BRAZOS RIVER BASIN
WACO AREA WATERSHEDS
DATA REPORT

July 2022

The Meadows Center for Water and the Environment
Texas State University
Texas Stream Team

Photo credit: City of Waco on Twitter

EPA United States Environmental Protection Agency

Texas Commission on Environmental Quality

Texas State University
The rising STAR of Texas

This report was prepared in cooperation with, and financed through, grants from the U.S. Environmental Protection Agency through the Texas Commission on Environmental Quality.

TABLE OF CONTENTS

LIST OF TABLES 3
LIST OF FIGURES 3
ACKNOWLEDGEMENTS 4
INTRODUCTION 5
Texas Stream Team 5
WATERSHED DESCRIPTION 6
Location and Climate 6
Physical Description 8
Land Use 9
History 10
Endangered Species and Conservation Needs 10
Texas Water Quality Standards 11
Water Quality Impairments 12
WATER QUALITY PARAMETERS 12
Water Temperature 12
Specific Conductance and Salinity 13
Dissolved Oxygen 13
pH 14
Water Transparency and Total Depth 14
E. coli and Enterococci Bacteria 15
Orthophosphate 15
Nitrate-Nitrogen 16
DATA COLLECTION, MANAGEMENT AND ANALYSIS 16
Data Collection 16
Data Management 17
Data Analysis 17
DATA RESULTS 18
Site Analysis 19
Air and Water Temperature 19
Specific Conductance and Total Dissolved Solids 20

Dissolved Oxygen ..... **Error! Bookmark not defined.**

pH 21

Transparency and Total Depth 21

WATERSHED SUMMARY 24

REFERENCES 25

Appendix A. 26

LIST OF TABLES

Table 1. Texas Commission on Environmental Quality segment classifications (TCEQ, 2022). 7

Table 2. Land use in the Lake Waco and Cottonwood Creek watersheds within the central Brazos River Basin region in McLennan County, Texas (NLCD, 2016). 10

Table 3. State and federally listed species in the Lake Waco and Cottonwood Creek watersheds within the central Brazos River Basin region in McLennan County, Texas. 11

Table 4. State water quality criteria in the Lake Waco and Cottonwood Creek watersheds within the central Brazos River Basin region in McLennan County, Texas. (TCEQ, 2018). 12

Table 5. Texas Stream Team monitoring sites in Lake Waco and Cottonwood Creek watersheds within the central Brazos River Basin region in McLennan County, Texas. 19

Table 6. Texas Stream Team data summary for sites in Lake Waco (LW) and Cottonwood Creek (CC) watersheds within the central Brazos River Basin region in McLennan County, Texas (Nov 2010 to Apr 2022). Mean±Standard Deviation (range). 20

Table 7. Endangered species located with the Waco area Brazos River Basin Watersheds. 26

Table 8. Threatened species located within the Waco area Brazos River Basin Watersheds. 26

LIST OF FIGURES

Figure 1. Lake Waco and Cottonwood Creek watersheds within the central Brazos River Basin region in McLennan County, Texas. 7

Figure 2. Long-term (1991-2020) monthly average precipitation (inches) and air temperature (°C) from Waco Dam in Waco, Texas (NOAA Climate Data, 2020). 8

Figure 3. Land cover for Lake Waco and Cottonwood Creek watersheds within the central Brazos River Basin region in McLennan County, Texas (NLCD, 2016). 9

Figure 4. Texas Stream Team monitoring sites in Lake Waco and Cottonwood Creek watersheds within the central Brazos River Basin region in McLennan County, Texas. 18

Figure 5. Water temperature for Texas Stream Team sites in Lake Waco (▲) and Cottonwood Creek (●) watersheds within the central Brazos River Basin region in McLennan County, Texas (Nov 2010 to Apr 2022). BR WQS = Brazos River Water Quality Standard, LW WQS = Lake Waco Water Quality Standard...21

Figure 6. Total dissolved solids (mg/L) for Texas Stream Team sites in Lake Waco and Cottonwood Creek watersheds within the central Brazos River Basin region in McLennan County, Texas (Nov 2010 to Apr 2022). BR WQS = Brazos River Water Quality Standard, LW WQS = Lake Waco Water Quality Standard...22

Figure 7. Dissolved oxygen (mg/L) for Texas Stream Team sites in Lake Waco and Cottonwood Creek watersheds within the central Brazos River Basin region in McLennan County, Texas (Nov 2010 to Apr 2022). 23

Figure 8. pH (s.u.) for Texas Stream Team sites in Lake Waco and Cottonwood Creek watersheds within the central Brazos River Basin region in McLennan County, Texas (Nov 2010 to Apr 2022). 23

ACKNOWLEDGEMENTS

The Texas Stream Team encourages life-long learning about the environment and people's relationship to the environment through its multidisciplinary citizen science programs. We also provide hands-on opportunities for Texas State University students and inspire future careers and studies in natural resource related fields. Preparation of this report fulfills a contract deliverable for the granting entity, but it also serves as a valuable educational experience for the students that assisted in preparing the report. The Texas Stream Team staff values the student contributions and recognizes each individual for their role. The following staff and student workers assisted in the preparation of this report and are acknowledged for their contributions:

Sandra S. Arismendez, Senior Watershed Scientist and Research Coordinator
Haley Busse, Student Research Assistant
Tina Cunningham, Student Research Assistant
Aspen Navarro, Program Coordinator
Laura M. Parchman, GIS and Data Management Associate

INTRODUCTION

Texas Stream Team

Texas Stream Team is a volunteer citizen science water quality monitoring program. Citizen scientist water quality monitoring occurs at predetermined monitoring sites, at approximately the same time of day each month. Information collected by Texas Stream Team citizen scientists is covered by a Texas Commission on Environmental Quality-approved Quality Assurance Project Plan to ensure a standard set of methods are used. Citizen scientist data may be used to identify surface water quality trends, target additional data collection needs, identify potential pollution events and sources of pollution, and to test the effectiveness of water quality management measures. Texas Stream Team citizen scientist data are not used by the state to assess whether water bodies are meeting the designated surface water quality standards. Data collected by Texas Stream Team provide valuable records, often collected in water bodies professionals are not able to monitor frequently or monitor at all.

For additional information about water quality monitoring methods and procedures, including the differences between professional and volunteer citizen science monitoring, please refer to the following sources:

- Texas Stream Team Core Water Quality Citizen Scientist Manual
- Texas Stream Team Advanced Water Quality Citizen Scientist Manual
- Texas Stream Team Program Volunteer Water Quality Monitoring Program Quality Assurance Project Plan
- Texas Commission on Environmental Quality Surface Water Quality Monitoring Procedures

The purpose of this report is to provide a summary of the data collected by Texas Stream Team citizen scientists. The data presented in this report should be considered in conjunction with other relevant water quality reports for a holistic view of water quality in two Waco area Brazos River Basin Subwatersheds – the Waco Lake-Bosque River and the Cottonwood Creek–Brazos River. Such sources may include, but are not limited to, the following:

- Texas Surface Water Quality Standards
- Texas Water Quality Inventory and 303(d) List (Integrated Report)
- Texas Clean Rivers Program partner reports, such as Basin Summary and Highlight Reports
- Texas Commission on Environmental Quality Total Maximum Daily Load reports
- Texas Commission on Environmental Quality and Texas State Soil and Water Conservation Board Nonpoint Source Program funded reports, including watershed protection plans

To get involved with Texas Stream Team or for questions regarding this watershed data report contact us at TxStreamTeam@txstate.edu or at (512) 245-1346. Visit our website for more information on our programs at www.TexasStreamTeam.org.

WATERSHED DESCRIPTION

Location and Climate

Two watersheds in the central Brazos River Basin from the Waco area are included in this report, the Waco Lake – Bosque River and the Cottonwood Creek – Brazos River (Figure 1). For the purposes of this report, the watersheds will be referred to as the Lake Waco and Cottonwood Creek watersheds, respectively.

The Lake Waco and Cottonwood Creek watersheds encompass most of the City of Waco (95.5 square miles), the county seat of McLennan County. Waco is located along the Brazos River and IH-35 about midpoint between Dallas and Austin, Texas, and in 2020 the population was 138,486 (U.S. Census Bureau, 2022). Both watersheds combined extend 91.3 square miles. The Cottonwood Creek watershed is about 10 square miles larger than the Lake Waco watershed. This area is not only important locally for aesthetics, recreation, and the ecosystem it supports, but it is also historically significant, provides economic opportunity, and features rich cultural and educational experiences (City of Waco, 2022).

The Waco area is home to Mammoth National Monument and Cameron Park. Mammoth National Monument is part of the National Parks System and extends over 100 acres along the riparian habitat of the Bosque River. Cameron Park is one of the biggest (>400 acres) municipal parks in Texas and is centrally located in downtown Waco on the Brazos and Bosque Rivers.

The Texas Commission on Environmental Quality designates classifications for stream segments in the Brazos River Basin and throughout Texas (Table 1). Both the North Bosque River (Segment 1226) and the Brazos River/Lake Brazos (Segment 1256) flow into Waco Lake (Segment 1225) which is classified as a reservoir and extends 7,309.5 acres or about 11.4 square miles within the Lake Waco watershed (Texas Commission on Environmental Quality, 2022). The Cottonwood Creek watershed includes two classified freshwater streams of the Brazos River, the Brazos River/Lake Brazos (Segment 1256) and the Brazos River Above Navasota River (Segment 1242) and has at least one tributary, Waco Creek.

