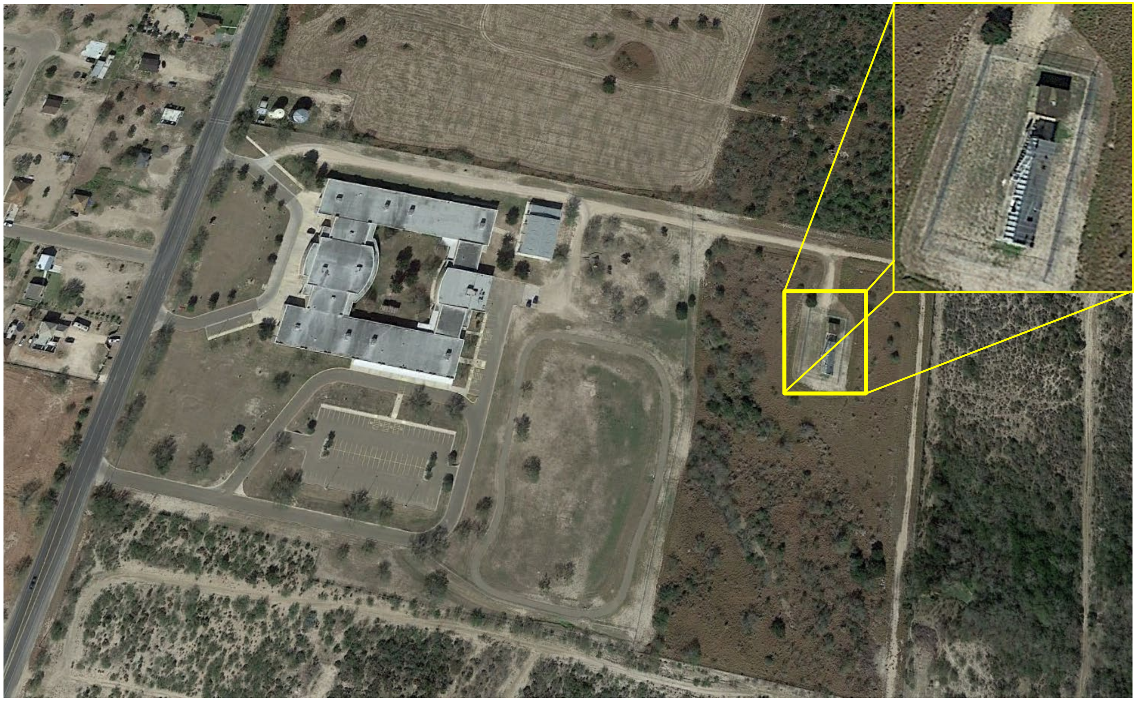
5. The AGUA Special Utility District's Wastewater Treatment Facility

The AGUA Special Utility District's (SUD's) wastewater treatment facility is located approximately 1.4 kilometers from the LRG/RB. The facility provides wastewater treatment services to approximately 3,250 residents living in the largely rural communities of Sullivan City, Los Ebanos and Cuevitas and surrounding areas. A sequencing batch reactor (SBR) plant, AGUA SUD's wastewater treatment facility discharges treated wastewater intermittently during the day. Discharge monitoring reports show this facility discharges a daily average effluent flow of between 5.5 and 8.3 L/s, with an overall daily average discharge of 7.7 L/s.

The AGUA Special Utility District's Wastewater Treatment Facility

6. La Joya Independent School District's Wastewater Treatment Facility

The La Joya Independent School District's wastewater treatment facility is located approximately 2.0 kilometers from the LRG/RB. This small "package plant" facility provides wastewater treatment services to approximately 500 students of the Sam Fordyce Elementary School near Sullivan City. The facility uses an activated sludge process operated in the extended aeration mode with chlorination. Discharge monitoring reports show this facility discharges at highly irregular intervals during the year, with large intervals of little to no discharge, especially during the summer months and during other scholastic breaks in the school year. Discharge monitoring reports show that daily average effluent flows range between 0.02 and 0.3 L/s, with an overall daily average discharge of 0.1 L/s. Although considered a surface water discharge to the LRG/RB, the effluent flow from this outfall is unlikely to affect water quality in the LRG/RB, due to its small volume and distance from the river.



La Joya Independent School District's Wastewater Treatment Facility

7. The City of La Joya's Wastewater Treatment Facility

The City of La Joya's wastewater treatment facility is located approximately 1.0 kilometer from the LRG/RB. Constructed in 1982, this facility is a facultative lagoon system that provides wastewater treatment services to approximately 3,985 city residents. Discharge monitoring reports show that daily average effluent flows range between 4.6 and 15.3 L/s, with an overall daily average discharge of 11.0 L/s. In recent years, the ability of this wastewater treatment facility to meet its permitted discharge limits for $CBOD_5$, TSS and E. coli has diminished significantly due to a combination of several factors, including population growth and the facility's advanced age.

The City of La Joya's Wastewater Treatment Facility

8. The City of Peñita's Wastewater Treatment Facility

The City of Peñita's wastewater treatment facility is located approximately 500 meters from the LRG/RB. The facility provides wastewater services to approximately 4,632 residents of the city and surrounding areas. The wastewater treatment technology used by the facility is an oxidation ditch system with activated sludge and chlorination. Daily average effluent flows range between 1.3 and 12.8 L/s, with an overall daily average discharge of 7.7 L/s.

The City of Peñita's Wastewater Treatment Facility

9. Brownsville Public Utilities Board's Silas Ray Power Plant Outfall

Brownsville Public Utility Board's (BPUB's) Silas Ray Power Plant is a 181.4 MW gas powered steam turbine electric generating facility. Originally built in 1947, this power plant serves as the primary source of electricity for the residents of the City of Brownville and also for residents living in portions of Harlingen and San Benito, Texas. The facility is located approximately 660 meters from the LRG/RB and occasionally discharges blowdown water from its cooling towers. Discharges from this facility flow into a dry oxbow lake prior to flowing into the LRG/RB. The oxbow lake has a capacity of approximately 150,000 m^3 and fills only on rare occasions. Discharge monitoring reports show this facility discharges at highly irregular intervals (flows are reported for only 69 of the 180 months between 2000 and 2015). Daily average flows during the months of discharge ranged between 0.003 and 16.3 L/s, with an overall daily average discharge of 0.9 L/s.

The Brownsville PUB's Silas Ray Power Plant

10. Brownsville PUB's Southside Wastewater Treatment Facility

The Brownsville PUB's Southside Wastewater Treatment Facility is located approximately 880 meters from the LRG/RB. The largest of the US wastewater treatment facilities discharging to the Lower Rio Grande, the facility provides wastewater services to approximately 27,500 residents of the city using a complete mix activated sludge treatment system. Daily average effluent flows range between 215.7 and 436.6 L/s, with an overall daily average discharge of 276.4 L/s. The facility discharges directly to the tidally-influenced portion of the LRG/RB.

The Brownsville PUB's Southside Wastewater Treatment Facility

4.1.2 Mexican Point Source Discharges

Nine point source outfalls currently discharge wastewater to the LRG/RB from the Mexican side of the river (Figure 4-3). Six of these outfalls are associated with municipal wastewater treatment facilities and 3 of the outfalls are discharges of untreated wastewater attributable to faulty sanitary sewer infrastructure.

Table 4-3 provides further information on the point source outfalls currently discharging wastewater to the LRG/RB from the Mexican side of the river. Like US wastewater treatment facilities, Mexican wastewater treatment facilities must obtain a permit from CONAGUA to discharge their effluent to surface waters. While limits on flow rates and pollutant concentrations of effluent discharged from wastewater treatment facilities located on the Mexican side of the LRG/RB are not based on values prescribed by individual discharge permits tailored to each facility, all Mexican wastewater treatment facilities must be constructed and operated so as to meet Mexican federal criteria designed to protect surface water quality. The criteria are specified in the country's federal regulation NOM-001-SEMARNAT-1996, which establishes the maximum permissible levels of contaminants in wastewater discharges to surface water.

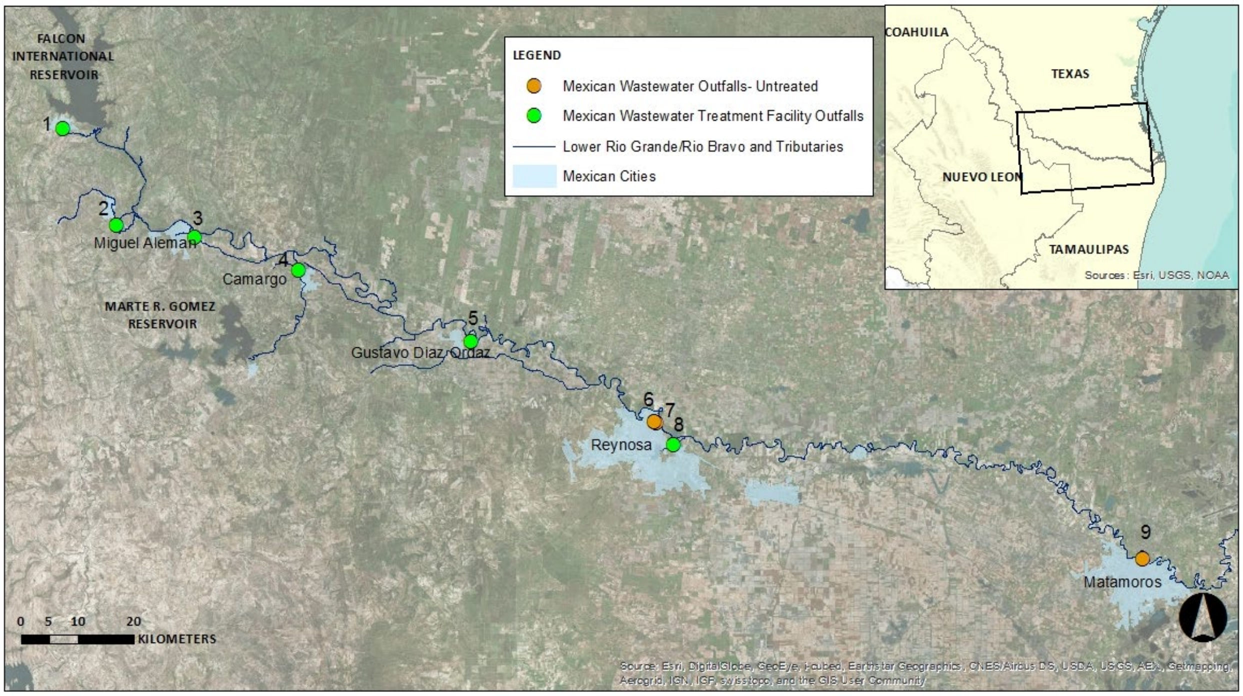


Figure 4-3. Mexican Point Source Discharges to the LRG/RB.

Table 4-3. Mexican Point Source Discharges to the Lower Rio Grande/Río Bravo

Map No.	Facility Name	Discharge Type	Design Flow (l/s)
1	Nueva Ciudad Guerrero (Imhoff Tank)	Treated Municipal Wastewater	12
2	Ciudad Mier	Treated Municipal Wastewater	20
3	Ciudad Miguel Aleman	Treated Municipal Wastewater	75
4	Ciudad Camargo	Treated Municipal Wastewater	30
5	Ciudad Gustavo Diaz Ordaz	Treated Municipal Wastewater	3
6	Descarga Municipal D2 Libramiento Luis Echeverria, Reynosa	Untreated Municipal Wastewater	NA*
7	Descarga Municipal D3 Libramiento Luis Echeverria (International Bridge), Reynosa	Untreated Municipal Wastewater	NA*
8	Ciudad Reynosa PTAR 1	Treated Municipal Wastewater	1000
9	Descarga Municipal D4 Colonia El Jardín, Matamoros	Untreated Municipal Wastewater	NA*

* Not a wastewater treatment facility, therefore a design flow cannot be specified

Table 4-4 shows the discharge criteria currently used to design Mexican wastewater treatment facilities in the LRG/RB. It is important to note that these general criteria are applicable on an interim basis. Like the federal Clean Water Act in the US, Mexican federal law provides for the establishment of individual wastewater discharge permits with effluent concentrations and flow limits specific to each permitted wastewater outfall. The establishment of individual wastewater permits is often preceded by the development of a "Declaratoria de Clasificación," which among other things, includes a study of the assimilative capacity of the receiving water body. CONAGUA has undertaken the task of developing a Declaratoria de Clasificación for the LRG/RB and anticipates completing it by the end of 2019.

Depending on the results of the Declaratoria de Clasificación developed for the LRG/RB, CONAGUA could begin requiring individual permits for new wastewater treatment facilities or for future upgrades to existing wastewater treatment facilities in the LRG/RB, if deemed warranted. A brief description of each of the Mexican point source discharges to the LRG/RB is provided in the following sections.

Table 4-4 Discharge Criteria Applicable to Mexican Wastewater Treatment Facilities

Parameter	Maximum Daily Average*	Maximum Monthly Average*
Flow (L/s)	-	-
Biochemical Oxygen Demand – 5 Day (mg/L)	150	75
Total Nitrogen (mg/L)	60	40
Phosphorus (mg/L)	30	20
Total Suspended Solids (mg/L)	125	75
Settable solids (mg/L)	2	1
Temperature	40	40
pH minimum (NTU)	6	6
pH maximum (NTU)	9	9
Fecal Coliform (MPN/100ml)	2000	1000
Grease and Oil	25	15

NOM-001-SEMARNAT-1996

1. Nueva Ciudad Guerrero's Wastewater Treatment Facility

Located 5.1 Kilometers from the LRG/RB, the city of Nueva Ciudad Guerrero's wastewater treatment facility provides wastewater treatment services to approximately 4010 residents living within city limits and surrounding area. The facility consists of an Imhoff tank located in the southern portion of the city. The Imhoff tank is a relatively old facility and does not currently function in the way it was originally designed, providing only marginal primary treatment of influent wastewater. LRGWQI researchers estimate this facility produces daily effluent flows of between 2.5 and 4.3 L/s (highest and lowest average values estimated by LRGWQI researchers), with an overall average daily effluent flow of 3.1 L/s.

Ciudad Nueva Guerrero's Wastewater Treatment Facility

2. Ciudad Mier's Wastewater Treatment Facility

Located 3.2 Kilometers from the LRG/RB, the city of Mier's wastewater treatment facility provides wastewater treatment services to approximately 5,435 residents living within its city limits. The facility utilizes a natural/lagoon processes for treatment and consists of an anaerobic pond, an integrated facultative pond, and polishing lagoons. The treatment plant also includes headworks with a coarse screen and sand settling chamber. Mier has experienced a negative population growth rate since 2008 and, although the city's wastewater facility is designed to treat 20 L/s of raw sewage, the actual average daily effluent flow is estimated to be in the order of 2.8 L/s.

Ciudad Mier's Wastewater Treatment Facility

3. Ciudad Miguel Aleman's Wastewater Treatment Facility

Located 630 meters from the LRG/RB, the city of Miguel Aleman's wastewater treatment facility provides wastewater treatment services to approximately 23,500 residents living within its city limits and in the nearby village of Los Guerra. The facility consists of a dual lagoon system composed of three treatment levels, first anaerobic, then facultative, and finally polishing. The treatment plant also includes headworks with coarse screens and sand settling chambers. Although the facility is designed to treat 75 L/s of raw sewage, the average daily effluent flow is estimated to be between 27 and 45 L/s, with an overall average daily effluent flow of 37.3 L/s.

Ciudad Miguel Aleman's Wastewater Treatment Facility

4. Ciudad Camargo's Wastewater Treatment Facility

Located 2.4 Kilometers from the LRG/RB, the city of Camargo's wastewater treatment facility provides wastewater services to approximately 15,075 residents living within its city limits. The facility consists of a four-celled oxidation and facultative lagoon system situated 0.88 kilometers north of the city. Originally designed to treat 20 L/s of raw sewage, the facility does not have a visible discharge of effluent. However, due to its advanced age, poor working condition and proximity to the Río San Juan, LRGWQI researchers estimate that two thirds of the current influent flow to the plant reaches the Río San Juan through infiltration from its oxidation lagoon. This volume amounts to an average daily effluent flow of between 2.3 and 4.3 L/s, with an overall average daily effluent flow of 3.3 L/s.

Ciudad Camargo's Wastewater Treatment Facility

5. Ciudad Gustavo Díaz Ordaz's Wastewater Treatment Facility

The wastewater treatment facility for the city of Gustavo Díaz Ordaz is located 680 meters from the LRG/RB. The facility is a small (3.4 Ha) two-lagoon system which is currently non-functioning and essentially operates as an infiltration/evaporation basin. The wastewater collection system for the city of Gustavo Díaz Ordaz services approximately 1,728 residents living within its city limits. It is estimated that the city's collection system generates an average daily flow of raw sewage of 27.6 L/s to the plant. LRGWQI researchers estimate that, on average, at least 10% of the total volume of sewage conveyed to the wastewater facility reaches the LRG/RB (2.8 L/s).

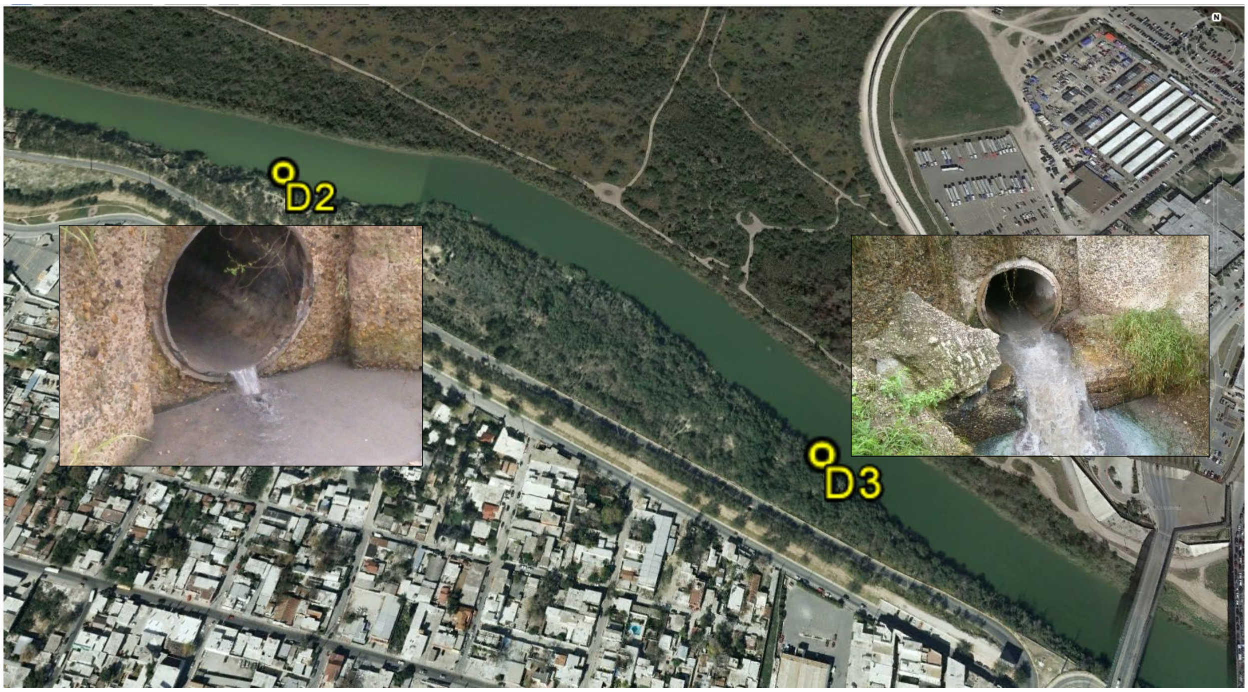
Ciudad Gustavo Díaz Ordaz's Wastewater Treatment Facility

6. **Municipal Discharge D2 Libramiento Luis Echeverria, Reynosa**

   Located on the south bank of the LRG/RB within the city limits of the City of Reynosa, this discharge of untreated wastewater is associated with faulty or inadequate wastewater conveyance. The flow of untreated wastewater reaches the LRG/RB directly through a stormwater pipe. It is estimated this highly variable discharge contributes a daily flow of untreated wastewater to the LRG/RB of between 0.01 and 0.58 L/s, with an overall daily average flow of 0.33 L/s.

7. **Municipal Discharge D3 Libramiento Luis Echeverria (International Bridge), Reynosa**

   Also located on the south bank of the LRG/RB in the City of Reynosa just upstream of the Reynosa-Hidalgo International Bride and only 575 meters from Municipal Discharge D2, this discharge of untreated wastewater (D3) is also associated with faulty or inadequate wastewater conveyance. Like Municipal Discharge D2, the flow of untreated wastewater from discharge D3 reaches the LRG/RB directly through a stormwater pipe. It is estimated this highly variable discharge (D3) contributes a daily flow of untreated wastewater to the LRG/RB of between 0.01 and 8.11 L/s, with an overall daily average flow of 4.1 L/s.



Municipal Discharges D2 and D3 Libramiento Luis Echeverria, Reynosa

8. The City of Reynosa Wastewater Treatment Facility No. 1 (PTAR No. 1)

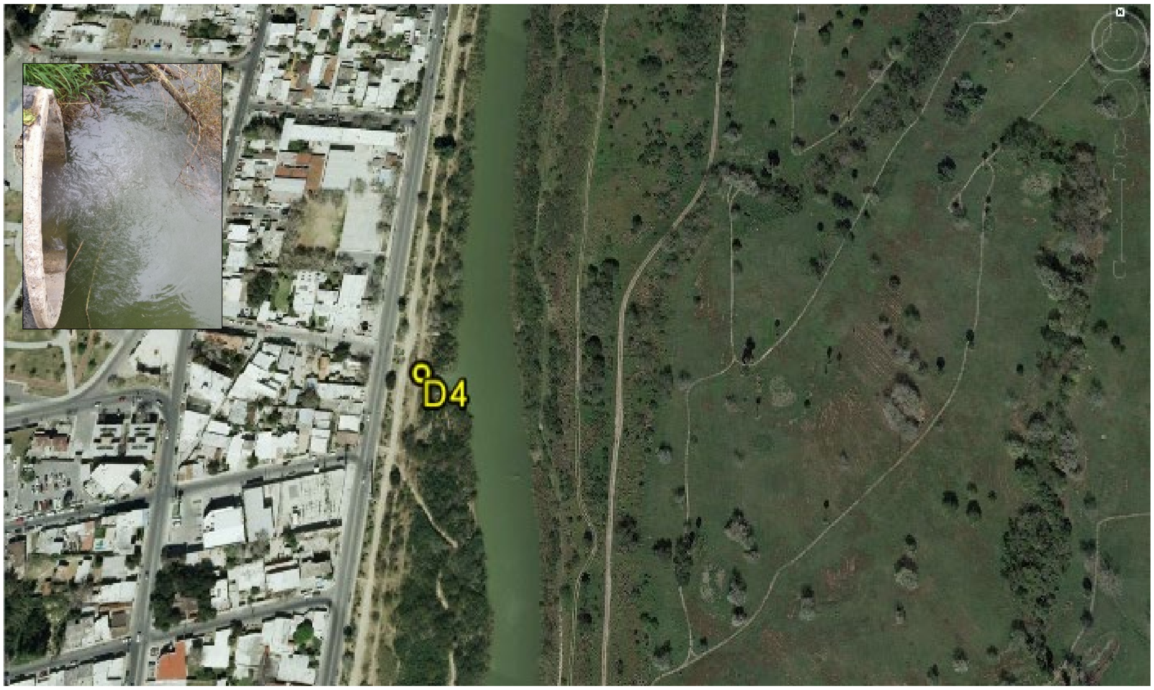
Located less than 50 meters from the LRG/RB, the city of Reynosa's Wastewater Treatment Facility No.1 (acronymed PTAR 1 in Spanish) provides wastewater treatment services to approximately 247,000 residents living within its city limits. Originally built in 1970, Reynosa's PTAR No. 1 has undergone a number of expansions and rehabilitations over the last 46 years, the last of which occurred in 2001. Originally constructed as a large, multi-celled lagoon system, the facility now consists of an activated sludge unit with anaerobic ponds followed by aeration and facultative lagoon units arranged in sequence. The new treatment system was constructed adjacent to the original lagoon system. The average daily effluent flow from Reynosa's PTAR No. 1 is estimated to be between 550 and 750 L/s, with an overall daily average flow of 616.7 L/s.

Although the Reynosa PTAR No. 1 facility is currently designed to treat 1000 L/s of influent raw sewage, a portion of the raw wastewater conveyed to the facility is occasionally diverted directly to the aged lagoon system adjacent to the activated sludge unit in PTAR No. 1, bypassing the activated sludge treatment system. The lack of capacity to accommodate existing influent flows conveyed to Reynosa's PTAR No.1 results in the discharge of untreated wastewater into the LRG/RB via a drainage canal known as Dren El Anhelo.

The City of Reynosa Wastewater Treatment Facility No. 1 (PTAR No. 1)

9. **Municipal Discharge D4 Calle Ignacio Ramirez y Tamaulipas, Matamoros**

   Located on the south bank of the LRG/RB in the City of Matamoros, this discharge of untreated wastewater is associated with faulty wastewater conveyance. The flow of untreated wastewater reaches the LRG/RB directly through a stormwater culvert. LRGWQI researchers visually estimated that this discharge contributes a daily flow of untreated wastewater to the LRG/RB of 0.75 L/s.



Municipal Discharge D4 Calle Ignacio Ramirez y Tamaulipas, Matamoros (the inset is a vertical, bird's eye, view of the outfall)

4.2 Steady State Nonpoint Sources

The diffuse nature of nonpoint sources of pollution complicates their characterization and quantification. Unlike point sources, which can be monitored at their point of discharge, nonpoint sources affect the receiving water body over wide geographic areas making them hard to measure directly. The most widely used method for characterizing nonpoint sources is a technique known as geospatial analysis.

As previously discussed, the Terms of Reference for the LRGWQI limit the investigation of nonpoint sources in the LRG/RB watershed to steady state nonpoint sources, which excludes sources of pollutants entering the river under rainfall runoff conditions. Steady state nonpoint sources in the LRG/RB can be classified into three broad categories based on their sector of origin; they include (1) residential nonpoint sources, (2) agricultural nonpoint sources, and (3) wildlife nonpoint sources. To characterize steady state nonpoint sources in the LRG/RB watershed, LRGWQI researchers used a modified version of the geospatial analysis method developed by Lynch, 2012. The information presented in the following sections details the results of this modified geospatial analysis as applied to the LRG/RB watershed under the LRGWQI.

4.2.1 Residential Nonpoint Sources

Residential nonpoint sources in the LRG/RB watershed can be subdivided into two main categories, (1) pollutant contributions from malfunctioning or inadequate onsite sewage facilities (e.g., leaking or malfunctioning septic systems, cesspools and pit privies) and (2) pollutant contributions from residents lacking any form of sewage treatment.

Since both of these sources emanate from residents living in the watershed, LRGWQI researchers used a combination of census data, sanitation information, and the geographic boundaries of the LRG/RB watershed, to quantify the number of watershed residents with (1) access to centralized sewer services, (2) access only to onsite wastewater treatment systems and (3) no access to wastewater treatment systems. The data sources used by LRGWQI researchers included the 2010 Decennial Census of the US (US Census Bureau, 2010) the 2010 Censo de Poblacion y Vivienda (INEGI, 2010), the Border Colonia Geographic Database (State of Texas Office of Attorney General, 2016) and the LRG/RB watershed boundary (modified from USGS [BEHI], 2015).

4.2.1.1 US Residential Nonpoint Sources

Figure 4-4 shows an image of 2010 US Census Blocks located within the LRG/RB watershed. Using the geographic information systems (GIS) census blocks polygon layer for the state of Texas, available from the US Census Bureau, LRGWQI researchers extracted the census blocks included only within the US portion of the LRG/RB watershed. They then determined the number of residents living within the US portion of the watershed by summing the number of residents in the resulting subset of US Census Blocks. For census blocks intersected by the watershed boundary, researchers determined population in those blocks by applying the relative proportion, or ratio, of the census block area within the watershed to the total area of the intersected census block.

Using geographic information about wastewater service areas in the US portion of the LRG/RB watershed, LRGWQI researchers then determined the number of US watershed residents with access to centralized wastewater treatment systems by extracting the number of residents living in the watershed census blocks that also lived within wastewater service areas.

Next, LRGWQI researchers used the Border Colonia Geographic Database, which contains information about geographic areas within the Texas side of the US-Mexico border region where residents lack wastewater services (i.e., "Red" Colonias), to determine the number of residents living in US census blocks within the LRG/RB watershed who lacked any type of wastewater treatment services (Figure 4-5). As with the geospatial analysis determining total watershed population, researchers used census block area ratios to determine the resulting 2010 population values.

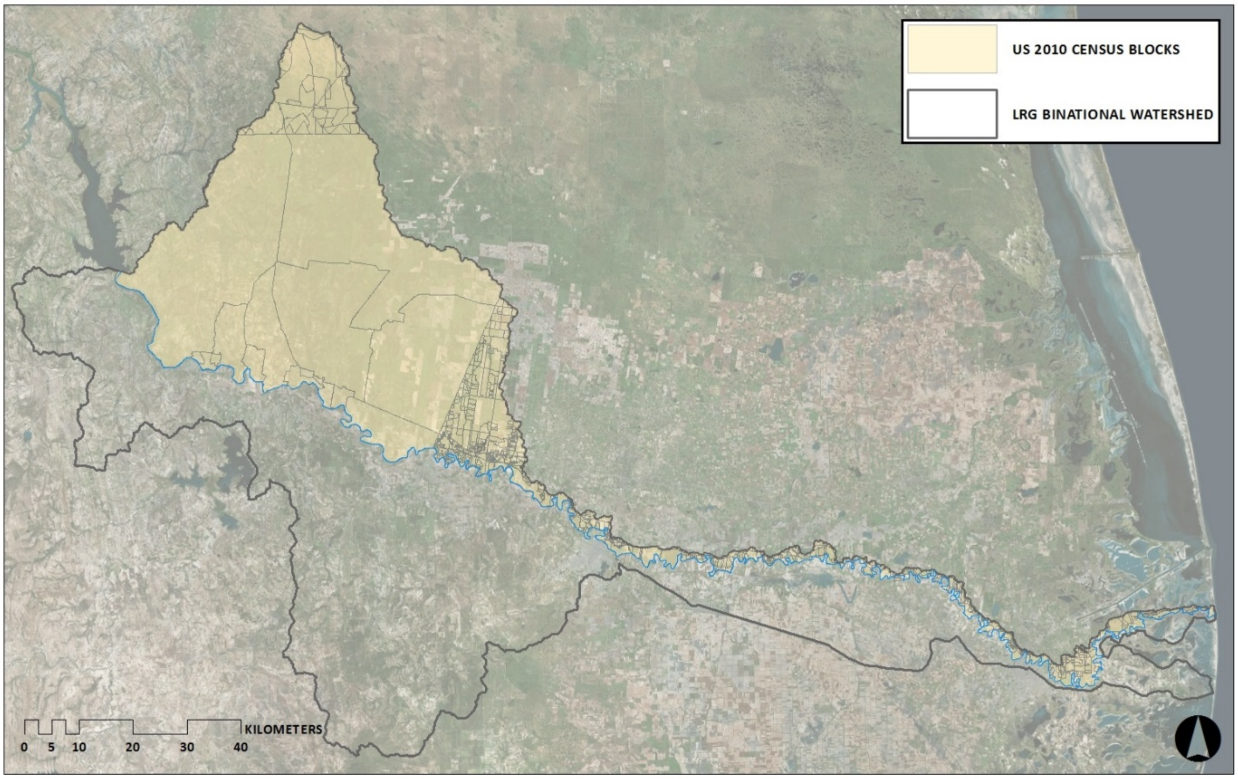


Figure 4-4. 2010 US Census Blocks Within the LRG/RB Watershed

LRGWQI researchers assumed that the remaining population living in watershed census blocks, that is, the watershed census block population living neither within a service area nor within a red colonia, consisted of watershed residents with onsite wastewater treatment systems (i.e., septic systems, cesspools, pit privies, etc.).

Lacking the wash off and transport mechanism provided by rainfall runoff, pollutants emanating from steady state nonpoint sources are much less mobile in the environment. In the case of residential nonpoint sources, only two pollutant transport mechanisms are available: (1) direct and indirect deposition into the receiving water body, including tributaries and ditches, and (2) infiltration into, and transport through, shallow, phreatic groundwater. For this reason, LRGWQI researchers considered potential pollutant loadings only from residential nonpoint sources located within a 500 meter riparian buffer around the LRG/RB and its tributaries (Figure 4-6).

Figure 4-7 shows an image exemplifying the results of the geospatial analysis used by LRGWQI researchers to determine the number of US LRG/RB watershed residents living within 500 meters of the LRG/RB or one of its tributaries who: (1) have access to centralized wastewater services, (2) have access to onsite wastewater treatment services, and (3) have no access to wastewater treatment services.

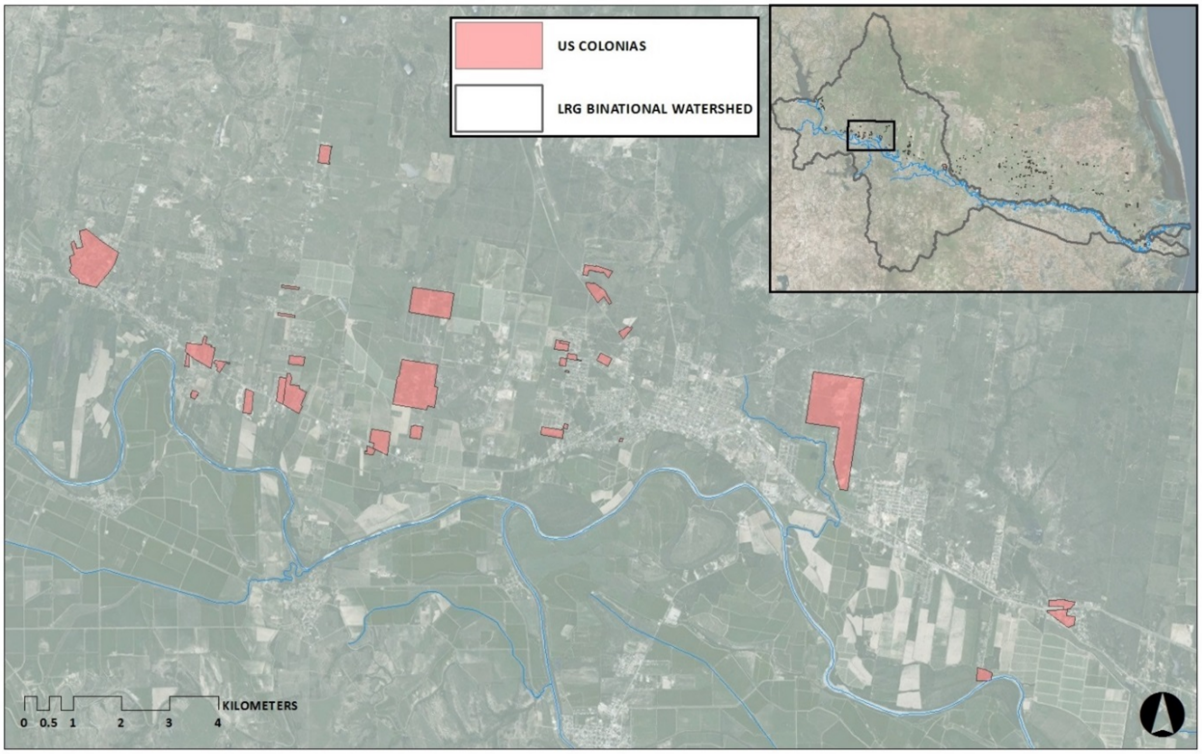


Figure 4-5. Red Colonia Areas within the LRG/RB Watershed

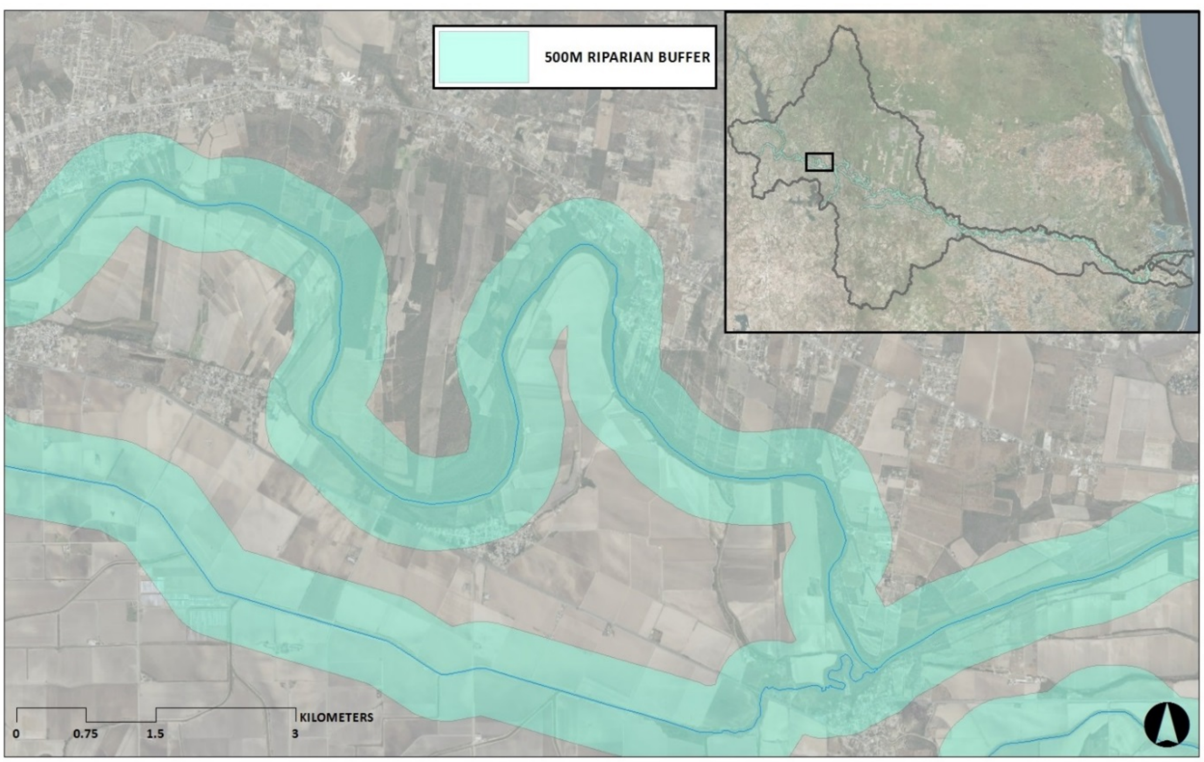


Figure 4-6. 500 Meter Riparian Buffer

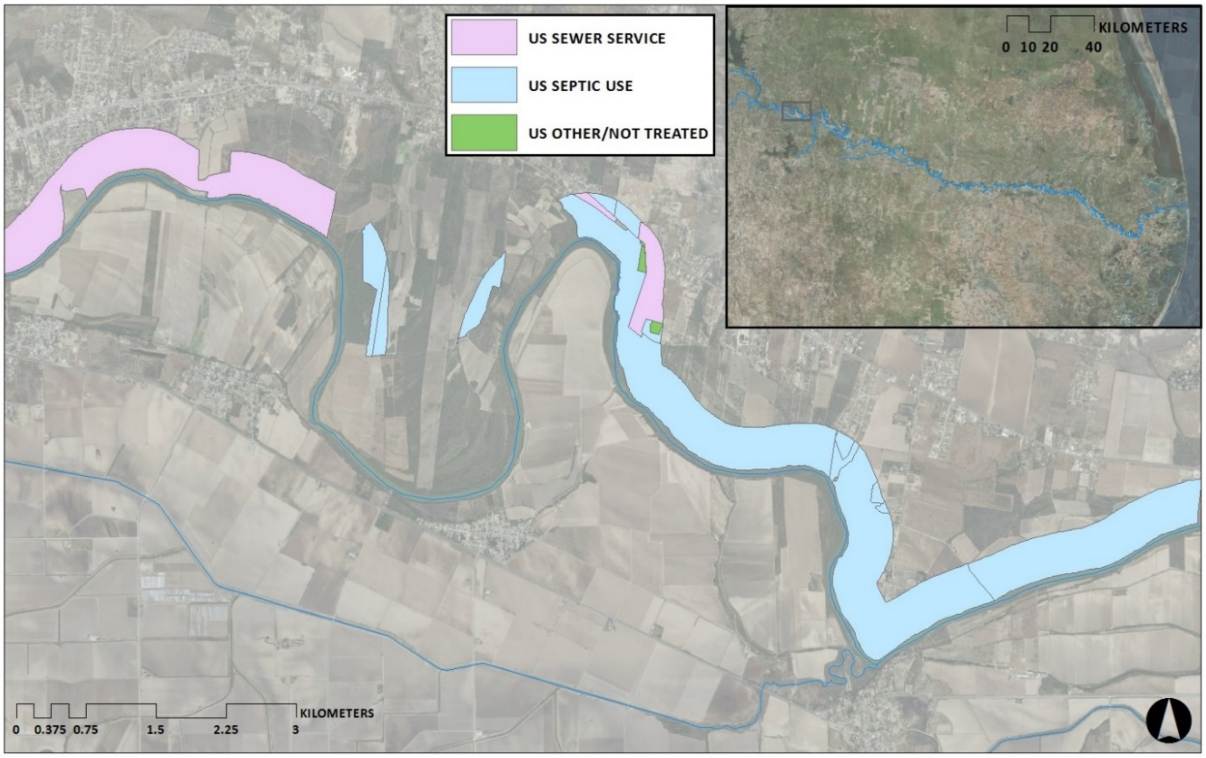


Figure 4-7. Geospatial Analysis of US Residential Nonpoint Sources in the LRG/RB Watershed

4.2.1.2 Mexican Residential Nonpoint Sources

While similar to the geospatial analysis conducted to estimate population values associated with US residential nonpoint sources, the geospatial analysis conducted by LRGWQI researchers to estimate population values associated with Mexican residential nonpoint sources differs in several important aspects. First, researchers used data from INEGI's 2010 Censo de Población y Vivienda at two separate levels: (1) the municipio level, and (2) the localidad level. Second, unlike the 2010 US census data, the 2010 INEGI census data contained sanitation and drainage information useful in categorizing the type of wastewater treatment received by residents living on the Mexican portion of the LRG/RB watershed.

The 2010 INEGI census data, aggregated at the municipio level, categorizes municipio residents according to the type of sewage disposal available to them. The categories include (1) public sewer, (2) septic tanks, (3) piping directly to a crevice or cliff, (4) piping directly to surface water bodies, and (5) no "drainage." However, the coarse aggregation of municipio level data renders it inadequate for estimating the number of Mexican municipio residents living within a 500 m riparian buffer of a receiving water body. The 2010 INEGI data aggregated at the localidad level (Principales Resultados por localidad [ITER]), available as a GIS point layer from INEGI, provides sufficient geospatial detail for the analysis (Figure 4-8), however these data do not provide detailed information about the type of sewage disposal available to the residents of the each localidad; only information on whether "drainage" is available to the residents.

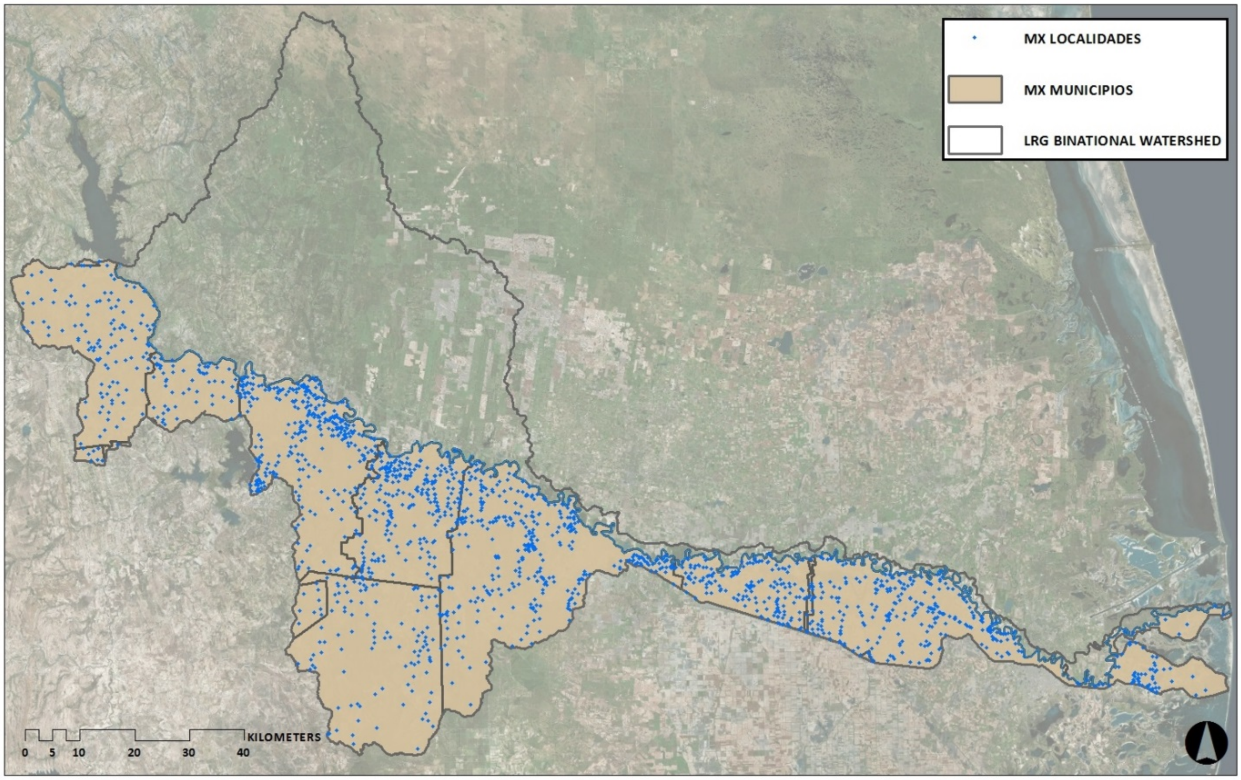


Figure 4-8. Localidades and Municipios within the LRG/RB Watershed

To estimate the distribution of residents living within the 500m riparian buffer, by sewage disposal type, in the Mexican portion of the LRG/RB watershed, LRGWQI researchers applied the proportions of municipio residents falling under each sewage disposal category to the numbers of residents of localidades within each municipio that were also located inside the 500m riparian buffer (Figure 4-9).

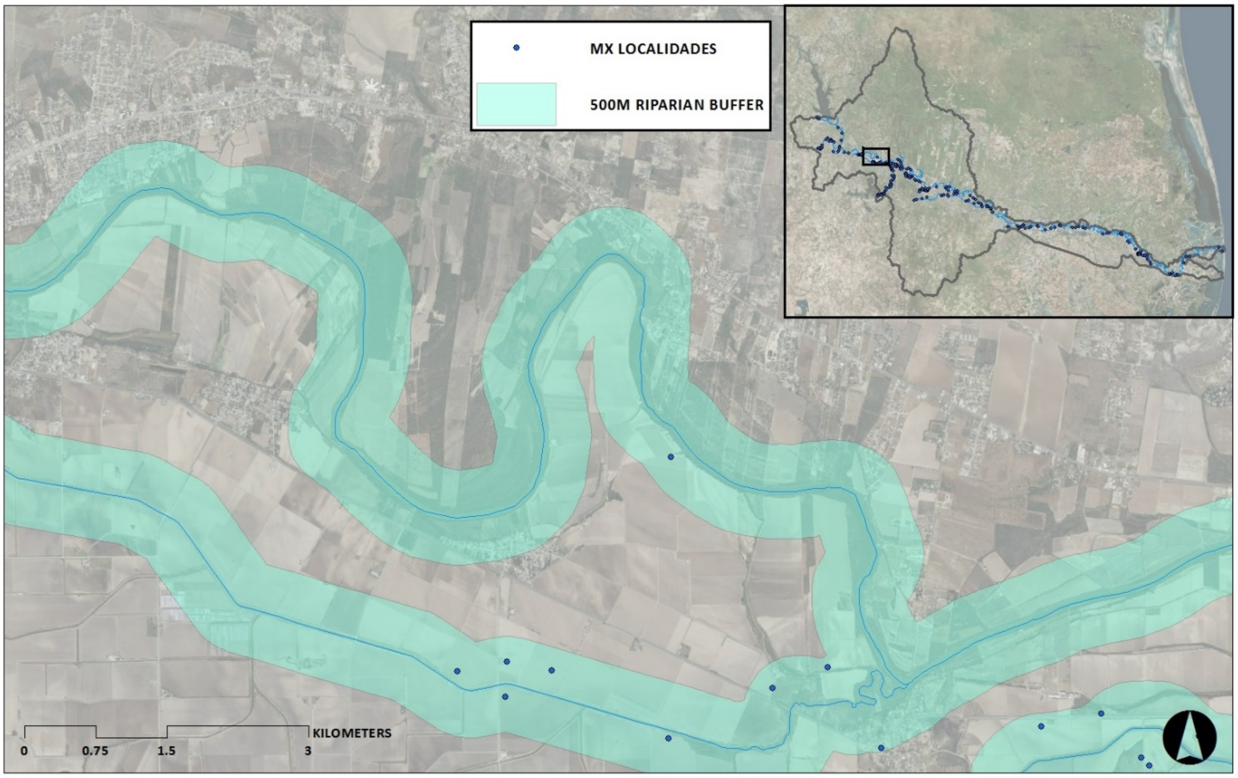


Figure 4-9. Geospatial Analysis of Mexican Residential Nonpoint Sources in the LRG/RB Watershed

Table 4-5 summarizes the results of the geospatial analysis conducted by LRGWQI researchers to determine the number, and distribution by sewage disposal type, of LRG/RB watershed residents living within 500 meters of the LRG/RB or one of its tributaries.

Table 4-5. Number of LRG/RB Watershed Residents Living within 500 Meters of the LRG/RB or One of Its Tributaries, Distributed by Sewage Disposal Type

Country	Total Number of LRG/RB Watershed Residents Living within 500 m of the LRG/RB or a Tributary	Number of LRG/RB Watershed Residents Living within 500 m of the LRG/RB or a Tributary Receiving Centralized Sewage Disposal Services	Number of LRG/RB Watershed Residents Living within 500 m of the LRG/RB or a Tributary Using Septic Systems	Number of LRG/RB Watershed Residents Living within 500 m of the LRG/RB or a Tributary Lacking Sewage Disposal Services
US	10,641	7,290	3,065	286
Mexico	44,449	31,732	8,580	4,137

4.2.2 Agricultural Nonpoint Sources

Within the context of the LRGWQI, steady state agricultural nonpoint sources in the LRG/RB watershed can be subdivided into two main categories, (1) pollutant contributions from livestock and domestic animals (2) pollutant contributions from irrigation return flows. These two types of nonpoint sources of pollution result from distinctly different agricultural activities and their characterization requires different data sources and data analysis methods.

The data sources used by LRGWQI researchers to characterize agricultural nonpoint sources in the LRG/RB watershed included (1) the LRG/RB watershed boundary (modified from USGS, 2015), (2) the binational land use/land cover GIS layer developed as part of the BEHI (USGS, 2015), (3) INEGI's Censo Agrícola, Ganadero y Forestal 2007 (INEGI, 2007) and (4) the USDA's 2007 Census of Agriculture (USDA, 2007).

4.2.2.1 Livestock and Domestic Animals

The analysis method used by LRGWQI researchers to characterize agricultural nonpoint sources in the LRG/RB watershed was modified from Lynch, 2012. Although conducted using different data sources, the methods used to determine the number of livestock and domestic animals in the US and Mexican portions of the LRG/RB watershed are identical and rely on county and municipio level agricultural census values for animal populations of interest, including cattle, horses, sheep and goats. Domestic pigs, chickens, ducks and geese were excluded from the analysis, because unlike grazing livestock animals, these species are generally confined to areas where steady state nonpoint source pollutant contributions do not occur.

For each of the counties and municipios included in the LRG/RB watershed, LRGWQI researchers calculated the densities of the cattle, horses, sheep and goats per square kilometer. LRGWQI researchers then calculated the area of land that supports grazing in the portions of these counties/municipios that fell within the LRG/RB watershed. Lynch, 2012 defines these grazing habitats as forest, shrub, and grass/pasture (Figure 4-10). Equation 1 calculates the total number of grazing animals in each national sub-watershed (US and Mexican) by multiplying the area of grazing habitat by the density of each of the four types of grazing animal in the county/municpio areas within each national subwatershed.

$$AN_j = AR_j * \rho_i \qquad (1)$$

Where AN_j is the total animals in each subwatershed j, AR_j is the total area of grazing habitat (km^2) in subwatershed j, ρ_i is the density of the animal in each county/municipio i. Table 4-6 shows the results of the analysis.

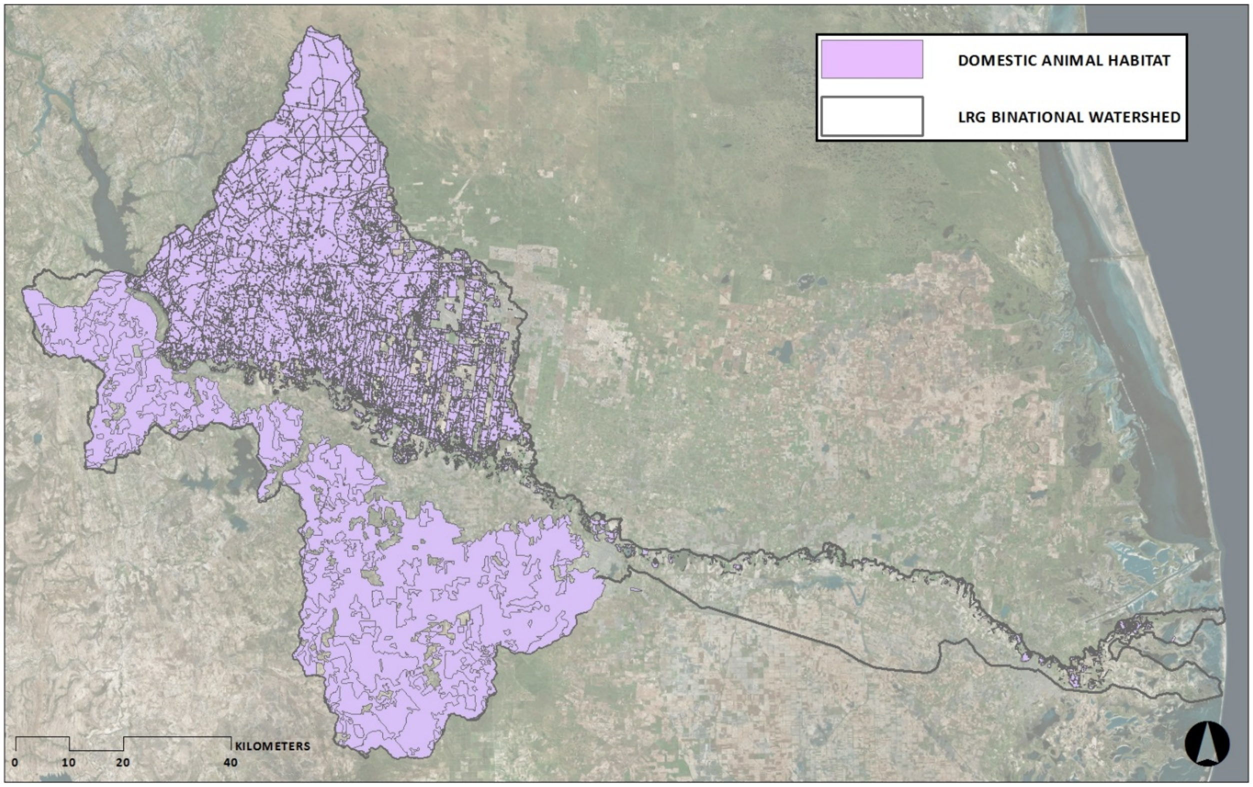


Figure 4-10. Grazing Habitat for Livestock and Domestic Animal in the LRG/RB Watershed

Table 4-6. Estimated Number of Livestock and Domestic Animals in the US and Mexican Portions of the LRG/RB Watershed

Country	Cattle	Horses	Sheep	Goats
US	24,410	420	417	714
Mexico	1,879	16	113	19

4.2.2.2 Irrigation Return Flows

Another source of surface water pollution related to agricultural activities in the LRG/RB watershed is irrigation return flows. The most common irrigation method used on both sides of the watershed is flood irrigation, which commonly saturates soils producing excess irrigation water. Excess irrigation water can flow directly from agricultural fields into drainage ditches as irrigation return flows, but most commonly, excess irrigation water pools in the shallow subsurface below the root zone where it can travel laterally as phreatic groundwater, which also flows into agricultural drainage ditches or directly into the LRG/RB as base flow.

Under the right conditions, excess irrigation water can leach dissolved salts from agricultural soils, mobilizing and concentrating them below the root zones of irrigated crops, along with other constituents commonly produced during agricultural production, including dissolved organic matter, fertilizers, and pesticides. As a result, irrigation return flows can be a substantial source of these pollutants in the LRG/RB watershed.

A significant amount of agricultural land in the LRG/RB watershed is irrigated using water from the LRG/RB or one of its two major tributaries, the Río Álamo or the Río San Juan. As described in Section 3.2 of this report, approximately 1770 Km^2 of the LRG/RB watershed (24.3%) is used for crop production. However, not all of this agricultural land is irrigated. To calculate the area of irrigated land within the LRG/RB watershed, LRGWQI researchers used the binational land use GIS layer developed for the BEHI project (USGS, 2015). Using the assumption that most of the irrigated agricultural land contributing irrigation return flows to the LRG/RB is found adjacent to or in close proximity to the LRG/RB or one of its tributaries or drains, LRGWQI researchers clipped the agricultural land areas located within a 30 Km buffer of the LRG/RB or one of its tributaries (Figure 4-11). For quality assurance, the resulting land use polygons were then checked against satellite imagery to verify that the land uses in the resulting irrigated agricultural land layer appeared to be irrigated crop fields and that the clipped areas were likely to drain to the LRG/RB (Figure 4-12).

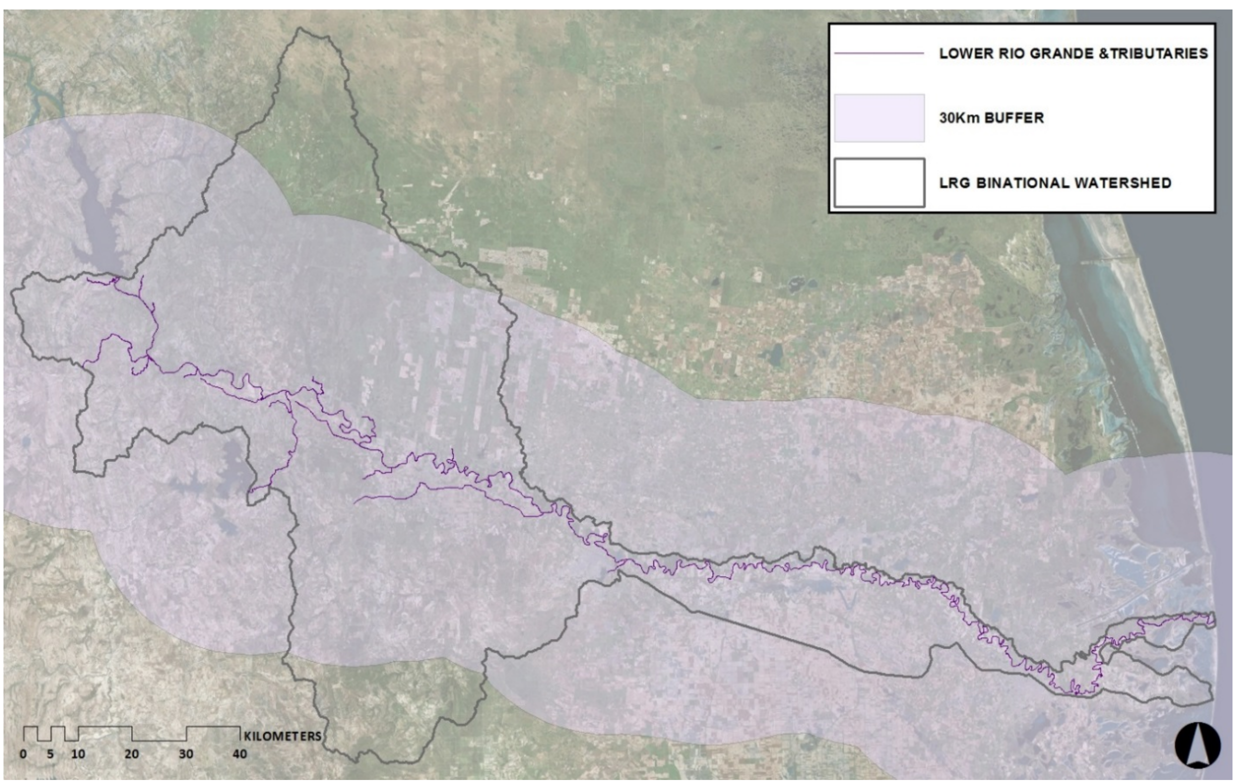


Figure 4-11. 30 Km Ag Buffer in the LRG/RB Watershed

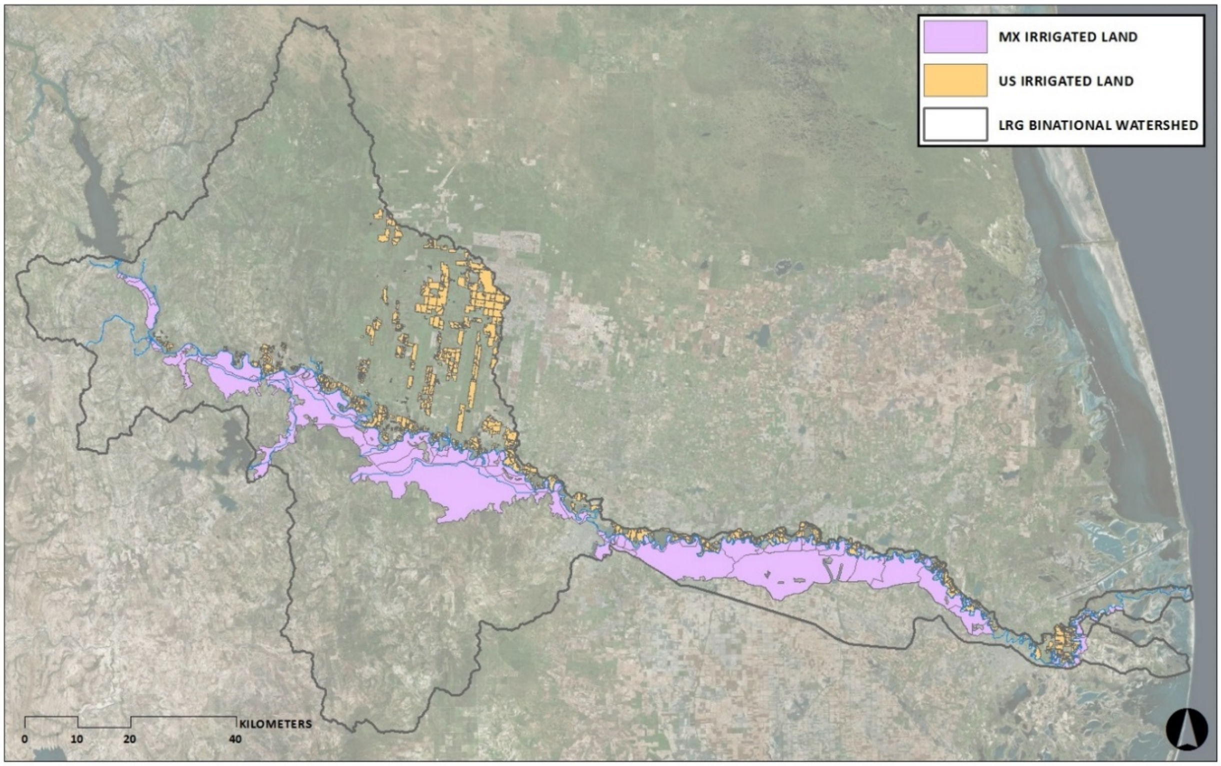


Figure 4-12. Irrigated agricultural land in the LRG/RB Watershed

Figure 4-12 shows the estimated areas of irrigated agricultural land in the LRG/RB watershed. Evident from this figure is the relatively uneven distribution of irrigated land between the two national subwatersheds of the LRG/RB. While irrigated agricultural land in the US portion of the LRG/RB watershed is estimated to total 227.24 Km^2, the total amount of irrigated agricultural land on the Mexican side of the watershed is estimated to be 887.83 Km^2, nearly four times the area on the US portion of the LRG/RB watershed.

The disparity in the amount of irrigated agricultural land on either side of the LRG/RB watershed is due as much to the difference in hydrology between the two national subwatersheds as it is to the way in which each country diverts or pumps water from the RG/RB for irrigation.

US

Although there are an estimated 2,392 Km^2 of agricultural land in the three US counties that border the LRG/RB below Falcon Dam (USDA, 2012), most of the irrigated land in these counties is outside of the LRG/RB watershed. The water used for irrigation of the crops in these counties comes from the 20 irrigation districts located in the three US border counties. These irrigation districts pump water directly from the Rio Grande at various locations on the LRG/RB.

Irrigation return flows generated from the vast majority of the irrigated land in Cameron and Hidalgo counties flows to the Arroyo Colorado, a perennial stream that flows roughly parallel to the LRG/RB on the US side and empties into the US Laguna Madre.

A portion of the irrigated land in Starr County also produces irrigation return flows seasonally. These irrigation return flows are collected by a number of non-perennial tributaries and drainage ditches that flow into the LRG/RB from the US side. Although very little flow data is available for these ditches, their contributions to the LRG/RB are thought to be small compared to those of Mexican agricultural ditches (Halbert, 2016).

Mexico

In contrast to the US side, most of the water used for agricultural irrigation on the Mexican side of the LRG/RB watershed is diverted from the Las Blancas and Marte R. Gomez reservoirs, which are impoundments of the two main tributaries of the river, the Río Álamo and the Río San Juan, respectively. Water used for irrigation on the Mexican side of the LRG/RB watershed is also diverted directly from the LRG/RB at one of two in-stream dams on the river, Anzalduas Dam and Retamal Dam. Irrigation water is diverted into delivery canals that flow through large agricultural areas where it is distributed to individual agricultural fields through lateral canals.

Upstream of Anzalduas Dam, which is located near the Mexican city of Reynosa, five large agricultural drains collect irrigation return flows from these large agricultural areas in the Mexican portion of the LRG/RB watershed; they are the Rancherias, Los Fresnos, Puertecitos, Huizache and El Morillo drains. Four of these five drains flow directly into the LRG/RB upstream of Anzalduas Dam. The fifth drain, Los Fresnos, flows into the Río San Juan approximately 4 Km from the confluence with the LRG/RB (Figure 4-13).

Downstream of Anzalduas, Mexican irrigation return flows are diverted away from the LRG/RB through a series of drains that flow in a southeast direction and ultimately empty into the marshlands that border the Mexican Laguna Madre.

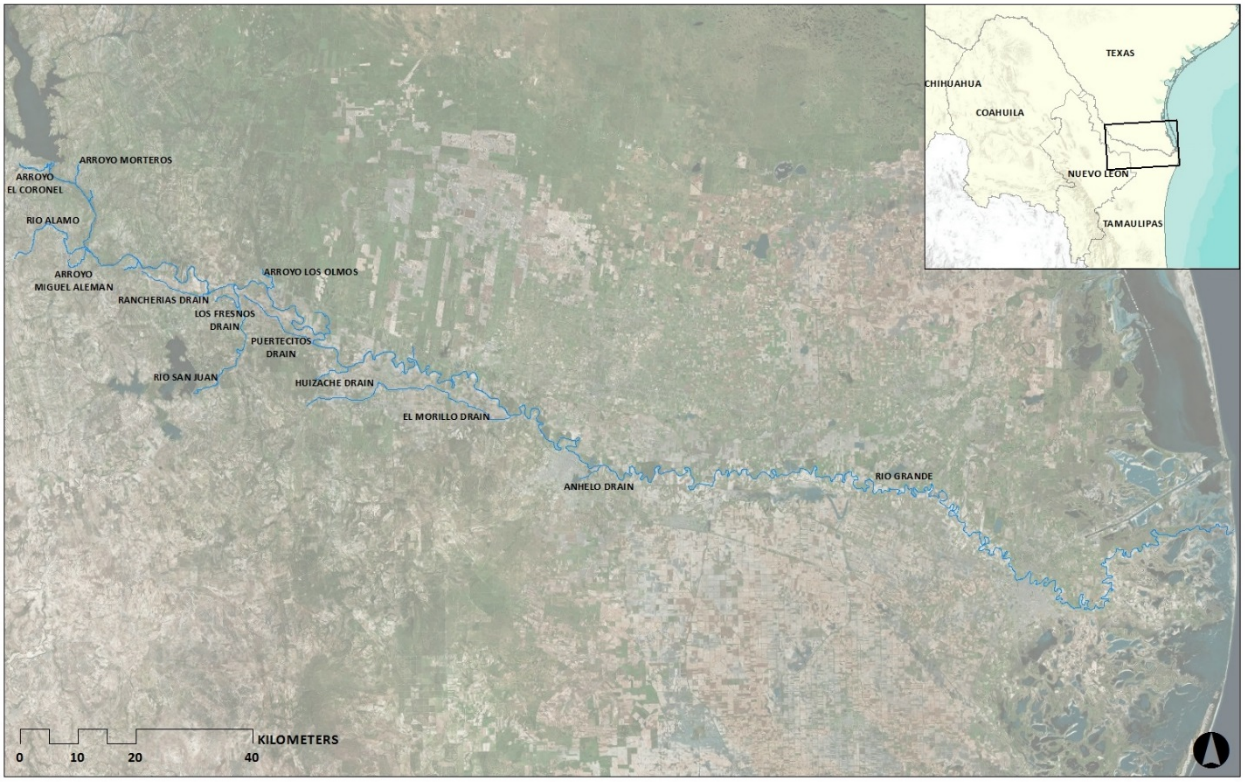


Figure 4-13. Tributaries and Drains of the LRG/RB

4.2.3 Wildlife Nonpoint Sources

Grazing wildlife species are considered sources of pollutants in surface water because of the wastes they produce in the form of feces. As was the case with LRGWQI analysis of livestock and domestic animals, the contribution of pollutants from wildlife to surface water under steady state conditions is limited to direct deposition of feces into the LRG/RB or a tributary or ditch. LRGWQI researchers chose to concentrate their analysis on three main wildlife species, deer, feral hogs and waterfowl, based on the abundance and pollutant contribution potential of these animals. The data sources used by LRGWQI researchers to characterize wildlife nonpoint sources in the LRG/RB watershed include the binational land use GIS layer developed as part of the BEHI (USGS, 2015) and estimates of wildlife population densities from (1) Texas Parks and Wildlife Department (TPWD, 2010), (2) the Institute of Renewable and Natural Resource at Texas A&M University (Texas A&M, 2002) and (3) Smith, 2002.

4.2.3.1 Deer and Feral Hogs

Unlike livestock and domestic animals, which graze openly and can often access surface water bodies at will, wild animals tend to concentrate in riparian areas. Following Lynch, 2012, LRGWQI researchers defined a 300 foot (91 meter) riparian wildlife corridor to account for this tendency. A standard density of wild animals of interest was assumed in all the LULC types in which the species is typically are found.

For both deer and feral hogs, LRGWQI researchers assigned the LULC categories of forest, shrub, grass/pasture, agriculture, and wetlands as suitable habitats (Figure 4-14).

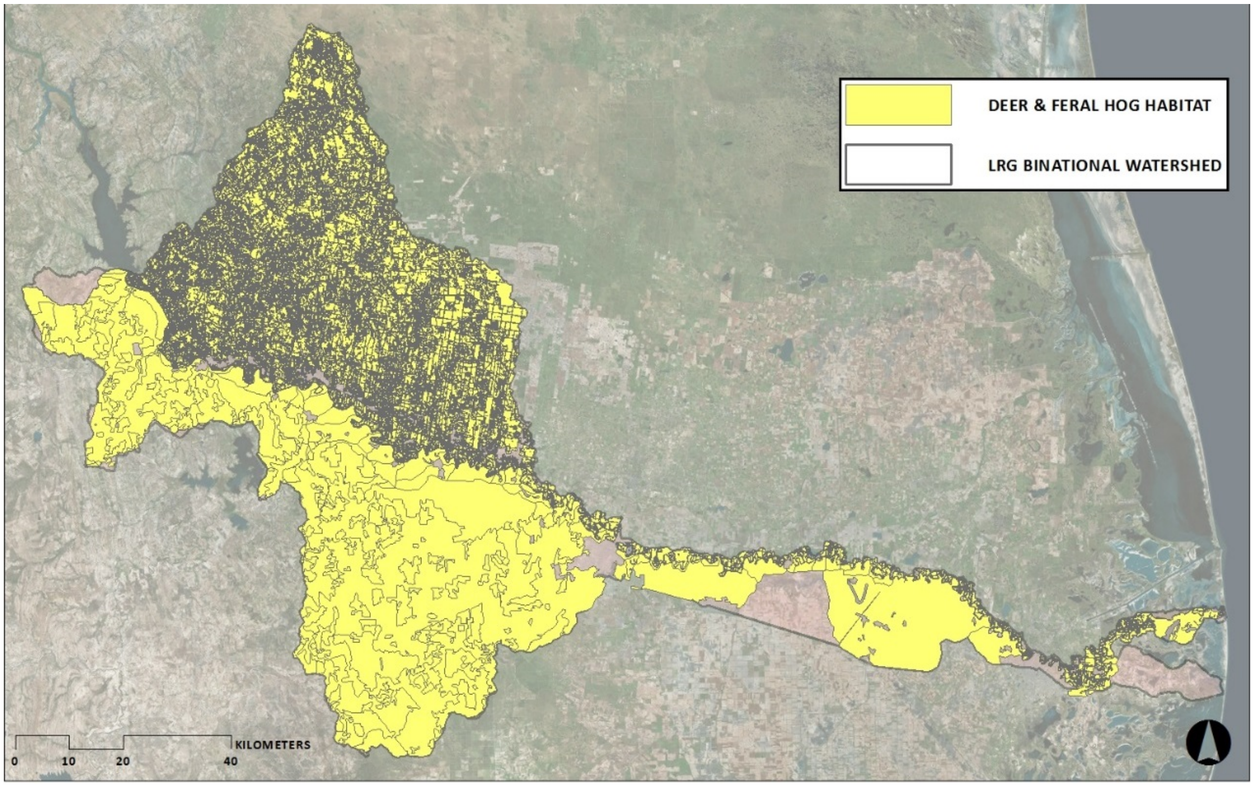


Figure 4-14. Deer and Feral Hog Habitat in the LRG/RB Watershed

In Texas, deer populations are monitored according to Range Management Units, which are units of land in which deer concentrations are surveyed by the Texas Parks and Wildlife Department. The Resource Management Unit Number 8 includes the US portion of the LRG/RB watershed. From recent surveys conducted in 2009 and 2010, the TPWD estimated that Resource Management Unit Number 8 had a deer density of 3.21 deer per square kilometer (Lynch, 2012). For Feral Hog population densities, LRGWQI researchers used values derived from Texas A&M University's Institute of Renewable and Natural Resource, which estimates densities of feral hogs in Texas ranging between 0.51-0.95 hogs per square kilometer (Texas A&M, 2011). The analysis conducted by LRGWQI researchers uses a conservative estimate of 0.95 hogs per square kilometer.

Equation 2 calculates the total number of wildlife species in a given subwatershed (US and Mexican). It multiplies the total area of suitable habitat for each animal of interest by the population density of that species as previously described.

$$ANW_j = HB_j * pRA_j * \rho \qquad (2)$$

Where ANW_j is the total number of animals in subwatershed j, HB_j is the total area of suitable habitat in subwatershed j (km^2), is pRA_j the proportion of suitable habitat in subwatershed j that is within the riparian wildlife (91m) buffer and ρ is the wildlife animal population density (population/km^2) in the management unit (which encompasses the watershed).

The analysis found that, in the entire watershed there is a total of 84.3 km^2 of suitable habitat for deer and feral hogs within the riparian corridors (i.e., 91m buffer) of the LRG/RB or one of its tributary, streams, drains, or ditches.

Since no deer or feral hog population estimates were found for the Mexican side of the LRG/RB, LRGWQI researchers used US wild animal population densities for the same suitable habitats on the Mexican side of the LRG/RB watershed.

4.2.3.2 Waterfowl

The Texas Gulf Coast is an important location for seasonal waterfowl migrations. Many of the waterfowl in the Texas Gulf Coast stay in the wetland areas of the Rio Grande delta, defined by Tunnel as the area which divides the Laguna Madre in Texas from the Laguna Madre de Tamaulipas; from the coast to approximately the Brownsville/Matamoros urban area (Tunnel, 2002). The area is the favored wintering grounds for many types of wild geese, as well as mottled ducks and green-winged teal ducks. Other types of migratory and coastal waterfowl can also be found in the watershed of the Rio Grande/ Río Bravo, however, the dominant waterfowl species in the LRG/RB watershed are wild geese and ducks (Lynch, 2012).

Following the method described in Lynch, 2012, LRGWQI researchers estimated population densities for waterfowl in the LRG/RB watershed by using the percentages of the most abundant species in the Rio Grande Delta, from Smith, 2002, and multiplying them by the waterfowl population in the Lower Texas Coast area, from a survey conducted by the USFWS during the 1980-81 winter season (USFWS, 1981). The resulting population densities, 31.77 #/Km^2 for geese and 34.54 #/ Km^2 for ducks, were used in the analysis of waterfowl species in the Rio Grande Delta area.

The land uses attributed to waterfowl in the LRG/RB watershed are water and wetlands (Figure 4-15).

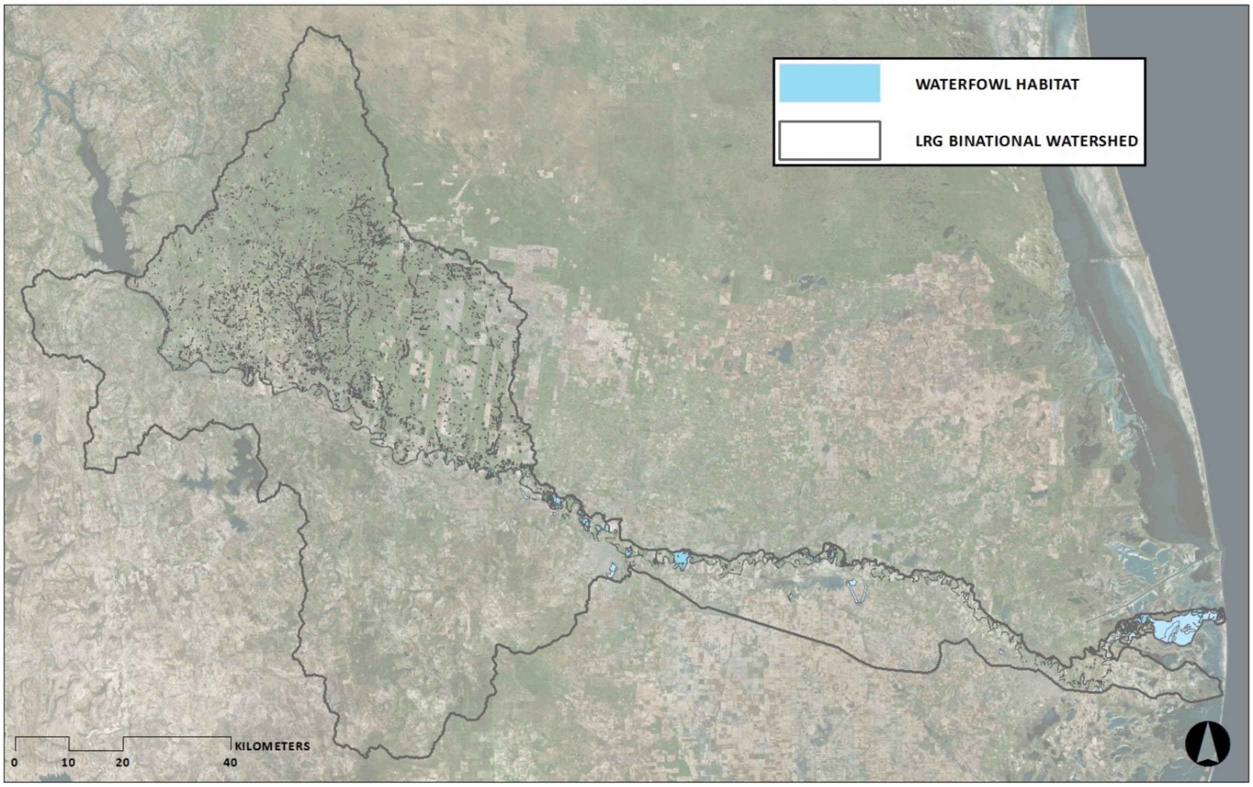


Figure 4-15. Waterfowl Habitat in the LRG/RB Watershed

Of the approximately 197 Km^2 total water and wetlands area in the LRG/RB watershed, LRGWQI researchers estimated a total of 22.4 km^2 of suitable habitat for waterfowl within the riparian corridors (91m buffer) in the LRG/RB watershed.

Unlike the assumption of even population densities across suitable habitats, made by LRGWQI researchers with other wildlife species, waterfowl densities were considered variable. Following Lynch, 2012, LRGWQI researchers decreased the population densities of geese and ducks with distance from the coast using an inverse distance weighting method based on the distance from the Rio Grande Delta area (i.e., decreasing from Brownsville/Matamoros to Falcon Dam).

Table 4-7 shows the estimated populations of representative wildlife species within the riparian corridors (91m buffer) on both sides of the LRG/RB watershed.

Table 4-7. Estimated Wildlife Populations within the Riparian Corridors (91m) on both sides of the LRG/RB Watershed

Wildlife Species	US	Mexico
Deer	72	174
Feral Hogs	12	39
Waterfowl	528	258

Figure 4-16 shows a visual example of the results of the geospatial analysis conducted by LRG/RB researchers to estimate the number of domestic and wildlife animals of interest in the LRG/RB watershed.

