Shoal Creek Characterization Report (Draft 3 – 3/29/2019)

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Contents

I. Executive Summary

Stretching from north to central Austin, the Shoal Creek watershed has an area of 8,300 acres, a length of 16 miles, and includes more than 30 miles of streams. Once home to popular swimming and fishing destinations, the creek suffers from poor water quality, including elevated fecal bacteria and nutrient levels. Since 2002, elevated bacteria concentrations have been found in a tributary to Shoal Creek, the Spicewood Tributary (Segment 1403J), which is currently listed as impaired for bacteria the Draft 2016 Texas Integrated Report of Surface Water Quality, as well as a concern for nitrate. In 2012, a Total Maximum Daily Load (TMDL) was developed to address bacteria and to evaluate attainment of the contact recreation use in Waller Creek, Walnut Creek, Spicewood Tributary on Shoal Creek and Taylor Slough South. TMDL compliance is based on maintaining bacteria mean concentrations below 126 MPN/100 mL (TCEQ, 2015). Water quality monitoring shows that bacteria in Shoal Creek often exceeds these levels and storm flows also have high levels of nutrients, sediments, and other contaminants.

The Shoal Creek watershed is both highly impervious and developed prior to a modern understanding of the impact of development on watershed systems. This combination presents special challenges and requires a multifaceted approach to restoring water quality. The watershed is the fourth most impervious watershed in the city, with appromximately 54% of the watershed surfaced in impervious cover. Based on a City of Austin Watershed Protection Department (COA-WPD) analysis, Shoal Creek watershed could reach approximately 64% impervious cover if each site developed to maximum allowed impervious cover (COA-WPD, 2018).

Because Shoal Creek was among the first areas to be developed in Austin, large portions of the watershed were developed prior to modern drainage and water quality regulations. Over 56% of development in Shoal Creek was built built before the adoption of drainage regulations in 1974, and 71% was constructed before the adoption of water quality regulations in 1991. Currently, only 19% of the watershed's impervious cover area is treated for water quality. Over 1,300 residences and 94 commercial properties are located directly along Shoal Creek. The watershed currently has a population of approximately 72,000 people, and is expected to reach approximately 104,000 people by 2040. Due to the culimation of these factors, the watershed suffers from uncontrolled, polluted stormwater runoff. Nonpoint source pollution is a major challenge for the watershed, and the severity of this issue will increase if not addressed with a management plan as the population of the watershed grows.

In addition to nonpoint source pollution, Shoal Creek also faces significant flooding challenges. Shoal Creek is best known for the 1981 Memorial Day Flood that devastated lower Shoal Creek and claimed 13 lives, but it has experienced several severe flooding events throughout Austin's history. Lower Shoal Creek between 15th Street and Lady Bird Lake is the top-ranked creek flooding problem area in the city, with 66 buildings and two low-water crossings expected to by impacted in a 100-year event. Shoal Creek also has a high prevalence of localized flooding concerns because much of the development in the Shoal Creek watershed predates the implementation of modern drainage criteria in 1977. Many of the storm drains are undersized, which can cause ponding of runoff in roadways and yards.

This Watershed Characterization Report gathers existing data to characterize the historic and current state of the Shoal Creek watershed as part of an effort to develop a Watershed Protection Plan (WPP). It will identify water quality trends in the watershed and guide the identification of both sources of pollution and target areas for the development of solutions. The development of the Shoal Creek WPP will build on existing efforts to improve water quality on the part of WPD-COA and nonprofit groups. The Shoal Creek Conservancy (SCC) currently serves as the lead entity in the WPP development process with primary partners including the COA, Texas State University - The Meadows Center for Water and the Environment (Meadows), and Doucet & Associates (Doucet). Project funding and guidance is provided by the United States Environmental Protection Agency (EPA) and Texas Commission on Environmental Quality (TCEQ).

II. Introduction

A. Watershed

A watershed is the area of land that drains to a particular waterway, in this case Shoal Creek. The Shoal Creek watershed encompasses approximately 8,000 acres (13 square miles) of central and north-central Austin. The creek served as the original western boundary of the city—the area to the west of the creek remained largely undeveloped into the 1920s. The Shoal Creek watershed has been impacted by human activities since the early 1800s, when settlers established the community of Waterloo on the land between Waller Creek and Shoal Creek. Figure 1 below shows a bird's eye view of Austin illustrated in 1887. Shoal Creek and its largely undisturbed floodplain are visible on the left-hand edge of the illustration. The right-hand image shows current-day Austin, which has seen intense development within the Shoal Creek watershed.

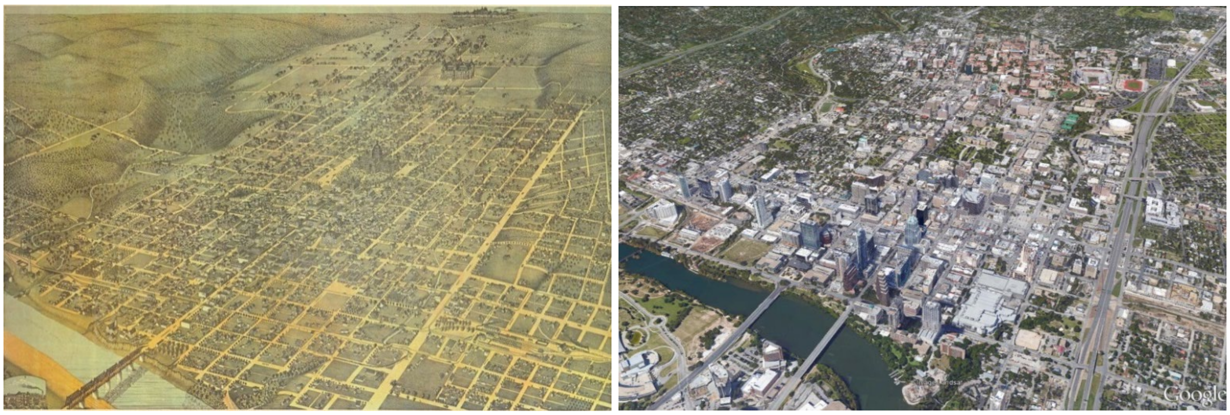


Figure 1 Austin circa 1887 (Source: Amon Carter Museum) and Austin 2016 (Source: Google Earth, Landsat)

The City of Austin Watershed Protection Department (COA-WPD) breaks the watershed into four study reaches for purposes of analysis—SHL1, SHL2, SHL3, and SHL4 (see Figure 2). Reaches are a segment of a creek, with the land area draining to those segments defining the reaches' subwatershed. These reaches and their subwatersheds comprise the basic unit of analysis throughout this report. Reach boundaries are determined based on patterns in geomorphology, hydrology, and land use. Dividing the watershed into reaches provides the ability to evaluate trends at a higher level of detail, while providing the flexibility to move sampling site locations if necessary.

B. Shoal Creek and Major Tributaries

Shoal Creek begins just north of the junction of Loop 360 and Mopac and flows south until it empties into Lady Bird Lake between West Avenue and Nueces Street. The creek is best known for the 1981 Memorial Day Flood that devastated lower Shoal Creek and claimed 13 lives, but it has experienced significant flooding events throughout Austin's history. Shoal Creek has two major tributaries. Spicewood Springs is a small tributary in northwest Austin, named for a nearby spring. The Hancock Branch drains the area between Burnet Road and North Lamar Boulevard. Shoal Creek also has the distinction of having the oldest trail in Austin, which was built by volunteers in the early 1960s (Shoal Creek Conservancy, 2013).

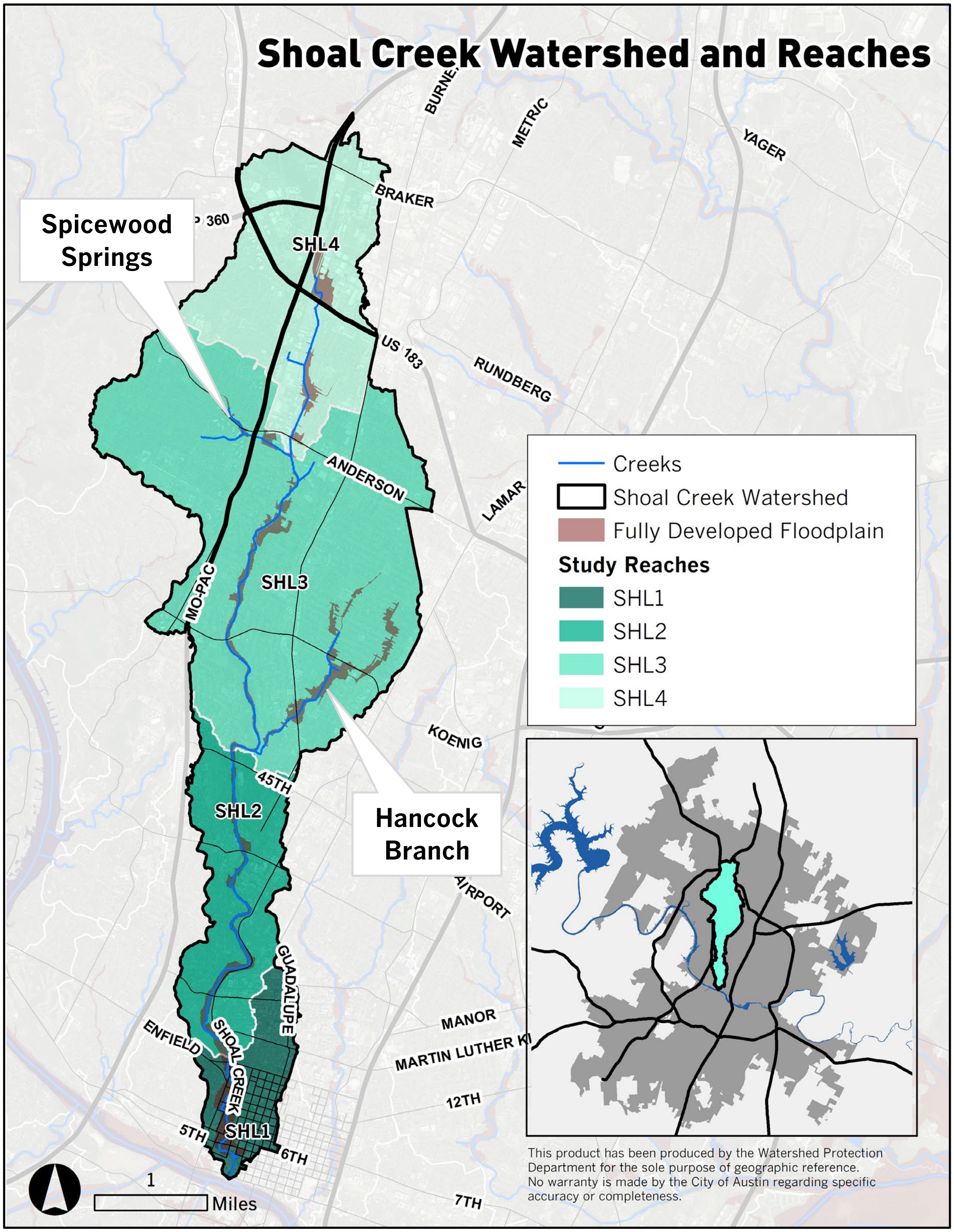


Figure 2 Shoal Creek Watershed and Reaches (COA-WPD, 2018)

III. Watershed Characteristics

A. Climate and Rainfall

Austin is in what the National Weather Service calls "Flash Flood Alley"—an area prone to intense rainfall events and flooding. Austin's rainfall patterns are influenced by its location along the Balcones Escarpment, which separates the Edwards Plateau ("Hill Country") from the Blackland Prairie to the east. The Balcones Escarpment is a series of cliffs dropping from the Edwards Plateau to the Balcones Fault Line. As Texas receives warm, moist air from the Gulf of Mexico as well as cooler air masses from the north and west, the Balcones Escarpment acts as the formation point for large thunderstorms that have the potential to produce many inches of rainfall over a short period. The record rainfall event for Austin occurred in September 1921, when 19.03" of rain fell over a two-day period (NWS, 2018).

Austin's climate is characterized by long, hot summers and short, mild winters, with warm spring and fall transitional periods. Austin averages around 34 inches of rainfall per year, with May, September, and October being the wettest months. Yearly total rainfall varies widely, from 11.42 inches in 1954 to 65.31 inches in 1919 (NWS, 2018). Austin also experiences periodic drought conditions, with a record of 88 days without precipitation in 1894-1895 (NWS, 2018). According to the Climate Change Projections for the City of Austin report, projected changes in Austin's climate include increases in annual average temperatures, more frequent high temperature extremes, and more frequent drought conditions in the summer. The report also projects little change in annual average rainfall, but more frequent extreme rainfall (Hayhoe, 2014).

The National Oceanic and Atmospheric Administration, in partnership with many other federal, state, and local agencies, has completed a historical rainfall intensity study called Atlas 14 (Volume 11 for Texas). Rainfall intensities are used by Federal Emergency Management Agency (FEMA) and local communities to determine flood risk, design public drainage infrastructure, and to make floodplain maps. Rainfall intensities for the State of Texas were last assessed in 1994. Atlas 14 is an update of this data that incorporates almost a quarter century of rainfall data collected statewide since the last study, up to and including Hurricane Harvey. The Atlas 14 study shows that portions of Texas, including the City of Austin, are more likely to experience larger storms than previously thought. This means that what used to be considered a 500-year rain event is more likely a 100-year rain event (a 1% chance of happening in any given year as opposed to a 0.2% chance) (Perica et al., 2018) The data from the study will be used by the City of Austin to update floodplain maps citywide, including the maps for the Shoal Creek watershed.

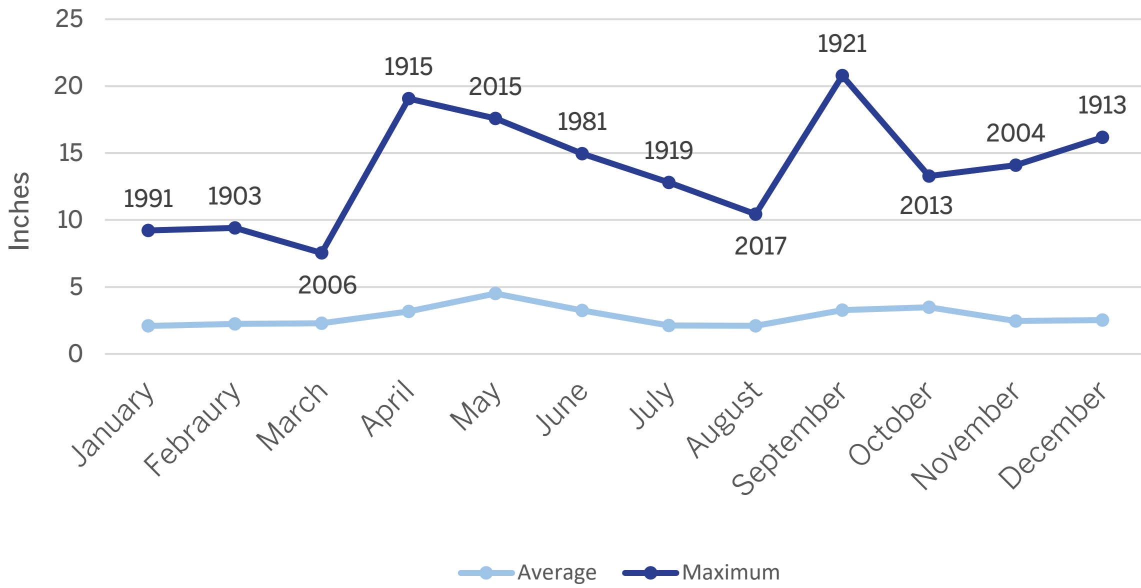


Figure 3 Austin Monthly Rainfall (1897 - 2018) (NWS, 2019)

B. Geology, Groundwater, and Springs

Austin lies along the boundary of two ecological regions: the Edwards Plateau ("Hill Country") to the west and the Blackland Prairie to the east (U.S. Environmental Protection Agency, 2013). The Edwards Plateau features steep slopes with narrow floodplains. In contrast, the Blackland Prairie features broad, alluvial floodplains as well as deep but erosive clay soils and creek banks. The majority of the Shoal Creek watershed lies within a transitional area, with characteristics of both ecological regions.

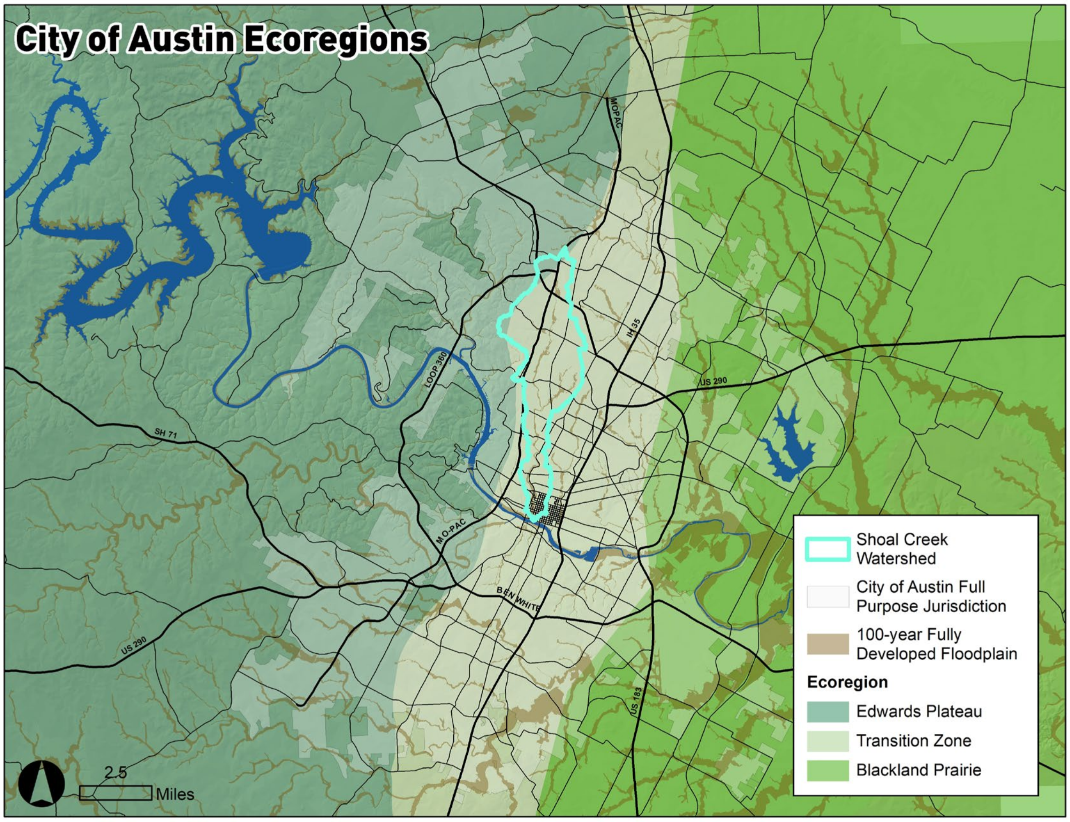


Figure 4 City of Austin Ecoregions (U.S. Environmental Protection Agency, 2013)

One of Austin's defining natural features is its sensitive karst geology—portions of the city contribute to and directly recharge the Edwards Aquifer, a subsurface layer of porous limestone that stores and conveys water. The aquifer's recharge zone is where this limestone is exposed at the land surface, allowing water to flow directly into the aquifer. Most recharge occurs in streambeds, entering the aquifer through sinkholes or fault planes. Because the limestone is close to the land's surface and there is little soil to filter out pollutants, the aquifer is particularly sensitive to pollutants from yards, roadways, and construction sites within its recharge zone. Approximately 27% of the Shoal Creek watershed is within the recharge zone (COA-WPD, 2018).

With 30 identified natural seeps or springs, the Shoal Creek watershed contains approximately 5% of the identified seeps/springs within the City of Austin full purpose jurisdiction (COA-WPD, 2018). Two notable springs within the Shoal Creek watershed include Seiders Spring and Spicewood Spring. Seider Spring was the site of popular resort and bathhouse that operated from 1871 to 1896 (Brune, 2002). Spicewood Spring is a verified habitat for the Jollyville Plateau salamander (Eurycea tonkawae), which was listed as federally threatened under the Endangered Species Act in 2012. The Jollyville Plateau salamander has a very limited range—it is found only in springs, spring-fed streams, and subterranean streams of nine watersheds within the Northern Edwards Aquifer. Because this species remains aquatic throughout its life, it depends on the quality and quantity of groundwater for its survival (O'Donnell et al. 2008).

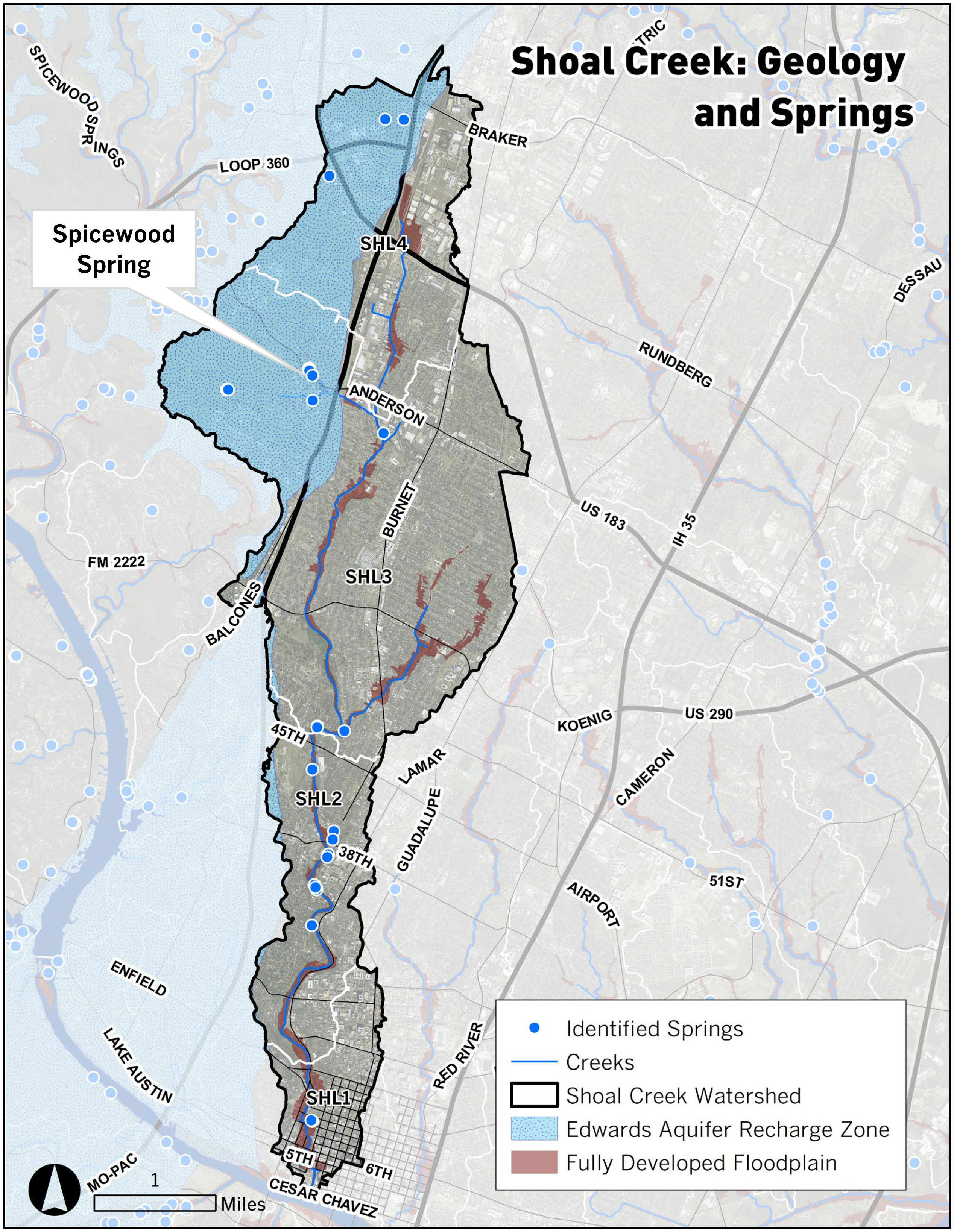


Figure 5 Shoal Creek Geology and Springs (COA-WPD, 2018)

C. Development Patterns

Population

The Shoal Creek watershed currently has a population of approximately 72,000 people. Based on the Austin City Demographer's projections at the census tract level, the population is expected to reach approximately 104,000 people by 2040. From 2010 to 2015, the population of the watershed grew by approximately 13%, exceeding the growth rate of the Austin area as a whole for that time period (11%). From 2015 to 2020, this rate is expected to slow to 9.1%, approximately on par with the Austin area rate (9.7%). The Shoal Creek watershed has a population density of approximately 7.5 persons per acre, making it the 10th most dense watershed in the city (see Figure 8). It is expected to reach approximately 12.5 persons per acre by 2040 (COA-WPD, 2019; City of Austin Demographer, 2018).

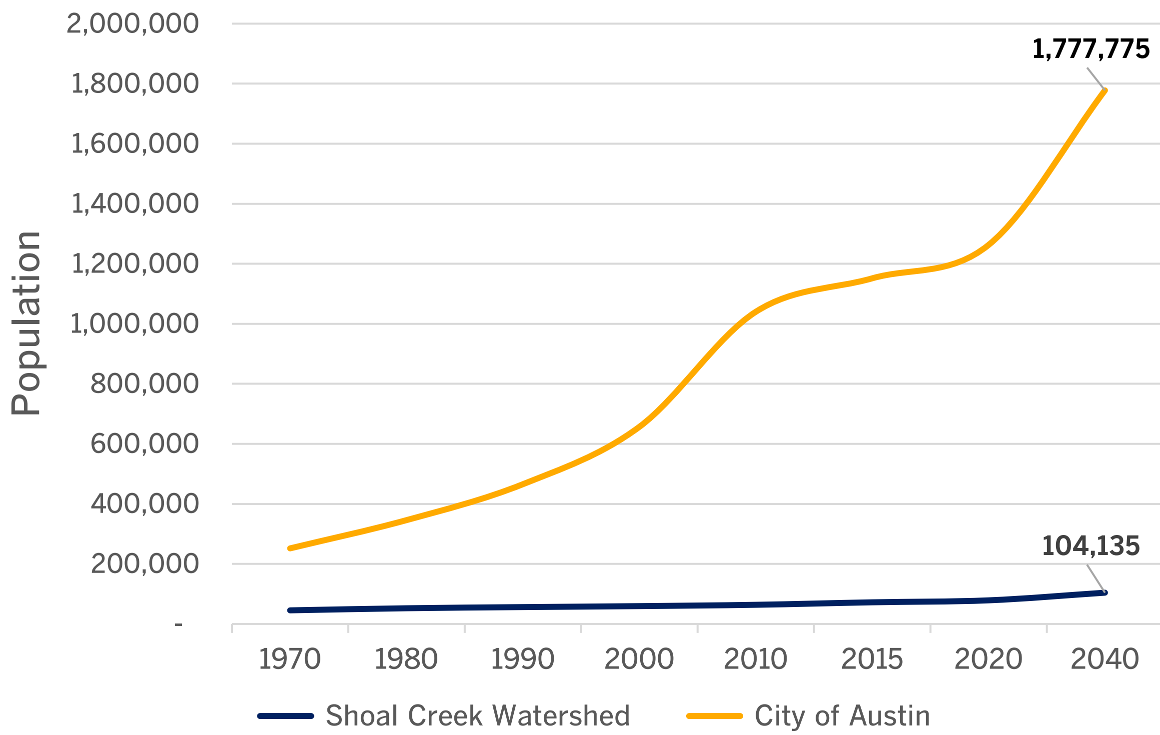


Figure 6 City of Austin and Shoal Creek Population Projections (COA-WPD, 2019; City of Austin Demographer, 2018; IPUMS NHGIS, University of Minnesota, 2018)

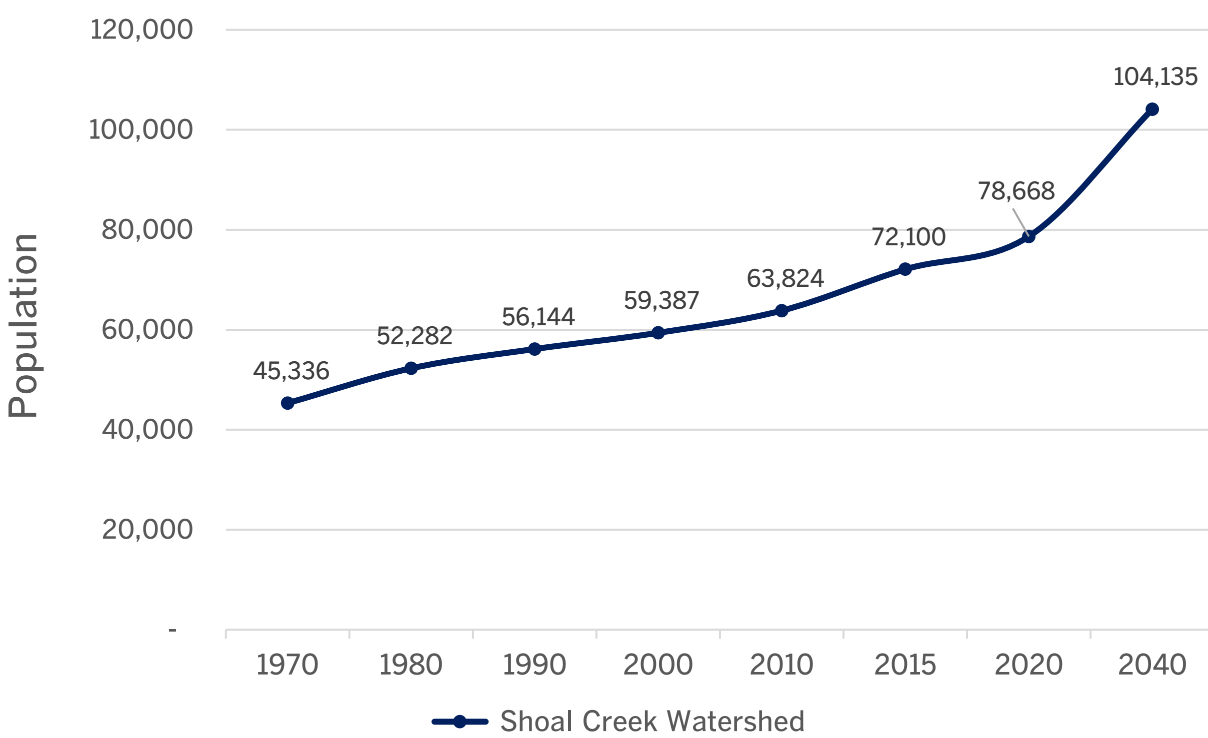


Figure 7 Shoal Creek Population Projections (COA-WPD, 2019; City of Austin Demographer, 2018; IPUMS NHGIS, University of Minnesota, 2018)

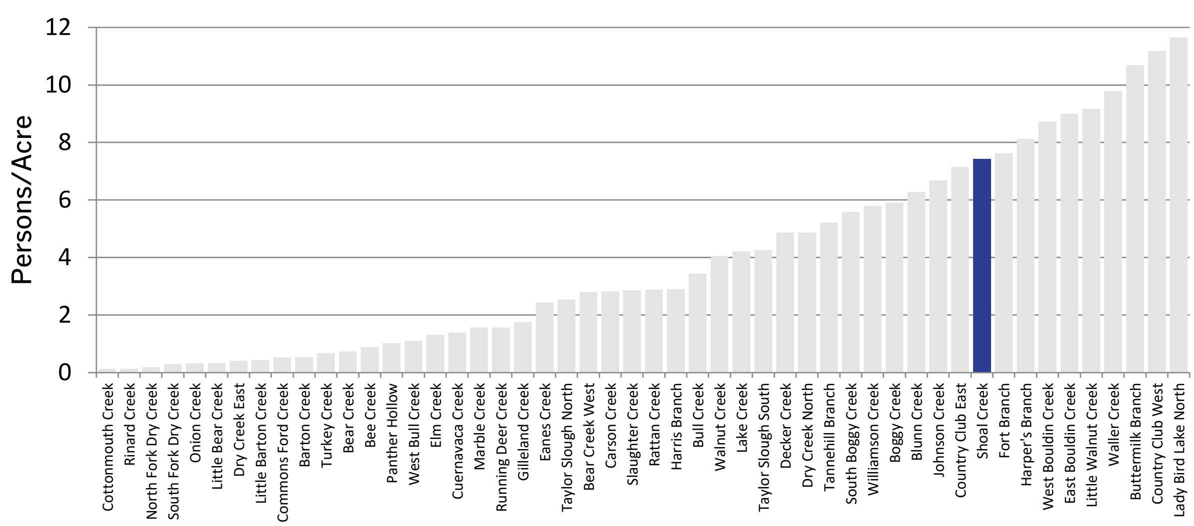


Figure 8 2010 Population Density of Shoal Creek and Other Austin Watersheds (COA-WPD, 2019; City of Austin Demographer, 2018).

