Shoal Creek Characterization Report

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Placeholder for Executive Summary (2 pages)

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.

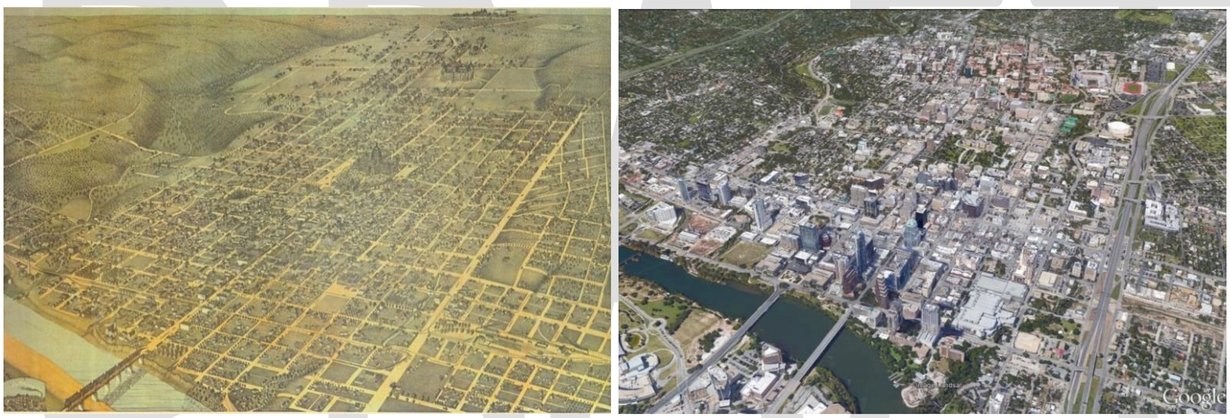


Figure 1 Austin circa 1887 (Source: Amon Carter Museum) and Austin 2016 (Source: Google Earth, Landsat)

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). These reaches 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 over time, 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).

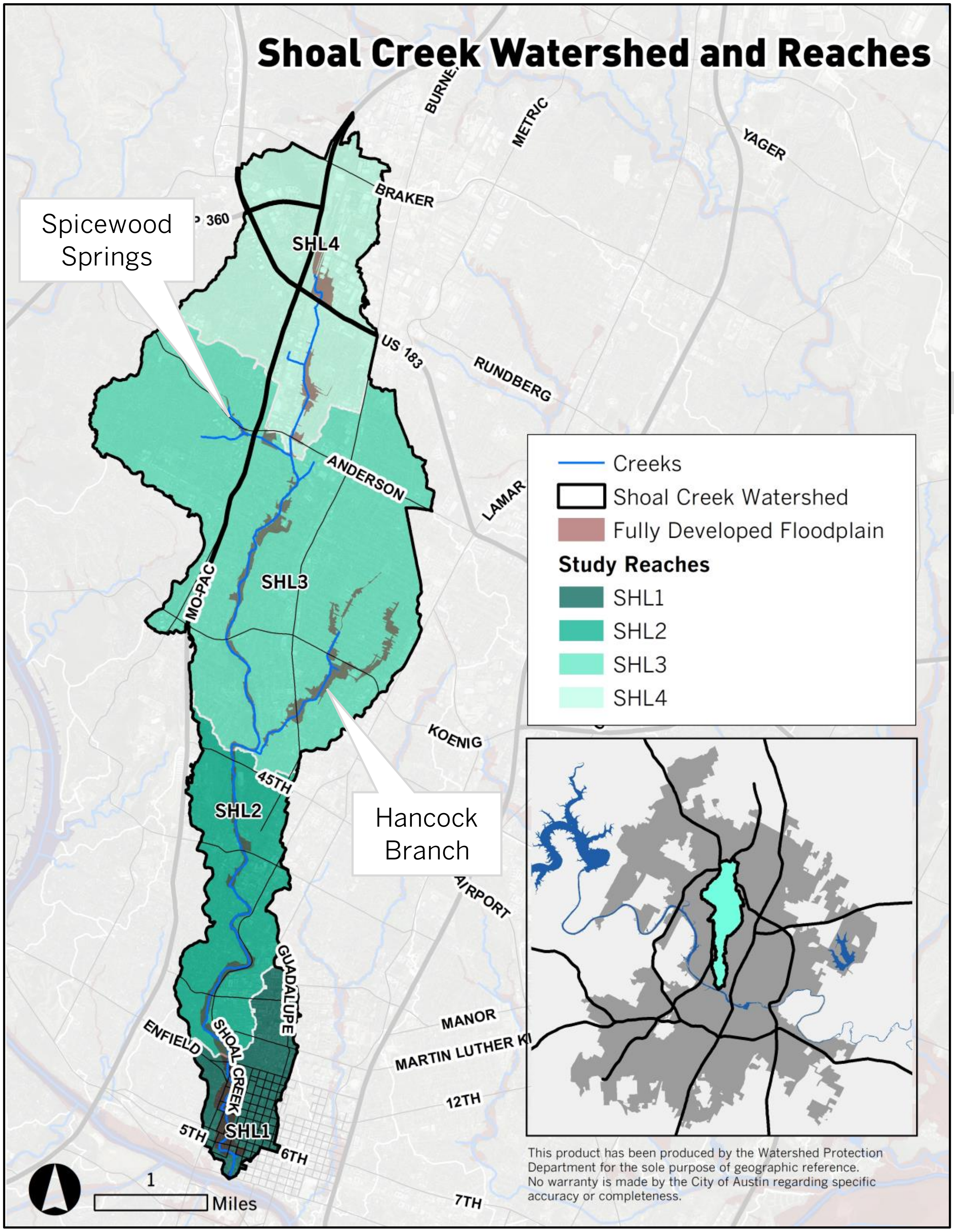


Figure 2 Shoal Creek Watershed and Reaches

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.

Austin's climate is characterized by long, hot summers and short, mild winters, with warm spring and fall transitional periods. 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 (Hayhoe, 2014). 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.

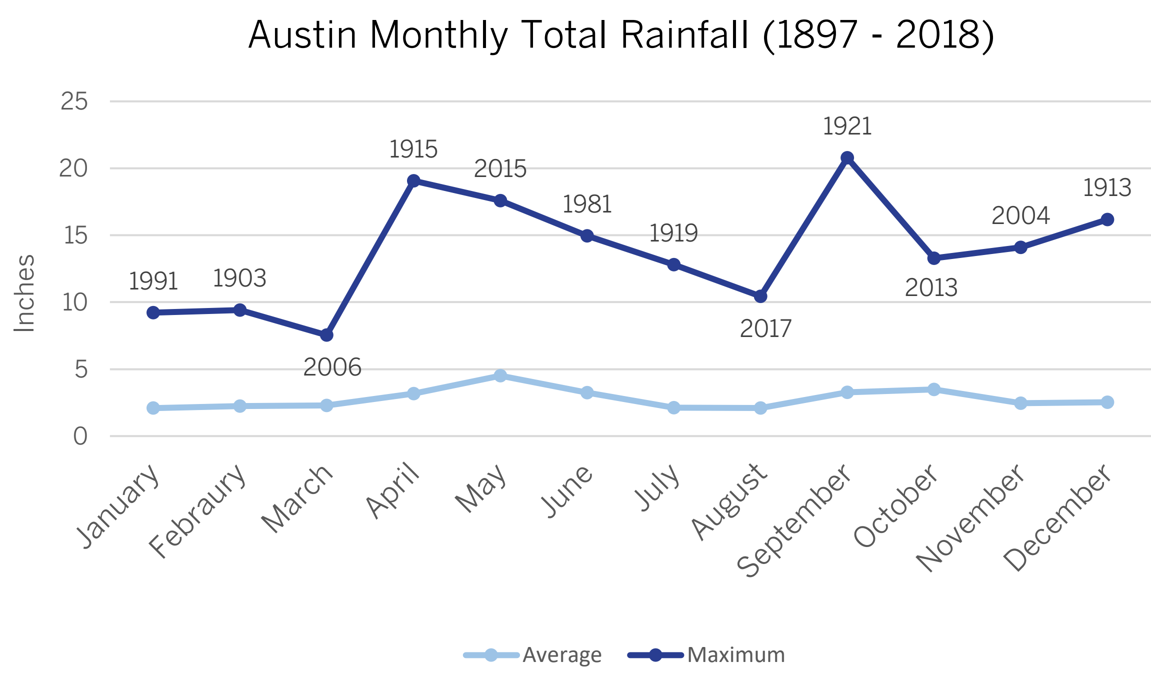


Figure 3 Austin Monthly Total Rainfall (1897 - 2018)

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. 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.

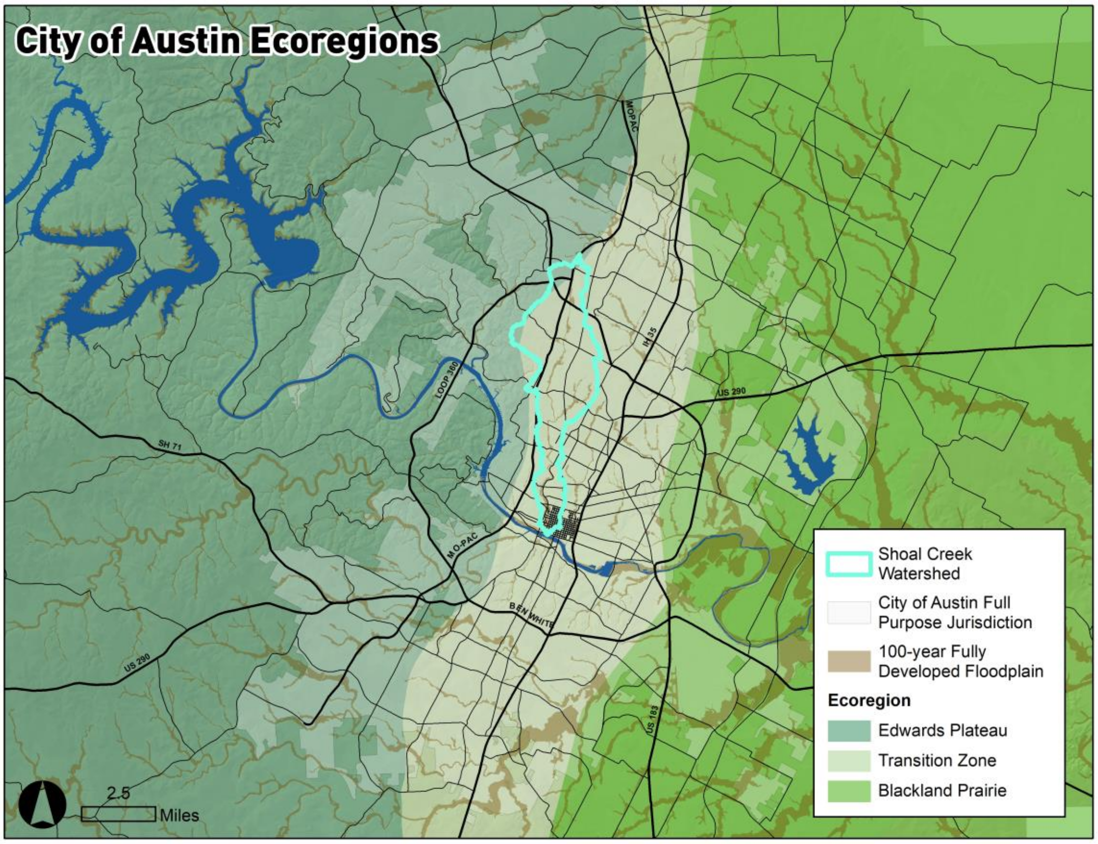


Figure 4 City of Austin Ecoregions

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.

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. A notable spring within the Shoal Creek watershed is Spicewood Springs. This 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 runs, 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).

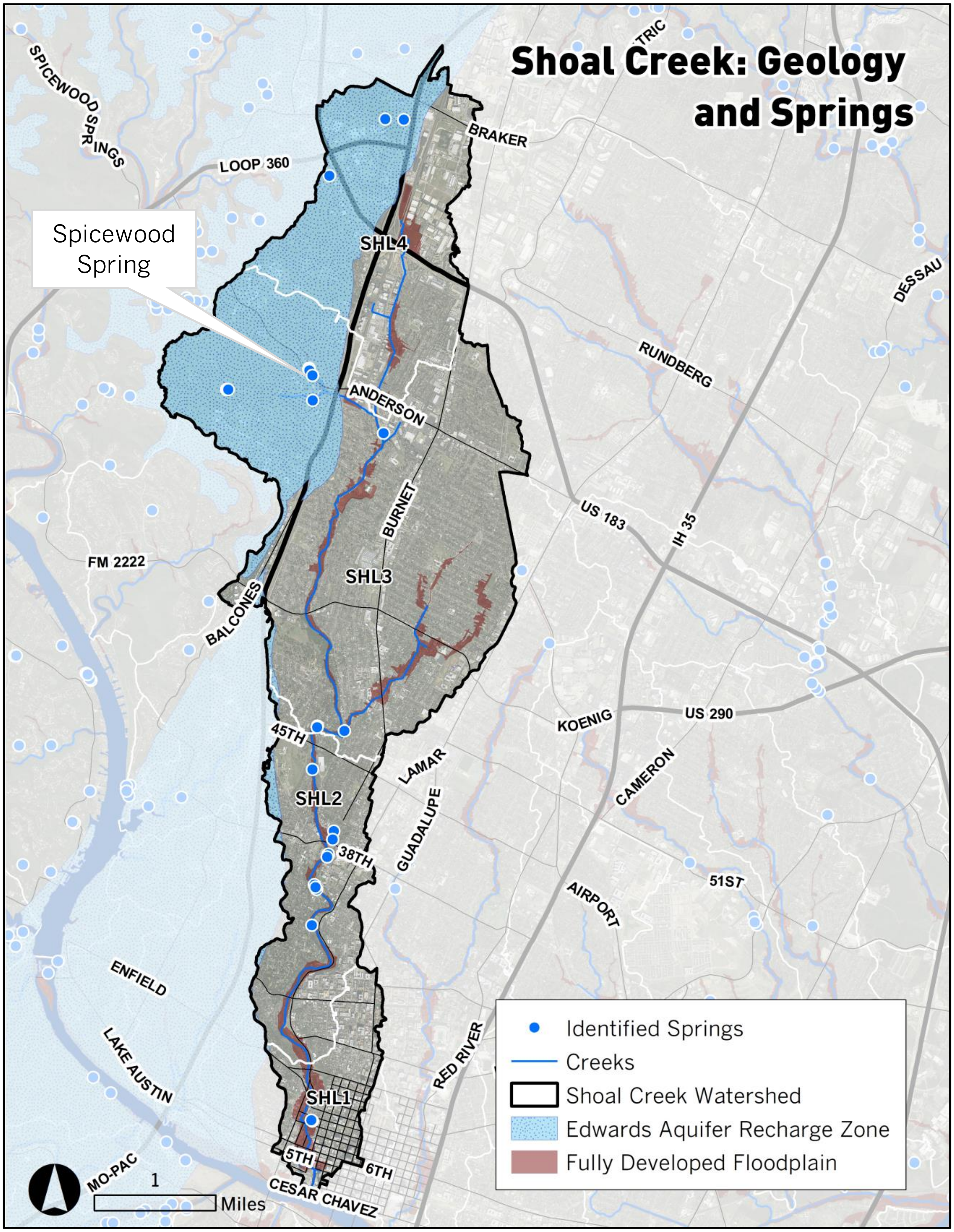


Figure 5 Shoal Creek Geology and Springs

C. Development Patterns

Population

Shoal Creek watershed currently has a population of approximately 72,000 people, and 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 and is expected to reach approximately 12.5 persons per acre by 2040 (City of Austin Demographer).

