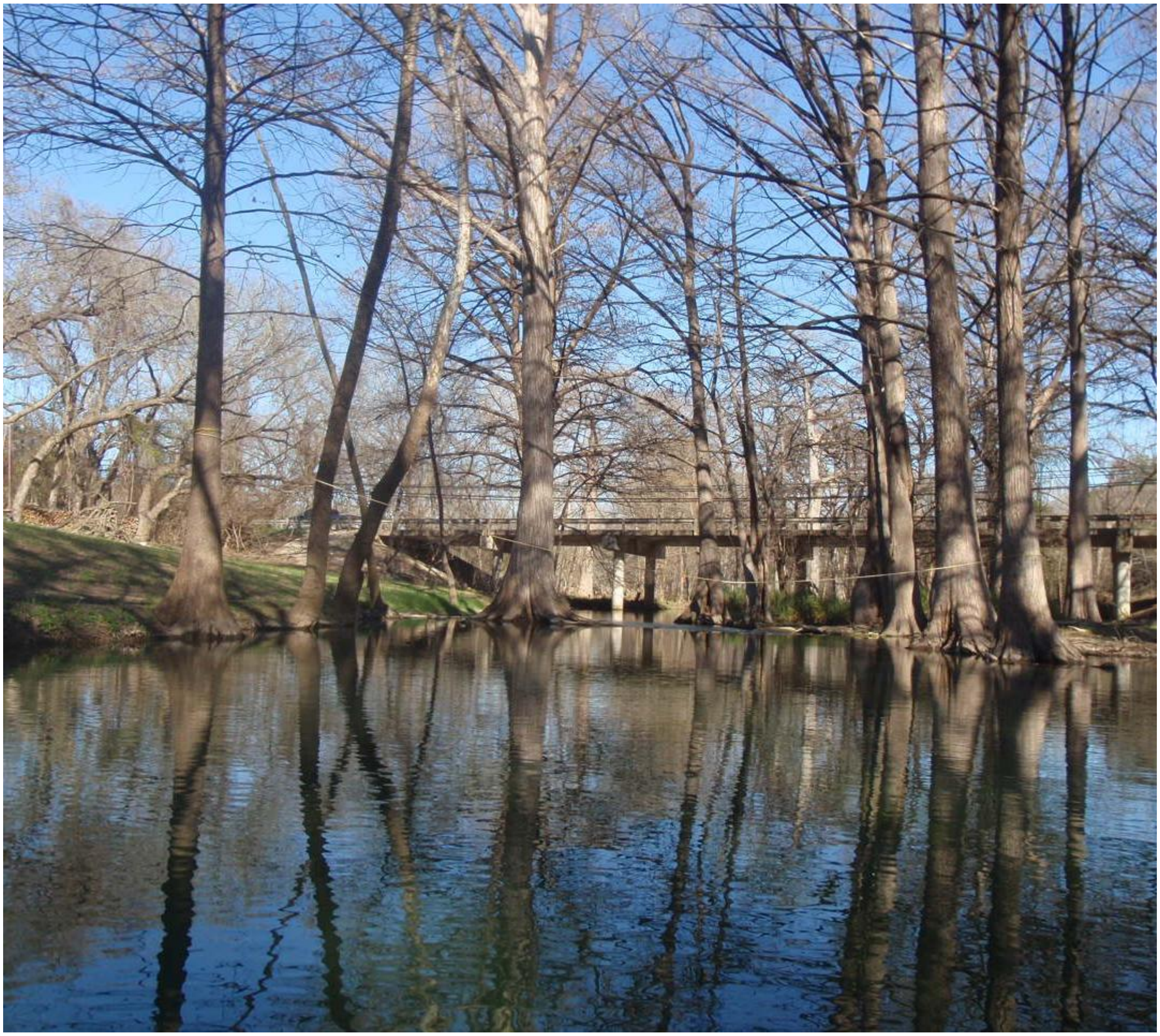
Cypress Creek Project
Watershed Characterization Report



PREPARED IN COOPERATION WITH THE TEXAS COMMISSION ON ENVIRONMENTAL QUALITY AND U.S. ENVIRONMENTAL PROTECTION AGENCY

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CYPRESS CREEK WATERSHED PROTECTION PLAN

Characterization Report

August 31, 2010

The River Systems Institute
Texas State University-San Marcos

Prepared for the Cypress Creek community, Texas Commission on Environmental Quality and U.S. Environmental Protection Agency, Region VI

Cypress Creek Project Partners (in alphabetical order):

City of Wimberley
City of Woodcreek
Cypress Watershed Committee
Hays County
Hays-Trinity Groundwater Conservation District
Guadalupe-Blanco River Authority
Texas State University-San Marcos
Texas State University-San Marcos, Watershed Science Lab
Texas Stream Team
Texas Water Development Board
The Nature Conservancy
The Texas Clean Rivers Program
Way Family Foundation
Wimberley Valley Watershed Association

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Cypress Creek Watershed Subcommittees

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List of Acronyms and Abbreviations

AGWA	Automated Geospatial Watershed Assessment tool
BFZ	Balcones Fault Zone
BMP	Best Management Practices
BOD	Biochemical Oxygen Demand
CAPCOG	Capital Area Council of Governments
CCN	Certificate of Convenience and Necessity
CCP-DSS	Cypress Creek Project Decision Support System
cm	Centimeter
cfs	Cubic feet per second
cfu	Colony forming units
CRP	Clean Rivers Program
CSA	Contributing source area
DO	Dissolved oxygen
DSS	Decision Support System
E.coli	*Escherichia coli*
EMC	Event mean concentration
ft	Foot
GIS	Geographical Information Systems
HaysCAD	Hays County Appraisal District
HTGCD	Hays Trinity Groundwater Conservation District
ISC	Impervious surface cover
km^2	Kilometer(s) squared
L	Liter
LDC	Load Duration Curve
m	meter
mg	Microgram
mm	Millimeter
mi^2	Mile(s) squared
N	Nitrogen
NOAA	National Oceanic and Atmospheric Administration
NPS	Non-point source
OSSF	On-site sewage facility
P	Phosphorus
RSI	River Systems Institute
TCEQ	Texas Commission on Environmental Quality
TSS	Total Suspended Solids
USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WISD	Wimberley Independent School District
WPP	Watershed Protection Plan
WWTP	Waste Water Treatment Plant

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Overview of Cypress Creek Project

The Cypress Creek Project is a coalition of voluntary efforts of community stakeholders, coordinated with technical and research assistance provided by River Systems Institute. The main goal for this project is to ensure that the long-term integrity and sustainability of the Cypress Creek watershed is preserved and that water quality standards are maintained for present and future generations. ***The project aims to keep Cypress Creek clean, clear, and flowing.*** A core belief is that good water quality is essential to all, and that protection of water resources is an individual as well as governmental responsibility.

Much of the Cypress Creek community recognizes that the balance between growth and protection and between regulation and the rights of individuals is tenuous. Understanding that new development is certain, there is a recognized community need to create a watershed protection plan to ensure that Cypress Creek flow and water quality conditions are maintained and remain healthy. The Characterization Report is the first of several reports about the Cypress Creek watershed. The report collates available data and information about the watershed. Information is also reported concerning the initial analyses of land use, pollution loadings in the watershed, vulnerability of the watershed to future pollution, and overall water quality. The purpose of the report is not only to bring together relevant facts and the first stages of data generation but also to provide a cohesive document as a starting point for understanding the watershed. In addition, the report contains a summary of Watershed Committee and subcommittee activities under the Cypress Creek Project.

The Cypress Creek project consists of two phases: Phase One 2008-2010 and Phase Two 2010-2012. The first phase set the process in motion that created opportunities and acquired knowledge necessary to develop a watershed protection plan. Phase Two involves development and implementation of a watershed protection plan. A watershed protection plan is a holistic document that approaches water quality and watershed issues through a collaborative approach by recommending management strategies that address more than one watershed and community concern. This Characterization Report is prepared under Phase One.

With the aid of strong Cypress Creek community partnerships, the River Systems Institute (RSI) of Texas State University-San Marcos is facilitating this project. The majority is paid for by grant funds from the Texas Commission on Environmental Quality through the U.S. Environmental Protection Agency Region VI. The River Systems Institute and Texas State University-San Marcos, along with numerous project partners, are providing substantial funds to achieve project success.

Project Overview:

The work involved in the entire project is comprised of the following:

(1) Watershed **characterization**
(2) Cypress Creek source water **delineation**
(3) **Stakeholder** participatory input process
(4) **Decision support system** development and training
(5) **Partnership** development
(6) Additional **resource development**
(7) Watershed **education**

(1) Compiling, analyzing, and **characterizing** surface water resources. Qualified information from existing sources of water quality information is used to assess water quality trends, to determine areas of nonpoint source pollution susceptibility, and to identify areas of interest concerning surface and groundwater interactions. Based on guidance from the EPA and TCEQ the characterization report will address a series of questions including: are water standards being met; is water quality threatened; are there known or expected sources causing impairment; when and where and under what conditions do impairments occur; and what are the current and future development projections and how will they affect habitat and water quality.

(2) **Delineating** the contributing and recharge zones in the Trinity Aquifer for the source waters of Cypress Creek has begun through a joint partnership with the United States Geological Survey (USGS), Hays-Trinity Groundwater Conservation District (HTGCD), and Texas State University-San Marcos (Texas State). Determining the recharge zones and features for Cypress Creek headwaters is significant due to the interconnectedness of spring flow, nonpoint source pollution susceptibility, and water quality in the Cypress Creek basin.

(3) Establish a **stakeholder process** to involve the community in project decisions and conduct a community education campaign. The stakeholders review modeling inputs and outputs, water quality information, watershed characterizations, development and other nonpoint source issues, and provide input on best management practices that may be incorporated into the Decision Support System. Surveys of the community will be designed and distributed as needed to gauge interests and priorities.

(4) Develop the **Decision Support System (DSS)** incorporating information from modeling efforts, stakeholder input and priorities, best management practices, and watershed characteristics to allow the stakeholder group to assess best management practice (BMP) options to maximize their impacts on reducing NPS pollution. Through an iterative, collaborative process involving stakeholders, the DSS is being developed to incorporate a database management system, biophysical and socio-economic models, evaluation criteria developed in stakeholder workshops, and a graphical user interface to aid decision makers in understanding the results of the model outputs. **Training** will be provided for how to use the

DSS and on how to modify the model(s) and evaluation criteria so that it may be adapted to changing future needs.

(5) Establish **partnership** efforts that help guide a stakeholder-driven process to begin the implementation of pollution prevention efforts. Project partners will seek implementation resources and initiate partnerships with the development community within the watershed. Based on results from the watershed characterization, additional resources will be sought to begin on-the-ground implementation where new developments occur in proximity to environmentally sensitive areas. The general approach is to enhance the capacity of the development community to increase BMP pollution mitigation efforts.

(6) Additional **resources** are essential for the successful development and implementation of this project. Grant awards, partner in-kind contributions, volunteers, and other resources have been and will continue to be utilized in this project.

(7) Watershed **education** is ongoing and will continue in various forms to include presentations, curriculum development, special events, education forums, meetings, website, written materials, and other forums.

Voluntary Participation

It is pertinent to emphasize that this project will aim to establish cooperative efforts that will be implemented on a voluntary basis. No one will be required to implement the management strategies recommended though the stakeholder processes; however, sustainable management of the watershed's health may not be realized unless people are willing to collectively cooperate and act to implement the recommended management measures.

Executive Summary

Understanding a watershed, its distinctive setting, physical characteristics, and water quality, is a significant step in understanding how land use change may impact water resource integrity. This Cypress Creek characterization was undertaken as a primary step towards developing a watershed protection plan. This report details the characterization of the watershed, data and analysis conducted to date, and trends in surface water resources. Based on guidance from the Environmental Protection Agency and the Texas Commission on Environmental Quality, this report addresses a series of questions including: are water quality standards being met; is water quality threatened; are there known or expected sources of pollution causing impairment; when, where, and under what conditions do impairments occur; and what are the current and future development projections and how will they affect habitat and water quality.

Located in the Hill Country of central Texas, the Cypress Creek watershed has recognizable features of the region. Fairly rugged terrain, narrow canyons, and springs dominate the landscape and provide a desirable area for residential and rural living. The terrain also reflects the underlying karstic, faulted, and fractured limestone geology of central Texas, that form the basis of the regional aquifers with excellent groundwater that are used for the majority of water supply in the area. Climate is temperate with hot dry summers and rainfall that ranges from infrequent and sparse to heavy downpours and flash flooding.

Watershed protection stems from the knowledge of how natural and man-made processes affect watershed functions. Direct pollutants from permitted sources are not found within the Cypress Creek watershed to date. However, due to the karstic limestone and the interconnectivity between rainfall, surface waters (creeks) and groundwater, the watershed and the Upper and Middle Trinity Aquifers are vulnerable to nonpoint source pollutants. Such dispersed pollutants can be part of infiltration or surface water runoff from development, animal waste, septic systems, spray and subsurface effluent irrigation systems, spills or dumping of chemical pollutants, and fertilizer applications. In addition, future development in the watershed will increase the opportunities for water quality impairments due to elevated pathogens, nutrients, sedimentation/siltation, organic enrichment, depressed oxygen levels, reduced aquifer recharge, habitat alterations, and biological impairments. Water quality in streams can directly affect water quality in the aquifer because of rapid recharge through fractures and sinkholes in streambeds. In addition, the health of the creek is highly dependent on maintaining adequate spring flows, making recharge and groundwater management in the larger region critical to maintaining a healthy system in Cypress Creek.

The watershed characterization and supporting information were compiled and assessed with a focus on identifying vulnerable areas, such as creek tributaries subject to high sediment runoff and areas with high potential for pollutant loadings. An economic assessment conducted by business and landowner stakeholders in the watershed showed that decreased water quality and quantity will not only negatively impact the creek but also land and business values.

As part of the watershed characterization, data collection and analysis of relevant parameters were undertaken to better understand the current state of water quality in the watershed. A watershed delineation analysis defined 46 subwatersheds. Monitoring stations were established to characterize rainfall, streamflows, and storm runoff data. Land use and land cover analysis allowed determination of changes over time and provided the basis for estimation of average pollutant loading. Through a comprehensive analysis of all available data, this report identifies target constituent levels for pollutants that may not have specific numeric criteria. Load duration curves, the SELECT analytical approach, and numerous statistical analysis techniques were employed to understand watershed functions.

The status of water quality was evaluated through a sampling and analysis program, including water chemistry parameters, nutrients, *E.coli*, sediments, and dissolved oxygen. The results showed impacts from both natural processes and anthropogenic activities:

- **Impervious cover** was estimated at 6% in 1996. By 2005, total impervious cover increased to 9% in the Cypress Creek watershed. A 2010 USGS study showed that healthy watershed functions are impacted at impervious cover rates as low as 10%.

- **Nitrogen** levels in the Cypress Creek reflect conditions typically observed in Hill Country karst systems where artesian springs produce the majority of baseflow. Background levels were typically higher at Jacob's Well (most upstream perennial flow location) and decrease downstream as nitrogen is assimilated. Elevated nitrogen levels were observed during high flow conditions, indicating nonpoint sources in surface runoff.

- **Phosphorus** levels were low and indicate that Cypress Creek is a phosphorus limited system. However, data show that phosphorus levels in the creek at RR12 (downtown Wimberley) have been elevated during low to moderate flow periods, indicating nonpoint sources in areas adjacent to the perennial creek.

- **Ammonia** levels were low and below the detection limit at most sites with the exception of the Cypress Creek at RR12 (downtown Wimberley) location. Elevated ammonia levels were observed at low to moderate flow conditions at this site.

- Elevated **sediment** loads were observed during low, moderate, and high flow conditions, indicating both nonpoint and localized sources. The largest increase in median sediment concentrations occurred between the RR12 north site and Blue Hole. Stakeholders have reported reduced stream clarity since 2006.

- ***E.coli*** levels were elevated at all sites, including Jacob's Well, during median and high flow periods. A cluster of very high values was observed under the highest flow conditions, indicating nonpoint source pollutants and transport of *E. coli* with higher surface and/or shallow sub-surface flows. During low flow conditions, high *E.coli* levels were observed at the Cypress Creek at RR12 downtown location. These high levels were also observed in conjunction with elevated ammonia and phosphorus levels.

- **Dissolved oxygen** (DO) varied considerably from site to site with flow and air temperature predominantly influencing these changes. Our analysis indicates that flow plays a primary role in dissolved oxygen concentrations. When streamflows are between 4 and 6 cfs, DO exceeds 6.0 mg/L at least 75% of the time. 6.0 mg/L is a dissolved oxygen target level for maintaining a healthy aquatic community.

Cypress Creek is attaining water quality standards as established by the State, but the stream does show signs of degradation. Due to its location in the fastest growing county in the nation, substantial growth and development is imminent. Stakeholders and experts have agreed that meeting State water quality standards would be insufficient to maintain the desired health and historical nature of the creek as a spring-run stream. Although this report focuses primarily on water quality associated issues, it is important to acknowledge the importance of properly managed groundwater. Efforts to maintain good water quality conditions are constrained by the reliance on adequate baseflow conditions from Cypress Creek's artesian headwaters. Community expectations of maintaining a clear, clean, and flowing stream could succeed with a unified management plan that incorporates aquifer and surface water components, spans agency jurisdictions, and is comprehensive in its approach for maintaining balance between natural resource management and economic progress.

1.0 General Watershed Information

The Cypress Creek watershed is home to a unique set of rural and urban communities, ecosystems, and a long-standing reliance on groundwater for both drinking supply and recreational uses. A detailed discussion of the geography and physical setting of the watershed is given in Section 2.0. Cypress Creek flows through unincorporated portions of Hays County and the cities of Wimberley and Woodcreek. It meets the Blanco River near the Wimberley town center (Figure 1.1).

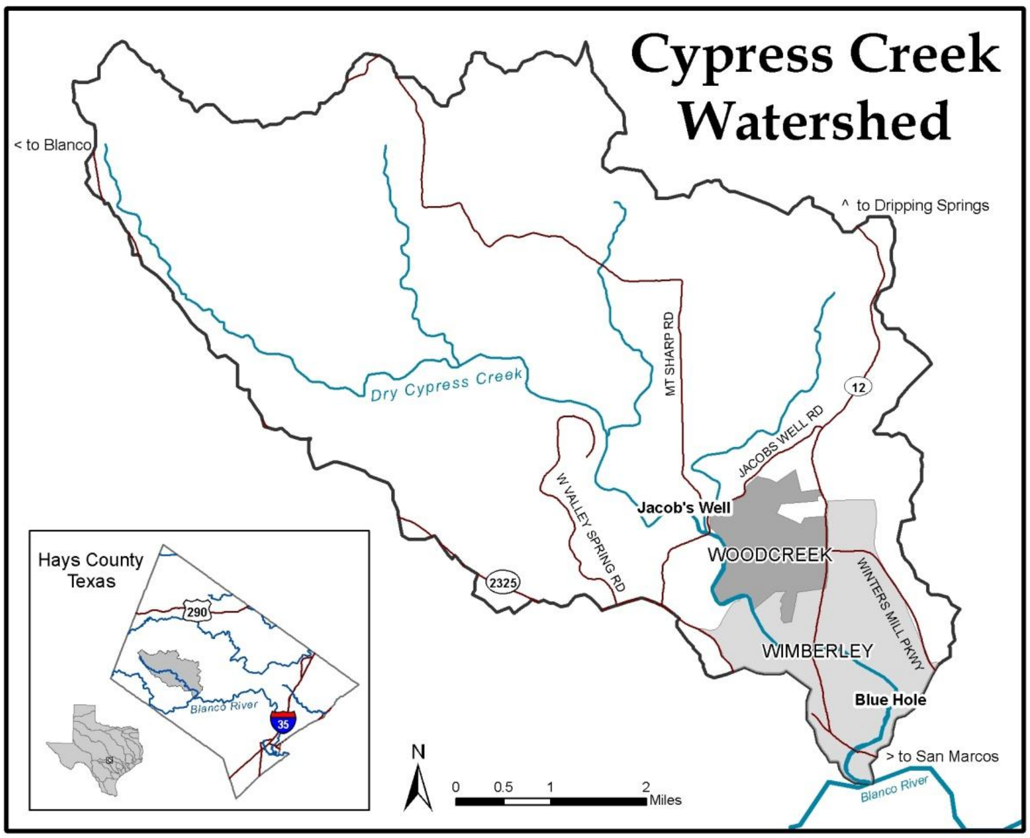


Figure 1.1 Cypress Creek watershed, central Texas.

About five and a half miles upstream of the confluence, near the City of Woodcreek, is Jacob's Well, the headwaters of the perennial Cypress Creek. This artesian spring is considered the lifeblood of the community as it perennially feeds water to the lower third of the creek. Jacob's Well is an expression of underground water stored in the Trinity Aquifer that discharges at the land surface. During rain events, however, water flows downhill from the distant hilltops in the watershed and into the creek. Once the water is in the creek bed, part of it flows back underground into the aquifer. Flow between land surface and the subsurface creates a complex interaction between groundwater and surface water in the Cypress Creek watershed as well as unique features such as Jacob's Well.

The watershed's excellent water quality is shown in the health of the ecosystems as well as drinking and recreational water quality. The creek offers habitat to a diverse number of species, including fishes, water fowl, reptiles and amphibians, mammals, and insects. In 2000, however, the lower 5.5 miles of the Cypress Creek made the U.S. Environmental Protection Agency (USEPA) impaired stream segment list (also known as the 303(d) list) because of a quantity of dissolved oxygen lower than needed to support aquatic life. The degraded water quality correlated with the creek's recorded low flow of 0.33 cubic feet per second (cfs) in July of 2000.

This report documents the work to date involved in the Cypress Creek Project, a consortium of stakeholder groups, watershed and water quality experts dedicated to improving and maintaining the health and unique characteristics of the watershed. The purpose of this report is to define the Cypress Creek watershed in terms of physical characteristics, water quality, its history, development, and land use in order to help stakeholders and decision makers understand the watershed. The following subsections provide an introduction to concepts and terms commonly used throughout the report.

1.1 Watershed Definition

A watershed is an area of land that contributes water, nutrients, pollutants, and sediments to a common downstream point such as a stream, river or lake. Watersheds can be large or small. When it rains, water moves downhill across the surface or underground. Moving farther downhill by force or gravity, the water converges into a progressively larger system. The Cypress Creek watershed, located around the City of Wimberley in Hays County, central Texas, has a total area of about 38 square miles (mi^2) or 98 square kilometers (km^2). Downstream of Wimberley, Cypress Creek joins the larger Blanco River watershed with a land coverage area of approximately 500 mi^2 (1,295 km^2).

Though watersheds are defined by their landscape characteristics, natural forces and human activities can influence the hydrologic nature of watersheds. Climatic conditions over time have measurable effects such as creek bank erosion due to flash flooding. Human activities and the political and institutional environments within a watershed can also have significant effects. The Cypress Creek watershed is a rapidly urbanizing ecosystem under increasing demands from a variety of sources. For example, should Hays County continue to experience the high growth rates of the 1990's, the population of Hays County may grow from 97,589 in 2000 to as much as 570,869 in 2040 (Texas State Data Center, 2009). While this projection is for the entire county, due to the natural beauty and desirable rural living conditions much of this growth is anticipated to occur either within the Cypress Creek watershed or the adjacent aquifer recharge and contributing zones.

1.1.1 Surface Water

Surface water bodies are those that store water or through which water flows. Water that falls onto the earth from precipitation and continues to flow overland or in channels such as creeks, tributaries, and rivers, or is stored for some period of time in natural lakes or reservoirs, is considered surface water. In climates with low rainfall or seasonally high temperatures, surface water can be easily evaporated to the atmosphere. Surface water may also infiltrate into the vadose zone, the non-saturated soil layers found below ground level. Surface water that percolates to water-saturated strata becomes part of the groundwater table (Figure 1.2). When water moves between surface water bodies and groundwater, for example through groundwater discharges to a stream, such movement is known as surface water-groundwater interactions. Understanding surface water flow and its movement as affected by a range of factors is especially critical for defining the volume of water available within a watershed for both aquatic ecosystems and its human inhabitants.

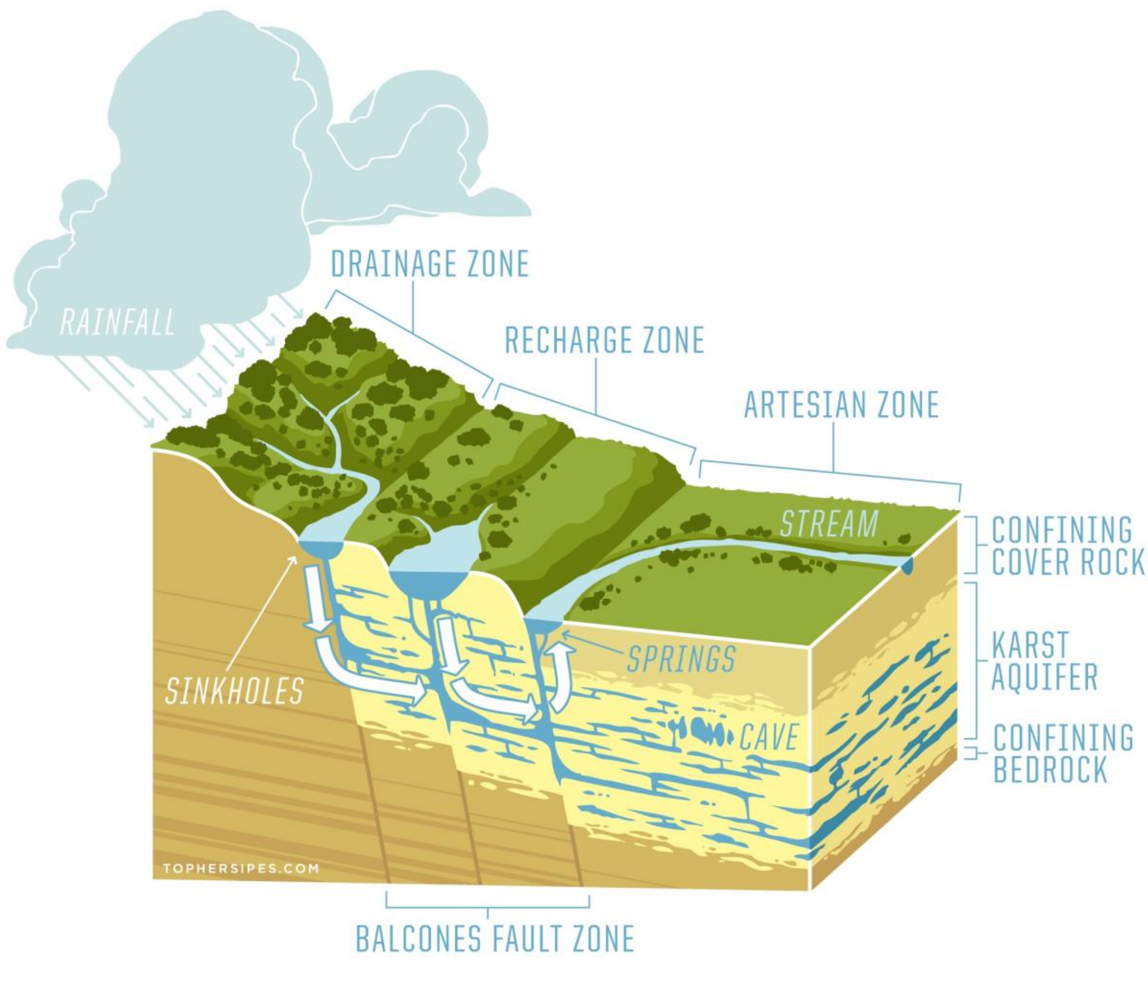


Figure 1.2. Diagram of surface water recharge to groundwater. Courtesy of Topher Sipes.

1.1.2 Groundwater

Groundwater is subsurface water that saturates and moves through the subsurface soils or rocks. It is water that has percolated below the vadose, or soil moisture, zone down to the saturated zone often referred to as a "water table" aquifer. Water fills the pore spaces in the soils, and the saturation pressure is equal to that of the atmosphere. Groundwater flow in a water table, or unconfined, aquifer is dominated by gravity-driven, or generally downhill, flow through the soil or rock layers. Groundwater in a confined or pressurized aquifer moves under pressure, but is restricted by overlying soil or rock layers that allow very little vertical water movement. The confined groundwater moves through the more permeable layers to discharge at springs or moves into deeper, downgradient geologic layers.

Groundwater is said to be "stored" in an aquifer, though the volume stored and its residence time varies greatly. Some aquifers support very slow flows and the groundwater can be dated to thousands of years in residence, while others support much more rapid flow through the overall water system. In fact, aquifers can have greatly different characteristics even if the rock type is similar. Understanding an aquifer and its flow of groundwater depends on the type of rock layers, the degree of porosity and connections between different layers, the rate of recharge from upgradient waters, the type of discharges in the system, and other related information. Groundwater can provide the physical water "bank" below a watershed. Though it is more difficult to define, groundwater can be as essential to the health of a watershed as the more easily observed and used water in streams.

1.1.3 Point Source Pollution

Point source pollution is a single, identifiable source of pollution such as a discharge from a municipal or industrial wastewater treatment plant. Point sources are regulated under the Clean Water Act and Texas state law and are subject to permit requirements that focus on water quality protection. These permits specify effluent limits, monitoring requirements, and enforcement mechanisms. To date, there are no identifiable point sources of pollution in the Cypress Creek watershed.

1.1.4 Nonpoint Source Pollution

Nonpoint source (NPS) pollution is caused by wind, rainfall, and snowmelt carrying pollutants to surface water and groundwater systems. Because moving water is the most common driving force of nonpoint source pollutant movement into a waterway, the amount of pollution from nonpoint sources varies over time and location. In a rural-to-urbanizing system such as the Cypress Creek watershed, nonpoint source pollution threats arise from a variety of human-based activities, including but not limited to increased intensity of land use, construction, alteration of natural drainage densities, and soil compaction. Fortunately, NPS pollution can be minimized through careful planning and land management practices, and public education to prevent negative impacts.

NPS pollution and detection does not lend itself directly to the traditional discharge control method that involves routine sampling from a treatment facility's permitted outfall pipe, testing for likely contaminants, and comparison to ensure permitted pollution standards are met. Rather, the nonpoint sources are widely dispersed across a landscape, making it difficult to define each source location and the impact of its contributing load to the concentration of oxygen or pollutants in the creek. Years of NPS pollution research have instead shown the most applicable solutions to come from workable land management practices, education about nonpoint source concerns, and changes through social and economic actions.