The climate in this part of the state is described as subtropical with an average growing season of 353 days per year (Smyrl, 2022). National Oceanic and Atmospheric Administration climate data from a weather station at Waco Dam, Texas, was acquired from the National Data Center. Precipitation at Waco Dam averaged 37.5 inches annually and occurred year-round (Figure 2). Long-term monthly average precipitation has a bimodal distribution with peaks occurring in May and October. Average rainfall during these months was about 4 inches each month, respectively. The least amount of rainfall occurred in July (1.9 inches). The warmest and coldest months of the year were August (29.5°C) and January (8.4°C), respectively (National Oceanic and Atmospheric Administration, 2020).

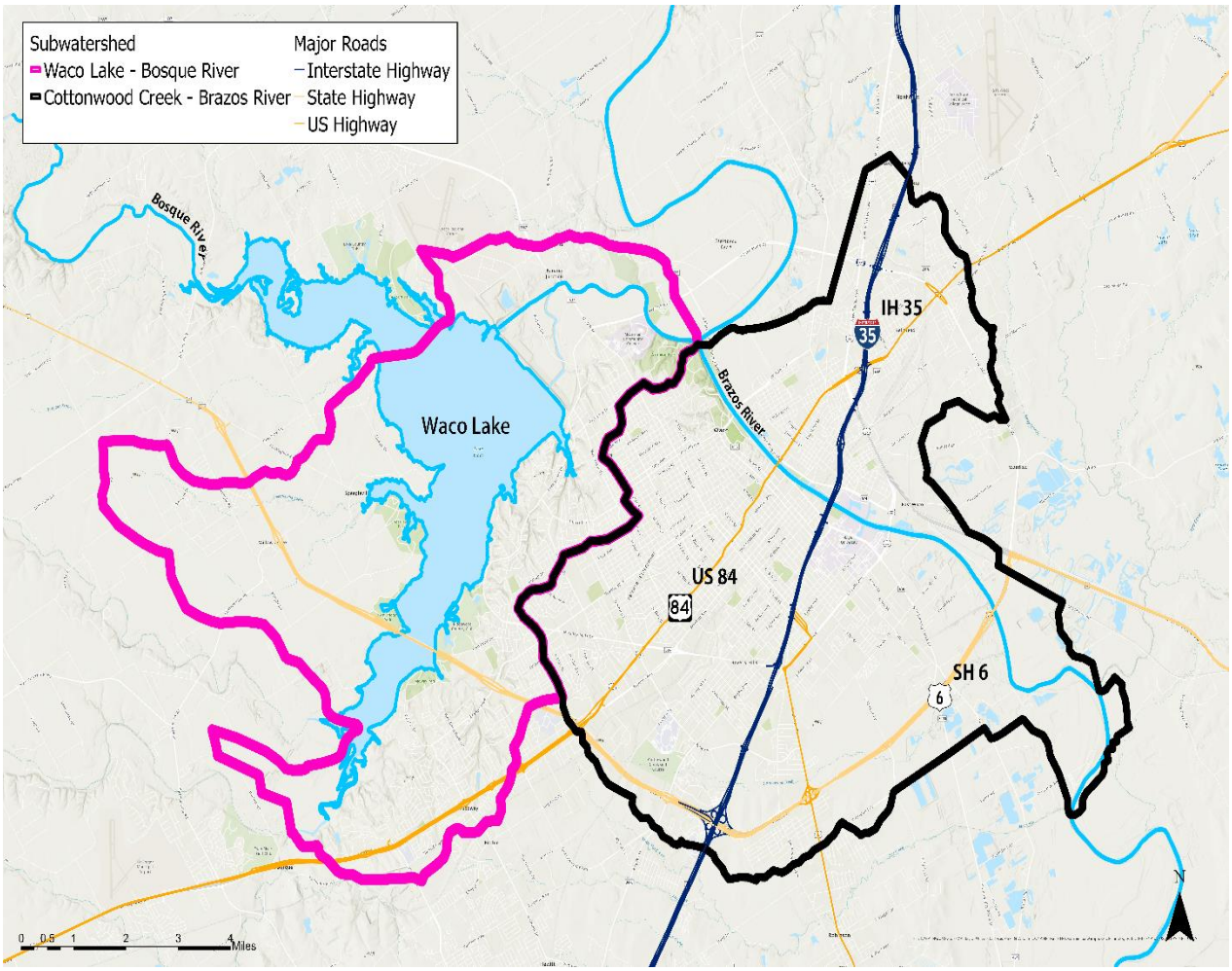

Figure 1. Waco Lake – Bosque River and Cottonwood Creek – Brazos River watersheds within the central Brazos River Basin in McLennan County, Texas.

Table 1. Texas Commission on Environmental Quality segment classifications (Texas Commission on Environmental Quality, 2022).

Segment Number	Segment Name	Segment Description
1225	Waco Lake	From Waco Lake Dam to a point immediately upstream of the confluence of Long Branch on the North Bosque River; and to a point on the Middle Bosque River 1.64 km (1.02 mi) and to a point on the South Bosque River 1.35 km (0.84 mi) upstream of the confluence of the Middle and South Bosque Rivers
1256	Brazos River/Lake Brazos	From the low water dam forming Lake Brazos in McLennan County to a point immediately upstream of the confluence of Aquilla Creek in McLennan County (includes the Bosque River Arm to the Waco Lake Dam)
1242	Brazos River	From a point immediately upstream of the confluence of the Navasota River in Brazos/Grimes/Washington County to the low water dam forming Lake Brazos in McLennan County

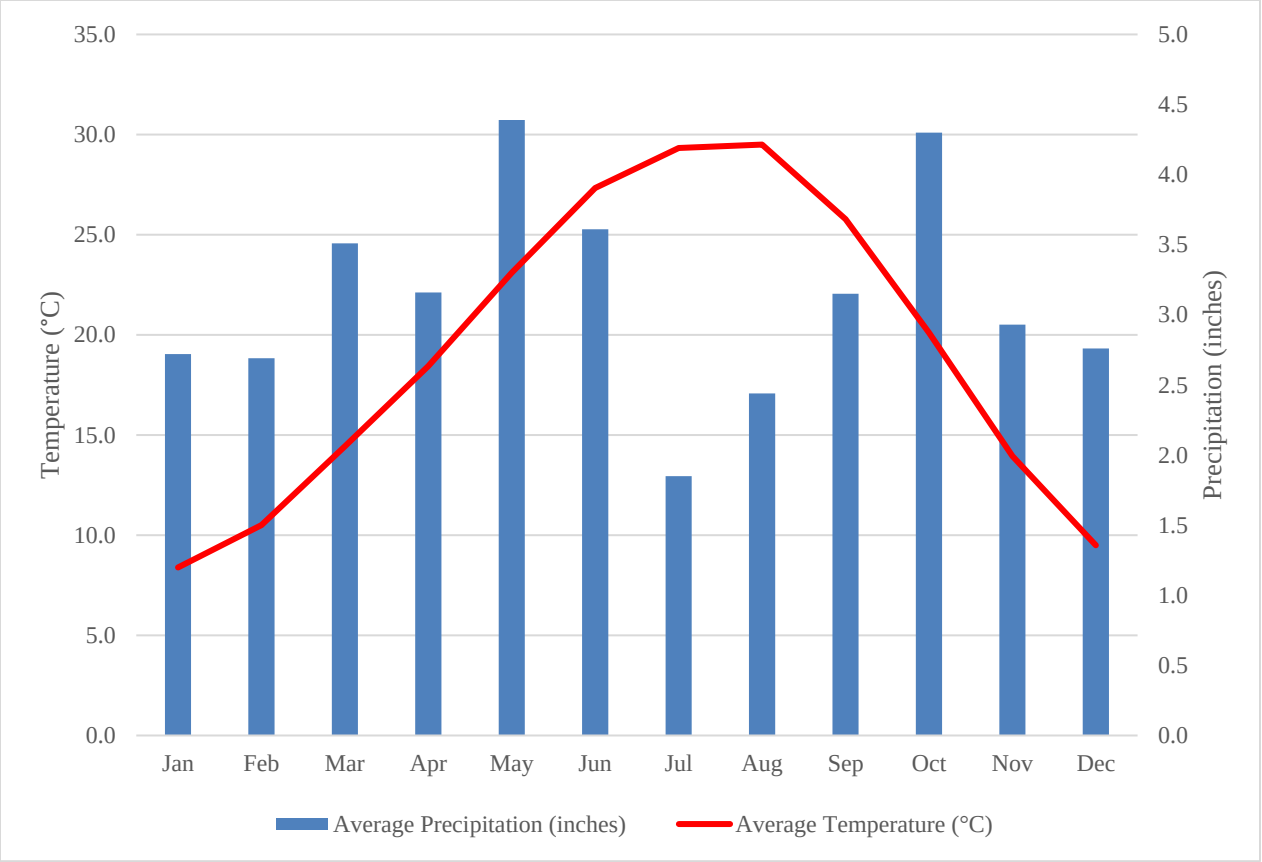

Figure 2. Long-term (1991-2020) monthly average precipitation (inches) and air temperature (°C) from Waco Dam in Waco, Texas (National Oceanic and Atmospheric Administration Climate Data, 2020).