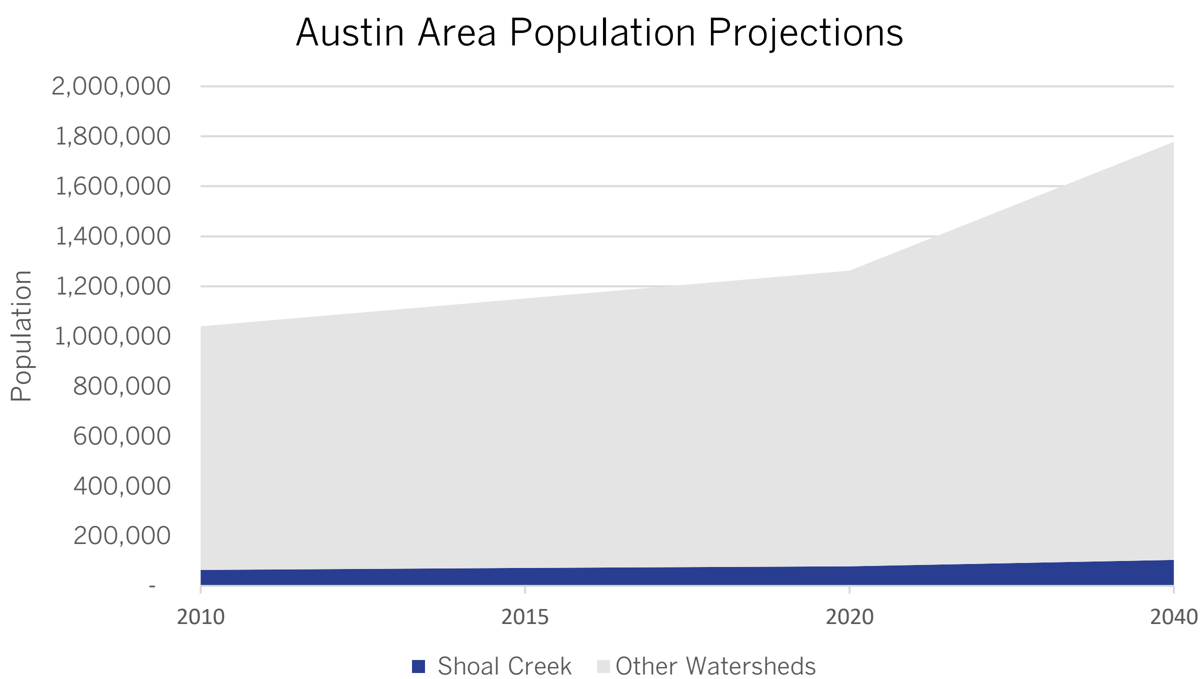


Figure 6 Austin and Shoal Creek Population Projections

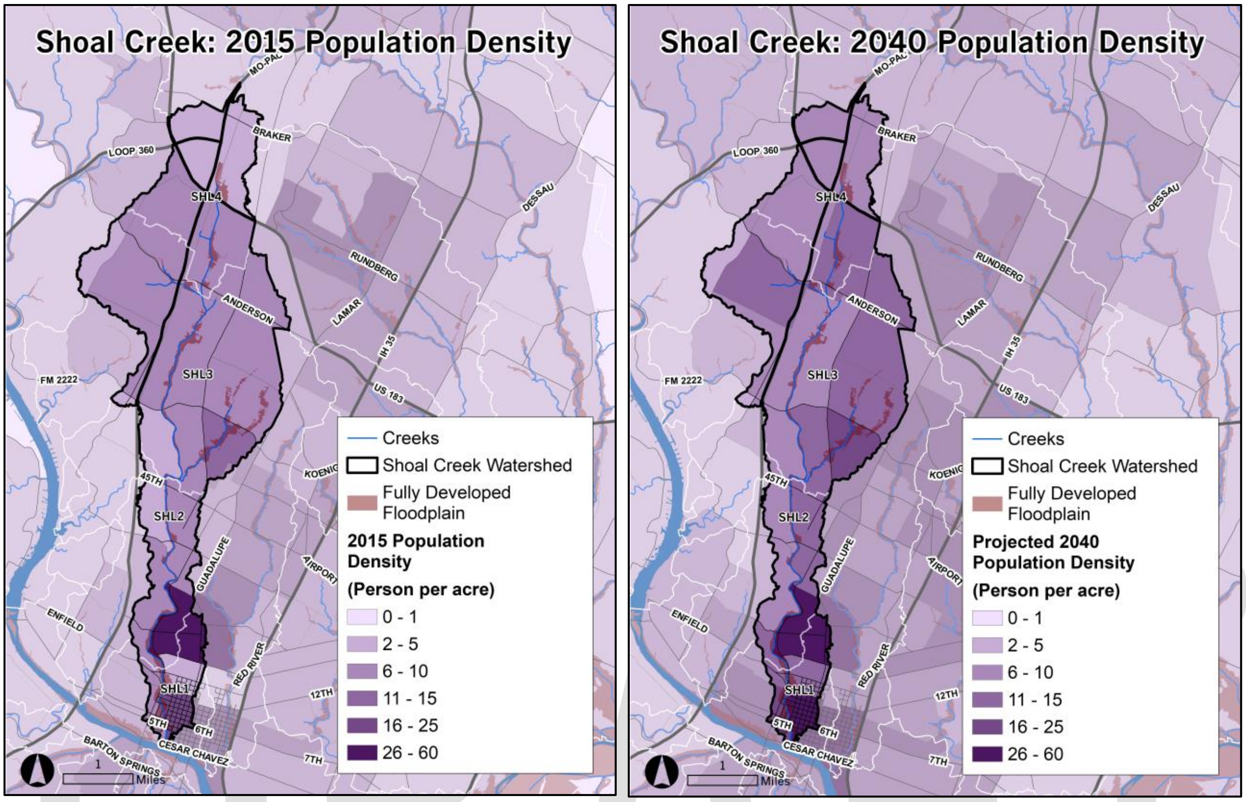


Figure 7 2015 and Projected 2040 Population Density

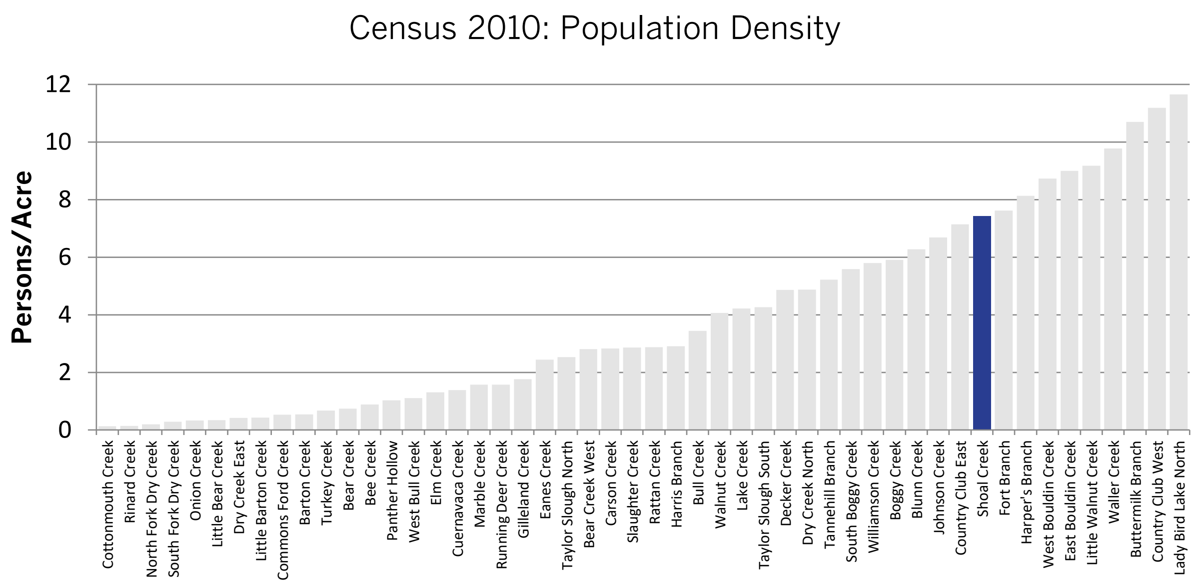


Figure 8 2010 Population Density of Austin Watersheds

Social 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 predominated 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.

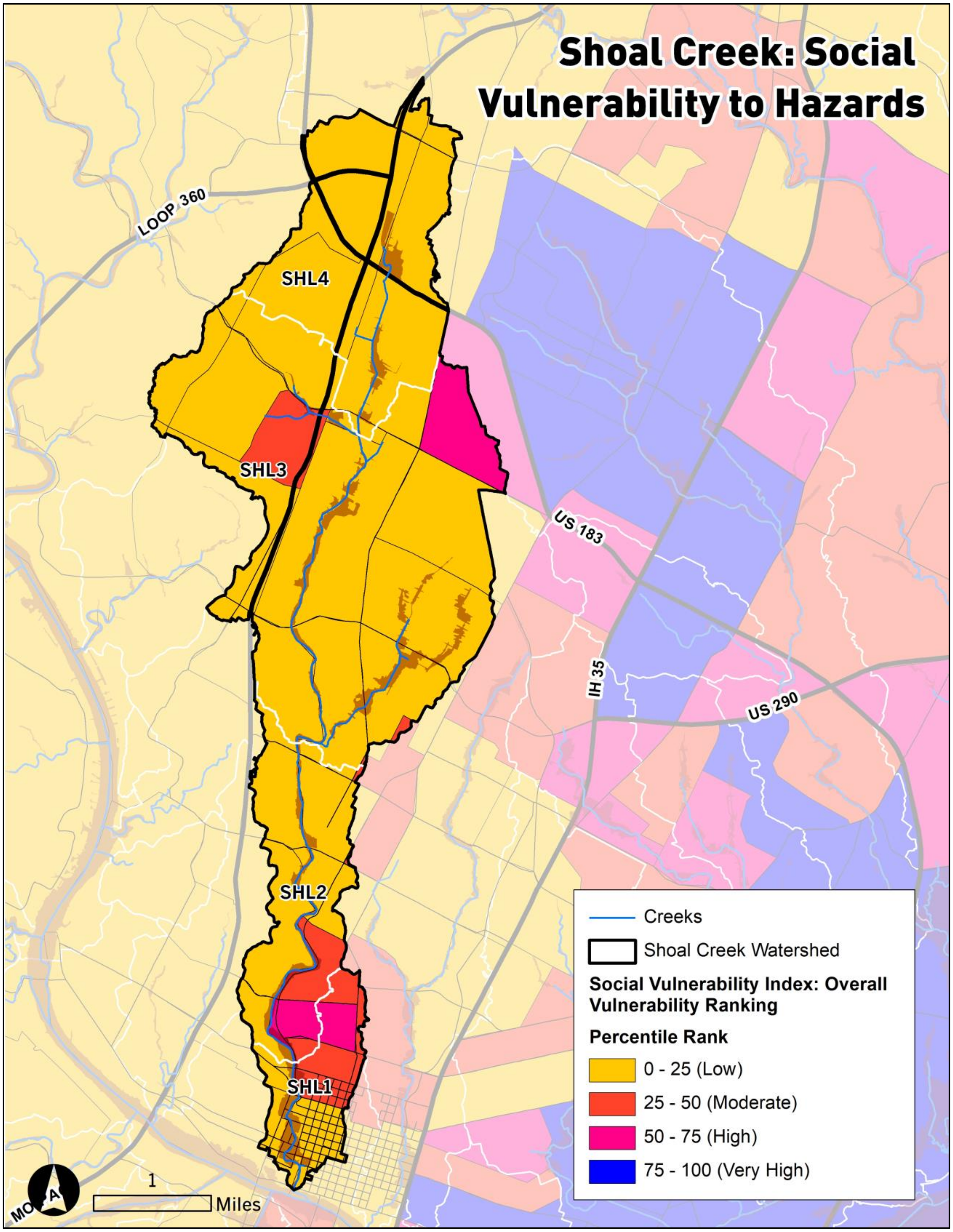


Figure 9 Social Vulnerability Index

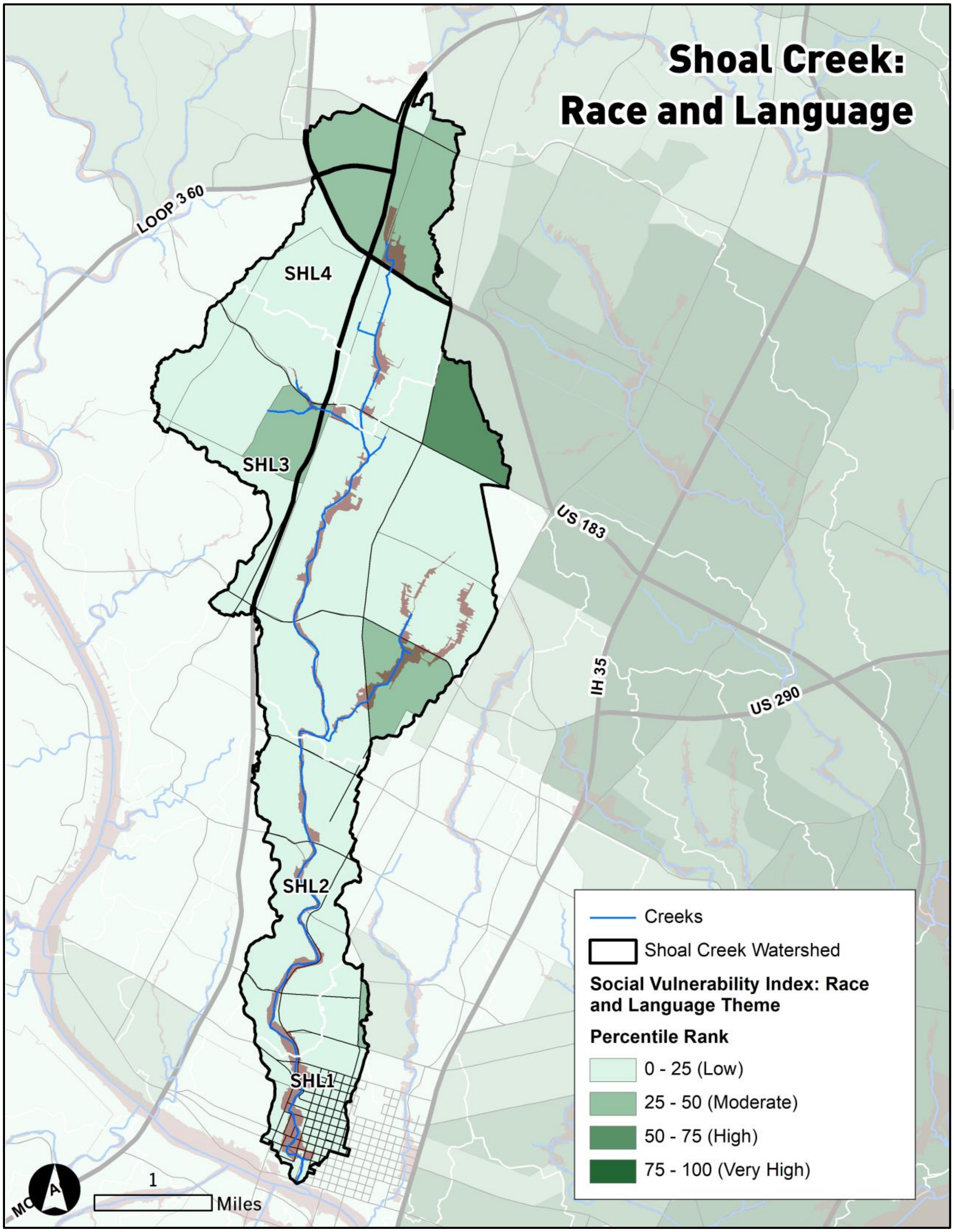


Figure 10 Social Vulnerability Index: Race and Language Theme

Land Use

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. Almost a quarter of the watershed is dedicated to roads and other transportation infrastructure. SHL1 and SHL4 are predominated by transportation and commercial development, while SHL2 and SHL3 are largely predominated by single-family land uses.

Table 1 Land Use by Reach (Percent of Reach Area)

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%

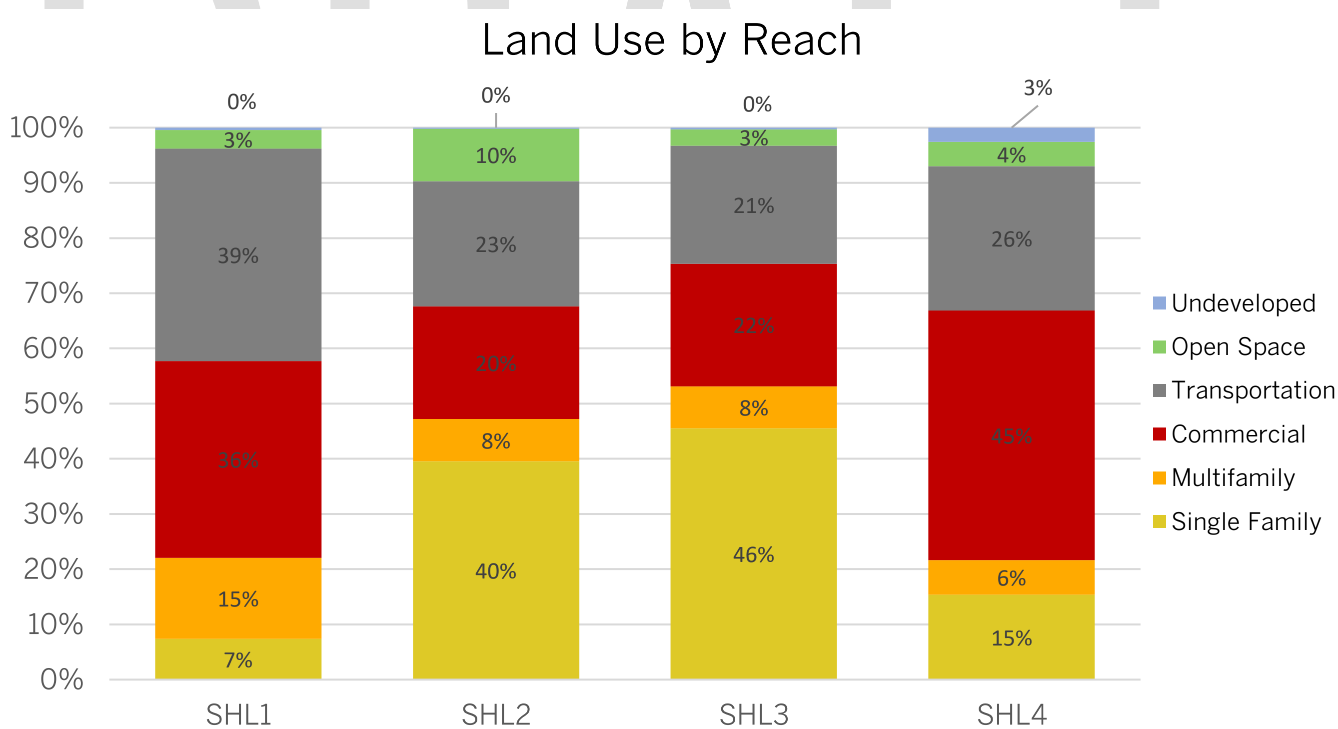


Figure 11 Land Use by Reach (Percent of Reach Area)