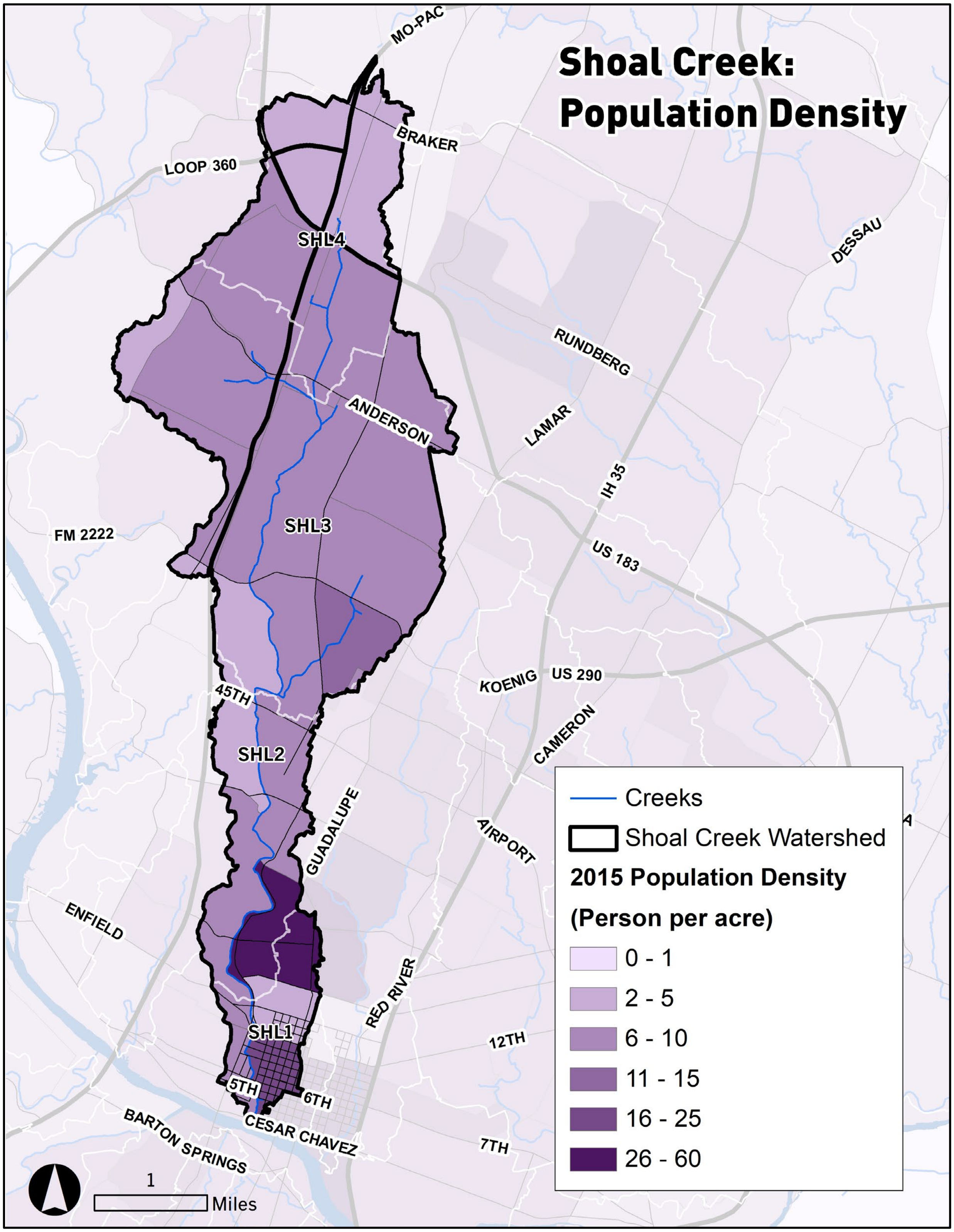


Figure 9 2015 Population Density by Census Tract (COA-WPD, 2019; City of Austin Demographer, 2018)

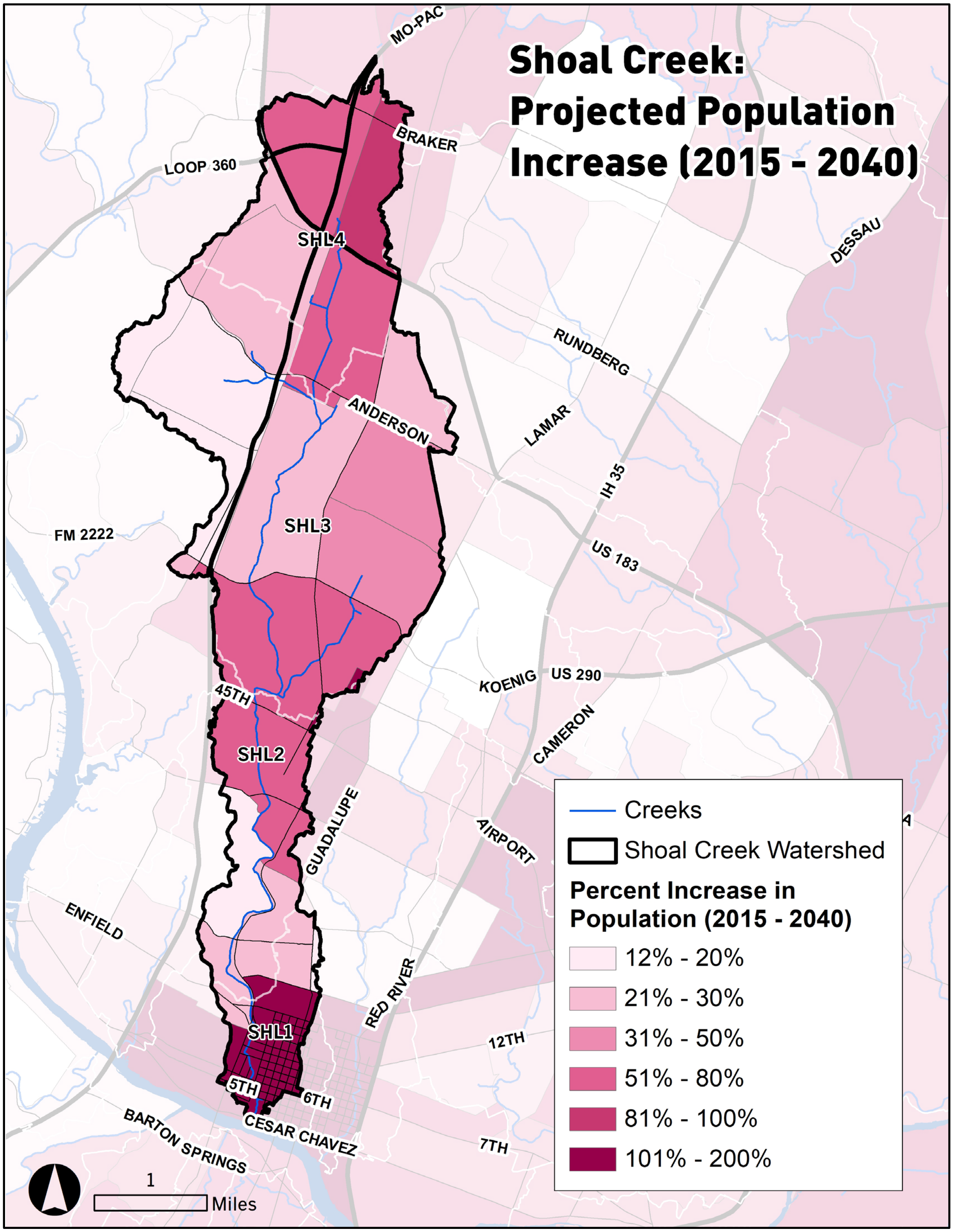
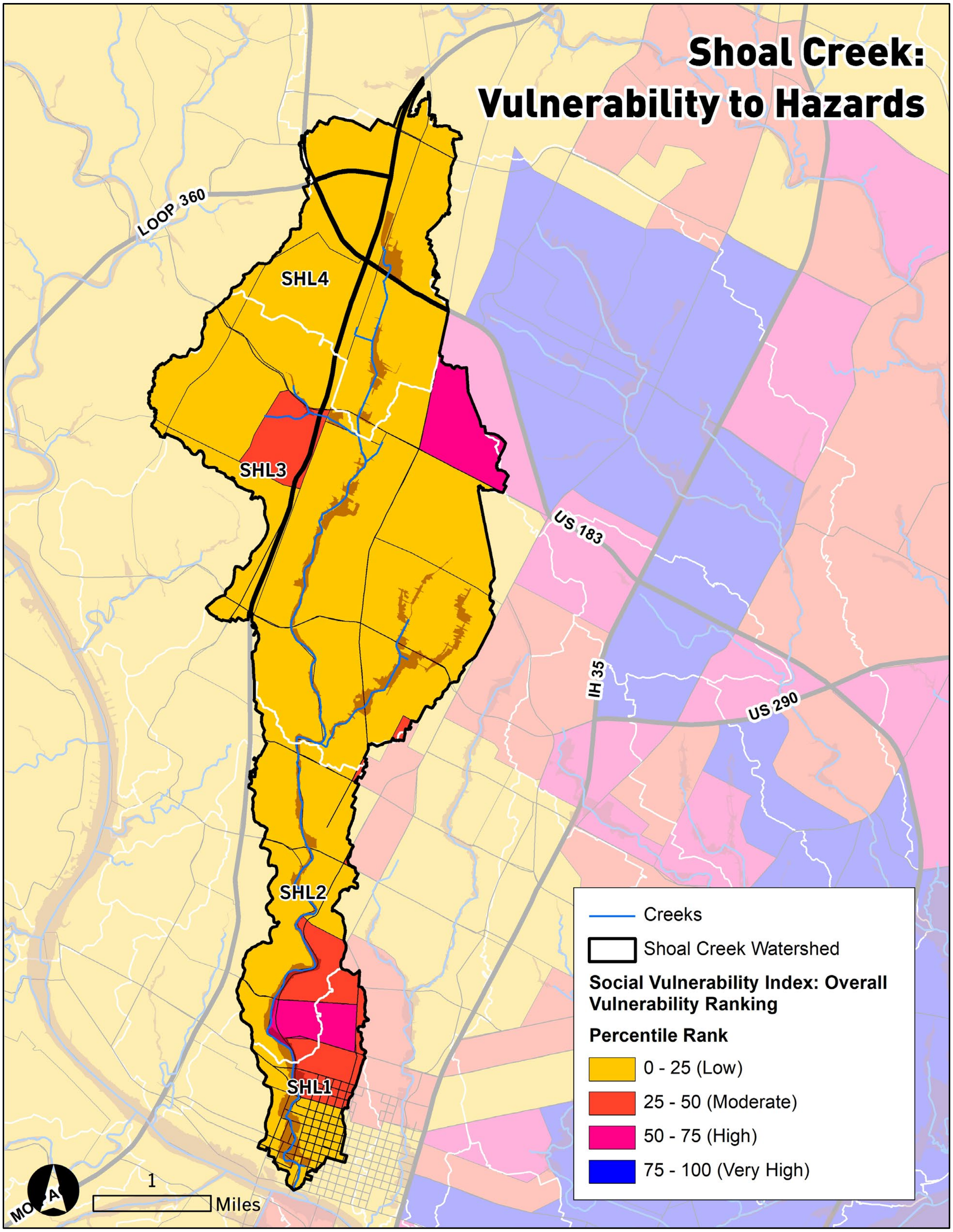


Figure 10 Projected Population Increase by Census Tract (COA-WPD, 2019; City of Austin Demographer, 2018)

Vulnerability to Hazards

The Centers for Disease Control's Geospatial Research, Analysis & Services Program created the Social Vulnerability Index (SVI) to identify and map the communities that are most vulnerable to hazardous events. CDC's SVI indicates the relative vulnerability of every U.S. Census tract by ranking the tracts on 15 social factors, including unemployment, race, language, age, and disability, and further groups them into four related themes: socioeconomic status; household composition and disability; race and language; and housing and transportation. Each tract receives a ranking for each Census variable for each of the four themes, as well as an overall ranking, with higher values indicating higher vulnerability to adverse events. Together these factors help describe a community's resiliency to flooding, erosion, and water quality degradation

Most of the Shoal Creek watershed scores in the lowest quartile for overall social vulnerability, with the exception of the areas surrounding the University of Texas, the Wooten neighborhood, and the area between Spicewood Springs Road and Far West Boulevard. Similarly, the Shoal Creek watershed is dominated by areas in the lowest quartile for the race and language subindex, with higher concentrations of people of color and/or low English-language proficiency in the Wooten neighborhood (Centers for Disease Control, 2016).



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263 *Figure 11 Social Vulnerability Index by Census Tract (Centers for Disease Control, 2016)*

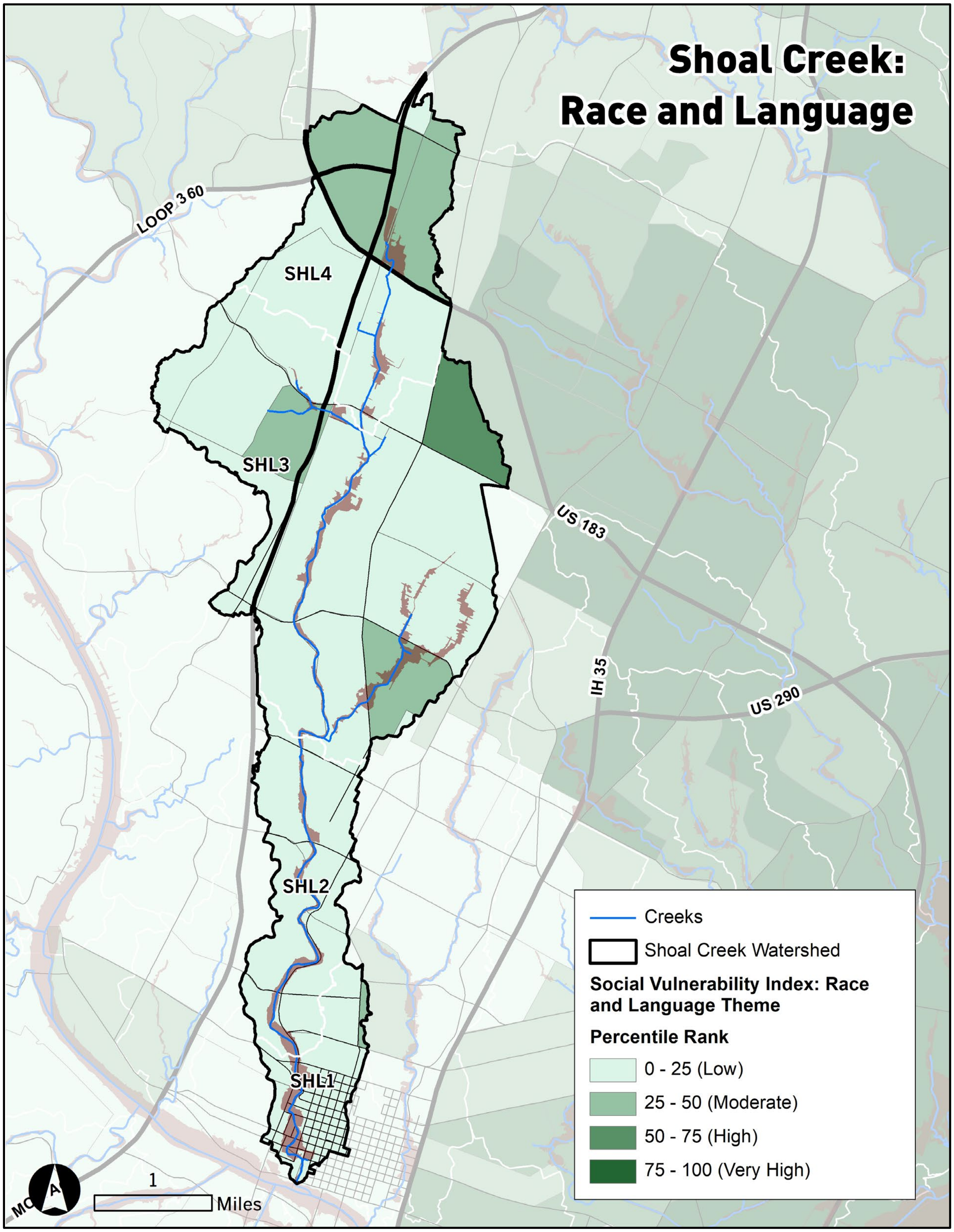


Figure 12 Social Vulnerability Index by Census Tract: Race and Language Theme (Centers for Disease Control, 2016)

Land Use

The Shoal Creek watershed is almost completely urbanized, with only 5% of its land area remaining undeveloped/open space. The watershed is largely dominated by single family and commercial land uses. Approximately a quarter of the watershed is dedicated to roads and other transportation infrastructure. SHL1 and SHL4 are dominated by transportation and commercial development, while SHL2 and SHL3 are largely dominated by single-family land uses.

Table 1 Land Use by Reach (Percent of Reach Area) (COA-WPD, 2018)

Reach	Single Family	Multifamily	Commercial	Transportation	Open Space	Undeveloped
SHL1	7%	15%	36%	39%	3%	0%
SHL2	40%	8%	20%	23%	10%	0%
SHL3	46%	8%	22%	21%	3%	0%
SHL4	15%	6%	45%	26%	4%	3%
Grand Total	**35%**	**8%**	**28%**	**24%**	**4%**	**1%**

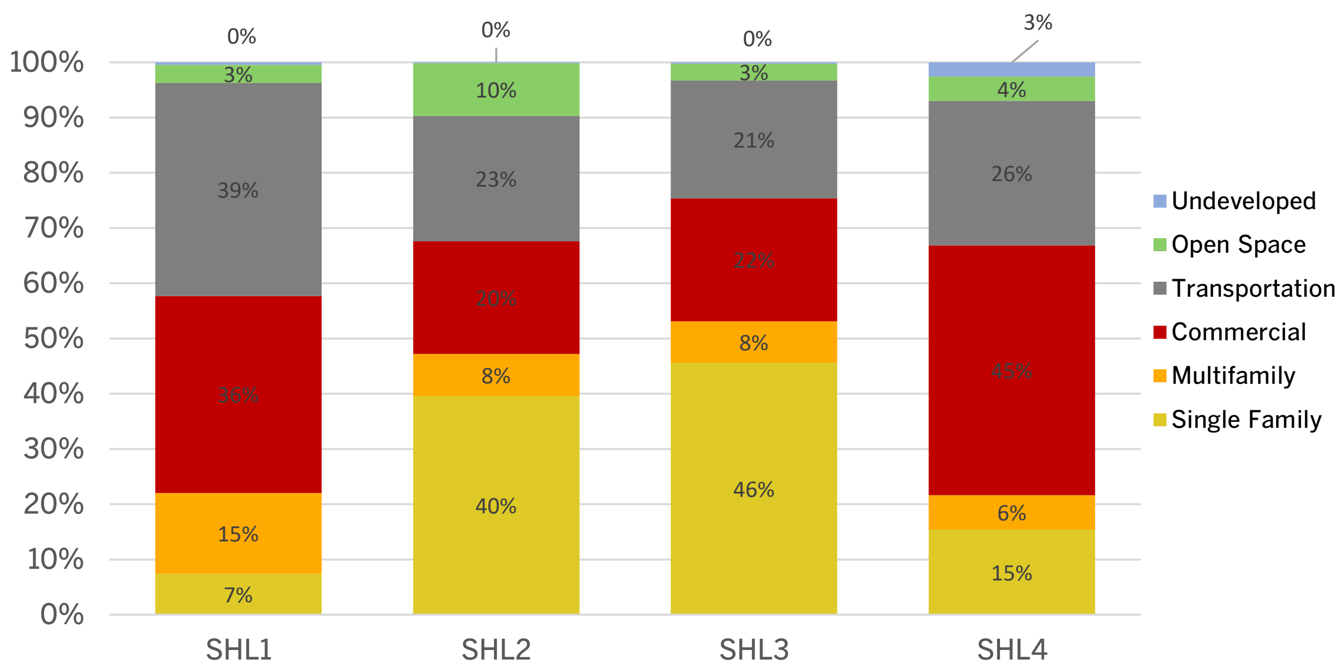


Figure 13 Land Use by Reach (Percent of Reach Area) (COA-WPD, 2018)

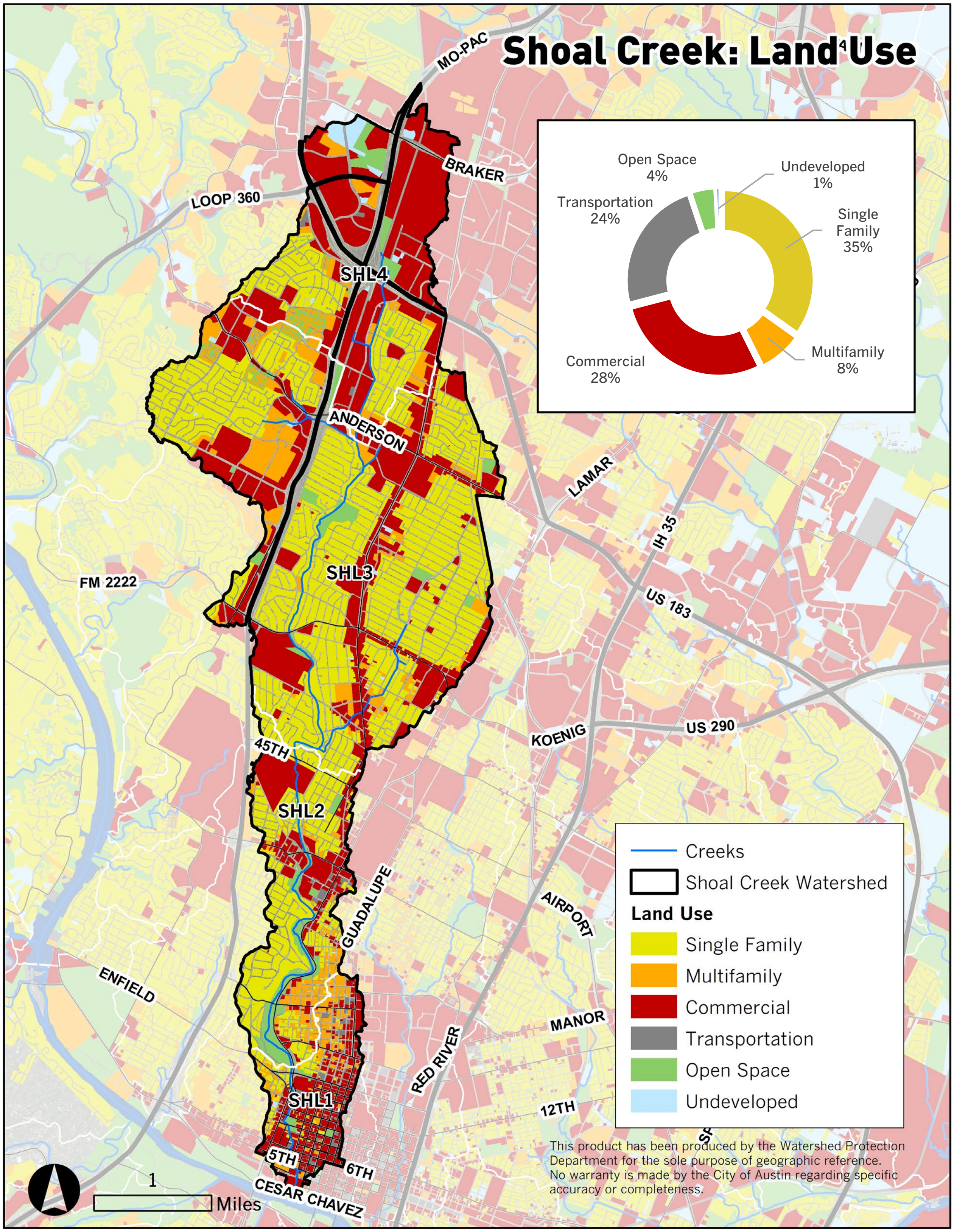


Figure 14 Land Use by Parcel (COA-WPD, 2018)

Impervious Cover

Impervious cover is any surface that prevents the infiltration of water into the ground, such as roads, parking lots, and buildings. When rainwater falls on impervious surfaces, the increased volume and velocity of runoff from these surfaces can contribute to erosion and flooding and impair water quality by carrying contaminants such as sediment, bacteria, and nutrients into Austin's aquifer and creeks. Impervious cover also displaces soils, trees, and other plants, increasing ambient temperatures and reducing stream baseflows and natural habitat.

The Shoal Creek watershed is the fourth most impervious watershed in the city, with 54% existing impervious cover. Roadways comprise approximately 27% of the watershed's impervious cover (see Figure 15). Most roadway impervious cover is not currently treated for water quality, with approximately 16% of roadway impervious cover treated via water quality controls (COA-WPD, 2019).

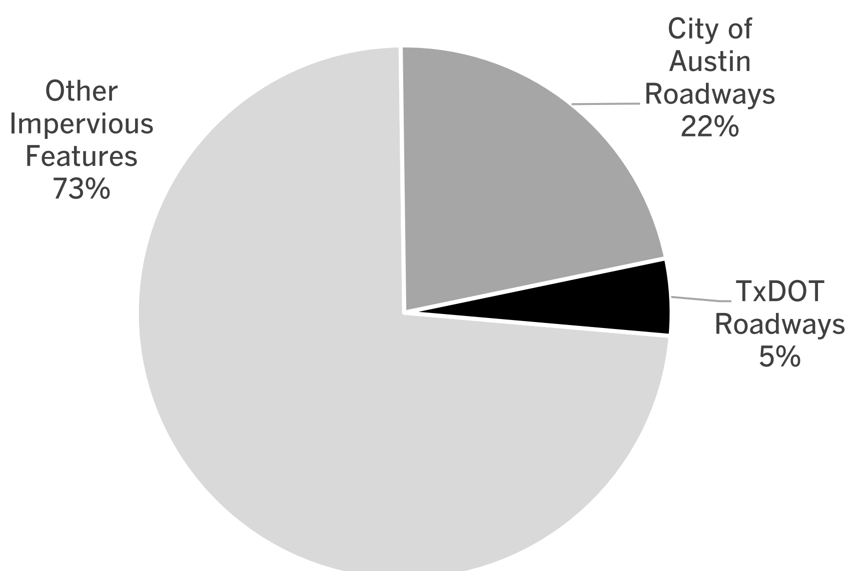


Figure 15 Composition of Shoal Creek Watershed's Impervious Cover (COA-WPD, 2019)

Based on a City of Austin Watershed Protection Department (COA-WPD) analysis of impervious cover maximum buildout, Shoal Creek watershed could reach approximately 64% impervious cover if each site within the watershed developed to its impervious cover maximum (COA-WPD, 2018). This analysis represents a conservative estimate of maximum buildout, as it does not account for site-specific environmental features such as steep slopes, sensitive features, and trees. The regulatory protections associated with these features could potentially lower the total amount of impervious cover achieved for any given site. Thus, the maximum percentage of impervious cover shown below for each watershed is higher than the ultimate anticipated buildout.

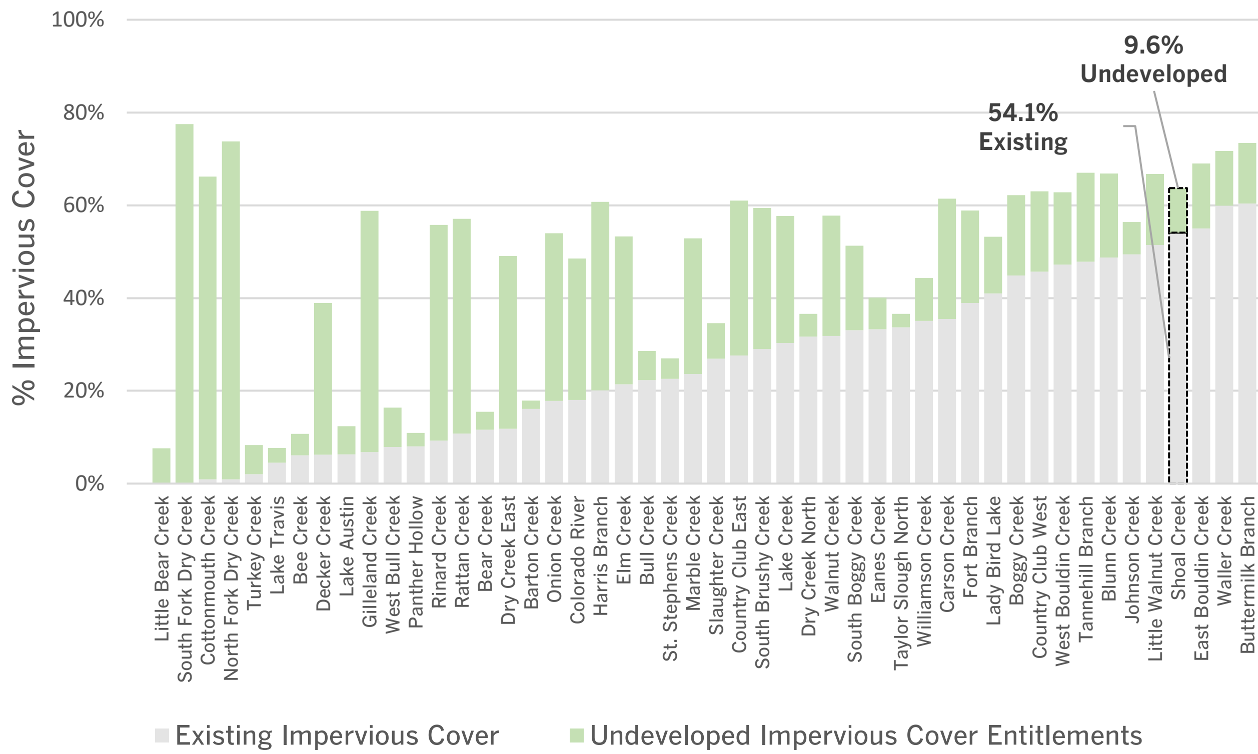


Figure 16 Existing and Maximum Allowed Impervious Cover; Full Purpose Jurisdiction (COA-WPD, 2018)

IV. Watershed Health

A. Overview of Watershed Concerns

Introduction to the Watershed Protection Master Plan Approach

The City of Austin's Watershed Protection Department (COA-WPD) protects the lives, property, and environment of the community by reducing the impacts of flooding, erosion, and water pollution. To accomplish this mission, the department maintains the Watershed Protection Master Plan to prioritize service needs. A central principle of the Master Plan is that the most severe problems should be considered first for solutions identification. The plan therefore outlines a prioritization approach in which COA-WPD performs technical studies to identify areas where watershed protection goals are not being achieved. Problem score systems then quantify and prioritize problem areas for each of the department missions: Water Quality, Creek Flooding, Localized Flooding, and Erosion Control. Each mission develops problem scores to assign a numeric score and severity description to watershed problems, such as individual erosion sites or buildings in floodplains. The areas with the highest problem scores are designated with a Narrative Score; "Very High" or "High" severity problem areas are considered to be at the highest risk of flood, erosion, or water quality degradation.

As part of the yearly capital budget planning process, problem scores are updated and Top 20 Priority Problem Areas are identified for each mission. These Top 20 Priority Problem Areas are submitted for the annual project funding appropriations processes to be evaluated by COA-WPD for capital project feasibility. Each mission completes a feasibility analysis to determine the range of capital projects that could address the problem and a rough cost estimate. Once a priority problem area is determined to have a feasible solution, it is reviewed to determine the mission integration potential of the project. This review ultimately results in the identification of capital projects that are included in the five-year Capital Improvement Program (CIP) appropriation plan.

For more information about the Master Plan and problem scores can be found at the following links:

Problem Score Viewer (COA-WPD, 2018)

City of Austin Watershed Protection Master Plan (COA-WPD, 2016).

Water Quality - Environmental Integrity Index Scores

Sources of water quality problems are complex to study and control. Key concerns include increases in runoff, sediment, nutrients, metals, litter, fecal indicator bacteria, and degradation of aquatic and riparian habitat. To assess this complexity, the Environmental Integrity Index (EII) was developed by the City of Austin Watershed Protection Department (COA-WPD) to monitor and assess the ecological integrity and degree of impairment of local creeks and streams. The EII is a multi-metric index that integrates information about the physical integrity, chemical, and biological conditions of a sampling location into a single score that reflects the overall ecological function of a stream system. Water quality is sampled quarterly and biological and habitat surveys are completed once per year. The Environmental Integrity Index assesses Shoal Creek at four discrete sampling points, which are then generalized to the study reaches as watershed effects aggregate at a downstream point (COA-WPD, 2002).