Physical Description

The Lake Waco and Cottonwood Creek watersheds are located within the central Brazos River Basin near the City of Waco where the Brazos and Bosque Rivers converge (Conger, 2022). The landscape is described as flat to rolling terrain with Grand and Blackland Prairie comprised of mountain cedar, oak, mesquite, scrub brush, and grasses (Smyrl, 2022). Soils that support the prairie include shallow, stony soils, and black, waxy soils made up of clay and sand loams (Smyrl, 2022). The Balcones Fault straddles this area contributing to the changing steep slopes along the rolling prairie (Smyrl, 2022). Mineral resources found in the area include limestone, sand, gravel, oil, and gas.

This area supports diverse wildlife including deer, coyotes, rabbits, bobcats, beaver, opossums, fox, raccoon, mink, skunks, and squirrels, along with an assortment of birds, fish, and reptiles (Smyrl, 2022). Historically, before widespread urbanization, the area also supported antelope, buffalo, bear, and wild hogs (Smyrl, 2022).

Land Use

Land cover types were identified and mapped for the Lake Waco and Cottonwood Creek watershed (Figure 3) (National Land Cover Data, 2016). Eighty-eight percent of the land cover in the combined watersheds consists of developed land (47.8%), planted/cultivated (18.7%), open water (11.2%), and grassland (10.7%) (Table 2). The Cottonwood Creek watershed has higher percent developed land use (63.7%) than the Lake Waco watershed (28.3%), and the latter has more planted/cultivated (22.4%) and open water (20.8%) land use types than Cottonwood Creek.

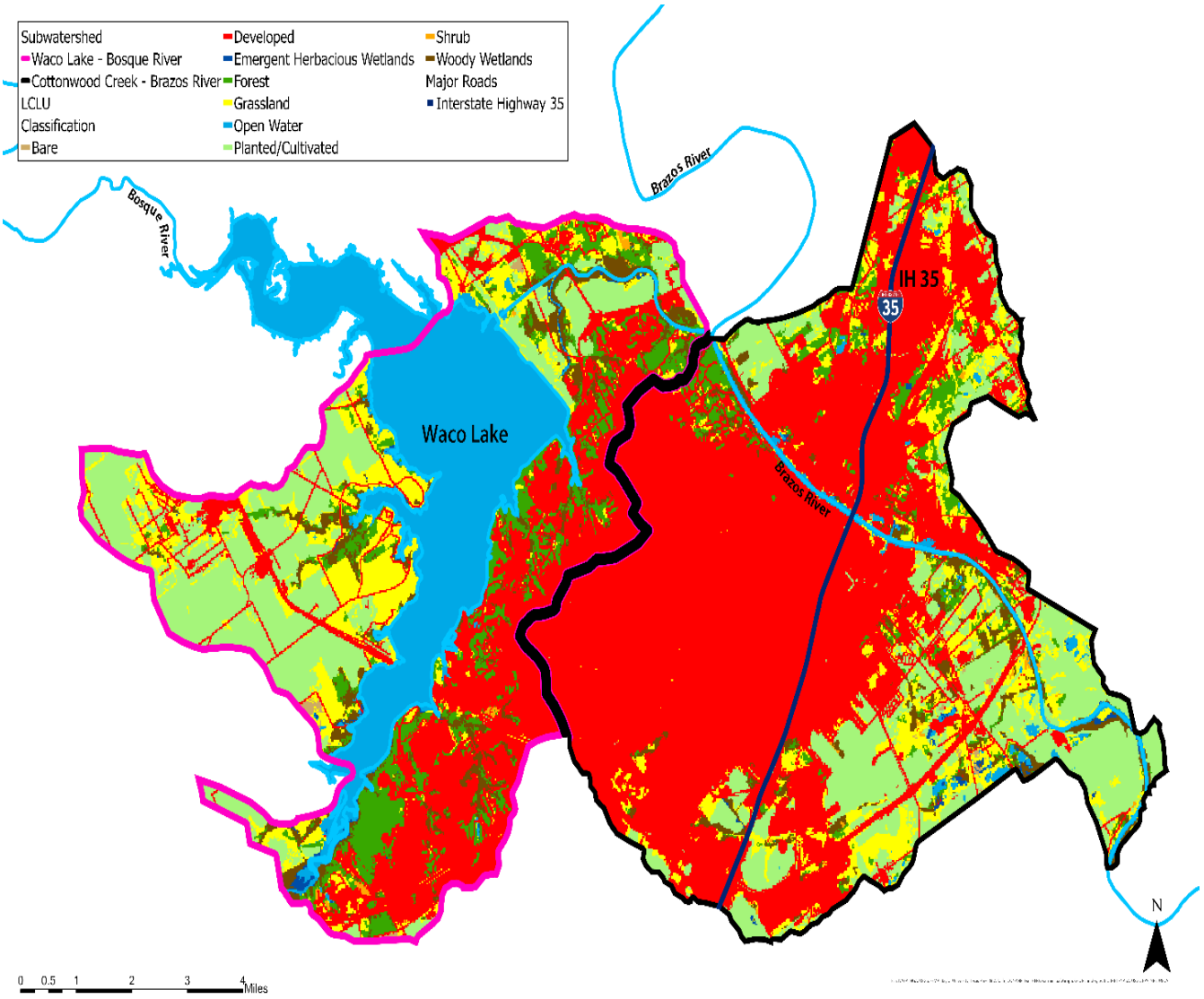

Figure 3. Land cover for Lake Waco and Cottonwood Creek watersheds within the central Brazos River Basin in McLennan County, Texas (National Land Cover Data, 2016).

Table 2. Land use in the Lake Waco and Cottonwood Creek watersheds within the central Brazos River Basin in McLennan County, Texas (National Land Cover Data, 2016).

Land Use Type	Lake Waco Watershed		Cottonwood Creek Watershed		Total	
	Area (acre)	Percent (%)	Area (acre)	Percent (%)	Area (acre)	Percent (%)
Developed	7,413.74	28.3%	20,506.55	63.7%	27,930.37	47.8%
Planted/Cultivated	5,876.78	22.4%	5,470.46	17.0%	10,954.05	18.7%
Open Water	5,455.34	20.8%	3,125.98	9.7%	6,556.42	11.2%
Grassland	3,118.64	11.9%	1,295.23	4.0%	6,252.56	10.7%
Forest	2,646.50	10.1%	930.721	2.9%	3,940.83	6.7%
Woody Wetlands	1,438.23	5.5%	667.1835	2.1%	2,376.19	4.1%
Herbaceous Wetlands	112.09	0.4%	97.85358	0.3%	211.39	0.4%
Bare	86.29	0.3%	47.59242	0.1%	123.144	0.2%
Shrub	60.71	0.2%	36.91749	0.1%	109.14	0.2%
Total	**26,208.30**	**100.00%**	**32,178.48**	**100.00%**	**58,454.11**	**100.00%**

History

The City of Waco was established on an ancient agricultural village by the Huaco Indians in 1849; they lived on the land in the area known today as downtown (City of Waco, 2022). During the early settlement years, property owners called the town Lamartine, but later became Waco Village, the county seat for McLennan County (Conger, 2022).

The town experienced population growth, primarily as a result of the cotton industry. The area later flourished as the Chisholm Trail used to drive cattle to market from San Antonio to Fort Worth travelled through Waco. Cattlemen often stopped to purchase supplies and for recreation, adding to the local economy. Construction of a suspension bridge across the Brazos River and the railroad both spurred the local economy in the late 1800's, allowing this area to become an important arrival and departure site for future settlers (Conger, 2022).

Endangered Species and Conservation Needs

The common names of 13 species listed as threatened or endangered (under the authority of Texas state law and/or under the US Endangered Species Act) within the Waco area are included in Appendix I at the end of this report. A summary of the number of species per taxonomic group listed as state or federally endangered, threatened, G1 or G2 (critically imperiled or imperiled), species of greatest conservation need, and/or endemic are provided in Table 3.

Table 3. State and federally listed species in the Lake Waco and Cottonwood Creek watersheds within the central Brazos River Basin in McLennan County, Texas.

Taxon	Endangered (Federal or State)	Threatened (Federal or State)	G1 or G2 (Critically imperiled or imperiled)	Species of Greatest Conservation Need (NPWD) (S1 or S2)	Endemic Total Count
Birds	2	5	2	10	0
Fish	2	1	1	3	3
Mammals	0	0	0	4	0
Reptiles	0	1	0	4	1
Insects	0	0	0	1	1
Mollusks	0	2	1	1	2
Plants	0	0	0	1	3
Total Count	**4**	**9**	**4**	**24**	**10**

Texas Water Quality Standards

The Texas Surface Water Quality Standards establish explicit goals for the quality of streams, rivers, lakes, and bays throughout the state. The standards are developed to maintain the quality of surface waters in Texas to support public health and protect aquatic life, consistent with the sustainable economic development of the state. Water quality standards identify appropriate uses for the state's surface waters, including aquatic life, recreation, and sources of public water supply as drinking water. The criteria for evaluating support of those uses in the classified segments of Waco Lake (Segment 1225), Brazos River/Lake Brazos (Segment 1256), and Brazos River above Navasota River (Segment 1242) included in this report are provided in Table 4. The total dissolved solids criteria are for maximum annual averages, the dissolved oxygen criteria are for minimum 24-hour dissolved oxygen means at any site within the segment, the minimum and maximum values for pH apply to any site within the segment, the *E. coli* indicator bacteria for freshwater is a geometric mean, and the temperature criteria is a maximum value at any site within the segment.