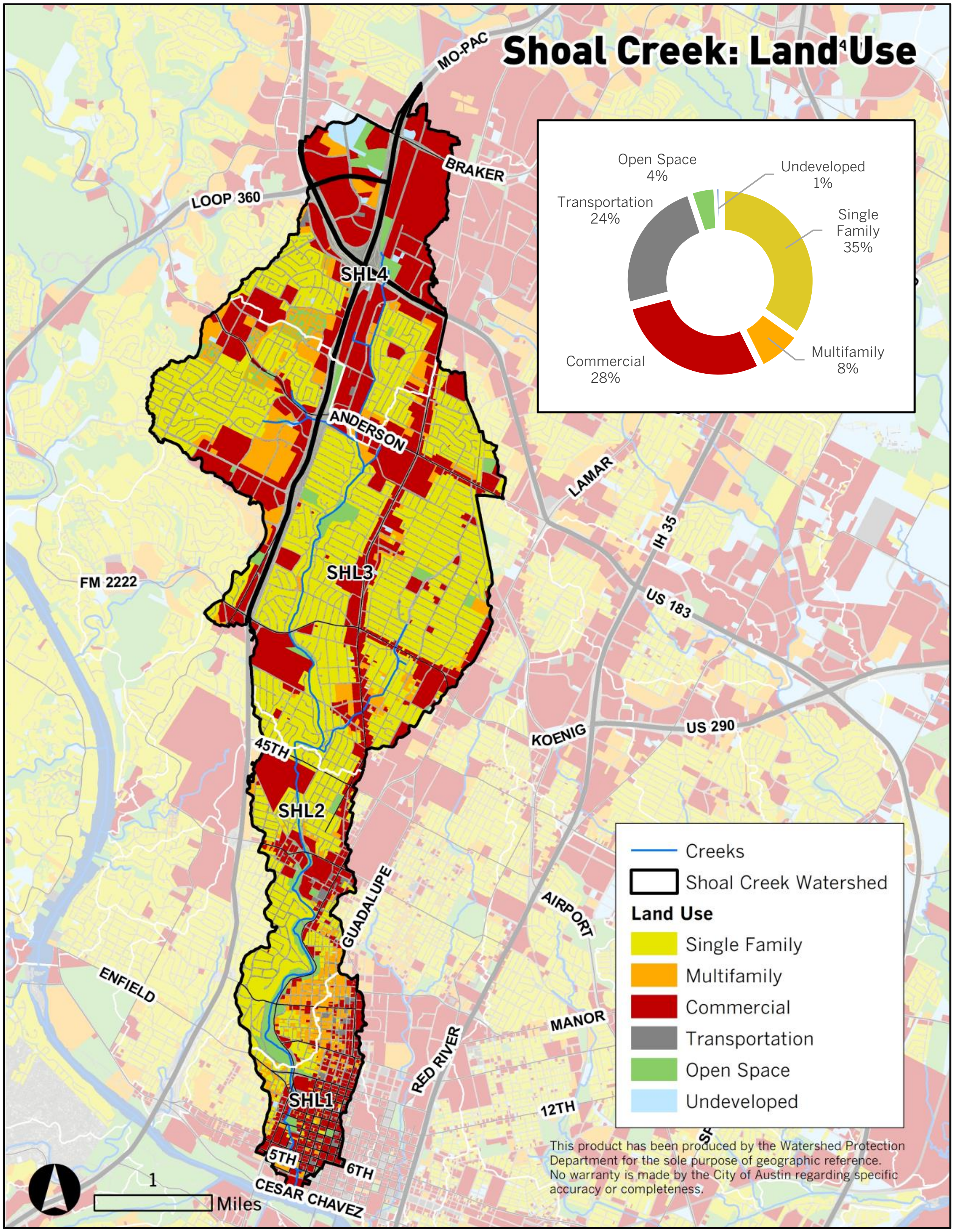


Figure 12 Land Use

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. 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 developed to its impervious cover maximum. 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.

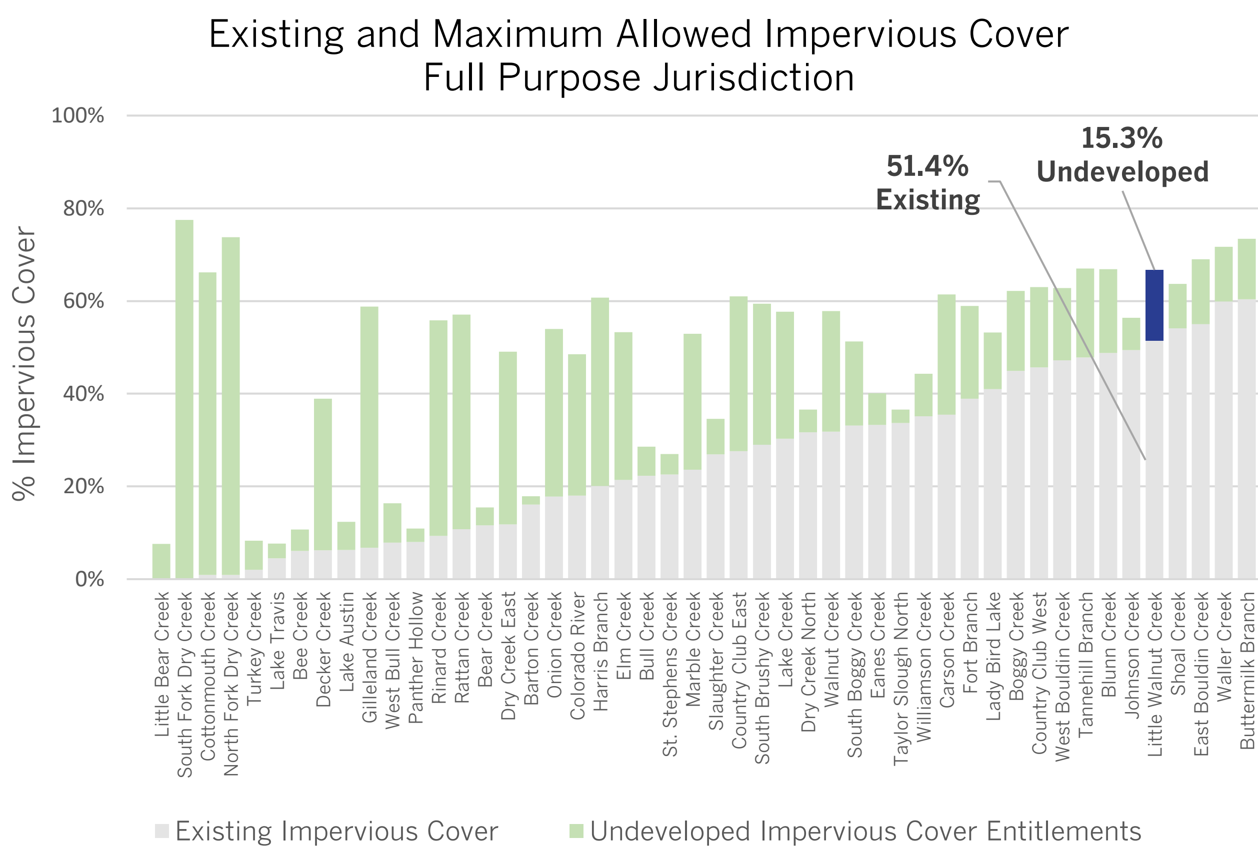


Figure 13 Existing and Maximum Allowed Impervious Cover

IV. Watershed Health

A. Overview of Watershed Concerns

Environmental Integrity Index

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.

Table 2 COA-WPD Environmental Integrity Index Scores (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 Excellent	87.5 - 75 Very Good	75 - 62.5 Good	62.5 - 50 Fair	50 - 37.5 Marginal	37.5 - 25 Poor	25 - 12.5 Bad	12.5 - 0 Very Bad

The overall EII score is calculated as the average of the subindices, which equally weights 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. Unfortunately, the 2017 EII indicates that Shoal Creek is not within this range with a score of 57.5 ("Fair") (See Figure 14). The full EII summary for Shoal Creek can be found in Appendix #.

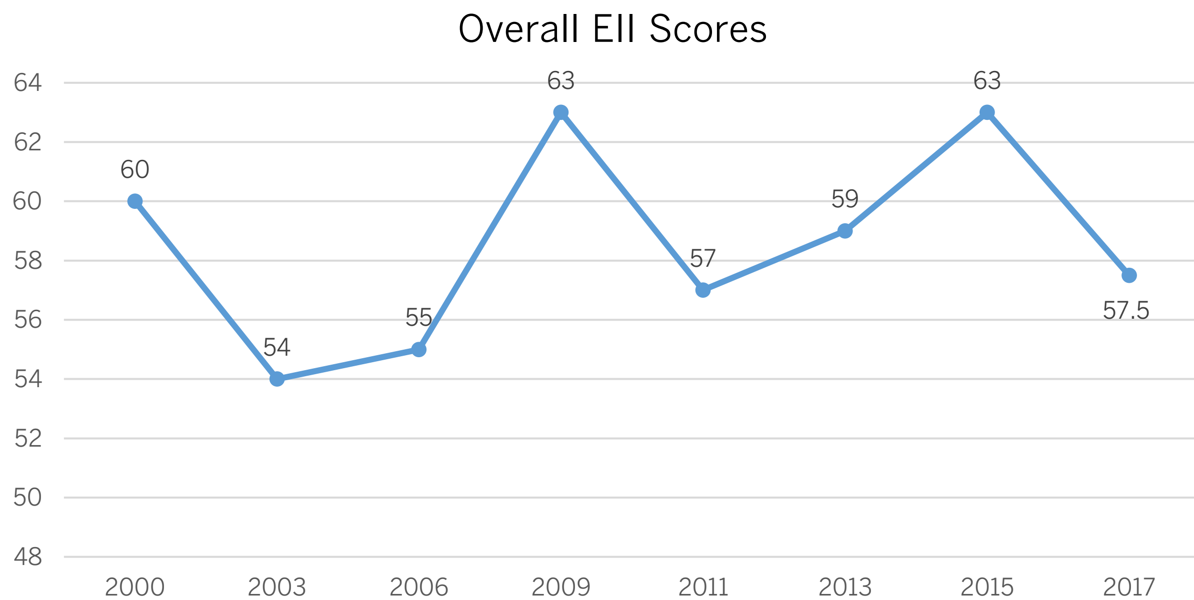


Figure 14 Overall Environmental Integrity Index Score (2003 - 2017)

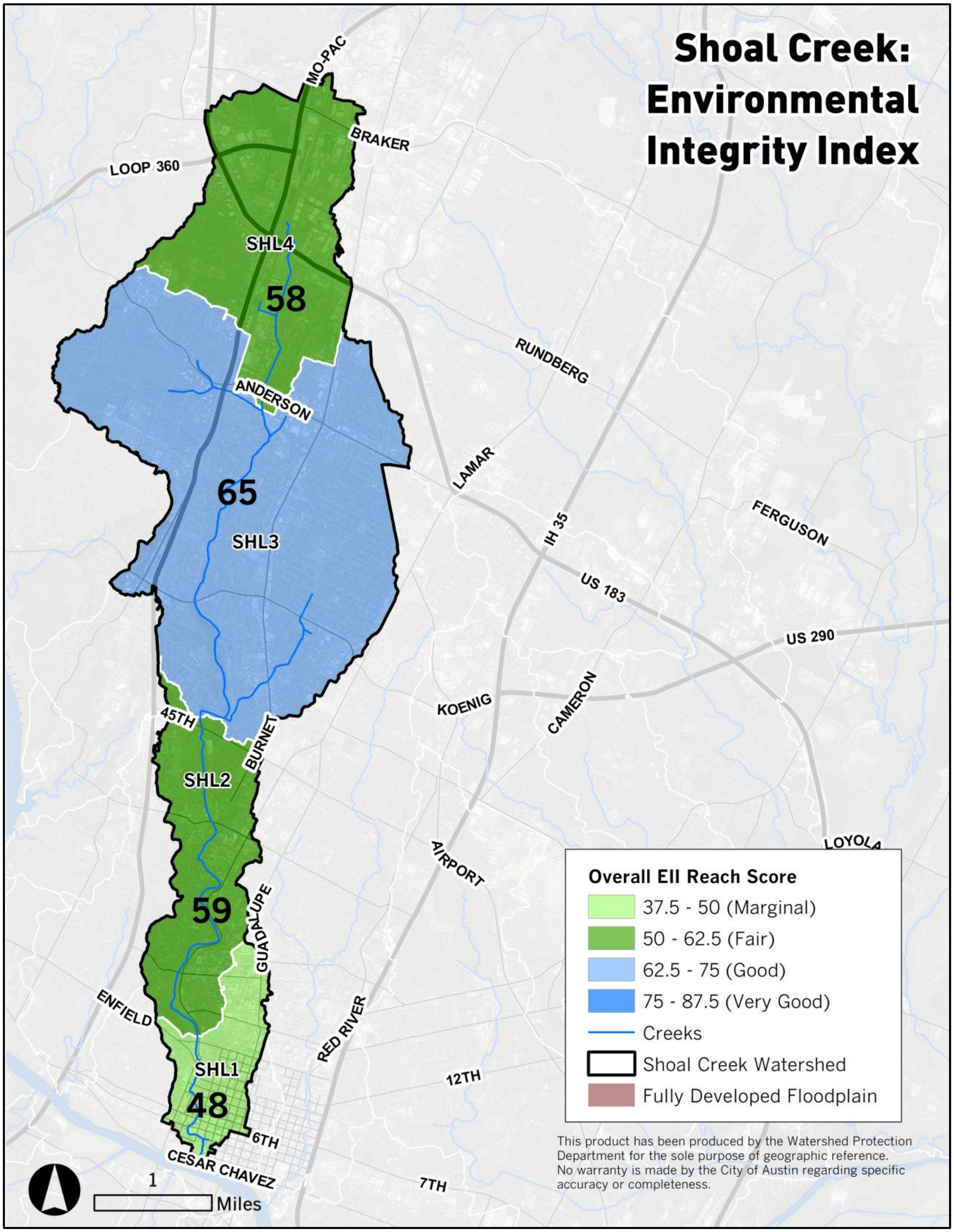


Figure 15 Environmental Integrity Index (2015)

Creek Flooding

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. The table below summarizes the areas and low-water crossings within the Shoal Creek watershed that are among the fiscal year 2019 Top 20 most severe creek flood risk areas in the city.

Table 3 FY 2019 Top 20 Ranked Creek Flood Building Clusters

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

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

"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 and/or experiences failure of components due to aging materials. Both factors contribute to localized flooding. COA-WPD currently prioritizes localized flood problems areas using reports of flooding from residents. Building flooding is considered the most severe. The table below summarizes the localized flood problem areas within the Shoal Creek watershed that are among the fiscal year 2019 Top 20 most severe problem areas in the city.

Table 5 FY 2019 Top 20 Ranked Localized Flood Problem Areas

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

Erosion

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 downcutting and widening due to increased runoff. As a result, development along Shoal Creek has been significantly impacted by erosional processes. 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.

Table 6 FY 2019 Top 20 Ranked Erosion Reaches

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

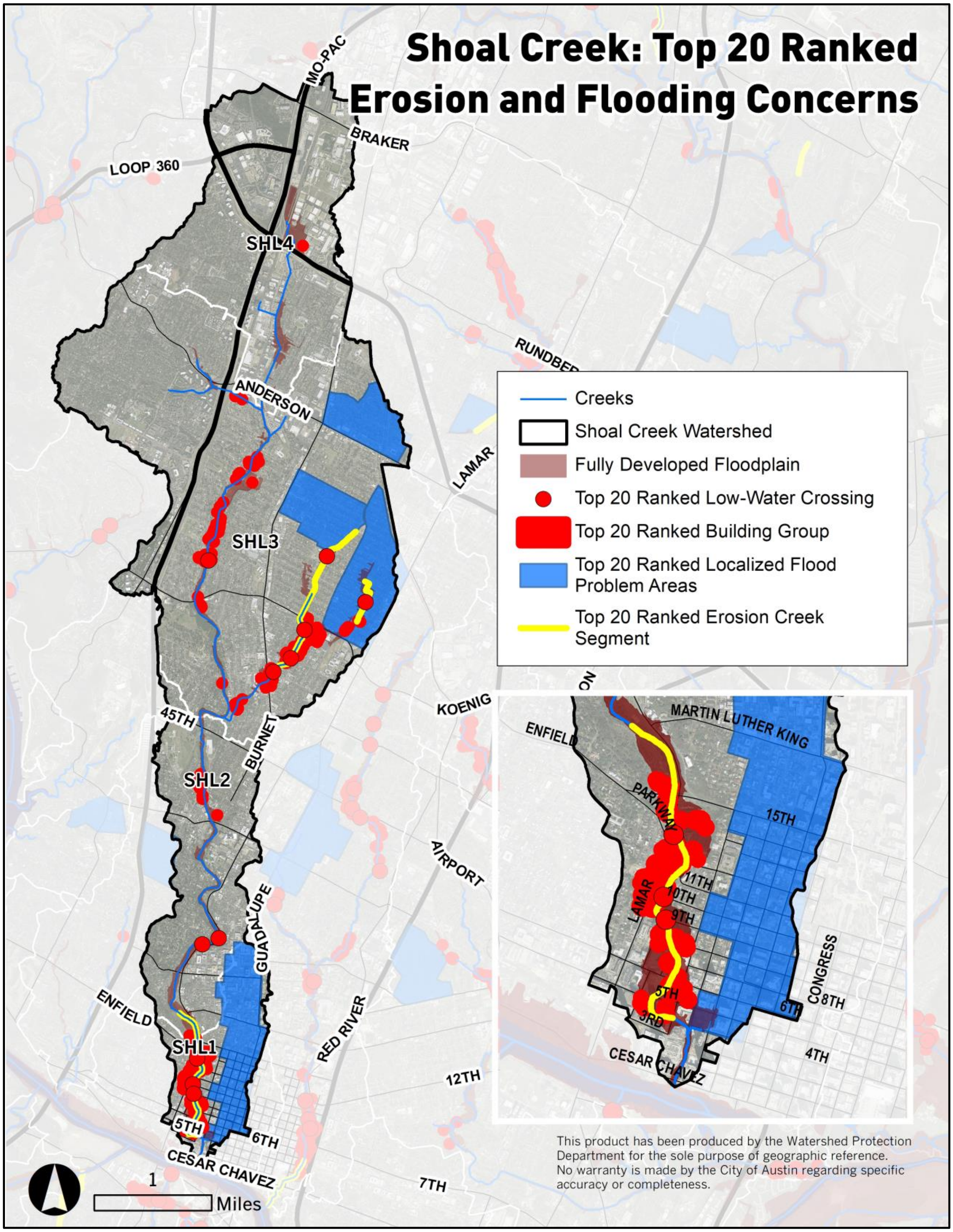


Figure 16 COA-WPD Fiscal Year 2019 Top 20 Ranked Erosion and Flooding Concerns

B. Springflow and Groundwater Concerns

It is likely that more springs/seeps existed in the Shoal Creek watershed in the past, but the watershed has been almost completely urbanized. Urbanization and its associated impervious cover has altered the hydrology to greatly decrease infiltration of rainwater into the groundwater system. As more runoff is quickly conveyed downstream during storm events instead of infiltrating and contributing to baseflow, springflow volumes decrease.