Urban NPS pollution typically moves via surface runoff and generally includes suspended and dissolved solids, bacteria, metals, oxygen demanding substances, nutrients, oil and grease, and pesticides. NPS pollution sources include vehicles, construction activities, fertilizer and pesticide application, erosion, animal wastes, and atmospheric deposition. NPS pollutants associated with agricultural areas include nutrients, pesticides, organic matter, and animal wastes, any of which can be transported in solution, suspended in surface runoff, or adsorbed onto eroded soil particles (Baird et al., 1996). Browne (1989) provides an overview of NPS pollution that stresses the following:

- Nonpoint sources are diffuse, cover substantial areas, and act either in response to human activity or as "background pollution" from natural lands.
- NPS pollution is related to land management, geologic, and hydrologic variables which may vary over time. Only the land management factors may be controlled by society.
- NPS pollutants are generated and transported as part of the hydrologic cycle. Surface runoff transports eroded soil particles from pervious areas, and picks up and transports pollutants deposited on impervious areas. Groundwater transports pollutants from septic tanks and landfills.
- Urban runoff includes suspended solids, bacteria, metals, oxygen-demanding substances, nutrients, and oil and grease. Sources of these pollutants include vehicles, fertilizer and pesticide application, animal wastes, spills or dumping of chemical waste, construction activities, and road salting.
- Non-urban pollutants are often related to agricultural activities. Agricultural pollutants include pesticides, sediments, nutrients, and organic materials. NPS loading from agricultural areas tends to be seasonal with higher loading associated with planting and harvesting activities.

Because of its unique geologic setting and the high degree of connectedness between surface- and ground-waters in this area of central Texas, the Cypress Creek watershed and adjacent aquifer recharge and contributing zones of the lower Trinity Aquifer may be particularly susceptible to NPS pollutants from development, septic systems, spray and subsurface effluent irrigation systems, fertilizer applications, and more direct public health threats from leaking petroleum storage tanks. Future development will increase opportunities for water quality impairments for pathogens, nutrients, sedimentation/siltation, organic enrichment and depressed oxygen levels, habitat alterations, and biological impairments. At the same time, future development may also strain local groundwater resources, impacting aquifer levels and springs that provide critical baseflow. The watershed planning and protection process is intended to specifically address and minimize such possible degradation of the watershed.

1.2 Watershed Protection Plan

Since the late 1980s, watershed organizations, tribes, and federal and state agencies have moved toward managing water quality through a watershed approach. A watershed approach is a flexible framework for managing water resource quality and quantity within specified drainage areas, or watersheds. This approach includes stakeholder involvement and management actions supported by sound science and appropriate technology.

Because watersheds are determined by the landscape and not political borders, watersheds often cross municipal, county, and state boundaries. By using a watershed perspective, all potential sources of pollution entering a waterway can be better identified and evaluated. Just as important, all stakeholders in the watershed can be involved in the process. A watershed stakeholder is anyone who lives, works, or engages in recreation in the watershed. They have a direct interest in water quality issues and will be affected by planned efforts to address these. Individuals, groups, and organizations within a watershed can become involved as stakeholders in initiatives to protect and improve local water quality. Stakeholder involvement is critical to successful improvement of water quality through selection, design, and implementation of management measures (Berg et al., 2008).

The *watershed planning process* works within this framework by using the following:

- A series of cooperative, iterative steps to characterize existing conditions,
- Identification and prioritization of problems,
- Definition of management objectives,
- Development of protection or remediation strategies, and
- Implementation and adaptation of selected actions as necessary.

The outcomes of this process are documented or referenced in a *watershed protection plan (WPP),* a strategy that provides assessment and management information for a geo-graphically defined watershed. The plan includes the analyses, actions, participants, and resources related to developing and implementing the plan. Most watershed protection plans follow the outline of the U.S. Environmental Protection Agency *Handbook for Developing Watershed Plans to Restore and Protect Our Waters* (USEPA, 2008). The development of watershed plans requires a certain level of technical expertise and the participation of a variety of people with diverse skills and knowledge. Using a watershed approach to restore impaired water bodies is beneficial because it addresses the problems in a holistic manner, and the stakeholders in the watershed are actively involved in selecting the management strategies that will be put into practice to solve the problems. NPS pollution poses the greatest threat to water quality and is the most significant source of water quality impairment in the nation. Therefore, USEPA is working with states, tribes, and watershed groups to realign its programs and strengthen support for watershed-based environmental protection programs.

Based on available information, the Cypress Creek watershed protection plan will include management, funding, and implementation strategies that will improve water quantity, quality and the health of watershed in the face of land use changes. The basis is voluntary stakeholder involvement, input, feedback, and stewardship, along with selected technical expertise and state water agency guidance throughout the process of WPP development and implementation. The development of the WPP is not the final answer to water challenges over time; rather, it is a starting point. New information will undoubtedly be discovered within and adjacent to Cypress Creek as the implementation process is carried out and will add to the collective knowledge of how to better manage the watershed. Additional information and data will be incorporated into the plan to improve management strategies, refine the areas where specific measures will be incorporated, and to better focus available resources so as to achieve maximum water quality benefits.

1.2.1 Adaptive Management

Watershed management that focuses on a holistic approach to defining water quality problems and workable solutions requires an iterative process. Such a process can be simplified to a cycle of "plan development, implementation, evaluation, and changes as necessary," followed by additional iterative cycles (USEPA, 2008). During the WPP development, multiple steps may be concurrent. During collection and analysis of available data, stakeholder discussions target priorities in water quality issues that are specific to the watershed. It is unlikely, however, that all data necessary to understand water quality impairment may be available or that stakeholder concurrence on all issues and possible solutions will be agreed upon during the early cycles of the WPP. Adaptive management through these information-decision-implementation cycles supports changes to the WPP and its realization. The results are anticipated to improve water quality and watershed management through positive actions supported by the watershed stakeholders.

2.0 Geography

2.1 Description of Watershed

Located in the Hill County area of central Texas in southern Hays County, Cypress Creek is a tributary of the Blanco River. The Cypress Creek watershed trends northwest to southeast, and the creek flows through the cities of Woodcreek and Wimberley. The confluence of the creek and the Blanco River is on the south side of Wimberley, just upstream from the Blanco River/RR12 junction. To the north, the Onion Creek watershed drains to the Colorado River. The Cypress Creek watershed encompasses approximately 38 mi^2 (98 km^2), most of which is in low-intensity ranching except for dense residential development in Woodcreek and commercial/residential development in the City of Wimberley.

Based on historic streamflows, Cypress Creek can be subdivided into dry and flowing segments (HTGCD, 2008). Unless a major rainfall takes place, the 9.5-mile segment above Jacob's Well is usually dry (Figure 2.1). The spring at Jacob's Well augments creek flows during the year for the downstream, 5.5-mile long stream segment trending southeast of Jacob's Well. The downstream segment is referred to as Cypress Creek. The stream gradient of the lower part of the creek is calculated at 21.4 feet per mile.

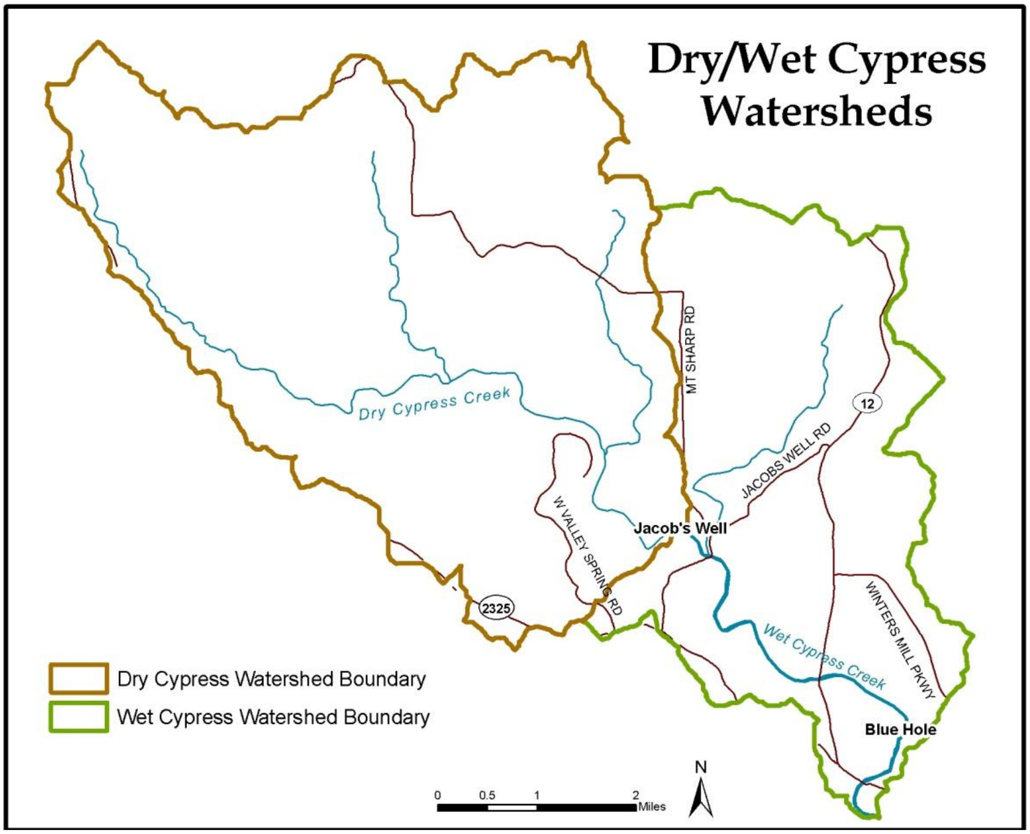


Figure 2.1. Dry and flowing segments of Cypress Creek.

2.2 Climate, Temperature, and Rainfall

Climate in central Texas can be characterized as semi-arid due to average rainfalls and temperatures and their effects on the land. Using data from 1971-2000, average annual temperature in Hays County was 76 to 78 ^{o}F (24.4 - 25.6 ^{o}C), average annual rainfall was around 35 inches (889 mm), and during the years 1950-1979, annual gross lake surface evaporation averaged around 60-65 inches (1,524 – 1,651 mm) (TWDB, 2007). The region has also experienced extremes in weather patterns, observed over the decades as flash floods and droughts.

Climate in the study area follows the general pattern of the Hill Country; peak rainfall tends to occur in the summer and fall. For example, at the Fischer's Store gauge that is located about 6 miles (9.6 km) west-southwest of the watershed, 23% of annual rainfall occurs between May and June, while 30% occurs between September and November (Figure 2.2).

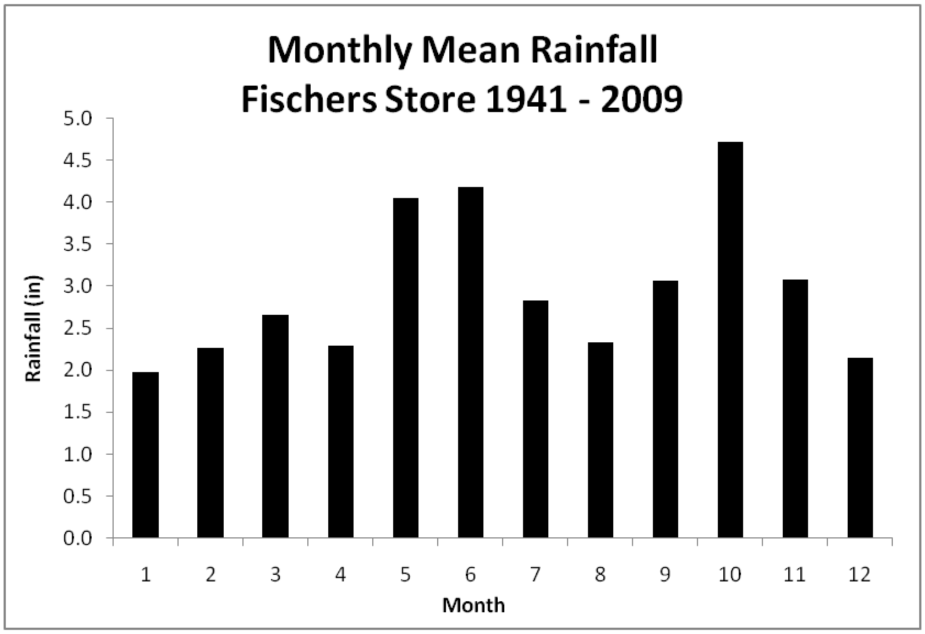


Figure 2.2. Monthly mean rainfall at Fischer's Store (1941 – 2009).

Temperature in the area is highest from May through October, resulting in fairly predictable summer weather patterns (Figure 2.3). The period of July through September is often both hot and dry, with average daily temperatures above 80^{o}F (26.67 ^{o}C) and little rainfall. Since water quality in the Cypress Creek is highly dependent upon flow, summer months are the most likely to have water quality impairments in the creek including low dissolved oxygen, high algal density, and increased water temperature.

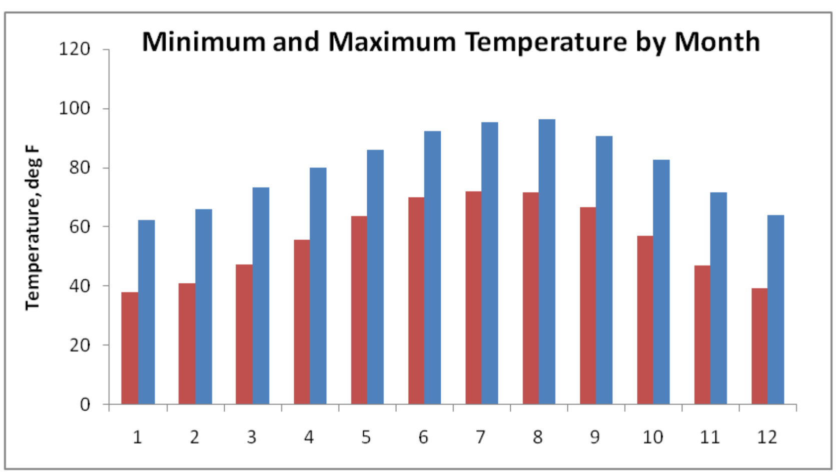


Figure 2.3. Monthly temperature ranges in Cypress Creek watershed.
Mean minimum and maximum temperatures recorded at the National Weather Service's San Marcos station from 1901 to 2007.

2.2 Topography and Karst Features

This watershed is a part of the Edwards Plateau region of the Texas Hill Country. The topography of the Hill Country varies from hills of predominantly karstic limestone terrain to plateaus that serve as major recharge zones to the underlying Edwards, Edwards-Trinity, and Trinity Aquifers (Longley, 1986). The hills are characterized by unstable inter-bedded limestone, shale and clays (Riskind and Diamond 1986). The limestone plateaus are karstic, thus the dissolved bedrock can provide many conduits for recharge from rain events. Spring-fed waterways such as Cypress Creek dissect the hills and provide recharge to underlying aquifers.

Slopes are higher in the northern portion of the watershed, where there are many of the characteristic hills that make up the Hill Country region, and slope generally decreases toward the City of Wimberley near the outlet of the watershed (Figure 2.4). Urban development has thus far been concentrated in the lower third of the watershed around Woodcreek and the City of Wimberley. Therefore the highest risk for excess sediment flow in the creek due to high slope comes from agriculture (primarily grazing) activities in the upper and northern portions of the watershed, and in bottomland areas the primary threat for excess sediment flow results from development activities and land clearing. Numerous cliffs and deep valleys typify the topography of the watershed. Elevations range between 812 and 1,571 ft (247 to 479 m) above mean sea level. Approximately 759 feet (231.5 m) of topographic relief is found across the study area.

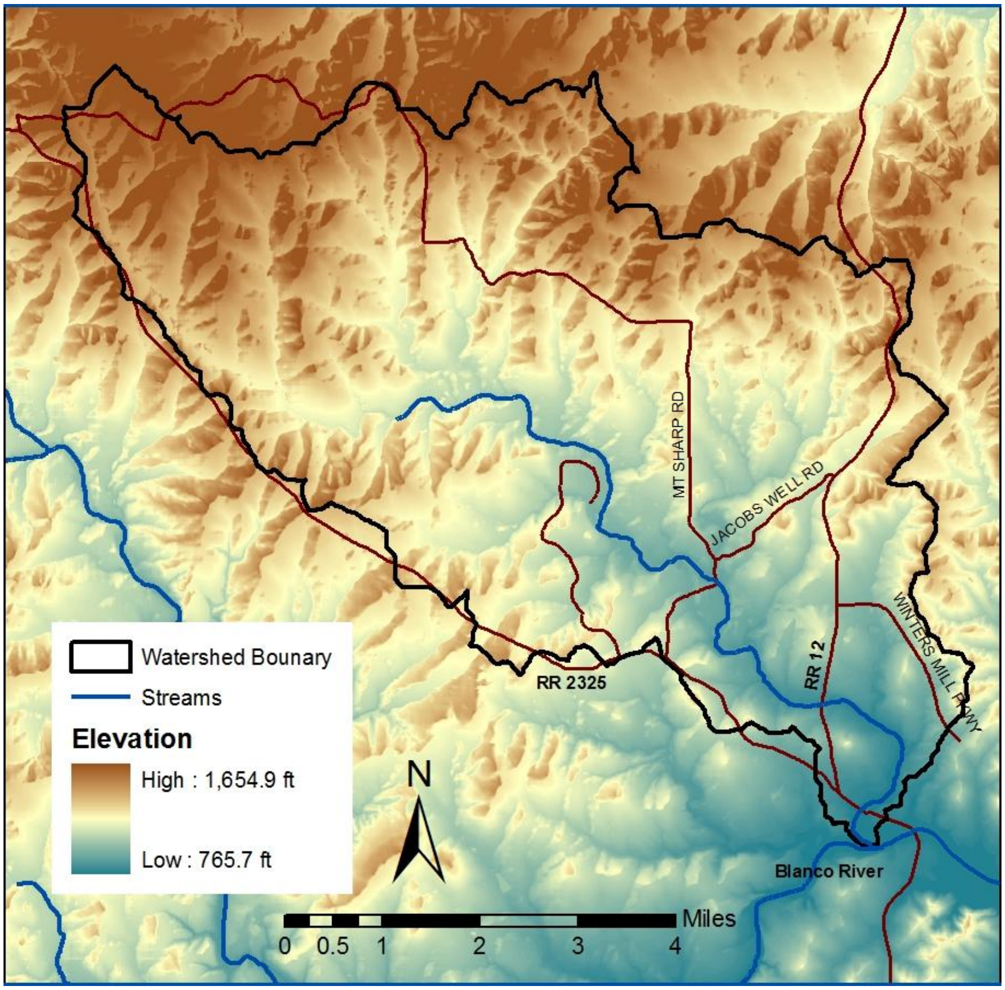


Figure 2.4. Watershed topography.

The Cypress Creek watershed is predominately a karstic limestone region. Karst areas contain soluble rocks, such as limestone, whose structures are dominated by occasionally, but not necessarily, interconnected conduits created by dissolution. Water and its interaction with the rock take hundreds of thousands to millions of years to create these features. Unique characteristics of karst areas include (1) a general lack of permanent surface streams; (2) swallow holes into which surface streams sink; (3) underground channels (conduits or drains) in which rapid water flow occurs; and (4) the occurrence of large springs (Kacaroglu, 1999).

Karst areas are highly susceptible to groundwater contamination for several reasons. The dissolved rocks form conduits and channels for underground flow and increase the ability of water to enter into these conduits from the surface. Secondly, the protective rock and soil deposits normally found in non-karst systems are minimal, making the system more vulnerable. Particularly in urbanizing areas, construction can destroy the few covering layers of karst rocks and increase the risk of pollution. Not only is pollution entry into the system a concern, high velocities of groundwater flow through the conduits can also be problematic. Fast pollution transport rates can create detrimental consequences without sufficient time to identify the causes and prevent the effects (Kacaroglu, 1999).

In the Cypress Creek watershed as in much of the Hill Country, karstic features are found throughout the landscape (Figure 2.5). Rounded limestone hills, cliffs and narrow valleys, springs and seeps are all part of this landform. Rock layers that alternate between easily eroded and hard rock form jagged cliff profiles and overhangs. The exposed limestone formation along Cypress Creek is a key karst feature that supports groundwater recharge to the underlying aquifer (HTGCD, 2008).

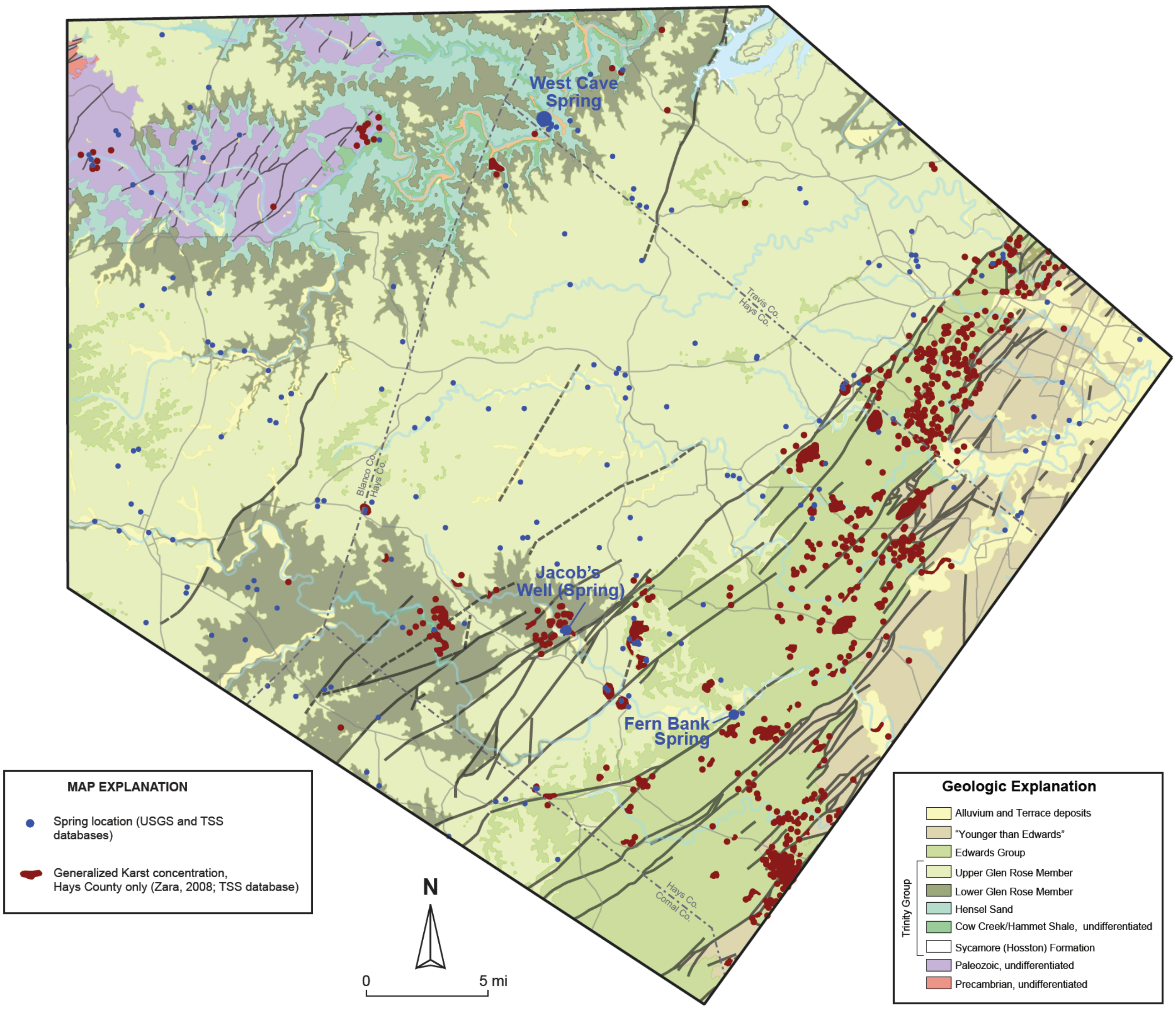


Figure 2.5. Generalized karst features, courtesy of HTGCD.

2.3 Soils

Soils in the watershed are predominantly shallow clay loams and shallow clays such as the Brackett-Rock outcrop-Comfort complex (41.5%) and the Brackett-Rock outcrop-Real complex (15.3%) on the uplands; and shallow stony clays such as the Comfort-Rock outcrop complex (17.9%) and the Real-Comfort-Doss complex (5.6%) on hill slopes. The remaining 20 % of the watershed is a mix of deep clay and clay loam uplands and hydric loamy bottomland soils along creek beds in the lower portion of the watershed (Figure 2.6). Table 1 gives the types and relative area of soils present in the watershed. Soil classes are based on the Natural Resources Conservation Service (NRCS) soil survey geographic database (NRCS, 2008).

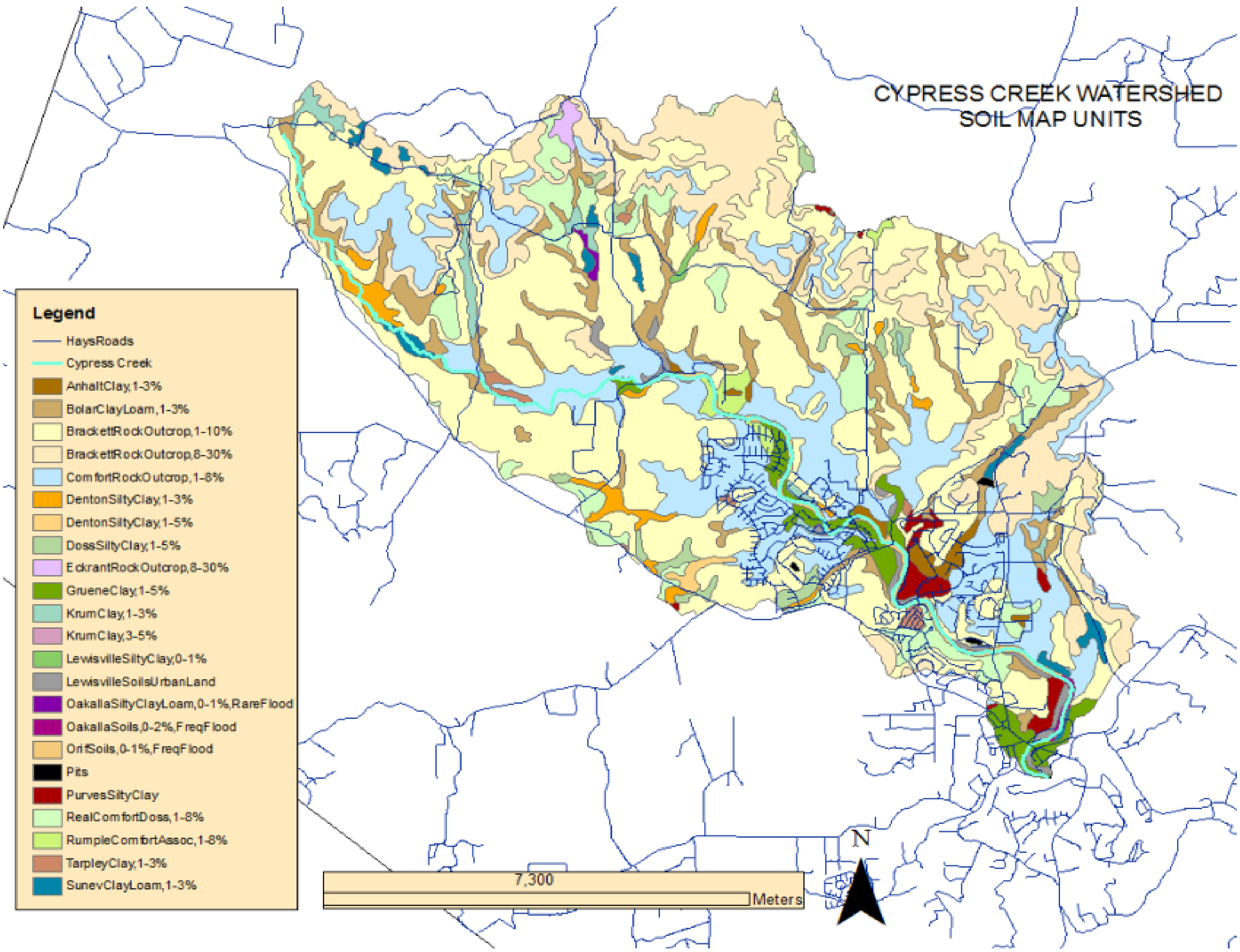


Figure 2.6. Soil units in the watershed.

Table 2.1. Soil types and relative areas present in the watershed (NRCS, 2008).

Soil Type	Area (mi^2)	% of total	Description
BtD	15.79	41.54	Brackett-Rock outcrop-Comfort complex, 1 to 8 percent slopes
CrD	6.80	17.88	Comfort-Rock outcrop complex, 1 to 8 percent slopes
BtG	5.83	15.34	Brackett-Rock outcrop-Real complex, 8 to 30 percent slopes
BrB	2.60	6.82	Bolar clay loam, 1 to 3 percent slopes
RcD	2.14	5.62	Real-Comfort-Doss complex, 1 to 8 percent slopes
GrC	0.85	2.24	Gruene clay, 1 to 5 percent slopes
DoC	0.60	1.56	Doss silty clay, 1 to 5 percent slopes
DeB	0.54	1.43	Denton silty clay, 1 to 3 percent slopes
SuB	0.42	1.11	Sunev clay loam, 1 to 3 percent slopes
Or	0.39	1.03	Orif soils, 0 to 1 percent slopes, frequently flooded
KrB	0.38	1.01	Krum clay, 1 to 3 percent slopes
PuC	0.37	0.98	Purves clay, 1 to 5 percent slopes
LeB	0.29	0.76	Lewisville silty clay, 1 to 3 percent slopes
AnB	0.26	0.68	Anhalt clay, 1 to 3 percent slopes
RUD	0.24	0.64	Rumple-Comfort association, 1 to 8 percent slopes
TaB	0.16	0.42	Tarpley clay, 1 to 3 percent slopes
ErG	0.10	0.25	Eckrant-Rock outcrop complex, 8 to 30 percent slopes
DeC3	0.09	0.25	Denton silty clay, 1 to 5 percent slopes, eroded
Ok	0.05	0.15	Oakalla soils, 0 to 2 percent slopes, frequently flooded
Oa	0.04	0.10	Oakalla silty clay loam, 0 to 1 percent slopes, rarely flooded
LeA	0.04	0.10	Lewisville silty clay, 0 to 1 percent slopes
Pt	0.03	0.08	Pits
KrC	0.00	0.002	Krum clay, 3 to 5 percent slopes

2.4 Vegetation

Vegetation on the hilltops is often sparse because of thin layers of topsoil. In the northern portion of the study area, shallow or disturbed soils support evergreen shrubs and grasses. Woodlands of juniper, oak and mesquite are interspersed along the hillsides and, towards the bottom of the slopes, more native grasses can be found. The plateau-like uplands in the western portion of the watershed support woody species such as Ashe Juniper (*Juniperus ashei*), Texas Oak (*Quercus buckleyi*), and Lacey Oak (*Quercus laceyi*) along with grasses. In the lower portion of the watershed along the floodplain and stream course of Cypress Creek, deciduous stands of Bald Cypress (*Taxodium distichum)*, Sycamore (*Platanus occidentalis*), and Black Willow (*Salix nigra*) exist (Riskind and Diamond, 1986). Grasses commonly found include Little bluestem (*Schizachyrium scoparium*), Curly mesquite (*Hilaria belangeri*), Texas wintergrass (*Stipa leucotricha*), White tridens (*Tridens muticus*), Texas cupgrass (*Eriochloa sericea*), Tall dropseed (*Sporobolus asper*), Seep muhly (*Muhlenbergia reverchonii*), Hairy grama (*Bouteloua hirsuta*), and Side oats grama (*Bouteloua curtipendula*; Riskind and Diamond, 1986).