The Texas Surface Water Quality Standards also contain narrative criteria (verbal descriptions) that apply to all waters of the state and are used to evaluate support of applicable uses. Narrative criteria include general descriptions such as the existence of excessive aquatic plant growth, foaming of surface waters, taste- and odor-producing substances, sediment build-up, and toxic materials. Narrative criteria are evaluated by using screening levels, if they are available, and other information, including water quality studies, existence of fish kills or contaminant spills, photographic evidence, and local knowledge. Screening levels serve as a reference to indicate when water quality parameters may be approaching levels of concern.

Table 4. State water quality criteria in the Lake Waco and Cottonwood Creek watersheds within the central Brazos River Basin in McLennan County, Texas (Texas Commission on Environmental Quality, 2018).

Segment	**Total Dissolved Solids (mg/L)**	**Dissolved Oxygen (mg/L)**	**pH Range (s.u.)**	***E. coli* Bacteria (#/100 mL)**	**Temperature (°C)**
1225 – Waco Lake (Reservoir)	400	Grab screening level and min. 24-hour mean: 5.0 Grab min.: 3.0	6.5-9.0	Primary Contact Recreation: 126 geometric mean, 399 single sample	33.9
1256 – Brazos River/Lake Brazos (Freshwater Stream)	1,150	Grab screening level: 5.0 Grab min.: 3.0	6.5-9.0	Primary Contact Recreation: 126 geometric mean, 399 single sample	35
1242 – Brazos River Above Navasota River (Freshwater Stream)	1,000	Grab screening level and min. 24-hour mean: 5.0 Grab/24-hour min.: 3.0	6.5-9.0	Primary Contact Recreation: 126 geometric mean, 399 single sample	35

Water Quality Impairments

The 2020 Texas Water Quality Inventory and 303(d) List (Integrated Report) assessed the Waco Lake (Segment 1225), Brazos River/Lake Brazos (Segment 1256), and Brazos River above Navasota River (Segment 1242) and found no impairments. However, some concerns were identified for chlorophyll a and nitrate in water in portions of both segments of the Brazos River included in this report. No total maximum daily loads or watershed protection plans have been developed or adopted in the study area for this project.

WATER QUALITY PARAMETERS

Water Temperature

Water temperature influences the physiological processes of aquatic organisms, and each species has an optimum temperature for survival. High water temperatures increase oxygen-demand for aquatic communities and can become stressful for fish and aquatic insects. Water temperature variations are most detrimental when they occur rapidly, leaving the aquatic

community no time to adjust. Additionally, the ability of water to hold oxygen in solution (solubility) decreases as temperature increases. This effect is exacerbated in coastal water bodies influenced by tidal, saline waters.

Warm water temperatures occur naturally with seasonal variation, as water temperatures tend to increase during summer and decrease in winter in the Northern Hemisphere. Daily (diurnal) water temperature changes occur during normal heating and cooling patterns. Man-made sources of warm water include power plant effluent after it has been used for cooling or hydroelectric plants that discharge warm water. Citizen scientist monitoring may not identify fluctuating patterns due to diurnal changes or events such as power plant releases because of the monthly sampling frequency. While citizen scientist data may not show diurnal temperature fluctuations, they could demonstrate the fluctuations over seasons and years when collected consistently at predetermined monitoring sites and monthly frequencies.

Specific Conductance and Salinity

Specific conductance is a measure of the ability of a body of water to conduct electricity. It is measured in microsiemens per centimeter (µS/cm). A body of water is more conductive if it has more total dissolved solids such as nutrients and salts, which indicates poor water quality if they are overly abundant. High concentrations of nutrients can lead to eutrophication, which results in lower levels of dissolved oxygen. High concentrations of salt can inhibit water absorption and limit root growth for vegetation, leading to an abundance of more drought tolerant plants, and can cause dehydration of fish and amphibians. Sources of total dissolved solids can include agricultural runoff, domestic runoff, or discharges from wastewater treatment plants.

Salinity is a measure of the saltiness or the dissolved inorganic salt concentration in water. Salinity is often measured in ocean, estuarine, or tidally-influenced waters, but in Texas there are some inland streams that have a high salt content due to the local geology and require salinity measurements. Some common ions measured as salinity include sodium, chloride, magnesium, sulfate, calcium, and potassium. Seawater typically has a salt content of 35 parts per thousand (ppt or ‰). Like other water quality parameters, salinity affects the homeostasis or the balance of water and solutes within both plants and animals. Too much or too little salt can affect plant and animal cell survival and growth, therefore salinity is an important measurement.

Dissolved Oxygen

Oxygen is necessary for the survival of organisms like fish and aquatic insects. The amount of oxygen needed for survival and reproduction of aquatic communities varies according to species composition and adaptations to watershed characteristics like stream gradient, habitat, and available streamflow.

The dissolved oxygen concentrations can be influenced by other water quality parameters such as nutrients and temperature. High concentrations of nutrients can lead to excessive surface vegetation and algae growth, which may starve subsurface vegetation of sunlight and, therefore, reduce the amount of oxygen they produce via photosynthesis. This process is known as eutrophication. Low dissolved oxygen can also result from high groundwater inflows (which have low dissolved oxygen due to minimal aeration), high temperatures, or water releases from deeper portions of dams where dissolved oxygen stratification occurs. Supersaturation typically occurs underneath waterfalls or dams with water flowing over the top where aeration is abundant.

pH

The pH scale measures the concentration of hydrogen ions on a range from zero to 14 and is reported in standard units (s.u.). The pH of water can provide information regarding acidity or alkalinity. The range is logarithmic; therefore, every one-unit change is representative of a 10-fold increase or decrease in acidity or alkalinity. Acidic sources, indicated by a low pH level, can include acid rain and runoff from acid-laden soils. Acid rain is predominantly caused by coal powered plants with minimal contributions from the burning of other fossil fuels and other natural processes, such as volcanic emissions. Soil-acidity can be caused by excessive rainfall leaching alkaline materials out of soils, acidic parent material, crop decomposition creating hydrogen ions, or high-yielding fields that have drained the soil of all alkalinity. Sources of high pH (alkaline) include geologic composition, as in the case of limestone increasing alkalinity and the dissolving of carbon dioxide in water. Carbon dioxide is water soluble, and as it dissolves it forms carbonic acid. A suitable pH range for healthy organisms is between 6.5 and 9.0 s.u.

Water Transparency and Total Depth

Two instruments can be used by Texas Stream Team Citizen scientists to measure water transparency, a Secchi disc or a transparency tube. Both instruments are used to measure water transparency or to determine the clarity of the water, a condition known as turbidity. The Secchi disc is lowered into the water until it is no longer visible, then raised until it becomes visible, and the average of the two depth measurements is recorded. A transparency tube is filled with sample water and water is released until the Secchi pattern at the bottom of the tube can be seen. The tube is marked with two-millimeter increments and is used to measure water transparency. Transparency measurements less than the total depth of the monitoring site are indicative of turbid water. Readings that are equal to total depth indicate clear water. Highly turbid waters pose a risk to wildlife by clogging the gills of fish, reducing visibility, and carrying contaminants. Reduced visibility can harm predatory fish or birds that depend on good visibility to find their prey. Turbid waters allow less light to penetrate deep into the water, which, in turn, decreases the density of phytoplankton, algae, and other aquatic plants. This reduces the dissolved oxygen in the water due to reduced photosynthesis. Contaminants are mostly

transported in sediment rather than in the water. Turbid waters can result from sediment runoff from construction sites, erosion of farms, or mining operations.

E. coli and Enterococci Bacteria

E. coli bacteria originate in the digestive tract of endothermic organisms. The United States Environmental Protection Agency has determined *E. coli* to be the best indicator of the degree of pathogens in a freshwater system. A pathogen is a biological agent that causes disease.

Enterococci bacteria are a subgroup of fecal streptococci bacteria (mainly *Streptococcus faecalis* and *Streptococcus faecium*) that are present in the intestinal tracts and feces of warm-blooded animals. It is used by the Texas Commission on Environmental Quality as an indicator of the potential presence of pathogens in tidally-influenced saltwater along the Texas Gulf Coast.

The segments within the Lake Waco and Cottonwood Creek watersheds are designated a primary contact recreation 1 use. This means that recreation activities are presumed to involve a significant risk of ingestion of water (e.g., wading by children, swimming, water skiing, diving, tubing, surfing, handfishing as defined by Texas Parks and Wildlife Code, §66.115, and the following whitewater activities: kayaking, canoeing, and rafting).

The standard for a bacteria impairment is based on the geometric mean (geomean) of the bacteria measurements collected. A geometric mean is a type of average that incorporates the high variability found in parameters such as *E. coli* and enterococci which can vary from zero to tens of thousands of colony forming units per 100 milliliters (CFU/100 mL). The standard for contact recreational use of a water body is 126 CFU/100 mL for *E. coli* in freshwater or 35 CFU/100 mL for enterococci in saltwater. A water body is considered impaired if the geometric mean is higher than the corresponding water quality standard.