Placeholder. Spring flow monitoring information from COA WPD and other entities to be added.

C. Habitat and Native Species Concerns

Riparian Zones

A riparian zone is the area adjacent to a waterway that comprises 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 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 these areas are left alone, grasses and trees become established and transform them 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 adds habitat for fish and macroinvertebrates. A robust riparian tree canopy also protects organisms in the creek from large fluctuations in temperature.

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 (Scoggins et al 2013) is an effort to utilize remote sensing data to fully assess riparian condition throughout an entire stream corridor and identify areas with a high potential of functional deficiency. This method characterizes 37 riparian areas along the creek corridor that are defined based on the upstream drainage area of the creek, with the width of the riparian zone increasing as the drainage area increases. Table 8 below shows the percent impervious cover, percent tree canopy, and percent of pervious non-canopy area in each of these 37 riparian areas. (Please note that tree canopy can overlap impervious areas for this analysis.) These three measures are a good indicator of the relative functionality of the riparian buffer and help guide both protection of higher scoring areas and restoration of degraded areas.

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

IRI Reach ID	Tree Canopy (%)	Non-Canopy Pervious Area (%)	Impervious Cover (%)
SHL_0	9%	11%	83%
SHL_1	21%	14%	72%
SHL_2	31%	15%	63%
SHL_3	45%	30%	30%
SHL_4	57%	25%	26%
SHL_5	47%	16%	45%
SHL_6	54%	15%	42%

SHL_7	61%	16%	33%
SHL_8	49%	13%	50%
SHL_9	33%	18%	54%
SHL_10	38%	17%	56%
SHL_11	50%	29%	29%
SHL_12	63%	15%	37%
SHL_13	58%	14%	43%
SHL_14	60%	13%	41%
SHL_15	59%	26%	22%
SHL_16	54%	16%	42%
SHL_17	56%	16%	42%
SHL_18	52%	18%	42%
SHL_19	40%	28%	42%
SHL_20	41%	20%	50%
SHL_21	21%	20%	65%
SHL_22	38%	19%	52%
SHL_23	24%	15%	67%
SHL_24	18%	22%	66%
SHL_25	8%	48%	44%
SHL_26	2%	73%	25%
SHL_27	2%	19%	79%
SHL_28	70%	15%	15%
SHL_29	86%	6%	9%
SHL_30	28%	21%	59%
SHL_31	56%	11%	40%
SHL_32	41%	18%	53%
SHL_33	19%	11%	77%
SHL_34	40%	23%	47%
SHL_35	48%	17%	50%
SHL_36	32%	24%	53%
SHL_37	29%	26%	51%
Total	40%	19%	49%

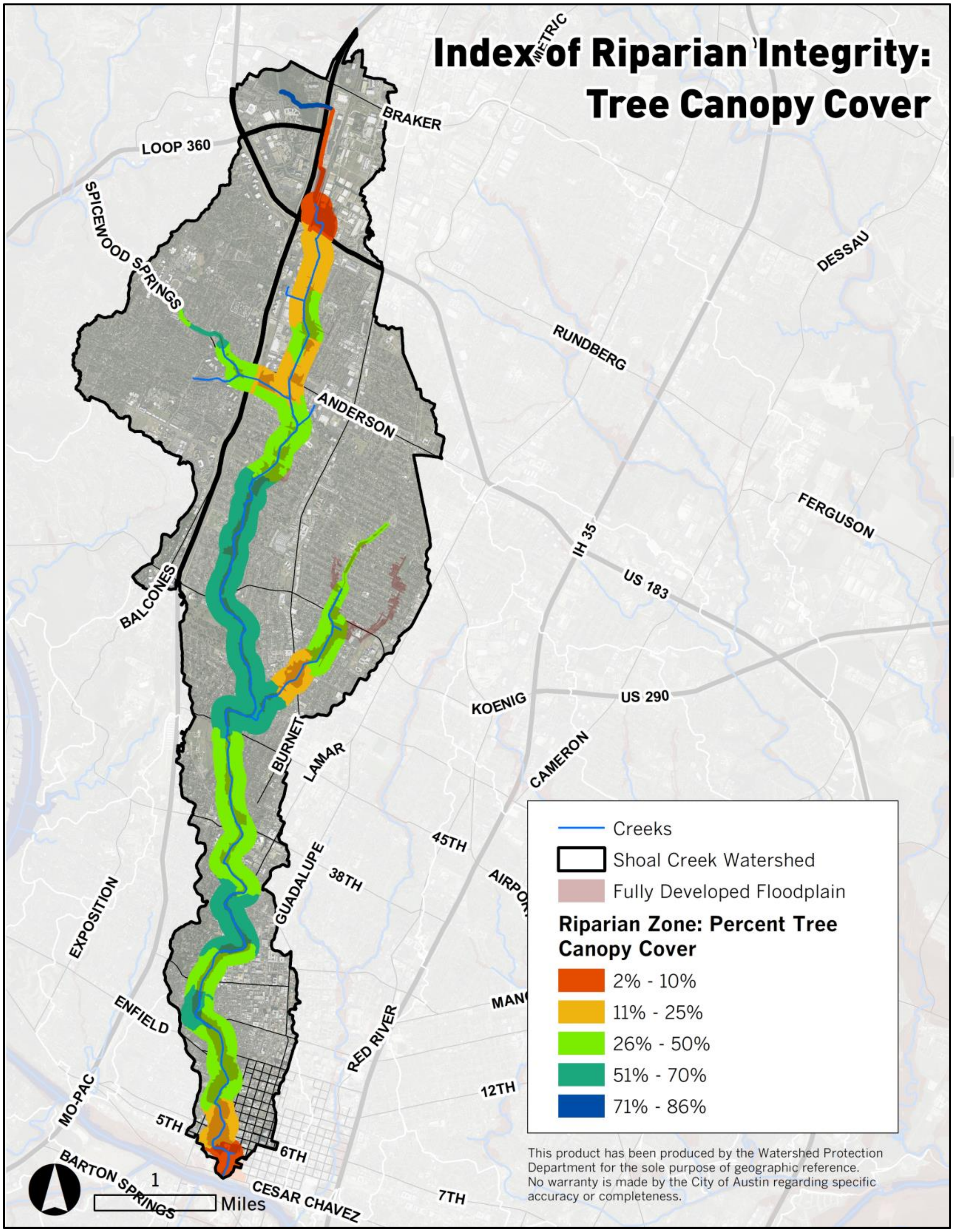


Figure 17 Index of Riparian Integrity: Tree Canopy Cover

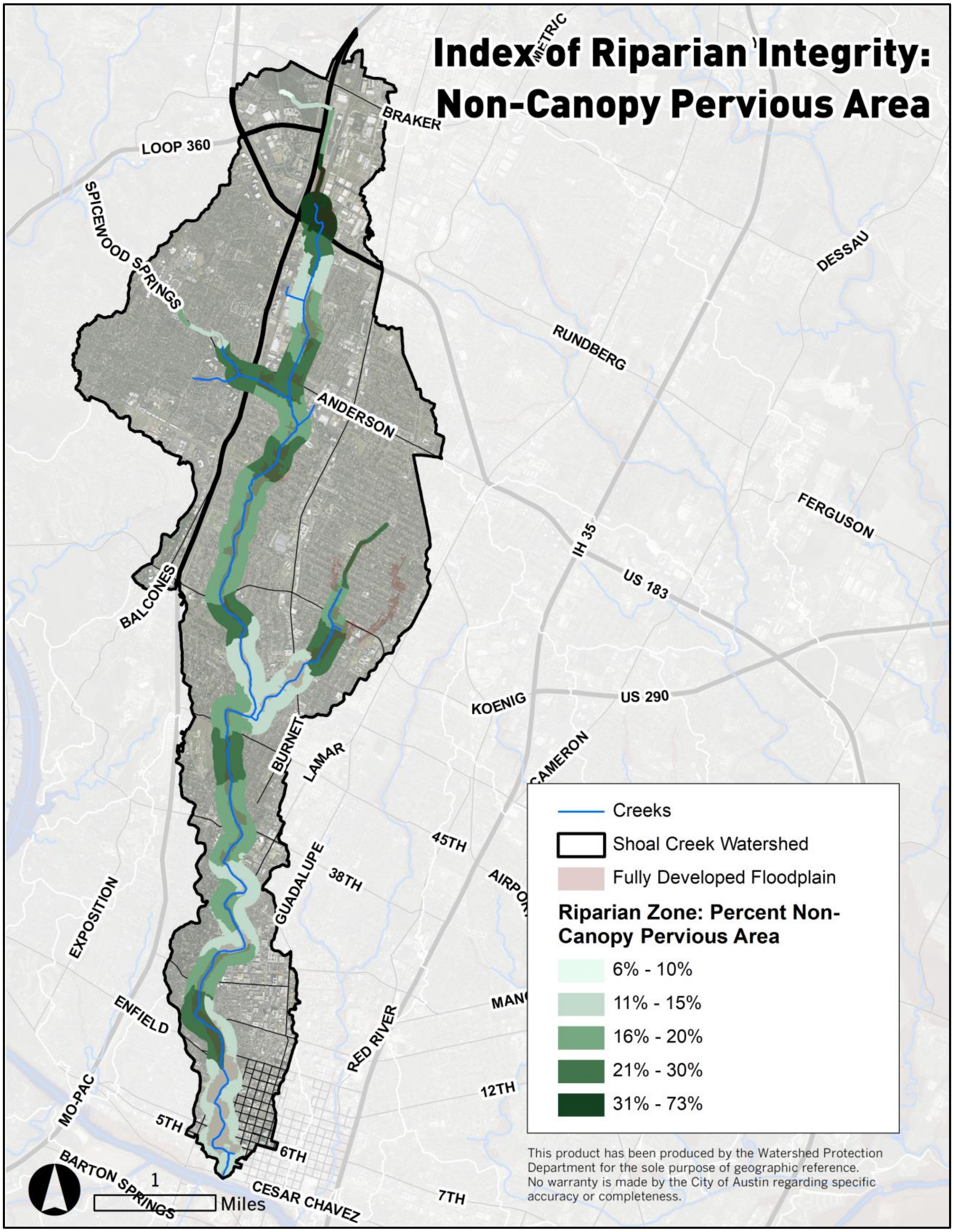


Figure 18 Index of Riparian Integrity: Non-Canopy Pervious Area

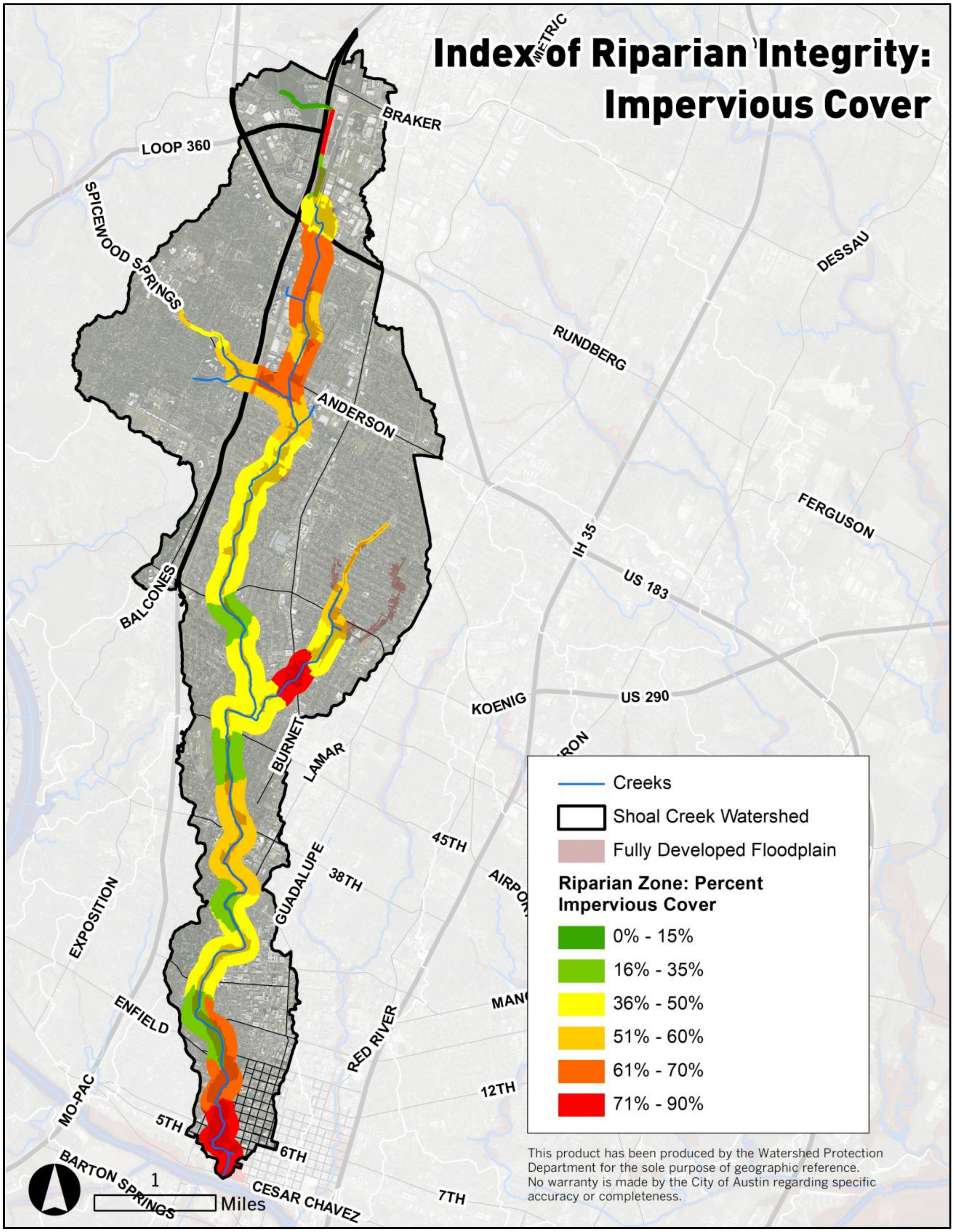
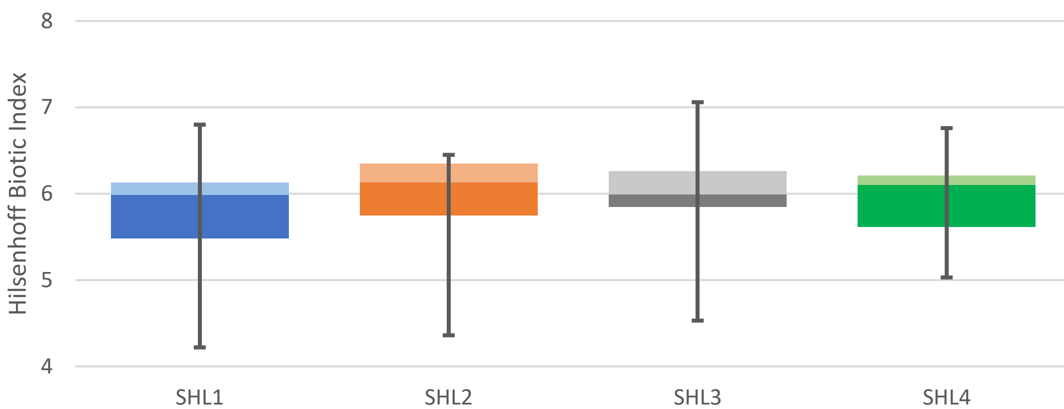