2.5 Aquatic Life

Recent aquatic life monitoring and habitat assessments conducted by TCEQ between Jacob's Well and the Blanco River confluence from 2002 to 2007 revealed the presence of an intermediate to high aquatic life use in Cypress Creek based upon the index of biotic integrity (IBI) developed for the Central Texas Plateau (Linam et al., 2002; Walther and Palma, 2005). The IBI provides a means of assessing the overall health of the aquatic life in a river. Similar assessment tools are typically applied to the benthic macroinvertebrate, habitat, and water quality data, which contribute to an overall aquatic life use designation. Possible rankings include exceptional, high, intermediate, and limited. Fish collections yielded a total of 22 species in eight families, including at least one species that has been shown to be sensitive to organic enrichment, the greenthroat darter (*Etheostoma lepidum*; Linam and Kleinsasser 1998). The most numerous species collected were the green sunfish (Lepomis cyanellus), spotted sunfish (*Lepomis punctatus*), central stoneroller (*Campostoma anomalum*), Texas shiner (*Notropis amabilis*), Rio Grande cichlid (*Cichlasoma cyanoguttatum*), and western mosquitofish (*Gambusia affinis*).

2.6 Endangered Species

The caves, seeps, sinkholes, springs and vegetative cover in the Hill Country region provide habitat to many federally endangered species such as the Golden-cheeked warbler (*Dendroica chrysoparia*), Black-capped-vireo (*Vireo atricapilla*), San Marcos salamander (*Eurycea nana*), Texas blind salamander (*Eurycea rathbuni*), San Marcos Gambusia (*Gambusia gerogei*), Comal Springs drypoid beetle (*Stygoparnus comalensis*) and Texas wild-rice (*Zizania texana* (TPWD, 2008).

Recent sampling in the area of Jacob's Well and nearby stream segments demonstrated results of interest to threatened species in the area (Zara Environmental, 2009); see Appendix A. With regard to benthic macroinvertebrate assemblages, three of the genera identified in the Zara 2009 study have congeners that are state listed species of concern (*Elmia*, *Hyalella* and *Callibaetis*), and one genus has a congener that is endemic to the state of Texas (*Ceratopogon*). A Golden-cheeked Warbler (*Dendroica chrysoparia*) was identified by song approximately 10 meters from the spring. No federally listed aquatic species have been confirmed at the site.

2.7 Geology and Water Resources

As noted in previous sections in this report, the geology of the Hill Country region plays a significant role in the development of the landscape, soils, and water resources. The following sections are adapted from the Hays-Trinity Groundwater Conservation District (HTGCD)'s detailed report on the geology and hydrogeology in the Cypress Creek watershed, including analysis of groundwater flows around Jacob's Well (HTGCD, 2008).

2.7.1 Overview of Geologic Strata

Geologic rock formations in the Cypress Creek watershed are primarily limestone with some Quaternary sediments found along creek beds. The rock strata are identified as basal conglomerates and limestones of the Trinity Group, formed during cyclical development of shallow seas in the Cretaceous. The Trinity Group is comprised of seven formations with distinct characteristics. Hydrogeologically, the formations are recognized as the Lower, Middle, and Upper Trinity Aquifers due to variations in lithology and water production characteristics. The deepest geologic unit of these three is the Lower Trinity, estimated at 300 feet thick. It is comprised of two formations, the Sycamore/Hosston basal conglomerate and sand and the Sligo Formation, an interbedded dolomite, sandstone, siltstone, and limestone formation. A confining zone, the Hammett Shale, separates the Lower and Middle Trinity aquifers. The Middle Trinity Aquifer contains three formations, of which the Cow Creek Member and the Lower Glen Rose formations are water producing, separated by the Hensel Member, a semi-confining zone. The Upper Trinity Aquifer contains multiple strata of the Upper Glen Rose Formation. The three strata exposed at land surface within the watershed are the lower Glen Rose of the Middle Trinity Aquifer, the upper Glen Rose of the Upper Trinity Aquifer, and Quaternary sediments (Figure 2.8).

Of note are the multiple faults trending northeast-southwest throughout the region. These normal faults may have downdropped the Trinity Group as much as 1,200 feet to the southeast, juxtaposing rocks of the Edwards Group against the Trinity Group just southeast of the Cypress Creek watershed.

2.7.2 Groundwater Resources in the Trinity Aquifer

Other than a small number of individual residential rainwater harvesting systems, the Wimberley Valley is primarily dependent on groundwater for its potable water. With the continued rapid growth and development of the Wimberley Valley, and several hot, dry Texas summers, a great deal of pressure has been placed on the groundwater resources of the community. Researchers with the Groundwater District have estimated that at current pumping rates water levels in the Trinity Aquifer are being depleted by 1 foot per year in the Wimberley area.

Figure 2.7. Jacob's Well. Photo by Vanessa Lavender.

2.7.3 Jacob's Well

Jacob's Well, a Middle Trinity Aquifer artesian spring, provides the majority of flow in Cypress Creek and has been described as the "heart and soul" of the Hill Country. Blue Hole, located in Cypress Creek just upstream of Wimberley, is a swimming hole that has been enjoyed by generations of local residents and considered one of the top swimming holes in Texas (HTGCD, 2008).

The opening of Jacob's Well (Figure 2.7) in the bed of Cypress Creek occurs in the Lower Glen Rose unit of the Middle Trinity Aquifer. The nearly vertical shaft of Jacob's Well probably follows a former fracture or joint set that has been enlarged by solution activity. Approximately 70 feet below the mouth of the spring is the contact between the Lower Glen Rose and Hensel Member. There are two large caverns at the contact. At 100 feet is the contact between the Hensel and Cow Creek. The passageway becomes roughly parallel to the horizontal bedding and continues several thousand feet in a karst zone of the Cow Creek.

(Figure 2.8). At the current time divers have mapped in excess of 5,000 feet of passages linked to Jacob's Well. Several passages terminate in constrictions that divers cannot proceed beyond; others are still in the process of being fully explored.

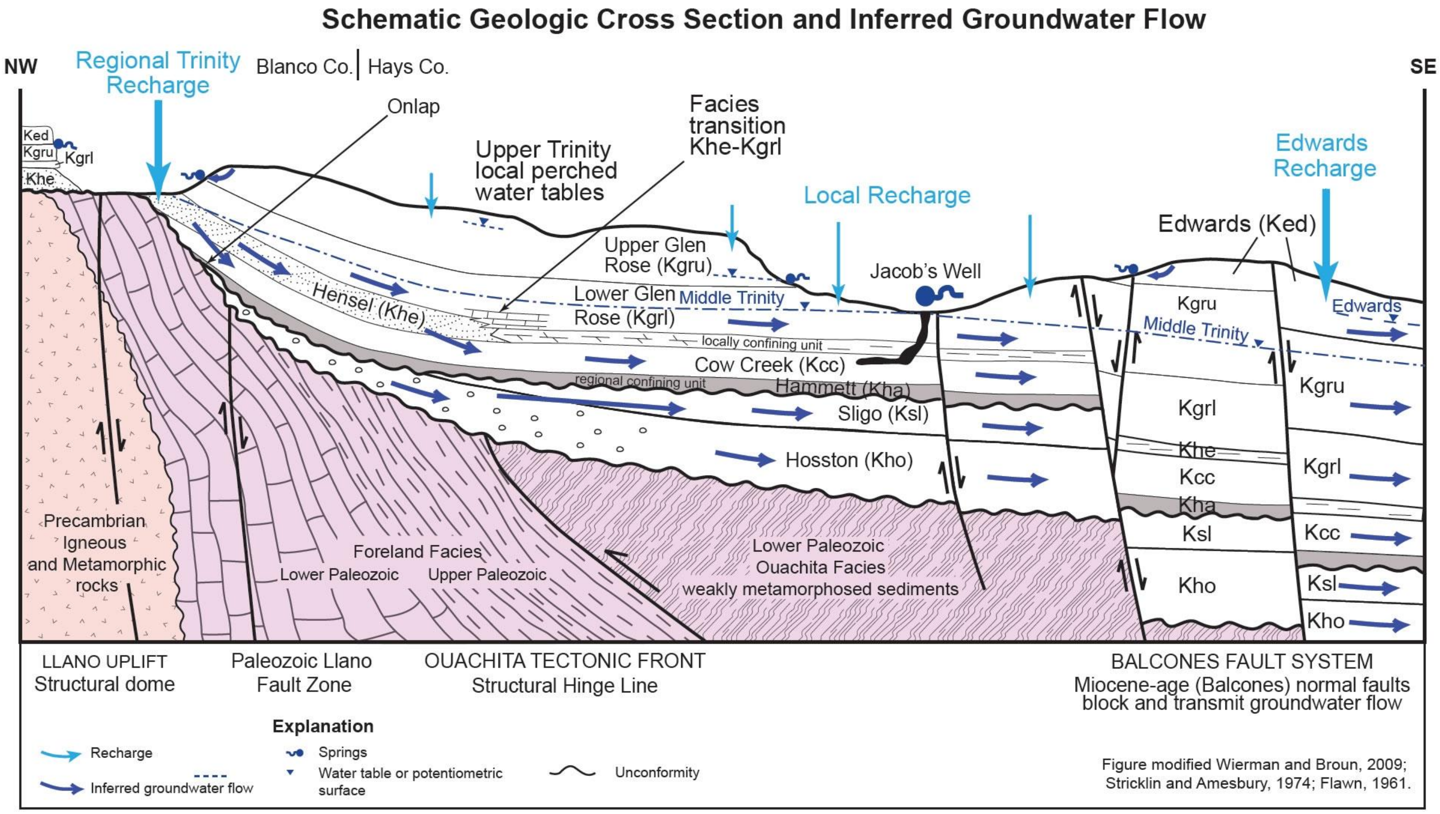


Figure 2.8. General Stratigraphy and Movement of Groundwater of the Trinity Group. Courtesy of HTGCD, 2010.

Baseflow to Jacob's Well is artesian flow from the Cow Creek up through the confining Hensel and Lower Glen Rose. The major source of recharge to the Cow Creek occurs west of the Cypress Creek watershed from the downward leakage of water from the Upper and Lower Glen Rose and Hensel where these formations are exposed at the surface and exposed to precipitation. Water moves downward into the Cow Creek and down dip towards the Balcones Fault Zone (BFZ) to the east. As the overlying Hensel changes facies from a sand to a calcareinite/dolomite facies, it tends to act as a confining layer creating artesian conditions in the Cow Creek. The faults of the BFZ (Tom Creek Fault Zone) tend to restrict the horizontal movement of groundwater forcing groundwater upward with surface discharge via Jacob's Well. Groundwater under artesian conditions in the Cow Creek provides the majority, if not all of the base flow at Jacob's Well.

The flow from Jacob's Well also varies significantly with major precipitation periods and events. Artesian flow from the Cow Creek generally maintains a discharge of 3-7 cfs. During major precipitation events, peak discharge has been measured at over 60 cfs indicating a pressure surge in the Cow Creek or possibly direct recharge from the open karst features observed locally in the Lower Glen Rose. Gunn (2004) says that large changes in spring discharge may be due to rapidly filling open karst features becoming full and then exerting rapid changes in pressure in the aquifer, thus increasing spring discharge.

2.7.5 Groundwater Pumping

Groundwater discharge from the Middle Trinity Aquifer also occurs from the pumping of groundwater from wells. There are both low volume residential wells and high volume public water supply wells in the watershed. Through aerial mapping, the HTGCD estimates that there are approximately 520 residential wells located upgradient of the major fault block in the vicinity of Jacob's Well. There are four public water supply companies in this area drawing water from the Middle Trinity/Cow Creek. Pumpage has increased significantly over the last few decades as a result of the area's explosive growth in population, particularly north of the Blanco River. This increasing use of groundwater has placed unprecedented stress on the Trinity aquifer, which conceivably has affected the amount of springflow from both Jacob's Well and Blue Hole.

Using public water supply pumping records and residential use estimates made by the HTGCD, the average discharge (pumping) from wells over the period of record at Jacob's Well is approximately 1 cfs, or 722 acre-feet/year. The average baseflow from Jacob's Well is approximately 7.25 cfs. During periods of low flow from Jacob's Well (1- 2 cfs) during drought periods, the pumpage of wells may equal the discharge at Jacob's Well. Reductions in pumpage during drought conditions will increase the discharge of Jacob's Well and help ensure adequate baseflow to Cypress Creek (HTGCD, 2008).

Karst springs, such as Jacob's Well, are excellent indicators of the health of the aquifer. As stated by Gunn (2004) "Karst springs are now regarded as valuable integrators of the aquifer, and, compared to monitoring wells, provide comprehensive monitoring sites for assessment of contamination and supply." Pumping of nearby commercial wells drawing water from the same karst conduits influence discharge from Jacob's Well. The combination of periodic drought and increased groundwater pumping is tending to make Jacob's Well more of a perennial spring than a constant base flow spring. Flows from Jacob's Well were significantly reduced during the droughts of 2005–2006 and 2008. During dry conditions of July 2000, Jacob's Well ceased to flow for the first time in recorded history, degrading fish, wildlife, and water quality in the creek. Cypress Creek also was placed on the USEPA 303(d) list for low dissolved oxygen levels for the first time during the same year.

Exactly why Jacob's Well stopped flowing is unknown; however, recent increases in groundwater demand are likely contributors. Because Jacob's Well spring continued to flow during the drought of record in the 1950s, it is thought that increased aquifer pumping and resulting water level draw-downs exacerbated dry conditions and led to the lack of flow in 2000. Due to drought conditions, the Well also ceased to flow in the summer of 2008. Texas Water Development Board (TWDB) groundwater availability models predict an approximate 40 feet drawdown in the area around Jacob's Well by 2050 (Mace et al., 2000), which if realized will have a significant impact on the water flows and quality in the creek.

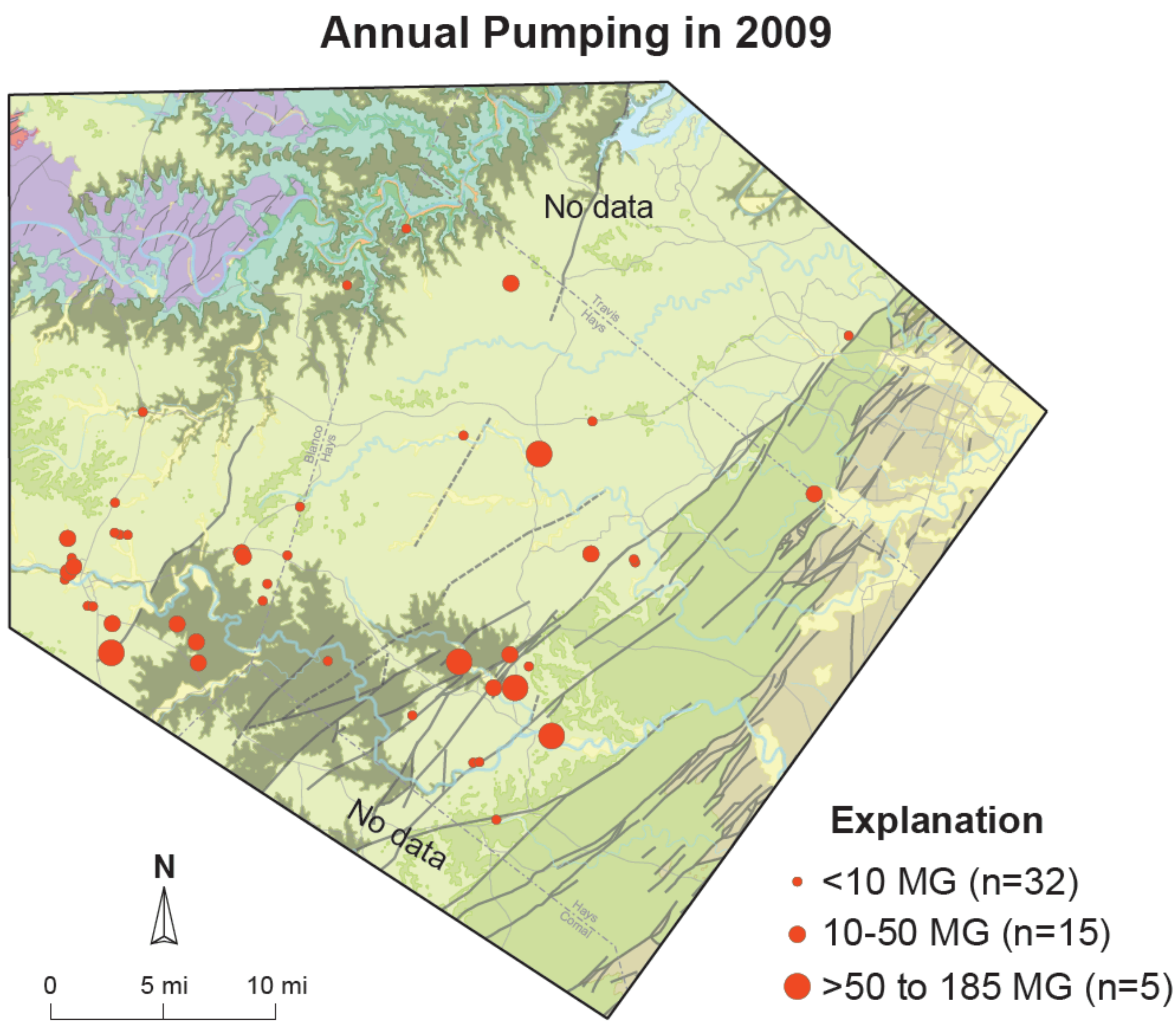


Figure 2.9. Groundwater pumping. Courtesy of HTGCD.

2.7.6 Water Quality

Although water quality in the Cypress Creek is meeting water quality standards, data reveal both spatial and temporal trends that may be due to climate variability, nonpoint source pollution, or changes in land use and/or management in the watershed. Water quality parameters vary considerably from site to site throughout the perennial part of the stream. In general, the upper three sites (Jacob's Well, RR12 north, and Blue Hole) tend to be highly influenced by inflow of groundwater in terms of their water chemistry, while the lower two sites (RR12 downtown and the Blanco confluence) tend to cluster closer together and show more of an influence of local stream conditions and runoff from contributing watersheds. Issues of concern include excess sediment in the creek, high bacteria concentrations and occasionally very high nutrient levels. These indicate potential nonpoint sources of pollution including pet and animal waste, excess fertilizer application, and poorly performing septic systems.

Stormflow monitoring of the Dry Cypress watershed area shows that the upper watershed has a tendency toward high bacterial and sediment concentrations washing down through the channel after a storm, with occasionally high nitrogen levels as well. BMPs that retain water and sediment in the upper watershed will help to maintain high water quality in the lower creek during storm events. See Section 8 for a detailed analysis of water quality data.

3.0 History and Development

3.1 History and Settlement

Texas joined the Union in 1846, and soon after began giving land grants. Many earlier settlers were former soldiers who had fought at the battle of San Jacinto and were given land grants in appreciation by the Republic of Texas. In 1856, William C. Winters bought 34 acres and built the first grist mill. In 1874, Pleasant Wimberley bought the mill and it was renamed "Wimberley's Mill". An application for a post office was made in 1880 with the town name "Wimberleyville". The post master dropped the –ville and approved the application, thus creating the town of Wimberley. Soon after, churches and schools opened and the town flourished. An instant draw to the area was the water. The Blanco River, Cypress Creek and Jacob's Well all flowed with clean, clear water and springs. Today, Wimberley is home to over 6,000 people, many shops and restaurants, and is a popular tourist destination.

In 1943, land was purchased in what is now known as Woodcreek for a resort community (Woodcreek, 2010). More people bought land and built houses. A golf course, a swimming pool, a hotel and a restaurant were added. The City of Woodcreek was incorporated in 1984. As of 2007, the population of Woodcreek had grown to over 1,600 people (City Data, 2010).

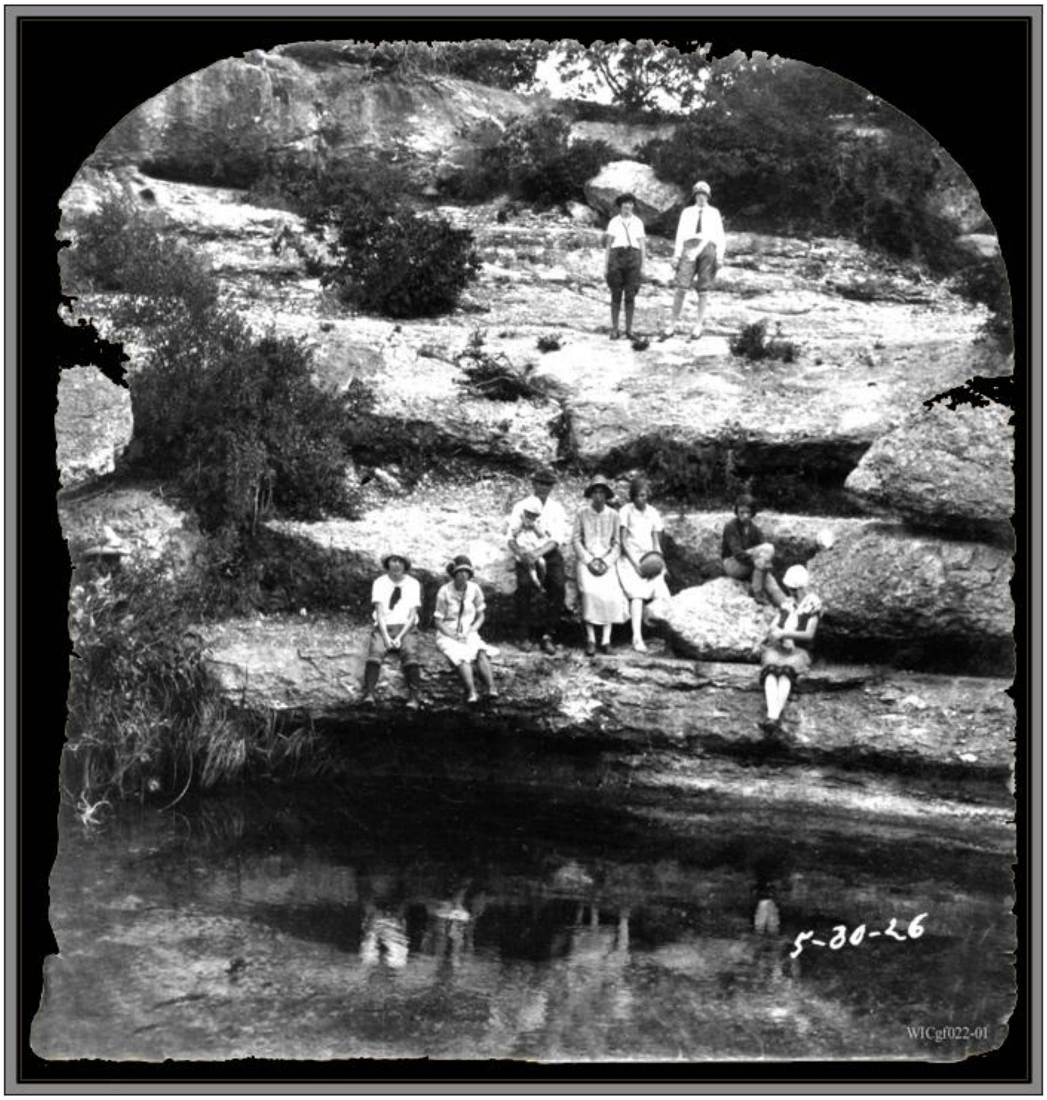


Figure 3.1. Jacob's Well, circa 1926. Photo courtesy of Wimberley Institute of Cultures.

3.2 Population and Growth Predictions

Land and water resources of the Cypress Creek watershed are under increasing demands from different sources. The watershed is located between the major metropolitan areas of Austin and San Antonio and is easily accessed by major roadways. The entire region is undergoing rapid urbanization. Hays County is listed as the 31st fastest growing county in the

United States. According to the Texas State Data Center (2010), Wimberley and Woodcreek's combined population grew approximately 21% from 2000-2009. By the year 2040, population in Hays County is expected to grow from 97,589 in 2000 to over 130,000, or possibly as high as 574,000 (TSDC, 2009).

The two communities of Wimberley and Woodcreek are located within the watershed and their populations have expanded rapidly over the past 20 years. There are over 70 approved subdivisions in the Cypress Creek watershed, several of which are only partially built out (Hays County, 2009). Areas that are most likely to experience rapid growth in the near future should be priority when developing a watershed protection plan and targeting education and outreach.

The primary growth areas shown in Figure 3.1 are based on existing road networks, Hays County's 2025 Transportation Plan, city limits and extra-territorial jurisdiction areas (ETJs), water and wastewater service areas, and existing parcel boundaries. Major transportation corridors were defined as 150 m (approximately 500 ft) buffers along both sides of roadway. The primary growth areas (Figure 3.2) are:

1. CR218 corridor: This area includes the Shadow Valley subdivision in the north and a swath of land to the south approximately ½ mile wide along CR218.
2. Ledgerock subdivision: This area follows the Ledgerock subdivision boundaries.
3. Woodcreek North: This area follows the subdivision boundaries for Woodcreek Phase II, west of Jacob's Well Road.
4. Wimberley & Woodcreek: Includes the remainder of the Woodcreek subdivision east of Jacob's Well Rd. and some surrounding parcels, plus areas of northern Wimberley and its ETJ to the RR12/RR2325 intersection in downtown Wimberley.
5. Skyline Ranch subdivision: Includes the Skyline Ranch, Skyline Acres, Sagemont, and Wimberley Heights subdivisions.
6. Wimberley East: Includes downtown Wimberley along RR12 and areas to the north and east of RR12. Includes several large-lot inholdings, the Cypress Creek Acres, Ranch at Wimberley, and Pinnacle Ridge subdivisions, and areas along Winter's Mill Pkwy. Much of this area is within Wimberley and Woodcreek ETJs.

Recently the GBRA and other local partners have been reviewing plans to provide approximately 4 million gallons per day (MGD) of surface water to residents in the Wimberley Valley. Assuming each household and business in the watershed uses about 350 gallons of water per day, the current total water use would be approximately 980,000 gallons per day. If 4 MGD are supplied through surface water, the number of households in the watershed could increase 400% to over 11,000 homes and businesses, an average density of just over 2 acres per household.

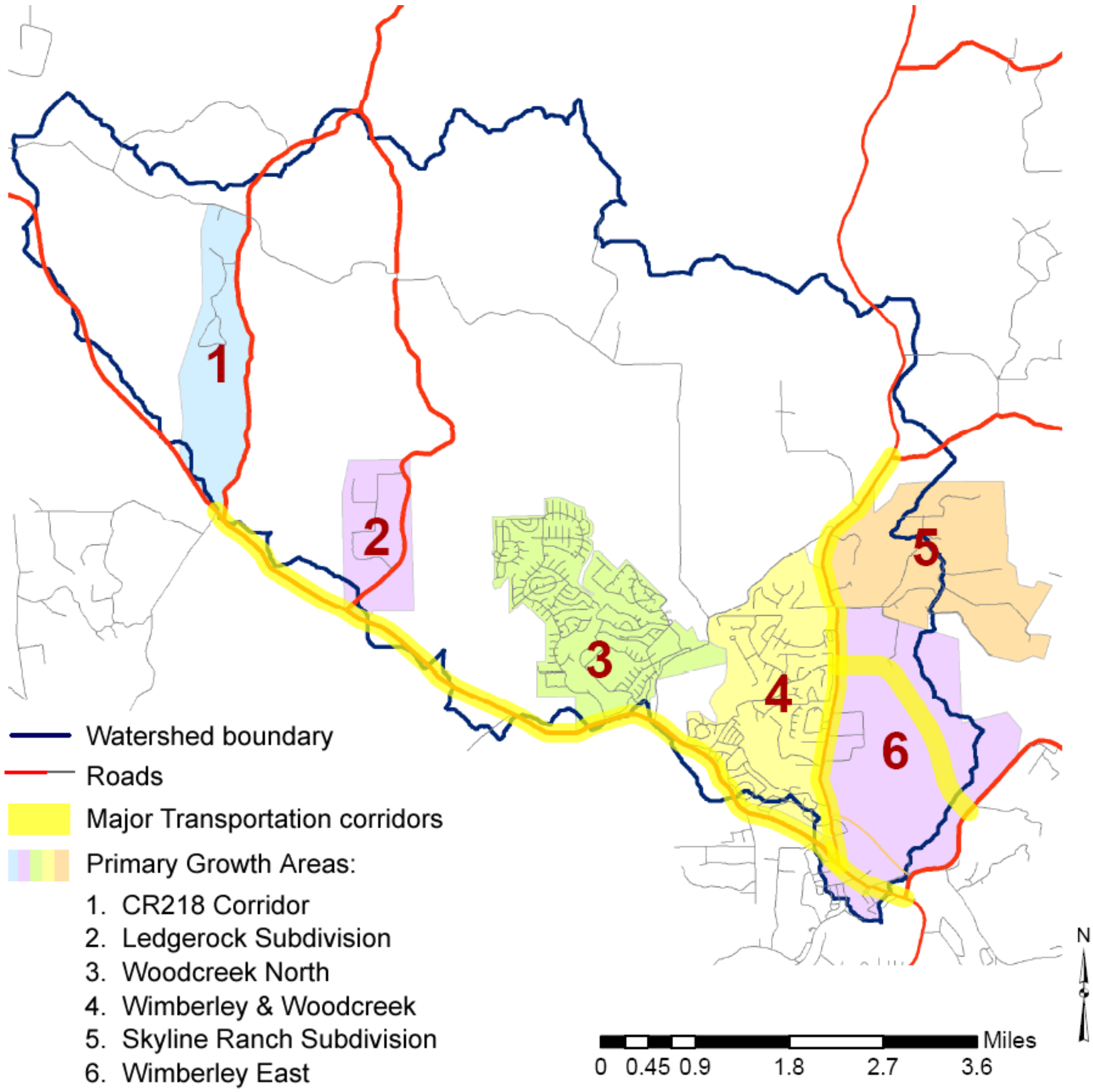


Figure 3.2*. *Primary growth areas in the Cypress Creek watershed.