Texas Stream Team does not monitor water quality for enterococci in coastal waters, instead citizen scientists can get certified in *E. coli* bacteria monitoring, the indicator used by the Texas Commission on Environmental Quality for freshwater streams.

Orthophosphate

Orthophosphate is the phosphate molecule all by itself. Phosphorus almost always exists in the natural environment as phosphate, which continually cycles through the ecosystem as a nutrient necessary for the growth of most organisms. Testing for orthophosphate detects the amount of phosphate in the water itself, excluding the phosphate bound up in plant and animal tissue. There are other methods to retrieve the phosphate from the material to which it is bound, but they are too complicated and expensive to be conducted by citizen scientists. Testing for orthophosphate provides an idea of the degree of phosphate in a water body. It can be used for problem identification, which can be followed up with more detailed professional monitoring, if

necessary. Phosphorus inputs into a water body may be caused by the weathering of soils and rocks, discharge from wastewater treatment plants, excessive fertilizer use, failing septic systems, livestock and pet waste, disturbed land areas, drained wetlands, water treatment, and some commercial cleaning products. The effect excess orthophosphate has on a water body is known as eutrophication and is described above in the "Dissolved Oxygen" section.

Nitrate-Nitrogen

Nitrogen is present in terrestrial or aquatic environments as nitrate-nitrogen, nitrites, and ammonia. Nitrate-nitrogen tests are conducted for maximum data compatibility with TCEQ and other partners. Just like phosphorus, nitrogen is a nutrient necessary for the growth of most living organisms. Nitrogen inputs into a water body may be from livestock and pet waste, excessive fertilizer use, failing septic systems, and industrial discharges that contain corrosion inhibitors. The effect excess nitrogen has on a water body is known as eutrophication and is described previously in the "Dissolved Oxygen" section. Nitrate-nitrogen dissolves more readily than orthophosphate, which tend to be attached to sediment, and, therefore, can serve as a better indicator of possible sewage or manure pollution during dry weather.

DATA COLLECTION, MANAGEMENT AND ANALYSIS

Data Collection

The field sampling procedures implemented by trained citizen scientists are documented in the Texas Stream Team Core Water Quality Citizen Scientist Manual and the Texas Stream Team Advanced Water Quality Citizen Scientist Manual. The sampling protocols in both manuals adhere closely to the Texas Commission on Environmental Quality Surface Water Quality Monitoring Procedures Manual, Volume 1 (August 2012). Additionally, all data collection adheres to Texas Stream Team's approved Quality Assurance Project Plan.

Procedures documented in Texas Stream Team Water Quality Citizen Scientist Manuals or the Texas Commission on Environmental Quality Surface Water Quality Monitoring Procedures Manual, Volume 1 (August 2012) outline the necessary steps to prevent contamination of samples, including direct collection into sample containers, when possible. Field quality control samples are collected and analyzed to detect whether contamination has occurred and to ensure data accuracy and precision.

Field sampling activities are documented on Environmental Monitoring Form data sheets. The following items are recorded for each field sampling event: station ID, location, sampling time, date, depth, sample collector's name/signature, group identification number, meter calibration information, and reagent expiration dates. Specific conductance values are converted to total dissolved solids using a conversion factor of 0.65 and are reported as mg/L.

Values for measured parameters are recorded. If reagents or media are expired, it is noted, and data are flagged and communicated to Texas Stream Team staff. Sampling is not permitted with expired reagents or bacteria media; the corresponding values will be flagged in the database and excluded from data reports. Detailed observational data recorded include water appearance, weather, field observations (biological activity and stream uses), algae cover, unusual odors, days since last significant rainfall, and flow severity. Comments related to field measurements, number of participants, total time spent sampling, and total round-trip distance traveled to the sampling site are also recorded for grant reporting and administrative purposes.

Data Management

The citizen scientists collect field data and report the measurement results to Texas Stream Team, either by submitting a hard copy of the Environmental Monitoring Form or by entering the data directly into the online Waterways Dataviewer. All data are reviewed to ensure they are representative of the samples analyzed and locations where measurements were made. The measurements and associated quality control data are also reviewed to ensure they conform to specified monitoring procedures and project specifications as stated in the approved Quality Assurance Project Plan.

Data review and verification is performed using a data management checklist and self-assessments, as appropriate to the project task, followed by automated database functions that will validate data as the information is entered into the database. The data are verified and evaluated against project specifications and are checked for errors, especially errors in transcription, calculations, and data input. Potential errors are identified by examination of documentation and by manual and computer-assisted examination of corollary or unreasonable data. Issues that can be corrected are corrected and documented. Once entered, the data can be accessible publicly through the online Texas Stream Team Datamap.

Data Analysis

Data were compiled, analyzed, summarized, and compared to state water quality standards and/or criteria to provide readers with a reference point for parameters that may be of concern. The statewide, biennial assessment performed by the Texas Commission on Environmental Quality involves more stringent monitoring methods and oversight than those used by citizen scientists and staff in this report. The Texas Stream Team citizen scientist water quality monitoring data are not currently used in the Texas Commission on Environmental Quality assessments mentioned above. However, the Texas Stream Team data are intended to inform stakeholders about general characteristics and assist professionals in identifying areas of potential concern to plan future monitoring efforts.

All data collected by citizen scientists in the study watersheds were exported from the Texas Stream Team database and grouped by site. Sites with 10 or more monitoring events were maintained in the dataset for analysis. Sites with fewer than 10 monitoring events were

excluded from the analysis for this report but may be used in future data summary reports. Once compiled, data were sorted, summary statistics were generated and reviewed, and results were graphed in JMP Pro 14.0.0 (SAS Institute Inc., 2018) using standard methods. Best professional judgement was used to verify outliers. Outlier box or scatter plots were prepared to provide a compact view of the distribution of the data for each parameter and site(s). The horizontal line within the box plot represents the median sample value, while the ends of the box represent the 25th and 75th quantiles or the interquartile range. The lines extending from each end of the box, or whiskers, are computed using the 25th/75th quartiles ± 1.5 x (interquartile range). Outliers are plotted as points outside the box plot.

DATA RESULTS

Water quality data from eight Texas Stream Team monitoring sites in the Lake Waco and Cottonwood Creek watersheds were acquired for analysis (Figure 4). Three sites are in the Lake Waco watershed and five sites are in the Cottonwood Creek watershed. Trained citizen scientists conducted between 11 and 39 sampling events at each site, for a total of 164 monitoring events (Table 5). The period of record for the sampling events ranged from November 2010 to April 2022, with all sites experiencing temporal intermittent sampling.

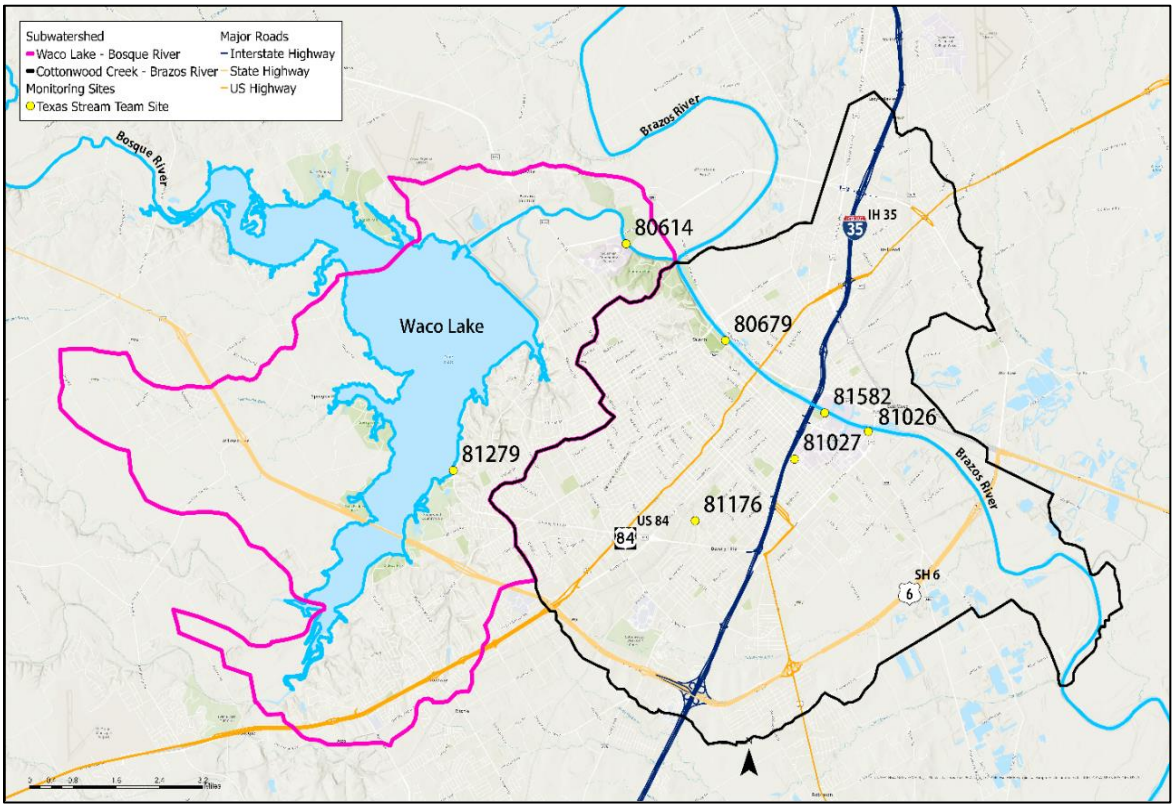

Figure 4. Texas Stream Team monitoring sites in Lake Waco and Cottonwood Creek watersheds within the central Brazos River Basin in McLennan County, Texas.