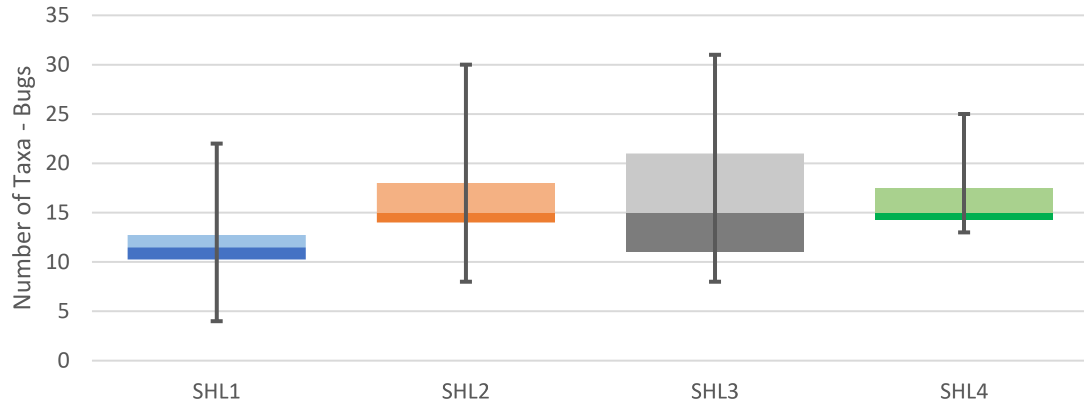
Figure 19 Index of Riparian Integrity: Impervious Cover

Aquatic Life

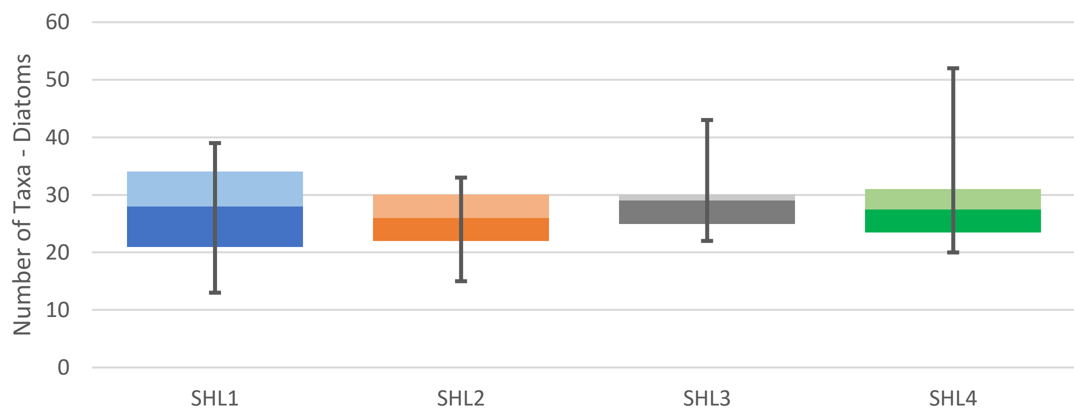
Biological sampling enables a more holistic perspective of water quality than water chemistry sampling alone. The diversity and tolerance of the biological community can provide insight to the conditions of water quality over months and even years rather than a single discrete point in time. As part of its Environmental Integrity Index (EII) sampling, COA-WPD samples benthic macroinvertebrates or bugs(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 (metrics) and ability to tolerate stressors from the urban environment like pollutants and altered flow.



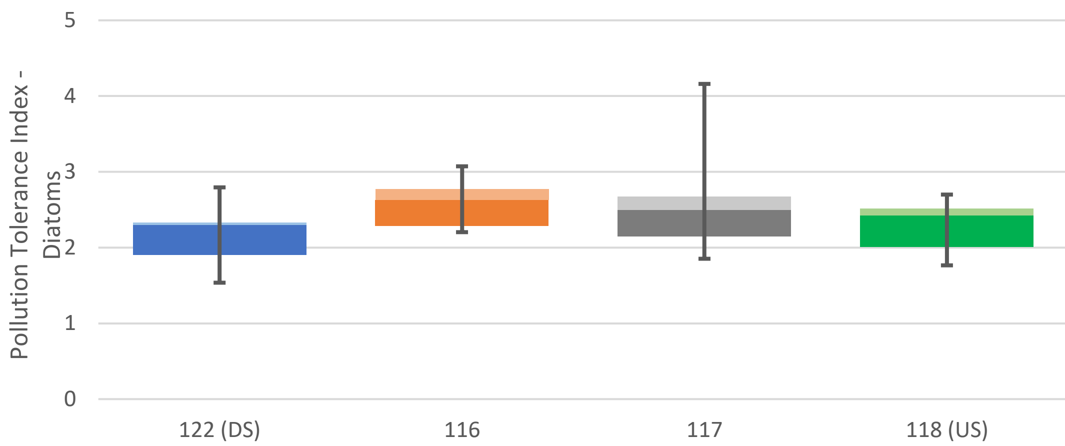
The Hilsenhoff Biotic Index (HBI) metric estimates the overall tolerance of the community. Organisms are assigned a tolerance number from 0 to 10 pertaining to that group's known sensitivity to organic pollutants; 0 being most sensitive, 10 being most tolerant. All of the sites on Shoal Creek have a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



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.



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.



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

D. Overview of Water Quality Impairments

Water Chemistry

The following graphs are a brief overview of the EII water chemistry subindices for the Shoal Creek watershed. The dashed horizontal line on each graph indicates the historic EII average value. The whiskers indicate the minimum/maximum values and the boxes indicate the interquartile range. The median and mean of each data set are shown within the boxes as stars and horizontal lines respectively.

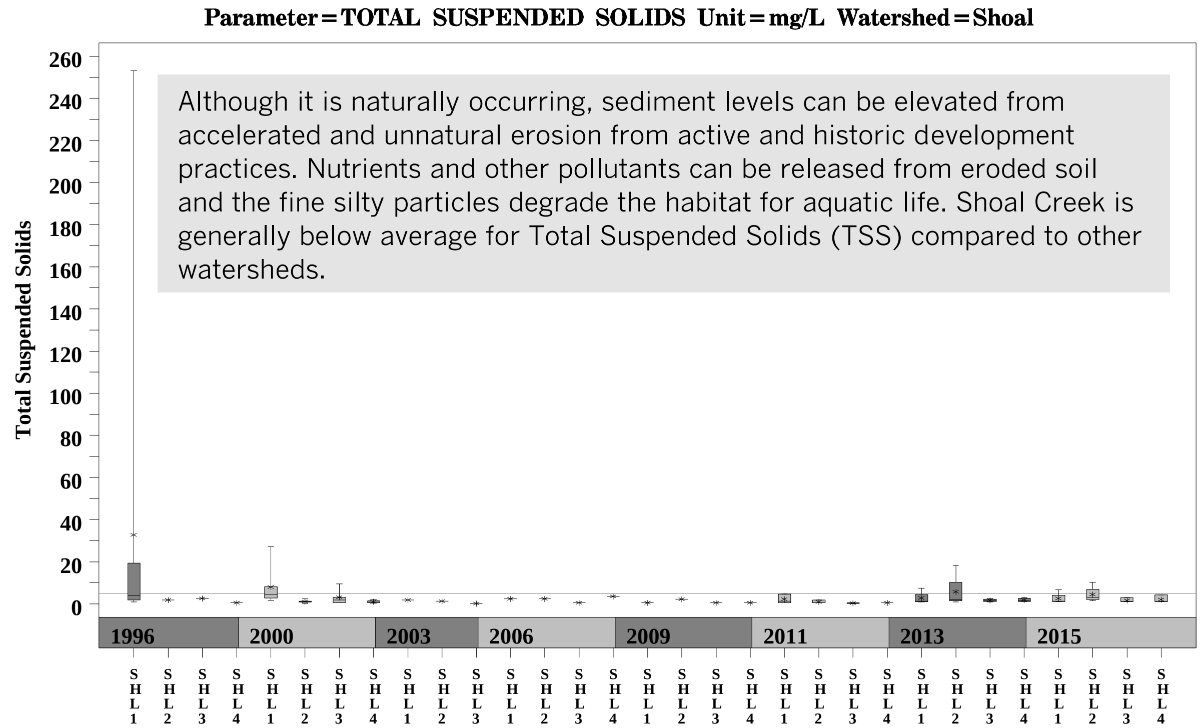


Figure 20 Total Suspended Solids (mg/L) (1996 – 2015)

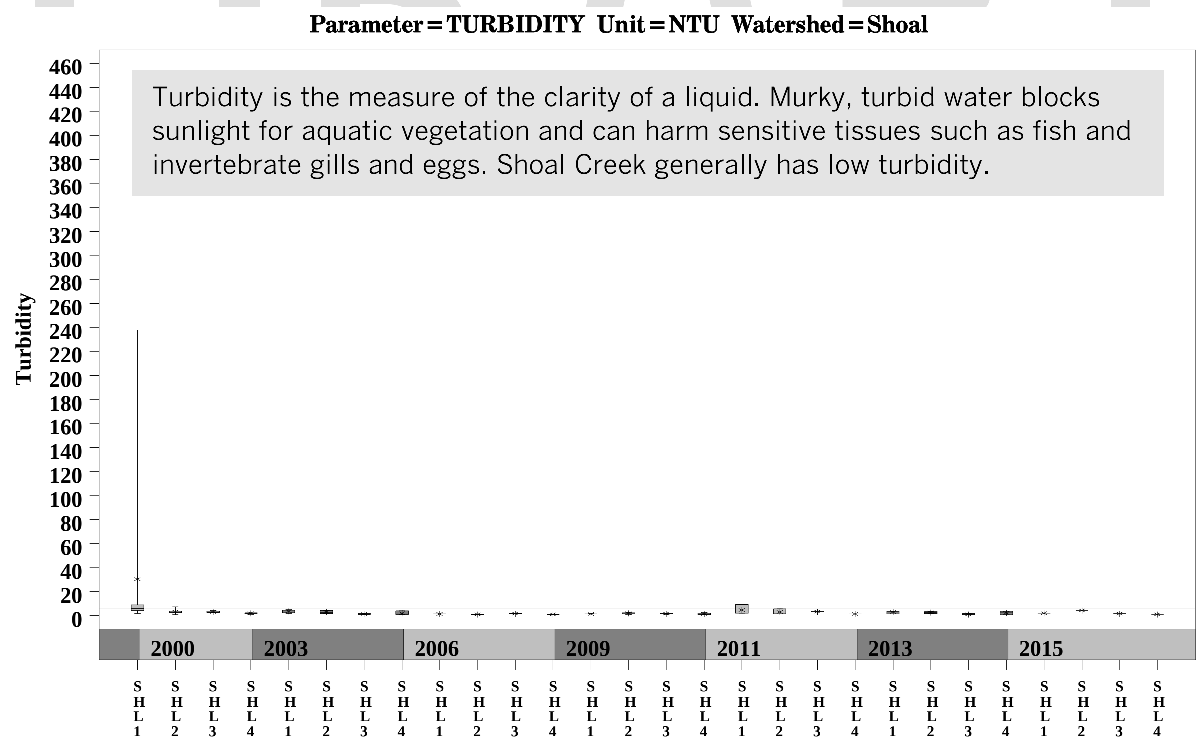


Figure 21 Turbidity (2000 - 2015)

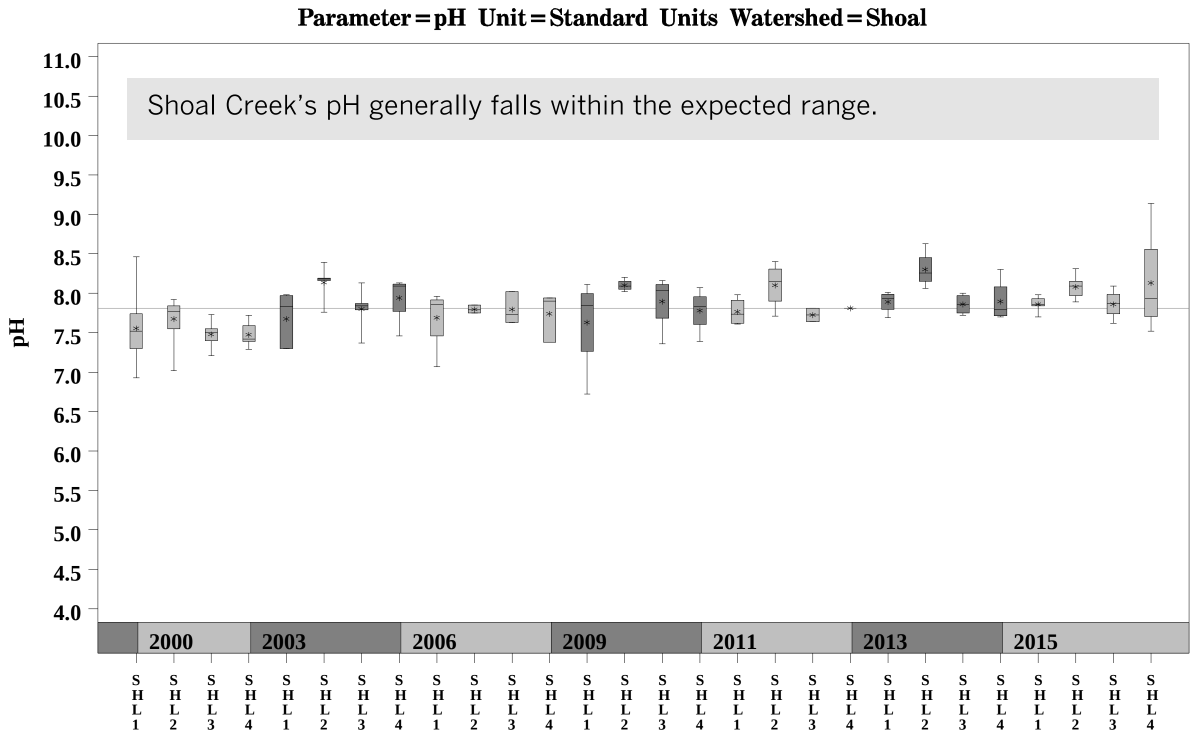


Figure 22 pH (2000 – 2015)

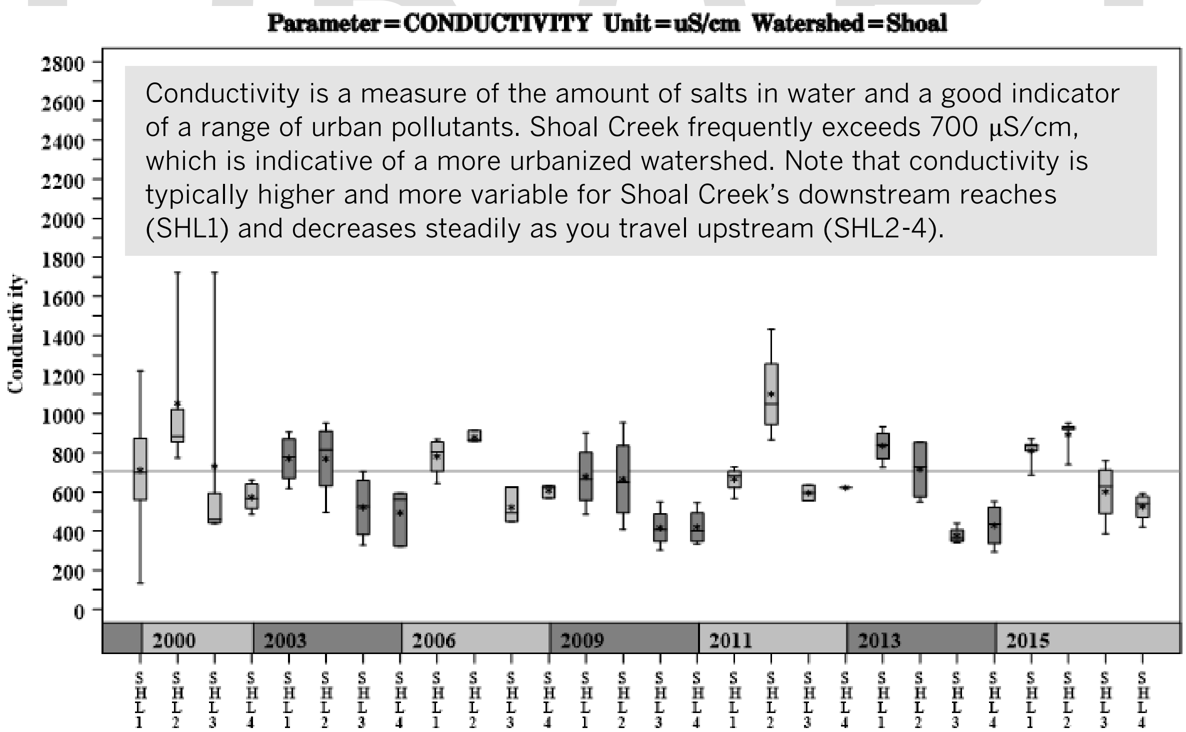


Figure 23 Conductivity (µS/cm) (2000 – 2015)