These areas are based on existing road networks, Hays County's 2025 Transportation Plan, city limits and extra-territorial jurisdiction areas (ETJs), water and wastewater service areas, existing parcel boundaries, and input from the DSS/Technical Subcommittee.

4.0 Data Collection and Analysis

The following sections describe data collected to define and characterize the Cypress Creek watershed. These characterization efforts include spatial delineation of the watershed and subwatersheds, installation, data collection, and analysis of water monitoring stations, and watershed simulation modeling. Due to the differing techniques and analytical methods necessary to observe and measure these watershed characteristics, streamflow, and water quality parameters, applicable methods are described at the beginning of each section.

4.1 Watershed and Subwatershed Delineation

Watershed delineation was performed using the Automated Geospatial Watershed Assessment (AGWA) tool, an interface for ESRI's ArcGIS jointly developed by the U.S. Environmental Protection Agency, U.S. Department of Agriculture (USDA) Agricultural Research Service, and the University of Arizona to automate the parameterization and execution of two commonly-used hydrologic models (Miller et al., 2007). The AGWA delineation and discretization process utilizes the hydrology utilities provided by ArcGIS to define watersheds and stream networks. Watershed delineation segments a region into several hydrologically connected subwatersheds for use in characterization and modeling.

AGWA's delineation tool requires an elevation raster, which was obtained from the USGS's National Map Seamless Server (USGS, 2010). This data set has a resolution of approximately 10 meters and is processed to filter artifacts and fill missing data at quadrangle seams. Automatic delineation uses a threshold method of contributing source areas (CSA) to delineate hydrologically distinct areas. The threshold parameter may be increased to decrease the number of sub-basins, or conversely, decreased to increase the number of sub-basins. CSA was varied from 1.0% (243 acres) to 2.5% (608 acres). In addition, stormflow gauge locations were used to create breaks between watersheds so that model output at those locations can be directly compared to measured values. The resulting delineations were compared to roads and other infrastructure to choose the best balance between the number and resolution of basins and potential watershed management units. The final delineation is 46 subwatersheds within the watershed of Cypress Creek (Figure 4.1). This subwatershed delineation was used to calculate statistics for soils, land uses, and pollutant loadings.

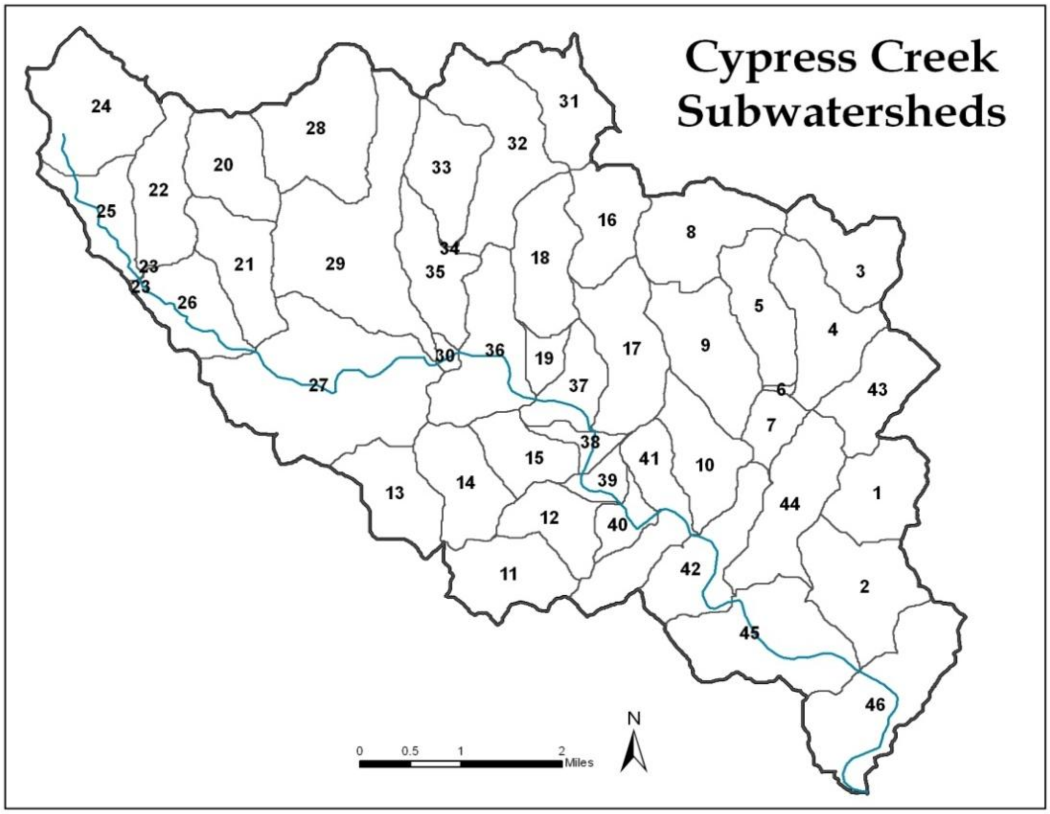


Figure 4.1. Subwatershed delineation map.

4.2 Monitoring Stations Data and Analysis

4.2.1 Rainfall

The mean annual precipitation at Wimberley, located near the southeast outlet of the watershed, is 37.2 inches (945 mm). At Fischer's Store (southwest of the watershed) , mean annual precipitation is 33.3 inches (846 mm) as shown in Figure 4.2. The difference in long-term statistical means at these two stations is probably due to two factors: (1) the period of record at Fischer's Store includes the drought of record in the 1950s, but Wimberley records do not extend back to the 1950's; and (2) a west-east gradient of increasing precipitation exists throughout Texas (TWDB, 2007), and the rainfall station at Fischer's Store station lies approximately 10 mi west of Wimberley. Annual mean precipitation is highly variable from year to year, making responsible water resources management in this area critical. There is some evidence that interannual variability in rainfall has increased in the last two decades, since the autocorrelation of annual precipitation measured at Fischer's store from 1941 to 1989 is positive, while the period 1990-2009 is negative. This means that prior to 1990, if one year was wet then the next year was likely to be wet as well. Beginning in 1990, however, a very wet year is more likely to be followed by a very dry year. If this trend continues it could have implications for both water management and water quality in the Cypress Creek.

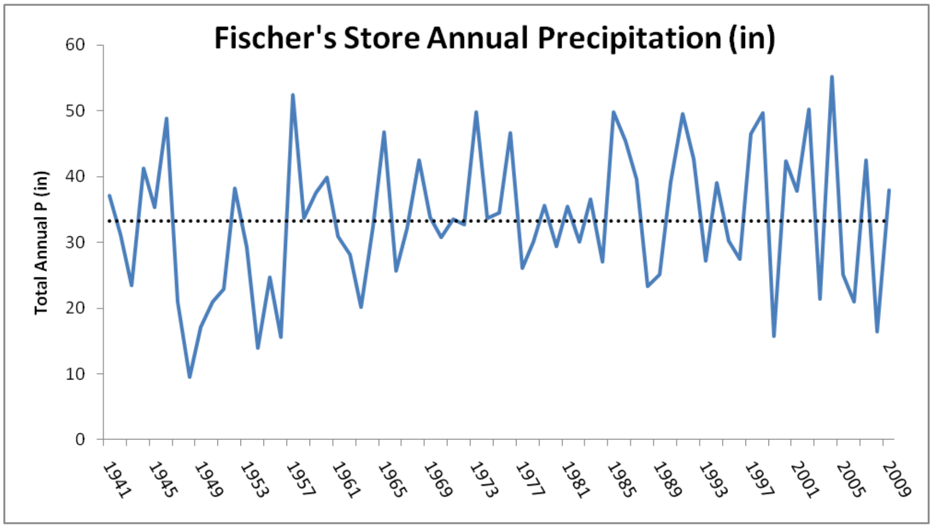


Figure 4.2. Annual precipitation, Fischer's Store (1941-2009).

Because of the highly variable nature of precipitation in the study area, the Cypress Creek Project installed three tipping-bucket rain gauges inside the watershed boundary to record rainfall at a higher resolution than is available with National Weather Service data (Figure 4.3). Rainfall data has been collected at these stations since September 2009. The results suggest that rain can be highly variable even within the small watershed area; one storm in January 2010 recorded 2.2 and 2.8 inches of rain at the two northern gauges, while the southern gauge recorded 0 inches. This north-south gradient is common in the data, as indicated from the results of a linear regression calculated on daily total precipitation at various weather stations. A linear regression is a statistical tool that compares values for two datasets and indicates how good one term is at predicting the value of another term. The "goodness-of-fit," or R^2 value, is a measure of how well the linear regression describes the relationship between the two data sets. If daily precipitation recorded at two stations is always the same, the R^2 value would approach 1. R^2 values closer to 0 indicate that the values measured were very different. In this study, linear regression was used to see how closely the precipitation recorded at various weather stations compared to each other. In general, the northern two gauges are similar (R^2 = 0.83) but quite different from the rain recorded at Wimberley (R^2 = 0.16 and 0.29). Data at the southern gauge are more closely correlated to rain recorded at Wimberley (R^2 = 0.37) and, within a range of variability over time, can be very different from rain data recorded at the upper two gauges. Therefore, relying upon the weather station at Wimberley and Fischer's Store may be adequate for long-term annual and monthly averages, but to understand historic and probable future daily rainfall patterns within the Cypress Creek watershed, a higher resolution is necessary to capture the natural spatial variability in the area.

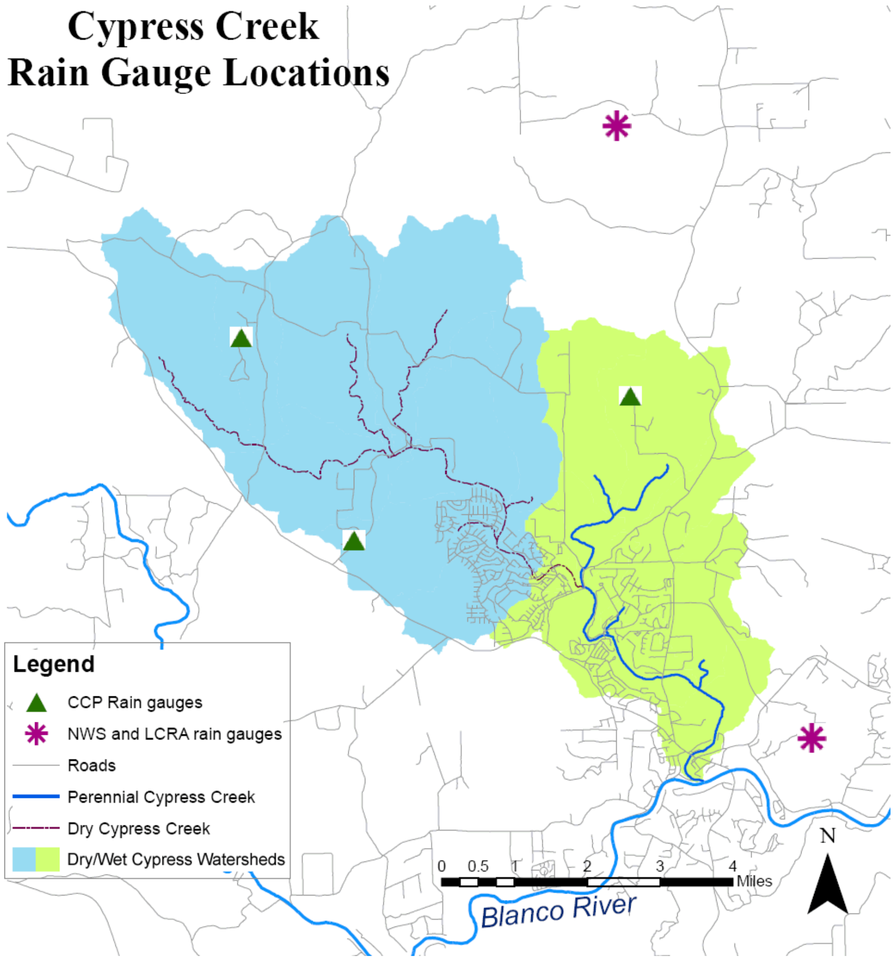


Figure 4.3. Rainfall monitoring stations in and adjacent to watershed.

4.2.2 Water Quality Data

Routine monitoring of climate, hydrology, and water quality in the Cypress Creek aids our understanding of the physical context of the creek and its response to activities within the watershed area. Routine water quality monitoring through the Clean Rivers Program (CRP) is performed at five sites along the creek, from Jacob's Well to the confluence with the Blanco River. No routine water quality monitoring or flow data are collected above the headwaters at Jacob's Well. TCEQ site 12674 (at Ranch Road 12 in downtown Wimberley) has been sampled monthly or quarterly from 1973 to present by TCEQ and GBRA. Data from December 1973 to January 2010 were analyzed in this study, and represent the best long-term data for surface water quality in the creek. The Jacob's Well CRP site (12677) has been sampled monthly from 08-08-2002 to present by CRP, and continuously (USGS site #08170990) from 04-23-2005. Additional sites on the creek include Ranch Road 12 approximately 4.5 river km downstream from Jacob's Well (12676) sampled from 02-27-2003; at Blue Hole spring (12675) approximately 6.7 river km from the Well sampled from 12-27-05; and at the confluence with the Blanco (12673) sampled from 08-08-2002. Clean Rivers Program sites are sampled monthly or bi-monthly, and data through December 2009 were used in this study.

TCEQ and CRP sites include instantaneous flow data and the following water quality parameters: temperature (^{o}C), dissolved oxygen (milligram per liter; mg/L), specific conductance (*u*mhos/cm), pH (SU), nitrate-nitrogen (mg/L), total phosphorus (mg/L), total suspended solids (mg/L), ammonia (mg/L), *E. coli* (colonies/100mL). Ortho phosphorus (mg/L), total dissolved solids (mg/L), and fecal coliform have been sampled infrequently at various sites. For this study, values below detection limits were replaced with 50% detection limits.

Concentrations of various pollutants were analyzed in relation to one another and to available data on precipitation, temperature, and streamflow, in order to better understand both the physical nature of the watershed and the potential sources and distributions of nonpoint source pollution throughout the contributing area. Load duration curves were constructed using daily mean flow estimated at the Blanco confluence and available water quality data (see below for methods of streamflow estimation). For site 12674, data from 1973 to 1999 were compared to data from 2000 to 2009 to evaluate any long-term changes in water quality.

4.2.3 Stormflow Monitoring

In general, ambient monitoring data are collected under baseflow conditions and occasionally following storm events when flows are elevated. Data are never collected when flows are elevated to a point that would compromise the safety of monitoring teams, nor are daily streamflow measurements routinely collected. However, proper characterization of the hydrology and water quality of the creek requires reliable data on streamflow, and this information is also necessary to calculate average pollutant loads using ambient data. In addition data on both streamflow and water quality should characterize the range and temporal variability of water quantity and quality under the full range of natural conditions. Because water quality parameters are highly influenced by flow rates, it is important to understand the hydrologic response of the watershed to identify causes and sources of NPS pollution, in addition to identifying and developing appropriate best management practices (BMPs) to address pollution issues of concern. Modeling efforts of the Cypress Creek Project are also dependent on accurate flow estimates to ensure the greatest possible accuracy when evaluating potential impacts of future development.

To help address these data gaps, the Cypress Creek Project installed two automatic stormflow monitoring devices along the main creek channel to record stage, sediment, nutrient, and bacteria concentrations during runoff events (Figure 4.4). One station draws samples from Cypress Creek near its confluence with the Blanco River, and a second station draws samples from the low water crossing at Woodacre Drive, about 100 yards upstream of Jacob's Well. The stations consist of a large metal box (about 2ft x 2ft x 3ft) which is attached to a metal platform. The sampler inside the box connects to plastic tubes running through gray electrical conduit down to the creek. An ISCO 730 bubbler flow module inside continually records the height of water ("stage") every five minutes, and triggers a pump to start collecting water samples when an increase in flow is detected, indicating that runoff has started from a rain storm. The samples are later taken to a lab and tested for sediment, analyzed in the lab for total suspended solids (TSS), nitrate-nitrogen, total phosphorus, and *E. coli*.

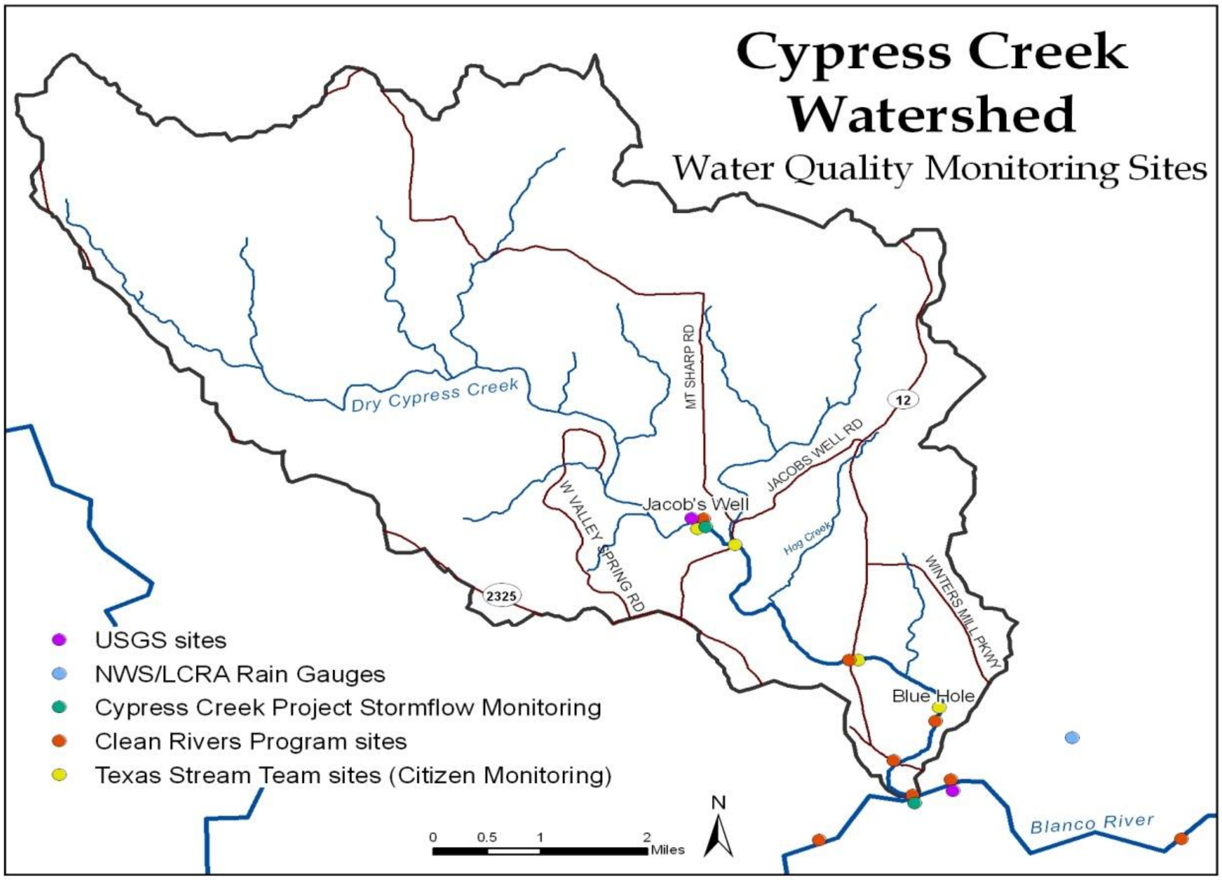


Figure 4.4. Water quality monitoring sites.

Table 4.1. Monitoring sites.

Station ID	Entity	Site Description	Latitude Longitude	Start Date	End Date	Data recorded/frequency
12677	CRP	Cypress Creek at Jacob's Well	30.034 98.126	8/8/2002	12/30/2009	Temperature, DO, Conductivity, pH, Nitrate-N, Phosphorus, *E. coli*, Suspended Sediment, Ammonia
12676	CRP	Cypress Creek at RR12 (north)	30.012 98.104	2/27/2003	12/30/2009	Temperature, DO, Conductivity, pH, Nitrate-N, Phosphorus, *E. coli*, Suspended Sediment, Ammonia
12675	CRP	Cypress Creek – Blue Hole Campground	30.003 98.091	12/27/05	12/30/2009	Temperature, DO, Conductivity, pH, Nitrate-N, Phosphorus, *E. coli*, Suspended Sediment, Ammonia
12674	TCEQ	Cypress Creek at FM12 (downtown)	29.997 98.098	12/3/1973	1/11/2010	Flow, Temperature, DO, Conductivity, pH, Nitrate-N, Phosphorus, *E. coli*, Suspended Sediment, Ammonia
12673	CRP	Cypress Creek at Blanco River	29.991 98.095	8/8/2002	12/30/2009	Temperature, DO, Conductivity, pH, Nitrate-N, Phosphorus, *E. coli*, Suspended Sediment, Ammonia
20828	RSI	Jacob's Well Stormflow #1	30.033 98.133	2/1/2010	2/5/2010	Stage height at 5 minute intervals Suspended Sediment, Nitrate-N, Phosphorus, and *E. coli* – triggered by 1 in rise in water level.
12673	RSI	Confluence Stormflow #2	29.991 98.095	2/1/2010	4/15/2010	Stage height at 5 minute intervals Suspended Sediment, Nitrate-N, Phosphorus, and *E. coli* – triggered by 1 in rise in water level.
08170990	USGS	Jacobs Well Spring nr Wimberley, TX	30.034 98.126	4/23/2005	3/17/2010	Stage height, Velocity, Flow, Temperature, Conductivity, Turbidity – 15 minute intervals and Daily Means
08171000	USGS	Blanco Rv at Wimberley, TX	29.994 98.089	8/6/1924	3/17/2010	Stage height, Flow – 15 minute intervals and Daily Means
CCP1	RSI	Rolling Hills Rain gauge #1	30.074 98.202	6/3/2009	3/31/2010	Rainfall at 0.01 in intervals
CCP2	RSI	Golds Rd. Rain gauge #2	30.068 98.110	5/8/2009	3/31/2010	Rainfall at 0.01 in intervals
CCP3	RSI	Ledgerock Rain gauge #3	30.039 98.175	7/3/2009	3/31/2010	Rainfall at 0.01 in intervals
419815	NCDC	Wimberley 2	29.999 98.050	3/1/1984	3/31/2010	Rainfall – daily totals
413156	NCDC	Fischers Store	29.980 98.270	2/1/1930	3/31/2010	Rainfall – daily totals
4593	LCRA	Dripping Springs 5 SSW	30.122 98.114	1/1/2000	3/31/2010	Rainfall – hourly and daily totals Temperature – daily min, max, mean
3528	LCRA	Dripping Springs 8 W	30.197 98.223	1/1/2000	3/31/2010	Rainfall – hourly and daily totals

The total suspended solids (TSS) parameter was chosen for monitoring because it is a key output variable in the event-based hydrologic model under development for the watershed. In addition, elevated TSS levels can be an indicator of other nonpoint source pollutants in the creek, since often these are transported adsorbed to soil particles. Water quality data from ambient monitoring on the Cypress Creek have not indicated levels of nutrient pollutants sufficient to qualify the segment as listed for water quality impairments. Data have shown that both nitrate-nitrogen and total Phosphorus levels have been elevated at times above screening limits, and these measurements cannot be correlated with flow levels under the current ambient monitoring scheme. Bacteria data also show some very high values, which have created a concern among stakeholders in the area sampled for potential bacteria loading to the creek. Because Cypress Creek is not currently listed for water quality impairments for any monitoring parameters and given the project's budgetary constraints, it was determined that stormflow monitoring of sediment, nutrients, and bacteria will provide sufficient baseline data to characterize the most common nonpoint source pollutants that may affect the creek in the near future.

The goal of the stormflow sampling project is to provide an overall characterization of the hydrology, sediment, and nonpoint source pollution loadings in both rural and urban/residential portions of the Cypress Creek watershed. Therefore the distribution of sites is designed to capture data on streamflow and pollutant loadings from areas of the watershed with different levels of residential and urban development. Figure 4.4 shows the locations of the various in-stream monitoring sites. Table 4.1 lists all the climate and water quality data that were analyzed for the watershed characterization.

4.2.4 Streamflow

As noted above, Cypress Creek is commonly divided into two segments: the 15.42 km (9.5 mile) segment above Jacob's Well is usually dry, except during major rainfall events, and is referred to as Dry Cypress Creek; the 5.5 mile (8.9 km) long stream segment below Jacob's Well that consistently contains flowing water is referred to as Cypress Creek (see Figure 2.1). Jacob's Well spring forms the headwaters of Cypress Creek during ambient conditions. Continuous 15 minute spring flow data is currently collected by the USGS at Jacob's Well spring (08170990); however, flow data collected at that station represent only baseflow to the stream. The USGS gauge at Jacob's Well spring does not record surface flows in that portion of the creek during rain events, and efforts are made to ensure that these data represent groundwater flow only, often requiring adjustments in recorded data to discount the potential influence of surface flows. Storm runoff from the Dry Cypress watershed may significantly impact the timing and quality of stormflow in the perennial portions of the creek. Until 2009 there were no data collected on flow and water quality for the upper section of the creek to quantify any potential impact. In addition, daily mean streamflow is recorded at the Blanco River gauge just downstream of the confluence with the Cypress Creek. These values represent potential runoff from the Blanco River catchment of approximately 500 mi^2 (1,295 km^2), of which the Cypress Creek watershed comprises only 38 mi^2 (98 km^2).

A stream gauging project was conducted in 2005 by a Texas State University student (Dedden, 2008). The gauging program was conducted monthly during baseflow conditions between March and October 2005. Surface runoff into Cypress Creek during storm events was not measured during this study. The data indicate that Cypress Creek had very little net loss or gain in baseflow between Jacob's Well and Cypress Creek at RR12 in Wimberley. Immediately downstream of Jacob's Well, Cypress Creek flows over several major faults. The Upper Glen Rose is considerably more resistant to stream losses through the bed of the stream. Since Cypress Creek above Jacob's Well is typically dry, the majority of baseflow to Cypress Creek originates from Jacob's Well discharge and therefore maintaining baseflow requires maintaining flow at Jacob's Well. It must be noted, however, that this study was done during a period of drought (March to October 2005). Annual rainfall in 2005 was only 25.1 inches, compared to an average of 35.6 inches. It is likely that during wetter periods the Cypress Creek gains flow from numerous small springs and seeps throughout its course and feeding in from several major tributaries. There is a wealth of anecdotal evidence of such springs and seeps from residents and visitors to the area.

Method

A record of historical flows is important to explain variations in measured pollutant concentrations and to help distinguish between point and nonpoint source pollution problems. As discussed above, daily mean flow is not available at the outlet of the watershed, and records of daily mean baseflow from Jacob's Well Spring start in April 2005. While these baseflow records are useful, any additional flow being contributed to the creek either by surface runoff or other minor springs is not included in this record. Therefore, historical daily mean flows at the Blanco confluence were estimated based on a comparison between daily mean stage recorded at the confluence and daily mean stage at the USGS Blanco River gauge (08171000) from 2/1/2010 through 3/17/2010. The relationship between the two was found to be very good for Blanco River stage heights below 6.4 feet. A linear regression using Blanco stage as the predictor and Cypress Creek stage as the response variable resulted in a goodness-of-fit (R^2) value of 0.86 (n = 45). Removing values of Blanco stage above 6.4 ft resulted in:

$$S_C = 2.0688\, lnS_B - 2.0497$$

where S_C = Stage height at Cypress Creek (ft)
S_B = Stage height at Blanco River (ft)

For the above equation, R^2 = 0.95 for a sample size of n = 43. Stages estimated using this equation were compared to recorded stages, and the resulting error ranged from -3.9% to 7.0%. Flow velocities at the Cypress confluence are calculated using estimated stage height and Manning's equation:

$$V_t = \frac{1.486}{n}\left(\frac{A}{P}\right)^{\frac{2}{3}} S^{\frac{1}{2}}$$

where V_t = cross-sectional average velocity at time t (ft/sec)
n = Manning coefficient
A = cross-sectional area of flow (ft^2)
P = wetted perimeter (ft)
S = slope of water surface (ft/ft)

Instantaneous flow measurements were taken a few meters downstream from the bubble gauge on four occasions between 2/1/2010 and 3/17/2010. These measurements, along with data on the bank slopes and bottom width obtained from a channel cross-section, were used to estimate the Manning coefficient *n.* The resulting value (0.08) is relatively high but is within the range reported for similar watersheds in central Texas (0.016 to 0.213), and is consistent with findings that Hill Country watersheds tend to have higher observed hydraulic resistance values than are commonly estimated using methods based on physical properties alone (Conyers and Fonstad, 2005). The cross-sectional area of flow (*A*) is calculated using recorded stage height and data from the channel cross-section. Flow rates are then calculated using the discharge formula:

$$Q_t = AV_t$$

where Q_t = discharge at time t (ft^3/sec)
A = cross-sectional area of flow ft^2
V_t = cross-sectional average velocity at time t (ft/sec)

Results

Flows estimated using the above method were compared to recorded instantaneous flows, and the resulting error ranged from -2.5% to 11.9%. This method was used to estimate historical daily mean flows for the Cypress Creek for January 2000 to February 2010. The resulting estimated flows are correlated very strongly with recorded spring flow at Jacob's Well starting in April 2005 (R^2 of linear regression = 0.86, n = 1,745; see Figure 4.5).