Components within some of the EII sub-indices have been identified to indicate problems that are feasibly addressed by engineering or land management solutions (as opposed to regulatory or programmatic solutions). These components are used to calculate problem scores for purposes of capital project prioritization. The components are unstable channels (hydrology), nutrients, toxins, and poor riparian vegetation. EII study reaches can be scored and ranked based on these individual problem score components, allowing WPD to identify and prioritize areas that require specific water quality solutions. These four problem score components can also be combined to produce an overall water quality problem score. SHL 1 and SHL2 rank 12^{th} and 5^{th} for overall water quality problem scores, respectively (COA-WPD, 2019)

Table 2 COA-WPD Environmental Integrity Index Scores (COA-WPD, 2017)

Study Reach	Overall Reach Score	Aquatic Life	Contact Recreation	Non-Contact Recreation	Habitat	Sediment	Water Quality
SHL2	59	82	38	85	44	51	56
SHL1	48	73	25	62	47	51	32
SHL3	65	79	47	75	77	51	62
SHL4	58	52	37	82	53	51	75
Average	**57.5**	**71.5**	**36.8**	**76.0**	**55.3**	**51.0**	**56.3**

Key

100 - 87.5	87.5 - 75	75 - 62.5	62.5 - 50	50 - 37.5	37.5 - 25	25 - 12.5	12.5 - 0
Excellent	Very Good	Good	Fair	Marginal	Poor	Bad	Very Bad

The overall EII score is calculated as the average of the subindices, which results in equal weighting of each subindex. The scores range between 0 and 100, with higher EII scores indicating more fully functional creek reaches that are less degraded by human disturbance. A reach with an overall EII score ranging from 62.5 to 75 is classified as in "Good" health. The 2017 EII indicates that Shoal Creek is within the "Fair" range with a score of 57.5 (See Figure 17). The full EII summary for Shoal Creek can be found in Appendix A.

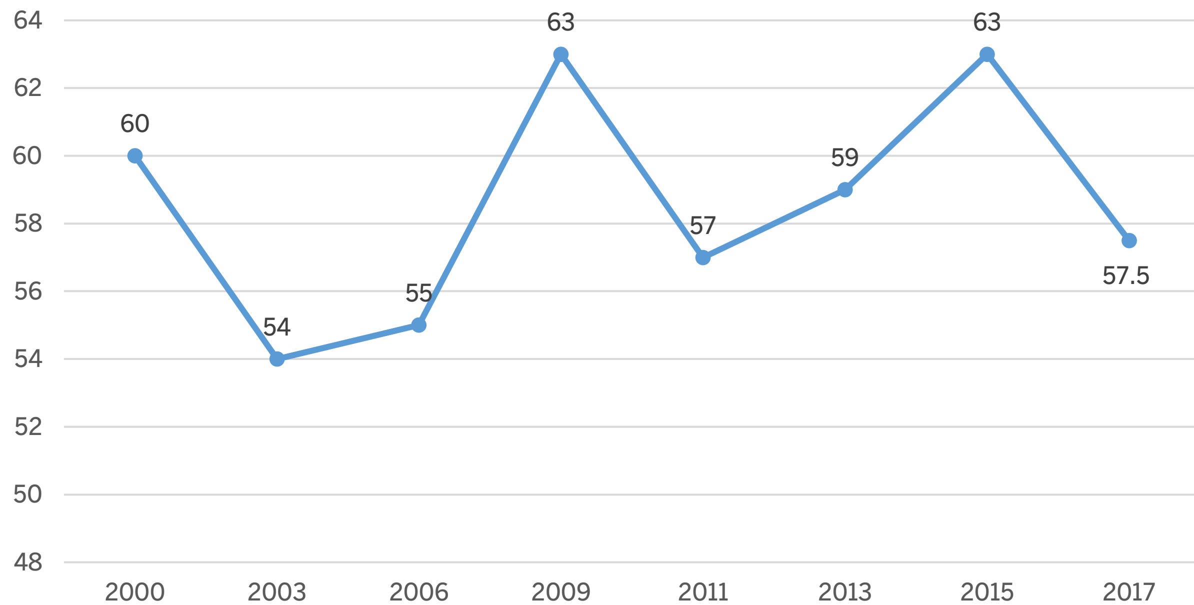


Figure 17 Overall Environmental Integrity Index Score (2003 - 2017) (COA-WPD, 2017)

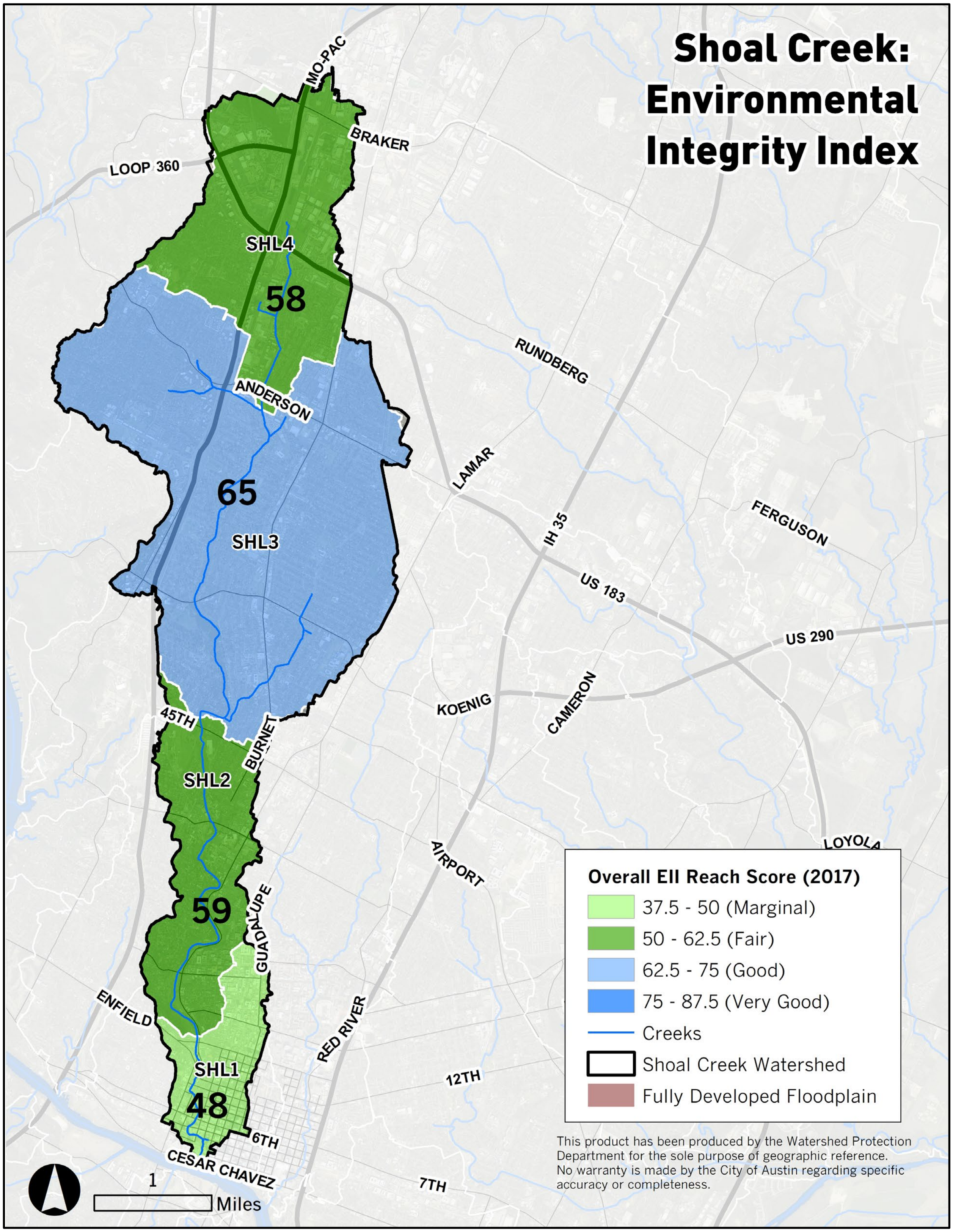


Figure 18 Environmental Integrity Index (2017) (COA-WPD, 2017)

Creek Flooding – Problem Scores

Austin is in an area known as "Flash Flood Alley." Its unique combination of intense rainstorms, steep slopes, and slow-draining soils make it especially prone to severe flooding conditions. Floods in 1981 (Memorial Day Flood), 1991, 1998, 2001, 2010, 2013 (the "Halloween Flood"), and 2015 are reminders of the public safety and property hazards associated with flooding. In nearly every decade, there is a record of significant flood events. COA-WPD identifies and prioritizes flooding risks of the primary drainage system (the creeks) for both buildings and roadway crossings. In order to identify problem areas, flood problem scores are developed for all buildings in the floodplain based on their expected frequency and depth of flooding. Buildings are then combined into "clusters" based on their proximity to other buildings with flood risk and a composite score is determined for the cluster. Cluster scores are impacted by the number of buildings with flood risk as well as the relative flood risk to each building. The table below summarizes the problem areas and low-water crossings within the Shoal Creek watershed that are among the fiscal year 2019 Top 20 most severe creek flooding risk areas in the city. See Figure 19 for a map of these problem areas. Lower Shoal Creek is the top-ranked problem area in the city, with 66 buildings expected to by impacted in a 100-year event.

The number of buildings and roadways impacted by flooding is expected to increase when rainfall data from the National Weather Service's Atlas 14 rainfall study is incorporated into updated floodplain studies.

Table 3 FY 2019 Top 20 Ranked Creek Flooding Problem Areas (COA-WPD, 2018)

Problem Area	Buildings Impacted	Narrative Score	Citywide Rank
Lower Shoal Creek	66	Very High	1
Shoal Creek - Hancock & Grover Tributaries	96	Very High	8
Shoal Creek at 49th St	7	High	17
Shoal Creek - White Rock to Northwest Park	28	High	19

Table 4 FY 2019 Top 20 Ranked Low-Water Crossings (COA-WPD, 2018)

Street	Modeled Depth in 100-year event	Modeled Depth in 25-year event	Modeled Depth in 10-year event	Modeled Depth in 2-year event	Narrative Score	Citywide Rank
10th Street Bridge	9.3	7.8	6.9	2.8	Very High	2
9th Street Bridge	9.1	7.8	6.8	2.0	Very High	2
Shoal Creek Boulevard Bridge	6.6	5.4	4.5	0.9	Very High	12

Localized Flooding – Problem Scores

"Localized flooding" is a term used when flooding occurs away from creeks and due to problems with the secondary drainage system. The secondary, or engineered drainage system is composed of pipes, curb inlets, manholes, minor channels, roadside ditches, and culverts. This system is intended to convey stormwater runoff to the primary drainage system, the creek. Because the Shoal Creek watershed was largely built-out prior to the implementation of drainage criteria in 1977, much of Shoal Creek's infrastructure is undersized or experiences failure of components due to deteriorating materials. Both factors contribute to localized flooding. COA-WPD currently prioritizes localized flooding problems areas using reports of flooding from residents. Reports of flooding of buildings is considered the most severe for purposes of prioritizing projects for implementation. The table below summarizes the localized flooding problem areas within the Shoal Creek watershed that are among the fiscal year 2019 Top 20 most severe problem areas in the city. See Figure 19 for a map of these problem areas.

Table 5 FY 2019 Top 20 Ranked Localized Flooding Problem Areas (COA-WPD, 2018)

Problem Area	Reports of Building Flooding	Reports of Yard Flooding	Reports of Street Flooding	Total Reports of Flooding	Citywide Rank
Brentwood	31	26	12	69	2
Nueces Street	23	11	13	47	4
Burrell Drive	11	15	0	26	13
Madison Avenue	10	9	5	24	16

Erosion – Problem Scores

Erosion problems can stem from changing land use conditions (i.e., urbanization) that modify watershed hydrology by increasing stormwater runoff. Other problems occur due to improper placement of man-made resources near stream banks. Changes in streamflow have resulted in accelerated changes in local creek characteristics across Austin. The Shoal Creek watershed was largely developed before this relationship between urbanization and erosion was well-understood—development was often placed too close to creek banks, which put those resources at risk when Shoal Creek experienced deepening and widening due to increased runoff. As a result, development along Shoal Creek has been significantly impacted by erosion. The table below summarizes the reaches within the Shoal Creek watershed that are among the fiscal year 2019 Top 20 most severe problem reaches in the city. See Figure 19 for a map of these problem areas.

Table 6 FY 2019 Top 20 Ranked Erosion Reaches (COA-WPD, 2018)

Location	Reach	Narrative Score	Citywide Rank
Grover Tributary - From confluence with Shoal Creek to upstream end near Grover Dr	Hancock-Grover-2	Very High	3
Arroyo Seco - From 550 ft. upstream of North Loop Rd. to W St. Johns	Hancock-3	Very High	9
Shoal Creek Mainstem - From W. 6th St to W. 15th Street	Shoal-3	Very High	20

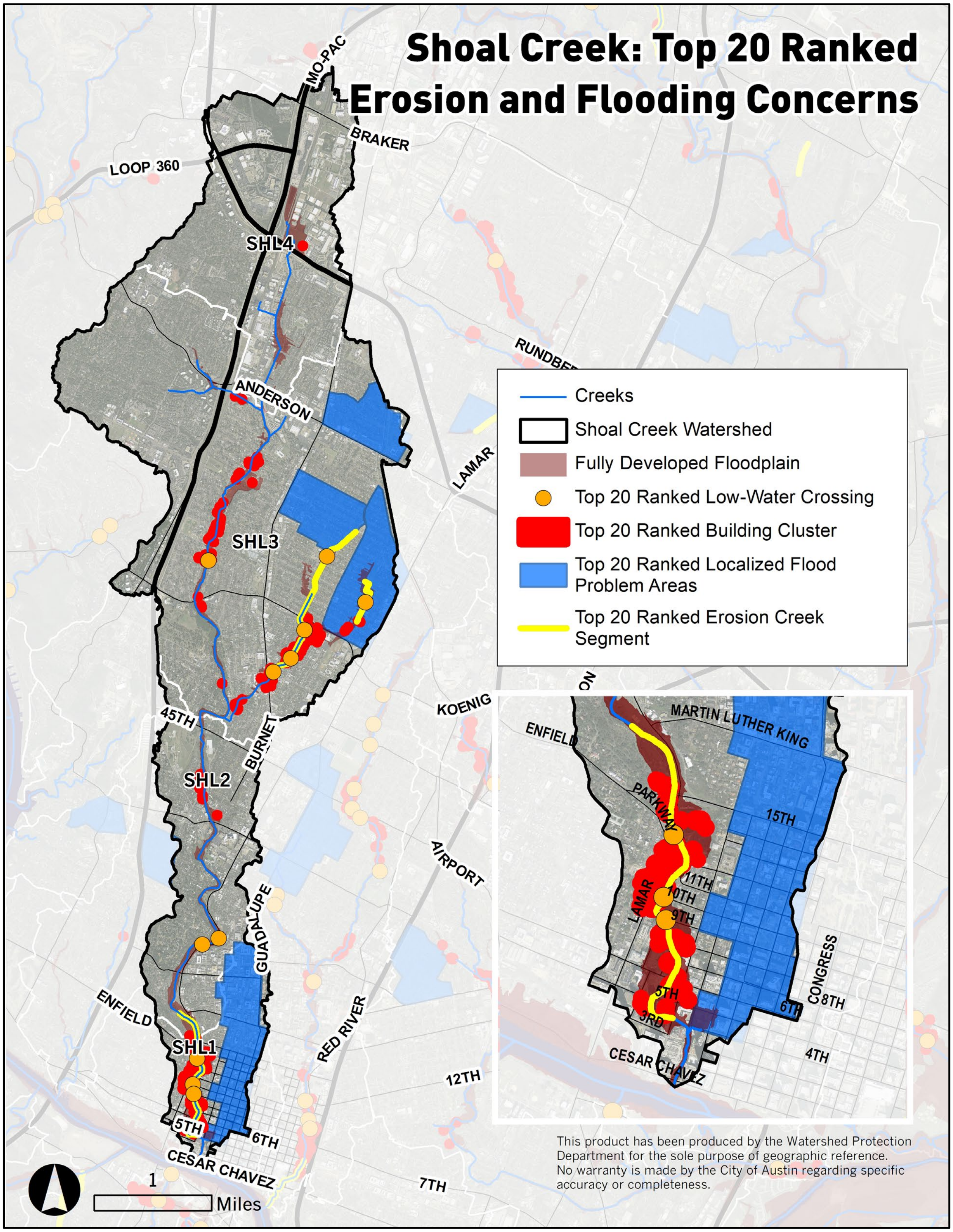


Figure 19 COA-WPD Fiscal Year 2019 Top 20 Ranked Erosion and Flooding Concerns (COA-WPD, 2018)

B. Springflow and Groundwater Concerns

Shoal Creek is an intermittent creek that flows primarily as a response to rainfall. However, there are several springs and seeps that contribute less than 5% of the annual Shoal Creek streamflow to Lady Bird Lake (COA-WPD, 1990). It is likely that more springs/seeps existed in the Shoal Creek watershed in the past, but the watershed was largely urbanized prior to the identification and tracking of these features by COA-WPD. Urbanization and its associated impervious cover has altered the hydrology to decrease the natural infiltration of rainwater into the groundwater system, potentially resulting in lower overall baseflow of springs. Increased impervious cover can result in flashy discharge during storms, increased runoff to streams, and reduced diffuse recharge via reduced infiltration through soils. Urban recharge from leaking water supply, sewer lines, storm drains, and irrigation may moderate this reduction in natural recharge caused by runoff from impervious cover. This urban leakage provides a source of baseflow to Shoal Creek (Christian et al. 2011). These water sources (e.g., chlorinated water, raw sewage, irrigation water) often contain pollutants and are less likely to interact with groundwater ecosystems in the same manner as natural recharge from precipitation and percolation (Bendick, 2014). The impact of these urban sources on the quantity and quality of baseflow is not yet well understood.

As there is a small documented population of the threatened Jollyville Plateau salamander (Eurycea tonkawae) at the Spicewood Spring discharge point, this spring has been monitored since the mid-nineties. Levels for nutrients are generally within normal range compared to other Austin creeks, but E. coli and nitrate levels are chronically high relative to other watersheds. Where fecal contamination from an urban source is suspected, a combination of high E. coli counts and high nitrates may suggest a source of contamination originating from a location some distance from the surface water being evaluated (Jackson & Herrington, 2012). Flooding is problematic as well—following rain events, Spicewood Spring becomes inundated with leaf litter, woody debris, and trash (O’donnell et al., 2006).

C. Habitat and Native Species Concerns

Riparian Zones

A riparian zone is the area adjacent to a waterway that serves as the transition zone between the upland and aquatic ecosystems. Healthy, vegetated riparian buffers enhance water quality and quantity in a wide variety of ways, including by reducing nutrients and suspended solids. Riparian buffers also reduce bacteria loads to streams from stormwater, as bacteria tend to adhere to sediment particles that are the most easily filtered out pollutant in stormwater as it runs through vegetation and soil.

Aside from the water quality benefits of healthy riparian areas, these areas also generally have a more biologically diverse plant community due to the resources that creeks bring (water, nutrients, etc). If riparian zones are left alone, grasses and trees become established and transform these areas into more ecologically functional landscapes. This riparian vegetation can reduce erosion by stabilizing bank soils and reducing the velocity of water, while debris produced from fallen or dead vegetation provides habitat for fish and macroinvertebrates. A robust riparian tree canopy also protects organisms in the creek from large fluctuations in water temperature. More broadly, intact riparian areas form one piece of an integrated system of green infrastructure that provides multiple benefits to humans.

Because the Shoal Creek watershed has been urbanized for over 100 years, the riparian zones have been both encroached upon and largely denuded of vegetation. Human activities such as mowing and development remove the original mature vegetation, degrade soil carbon content, and compact the soil. When repeated over decades, this makes passive restoration techniques more difficult to implement to achieve a healthy riparian vegetative community.

The Index of Riparian Integrity (IRI) (Scoggins et al., 2013) represents an effort to utilize remote sensing techniques (e.g., aerial photography) to assess riparian condition throughout an entire stream corridor and identify areas with a high potential of functional deficiency. Aerial mapping and interpreting technologies have advanced to a point where it is possible to use aerial imagery to evaluate riparian zones rather than labor-intensive field studies. The IRI approach uses aerial imagery to characterize 37 riparian areas along the creek corridor according to their percent impervious cover, percent tree canopy, and percent of pervious non-canopy area. Table 7 and Figures 20, 21, and 22 show these values in each of these 37 riparian areas (Please note that tree canopy can overlap impervious areas for this analysis.). Figure 23 identifies the study segments for use with Table 7. Together, these three measures are a good indicator of the relative functionality of the riparian buffer and can help guide both protection of higher scoring areas and restoration of degraded areas.

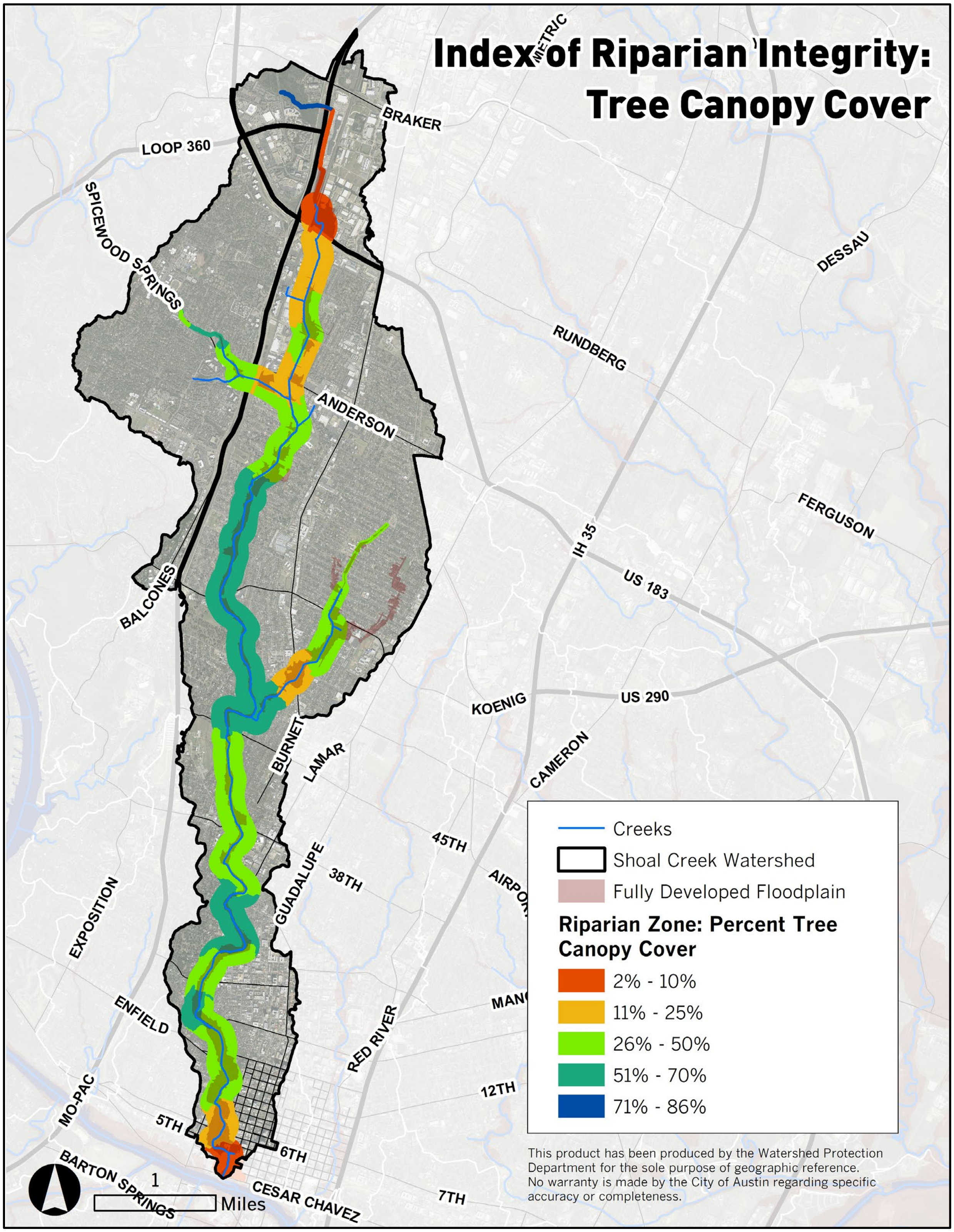


Figure 20 Index of Riparian Integrity: Tree Canopy Cover (COA-WPD, 2018)

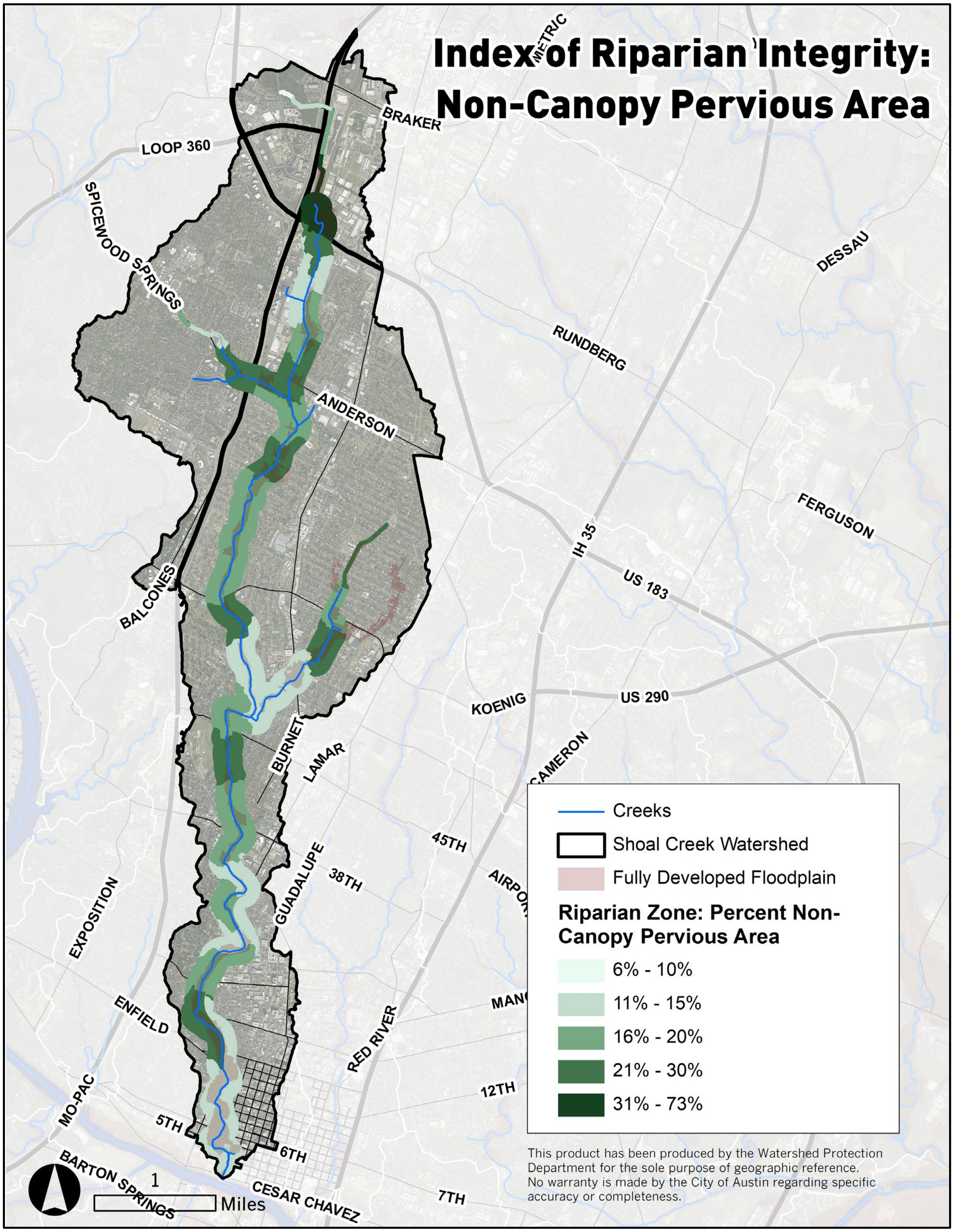


Figure 21 Index of Riparian Integrity: Non-Canopy Pervious Area (COA-WPD, 2018)

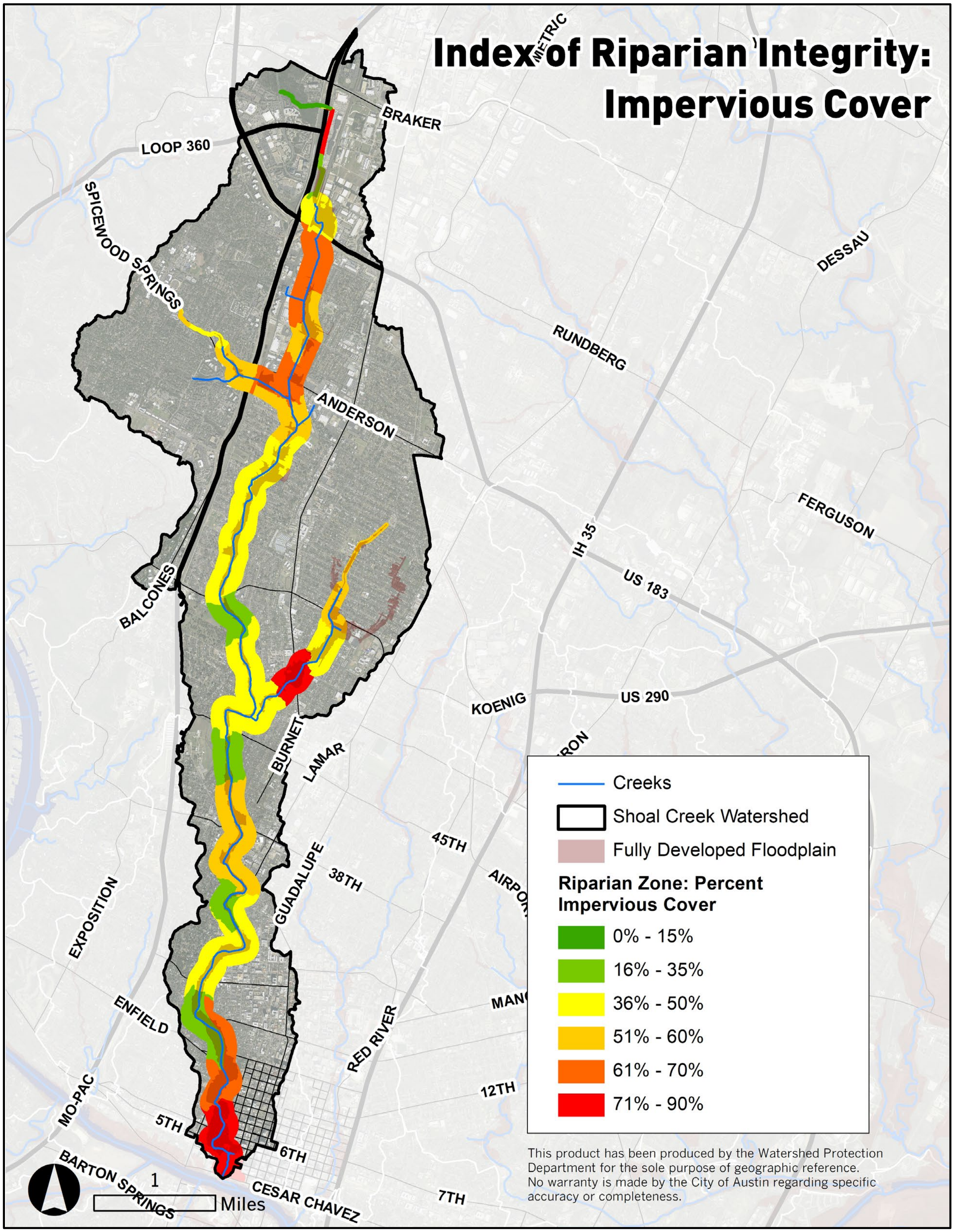


Figure 22 Index of Riparian Integrity: Impervious Cover (COA-WPD, 2018)