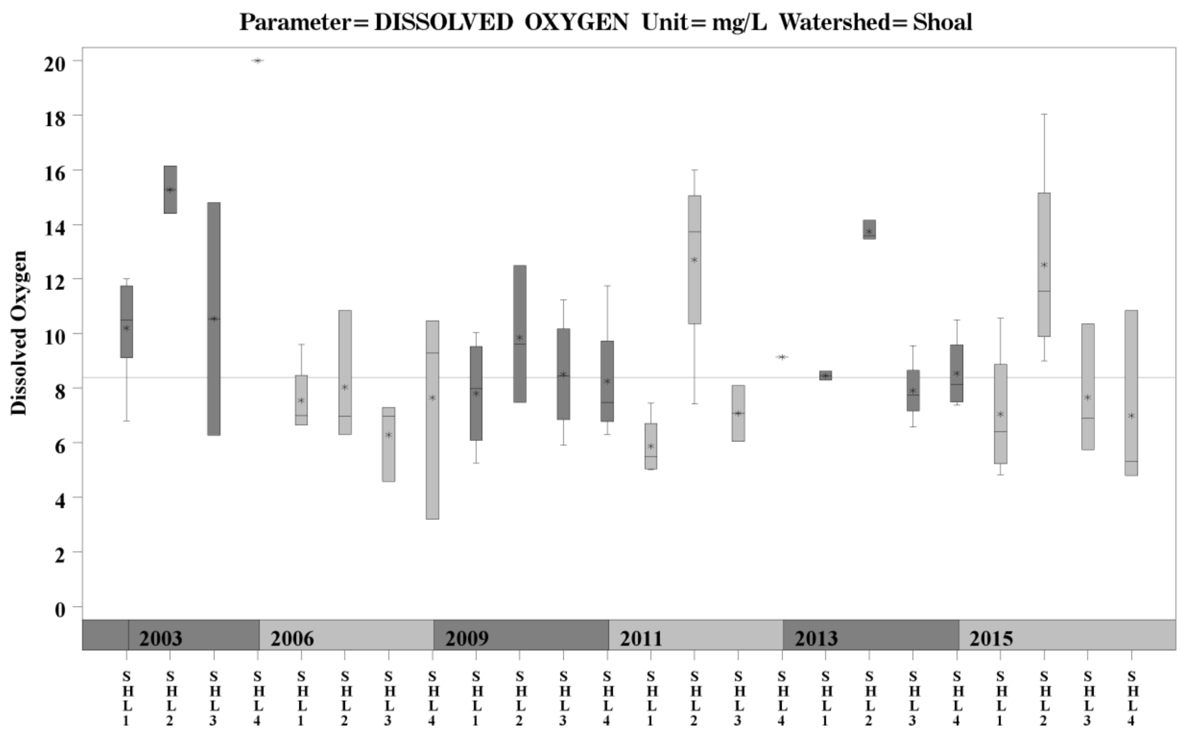


Figure 24 Dissolved Oxygen (mg/L) (2003 – 2015)

Dissolved Oxygen (DO) is used as an indicator of overall water quality because many things 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 DO for aquatic life, but does exhibit somewhat lower levels as you move to the upstream reaches. This is probably related to lower flows as the drainage area gets smaller.

Nutrients

Nutrients in surface water are an important component for 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.

A 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.

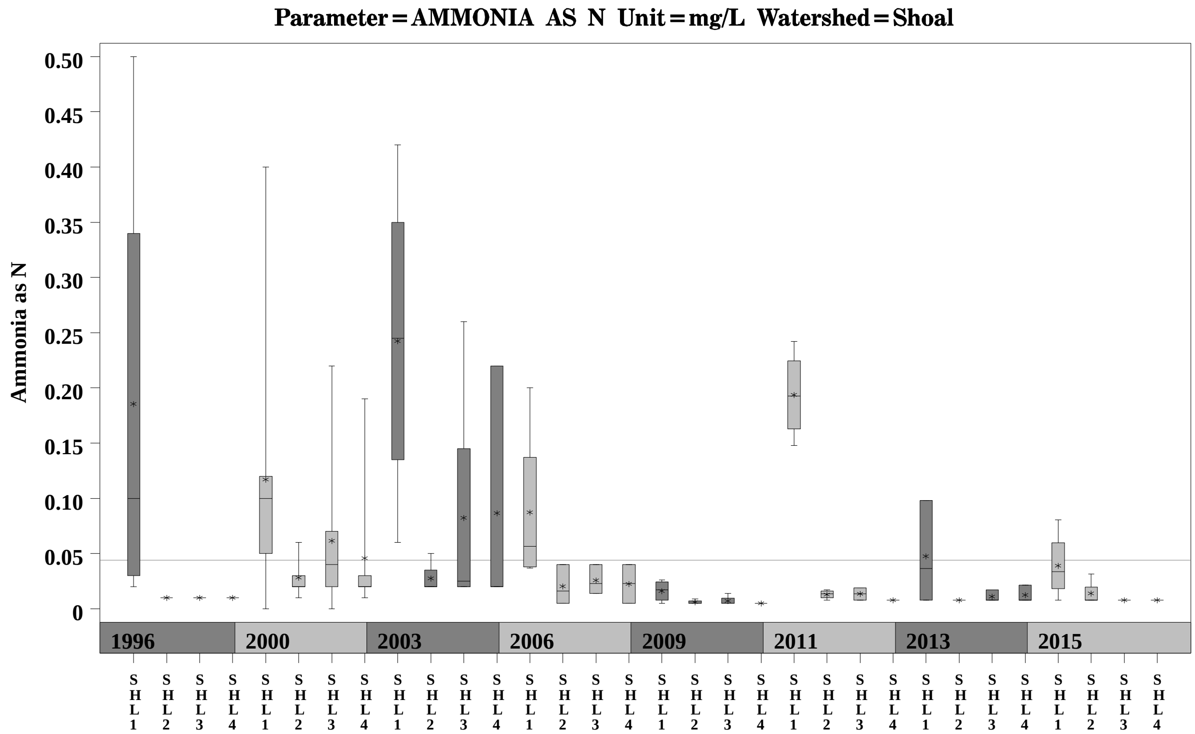


Figure 25 Ammonia (mg/L) (1996 – 2015)

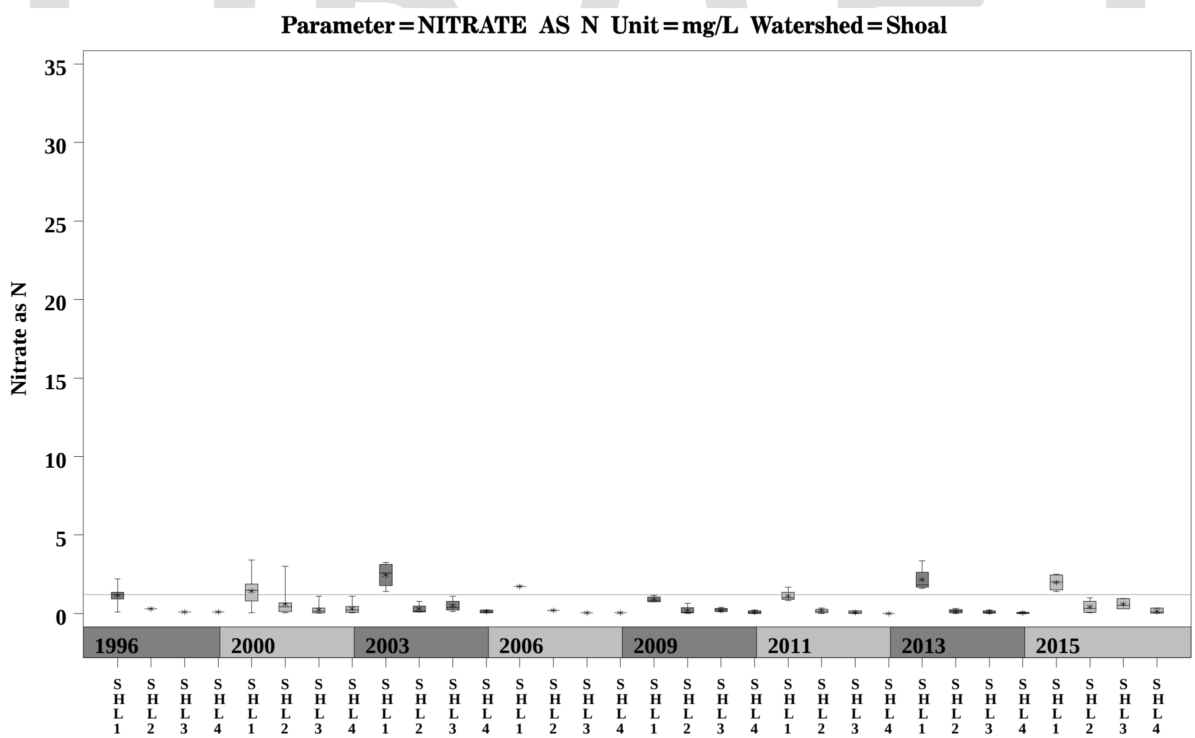


Figure 26 Nitrate (mg/L) (1996 – 2015)

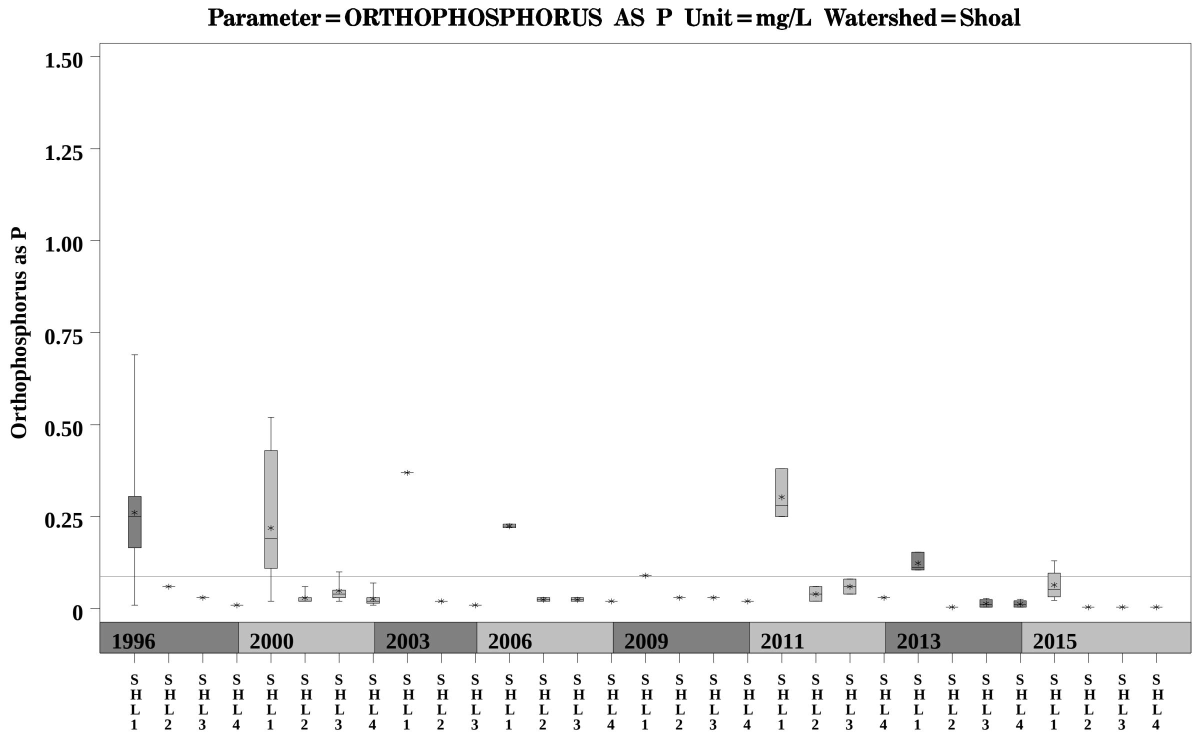


Figure 27 Orthophosphorus (mg/L) (1996 – 2015)

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 that are associated with it such as nutrients and low dissolved oxygen. E. coli concentrations have historically been elevated throughout Shoal Creek, likely due to aging wastewater infrastructure in which spills and overflows are common. Many wastewater lines within and adjacent to the creek have been removed, but several remain. This watershed has a large residential component that was 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 that services this watershed, the total bacteria load should decrease.

Urban areas also tend to have a higher concentration of human and animal fecal inputs. Placeholder for more information regarding fecal inputs.

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. After the combined actions of COA-WPD, Austin Water (AW), and regional partners managed to remove three watersheds from the 2012 draft list of contact recreation impairments, the City decided to pursue a Total Maximum Daily Load (TMDL) in cooperation with TCEQ for the remaining four watersheds, including the Spicewood Tributary to Shoal Creek. 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.

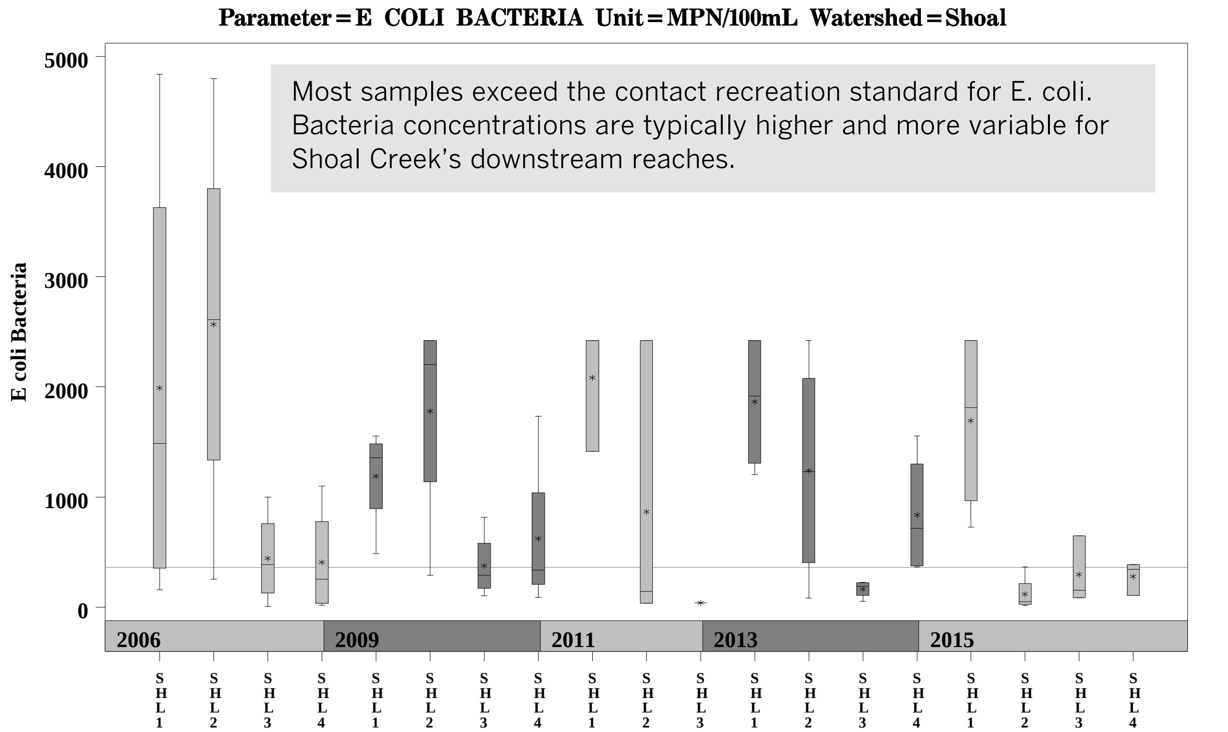
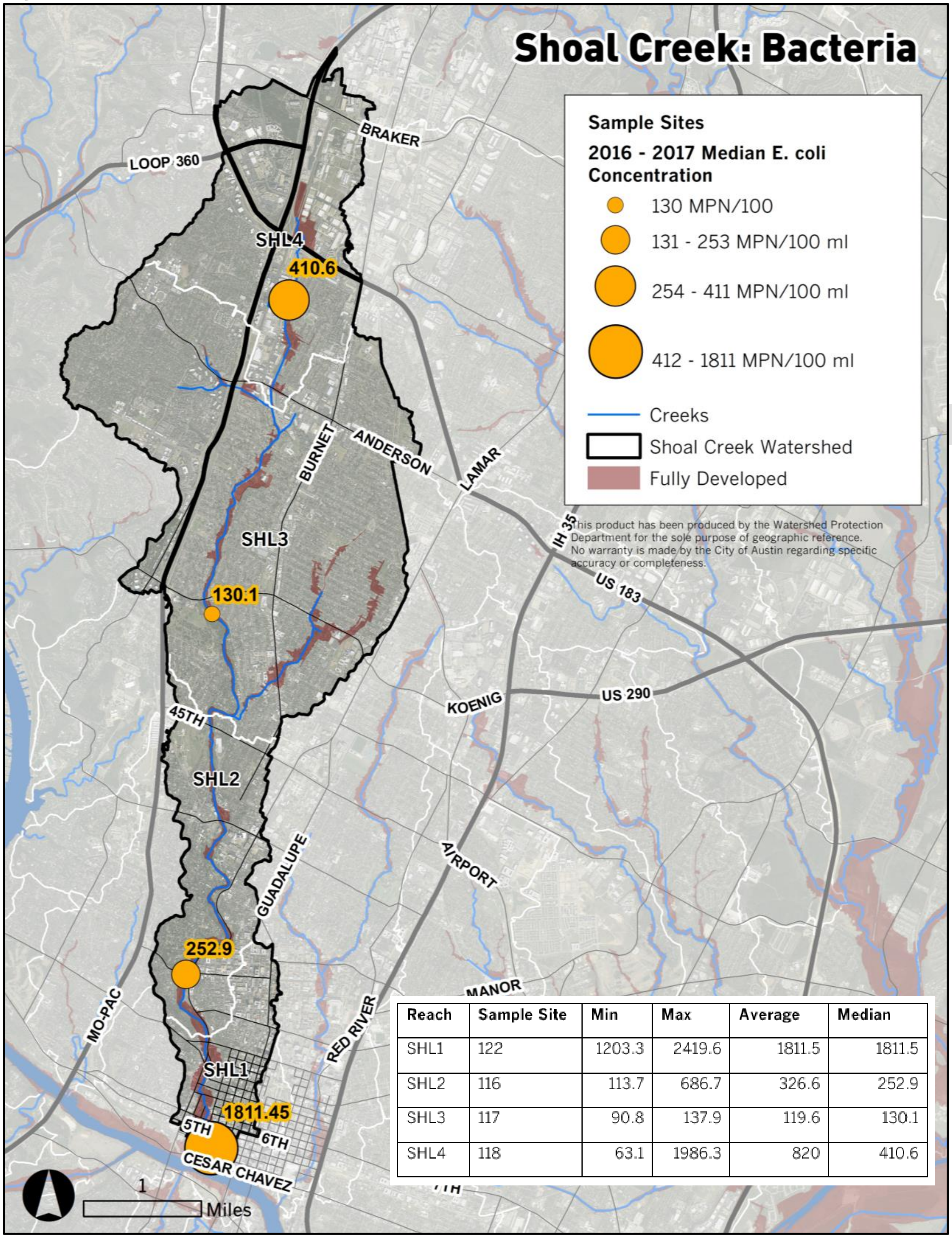

Parameter=E COLI BACTERIA Unit=MPN/100mL Watershed=Shoal
Most samples exceed the contact recreation standard for E. coli. Bacteria concentrations are typically higher and more variable for Shoal Creek's downstream reaches.
E coli Bacteria
5000
4000
3000
2000
1000
0
2006
2009
2011
2013
2015
SHL1
SHL2
SHL3
SHL4

Figure 28 E. Coli Bacteria (2006 – 2015) (MPN/100 ml)



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 29 Bacteria Concentration (2016 – 2017)

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 1991 (Urban Watersheds Ordinance). 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.