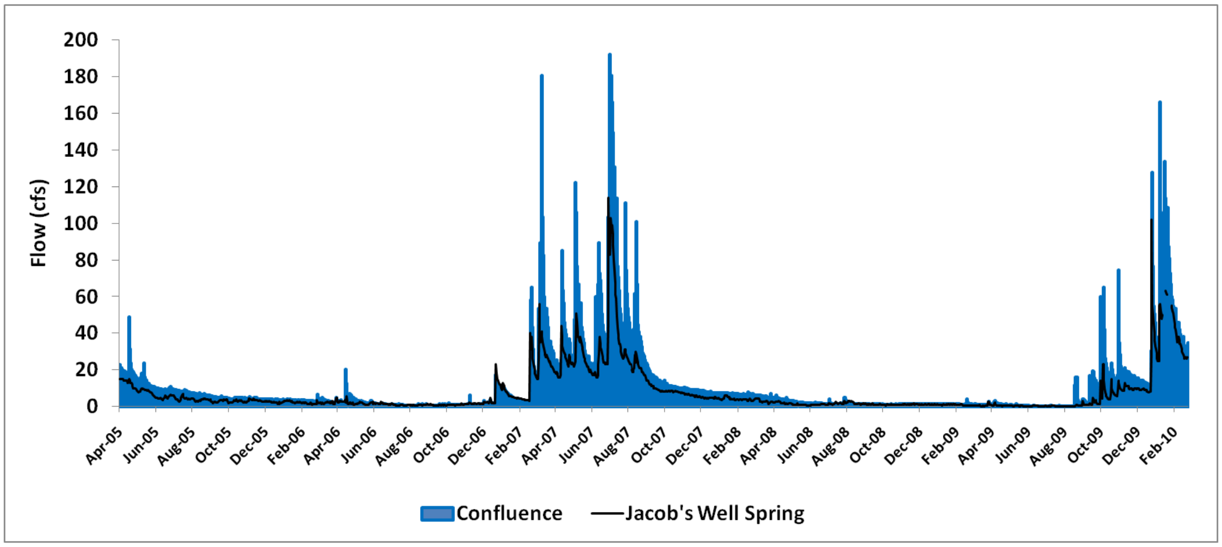


Figure 4.5. Flow estimated at the Cypress Creek confluence and recorded at Jacob's Well Spring (April 2005 – February 2010).

4.3 Land Use and Land Cover

4.3.1 Land Use Analysis

Methods

Land use characterization for the Cypress Creek watershed was determined using Hays Central Appraisal District (HaysCAD) 2009 cadastral data. At the time that the work on characterizing the watershed began, this data was received as an incomplete GIS parcel layer from HaysCAD, with parcel polygons outlined and a separate, partially completed annotation file containing tax reference numbers (R numbers). Thus, identification of parcel by R number was available for approximately 82% of the watershed. Spatial parcel data was joined (by R number) to a Wimberley Independent School District (WISD) 2009 tax roster, allowing each parcel to have data populated regarding relevant owner name, address, property values and existing land use/land type codes.

HaysCAD state code values were reclassified into a land use system of eight classes: Residential (A,B), Large Lot Residential (ALg), Undeveloped/Open Space (C), Agriculture (E), Commercial (F), Industrial (J), Parks (P) and Transportation (T). Since the protocol at HaysCAD is to identify properties by their zoned/potential land use type, many of the parcels that were coded as a residential type of land use were in fact still vacant lots, i.e. platted but undeveloped. The goals of the characterization involved evaluating current land use practices, so ground-truthing was conducted using 2008 aerial imagery from Capital Area Council of Governments (CAPCOG). Any parcel that was coded as residential but had no structure built on the property was re-coded as undeveloped. Also, any other necessary updates were made, such as coding all roads as transportation and creating and coding the parks classification. This allows for an accurate assessment of where and what type of development has occurred in the watershed to date. There are a few known conservation easements and wildlife management areas within the watershed, but the exact nature and impacts on land management are not known. Therefore, in those areas the initial land use classification was used, which for these parcels was predominantly Rangeland.

Results

As shown in Figure 4.6, land use in the Cypress Creek watershed is predominantly Agriculture/Rangeland (26,523 acres; 75%), followed by Residential (3,150 acres; 11%), Open/ Undeveloped (2,762 acres; 9%), and Transportation (925 acres; 3%). Commercial land uses are concentrated in and around downtown Wimberley and Woodcreek, and comprise only 1.1% of the total watershed area (271 acres) (Table 4.2). Due to the population increases in the past two decades, land use in the Cypress Creek Watershed has changed. The trend for the past two decades, which is expected to continue into the future, is a shift from predominantly ranching to residential land uses as formerly large acreage holdings are subdivided for both high-density residential (<5 acres) and large lot "ranchettes" (>5 acres).

Table 4.2. Land Use Calculations

Land Use Type	Acreage	Percent
Residential-Single	1,417	6%
Residential-Large lot	1,723	5%
Residential-Multi	10	<1%
Undeveloped	2,762	9%
Agriculture/Rangeland	26,523	75%
Commercial	255	1%
Industrial	16	<1%
Parks	162	1%
Transportation	925	3%
Total	**33,793**	

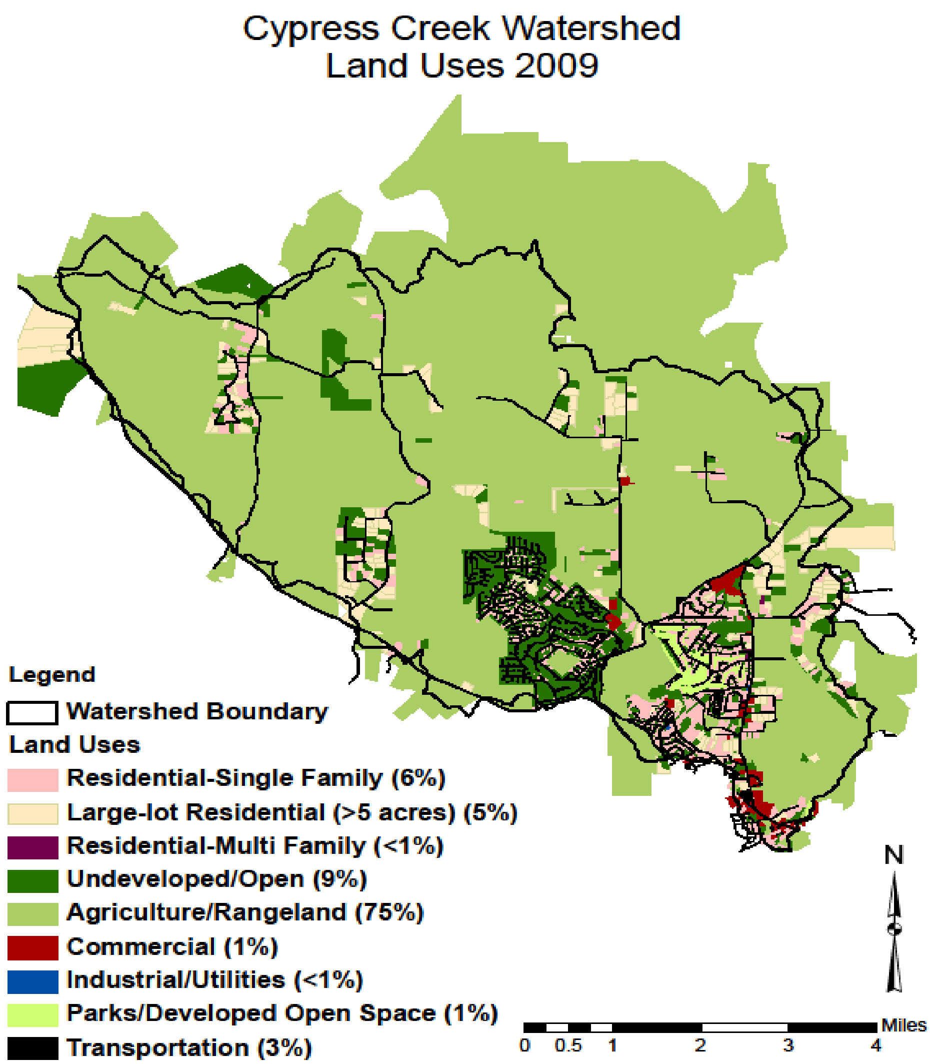


Figure 4.6. Land use in Cypress Creek watershed, 2009.

4.3.2 Land Cover Analysis

Method

To obtain baseline land cover for 2009, the above-mentioned land use layer was used to update the 2000 National Land Cover Dataset map (MRLC, 2000). This was done using the Land Cover Modification Tool in the AGWA2 GIS extension. The 2000 land cover raster was used as a base and parcels were overlain in order of increasing impervious cover. First, Parks (P) were converted to the Developed, Open Space land cover class; Single-family residential (A) land uses were converted to the Developed, Low Intensity class; Multi-family residential (B) were converted to Developed, Medium Intensity. For Commercial (F) and Industrial (J) land uses, ground truthing using 2008 aerial photos was employed to determine if the areas were to be classed as Medium or High Intensity development, or in some cases Developed, Open Space. Finally Transportation land uses were converted to the Developed, High Intensity land cover class. We assumed that Large-lot Residential (ALg), Agriculture/Rangeland (E), and Open/Undeveloped (C) land uses would have little impact on the overall land cover, and so these areas were not changed from the 2000 base map. The results are shown in Figure 4.7.

Urban sprawl and associated increases in impervious cover can have a profound effect on natural systems. Thus, growing cities, human culture and natural systems often have competing interests. It is important to assess changes associated with urban development in areas located within hydrologically and ecologically sensitive watersheds in order to understand the state of the water resources and to plan for future development (Nataluk and Dooley, 2003; France, 2006). Characteristics of urban sprawl include increased infrastructure such as roads, fire services, utilities, buildings, storm drainage systems, and sewer services. With these changes comes the conversion of formerly rural or pastoral lands into lands with increased impervious surface cover (ISC).

Many studies have been performed on the various effects of imperviousness, the "sum of roads, parking lots, sidewalks, rooftops, and other impermeable surfaces on the urban landscape" (Schueler, 1994), on natural systems (Ourso and Franzel, 2003; Paul and Meyer, 2001; Sadler et al., 2006; Snyder et al., 2003; Wissmar and Timm, 2004). In ecologically and hydrologically sensitive areas with karst topography, these effects can be profound. Recent urbanization of karst terrains has increased the risk and frequency of water pollution with toxic pollutants and increased sediment transport through overland flow (Veni, 1999). Studies on the relationship between water quality and ISC show that adverse environmental impacts increase when ISC nears 10% to 15% land cover (Nataluk and Dooley, 2003; Veni, 1999). Therefore, the changes in ISC should be measured and used in projections for future growth and vulnerability. In addition to the hydrologic effects, urbanization has been proven to fragment the landscape, creating loss in biodiversity.

While land use in the watershed is predominantly rangeland, the combined residential, commercial, and transportation uses account for 16% of total area (Figure 4.7). However much of this 16% is impervious surface cover, and is concentrated at the southern and eastern portions of the watershed. Increased impervious surface cover has been proven to alter hydrologic and ecologic functioning. In a recent study of land cover change from 1996 to 2005, impervious surface cover increased by 3% over the watershed (Carter, 2008). In 1996 impervious cover was calculated at 6.03% and in 2005 it was 9.04%. This is likely to have altered watershed functioning from the previous less developed states by increasing flood peaks and potentially decreasing recharge to the underlying aquifer.

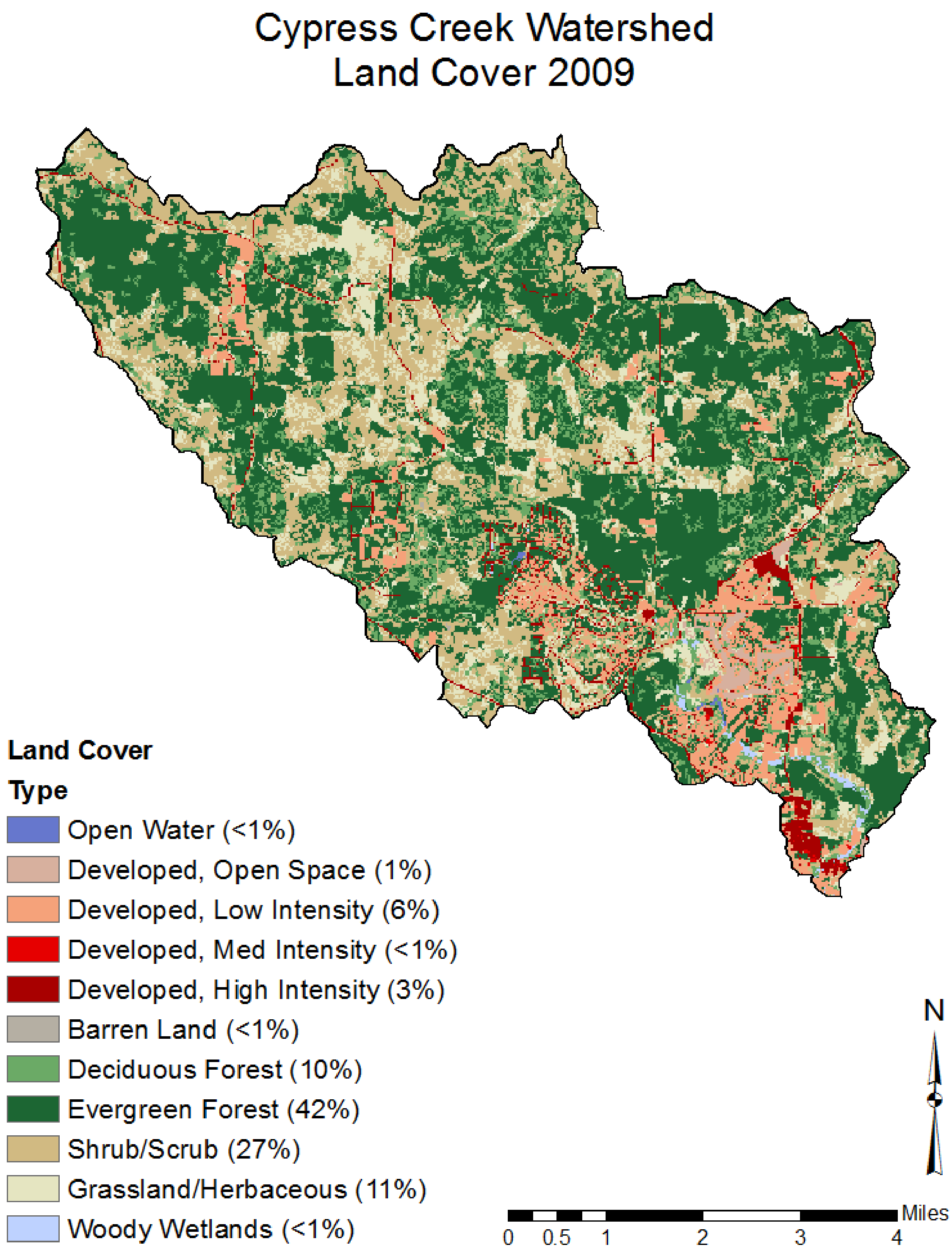


Figure 4.7. Land cover in the watershed, 2009.

Other results from Carter (2008) show a pattern consistent with an urbanizing watershed. From 1996-2005, patch number increased for four out of six land cover types, while mean patch area decreased slightly. Cover classes associated with undeveloped land (dense canopy, woodland, dense grasses) declined as a percentage of total watershed area, while those associated with development (open park, sparse/bare soil, and impervious cover) increased in their relative area (Carter, 2008; Figure 4.8). Overall, an increase in impervious cover and decrease in average patch size for other land cover classes indicate a typical pattern of landscape fragmentation as urban development encroaches on previously open areas. In addition, landscape fragmentation caused by anthropogenic activity can have profound effects on biotic communities, ecological processes, and hydrologic functioning. There is also some indication that clearing of previously forested areas may have occurred, though conclusions are not entirely reliable given limitations of the remote sensing approach used for analysis. Additional analysis will need to be done to determine the spatially distributed impacts of this change across the watershed, though it is clear that the largest increase in ISC from urban development has occurred in the lower portions of the watershed around Wimberley, Woodcreek and Woodcreek North, and much of the projected development is expected to occur in these areas along major transportation routes such as RR12 and RR2325.

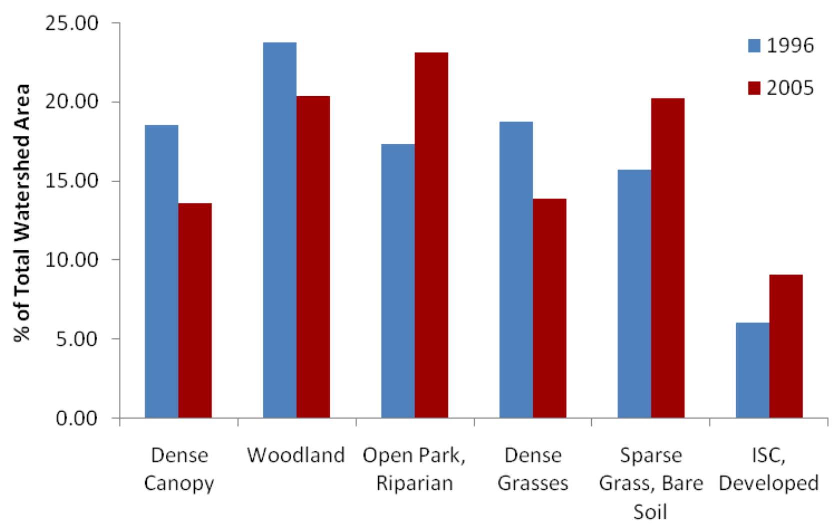


Figure 4.8. Change in relative area of six land cover classes from 1996 to 2005 (Adapted from Carter, 2008).

4.4 Watershed Modeling

Watershed modeling of the Cypress Creek contributing area was performed using the Cypress Creek Decision Support System (CCP-DSS), a modeling and results visualization package based on the Automated Geospatial Watershed Assessment (AGWA2) tool. AGWA2 is an interface for ESRI's ArcGIS jointly developed by the U.S. Environmental Protection Agency, U.S. Department of Agriculture (USDA) Agricultural Research Service, and the University of Arizona to automate the parameterization and execution of two commonly-used hydrologic models, SWAT and KINEROS (Miller et al., 2007). The CCP-DSS is based on the AGWA2 system and in addition has been populated with all the relevant local data to perform scenario analyses on the Cypress Creek watershed.

The Soil and Water Assessment Tool (SWAT) was used to model flow, sediment, and nutrients across the watershed and stream channels. This model uses information on soils, topography, land cover, rainfall, and temperature to simulate hydrologic processes on the land surface that create surface flow, infiltration and subsurface flow, and routes these flows, sediment and nutrients through stream channels. It is a continuous simulation model, so outputs can be daily, monthly, or annual means for a period of several years to decades. Daily data from 2000 to 2009 were used to run the model and to compare the simulated outputs to observations. Daily flows and nutrient loadings simulated in each subwatershed from 2000-2009 were averaged and selected results are presented below. Existing BMPs were not surveyed for this study; therefore the model results presented here represent initial estimates of average runoff and pollutant loadings based on known land uses and the physical properties of the area. Additional calibration of the model to incorporate existing BMPs and new monitoring data is recommended. See Appendix B for more details on model development, inputs, and calibration.

Water yield is the average amount of water leaving a subwatershed or channel. Model results show an average water yield across the watershed of 8.5 in, meaning that for an average annual rainfall of 35 in, about 8.5 in of that will flow out of the upland areas to the main stream channel. Model results indicate that a great deal of flow losses occur in the upper portions of the watershed through rapid infiltration and channel loss. Some of these flows travel through the shallow subsurface and reappear in downstream channels, while others are lost to deep percolation and/or used by vegetation. Areas that yield the largest amounts of water also have the greatest potential to carry high volumes of pollutants in this water, so these areas should be targeted for BMP implementation to mitigate both nonpoint source pollution and flood risk (Figure 4.9). Simulated average water yields for each subwatershed were also used along with data on land uses to calculate pollutant loadings for some additional parameters of interest as discussed in Section 5.0.

Sediment yields tend to be largest in the northern and eastern portions of the watershed where slopes are high and vegetation cover is more sparse (Figure 4.10). Sediment yield tends to be highest during the summer months, when large and intense storms are more common. Average sediment yield for the watershed was 275 lb/acre/year.

Simulated organic nitrogen yields range from 0 to 2.5 lb/acre/year and are highest in upland areas and the more developed areas along the perennial creek (Figure 4.11). Simulated organic Phosphorus yields range from 0 to 0.4 lb/acre/year, and follow a similar spatial pattern to nitrogen (Figure 4.12).

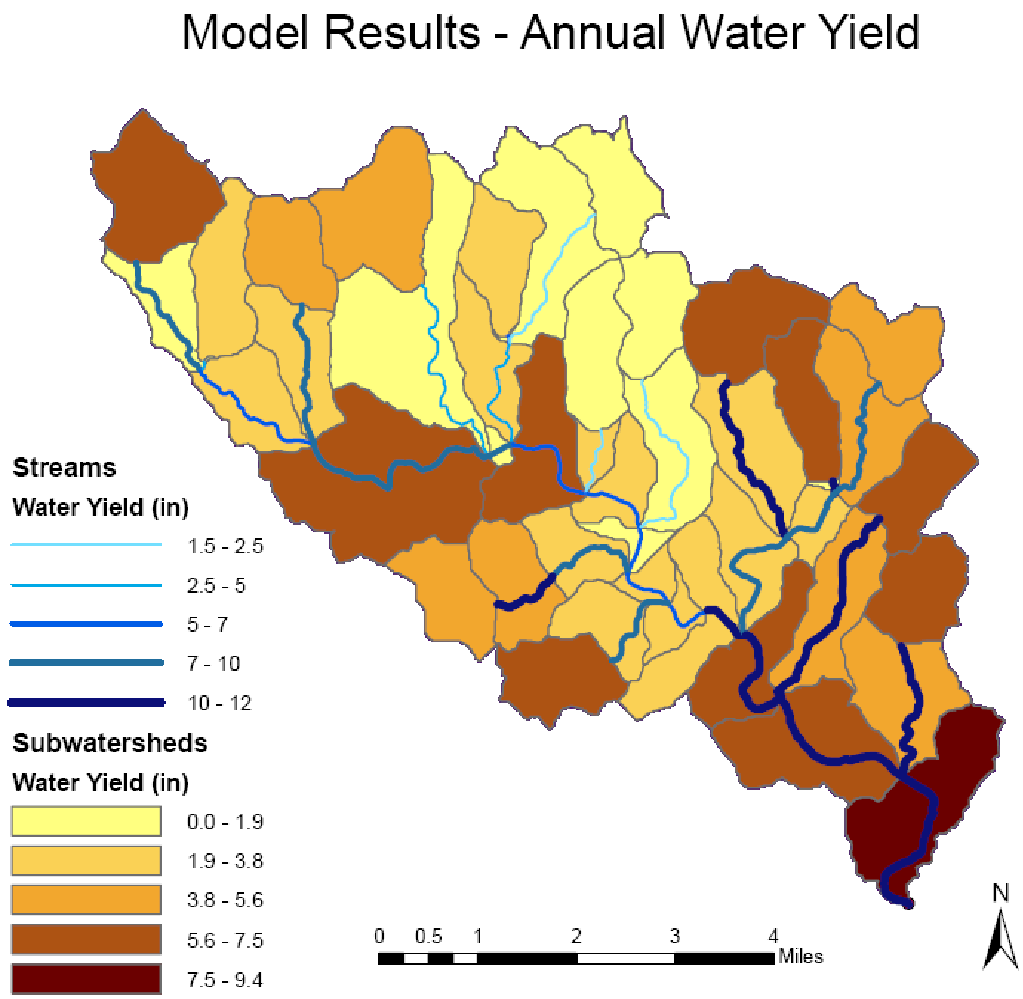


Figure 4.9. Simulated average water yield by subwatershed and reach, 2000-2009, using the SWAT hydrologic model.

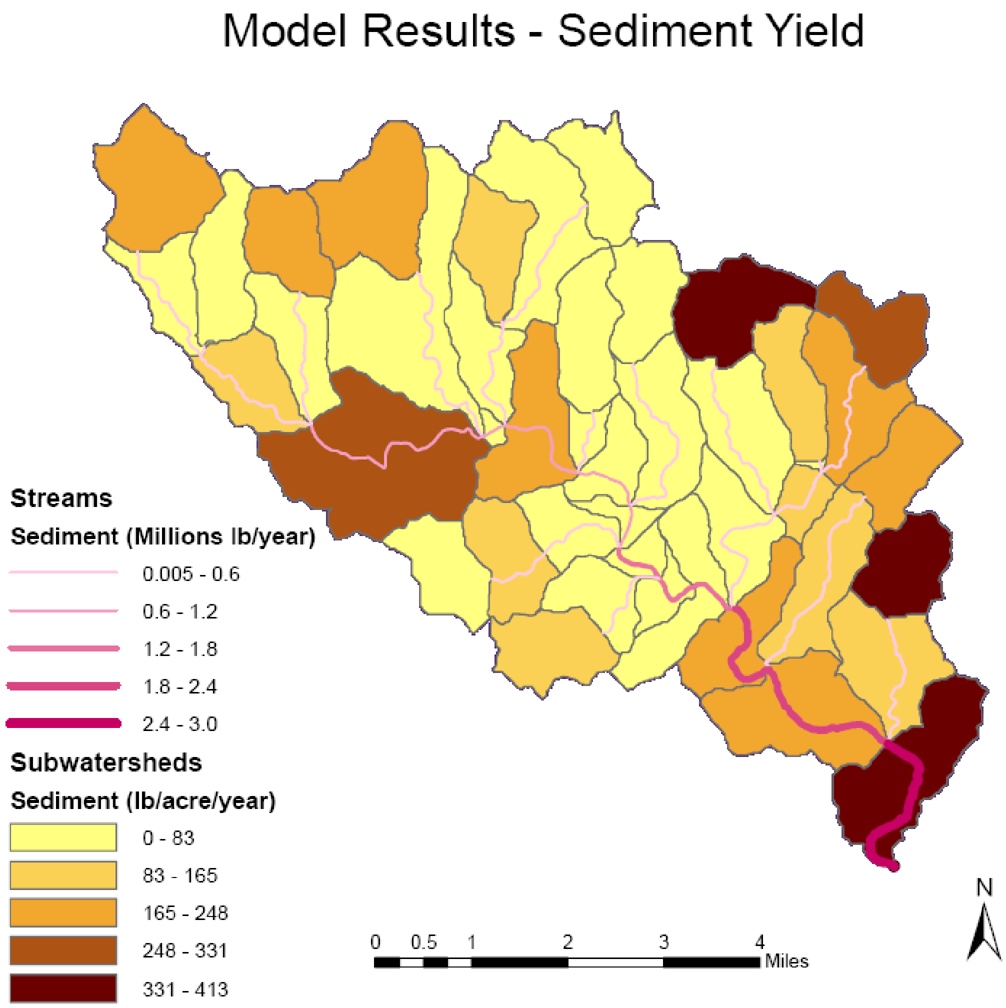


Figure 4.10. Simulated average sediment yield by subwatershed and reach, 2000-2009, using the SWAT hydrologic model.

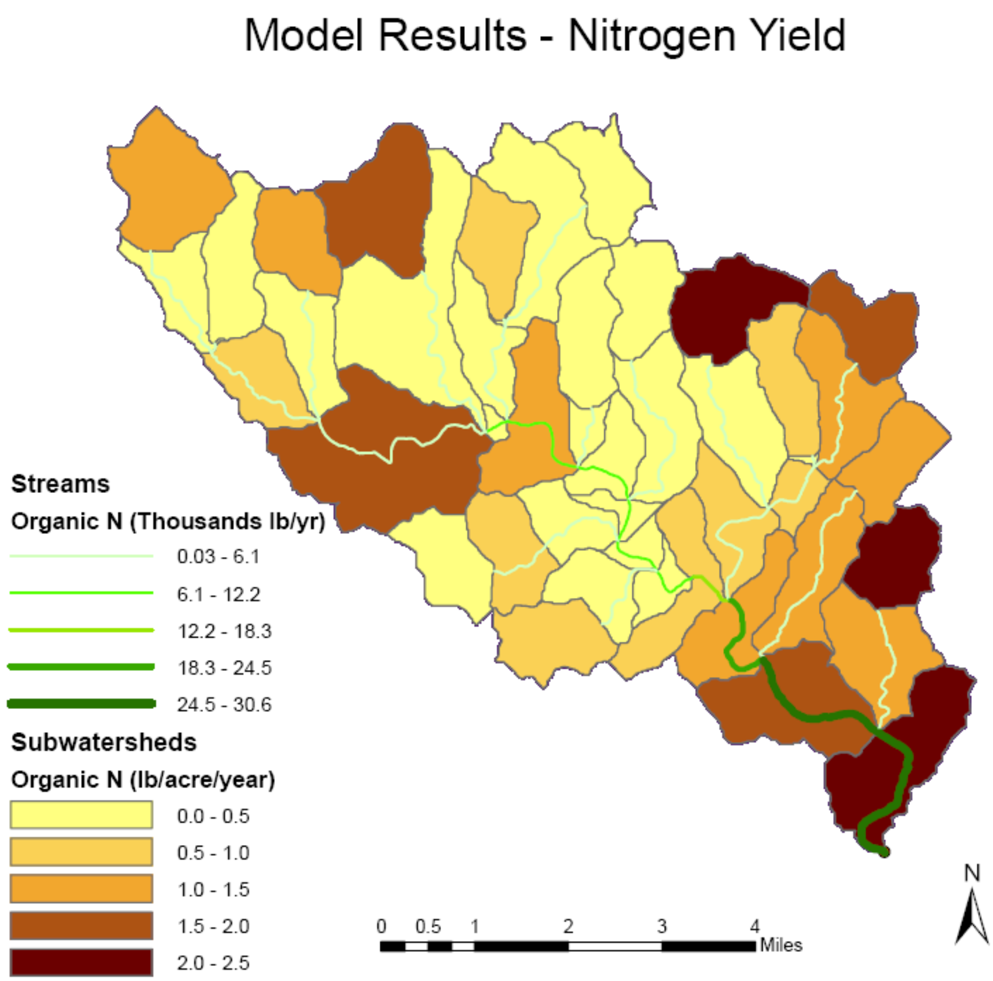


Figure 4.11. Simulated average organic nitrogen yield by subwatershed and reach, 2000-2009, using the SWAT hydrologic model

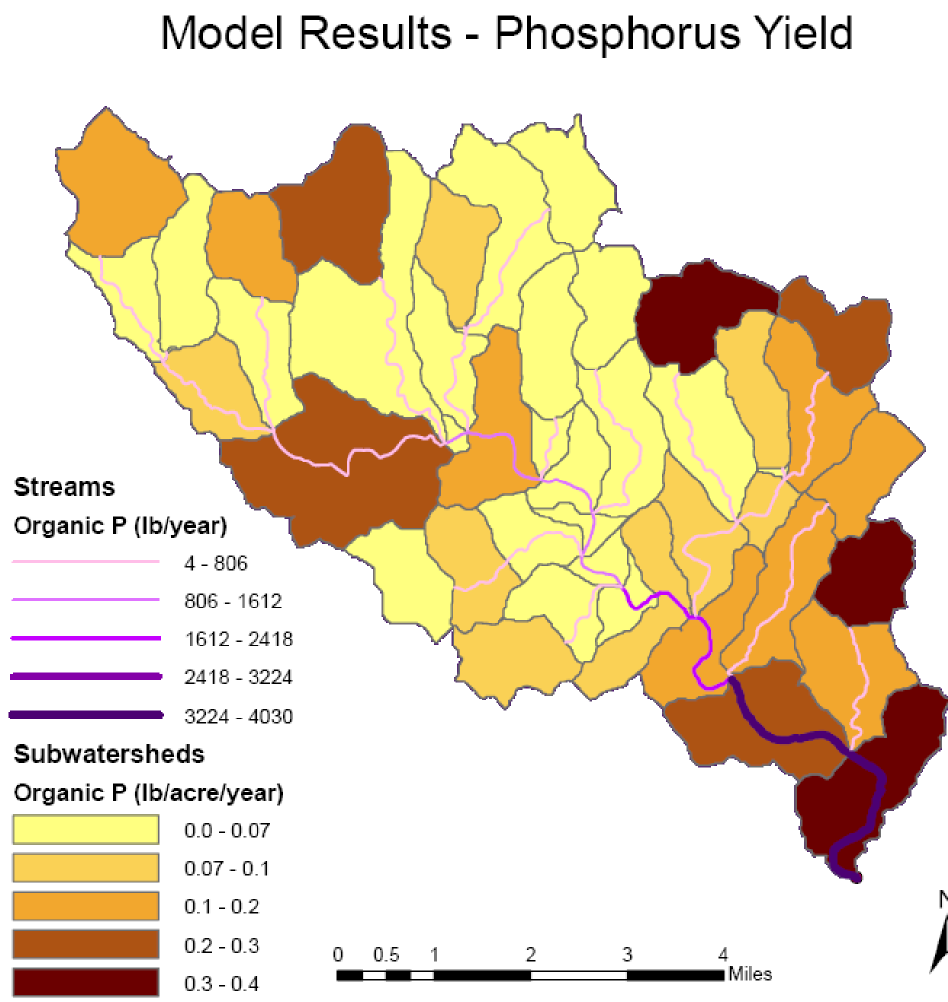


Figure 4.12. Simulated average organic phosphorus yield by subwatershed and reach, 2000-2009, using the SWAT hydrologic model.