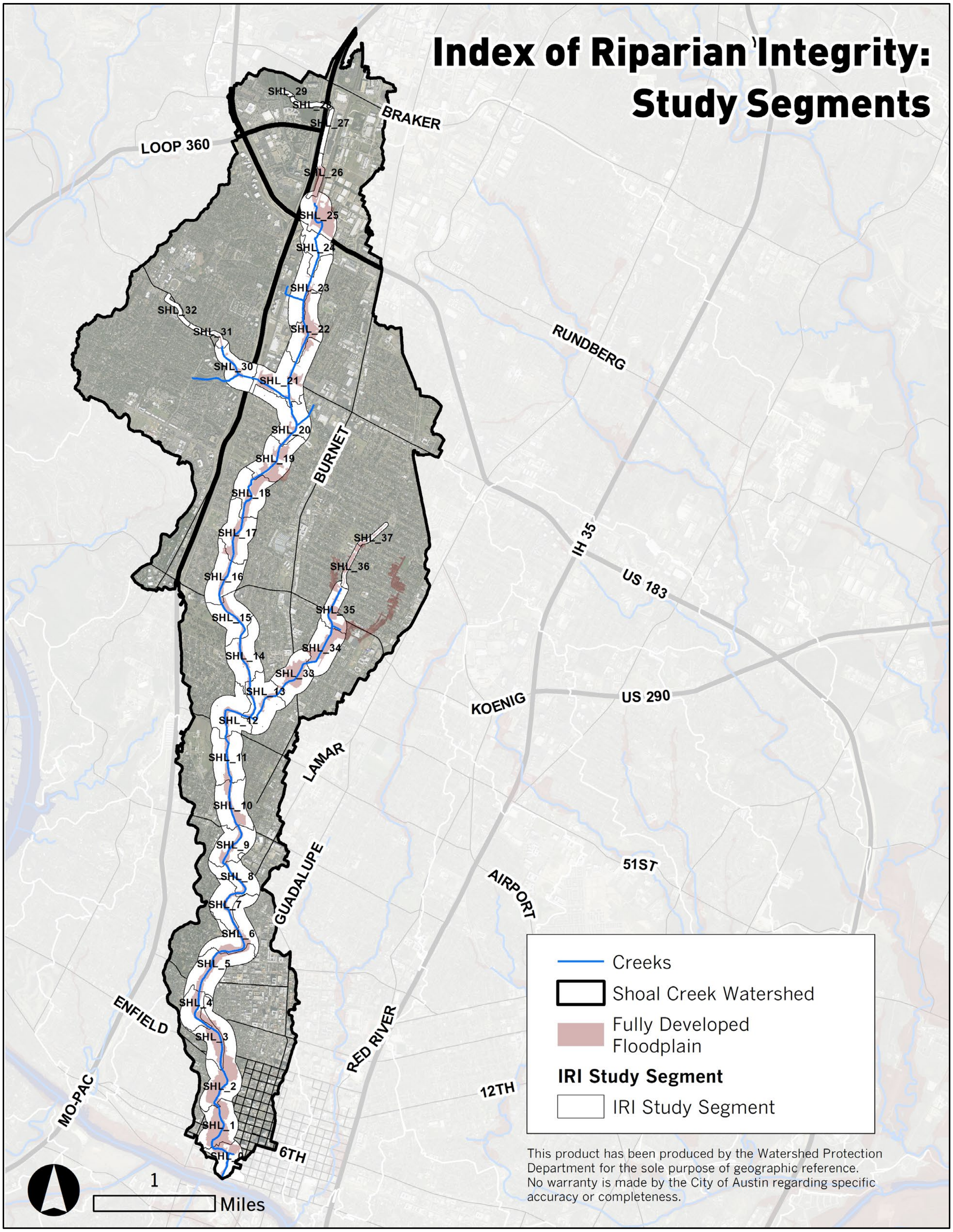


Figure 23 Index of Riparian Integrity Study Segments (COA-WPD, 2018)

Table 7 Index of Riparian Integrity: Tree Canopy, Non-Canopy Pervious Area, and Impervious Cover

IRI Segment	Tree Canopy (%)	Non-Canopy Pervious Area (%)	Impervious Cover (%)
Segment 0	9%	11%	83%
Segment 1	21%	14%	72%
Segment 2	31%	15%	63%
Segment 3	45%	30%	30%
Segment 4	57%	25%	26%
Segment 5	47%	16%	45%
Segment 6	54%	15%	42%
Segment 7	61%	16%	33%
Segment 8	49%	13%	50%
Segment 9	33%	18%	54%
Segment 10	38%	17%	56%
Segment 11	50%	29%	29%
Segment 12	63%	15%	37%
Segment 13	58%	14%	43%
Segment 14	60%	13%	41%
Segment 15	59%	26%	22%
Segment 16	54%	16%	42%
Segment 17	56%	16%	42%
Segment 18	52%	18%	42%
Segment 19	40%	28%	42%
Segment 20	41%	20%	50%
Segment 21	21%	20%	65%
Segment 22	38%	19%	52%
Segment 23	24%	15%	67%
Segment 24	18%	22%	66%
Segment 25	8%	48%	44%
Segment 26	2%	73%	25%
Segment 27	2%	19%	79%
Segment 28	70%	15%	15%
Segment 29	86%	6%	9%
Segment 30	28%	21%	59%
Segment 31	56%	11%	40%
Segment 32	41%	18%	53%
Segment 33	19%	11%	77%
Segment 34	40%	23%	47%
Segment 35	48%	17%	50%
Segment 36	32%	24%	53%
Segment 37	29%	26%	51%
Total	**40%**	**19%**	**49%**

(COA-WPD, 2018)

Aquatic Life

Biological sampling enables a more holistic perspective of water quality than water chemistry sampling alone. The diversity and tolerance of the biological community can provide insight into the conditions of water quality over months and even years rather than a single discrete point in time. As part of its Environmental Integrity Index (EII) sampling, COA-WPD samples benthic macroinvertebrates (oftentimes simply referred to as "bugs"). Benthic macroinvertebrates are visible to the naked eye (macro), lack a backbone (invertebrate), and are found in and around water bodies during some period of their lives. Common freshwater benthic macroinvertebrates include the larvae of mayflies, stoneflies, beetles, dragonflies, as well as non-insects such as snails, worms, and clams. Diatoms, which are a type of microscopic algae, are also scraped from the surface of rocks within the creek as a alternative measure of biological health. The diatom and benthic macroinvertebrate data are combined and scored based on their community structure (i.e., number of taxa) and ability to tolerate stressors from the urban environment like pollutants and altered flow.

Figures 24 - 27 describe the diversity and tolerance of the macroinvertebrate and diatom communities found at each EII sampling site during the most recent sampling. The whiskers indicate the minimum and maximum values and the boxes indicate the interquartile range. Throughout the report, individual EII reaches are indicated with the following colors:

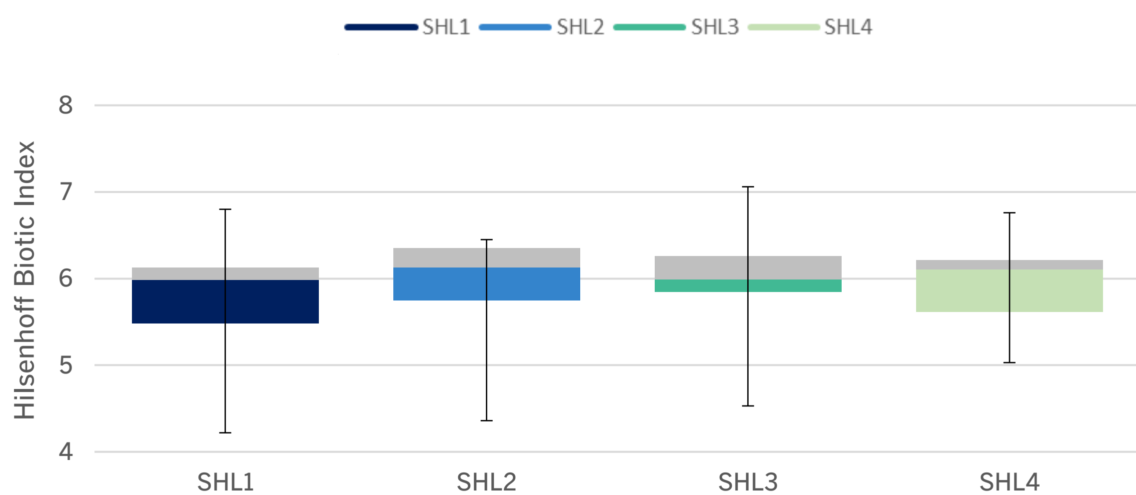


Figure 24 Hilsenhoff Biotic Index (COA-WPD, 2017)

The Hilsenhoff Biotic Index (HBI) metric estimates the overall tolerance of the community. Organisms are assigned a tolerance number from 0 to 10 pertaining to that group's known sensitivity to organic pollutants; 0 being most sensitive, 10 being most tolerant. All of the sites on Shoal Creek have a community that is relatively tolerant to nutrient stressors, with a relative lack of sensitive species.

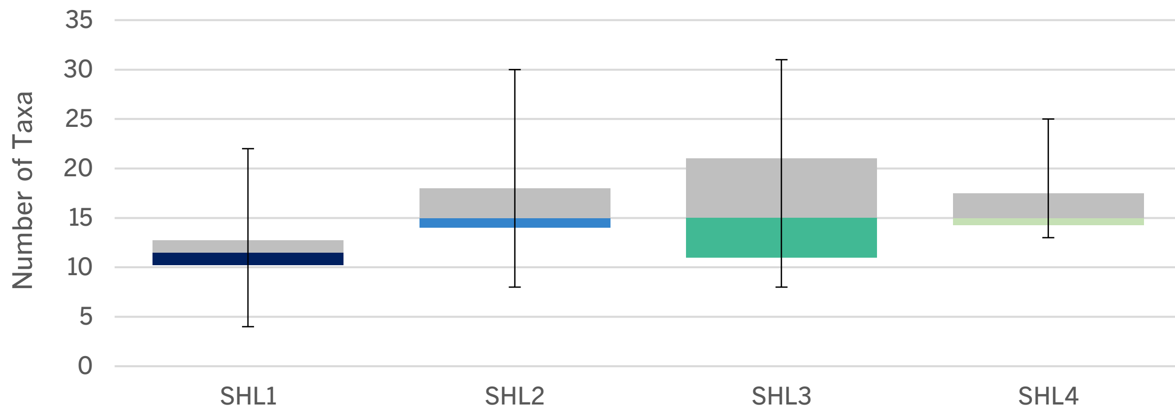


Figure 25 Number of Benthic Macroinvertebrate Taxa (COA-WPD, 2017)

Total number of bug taxa is a measure of diversity and an excellent indicator of overall stream health. The number of taxa generally increases from downstream to upstream reaches, but the difference is relatively small among reaches. This suggests that the upstream reaches have a healthier bug community.

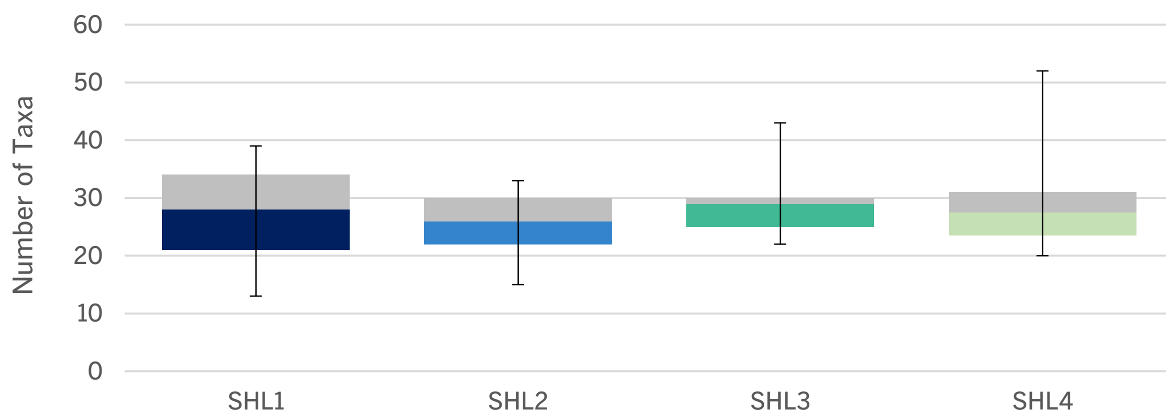


Figure 26 Number of Diatom Taxa (COA-WPD, 2017)

The number of diatom taxa is not very different among the four Shoal Creek sites, suggesting that for this measure the sites are relatively similar, with total taxa counts around 25.

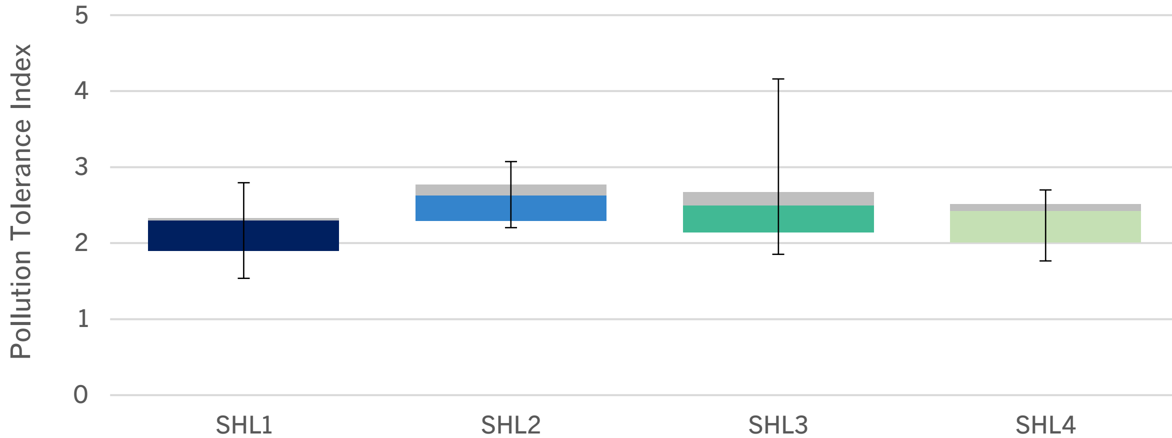


Figure 27 Diatom Pollution Tolerance Index (COA-WPD, 2017)

The Pollution Tolerance Index rates diatom taxa by their sensitivities to increased environmental degradation. There is some improvement of scores at the middle sites, but generally all sites are similar, with scores between 2 and 3.

D. Overview of Water Quality Impairments

Water Chemistry

On the following pages are figures depicting the water chemistry subindices for the Shoal Creek watershed (Figures 28 - 36). Spicewood Tributary information is provided where available. A full summary of the EII reaches, including tables and box and whisker plots, is found in Appendix A. The raw data can be found at data.austintexas.gov/Environment/Water-Quality-Sampling-Data/.

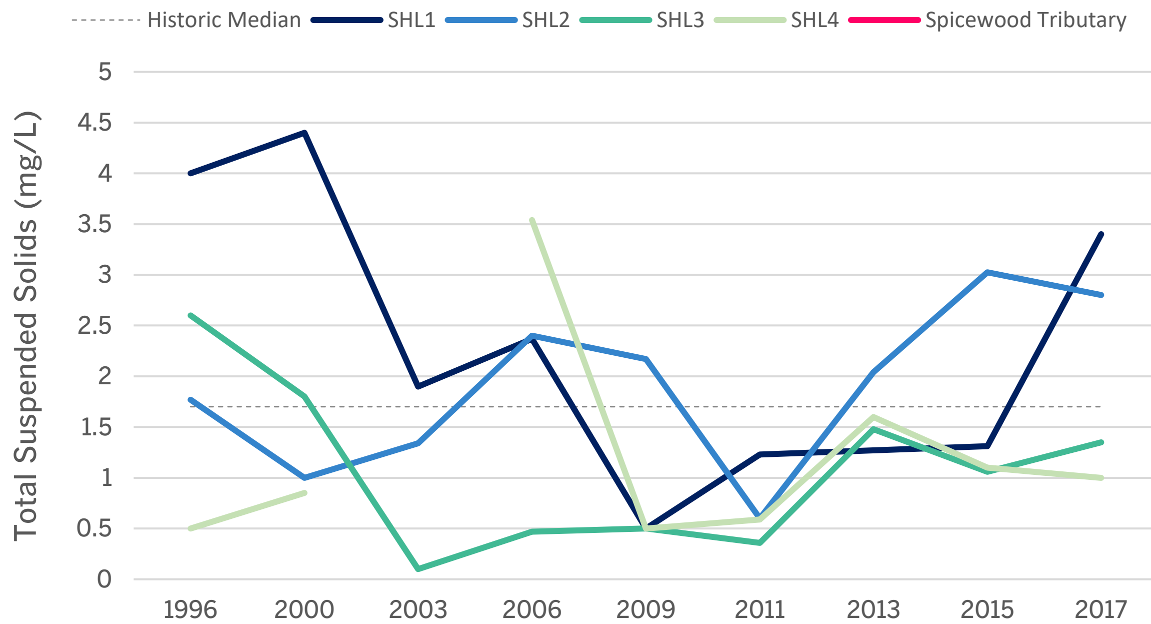


Figure 28 Total Suspended Solids (mg/L) (1996 – 2017) (COA-WPD, 2018)

Although it is naturally occurring, sediment levels can be elevated from accelerated and unnatural erosion from active and historic development practices. Nutrients and other pollutants can be released from eroded soil and the fine silty particles degrade the habitat for aquatic life. Shoal Creek is generally below average for Total Suspended Solids compared to other watersheds. Total Suspended Solids is typically higher and more variable for Shoal Creek's downstream reaches (SHL1-2) and decreases as you travel upstream (SHL3-4).

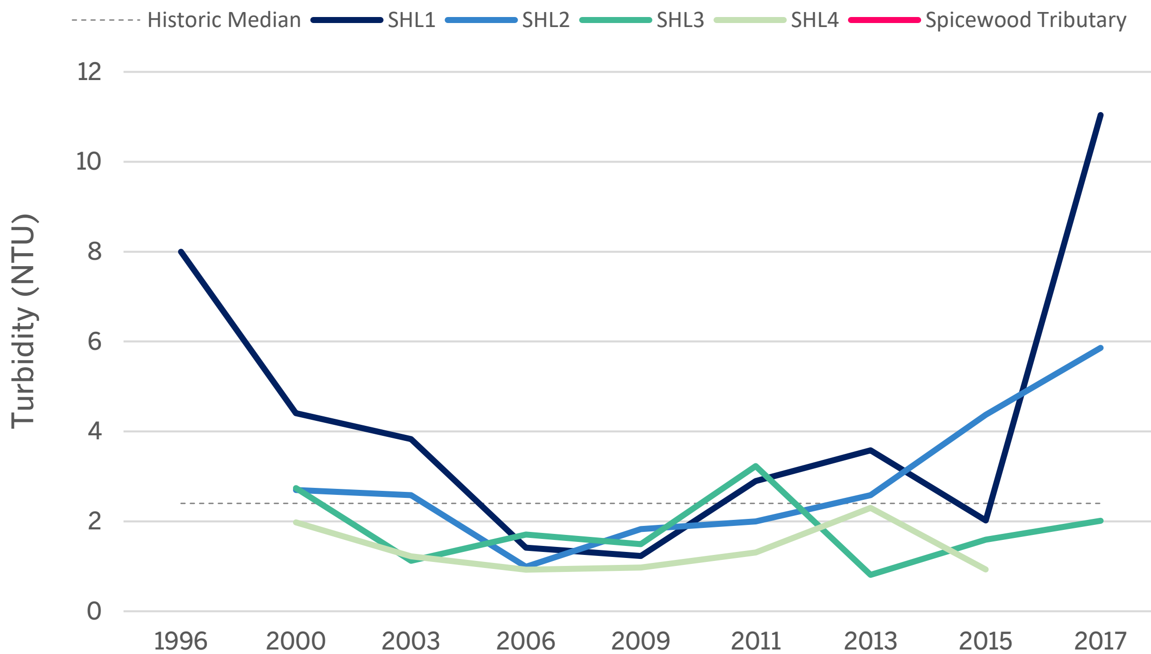


Figure 29 Turbidity (2000 - 2017) (COA-WPD, 2018)

Turbidity is the measure of the clarity of a liquid. Murky, turbid water blocks sunlight for aquatic vegetation and can harm sensitive tissues such as fish and invertebrate gills and eggs. Shoal Creek generally has low turbidity.

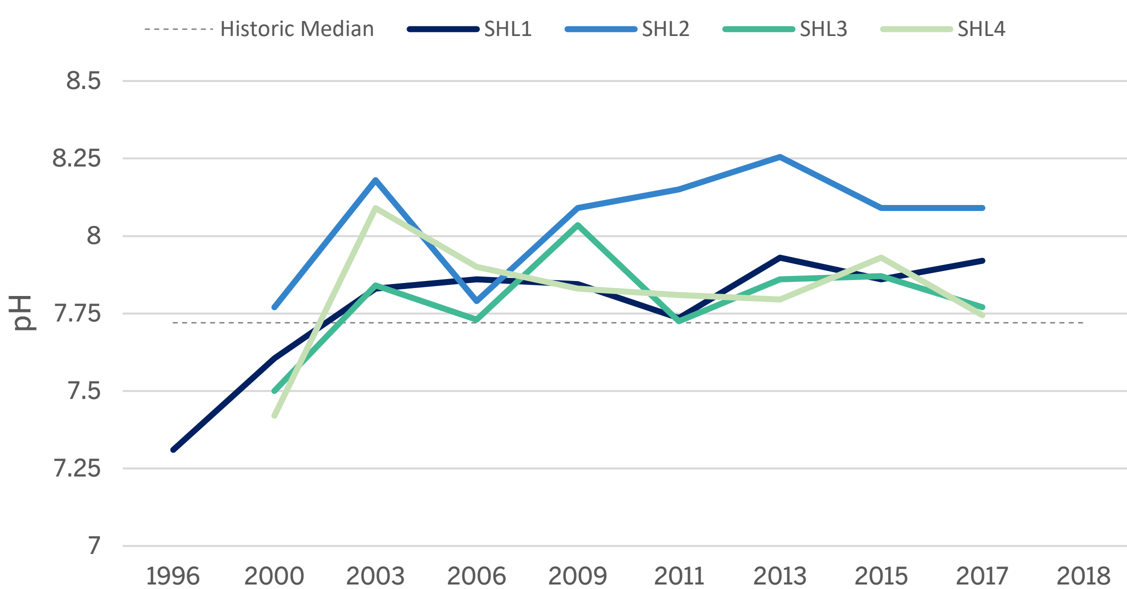


Figure 30 pH (2000 – 2017) (COA-WPD, 2018)

Shoal Creek's pH generally falls within the expected range.

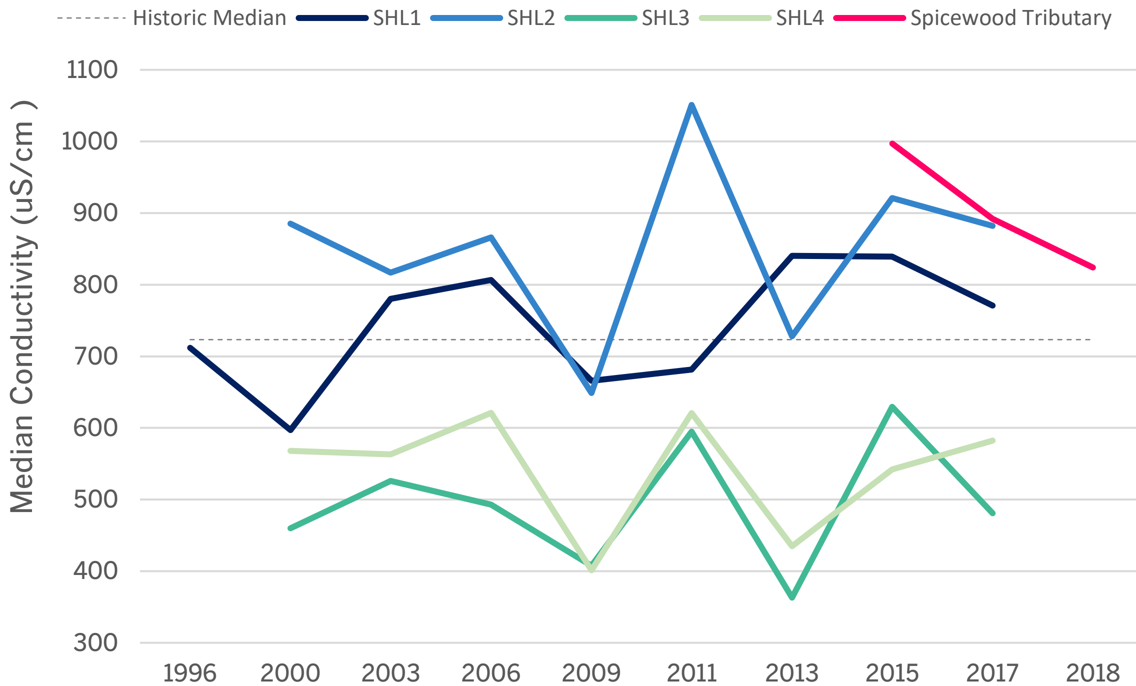


Figure 31 Conductivity (µS/cm) (2000 – 2018) (COA-WPD, 2018)

Conductivity is a measure of the amount of salts in water and a good indicator of a range of urban pollutants. Shoal Creek frequently exceeds 700 µS/cm, which is indicative of a more urbanized watershed. Note that conductivity is typically higher and more variable for Shoal Creek's downstream reaches (SHL1) and decreases steadily as you travel upstream (SHL2-4).

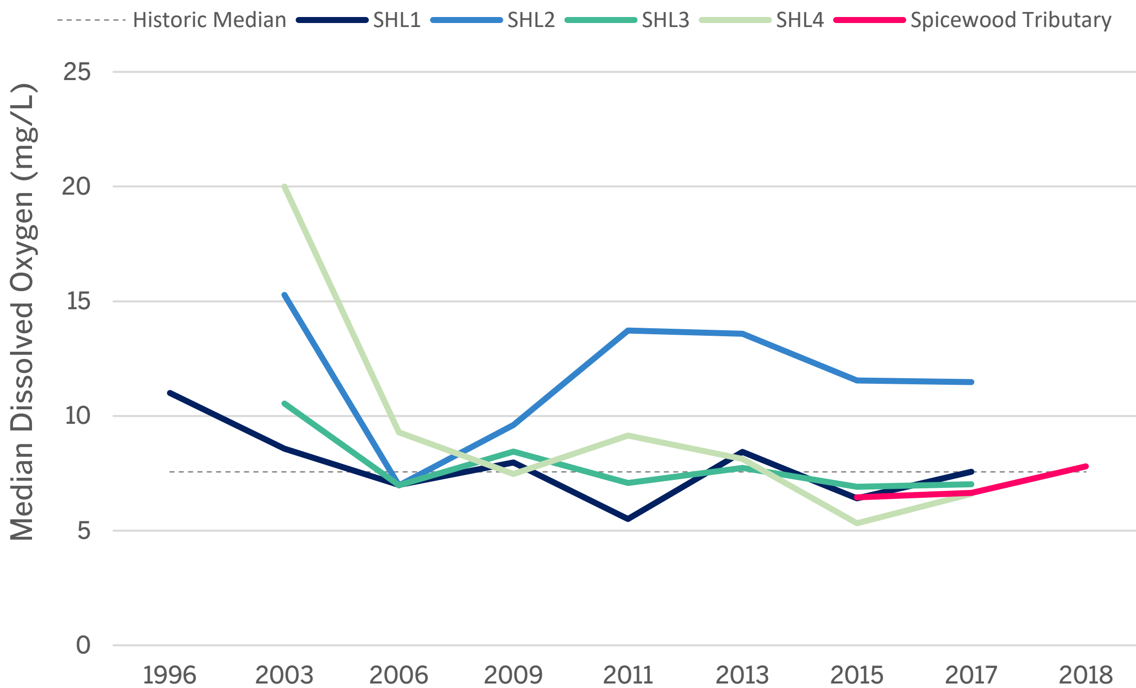


Figure 32 Dissolved Oxygen (mg/L) (2003 – 2018) (COA-WPD, 2018)

Dissolved Oxygen (DO) is used as an indicator of overall water quality because many organisms that live in water rely on oxygen to live. Many organisms are sensitive to low levels (below 5 mg/L) and will die and disappear if it drops too low. Generally Shoal Creek maintains sufficient levels of dissolved oxygen for aquatic life.

Nutrients

Nutrients in surface water are an important component of aquatic ecosystems, but excess nutrient load (called eutrophication) can create several serious problems for aquatic life. Elevated phosphorus and nitrate concentrations are commonly associated with algal blooms, which can result in dissolved oxygen spikes/troughs, fish kills, bad odors, and other associated water quality problems. Ammonia in surface water converts readily to nitrate, so it is important to monitor both ammonia and nitrate. One of the more common sources for these nutrients in urban environments is wastewater from raw sewage. Accordingly, creeks that exhibit higher concentrations of these nutrients are typically known to either be driven in part by aging infrastructure in which spills, leaks, and overflows are common (Clamann et al., 2015).

Another key source of nutrient pollution is the application of fertilizers. Synthetic nitrogen and phosphorus fertilizers are often applied in excess. The excess nutrients are lost through surface runoff and leaching to groundwater. Rainfall events also flush nutrients from common sources such as residential lawns, athletic fields, and golf courses into adjacent creeks.

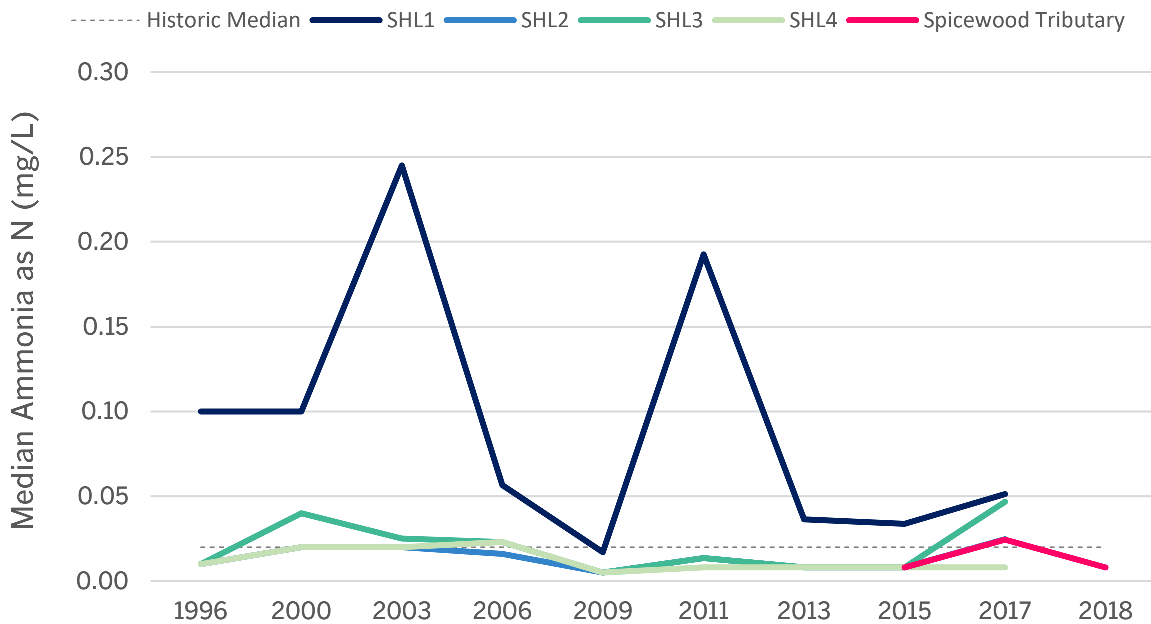


Figure 33 Ammonia (mg/L) (1996 – 2018) (COA-WPD, 2018)

Ammonia is one of several forms of nitrogen that exist in aquatic environments. Ammonia is typically higher and more variable for Shoal Creek's most downstream reach (SHL1).

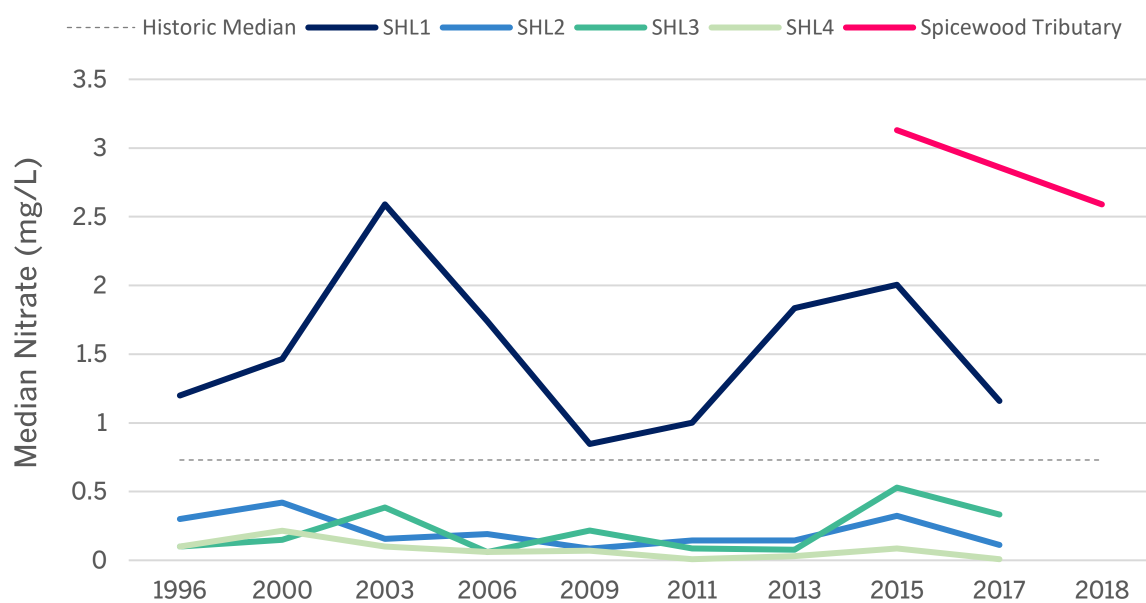


Figure 34 Nitrate (mg/L) (1996 – 2018) (COA-WPD, 2018)

Nitrates are a form of nitrogen, which is found in several different forms in terrestrial and aquatic ecosystems. Levels of nitrate are very high for the Spicewood Spring Tributary.