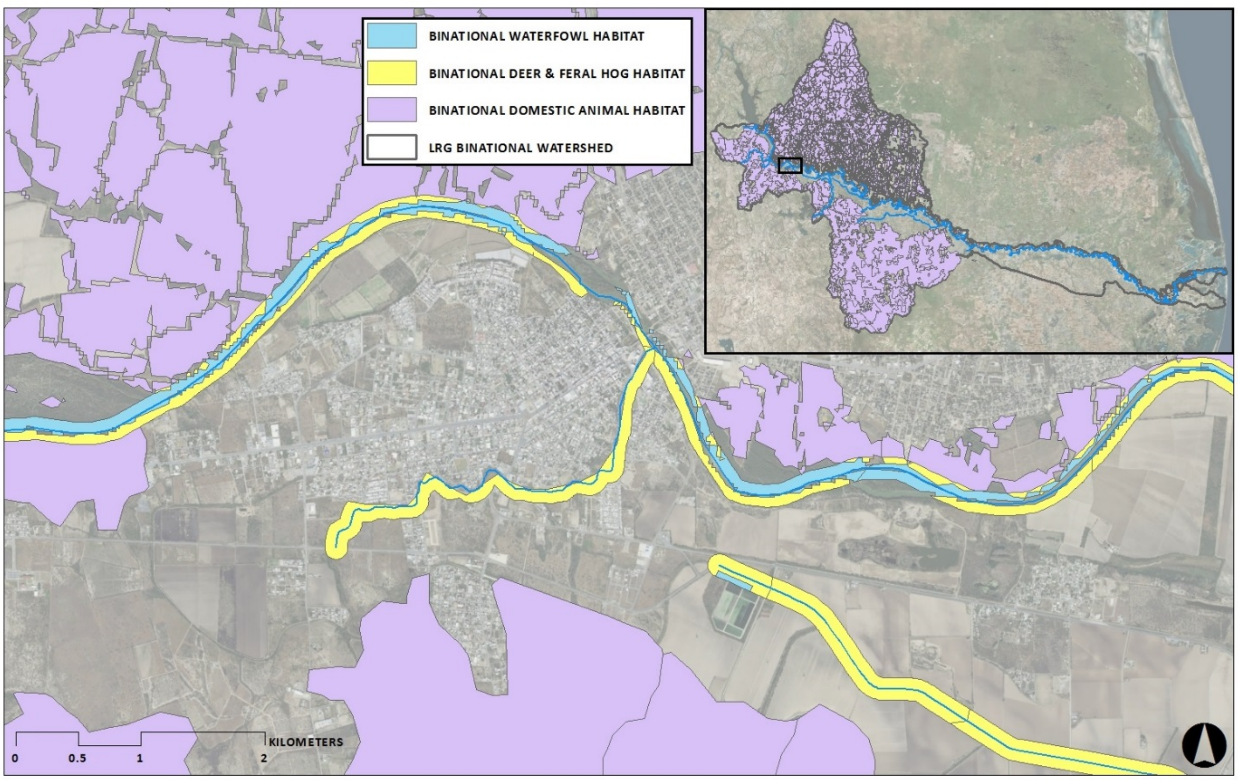


Figure 4-16. Geospatial Analysis of Domestic and Wildlife Animal Nonpoint Sources in the LRG/RB Watershed

5.0 Pollutant Loading Analysis

LRGWQI researchers analyzed the sources of surface water pollution in the LRG/RB watershed described in Section 4 of this report to estimate potential pollutant loads to the LRG/RB. Each broad category of pollutant source was examined with the goal of estimating its potential daily contribution of pollutants of concern to the LRGWQI. The following sections describe the methods used in the analysis, as well as the analysis results.

5.1 Point Sources

LRGWQI researchers used the daily average effluent flow information associated with the individual point sources of pollution described in Section 4 of this report, in combination with reported loads and reported and estimated concentrations of selected constituents of concern, to estimate the average daily loadings, to the LRG/RB, of pollutants emanating from point source discharges in the watershed.

For US point sources, average daily loading data for constituents such as five-day biochemical oxygen demand (BOD5) and total suspended solids (TSS) is generally available from the USEPA's Integrated Compliance Information System (ICIS) database, along with average daily effluent flow and bacteria concentrations (USEPA, 2016). If required to do so under their NPDES permits, individual wastewater facilities in the US will also report average daily loadings of ammonia nitrogen (NH_3-N), as well as effluent concentrations of other constituents for which they are permitted to discharge, such as total dissolved solids (TDS).

To estimate loadings of constituents not reported to the USEPA under the NPDES, such as total nitrogen (TN) and total phosphorus (TP), LRGWQI researchers used the average daily effluent flow from the ICIS database in combination with constituent concentrations derived from stoichiometric ratios of these constituents to the daily average BOD5 concentrations in their wastewater effluent, as reported in ICIS. These stoichiometric ratios were conservatively established based on their relative concentrations in wastewater of "weak" strength as reported in Metcalf and Eddy, 1991. The concentration of TDS in effluent from US wastewater treatment facilities that do not report this constituent to the USEPA was also obtained from Metcalf and Eddy, 1991.

Although the preferred indicator bacteria used by USEPA and the State of Texas to assess fecal contamination in surface waters are *E. coli* and *Enterococcus*, the fecal indicator bacteria common to both the US and Mexico is fecal coliform. Under some circumstances, the State of Texas continues to use fecal coliform to assess surface water quality. Also, two of the US wastewater facilities in the LRG/RB watershed, the City of Roma and the City of Rio Grande City, reported more fecal coliform effluent data than any other indicator bacteria to the USEPA during the LRGWQI period of record (2000-2015). Partly for these reasons, but mainly out of a need to harmonize water quality criteria for the project, the LRGWQI's Binational Technical Workgroup agreed to use fecal coliform as the indicator bacteria for the LRGWQI. For US facilities that exclusively report *E. coli* or *Enterococcus* in their discharge monitoring reports to USEPA, LRGWQI researchers converted the daily average concentrations of these parameters to fecal coliform using the ratio of their geometric mean criteria as specified in the State of Texas' Surface Water Quality standards (126 MPN *E. coli*:200 MPN fecal coliform and 35 NPM *Enterococcus*:200 MPN fecal coliform).

For Mexican point sources, LRGWQI researchers used the estimated average daily effluent flow values for each Mexican wastewater outfall, as described in Section 4.1.2 of this report, in combination with the maximum monthly average constituent criteria specified in the Mexican federal standard NOM-001-SEMARNAT-1996 (Table 4-4) to calculate average daily loadings of constituents of concern. Ammonia nitrogen loadings were calculated using effluent concentrations derived from the stoichiometric ratio of ammonia nitrogen to BOD from Metcalf and Eddy, 1991. Total dissolved solids loadings were calculated using the concentration of TDS in wastewater from Metcalf and Eddy, 1991. Table 5-1 shows the results of the analysis of daily point source loadings of constituents of concern to the LRG/RB.

5.2 Steady State Nonpoint Sources

In order to estimate potential daily loading rates of constituents of concern to the LRG/RB from steady state nonpoint sources in the LRG/RB watershed, LRGWQI researchers used the population values calculated and reported in Section 4 of this report in combination with literature-derived per capita wastewater and animal waste production rates and average constituent concentrations in untreated wastewater and animal waste. The resulting daily loading rates can only be considered potential loading rates to the river due to uncertainty in the analysis.

5.2.1 Residential Nonpoint Sources

Using the estimated number of LRG/RB watershed residents, living within 500 m of the LRG/RB or one of its tributaries/drains, that use septic systems for sewage treatment and those residents living in the same 500 m buffer that lacked any wastewater treatment (Table 4-4), LRGWQI researchers calculated the loading of constituents of concern to the LRG/RB from residential nonpoint sources located on both sides of the LRG/RB by applying average per capita wastewater production rates and typical concentrations of constituents in untreated domestic wastewater of medium strength from Metcalf and Eddy, 1991.

Table 5-1. Estimated Daily Loading of Constituents of Concern from Point Source Discharges to the LRG/RB

Facility Name	Flow (L/day)	BOD5 (Kg/day)	TSS (Kg/day)	TDS (Kg/day)	TP (Kg/day)	TN (Kg/day)	NH_3-N (Kg/day)	Fecal Coliform (CFU/day)
Nueva Ciudad Guerrero (Imhoff Tank)	268,704	20	20	134	5	11	2	2.69E+11
Ciudad Mier	241,920	18	18	121	5	10	1	2.42E+11
Ciudad Miguel Aleman	3,222,720	242	242	1,611	64	129	26	3.22E+12
City of Roma 3	310,933	-	3	155	-	-	-	-
City of Roma 2	13,595,760	9	12	6,798	<1	2	1	2.46E+10
Ciudad Camargo	285,984	21	21	143	6	11	2	2.86E+11
City of Rio Grande City	3,163,449	21	25	1,582	1	4	2	4.53E+12
Union Water Supply Corporation	667,305	3	3	334	<1	4	2	5.51E+09
AGUA Special Utility District	631,551	2	4	316	<1	2	1	5.21E+09
Ciudad Gustavo Diaz Ordaz	238,464	18	18	119	5	10	2	2.38E+11
La Joya Independent School District	9,694	<1	<1	5	<1	<1	<1	1.93E+07
City of La Joya	952,067	39	116	476	1	7	4	7.85E+11
City of Peñitas	666,280	4	3	333	<1	1	<1	2.59E+09
Descarga Municipal D2 , Reynosa	28,080	2	2	14	1	1	<1	2.81E+10
Descarga Municipal D3, Reynosa	354,326	27	27	177	7	14	2	3.54E+11
Ciudad Reynosa PTAR 1	53,280,029	3,996	3,996	26,640	1,066	2,131	436	5.33E+13
Brownsville Public Utility Board (Silas Ray Power Plant)	76,455	-	-	38	-	-	-	-
Descarga Municipal D4, Matamoros	64,800	5	5	32	1	3	1	6.48E+10
Brownsville Public Utility Board (Southside Wastewater Treatment Plant)	23,882,877	67	203	11,941	2	12	11	1.90E+11
Total	**101,941,398**	**4,494**	**4,719**	**50,971**	**1,165**	**2,350**	**494**	**6.35E+13**

Based on information found in BECC project certification and environmental impact assessment documents for projects in the LRG/RB watershed, LRGWQI researchers used different per capita wastewater production rates for US and Mexican residents: 245 L/person/day for US residents and 184 L/person/day for Mexican residents. The value for typical fecal coliform concentrations in untreated wastewater was obtained from Schuller, 2000.

Table 5-2 shows the result of the estimates of potential daily loadings of constituents of concern to the LRG/RB from steady state residential nonpoint sources in the LRG/RB watershed.

Table 5-2. Estimated Potential Daily Loading of Constituents of Concern to the LRG/RB from Steady State Residential Non-Point Sources in the Watershed

Constituent Load	US Subwatershed	Mexican Subwatershed	Total LRG/RB Watershed
BOD (Kg/day)	32	202	234
TSS (Kg/day)	32	202	234
TDS (Kg/day)	73	460	533
TP (Kg/day)	1	7	8
TN (Kg/day)	6	37	43
NH3-N (Kg/day)	4	23	27
Fecal Coliform (MPN/day)	9.29E+14	5.88E+15	6.81E+15

5.2.2 Agricultural Nonpoint Sources (Livestock and Domestic Animals)

Using the number of livestock and domestic animals estimated in the LRG/RB watershed, and presented in Section 4 of this report (Table 4-5), in combination with literature-derived, per animal type, manure composition and production rates, LRGWQI researchers calculated the potential daily average loading rates of constituents of concern to the LRG/RB from livestock and domestic animals.

The manure production and composition values used in the calculations were derived from the American Society of Agricultural Engineers Standard D384.2 (ASAE, 2005). However, for constituents not listed in the ASAE standard, such as total suspended solids, total dissolved solids and total nitrogen, LRGWQI researchers used conversions of total solids values and stoichiometric ratios of BOD values, respectively found in ASAE, 2005.

Since the LRGWQI characterizes water quality in the LRG/RB under steady state conditions, LRGWQI researchers considered loadings of constituents of concern in situations where direct deposition of these pollutants is occurring (i.e., direct defecation into the LRG/RB or one of its tributaries). This assumes that livestock and domestic animals spend a small fraction of their time directly in the water. Following a method adapted from Lynch, 2012, LRGWQI researchers applied a factor, to the total constituent loading values, equal to the maximum amount of time livestock and domestic animals are likely to spend directly in the LRG/RB or one of its tributaries (estimated to be 1.4% of the time).

Table 5-3 shows the result of the estimates of potential daily loadings of constituents of concern to the LRG/RB from livestock and domestic animals in the LRG/RB watershed under steady state conditions.

Table 5-3. Estimated Potential Daily Loading Rates of Constituents of Concern to the LRG/RB from Livestock and Domestic Animals under Steady State Conditions

Constituent Load	US Subwatershed	Mexican Subwatershed	Total LRG/RB Watershed
BOD (Kg/day)	254	20	274
TSS (Kg/day)	206	16	222
TDS (Kg/day)	69	5	74
TP (Kg/day)	15	1	16
TN (Kg/day)	23	2	25
NH3-N (Kg/day)	14	1	15
Fecal Coliform (MPN/day)	4.37E+13	3.42E+12	4.71E+13

As discussed in Section 4 of this report, irrigation return flows are also an important source of pollutant loading to the LRG/RB. However, LRGWQI researchers lacked the data and information necessary to adequately estimate these potential loads.

5.2.3 Wildlife Nonpoint Sources

Using a method identical to that used for livestock and domestic animals, LRGWQI researchers used the population numbers of wildlife species of interest found within the riparian corridors (91m) on both sides of the LRG/RB watershed, and presented in Section 4 of this report (Table 4-6), in combination with best professional estimates of wildlife excrement composition and production rates to calculate the potential daily average loading rates of constituents of concern to the LRG/RB from deer, feral hogs and migratory waterfowl.

Since no excrement composition or production rates were available in the technical literature for the deer, feral hogs and waterfowl, LRGWQI researchers used manure composition and production values associated with sheep and ducks, from ASAE, 2005, as surrogates. Sheep manure production values were multiplied by a factor of 1.5 for use in feral hog loading calculations. This was based on the assumption that feral hogs produce more excrement per day than sheep. Similarly, LRGWQI researchers used half of the ASAE domestic duck manure production values to calculate daily loading rates of constituents of concern for waterfowl based on the assumption that migrating waterfowl produce approximately half the waste produced by domestic ducks.

As with the calculation of livestock and domestic animal loadings, LRGWQI researchers assumed that deer and feral hogs spend only a small fraction of their time directly in the water, where direct defecation can occur under steady state conditions. To account for this, LRGWQI researchers applied the same factor, to the total constituent loading calculations as they did to livestock and domestic animal loading estimates (0.014).

Table 5-4 shows the result of the estimates of potential daily loadings of constituents of concern to the LRG/RB from wildlife species of interest under steady state conditions. The use of surrogate excrement composition or production values in the calculation of constituent loading rates for wildlife species introduces a higher level of uncertainty in their analysis. Consequently, the results of these calculations contain a higher level of uncertainty than the results of similar calculations associated with residential and agricultural nonpoint sources. Fortunately, the number of deer, feral hogs and waterfowl thought to contribute pollutants of concern to the LRG/RB are small compared to number of contributing livestock, domestic animals and residential nonpoint sources. This is reflected in the loading values shown in Table 5-4.

5.3 Comparison of Point Source and Nonpoint Source Pollutant Loadings

While estimates of nonpoint source pollutant loadings are typically not as reliable as those of point sources, due primarily to the higher uncertainty associated with the former, it is sometimes informative to compare the results of these estimates to gain some insight of the relative magnitude of each broad category of pollutant source in a watershed. Table 5-5 shows a comparison of estimated daily loading rates of constituents of concern form point and nonpoint sources in the LRG/RB watershed.

Table 5-4. Estimated Potential Daily Loading Rates of Constituents of Concern to the LRG/RB, under Steady State Conditions, from Deer, Feral Hogs and Migratory Waterfowl in the LRG/RB Watershed

Constituent Load	US Subwatershed	Mexican Subwatershed	Total LRG/RB Watershed
BOD (Kg/day)	<0.5	<0.5	<0.5
TSS (Kg/day)	<0.5	<0.5	0.5
TDS (Kg/day)	<0.5	<0.5	<0.5
TP (Kg/day)	<0.5	<0.5	<0.5
TN (Kg/day)	<0.5	<0.5	<0.5
NH3-N (Kg/day)	<0.5	<0.5	<0.5
Fecal Coliform (MPN/day)	5.20E+10	9.05E+10	1.00E+11

Table 5-5. Estimated Daily Loading of Constituents of Concern from Point Sources and Steady State Nonpoint Sources in the LRG/RB Watershed

General Category of Pollutant Source	BOD (Kg/day)	TSS (Kg/day)	TDS (Kg/day)	TP (Kg/day)	TN (Kg/day)	NH_3-N (Kg/day)	Fecal Coliform (CFU/day)
Point Sources*	4,494	4,719	50,971	1,165	2,350	494	6.35E+13
Nonpoint Sources‡	508	457	607	24	68	42	6.86E+15
Total	5,002	5,176	51,578	1,189	2,418	536	6.92E+15

*$CBOD_5$ loading values were used for point sources
‡ Does not include loadings from irrigation return flows

It is important to note that the nonpoint source loading estimates presented in Table 5-5 do not include inputs of constituents of concern from irrigation return flows, which could increase the estimates of daily pollutant loadings by, at least, an order of magnitude, especially for total dissolved solids (TDS) and nutrients (TP, TN and NH3-N).

6.0 Review and Analysis of Historical Water Quality

As part of the technical effort associated with the LRGWQI, researchers from the US and Mexico compiled and analyzed historical water quality data collected in the LRG/RB by the respective agencies participating in the initiative. Data from each country were shared between LRGWQI researchers through a formal process of information exchange conducted in 2012 under the auspices of the IBWC/CILA. As a follow up to the binational data exchange conducted in 2012, additional water quality and meteorological data were again exchanged between the TCEQ and CONAGUA in 2015.

The following sections discuss the data, data sources, and analysis methods used by LRGWQI researchers. The results of the analyses are presented in Appendices C through H of this document. However, this document does not provide an interpretation of the analyses presented in Appendices C through H. In the future, the LRGWQI Binational Technical Work Group may jointly propose an interpretation of these analysis as part of the recommendations provided to the LRGWQI Binational Core Group in accordance with the provisions specified in the Terms of Reference of the LRGWQI (Appendix B).

6.1 Analysis of Historical Water Quality

LRGWQI researchers chose methods of analysis that would help (1) visualize the data, (2) investigate associations between water quality parameters, (3) investigate the effects of meteorological conditions and seasonality on water quality parameters, and (4) investigate water quality trends with time. The analytical methods used by the LRGWQI researchers are conventional analyses commonly performed by water quality professionals on historical water quality datasets.

Data from both the US and Mexico were used in the analyses. In some instances the data were analyzed separately and in other instances the data were pooled prior to analysis. All data analyzed by LRGWQI researchers were collected between the years 2000 and 2015. Although all US historical water quality data was obtained from the TCEQ's Surface Water Quality Monitoring Information System (SWQMIS), the entities that contributed data to SWQMIS, in addition to the TCEQ, include the USGS and the IBWC, as well as local partner agencies, such as the University of Texas at Brownsville and BPUB. Mexican historical water quality data was obtained from CONAGUA's Red Nacional de Monitoreo de la Calidad de las Aguas Nacionales.

The water quality parameters chosen for analysis were selected based on the stated goals of the LRGWQI, the LRG/RB's uses and the common water quality concerns identified for this portion of the river. The parameters analyzed include $CBOD_5$, dissolved oxygen, chloride, sulfate, chlorophyll-*a*, ammonia nitrogen, nitrate, total phosphorus, total dissolved solids, total suspended solids, fecal coliform, *E. coli*, and Enterococcus. To facilitate comparison of US and Mexican data and to enable pooling of the data from both countries for joint analysis, the data were grouped by assessment units (AUs), however some data were not available for all AUs.

In addition to simple scatter plots and box plots, for data visualization and comparison with established water quality criteria and screening levels, LRGWQI performed the following analyses: (1) cross-plots between various parameters (using linear regression to find significance), (2) descriptive statistical estimators, such a minimums, maximums, averages, standard deviations and percent of samples not meeting established criteria or screening levels (3) seasonality tests based on temperature (using ANOVA), (4) seasonality tests based on precipitation using parametric (linear regression) and nonparametric (Mann Whitney U-tests) analysis methods and (5) trends over time using parametric (linear regression) and nonparametric (Mann-Kendall's Tau) analytical methods. For all statistical tests, the threshold for statistical significance was set at a p-value of 0.05.

For seasonality analysis associated with temperature, the Analysis of Variance (ANOVA) test was conducted along with an associated Tukey HSD test. For these analyses, average "season types" were determined for each month of the year based on data available from US weather stations located in the Lower Rio Grande Valley. Season types were held consistent throughout the LRG/RB watershed. After grouping the water quality data into each of three season types (cool, neutral, and warm), LRGWQI researchers analyzed the data to determine if a significant (general) seasonal difference was present using ANOVA tests. To determine if a specific difference existed between any two of the three season types LRGWQI researchers used a Tukey HSD test; p-values were used to determine if significant differences could be seen between season types.

For seasonality analysis associated with precipitation, LRGWQI researchers used only US data. The Mann-Whitney U test (also known as the Wilcoxon rank-sum test) was used along with linear regression analysis to establish covariance between specific water quality parameters and precipitation. The Mann-Whitney U test is a nonparametric statistical test commensurate with the parametric Student's t-test, which examines differences in means. The Mann-Whitney U test is used to determine if two sample sets (in this case data collected under Wet v. Dry conditions) are significantly different.

For the temporal trend analysis, LRGWQI researchers used the Mann-Kendall Tau test along with linear regression analysis. All analysis results are included in Appendices C through H of this report.

6.2 Identification of Data Gaps

During the historical water quality review and analysis effort, LRGWQI researchers identified a number of data gaps related to the parameters of interest and constituents of concern associated with the LRGWQI.

Although more historical water quality data was generally available for the LRG/RB from US data sources overall, a geographic data gap was apparent in US historical data for the 100 Km portion of the LRG/RB upstream of Reynosa/Hidalgo (AU 2302_05). US historical water quality data was also generally lacking in BOD measurements, which were scarce in all portions of the LRG/RB. Chlorophyll *a* values were also very scarce in US data in the portion of the LRG/RB near Matamoros/Brownsville.

Mexican historical water quality data, though less abundant, was well distributed geographically. A number of the Mexican water quality monitoring stations are located at, or very near, US water quality monitoring stations. In the case of some nutrient parameters, such as nitrate and total phosphorus, Mexican water quality monitoring stations showed a significant temporal gap (i.e., 2005-2013) and for other water quality parameters, Mexican data was only available from 2012 until present. This is partly due to the fact that CONAGUA redesigned their national water quality monitoring network in 2011, adding new sites and reactivating old sites. Interestingly, CONAGUA's historical water quality monitoring efforts have also been less intensive in the portion of the river immediately above Reynosa/Hidalgo. This situation has improved significantly since 2012.

6.3 Continued Water Quality Monitoring Efforts

The TCEQ and the IBWC continue to monitor water quality in the LRG/RB, conducting surface water sampling and field measurements at 15 water quality stations on the river and 3 stations on Arroyo Los Olmos, as part of the state-federal monitoring partnership known as the Texas Clean Rivers Program. Under its Red Nacional de Monitoreo de la Calidad de las Aguas Nacionales, CONAGUA has monitored 14 water quality monitoring stations on the LRG/RB and 4 major tributaries since 2012. CONAGUA plans to continue monitoring these stations for the foreseeable future. In addition to this monitoring, CILA staff also monitor a limited number of water quality parameters at monitoring stations located in the LRG/RB and in five major agricultural drains flowing to the LRG/RB.

In addition to conventional water quality monitoring, the TCEQ operates seven continuous water quality monitoring network (CWQMN) stations located along the LRG/RB. The main purpose of these stations is to supply real-time data about water temperature and specific conductance of the LRG/RB to the TCEQ Rio Grande Water Master (Figure 6-1). The usefulness of LRG/RB CWQMN stations in the historical analysis of water quality in the river is limited because the stations only measure two parameters, namely temperature and specific conductance. Also, due to the long period of time CWQMN probes are usually deployed, the data collected at these stations are subject to distortions associated with instrument drift and natural fowling. In order to make TCEQ CWQMN data useful for analysis, a significant effort must be expended to "clean up" the data using various digital time series techniques. For this reason, TCEQ CWQMN data is used almost exclusively as an early warning system to alert US water diverters when salinity levels reach high levels.

Figure 6-1. TCEQ Continuous Water Quality Monitoring Stations in the LRG/RB

In 2015 and 2016, LRGWQI researchers conducted a series of synoptic water quality monitoring surveys on the LRG/RB. The purpose of these surveys was to develop synoptic datasets of water quality parameters for use in the calibration and verification of steady state water quality models of the LRG/RB. The models will be used by LRGWQI researchers as tools in the development of a binational watershed restoration and protection plan for the LRG/RB. Analysis of the synoptic data may also help to further inform the participants of the initiative about water quality in the LRG/RB. However, public release of the LRGWQI synoptic data, and/or any analysis of the data, will only occur after completion of the initiative, tentatively scheduled for the fall of 2018.

7.0 Water Quality Outlook for the Lower Rio Grande Watershed

The trends in water quality investigated by LRGWQI researchers indicate several areas of lingering concern in the LRG/RB. Notably, both US and Mexican historical water quality data show increasing trends in fecal coliform in the lower portion of AU 2302_07, upstream of Rio Grande City, possibly indicating inflows of untreated sewage in this portion of the river. Similarly, there appears to be general agreement between US and Mexican historical water quality trends showing decreasing levels of dissolved oxygen in the LRG/RB downstream of Camargo and Rio Grande City (AU 2302_06).

Among the strongest trends found by LRGWQI researchers, in their analysis of Mexican historical water quality data, occurred in the BOD values recorded upstream of the city of Reynosa and downstream of the Matamoros/Brownsville urban area, possibly indicating potential problems with existing sewage collection and/or treatment in those portions of the river.

Although LRGWQI researchers found little agreement between US and Mexican historical trends in chlorides, sulfate and total dissolved solids, US historical water quality monitoring shows significant upward trends in these constituents, the strongest of which seem to occur in the lower assessment units of Segment 2302 (i.e., 2302_03 and 2302_04).

Despite these persisting water quality problems, a longer historical view of water quality in the LRG/RB shows significant improvements, particularly in the geographic extent of fecal bacteria contamination. Between the years 2000 and 2015 water quality assessments conducted by the TCEQ prompted the removed of several LRG/RB AUs from the State of Texas' list of impaired water bodies, including (1) the lower 25 kilometers of Segment 2302 from the Matamoros/Brownsville urban area to the lower segment boundary (AU 2302_01), (2) a 10.8 Km stretch of the river between the Pharr International Bridge and the Santa Anna National Wildlife Refuge (AU 2302_03) and (3) the portion of the river between Anzalduas Dam and the Reynosa/Hidalgo International Bridge (AU 2302_05). Much of the reduction in fecal bacteria contamination seen in the LRG/RB is thought to be due to the large investments in wastewater collection and treatment in the LRG/RB watershed made over the last 20 years.

7.1 Binational Wastewater Infrastructure Projects

As previously mentioned, several major wastewater collection and treatment projects were completed in the LRG/RB watershed between 1995 and 2015. These projects included the construction of four new wastewater treatment facilities on the Mexican side of the LRG/RB watershed (i.e., Reynosa PTAR No. 2, Matamoros Zona Este, PTAR de Ciudad Mier, PTAR de Ciudad Miguel Aleman) and three new wastewater treatment facilities on the US side (i.e., City of Peñitas, AGUA SUD and Union WSC). Additionally, over the same time period (1995-2015), several projects involving the installation of hundreds of new household sewer connections, rehabilitation of existing sewer lines, replacement of broken lift stations and upgrades/expansions of existing wastewater treatment facilities were also completed on both sides of the LRG/RB watershed.

Although a direct link between expenditures in wastewater infrastructure and improvements in water quality has not been established for projects in the LRG/RB watershed, a 2012 study conducted in the adjacent Arroyo Colorado watershed, on the US side, showed that expenditures in wastewater infrastructure between 1999 and 2009 significantly improved bacterial water quality in the Arroyo Colorado (Miranda, 2012).

Several wastewater infrastructure projects planned for construction prior to the year 2020 are also likely to further improve water quality in the LRG/RB (Table 7-1). On the Mexican side of the LRG/RB watershed, new wastewater treatment facilities are planned for Nueva Ciudad Guerrero, Ciudad Camargo and Gustavo Díaz Ordaz. Also on the Mexican side of the LRG/RB watershed, expansion of the Reynosa PTAR No. 2 will increase wastewater treatment capacity by 500 L/s, mitigating the flow of untreated sewage currently entering the LRG/RB through the Anhelo Drain. These projects will also provide new wastewater services for 49,182 households and improved wastewater collection services for 2,048 households. In all the projects will benefit approximately 291,778 residents living on the Mexican side of the LRG/RB watershed.

On the US side of the LRG/RB watershed, two new wastewater treatment facilities are planned in the urban and suburban areas in and near the City of La Joya. Also, new wastewater collection systems are planned for suburban areas near the cities of Peñitas and Brownsville. These projects will provide new wastewater services for 4,372 households and improved wastewater collection services for 8,998 households, benefiting approximately 47,706 residents living on the US side of the LRG/RB watershed.

Table 7-1. Wastewater Infrastructure Projects Planned in the LRG/RB Watershed

Project Name	Project Type	Population Affected	Projected Completion Date
Nueva Ciudad Guerrero, Tamps	New WWTF / collection system improvements	5,488	2019
Ciudad Camargo, Tamps	New WWTF / new sewer connections / collection system improvements	8,453	2019
Ciudad Gustavo Diaz Ordaz, Tamps	New WWTF / new sewer connections	10,984	2020
Reynosa, Tamps	WWTF expansion / new sewer connections	266,853	2017
La Joya, TX	Two New WWTFs / new sewer connections / collection system improvements	40,128	2020
Peñitas, TX	New sewer connections	5,792	2018
Brownsville, TX	New sewer connections	1,786	2018

7.2 LRGWQI Binational Water Quality Protection and Restoration Plan

The ultimate goal of the LRGWQI is the restoration and protection of water quality in the LRG/RB. However, the transboundary nature of the LRG/RB watershed makes achievement of this goal difficult because the authority of US and Mexican regulatory and natural resource agencies is limited by the international border between the two countries. The ability of either government to control, or even monitor, pollutants entering the river is confined to their respective national jurisdictions. For this reason, the LRGWQI promotes a binational approach to restoring and protecting water quality in the LRG/RB, calling for the cooperative development of a binational watershed restoration and protection plan negotiated, agreed upon, and implemented by both countries under the auspices of the IBWC/CILA.

The LRGWQI Water Quality Protection and Restoration Plan (WQPRP) is intended to be used as a planning tool to guide infrastructure investment decisions and implementation of best management practices on both sides of the LRG/RB watershed. In addition to the information and data analysis presented in this report, the technical approach specified in the LRGWQI includes binational data collection and the development of predictive water quality models. Together, these technical efforts will be used to target restoration and protection efforts and to predict water quality in the LRG/RB resulting from various development, investment and management scenarios in the LRG/RB watershed, including "no action" scenarios that simulate the effects on water quality of unmanaged growth and development.

LRGWQI researchers are currently developing a decision support system (DSS) that will incorporate the LRGWQI water quality models and all other data and information useful in predicting the effects on water quality of various watershed management scenarios. The LRGWQI DSS will guide the development of the binational recommendations ultimately included in the LRGWQI WQRPP.

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Appendix A

Official Exchange of Letters between the US and Mexican Sections of the International Boundary and Water Commission authorizing the Lower Rio Grande/Río Bravo Water Quality Initiative.

INTERNATIONAL BOUNDARY AND WATER COMMISSION
UNITED STATES AND MEXICO

Cd. Juárez, Chihuahua
September 10, 2013

Lower Rio Grande/Rio Bravo Water Quality Initiative
Pilot Project

Introduction

Binational efforts to improve water and wastewater infrastructure along the U.S./Mexico border have resulted in marked improvements in water quality in the Rio Grande. However, there are areas where continued efforts are needed. In particular, the portion of the river from the Falcon International Reservoir to where the river enters the Gulf of Mexico (hereafter termed the Lower Rio Grande/Río Bravo) has experienced persistently high bacteria levels.

Binational water quality planning efforts can be an effective tool in controlling the effects of growth and development on transboundary water resources. In addition to enhancing and improving the effectiveness of existing unilateral efforts to improve water quality, by focusing and coordinating those efforts, binational water quality planning can reduce the cost of water quality management and increase the level of protection of the resource through increased collaboration of stakeholders on both sides of the border.

This document describes a binational effort to improve and protect water quality in the Lower Rio Grande/Río Bravo, which currently experiences bacteria levels that have, at times, been higher than recommended for approved water uses of the river. This effort, the Lower Rio Grande/Río Bravo Water Quality Initiative (LRGWQI), is intended to serve as a pilot project to develop the binational mechanisms necessary to improve water quality throughout the Rio Grande/Río Bravo.

Goals and Objectives

The Mexican partner agencies (International Boundary and Water Commission, Mexican Section [CILA], the Mexican National Water Commission [CONAGUA], and the Tamaulipas State Water Commission [CEAT]) and the U.S. partner agencies (International Boundary and Water Commission, U. S. Section [USIBWC], the U.S. Environmental Protection Agency [USEPA] and the Texas Commission on Environmental Quality [TCEQ]) agree that the goals and objectives of the LRGWQI pilot project should be to restore, protect, and improve the water quality in the Lower Rio Grande/Río Bravo, downstream of Falcon Reservoir. Additional efforts could include a survey to identify sources of salinity in the Lower Rio Grande/Río Bravo. Specific water quality targets are to be agreed-upon through a binational consultation and deliberation processes conducted under the auspices of the IBWC, U.S. and Mexico.

INTERNATIONAL BOUNDARY AND WATER COMMISSION
UNITED STATES AND MEXICO

Geographic Scope

The focus of the LRGWQI pilot project is on water quality management in the Lower Rio Grande/Río Bravo, below Falcon Dam to the Gulf of Mexico. This effort is a pilot project for a single reach, which, if successful, may serve as a model for other segments along the river.

Technical Approach

The set of technical tasks for the LRGWQI project includes:

1. Historical data review
2. Identification of data gaps
3. Data collection
4. Data analysis and modeling

The analysis is to include point and steady-state nonpoint sources of pollution. The first phase of analysis will focus on characterizing and modeling water quality under steady state conditions. The technical work associated with the LRGWQI should be conducted through cooperation between Mexico and the United States.

Identifying Feasible Options to Improve Water Quality

A goal of this initiative is to identify potential feasible pollution prevention and control options (the options) that will result in the restoration, conservation, and improvement of the water quality in the Lower Rio Grande/Río Bravo through a facilitated stakeholder process that includes the participating agencies, stakeholders from both sides of the river and representatives of the local binational community of water users. The options will be incorporated into a binational water quality improvement plan along with the technical analysis justifying their selection, including estimation of option costs.

Legitimizing the Analysis

The official mechanism for obtaining binational concurrence on technical aspects of the plan is the IBWC process. Once completed, the binational water quality plan resulting from the LRGWQI effort (or the main elements of the plan) could be incorporated as an agreement approved through the IBWC, US and Mexico.

Legal Framework

The 1944 Water Treaty is the most appropriate institutional mechanism for reaching a binational agreement on the elements of any binational water quality plan in the Lower Rio Grande/Río Bravo resulting from the LRGWQI.

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Plan Development and Implementation

The LRGWQI pilot project should proceed in three stages:

- The **first stage** will include initial binational discussions and development of a binational study plan. The first stage will also include initial historical data review, identification of key stakeholders, and development of a stakeholder participation strategy
- The **second stage** will include binational data collection, technical analysis/modeling, and stakeholder involvement. The second stage of the LRGWQI will result in a binational water quality improvement plan.
- The **third stage** would assess implementation and would result in a report(s) evaluating the progress achieved under the LRGWQI.

Implementation and Monitoring

Two (2) types of monitoring associated with the LRGWQI pilot project, programmatic monitoring and ambient monitoring are envisioned:

- Programmatic Monitoring - the project will develop a plan to monitor the progress of implementation of the measures and solution strategies detailed in the binational water quality plan.
- Ambient Monitoring - the project will also develop a plan for each nation to monitor the progress in achieving the water quality goals specified in the plan.

Both nations should be willing to share Mexican and U.S. information sources so that each side and its residents have confidence regarding sources of effluents and the ambient quality of the river.

Sustaining the Effort

The LRGWQI pilot project should develop consensus procedures for Mexico and the U.S. to cooperate in future water quality planning beyond the scope of the initial plan. Both parties should state their interest in continuing with a long-term effort to improve water quality of the river.

Stakeholder Involvement

Each of the binational partner agencies involved in water quality (TCEQ, EPA, IBWC-U.S. and Mexico, CONAGUA, and CEAT) will determine their appropriate stakeholder involvement. There can be a benefit from utilizing research or outreach efforts of other organizations and agencies from both countries. The stakeholder involvement processes

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will rely as much as possible on existing public and stakeholder outreach forums and mechanisms such as EPA-SEMARNAT Border 2012 (2020) Program, USIBWC's Citizen Forums and the TCEQ and USIBWC's Clean Rivers Program Basin Steering Committee meetings in the United States, as well as other efforts led by Mexican organizations such as Basin Councils.

Schedule

The development of a binational water quality plan resulting from the LRGWQI, based on a starting point of September 2012, would consist of the following stages:

- Stage 1 – 12 months: beginning in September 2012;
- Stage 2 – up to 2 years (2014); and
- Stage 3 – 12 months (2015).

/PE
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Appendix B

Official Terms of Reference for the Lower Rio Grande/Rio Bravo Water Quality Initiative.

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Cd. Juárez, Chihuahua
September 10, 2013

TERMS OF REFERENCE

UNITED STATES-MEXICO JOINT COOPERATIVE ACTIONS IN THE LOWER RIO BRAVO/RIO GRANDE RIVER BASIN

Legal Framework

Article 3 of the 1944 Treaty Relating to Utilization of Waters of the Colorado and Tijuana Rivers and of the Rio Grande authorizes the International Boundary and Water Commission (IBWC) "to give preferential attention to the solution of all border sanitation problems…." Article 24 authorizes the Parties "to initiate and carry on investigations and develop plans for the works which are to be constructed or established" dealing with transboundary waters.

The Commission in Minute 261 agreed to define as a "border sanitation problem" each case in which the waters that cross the boundary, including coastal waters, or that flow in the limitrophe reaches of the Rio Grande and the Colorado River, have sanitary conditions that present a hazard to the health and well-being of the inhabitants of either side of the border or impair the beneficial uses of these waters.

The IBWC Commissioners agreed in Point 6 of Minute 261 "That in each case where the approved course of action provides that the border sanitation problem be jointly corrected by the two Governments, the Commission develop the plans and designs for the work necessary therefore, as well as the division of work and costs between the two countries, submit them for approval of the two Governments, and upon such approval, each Government through its Section of the Commission proceed to carry out the construction, operation and maintenance, with the greatest speed and timeliness possible." Under IBWC Minute No. 289 entitled "Observation of the Quality of the Waters along the United States and Mexico Border," the Commission agreed to evaluate water quality and develop an integrated program for the observation of water quality in the international waters of the United States and Mexico.

IBWC Position and Process Framework

Both Sections of the IBWC are aware of the binational interest to pursue the evaluation of cooperative, innovative and holistic measures that could benefit water users in the United States and Mexico. As binational initiatives that can affect international waters

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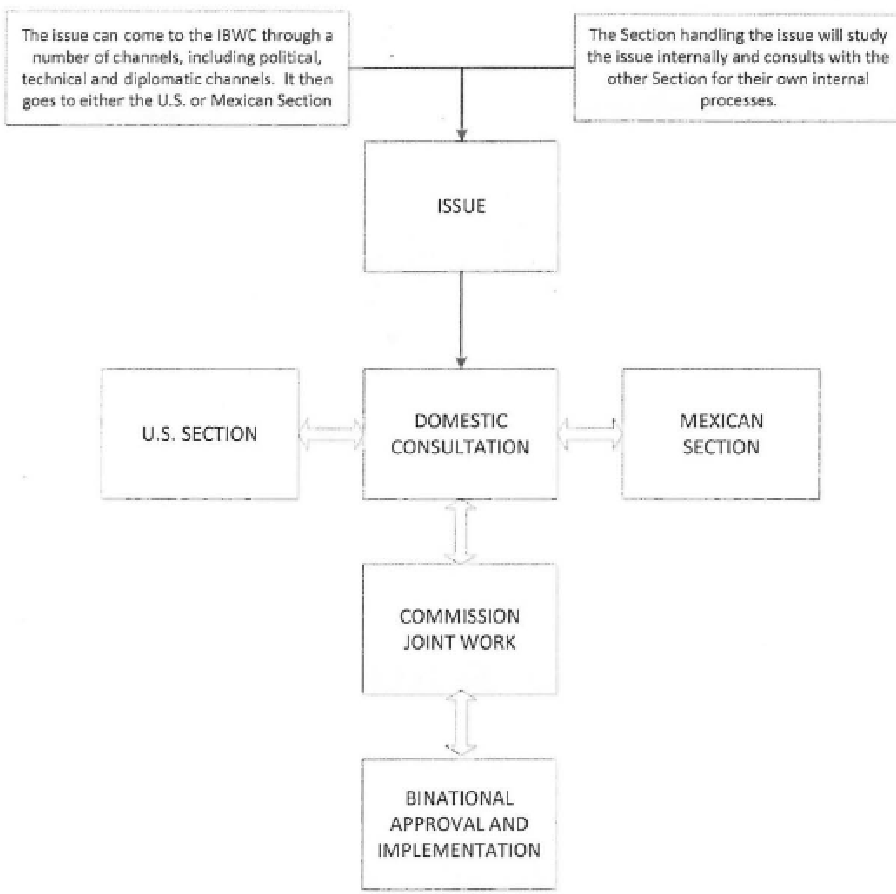
between the U.S. and Mexico have to be accomplished under IBWC auspices, the Commission will follow the normal binational cooperation process used by both Sections. Due to the complexity and the numerous stakeholders involved, both sections of the Commission will establish the necessary framework to allow for the joint evaluation of proposed cooperative measures that could benefit both nations.

The Terms of Reference will serve as the framework used by all entities participating in the joint cooperative process. The following flowchart depicts the binational cooperation process that is normally followed by the Commission when addressing binational issues.

COMMISSION PROCESS



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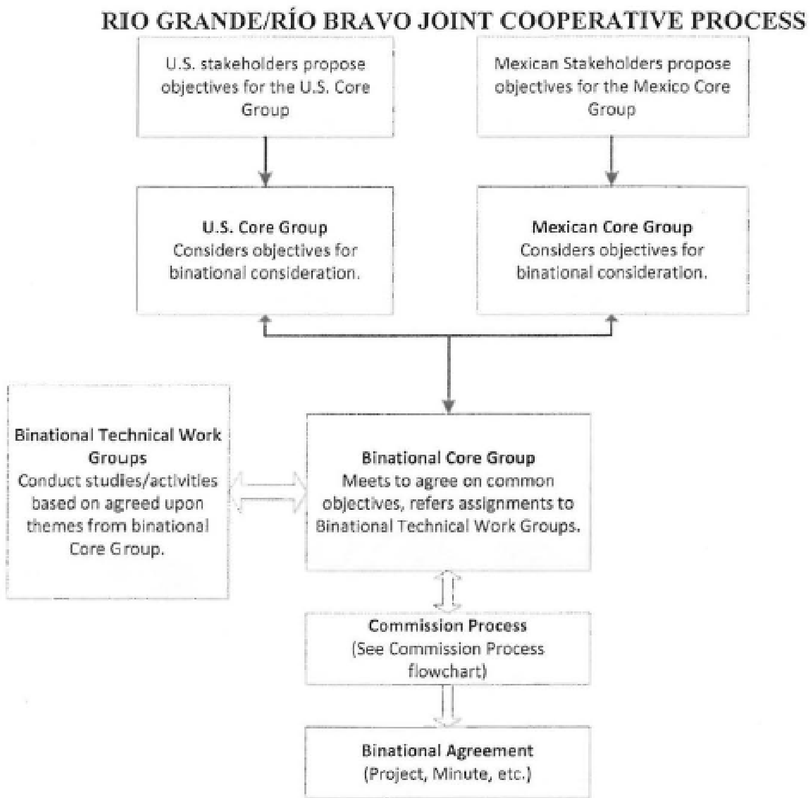
The following chart shows the framework that will be used in the evaluation of binational cooperative actions.



Once a project is agreed for implementation by the binational Core Group, the Commission will determine the appropriateness of preparing a Minute to ensure continuity of projects regardless of administration changes in each government.

Not all projects may require the development of a Commission Minute. The necessity for a Minute will be determined on a case-by-case basis.

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General Objective

The objective of the joint cooperative process is to establish, under the auspices of the IBWC, a group of representatives from the United States and Mexico to explore border sanitation issues and water quality management with potential binational benefits. Any joint cooperative projects and measures must be consistent with the 1944 Treaty.

Specific Objectives

a. Address current and future water quality issues of the Lower Rio Grande/Río Bravo.
b. Implement management procedures and programs that enable affected parties to manage wastewater discharges and improve water quality conditions.
c. Evaluate current wastewater discharge infrastructure and management strategies for the potential for improving the quality of effluent discharges into the Lower Rio Grande/Río Bravo.
d. Evaluate new mechanisms and strategies for system operations that could improve ambient water quality and address border sanitation concerns.
e. Improve salinity management for return flows into the Lower Rio Grande/Río Bravo.
f. Based on the results of the evaluations carried out, implement programs and projects to meet these objectives as appropriate, and result in measurable and sustainable improvements in the ambient water quality of the Lower Rio Grande/Río Bravo.

Organization and Management

The IBWC, acting under the foreign policy guidance respectively of the U.S. Department of State and the Mexican Foreign Ministry, will be the lead in the joint cooperative process.

The Commission will form a binational Core Group of members representing each Section of the IBWC, other federal agencies, and the States of Tamaulipas and Texas. Other stakeholders, which may include local government officials or non-governmental organizations (NGOs), may be invited to participate in the Core Group. To enhance the availability of information to all parties, any U.S. or Mexican Core Group member may invite a technical expert to advise the Core Group with approval from IBWC, as there can be a benefit from utilizing research or outreach efforts of other organizations and agencies.

The composition of the U.S. Core Group will be as follows:

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- U.S. Section, International Boundary and Water Commission (USIBWC)
- U.S. Environmental Protection Agency (EPA)
- Government of Texas, through the Texas Commission on Environmental Quality (TCEQ)

U.S.-based non-governmental organizations or local government institutions may participate if invited by the Core Group, but not as members of the U.S. Core Group.

The composition of the Mexican Core Group will be as follows:

- Mexican Section, International Boundary and Water Commission (MxIBWC)
- National Water Commission (CONAGUA)
- Government of the State of Tamaulipas, through the State Water Commission of Tamaulipas (CEAT)

Mexican-based non-governmental organizations or local government institutions may participate if invited by the Core Group, but not as members of the Mexican Core Group.

The binational Core Group may form technical work groups to work on specific issues, measures and projects selected by the binational Core Group. Each binational Technical Work Group will be composed of a representative from each Section of the IBWC and members from each country with the required knowledge and expertise to work on specific issues related to the objectives. A group leader from each country will be selected by the binational Core Group members from that country. To enhance the availability of information to all parties, any member of the U.S. or Mexican Core Group may invite a technical expert to advise the Core Group with approval from IBWC. The BECC and NADB representatives also may be helpful when binational work groups meet.

The names of the members that participate in each work group will be documented in the meeting minutes for these groups.

__Conduct of Meetings__

Each nation's Core Group meetings will be conducted as necessary and as determined by each delegation. Each nation's Core Group will be free to schedule and conduct its meetings.

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Binational meeting minutes will be exchanged between U.S. and Mexican Core Group delegations following each meeting that takes place. The binational Core Group meetings will be conducted as follows:

- Meetings will be convened by the U.S. and Mexican Commissioners of the IBWC or their designated representatives and will be held, as required, at alternating meeting sites in the United States and Mexico if possible. When a Core Group member or stakeholder is unable to attend a meeting in person, other methods of participation will be made available.

- Binational Core Group meetings will be chaired jointly by the U.S. and Mexican Principal Engineers of the IBWC or by their designated representatives. The binational Core Group can establish work groups to undertake specific tasks or projects under the direction of the binational Core Group and then present the results to them. These work groups will not have decision-making authority.

- The binational Core Group will develop joint work plans and meeting agendas. The agendas will, to the extent practical, be shared in advance of the meetings.

- The co-chairing Principal Engineers will make every effort possible to achieve a consensus among the binational Core Group for all those activities under consideration.

- The binational Core Group will strive to ensure that the principal points of the presentations and dialogue at the meetings and events are documented in summary reports in the English and Spanish languages. All binational meetings will have professional simultaneous interpretation support furnished by the country hosting the meeting and/or event. To the extent possible each Section will provide its presentation documents to the other Section prior to binational Core Group meetings so that the documents can be translated. Also, to the extent possible, each Section will provide presentation documents in the primary language of the country to its Core Group committee members 48 hours prior to the meeting.

- Every effort will be made to convene meetings at times and places where all members can be present. In the event that a designated primary Core Group member is not able to be present, the designated alternate person may represent the primary person. In extraordinary circumstances, accommodations may be made for group members to participate by telephone or video conference; however, the availability of simultaneous interpretation cannot be guaranteed for remote participants.

- Other personnel of the government and non-government organizations and agencies, including consultants, personnel involved in presentation of information studies and

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progress reports, may participate in support of work groups as established in the work plan and meeting agendas. The binational Core Group must approve their participation. Representatives of the U.S. Department of State and the Mexico's Secretariat of Foreign Relations may attend national and binational Core Group meetings at their discretion. The two Principal Engineers or their designees must approve the participation of other personnel who are not members of the Core Group.

Framework of Activities

The binational Core Group will conduct its activities in accordance with work plans that cover the following framework:

- Definition of objectives and selection of binational items to be evaluated.
- Selection and establishment of binational work groups that will be working on the topics for which binational data gathering, analysis and other work can be advanced through work groups.
- Identification of tours and field visits necessary to initiate dialogue and enhance understanding of U.S. and Mexican objectives.
- Definition of obligations for Core Group and work group members and definition of the required progress reports and work products for presentation by binational work groups at binational Core Group meetings.
- Provide advice and guidance to each work group in reference to assignments.
- Establishment of deadlines for exchange of information required for binational review.
- Recommendation of projects for binational implementation.

Binational work groups will conduct their activities in accordance with the guidance provided by the binational Core Group. National work groups will conduct their activities in accordance with the guidance provided by each country's Core Group. The binational technical work groups will be responsible for the following activities:

- Evaluation of assigned issues to include feasibility, cost and potential benefit for both nations.

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- Arrangement of tours and field visits.
- Preparation of reports outlining findings and recommendations.
- Presentation of reports.

Unofficial interaction between U.S. and Mexican interest groups is encouraged in order to have a creative environment, foster better relations and promote productive dialogue that could lead to the generation and/or positive evaluation of joint cooperative measures and projects that could be beneficial to both nations. Any formal discussions and evaluations of any proposal will follow the Terms of Reference established for the "United States-Mexico Joint Cooperative Actions in the Lower Rio Grande/Río Bravo River Basin."

Funding and cost share decisions will be made on a case-by-case basis and are subject to appropriations. All projects and measures considered under this joint cooperative process are subject to the availability of funds. Any agreement to pursue the evaluation of a specific project or measure does not commit any of the parties to provide funding for the execution of projects and measures.

Core group members and work group members participating in this process will not be compensated by either Section of the Commission, nor will participants' travel expenses related to this process be reimbursed by either Section.

Communication and Use of Information

The two Sections of the IBWC will be the official repository of records generated by the national or binational Core Group and work groups, at meetings, studies, and any information exchanged and/or presented to the Core Group.

Credit shall be given to those who provide information.

Outcomes and Performance Measurement

The United States and Mexican Sections of the IBWC will prepare reports on the progress of United States-Mexico joint cooperative actions in the Lower Rio Grande/Rio Bravo. Each report will include results from monitoring of ambient water quality within the Lower Rio Grande/Río Bravo. This effort seeks significant and sustainable improvements in ambient water quality within the main stem of the Lower Rio

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Grande/Río Bravo from the Falcon Reservoir to the Gulf of Mexico. This project will be considered a success if it has demonstrated that:

1. Opportunities to improve water quality have been identified, and
2. Implementation of these opportunities improves water quality in the Lower Rio Grande/Río Bravo.

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Appendix C

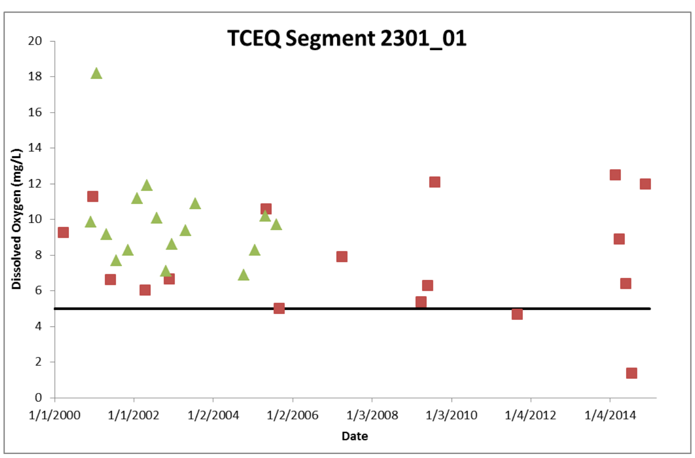
Scatter plots and descriptive statistics of US and Mexican historical water quality data collected in the Lower Rio Grande/Río Bravo.

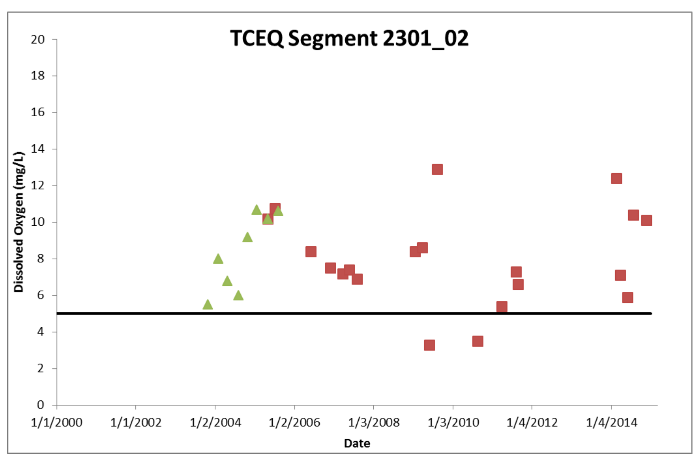
Scatter Plots of US Historical Water Quality Data

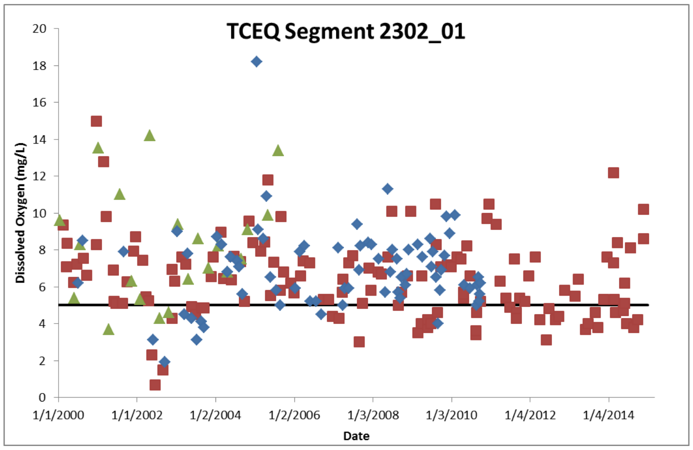
Date range: 2000-2014 (some years contain data gaps). All data were obtained from the TCEQ's SWQMIS database. Water quality criteria and screening levels established by Texas Surface Water Quality Standards and the TCEQ.

IBWC TCEQ USGS Criteria / Screening Level

Dissolved Oxygen



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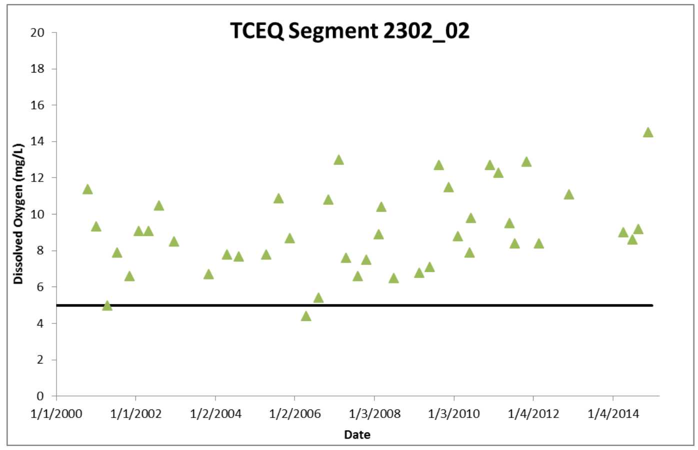
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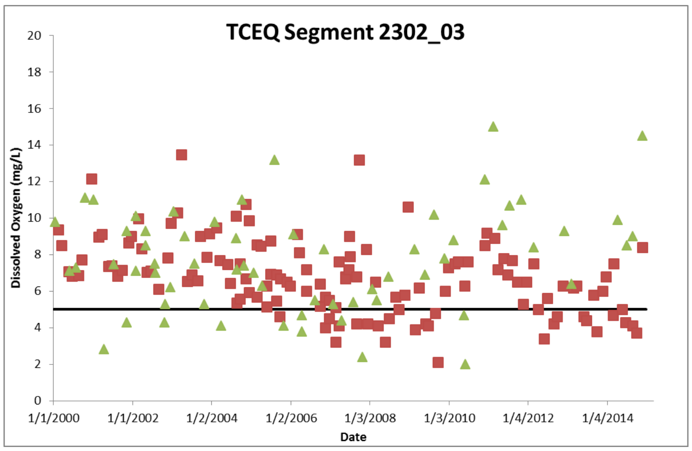
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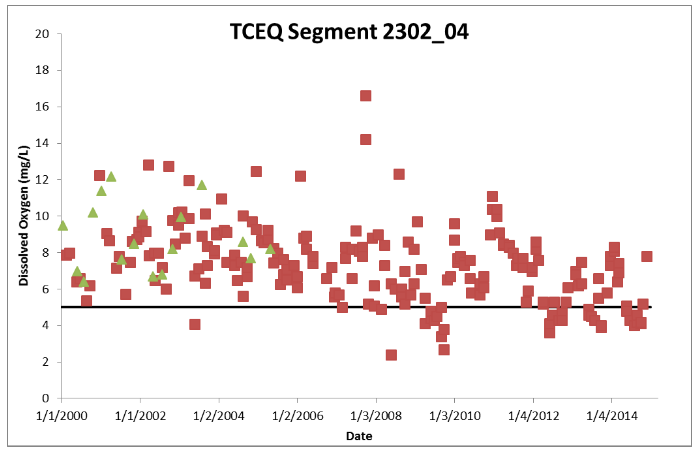
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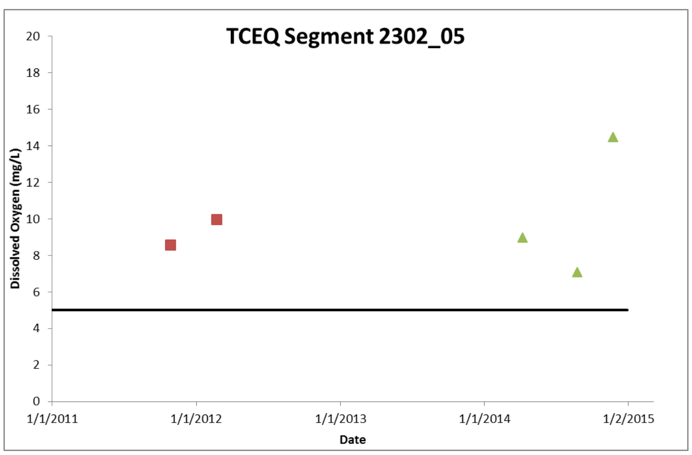
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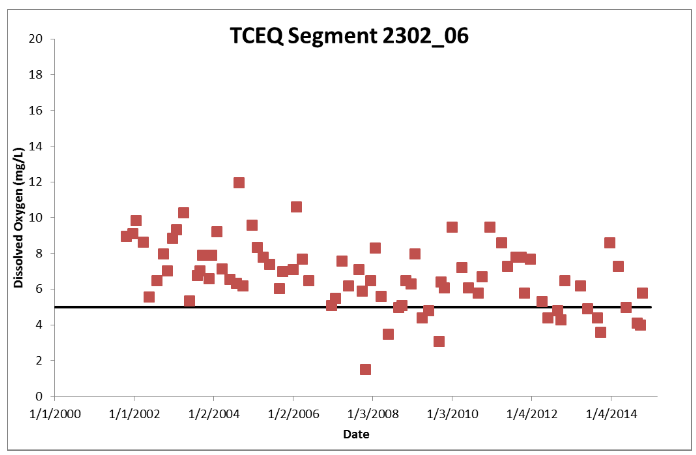
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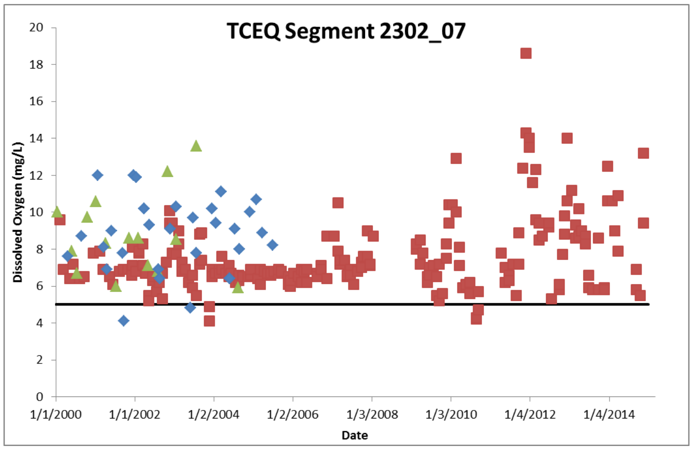
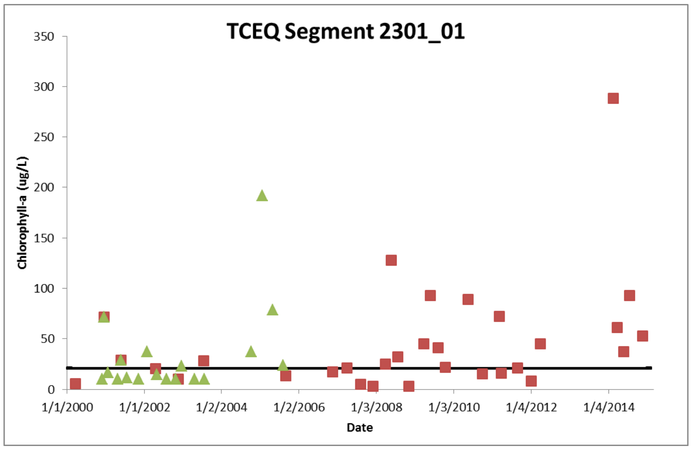
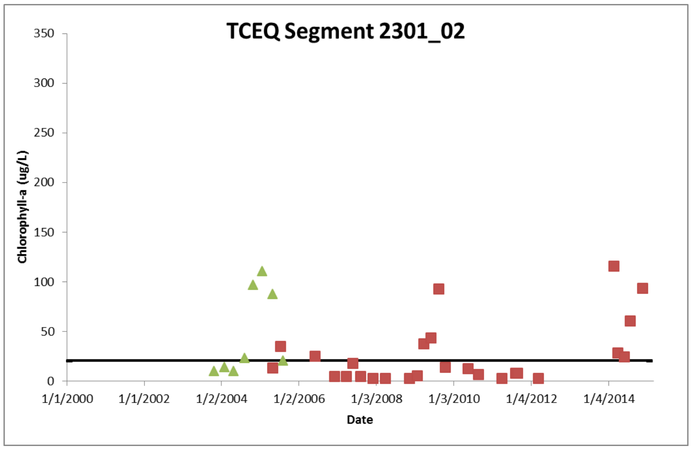
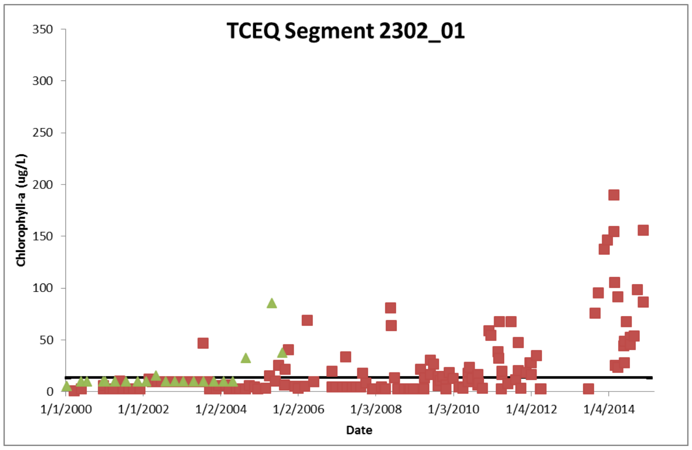
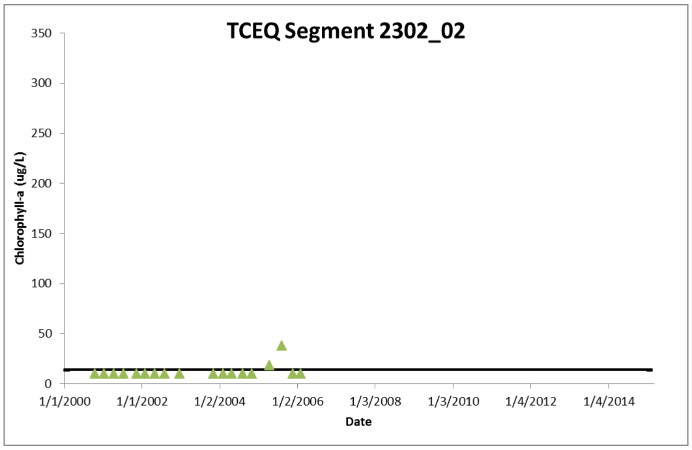


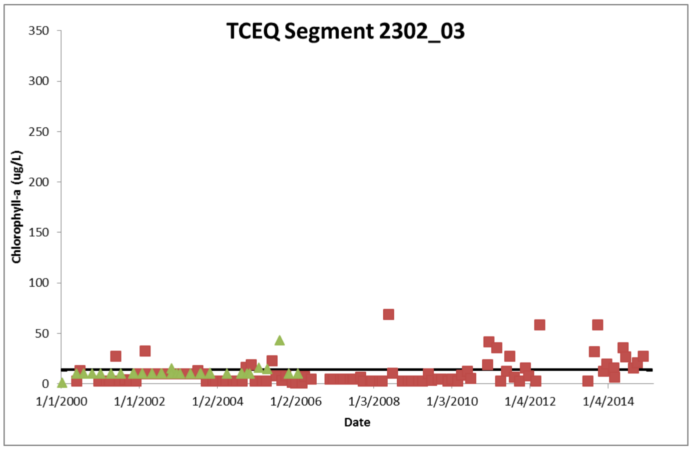
Chlorophyll-a

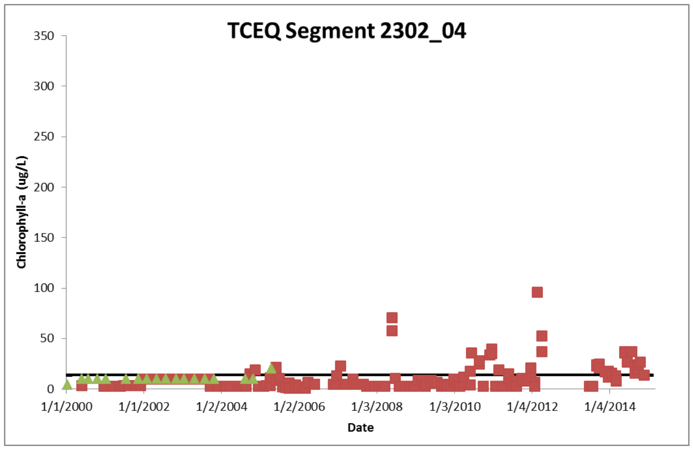


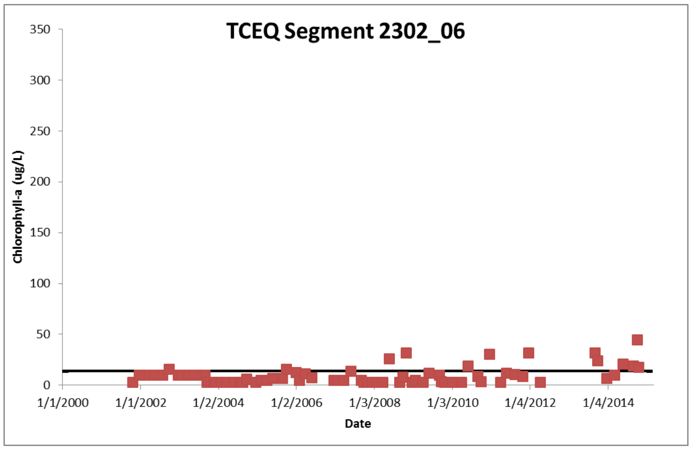


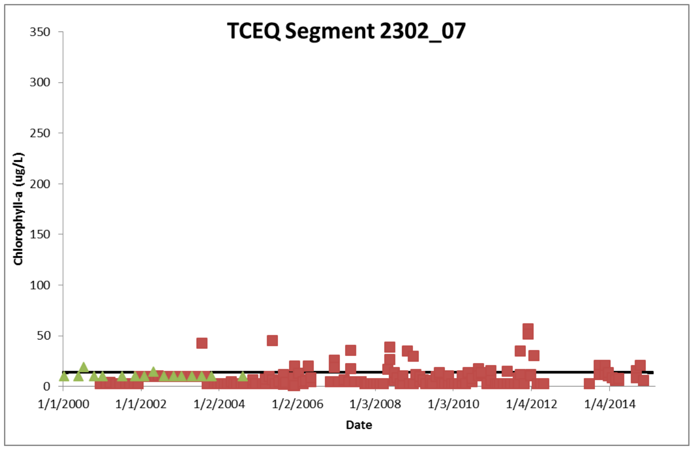












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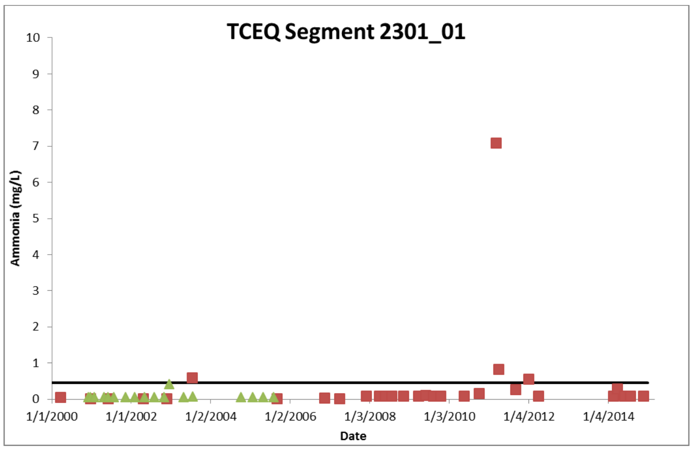

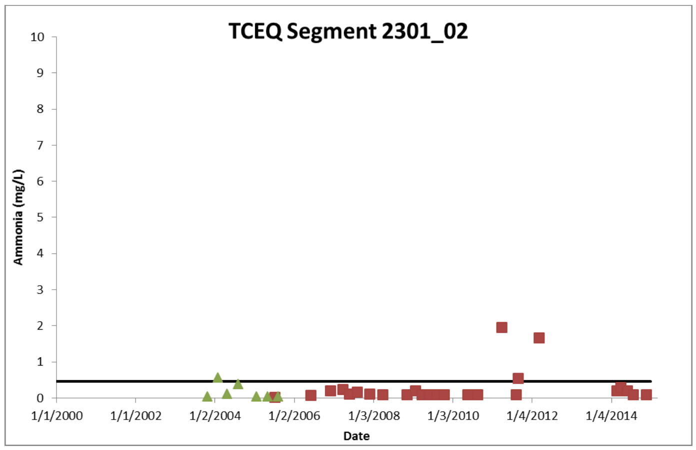

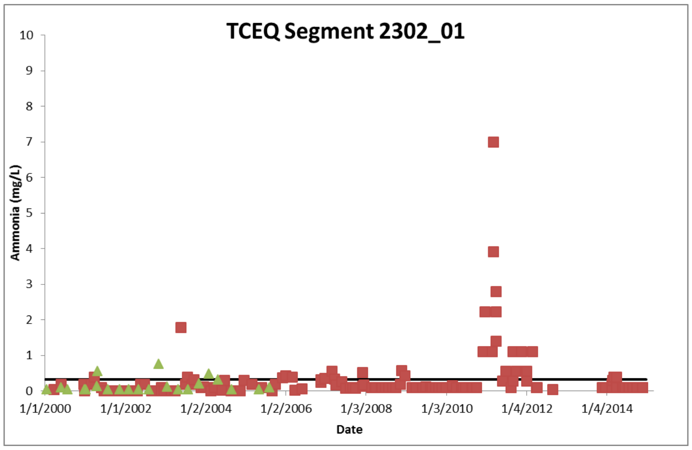
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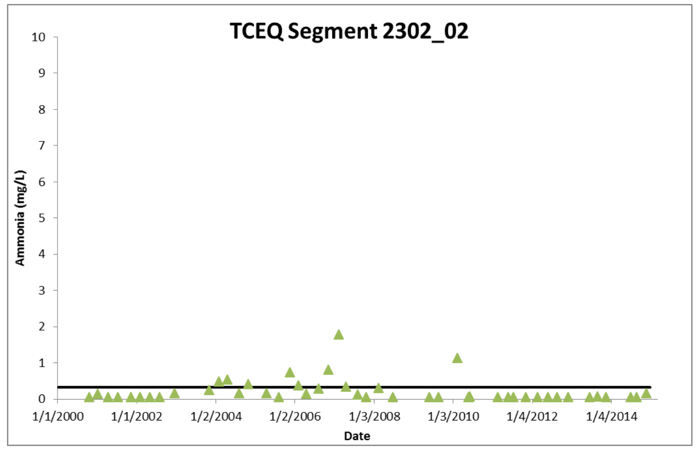
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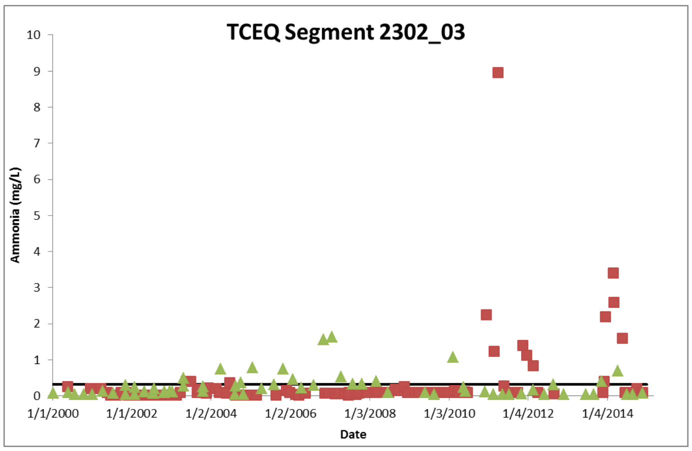
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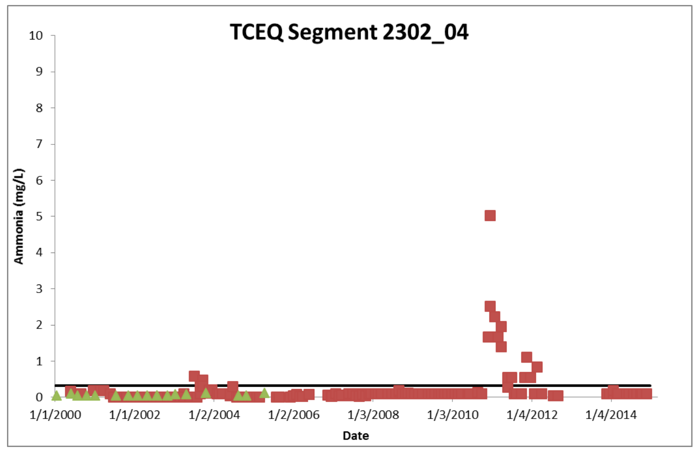
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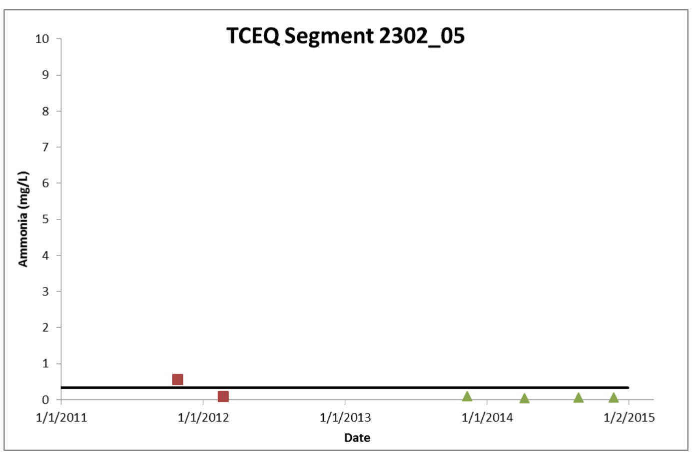
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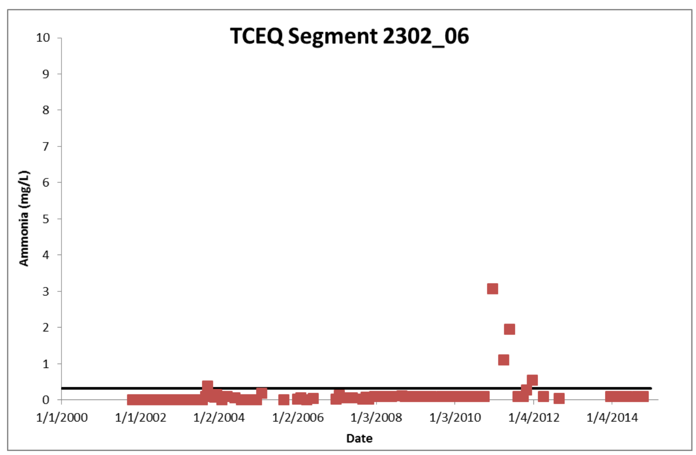
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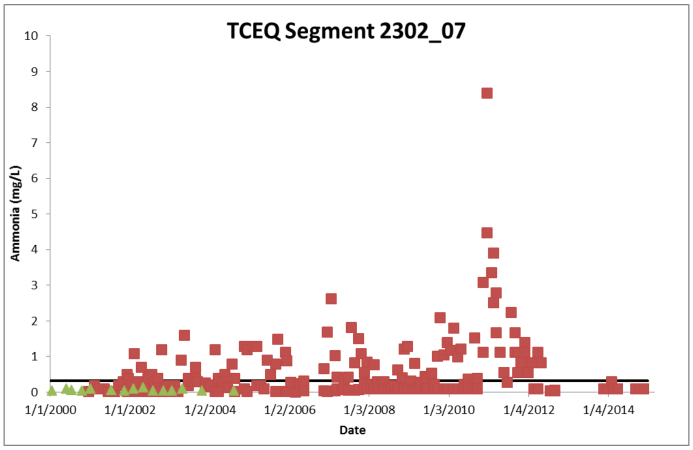
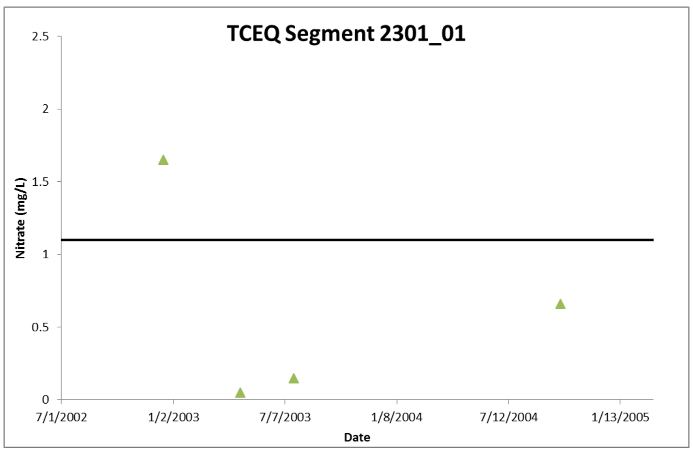
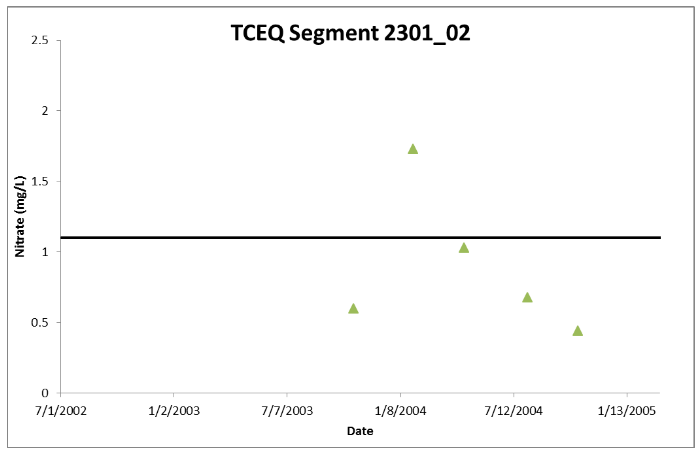
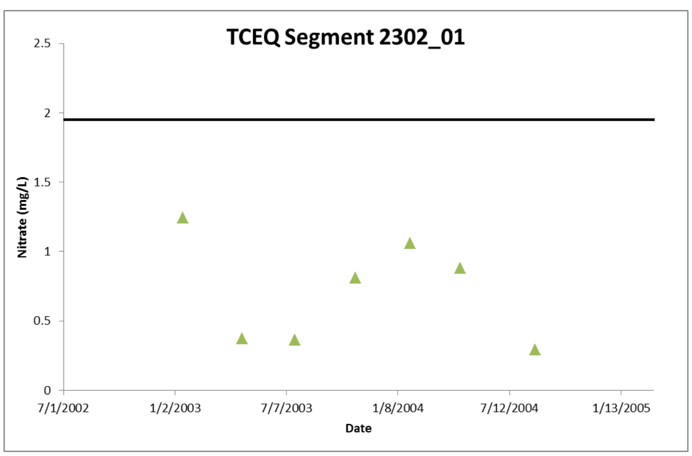
1/4/2014