Table 5. Texas Stream Team monitoring sites in Lake Waco and Cottonwood Creek watersheds within the central Brazos River Basin in McLennan County, Texas.

Site ID	Description	Number of Samples (n)	Period of Record
Lake Waco Watershed Sites			
80614	Brazos River @ McLennan Community College Boat Ramp	39	11/28/2010 – 3/28/2022
81279	Lake Waco @ Koehne Park	18	11/2/2017 – 3/3/2021
80613	Lake Waco @ Midway Parl Boat Ramp Adjacent Hwy 6	17	11/21/2010 – 8/30/2017
Cottonwood Creek Sites			
80679	Brazos River @ Platform in Cameron Park	13	7/21/2011 – 7/20/2021
81582	Brazos River Near Mayborn Museum	11	9/14/2019 – 1/28/2022
81026	Lake Brazos @ Crew Dock	21	6/13/2014 – 4/22/2019
81176	Waco Creek @ Floyd Casey Stadium on Clay Avenue	18	9/3/2015 – 4/19/2022
81027	Waco Creek @ Fifth Street	27	6/13/2014 – 4/19/2019
	TOTAL	**164**	

Site Analysis

Water quality monitoring data from the eight sites were analyzed and summarized including the number of samples, mean, standard deviation, and range of values (Table 6). Citizen scientists monitored the sites for standard core water quality monitoring parameters, including air and water temperature, conductivity, total dissolved solids, dissolved oxygen, pH, Secchi disc/tube transparency, and total depth.

Air and Water Temperature

Average air temperature for all sites ranged from 20.5 to 27.3°C (Table 6). The lowest mean air temperature (20.5°C) was observed at Koehne Park in the Lake Waco watershed (Site 81279). The highest mean air temperature (27.3°C) was observed at Cameron Park in the Cottonwood Creek watershed (Site 80679).

Average water temperature at each site ranged from 17.8°C at Koehne Park (Site 81279) in the Lake Waco watershed to 23.8°C at Cameron Park (Site 80679) in the Cottonwood Creek watershed (Table 6). Water temperatures were below the water quality standard at all sites except site 81026 on the Brazos River (35.2°C) on August 10, 2016 (Figure 5).

Table 6. Texas Stream Team data summary for sites in Lake Waco (LW) and Cottonwood Creek (CC) watersheds within the central Brazos River Basin in McLennan County, Texas (Nov 2010 to Apr 2022). Mean±Standard Deviation (range).

Parameter	LW-MCC ID 80614 n=39	LW-Koehne Pk ID 81279 n=18	LW-Midway ID 80613 n=17	CC-Cam Pk ID 80679 n=13	CC-BR near Museum ID 81582 n=11	CC-Crew Dock ID 81026 n=21	CC-Clay Ave. ID 81176 n=18	CC-5th Str. ID 81027 n=27
Air Temp. (°C)	22.5±7.7 (31)	20.5±7.5 (23.5)	24.1±8.2 (31)	27.3±8.0 (28.3)	25.2±6.5 (19)	22.6±9.9 (30)	22.1±8.2 (33)	24.9±7.8 (28.5)
Water Temp. (°C)	20.7±7.2 (23.7)	17.8±6.9 (19)	19.3±7.1 (24.4)	23.8±6.9 (20.4)	21.4±7.4 (19.6)	20.9±8.2 (24.7)	19.2±6.3 (23.7)	22.2±5.6 (23.1)
Specific Conductance (µS/cm)	648±348 (1420)	350±44 (174)	336±34 (119)	1,120±567 (1490)	873±229 (654)	979±308 (940)	541±195 (828)	913±185 (707)
*Total Dissolved Solids (mg/L)	421±226 (923)	227±29 (113)	219±22 (77)	728±369 (969)	568±149 (425)	644±202 (611)	352±127 (538)	591±113 (460)
Dissolved Oxygen (mg/L)	7.7±1.7 (5.8)	8.2±1.5 (4.7)	7.7±1.8 (7.2)	8.7±3.0 (8.6)	8.2±1.3 (3.2)	7.8±2.8 (10.4)	9.1±2.3 (8.7)	8.8±1.8 (6.9)
pH (s.u.)	8.0±0.6 (2.5)	7.9±0.4 (1.6)	7.7±0.3 (1.2)	7.8±0.4 (1.6)	8.1±0.2 (0.7)	7.9±0.7 (2.1)	8.2±0.5 (1.5)	7.4±1.5 (8.5)
Secchi Tube Transp. (m)	0.6±0.2 (0.4)	0.4±0.1 (0.6)	ND	ND	ND	0.2±0.01 (0.03)	1.0±0.4 (1.1)	0.9±0.4 (1.2)
Secchi Disc Transp. (m)	0.7±0.2 (1.1)	ND	0.5±0.3 (1.3)	0.5±0.2 (0.7)	0.7±0.1 (0.3)	0.6±0.2 (0.8)	ND	0.8±0.3 (0.9)
Total Depth (m)	0.3±0.2 (0.7)	0.3±0.1 (0.4)	0.7±0.7 (2.2)	0.8±0.7 (1.7)	0.4±0.3 (1.0)	0.2±0.1 (0.2)	0.2±0.2 (1.0)	0.2±0.3 (1.7)

*Total dissolved solids were calculated from specific conductance (total dissolved solids = specific conductance * 0.65)

Specific Conductance and Total Dissolved Solids

Specific conductance measurements were converted to total dissolved solids for all sites (Table 6). Average total dissolved solids values at all sites ranged from 219 mg/L at Midway (Site 80613) in the Lake Waco watershed to 728 mg/L at Cameron Park (Site 80679) in the Cottonwood Creek watershed (Table 6). The water quality standard for total dissolved solids in Lake Waco is 400 mg/L, while the total dissolved solids standard for the Brazos River is 1,150 mg/L. Average total dissolved solids values were below the Lake Waco water quality standard at sites 81279 – LW and 80613 – LW (Figure 6). All sites on the Brazos River met the Brazos River water quality standard, but the Cameron Park site exceeded the standard in July, August, and September 2011.