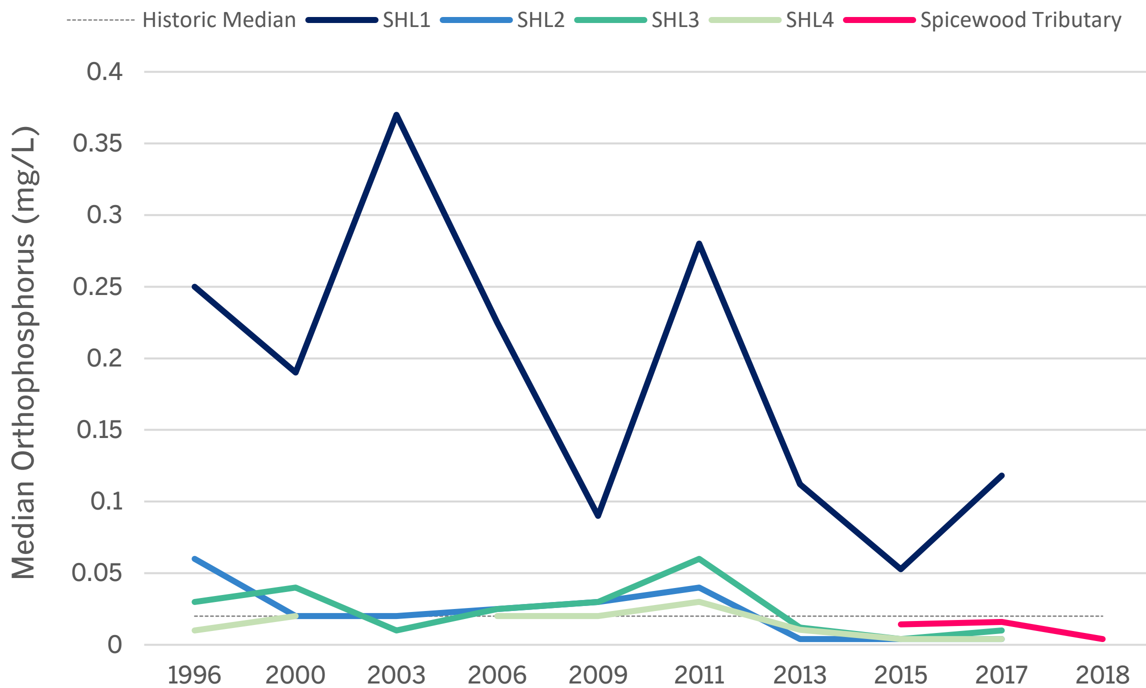


Figure 35 Orthophosphorus (mg/L) (1996 – 2018) (COA-WPD, 2018)

Orthophosphorus is typically higher and more variable for Shoal Creek's most downstream reach (SHL1).

Bacteria

Pathogenic bacteria in streams is a significant water quality problem because it restricts contact recreation, but it also serves as an indicator or surrogate for other pollutants such as nutrients and low dissolved oxygen. The potential sources of elevated bacteria in streams are diverse, diffuse, and often difficult to isolate. E. coli concentrations have historically been elevated throughout Shoal Creek, likely due to aging wastewater infrastructure in which spills and overflows are common. Although many wastewater lines within and adjacent to the creek have been removed, several remain. This watershed has a large residential component built in the early 1900s with low integrity wastewater lines. As these lines get replaced and there are other incremental improvements to the wastewater infrastructure, the total bacteria load should decrease (Clamann et al., 2015). Urban areas also tend to have a higher concentration of human and animal fecal inputs. The most probable sources of E. coli contamination in urban streams include sewage spills, chronic sewage leaks from wastewater lines, leakage from on-site sewage facilities, uncollected pet waste, untreated latrine sites that develop where indigent communities congregate, and areas where fecal material from urban wildlife accumulates (Jackson and Herrington, 2012). See Figure 36 for a summary of E. coli bacteria for EII reaches.

The Texas Commission on Environmental Quality (TCEQ) first identified bacteria impairments for contact recreation in the Spicewood Tributary to Shoal Creek in the 2002 State of Texas Clean Water Act Section 303(d) List. In 2012, a Total Maximum Daily Load (TMDL) was developed to address bacteria and to evaluate attainment of the contact recreation use in Waller Creek, Walnut Creek, Spicewood Tributary on Shoal Creek and Taylor Slough South. A TMDL is a determination made by TCEQ of the quantity that a pollutant must be reduced for a watershed to no longer be impaired. Although the segment was removed from the 303(d) list through the development of a TMDL and a TMDL Implementation Plan, the segment is still considered impaired with a average bacteria counts greater than the primary contact recreation standard. This segment is listed on the Draft 2016 Texas Integrated Report Index of Water Quality Impairments. See Figure 37 for a summary of E. coli bacteria for the Spicewood Springs Tributary.

For the adopted TMDL:
www.tceq.texas.gov/assets/public/waterquality/tmdl/101austinbacteria/101-AustinTMDLAdopted2015-01-21.pdf

See page 67 for more information regarding the TMDL Implementation Plan.

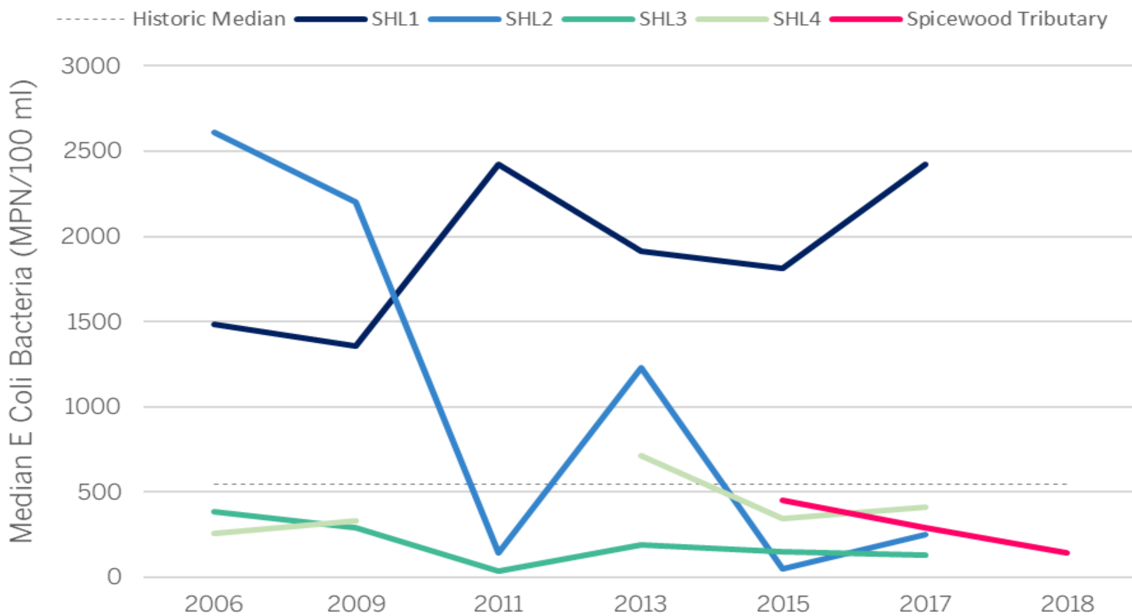


Figure 36 E. Coli Bacteria for EII Reaches and Spicewood Springs Tributary (2006 – 2018) (MPN/100 ml)

Most samples exceed the contact recreation standard for E. coli. Bacteria concentrations are typically higher and more variable for Shoal Creek's downstream reaches.

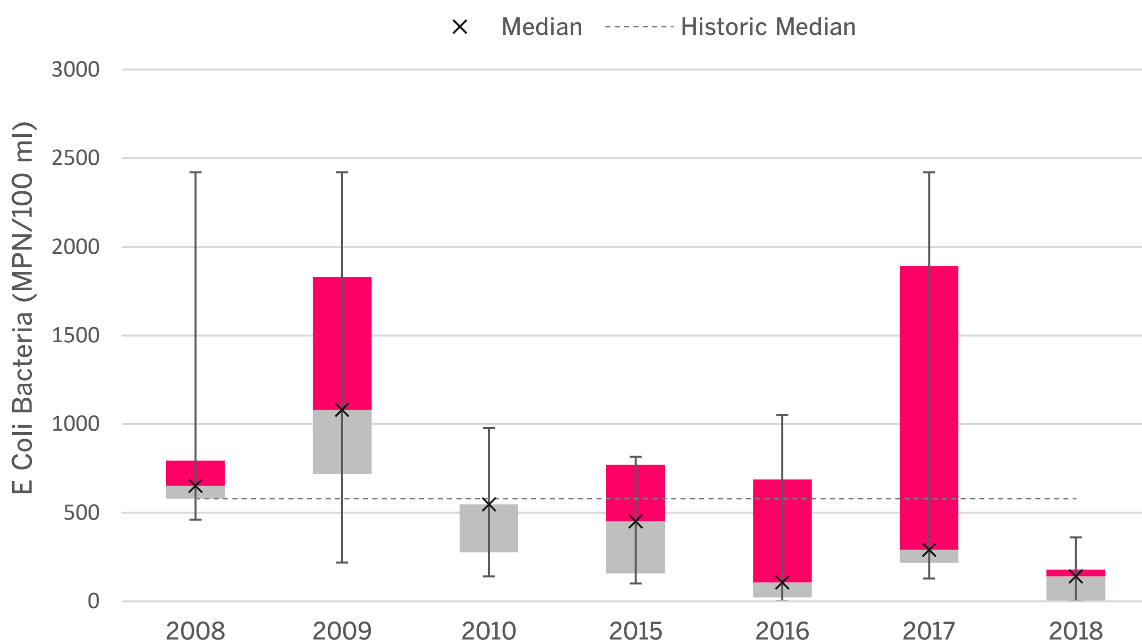
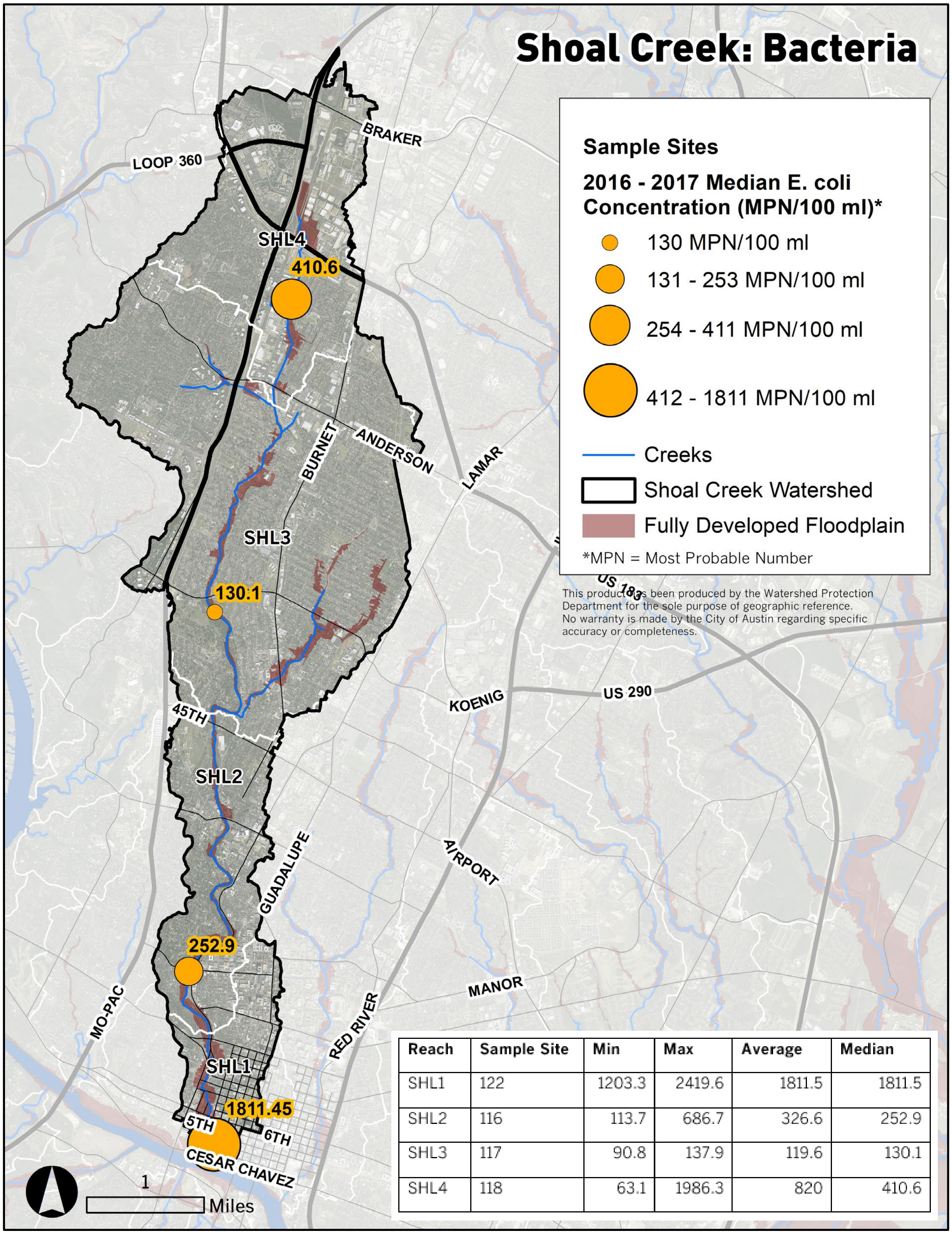


Figure 37 E. Coli Bacteria for Spicewood Springs Tributary (2008 - 2018) (MPN/100 ml) (COA-WPD, 2018)



Reach	Sample Site	Min	Max	Average	Median
SHL1	122	1203.3	2419.6	1811.5	1811.5
SHL2	116	113.7	686.7	326.6	252.9
SHL3	117	90.8	137.9	119.6	130.1
SHL4	118	63.1	1986.3	820	410.6

Figure 38 Bacteria Concentration (MPN/100 ml) (2016 – 2017) (COA-WPD, 2018)

Water Quality Treatment

In response to uncontrolled development in the Barton Creek and Lake Austin watersheds in the 1970s, the City of Austin began to place an emphasis on creek protection and the prevention of future problems through regulation. The Waterway Ordinance of 1974 limited development in the 25-year floodplain, required developments to identify appropriate sedimentation and erosion controls, and brought a new focus to protecting local creeks. The City's first water quality requirements were adopted in 1978 with the Lake Austin Ordinance, but water quality provisions were not extended to Shoal Creek until the adoption of the Urban Watersheds Ordinance in 1991. These watershed regulations are aimed at mitigating increased runoff rates and pollutant loadings from new land development.

Because Shoal Creek was among the first areas to be developed in Austin, large portions of the watershed were developed prior to modern watershed regulations. Thus, most watershed protection efforts in the Shoal Creek watershed must necessarily target the repair of problems caused by longstanding, unregulated development. Shoal Creek watershed has the largest number of parcels developed prior to the 1974 Waterway Ordinance. Over 56% of development in Shoal Creek was built prior to this ordinance, while 71% of development was built prior to the introduction of water quality control requirements in 1991. Because most development occurred prior to 1991, only 19% of the watershed's impervious cover is treated by water quality controls (see Figures 39 and 40). Please refer to Page 63 for a comprehensive description of watershed regulations.

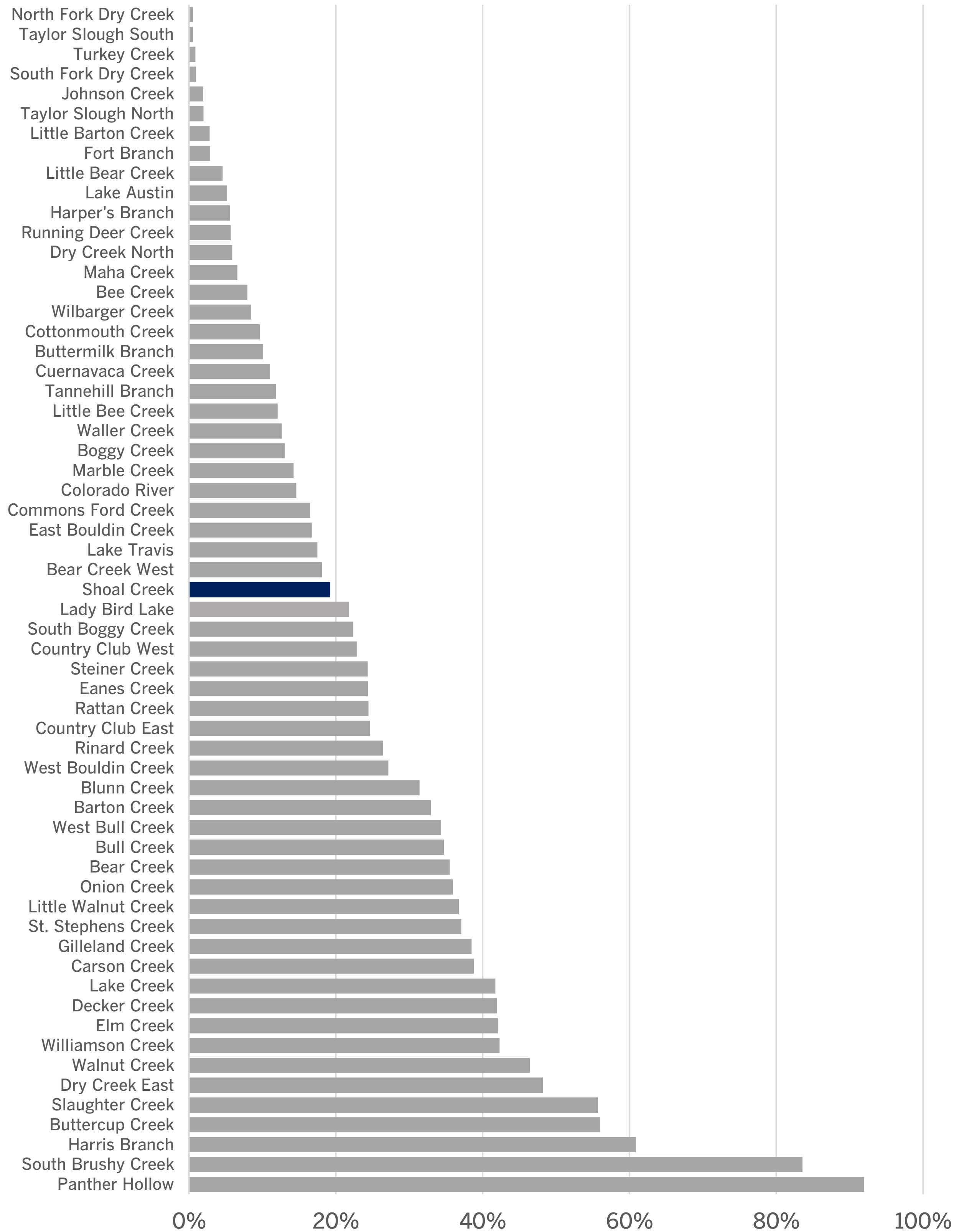


Figure 39 Percent Impervious Cover Treated for Water Quality (Full Purpose and ETJ) (WPD, 2019)

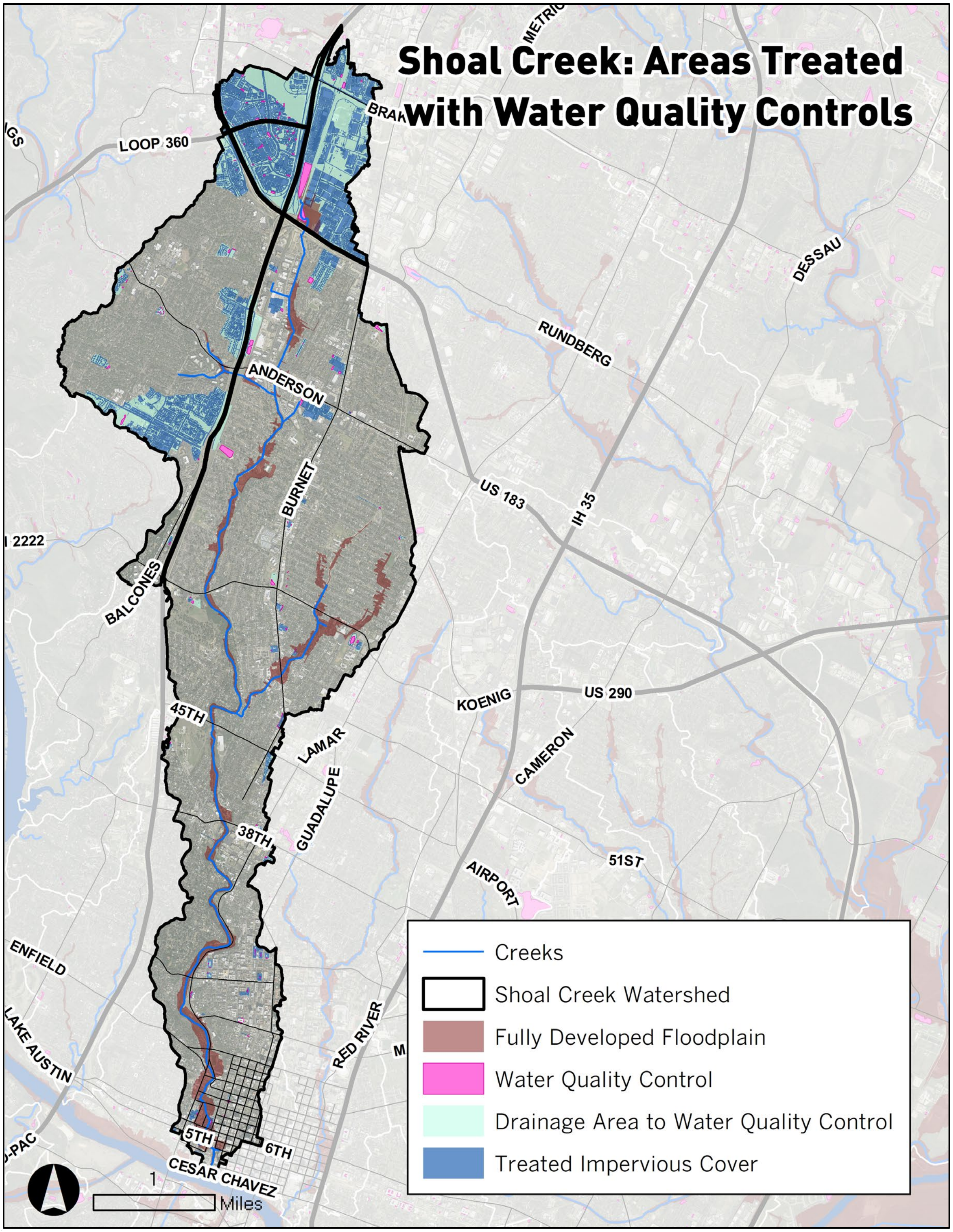


Figure 40 Areas Treated with Water Quality Controls - The dark blue areas represent impervious cover that is treated for water quality. While the portion of the Shoal Creek watershed north of US 183 is almost completely treated, approximately 80% of the watershed's impervious cover has no treatment. (COA-WPD, 2018)

Illicit Discharge Detection and Elimination

COA-WPD's Spills Response program investigates illicit discharges to the storm sewer system and spills of hazardous and non-hazardous materials that threaten waterways. Spills Response investigations include identifying the source of the discharge and monitoring cleanup. Discharges may occur through illicit plumbing connections to the City's storm sewer system, wastewater overflows, deliberate dumping, or accidental spills. Because the wastewater infrastructure tends to be older and more prone to failure, Shoal Creek has a relatively high rate of illicit discharges compared to other watersheds. Investigations of illicit discharges reports are concentrated in the SHL1 and SHL2 reaches, most likely due to a higher density of population and urban activity.

Common discharges include petroleum products (e.g., motor oil, gasoline, diesel fuel), sewage, soaps and detergents, sediment (e.g., silt, mud), antifreeze, latex and oil-based paints, solvents, trash and debris, restaurant grease, and fertilizers and pesticides. Investigators respond 24 hours a day, seven days a week to calls received through the Pollution Hotline at 512-974-2550.

Find more information at Austintexas.gov/PollutionPrevention.

Table 8 Illicit Discharge Investigations by Reach (COA-WPD, 2018)

Reach	Illicit Discharge Investigations	Illicit Discharge Investigations per Acre
SHL1	587	0.97
SHL2	444	0.36
SHL3	968	0.21
SHL4	239	0.12
Total	**2238**	**0.27**

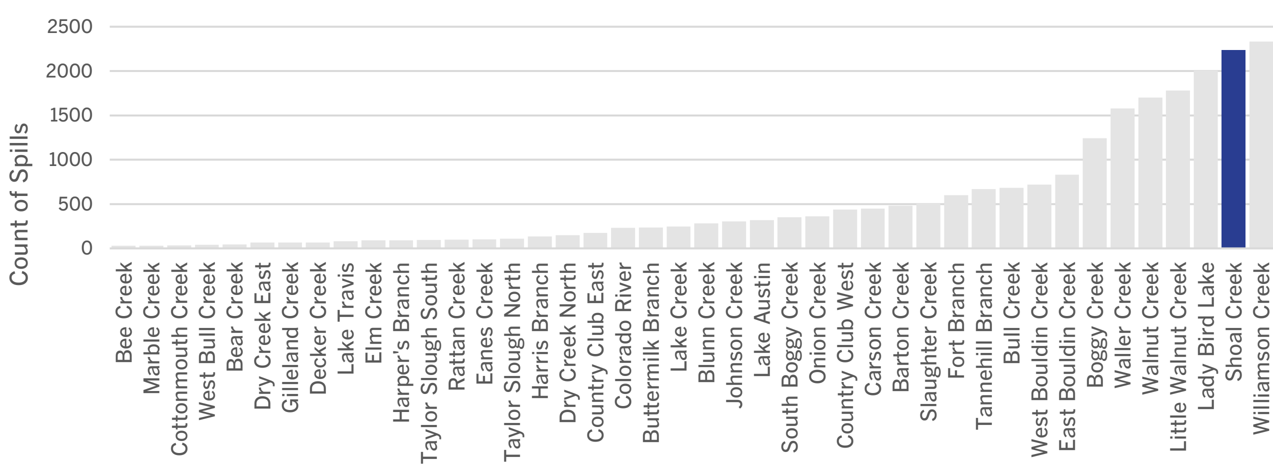


Figure 41 Total Reported Illicit Discharge Investigations, 1994 - 2018 (watersheds with discharge counts under 30 are excluded) (COA-WPD, 2018)

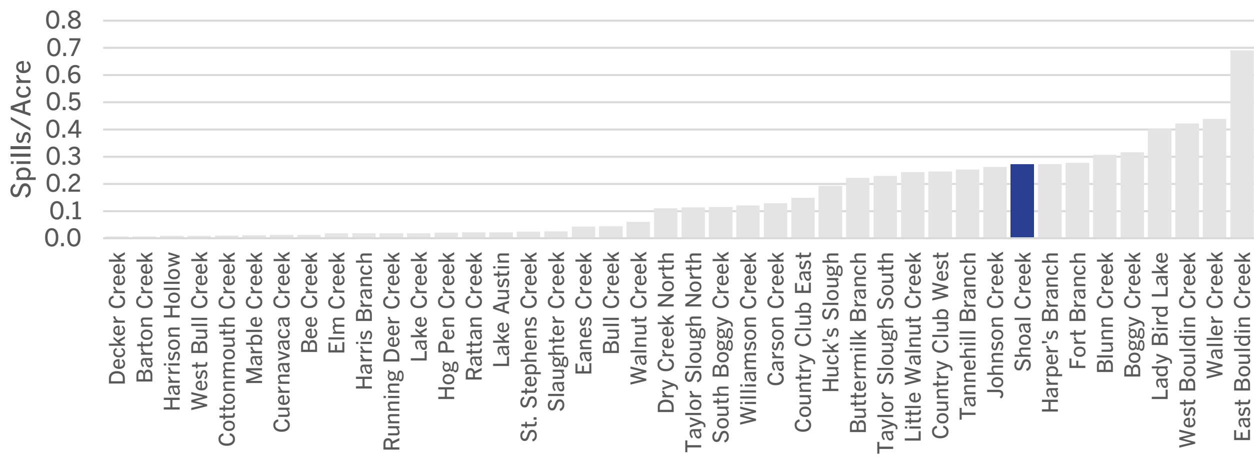


Figure 42 Illicit Discharge Investigations per Acre, 1994 - 2018 (watersheds with discharge counts under 30 are excluded) (COA-WPD, 2018)

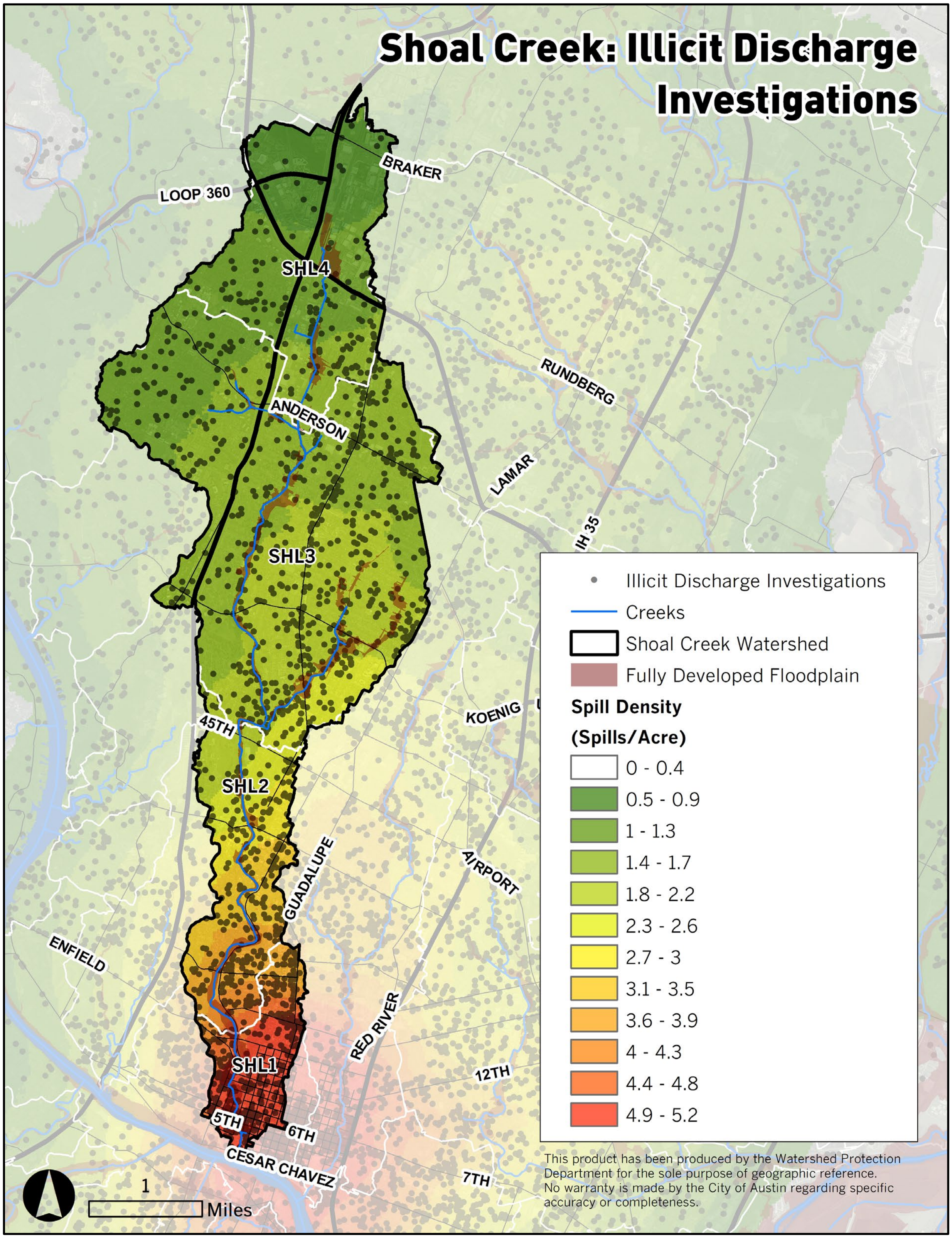


Figure 43 Illicit Discharge Investigations – Illicit discharge investigation density increases as proximity to downtown increases. (COA-WPD, 2018)

Discharge Permits

COA-WPD's Stormwater Discharge Permit Program (SDPP) is responsible for identifying and tracking business facilities that may contribute a substantial pollutant load to the City's municipal separate storm sewer system (MS4). This program permits and routinely inspects specific commercial and industrial businesses within the Austin City limits to ensure best management practices are followed to prevent polluting discharges. Site inspections evaluate waste handling, storage and disposal practices, maintenance activities, and operational condition of water quality controls. This program also maintains a database of industrial and high-risk facilities subject to Texas Pollution Discharge Elimination System (TPDES) permits. There are 83 SDPP city permits (7.6% of total permits) and 7 TPDES state permits (8.5% of total permits) within the Shoal Creek watershed.