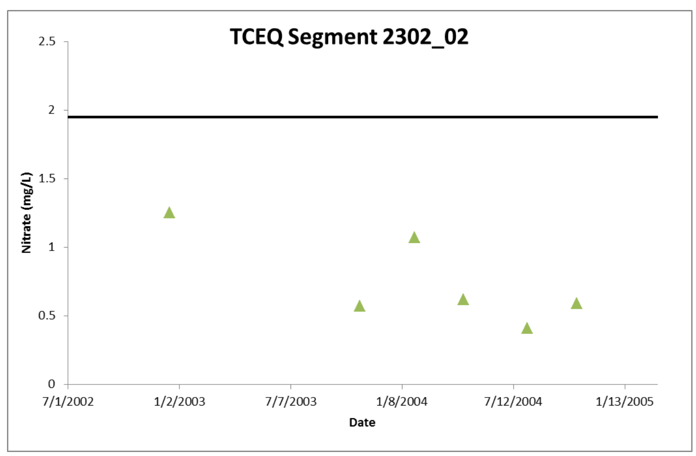

TCEQ Segment 2302_07
Ammonia (mg/L)
0
1
2
3
4
5
6
7
8
9
10
1/1/2000
1/1/2002
1/2/2004
1/2/2006
1/3/2008
1/3/2010
1/4/2012
1/4/2014
Date

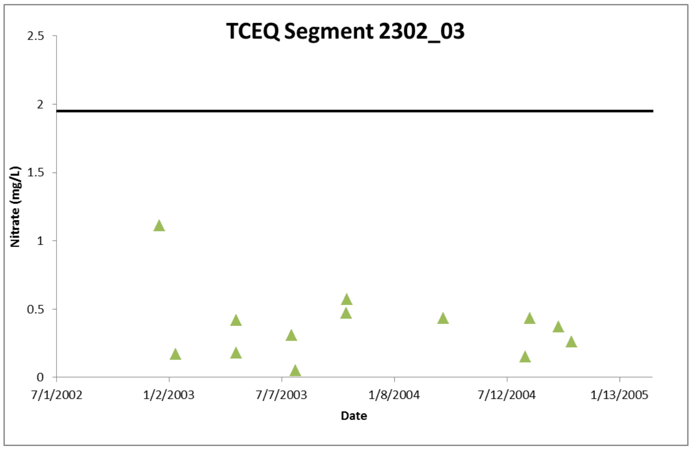
Nitrate

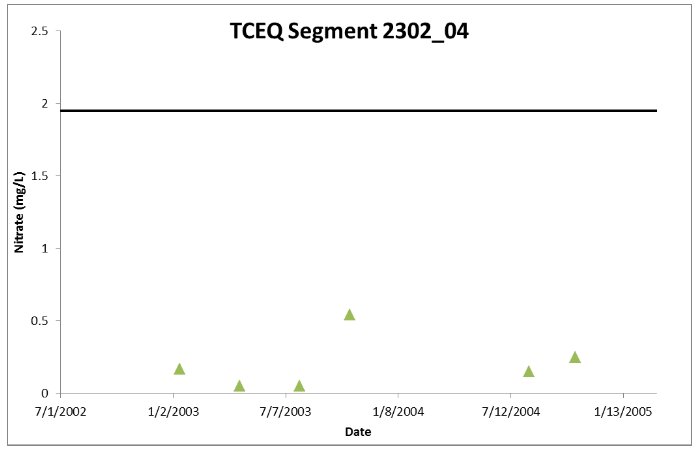

TCEQ Segment 2301_01
Nitrate (mg/L)
0
0.5
1
1.5
2
2.5
7/1/2002
1/2/2003
7/7/2003
1/8/2004
7/12/2004
1/13/2005
Date

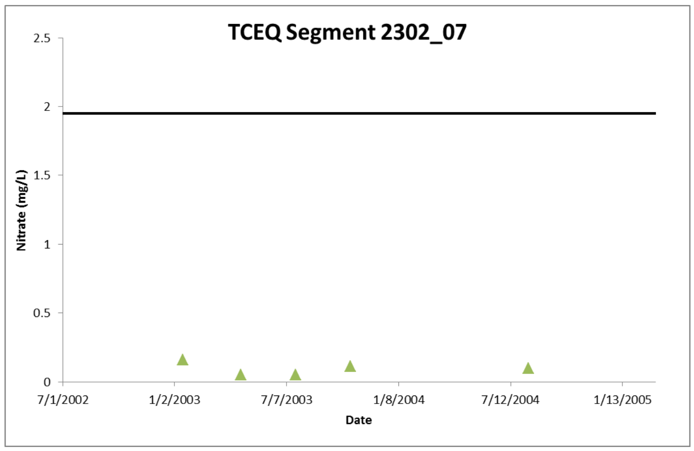

TCEQ Segment 2301_02
Nitrate (mg/L)
0
0.5
1
1.5
2
2.5
7/1/2002
1/2/2003
7/7/2003
1/8/2004
7/12/2004
1/13/2005
Date


TCEQ Segment 2302_01
Nitrate (mg/L)
0
0.5
1
1.5
2
2.5
7/1/2002
1/2/2003
7/7/2003
1/8/2004
7/12/2004
1/13/2005
Date

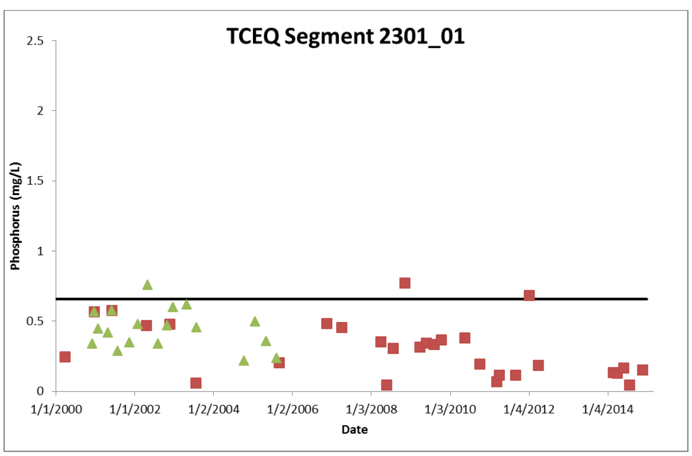

TCEQ Segment 2302_02
Nitrate (mg/L)
0
0.5
1
1.5
2
2.5
7/1/2002
1/2/2003
7/7/2003
1/8/2004
7/12/2004
1/13/2005
Date

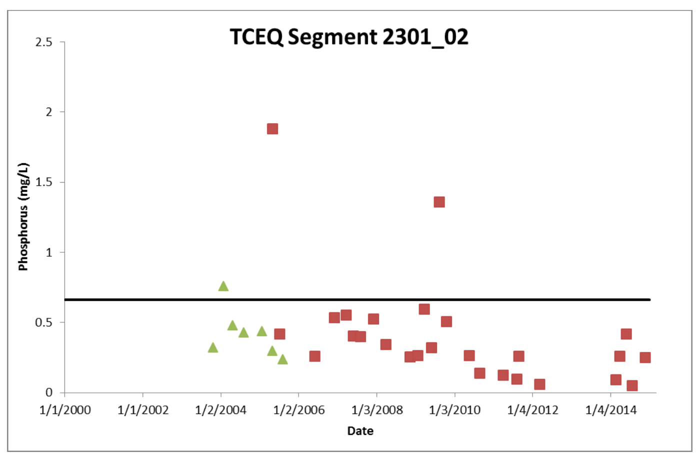


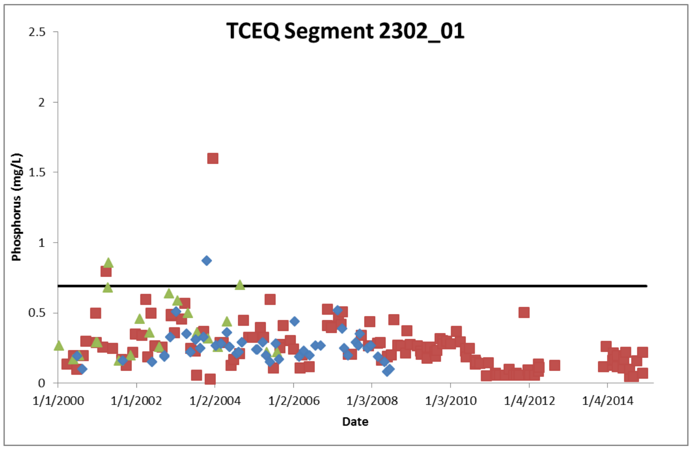


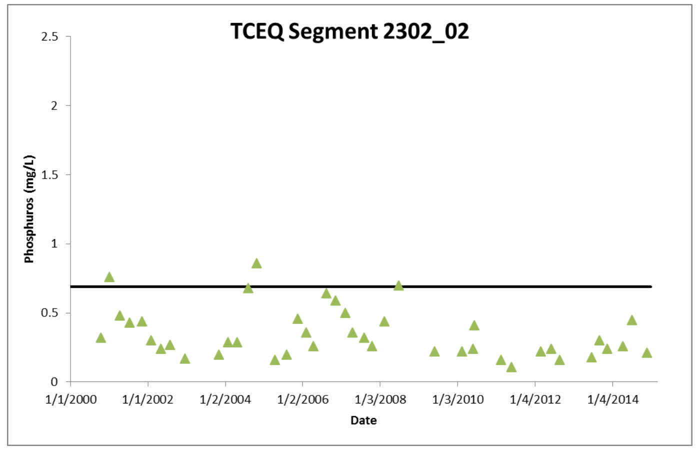


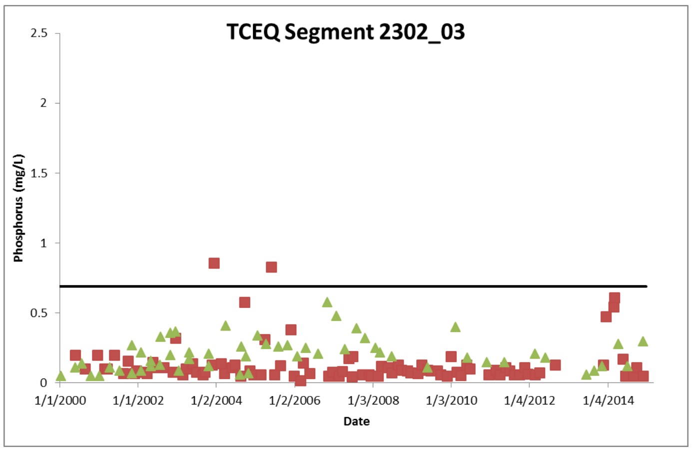
Total Phosphorus

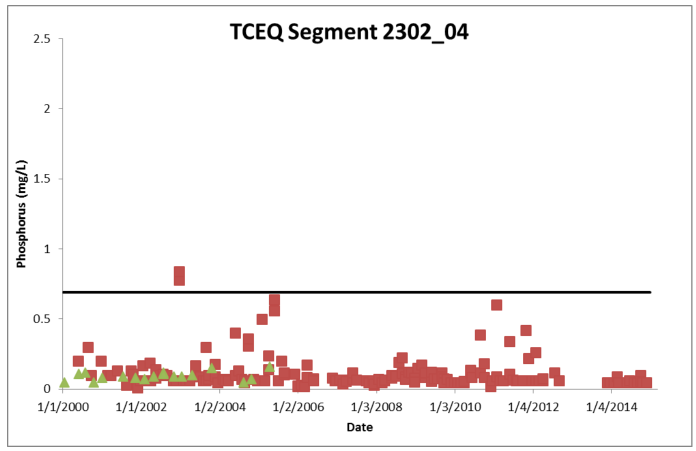


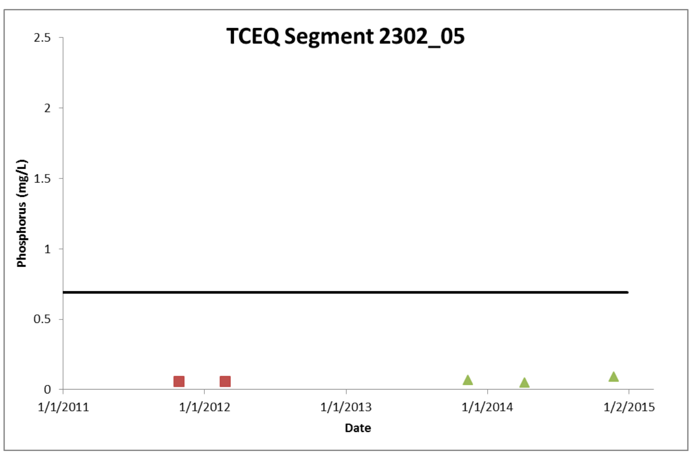


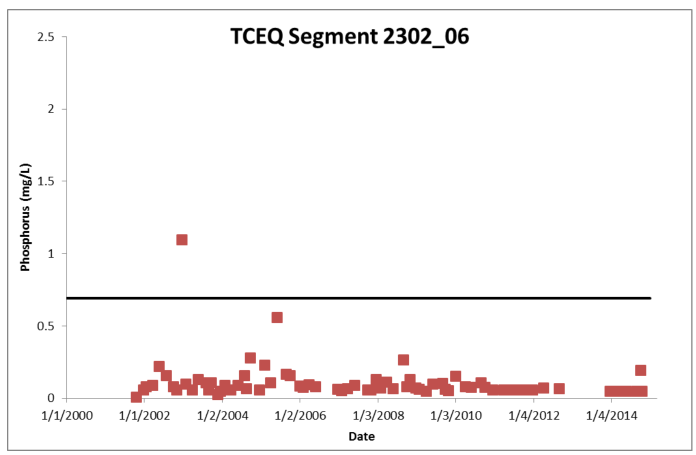

TCEQ Segment 2302_01
Phosphorus (mg/L)
2.5
2
1.5
1
0.5
0
1/1/2000
1/1/2002
1/2/2004
1/2/2006
1/3/2008
1/3/2010
1/4/2012
1/4/2014
Date

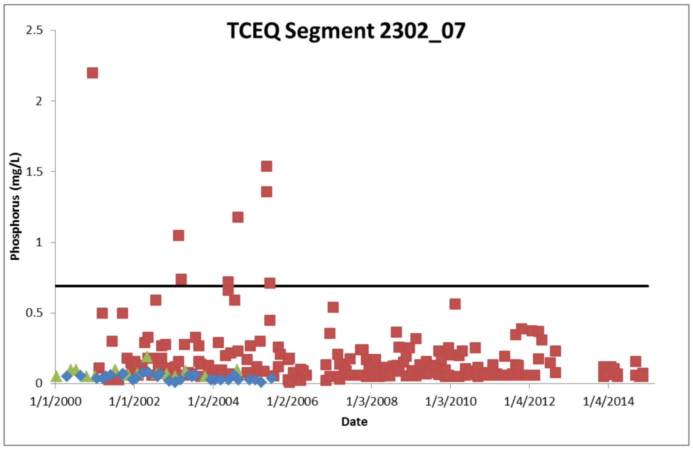

TCEQ Segment 2302_02
Phosphuros (mg/L)
2.5
2
1.5
1
0.5
0
1/1/2000
1/1/2002
1/2/2004
1/2/2006
1/3/2008
1/3/2010
1/4/2012
1/4/2014
Date


TCEQ Segment 2302_03
Phosphorus (mg/L)
2.5
2
1.5
1
0.5
0
1/1/2000
1/1/2002
1/2/2004
1/2/2006
1/3/2008
1/3/2010
1/4/2012
1/4/2014
Date

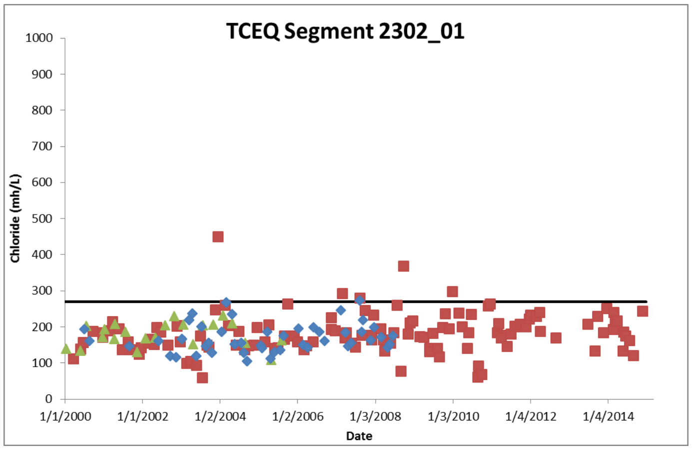

TCEQ Segment 2302_04
Phosphorus (mg/L)
2.5
2
1.5
1
0.5
0
1/1/2000
1/1/2002
1/2/2004
1/2/2006
1/3/2008
1/3/2010
1/4/2012
1/4/2014
Date

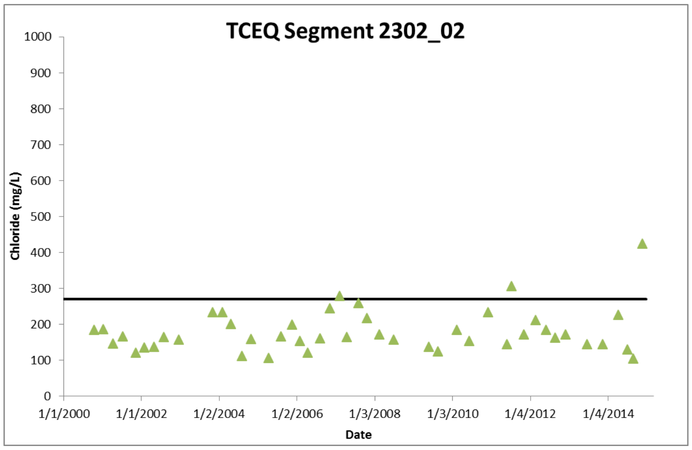

TCEQ Segment 2302_05
Phosphorus (mg/L)
2.5
2
1.5
1
0.5
0
1/1/2011
1/1/2012
1/1/2013
1/1/2014
1/2/2015
Date

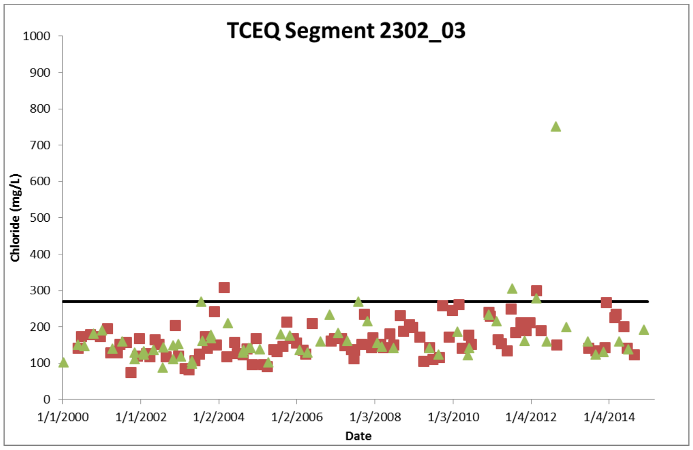

TCEQ Segment 2302_06
Phosphorus (mg/L)
2.5
2
1.5
1
0.5
0
1/1/2000
1/1/2002
1/2/2004
1/2/2006
1/3/2008
1/3/2010
1/4/2012
1/4/2014
Date

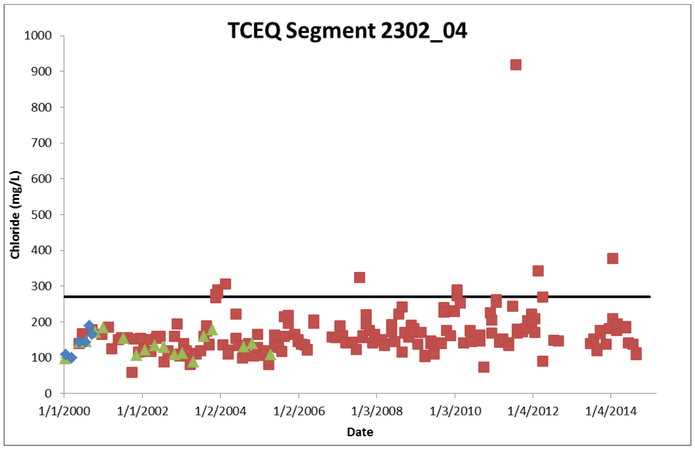

TCEQ Segment 2302_07
Phosphorus (mg/L)
2.5
2
1.5
1
0.5
0
1/1/2000
1/1/2002
1/2/2004
1/2/2006
1/3/2008
1/3/2010
1/4/2012
1/4/2014
Date

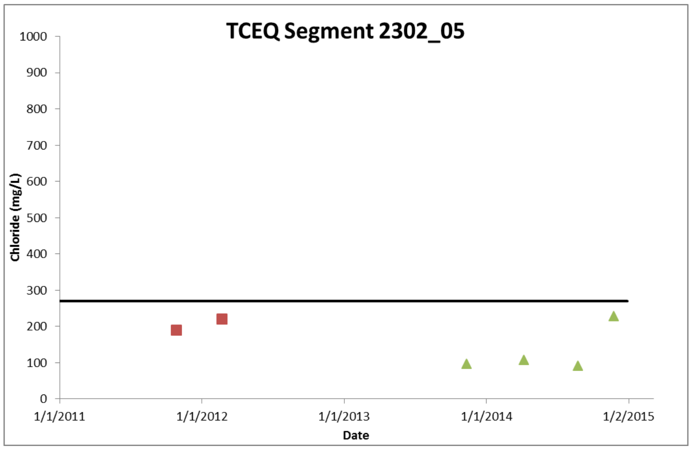
Chloride

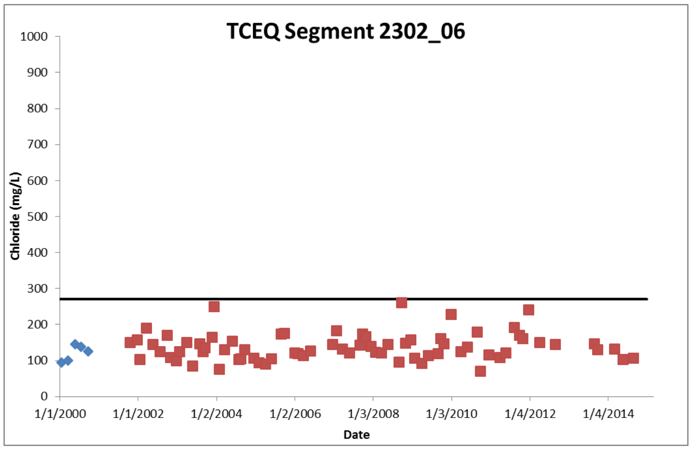

TCEQ Segment 2302_01
Chloride (mh/L)
1000
900
800
700
600
500
400
300
200
100
0
1/1/2000
1/1/2002
1/2/2004
1/2/2006
1/3/2008
1/3/2010
1/4/2012
1/4/2014
Date

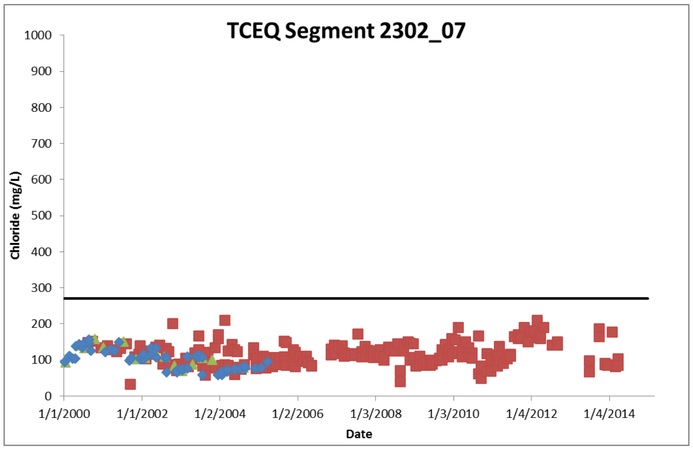

TCEQ Segment 2302_02
Chloride (mg/L)
1000
900
800
700
600
500
400
300
200
100
0
1/1/2000
1/1/2002
1/2/2004
1/2/2006
1/3/2008
1/3/2010
1/4/2012
1/4/2014
Date


TCEQ Segment 2302_03
Chloride (mg/L)
1000
900
800
700
600
500
400
300
200
100
0
1/1/2000
1/1/2002
1/2/2004
1/2/2006
1/3/2008
1/3/2010
1/4/2012
1/4/2014
Date

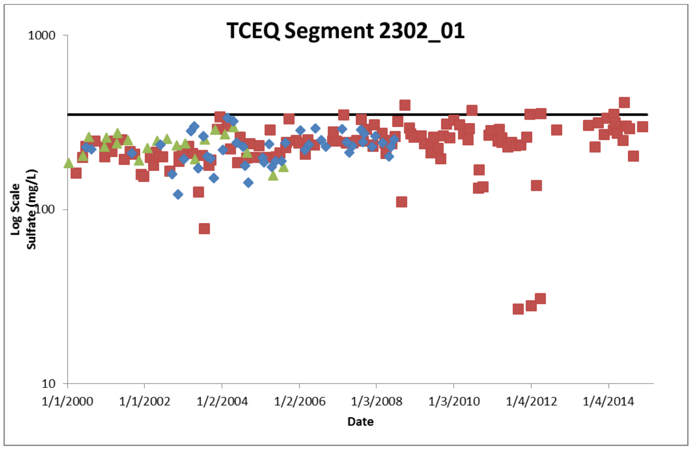

TCEQ Segment 2302_04
Chloride (mg/L)
1000
900
800
700
600
500
400
300
200
100
0
1/1/2000
1/1/2002
1/2/2004
1/2/2006
1/3/2008
1/3/2010
1/4/2012
1/4/2014
Date

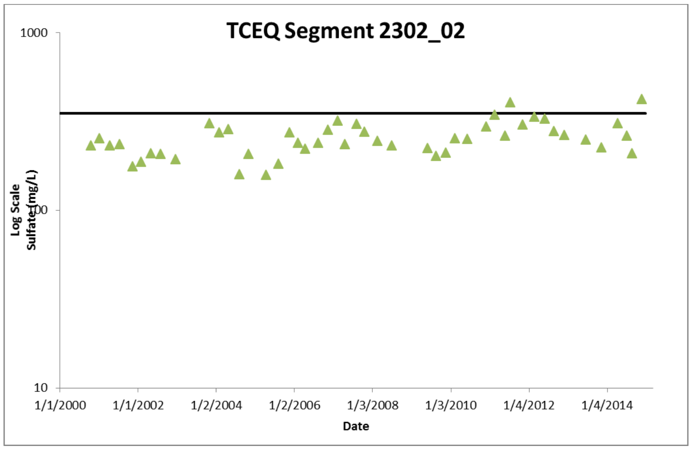

TCEQ Segment 2302_05
Chloride (mg/L)
1000
900
800
700
600
500
400
300
200
100
0
1/1/2011
1/1/2012
1/1/2013
1/1/2014
1/2/2015
Date

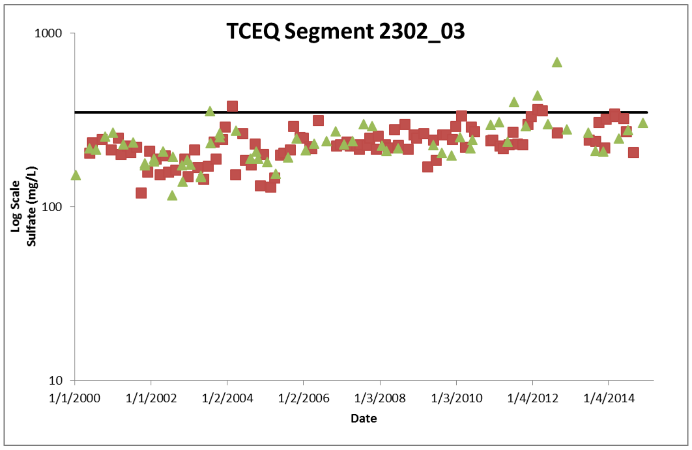

TCEQ Segment 2302_06
Chloride (mg/L)
1000
900
800
700
600
500
400
300
200
100
0
1/1/2000
1/1/2002
1/2/2004
1/2/2006
1/3/2008
1/3/2010
1/4/2012
1/4/2014
Date

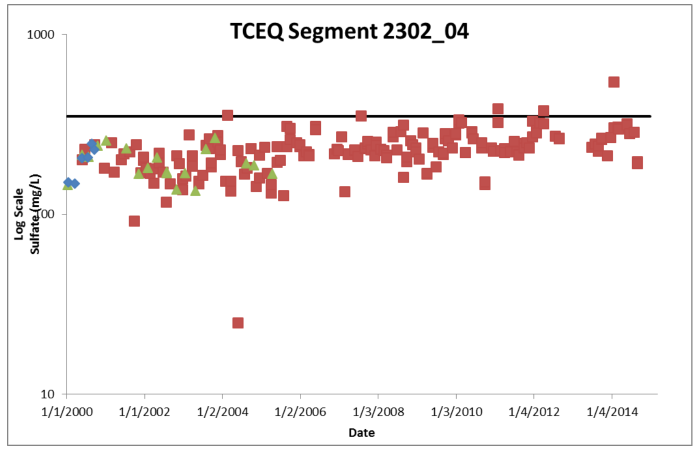

TCEQ Segment 2302_07
Chloride (mg/L)
1000
900
800
700
600
500
400
300
200
100
0
1/1/2000
1/1/2002
1/2/2004
1/2/2006
1/3/2008
1/3/2010
1/4/2012
1/4/2014
Date

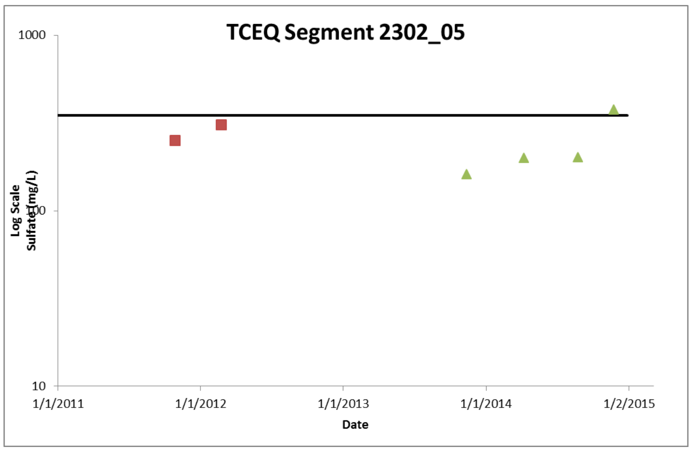
Sulfate

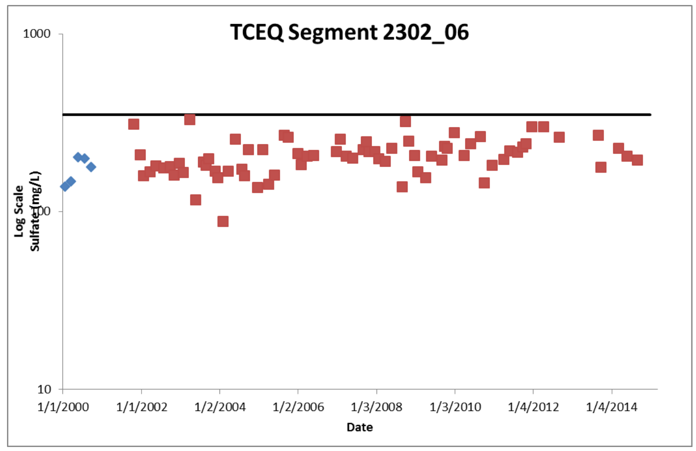

TCEQ Segment 2302_01
Log Scale
Sulfate (mg/L)
1000
100
10
1/1/2000
1/1/2002
1/2/2004
1/2/2006
1/3/2008
1/3/2010
1/4/2012
1/4/2014
Date

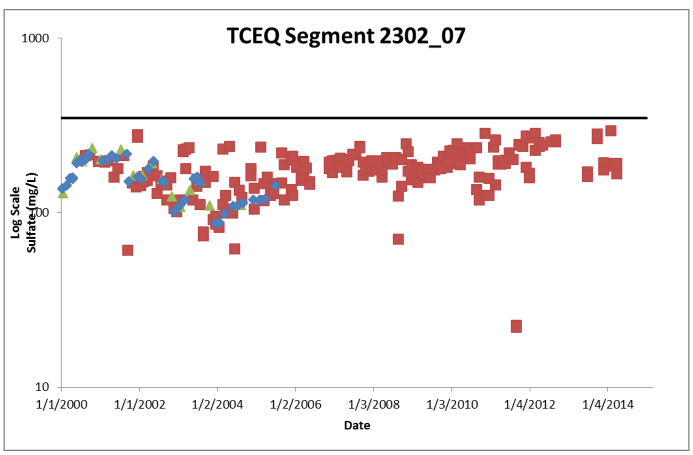

TCEQ Segment 2302_02
Log Scale
Sulfate (mg/L)
1000
100
10
1/1/2000
1/1/2002
1/2/2004
1/2/2006
1/3/2008
1/3/2010
1/4/2012
1/4/2014
Date


TCEQ Segment 2302_03
1000
100
10
Log Scale
Sulfate (mg/L)
1/1/2000
1/1/2002
1/2/2004
1/2/2006
1/3/2008
1/3/2010
1/4/2012
1/4/2014
Date

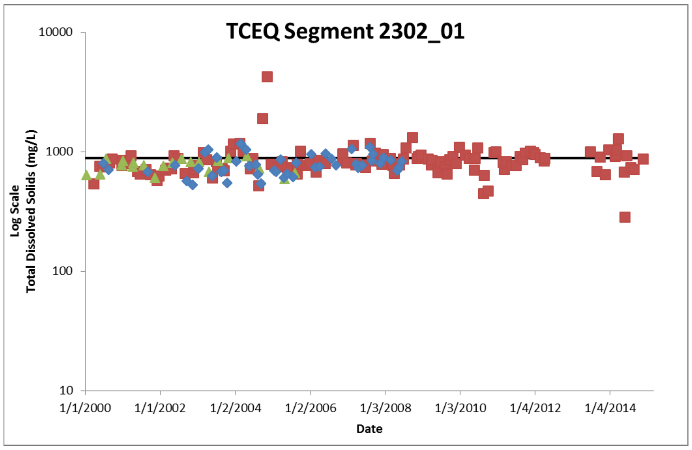

TCEQ Segment 2302_04
1000
10
Log Scale
Sulfate (mg/L)
1/1/2000
1/1/2002
1/2/2004
1/2/2006
1/3/2008
1/3/2010
1/4/2012
1/4/2014
Date

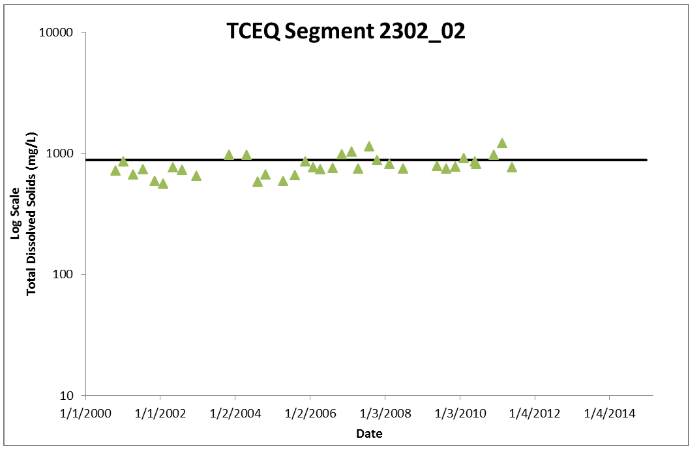

TCEQ Segment 2302_05
1000
10
Log Scale
Sulfate (mg/L)
1/1/2011
1/1/2012
1/1/2013
1/1/2014
1/2/2015
Date

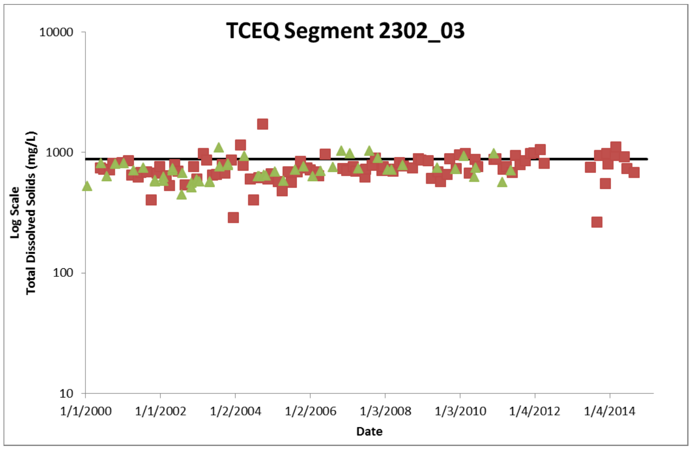

TCEQ Segment 2302_06
1000
10
Log Scale
Sulfate (mg/L)
1/1/2000
1/1/2002
1/2/2004
1/2/2006
1/3/2008
1/3/2010
1/4/2012
1/4/2014
Date

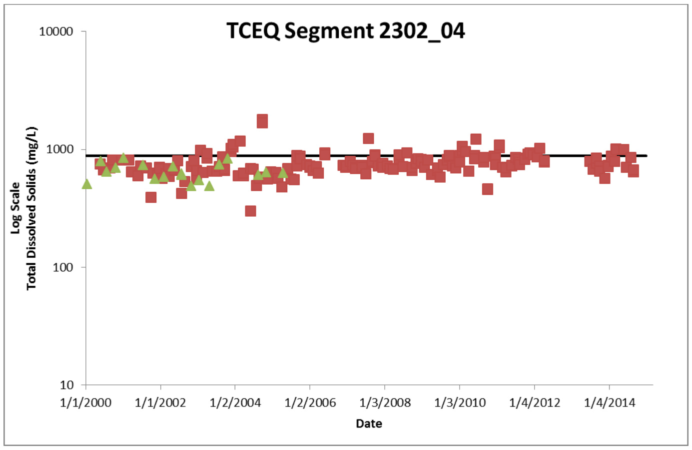

TCEQ Segment 2302_07
1000
10
Log Scale
Sulfate (mg/L)
1/1/2000
1/1/2002
1/2/2004
1/2/2006
1/3/2008
1/3/2010
1/4/2012
1/4/2014
Date

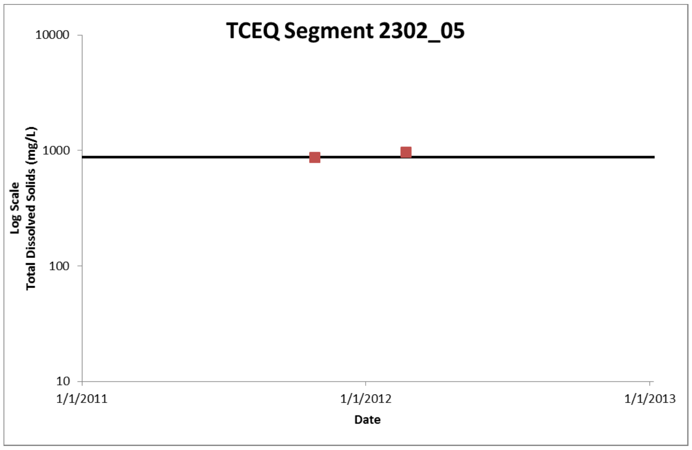
Total Dissolved Solids

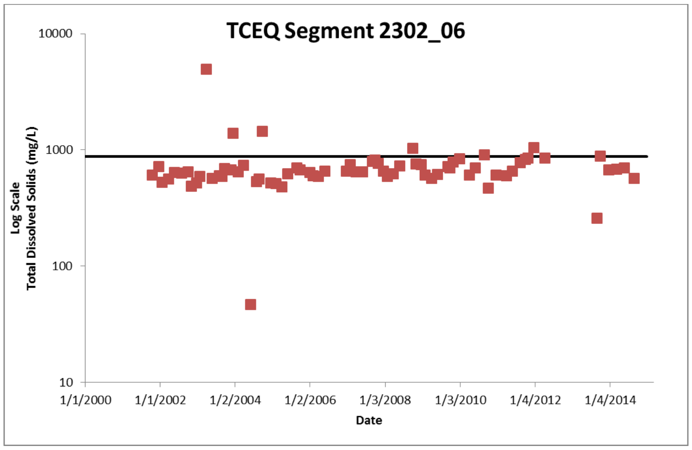


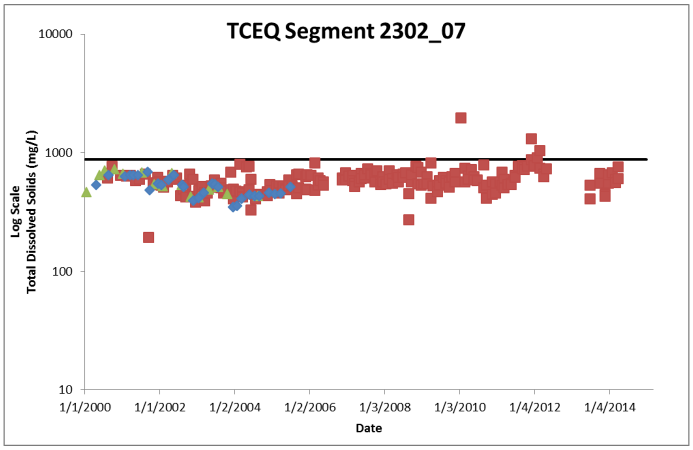




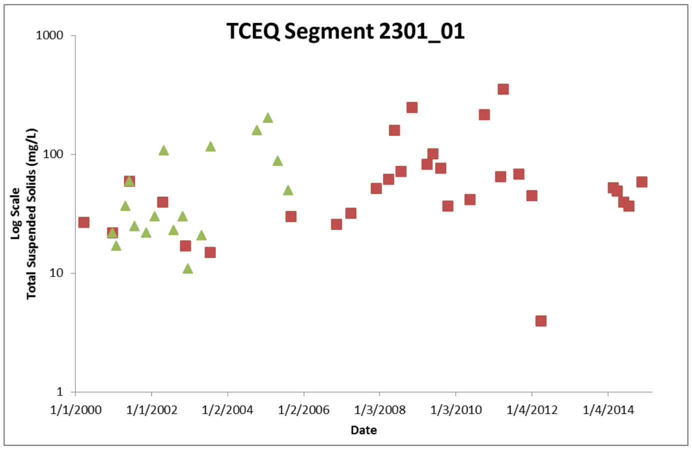


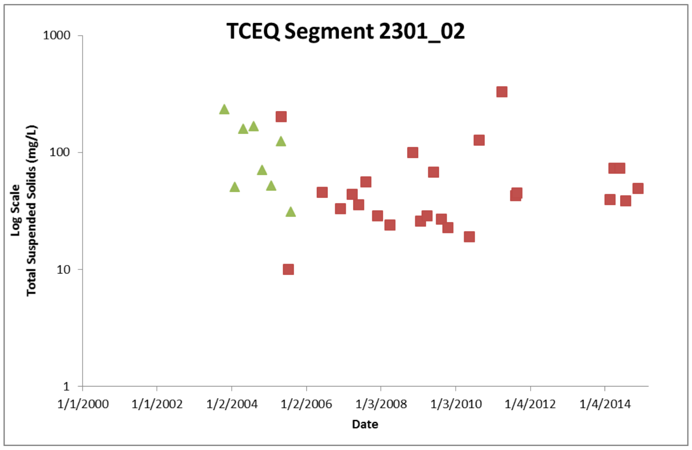


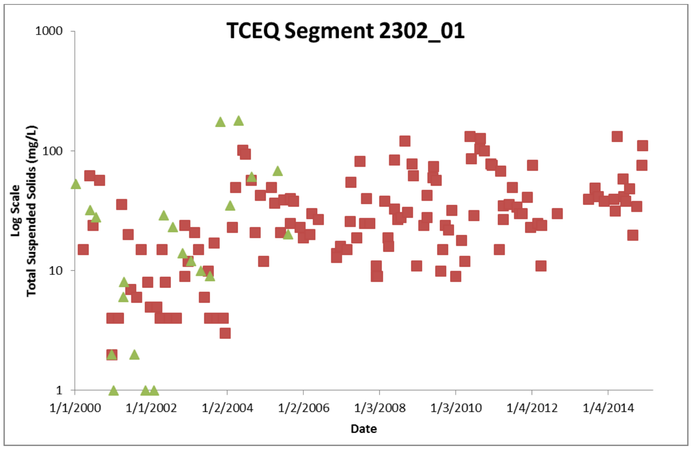


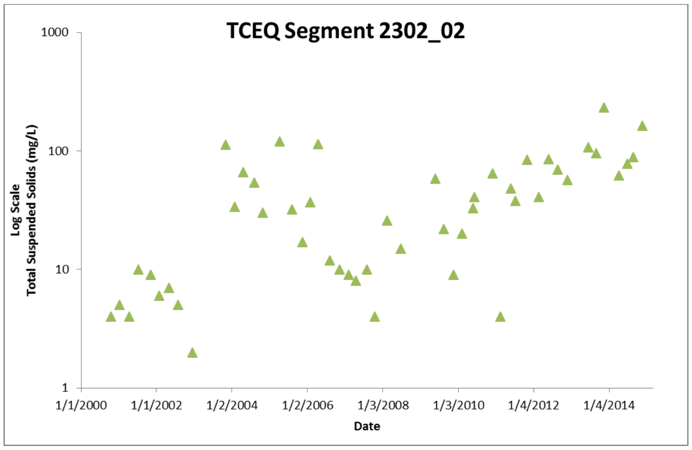


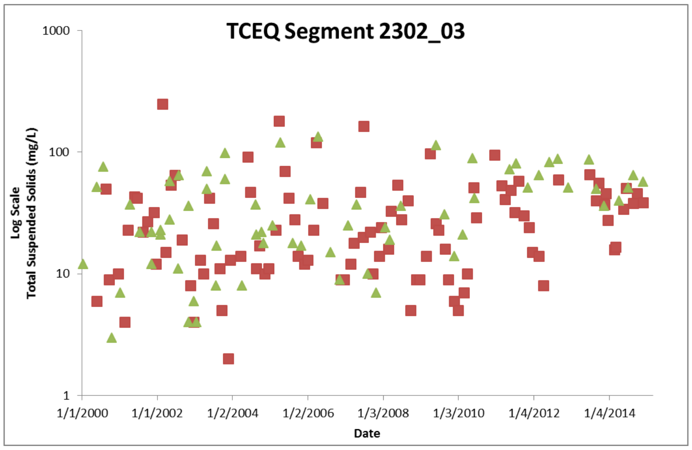
Total Suspended Solids

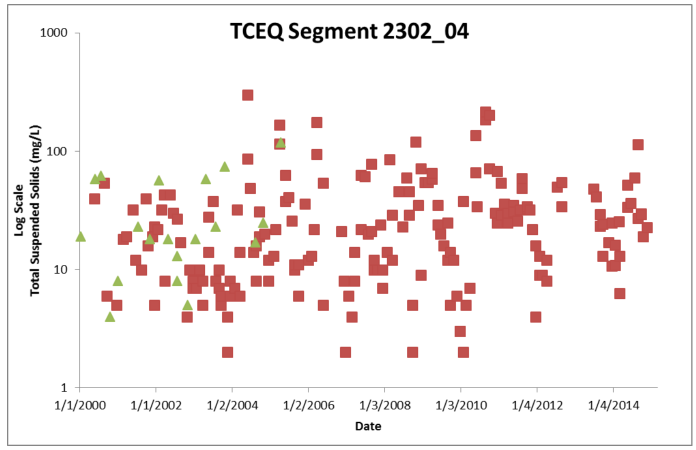


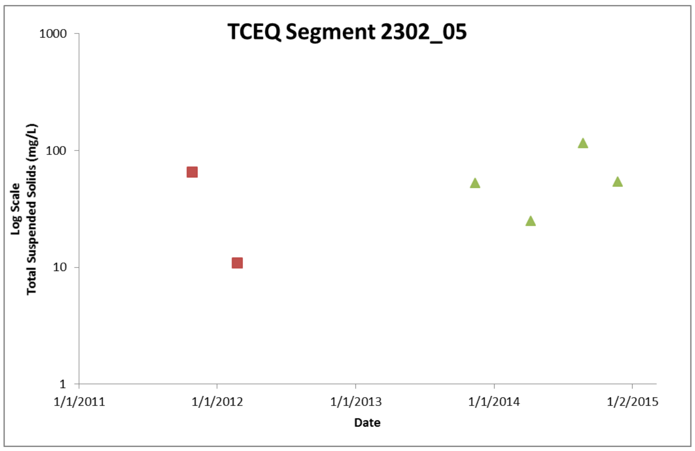


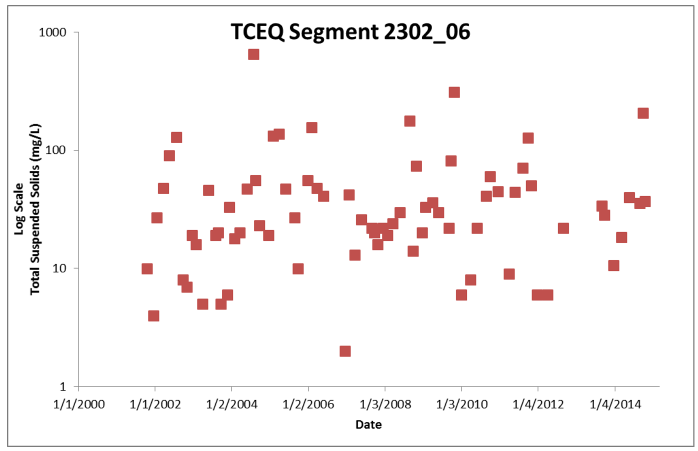


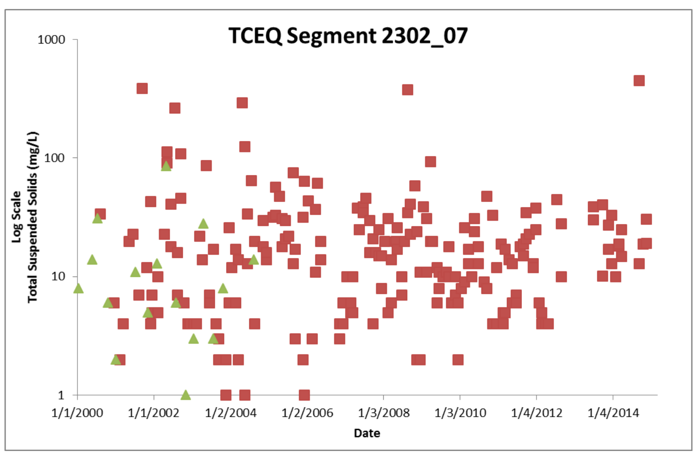



TCEQ Segment 2302_03
Log Scale
Total Suspended Solids (mg/L)
1000
100
10
1
1/1/2000
1/1/2002
1/2/2004
1/2/2006
1/3/2008
1/3/2010
1/4/2012
1/4/2014
Date

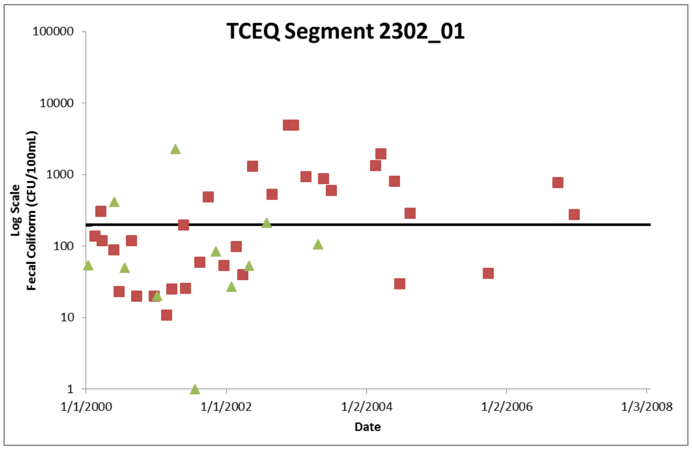

TCEQ Segment 2302_04
Log Scale
Total Suspended Solids (mg/L)
1000
100
10
1
1/1/2000
1/1/2002
1/2/2004
1/2/2006
1/3/2008
1/3/2010
1/4/2012
1/4/2014
Date

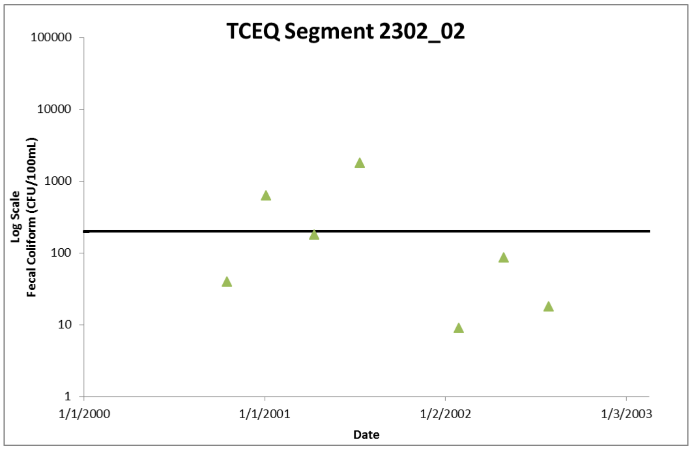

TCEQ Segment 2302_05
Log Scale
Total Suspended Solids (mg/L)
1000
100
10
1
1/1/2011
1/1/2012
1/1/2013
1/1/2014
1/2/2015
Date

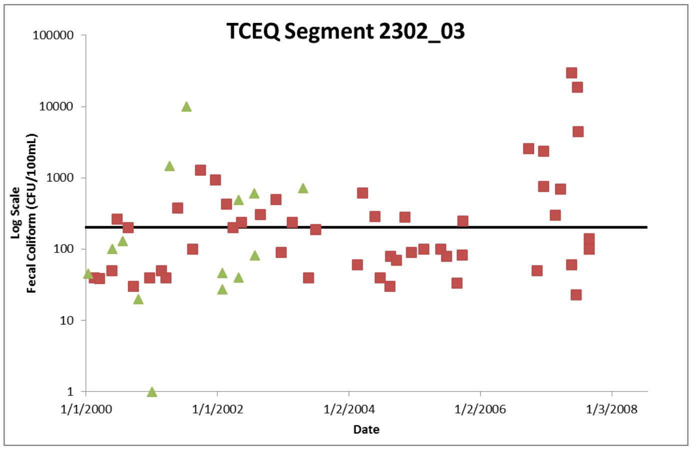

TCEQ Segment 2302_06
Log Scale
Total Suspended Solids (mg/L)
1000
100
10
1
1/1/2000
1/1/2002
1/2/2004
1/2/2006
1/3/2008
1/3/2010
1/4/2012
1/4/2014
Date

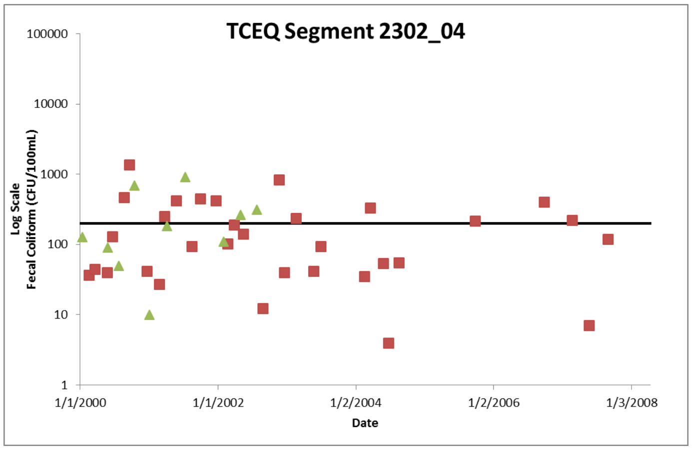

TCEQ Segment 2302_07
Log Scale
Total Suspended Solids (mg/L)
1000
100
10
1
1/1/2000
1/1/2002
1/2/2004
1/2/2006
1/3/2008
1/3/2010
1/4/2012
1/4/2014
Date

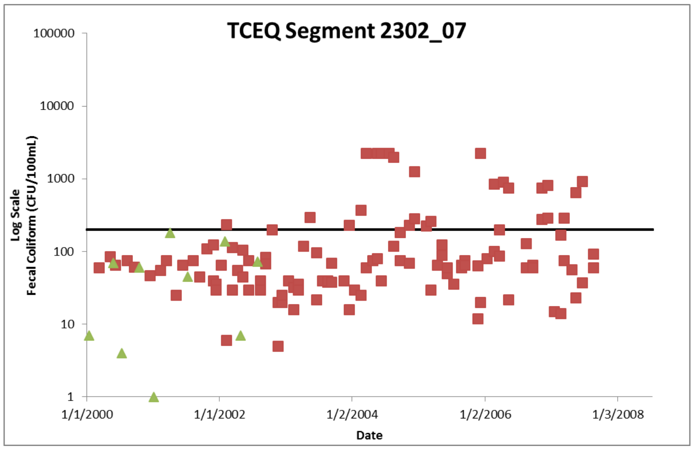
Fecal Coliform



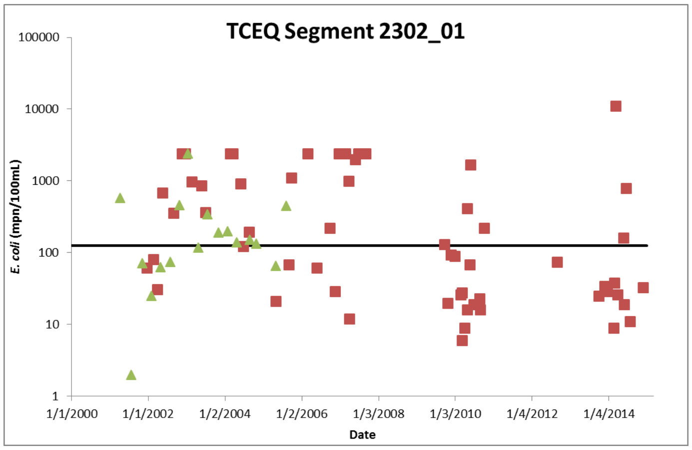








E. coli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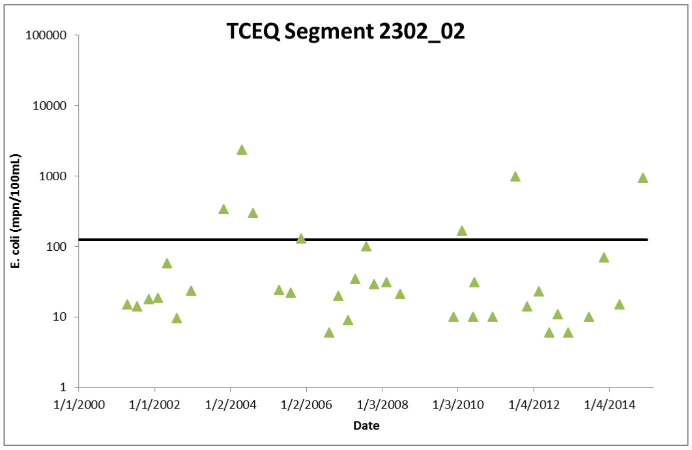
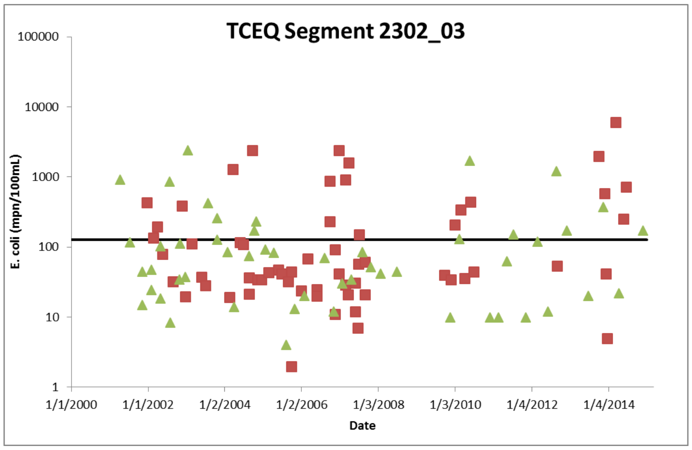
E. coli (mpn/100mL)
Date


TCEQ Segment 2302_02
E. coli (mpn/100mL)
Date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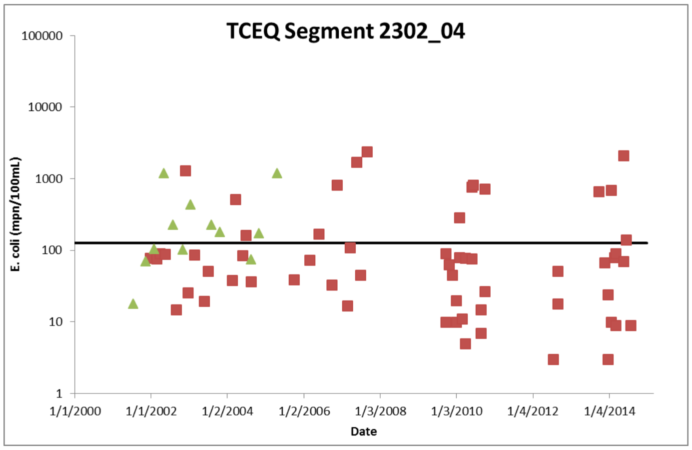
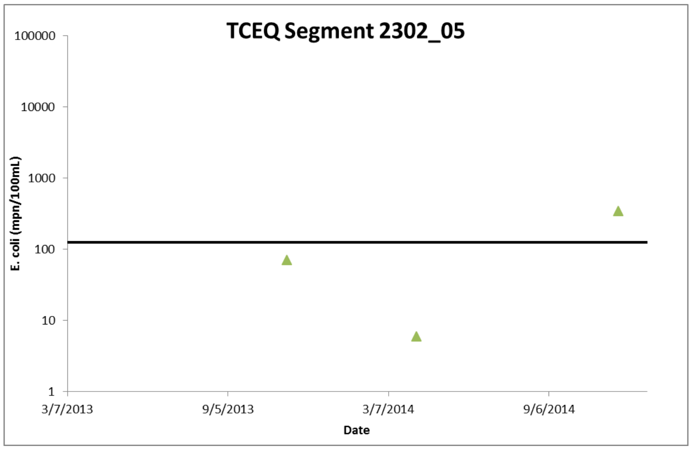
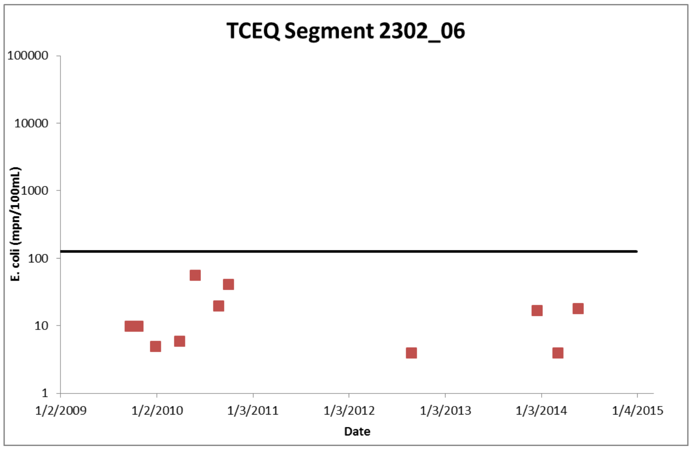
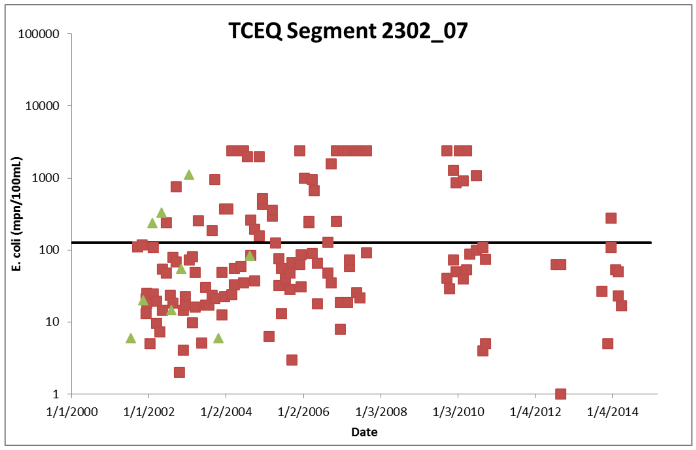
E. coli (mpn/100mL)
Date

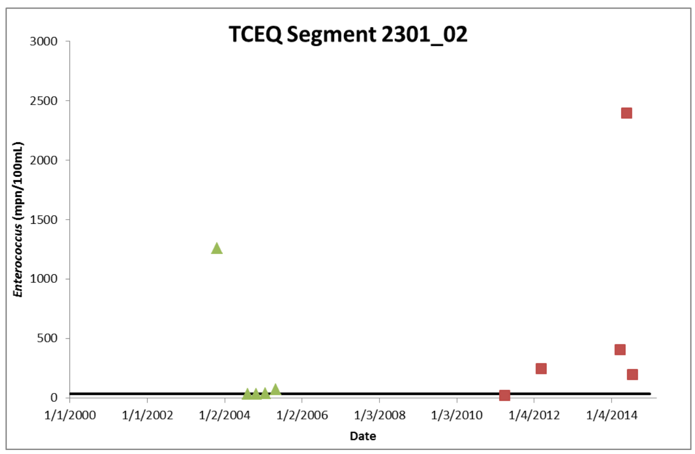

TCEQ Segment 2302_04
E. coli (mpn/100mL)
Date


TCEQ Segment 2302_05
E. coli (mpn/100mL)
Date


TCEQ Segment 2302_06
E. coli (mpn/100mL)
Date



Enterococcus



Tables of Descriptive Statistics (US Historical Water Quality Data)

Data range: 2000-2014 (some years contain data gaps). US data was obtained from the TCEQ's SWQMIS database. The "Percent of samples…" column values are based on criteria specified in the Texas Surface Water Quality Standards or on screening criteria developed by the TCEQ.

Dissolved Oxygen

TCEQ AU	No. of Samples	Sample Date Range	Minimum (mg/L)	Maximum (mg/L)	Average (mg/L)	Standard Deviation	Percent of samples < 5 mg/L
2301_01	33	2000-2014	1.4	18.2	8.81	3.03	6.06
2301_02	28	2003-2014	3.3	12.9	8.12	2.42	7.14
2302_01	252	2000-2014	0.68	18.2	6.68	2.34	22.22
2302_02	43	2000-2014	4.4	14.5	9.05	2.30	4.65
2302_03	195	2000-2014	2	15	7.09	2.33	18.46
2302_04	230	2000-2014	2.4	16.6	7.40	2.16	13.48
2302_05	5	2011-2014	7.1	14.5	9.84	2.81	0.00
2302_06	81	2001-2014	1.5	11.97	6.75	1.87	16.05
2302_07	280	2000-2014	4.1	18.6	7.82	2.05	2.86

Chlorophyll-*a*

TCEQ AU	No. of Samples	Sample Date Range	Minimum (ug/L)	Maximum (ug/L)	Average (ug/L)	Standard Deviation	Percent of samples > 14.1 ug/L
2301_01	49	2000-2014	3	288	41.12	51.23	69.39
2301_02	34	2003-2014	3	116	30.96	35.20	47.06
2302_01	162	2000-2014	1	190	23.39	33.03	37.04
2302_02	18	2000-2006	10	37.9	12.03	6.77	11.11
2302_03	134	2000-2014	1.15	69	10.95	11.36	18.66
2302_04	204	2000-2014	1	96	10.35	11.88	18.14
2302_06	72	2001-2014	3	45	9.76	8.77	18.06
2302_07	228	2000-2014	1.25	57	8.73	8.51	11.40

Ammonia Nitrogen

TCEQ AU	No. of Samples	Sample Date Range	Minimum (mg/L)	Maximum (mg/L)	Average (mg/L)	Standard Deviation	Percent of samples > 0.46 mg/L
2301_01	48	2000-2014	0.02	7.1	0.27	1.02	8.33
2301_02	32	2003-2014	0.02	1.96	0.26	0.43	12.50
2302_01	161	2000-2014	0.02	7	0.32	0.73	13.66
2302_02	46	2000-2014	0.05	1.79	0.22	0.33	13.04
2302_03	157	2000-2014	0.02	8.96	0.33	0.85	12.10
2302_04	196	2000-2014	0.02	5.04	0.19	0.49	8.16
2302_05	6	2011-2014	0.05	0.56	0.16	0.20	16.67
2302_06	71	2001-2014	0.02	3.08	0.17	0.44	5.63
2302_07	227	2000-2014	0.015	8.4	0.54	0.87	31.28

Nitrate Nitrogen

TCEQ AU	No. of Samples	Sample Date Range	Minimum (mg/L)	Maximum (mg/L)	Average (mg/L)	Standard Deviation	Percent of samples > 1.1 mg/L
2301_01	4	2002-2004	0.05	1.65	0.63	0.73	25
2301_02	5	2003-2004	0.44	1.73	0.90	0.51	20
2302_01	7	2003-2004	0.29	1.24	0.72	0.38	14.29
2302_02	6	2002-2004	0.41	1.25	0.75	0.33	16.67
2302_03	13	2002-2004	0.05	1.11	0.38	0.27	7.69
2302_04	6	2003-2004	0.05	0.54	0.20	0.18	0
2302_07	5	2003-2004	0.05	0.16	0.09	0.05	0

Total Phosphorus

TCEQ AU	No. of Samples	Sample Date Range	Minimum (mg/L)	Maximum (mg/L)	Average (mg/L)	Standard Deviation	Percent of samples > 0.66 mg/L
2301_01	47	2000-2014	0.05	0.776	0.36	0.19	6.38
2301_02	33	2003-2014	0.05	1.88	0.41	0.36	9.09
2302_01	225	2000-2014	0.03	1.6	0.27	0.18	3.11
2302_02	42	2000-2014	0.08	0.788	0.27	0.14	2.38
2302_03	151	2000-2014	0.02	0.86	0.16	0.14	1.32
2302_04	199	2000-2014	0.01	0.84	0.11	0.12	1.01
2302_05	5	2011-2014	0.05	0.0911	0.07	0.02	0.00
2302_06	73	2001-2014	0.01	1.1	0.11	0.14	1.37
2302_07	276	2000-2014	0.009	2.2	0.15	0.23	2.90

Chloride

TCEQ AU	No. of Samples	Sample Date Range	Minimum (mg/L)	Maximum (mg/L)	Average (mg/L)	Standard Deviation	Percent of samples > 270 mg/L
2302_01	217	2000-2014	60	450	178.61	49.23	2.76
2302_02	45	2000-2014	104	424	180.13	58.93	6.67
2302_03	164	2000-2014	76	751	166.19	65.26	3.05
2302_04	214	2000-2014	60	919	163.89	71.60	4.67
2302_05	6	2011-2014	91	229	156.33	64.30	0.00
2302_06	78	2000-2014	71.1	262	137.96	37.10	0.00
2302_07	290	2000-2014	34	210	114.00	31.15	0.00

Sulfate

TCEQ AU	No. of Samples	Sample Date Range	Minimum (mg/L)	Maximum (mg/L)	Average (mg/L)	Standard Deviation	Percent of samples < 5 mg/L
2302_01	217	2000-2014	27	411	235.82	59.10	2.76
2302_02	47	2000-2014	159	422	256.13	56.92	4.26
2302_03	168	2000-2014	117	2570	249.81	191.45	4.76
2302_04	214	2000-2014	25	548	227.69	58.20	2.34
2302_05	6	2011-2014	161	376	250.17	80.26	16.67
2302_06	78	2000-2014	88	329	205.88	47.15	0.00
2302_07	289	2000-2014	22.2	296	171.16	48.26	0.00

Total Dissolved Solids

TCEQ AU	No. of Samples	Sample Date Range	Minimum (mg/L)	Maximum (mg/L)	Average (mg/L)	Standard Deviation	Percent of samples > 880 mg/L
2302_01	216	2000-2014	284.58	4275	828.40	292.34	29.17
2302_02	35	2000-2011	568	1220	805.80	153.47	25.71
2302_03	154	2000-2014	266.3	1720	747.64	171.13	18.83
2302_04	205	2000-2014	300	1800	755.71	179.48	17.56
2302_05	2	2011-2012	880	968	924.00	62.23	50.00
2302_06	72	2001-2014	47	4961	741.84	539.98	9.72
2302_07	277	2000-2014	194	1990	576.57	148.33	1.44

Total Suspended Solids

TCEQ AU	No. of Samples	Sample Date Range	Minimum (mg/L)	Maximum (mg/L)	Average (mg/L)	Standard Deviation	Percent of samples above or below the State Criteria*
2301_01	47	2000-2014	4	354	68.53	69.46	NA
2301_02	33	2003-2014	10	330	75.35	71.53	NA
2302_01	153	2000-2014	1	180	35.30	33.15	NA
2302_02	49	2000-2014	2	233	46.33	47.51	NA
2302_03	168	2000-2014	2	3920	59.32	301.65	NA
2302_04	212	2000-2014	2	300	32.61	39.26	NA
2302_05	6	2011-2014	11	116	54.17	36.55	NA
2302_06	76	2001-2014	2	654	51.93	87.01	NA
2302_07	233	2000-2014	1	455.4	26.66	53.86	NA

***** Narrative criteria only

Fecal Coliform

TCEQ AU	No. of Samples	Sample Date Range	Minimum (MPN/ 100mL)	Maximum (MPN/ 100mL)	Average (MPN/ 100mL)	Standard Deviation	Percent of samples > 200 MPN/100mL
2302_01	43	2000-2006	1	5000	580.16	1118.23	41.86
2302_02	7	2003-2002	9	1818	398.57	663.36	28.57
2302_03	65	2000-2007	1	30000	1306.48	4504.03	41.54
2302_04	42	2000-2007	4	1367	230.49	282.54	38.10
2302_07	128	2000-2007	1	2250	230.12	487.10	19.53

E. coli

TCEQ AU	No. of Samples	Sample Date Range	Minimum (MPN/ 100mL)	Maximum (MPN/ 100mL)	Average (MPN/ 100mL)	Standard Deviation	Percent of samples > 126 MPN/100mL
2302_01	75	2001-2014	2	11000	686.55	1462.29	49.33
2302_02	36	2001-2014	6	2400	165.84	446.27	19.44
2302_03	112	2001-2014	2	6100	305.80	750.47	30.36
2302_04	71	2001-2014	3	2400	271.27	488.74	30.99
2302_05	3	2013-2014	6	350	142.33	182.76	33.33
2302_06	11	2009-2014	4	57	17.45	16.98	0.00
2302_07	149	2001-2014	1	2420	424.70	770.20	32.89

Enterococcus

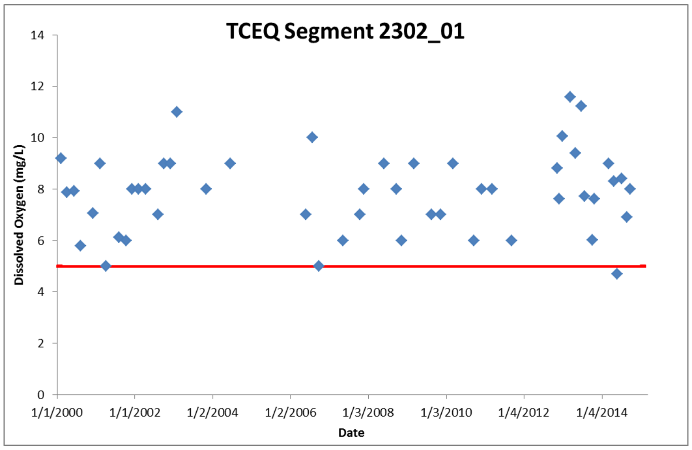
TCEQ AU	No. of Samples	Sample Date Range	Minimum (MPN/ 100mL)	Maximum (MPN/ 100mL)	Average (MPN/ 100mL)	Standard Deviation	Percent of samples > 35 MPN/100mL
2301_02	10	2003-2014	25	2400	472.50	774.26	80.00

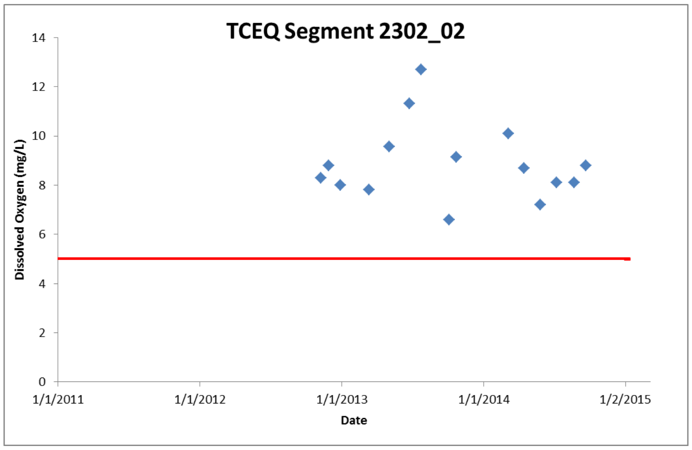
Scatterplots of Mexican Historical Water Quality Data

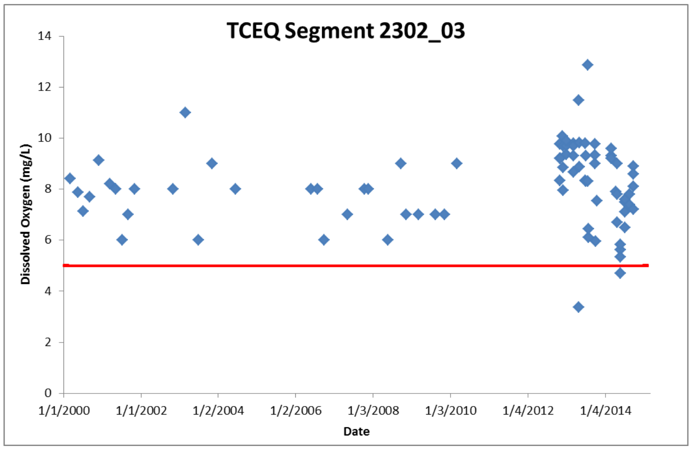
Data range: 2000-2014 (some years missing for some parameters). All data was obtained from CONAGUA (Red Nacional de Monitoreo de la Calidad del Agua). The Acceptable Limit criteria is based on CONAGUA's method for assessing surface water quality, which in turn is based on Mexico's Ley Federal de Derechos: Disposiciones Applicables en Materia de Aguas Nacionales 2016. The Ecological Criterion Level is based on Mexico's Criterios Ecológicos de Calidad del Agua CE-CCA-001/89: Diario Oficial de la Federación, Miércoles 13 de diciembre de 1989 (CE-CCA-00189RecuadroIII.2.2.1).