Placeholder: Figure 30 represents preliminary data

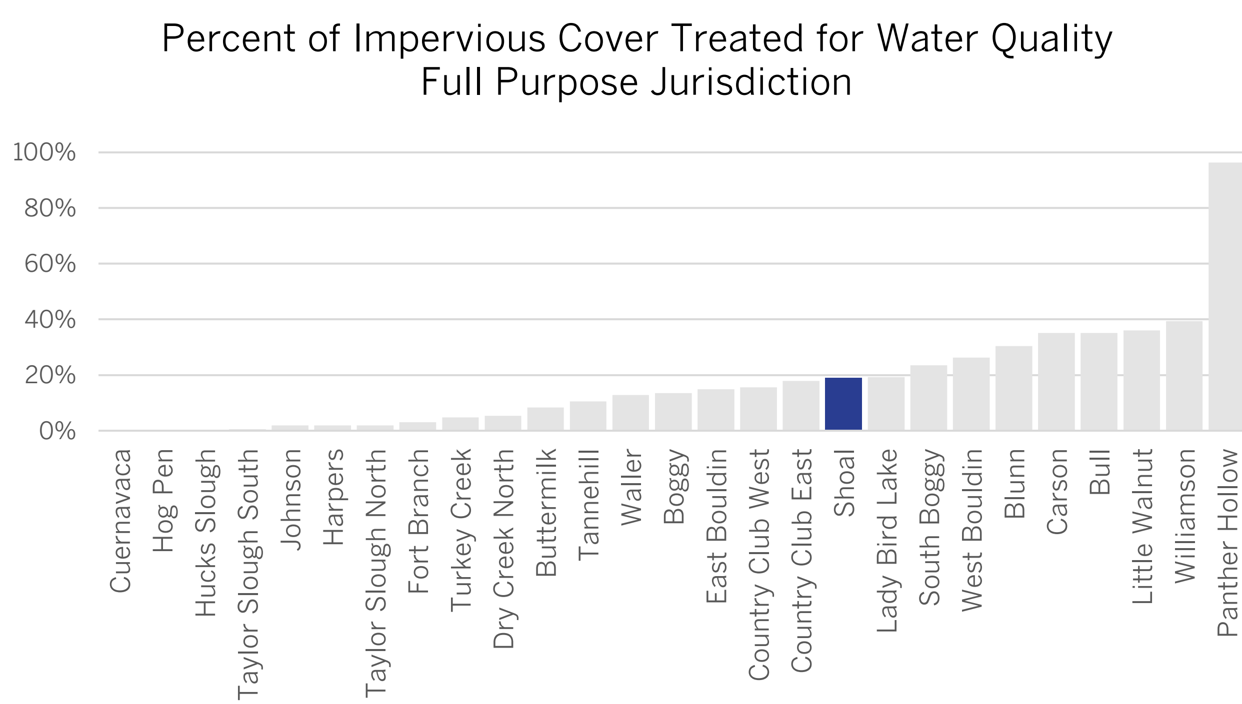


Figure 30 Impervious Cover Treated for Water Quality (Full Purpose Jurisdiction only)

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. 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 and many of Austin's major highways bisect this watershed, 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 due to a 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.

Table 8 Illicit Discharge Investigations by Reach

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

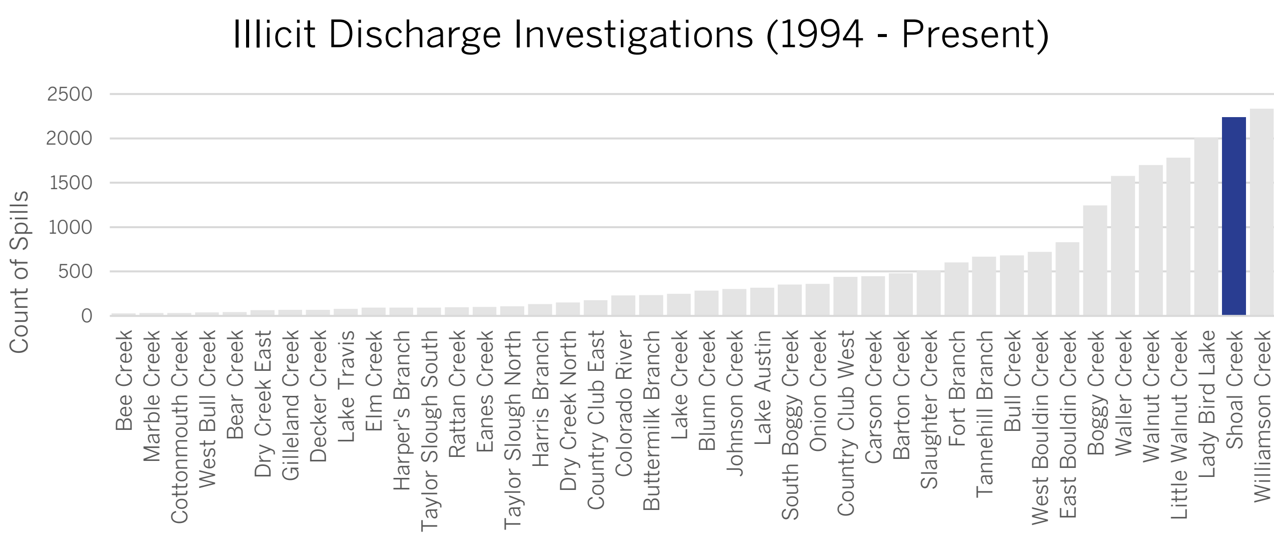


Figure 31 Total Reported Illicit Discharge Investigations, 1994 - Present (watersheds with discharge counts under 30 are excluded)

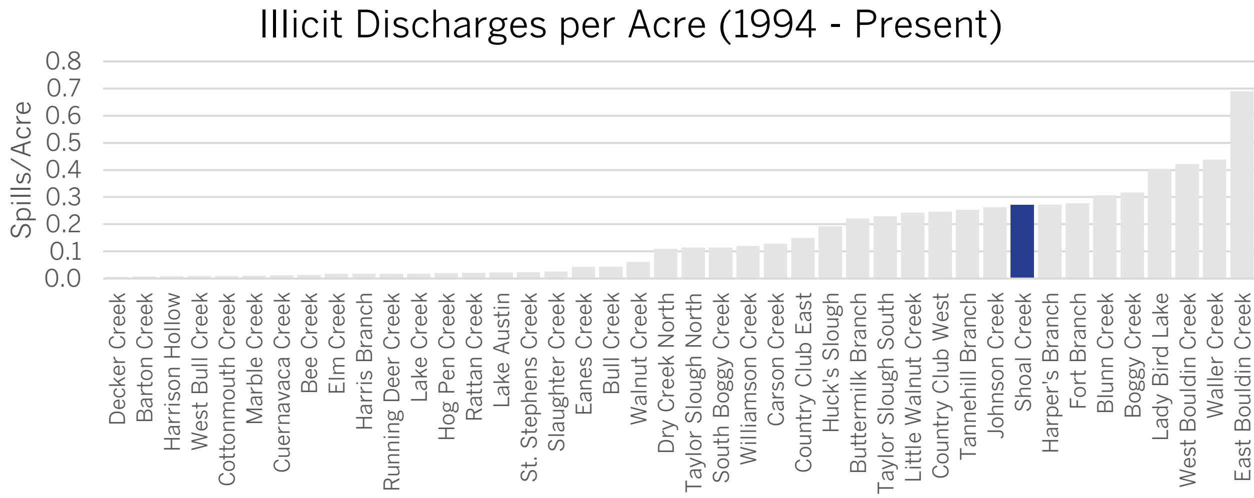


Figure 32 Illicit Discharge Investigations per Acre, 1994 - Present (watersheds with discharge counts under 30 are excluded)

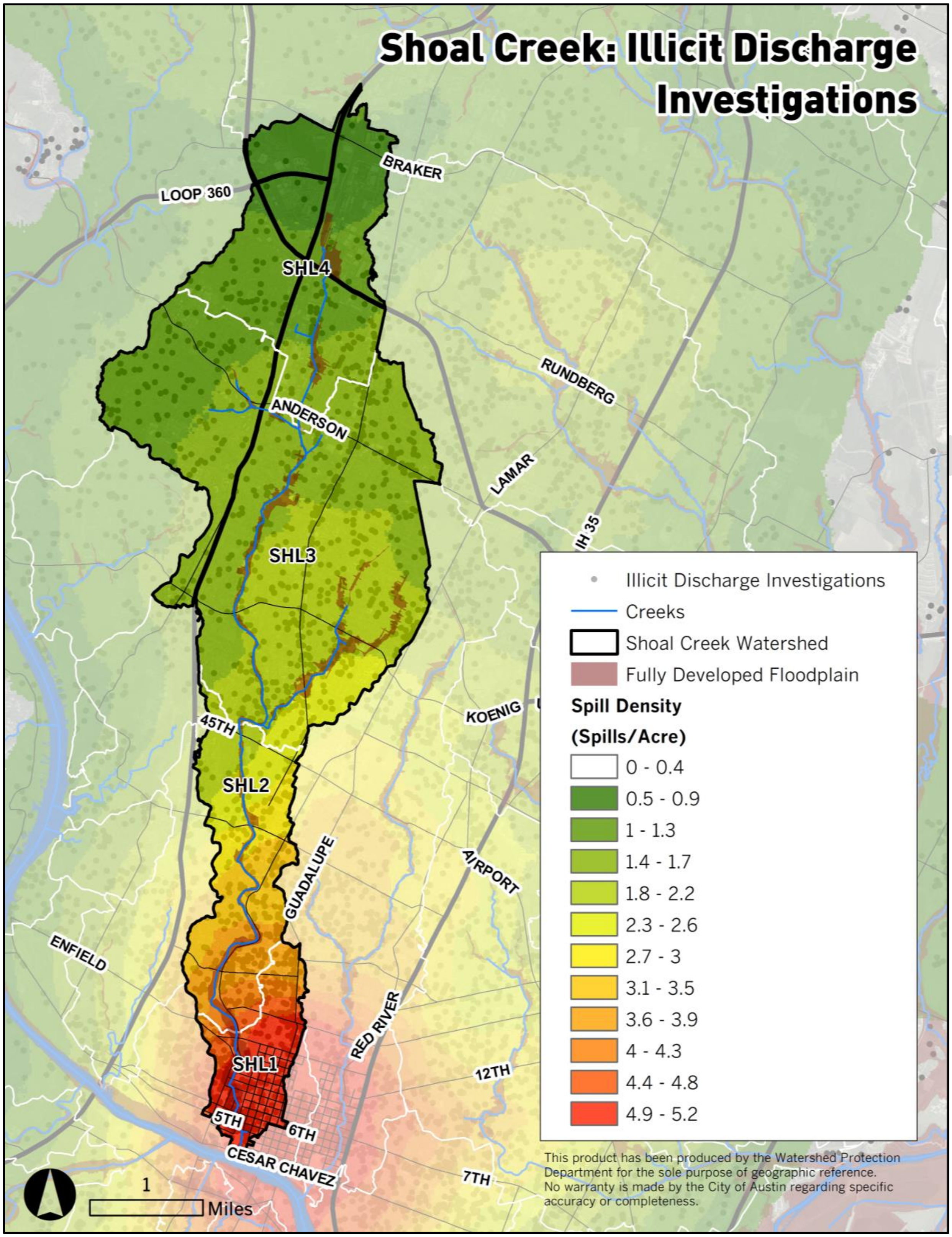


Figure 33 Illicit Discharge Investigations

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 establishes 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.

Table 9 TPDES and SDPP Stormwater Discharge Permits

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

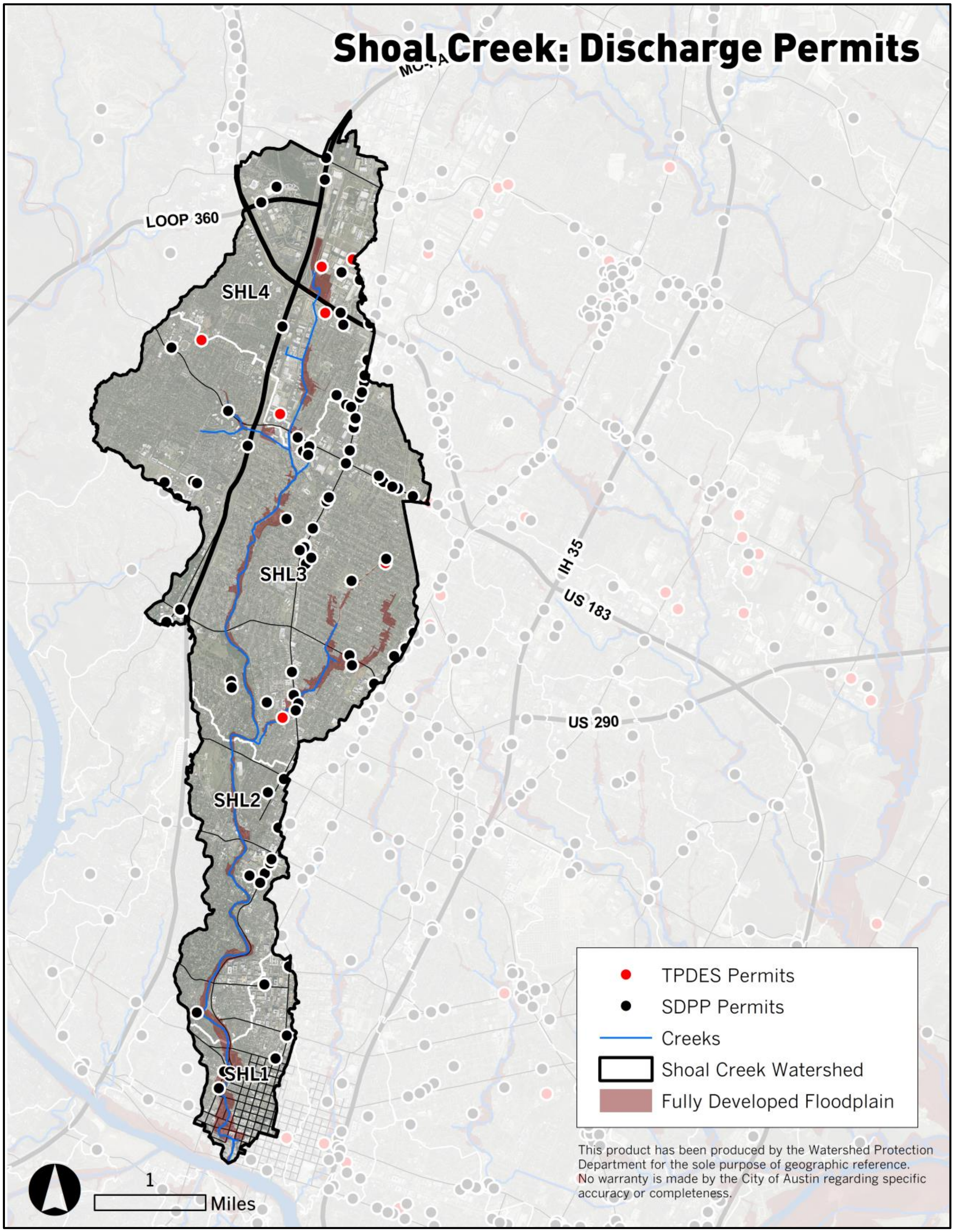


Figure 34 State and City Discharge Permits

V. Ongoing Efforts to Address Watershed Health

Potential solutions to Shoal Creek watershed problems include capital solutions, programs, and regulations. The following section outlines the capital projects, programs, and regulations that the City of Austin Watershed Protection Department (COA-WPD) uses 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. Placeholder: This $83 M figure will be updated to include expenditures prior to the use of the Capital Project Reporting and Information System database.