More information regarding the Stormwater Discharge Permit Program is found at Austintexas.gov/faq/stormwater-discharge-permit-program-description

Table 9 TPDES and SDPP Stormwater Discharge Permits (COA-WPD, 2018)

Reach	TPDES Permits	SDPP Permits	Total Permits
SHL1	0	6	6
SHL2	0	9	9
SHL3	3	54	57
SHL4	4	14	18
Total	**7**	**83**	**90**

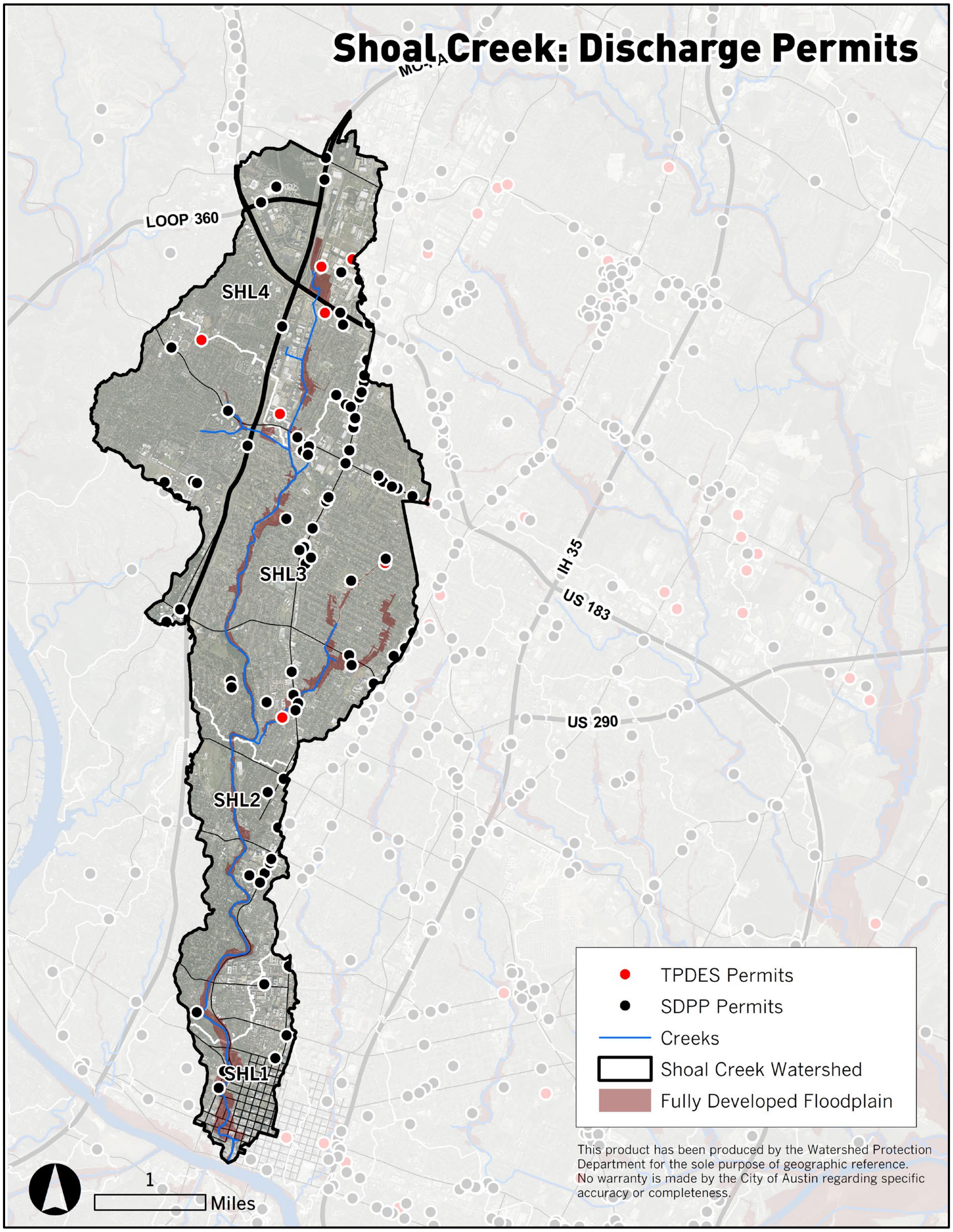


Figure 44 State and City Discharge Permits – There is a high density of SDPP discharge permits along North Lamar Boulevard. (COA-WPD, 2018)

V. Ongoing Efforts to Address Watershed Health

Potential solutions to Shoal Creek watershed problems include capital projects, programs, and regulations. The following section outlines the capital projects, programs, and regulations that the City of Austin Watershed Protection Department (COA-WPD) is using to target the suite of interrelated water quality, erosion, and flooding problems found within the Shoal Creek watershed.

A. Capital Improvement Projects

Capital projects, also called Capital Improvement Program (or CIP) projects, are typically large City-sponsored projects that construct, upgrade, or repair public infrastructure, including storm drain systems, low water crossings, and stream restoration. Capital projects are typically used to retrofit areas that were developed prior to modern drainage and environmental regulations. CIP projects differ from other COA-WPD projects in that they are generally large-scale, more expensive construction projects instead of routine maintenance or repairs. CIP projects are also planned and managed by the department's CIP program and funded by the capital budget instead of the operating budget. COA-WPD's capital budget is funded by a combination of sources, including the Drainage Utility Fund, Council and voter-approved bonds, and developer mitigation funds. COA-WPD has invested over $83 million in improvements to the Shoal Creek watershed.

Table 10 and Figure 45 below give an overview of completed COA-WPD capital projects within the Shoal Creek watershed. While these figures represent the best data available at this time, they are not comprehensive. This dataset may not capture all projects COA-WPD has completed, such as those in coordination with other City departments or those completed prior to the usage of the Capital Project Reporting and Information System database starting in 2001. Figure 46 depicts planned COA-WPD capital projects as of the time of this writing. Please note that planned project information is for planning purposes only and is subject to change at any time.

For more information regarding active capital improvement projects: www.austintexas.gov/department/watershed-protection/projects

For more information regarding the Brentwood Neighborhood Drainage Improvements Study: www.austintexas.gov/brentwoodrainagestudy

For more information regarding the Shoal Creek Flood Risk Reduction Study: www.austintexas.gov/shoalcreekfloods

For more information regarding the Shoal Creek slope failure: www.austintexas.gov/ShoalCreekLandslide

Table 10 Capital Improvement Program Projects with COA-WPD Expenditures (COA-WPD, 2018)

Project	Year
Water Quality	
Mopac / Steck Water Quality Pond	1997
Upper Shoal Creek Water Quality Retrofit	1999
Wet Pond Maintenance - Woodhollow	2009
10th and Rio Grande Rain Gardens	2011
18th and Rio Grande Rain Gardens	2012
Shoal Creek Restoration - 15th to 28th Streets	2016
Creek Flooding	
Greenlawn-Foster Channel Improvements	Pre-2001
Greenlawn Bridge Improvement	Pre-2001
Upper Shoal Creek Detention Pond	Pre-2001
Far West Pond	Pre-2001
Northwest Park Pond	Pre-2001
Silverway Bridge Removal	Pre-2001
Silverway Buyouts	Pre-2001
West 45th Street Bridge Improvements	Pre-2001
Grover Culvert and Channel Improvements	Pre-2001
Shoal Creek Blvd Bridge Replacement	Pre-2001
2222 Bridge Replacement and Channel Improvements	Pre-2001
MoPac Pond 1	Pre-2001
MoPac Pond 2	Pre-2001
Shoal Creek Buyouts	Pre-2001
PSP Pond 1	Pre-2001
PSP Pond 2	Pre-2001
West 1st Street Bridge at Shoal Creek	Pre-2001
Spicewood Springs Pond	Pre-2001
West 38th Street Bridge Improvements	Pre-2001
Jefferson Street Channel Improvements	Pre-2001
Steck Ponds	Pre-2001
Jefferson Buyouts	Pre-2001
Woodhollow Dam	Pre-2001
Benbrook Dam	Pre-2001
Shoal Creek Channel Improvements	Pre-2001
Upper Shoal Creek Detention Pond Improvements	2002

Localized Flooding	
Westover Hills Storm Sewer Improvements Phase I-A	1999
Westover Hills Storm Sewer Improvements Phase I-B	2000
MLK / San Jacinto to IH 35	2000
Arcadia Avenue Drainage Improvements	2001
Rosedale Storm Drain Improvements Phase 1	2006
23rd Street Streetscape Improvements	2009
Rickey Dr. Storm Drain Improvements	2011
Allandale Storm Drain Improvements	2012
Parkway Channel Improvement and Stream Stabilization	2012
West 34th Street from Shoal Creek Bridge to West Avenue Street Reconstruction	2012
Rosedale Storm Drain Improvements Phase 2	2012
Little Shoal Creek Tunnel Realignment and Utility Relocations - Phase I	2013
Pemberton Heights Water Rehabilitation Phase 3	2015
Shoal Creek - Ridgelea Storm Drain Improvements	2015
2nd Street Bridge and Extension / Shoal Creek to West Ave	2017
Erosion	
Lower Shoal Creek Erosion Project	1999
Shoal Creek Bank Stabilization West Avenue to 5th St	2000
Northwest Park to Foster Ln Erosion Stabilization Improvements	2003
5th St to Ladybird Lake Stream Restoration	2018
Multimission	
Arbor Walk Wet Pond	2006
Shoal Creek Greenbelt - Trail Improvements / 4th Street Gap	2018

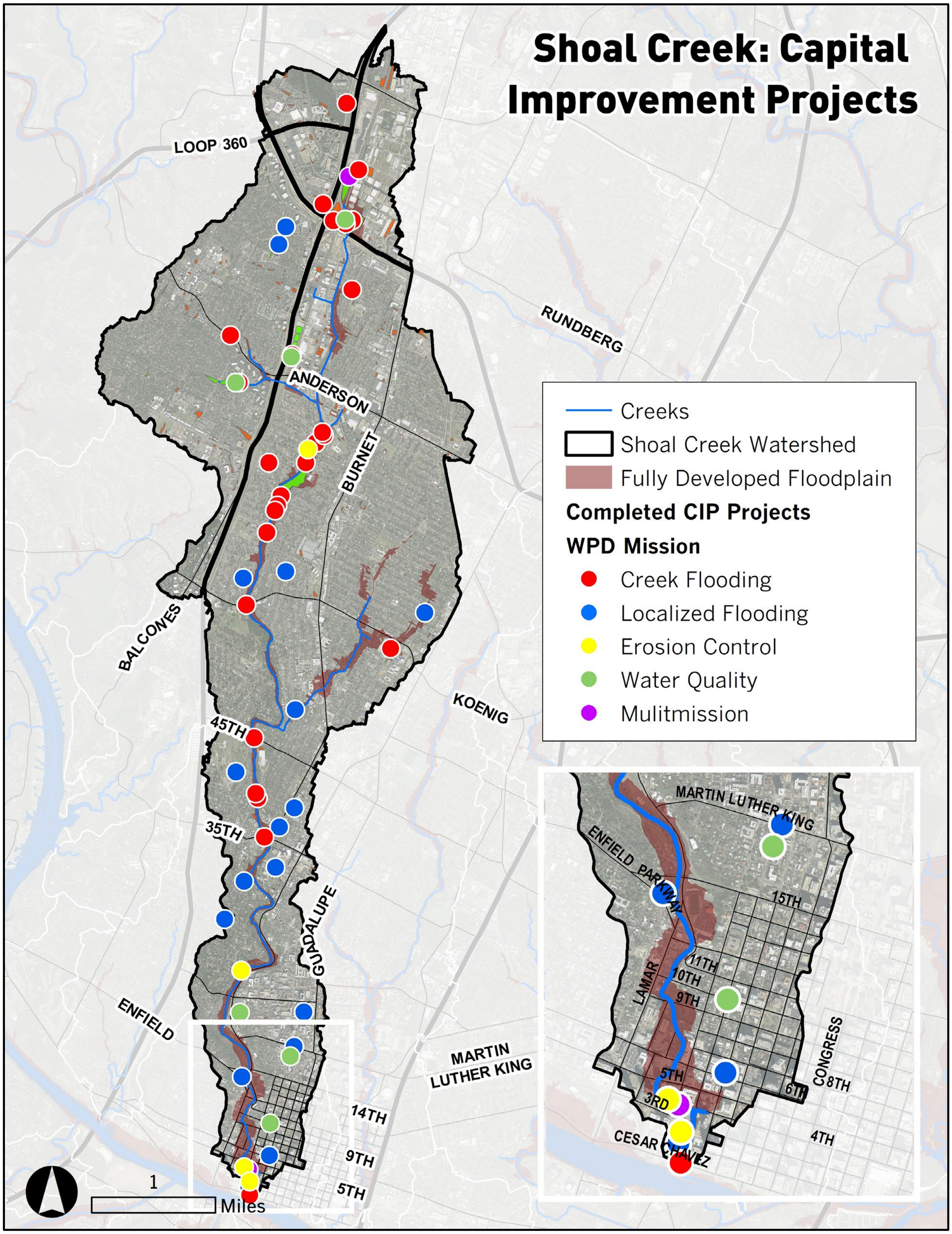


Figure 45 COA-WPD Capital Improvement Projects (COA-WPD, 2018)

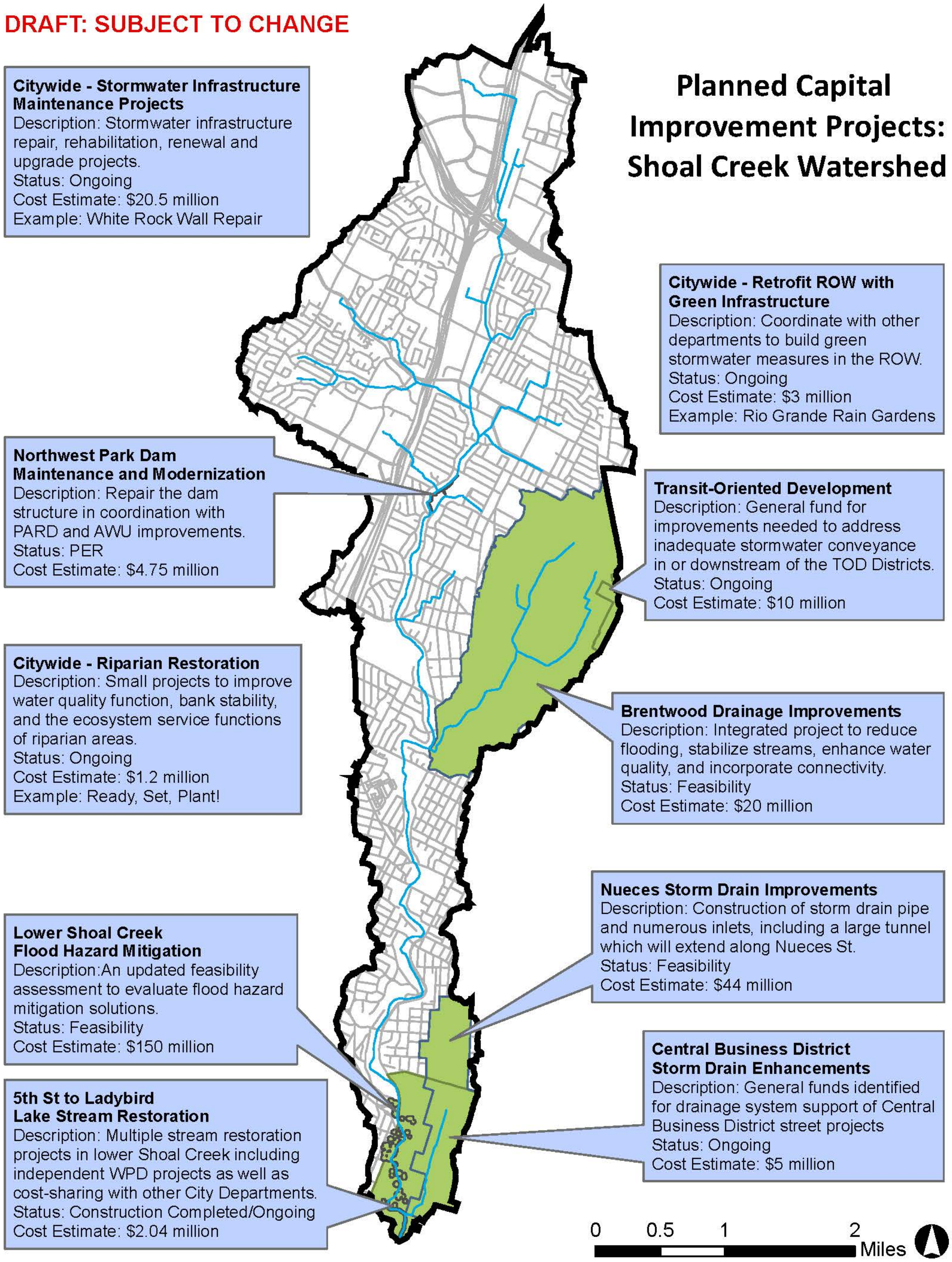


Figure 46 COA-WPD Planned Capital Improvement Projects (COA-WPD, 2018)

B. Regulations

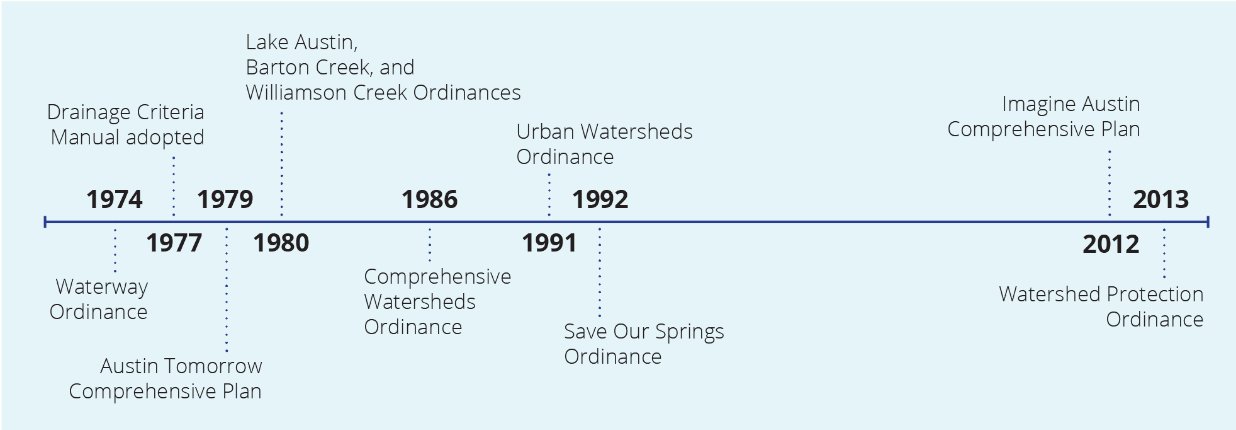


Figure 47 History of City of Austin Watershed Regulations (COA-WPD, 2018)

Watershed ordinances are one method of protecting Austin's creeks, rivers, lakes, and springs and protecting lives and property from flooding and erosion. Ordinances are a tool by which the City Council, with public review and input, modifies and improves Austin's Land Development Code.

The majority of the development in the Shoal Creek watershed occurred prior to the adoption of these regulations, leading to uncontrolled, polluted stormwater runoff; encroachment and alteration of natural waterways; placement of structures within harm's way in the floodplain; and undersized, deteriorating storm drain systems.

Drainage Regulations

The regulations for drainage were first adopted in 1974 to reduce flood hazards associated with large storm events by restricting development in floodplains and reducing the peak flows associated with these storms. In October 2013, City Council adopted the Watershed Protection Ordinance (WPO), a comprehensive overhaul of Austin's environmental and drainage code. This ordinance added the Erosion Hazard Zone to further protect infrastructure and property. Major provisions of Austin's drainage regulations include:

- ***Floodplain Protection.*** The City of Austin establishes a floodplain for any waterway with a drainage area of 64 acres or greater. Buildings and parking areas are prohibited from encroaching on the 25-year floodplain and restricted from encroaching on the 100-year floodplain. Proposed buildings within the Central Business Area bounded by IH-35, Riverside Drive, Barton Springs Road, Lamar Boulevard, and 15th Street may be permitted to encroach on the 100-year floodplain if the development meets requirements for not creating an adverse flooding impact, minimum height between the building's lowest floor and the floodplain (freeboard), safe access, improvements to the drainage system, and compensation for any floodplain volume displaced. Variances to these requirements must be considered and approved by City Council.

- ***No Adverse Impact.*** Proposed development must not result in additional adverse flooding on other property. This includes, but is not limited to, any increase in the depth of flooding; any increase in the water surface elevation that causes stormwater to travel outside defined public rights-of-way, defined drainage easements, or Federal Emergency Management Agency (FEMA) floodplains or to exacerbate any of these situations if the water surface elevation already exceeds these boundaries; and increased velocity of stormwater flows that overtop roadways or other crossings. Currently, compliance with this requirement is not reviewed for individual one- and two-unit building permits, as the requirements are not designed for this type and scale of development.

- ***Stormwater Management.*** Development must reduce post-development peak rates of discharge to existing pre-development peak rates of discharge for the 2-, 10-, 25- and 100-year storm events. The basic concept of stormwater management for peak rates of runoff is to provide for a temporary storage of stormwater runoff, often through an on-site or regional detention pond. Runoff is then released at a controlled rate which cannot exceed the capacities of the existing downstream drainage systems, or the predeveloped peak runoff rate of the site, whichever is less. Currently, compliance with this requirement is not reviewed for individual one- and two-unit building permits, as the requirements are not designed for this type and scale of development.
- ***Regional Stormwater Management Program.*** The Regional Stormwater Management Program (RSMP) provides developers an alternative way to comply with on-site detention regulations, if certain criteria are met. If approved for participation in the program, the applicant has additional options to comply by providing regional drainage improvements, dedicating land or easements for drainage improvements, providing an equivalent alternative to detention, and/or payment-in-lieu of detention. COA-WPD then uses these funds towards regional flood mitigation projects within the same watershed as the project. To participate in the program, the project must demonstrate that it has no adverse impact from flood or erosion potential and adequate downstream flood conveyance capacity.
- ***Erosion Hazard Zones.*** Creeks are dynamic, mobile systems. The Erosion Hazard Zone is the area where future stream channel erosion is likely to result in damage to or loss of property, buildings, infrastructure, utilities, or other valued resources. An Erosion Hazard Zone analysis is required to be performed for all development proposed for property within 100 feet of the centerline of a stream with a drainage area greater than 64 acres. Once the Erosion Hazard Zone is identified, property and infrastructure can be protected by either keeping it out of the zone or by building protective works that will safeguard the development from future erosion.

Water Quality Regulations

Shoal Creek is an Urban watershed, meaning that development within the watershed was governed by the Urban Watersheds Ordinance (UWO) that was adopted in 1991 to address water quality degradation in the urban core and protect the health and beauty of Lady Bird Lake and the Colorado River. In 2013, the Watershed Protection Ordinance enhanced water quality protection in the Urban watersheds by adding floodplain modification criteria. Major provisions of Austin’s water quality regulations include:

- ***Impervious Cover Limits.*** Impervious cover has been directly related to altered hydrology and degradation of aquatic systems. As an Urban watershed, impervious cover for development in the Shoal Creek watershed is limited by zoning impervious cover limits.
- ***Water Quality Controls.*** Stormwater can have significant impact on the water quality of Austin's creeks and the Colorado River. To minimize the effect of non-point source pollutants in stormwater, water quality controls are required for new development. These water quality controls are designed to improve water quality by removing suspended particulate matter and associated constituents such as bacteria, nutrients, and metals. Water quality controls must

capture and treat the first half inch of runoff, plus an additional volume based on impervious cover ("half inch plus").

- ***Urban Structural Control Fund.*** The Urban watersheds have a unique provision that allows payment into the Urban Structural Control Fund in lieu of on-site controls for small sites that meet certain conditions (e.g., not located adjacent to a waterway). These funds are used to study, design, implement, and construct large water quality improvement projects in Urban watersheds.
- ***Stream Setbacks.*** By promoting healthy soils and vegetation along the creek corridor and allowing the stream adequate space to migrate over time, stream buffers help control flood impacts, reduce channel erosion and property loss, help maintain good water quality, reduce operation and maintenance costs, and provide habitat. In an Urban watershed like Shoal Creek, the Critical Water Quality Zone setback coincides with the 100-year fully-developed floodplain, bounded by a minimum width of 50 feet and a maximum width of 400 feet from each side of the stream centerline. Most development is prohibited within this setback, except for low-impact uses like parks and trails. The Central Business District, which encompasses approximately 3.5% of the Shoal Creek watershed, does not require a Critical Water Quality Zone setback.
- ***Critical Environmental Features.*** Critical environmental features include caves, sinkholes, springs, seeps, wetlands, bluffs, faults and fractures, and canyon rimrocks. These areas are especially susceptible to pollution and may provide habitat for endangered or threatened species. Setbacks preserve the natural character and function of these features, which in turn protects the quality and quantity of both groundwater recharge and surfacewater runoff. The standard buffer distance for all features is 150 feet, with a 300-foot maximum for point recharge features. The Central Business District does not require protection for wetlands (protection for all other CEFs is still required in this area).
- ***Floodplain Protection.*** Naturally functioning streams with connected floodplains dissipate stream energy, reduce soil erosion, reduce flood damage, capture and treat pollutants, and promote healthy ecosystems. Periodic flood flows that overtop the banks of stream areas are essential to the health of riparian corridors. Floodplain modifications are prohibited in the Critical Water Quality Zone unless the modifications are necessary to protect the public health and safety, would provide a significant environmental benefit, or are necessary for development allowed by Code (e.g., a trail). For proposed floodplain modifications outside the Critical Water Quality Zone, modification is allowed if located in an area determined to be in poor or fair condition. Any alterations allowed in the floodplain or Critical Water Quality Zone must be designed to retain the integrity of protected riparian areas and minimize damage to the physical and biological characteristics of such areas.

C. Maintenance Activities

COA-WPD manages Austin's natural waterways, engineered channels, drainage pipelines, and stormwater ponds that together comprise the City's drainage system. The following summarizes the ongoing maintenance activities carried out in the Shoal Creek watershed by COA-WPD.

Open Waterways. COA-WPD Open Waterways evaluates creek channels and removes accumulated sediment, debris, trees, brush, and other obstructions when it is determined that the materials may obstruct stormwater conveyance. These maintenance activities must consider the needs of the watershed as a whole, as increasing efficiency in one location along a stream often translates to increased flow rates at downstream locations. Widespread vegetation clearing is a measure that is typically avoided since it can have severe negative consequences for erosion and water quality. In addition to the damage to drainage infrastructure that will occur from erosion, the elimination of a healthy, natural riparian zone degrades the recreational value and natural function of these areas.

Vegetation Maintenance. Whereas the Open Waterways crews investigate and remove materials that pose a conveyance concern throughout the city, areas that are known to require minor, routine vegetation management are maintained primarily through private sector maintenance contracts. The Vegetation Control Program (VCP) identifies areas where excess vegetation consistently poses a conveyance concern and establishes a maintenance schedule to remove excessive vegetation, trash, and debris from stormwater controls and creeks to reduce flood hazards. As with Open Waterways activities, widespread vegetation clearing is avoided unless it is deemed necessary for proper conveyance. In most cases, a healthy riparian area is encouraged to protect the channel from erosion and preserve water quality.

Pond Maintenance. COA-WPD inspects, maintains, and repairs approximately 35 stormwater controls in residential areas and inspects over 450 privately-maintained commercial stormwater controls in the Shoal Creek watershed.

Trash and Debris Booms. Trash and debris booms are modified oil spill containment booms that catch floatable trash and debris. COA-WPD installs and maintains the booms, which are cleaned weekly and after rainfall events.

Storm Drain Cleaning. COA-WPD inspects, maintains, and cleans inlets and associated storm drains, as well as maintenance for bar ditches along roadways within Shoal Creek. Crews reduce street flooding by removing accumulated sediment, trash, and debris. Over 3,000 inlets in the Shoal Creek watershed are inspected on a two-year rotation or in response to resident requests.

Field Operations Crews. COA-WPD crews maintain and install small-scale storm drain improvements and creek stabilization projects. COA-WPD staff selects projects that are appropriately sized for crew installation, then designs and oversees the project construction. COA-WPD crews have completed 16 projects that repaired over 2,500 linear feet of stream bank along Shoal Creek since 1995.

D. Ongoing Programs

Watershed Education. The Watershed Education program provides instruction and educational materials to students, teachers, and the general public. The program's goal is to increase awareness of the causes of non-point source pollution and to encourage the reduction of pollutant loads entering Austin's creeks. Watershed Education's campaigns are implemented citywide, but many of their campaigns are particularly relevant to the problems facing the Shoal Creek watershed. For example, the "Scoop the Poop" campaign specifically targets one of the non-point sources of bacteria that contribute to the impairment of Shoal Creek for contact recreation—household pets can be sources of E. coli when storm runoff carries dry-land deposits of animal waste into streams. Similarly, the Grow Green landscape program focuses on encouraging homeowners to adopt earth-wise landscaping practices. The "don't overfertilize" message describes the water quality impacts from excess nutrients in streams and then gives specific information on organic products and application guidelines.

Find more information at: www.austintexas.gov/department/watershed-protection/education

Endangered Salamander Protection. The purpose of the Endangered Salamander Protection program is to provide monitoring, impact assessments, and captive breeding of endangered aquatic species for the citizens of Austin and regulatory agencies in order to ensure the survival of the species, promote recovery of the species, and allow the continued use of Austin's unique natural resources. In the Shoal Creek watershed, this program monitors, evaluates stressors, habitat characteristics, and population parameters for the federally threatened Jollyville Plateau salamander population at Spicewood Spring.

Find more information at: www.austintexas.gov/department/salamanders

The Flood Early Warning System (FEWS). The FEWS program was initiated in response to the devastating 1981 flood on Shoal Creek. The FEWS program gathers real time rainfall and stream-flow data and uses this information to provide advance warning of potential flood conditions for emergency response personnel. It has improved the City's emergency response capabilities for road closings, evacuation of flood-prone areas, and public notification of hazardous conditions.

Find more information at: www.austintexas.gov/department/flood-early-warning-system

Flood Hazard Public Information/PIO Community Services. Because Shoal Creek has many crossings inundated in 2- and 10-year events and has very high velocity flows, public education is vital to protecting public safety. "Turn Around, Don't Drown" is a signature COA-WPD campaign that educates the public about the danger of traversing low-water crossings during storms.

Total Maximum Daily Load Implementation Plan. A TMDL is a determination made by TCEQ of the quantity that a pollutant (in this case fecal bacteria) must be reduced for a watershed to no longer be impaired. An Implementation Plan is a separate document that identifies the activities that will be conducted by stakeholders in the watershed that will achieve the necessary reductions of bacteria. In 2015 TCEQ staff developed a TMDL for four Austin watersheds, including the Spicewood Springs Tributary of Shoal Creek, and initiated an Implementation Plan process with a Coordinating Committee composed of City of Austin staff and the public, facilitated and organized by the University of Texas Law School as a paid contractor for the TCEQ. As the primary departments responsible for implementing fecal bacteria reduction actions in streams, staff from Austin Water and COA-WPD participated as members of the Coordinating Committee. Because the City of Austin recognizes this as a citywide issue, the proposed actions to reduce fecal pollution are being implemented on a citywide basis as much as possible, even though the TCEQ-mediated process focuses only on the TMDL watersheds. The Implementation Plan recommended five avenues of voluntary management measures to reduce nonpoint source fecal bacterial contamination in these four water bodies. These management measures are addressed through various City programmatic activities (1. Riparian Zone Restoration, 2. Wastewater Infrastructure, 3. Domestic Pet Waste, 4. Resident Outreach, and 5. Stormwater Treatment).

See the following for the Implementation Plan and the 2017 update:
https://www.tceq.texas.gov/assets/public/waterquality/tmdl/101austinbacteria/101A_AustinIPlanApproved2015-01-21.pdf

www.tceq.texas.gov/assets/public/waterquality/tmdl/101austinbacteria/101-Austin2017CheckIn.pdf

Riparian Zone Restoration. Shoal Creek is among the worst scoring watersheds for riparian vegetation (COA-WPD, 2018). The objective of the Riparian Zone Restoration program is to increase vegetation quantity and quality along streams as a means of improving water quality throughout the city. The program is focused on improving the vegetative communities in these buffers, improving soil health and infiltration capacity, and increasing the ability of storm flow to be slowly and evenly distributed through riparian areas. Healthy riparian buffers enhance water quality and quantity in a wide variety of ways, including reducing nutrients and suspended solids. Riparian buffers reduce bacteria loads to streams from stormwater, primarily due to the fact that bacteria tend to adhere to sediment particles that are then trapped by riparian vegetation.