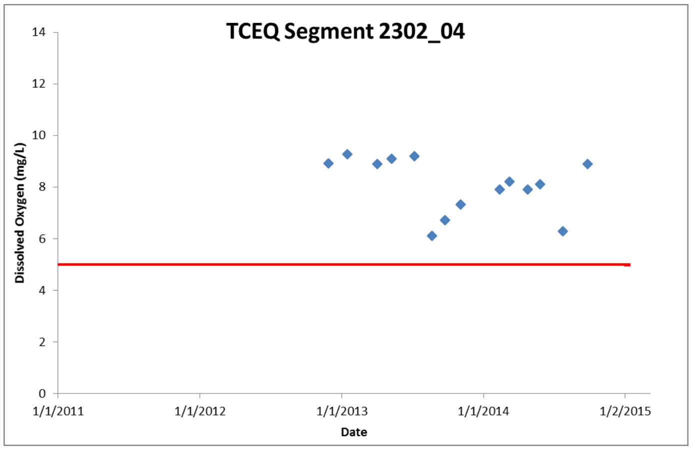
CONAGUA — Acceptable Limit — Ecological Criterion Level

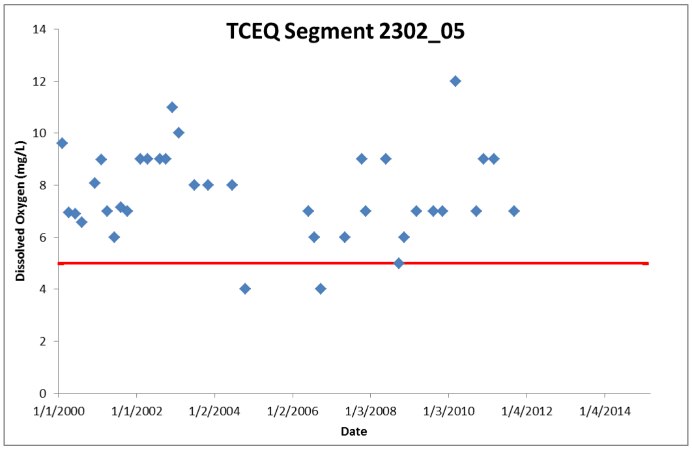
Dissolved Oxygen

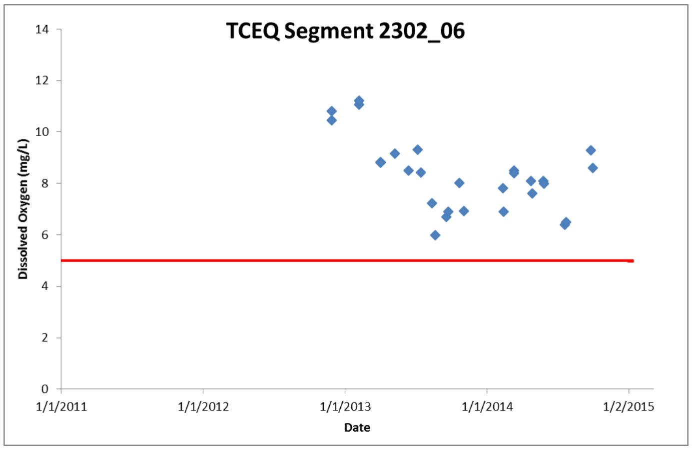


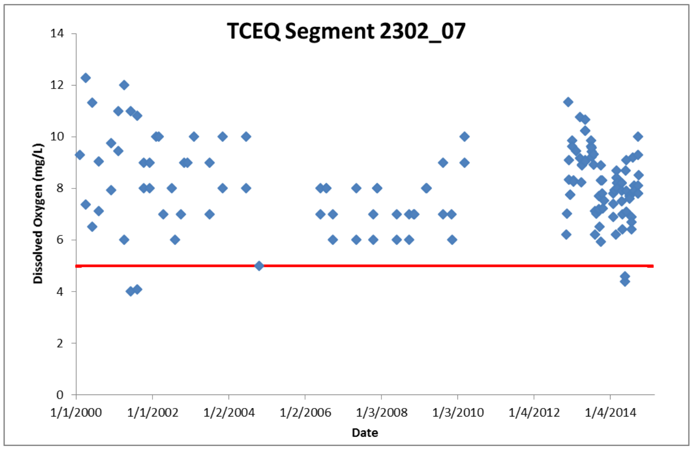




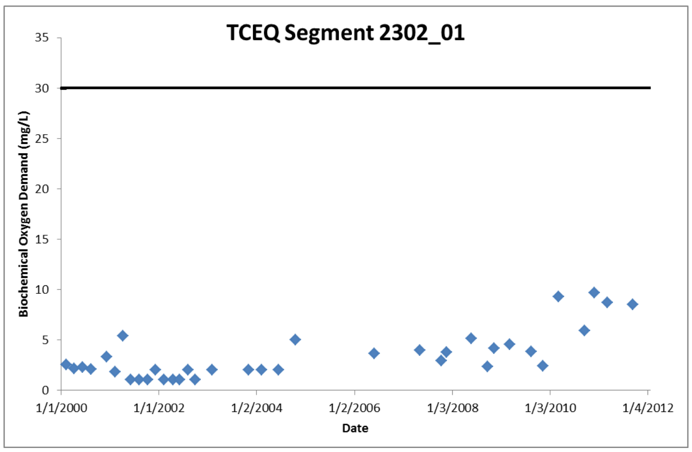


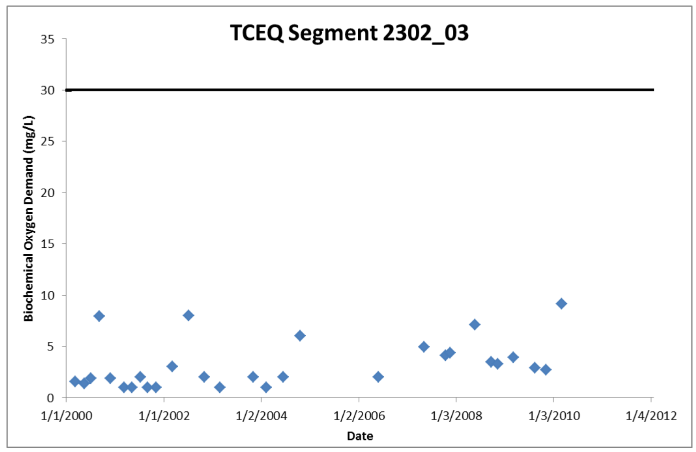


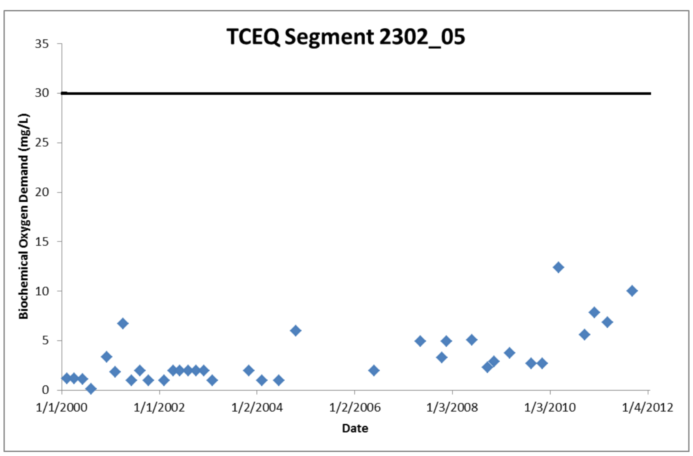


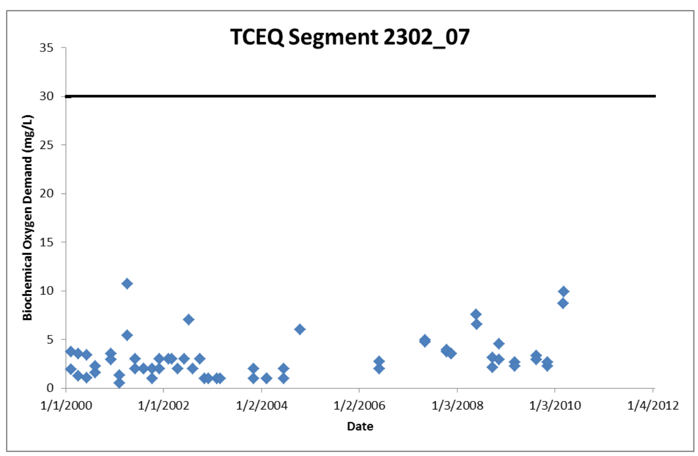


Biochemical Oxygen Demand

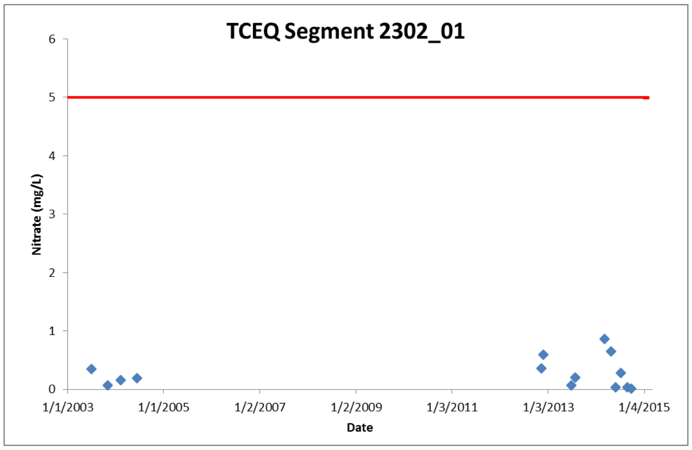








Nitrate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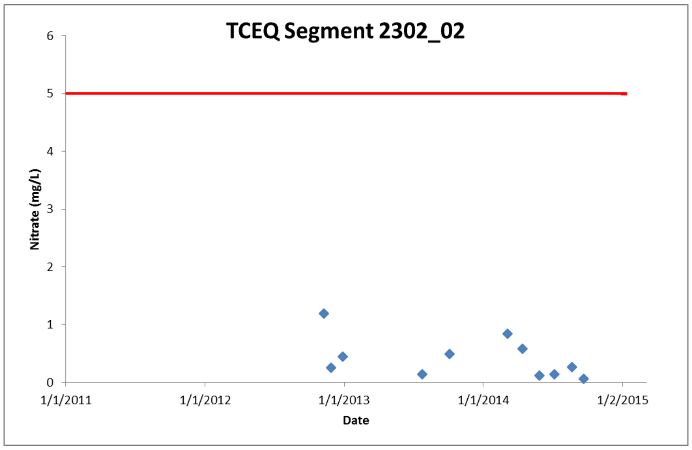
Nitrate (mg/L)
0
1
2
3
4
5
6
1/1/2003
1/1/2005
1/2/2007
1/2/2009
1/3/2011
1/3/2013
1/4/2015
Date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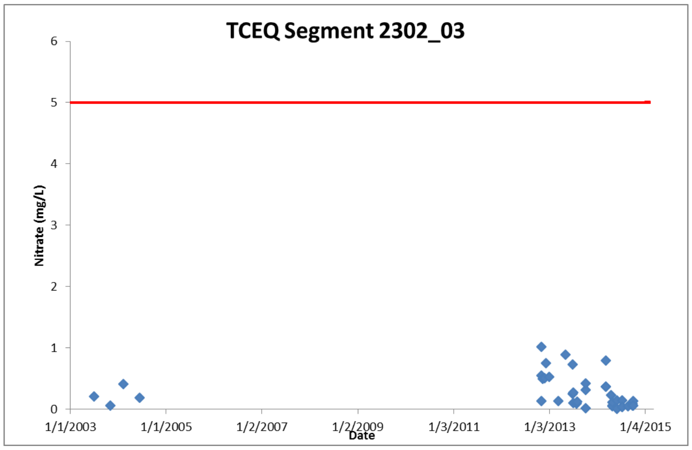
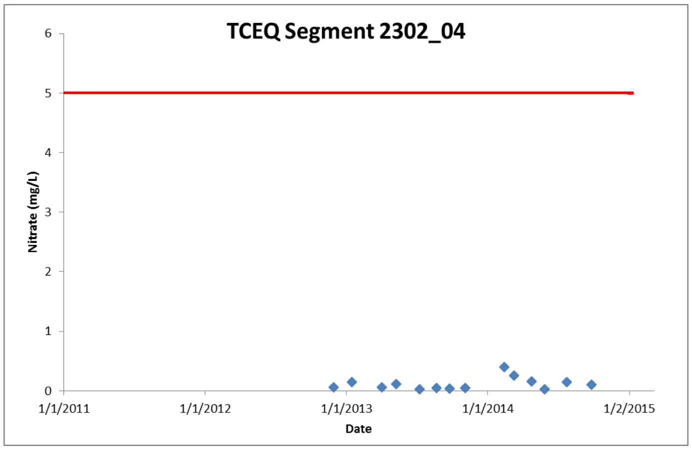
Nitrate (mg/L)
0
1
2
3
4
5
6
1/1/2011
1/1/2012
1/1/2013
1/1/2014
1/2/2015
Date


TCEQ Segment 2302_03
Nitrate (mg/L)
0
1
2
3
4
5
6
1/1/2003
1/1/2005
1/2/2007
1/2/2009
1/3/2011
1/3/2013
1/4/2015
Date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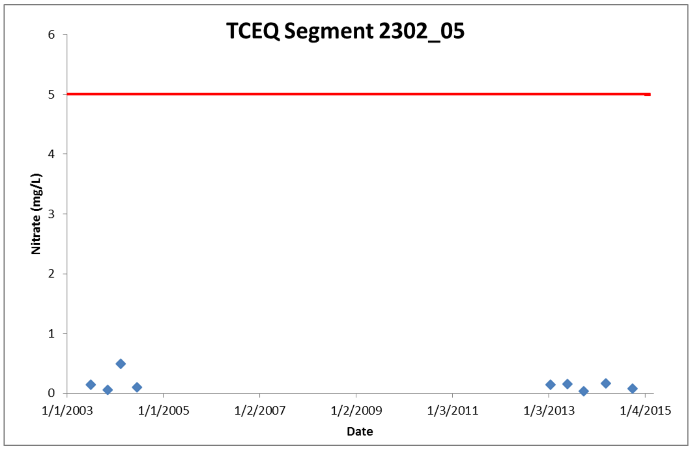
Nitrate (mg/L)
0
1
2
3
4
5
6
1/1/2011
1/1/2012
1/1/2013
1/1/2014
1/2/2015
Date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Nitrate (mg/L)
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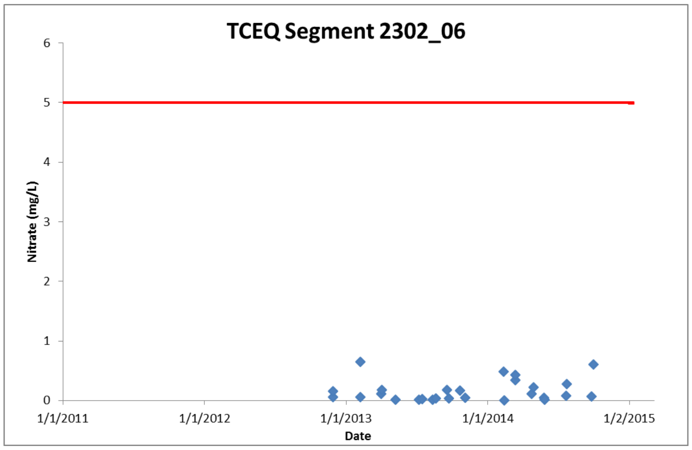
1
2
3
4
5
6
1/1/2003
1/1/2005
1/2/2007
1/2/2009
1/3/2011
1/3/2013
1/4/2015
Date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Nitrate (mg/L)
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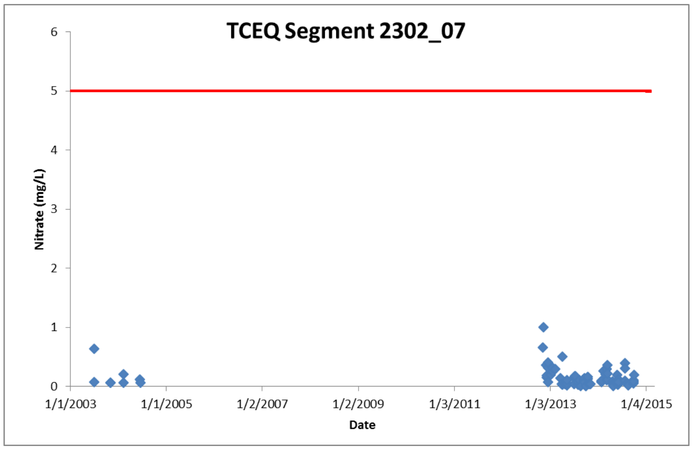
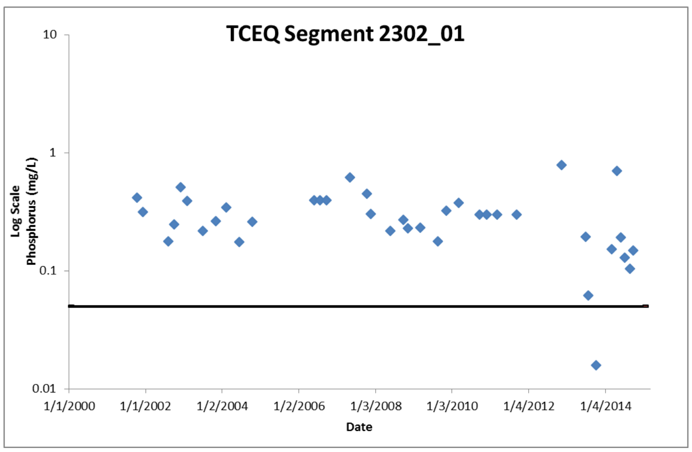
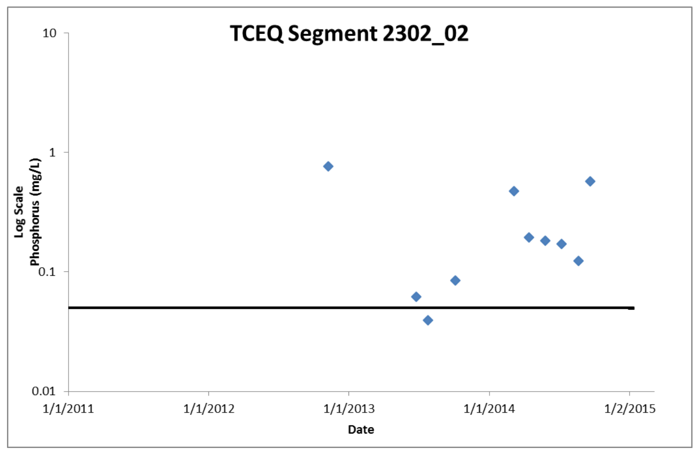
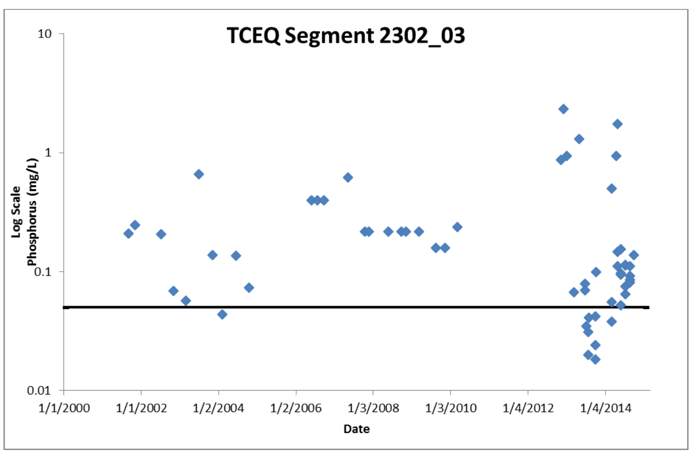
1
2
3
4
5
6
1/1/2011
1/1/2012
1/1/2013
1/1/2014
1/2/2015
Date

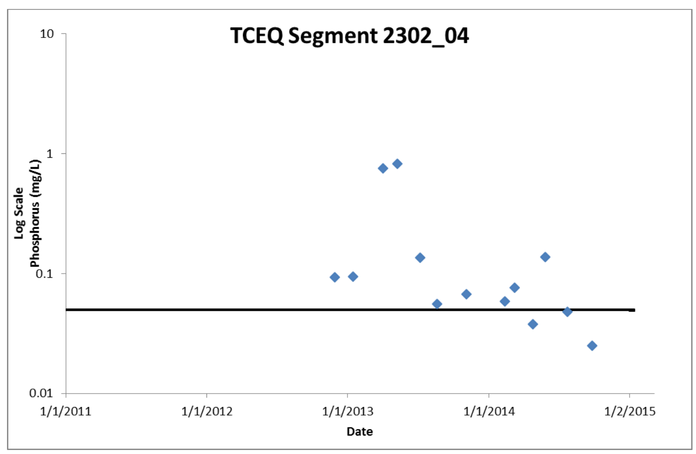


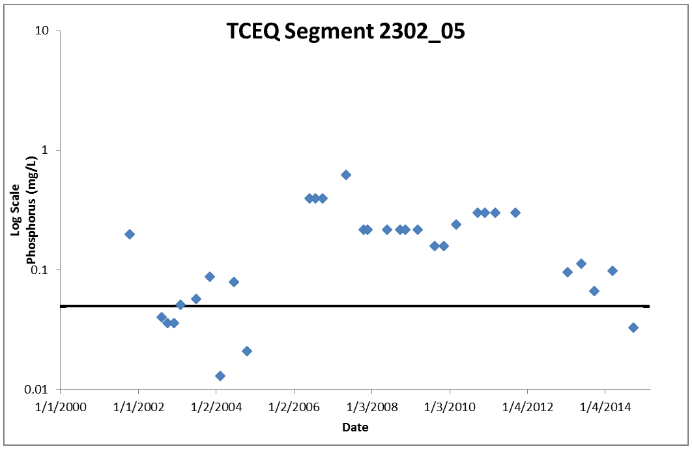
Total Phosphorus







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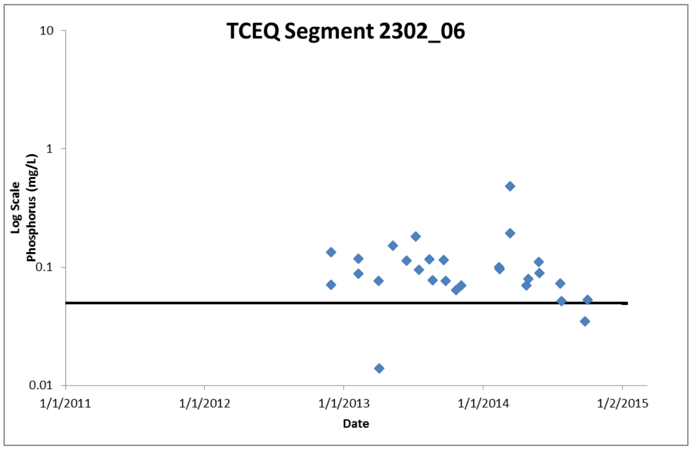
Log Scale Phosphorus (mg/L)
10
1
0.1
0.01
1/1/2000
1/1/2002
1/2/2004
1/2/2006
1/3/2008
1/3/2010
1/4/2012
1/4/2014
Date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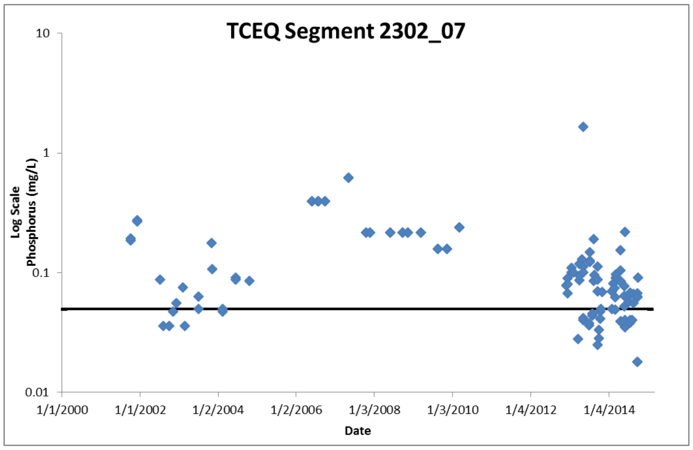
Log Scale Phosphorus (mg/L)
10
1
0.1
0.01
1/1/2011
1/1/2012
1/1/2013
1/1/2014
1/2/2015
Date


TCEQ Segment 2302_07
Log Scale Phosphorus (mg/L)
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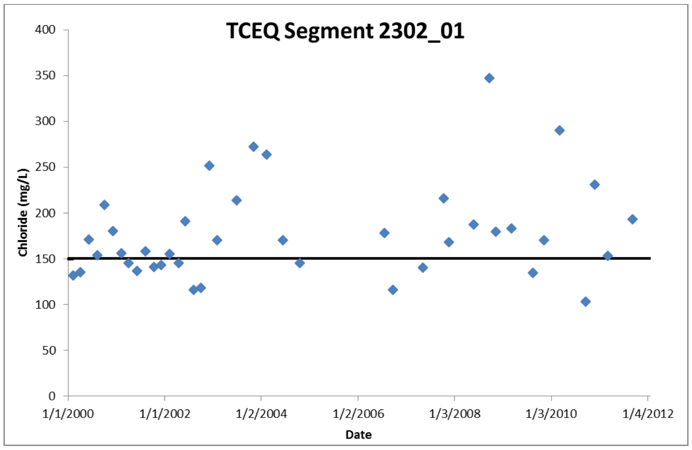
1
0.1
0.01
1/1/2000
1/1/2002
1/2/2004
1/2/2006
1/3/2008
1/3/2010
1/4/2012
1/4/2014
Date

Chloride


TCEQ Segment 2302_01
Chloride (mg/L)
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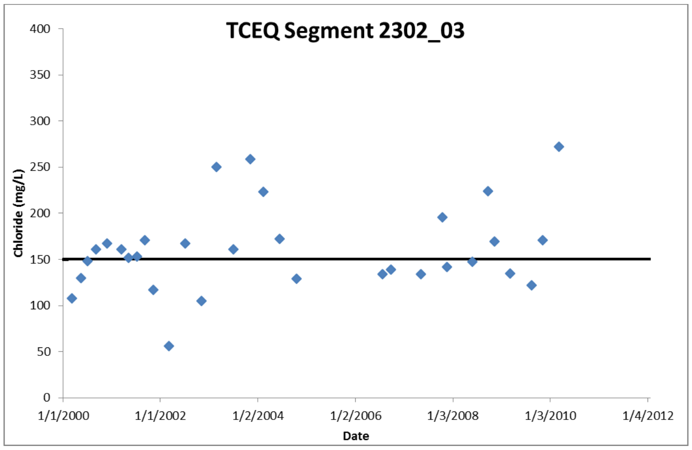
350
300
250
200
150
100
50
0
1/1/2000
1/1/2002
1/2/2004
1/2/2006
1/3/2008
1/3/2010
1/4/2012
Date


TCEQ Segment 2302_03
Chloride (mg/L)
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350
300
250
200
150
100
50
0
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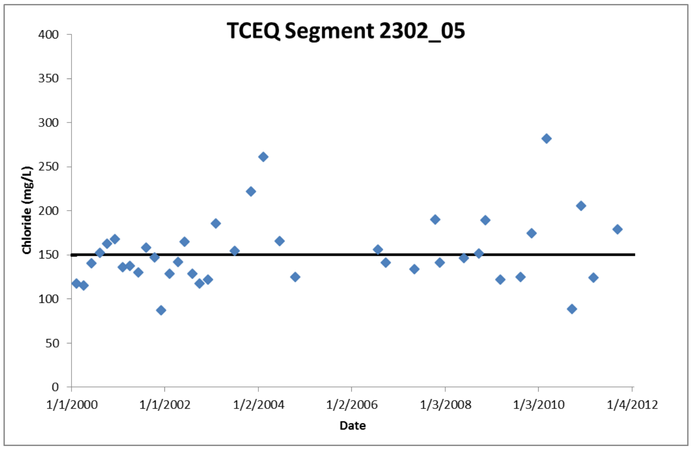
1/1/2002
1/2/2004
1/2/2006
1/3/2008
1/3/2010
1/4/2012
Date


TCEQ Segment 2302_05
Chloride (mg/L)
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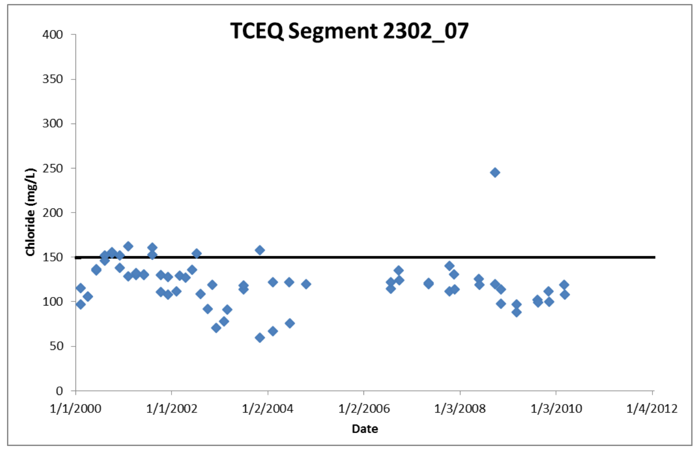
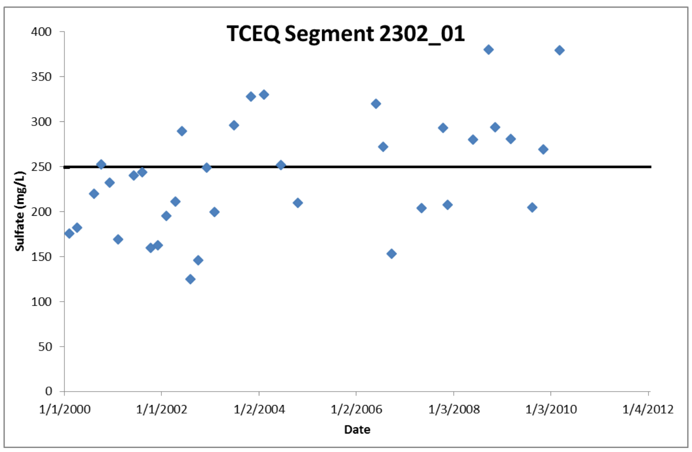
350
300
250
200
150
100
50
0
1/1/2000
1/1/2002
1/2/2004
1/2/2006
1/3/2008
1/3/2010
1/4/2012
Date


TCEQ Segment 2302_07
Chloride (mg/L)
400
350
300
250
200
150
100
50
0
1/1/2000
1/1/2002
1/2/2004
1/2/2006
1/3/2008
1/3/2010
1/4/2012
Date

Sulfate


TCEQ Segment 2302_01
Sulfate (mg/L)
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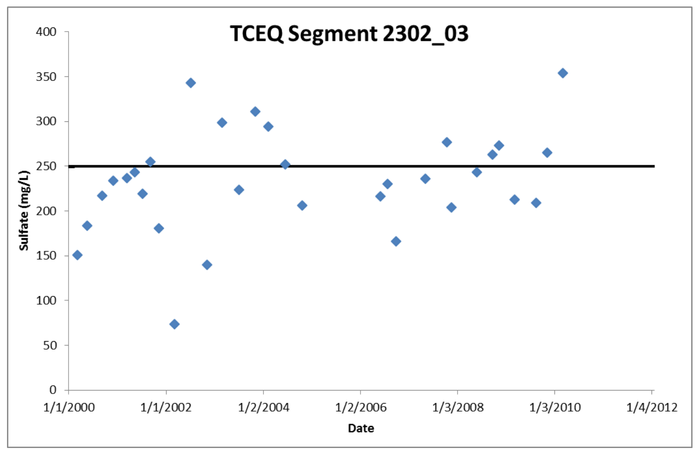
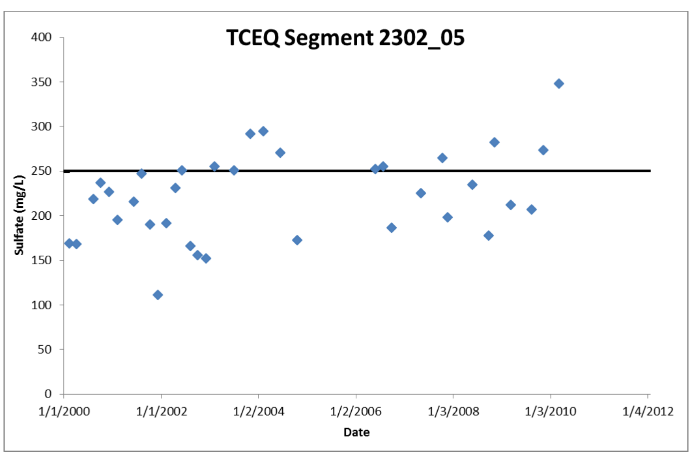
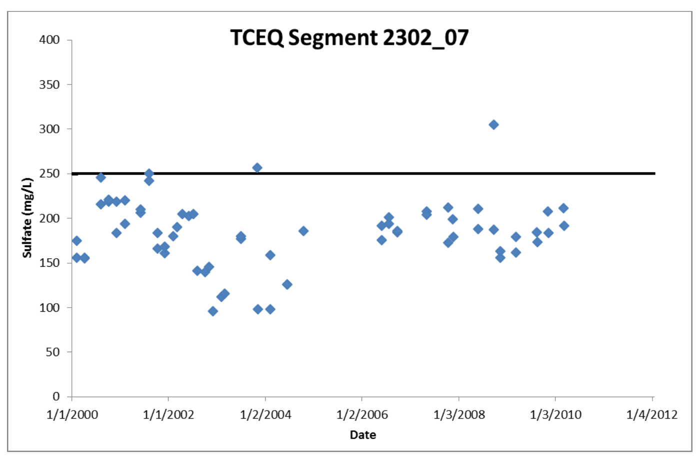
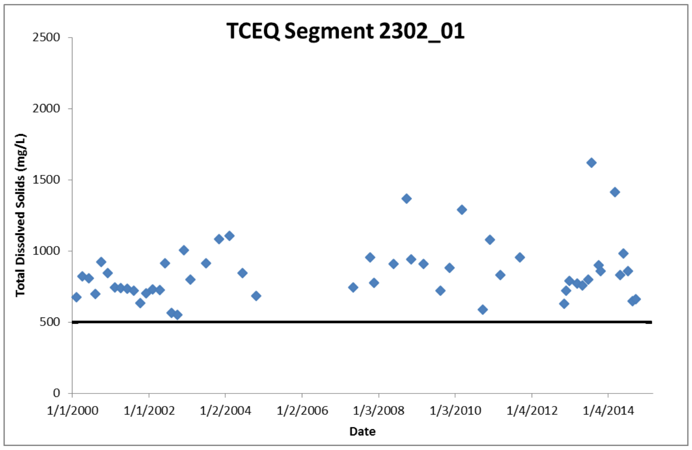
350
300
250
200
150
100
50
0
1/1/2000
1/1/2002
1/2/2004
1/2/2006
1/3/2008
1/3/2010
1/4/2012
Date

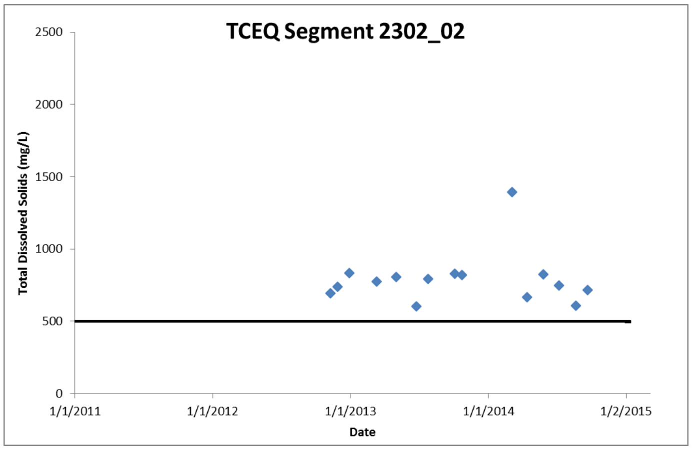

TCEQ Segment 2302_03
Sulfate (mg/L)
400
350
300
250
200
150
100
50
0
1/1/2000
1/1/2002
1/2/2004
1/2/2006
1/3/2008
1/3/2010
1/4/2012
Date

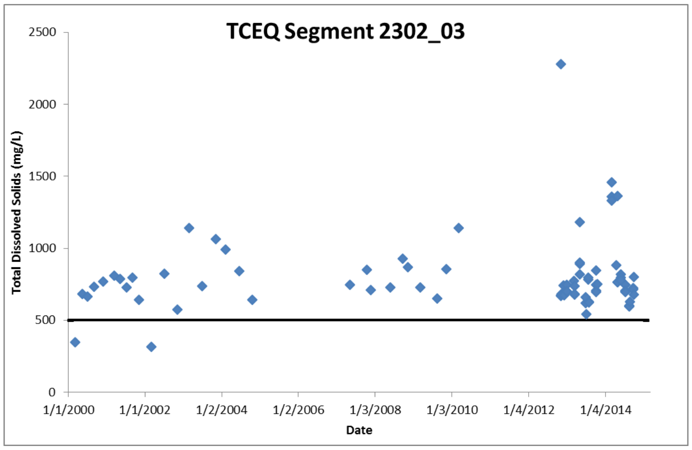

TCEQ Segment 2302_05
Sulfate (mg/L)
400
350
300
250
200
150
100
50
0
1/1/2000
1/1/2002
1/2/2004
1/2/2006
1/3/2008
1/3/2010
1/4/2012
Date

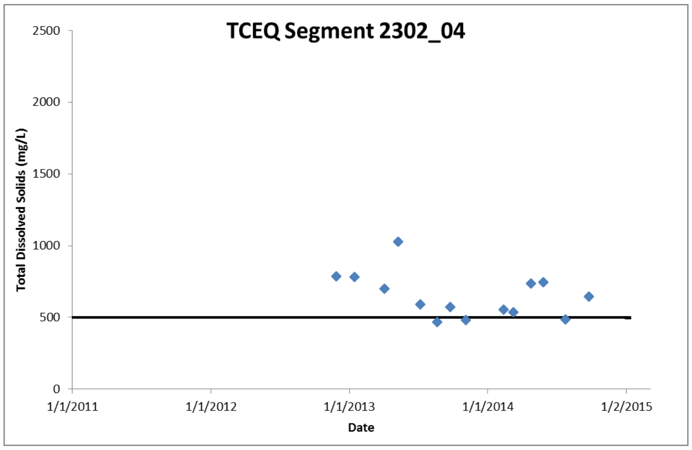

TCEQ Segment 2302_07
Sulfate (mg/L)
400
350
300
250
200
150
100
50
0
1/1/2000
1/1/2002
1/2/2004
1/2/2006
1/3/2008
1/3/2010
1/4/2012
Date

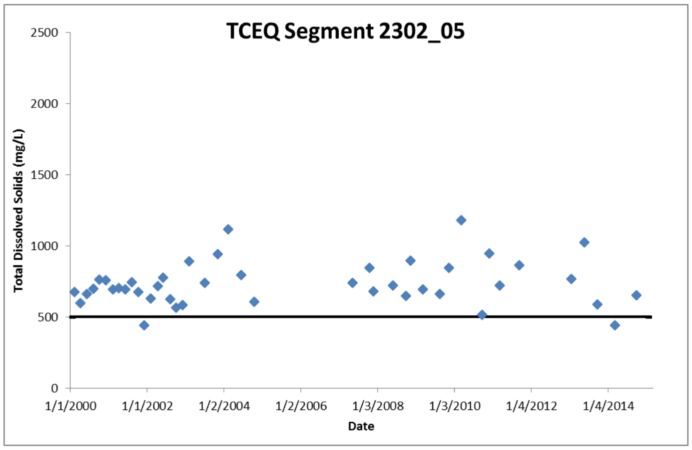
Total Dissolved Solids

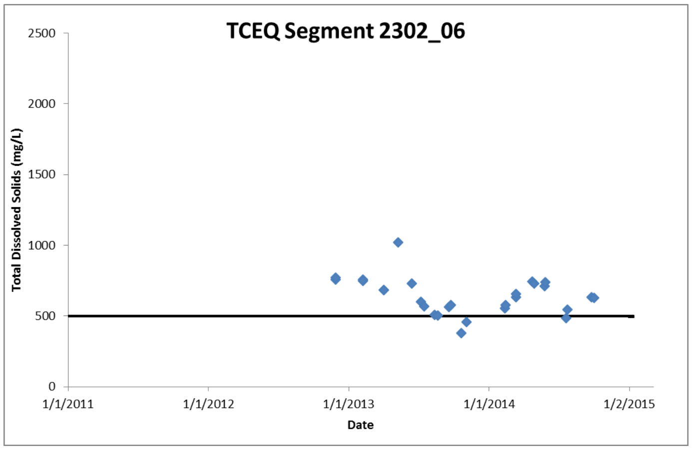


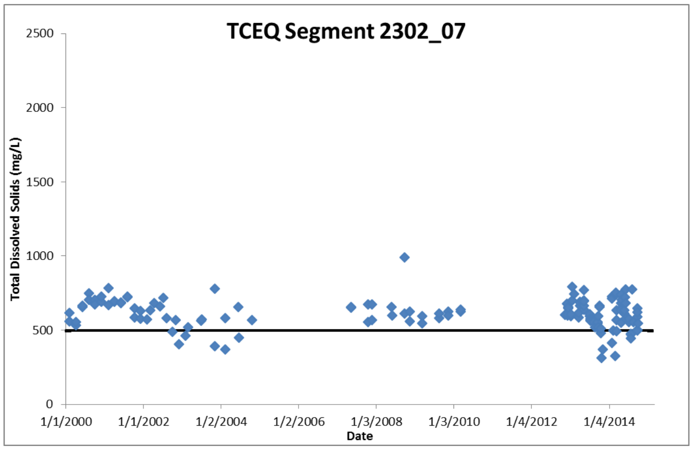




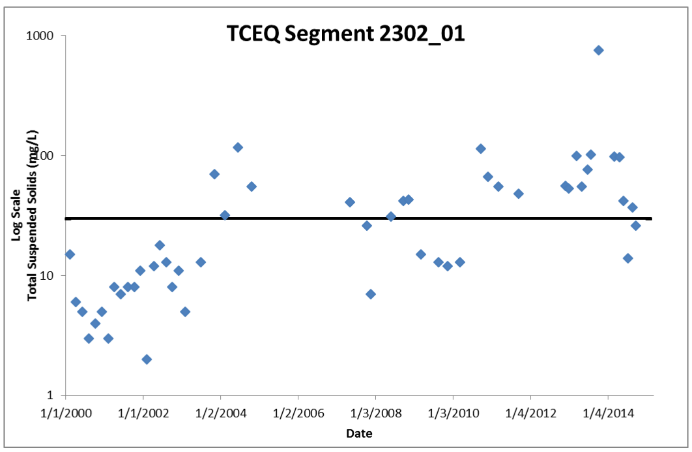


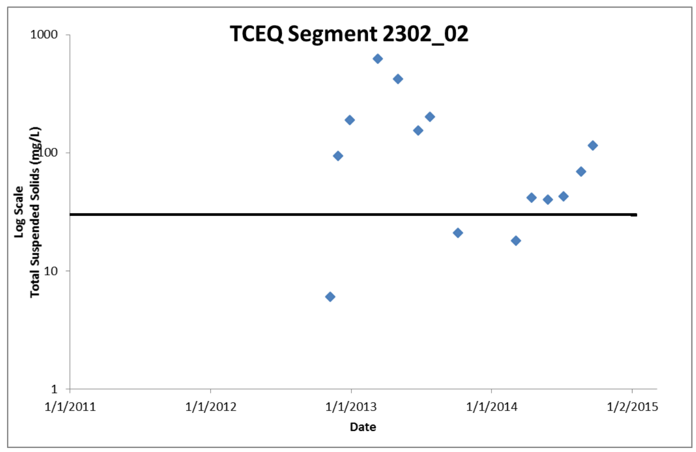


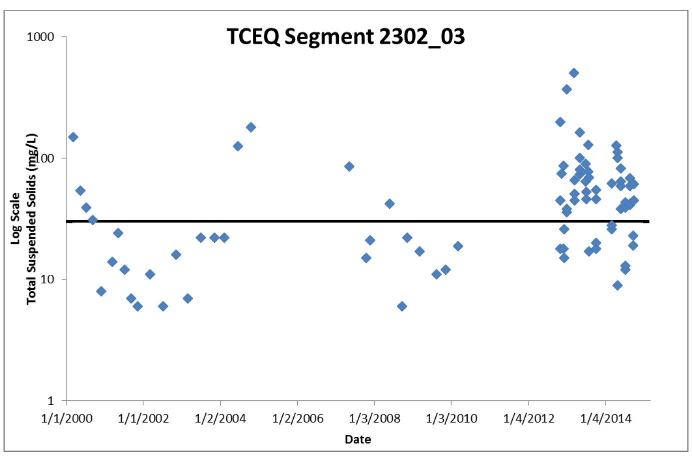


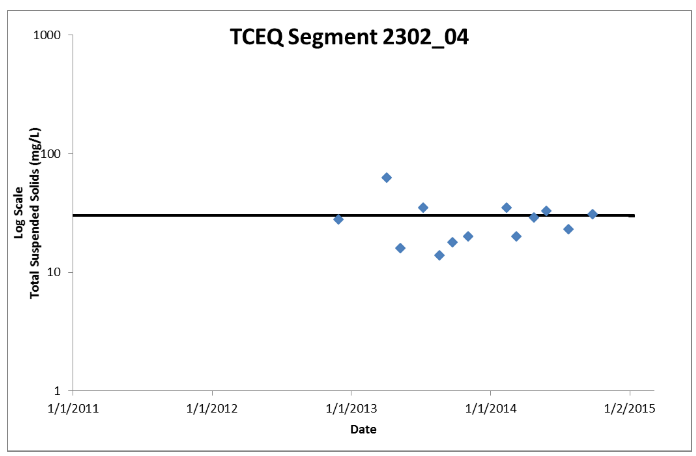


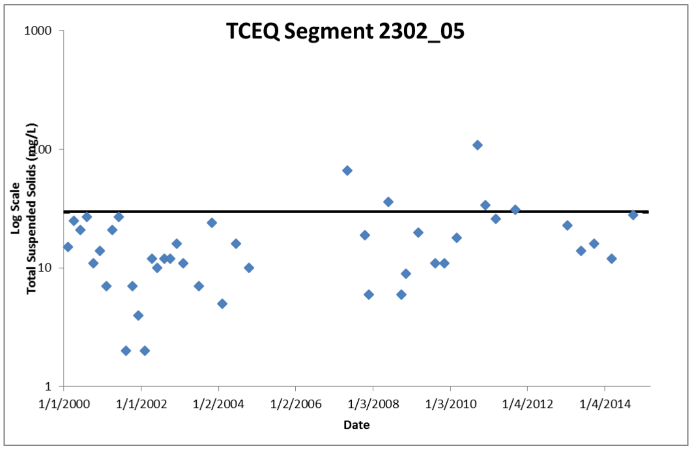
Total Suspended Solids

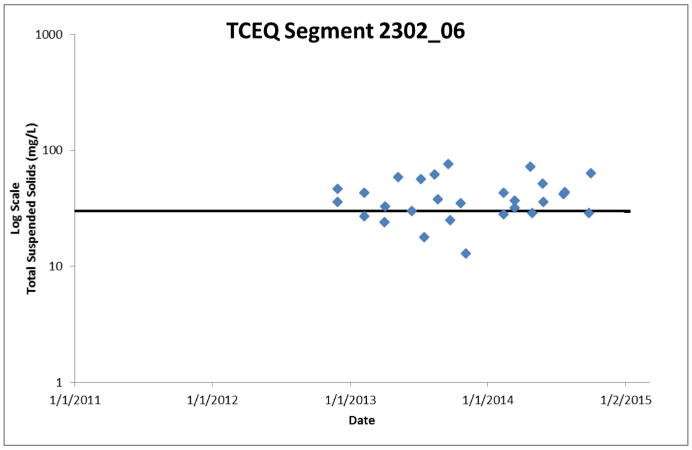


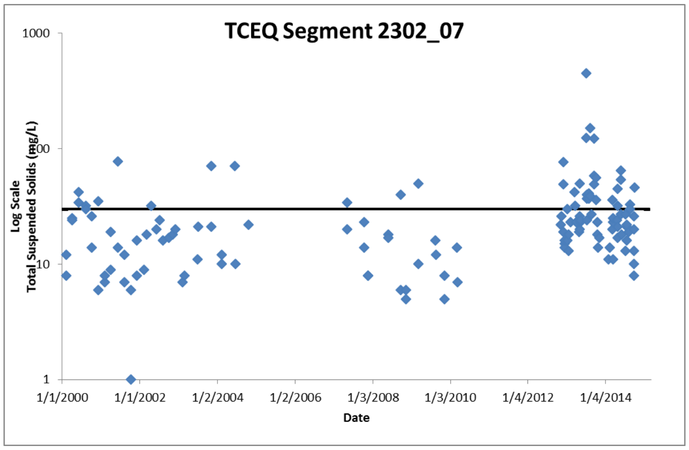




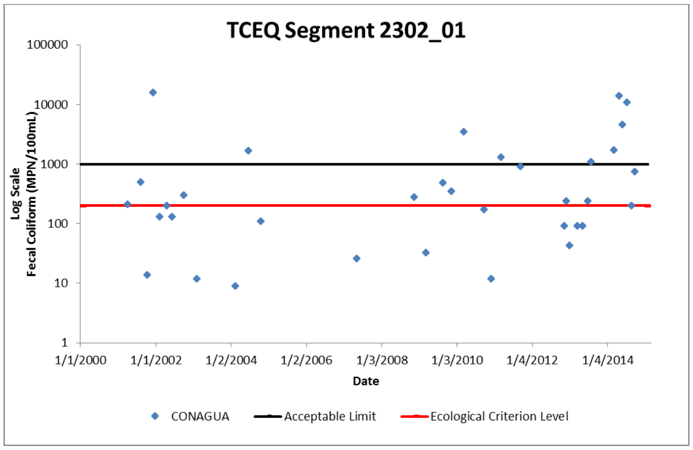


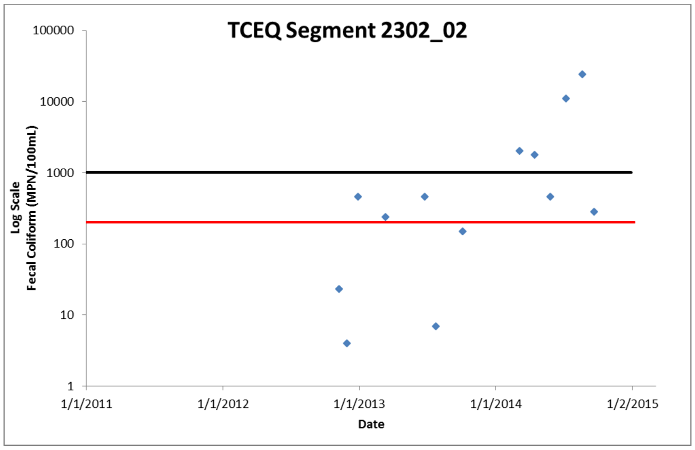


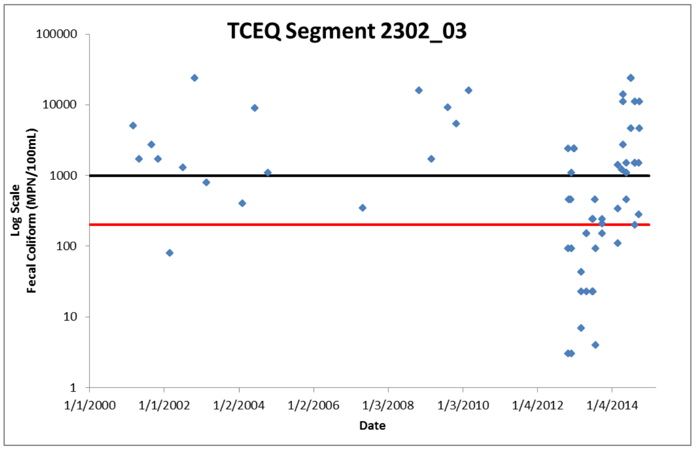


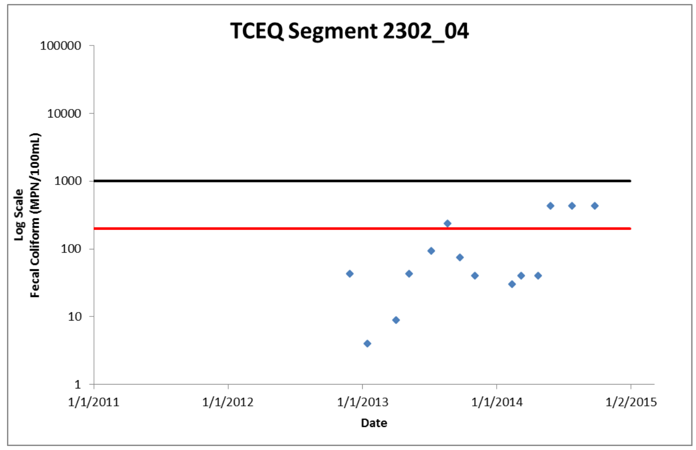


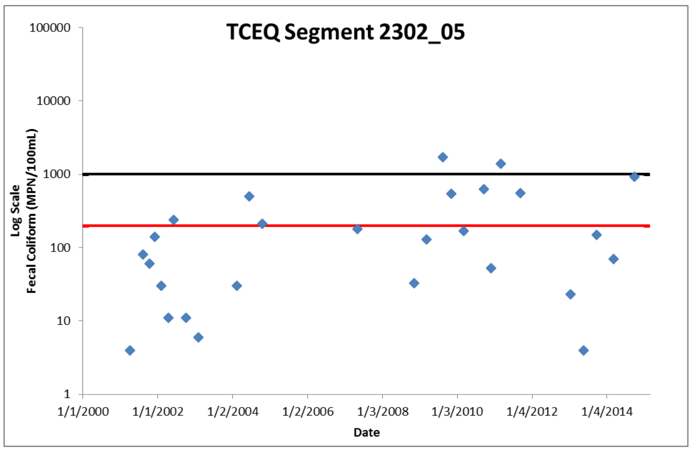
Fecal Coliform

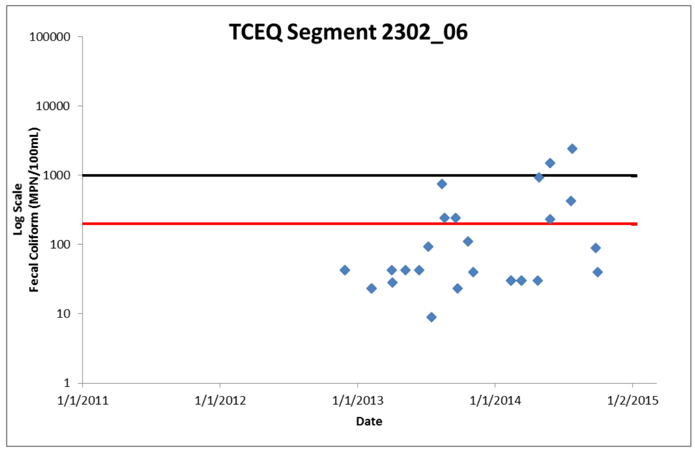


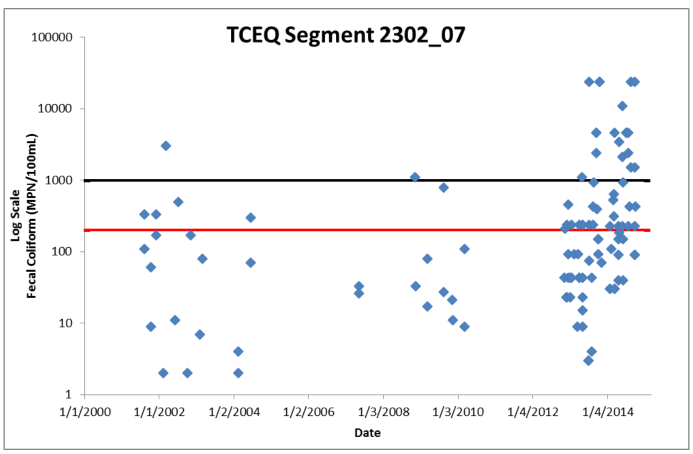



TCEQ Segment 2302_03
Log Scale
Fecal Coliform (MPN/100mL)
100000
10000
1000
100
10
1
1/1/2000
1/1/2002
1/2/2004
1/2/2006
1/3/2008
1/3/2010
1/4/2012
1/4/2014
Date


TCEQ Segment 2302_04
Log Scale
Fecal Coliform (MPN/100mL)
100000
10000
1000
100
10
1
1/1/2011
1/1/2012
1/1/2013
1/1/2014
1/2/2015
Date


TCEQ Segment 2302_05
Log Scale
Fecal Coliform (MPN/100mL)
100000
10000
1000
100
10
1
1/1/2000
1/1/2002
1/2/2004
1/2/2006
1/3/2008
1/3/2010
1/4/2012
1/4/2014
Date


TCEQ Segment 2302_06
Log Scale
Fecal Coliform (MPN/100mL)
100000
10000
1000
100
10
1
1/1/2011
1/1/2012
1/1/2013
1/1/2014
1/2/2015
Date


TCEQ Segment 2302_07
Log Scale
Fecal Coliform (MPN/100mL)
100000
10000
1000
100
10
1
1/1/2000
1/1/2002
1/2/2004
1/2/2006
1/3/2008
1/3/2010
1/4/2012
1/4/2014
Date

Tables of Descriptive Statistics (Mexican Historical Water Quality Data)

Data Range: 2000-2014 (some years contain data gaps for some parameters). All Data was obtained from CONAGUA (Red Nacional de Monitoreo de Calidad del Agua). The "Percent of samples…" column values are based on criteria specified in Mexico's Ley Federal de Derechos: Disposiciones Applicables en Materia de Aguas Nacionales 2016. The Ecological Criterion Level is based on Mexico's Criterios Ecológicos de Calidad del Agua CE-CCA-001/89: Diario Oficial de la Federación, Miércoles 13 de diciembre de 1989 (CE-CCA-00189RecuadroIII.2.2.1).

Dissolved Oxygen

TCEQ Segment	No. of Samples	Minimum (mg/L)	Maximum (mg/L)	Average (mg/L)	Standard Deviation	Percent of samples < 5 mg/L
2302_01	50	4.7	11.59	7.85	1.57	2.00
2302_02	15	6.58	12.69	8.88	1.56	0.00
2302_03	83	3.38	12.86	8.11	1.53	2.41
2302_04	14	6.11	9.26	8.06	1.08	0.00
2302_05	37	4	12	7.65	1.73	5.41
2302_06	28	5.98	11.22	8.31	1.40	0.00
2302_07	142	4	12.28	8.10	1.53	2.82

Biochemical Oxygen Demand

TCEQ Segment	No. of Samples	Minimum (mg/L)	Maximum (mg/L)	Average (mg/L)	Standard Deviation	Percent of samples > 30 mg/L
2302_01	36	1	9.69	3.39	2.45	0.00
2302_03	29	1	9.13	3.22	2.36	0.00
2302_05	36	0.15	12.4	3.30	2.76	0.00
2302_07	62	0.52	10.73	3.09	2.16	0.00

Nitrate

TCEQ Segment	No. of Samples	Minimum (mg/L)	Maximum (mg/L)	Average (mg/L)	Standard Deviation	Percent of samples > 5 mg/L
2302_01	14	0.016	0.863	0.28	0.26	0.00
2302_02	11	0.06	1.19	0.41	0.35	0.00
2302_03	41	0.009	1.017	0.27	0.26	0.00
2302_04	14	0.025	0.4	0.12	0.10	0.00
2302_05	9	0.0294	0.49	0.15	0.14	0.00
2302_06	27	0.008	0.6548	0.16	0.19	0.00
2302_07	82	0.0101	1	0.15	0.16	0.00

Total Phosphorus

TCEQ Segment	No. of Samples	Minimum (mg/L)	Maximum (mg/L)	Average (mg/L)	Standard Deviation	Percent of samples > 0.05 mg/L
2302_01	38	0.0158	0.782	0.30	0.16	97.37
2302_02	10	0.0392	0.762	0.27	0.25	90.00
2302_03	58	0.0184	2.321	0.28	0.43	84.48
2302_04	13	0.025	0.83	0.19	0.27	76.92
2302_05	32	0.013	0.619	0.18	0.14	81.25
2302_06	28	0.014	0.486	0.11	0.08	92.86
2302_07	119	0.018	1.648	0.14	0.18	73.95

Chloride

TCEQ Segment	No. of Samples	Minimum (mg/L)	Maximum (mg/L)	Average (mg/L)	Standard Deviation	Percent of samples > 150 mg/L
2302_01	40	103	347.1	176.57	51.76	65.00
2302_03	31	56	272	160.53	46.64	54.84
2302_05	40	87	282	153.08	39.65	45.00
2302_07	68	60	244.9	121.40	27.23	14.71

Sulfate

TCEQ Segment	No. of Samples	Minimum (mg/L)	Maximum (mg/L)	Average (mg/L)	Standard Deviation	Percent of samples > 250 mg/L
2302_01	35	125	380	240.29	64.64	42.86
2302_03	31	74	354.31	232.72	58.06	35.48
2302_05	35	111	348.44	222.37	49.19	34.29
2302_07	66	96	305	183.35	38.32	3.03

Total Dissolved Solids

TCEQ Segment	No. of Samples	Minimum (mg/L)	Maximum (mg/L)	Average (mg/L)	Standard Deviation	Percent of samples > 500 mg/L
2302_01	53	552	1618.56	852.09	211.01	100
2302_02	15	603.52	1393.6	789.66	183.90	100
2302_03	83	314	2278.4	793.35	253.61	97.59
2302_04	14	467.84	1029.12	650.97	156.93	78.57
2302_05	43	442.88	1184	734.56	155.33	95.35
2302_06	28	378.24	1018.88	640.84	128.49	89.29
2302_07	145	314.88	41440.8	894.35	3392.02	88.28

Total Suspended Solids

TCEQ Segment	No. of Samples	Minimum (mg/L)	Maximum (mg/L)	Average (mg/L)	Standard Deviation	Percent of samples > 30 mg/L
2302_01	51	2	760	48.71	106.77	45.10
2302_02	14	6	630	146.57	177.84	78.57
2302_03	83	6	507	58.76	73.81	57.83
2302_04	13	14	63	28.08	12.75	38.46
2302_05	43	2	108	18.88	18.07	11.63
2302_06	28	13	76	40.43	15.93	67.86
2302_07	137	1	448	29.07	42.32	26.28

Fecal Coliform

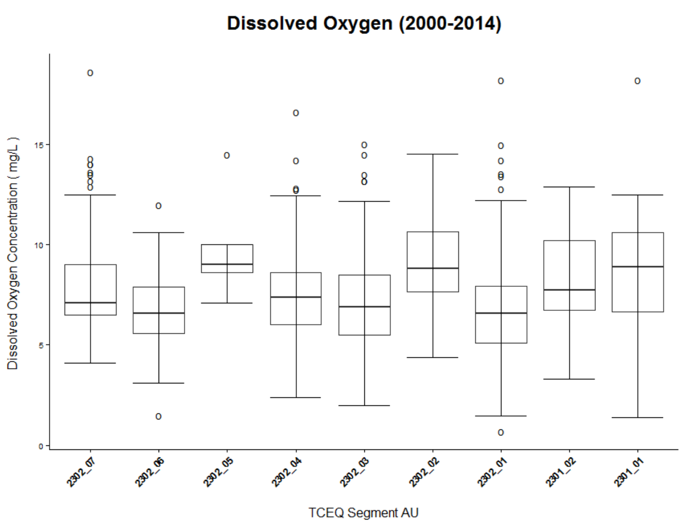
TCEQ Segment	No. of Samples	Minimum (MPN/ 100mL)	Maximum (MPN/ 100mL)	Average (MPN/ 100mL)	Standard Deviation	Percent of samples > 200 MPN/100mL
2302_01	35	9	16000	1734.51	3896.56	54.29
2302_02	13	4	24000	3147.92	6930.44	69.23
2302_03	67	3	24000	3788.12	6457.08	73.13
2302_04	14	4	430	139.07	167.63	28.57
2302_05	27	4	1700	291.98	433.98	33.33
2302_06	28	9	2400	270.14	537.32	28.57
2302_07	110	2	24000	1737.23	5109.20	43.64

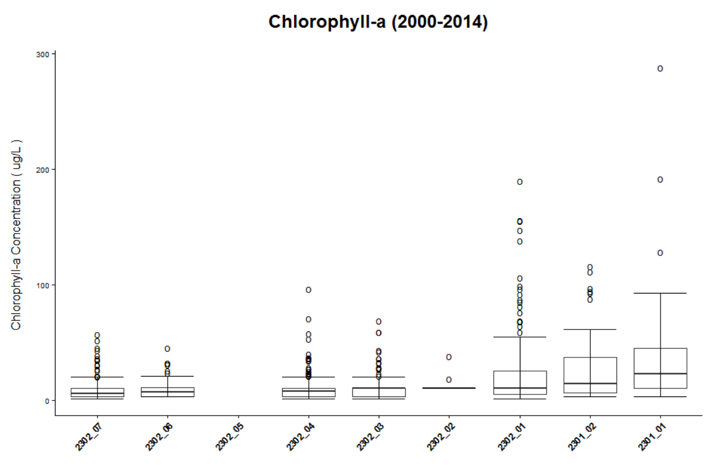
Appendix D

Boxplots of US and Mexican historical water quality data collected in the Lower Rio Grande/Río Bravo.

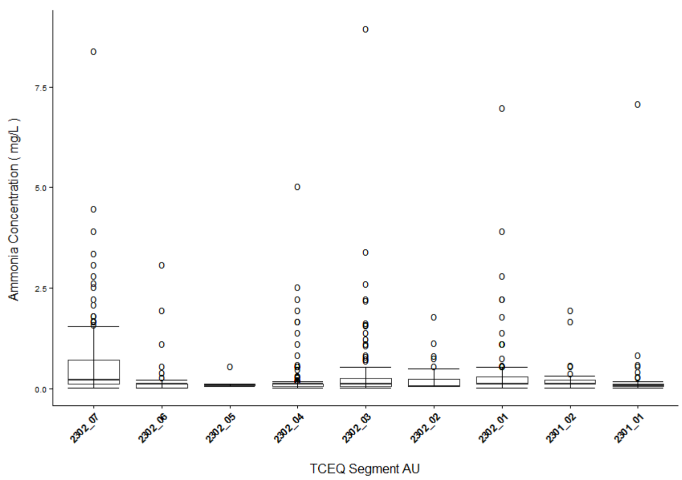
Boxplots of US Historical Water Quality Data

Data range: 2000-2014 (some years contain data gaps). All data was obtained from the TCEQ's SWQMIS database.

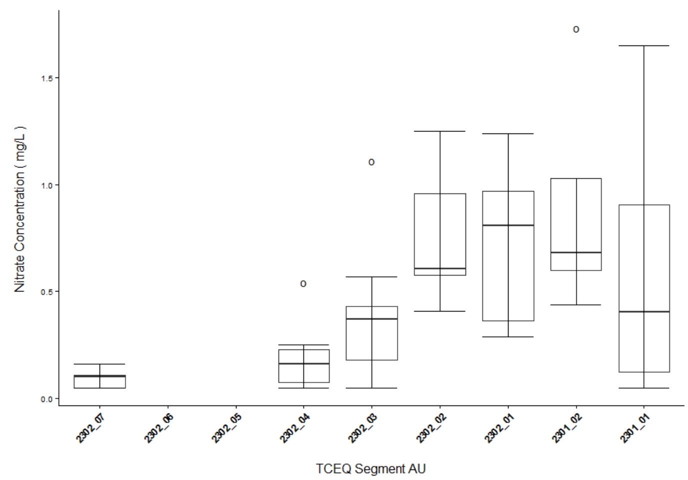




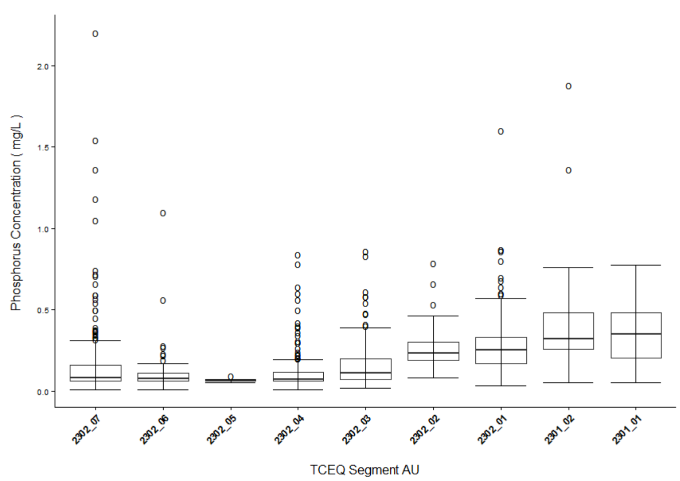
Ammonia (2000-2014)



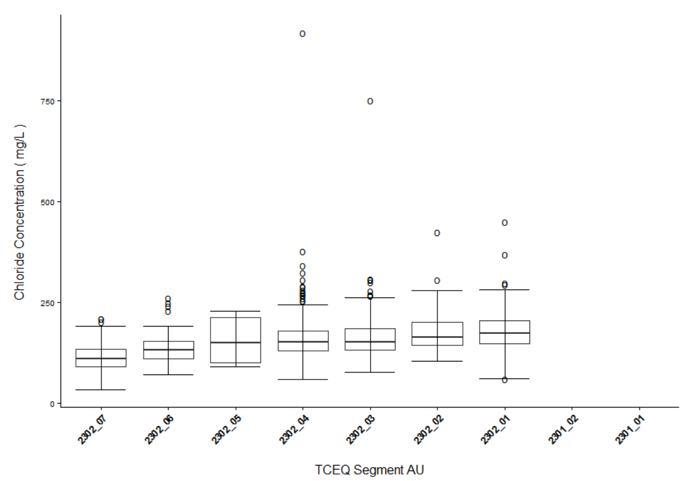
Nitrate (2000-2014)



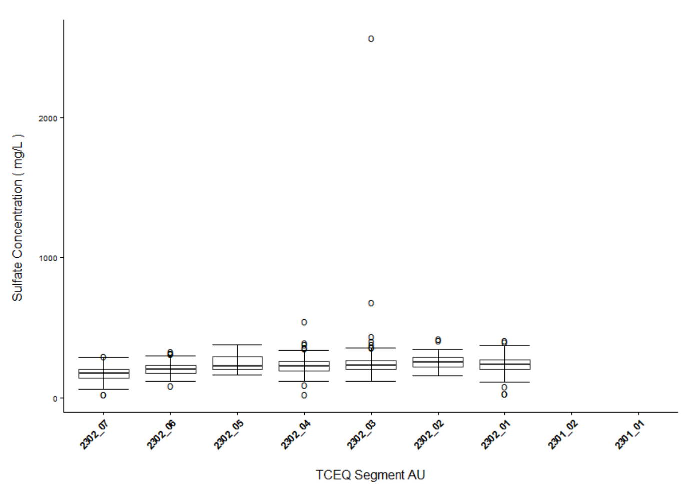
Phosphorus (2000-2014)

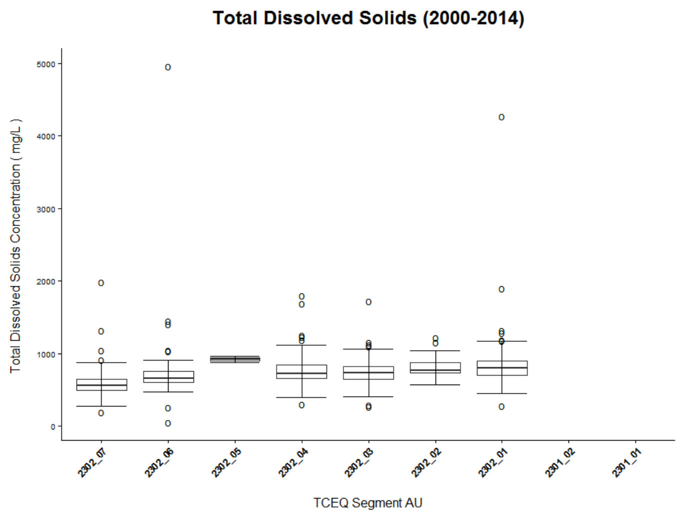


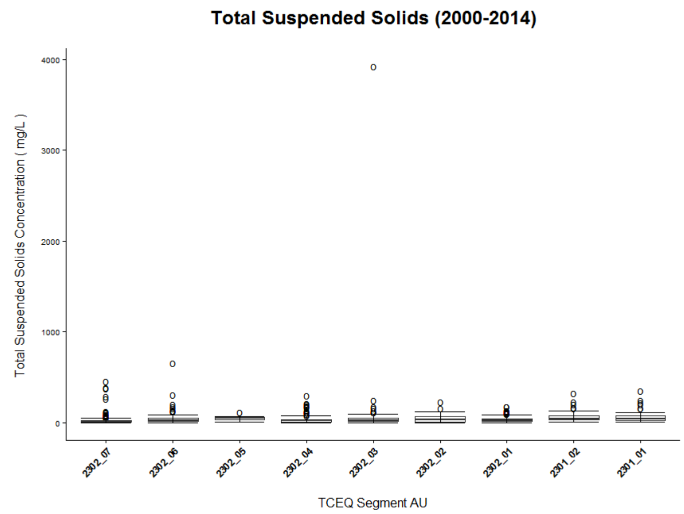
Chloride (2000-2014)

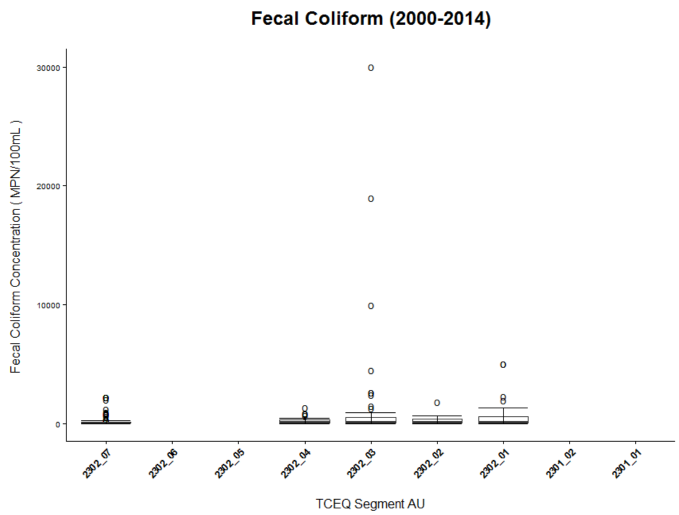


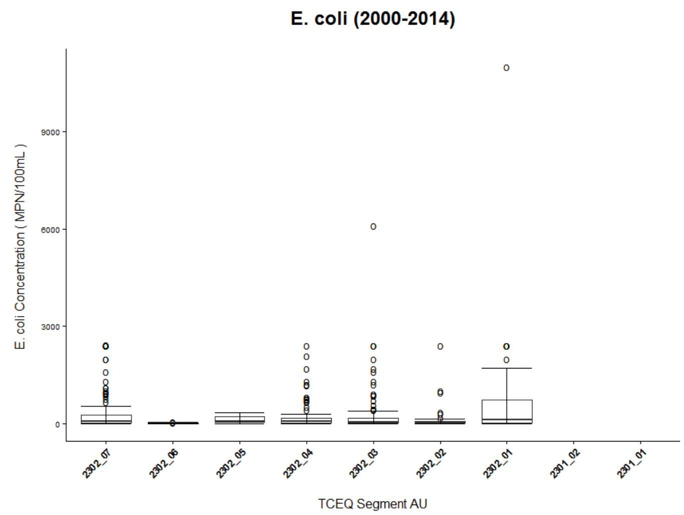
Sulfate (2000-2014)

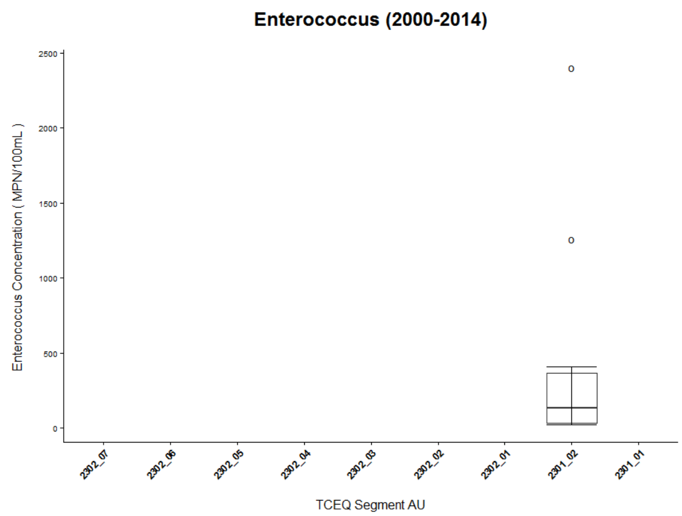



Total Dissolved Solids (2000-2014)
Total Dissolved Solids Concentration (mg/L)
0
1000
2000
3000
4000
5000
2302_07
2302_06
2302_05
2302_04
2302_03
2302_02
2302_01
2301_02
2301_01
TCEQ Segment AU

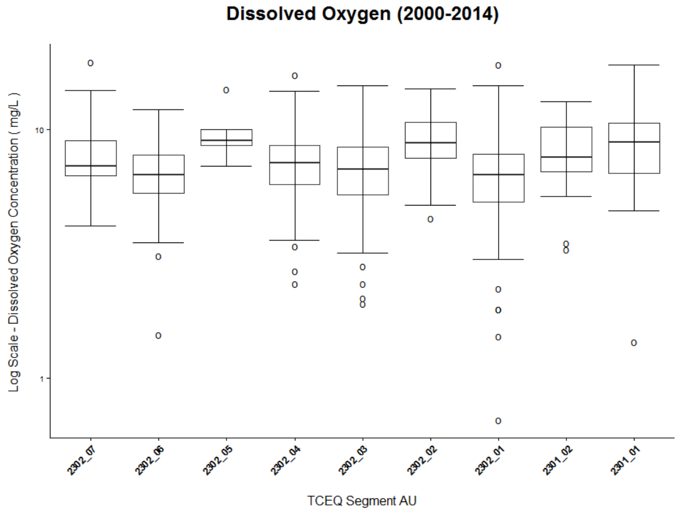

Total Suspended Solids (2000-2014)
Total Suspended Solids Concentration (mg/L)
0
1000
2000
3000
4000
2302_07
2302_06
2302_05
2302_04
2302_03
2302_02
2302_01
2301_02
2301_01
TCEQ Segment AU

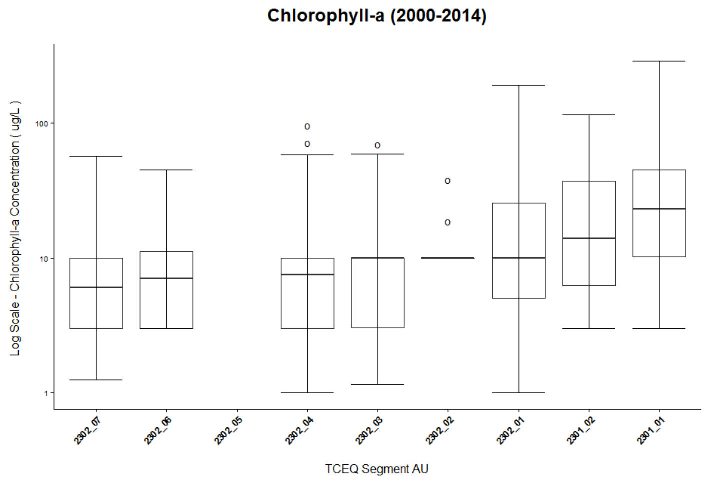

Fecal Coliform (2000-2014)
Fecal Coliform Concentration (MPN/100mL)
0
10000
20000
30000
2302_07
2302_06
2302_05
2302_04
2302_03
2302_02
2302_01
2301_02
2301_01
TCEQ Segment AU

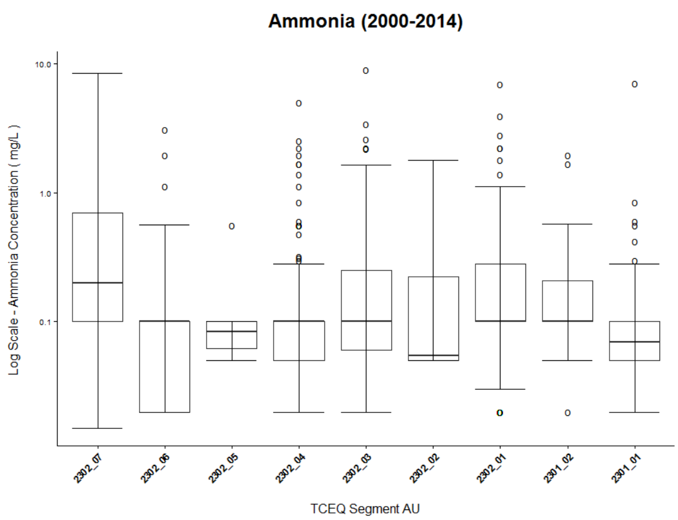

E. coli (2000-2014)
E. coli Concentration (MPN/100mL)
0
3000
6000
9000
2302_07
2302_06
2302_05
2302_04
2302_03
2302_02
2302_01
2301_02
2301_01
TCEQ Segment AU

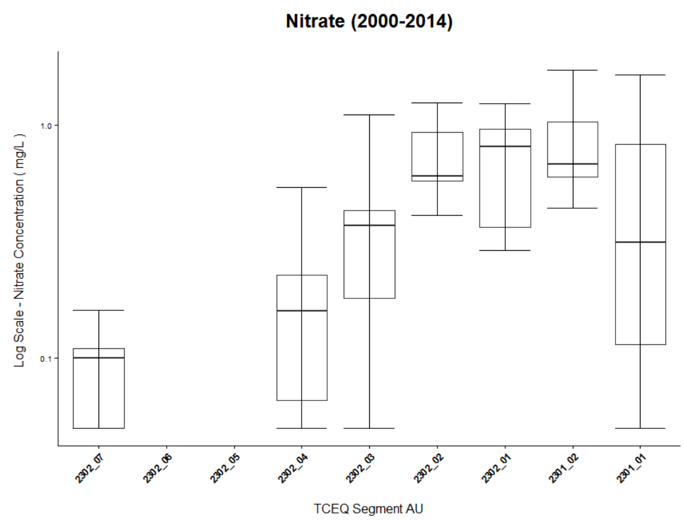

Enterococcus (2000-2014)
Enterococcus Concentration (MPN/100mL)
0
500
1000
1500
2000
2500
2302_07
2302_06
2302_05
2302_04
2302_03
2302_02
2302_01
2301_02
2301_01
TCEQ Segment AU

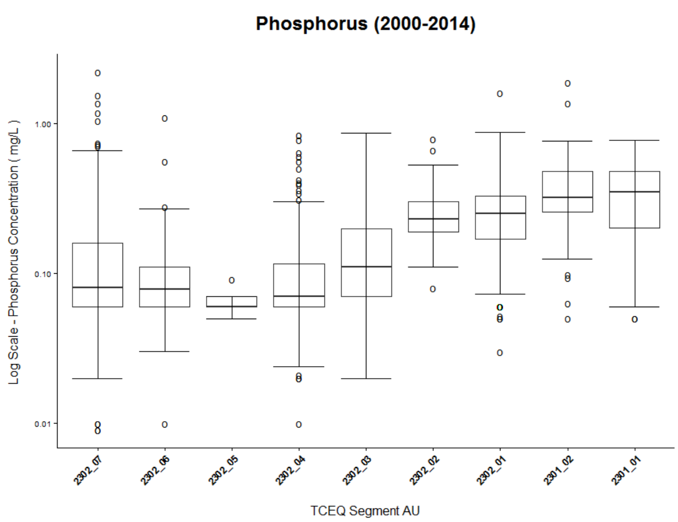
LOG SCALE

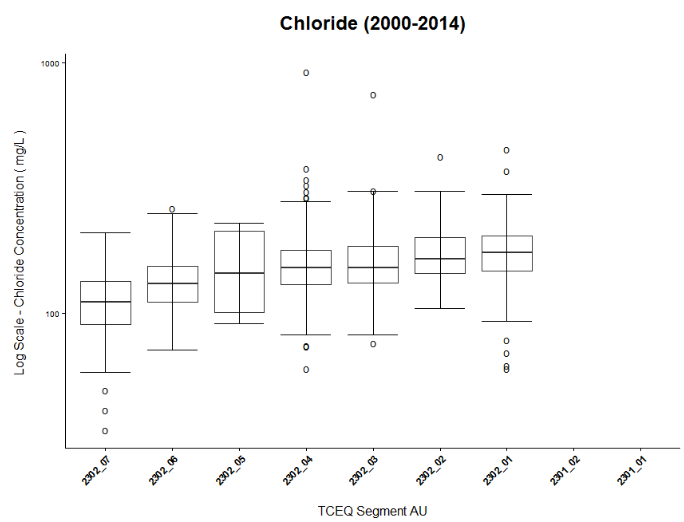

Dissolved Oxygen (2000-2014)
Log Scale - Dissolved Oxygen Concentration (mg/L)
10
1
2302_07
2302_06
2302_05
2302_04
2302_03
2302_02
2302_01
2301_02
2301_01
TCEQ Segment AU