5.0 Nonpoint Source Pollution

5.1 Pollution Loading Methods

Estimating annual pollutant loadings can be very useful for identifying the types of nonpoint source pollution from different parts of the watershed and understanding the magnitude of loadings that need to be managed with the Watershed Protection Plan. Although the Cypress Creek watershed has a good record of ambient water quality in the watershed, these values have not been separated into the contributions from component land uses. In addition some parameters, such as oil/grease and biochemical oxygen demand (BOD), are not included in the current data set. Estimates of event mean concentrations (EMC) of various agricultural and urban NPS pollution constituents are given in Baird et al., 1996. These values have been used in several studies in Texas when localized EMCs are not available. In order to augment the results from SWAT watershed modeling and to characterize the relative loading contribution from different land uses, annual loadings for various pollutants were estimated using modeled water yield along with EMCs given in the Baird et al. (1996) land use study (see Table 5.1).

Because there is a great deal of potential variability in runoff depths both spatially between subwatersheds and temporally between wet and dry years, the goal of this study is to characterize the distribution and relative magnitude of nonpoint source pollution loadings across the watershed, rather than to provide absolute loadings for any given year. For this analysis we focused on the pollutants of primary concern in the Cypress Creek watershed: total nitrogen, total Phosphorus, suspended solids, biochemical oxygen demand (BOD), and oil/grease.

Table 5.1. EMC estimates for selected NPS constituents (*from Baird et al., 1996*).

Constituent	Land Use						
	Residential	Commercial	Industrial	Transportation	Cropland	Rangeland	Undev/Open
Total Nitrogen (mg/L)	1.82	1.34	1.26	1.86	4.40	0.70	1.50
Total Kjeldahl Nitrogen (mg/L)	1.50	1.10	0.99	1.50	1.7	0.20	0.96
Nitrate + Nitrite (mg/L as N)	0.23	0.26	0.30	0.56	1.6	0.40	0.54
Total Phosphorus(mg/L)	0.57	0.32	0.28	0.22	1.3	<0.01	0.12
Dissolved Phosphorus(mg/L)	0.48	0.11	0.22	0.10	--	--	0.03
Suspended Solids(mg/L)	41.0	55.5	60.5	73.5	107	1.0	70
Dissolved Solids(mg/L)	134	185	116	194	1225	245.0	--
Total Lead (µg/L)	9.0	13.0	15.0	11.0	1.5	5.0	1.52
Total Copper (µg/L)	15.0	14.5	15.0	11.0	1.5	<10	--
Total Zinc (µg/L)	80	180	245	60	16	6.0	--
Total Cadmium (µg/L)	0.75	0.96	2.0	< 1	1.0	<1.0	--
Total Chromium (µg/L)	2.1	10.0	7.0	3.0	<10.0	7.5	--
Total Nickel (µg/L)	< 10	11.8	8.3	4.0	--	--	--
BOD (mg/L)	25.5	23.0	14.0	6.4	4.0	0.5	--
COD (mg/L)	49.5	116	45.5	59	--	--	40
Oil and Grease (mg/L)	1.7	9.0	3.0	0.4	--	--	--
Fecal Coliform(colonies/100 ml)	20,000	6,900	9,700	53,000	--	37	--
Fecal Strep.(colonies/100 ml)	56,000	18,000	6,100	26,000	--	--	--

-- Data not available
Values shown as <0.01, <1, and <10 indicate that all or most of the values were below the reporting limit.
Time period for data is 1992-1993 except for cropland and rangeland, which was collected 1970-1995.

Method

Mean annual water yields for each subwatershed were converted to runoff volume $(\frac{m^3}{yr})$ by converting to meters and multiplying by the total area of the subwatershed. EMCs for land use-constituent combinations for which no estimates are provided are not included in loading estimates. Also, EMC values below detection limits (i.e. <0.01) also were not included. NPS loadings for each constituent are calculated as the sum of EMCs for each land use multiplied by runoff volume and scaled by the relative area in each land use:

$$l_x = \sum(0.001EMC_{x1} * Q * a_1) + (0.001EMC_{x2} * Q * a_2) + \cdots + (0.001EMC_{ax} * Q * a_{n*})$$

Where l_x = annual loading of constituent *x* $(\frac{kg}{yr})$

EMC_{x1} = event mean concentration of constituent *x* from land use 1 $(\frac{mg}{L})$

Q = water yield (runoff volume) $(\frac{m^3}{yr})$

a_1 = percent of watershed area in land use 1

The results are then converted to unit loads (per unit area) given the formula:

$$L_x = \frac{10\,000 * l_x}{A}$$

Where L_x = annual unit loading of constituent *x* (kg/ha/yr)

A = total area of subwatershed (m^2)

Finally, loading estimates were converted to pounds per acre per year (lb/acre/year).

Method for SELECT Calculations:

The Spatially Explicit Load Enrichment Calculation Tool (SELECT) is an analytical approach for developing an inventory of potential bacterial sources, particularly nonpoint source contributors, and distributing their potential bacterial loads based on land use and geographical location (Berg et al., 2008). A thorough understanding of the watershed and potential contributors that exist is necessary to estimate and assess bacterial load inputs. Land use classification data and data from state agencies, municipal sources, and local stakeholders on the number and distribution of pollution sources are used as inputs. Pollutant sources in the landscape can then be identified and targeted where they are most likely to have significant effects on water quality, rather than looking at contributions on a whole-watershed basis (Berg et al., 2008).

Calculations used to calculate potential *E. coli* loadings were taken from the Plum Creek Watershed Protection Plan (Berg et al., 2008) and Zeckoski (2005) as follows:

$$PetsLoad = \#households \times \frac{0.8\ dogs}{household} \times 5.0 \times \frac{10^9\ cfu}{day} \times 0.5$$
$$CattleLoad = \#cattle \times 5.4 \times \frac{10^9\ cfu}{day} \times 0.5$$
$$GoatsLoad = \#goats \times 18.0 \times \frac{10^9\ cfu}{day} \times 0.5$$
$$HorsesLoad = \#horses \times 4.2 \times \frac{10^8\ cfu}{day} \times 0.5$$
$$HogsLoad = \#hogs \times 8.9 \times \frac{10^9\ cfu}{day} \times 0.5$$
$$DeerLoad = \#deer \times 3.5 \times \frac{10^8\ cfu}{day}$$
$$SepticsLoad = \#septics \times fail\ rate \times \frac{10^6\ cfu}{100mL} \times \frac{\#persons}{household} \times \frac{70\ gal}{day} \times \frac{3758.2\ mL}{gal} \times 0.5$$

These daily loadings were then converted to total yearly loads (billions cfu/year). For comparison between subwatersheds, total daily loads were divided by the area of each subwatershed to produce estimates of unit loads (billions cfu/acre/year).

Pollutant Sources*:*

Agriculture is not a large source of pollution in the Cypress Creek Watershed. The thin, rocky soil makes it difficult to grow row crops. In addition, there are no concentrated animal feeding operations in the watershed. Bacteria can enter waterways from waste excreted by humans, pets, wildlife and livestock directly or indirectly through inadequate sanitary systems. Die-off rates of bacteria vary depending on moisture, pH, soil and temperature. There is little cited information regarding the fate and transport of bacteria under the conditions at Cypress Creek, so this report assumes a 100% viability of *E. coli*, meaning that estimates are not adjusted for potential die-off that may occur before these bacteria are washed into the creek. Therefore the pollutant loadings should be considered POTENTIAL pollutant loadings. Further studies into the *E. coli* mortality rates are needed to assess true viability of bacteria on the landscape to refine estimates of *E. coli* entering Cypress Creek.

Pets*:*

When not properly disposed of, pet waste can enter waterways, lower the quality of the water, and increase pathogen levels. Pet waste contains *E.coli*, bacteria and other parasites that can be harmful to humans and aquatic life. The American Veterinary Medical Association estimates that there are 0.8 pets per household (AVMA, 2002). There are approximately 2,740 households in the Cypress Creek Watershed, and therefore approximately **2,192** pets are used in the calculation.

Horses:

According to the Texas AgriLife Extension, watershed stakeholders, and the Wimberley 4H Club, the exact number of horses in the Cypress Creek Watershed is unknown. However, both agencies estimate that a maximum number would be close to **100** horses. Horses in the watershed are typically used for recreational purposes. While the exact location of all horses is not known, horse numbers were distributed equally across agricultural land and home sites larger than 5 acres.

Deer:

White-Tailed deer are abundant throughout the Texas Hill Country. A Texas Parks and Wildlife Department report notes that the Texas Hill Country is "one of the best deer producing areas in the world" (TPWD, 2000). However, due to the excessive numbers of deer, the deer waste can contribute significantly to bacteria and nutrient loadings. While deer are difficult to count due to their movement, Texas AgriLife Extension estimates 3 acre per deer in the Cypress Creek Watershed. This equals to roughly **8,111** deer, divided evenly in the calculation across the watershed.

Feral Hogs:

Figure 5.1. Feral Hog, Courtesy of the Texas Dept of Agriculture

Feral hogs are a rapidly growing problem in Texas. Statewide, population estimates range from 1-2 million hogs. The hog population has grown due to their adaptability and reproduction rate. With adequate nutrition, a hog population can double in 4 months (Texas Cooperative Extension, 2004). Feral hogs are considered nuisances and can be hunted year round in Texas. Feral hogs tend to stay within riparian areas, and sometimes in the water body itself, thereby directly depositing their waste into the water. However, Cypress Creek has very steep embankments and hogs are not typically seen there. There is anecdotal evidence of hogs destroying fields and property in the watershed. "Extensive rooting of soils, forest litter and grasslands can cause serious erosion of riparian areas, which leads to siltation, lower water quality, and sometimes fish kills. Rooting may also disrupt native plants and change the plant and animal community" (Texas Cooperative Extension, 2004). Feral hogs will prey on other animal species when necessary.

Tracking the actual numbers of feral hogs is difficult due to their secretiveness. Hogs move at night, and their eyes are not reflective like a deer and cannot be seen with a spotlight. In addition, feral hogs are typically black in color and can be hard to spot. Feral hogs often travel great distances in a short amount of time. Evidence of hogs is found after they have left: destruction of land and property, feces, and dead or injured animals. Feral hogs carry a variety of diseases and can be a major contributor of *E. coli*. Based on an estimate of 1 million hogs in Texas, there is 1 hog per 75 acres, or roughly 8.5 hogs per square mile in the Cypress Creek Watershed. This results in **324** feral hogs in the watershed. This estimate is based on the assumption that the hogs are present in all areas year-round; as they tend to move around, the numbers could vary greatly from season to season.

Cattle:

According to the Texas AgriLife Extension, there is 1 cow per 40 acres in the Cypress Creek Watershed. Based on personal experience, the Cypress Creek Watershed Committee agreed with this number. Texas AgriLife estimates about three-quarters of the farms in the watershed have cows. Therefore the number of cows in each subwatershed was calculated based on the stocking rate of 1 cow per 40 acres on 75% of the total agricultural land. This resulted in a total of **342** cows estimated in the watershed.

Goats:

The 2009 Hays County estimates from Texas AgriLife Extension lists 7,500 goats total in Hays County. Per Texas AgriLife, about one-quarter of farms in the watershed have goats. Therefore the number of goats in each subwatershed was calculated based on the stocking rate of 1 goat per 40 acres on 25% of total agricultural land. This resulted in a total of **114** goats estimated in the watershed. Stakeholders have mentioned this number may be low; however, there is no citable evidence or ground-truthing that produced any results. Further research into the number of goats in the watershed would be needed to get an exact number.

Golf Course Effluent:

The Woodcreek golf course "Quicksand", located on the Woodcreek Country Club, is watered by using treated effluent and groundwater from the waste water treatment plant owned by AquaTexas. The State does not allow discharge of pollutants into water, but land application of effluent is permitted. Effluent ponding is not allowed, but this has occurred in the past. Once these ponds fill up, they overflow and could flow into the watershed. Further testing of vulnerable areas near the golf course would be needed in order to definitively affirm that there is no negative impact from effluent runoff. Therefore, no loading from the golf course was included in *E. coli* calculations.

Septic Tanks:

Many rural areas in Texas rely on on-site sewage facilities (OSSF's), and the Cypress Creek Watershed is no exception. In the 1980's, the USEPA began publishing manuals on how to design, site and maintain OSSFs. In 1987, Texas passed a bill to regulate sewage systems, which is handled by the TCEQ. Homeowners are responsible for the maintenance of their OSSFs. Although many owners have not been properly trained on how to maintain their systems, they are responsible for septic system maintenance. Septic systems work well when functioning correctly and sited in the correct soil. However, soil type, age, design and maintenance issues can contribute to OSSF failure. Septic system failure can impact the quality of ground and surface water.

According to a study conducted by the Texas On-Site Wastewater Treatment Council (Reed et al., 2001), septic systems built after 1987 have an estimated failure rate of 12%. Although age of septic systems, among other factors such as improper citing and soil type, contributes to the failure rate, there is no definitive literature value on the failure rates of older OSSF's.

A comprehensive database search for the date of the homes in the watershed (Hays County Appraisal District) did not yield the expected results. The data for "year built" was incomplete; there are 2,740 homes in the watershed, but year-built dates were present for only 1,750 homes. Of these, 318 or about 18% were built before 1987. Because of missing data and the uncertainty regarding failure rates for septic systems of any age, and considering the Steering Committee's input, OSSF calculations here assume a failure rate of 12% for all systems regardless of year built. The estimated number of OSSF's in the watershed is **1452** (Figure 5.2).

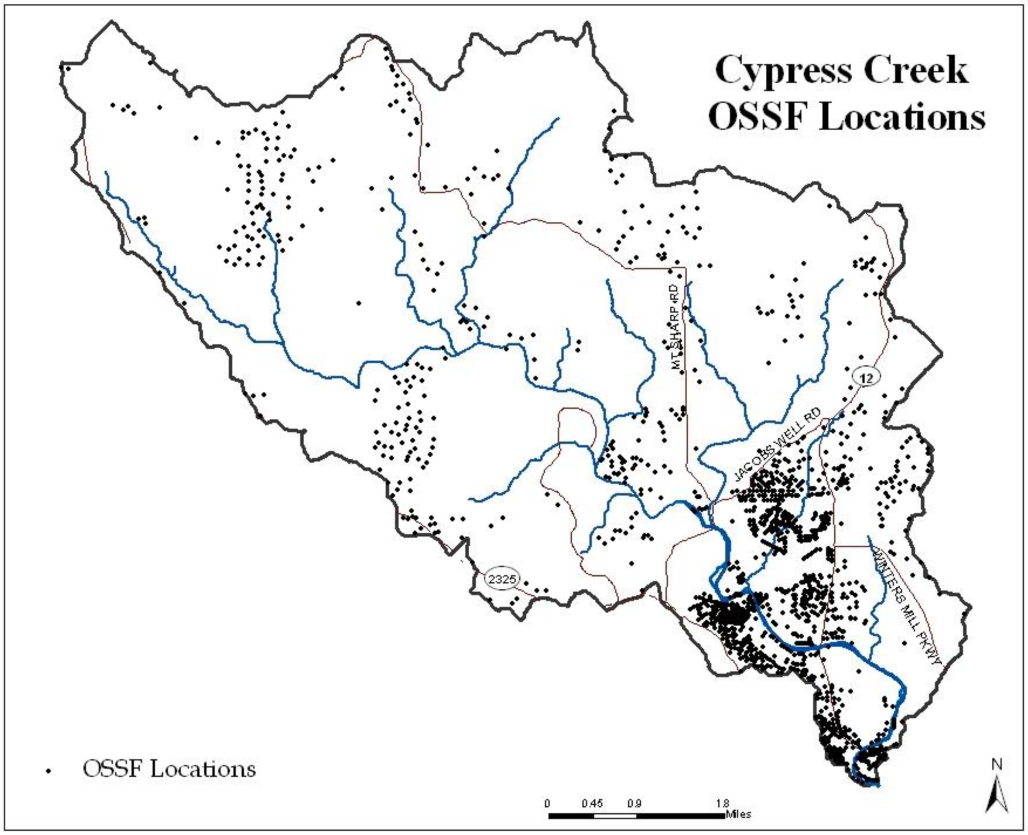


Figure 5.2. Locations of OSSF in the Cypress Creek Watershed.

Methodology for Determining OSSF Locations

Locations of OSSFs were estimated based on several circumstances. It was determined that any structure located outside of an existing TCEQ Sewer Certificate of Convenience and Necessity (CCN) boundary would be served by an individual septic tank. Therefore, it was necessary to determine the locations of all structures within the watershed. Hays County 911 addressing GIS data, which places a point for each address in the watershed (often aligned with aerial imagery of individual improvements), were updated to reflect that each structure in the watershed had one point associated with it and ground-truthed using 2008 aerial imagery (this allowed for some correction in the case that one building may have multiple addresses in the 911 system, etc). (Note: this same updated 911 structure points file was used to estimate number of households per subwatershed, which was necessary for calculating the pollution potential of pet wastes.)

Aqua Texas, Inc. operates a CCN in the Woodcreek and Woodcreek North developments in the watershed. An engineering study map (2005) with water and wastewater lines provided by Loomis Partners consulting was georeferenced to aerial imagery and all homes served by these lines were considered as not having an OSSF and were removed from the GIS points shapefile. What remained were representative points for each structure in the watershed, that could be summed by subwatershed and used to calculate estimated loadings for *E.coli*. The final numbers may be conservative estimates (i.e. higher numbers of septic systems than in reality) if the wastewater treatment lines were extended after 2005.

5.2 Pollution Loadings

Likely sources of NPS pollution in the watershed include on-site septic treatment, residential landscaping, fertilizer and pesticide application, land clearing for new construction, pet and livestock wastes, runoff from roads and parking lots, grazing activities, atmospheric deposition, and recreational use of the creek. NPS pollution sources associated with urbanizing areas includes on-site septic treatment, which remains the primary method of wastewater treatment in many areas of the watershed. It is not known how future developments will treat wastewater, but an increase in septic systems is likely, particularly in unincorporated areas. NPS pollution associated with residential land use includes the application of fertilizers and pesticides for landscaping. In addition, the removal of native vegetation and land clearing for new construction can increase erosion and runoff and decrease available habitat for native fauna. Urban areas and associated transportation networks increase runoff and are associated with higher levels of suspended and dissolved solids and metals. According to estimates from Baird et al. (1996), residential land use is the highest source of nutrient-based pollutants such as nitrogen, Phosphorus, and thus biochemical oxygen demand. Commercial land uses are associated with higher levels of heavy metals. Recreational use of the creek by humans and pets may contribute to sediment transport, bacteria and pathogens, and nitrogen levels in the creek, particularly in areas where there is heavy recreational use such as Blue Hole.

Assuming similar pollutant concentrations, larger volumes of runoff per unit area associated with impervious surface cover result in larger mass loads of pollutants for urban areas versus rural areas. In addition to an increase in impervious surface cover in urbanizing areas, the installation of drainage systems and concrete channels can result in pollutant loadings being delivered to the creek faster and in greater concentrations than in areas with natural drainage systems (Novotny and Olem, 1994).

Rangeland generates higher levels of suspended and dissolved solids. Potential loading results from animal wastes and increased erosion from soil compaction and vegetation removal. Therefore the upper areas of the watershed require different management activities to control excess sediment production than do urban areas where excess nutrients and metals represent a greater problem.

The following series of maps (Figures 5.3-5.9) show the results of the pollutant loading estimates by subwatershed. Each map shows the estimated annual loading for a single pollutant (BOD, total nitrogen, oil and grease, Phosphorus, suspended solids) in pounds per acre per year. The last two maps in the series show *E. coli* loadings estimated using the SELECT method, in billions of colony-forming units (cfu) per acre per year. The lightest colors represent the lowest annual loadings, while the darkest colors are the highest. These estimates were based primarily on land uses and estimates of numbers of homes, wildlife, livestock, etc. (see above for explanation of methods).

Estimates of total nitrogen and phosphorus using the land-use loading method described here produced loadings roughly twice the magnitude of those shown above using the SWAT model. This is partly due to the fact that SWAT results are for organic nitrogen and phosphorus, while this method uses total nitrogen and phosphorus (which includes both organic and nonorganic forms). Furthermore, the EMCs used here (Table 5.1) are slightly higher than concentrations normally observed in the Cypress Creek monitoring data. On the other hand, estimates of sediment yield using the land-use loading method here were roughly one-third of the estimates produced by the SWAT model. However the largest sediment loadings tend to occur during very large storm events that erode surrounding lands and wash large amounts of sediment into creek channels. Since the land-use loading method uses only average annual water yield it is reasonable that these estimates would tend to be lower.

The results highlight the fact that different areas of the watershed should be targeted for various pollution mitigation strategies. Areas with a high density of roads tend to have higher estimated loadings of suspended solids, oil and grease, etc., while areas with more residential land uses tend to have higher estimated nutrient loadings.

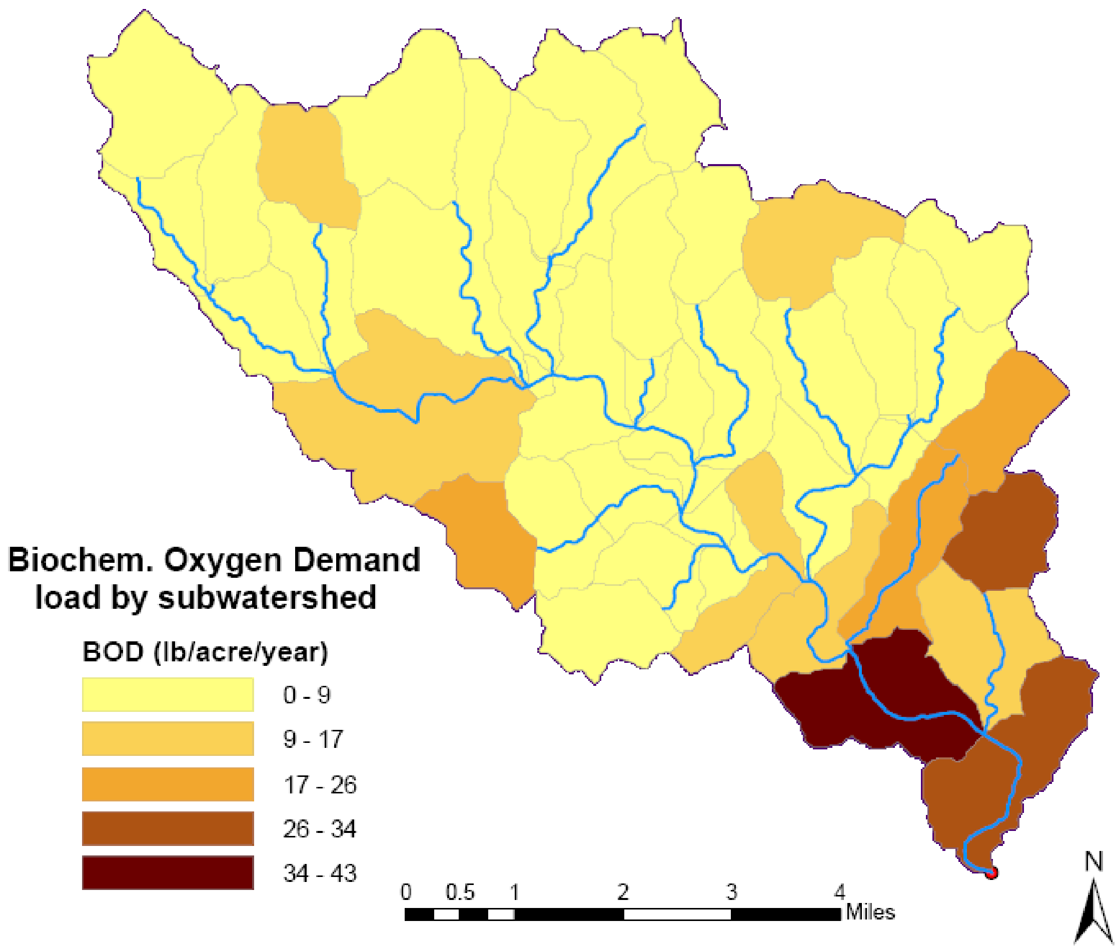


Figure 5.3. Biochemical oxygen demand, estimated load by subwatershed.

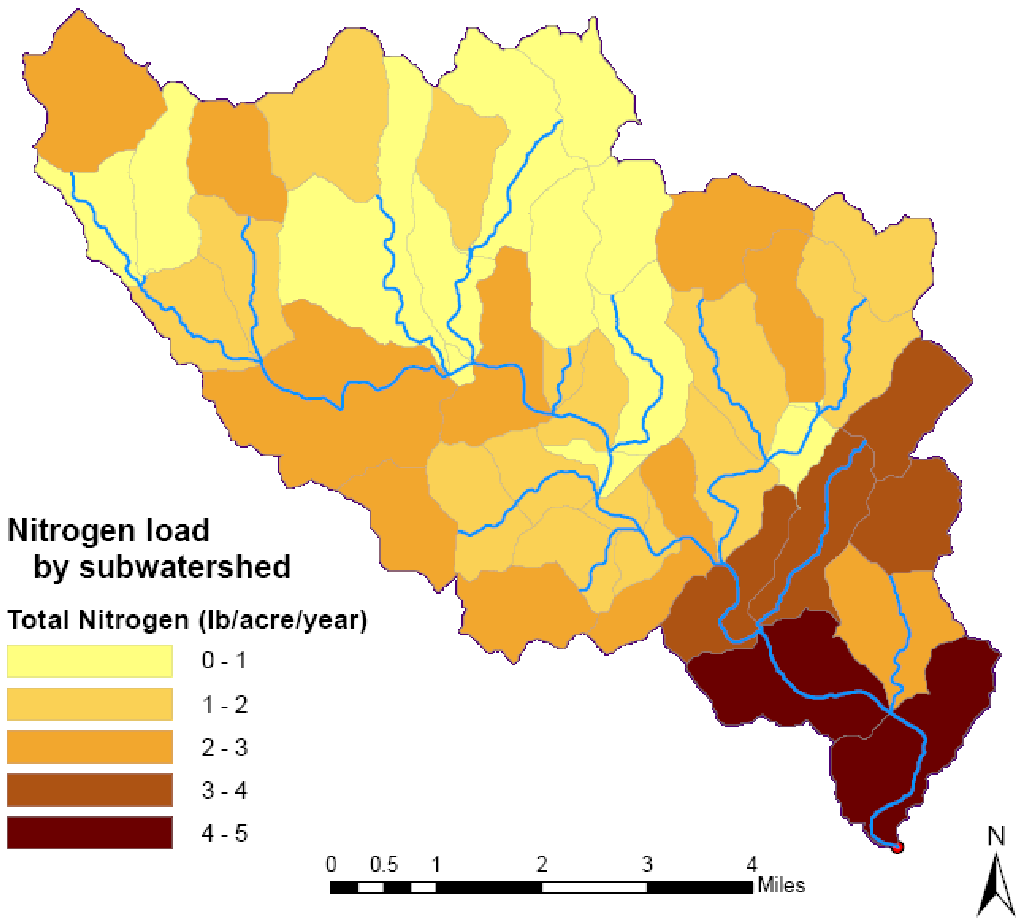


Figure 5.4. Total Nitrogen, estimated load by subwatershed.