Riparian restoration may be accomplished through capital improvement projects when more active slope modification, concrete removal, and large-scale vegetation management is needed to restore ecological function. Modification of mowing practices with a minimal amount of invasive species removal or native vegetation seeding is an effective passive approach that not only reduces land management maintenance burden, but also restores the ecological function of riparian zones over time. As passive ecological restoration is a long term process, control of exotic invasive species must be done gradually, particularly in areas with high densities of exotic invasive plants that stabilize soil and provide shade. In areas where invasive species are managed, tree seedling planting and/or seed bank enrichment are crucial to restore the native plant community.

Grow Zones (also known as "No Mow Zones"). Grow Zones are an effort to passively promote healthy riparian vegetation along creeks in City parks. This program works closely with the Riparian Zone Restoration program, but differs in its limitation to City of Austin parks. COA-WPD staff work with the Parks and Recreation Department to eliminate regular mowing along creeks severely impacted by mowing and other disturbance. COA-WPD actively monitors some of these sites to document the transition and evaluate whether restoration goals are being reached. They also meet with neighborhood associations, conduct educational creek walks, and post signs to explain the process. Over time, native grasses and, eventually, trees will become established and transform the areas into more ecologically functional, beautiful landscapes. COA-WPD supports active restoration by volunteers in Grow Zones and other creekside areas through co-sponsorship of the Keep Austin Beautiful Adopt-a-Creek program. Interested volunteers can sign up for work days with active groups, or consider adopting their own section of creek through the program. Potential activities include trash cleanup, wildflower and native grass seeding, management of invasive plants and small projects to improve trails and creek access.

In addition to the wide variety of ecological services that these buffers provide, Grow Zones are integral to the effort to reduce fecal bacteria loads in Shoal Creek. Shoal Creek currently has Grow Zones in Pease Park, the Shoal Creek Greenbelt near Allandale Rd, and Crestmont Greenspace (see Figure 48).

Find more information at: www.austintexas.gov/creekside and https://keepaustinbeautiful.org/programs/adopt-a-creek/.

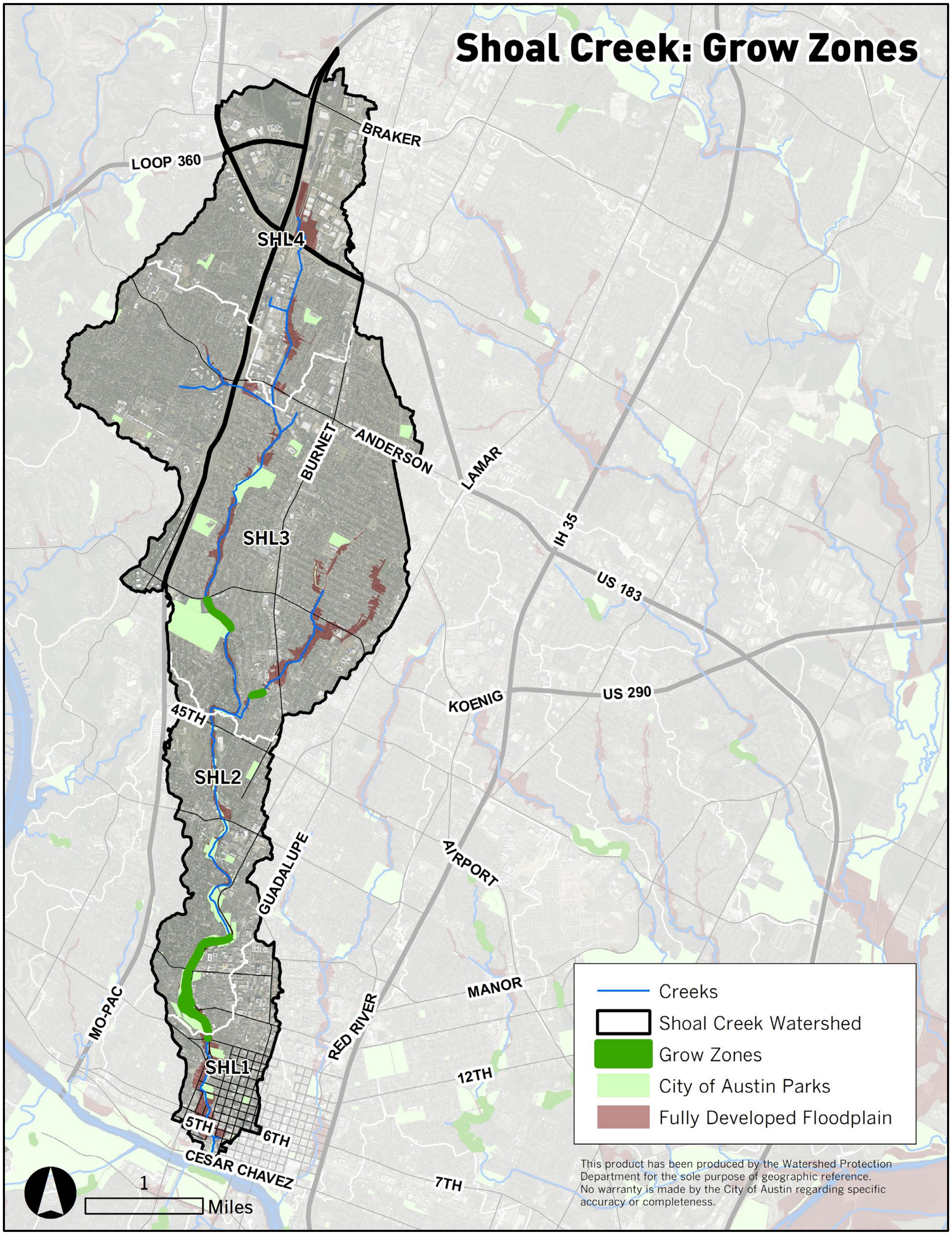


Figure 48 COA-WPD Grow Zones - Shoal Creek currently has Grow Zones in Pease Park, the Shoal Creek Greenbelt near Allandale Rd, and Crestmont Greenspace. (COA-WPD, 2018)

The following is to be completed after modeling and stakeholder conversations.

VI. Identification of Management Activities to Improve Health

A. Water quality modeling

- **Hydrological data**
- **Summary of data used in modeling/calculations**
- **Hydrologic calibration and key parameters**
- **Load reduction results**
- **Load reduction scenarios using proposed best management practices (BMPs)**
- **Estimated timeframe to meet water quality standards via BMP scenarios**
- **Final input files and compiled executable files for models/calculations**
- **Land use pollutant loadings**
- **Land based washoff loads to water body**

B. Recommended Management Activities

- **Water quality**
- **Habitat and native species**
- **Flooding and erosion**
- **Spring flow and groundwater**
- **One Water Concept**

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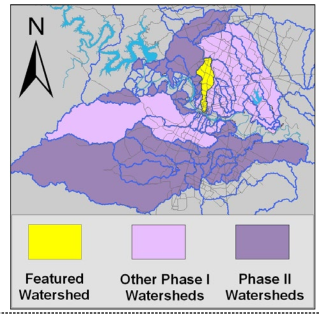
VIII. Appendix A – Shoal Creek EII Summary

Shoal Creek Watershed

Summary Sheet

Catchment	Total area	13 square miles
	Area in recharge	3 square miles
	Creek length	11 miles
	Receiving water	Town Lake
Demographics	2000 population	59,011
	2030 projected population	78,759
	30 year projected % increase	33 %
Land Use	Impervious cover (2003 estimate)	47.3 %
	Impervious cover (2013 estimate)	53.3 %

Overall EII Scores	2000	2003	2006	2009	2011	2013	2015
	60	54	55	63	57	59	63



Flow Regime* for Sample Sites on Shoal Creek Upstream to Downstream

Site	2001		2003						2006					2009					2010	2011				2013						2015			
	Feb	Feb	Feb	Mar	Mar	May	Sep	Dec	Feb	May	Jul	Aug	Nov	Feb	May	May	Oct	Dec	Dec	Mar	Jun	Jun	Sep	Jan	Apr	May	Jun	Jun	Sep	Jan	Apr	Jul	Sep
	WQ	Bio	WQ	WQ	Bio	WQ	WQ	WQ	WQ	WQ	Bio	WQ	WQ	WQ	WQ	Bio	WQ	WQ	WQ	WQ	WQ	Bio	WQ	WQ	WQ	Bio	WQ	Bio	WQ	WQ	WQ	WQ	WQ
118	B	B	B	B	B	B	B	n	B	B	B	n	B	B	B	B	B	B	n	B	n	n	n	B	B	B	B		B	B	B	B	n
117	B	B	B	B	B	B	B	B	B	B	B	n	B	B	B	B	B	B	B	B	n	n	n	B	B	B	B		B	B	B	B	n
116	B	B	B	B	B	B	B	B	B	B	B	n	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B		B	B	B	B	B
122	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B		B	B	B	B	B	B	B

* B = baseflow n = no flow S = storm flow blue = Samples were taken light blue = Samples were not taken blank = not visited

Index Scores* for Shoal Creek Sites by Year

Reach	Site	Site Name	Year	Water Quality	Sediment*	Contact Rec.	Non-Contact Rec.	Physical Integrity	Aquatic Life	Benthic subindex	Diatom subindex	Total EII Score
SHL1	122	Shoal Creek Upstream of 1st St.	1996	27	51	14	37	58	35	30	39	37
SHL2	116	Shoal Creek @ 24th Street	1996	41	51	45	68	51	52	52	51	51
SHL3	117	Shoal Creek @ Shoal Edge Court (EII)	1996	56	51	93	79	60	54	69	38	66
SHL4	118	Shoal Creek DS of Crosscreek Drive	1996	63	51	24	59	50	51	32	70	50
SHL1	122	Shoal Creek Upstream of 1st St.	2000	44	89	63	64	33	37	31	42	55
SHL2	116	Shoal Creek @ 24th Street	2000	53	89	74	63	26	38	40	36	57
SHL3	117	Shoal Creek @ Shoal Edge Court (EII)	2000	62	89	65	77	45	39	40	37	63
SHL4	118	Shoal Creek DS of Crosscreek Drive	2000	64	89	75	63	42	62	60	64	66
SHL1	122	Shoal Creek Upstream of 1st St.	2003	32	68	60	34	35	45	34	56	46
SHL2	116	Shoal Creek @ 24th Street	2003	51	68	41	66	32	36	29	43	49
SHL3	117	Shoal Creek @ Shoal Edge Court (EII)	2003	62	68	62	65	65	36	32	40	60
SHL4	118	Shoal Creek DS of Crosscreek Drive	2003	68	68	67	68	54	37	41	32	60
SHL1	122	Shoal Creek Upstream of 1st St.	2006	34	59	30	59	46	38	30	45	44
SHL2	116	Shoal Creek @ 24th Street	2006	48	59	24	79	47	64	62	66	54
SHL3	117	Shoal Creek @ Shoal Edge Court (EII)	2006	67	59	49	72	57	59	58	60	61
SHL4	118	Shoal Creek DS of Crosscreek Drive	2006	70	59	59	53	58	56	53	59	59
SHL1	122	Shoal Creek Upstream of 1st St.	2009	48	60	25	79	57	79	83	75	58
SHL2	116	Shoal Creek @ 24th Street	2009	64	60	28	84	59	94	91	97	65
SHL3	117	Shoal Creek @ Shoal Edge Court (EII)	2009	69	60	37	78	72	79	90	68	66
SHL4	118	Shoal Creek DSof Crosscreek Drive	2009	76	60	36	83	49	74	65	82	63
SHL1	122	Shoal Creek Upstream of 1st St.	2011	36	70	25	55	54	53	46	60	49
SHL2	116	Shoal Creek @ 24th Street	2011	62	70	48	80	50	62	61	63	62
SHL3	117	Shoal Creek @ Shoal Edge Court (EII)	2011	79	70	62	76	63	64	60	67	69
SHL4	118	Shoal Creek DS of Crosscreek Drive	2011	85	70	25	42	60				47
SHL1	122	Shoal Creek Upstream of 1st St.	2013	36	62	25	56	41	82	80	84	50
SHL2	116	Shoal Creek @ 24th Street	2013	60	62	31	83	47	81	80	82	61
SHL3	117	Shoal Creek @ Shoal Edge Court (EII)	2013	74	62	48	63	58	83	84	81	65
SHL4	118	Shoal Creek DS of Crosscreek Drive	2013	71	62	28	83	56	62	66	57	60

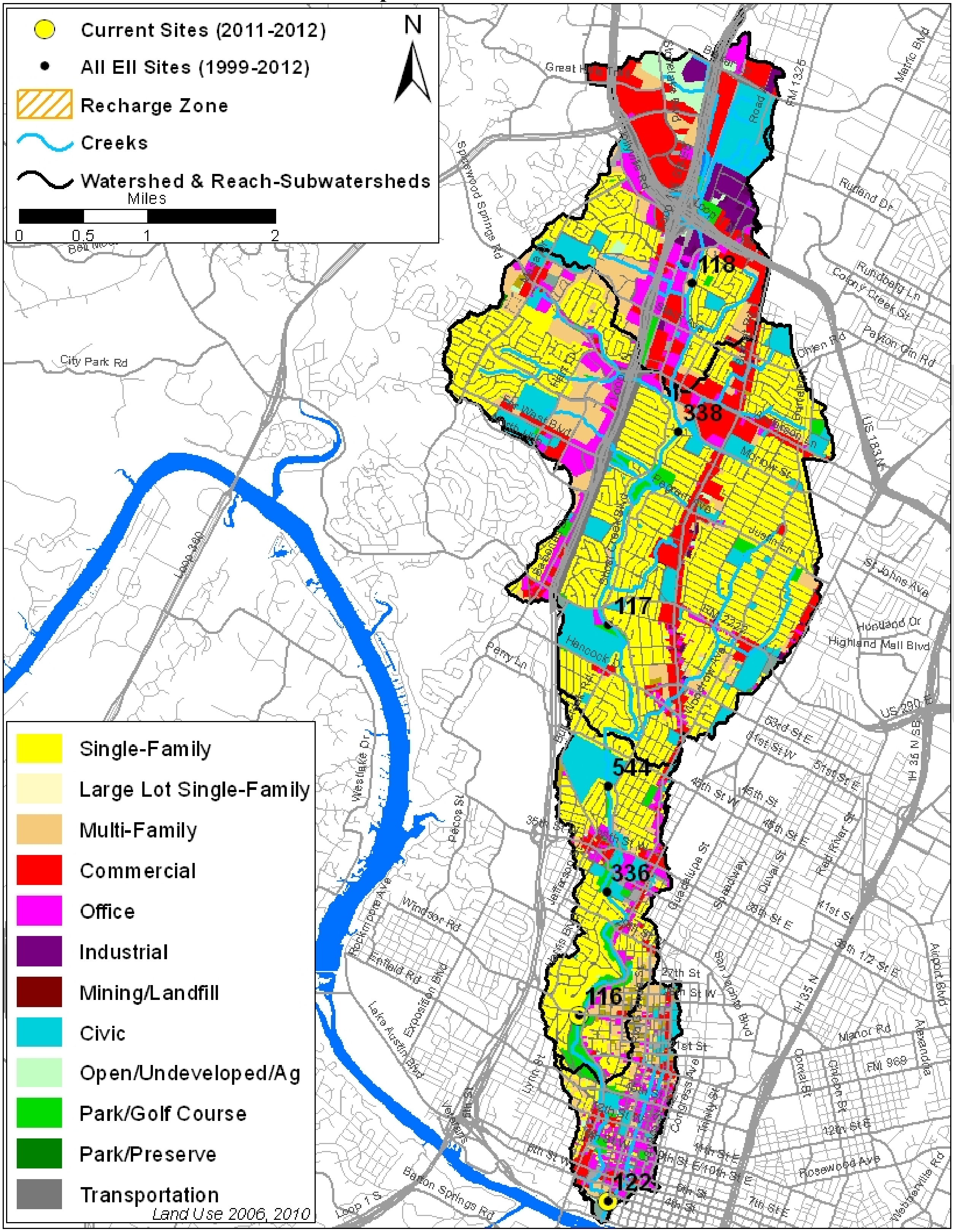
SHL1	122	Shoal Creek Upstream of 1st St.	2015	37	60	25	77	60	79	83	75	56
SHL2	116	Shoal Creek @ 24th Street	2015	57	60	65	72	51	79	87	71	64
SHL3	117	Shoal Creek @ Shoal Edge Court (EII)	2015	60	60	40	81	70	84	90	78	66
SHL4	118	Shoal Creek DS of Crosscreek Drive	2015	70	60	38	81	65	79	78	79	66

* blank cells indicate parameter was not collected, blank columns indicate site was dropped **sediment samples only collected at the downstream site

100-87.5 Excellent 87.5-75 V. Good 75-62.5 Good 62.5-50 Fair 50-37.5 Marginal 37.5-25 Poor 25-12.5 Bad 12.5-0 V. Bad

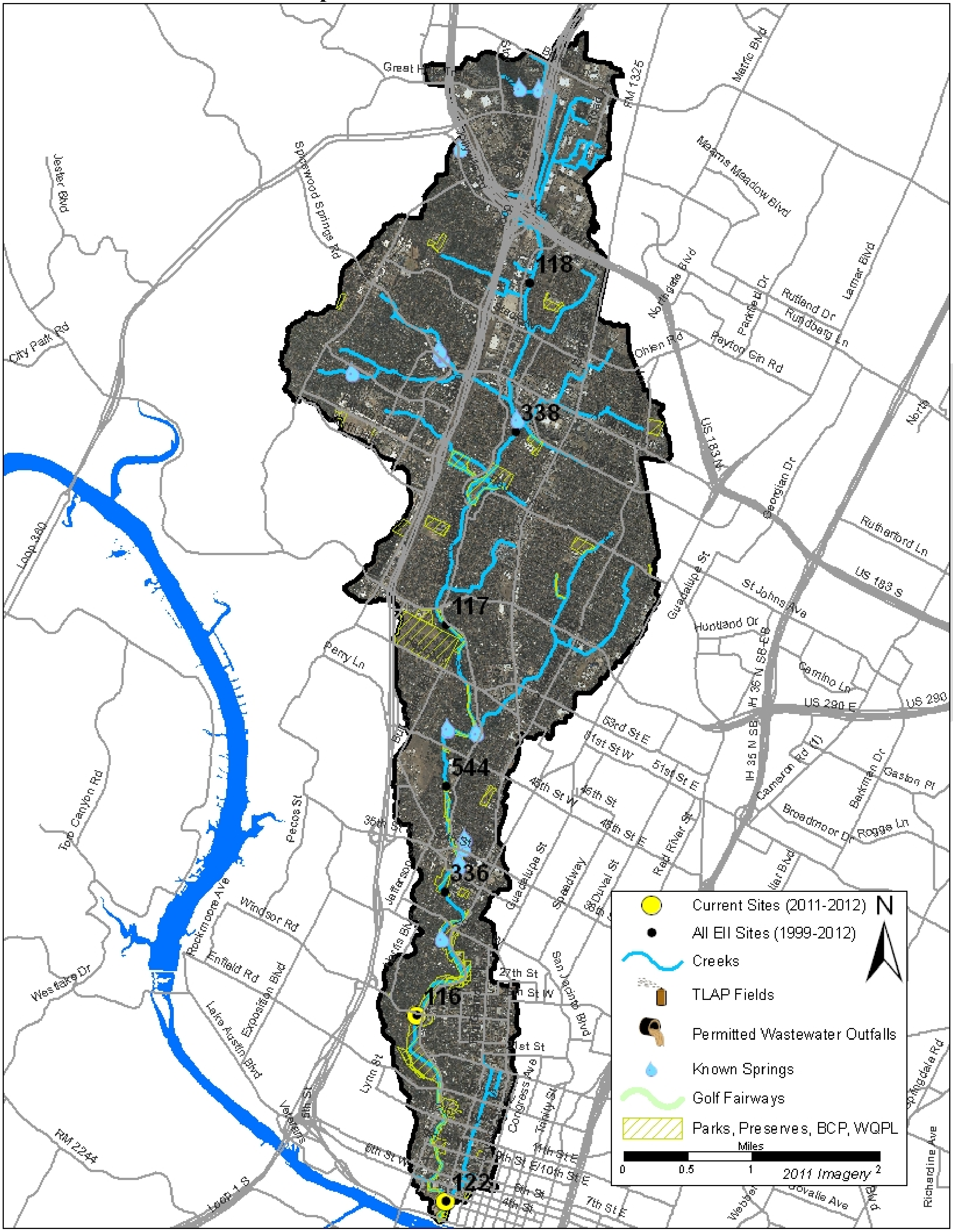
Shoal Creek Watershed

Land Use Map



Shoal Creek Watershed

Aerial Map



Shoal Creek Watershed

Water Quality Data – Temperature, Conductivity, pH, Dissolved Oxygen & *E. coli* for 2015 Sample Sites (Downstream to Upstream)

Qualifiers to the left of the value			Qualifiers to the right of the value		
	>	Greater than		(blank)	Useable
	<	Less than		S	Exceeds standard range
	<J	Less than detected limit		R	Rejected, failed QC
	J	Estimated			

Watershed	Site	EII Reach	Date	<>	Temp.	flag	<>	Cond.	flag	<>	pH	flag	<>	D.O.	flag	<>	E. Coli	flag
Shoal	122	SHL1	01/14/2015		9.9			687			7.93			10.6		>	2419.6	
Shoal	122	SHL1	04/15/2015		20.5			842			7.86			7.2		>	2419.6	
Shoal	122	SHL1	07/10/2015		25.9			839			7.84			5.6				
Shoal	122	SHL1	07/14/2015		26.9			873			7.98			6.7	R		1203.3	
Shoal	122	SHL1	09/09/2015		26.8			812			7.70			4.8			727.0	
		SHL1 Mean			22.0			810			7.86			7.0			1692.4	
Shoal	116	SHL2	01/14/2015		8.3			741			7.97			12.3			365.4	
Shoal	116	SHL2	04/15/2015		24.9			952			8.31			18.0			32.8	
Shoal	116	SHL2	07/10/2015		28.0			934			8.09			10.8				
Shoal	116	SHL2	07/14/2015		31.3			921			8.15			10.6	R		63.6	
Shoal	116	SHL2	09/09/2015		28.7			921			7.89			9.0			14.5	
		SHL2 Mean			24.2			894			8.08			12.1			119.1	
Shoal	117	SHL3	01/14/2015		6.6			387			7.88			10.4	R		86.7	
Shoal	117	SHL3	04/15/2015		17.9			759			7.62			5.8			153.9	
Shoal	117	SHL3	07/10/2015		28.1			593			8.09			10.4				
Shoal	117	SHL3	07/14/2015		26.0			666			7.86			6.9			648.8	
		SHL3 Mean			19.7			601			7.86			8.4			296.5	
Shoal	118	SHL4	01/14/2015		6.5			421			7.89			11.4	R		344.8	
Shoal	118	SHL4	04/15/2015		17.7			561			7.52			5.3			107.1	
Shoal	118	SHL4	07/10/2015		27.2			523			7.97			10.8				
Shoal	118	SHL4	07/14/2015		25.0			593			9.14			4.8			387.0	
		SHL4 Mean			19.1			524			8.13			8.1			279.6	
		Shoal Mean			21.5			724			7.98			9.0			641.0	

Gray highlighting indicates that the value exceeds one standard deviation from the mean of all E.I.I. sites combined.

Summary Statistics for all 2015-2016 E.I.I. Sites Combined

Parameter	2015-2016 Average	2015-2016 Minimum	2015-2016 Maximum	1 Standard Deviation Above	1 Standard Deviation Below
Temperature (C°)	20.7	5.8	34.2	27.5	
Conductivity (uS/cm)	722	160	3549	955	
pH (Standard units)	7.86	5.85	10.25	8.24	7.47
D.O. (mg/l)	7.9	0.1	18.7	10.4	5.5
E. Coli (col/100ml)	316.1	1.0	2420.0	883.7	

Shoal Creek Watershed

Water Quality Data – Ammonia, Nitrate / Nitrite, Ortho-Phosphorus, Total Suspended Solids & Turbidity for 2015 Sample Sites (Downstream to Upstream)

Qualifiers to the left of the value			Qualifiers to the right of the value		
	>	Greater than		(blank)	Useable
	<	Less than		S	Exceeds standard range
	<J	Less than detected limit		R	Rejected, failed QC
	J	Estimated			

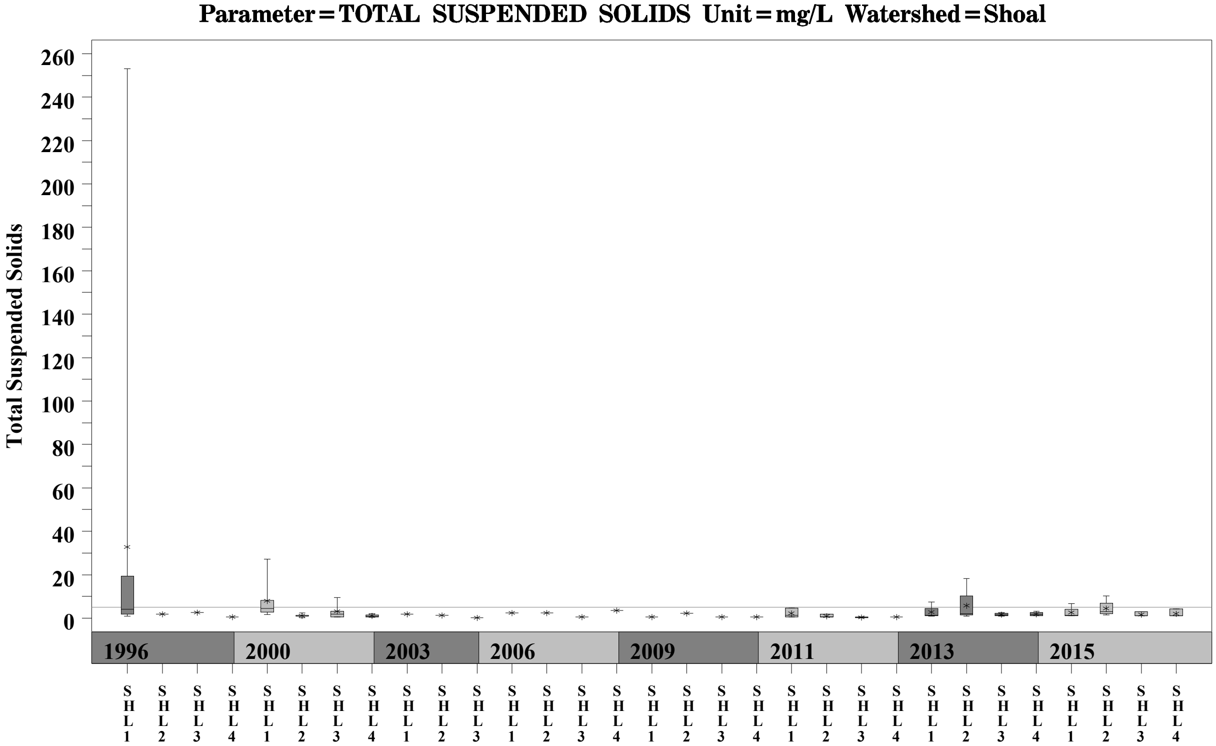
Watershed	Site	EII Reach	Date	NH3-N			NO3/NO2			Ortho-P			T.S.S			Turb.		
				<>		flag	<>		flag	<>		flag	<>		flag	<>		flag
Shoal	122	SHL1	01/14/2015	<J	0.008			1.40			0.023			1.3			4.2	R
Shoal	122	SHL1	04/15/2015		0.081			1.59			0.064			6.8			2.0	
Shoal	122	SHL1	07/10/2015															
Shoal	122	SHL1	07/14/2015		0.029			2.42			0.041			1.3			3.4	R
Shoal	122	SHL1	09/09/2015		0.039			2.50			0.130		<J	1.0			1.9	R
SHL1 Mean					0.039			1.98			0.064			2.6			2.8	
Shoal	116	SHL2	01/14/2015	<J	0.008			1.00		<J	0.004			3.5			12.1	R
Shoal	116	SHL2	04/15/2015	<J	0.008			0.11		<J	0.004			1.4			4.4	
Shoal	116	SHL2	07/10/2015															
Shoal	116	SHL2	07/14/2015		0.032			0.54		<J	0.004			10.2			2.2	R
Shoal	116	SHL2	09/09/2015	<J	0.008			0.04		<J	0.004			2.5			1.7	R
SHL2 Mean					0.014			0.42			0.004			4.4			5.1	
Shoal	117	SHL3	01/14/2015	<J	0.008			0.53		<J	0.004			3.0			5.3	R
Shoal	117	SHL3	04/15/2015	<J	0.008			0.29		<J	0.004		<J	1.1			1.6	
Shoal	117	SHL3	07/10/2015															
Shoal	117	SHL3	07/14/2015	<J	0.008			0.95		<J	0.004		<J	1.0			2.7	R
SHL3 Mean					0.008			0.59			0.004			1.7			3.2	
Shoal	118	SHL4	01/14/2015	<J	0.008			0.35		<J	0.004			4.2			2.7	R
Shoal	118	SHL4	04/15/2015	<J	0.008			0.09		<J	0.004		<J	1.1			0.9	
Shoal	118	SHL4	07/10/2015															
Shoal	118	SHL4	07/14/2015	<J	0.008			0.03		<J	0.004		<J	1.0			1.1	R
SHL4 Mean					0.008			0.16			0.004			2.1			1.6	
Shoal Mean					0.018			0.84			0.021			2.8			3.3	

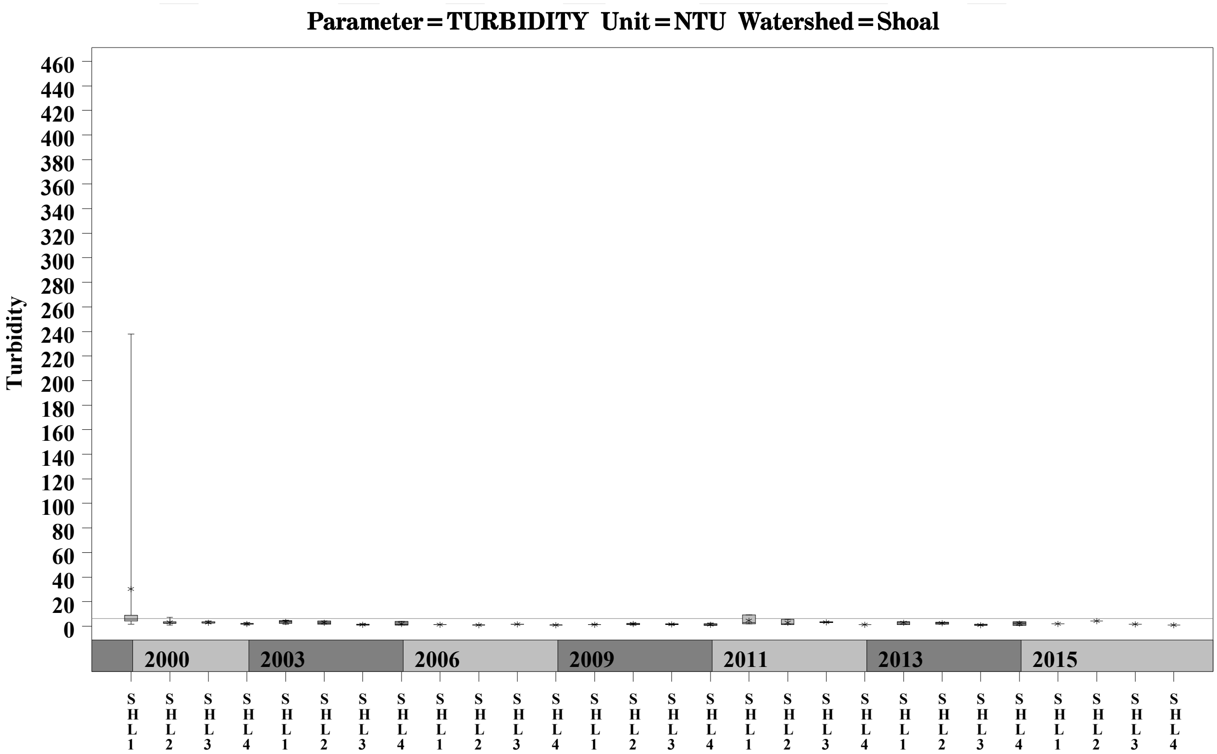
Gray highlighting indicates that the value exceeds one standard deviation from the mean of all E.I.I. sites combined.