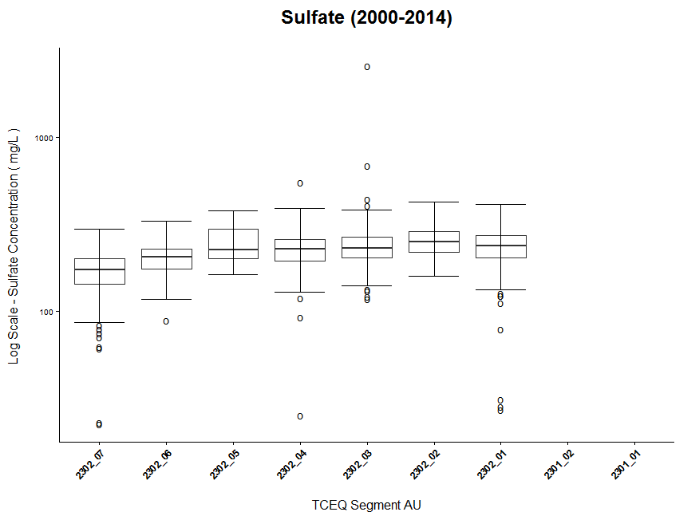

Chlorophyll-a (2000-2014)
Log Scale - Chlorophyll-a Concentration (ug/L)
100
10
1
2302_07
2302_06
2302_05
2302_04
2302_03
2302_02
2302_01
2301_02
2301_01
TCEQ Segment AU

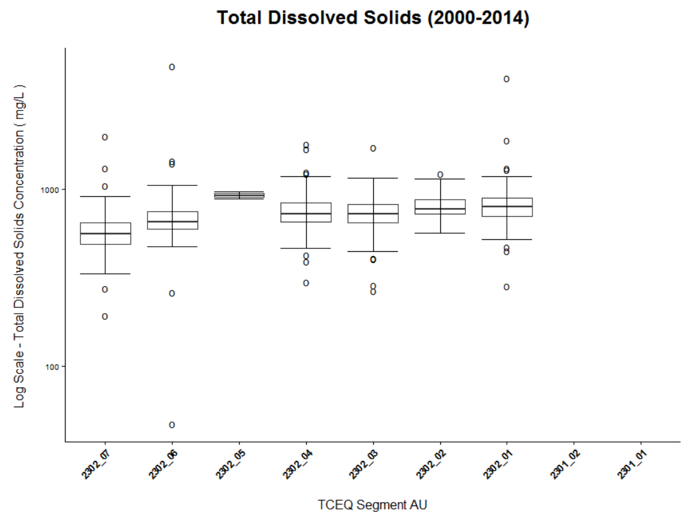

Ammonia (2000-2014)
Log Scale - Ammonia Concentration (mg/L)
10.0
1.0
0.1
2302_07
2302_06
2302_05
2302_04
2302_03
2302_02
2302_01
2301_02
2301_01
TCEQ Segment AU

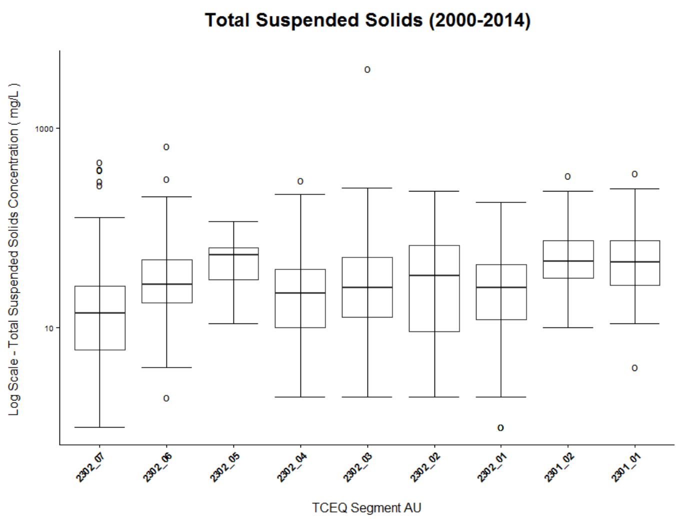

Nitrate (2000-2014)
Log Scale - Nitrate Concentration (mg/L)
1.0
0.1
2302_07
2302_06
2302_05
2302_04
2302_03
2302_02
2302_01
2301_02
2301_01
TCEQ Segment AU

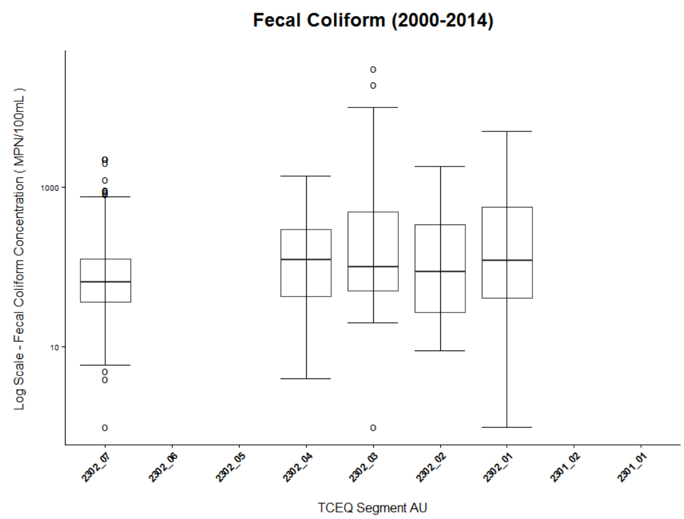

Phosphorus (2000-2014)
Log Scale - Phosphorus Concentration (mg/L)
1.00
0.10
0.01
2302_07
2302_06
2302_05
2302_04
2302_03
2302_02
2302_01
2301_02
2301_01
TCEQ Segment AU

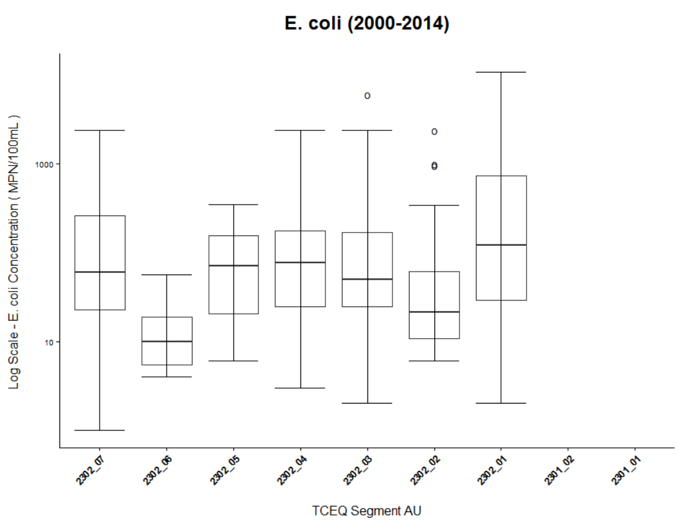

Chloride (2000-2014)
Log Scale - Chloride Concentration (mg/L)
1000
100
2302_07
2302_06
2302_05
2302_04
2302_03
2302_02
2302_01
2301_02
2301_01
TCEQ Segment AU

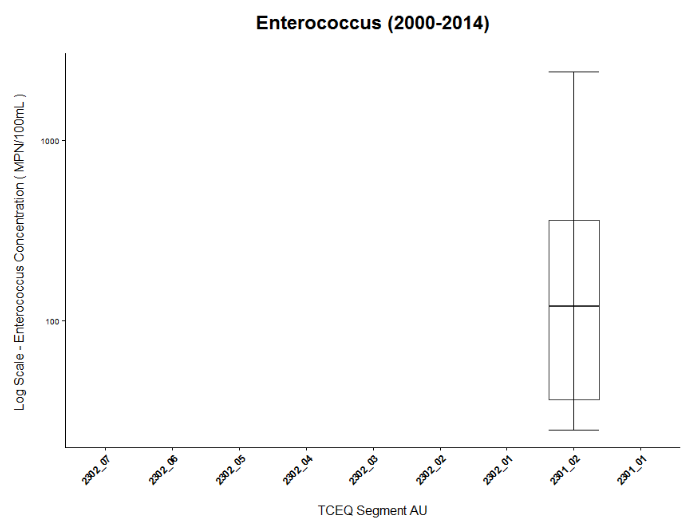

Sulfate (2000-2014)
Log Scale - Sulfate Concentration (mg/L)
1000
100
2302_07
2302_06
2302_05
2302_04
2302_03
2302_02
2302_01
2301_02
2301_01
TCEQ Segment AU


Total Dissolved Solids (2000-2014)
Log Scale - Total Dissolved Solids Concentration (mg/L)
1000
100
2302_07
2302_06
2302_05
2302_04
2302_03
2302_02
2302_01
2301_02
2301_01
TCEQ Segment AU


Total Suspended Solids (2000-2014)
Log Scale - Total Suspended Solids Concentration (mg/L)
1000
10
2302_07
2302_06
2302_05
2302_04
2302_03
2302_02
2302_01
2301_02
2301_01
TCEQ Segment AU

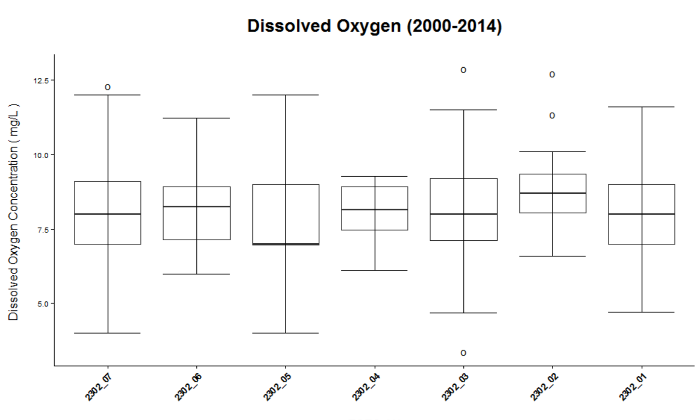

Fecal Coliform (2000-2014)
Log Scale - Fecal Coliform Concentration (MPN/100mL)
1000
10
2302_07
2302_06
2302_05
2302_04
2302_03
2302_02
2302_01
2301_02
2301_01
TCEQ Segment AU

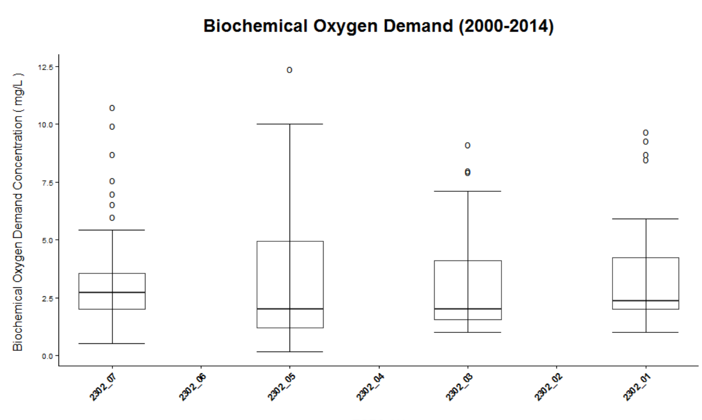

E. coli (2000-2014)
Log Scale - E. coli Concentration (MPN/100mL)
1000
10
2302_07
2302_06
2302_05
2302_04
2302_03
2302_02
2302_01
2301_02
2301_01
TCEQ Segment AU

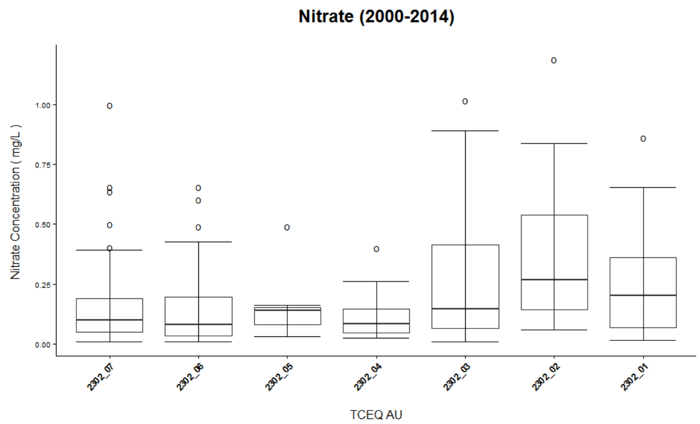

Enterococcus (2000-2014)
Log Scale - Enterococcus Concentration (MPN/100mL)
1000
100
2302_07
2302_06
2302_05
2302_04
2302_03
2302_02
2302_01
2301_02
2301_01
TCEQ Segment AU

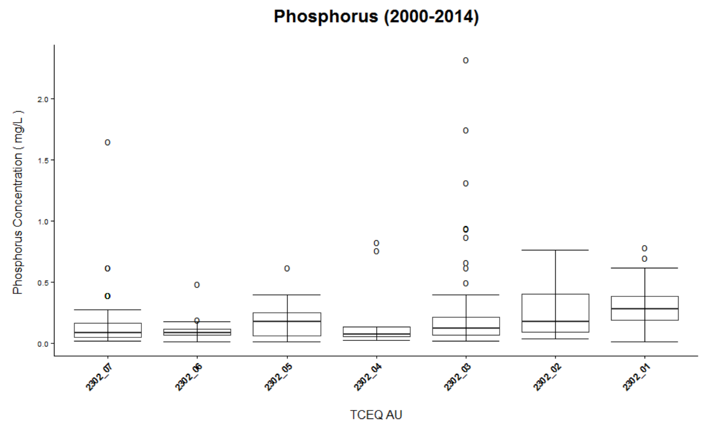
Boxplots of Mexican Historical Water Quality Data

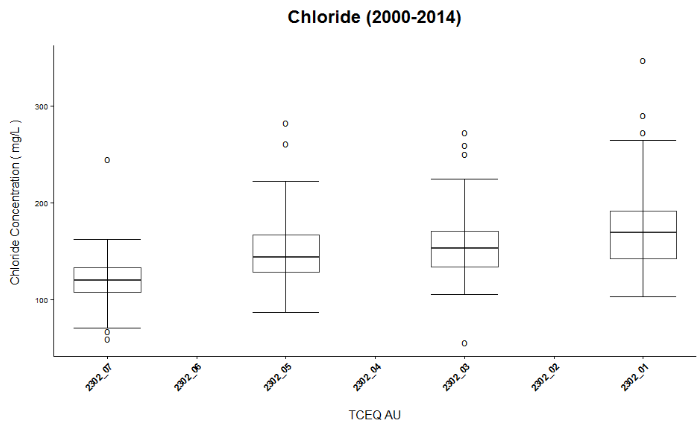
Data range: 2000-2014 (some years contain data gaps for some parameters). All data was obtained from CONAGUA (Red Nacional de Monitoreo de la Calidad del Agua).

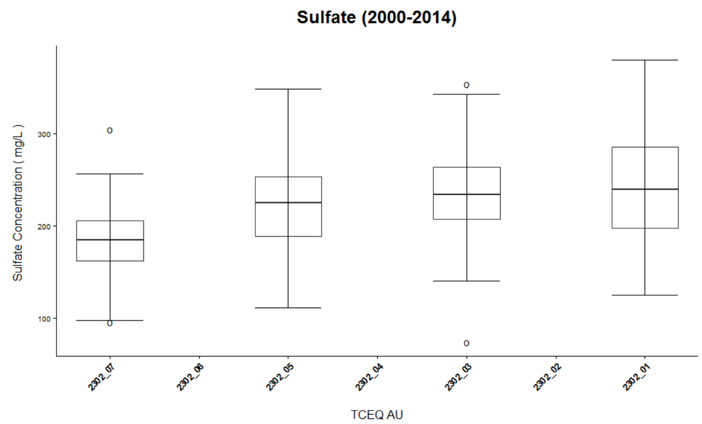


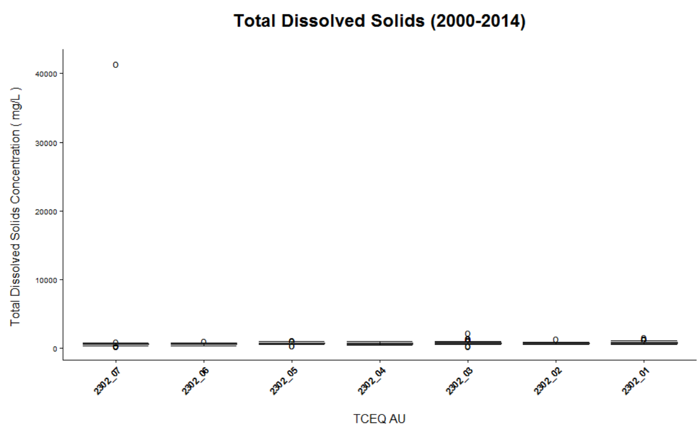


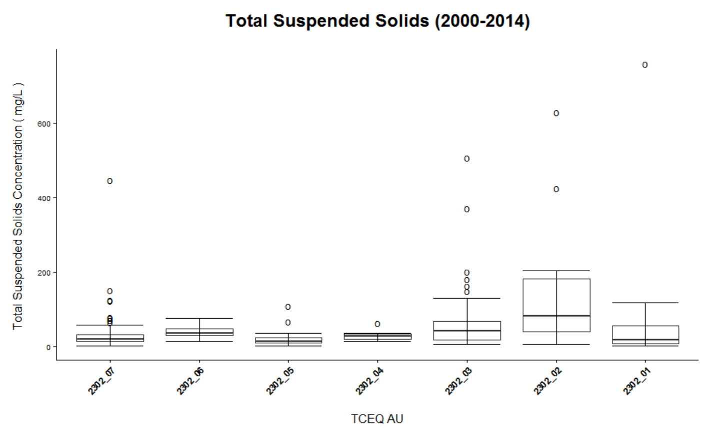

Nitrate (2000-2014)
Nitrate Concentration (mg/L)
0.00
0.25
0.50
0.75
1.00
2302_07
2302_06
2302_05
2302_04
2302_03
2302_02
2302_01
TCEQ AU

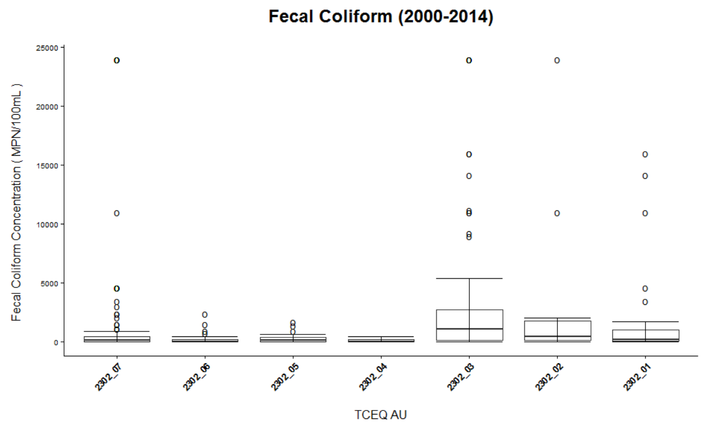

Phosphorus (2000-2014)
Phosphorus Concentration (mg/L)
0.0
0.5
1.0
1.5
2.0
2302_07
2302_06
2302_05
2302_04
2302_03
2302_02
2302_01
TCEQ AU


Chloride (2000-2014)
Chloride Concentration (mg/L)
100
200
300
2302_07
2302_06
2302_05
2302_04
2302_03
2302_02
2302_01
TCEQ AU

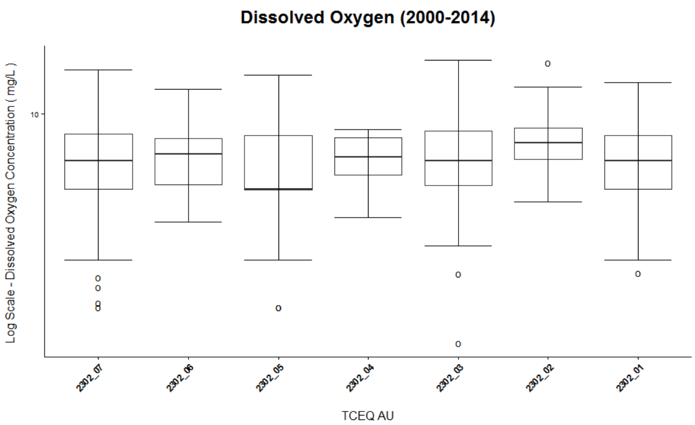

Sulfate (2000-2014)
Sulfate Concentration (mg/L)
100
200
300
2302_07
2302_06
2302_05
2302_04
2302_03
2302_02
2302_01
TCEQ AU

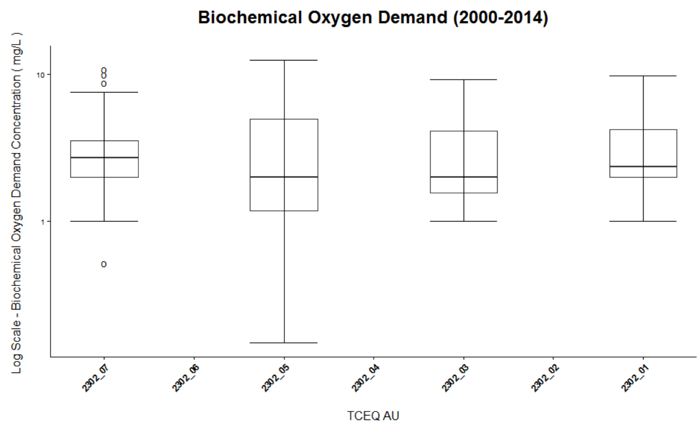

Total Dissolved Solids (2000-2014)
Total Dissolved Solids Concentration (mg/L)
0
10000
20000
30000
40000
2302_07
2302_06
2302_05
2302_04
2302_03
2302_02
2302_01
TCEQ AU

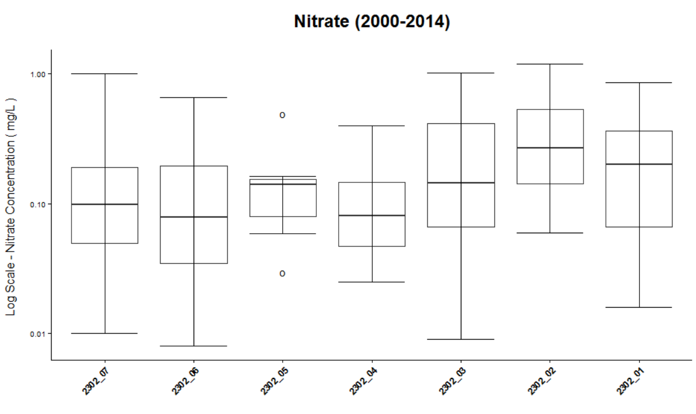

Total Suspended Solids (2000-2014)
Total Suspended Solids Concentration (mg/L)
0
200
400
600
2302_07
2302_06
2302_05
2302_04
2302_03
2302_02
2302_01
TCEQ AU

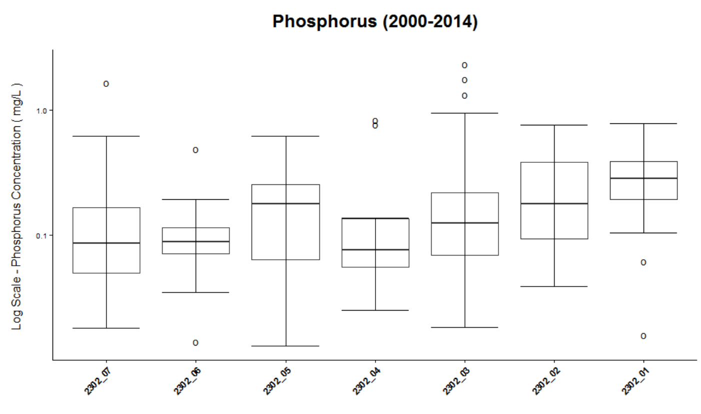

Fecal Coliform (2000-2014)
Fecal Coliform Concentration (MPN/100mL)
25000
20000
15000
10000
5000
0
2302_07
2302_06
2302_05
2302_04
2302_03
2302_02
2302_01
TCEQ AU

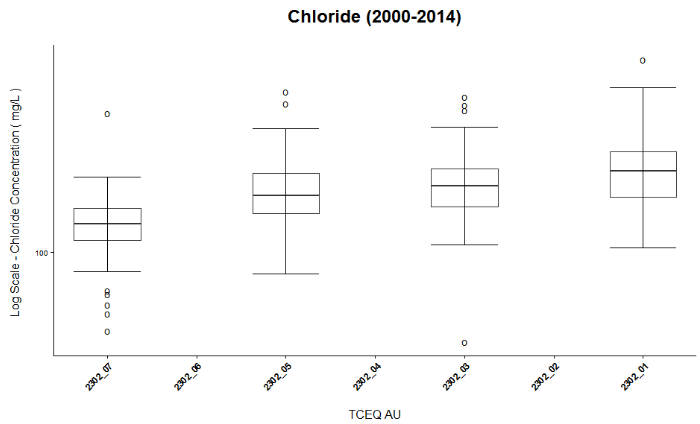
LOG SCALE

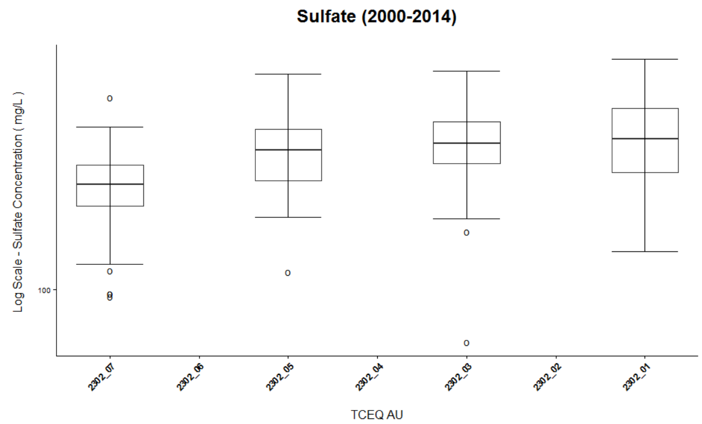

Dissolved Oxygen (2000-2014)
Log Scale - Dissolved Oxygen Concentration (mg/L)
10
2302_07
2302_06
2302_05
2302_04
2302_03
2302_02
2302_01
TCEQ AU

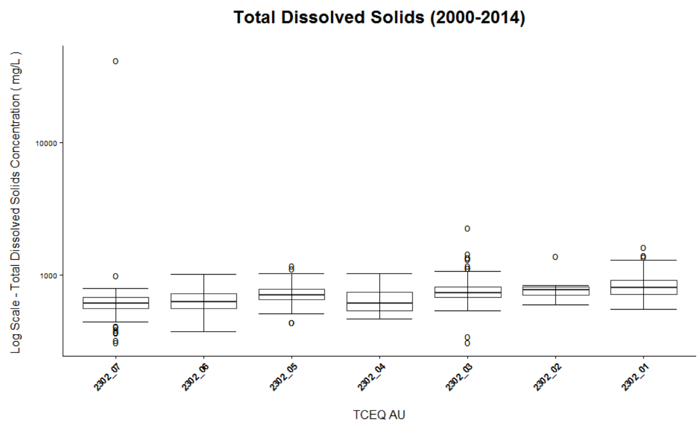

Biochemical Oxygen Demand (2000-2014)
Log Scale - Biochemical Oxygen Demand Concentration (mg/L)
10
1
2302_07
2302_06
2302_05
2302_04
2302_03
2302_02
2302_01
TCEQ AU


Nitrate (2000-2014)
Log Scale - Nitrate Concentration (mg/L)
1.00
0.10
0.01
2302_07
2302_06
2302_05
2302_04
2302_03
2302_02
2302_01
TCEQ AU

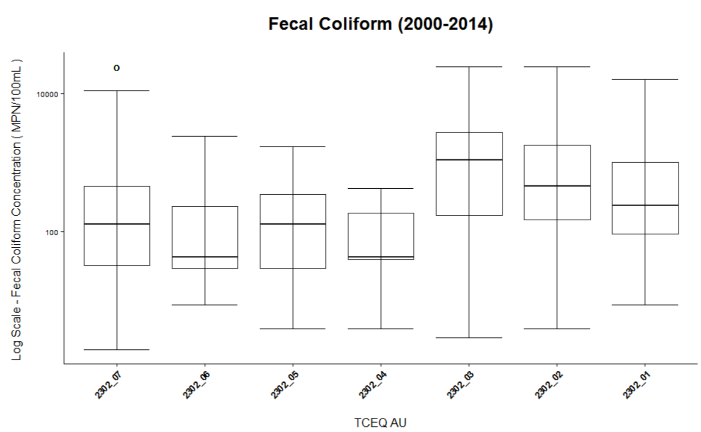

Phosphorus (2000-2014)
Log Scale - Phosphorus Concentration (mg/L)
1.0
0.1
2302_07
2302_06
2302_05
2302_04
2302_03
2302_02
2302_01
TCEQ AU


Chloride (2000-2014)
Log Scale - Chloride Concentration (mg/L)
100
2302_07
2302_06
2302_05
2302_04
2302_03
2302_02
2302_01
TCEQ AU


Sulfate (2000-2014)
Log Scale - Sulfate Concentration (mg/L)
100
2302_07
2302_06
2302_05
2302_04
2302_03
2302_02
2302_01
TCEQ AU


Total Dissolved Solids (2000-2014)
Log Scale - Total Dissolved Solids Concentration (mg/L)
10000
1000
2302_07
2302_06
2302_05
2302_04
2302_03
2302_02
2302_01
TCEQ AU


Total Suspended Solids (2000-2014)
Log Scale - Total Suspended Solids Concentration (mg/L)
1000
10
2302_07
2302_06
2302_05
2302_04
2302_03
2302_02
2302_01
TCEQ AU


Fecal Coliform (2000-2014)
Log Scale - Fecal Coliform Concentration (MPN/100mL)
10000
100
2302_07
2302_06
2302_05
2302_04
2302_03
2302_02
2302_01
TCEQ AU

Appendix E

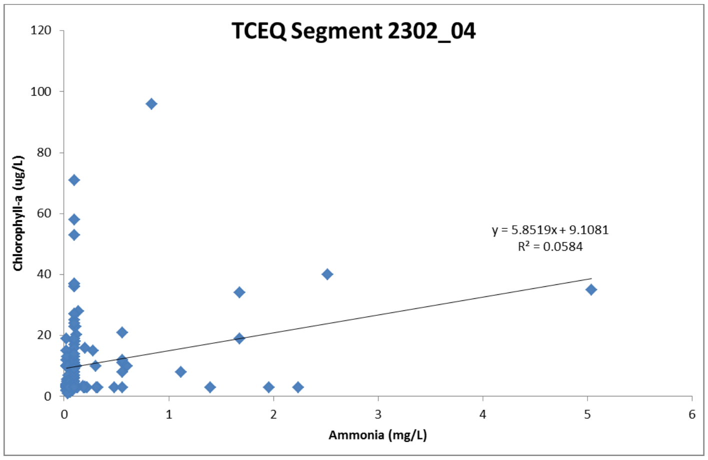
Crossplots of selected parameters from pooled US and Mexican historical water quality data collected in the LRG/RB and associated regression analyses.

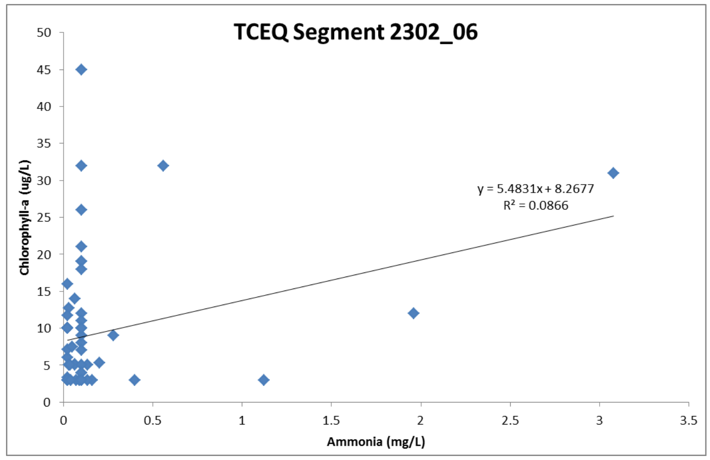
Crossplots of Pooled US and Mexican Historical Water Quality Data and Associated Linear Regressions

Data range: 2000-2014 (some years contain data gaps). US data was obtained from the TCEQ's SWQMIS database. Mexican (MX) data was obtained from CONAGUA (Red Nacional de Monitoreo de Calidad del Agua). Some parameters have data only from US or only from MX. Only data with significant p-values are shown (significance level of 0.05).

Ammonia v. Chlorophyll-a

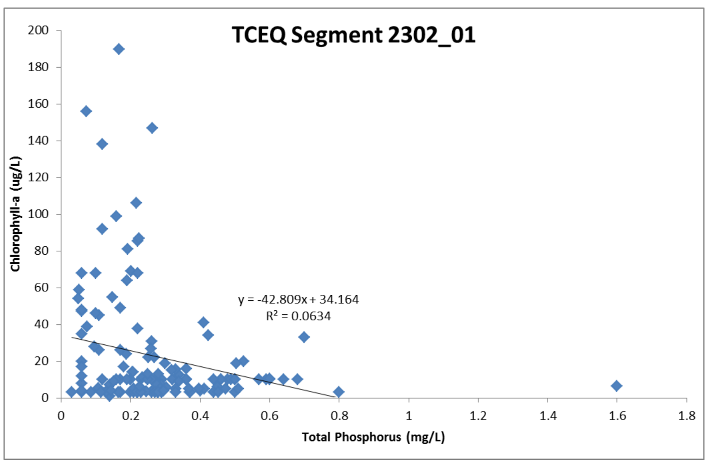
Linear Regression		
AU	**R Squared**	**p-value**
2302_04	0.058 (+)	0.0008
2302_06	0.087 (+)	0.0156





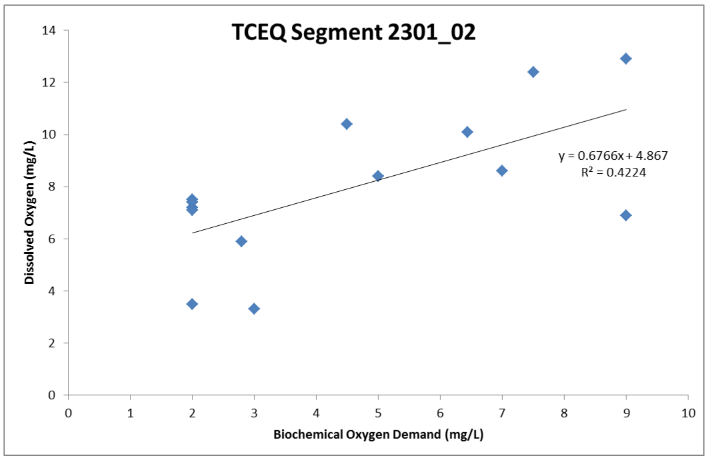
Total Phosphorus v. Chlorophyll-a

Linear Regression		
AU	**R Squared**	**p-value**
2302_01	0.063 (-)	0.0025



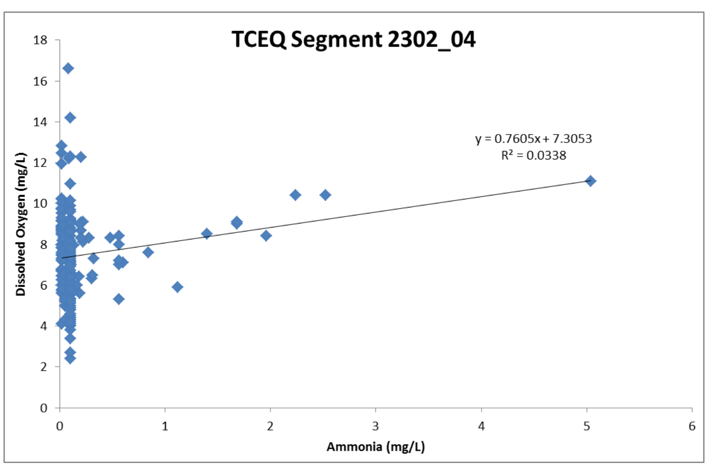
Biochemical Oxygen Demand v. Dissolved Oxygen

Linear Regression		
AU	**R Squared**	**p-value**
2301_02	0.422 (+)	0.0119



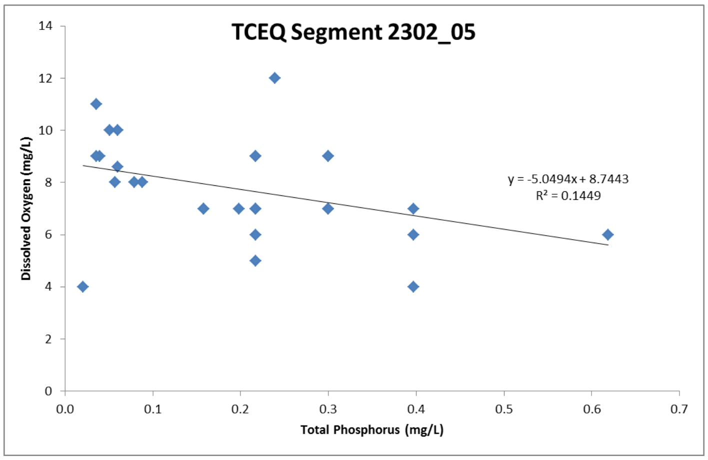
Ammonia v. Dissolved Oxygen

Linear Regression		
AU	**R Squared**	**p-value**
2302_04	0.034 (+)	0.0141



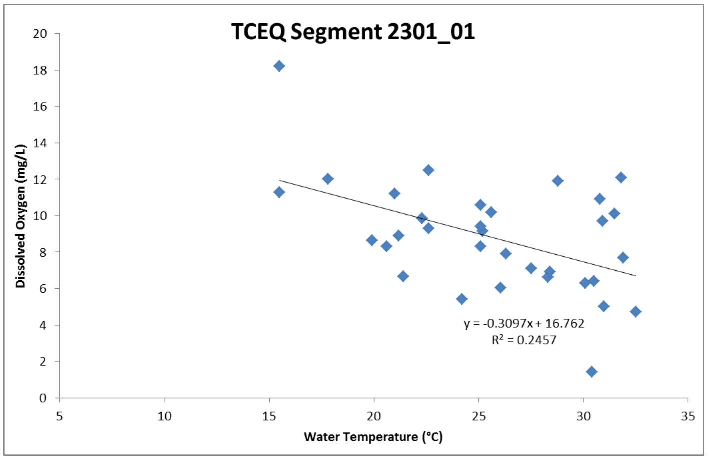
Total Phosphorus v. Dissolved Oxygen

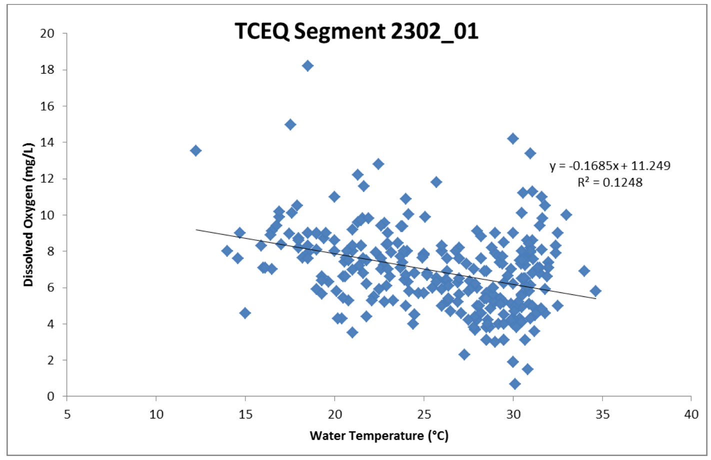
Linear Regression		
AU	**R Squared**	**p-value**
2302_05	0.145 (-)	0.0457

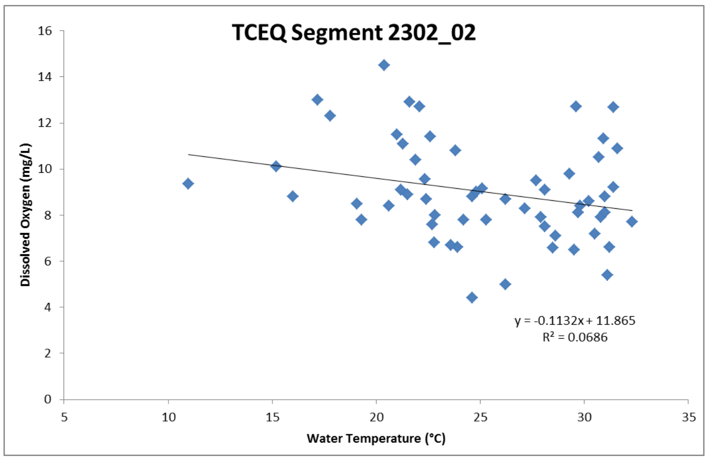


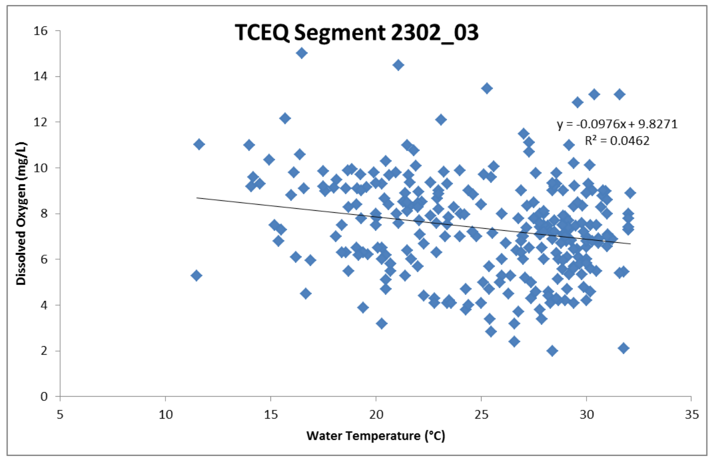
Water Temperature v. Dissolved Oxygen

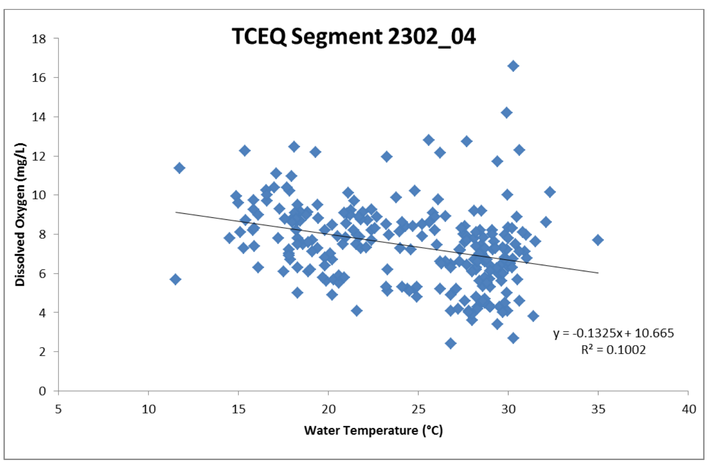
Linear Regression		
AU	**R Squared**	**p-value**
2301_01	0.246 (-)	0.0034
2302_01	0.125 (-)	5.6 E^{-10}
2302_02	0.069 (-)	0.0470
2302_03	0.046 (-)	0.0003
2302_04	0.100 (-)	4.4 E^{-7}
2302_05	0.241 (-)	0.0011
2302_06	0.089 (-)	00016
2302_07	0.167 (-)	2.4 E^{-18}

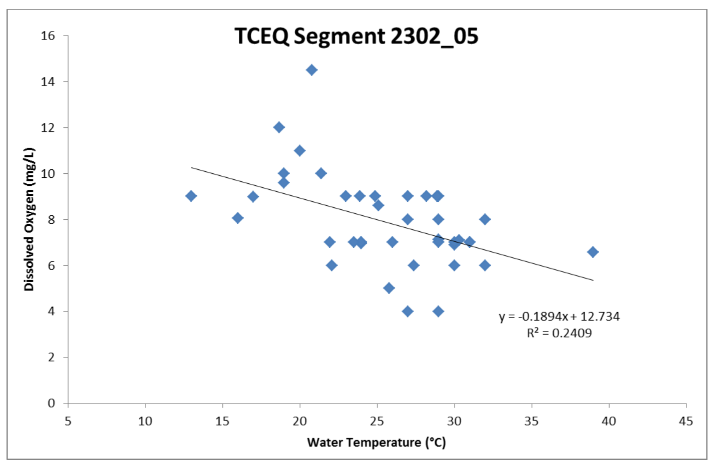

TCEQ Segment 2301_01
Dissolved Oxygen (mg/L)
Water Temperature (°C)
y = -0.3097x + 16.762
R² = 0.2457

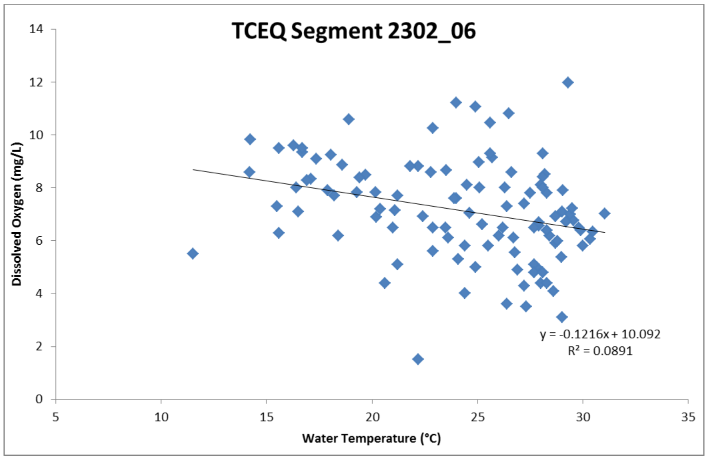

TCEQ Segment 2302_01
Dissolved Oxygen (mg/L)
Water Temperature (°C)
y = -0.1685x + 11.249
R² = 0.1248

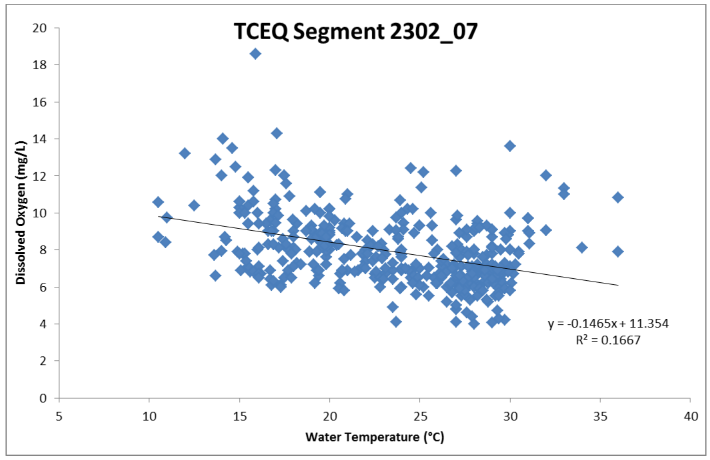

TCEQ Segment 2302_02
Dissolved Oxygen (mg/L)
Water Temperature (°C)
y = -0.1132x + 11.865
R² = 0.0686


TCEQ Segment 2302_03
Dissolved Oxygen (mg/L)
Water Temperature (°C)
y = -0.0976x + 9.8271
R² = 0.0462


TCEQ Segment 2302_04
Dissolved Oxygen (mg/L)
Water Temperature (°C)
y = -0.1325x + 10.665
R² = 0.1002

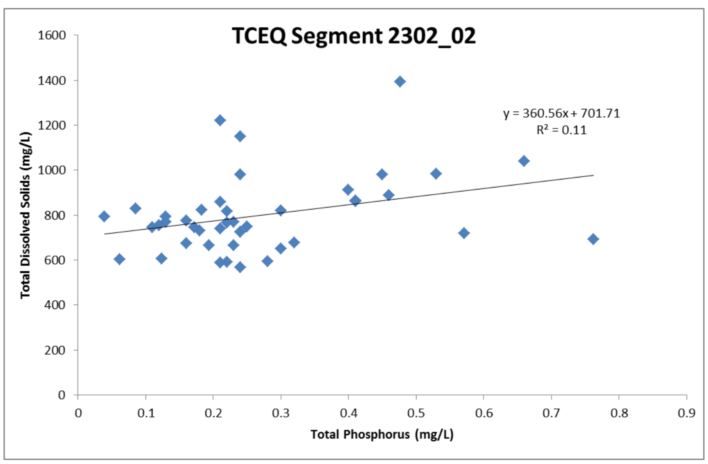

TCEQ Segment 2302_05
Dissolved Oxygen (mg/L)
Water Temperature (°C)
y = -0.1894x + 12.734
R² = 0.2409

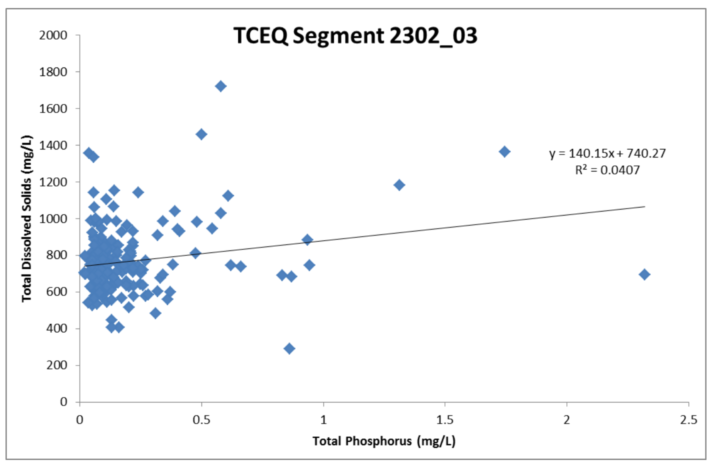




Total Phosphorus v. Total Dissolved Solids

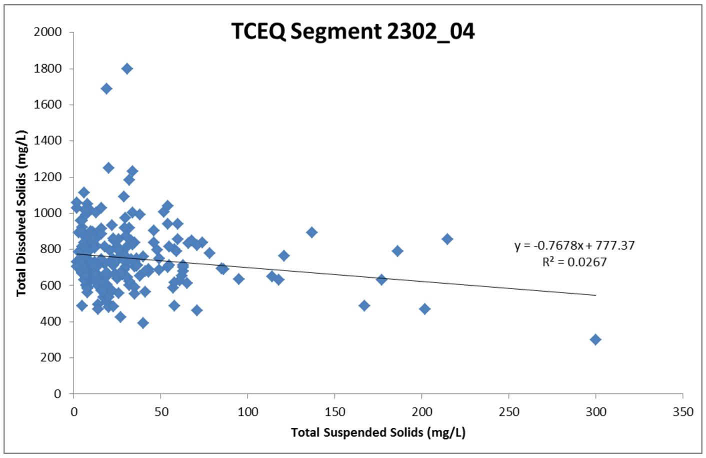
Linear Regression		
AU	R Squared	p-value
2302_02	0.110 (+)	0.0319
2302_03	0.041 (+)	0.0045





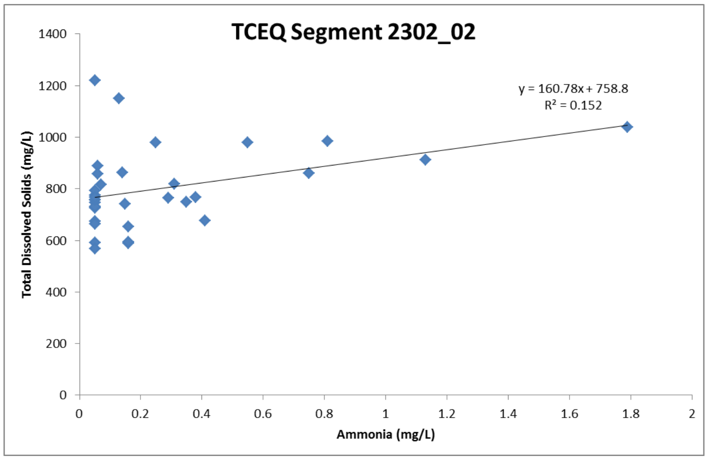
Total Suspended Solids v. Total Dissolved Solids

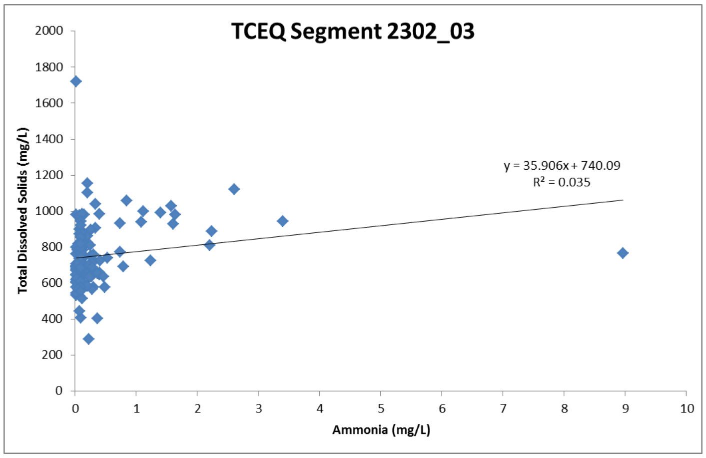
Linear Regression		
AU	**R Squared**	**p-value**
2302_04	0.027 (-)	0.0157

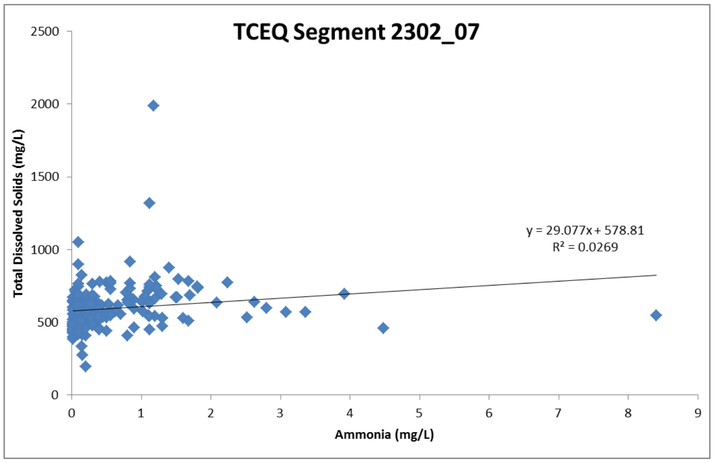


Ammonia v. Total Dissolved Solids

Linear Regression		
AU	**R Squared**	**p-value**
2302_02	0.152 (+)	0.0249
2302_03	0.035 (+)	0.0262
2302_07	0.027 (+)	0.0146

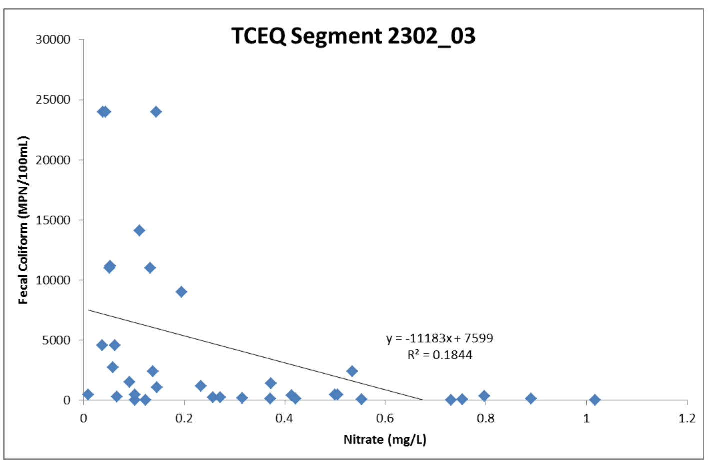






Nitrate v. Fecal Coliform

Linear Regression		
AU	**R Squared**	**p-value**
2302_03	0.184 (+)	0.0090

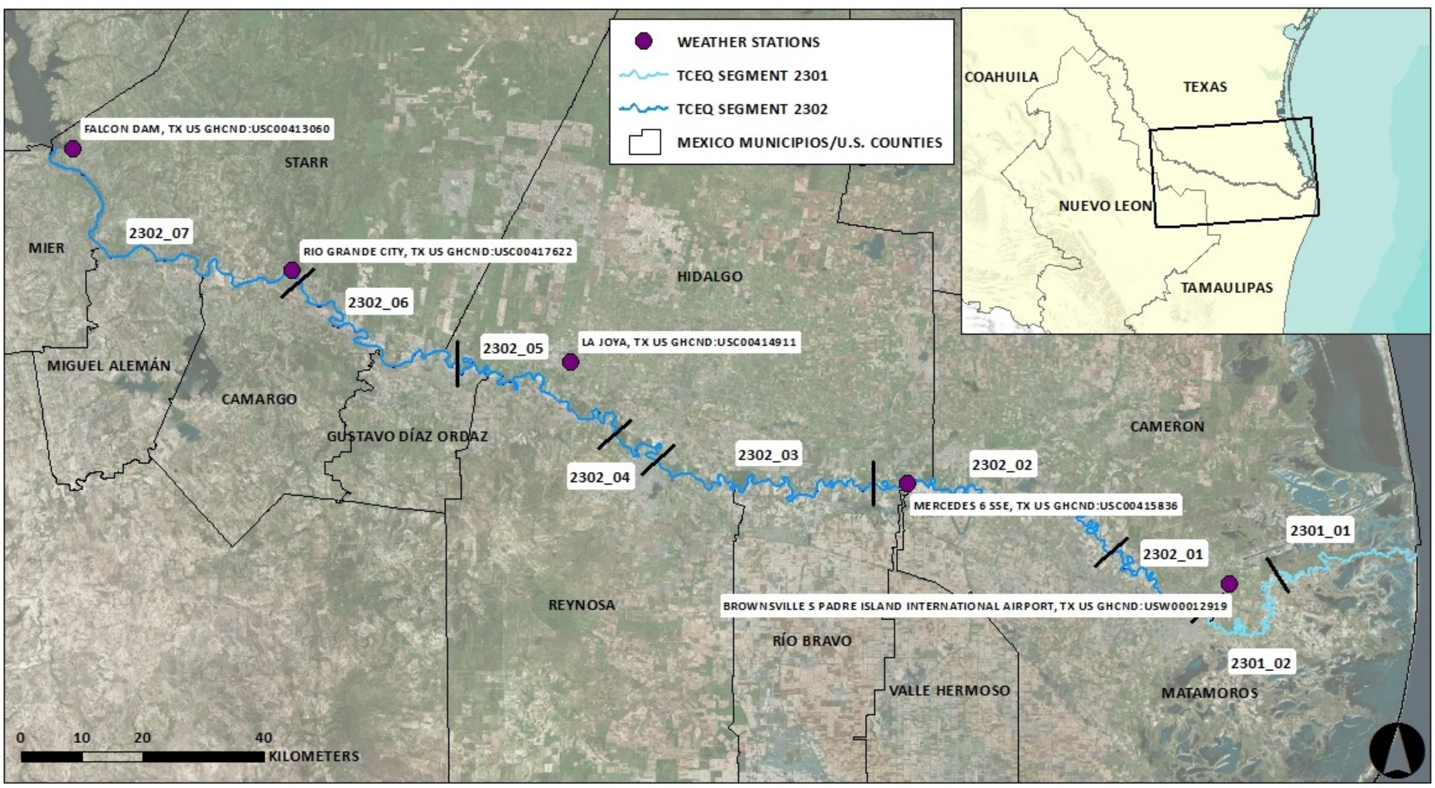


Appendix F

Seasonality analysis, with respect to temperature, of pooled US and Mexican historical water quality.

Boxplots of Pooled US and Mexican Historical Water Quality Plotted with Respect to Seasonality (as Determined by Temporal Differences in Temperature) and Associated ANOVA and Tukey Tests

Data range: 2000-2014 (some years contain data gaps). Plots and analyses are of pooled US and Mexican historical water quality data. All US data were obtained from the TCEQ's SWQMIS database. All Mexican data were obtained from CONAGUA (Red Nacional de Monitoreo de la Calidad del Agua). Due to data gaps, plots and analyses for some parameters include only US data or only Mexican data. Statistically significant results are highlighted (significance level of 0.05). Season-types for each month were determined by seasonal temperature thresholds applied to mean monthly air temperatures recorded at five US NCDC weather stations (see additional on the following page). All temperature data was obtained from NOAA(NCDC) (http://www.ncdc.noaa.gov/cdoweb/datatools/findstation).

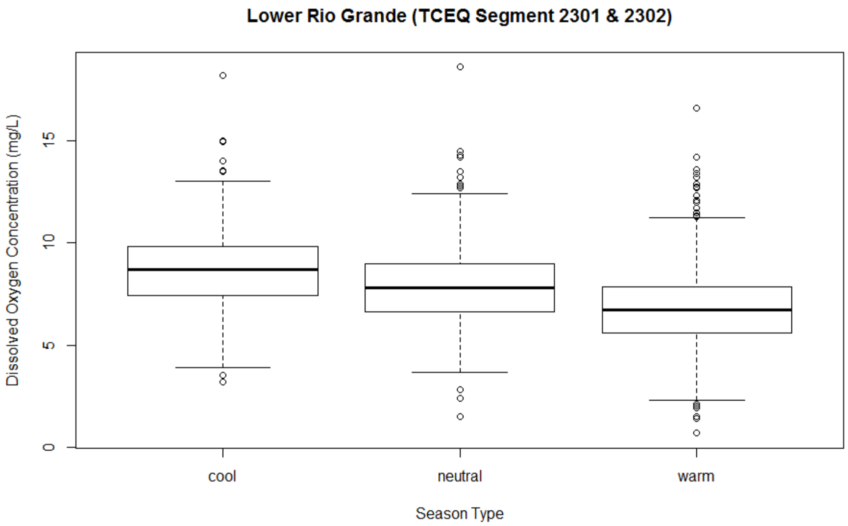


Weather Station	Lat	Long
BROWNSVILLE S PADRE ISLAND INTERNATIONAL AIRPORT, TX US GHCND:USW00012919	25.914	-97.423
RIO GRANDE CITY, TX US GHCND:USC00417622	26.377	-98.812
MERCEDES 6 SSE, TX US GHCND:USC00415836	26.062	-97.9
LA JOYA, TX US GHCND:USC00414911	26.242	-98.399
FALCON DAM, TX US GHCND:USC00413060	26.558	-99.137

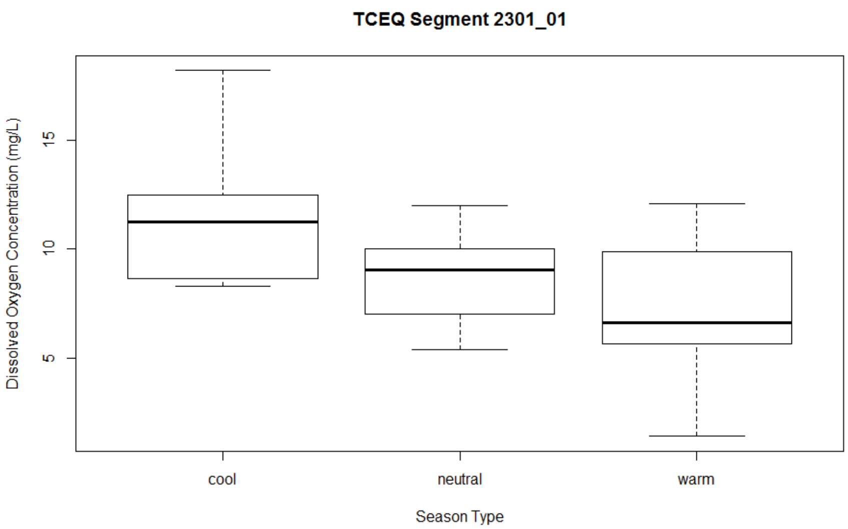
Season Type	Mean Monthly Air Temp (°C)
cool	<20
warm	>26
neutral	20-26

For all TCEQ segments:	
Month	**Season Type**
January	cool
February	cool
March	neutral
April	neutral
May	warm
June	warm
July	warm
August	warm
September	warm
October	neutral
November	neutral
December	cool

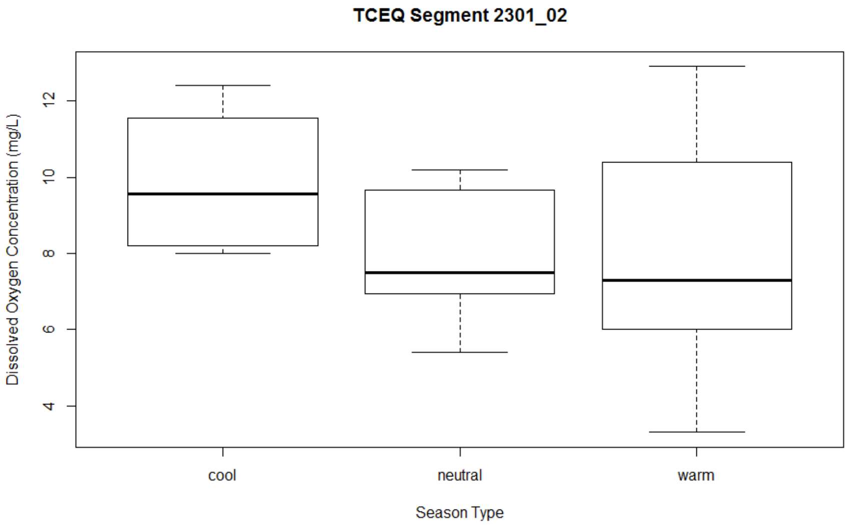
Dissolved Oxygen



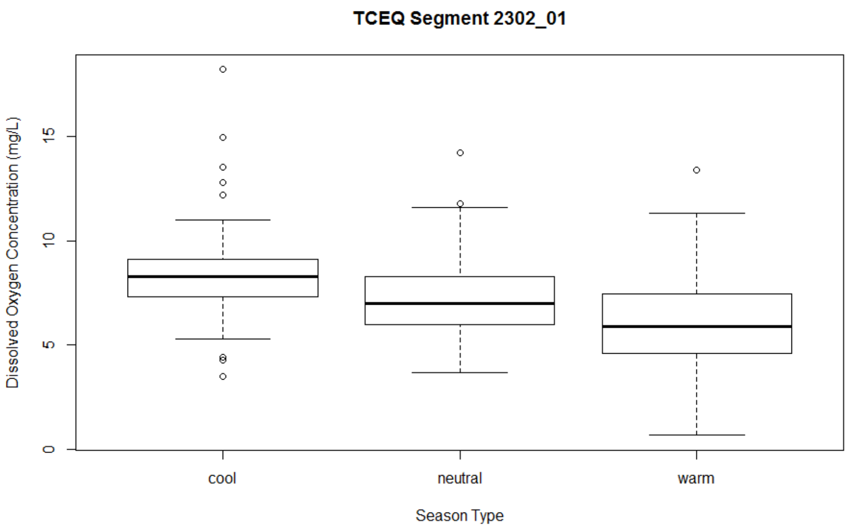
ANOVA		p-value
	Season Difference	2E-16
TUKEY	Season Comparison	p-value
	neutral-cool	0
	warm-cool	0
	warm-neutral	0



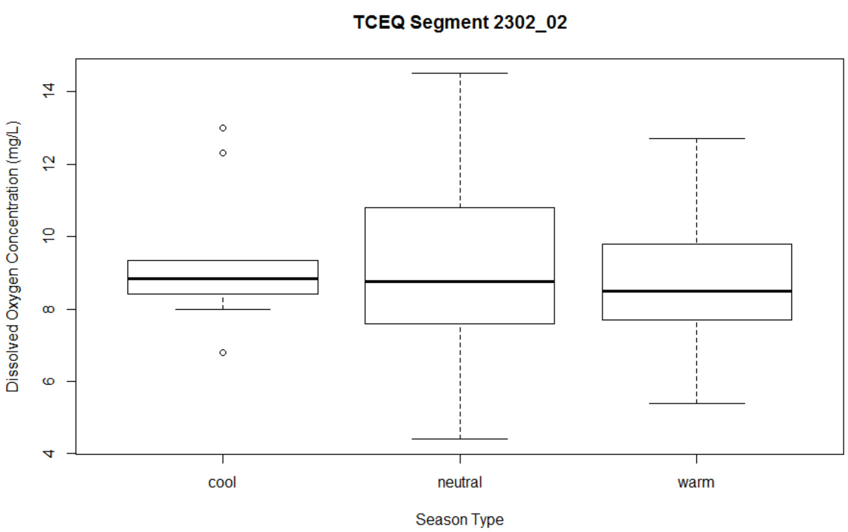
ANOVA		p-value
	Season Difference	0.0138
TUKEY	Season Comparison	p-value
	neutral-cool	0.0746
	warm-cool	0.0102
	warm-neutral	0.412



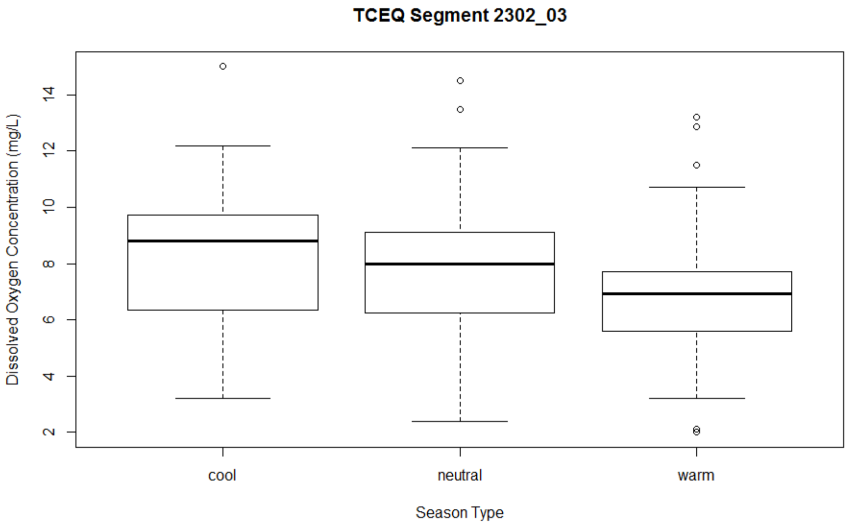
ANOVA		p-value
	Season Difference	0.287
TUKEY	Season Comparison	p-value
	neutral-cool	0.378
	warm-cool	0.264
	warm-neutral	0.952



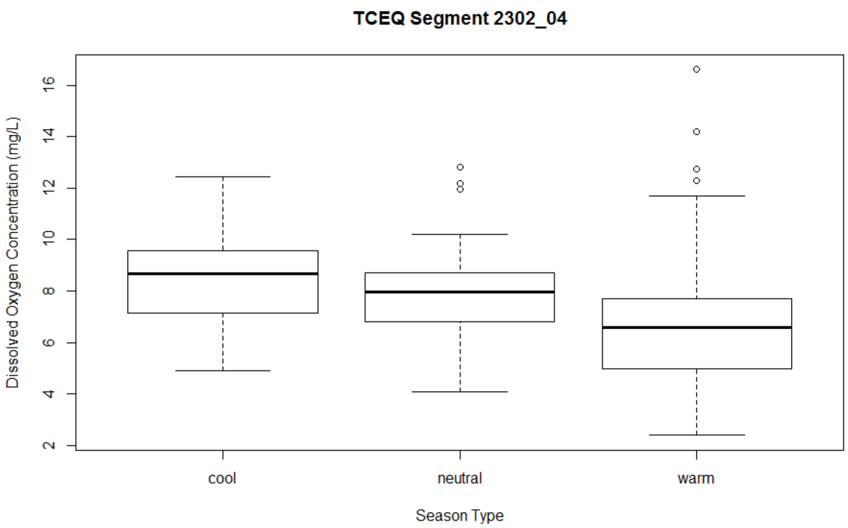
ANOVA		p-value
	Season Difference	6.05E-12
TUKEY	Season Comparison	p-value
	neutral-cool	0.0021
	warm-cool	0
	warm-neutral	0.000201



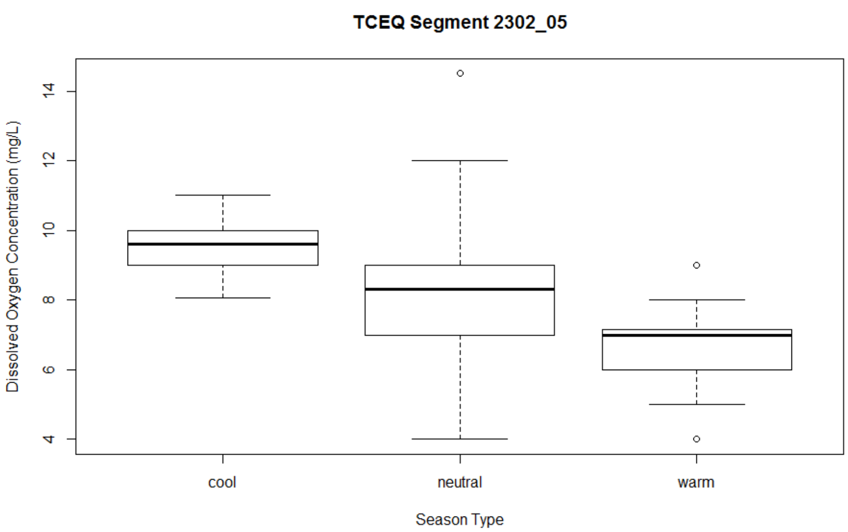
ANOVA		p-value
	Season Difference	0.844
TUKEY	Season Comparison	p-value
	neutral-cool	0.935
	warm-cool	0.831
	warm-neutral	0.948



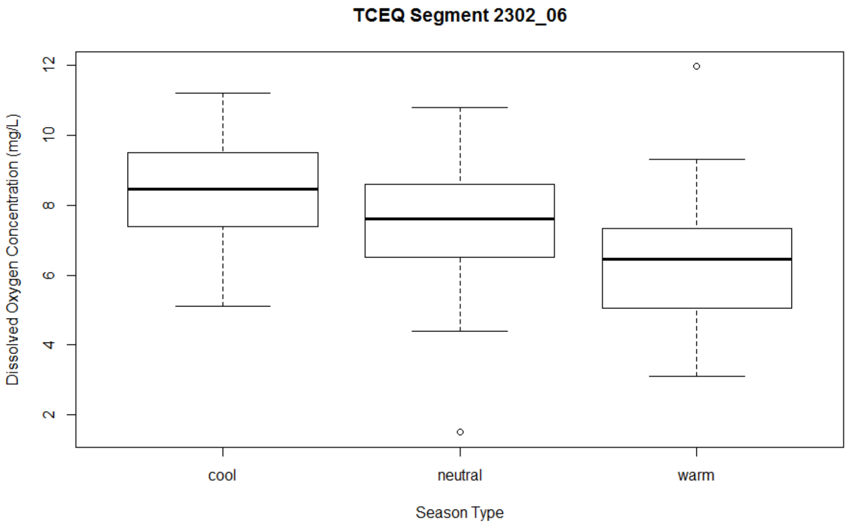
ANOVA		p-value
	Season Difference	0.0002
TUKEY	Season Comparison	p-value
	neutral-cool	0.486
	warm-cool	0.00058
	warm-neutral	0.0069



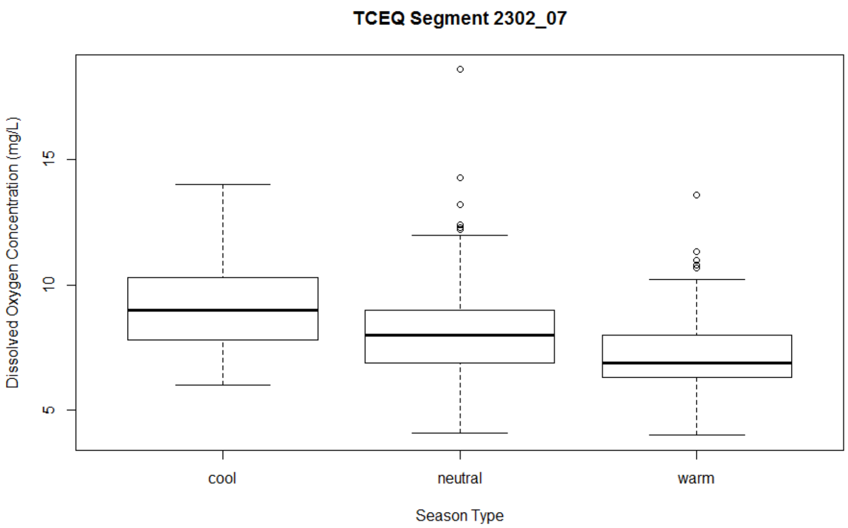
ANOVA		p-value
	Season Difference	2.39E-08
TUKEY	Season Comparison	p-value
	neutral-cool	0.17
	warm-cool	0
	warm-neutral	0.00057



ANOVA		p-value
	Season Difference	0.00413
TUKEY	Season Comparison	p-value
	neutral-cool	0.264
	warm-cool	0.0048
	warm-neutral	0.057

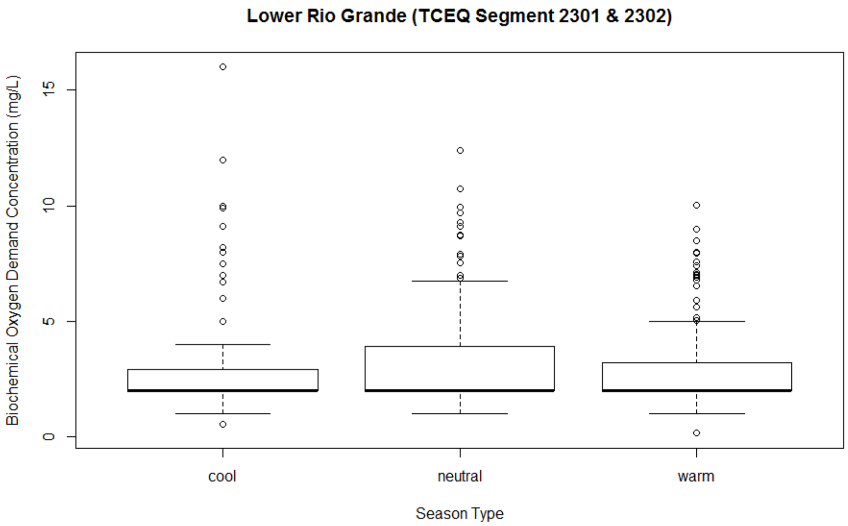


ANOVA		p-value
	Season Difference	0.0000323
TUKEY	Season Comparison	p-value
	neutral-cool	0.0711
	warm-cool	0.000025
	warm-neutral	0.0357

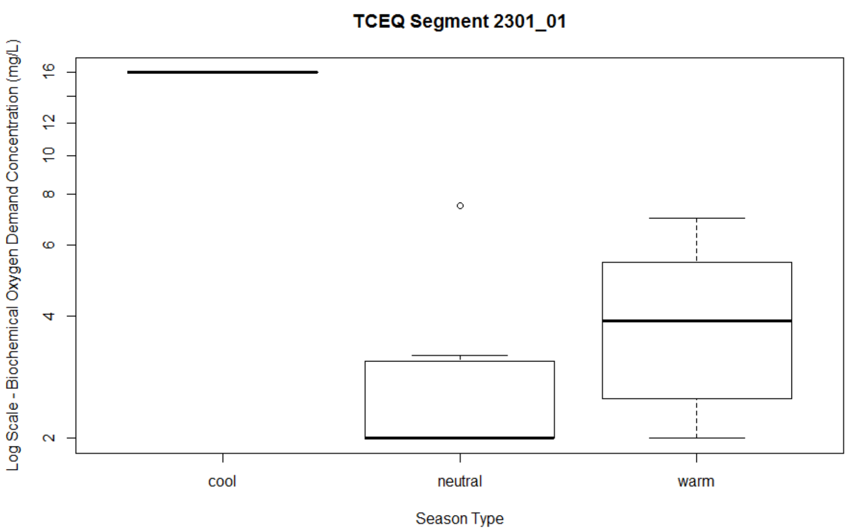


ANOVA		p-value
	Season Difference	2E-16
TUKEY	Season Comparison	p-value
	neutral-cool	0.00018
	warm-cool	0
	warm-neutral	0.0000029