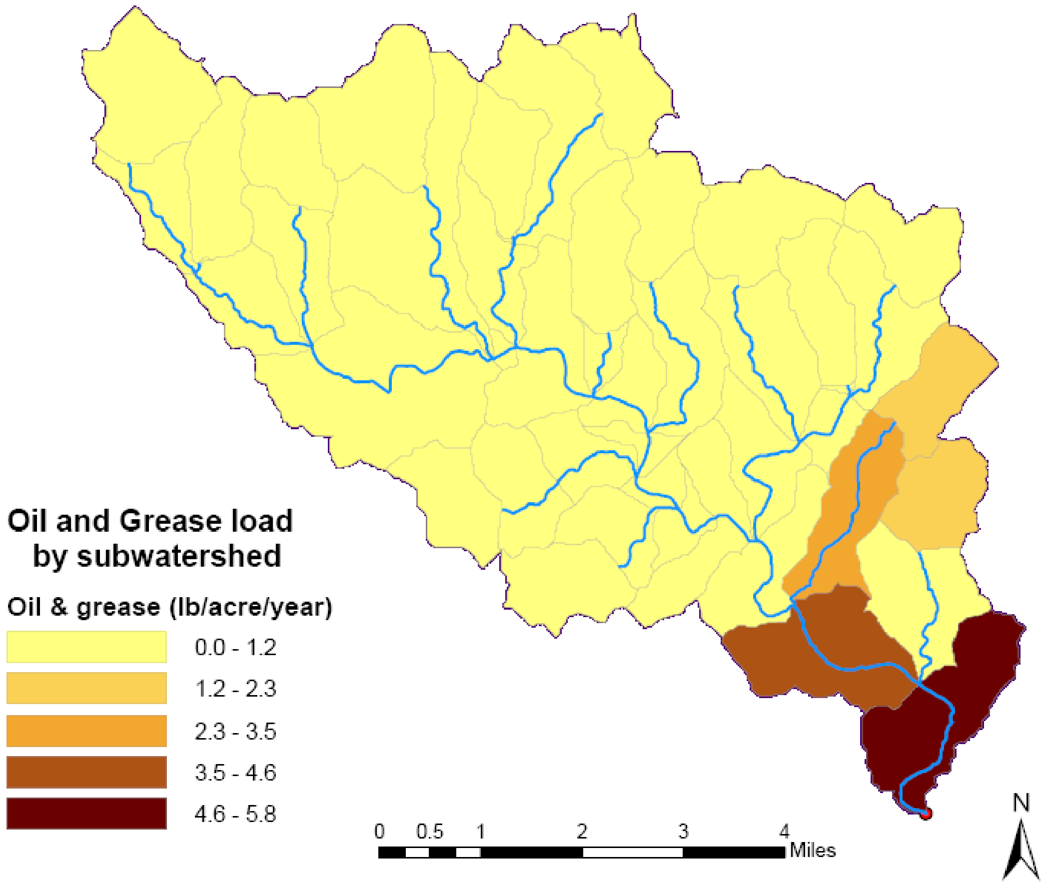


Figure 5.5. Oil and grease, estimated load by subwatershed.

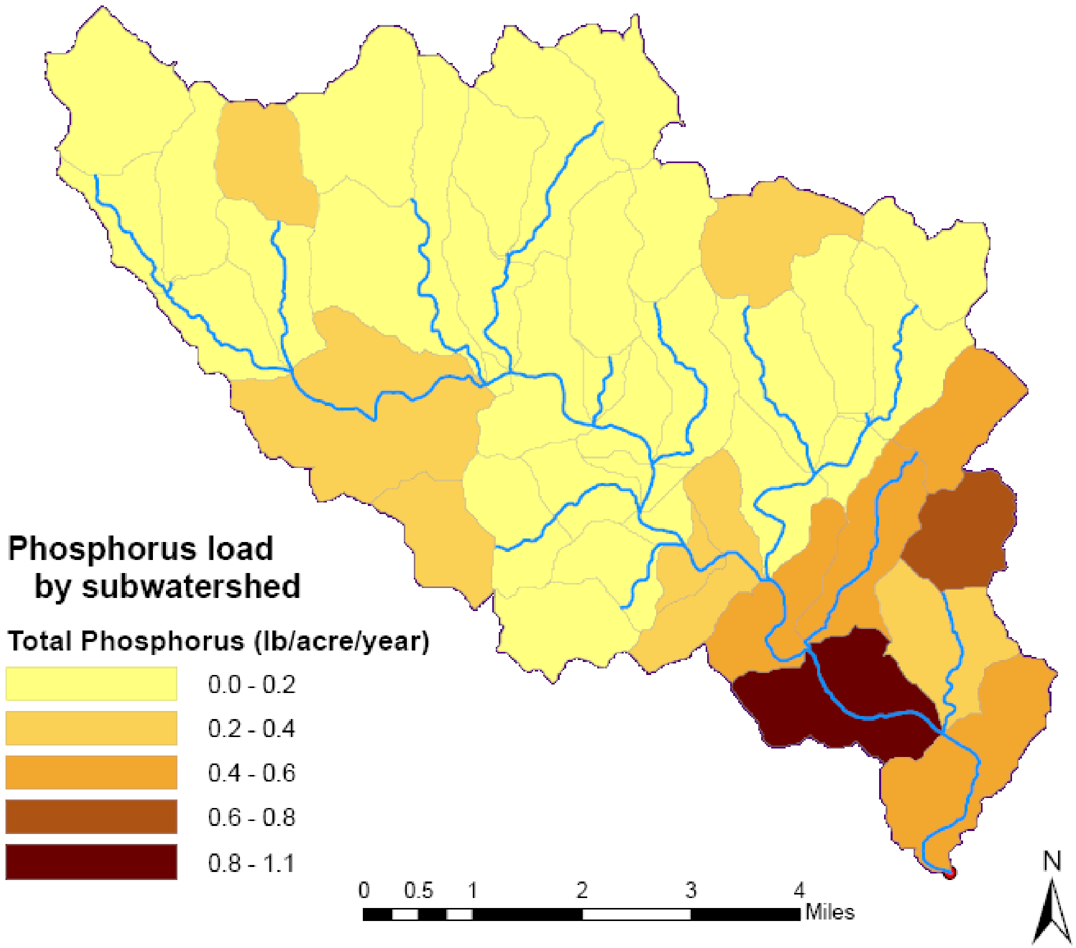


Figure 5.6. Total Phosphorus, estimated load by subwatershed.

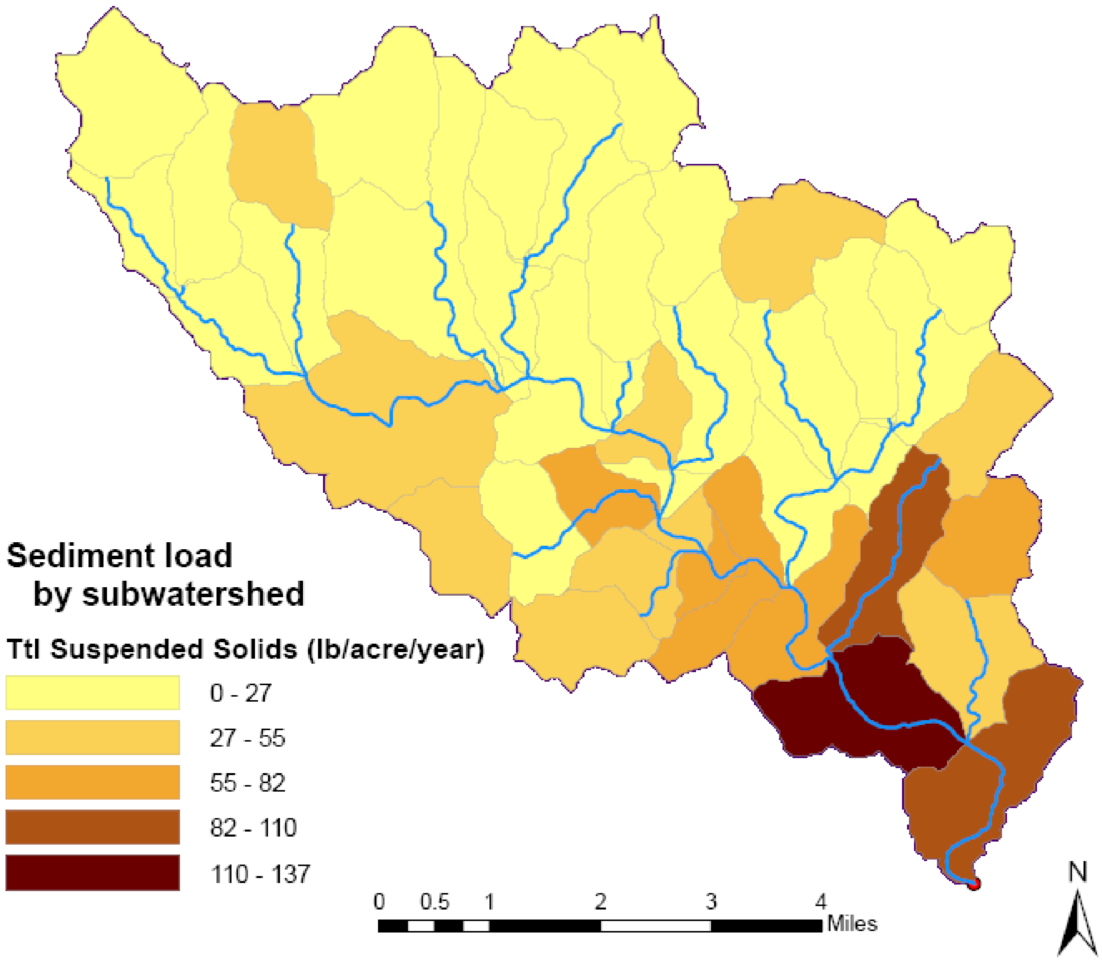


Figure 5.7. Total suspended solids, estimated load by subwatershed.

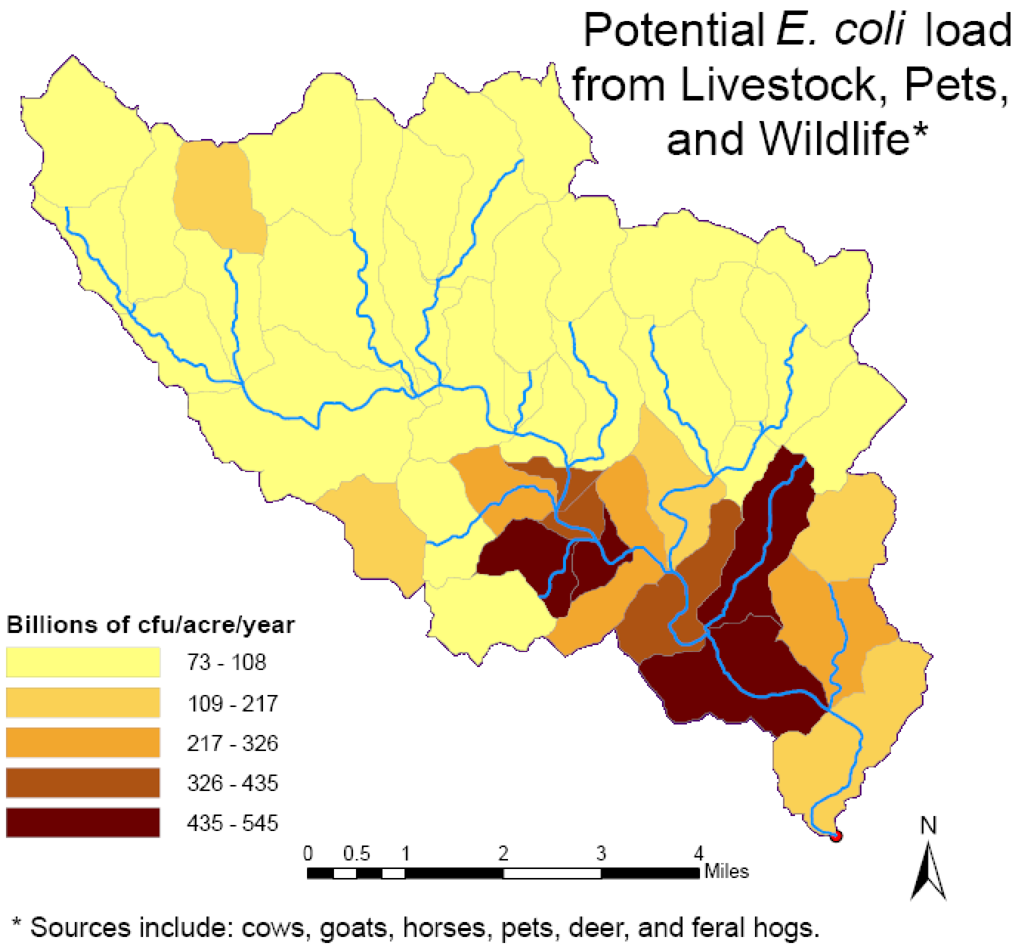


Figure 5.8. Potential E.coli load from livestock, pets, and wildlife.

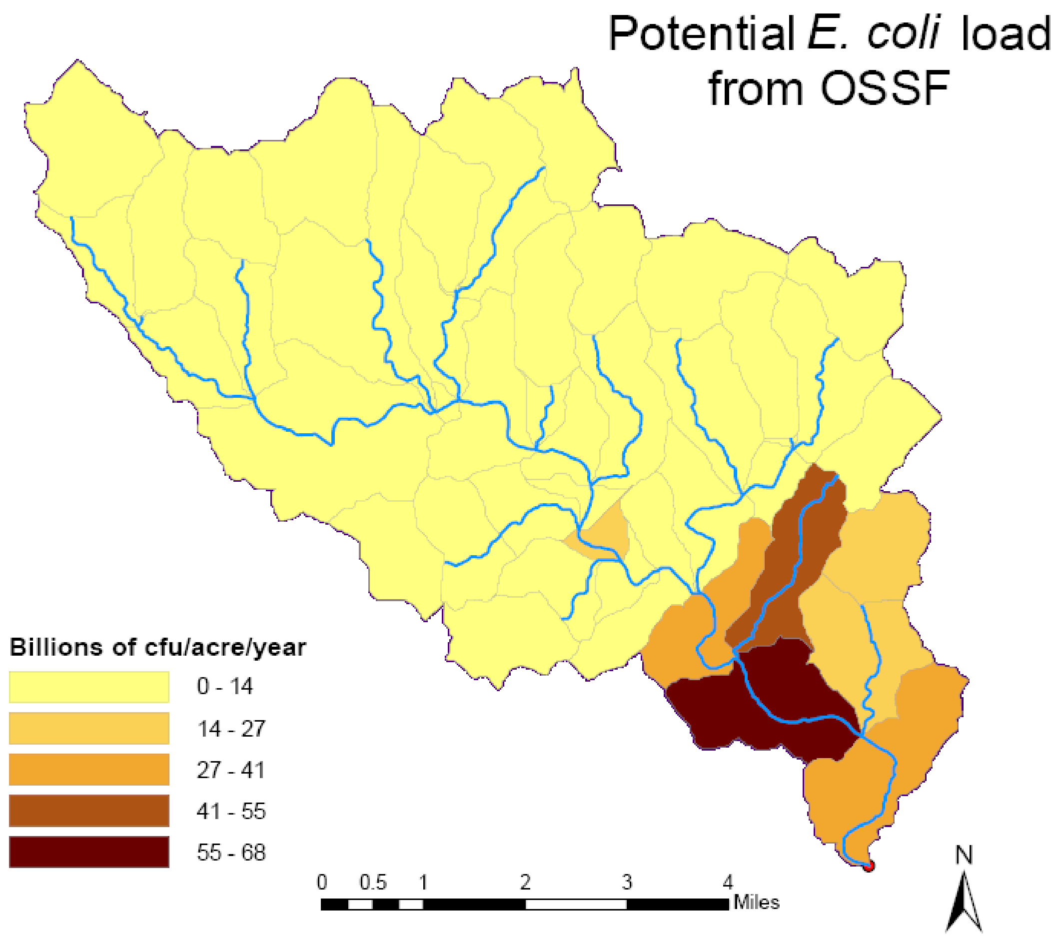


Figure 5.9. Potential E.coli load from OSSF.

Based on the land use and pollutant loading analysis described above, the following figures show total annual pollutant loading potential for six parameters: *E.coli*, BOD, oil and grease, total nitrogen, total phosphorus, and sediment (Figures 5.10-5.15). These figures illustrate the relative magnitude of the pollution load contributed from various sources and land uses. Land uses with the highest relative contribution should be targeted in watershed protection planning for BMPs that address those parameters of concern. For example, pets and deer are the largest sources of *E. coli* identified in the watershed, while residential land use is the largest contributor to BOD loadings. Therefore educating pet owners about picking up animal waste, limiting fertilizer applications, and controlling deer populations will be most effective in mitigating these problems. Nitrogen and sediment come predominantly from Rangeland and Undeveloped land uses, so BMPs for sediment retention and proper range management are recommended for those areas.

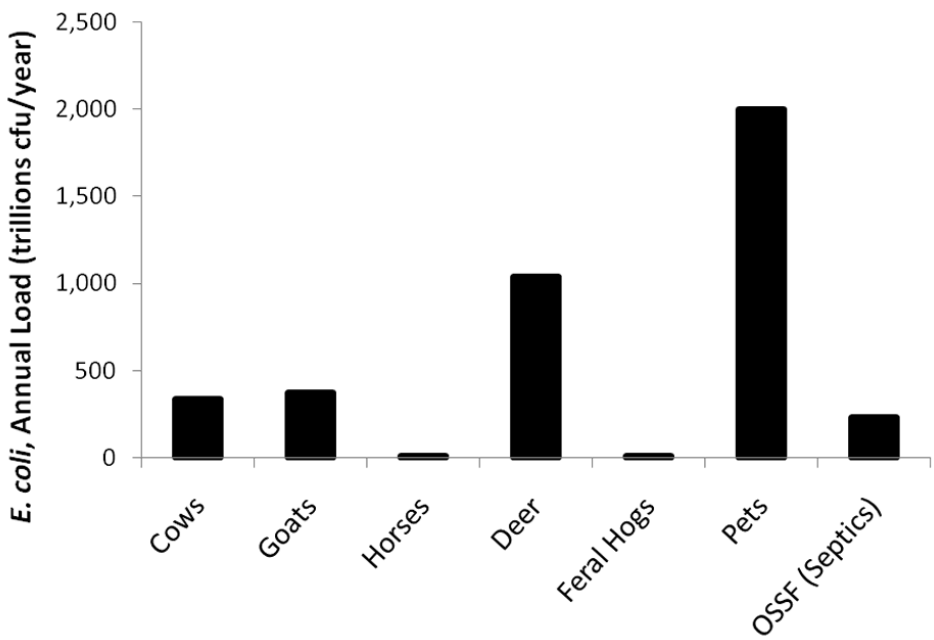


Figure 5.10. Total Potential E.coli load by source for watershed

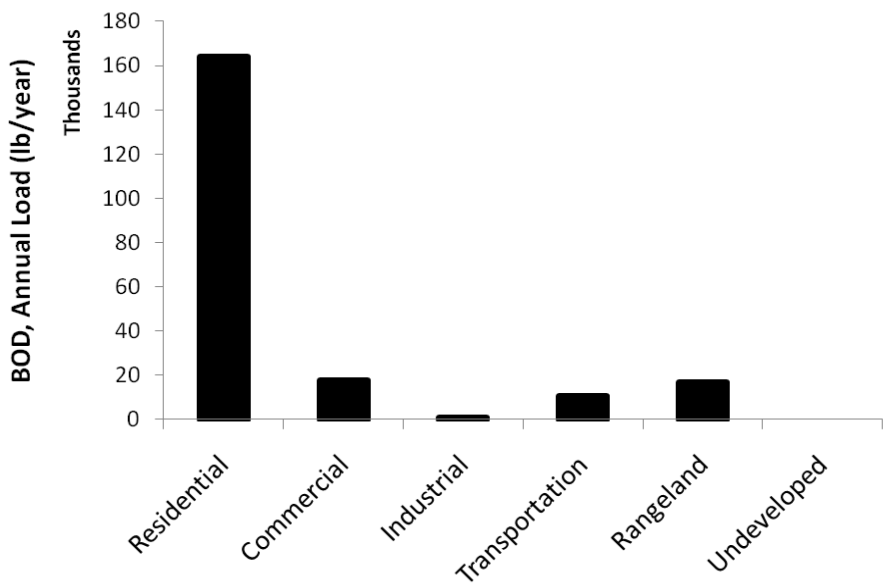


Figure 5.11. Total Potential BOD Annual Load by land use for watershed

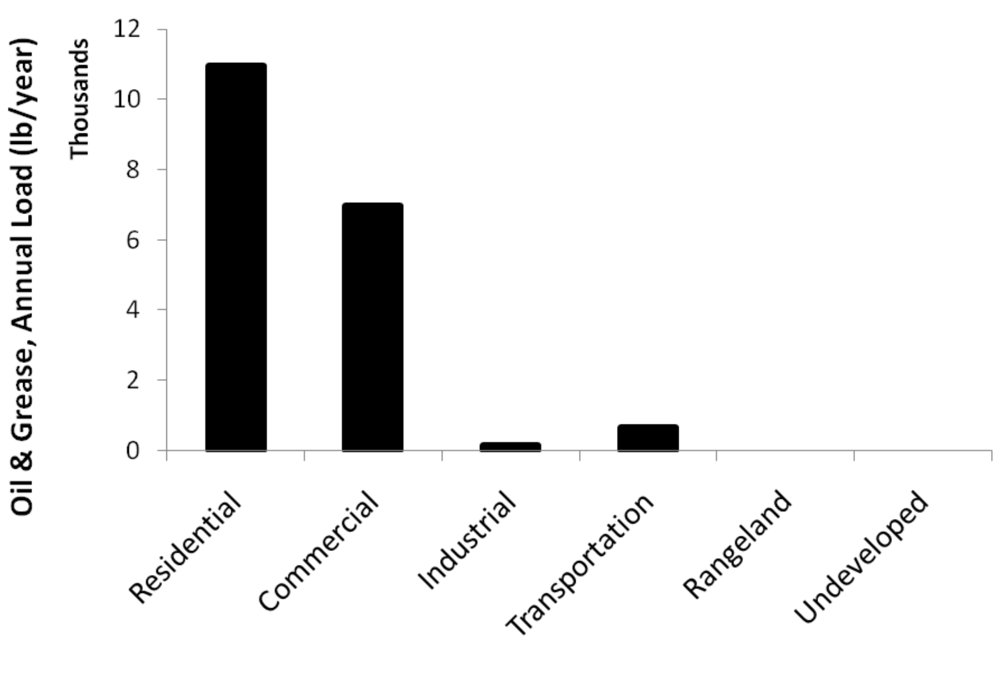


Figure 5.12. Total Potential Oil and Grease Annual Load by land use for watershed

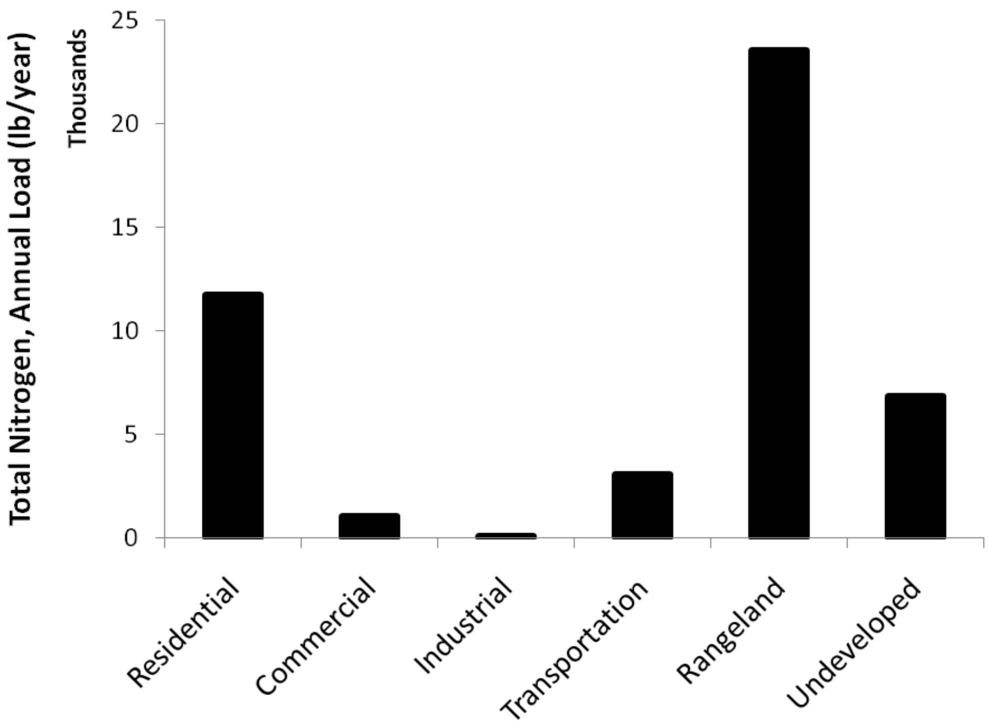


Figure 5.13. Total Potential Nitrogen Load by land use for watershed

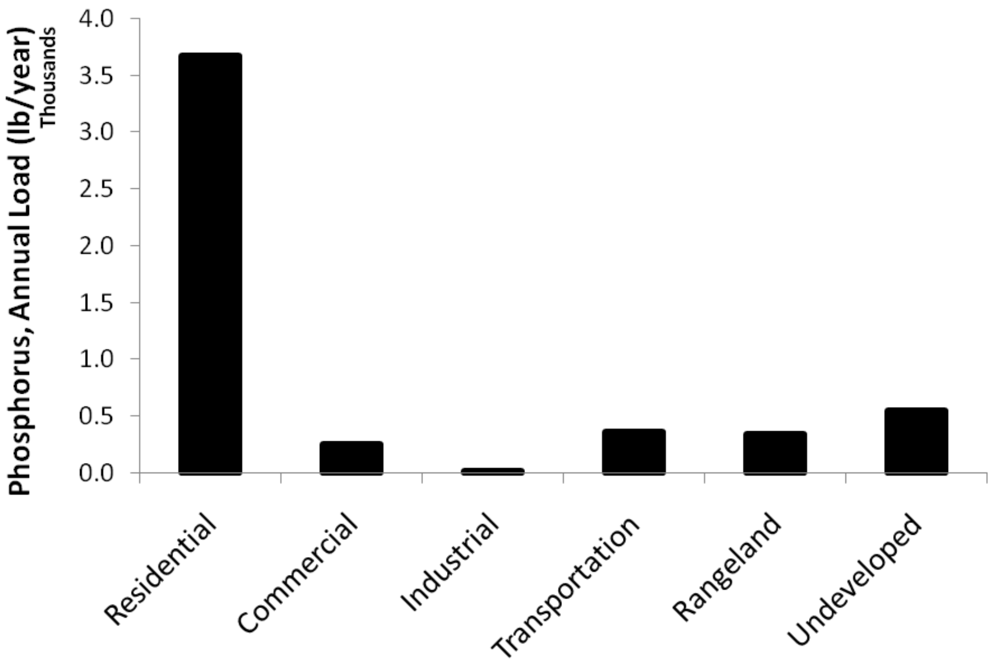


Figure 5.14. Total Potential Phosphorus Load by land use for watershed

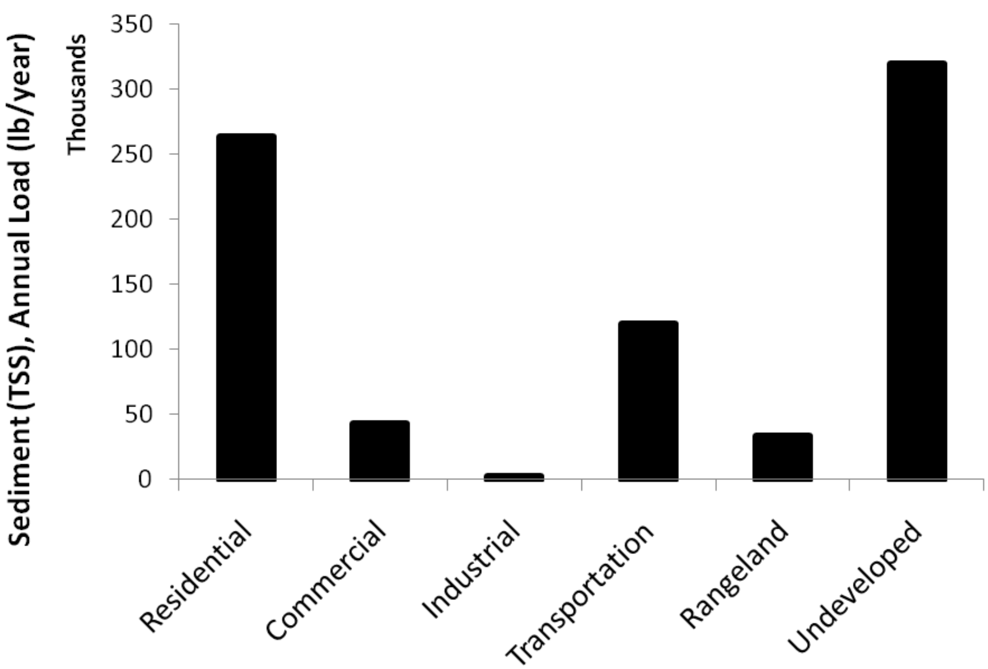


Figure 5.15. Total Potential Sediment Load by land use for watershed

6.0 Water Quality in the Watershed

6.1 Water Quality Analysis

Overall water quality in the Cypress Creek is meeting water quality standards set by TCEQ, though data reveal both spatial and temporal trends that may be due to climate variability, nonpoint source pollution, or changes in land use and/or management in the watershed. To help understand the physical context and factors that may be influencing water quality in the creek, load duration curves were constructed for the primary pollutants of concern in the area: suspended sediments, nitrogen, Phosphorus, and *E. coli*.

A load duration curve can be an effective tool used for analyzing the effects of pollution loading. Load duration curves define the relationship between flow (volume per time) and loading (mass pollutant per time) using data collected about streamflow and pollution concentrations. With *E.coli* bacteria, for example, staff generated a curve based on the criterion for the contact recreation use, individual sample criterion for *E.coli* (394 colonies/100mL). That curve represents the maximum allowable load of bacteria under different flow conditions. The comparison between the curve and the data points is then used to graphically demonstrate the frequency and magnitude of water quality target exceedances across various flow levels.

Load duration curves for each site were generated using daily mean flows estimated at the confluence from 2000 to 2009. Flow duration curves are first developed by ranking streamflows from highest to lowest and calculating the percent of days each flow is exceeded. Next, the load duration curve is developed by multiplying the daily mean flows by a target level for the parameter. Target levels are often modified by a margin of safety to account for uncertainties in measurement and varying physical conditions, often in the range of 10-20%.