Summary Statistics for all 2015-2016 E.I.I. Sites Combined				
Parameter	2015-2016 Average	2015-2016 Minimum	2015-2016 Maximum	1 Standard Deviation Above
NH3-N (mg/l)	0.018	0.008	0.881	0.085
NO3-N (mg/l)	1.14	0.01	12.0	3.16
Ortho-P (mg/l)	0.016	0.004	0.661	0.08
T.S.S. (mg/l)	3.7	1.0	58.2	9.7
Turbidity (NTU)	4.4	0.2	98.6	11.7

Shoal Creek Watershed

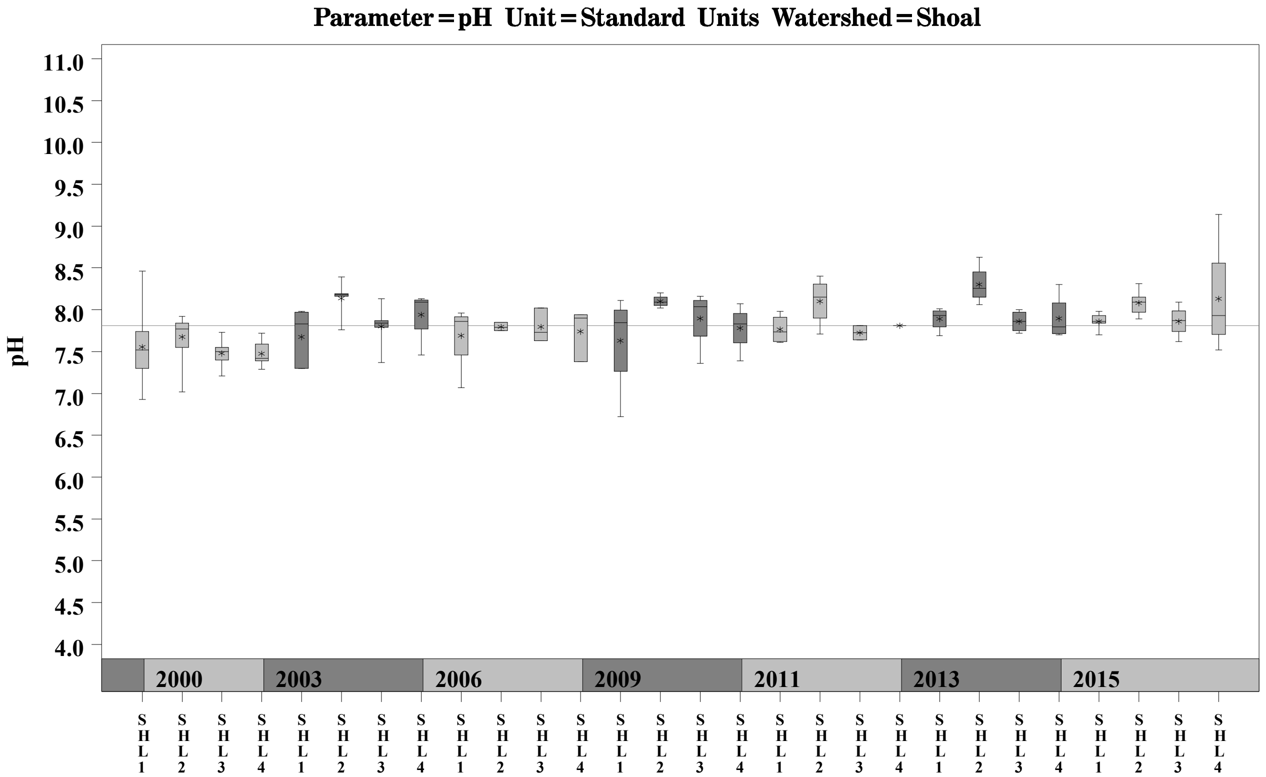
Data Summary Graphs – Total Suspended Solids and Turbidity (Downstream to Upstream by Year)

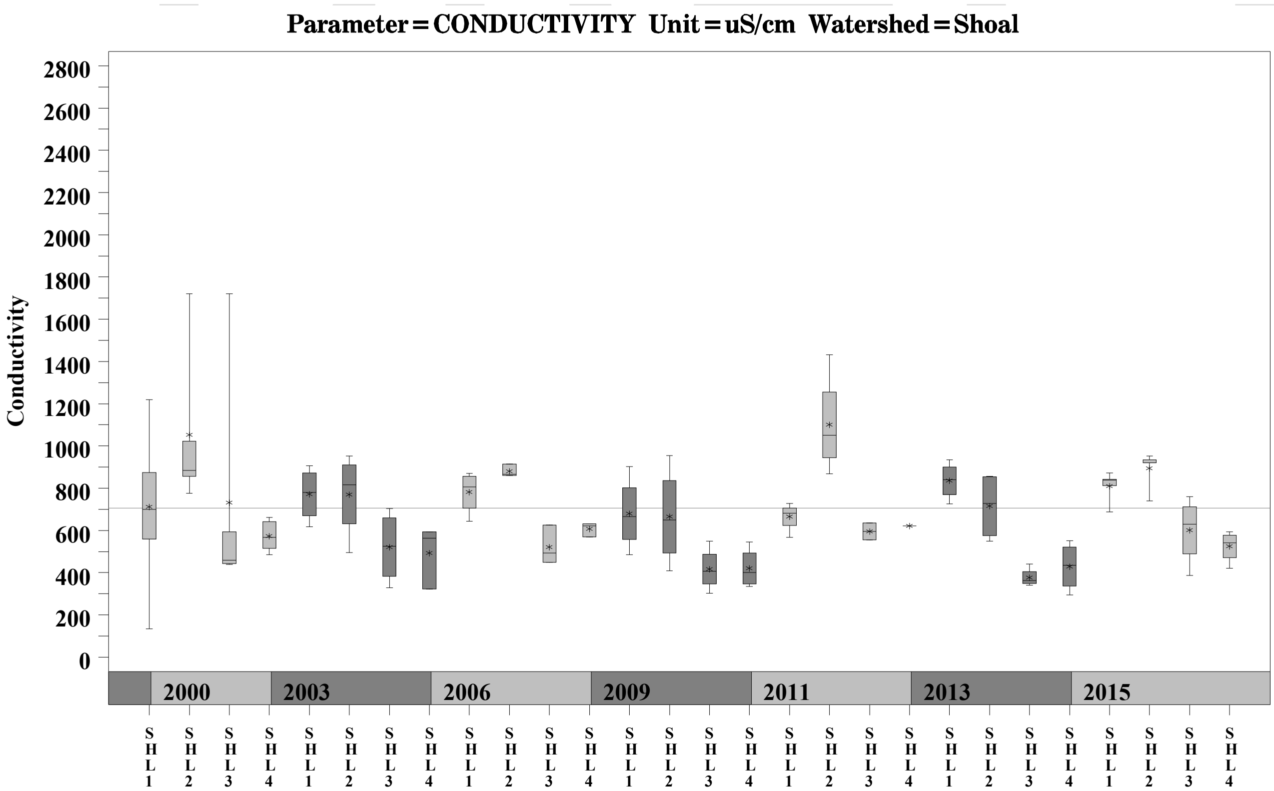




Shoal Creek Watershed

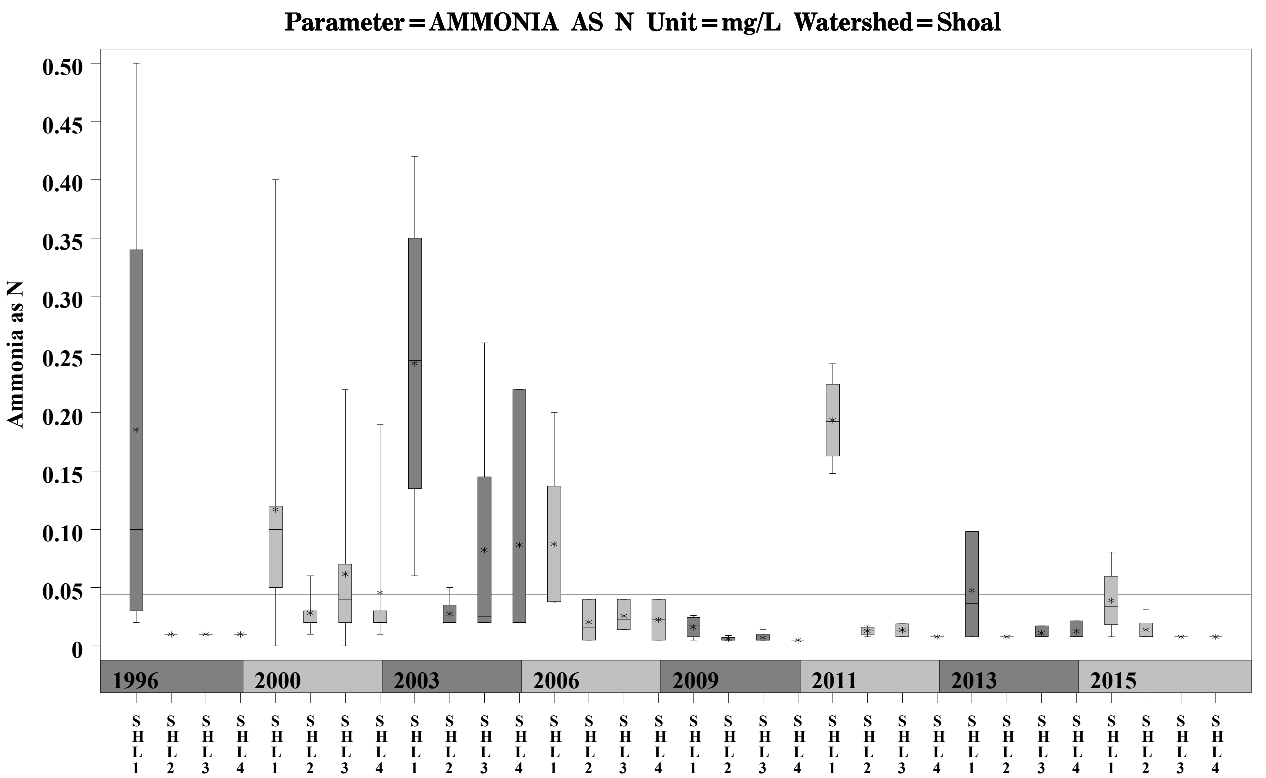
Data Summary Graphs – <u>pH</u> and <u>Conductivity</u> (Downstream to Upstream by Year)

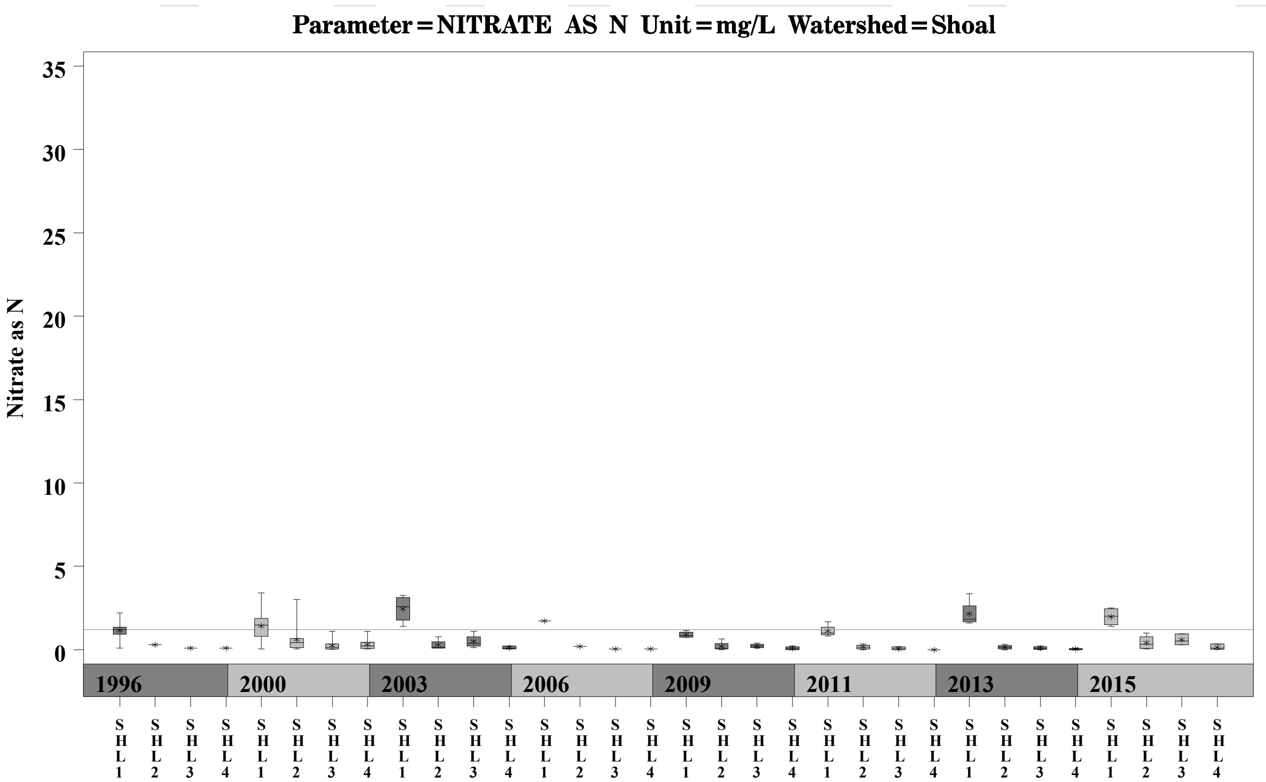




Shoal Creek Watershed

Data Summary Graphs – Ammonia and Nitrate/Nitrite (Downstream to Upstream by Year)





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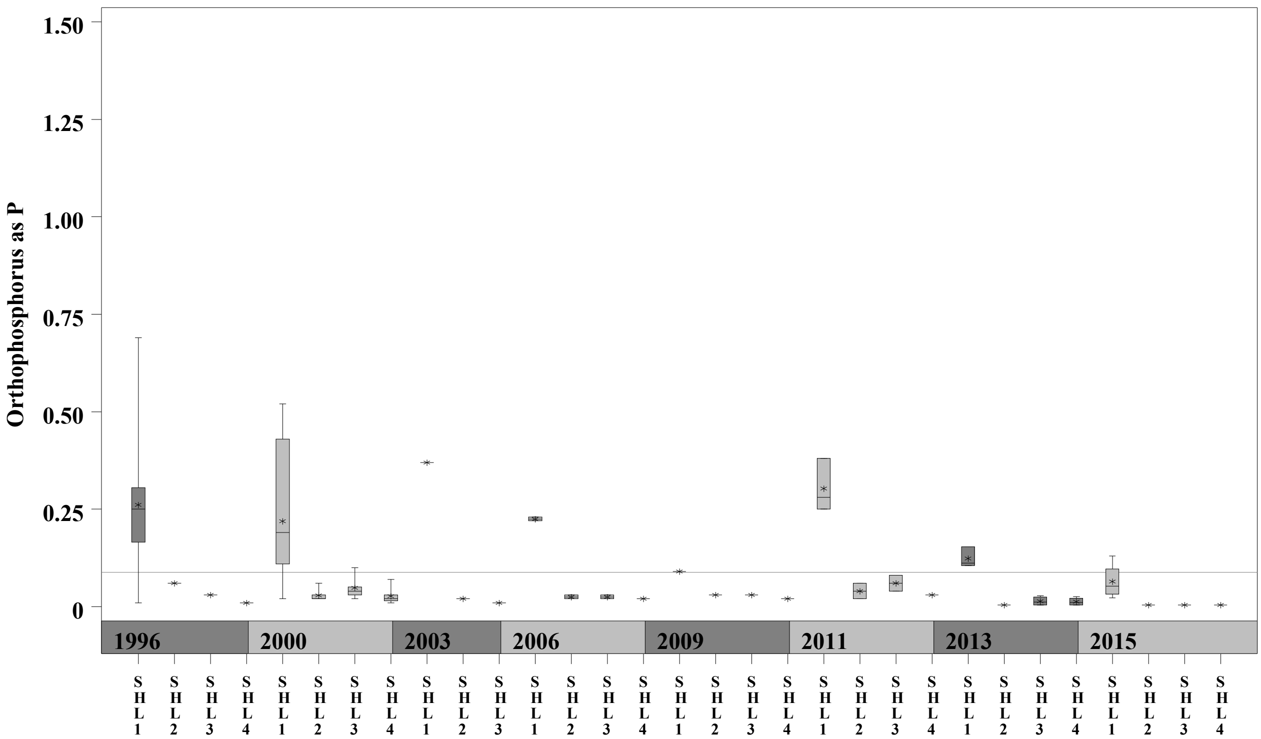
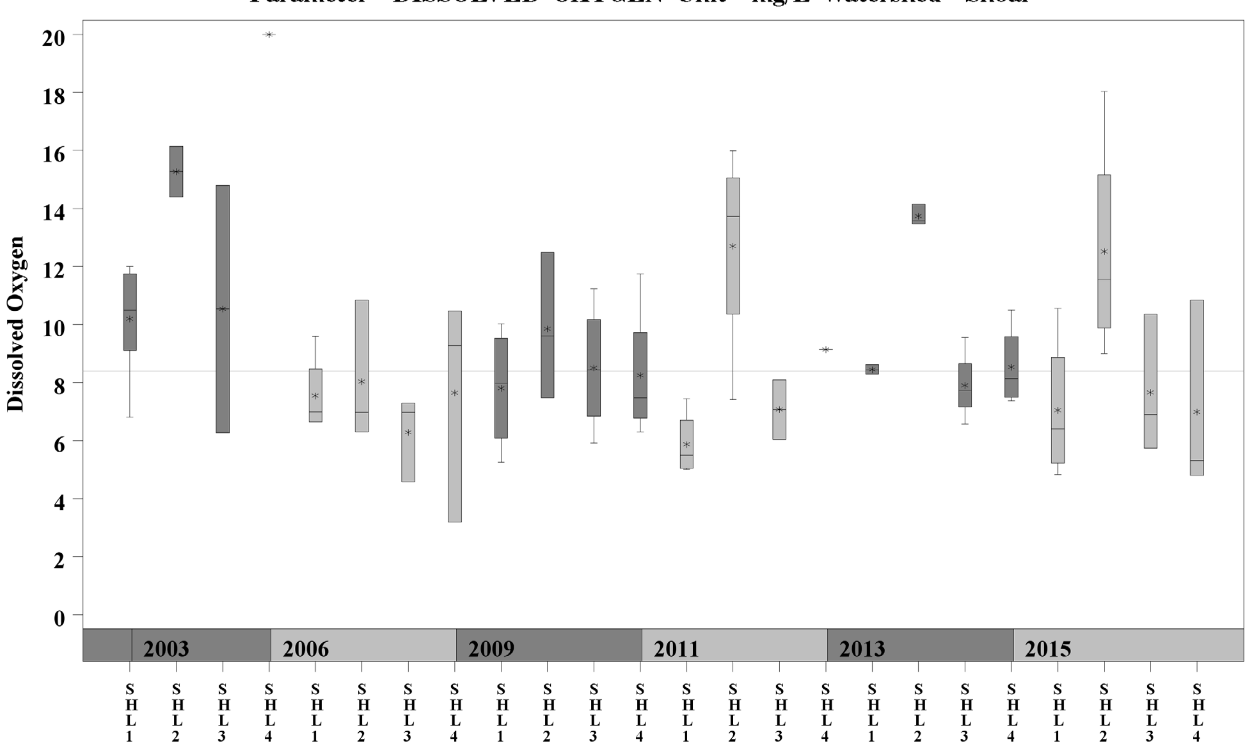
Shoal Creek Watershed

Data Summary Graphs – <u>Orthophosphate</u> and <u>Dissolved Oxygen</u> (Downstream to Upstream by Year)

Parameter=ORTHOPHOSPHORUS AS P Unit=mg/L Watershed=Shoal

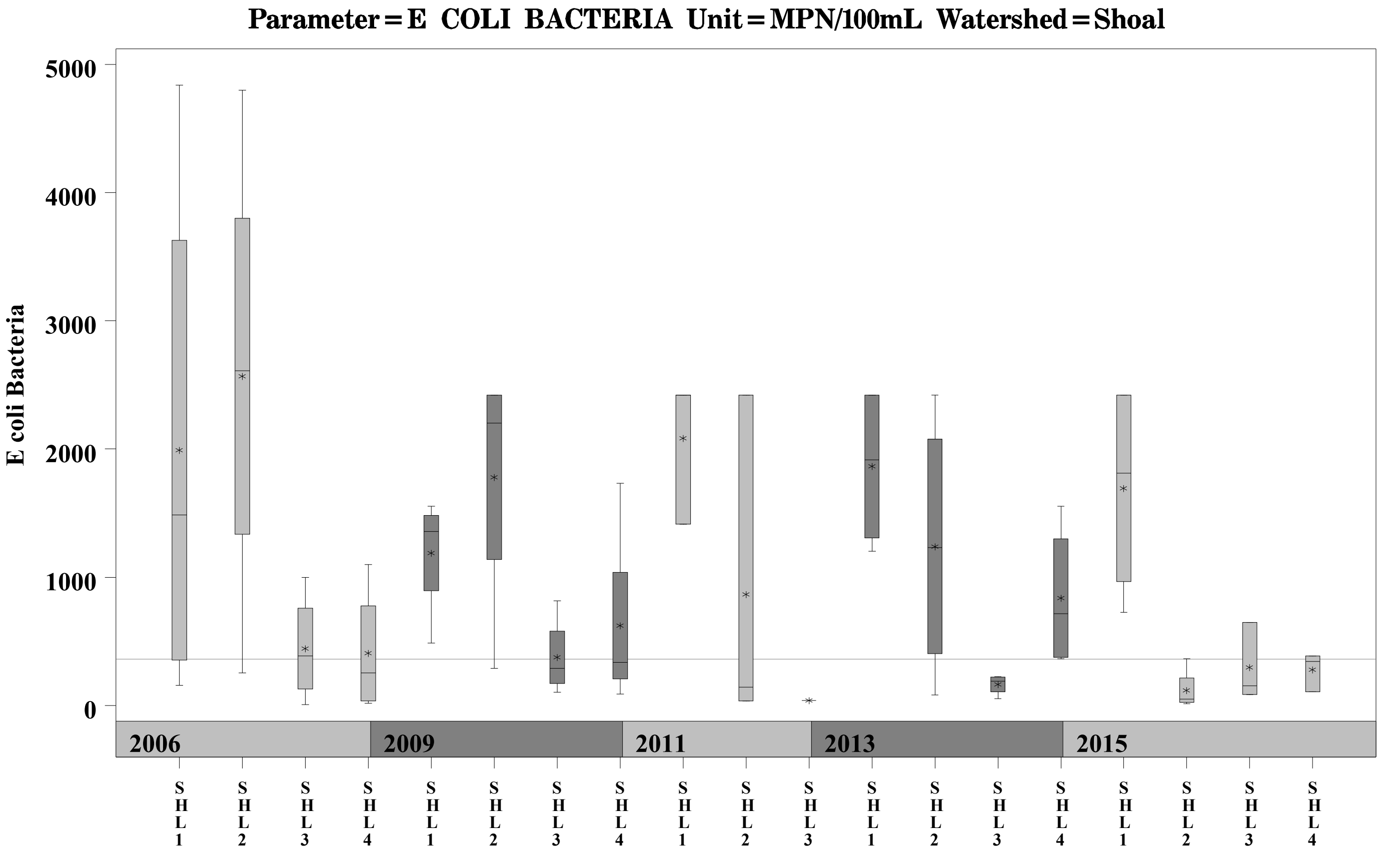


Parameter= DISSOLVED OXYGEN Unit= mg/L Watershed= Shoal



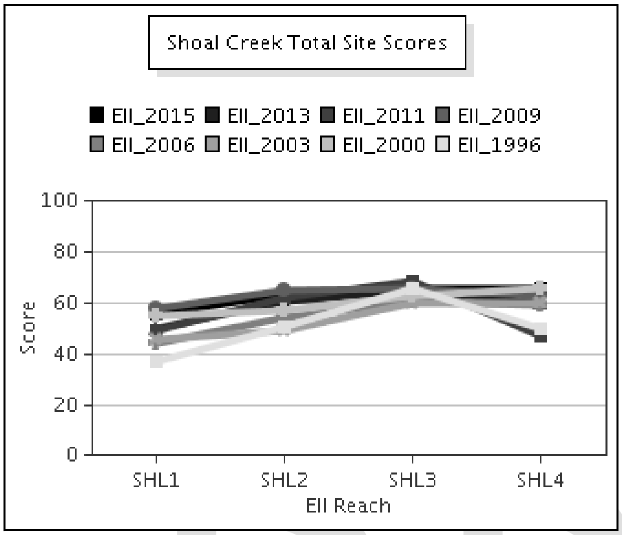
Shoal Creek Watershed

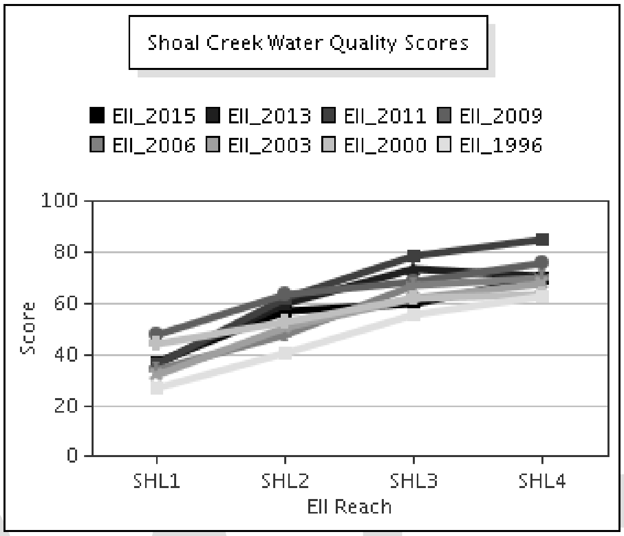
Data Summary Graphs – *E.coli* (Downstream to Upstream by Year)

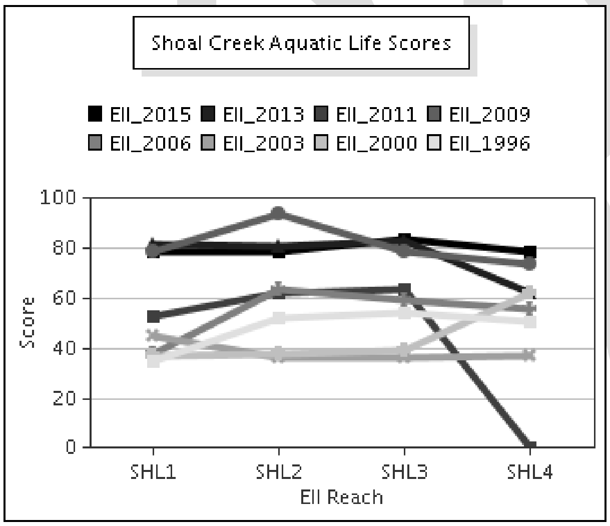


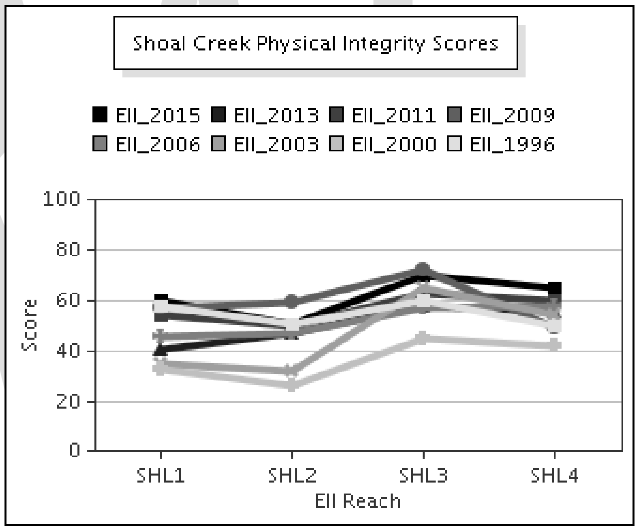
Shoal Creek Watershed

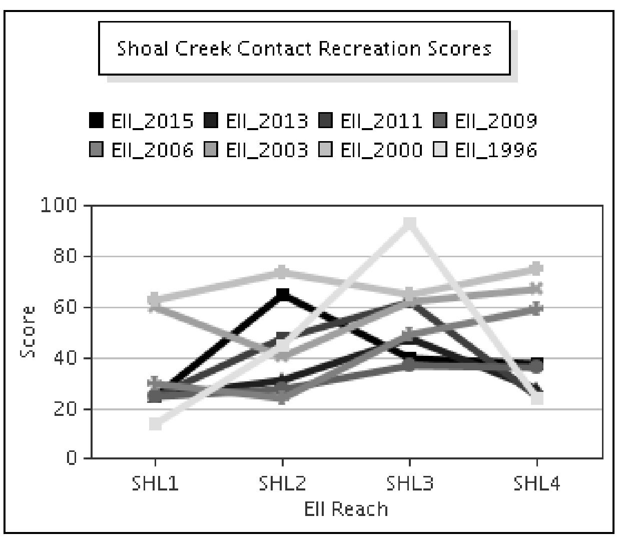
Score Summary – Reach scores for each sample year

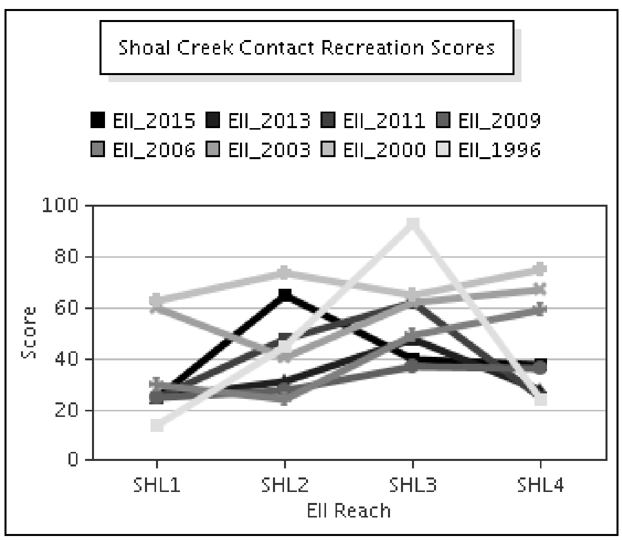










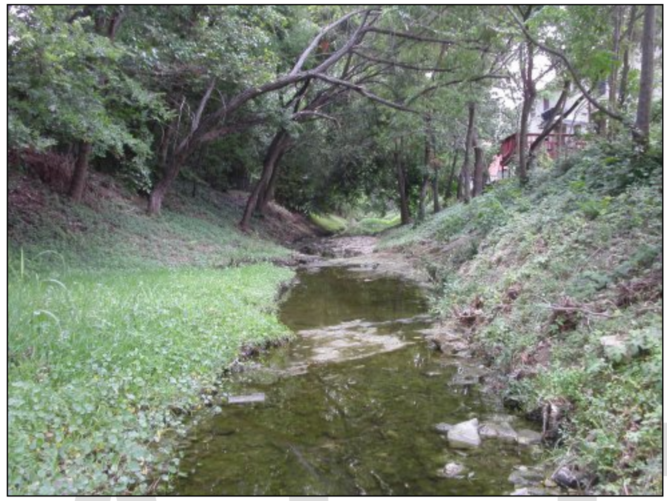


Shoal Creek Watershed

Benthic Macroinvertebrates – Taxa List, Pollution Tolerance Index & Functional Feeding Group for 2015 Sample Sites (Downstream to Upstream)

Benthic Macroinvertebrates - Shoal Creek			SHL @ Crosscreek (118) 07/08/2015 (WRE)	SHL @ Shl Edge Ct (117) 07/08/2015 (WRE)	SHL @ 24th (116) 07/10/2015 (WRE)	SHL us 1st (122) 07/10/2015 (WRE)
Benthic Macroinvertebrate ID	PTI	FFG				
Chimarra	2	FC	7	76	23	2
Hydroptila	2	PI,SC				1
Camelobaetidius	4	CG	3	30	18	3
Fallceon	4	CG,SC	44	83	158	119
Neochoroterpes	4	CG	7		2	
Ostracoda	4	CG,FC				1
Simulium	4	FC	1	11		3
Petrophila (Moth)	5	SC	1	2		
Argia	6	P	26	38		7
Brechmorhoga Mendax	6	P	7		1	
Cheumatopsyche	6	FC	4	71	26	2
Chironomidae	6	FC,P	17	32	10	3
Hetaerina	6	P		2		
Rhagovelia	6	P	3			
Tanypodinae	6	P	9		9	1
Caenis	7	CG,SC		1	12	
Stenelmis	7	CG,SC	2	1		
Hirudinea	8	P		2		
Hyalella	8	CG,SH	2	10	1	2
Oligochaeta	8	CG		1		1
Physella	9	SC			2	
Belostoma	10	P	1			
Dugesia		CG,P	64	1	5	

118_t00-us-07_07_2006



118_t00-ds-07_07_2006

117_t00-ds-02_12_2001

117_t00-us-07_07_2006

117-t00-us-05-28-2009

117-t00-ds-05-28-2009

Shoal Creek Watershed

Site Photographs

116_t00-ds-02_12_2001

116_t00-ds-03_11_2003

116_t00-us1-07_07_2006

116-t00-us-05-28-2009

122_t00-us-07_05_2006

122_t00-ds-07_05_2006