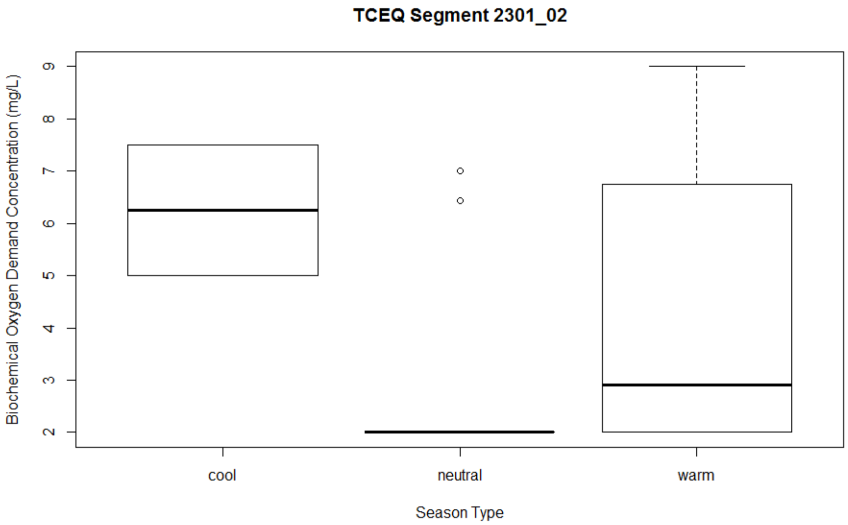
Biochemical Oxygen Demand



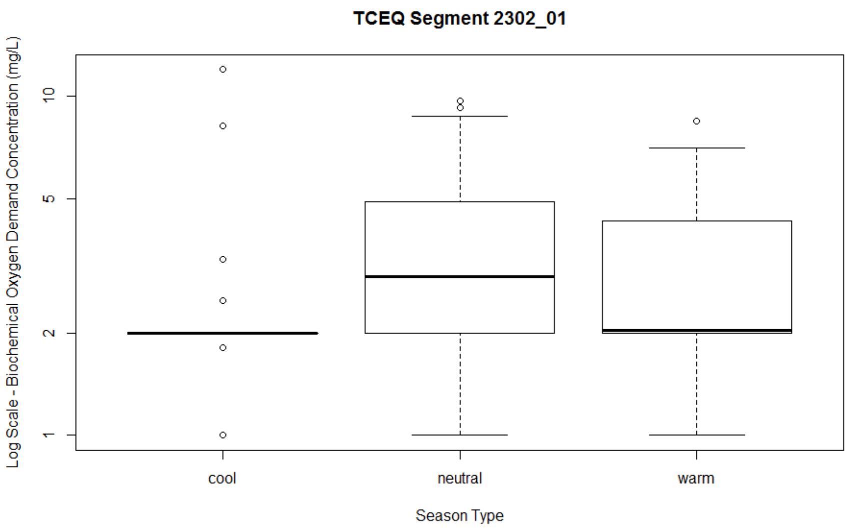
ANOVA		p-value
	Season Difference	0.307
TUKEY	Season Comparison	p-value
	neutral-cool	0.899
	warm-cool	0.578
	warm-neutral	0.197



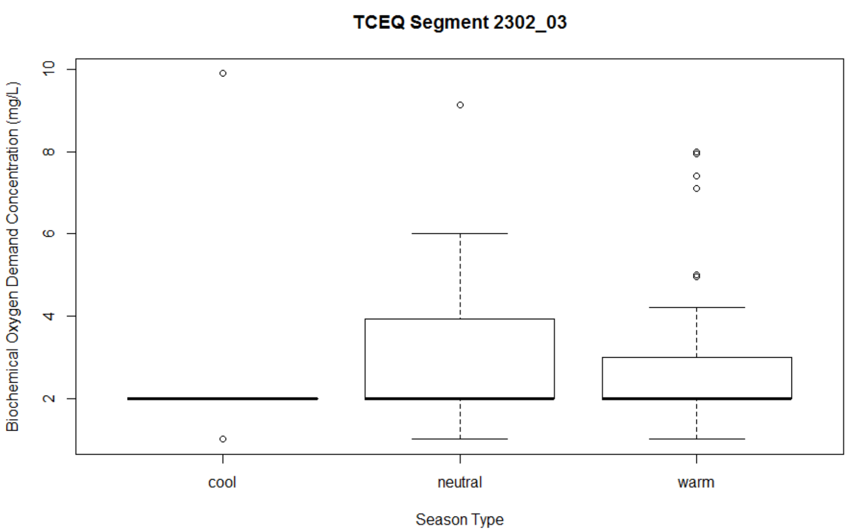
ANOVA		p-value
	Season Difference	0.000146
TUKEY	Season Comparison	p-value
	neutral-cool	0.000104
	warm-cool	0.00021
	warm-neutral	0.613



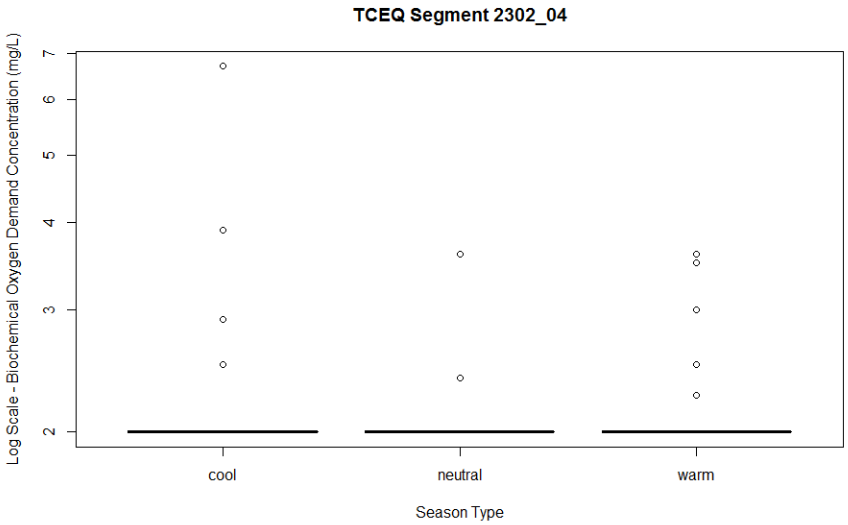
ANOVA		p-value
	Season Difference	0.259
TUKEY	Season Comparison	p-value
	neutral-cool	0.265
	warm-cool	0.597
	warm-neutral	0.582



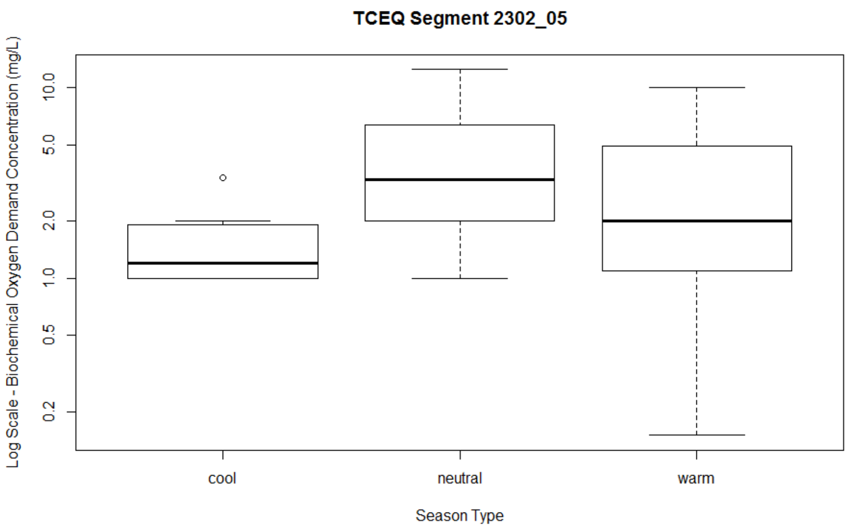
ANOVA		p-value
	Season Difference	0.454
TUKEY	Season Comparison	p-value
	neutral-cool	0.466
	warm-cool	0.873
	warm-neutral	0.626



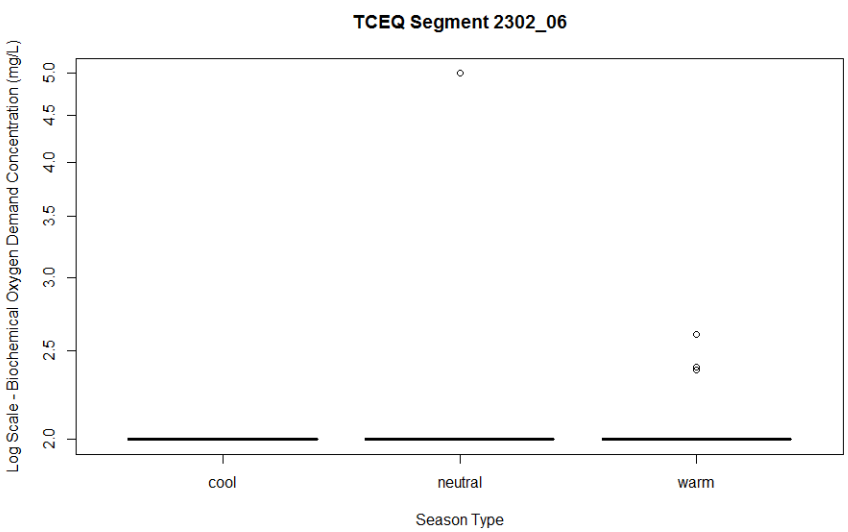
ANOVA		p-value
	Season Difference	0.99
TUKEY	Season Comparison	p-value
	neutral-cool	0.989
	warm-cool	0.992
	warm-neutral	0.999



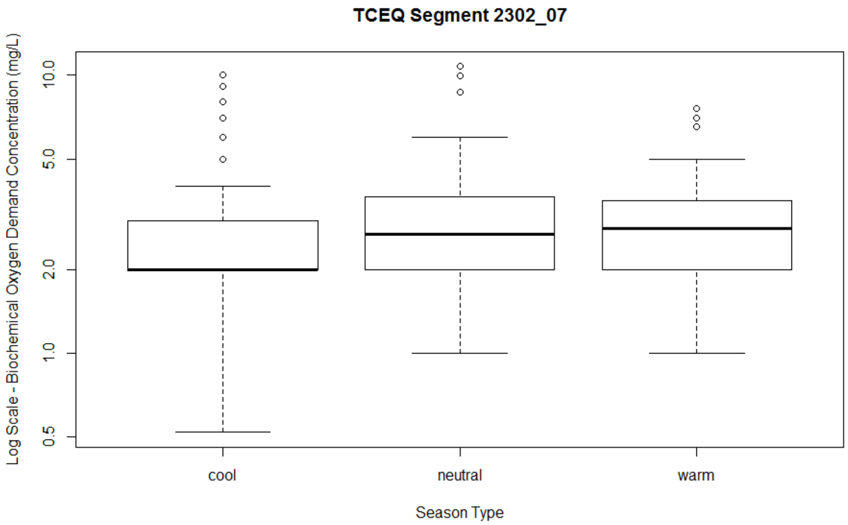
ANOVA		p-value
	Season Difference	0.295
TUKEY	Season Comparison	p-value
	neutral-cool	0.212
	warm-cool	0.155
	warm-neutral	0.434



ANOVA		p-value
	Season Difference	0.0787
TUKEY	Season Comparison	p-value
	neutral-cool	0.073
	warm-cool	0.507
	warm-neutral	0.349

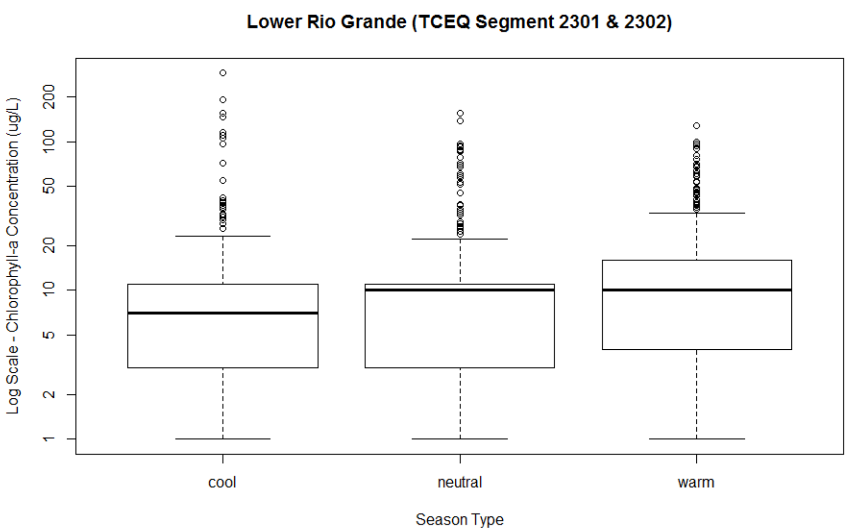


ANOVA		p-value
	Season Difference	0.382
TUKEY	Season Comparison	p-value
	neutral-cool	0.403
	warm-cool	0.931
	warm-neutral	0.483

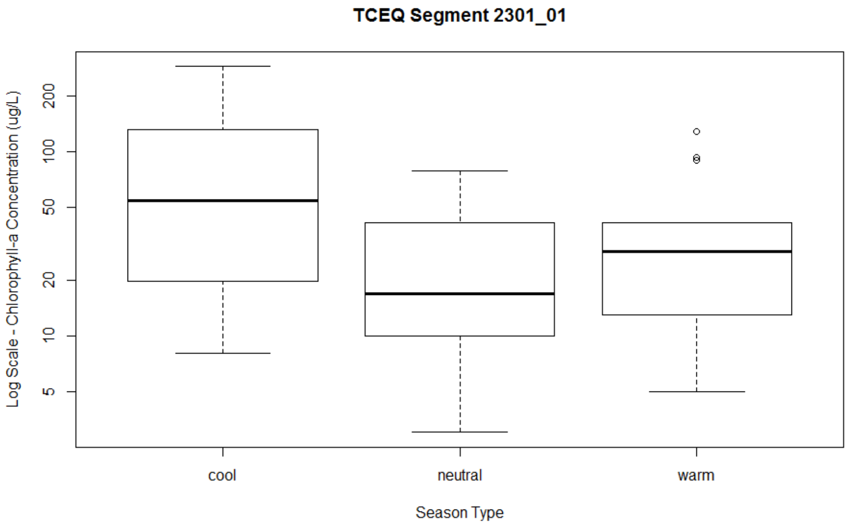


ANOVA		p-value
	Season Difference	0.823
TUKEY	Season Comparison	p-value
	neutral-cool	0.849
	warm-cool	0.997
	warm-neutral	0.855

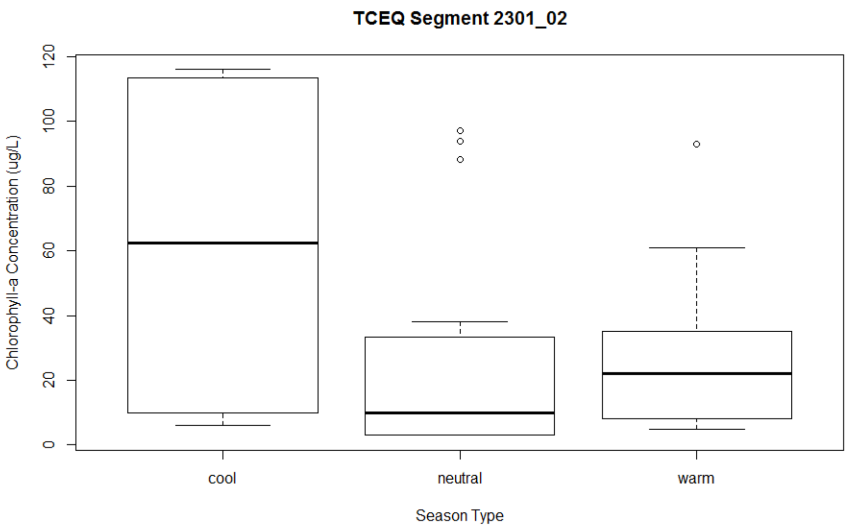
Chlorophyll-*a*



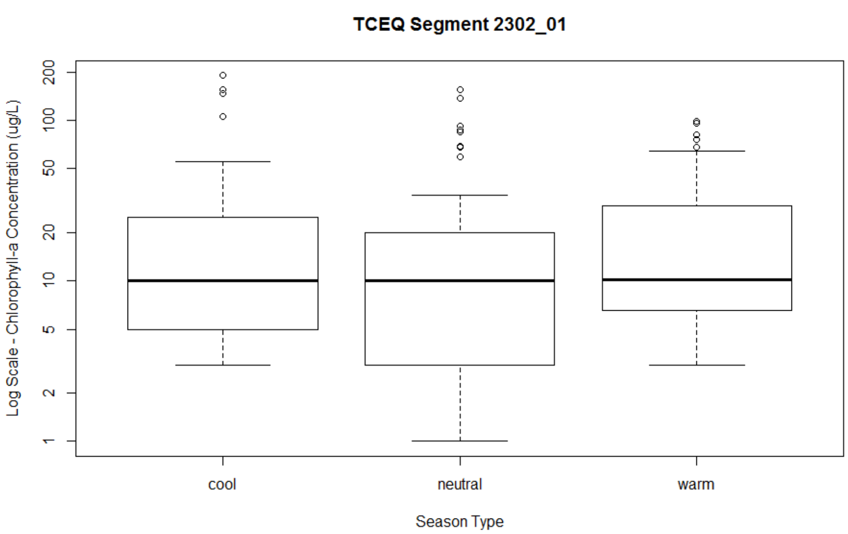
ANOVA		p-value
	Season Difference	0.617
TUKEY	Season Comparison	p-value
	neutral-cool	0.626
	warm-cool	0.958
	warm-neutral	0.732



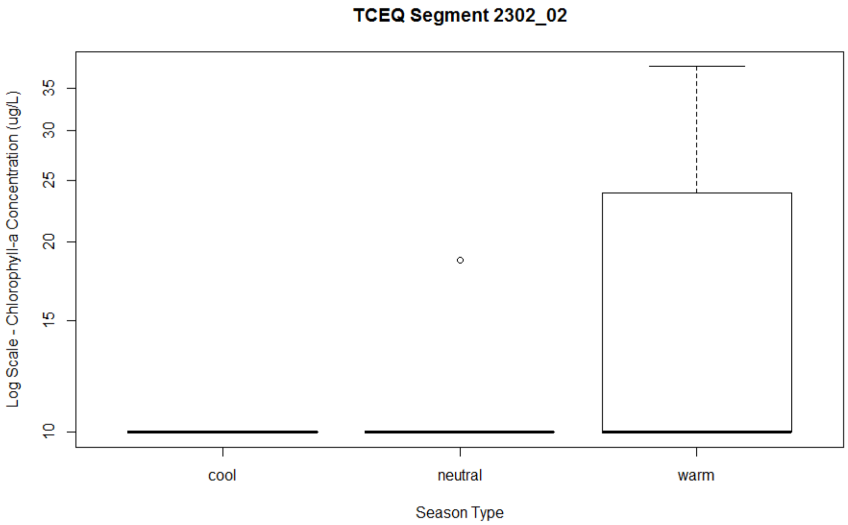
ANOVA		p-value
	Season Difference	0.00939
TUKEY	Season Comparison	p-value
	neutral-cool	0.0067
	warm-cool	0.0476
	warm-neutral	0.65



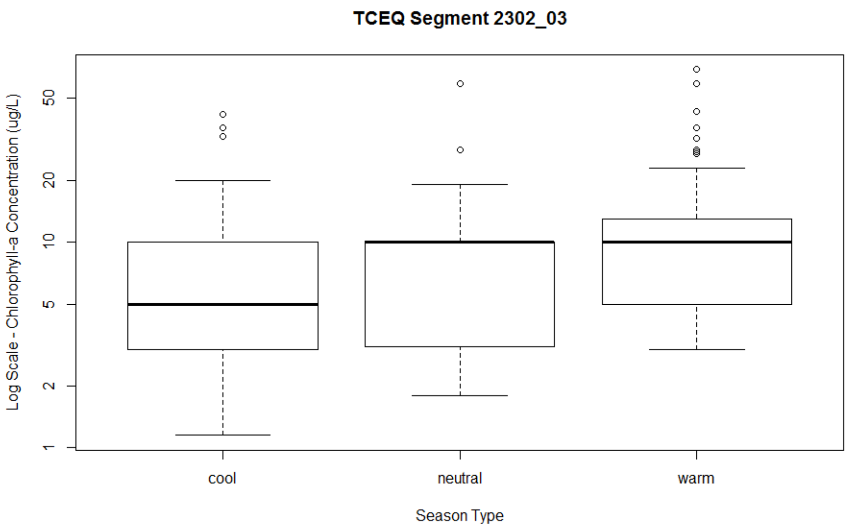
ANOVA		p-value
	Season Difference	0.178
TUKEY	Season Comparison	p-value
	neutral-cool	0.17
	warm-cool	0.203
	warm-neutral	0.992



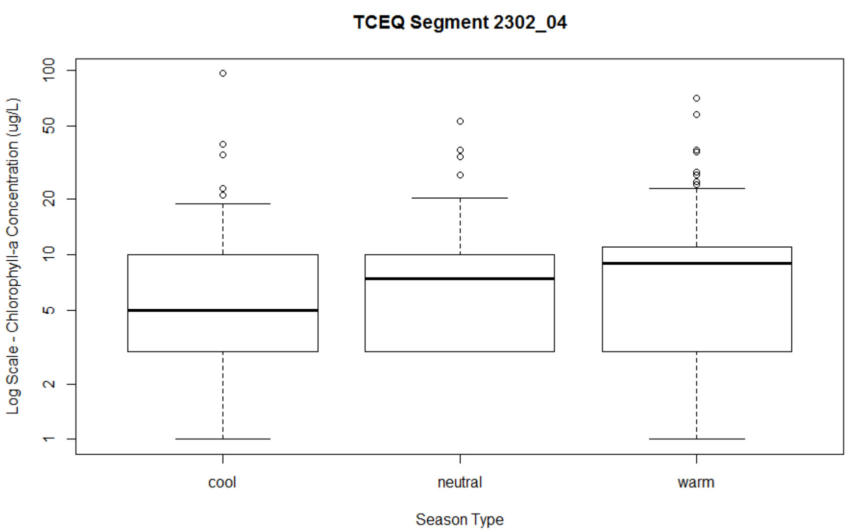
ANOVA		p-value
	Season Difference	0.699
TUKEY	Season Comparison	p-value
	neutral-cool	0.743
	warm-cool	0.709
	warm-neutral	0.999



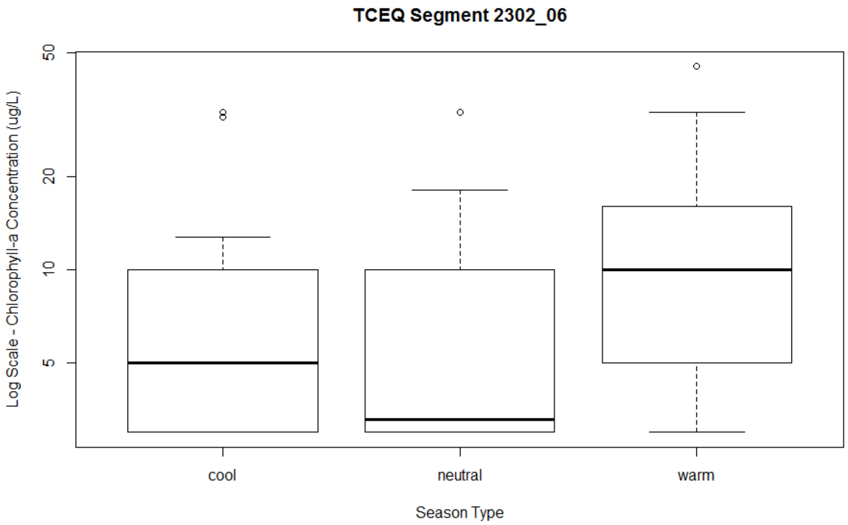
ANOVA		p-value
	Season Difference	0.259
TUKEY	Season Comparison	p-value
	neutral-cool	0.963
	warm-cool	0.285
	warm-neutral	0.311



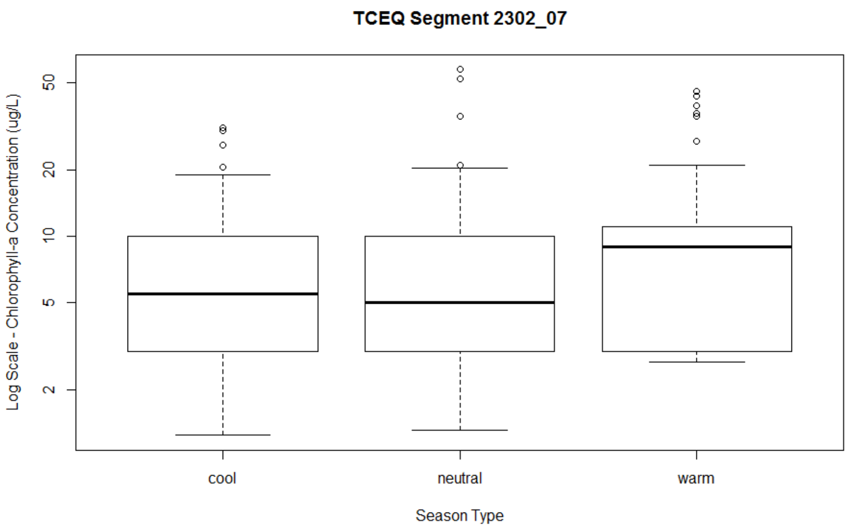
ANOVA		p-value
	Season Difference	0.29
TUKEY	Season Comparison	p-value
	neutral-cool	0.968
	warm-cool	0.342
	warm-neutral	0.437



ANOVA		p-value
	Season Difference	0.624
TUKEY	Season Comparison	p-value
	neutral-cool	0.978
	warm-cool	0.773
	warm-neutral	0.643

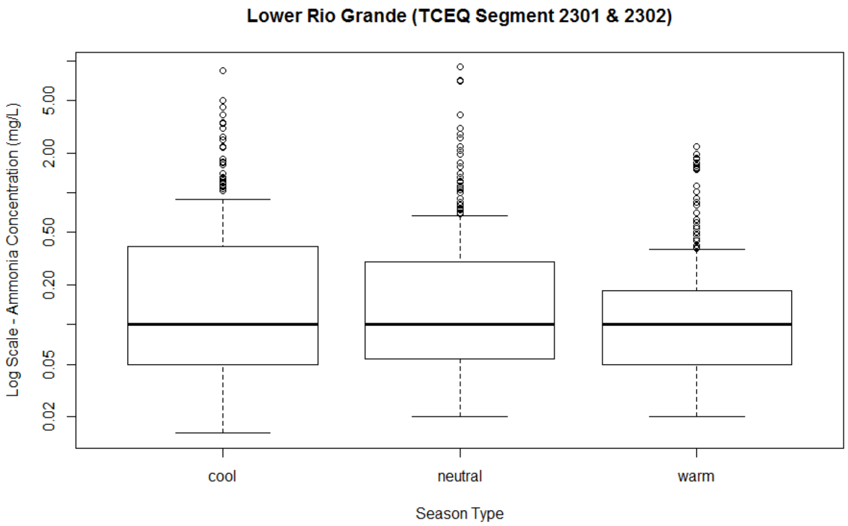


ANOVA		p-value
	Season Difference	0.157
TUKEY	Season Comparison	p-value
	neutral-cool	0.9406
	warm-cool	0.349
	warm-neutral	0.186

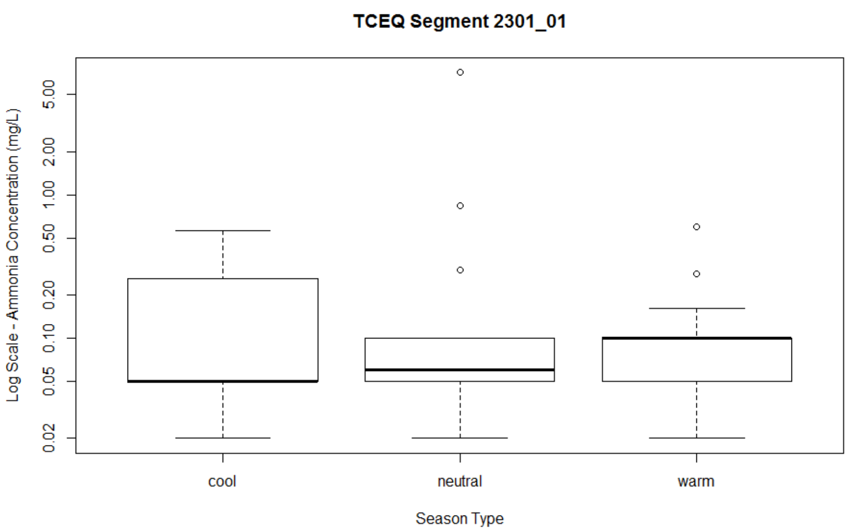


ANOVA		p-value
	Season Difference	0.457
TUKEY	Season Comparison	p-value
	neutral-cool	0.956
	warm-cool	0.447
	warm-neutral	0.636

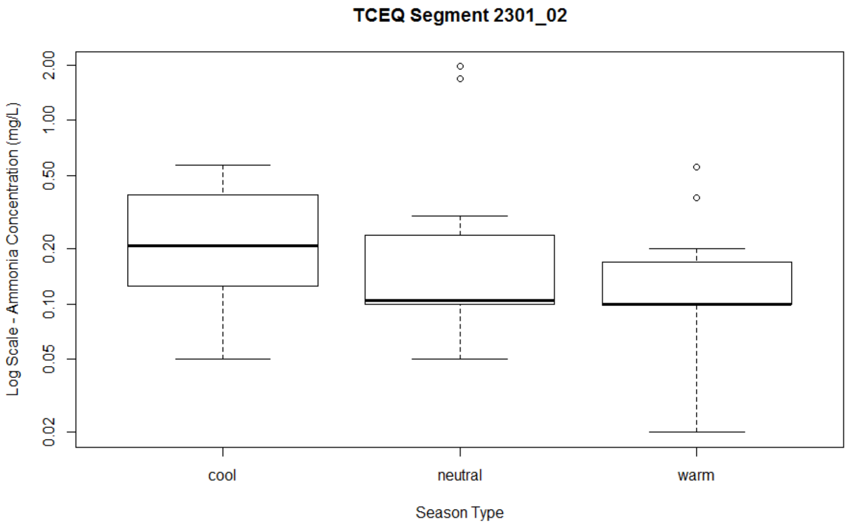
Ammonia Nitrogen



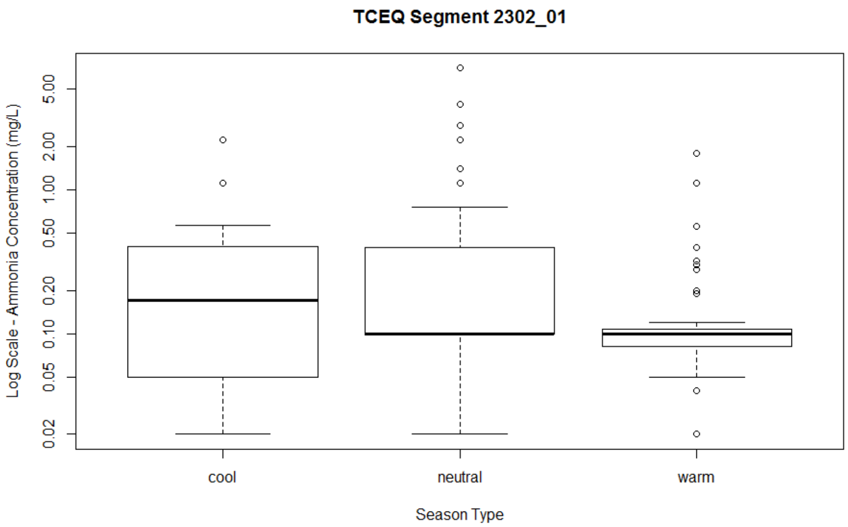
ANOVA		p-value
	Season Difference	8.86E-06
TUKEY	Season Comparison	p-value
	neutral-cool	0.641
	warm-cool	0.00004
	warm-neutral	0.00065



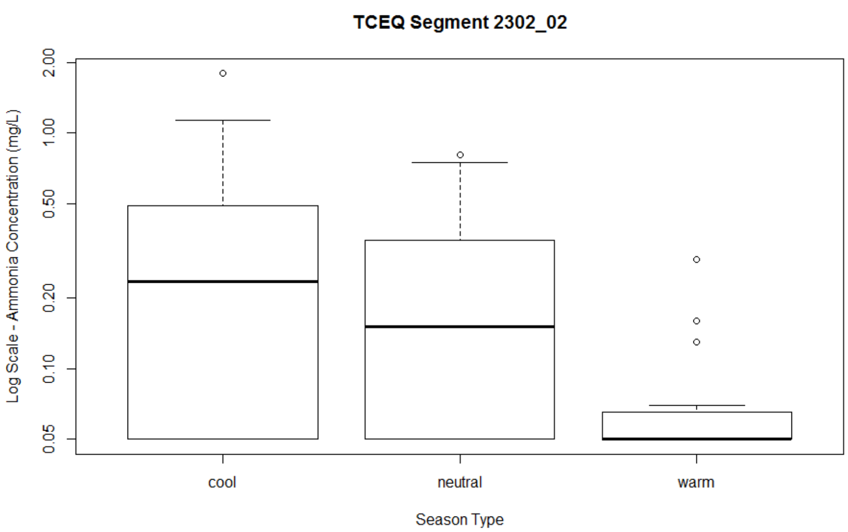
ANOVA		p-value
	Season Difference	0.646
TUKEY	Season Comparison	p-value
	neutral-cool	0.8245
	warm-cool	0.995
	warm-neutral	0.653



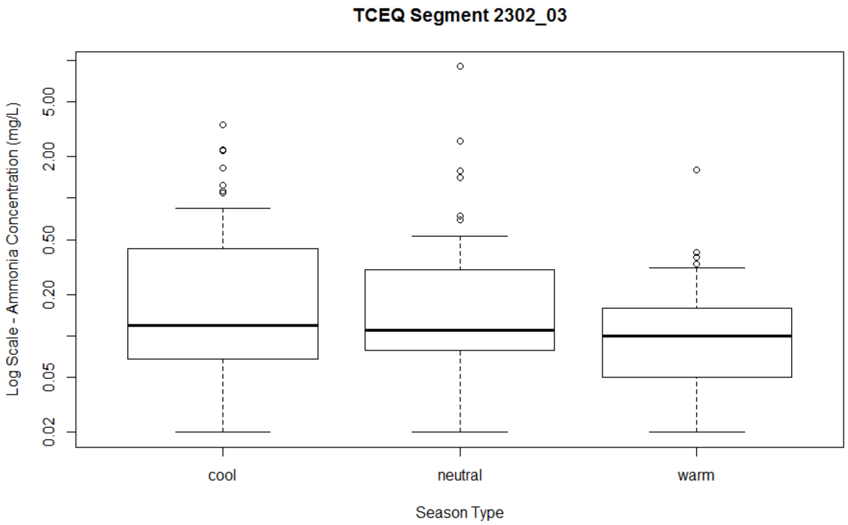
ANOVA		p-value
	Season Difference	0.425
TUKEY	Season Comparison	p-value
	neutral-cool	0.889
	warm-cool	0.907
	warm-neutral	0.392



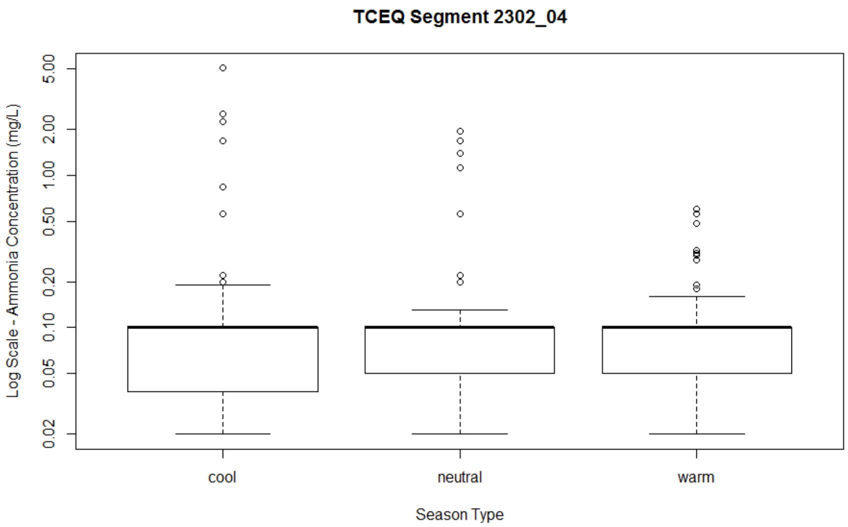
ANOVA		p-value
	Season Difference	0.0263
TUKEY	Season Comparison	p-value
	neutral-cool	0.356
	warm-cool	0.588
	warm-neutral	0.019



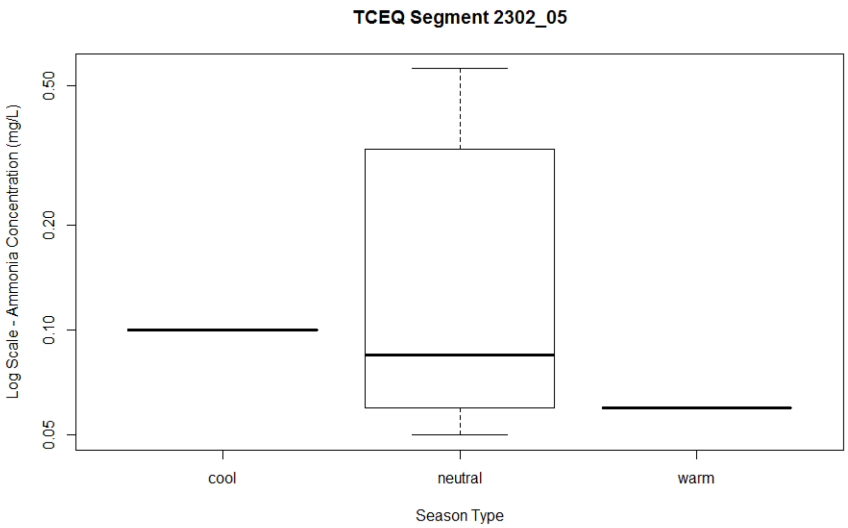
ANOVA		p-value
	Season Difference	0.0105
TUKEY	Season Comparison	p-value
	neutral-cool	0.182
	warm-cool	0.008
	warm-neutral	0.272



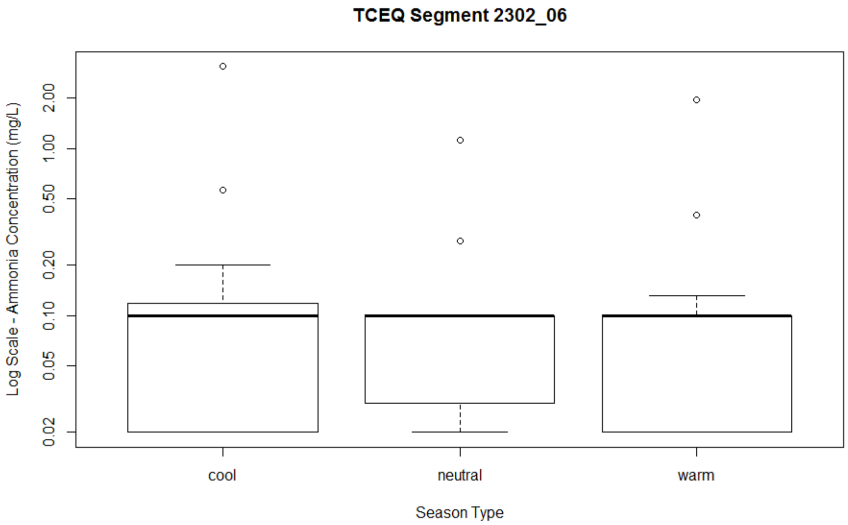
ANOVA		p-value
	Season Difference	0.0732
TUKEY	Season Comparison	p-value
	neutral-cool	0.994
	warm-cool	0.141
	warm-neutral	0.124



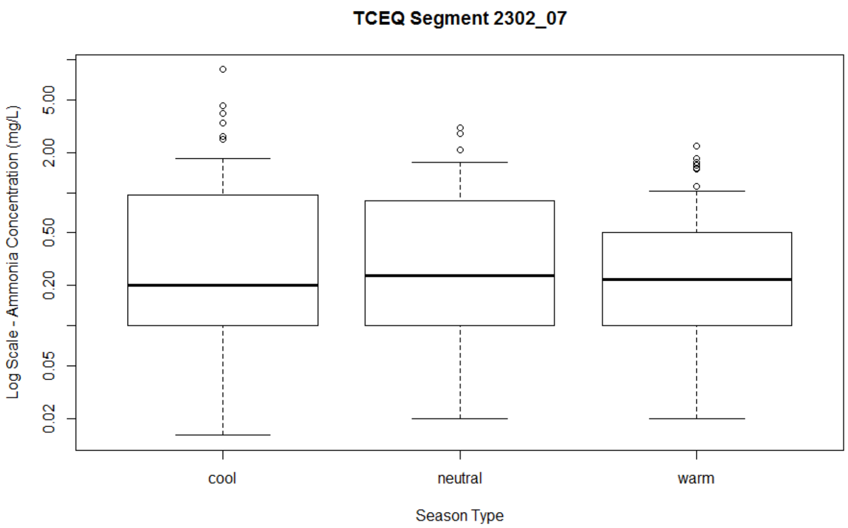
ANOVA		p-value
	Season Difference	0.0588
TUKEY	Season Comparison	p-value
	neutral-cool	0.50005
	warm-cool	0.0465
	warm-neutral	0.519



ANOVA		p-value
	Season Difference	0.863
TUKEY	Season Comparison	p-value
	neutral-cool	0.937
	warm-cool	0.993
	warm-neutral	0.879

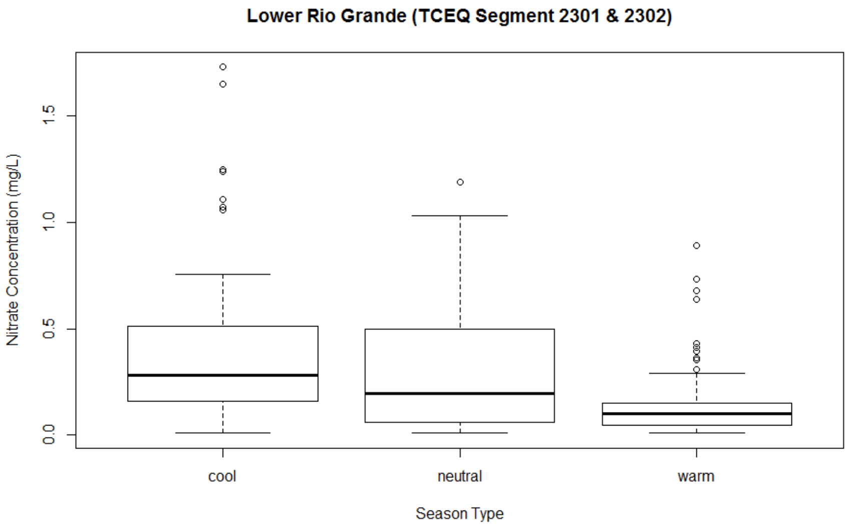


ANOVA		p-value
	Season Difference	0.638
TUKEY	Season Comparison	p-value
	neutral-cool	0.71
	warm-cool	0.658
	warm-neutral	0.999

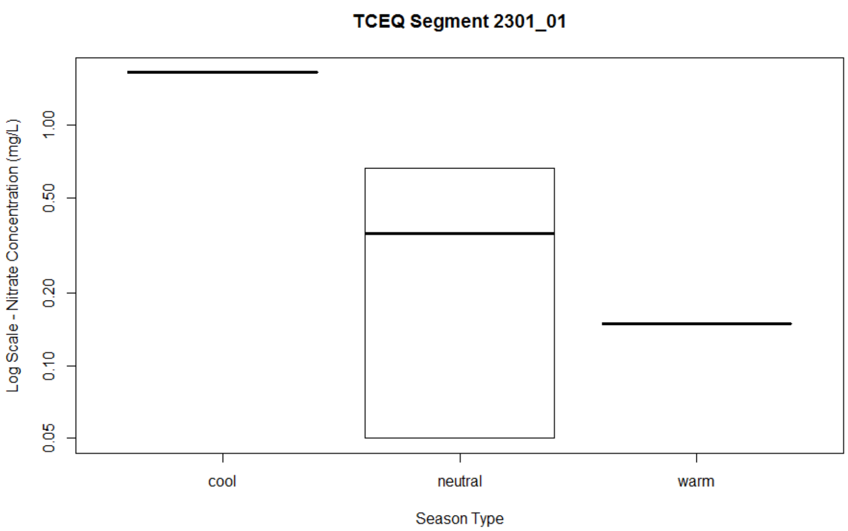


ANOVA		p-value
	Season Difference	0.0274
TUKEY	Season Comparison	p-value
	neutral-cool	0.18
	warm-cool	0.021
	warm-neutral	0.651

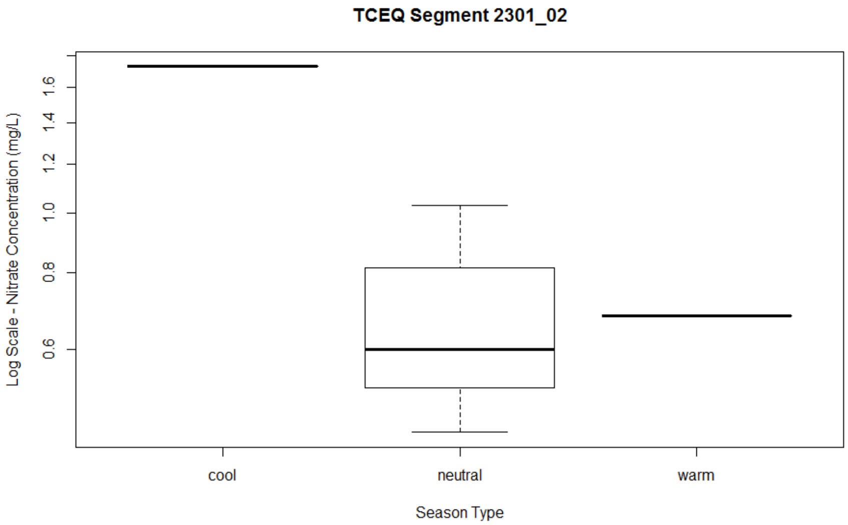
Nitrate



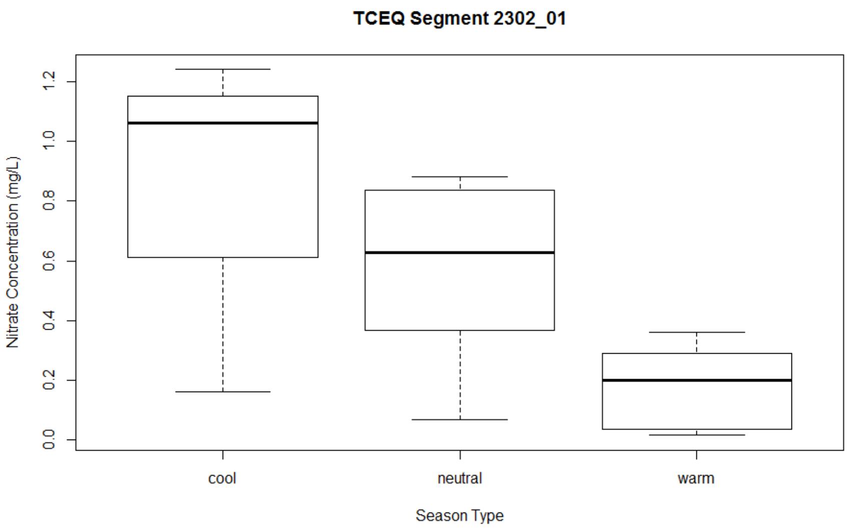
ANOVA		p-value
	Season Difference	2.25E-09
TUKEY	Season Comparison	p-value
	neutral-cool	0.017
	warm-cool	0
	warm-neutral	0.000045



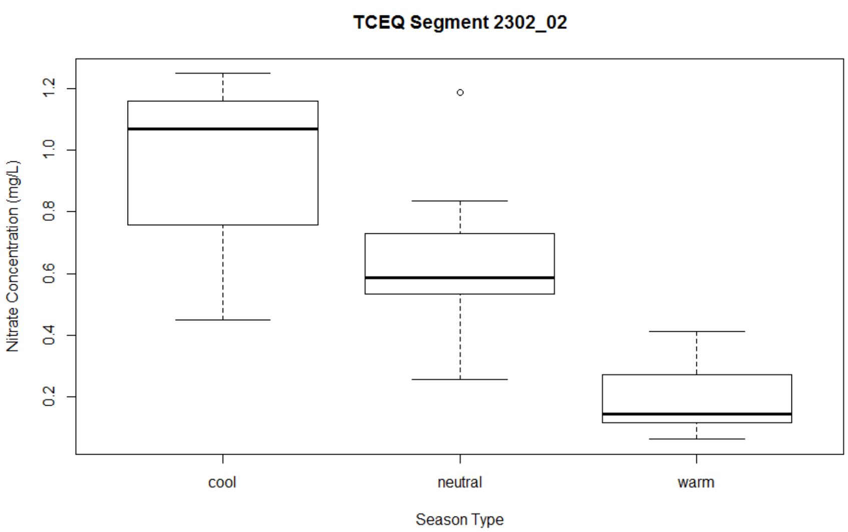
ANOVA		p-value
	Season Difference	0.34
TUKEY	Season Comparison	p-value
	not enough data	



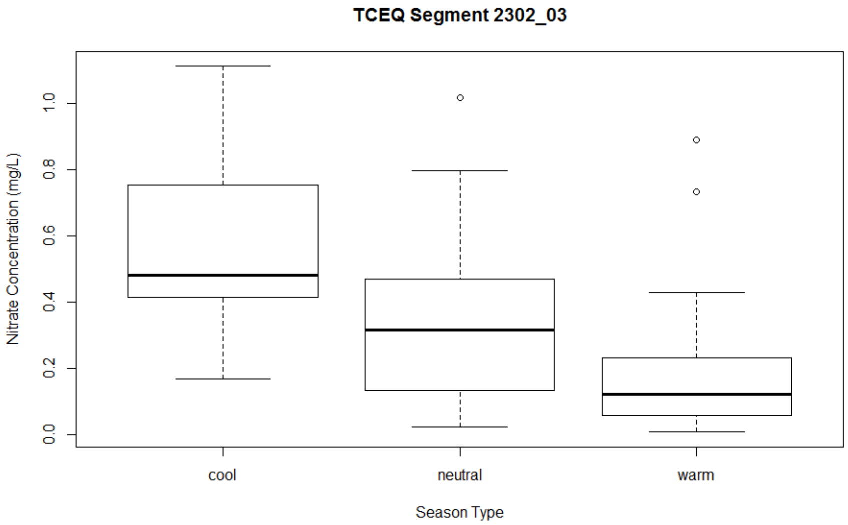
ANOVA		p-value
	Season Difference	0.176
TUKEY	Season Comparison	p-value
	neutral-cool	0.173
	warm-cool	0.236
	warm-neutral	0.999



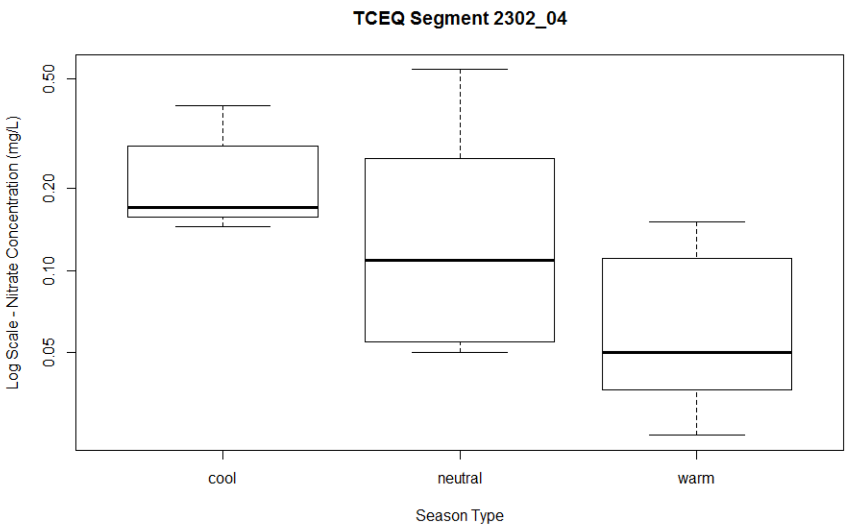
ANOVA		p-value
	Season Difference	0.00346
TUKEY	Season Comparison	p-value
	neutral-cool	0.42
	warm-cool	0.0075
	warm-neutral	0.022



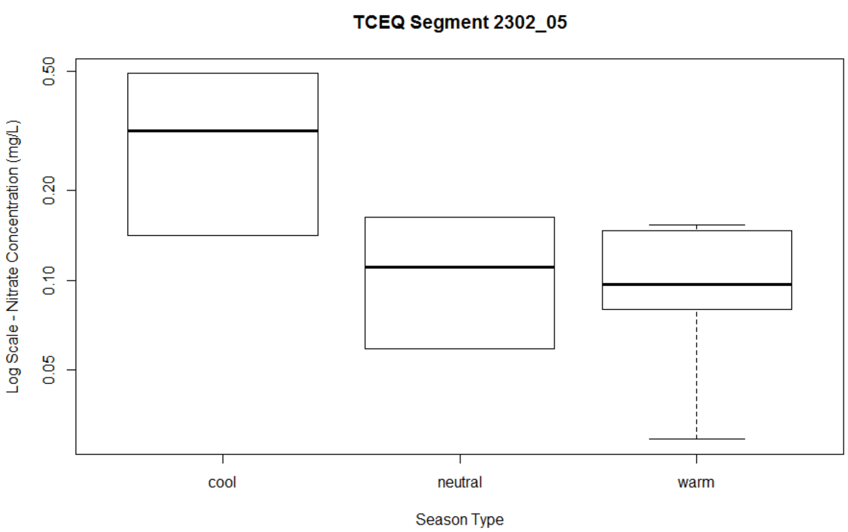
ANOVA		p-value
	Season Difference	0.00283
TUKEY	Season Comparison	p-value
	neutral-cool	0.284
	warm-cool	0.0038
	warm-neutral	0.0165



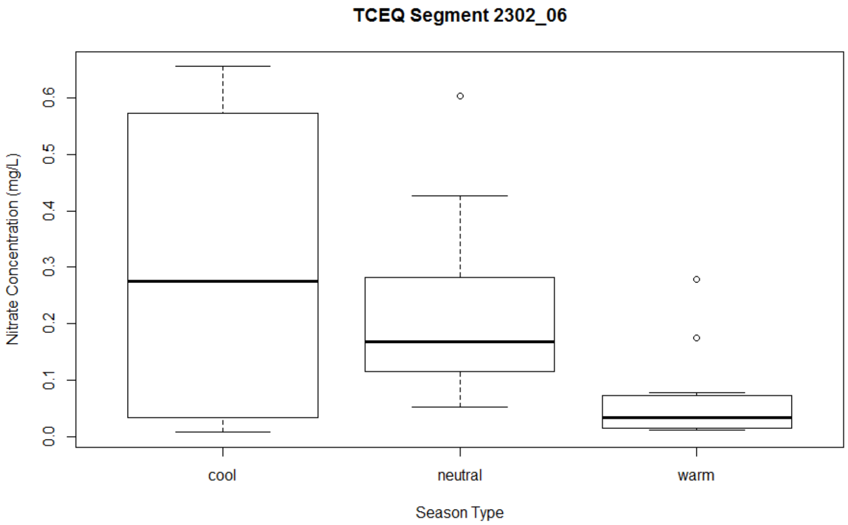
ANOVA		p-value
	Season Difference	0.0058
TUKEY	Season Comparison	p-value
	neutral-cool	0.084
	warm-cool	0.0051
	warm-neutral	0.181



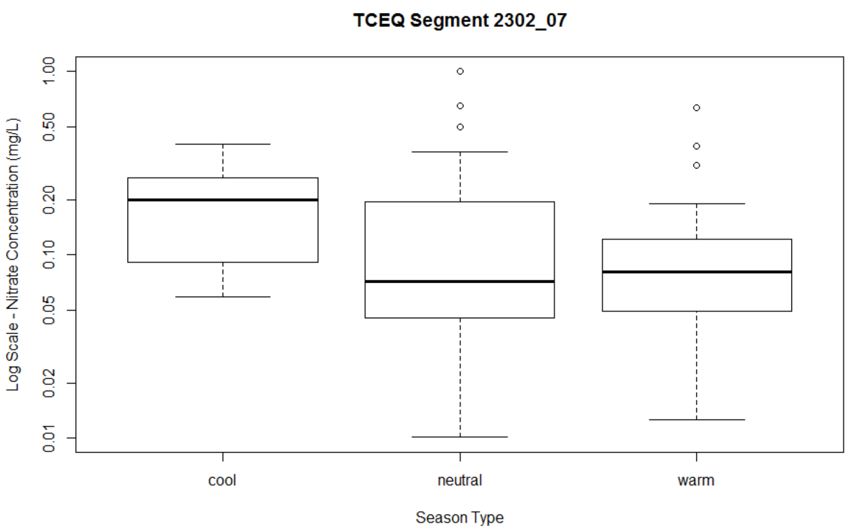
ANOVA		p-value
	Season Difference	0.117
TUKEY	Season Comparison	p-value
	neutral-cool	0.764
	warm-cool	0.16
	warm-neutral	0.246



ANOVA		p-value
	Season Difference	0.144
TUKEY	Season Comparison	p-value
	neutral-cool	0.244
	warm-cool	0.138
	warm-neutral	0.995

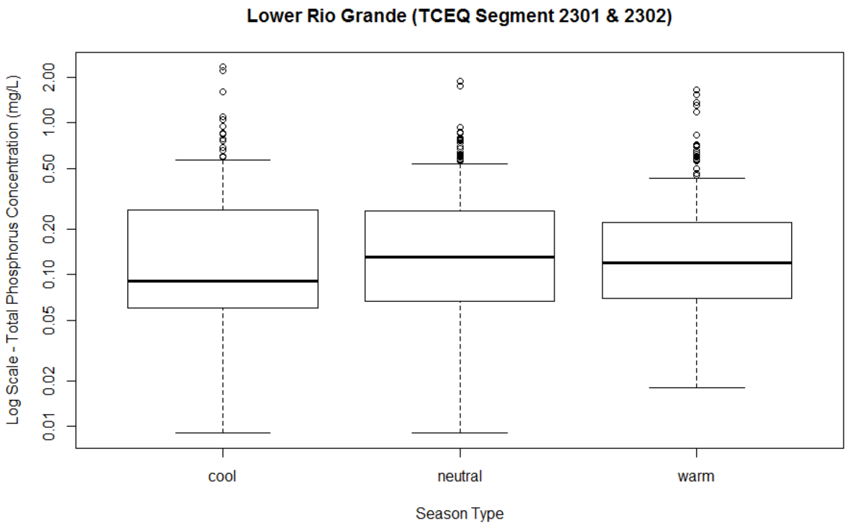


ANOVA		p-value
	Season Difference	0.029
TUKEY	Season Comparison	p-value
	neutral-cool	0.684
	warm-cool	0.054
	warm-neutral	0.086

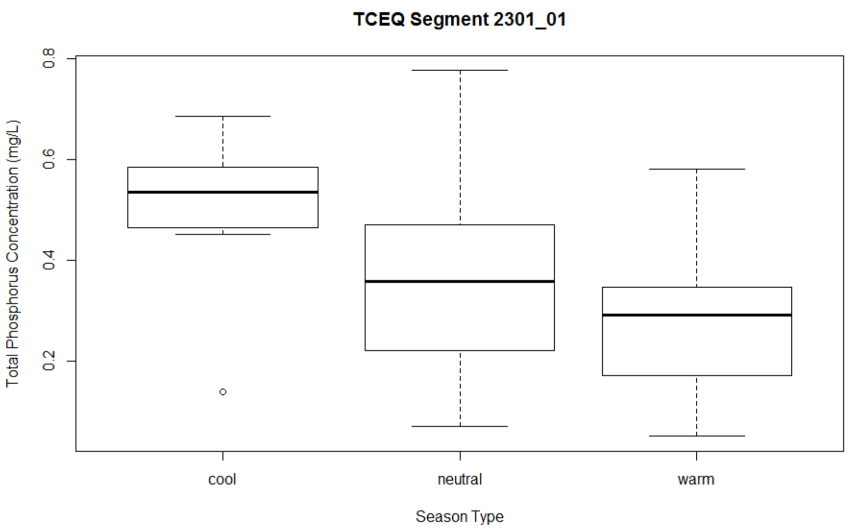


ANOVA		p-value
	Season Difference	0.126
TUKEY	Season Comparison	p-value
	neutral-cool	0.81
	warm-cool	0.153
	warm-neutral	0.311

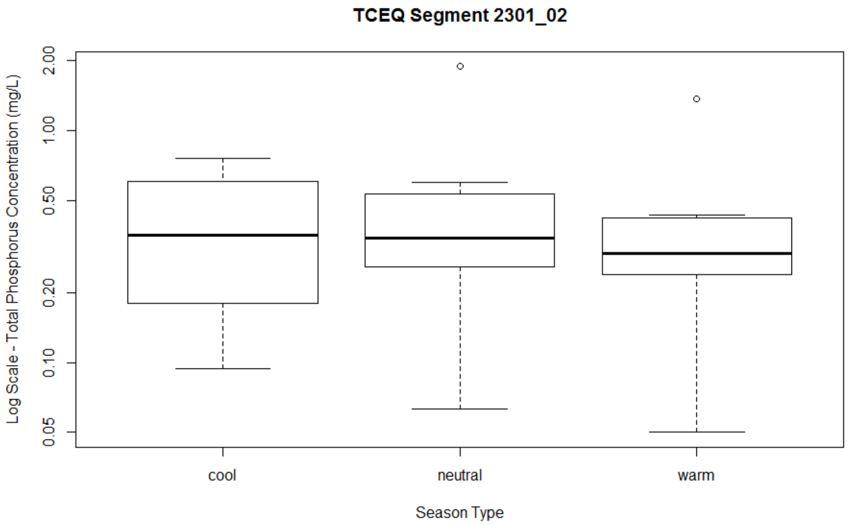
Total Phosphorus



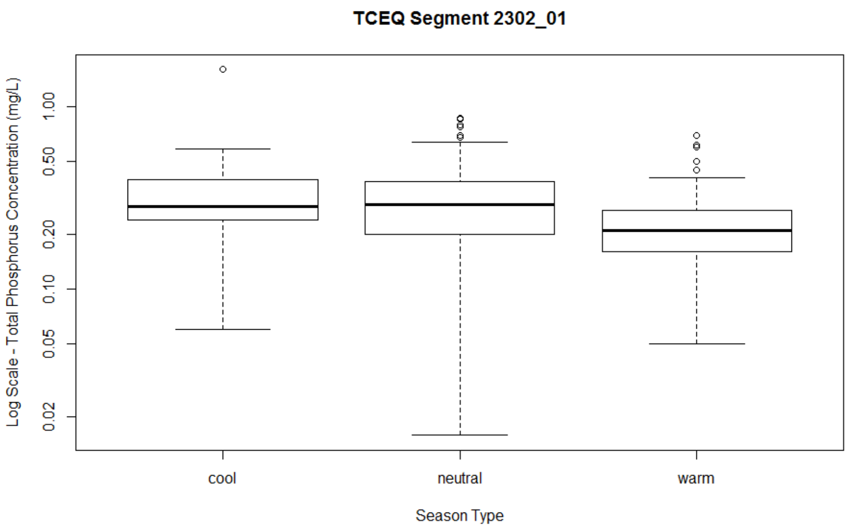
ANOVA		p-value
	Season Difference	0.272
TUKEY	Season Comparison	p-value
	neutral-cool	0.967
	warm-cool	0.526
	warm-neutral	0.281



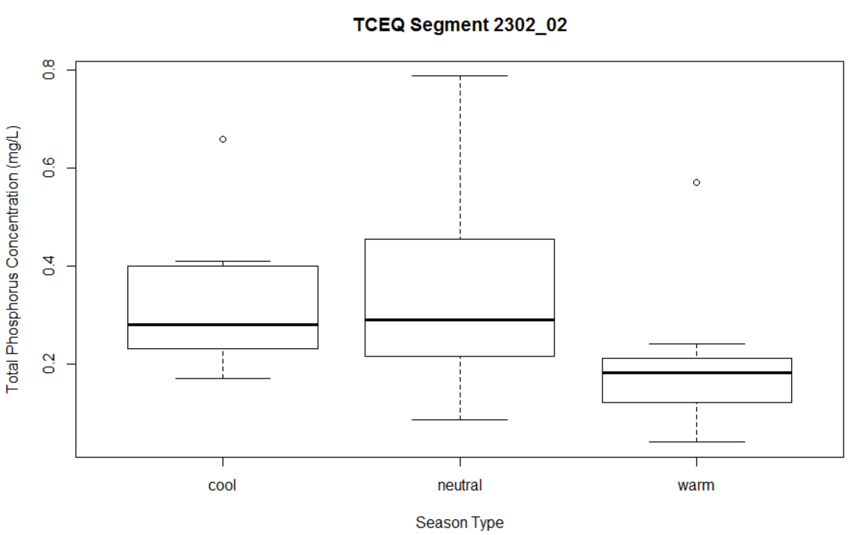
ANOVA		p-value
	Season Difference	0.0197
TUKEY	Season Comparison	p-value
	neutral-cool	0.201
	warm-cool	0.016
	warm-neutral	0.246



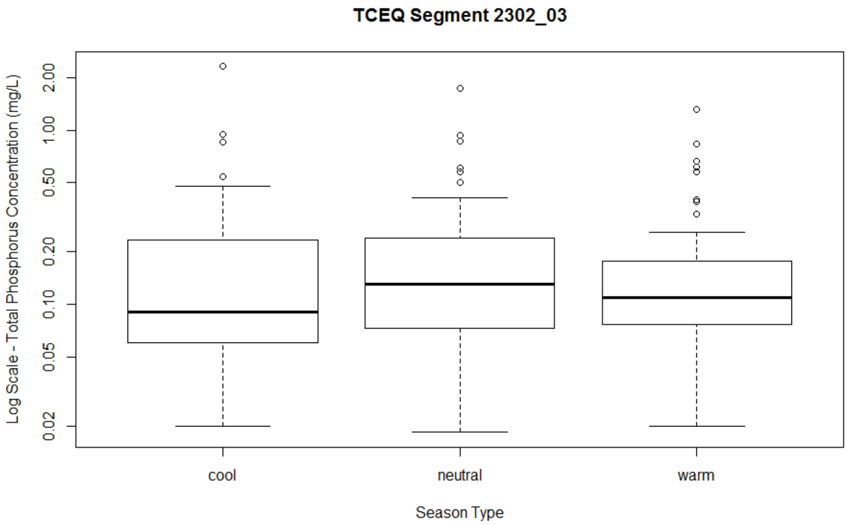
ANOVA		p-value
	Season Difference	0.739
TUKEY	Season Comparison	p-value
	neutral-cool	0.926
	warm-cool	0.99
	warm-neutral	0.724



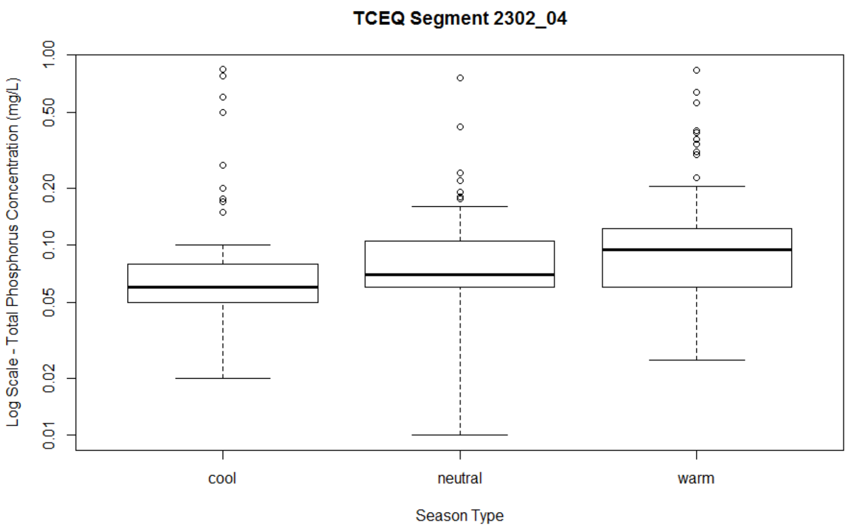
ANOVA		p-value
	Season Difference	0.0000464
TUKEY	Season Comparison	p-value
	neutral-cool	0.973
	warm-cool	0.0011
	warm-neutral	0.00038



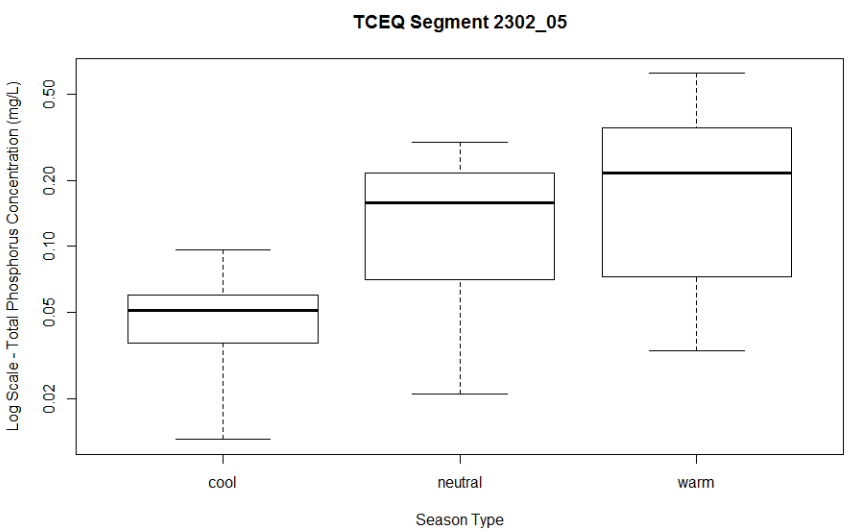
ANOVA		p-value
	Season Difference	0.00196
TUKEY	Season Comparison	p-value
	neutral-cool	0.893
	warm-cool	0.047
	warm-neutral	0.0022



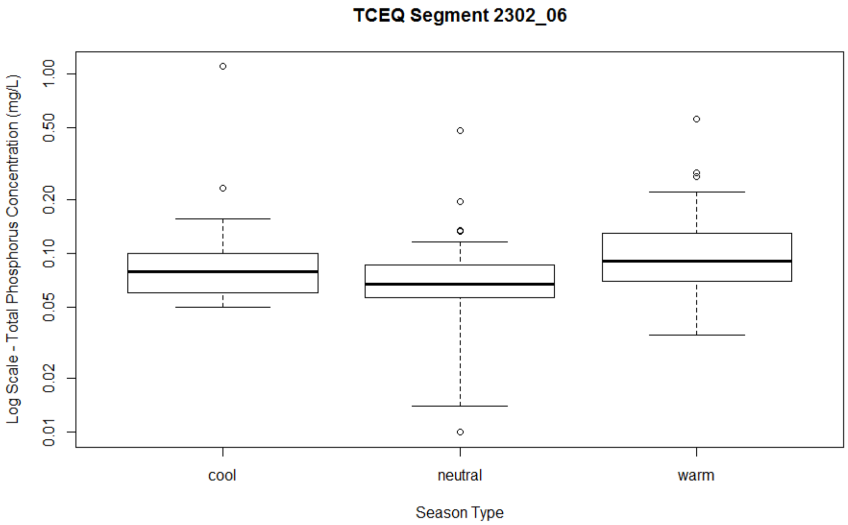
ANOVA		p-value
	Season Difference	0.304
TUKEY	Season Comparison	p-value
	neutral-cool	0.837
	warm-cool	0.311
	warm-neutral	0.562



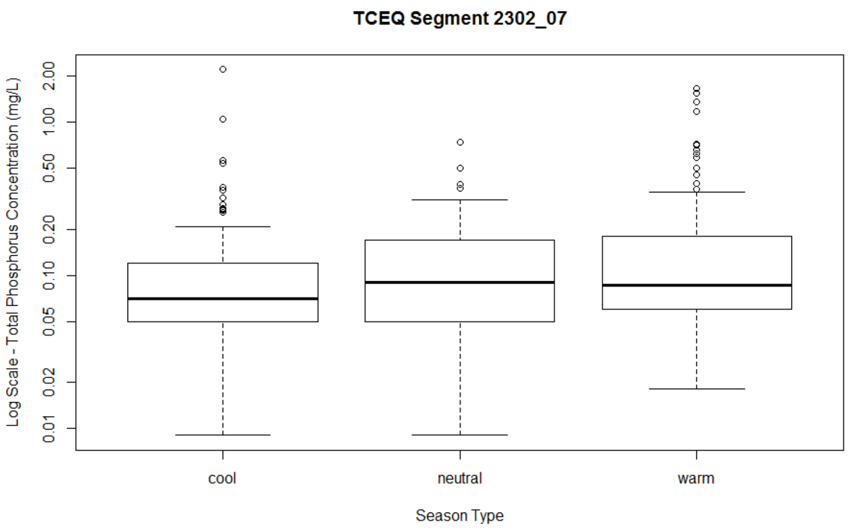
ANOVA		p-value
	Season Difference	0.419
TUKEY	Season Comparison	p-value
	neutral-cool	0.943
	warm-cool	0.646
	warm-neutral	0.427



ANOVA		p-value
	Season Difference	0.034
TUKEY	Season Comparison	p-value
	neutral-cool	0.286
	warm-cool	0.033
	warm-neutral	0.245

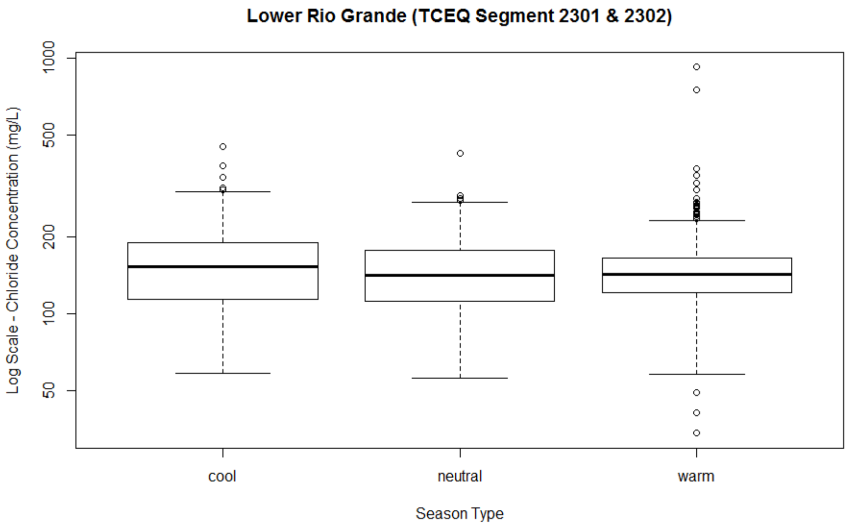


ANOVA		p-value
	Season Difference	0.406
TUKEY	Season Comparison	p-value
	neutral-cool	0.414
	warm-cool	0.908
	warm-neutral	0.557

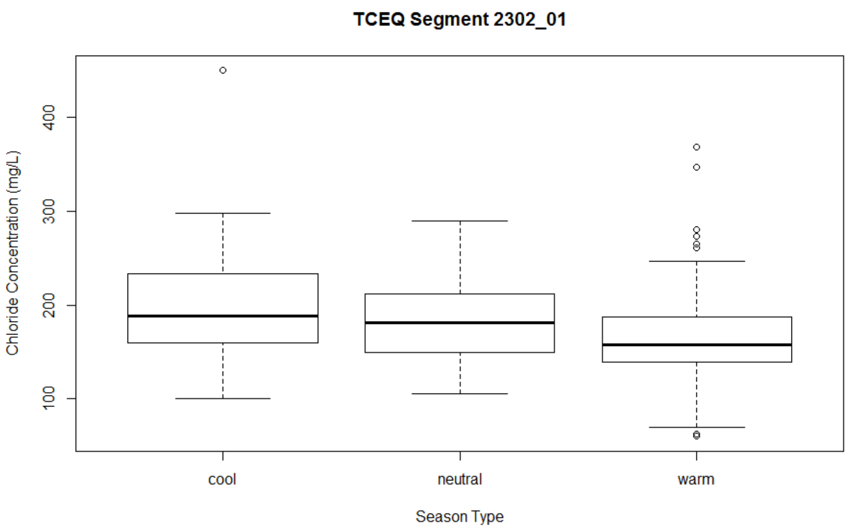


ANOVA		p-value
	Season Difference	0.0829
TUKEY	Season Comparison	p-value
	neutral-cool	0.774
	warm-cool	0.419
	warm-neutral	0.073

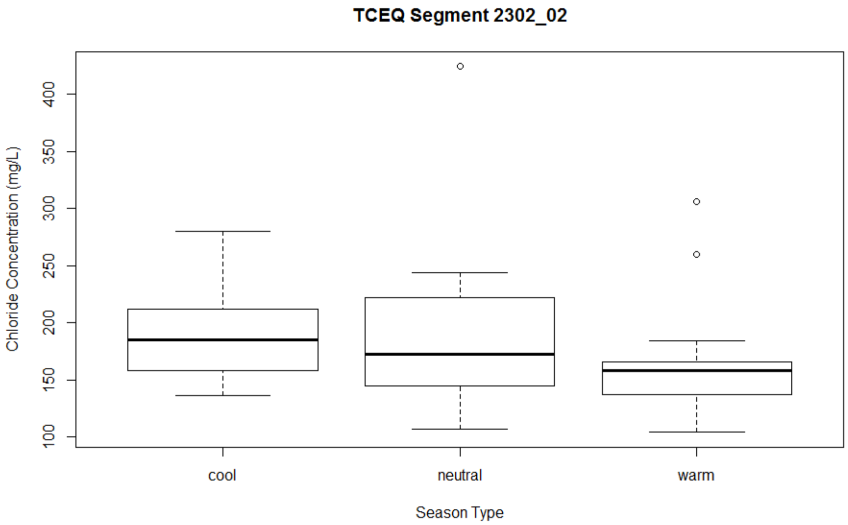
Chloride



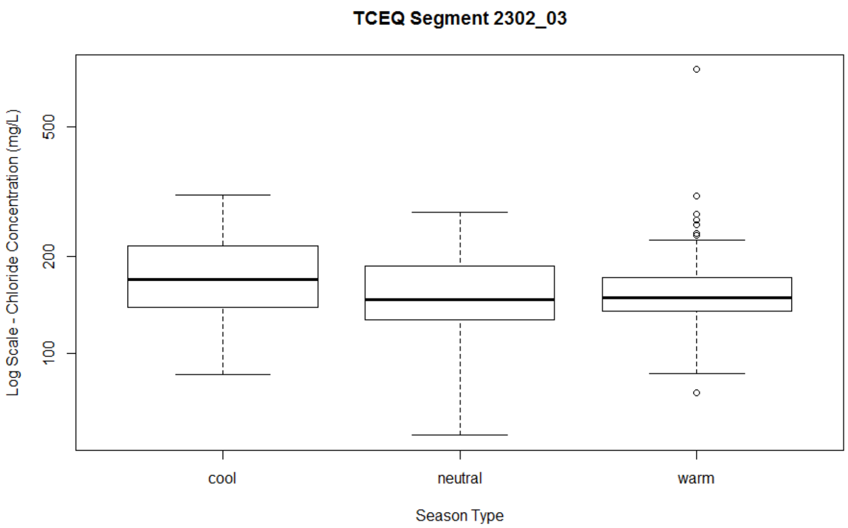
ANOVA		p-value
	Season Difference	0.0129
TUKEY	Season Comparison	p-value
	neutral-cool	0.029
	warm-cool	0.017
	warm-neutral	0.999



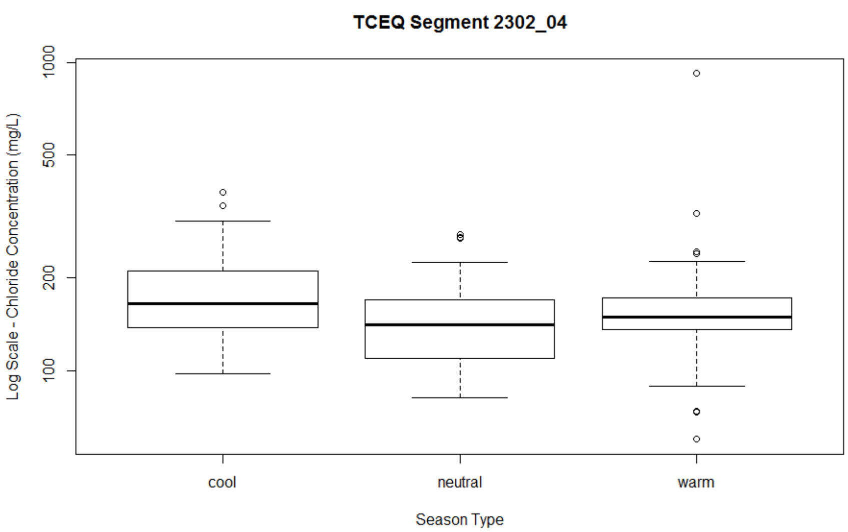
ANOVA		p-value
	Season Difference	0.0000428
TUKEY	Season Comparison	p-value
	neutral-cool	0.092
	warm-cool	0.000034
	warm-neutral	0.035



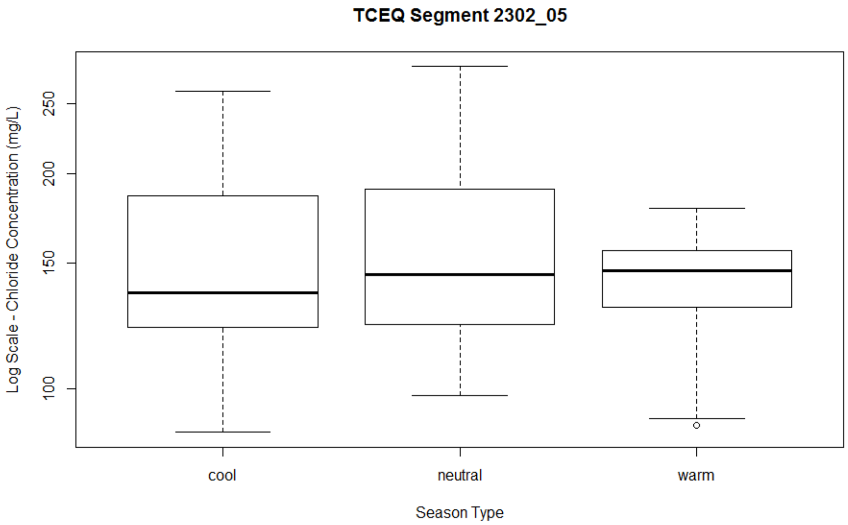
ANOVA		p-value
	Season Difference	0.348
TUKEY	Season Comparison	p-value
	neutral-cool	0.999
	warm-cool	0.507
	warm-neutral	0.382