Table 11 and Figure 35 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. Figure 36 depicts planned COA-WPD capital projects. Please note that planned project information is for planning purposes only and is subject to change at any time.

Table 10 Capital Improvement Program Projects with COA-WPD Expenditures

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 Flood	
Greenlawn-Foster Channel Improvements	Placeholder for dates 1981 – 1994
Greenlawn Bridge Improvement	
Upper Shoal Creek Detention Pond	
Far West Pond	
Northwest Park Pond	
Silverway Bridge Removal	
Silverway Buyouts	
West 45th Street Bridge Improvements	
Grover Culvert and Channel Improvements	
Shoal Creek Blvd Bridge Replacement	
2222 Bridge Replacement and Channel Improvements	
MoPac Pond 1	
MoPac Pond 2	
Shoal Creek Buyouts	
PSP Pond 1	
PSP Pond 2	
West 1st Street Bridge at Shoal Creek	
Spicewood Springs Pond	
West 38th Street Bridge Improvements	
Jefferson Street Channel Improvements	
Steck Ponds	
Jefferson Buyouts	
Woodhollow Dam	
Benbrook Dam	
Shoal Creek Channel Improvements	1994
Upper Shoal Creek Detention Pond Improvements	2002

Localized Flood	
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

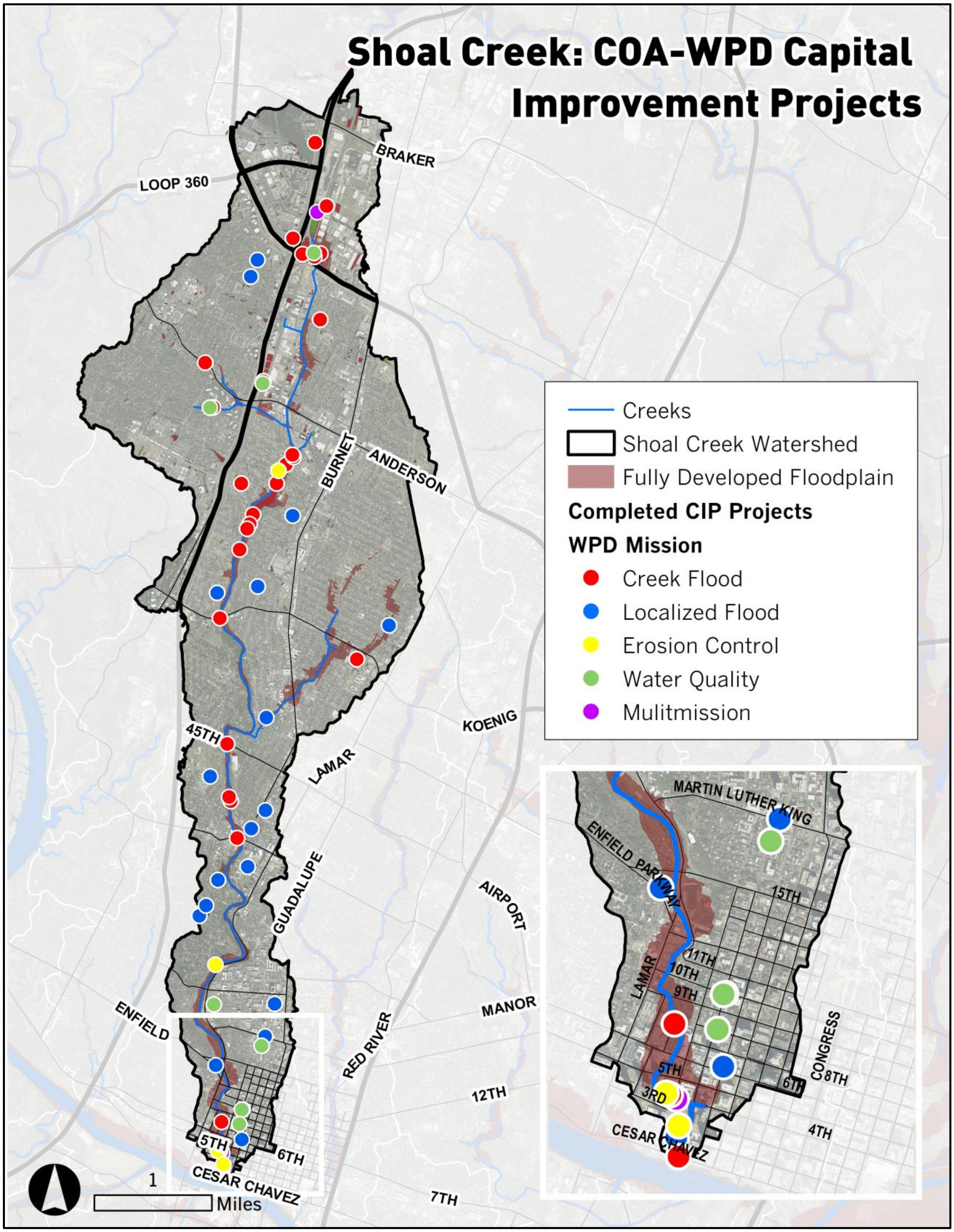


Figure 35 COA-WPD Capital Improvement Projects

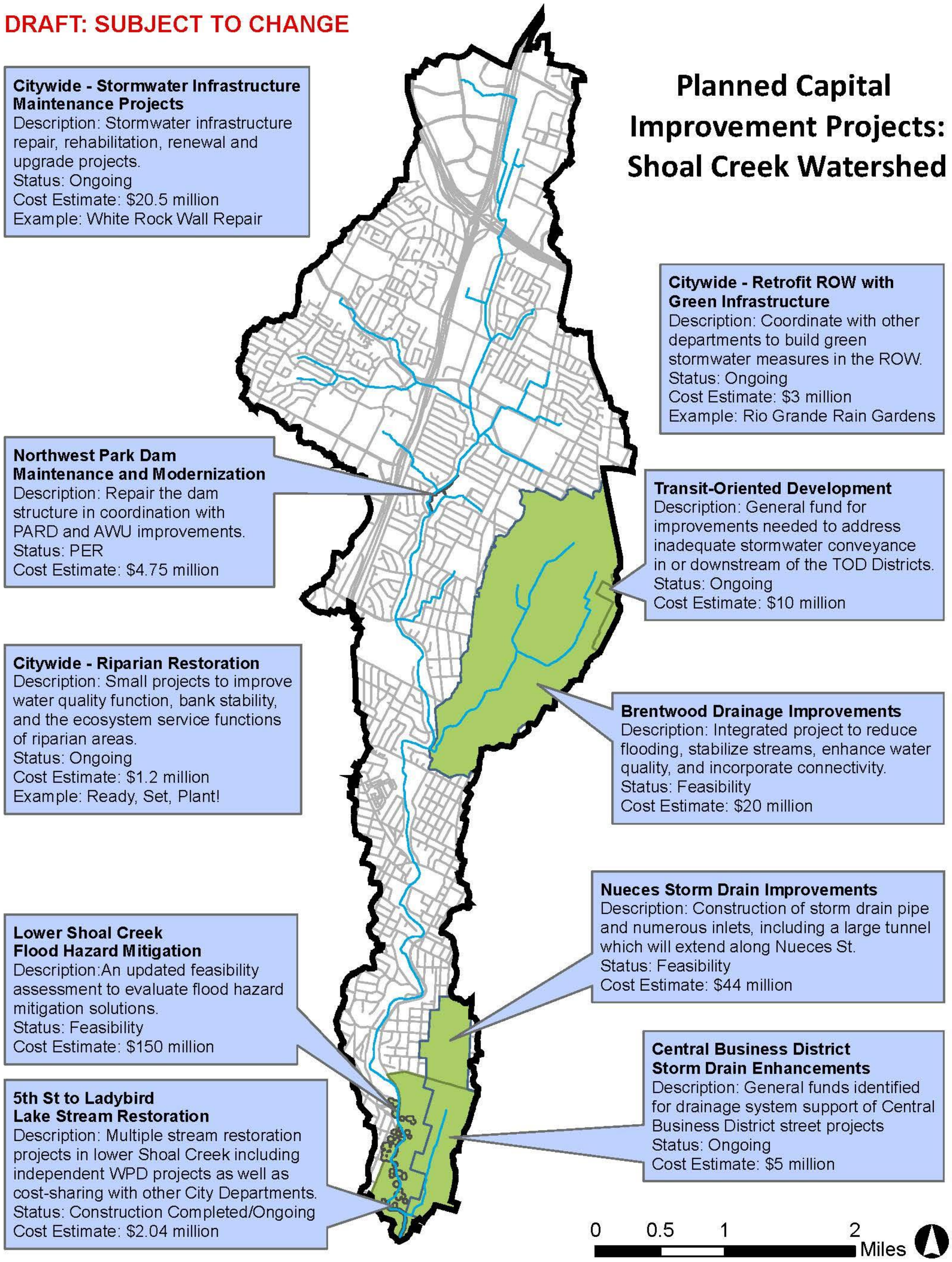


Figure 36 COA-WPD Planned Capital Improvement Projects (2018).

B. Regulations

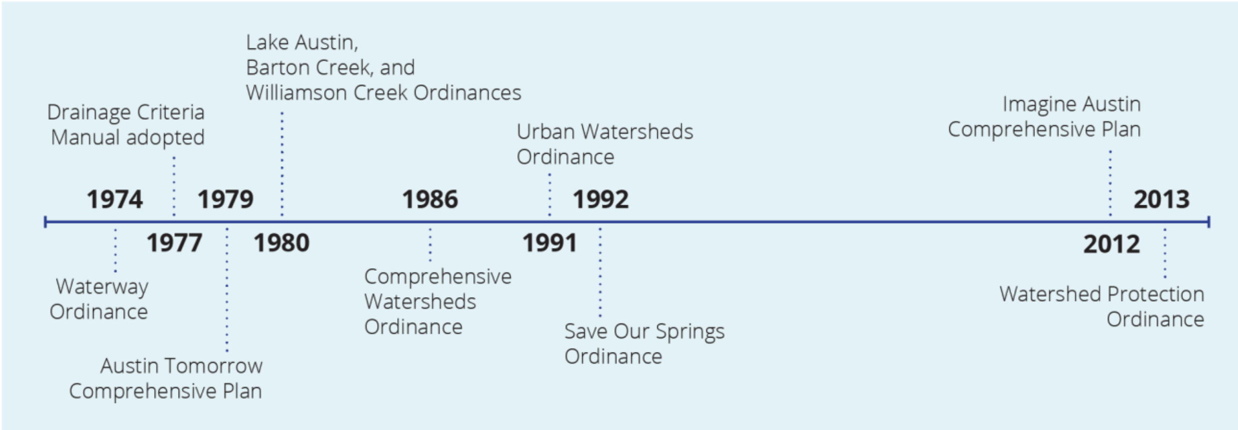


Figure 37 History of City of Austin Watershed Regulations

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. Encroachment of buildings and parking areas is prohibited on the 25-year floodplain and restricted 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, 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.

- ***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. 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.
- ***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.

Placeholder: Map of existing detention ponds and drainage areas

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. Setbacks protect the natural character and function of these features; protect groundwater quality and quantity by preserving and maintaining recharge; and protect surface water quality and quantity by maintaining the quality and quantity of surface water runoff and overland flow. The standard buffer distance for all features is 150 feet, with a 300-footmaximum for point recharge features. The Central Business District does not require protection for wetlands.
- ***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.

Placeholder: Map of existing water quality ponds and drainage 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.

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. Routine vegetation management is achieved primarily through private sector maintenance contracts. The Vegetation Control Program (VCP) identifies areas where excess vegetation poses a conveyance concern and establishes a maintenance schedule to removes excessive vegetation, trash, and debris from stormwater controls and creeks to reduce flood hazards.

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. The trash boom at the confluence of Shoal and Lady Bird Lake captures approximately 17 tons of trash per year.

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.

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.

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 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 AW and 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 Appendix # for the Implementation Plan (https://www.tceq.texas.gov/assets/public/waterquality/tmdl/101austinbacteria/101A_AustinIPlanApproved2015-01-21.pdf).

Grow Zones. Shoal Creek is among the worst scoring watersheds for riparian vegetation. "Grow Zones" are an effort to promote healthy riparian vegetation along creeks in City parks. COA-WPD staff work with the Parks and Recreation Department to decrease the regular mowing along the creek, which allows a more biologically diverse plant community to grow in place of the existing, degraded turf. COA-WPD then actively monitors these sites to document the transition and ensure that 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. In addition to the wide variety of ecological services that these buffers provide, they are also integral to the effort to reduce fecal bacteria loads in Shoal Creeks. Shoal Creek currently has Grow Zones in Pease Park, the Shoal Creek Greenbelt, and Crestmont Greenspace (see Figure 38).

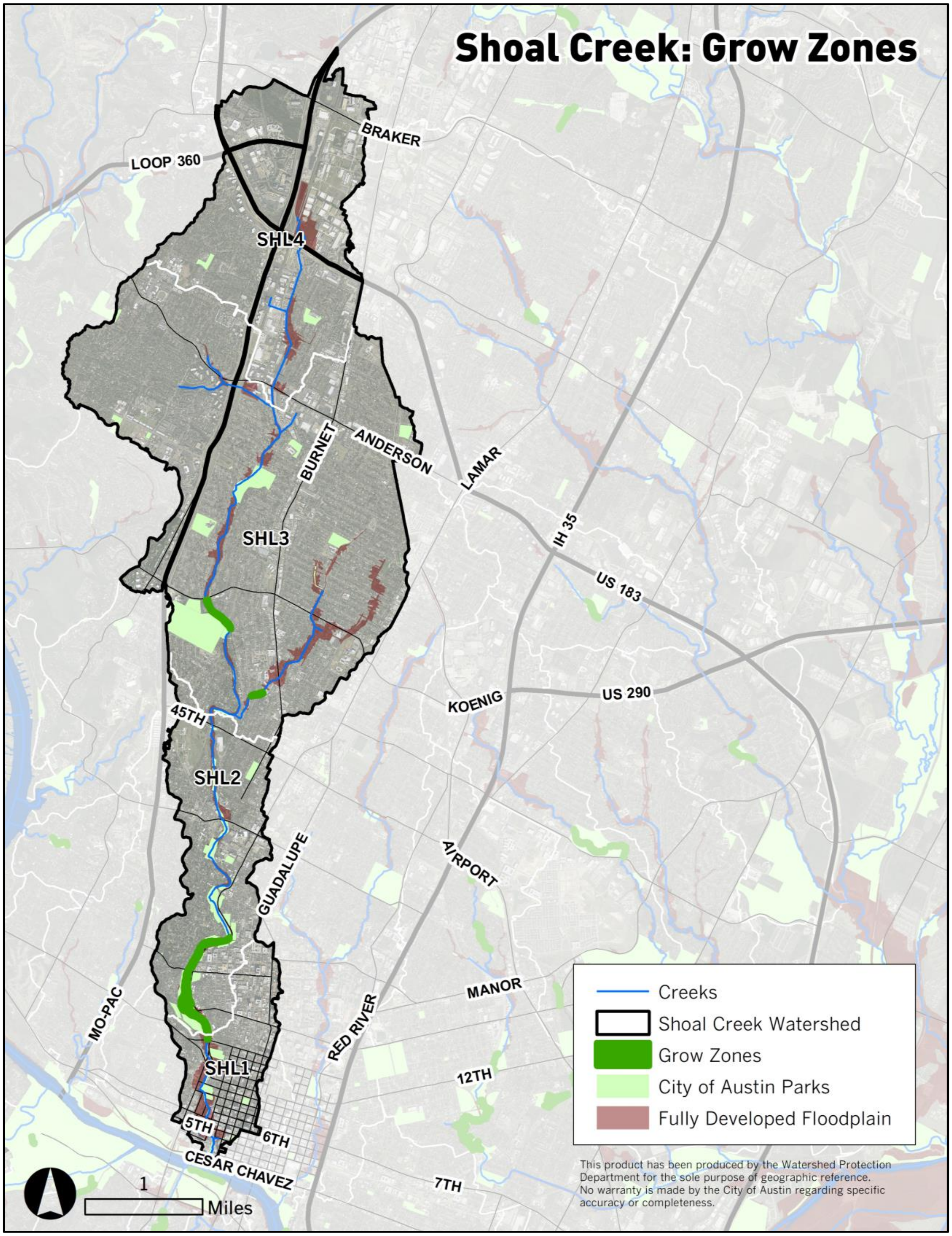


Figure 38 COA-WPD Grow Zones

Riparian Zone Restoration. Riparian Zone Restoration (RZR) is a program designed to increase vegetation quantity and quality along streams as a means of improving water quality. The program is focused on implementing passive restoration techniques to improve the vegetative communities in these buffers, improve soil health and infiltration capacity, and increase 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 will reduce bacteria loads to streams from stormwater, primarily due to the fact that bacteria tend to adhere to sediment particles that are the most easily filtered out pollutant in stormwater.

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