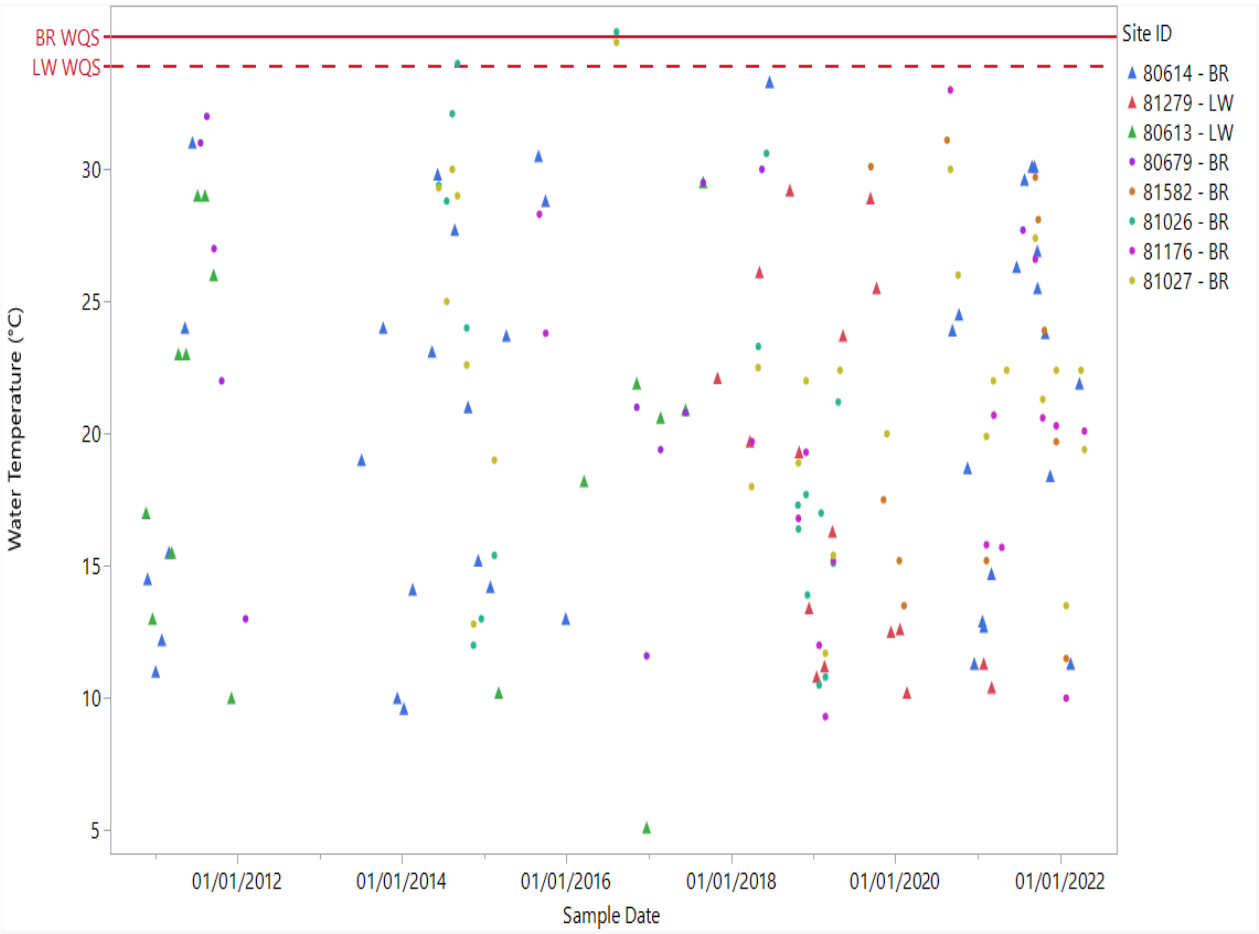

Figure 5. Water temperature for Texas Stream Team sites in Lake Waco (▲) and Cottonwood Creek (●) watersheds within the central Brazos River Basin in McLennan County, Texas (Nov 2010 to Apr 2022). BR WQS = Brazos River Water Quality Standard, LW WQS = Lake Waco Water Quality Standard.

Dissolved Oxygen

Average dissolved oxygen values at all eight sites in both watersheds were above the water quality standard of 5.0 mg/L (Table 6). The range of average dissolved oxygen values for all sites spanned from 7.7 to 9.1 mg/L. The distribution of dissolved oxygen measurements for each site are displayed in Figure 7. Individual dissolved oxygen values extended below the mean and minimum water quality standard at three sites (Sites 80614 – BR, 81026 – BR, and 80613 - LW) during the period of record evaluated, but all sites had averages at or above the water quality standard.

pH

The pH values at most sites were at or below the water quality standard of 6.5 to 9.0 s.u. (Figure 8). The site on the Brazos River within the Lake Waco watershed (Site 80614) had one value of 9.5 s.u. above the water quality standard. Average pH for all sites ranged from 7.4 to 8.2 s.u. (Table 6).

Transparency and Total Depth

Secchi tubes and discs were used for measuring transparency at the sites monitored in the Lake Waco and Cottonwood Creek watersheds (Table 6). The average Secchi tube transparency values reported at five sites (80614, 81279, 81026, 81176, and 81027) where this parameter was measured ranged from 0.2 to 1.0 m. The average range of Secchi disc transparency values reported was from 0.5 to 0.8 m (Table 6).

Total depth was measured at all sites monitored (Table 6). The site with the average largest depth (0.8 m) was at Cameron Park (Site 80679), while the sites with the average shallowest depths (0.2 m) were at 81026, 81176, and 81027 all within the Cottonwood Creek watershed.

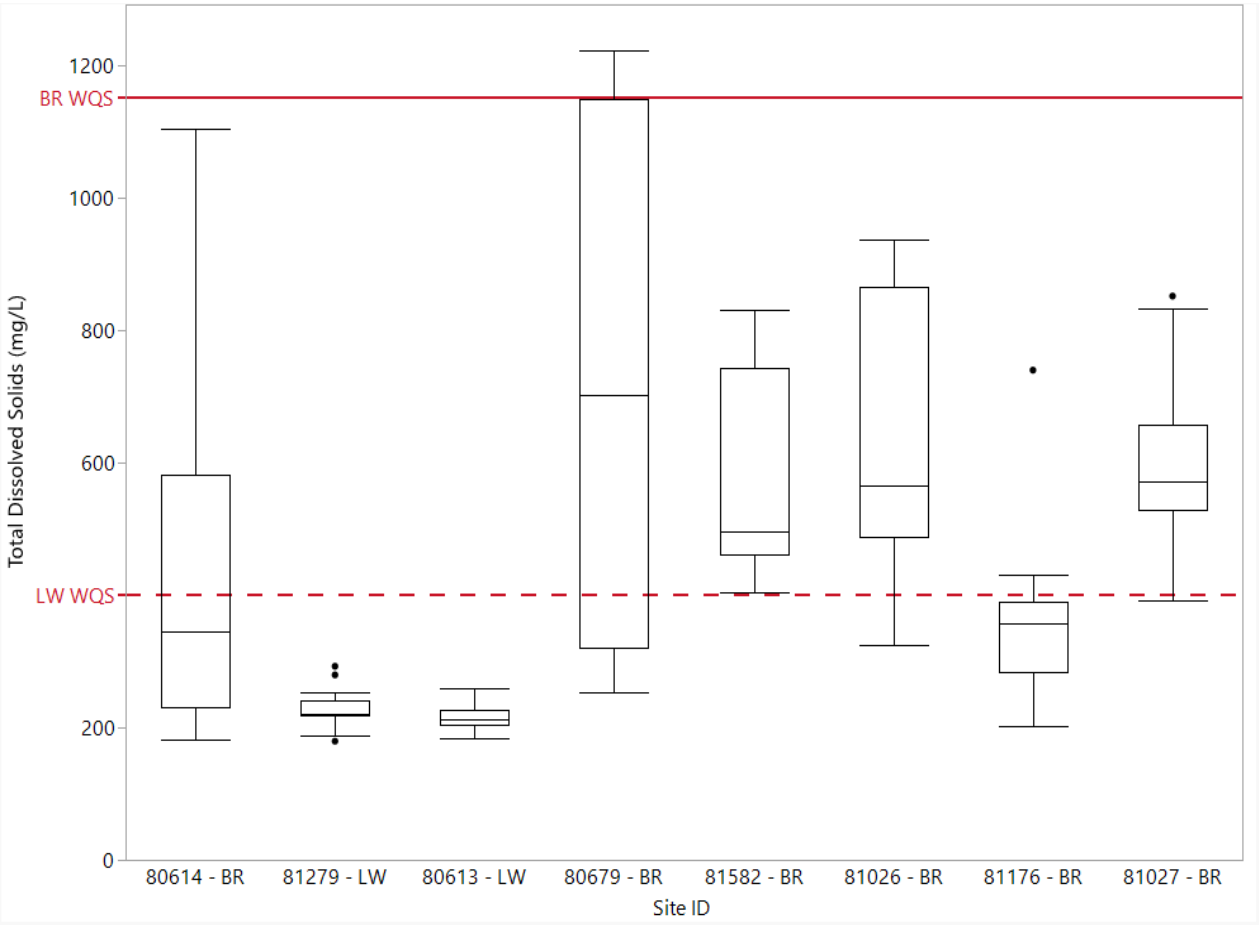

Figure 6. Total dissolved solids (mg/L) for Texas Stream Team sites in Lake Waco and Cottonwood Creek watersheds within the central Brazos River Basin in McLennan County, Texas (Nov 2010 to Apr 2022). BR WQS = Brazos River Water Quality Standard, LW WQS = Lake Waco Water Quality Standard.

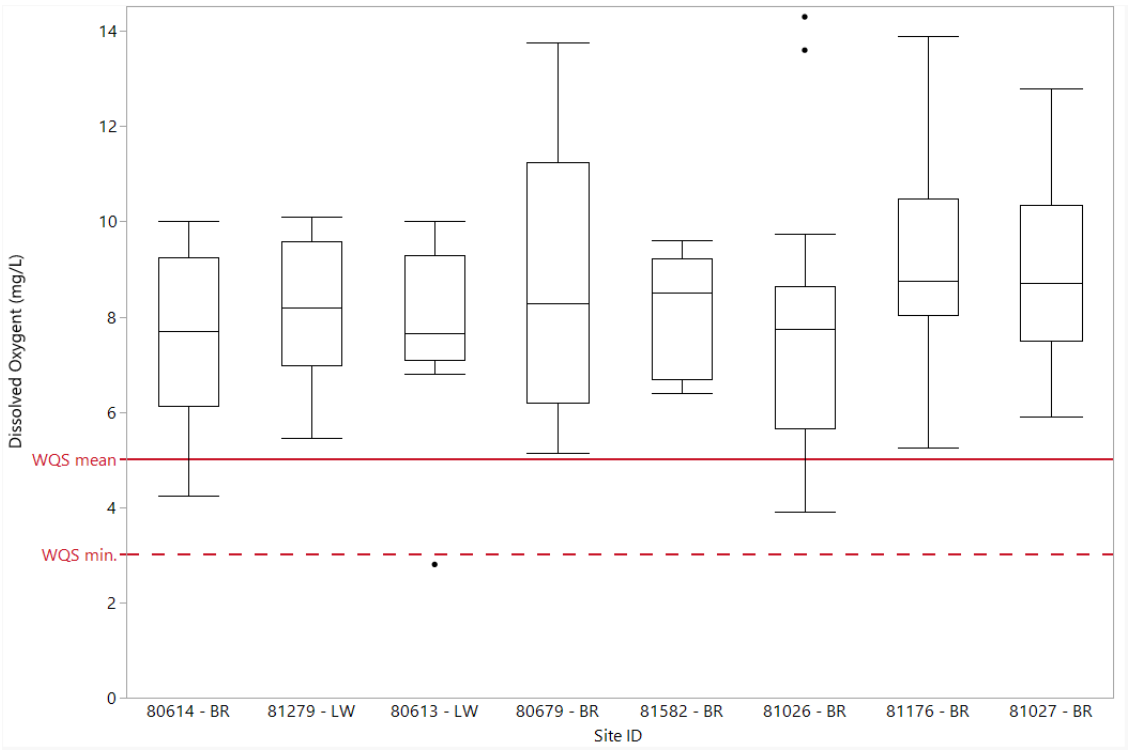

Figure 7. Dissolved oxygen (mg/L) for Texas Stream Team sites in Lake Waco and Cottonwood Creek watersheds within the central Brazos River Basin in McLennan County, Texas (Nov 2010 to Apr 2022).