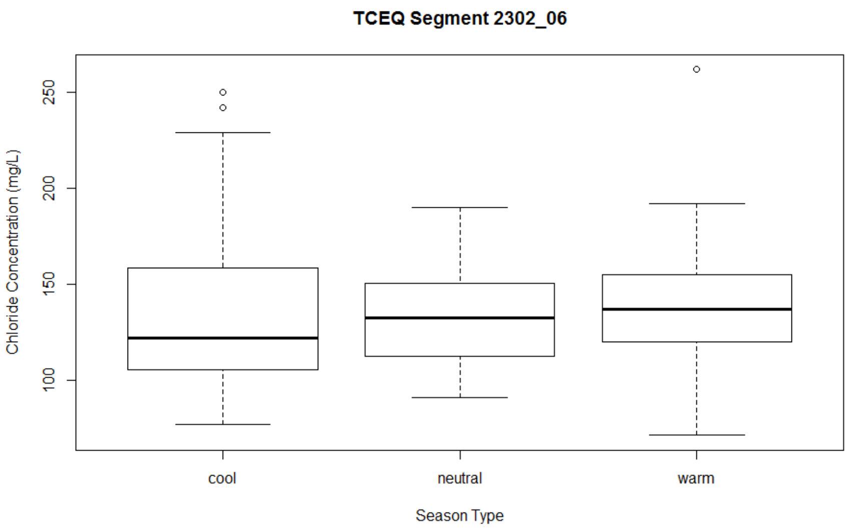
ANOVA		p-value
	Season Difference	0.146
TUKEY	Season Comparison	p-value
	neutral-cool	0.123
	warm-cool	0.357
	warm-neutral	0.709



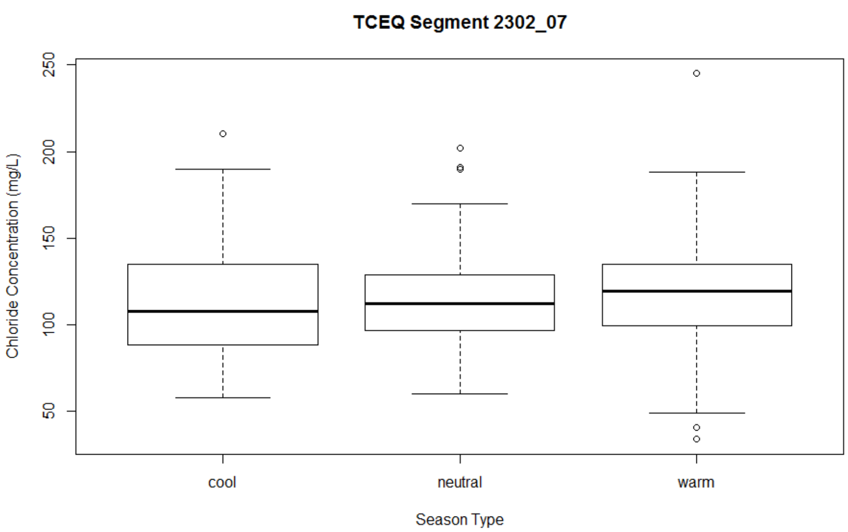
ANOVA		p-value
	Season Difference	0.0538
TUKEY	Season Comparison	p-value
	neutral-cool	0.042
	warm-cool	0.313
	warm-neutral	0.388



ANOVA		p-value
	Season Difference	0.358
TUKEY	Season Comparison	p-value
	neutral-cool	0.987
	warm-cool	0.602
	warm-neutral	0.353

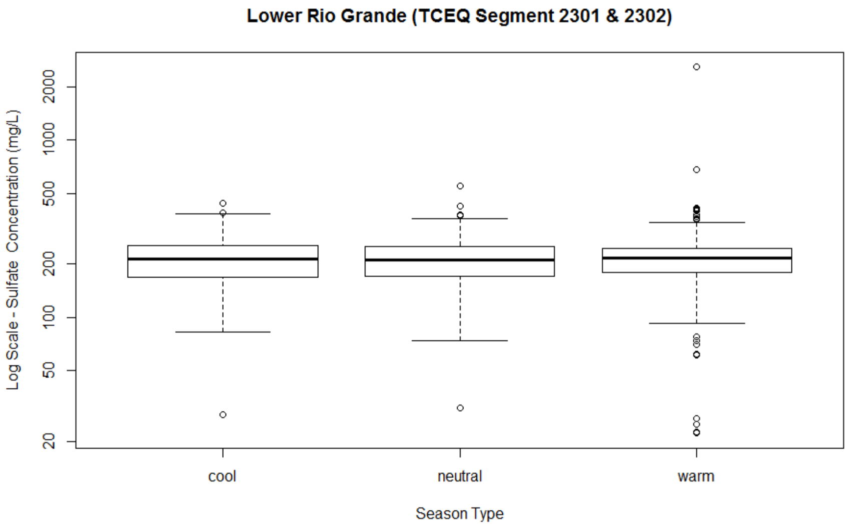


ANOVA		p-value
	Season Difference	0.893
TUKEY	Season Comparison	p-value
	neutral-cool	0.895
	warm-cool	0.992
	warm-neutral	0.92

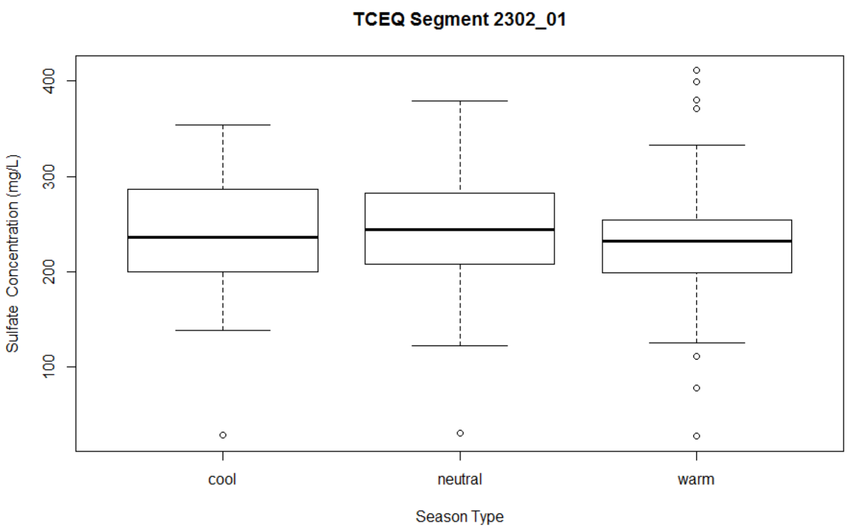


ANOVA		p-value
	Season Difference	0.493
TUKEY	Season Comparison	p-value
	neutral-cool	0.993
	warm-cool	0.65
	warm-neutral	0.526

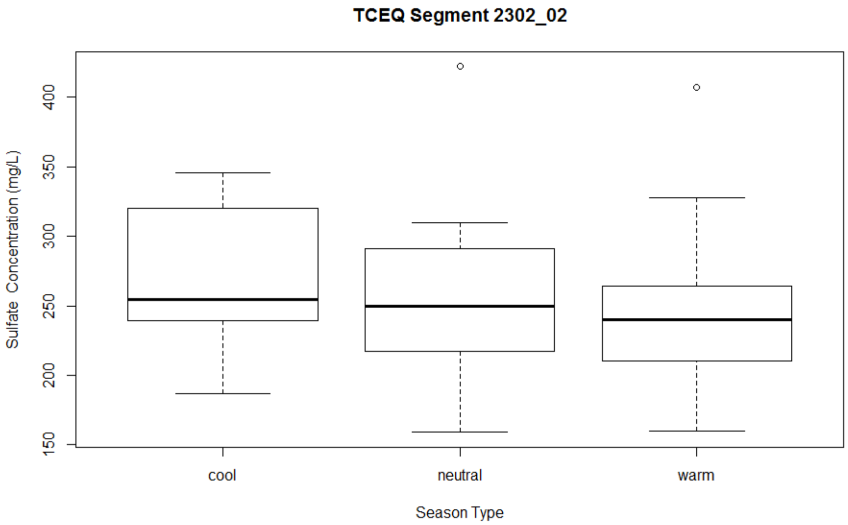
Sulfate



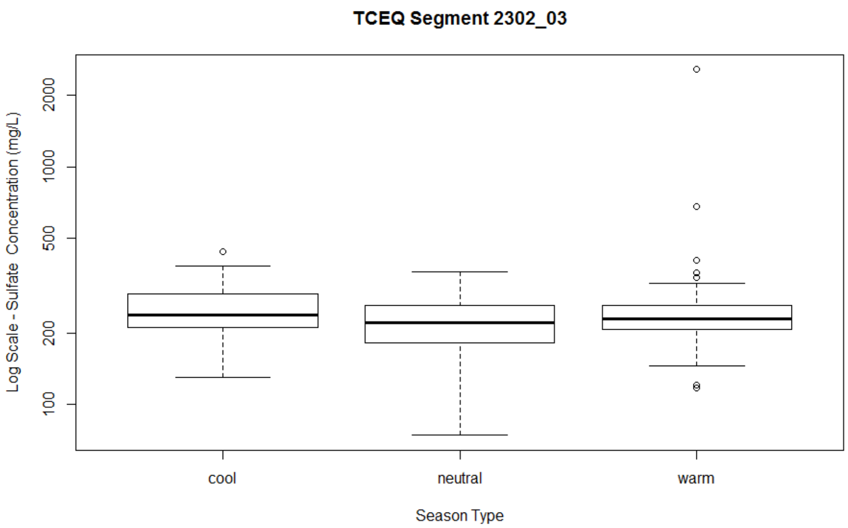
ANOVA		p-value
	Season Difference	0.813
TUKEY	Season Comparison	p-value
	neutral-cool	0.98
	warm-cool	0.927
	warm-neutral	0.806



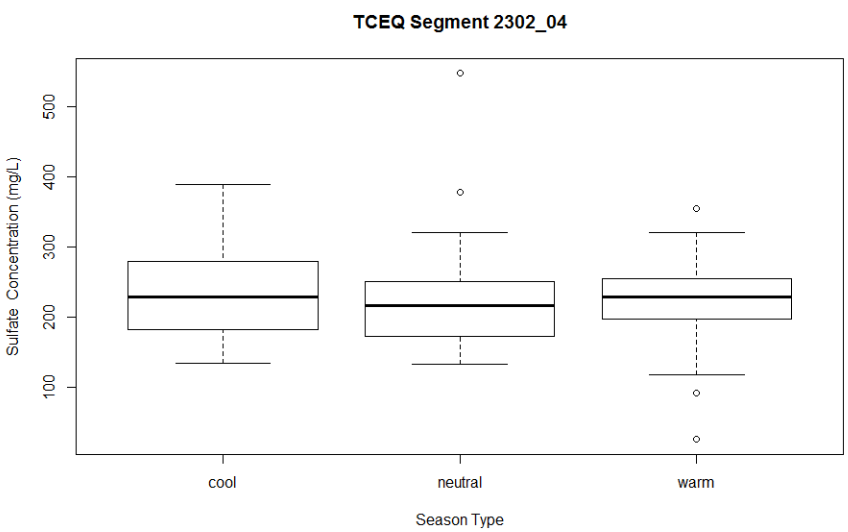
ANOVA		p-value
	Season Difference	0.309
TUKEY	Season Comparison	p-value
	neutral-cool	0.94
	warm-cool	0.355
	warm-neutral	0.497



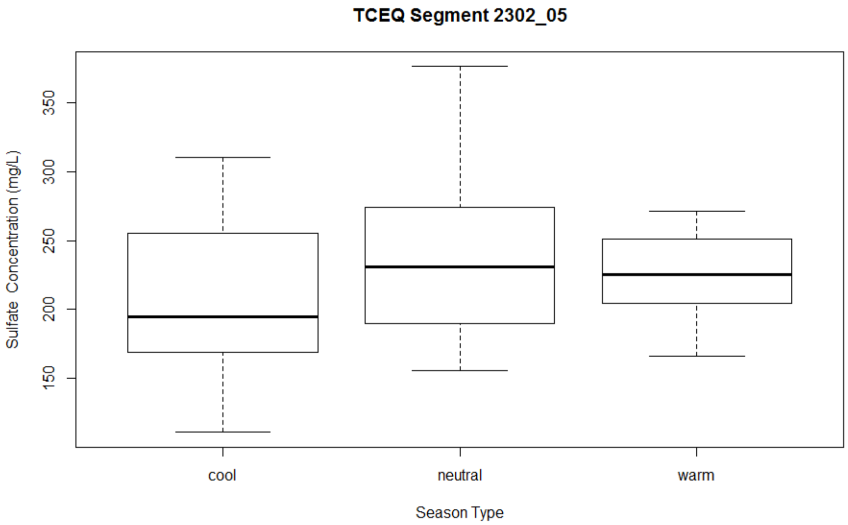
ANOVA		p-value
	Season Difference	0.799
TUKEY	Season Comparison	p-value
	neutral-cool	0.928
	warm-cool	0.784
	warm-neutral	0.926



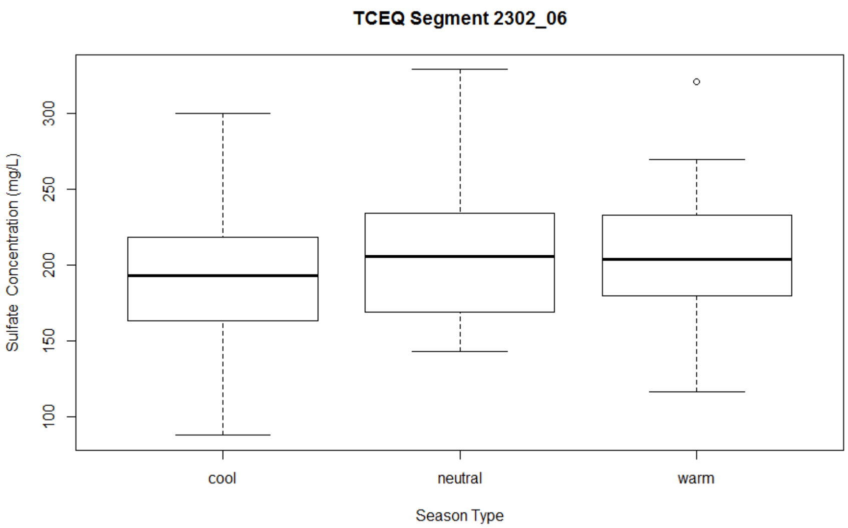
ANOVA		p-value
	Season Difference	0.343
TUKEY	Season Comparison	p-value
	neutral-cool	0.73
	warm-cool	0.893
	warm-neutral	0.311



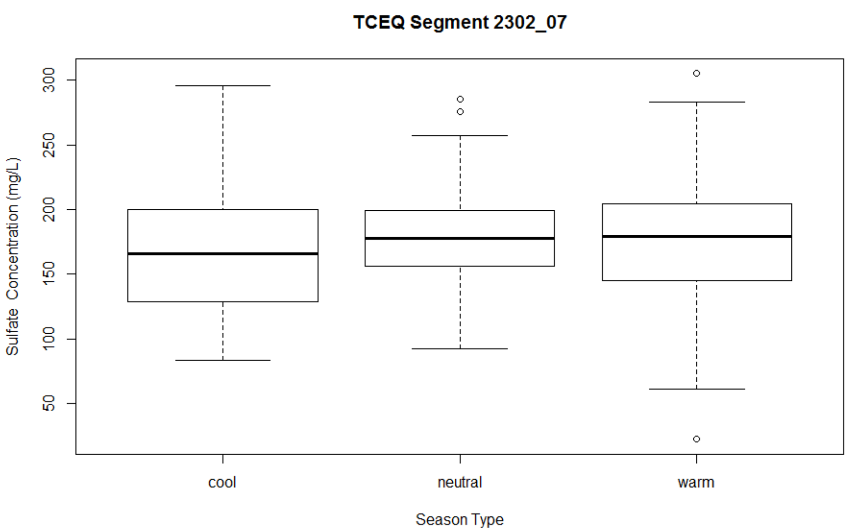
ANOVA		p-value
	Season Difference	0.502
TUKEY	Season Comparison	p-value
	neutral-cool	0.506
	warm-cool	0.607
	warm-neutral	0.948



ANOVA		p-value
	Season Difference	0.554
TUKEY	Season Comparison	p-value
	neutral-cool	0.534
	warm-cool	0.855
	warm-neutral	0.812

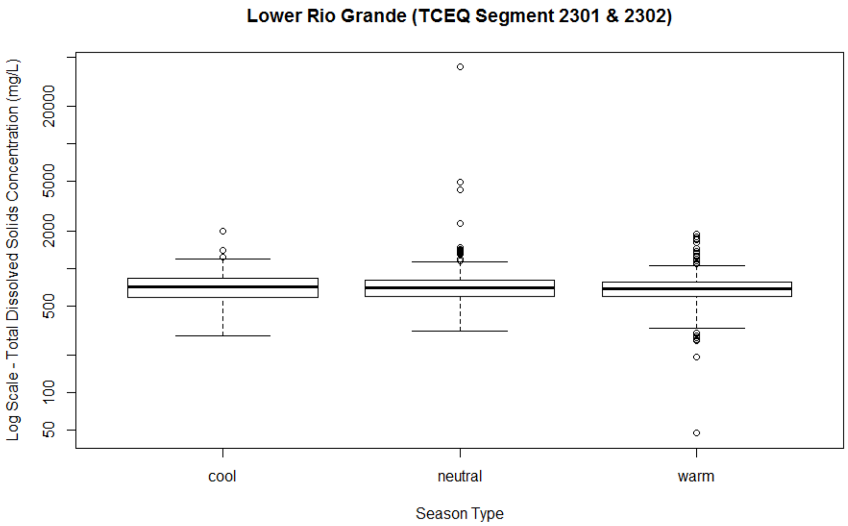


ANOVA		p-value
	Season Difference	0.456
TUKEY	Season Comparison	p-value
	neutral-cool	0.496
	warm-cool	0.518
	warm-neutral	0.978

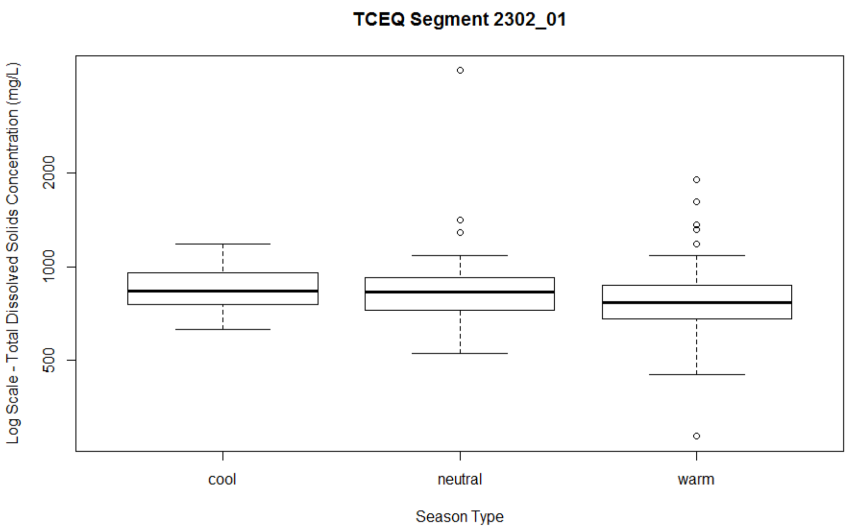


ANOVA		p-value
	Season Difference	0.687
TUKEY	Season Comparison	p-value
	neutral-cool	0.667
	warm-cool	0.815
	warm-neutral	0.944

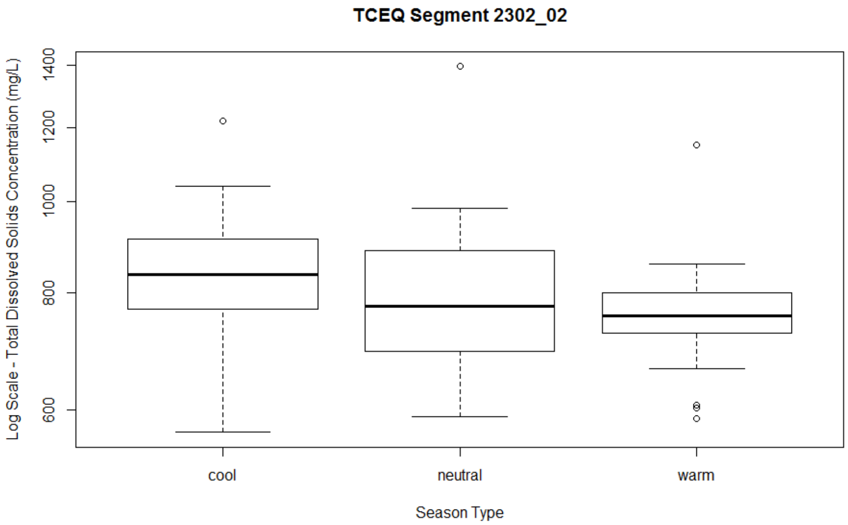
Total Dissolved Solids



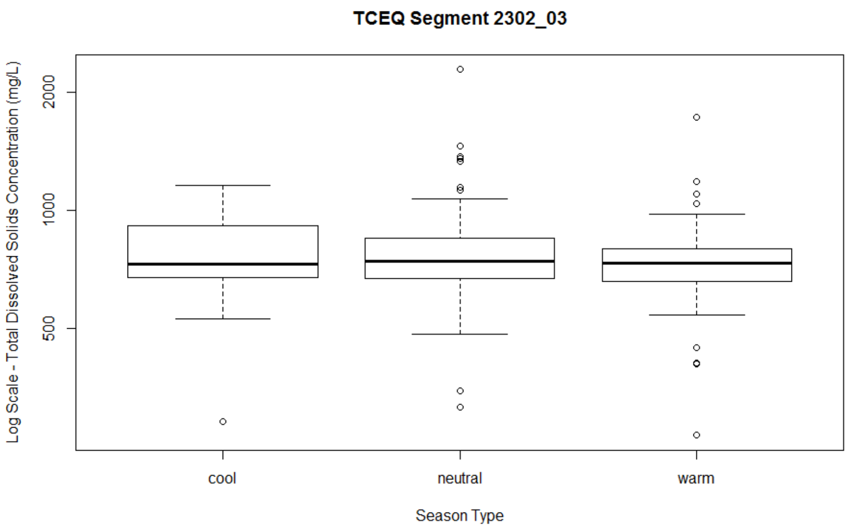
ANOVA		p-value
	Season Difference	0.215
TUKEY	Season Comparison	p-value
	neutral-cool	0.494
	warm-cool	0.936
	warm-neutral	0.198



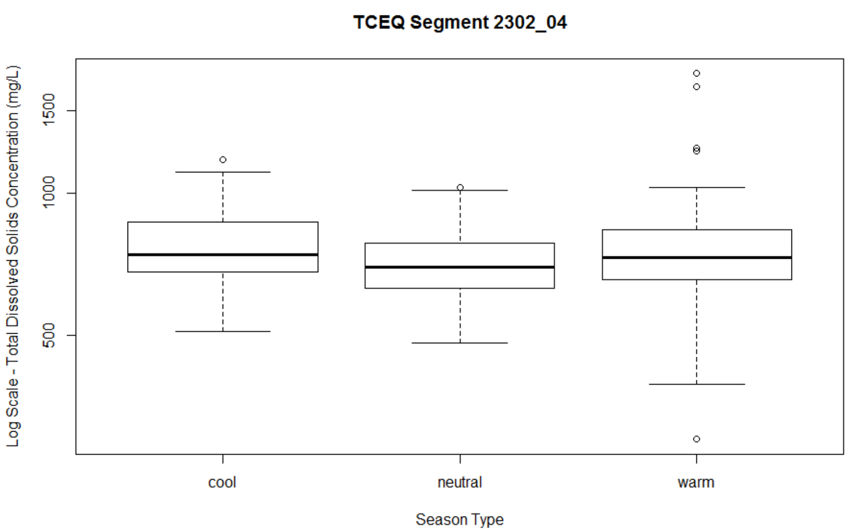
ANOVA		p-value
	Season Difference	0.0783
TUKEY	Season Comparison	p-value
	neutral-cool	0.999
	warm-cool	0.2
	warm-neutral	0.114



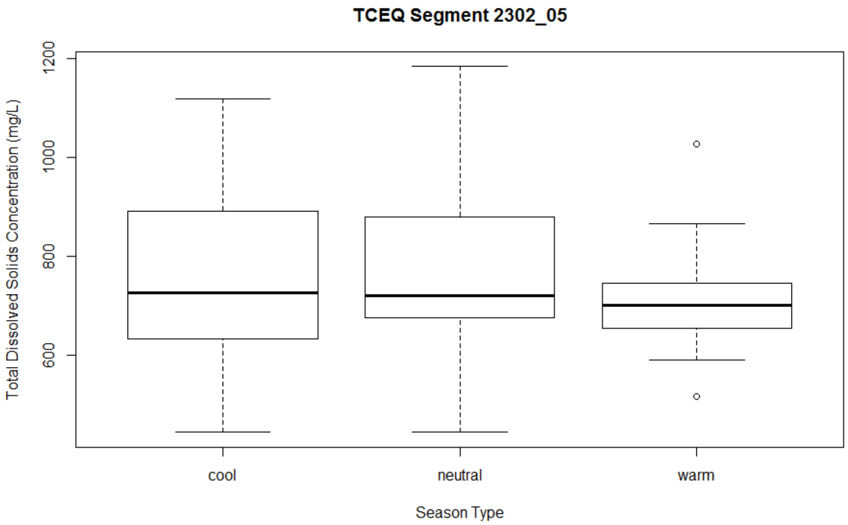
ANOVA		p-value
	Season Difference	0.35
TUKEY	Season Comparison	p-value
	neutral-cool	0.801
	warm-cool	0.353
	warm-neutral	0.583



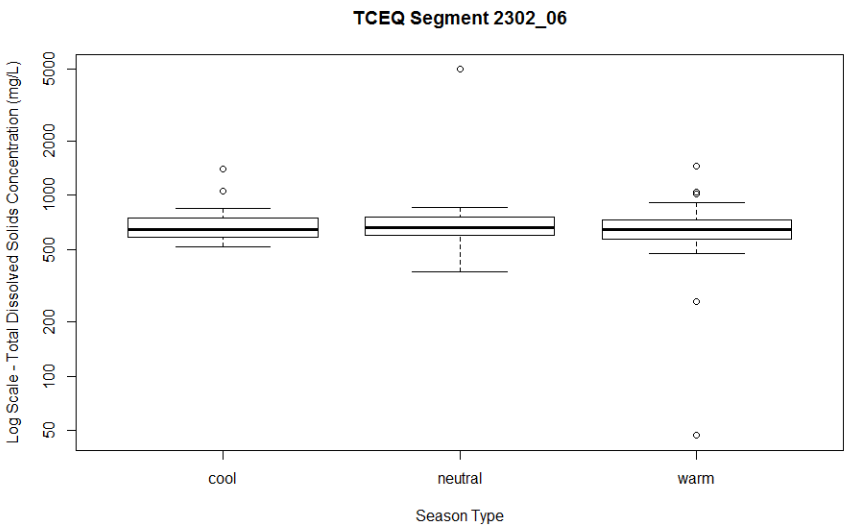
ANOVA		p-value
	Season Difference	0.325
TUKEY	Season Comparison	p-value
	neutral-cool	0.973
	warm-cool	0.604
	warm-neutral	0.324



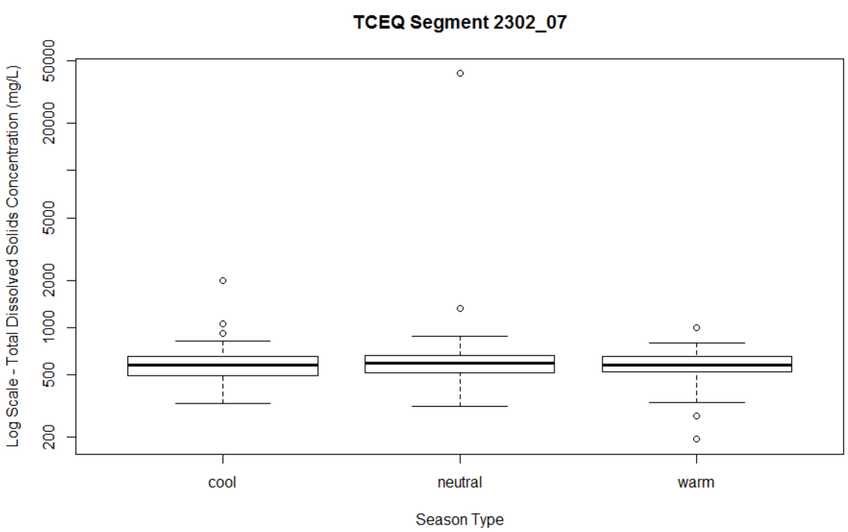
ANOVA		p-value
	Season Difference	0.0807
TUKEY	Season Comparison	p-value
	neutral-cool	0.0678
	warm-cool	0.591
	warm-neutral	0.276



ANOVA		p-value
	Season Difference	0.678
TUKEY	Season Comparison	p-value
	neutral-cool	0.991
	warm-cool	0.823
	warm-neutral	0.675

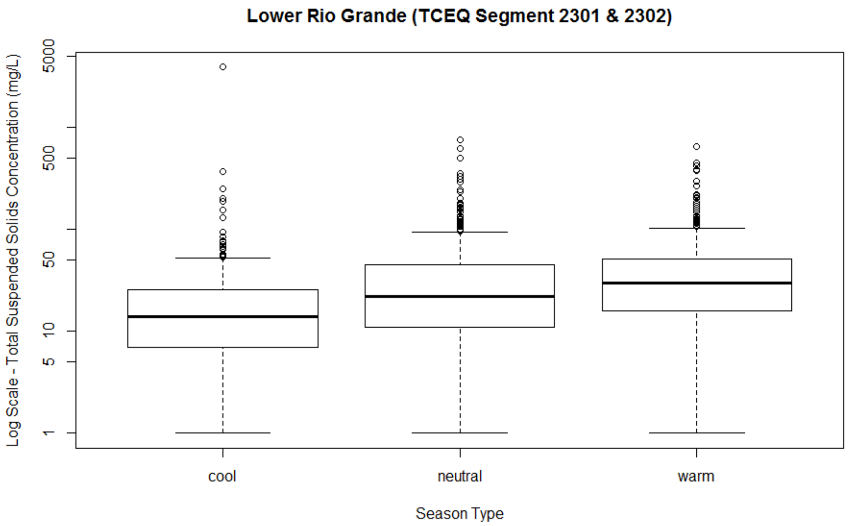


ANOVA		p-value
	Season Difference	0.46
TUKEY	Season Comparison	p-value
	neutral-cool	0.66
	warm-cool	0.98
	warm-neutral	0.445

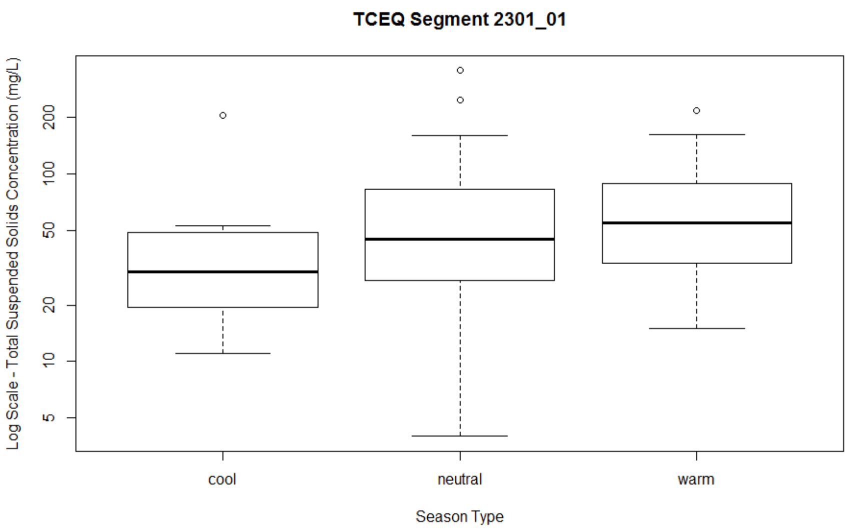


ANOVA		p-value
	Season Difference	0.363
TUKEY	Season Comparison	p-value
	neutral-cool	0.509
	warm-cool	0.999
	warm-neutral	0.384

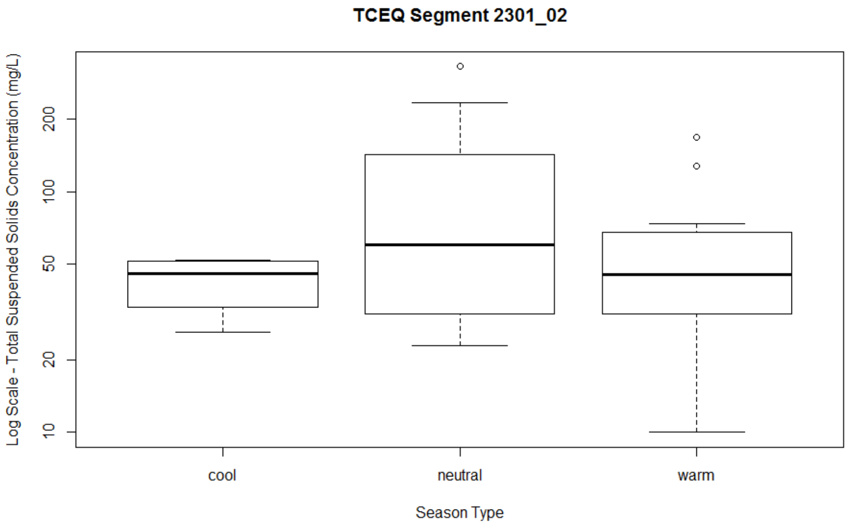
Total Suspended Solids



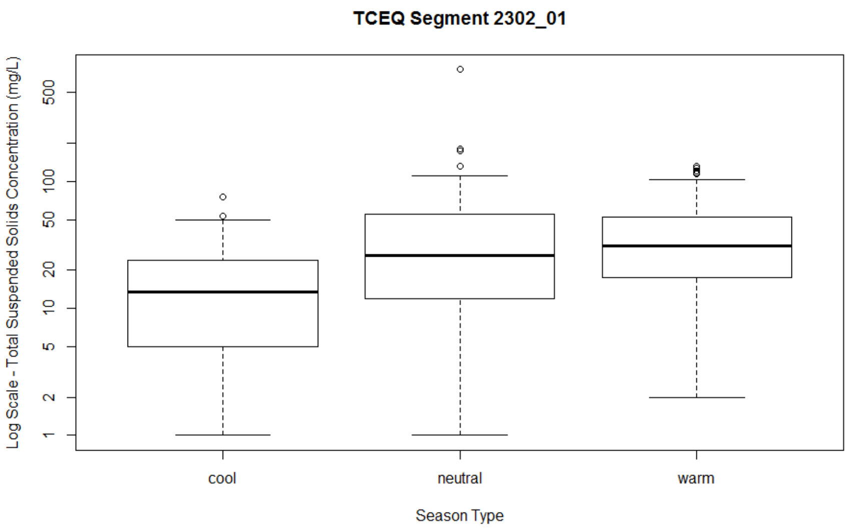
ANOVA		p-value
	Season Difference	0.598
TUKEY	Season Comparison	p-value
	neutral-cool	0.789
	warm-cool	0.568
	warm-neutral	0.924



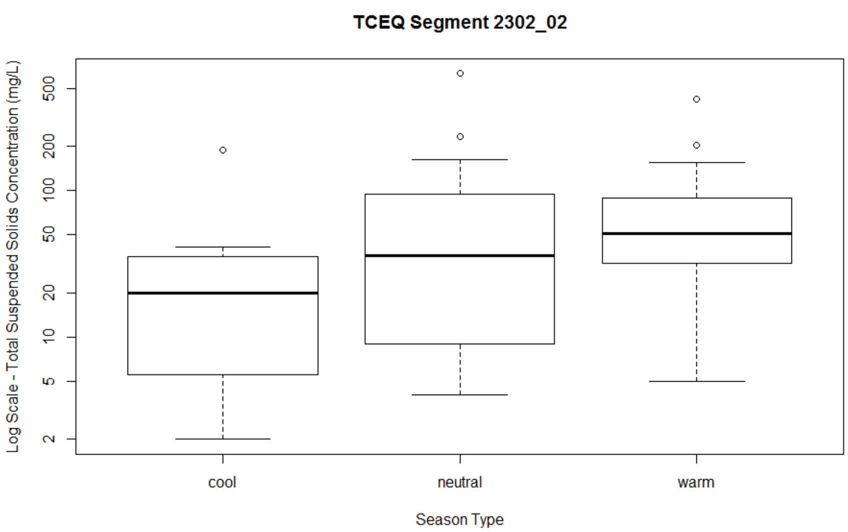
ANOVA		p-value
	Season Difference	0.826
TUKEY	Season Comparison	p-value
	neutral-cool	0.814
	warm-cool	0.87
	warm-neutral	0.993



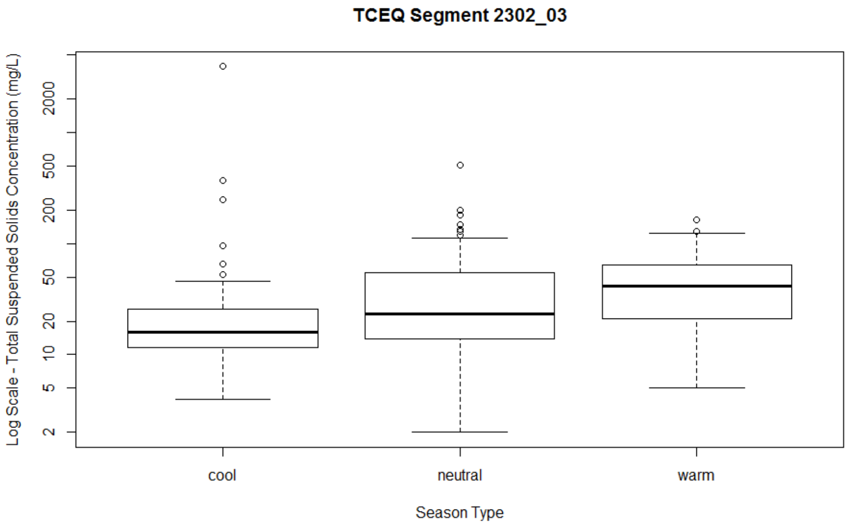
ANOVA		p-value
	Season Difference	0.206
TUKEY	Season Comparison	p-value
	neutral-cool	0.345
	warm-cool	0.919
	warm-neutral	0.296



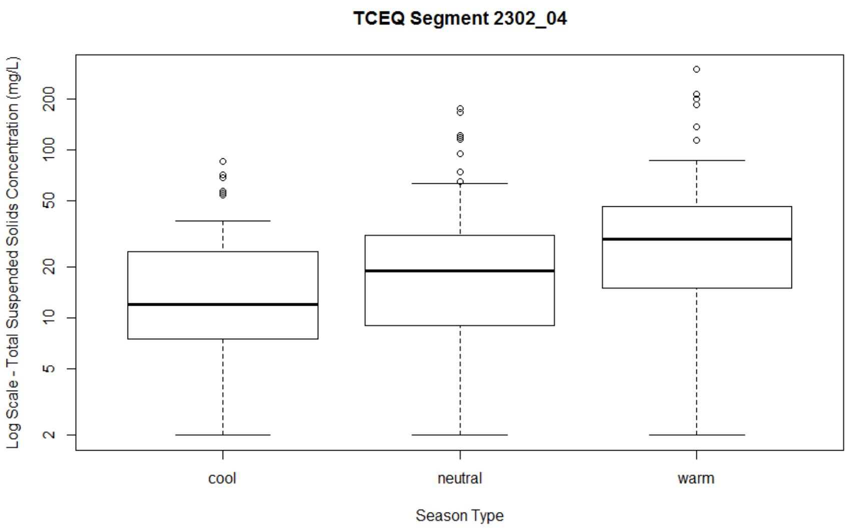
ANOVA		p-value
	Season Difference	0.0461
TUKEY	Season Comparison	p-value
	neutral-cool	0.036
	warm-cool	0.162
	warm-neutral	0.643



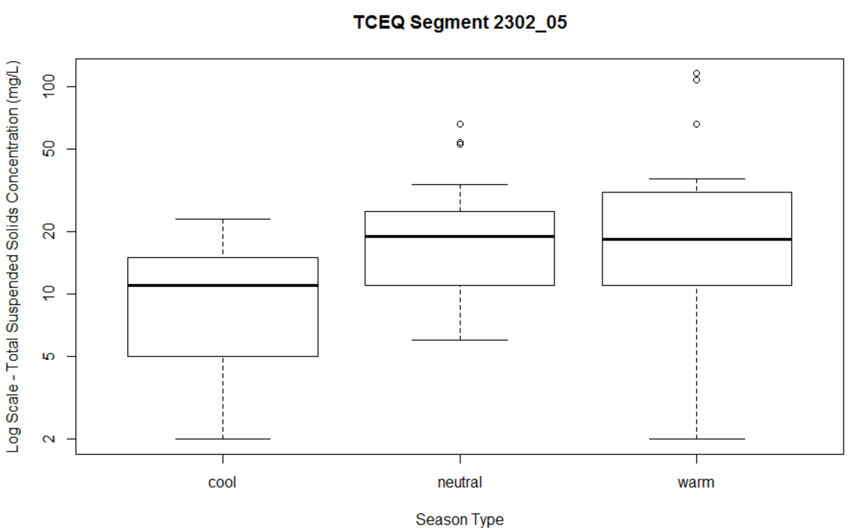
ANOVA		p-value
	Season Difference	0.462
TUKEY	Season Comparison	p-value
	neutral-cool	0.474
	warm-cool	0.498
	warm-neutral	0.995



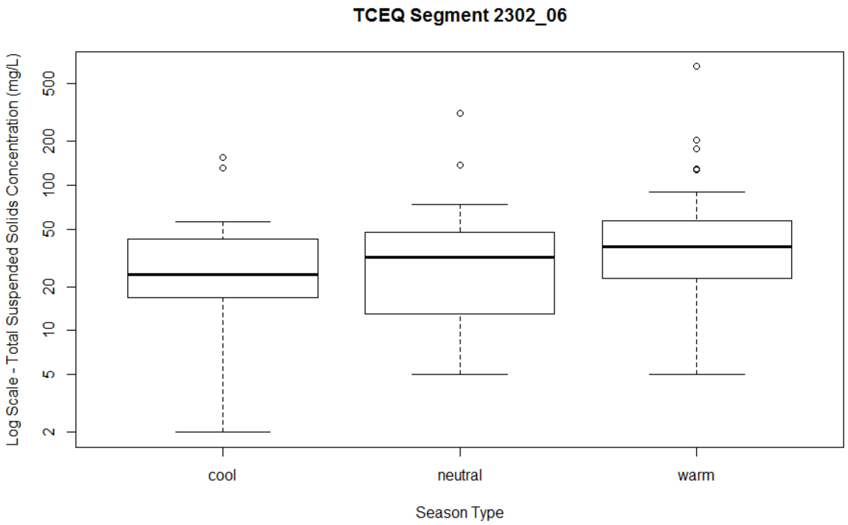
ANOVA		p-value
	Season Difference	0.222
TUKEY	Season Comparison	p-value
	neutral-cool	0.273
	warm-cool	0.23
	warm-neutral	0.999



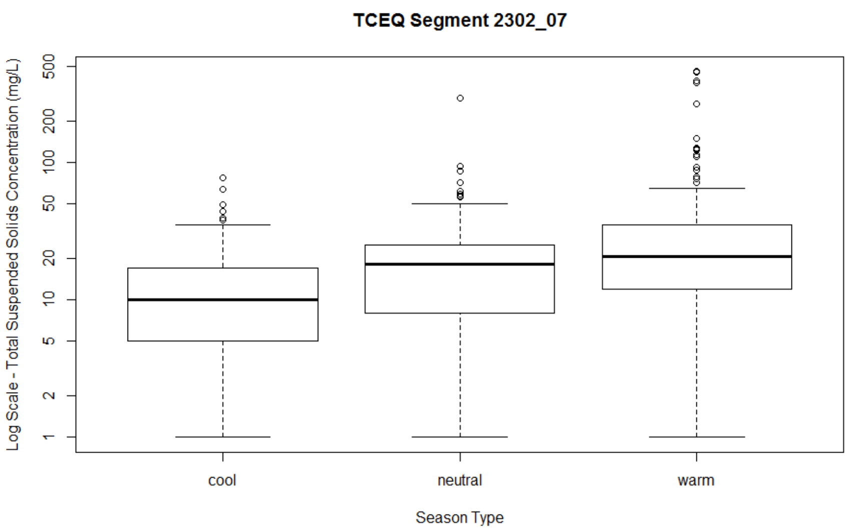
ANOVA		p-value
	Season Difference	0.00705
TUKEY	Season Comparison	p-value
	neutral-cool	0.162
	warm-cool	0.0047
	warm-neutral	0.511



ANOVA		p-value
	Season Difference	0.0989
TUKEY	Season Comparison	p-value
	neutral-cool	0.382
	warm-cool	0.082
	warm-neutral	0.517

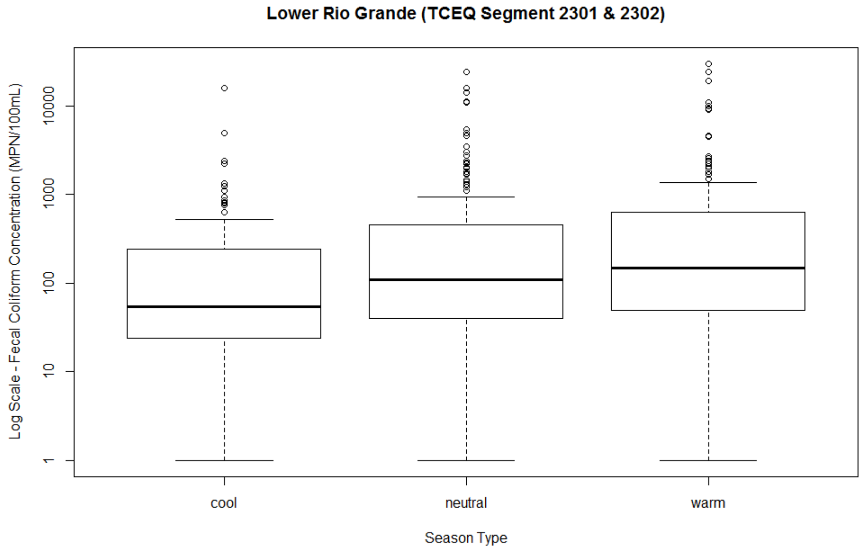


ANOVA		p-value
	Season Difference	0.329
TUKEY	Season Comparison	p-value
	neutral-cool	0.923
	warm-cool	0.357
	warm-neutral	0.551

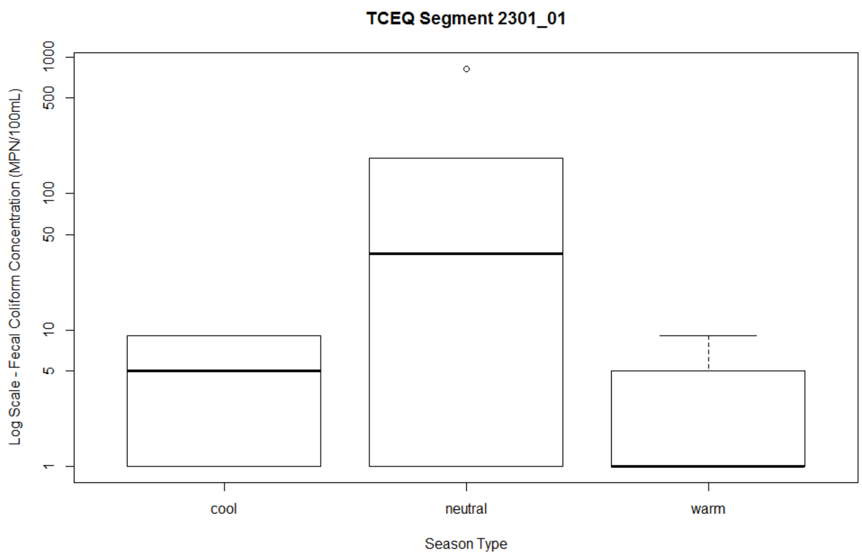


ANOVA		p-value
	Season Difference	0.000247
TUKEY	Season Comparison	p-value
	neutral-cool	0.436
	warm-cool	0.00038
	warm-neutral	0.012

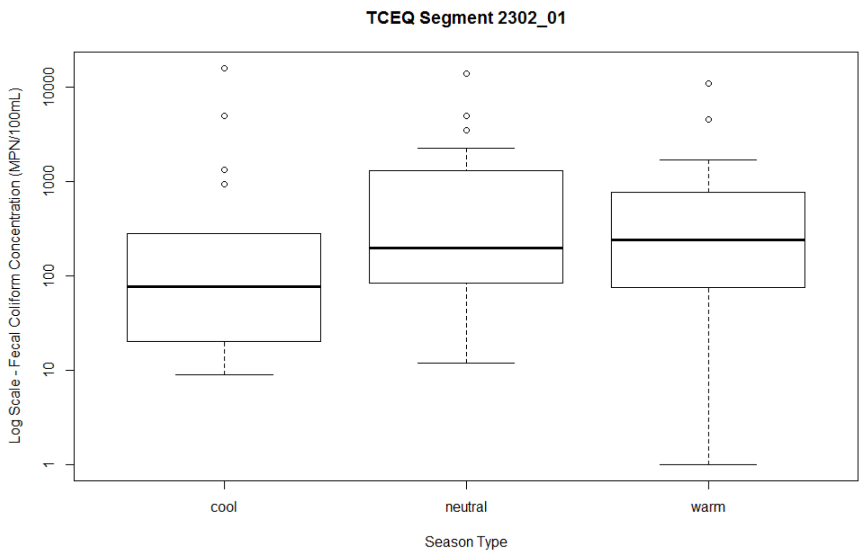
Fecal Coliform



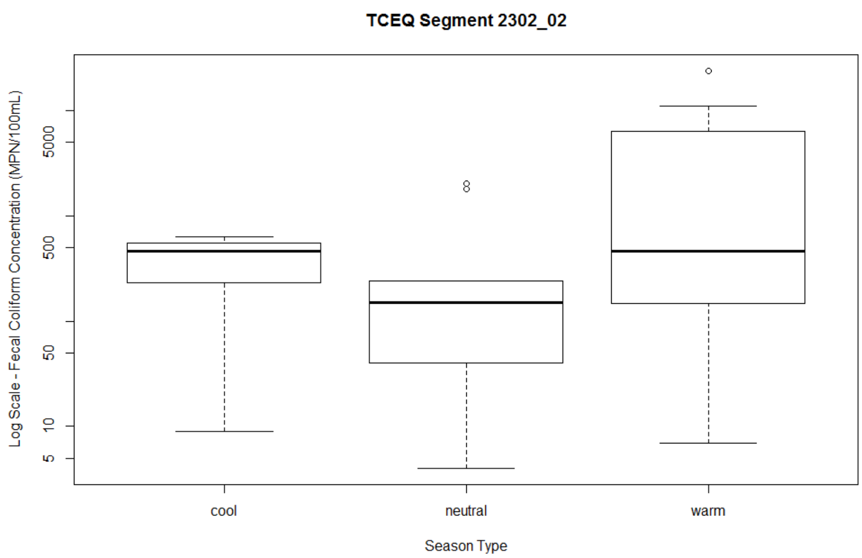
ANOVA		p-value
	Season Difference	0.0236
TUKEY	Season Comparison	p-value
	neutral-cool	0.139
	warm-cool	0.017
	warm-neutral	0.686



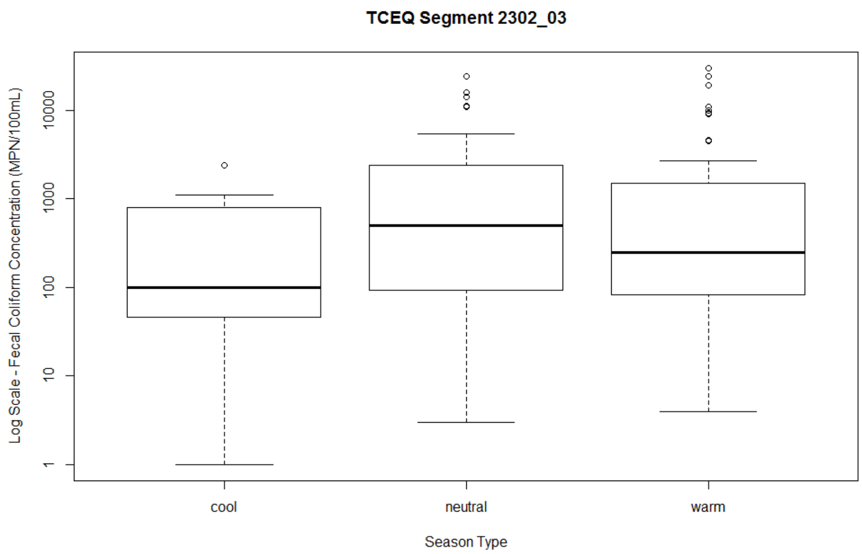
ANOVA		p-value
	Season Difference	0.548
TUKEY	Season Comparison	p-value
	neutral-cool	0.69
	warm-cool	0.999
	warm-neutral	0.61



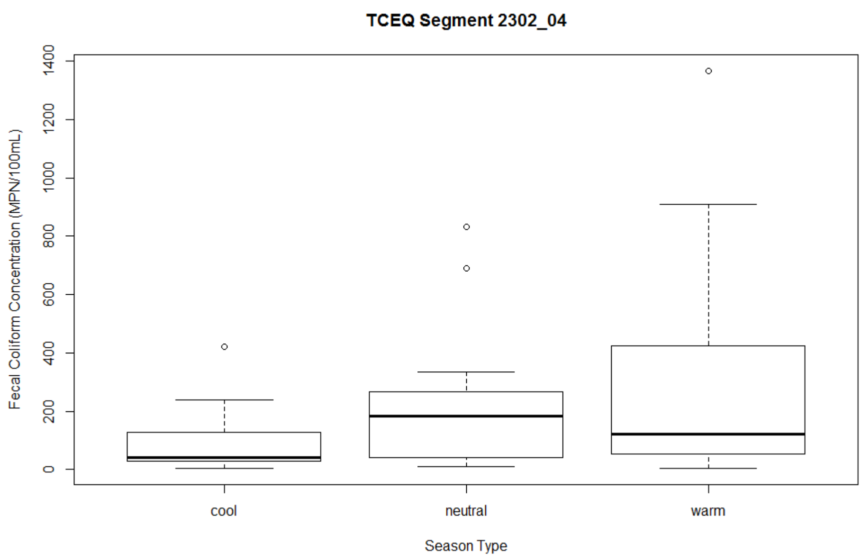
ANOVA		p-value
	Season Difference	0.74
TUKEY	Season Comparison	p-value
	neutral-cool	0.997
	warm-cool	0.79
	warm-neutral	0.802



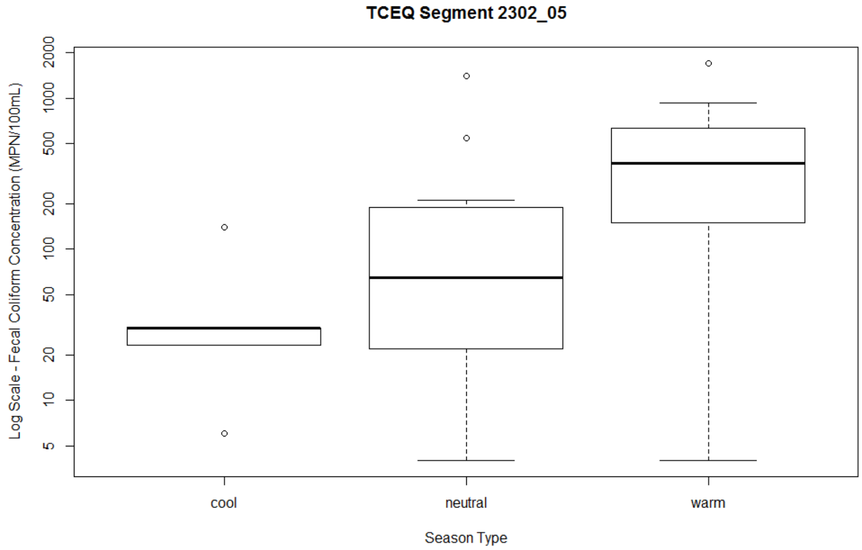
ANOVA		p-value
	Season Difference	0.268
TUKEY	Season Comparison	p-value
	neutral-cool	0.999
	warm-cool	0.489
	warm-neutral	0.284



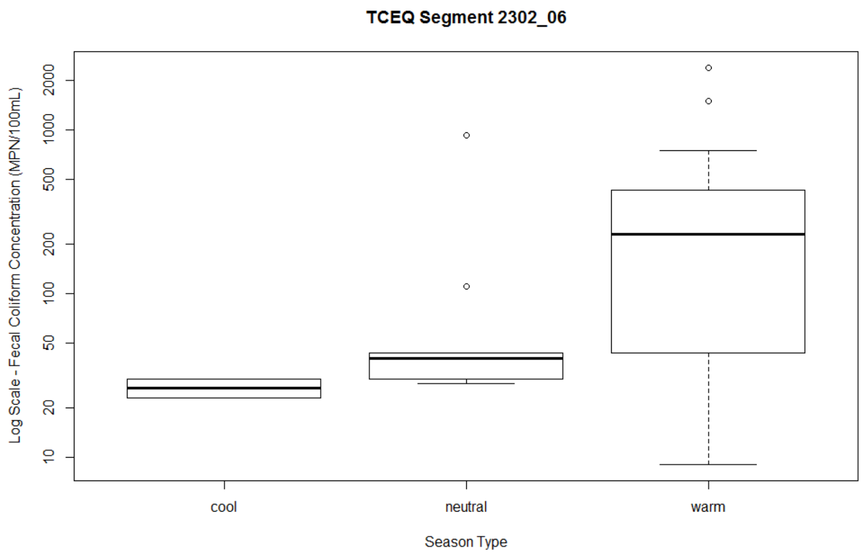
ANOVA		p-value
	Season Difference	0.163
TUKEY	Season Comparison	p-value
	neutral-cool	0.214
	warm-cool	0.17
	warm-neutral	1



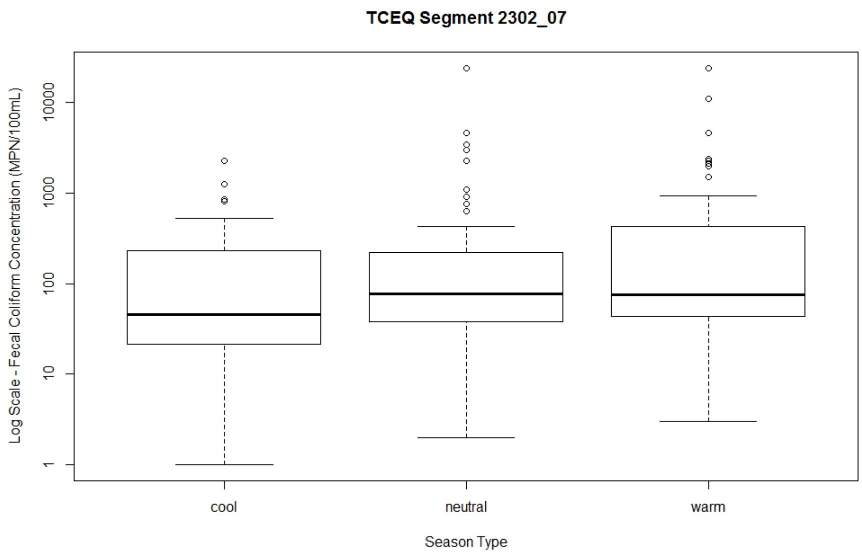
ANOVA		p-value
	Season Difference	0.217
TUKEY	Season Comparison	p-value
	neutral-cool	0.424
	warm-cool	0.199
	warm-neutral	0.967



ANOVA		p-value
	Season Difference	0.126
TUKEY	Season Comparison	p-value
	neutral-cool	0.701
	warm-cool	0.138
	warm-neutral	0.294



ANOVA		p-value
	Season Difference	0.185
TUKEY	Season Comparison	p-value
	neutral-cool	0.945
	warm-cool	0.317
	warm-neutral	0.26



ANOVA		p-value
	Season Difference	0.169
TUKEY	Season Comparison	p-value
	neutral-cool	0.446
	warm-cool	0.144
	warm-neutral	0.789

Appendix G

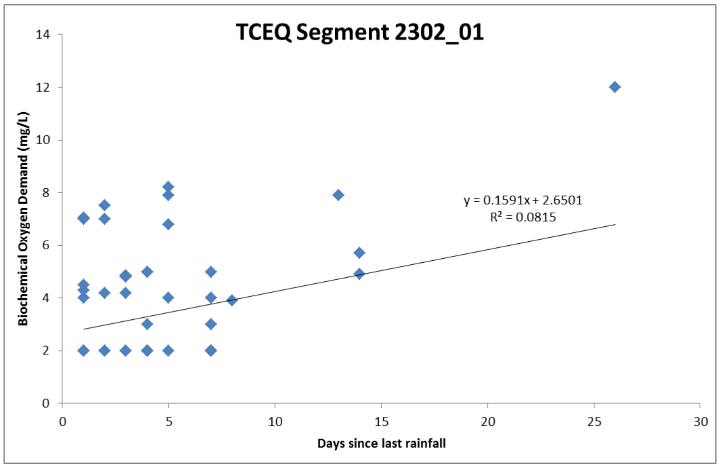
Seasonality analysis, with respect to precipitation, of US and historical water quality.

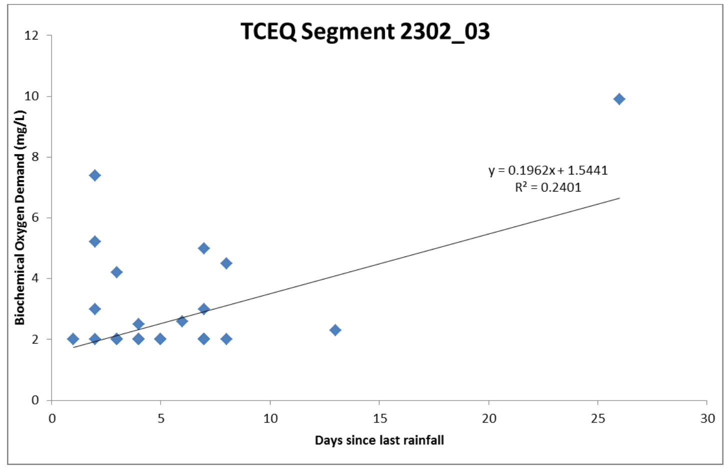
Linear Regression Analysis of Seasonality, with Respect to Precipitation, of US Historical Water Quality Data

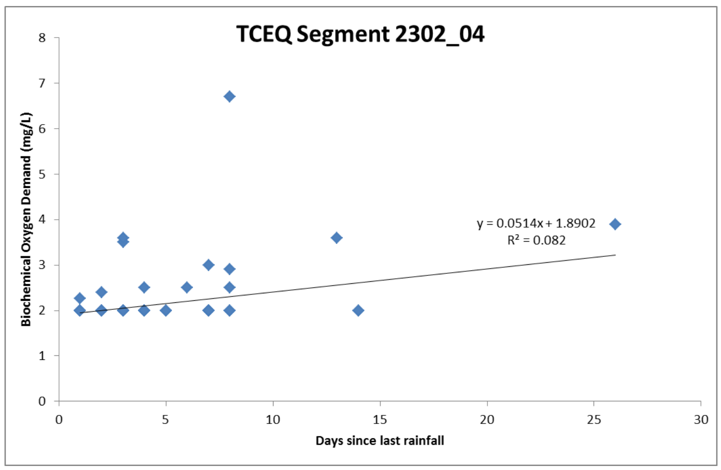
Data range: 2000-2014 (some years contain data gaps). All data analyzed was obtained from the TCEQ's SWQMIS database. Only analyses yielding statistically significant results are shown (i.e., $p \leq 0.05$).

Biochemical Oxygen Demand

Linear Regression		
AU	**R Squared**	**p-value**
2302_01	0.082 (+)	0.026
2302_03	0.240 (+)	0.0011
2302_04	0.079 (+)	0.0091

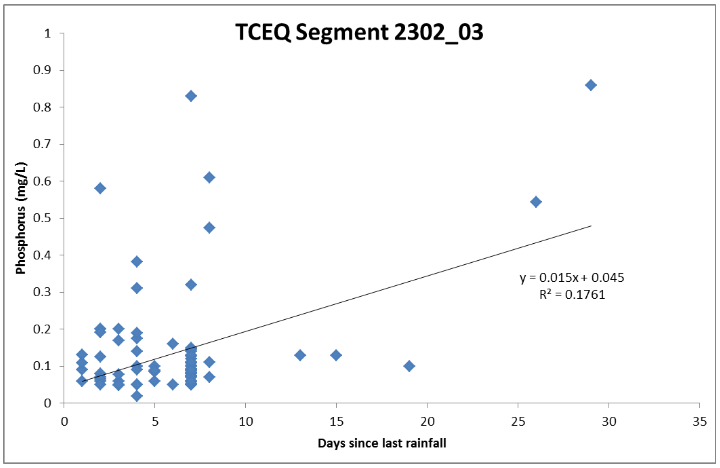

TCEQ Segment 2302_01
Biochemical Oxygen Demand (mg/L)
Days since last rainfall
y = 0.1591x + 2.6501
R² = 0.0815
0
2
4
6
8
10
12
14
0
5
10
15
20
25
30


TCEQ Segment 2302_03
Biochemical Oxygen Demand (mg/L)
Days since last rainfall
y = 0.1962x + 1.5441
R² = 0.2401
0
2
4
6
8
10
12
0
5
10
15
20
25
30


TCEQ Segment 2302_04
Biochemical Oxygen Demand (mg/L)
Days since last rainfall
y = 0.0514x + 1.8902
R² = 0.082
0
1
2
3
4
5
6
7
8
0
5
10
15
20
25
30

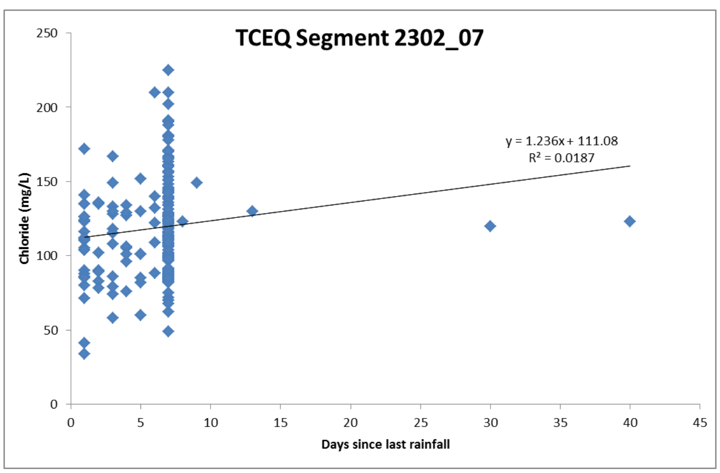
Total Phosphorus

Linear Regression		
2302_03	0.176 (+)	0.000028



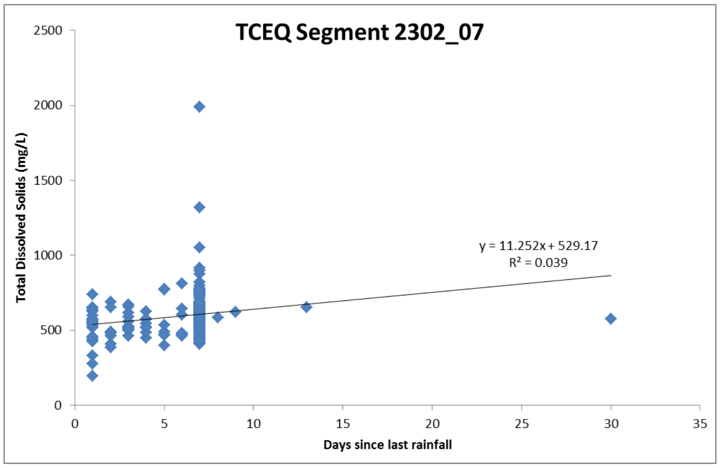
Chloride

Linear Regression		
2302_07	0.019 (+)	0.045



Total Dissolved Solids

Linear Regression		
2302_07	0.039 (+)	0.0039



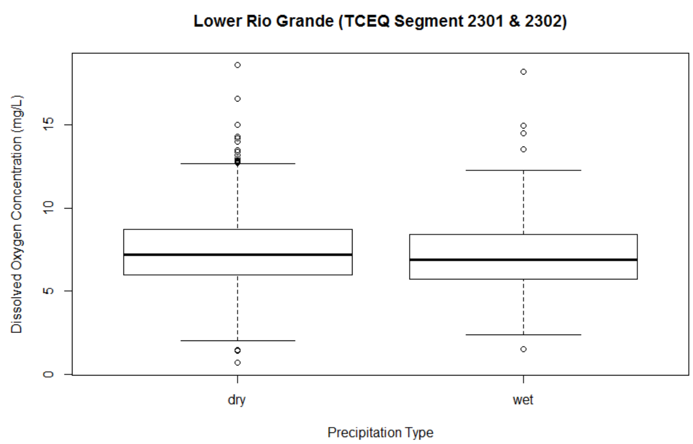
Boxplots and Nonparametric Analysis (Mann-Whitney U Tests) of Seasonality, with Respect to Precipitation, of US Historical Water Quality Data

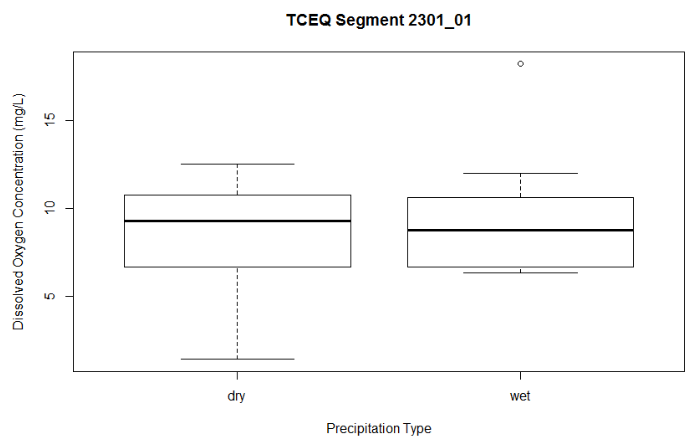
Data range: 2000-2014 (some years contain data gaps). All US water quality data was obtained from the TCEQ's SWQMIS database. Wet and dry categories are based on "days since last rainfall" as recorded in the SWQMIS database. Statistically significant results are highlighted ($p \leq 0.05$).

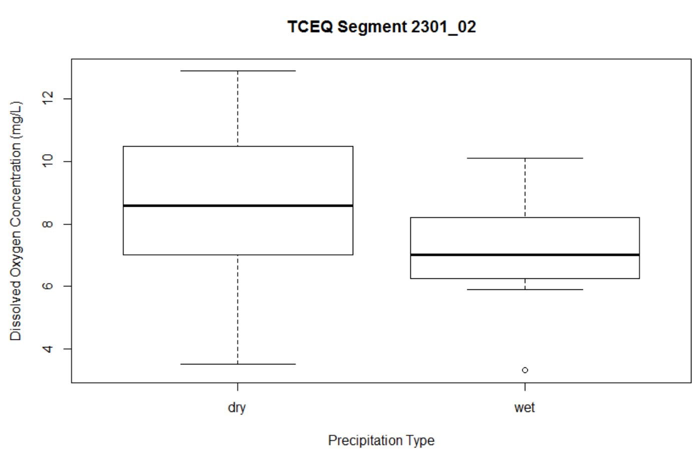
Days since last rainfall	Precipitation Type
0-4	wet
5+	dry

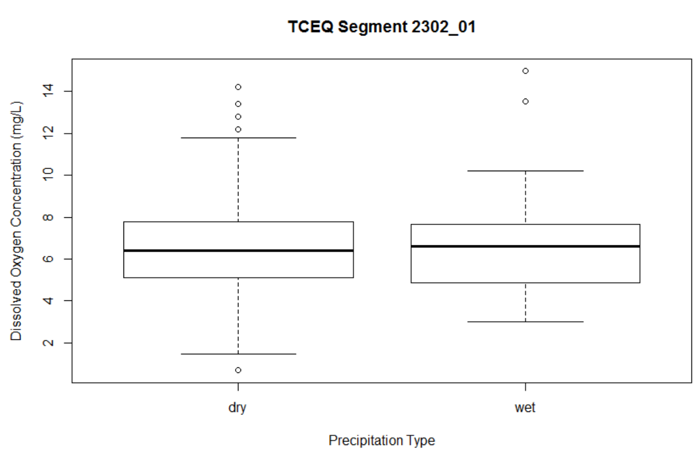
Dissolved Oxygen

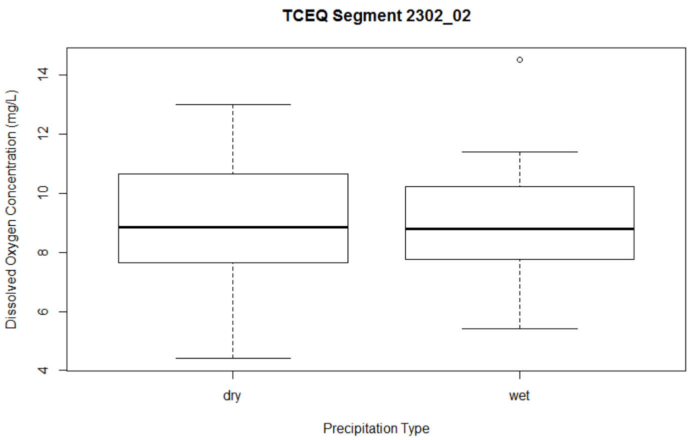
Mann-Whitney U Test		
AU	**W**	**p-value**
All	106630	0.099
2301_01	90	0.946
2301_02	106	0.117
2302_01	2593.5	0.997
2302_02	178.5	0.956
2302_03	3657	0.399
2302_04	5872	0.334
2302_05	0	0.4
2302_06	839	0.039
2302_07	5098	0.266

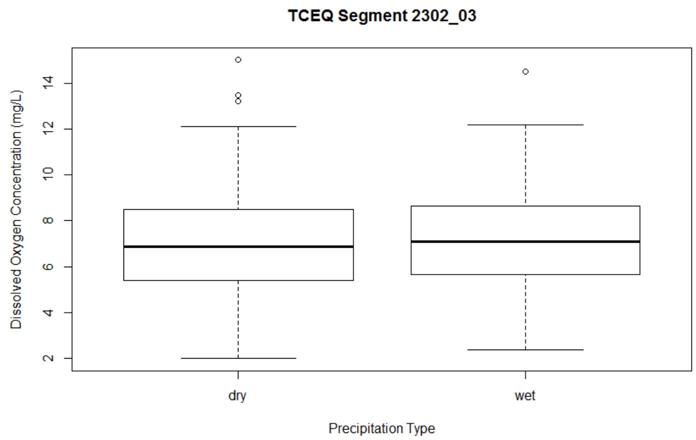


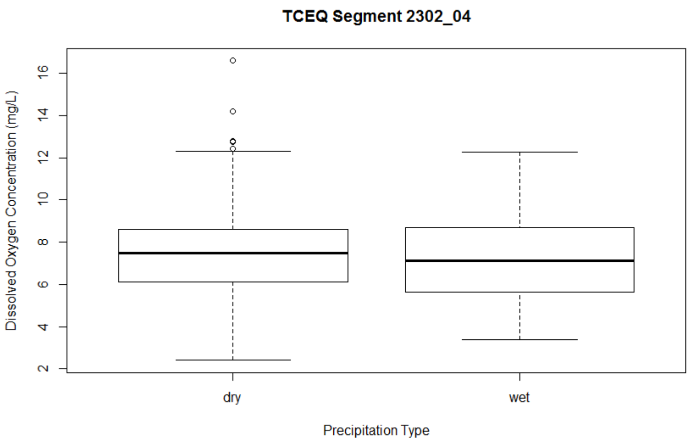


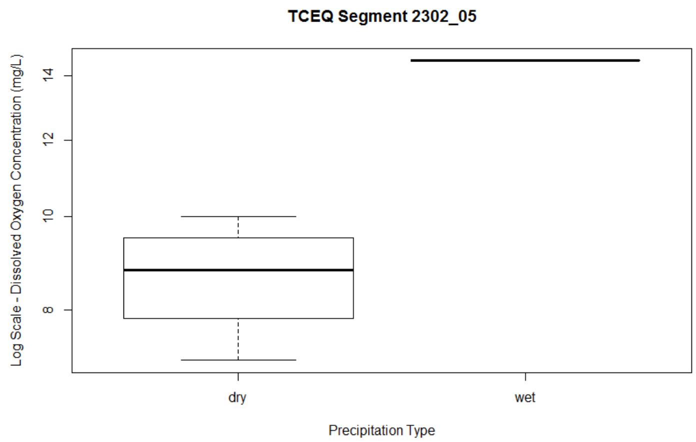


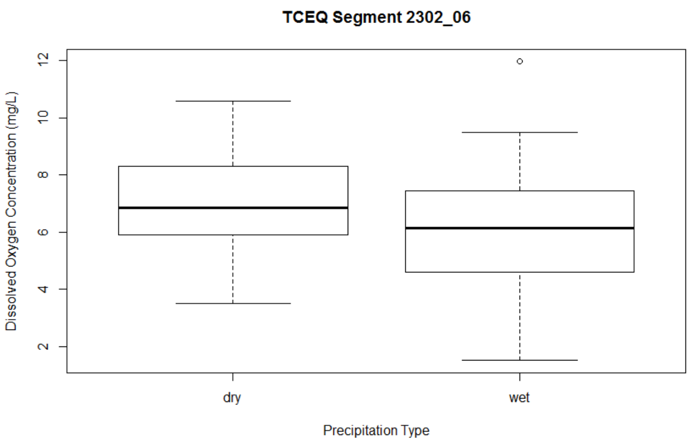


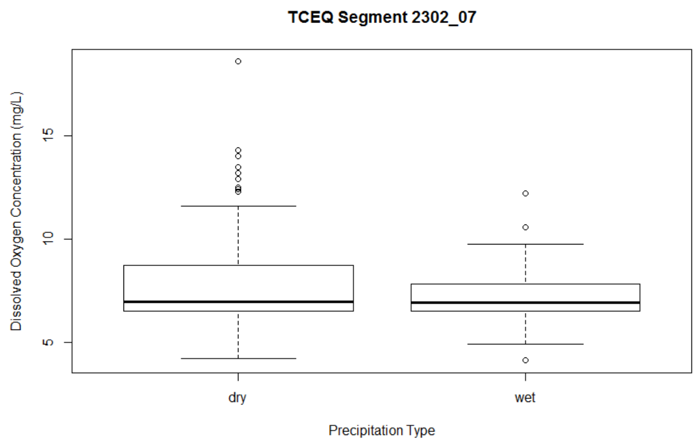

TCEQ Segment 2302_02
Dissolved Oxygen Concentration (mg/L)
4 6 8 10 12 14
dry
wet
Precipitation Type


TCEQ Segment 2302_03
Dissolved Oxygen Concentration (mg/L)
2 4 6 8 10 12 14
dry
wet
Precipitation Type


TCEQ Segment 2302_04
Dissolved Oxygen Concentration (mg/L)
2 4 6 8 10 12 14 16
dry
wet
Precipitation Type

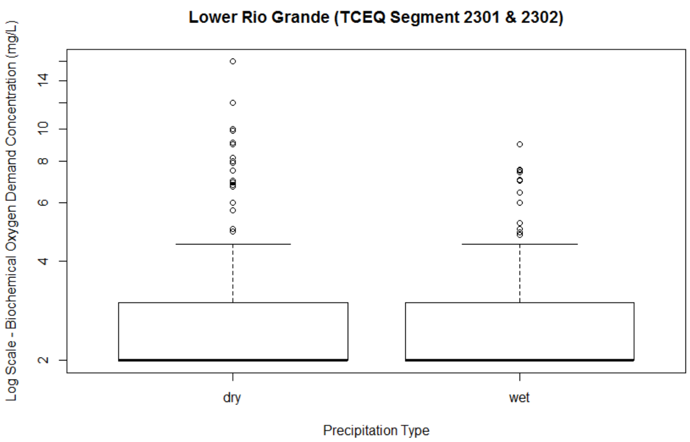

TCEQ Segment 2302_05
Log Scale - Dissolved Oxygen Concentration (mg/L)
8 10 12 14
dry
wet
Precipitation Type

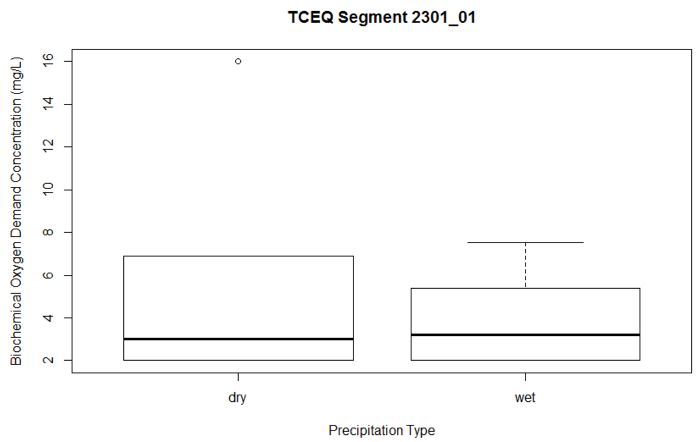

TCEQ Segment 2302_06
Dissolved Oxygen Concentration (mg/L)
2 4 6 8 10 12
dry
wet
Precipitation Type

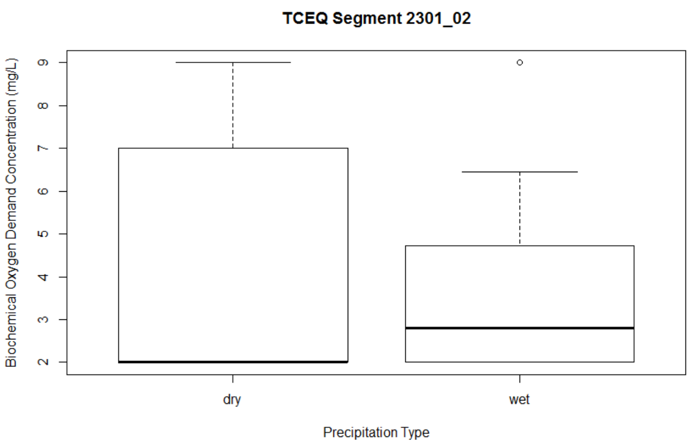

TCEQ Segment 2302_07
Dissolved Oxygen Concentration (mg/L)
5 10 15
dry
wet
Precipitation Type

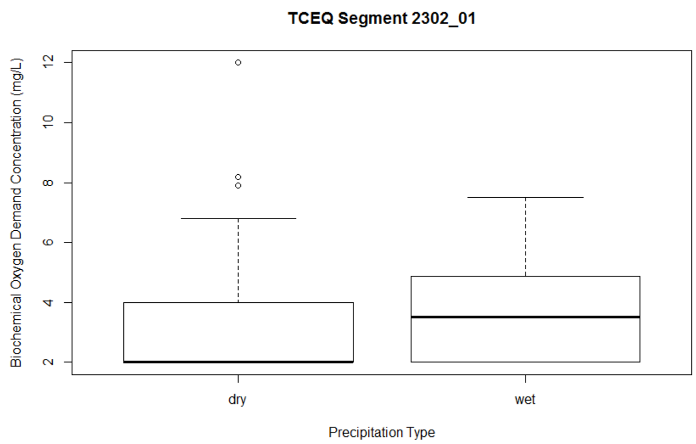
Biochemical Oxygen Demand

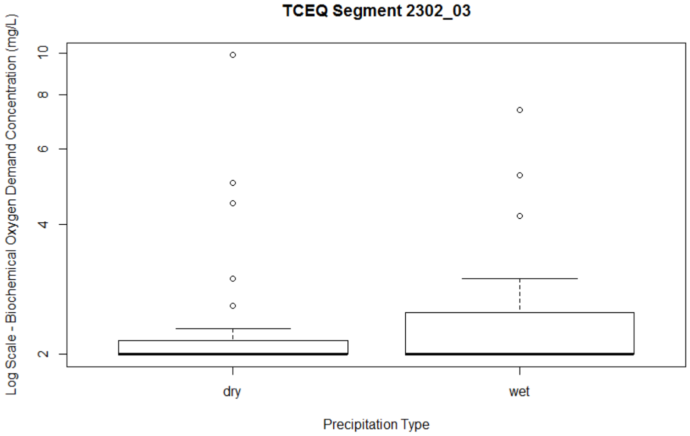
Mann-Whitney U Test		
AU	**W**	**p-value**
All	12613	0.844
2301_01	21	1
2301_02	32.5	0.833
2302_01	379.5	0.225
2302_03	193.5	0.734
2302_04	795	0.945
2302_06	113	0.210
2302_07	571.5	0.514

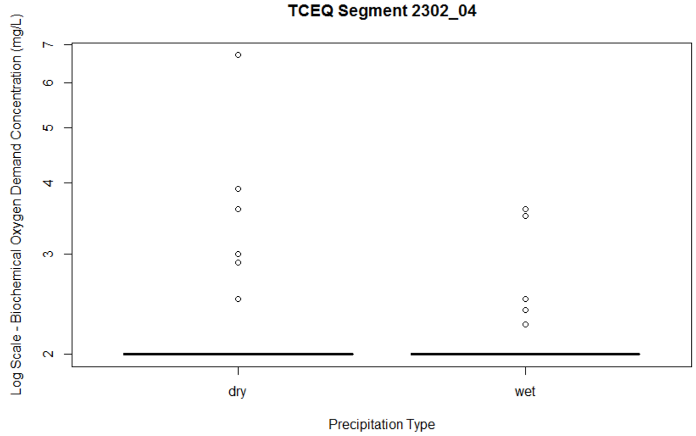


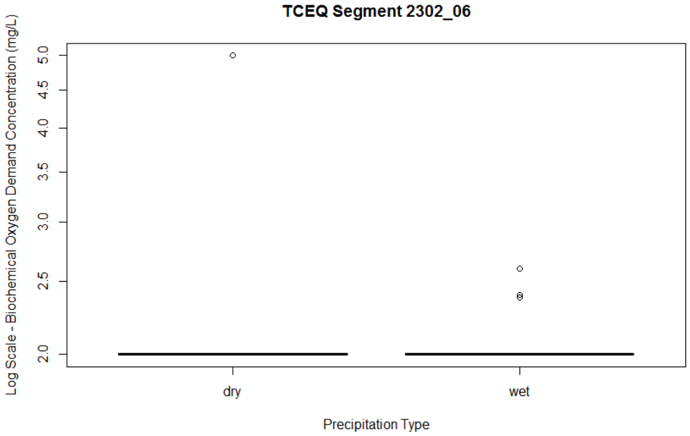


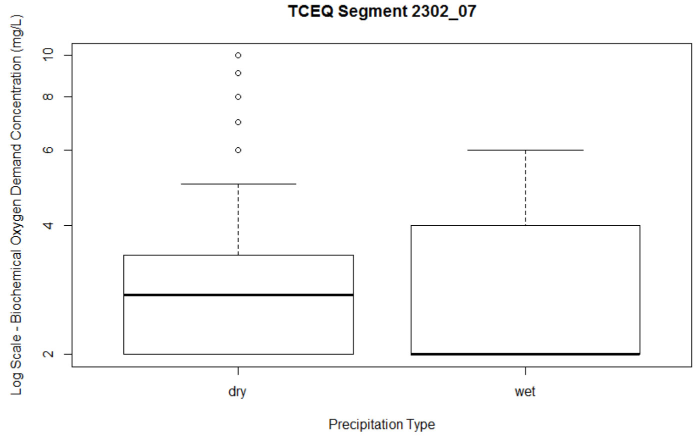






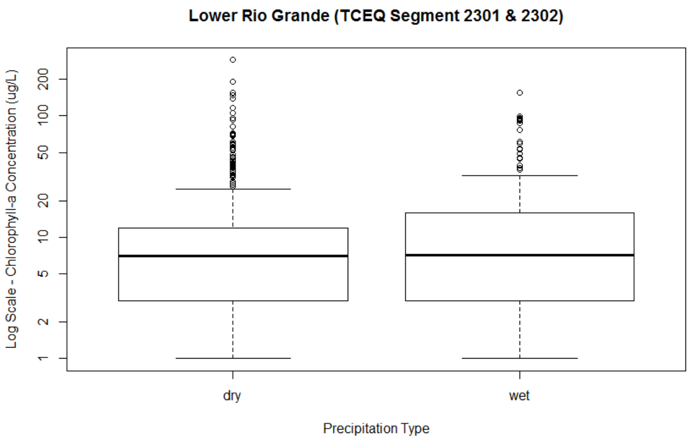


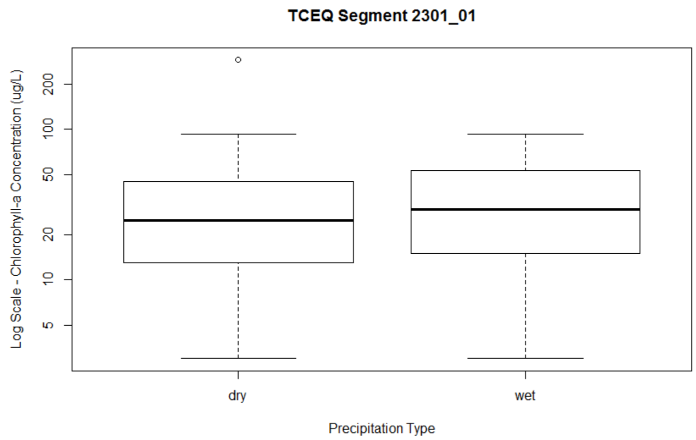


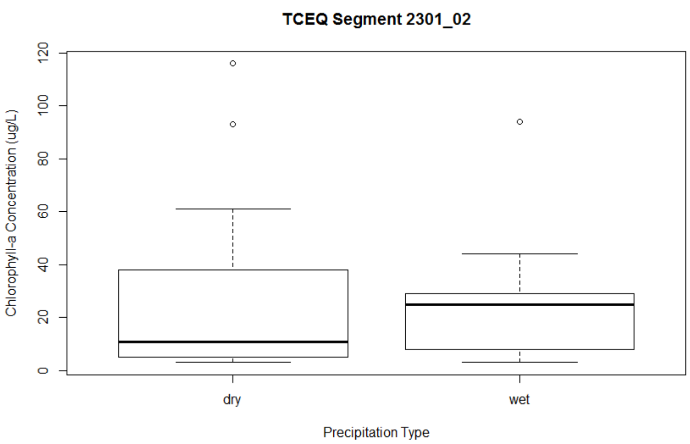


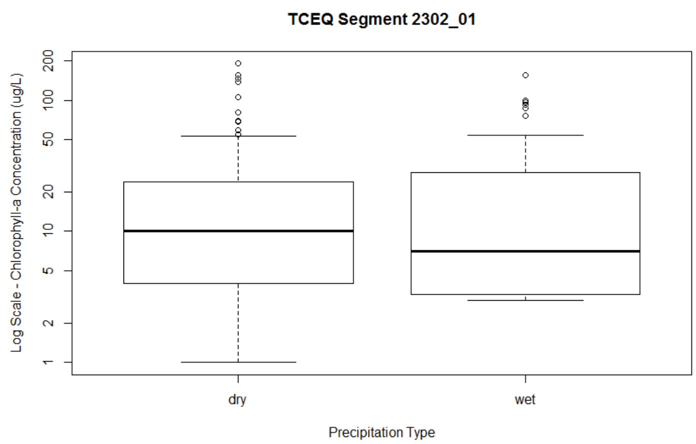
Chlorophyll-a

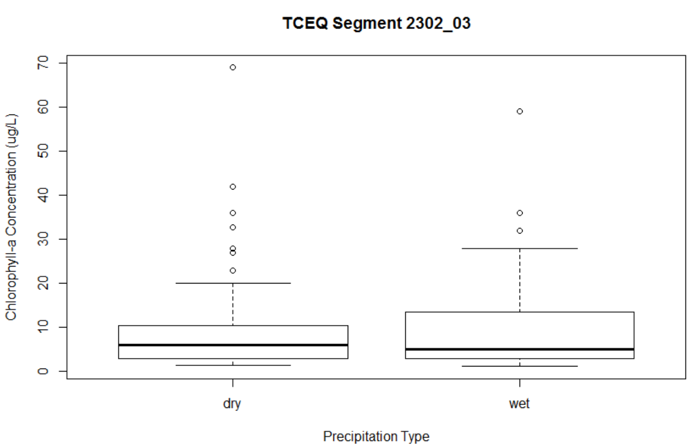
Mann-Whitney U Test		
AU	**W**	**p-value**
All	55904	0.481
2301_01	69.5	1
2301_02	55	0.635
2302_01	1911	0.740
2302_03	1176	0.583
2302_04	3539.5	0.853
2302_06	501.5	0.530
2302_07	3716.5	0.780

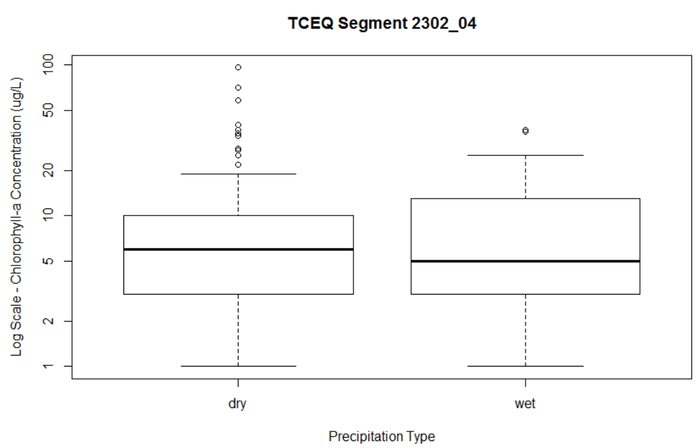

Lower Rio Grande (TCEQ Segment 2301 & 2302)
Log Scale - Chlorophyll-a Concentration (ug/L)
1
2
5
10
20
50
100
200
dry
wet
Precipitation Type

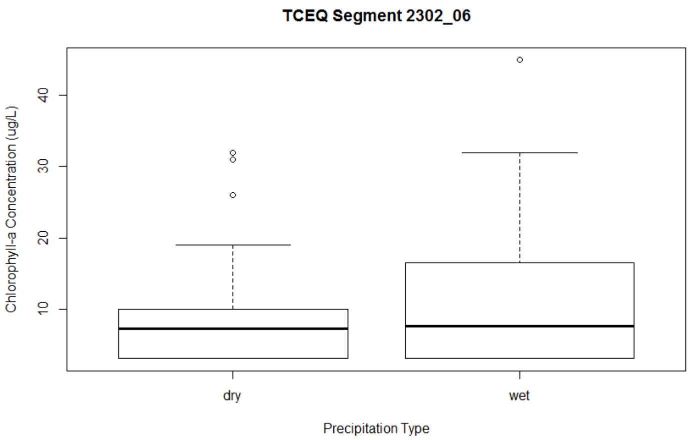

TCEQ Segment 2301_01
Log Scale - Chlorophyll-a Concentration (ug/L)
5
10
20
50
100
200
dry
wet
Precipitation Type

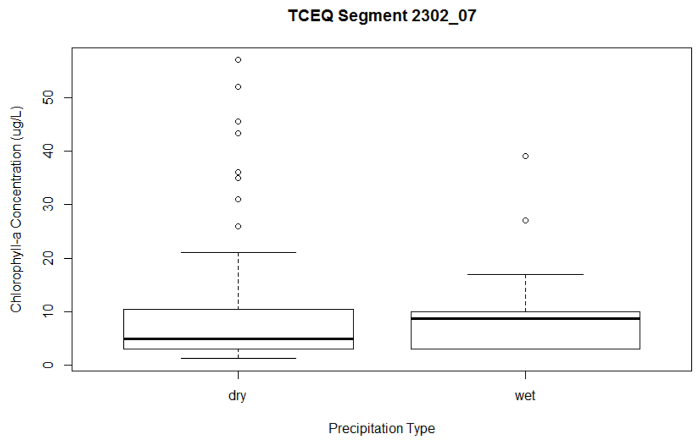

TCEQ Segment 2301_02
Chlorophyll-a Concentration (ug/L)
0
20
40
60
80
100
120
dry
wet
Precipitation Type


TCEQ Segment 2302_01
Log Scale - Chlorophyll-a Concentration (ug/L)
1
2
5
10
20
50
100
200
dry
wet
Precipitation Type


TCEQ Segment 2302_03
Chlorophyll-a Concentration (ug/L)
0
10
20
30
40
50
60
70
dry
wet
Precipitation Type

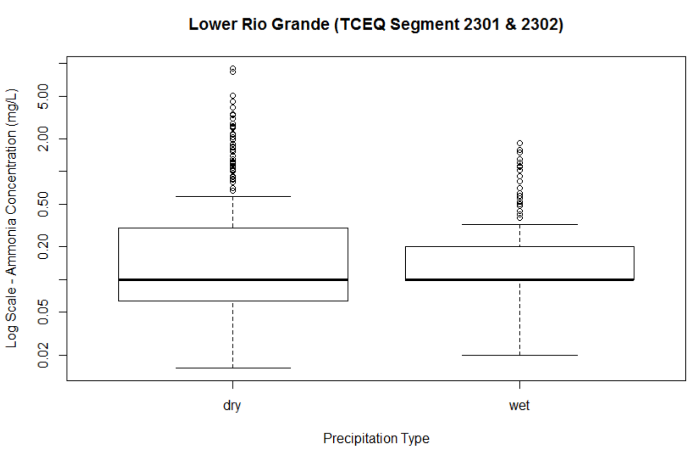

TCEQ Segment 2302_04
Log Scale - Chlorophyll-a Concentration (ug/L)
1
2
5
10
20
50
100
dry
wet
Precipitation Type

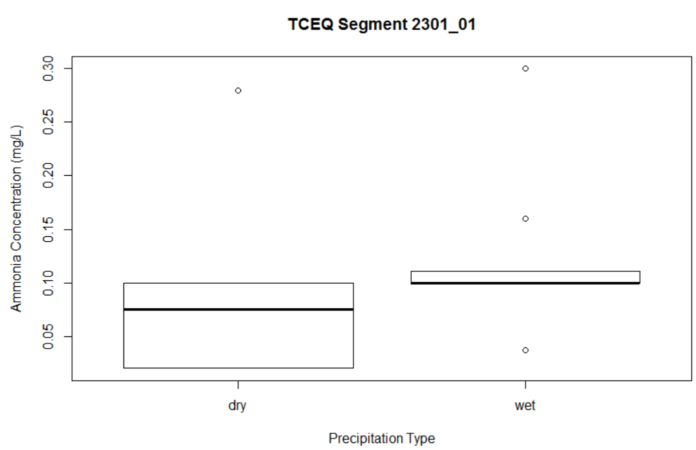


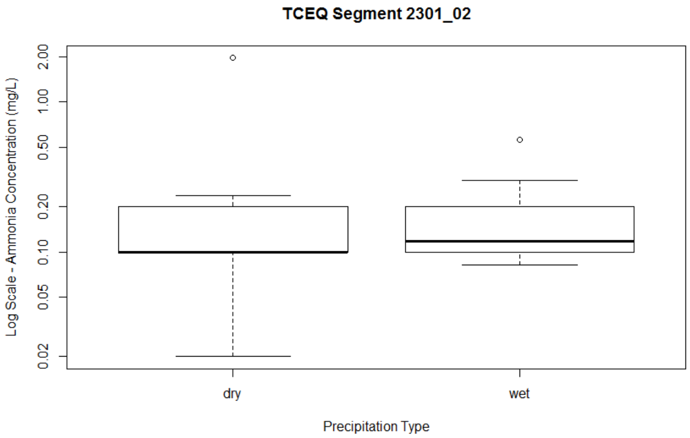


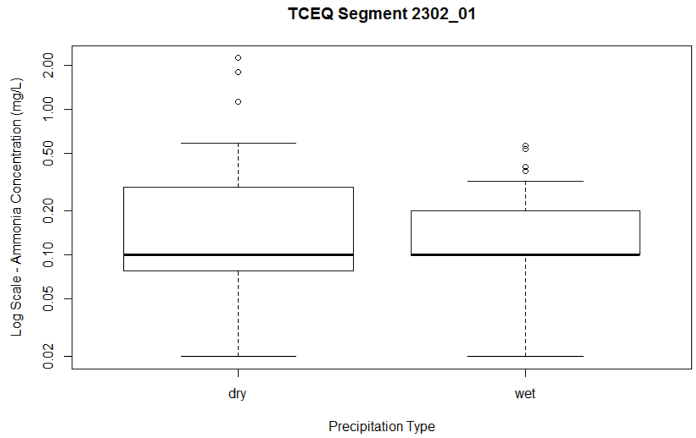
Ammonia Nitrogen

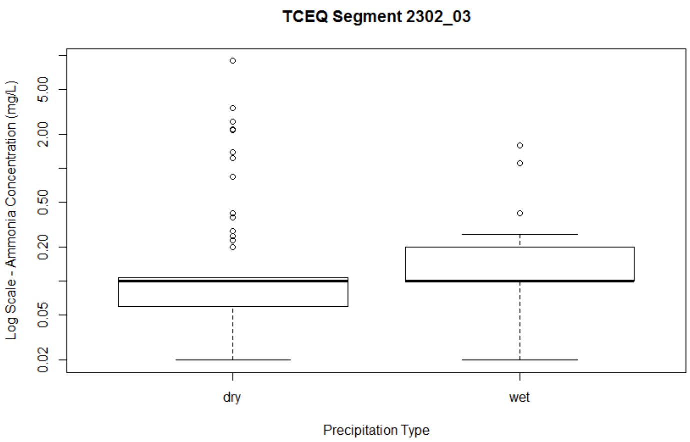
Mann-Whitney U Test		
AU	**W**	**p-value**
All	51712	0.590
2301_01	30	0.029
2301_02	51	0.623
2302_01	1671	0.785
2302_03	759.5	0.182
2302_04	2908.5	0.298
2302_06	444	0.497
2302_07	4165.5	0.420

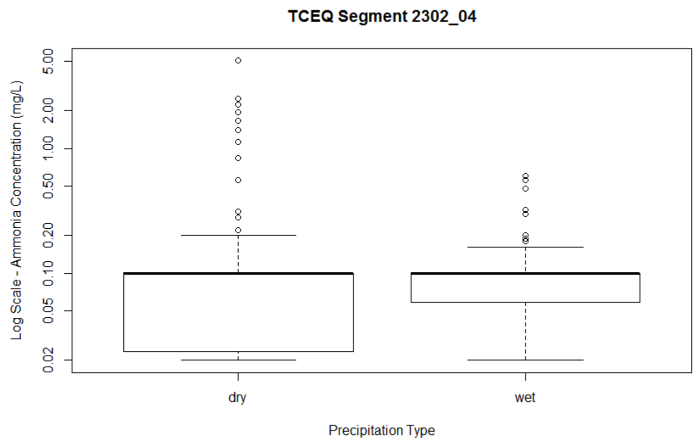


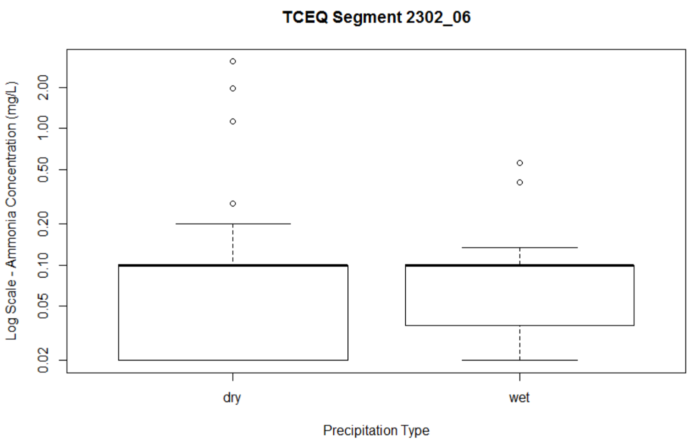


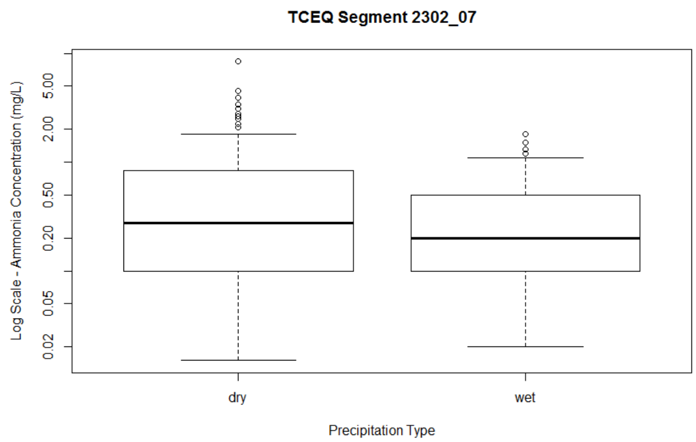

TCEQ Segment 2301_02
Log Scale - Ammonia Concentration (mg/L)
0.02
0.05
0.10
0.20
0.50
1.00
2.00
dry
wet
Precipitation Type


TCEQ Segment 2302_01
Log Scale - Ammonia Concentration (mg/L)
0.02
0.05
0.10
0.20
0.50
1.00
2.00
dry
wet
Precipitation Type


TCEQ Segment 2302_03
Log Scale - Ammonia Concentration (mg/L)
0.02
0.05
0.20
0.50
2.00
5.00
dry
wet
Precipitation Type

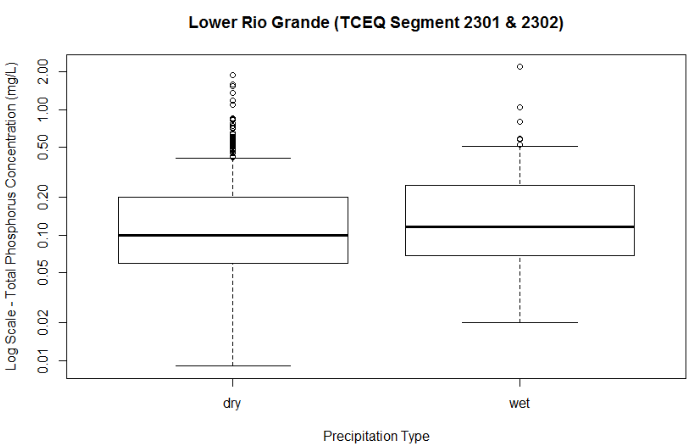

TCEQ Segment 2302_04
Log Scale - Ammonia Concentration (mg/L)
0.02
0.05
0.10
0.20
0.50
1.00
2.00
5.00
dry
wet
Precipitation Type

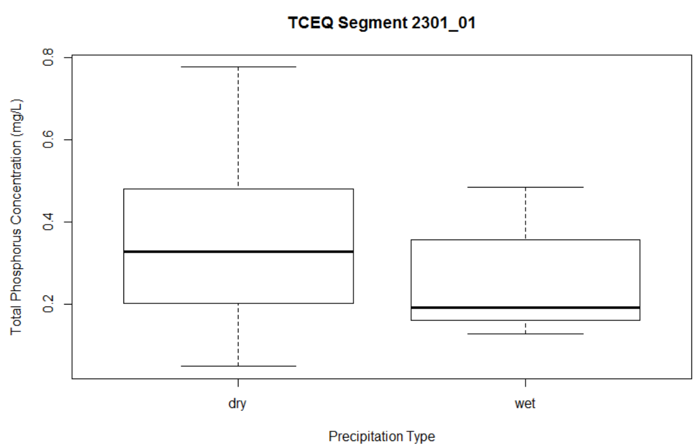

TCEQ Segment 2302_06
Log Scale - Ammonia Concentration (mg/L)
0.02
0.05
0.10
0.20
0.50
1.00
2.00
dry
wet
Precipitation Type

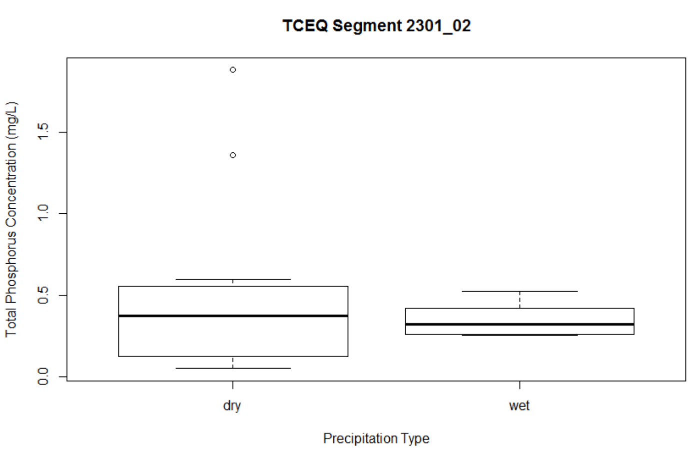

TCEQ Segment 2302_07
Log Scale - Ammonia Concentration (mg/L)
0.02
0.05
0.20
0.50
2.00
5.00
dry
wet
Precipitation Type

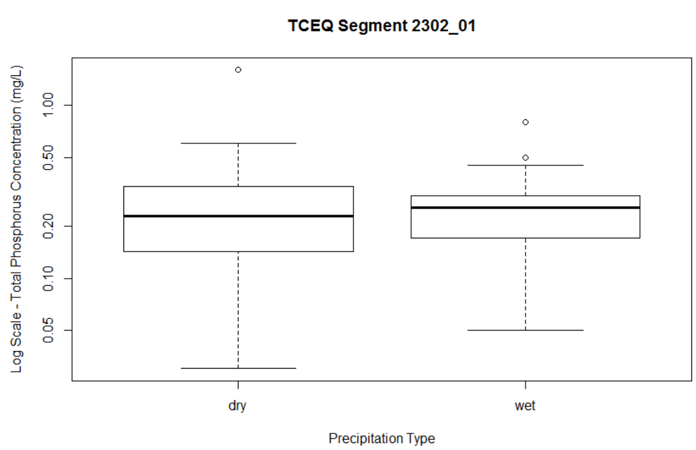
Total Phosphorus

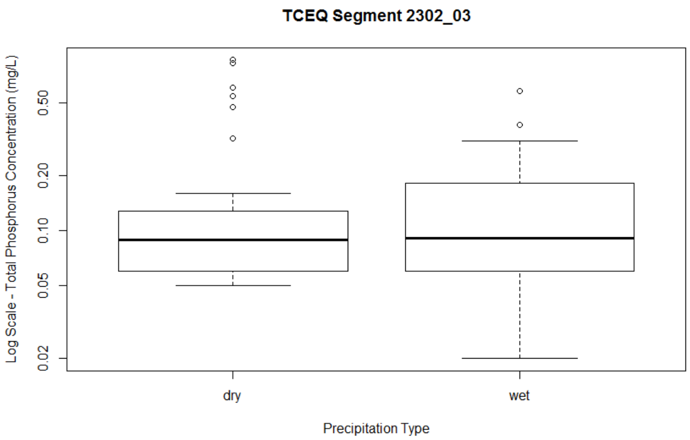
Mann-Whitney U Test		
AU	**W**	**p-value**
All	48847	0.0412
2301_01	71	0.330
2301_02	63.5	1
2302_01	1726.5	0.848
2302_03	912	0.692
2302_04	3295	0.918
2302_06	417	0.212
2302_07	3131.5	0.059

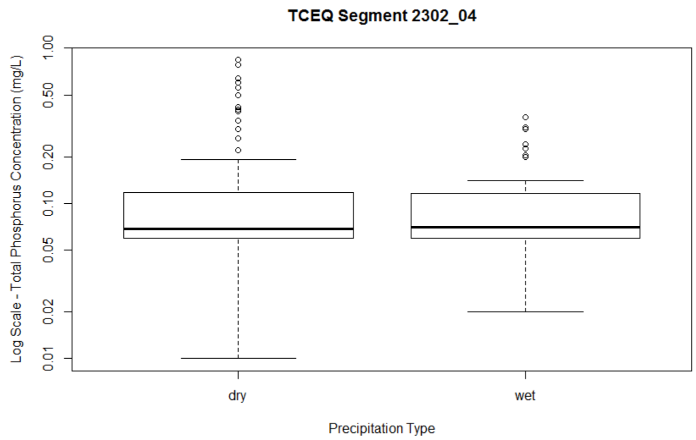


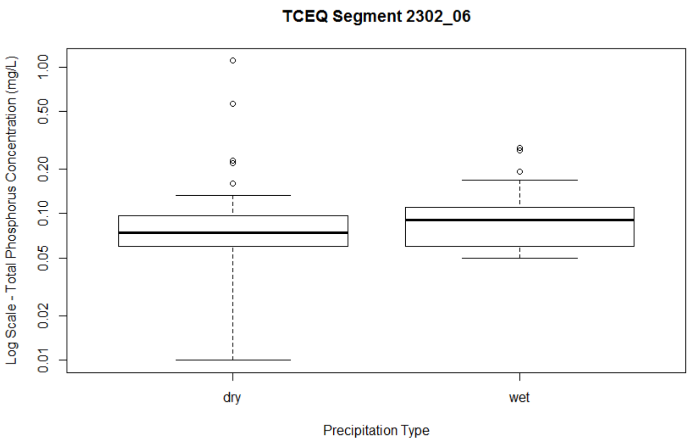


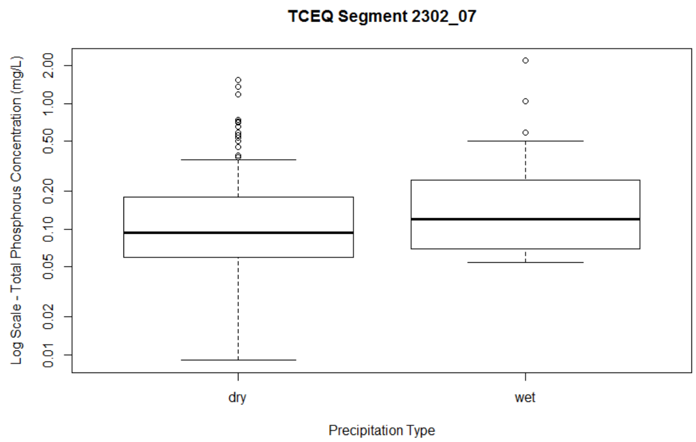






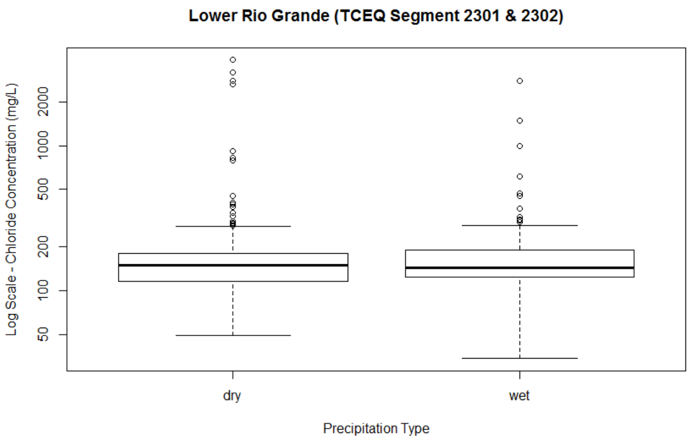


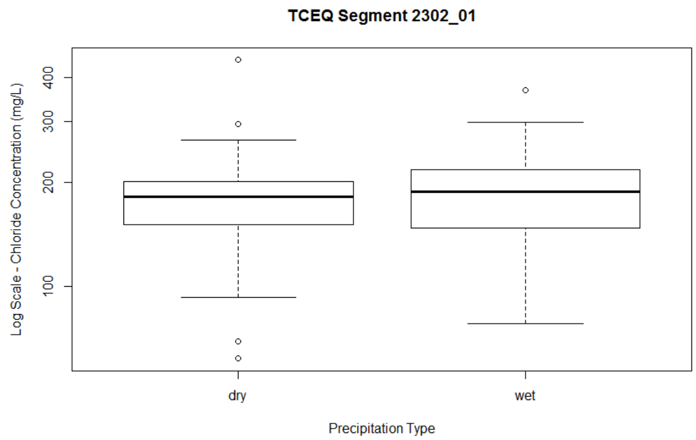


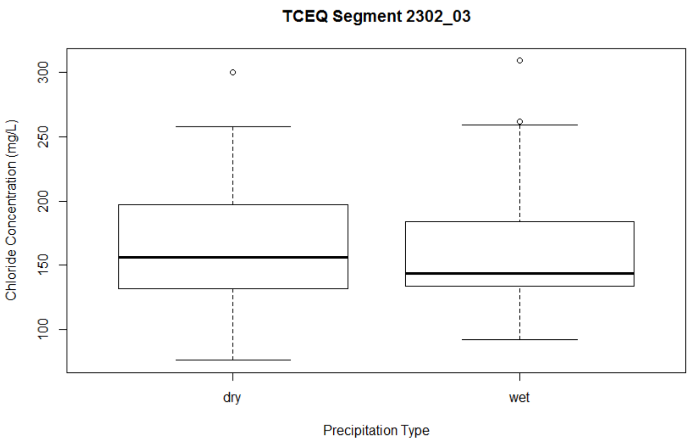


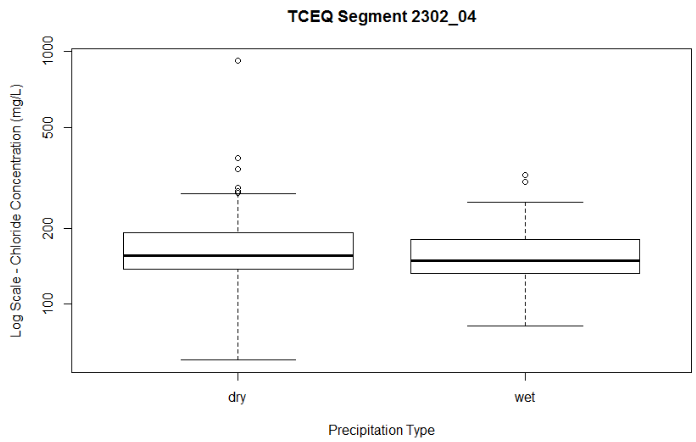
Chloride

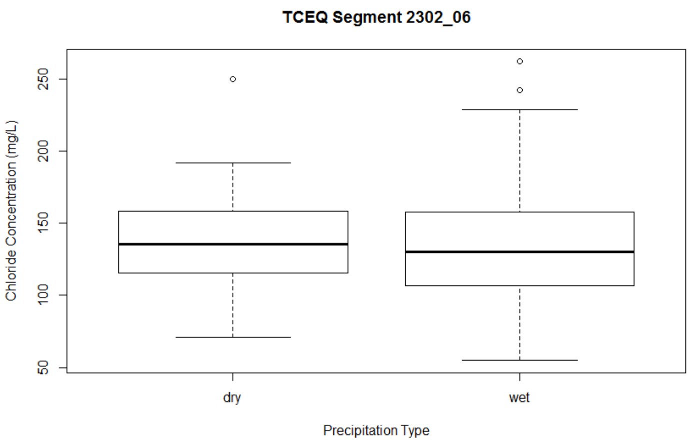
Mann-Whitney U Test		
AU	**W**	**p-value**
All	59340	0.425
2302_01	1806.5	0.377
2302_03	1180	0.741
2302_04	4193.5	0.525
2302_06	619	0.612
2302_07	5102.5	0.014

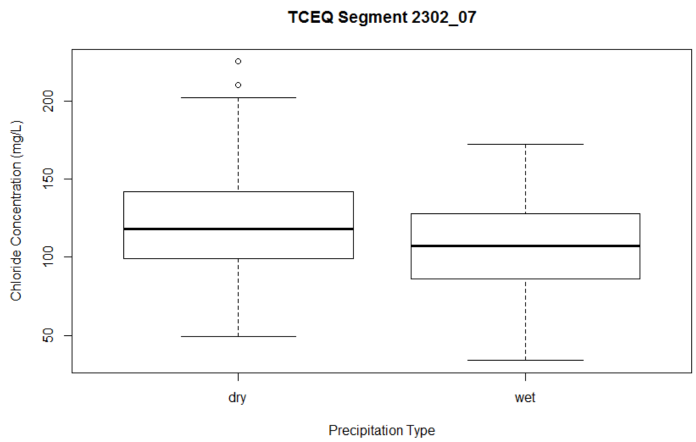

Lower Rio Grande (TCEQ Segment 2301 & 2302)
Log Scale - Chloride Concentration (mg/L)
50
100
200
500
1000
2000
dry
wet
Precipitation Type


TCEQ Segment 2302_01
Log Scale - Chloride Concentration (mg/L)
100
200
300
400
dry
wet
Precipitation Type


TCEQ Segment 2302_03
Chloride Concentration (mg/L)
100
150
200
250
300
dry
wet
Precipitation Type


TCEQ Segment 2302_04
Log Scale - Chloride Concentration (mg/L)
100
200
500
1000
dry
wet
Precipitation Type

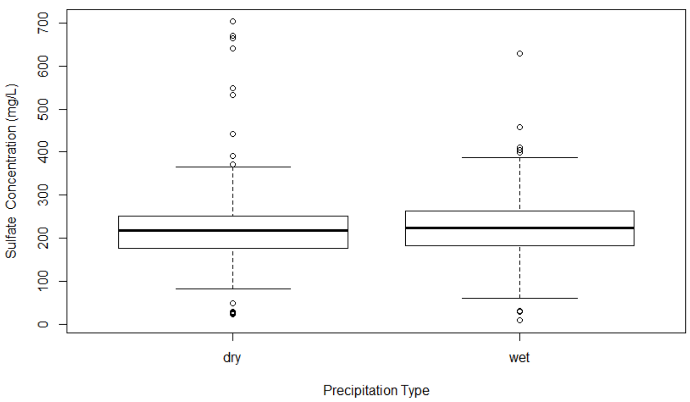

TCEQ Segment 2302_06
Chloride Concentration (mg/L)
50
100
150
200
250
dry
wet
Precipitation Type


TCEQ Segment 2302_07
Chloride Concentration (mg/L)
50
100
150
200
dry
wet
Precipitation Type

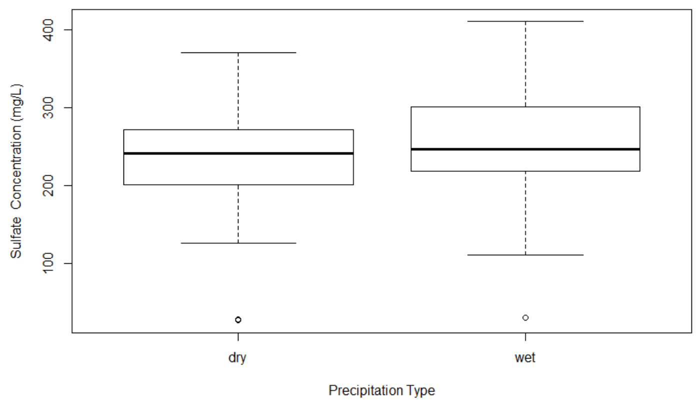
Sulfate

Mann-Whitney U Test		
AU	**W**	**p-value**
All	58177	0.206
2302_01	1681	0.138
2302_03	1080	0.544
2302_04	3862.5	0.767
2302_06	597.5	0.802
2302_07	5510.5	0.0003

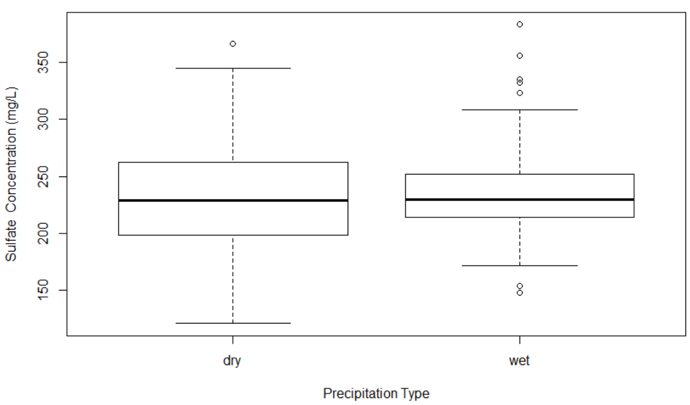
Lower Rio Grande (TCEQ Segment 2301 & 2302)



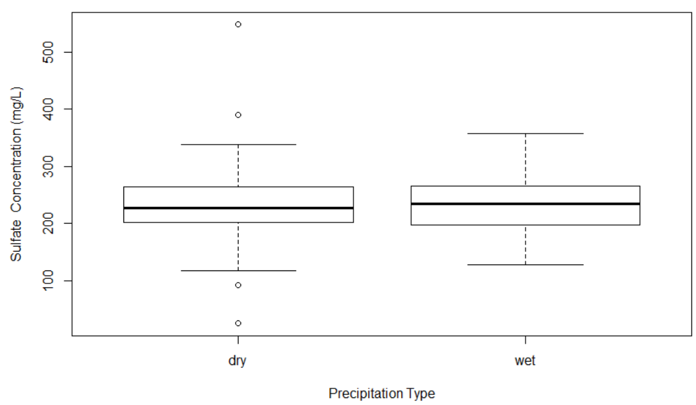
TCEQ Segment 2302_01

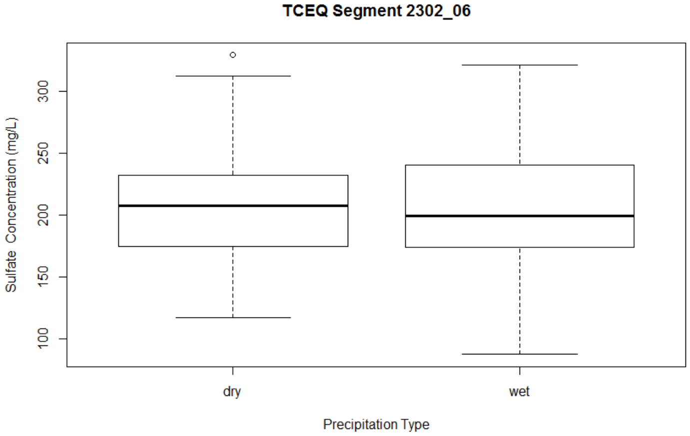


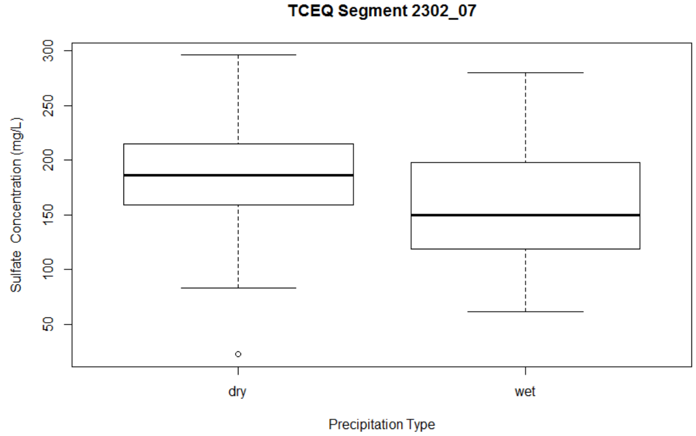
TCEQ Segment 2302_03



TCEQ Segment 2302_04

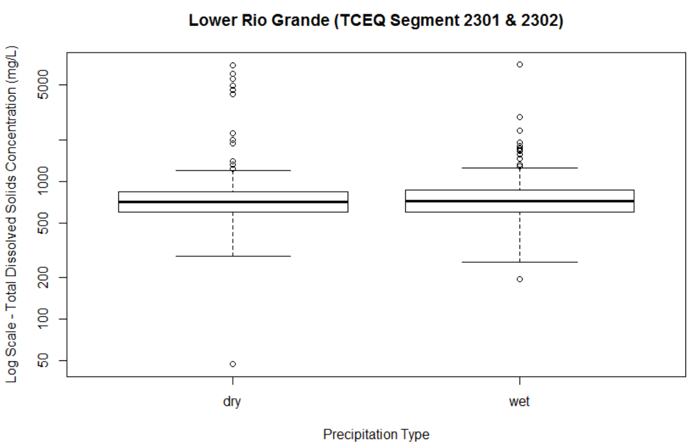


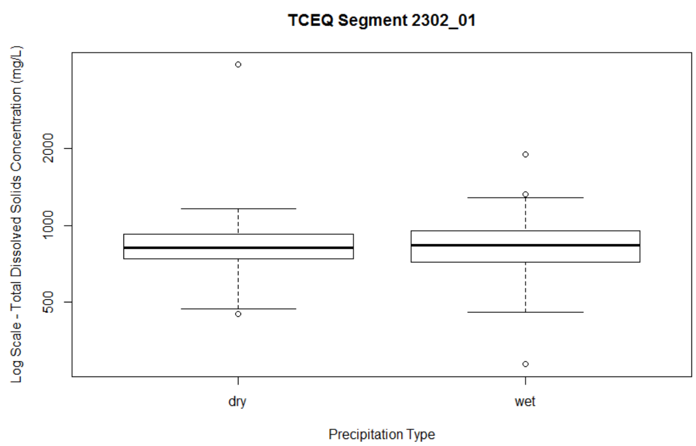


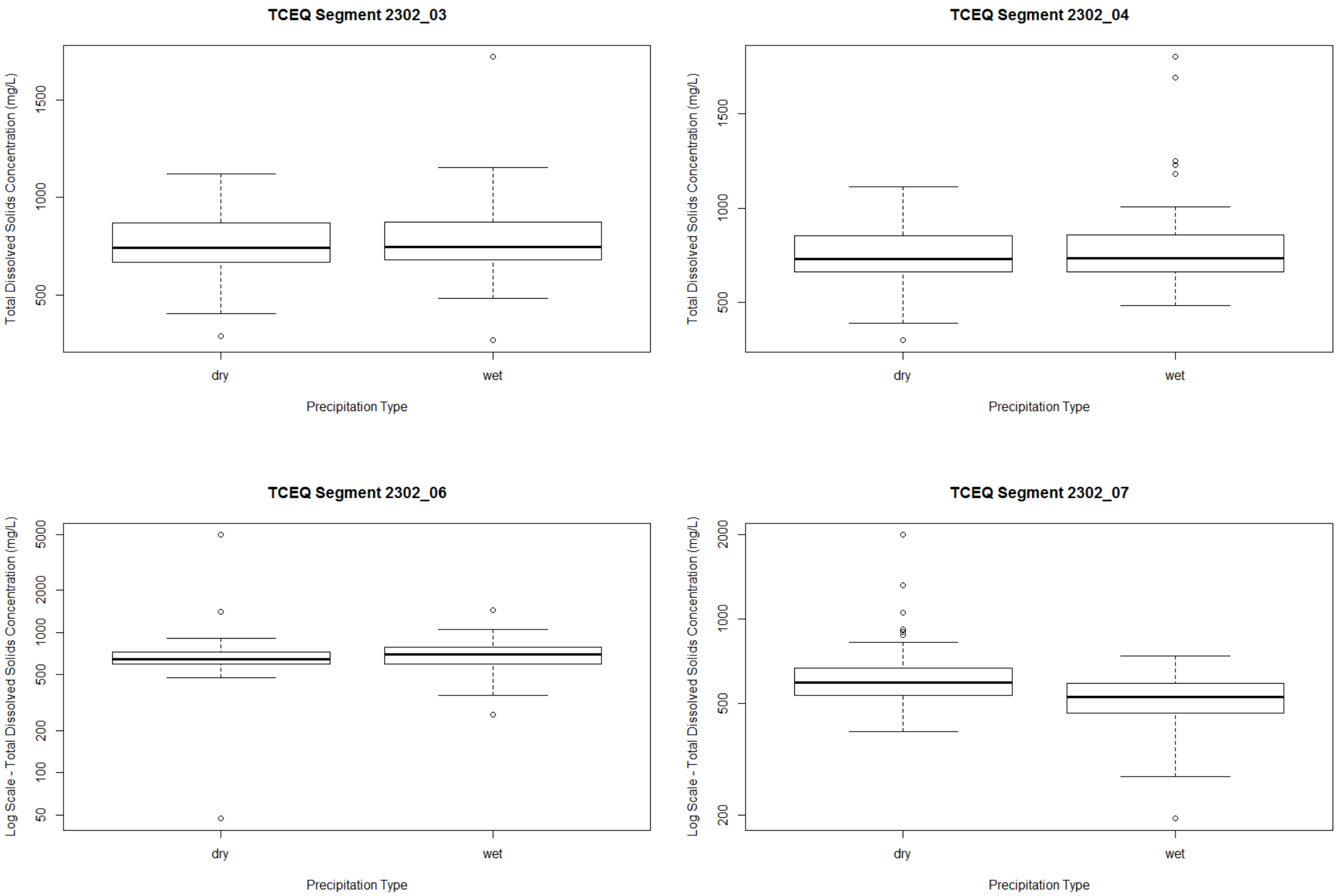


Total Dissolved Solids

Mann-Whitney U Test		
AU	**W**	**p-value**
All	57584	0.322
2302_01	1932.5	0.844
2302_03	1096.5	0.693
2302_04	3716	0.779
2302_06	472	0.329
2302_07	5577	5.7 E-5

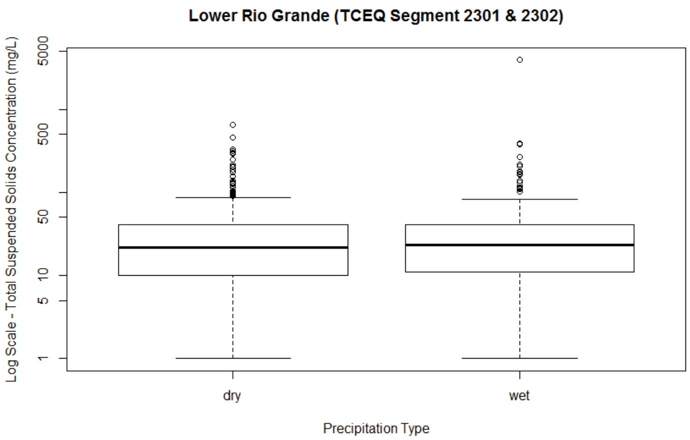


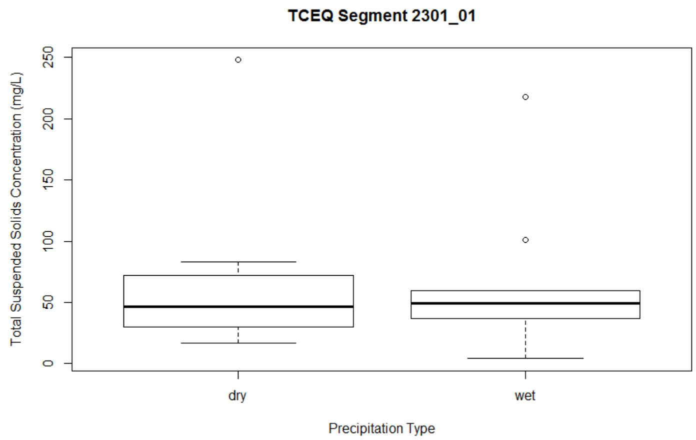


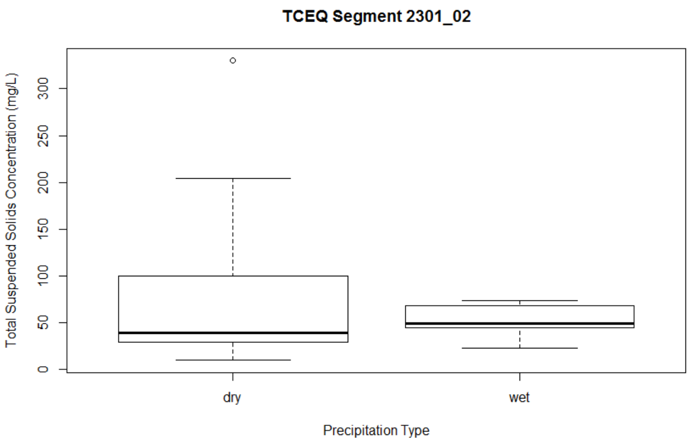


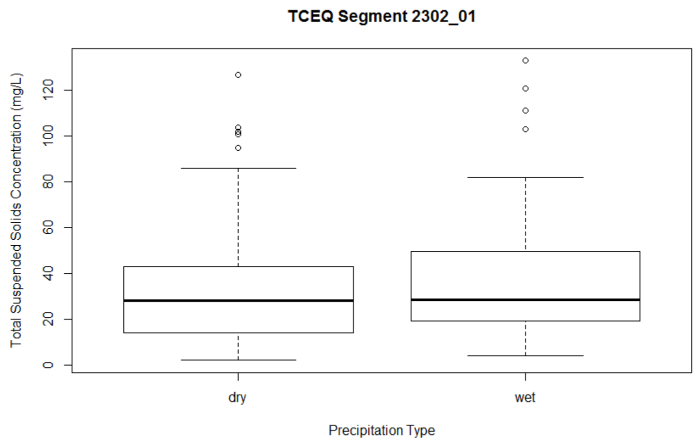
Total Suspended Solids

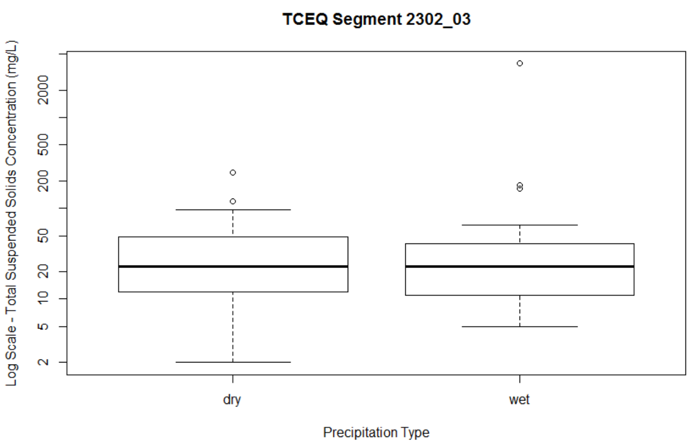
Mann-Whitney U Test		
AU	**W**	**p-value**
All	59073	0.476
2301_01	64	0.975
2301_02	51.5	0.488
2302_01	1757	0.350
2302_03	1190	0.788
2302_04	4377	0.212
2302_06	655	0.435
2302_07	4068	0.963

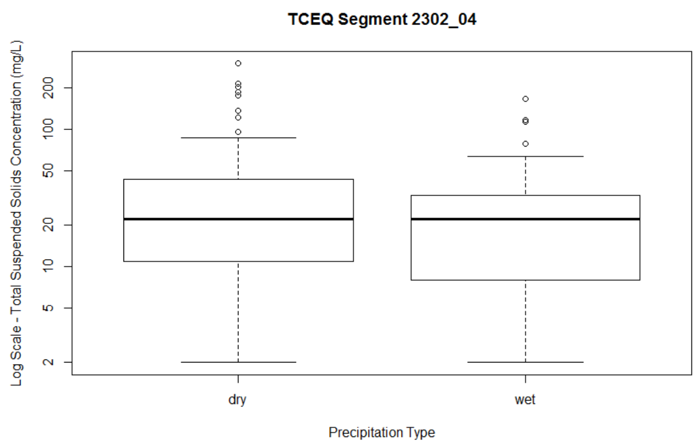

Lower Rio Grande (TCEQ Segment 2301 & 2302)
Log Scale - Total Suspended Solids Concentration (mg/L)
1
5
10
50
500
5000
dry
wet
Precipitation Type

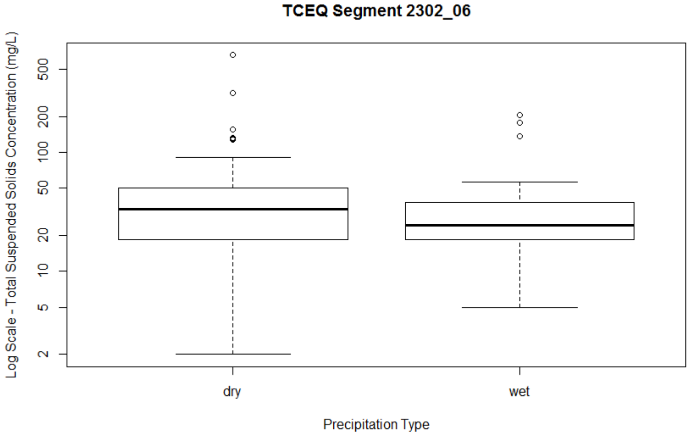

TCEQ Segment 2301_01
Total Suspended Solids Concentration (mg/L)
0
50
100
150
200
250
dry
wet
Precipitation Type

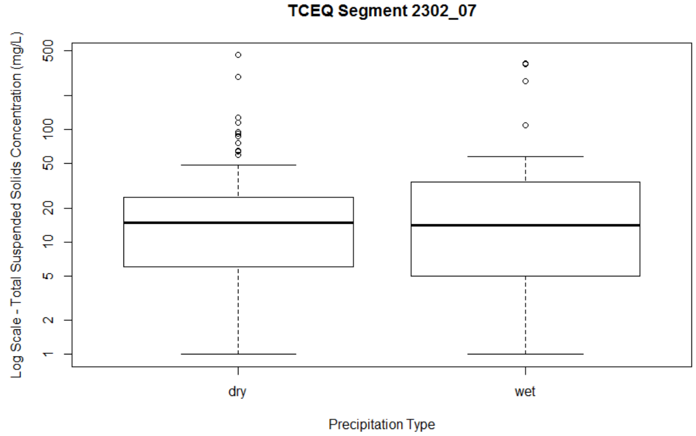

TCEQ Segment 2301_02
Total Suspended Solids Concentration (mg/L)
0
50
100
150
200
250
300
dry
wet
Precipitation Type


TCEQ Segment 2302_01
Total Suspended Solids Concentration (mg/L)
0
20
40
60
80
100
120
dry
wet
Precipitation Type


TCEQ Segment 2302_03
Log Scale - Total Suspended Solids Concentration (mg/L)
2
5
10
20
50
200
500
2000
dry
wet
Precipitation Type

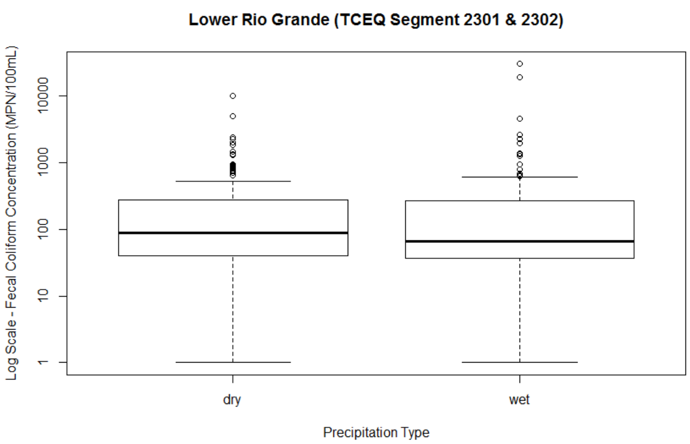

TCEQ Segment 2302_04
Log Scale - Total Suspended Solids Concentration (mg/L)
2
5
10
20
50
100
200
dry
wet
Precipitation Type

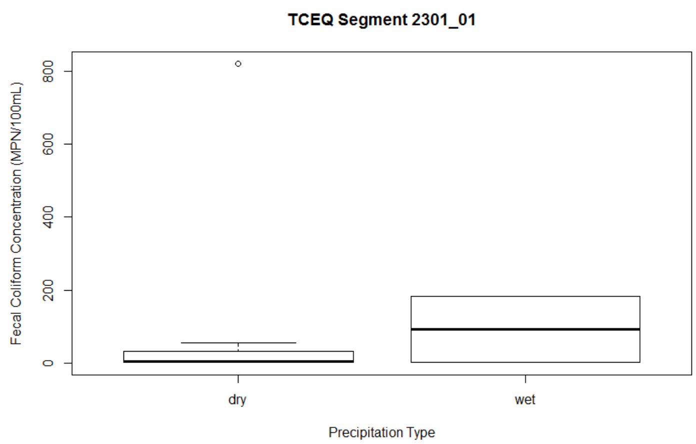


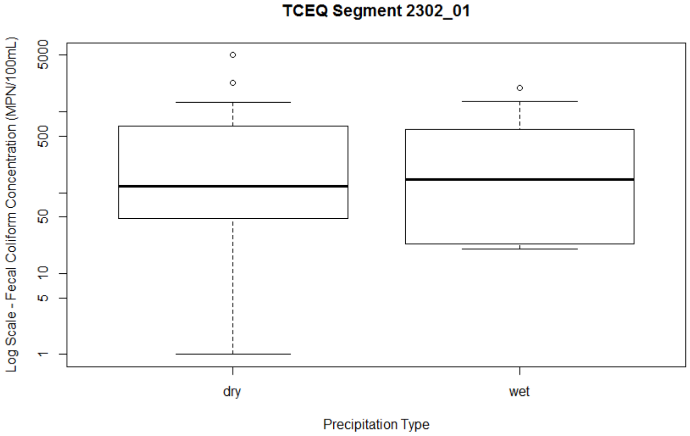


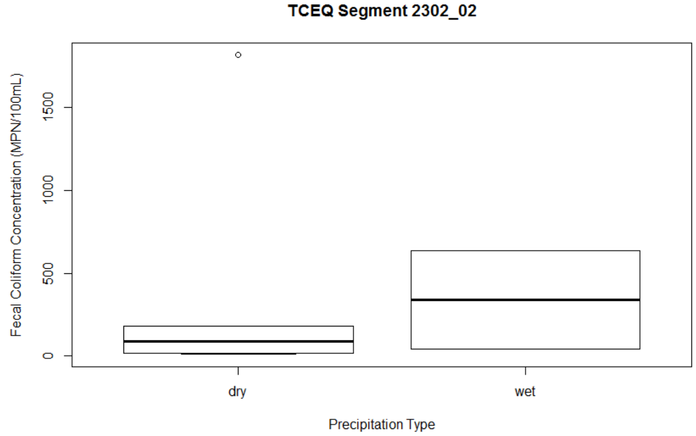
Fecal Coliform

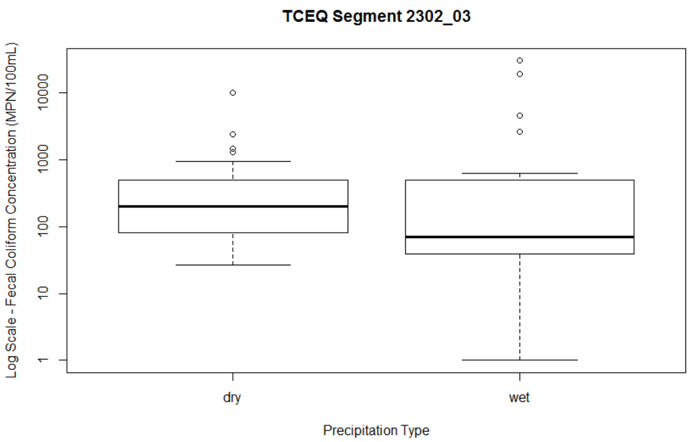
Mann-Whitney U Test		
AU	**W**	**p-value**
All	10166	0.313
2301_01	7	0.889
2302_01	211.5	0.545
2302_02	4	0.857
2302_03	543.5	0.147
2302_04	210	0.948
2302_07	2008.5	0.250

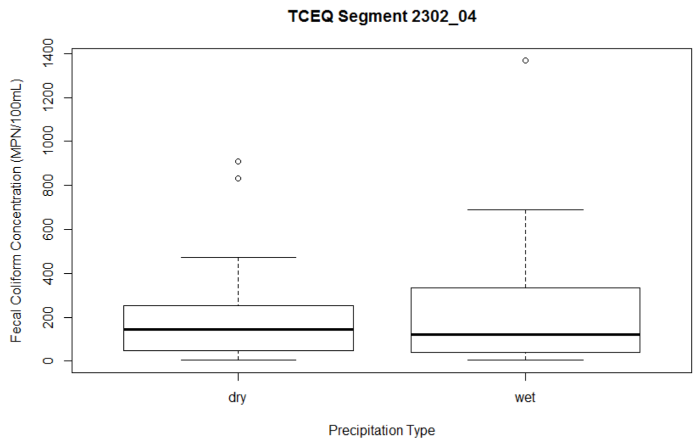


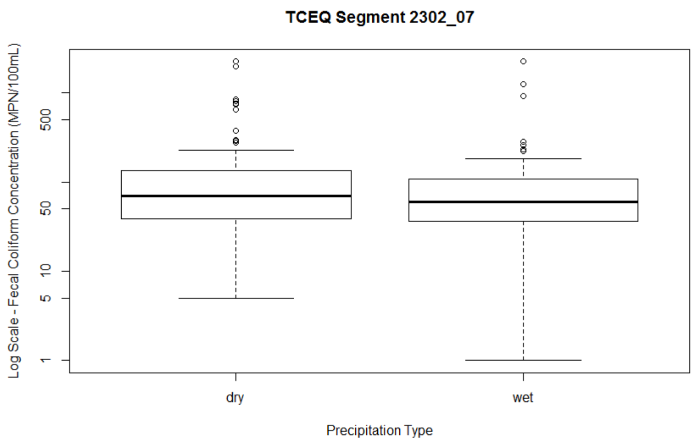



TCEQ Segment 2302_01
Log Scale - Fecal Coliform Concentration (MPN/100mL)
5000
500
50
10
5
1
dry
wet
Precipitation Type


TCEQ Segment 2302_02
Fecal Coliform Concentration (MPN/100mL)
1500
1000
500
0
dry
wet
Precipitation Type


TCEQ Segment 2302_03
Log Scale - Fecal Coliform Concentration (MPN/100mL)
10000
1000
100
10
1
dry
wet
Precipitation Type


TCEQ Segment 2302_04
Fecal Coliform Concentration (MPN/100mL)
1400
1200
1000
800
600
400
200
0
dry
wet
Precipitation Type


TCEQ Segment 2302_07
Log Scale - Fecal Coliform Concentration (MPN/100mL)
500
50
10
5
1
dry
wet
Precipitation Type

Appendix H

Parametric and nonparametric trend analysis of US and Mexican historical water quality data.

Parametric (Linear Regression) and Nonparamteric (Mann-Kendall) Analysis of US and Mexican Historical Water Quality Data

Data range: 2000-2014 (some years contain data gaps). All US data were obtained from the TCEQ's SWQMIS database. All Mexican data were obtained from CONAGUA (Red Nacional de Monitoreo de la Calidad del Agua). Due to data gaps, plots and analyses for some parameters include only US data or only Mexican data. Statistically significant results are highlighted (p ≤ 0.05).

Dissolved Oxygen

US		Mann-Kendall		Mexico		
AU	Tau	p-value		AU	Tau	p-value
2301_01	-0.154	0.215				
2301_02	-0.042	0.767				
2302_01	-0.090	0.035		2302_01	0.075	0.459
2302_02	0.212	0.047		2302_02	-0.048	0.843
2302_03	-0.186	0.00012		2302_03	-0.038	0.617
2302_04	-0.321	5.203E-13		2302_04	-0.243	0.250
2302_05	0.2	0.807		2302_05	-0.019	0.884
2302_06	-0.335	0.000011		2302_06	-0.374	0.0056
2302_07	0.014	0.740		2302_07	-0.082	0.151

US		Linear Regression		Mexico		
AU	R Squared	p-value		AU	R Squared	p-value
2301_01	0.064 (-)	0.155				
2301_02	0.00012 (-)	0.956				
2302_01	0.017 (-)	0.038		2302_01	0.0114 (+)	0.459
2302_02	0.114 (+)	0.027		2302_02	0.017 (-)	0.647
2302_03	0.039 (-)	0.0058		2302_03	0.0072 (+)	0.446
2302_04	0.195 (-)	2.22E-12		2302_04	0.150 (-)	0.171
2302_05	0.079 (+)	0.648		2302_05	0.0074 (-)	0.612
2302_06	0.206 (-)	2.11E-05		2302_06	0.299 (-)	0.0026
2302_07	0.017 (+)	0.027		2302_07	0.0098 (-)	0.241

Biochemical Oxygen Demand

Mann-Kendall	Mexico	
AU	Tau	p-value
2302_01	0.471	0.000083
2302_03	0.369	0.0065
2302_05	0.511	2.05E-05
2302_07	0.181	0.043

Linear Regression	Mexico	
AU	R Squared	p-value
2302_01	0.533 (+)	4.29E-07
2302_03	0.170 (+)	0.026
2302_05	0.440 (+)	1.05E-05
2302_07	0.112 (+)	0.0079

Chlorophyll-a

US Mann-Kendall		
AU	**Tau**	**p-value**
2301_01	0.232	0.020
2301_02	-0.0036	0.988
2302_01	0.304	2.22E-16
2302_02	0.352	0.093
2302_03	0.035	0.573
2302_04	0.139	0.005
2302_06	0.132	0.119
2302_07	-0.039	0.407

US Linear Regression		
AU	**R Squared**	**p-value**
2301_01	0.117 (+)	0.016
2301_02	0.0138 (+)	0.509
2302_01	0.273 (+)	9.68E-13
2302_02	0.147 (+)	0.116
2302_03	0.0876 (+)	0.00052
2302_04	0.117 (+)	5.7E-07
2302_06	0.176 (+)	0.00025
2302_07	0.0072 (+)	0.202

Ammonia Nitrogen

US Mann-Kendall		
AU	**Tau**	**p-value**
2301_01	0.533	7.15E-07
2301_02	0.181	0.168
2302_01	0.214	0.00013
2302_02	-0.17	0.125
2302_03	0.15	0.0069
2302_04	0.395	2.22E-16
2302_05	-0.552	0.1806
2302_06	0.537	2.22E-16
2302_07	0.188	0.000038

US Linear Regression		
AU	**R Squared**	**p-value**
2301_01	0.0404 (+)	0.171
2301_02	0.048 (+)	0.228
2302_01	0.036 (+)	0.015
2302_02	0.015 (-)	0.422
2302_03	0.055 (+)	0.003
2302_04	0.050 (+)	0.0016
2302_05	0.516 (-)	0.108
2302_06	0.063 (+)	0.035
2302_07	0.054 (+)	0.00043

Nitrate

US		Mann-Kendall		Mexico		
AU	Tau	p-value		AU	Tau	p-value
2301_01	0	1				
2301_02	-0.4	0.462				
2302_01	-0.238	0.548		2302_01	-0.143	0.511
2302_02	-0.467	0.260		2302_02	-0.382	0.119
2302_03	-0.039	0.903		2302_03	-0.379	0.00050
2302_04	0.276	0.566		2302_04	0.077	0.743
				2302_05	-0.056	0.917
				2302_06	0.126	0.3670
2302_07	-0.105	1		2302_07	-0.176	0.020

US		Linear Regression		Mexico		
AU	R Squared	p-value		AU	R Squared	p-value
2301_01	0.061 (-)	0.752				
2301_02	0.169 (-)	0.491				
2302_01	0.062 (-)	0.591		2302_01	0.029 (+)	0.561
2302_02	0.594 (+)	0.073		2302_02	0.208 (-)	0.159
2302_03	0.063 (-)	0.407		2302_03	0.0028 (-)	0.741
2302_04	0.047 (-)	0.679		2302_04	0.084 (+)	0.314
				2302_05	0.109 (-)	0.385
				2302_06	0.030 (+)	0.386
2302_07	0.013 (-)	0.857		2302_07	0.0077 (-)	0.434

Total Phosphorus

	US	Mann-Kendall		Mexico		
AU	Tau	p-value		AU	Tau	p-value
2301_01	-0.356	0.00044				
2301_02	-0.415	0.00073				
2302_01	-0.295	6.04E-11		2302_01	-0.274	0.017
2302_02	-0.074	0.501		2302_02	0.111	0.720
2302_03	-0.040	0.469		2302_03	-0.171	0.060
2302_04	-0.19	0.00011		2302_04	-0.436	0.044
2302_05	0.316	0.613		2302_05	0.157	0.22
2302_06	-0.222	0.0065		2302_06	-0.236	0.082
2302_07	0.063	0.128		2302_07	-0.323	2.32E-07

	US	Linear Regression		Mexico		
AU	R Squared	p-value		AU	R Squared	p-value
2301_01	0.271 (-)	0.00017				
2301_02	0.143 (-)	0.030				
2302_01	0.148 (-)	2.44E-09		2302_01	0.040 (-)	0.228
2302_02	0.0021 (+)	0.771		2302_02	0.036 (-)	0.599
2302_03	5.97E-06 (-)	0.976		2302_03	0.0019 (+)	0.744
2302_04	0.021(-)	0.040		2302_04	0.194 (-)	0.132
2302_05	0.256 (+)	0.385		2302_05	0.026 (+)	0.374
2302_06	0.047 (-)	0.065		2302_06	3.8E-05 (-)	0.975
2302_07	0.0061 (-)	0.195		2302_07	0.043 (-)	0.024

Chloride

US		Mann-Kendall		Mexico		
AU	Tau	p-value		AU	Tau	p-value
2302_01	0.148	0.0012		2302_01	0.184	0.098
2302_02	0.049	0.645				
2302_03	0.234	9.42E-06		2302_03	0.175	0.174
2302_04	0.213	6.96E-06				
2302_05	-0.067	1		2302_05	0.157	0.158
2302_06	0.082	0.290				
2302_07	0.063	0.110		2302_07	-0.265	0.0015

US		Linear Regression		Mexico		
AU	R Squared	p-value		AU	R Squared	p-value
2302_01	0.036 (+)	0.0049		2302_01	0.060 (+)	0.127
2302_02	0.040 (+)	0.185				
2302_03	0.103 (+)	2.87E-05		2302_03	0.056 (+)	0.198
2302_04	0.059 (+)	0.00032				
2302_05	0.178 (-)	0.404		2302_05	0.052 (+)	0.157
2302_06	0.0162 (+)	0.267				
2302_07	0.029 (+)	0.0034		2302_07	0.029 (-)	0.162

Sulfate

US			Mann-Kendall	Mexico		
AU	Tau	p-value		AU	Tau	p-value
2302_01	0.261	2.22E-16		2302_01	0.318	0.0076
2302_02	0.317	0.0018				
2302_03	0.392	2.22E-16		2302_03	0.198	0.122
2302_04	0.358	2.22E-16				
2302_05	0.2	0.707		2302_05	0.266	0.026
2302_06	0.285	0.00023				
2302_07	0.212	1.19E-07		2302_07	-0.029	0.740

US			Linear Regression	Mexico		
AU	R Squared	p-value		AU	R Squared	p-value
2302_01	0.086 (+)	1.08E-05		2302_01	0.243 (+)	0.0026
2302_02	0.236 (+)	0.00054				
2302_03	0.092 (+)	6.23E-05		2302_03	0.086 (+)	0.109
2302_04	0.252 (+)	4.39E-15				
2302_05	0.0044 (-)	0.901		2302_05	0.148 (+)	0.022
2302_06	0.126 (+)	0.0015				
2302_07	0.122 (+)	1.1E-09		2302_07	0.0034 (+)	0.641

Total Dissolved Solids

US		Mann-Kendall		Mexico		
AU	Tau	p-value		AU	Tau	p-value
2302_01	0.188	4.12E-05		2302_01	0.139	0.143
2302_02	0.35	0.0033		2302_02	-0.029	0.921
2302_03	0.244	7.75E-06		2302_03	-0.0067	0.931
2302_04	0.259	2.22E-16		2302_04	-0.275	0.189
				2302_05	0.118	0.267
2302_06	0.228	0.0047		2302_06	-0.246	0.069
2302_07	0.169	2.85E-05		2302_07	-0.139	0.0132

US		Linear Regression		Mexico		
AU	R Squared	p-value		AU	R Squared	p-value
2302_01	0.0092 (+)	0.160		2302_01	0.065 (+)	0.066
2302_02	0.201 (+)	0.0069		2302_02	0.0033 (+)	0.838
2302_03	0.077 (+)	0.00049		2302_03	0.014 (+)	0.279
2302_04	0.066 (+)	0.00021		2302_04	0.164 (-)	0.152
				2302_05	0.023 (+)	0.333
2302_06	0.0054 (-)	0.540		2302_06	0.095 (-)	0.110
2302_07	0.086 (+)	6.72E-07		2302_07	0.0023 (+)	0.564

Total Suspended Solids

US		Mann-Kendall		Mexico		
AU	Tau	p-value		AU	Tau	p-value
2301_01	0.243	0.017				
2301_02	-0.167	0.178				
2302_01	0.34	2.22E-16		2302_01	0.542	2.22E-16
2302_02	0.455	4.65E-06		2302_02	-0.0769	0.743
2302_03	0.17	0.0012		2302_03	0.179	0.017
2302_04	0.122	0.0090		2302_04	0.104	0.668
2302_05	0.2	0.707		2302_05	0.163	0.131
2302_06	0.106	0.178		2302_06	0.0877	0.527
2302_07	0.064	0.150		2302_07	0.196	0.00080

US		Linear Regression		Mexico		
AU	R Squared	p-value		AU	R Squared	p-value
2301_01	0.060 (+)	0.096				
2301_02	0.038 (-)	0.279				
2302_01	0.110 (+)	2.71E-05		2302_01	0.128 (+)	0.0099
2302_02	0.284 (+)	8.13E-05		2302_02	0.159 (-)	0.158
2302_03	0.0015 (-)	0.623		2302_03	0.032 (+)	0.107
2302_04	0.0099 (+)	0.150		2302_04	0.019 (-)	0.656
2302_05	0.131 (+)	0.481		2302_05	0.082 (+)	0.062
2302_06	6.99E-05 (-)	0.943		2302_06	0.017 (+)	0.507
2302_07	0.00050 (-)	0.734		2302_07	0.031 (+)	0.041

Fecal Coliform

US			Mann-Kendall	Mexico		
AU	Tau	p-value		AU	Tau	p-value
2302_01	0.274	0.010		2302_01	0.21	0.080
2302_02	-0.238	0.548		2302_02	0.484	0.027
2302_03	0.199	0.020		2302_03	0.059	0.488
2302_04	-0.0267	0.812		2302_04	0.389	0.067
				2302_05	0.246	0.076
				2302_06	0.255	0.067
2302_07	0.194	0.0013		2302_07	0.306	2.62E-06

US			Linear Regression	Mexico		
AU	R Squared	p-value		AU	R Squared	p-value
2302_01	0.047 (+)	0.164		2302_01	0.011 (+)	0.548
2302_02	0.060 (-)	0.596		2302_02	0.260 (+)	0.075
2302_03	0.081 (+)	0.0218		2302_03	0.0017 (-)	0.742
2302_04	0.019 (-)	0.378		2302_04	0.453 (+)	0.0083
				2302_05	0.124 (+)	0.071
				2302_06	0.155 (+)	0.038
2302_07	0.046 (+)	0.016		2302_07	0.033 (+)	0.056

E. coli

US Mann-Kendall		
AU	**Tau**	**p-value**
2302_01	-0.205	0.0095
2302_02	-0.0641	0.595
2302_03	0.00145	0.984
2302_04	-0.141	0.084
2302_05	0.333	1
2302_06	-0.0185	1
2302_07	0.17	0.0021

US Linear Regression		
AU	**R Squared**	**p-value**
2302_01	0.0006 (+)	0.830
2302_02	0.0002 (-)	0.939
2302_03	0.028 (+)	0.078
2302_04	3.3E-6 (+)	0.988
2302_05	0.703 (+)	0.367
2302_06	0.0301 (-)	0.610
2302_07	0.0177 (+)	0.106

Enterococcus

US Mann-Kendall		
AU	**Tau**	**p-value**
2301_02	0.333	0.2105

US Linear Regression		
AU	**R Squared**	**p-value**
2301_02	0.0897 (+)	0.4005