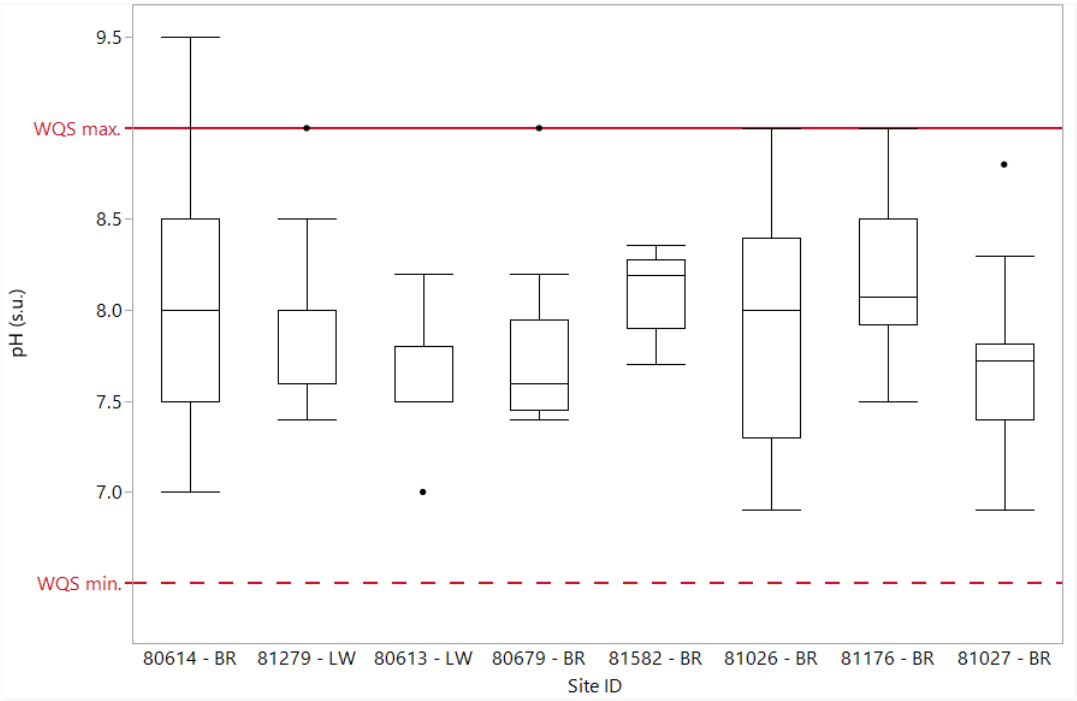

Figure 8. pH (s.u.) for Texas Stream Team sites in Lake Waco and Cottonwood Creek watersheds within the central Brazos River Basin in McLennan County, Texas (Nov 2010 to Apr 2022).

WATERSHED SUMMARY

Texas Stream Team citizen scientists monitored standard core water quality parameters at eight sites in the Lake Waco and Cottonwood Creek watersheds from November 2010 to April 2022. Three sites were in the Lake Waco watershed, while the remaining five sites were in the Cottonwood Creek watershed. The Lake Waco watershed receives river water from the North Bosque River and the Brazos River, while the Cottonwood Creek watershed receives river water from the Brazos River and a tributary, Waco Creek.

Parameters monitored by Texas Stream Team citizen scientists included water and air temperature, specific conductance, total dissolved solids, dissolved oxygen, pH, transparency, and total depth. Data from the eight monitoring sites were analyzed and summarized in this report.

The classified segments included in this report, Lake Waco (Segment 1225), Brazos River/Lake Brazos (Segment 1256), and Brazos River (Segment 1242), within the Lake Waco and Cottonwood Creek watersheds were assessed by the Texas Commission on Environmental Quality in the 2020 Texas Water Quality Inventory and 303(d) List. The assessment found no impairments or exceedances of the water quality standards and criteria. However, chlorophyll a and nitrate in water was identified as a concern for both segments of the Brazos River included in this report. Results presented in this data summary report revealed dissolved oxygen and water temperatures met the water quality standard at all sites. The temperature water quality standard was exceeded at one site on the Brazos River (Site 81026) on one occasion in 2016. We also identified exceedances of the water quality standard on the Brazos River for total dissolved solids in July, August, and September 2011, and one exceedance of the water quality standard for pH at site 80614. Although no impairments were identified by the Texas Commission on Environmental Quality, this area is showing signs of water quality degradation. In particular, the Cottonwood Creek watershed exhibited more developed land use than the Lake Waco watershed and had more of the single sample exceedances of the water quality standard indicative of the effects of urban nonpoint source pollution.

The Texas Stream Team citizen scientists monitoring standard core water quality parameters in the Lake Waco and Cottonwood Creek watersheds are encouraged to continue monitoring and consider pursuing Advanced and *E. coli* bacteria water quality monitoring. Continuation of the ongoing monitoring is crucial due to the results presented here and the potential for increased development in the watersheds. There is a need for continued water quality monitoring for the development of long-term data sets. Information gathered thus far has been useful to describe current water quality conditions. Continuation of this monitoring will allow future trend analysis to capture changes in water quality as the area grows. Texas Stream Team will continue to support citizen scientists by providing technical support, creating new monitoring sites, and re-activating existing sites. We look forward to training new citizen scientists to expand and grow

the water quality monitoring efforts in this area and beyond. For more information about Texas Stream Team and upcoming trainings contact us at TxStreamTeam@txstate.edu or visit the calendar of events on our website at www.TexasStreamTeam.org.

REFERENCES

City of Waco. 2022. City of Waco Municipal Information. Accessed May 24, 2022.

Conger, R.N. "Waco, TX." Handbook of Texas Online. Published by the Texas State Historical Association. Accessed June 10, 2022.

National Oceanic and Atmospheric Administration. (2020). National Oceanic and Atmospheric Administration National Climate Data Center: http://www.ncdc.noaa.gov/ Accessed November 2021.

Smyrl, V.E. "McLennan County," Handbook of Texas Online. Published by the Texas State Historical Association. Accessed June 10, 2022.

Texas Commission on Environmental Quality. 2020. Texas Integrated Report of Surface Water Quality for Clean Water Act Sections 305(b) and 303(d). Texas Commission on Environmental Quality, Water Quality Planning Division, Austin, Texas.

Texas Commission on Environmental Quality. 2018. Chapter 307 – Texas Surface Water Quality Standards, Rule Project No. 2016-002-307-OW. Texas Commission on Environmental Quality, Austin, Texas.

Texas Commission on Environmental Quality. 2012. Surface Water Quality Monitoring Procedures, Volume 1: Physical and Chemical Monitoring Methods. Texas Commission on Environmental Quality, Water Quality Planning Division, Austin, Texas. Publication RG-415.

Texas Parks and Wildlife Department, Wildlife Division, Diversity and Habitat Assessment Programs. (2020). Texas Parks and Wildlife Department County Lists of Protected Species and Species of Greatest Conservation Need: Travis and Williamson Counties. https://tpwd.texas.gov/state-parks/honey-creek Accessed November 2021.

U.S. Census Bureau. 2020. Waco city, Texas - Census Bureau Profile. Accessed May 24, 2022.

Appendix A.

Table 7. Endangered species located with the Waco area Brazos River Basin Watersheds.

Species Type	Common Name	Federal/State Listing
Birds	Whooping Crane	Federally Listed as Endangered, State Listed as Endangered
	Golden-cheeked Warbler	Federally Listed as Endangered, State Listed as Endangered
Fish	Smalleye Shiner	Federally Listed as Endangered, State Listed as Endangered
	Sharpnose Shiner	Federally Listed as Endangered, State Listed as Endangered

Table 8. Threatened species located within the Waco area Brazos River Basin Watersheds.

Species Type	Common Name	Federal/State Listing
Birds	White-faced Ibis	State Listed as Threatened
	Wood Stork	State Listed as Threatened
	Black Rail	Federally Listed as Threatened, State Listed as Endangered
	Piping Plover	Federally Listed as Threatened, State Listed as Endangered
	Rufa Red Knot	Federally Listed as Threatened, State Listed as Endangered
Fish	Chub Shiner	State Listed as Threatened
Reptiles	Texas Horned Lizard	State Listed as Threatened
Mollusks	Brazos Heelsplitter	State Listed as Threatened
	Texas Fawnsfoot	State Listed as Threatened