In order to compare observed water quality data to the load duration curve, the first task is to calculate daily loads for each sample using measured pollutant concentration and streamflow for the particular day. Next, the flow values when samples were collected are compared to the flow duration curve in order to determine the value for “Percent of Days Flow Exceeded” which is equivalent to “Percent of Days Load Exceeded”. These load and percent data points are then plotted on the load duration curve. Points above the curve represent exceedances of water quality targets and the associated allowable loadings (NDEP, 2003).

Target levels for the Cypress Creek were determined as follows:

— ***Nitrogen***: Texas has no nitrogen standard for aquatic life use, but 2.0 mg/L is commonly used as a screening level to identify excessive nitrogen. Nitrogen in the Cypress Creek has historically been well below this level, with median values at the four downstream sites averaging 0.11 mg/L and 0.47 at Jacob’s Well. Therefore a conservative target for nitrogen is set at 0.1 mg/L, with 0.5 as an alternative target that still supports a healthy aquatic ecosystem within historical conditions.

— ***Phosphorus***: Phosphorus levels are routinely below detection limits in the creek (<0.05 mg/L), although very high values have been recorded, particularly at downstream sites. A standard of 1.0 mg/L is often used for screening analyses, so this target was chosen as an adequate indicator of excessive Phosphorus loading.

— ***Ammonia***: Ammonia levels measured at the five TCEQ and CRP sites range from <0.02 to 0.92 mg/L. Median values are highest at Blue Hole, at 0.05 mg/L, but occasionally very high values have been recorded at the three downstream sites. Therefore 0.08 mg/L was chosen as a target screening level for this study.

— ***Suspended Sediment***: Sediment levels and impacts on aquatic habitats are highly site-specific and so standards are difficult to quantify. Median TSS ranges from 0.5 mg/L at Jacob's Well, 1.3 mg/L at RR12 north, 3.3 mg/L at Blue Hole, 1.8 mg/L at RR12 downtown, to 1.25 mg/L at the confluence. A conservative approach would be to set a target of 1.3 mg/L, the overall median for all samples historically. However the load duration curve for TSS seems to show a cluster of values across all flow levels ranging from 0.5 to 5.0 mg/L. Therefore 5.0 mg/L is used as a screening level above which exceedances are examined to help determine nonpoint sources.

— ***E. coli***: *E. coli* standards for contact recreation require that the geometric mean of *E. coli* samples should not exceed 126 per 100 ml. In addition, single samples of *E. coli* should not exceed 394 per 100 ml. Because the load duration curve method requires a single target for each individual sample, the standard of 394 cfu/100 ml is used.

The load duration curve approach is useful for characterizing the nature of pollution problems to assist in watershed management by identifying target load limits over the entire flow range and where these targets are exceeded, rather than relying on annual averages targets. Load duration curves can also be used to characterize the types of flow conditions under which load exceedances happen. In general, exceedances that occur in the 0 to 10% range indicate problems unique to high flow conditions, while exceedances in the 99 to 100% range reflect problems that result from extreme low flow conditions. The load duration curve can be used to help differentiate between point and nonpoint source pollution loading issues, because different loading mechanisms can dominate at different flow levels. Exceedances of the target load duration curve during medium to high flows can indicate nonpoint source pollution issues, while exceedances during lower flows can indicate point source problems. In addition, points that cluster within a narrow range of flows can be associated with the season when such flows typically occur. The load duration curve approach also has its limitations, primarily the reliance on a single target concentration for the full range of flow conditions, which may not be appropriate for all water bodies and pollutants. In general, load duration curves should be considered only one part of a very complex picture. In addition, an allowable exceedance for the highest flow levels is usually incorporated, and is often set at 10%. This allowable exceedance should be determined on a case-by-case basis and taking into account biophysical and historical conditions, the pollutant under consideration, priority uses, etc. (NDEP, 2003).

The following are results of a water quality data analysis from the five TCEQ and CRP sites from Jacob's Well to the confluence of the creek. We present load duration curves where applicable, and briefly discuss trends and potential issues in water quality for the perennial portions of Cypress Creek.

6.1.1 Water Chemistry

Median water temperatures are lowest at Jacob's Well (20.6 ^{o}C) and at Blue Hole (21.3 ^{o}C), where spring flows provide fresh inflows of groundwater to the creek. There is increasing variability in temperature downstream from the headwaters, and the highest median temperatures are at the confluence site (21.8 ^{o}C). The hottest water temperature on record was 52.6 ^{o}C in July 2001, at RR12 in downtown Wimberley. At the confluence, the next highest temperature of 32.4 ^{o}C was recorded in June 2009. 99% of samples fall below the TCEQ standard of 30 degrees maximum temperature for the segment. The majority of temperature readings fall in a relatively narrow range between 17 and 24 ^{o}C (Figure 6.1 a). Temperature is more highly variable as you move downstream, indicating the influence of air temperature and solar radiation as the channel widens downstream.

Measurements of pH generally increase downstream from Jacob's Well, while specific conductance generally decreases (Figures 6.1 b, c). This pattern is typical of this type of karst spring run, which has a near-constant inflow of cold groundwater at Jacob's Well and from numerous small springs and seeps along its course and feeding in from major tributaries. Highly variable readings of pH at the downtown site and the confluence suggest that other nonpoint source pollutants may be impacting water chemistry as the creek flows through downtown Wimberley.

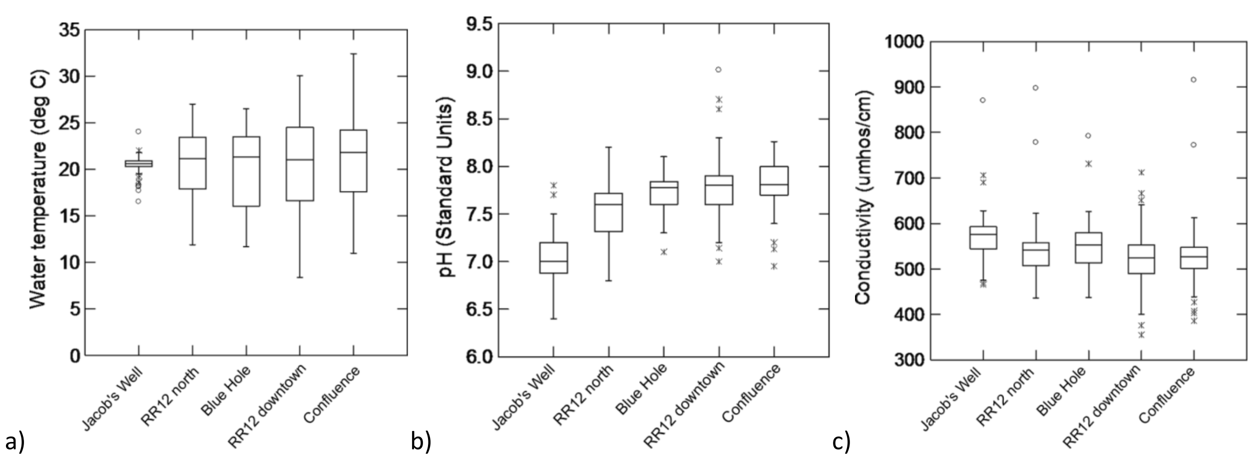


Figure 6.1 (a,b,c). Water chemistry-related parameters.

Parameters were measured at five sites along the Cypress Creek: a) water temperature; b) pH; and c) conductivity. Lines through the center of boxes represent the median value, bottom and top of boxes represent the 25th and 75th percentiles, respectively, and whiskers show the 5th and 9th percentiles. Dots are outlying values.

6.1.2 Nutrients

Ambient concentrations of nutrients (nitrate-nitrogen, Phosphorus, ammonia) are at very low levels in the perennial Cypress Creek. Median values of Phosphorus are 0.025 mg/L at all sites, which means that in reality they are below the laboratory detection limit of 0.05 mg/L. For all sites, Phosphorus remains below 0.05 mg/L in 83% of samples. The highest P values and the most variable are measured at RR12 downtown, with a maximum of 3.06 mg/L (Figure 6.2a,b). Phosphorus has never been measured above detection limits at Blue Hole. The load duration curve for P shows that load exceedances tend to occur at medium to low flows, and primarily at downtown Wimberley (Figure 6.3). These lower flow exceedances often occur in mid-winter and mid-summer (January and June). However most of the elevated Phosphorus levels (>0.05 mg/L) occurred between 1998 and 2004. Since 2004 only one exceedance has occurred at Jacob's Well in December 2008 and at RR12 downtown in January 2010. At the Jacob's Well site this corresponds to a time when flows were reduced to about 1 cfs. RR12 downtown is just over 1 km downstream from Blue Hole, where Phosphorus has never been found above detection limits. This segment of the creek is at a low elevation very close to the Blanco River and has the greatest potential for groundwater interactions to alter chemistry. The surface area contributing flow between Blue Hole and downtown is a mix of agriculture in the upper portions, residential and commercial along the creek channel, and a cemetery on the eastern edge. Such a pattern of exceedances could be caused by natural decomposition of minerals and vegetation, erosion and sedimentation, failing OSSF systems, direct input by animals/wildlife, and other nonpoint source pollutants. It could also indicate untreated or poorly treated wastes, though elevated Phosphorus is more common with point discharges from wastewater treatment, whereas nitrogen is more often cited as a concern from failing septic systems. Another potential source is the excessive application of fertilizer.

Nitrogen is present at low concentrations at all sites under ambient conditions and is actually highest in spring flows out of Jacob's Well with a median concentration of 0.47 mg/L. Nitrogen levels at Jacob's Well track closely with the target maximum load of 0.5 mg/L (Figure 6.4). Exceedances of this level occur at higher flows and at all sites except the confluence, indicating a nonpoint source that washes nitrogen into the creek above downtown Wimberley along with high flows. High nitrate concentrations may not be strictly from natural sources and can indicate contamination from fertilizers, manure, or sewage. The fact that the confluence has the lowest maximum level recorded, only 1.13 mg/L, means that biological processes in the stream may be assimilating excess nitrogen before reaching the confluence, which could potentially explain algal blooms observed in upper portions of the perennial Cypress Creek during dry periods. The 0.1 mg/L target is always exceeded at 0 to 20% flows (above about 25 cfs), suggesting that surface runoff consistently contains higher concentrations. Below that flow level, all sites exceed this target at various times along the full range of flows, although the confluence has the lowest number of exceedances.

Nitrogen exceedances above 0.5 mg/L tend to happen at higher flows, and these often correspond to times of high flow in the fall and summer months. The highest exceedances are often seen when a period of very low flow is followed by a high flow event. In particular the very dry period 2005-2006 was followed by exceedances in nitrogen targets at all sites from

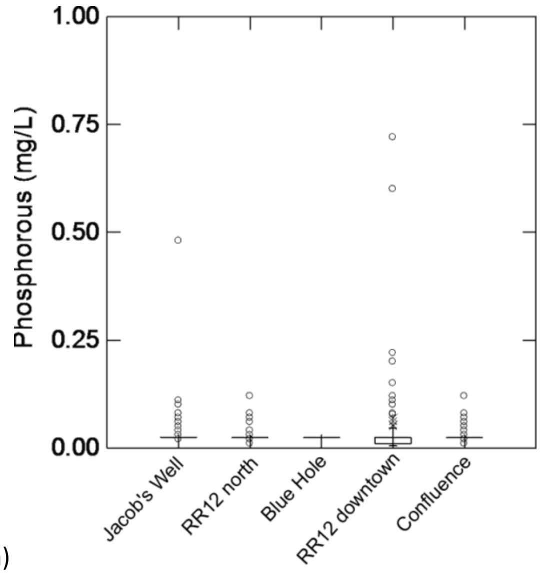
January through April 2007 (Figure 6.5). This evidence supports a nonpoint source of nitrogen in the contributing area, such as fertilizer or animal waste that builds up on the surface during dry periods and is washed in when rainfall produces surface runoff. This pattern is in contrast to the pattern of Phosphorus loads, which points instead to a loading mechanism that acts at moderate flow levels.

Generally ammonia levels in the creek are relatively low, often registering below detection limits. However elevated levels have been measured at various times, and a maximum of 0.92 mg/L was recorded at RR12 downtown (Figure 6.6). Lethal ammonia concentrations for a variety of fish species range from 0.2 to 2.0 mg/L and chronic ammonia toxicity is particularly harmful to juveniles (US-EPA, 2009). The load duration curve for ammonia indicates that exceedances occur across all flow levels at RR12 downtown, but the magnitude of exceedances is much higher at lower flows (Figure 6.7). Many of the highest magnitude exceedances happened at RR12 downtown between 1998 and 2000, while later problems are less severe. No exceedances are seen at the two uppermost sites, where the maximum levels recorded are only 0.06 mg/L. Exceedances at Blue Hole and the confluence sites occur at medium to low flows, again with the magnitude of exceedance increasing at low flows. A product of microbiological activity, ammonia in freshwater often indicates a failing septic system or source of untreated waste. Because the highest exceedances occur at the lowest flows, this points to a local source of untreated waste, either failing septic systems or wildlife, bird, or pet waste deposited directly into the stream and/or riparian area. However the fact that the highest magnitude exceedances have not been seen in the last 10 years suggests that some previous sources may have been mitigated since that time. Exceedances at higher flows result from untreated waste in upland areas washing into the stream during rain events.

Stormflow monitoring results at the confluence are available from six storms February to March 2009. Flow-weighted composites of storm runoff were taken from each event and analyzed for nitrate-N and Phosphorus concentrations. Water from 2 to 25 individual samples was composited for the analysis depending on the duration of stormflows. The amount of surface runoff generated by these storms was variable, but flow is estimated to have peaked at about 130-150 cfs for two storm events and only 30-60 cfs for the other four. Phosphorus was present at the detection limit (0.05 mg/L) for only one event. Nitrogen, however, was elevated above the 0.5 mg/L target concentration for all storm events. Levels ranged from 0.61 to 1.22 mg/L, with a mean of 0.87 mg/L. This evidence supports significant nitrogen loading coming from the contributing watershed area from surface wash-off into the creek. Because levels are not so highly elevated at the confluence site during routine monitoring, it suggests that these nutrients are being taken up by biota under ambient conditions. At the Dry Cypress stormflow site above Jacob’s Well, data for only one storm event are available from February 2009. During this event, nitrate-N were 0.85 mg/L, consistent with results at the confluence, and also indicating a source of nitrogen from the Dry Cypress watershed to the north and west of Jacob’s Well spring.

Elevated levels of Phosphorus, nitrogen and ammonia point to fertilizer application, contributions from poorly maintained septic systems, and pet/animal waste either directly in the stream or on the surface of contributing areas as likely nonpoint sources, particularly in the area above RR12 downtown. Different forms of nitrogen have been monitored at different times throughout the period of record, and these different forms can indicate different pollution sources. From November 2004 to present, reported values for nitrogen are for nitrate-N only, often associated with excess fertilizer use, as opposed to ammonia which tends to indicate organic wastes. However ammonia from organic waste can also be converted by instream processes into nitrate, a reaction which also depletes oxygen in the water. Further examination of the relative abundances of specific forms of nitrogen found in the creek will help to pinpoint exactly the contributing sources. Phosphorus is generally not above detection limits even when nitrogen is elevated, and Phosphorus exceedances are often associated with relatively low levels of nitrogen. Furthermore, P exceedances are correlated with elevated TSS only in a few instances and often occur at very low TSS concentrations, a fact that tends to rule out sediment inflow as a source of natural Phosphorus. In a Phosphorus-limited stream such as the Cypress Creek, it is possible that excess P from fertilizer application could be more quickly assimilated than N, resulting in elevated N only. However further study is needed to help pinpoint specific sources of excess P when N is not also elevated, near RR12 downtown in particular.

a)



b)

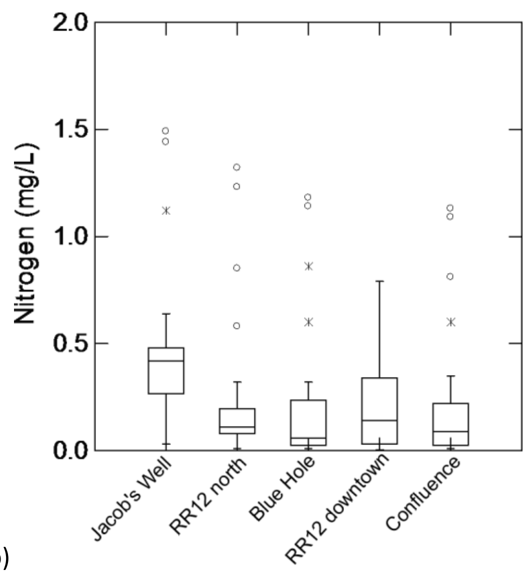


Figure 6.2 (a,b). Phosphorus and nitrogen data.

Box-and-whisker plots that show the variability of a) phosphorus (mg/L) and b) nitrogen (mg/L) measured at five sites along the Cypress Creek. Lines through the center of boxes represent the median value, bottom and top of boxes represent the 25th and 75th percentiles, respectively, and whiskers show the 5th and 9th percentiles. Dots are outlying values.

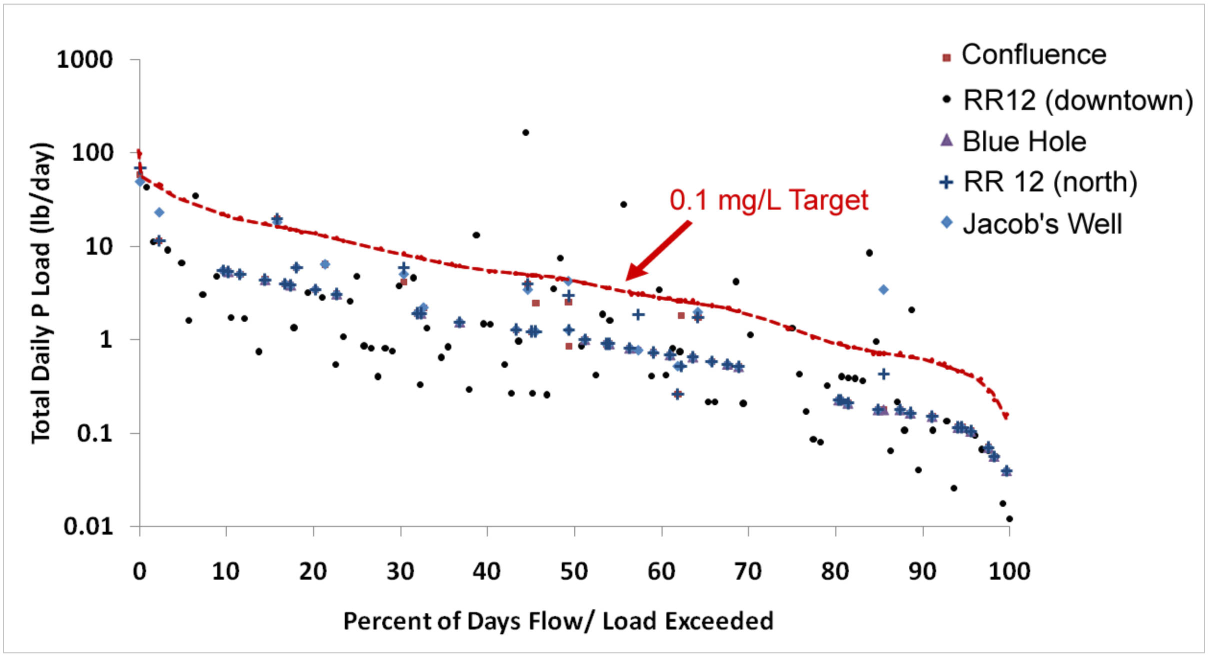


Figure 6.3. Load duration curve of total phosphorus at five sites along Cypress Creek.

The red dashed line represents Phosphorus loads at a target max concentration of 0.1 mg/L, and dots represent loads calculated for observed conditions.

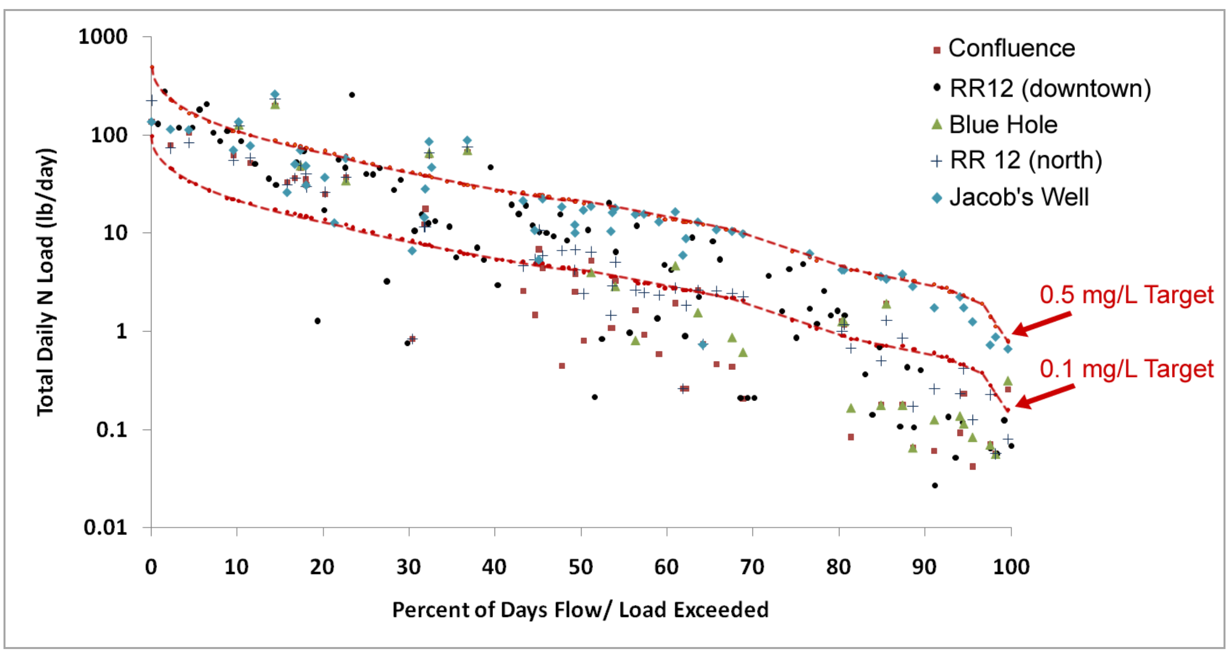


Figure 6.4. Load duration curve of nitrogen at five sites along Cypress Creek.

The red dashed line represents nitrogen loads at target concentrations of 0.1 and 0.5 mg/L, and dots represent loads calculated for observed conditions.

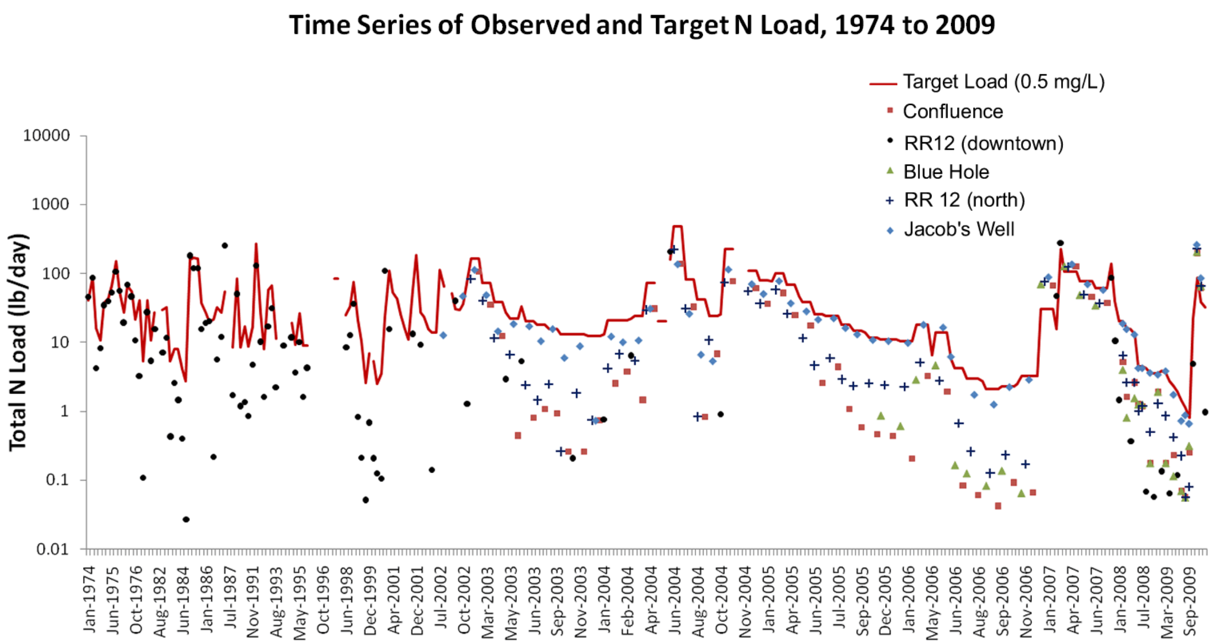


Figure 6.5. Time series of observed and target nitrogen load for five sites along Cypress Creek.

Samples are taken monthly (CRP sites) or quarterly (TCEQ site). The red line indicates target loads calculated based on available flow estimates and 0.5 mg/L concentration. Points above this line represent exceedances of the target load.

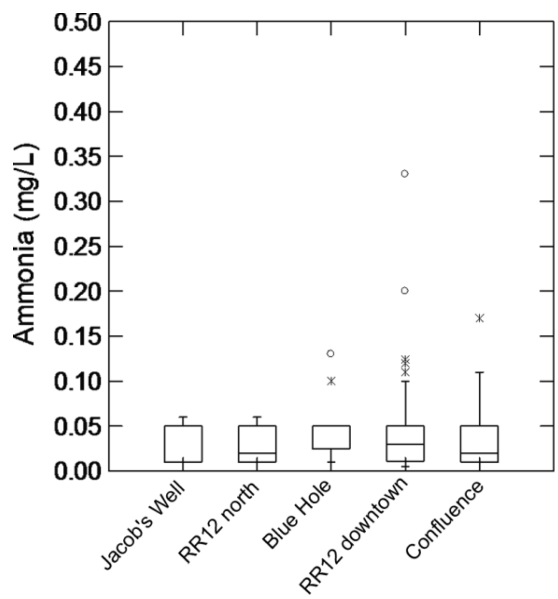


Figure 6.6. Box-and-whisker plot showing the variability of ammonia (mg/L) measured at five sites along the Cypress Creek.

Lines through the center of boxes represent the median value, bottom and top of boxes represent the 25th and 75th percentiles, respectively, and whiskers show the 5th and 9th percentiles. Dots are outlying values.

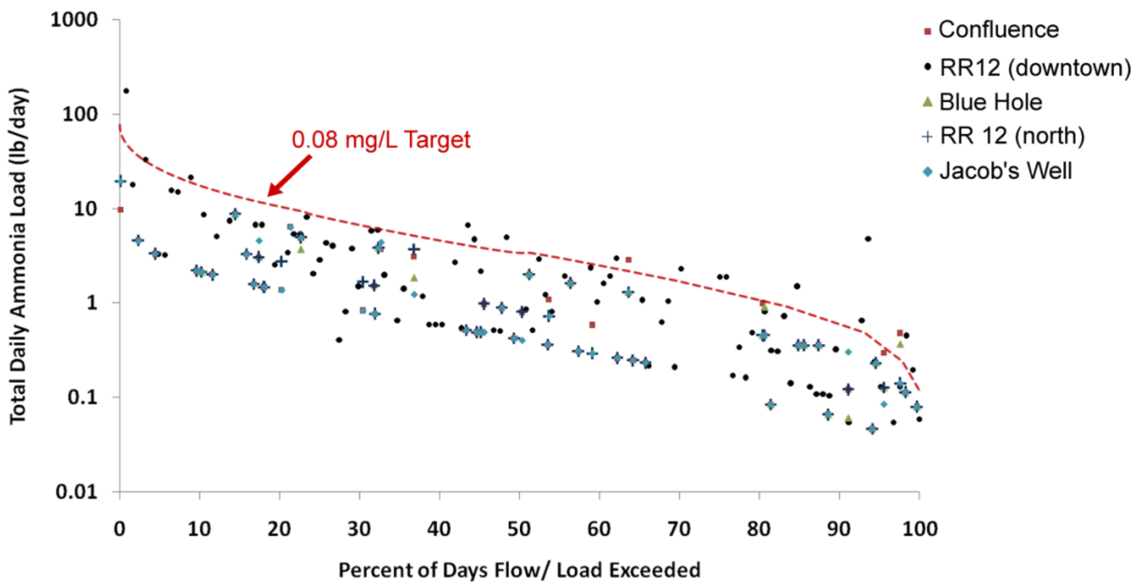


Figure 6.7. Load duration curve of ammonia at five sites along Cypress Creek.

The red dashed line represents ammonia loads at a target concentration of 0.08 mg/L, and dots represent loads calculated for observed conditions.

6.1.4 Sediments

Sediment concentrations are highly site-specific, and the impacts on local ecosystems can be localized as well. Spring-fed streams like Cypress Creek have naturally very low sediment levels, and it is natural that some sediment washes into the creek during storm events. Examining the load duration curve (LDC), it is apparent that there is a natural range of variability in sediment concentrations in the Cypress Creek from 0.5 mg/L to 5.0 mg/L (Figure 6.8). Sediment levels at the upper end of this range may still be undesirable, particularly at locations such as Jacob's Well spring, but for the purposes of characterizing and prioritizing the sources of excess loads we will focus on those points that fall above 5.0 mg/L. Above this level there are three distinct groups of exceedances, characterized by high, median, and low flow conditions. It is likely that three different mechanisms are operating during these times to produce excess sediment in the creek.

At times of low flow, exceedances are seen in all sites, and tend to be in the hottest months of the summer, July through September. This points to recreation as a major contributor to sediment, as both people and animals spend more time traveling into and out of the riparian area. Exceedances at moderate flows tend to occur earlier in the year, often in the spring (January through April) and could indicate spring showers bringing surface runoff full of sediment and particulates that have accumulated on the land surface. Very high flow exceedances represent sediment washing off the watershed from large and intense storm events, also seen in the late fall and early spring. No exceedances are recorded at Jacob's Well under moderate flow conditions; instead these tend to occur at very high flows (likely caused by runoff from the upstream Dry Cypress) and very low flows (likely caused by recreation activities at the Well). The confluence recorded only one exceedance at a high flow level, consistent with its overall low nitrogen concentrations even during higher flows.

The primary area where sediment is chronically problematic is the stretch of river from RR12 north to the confluence. There are two major tributaries that join the main creek from the north between Jacob's Well and RR12 north. These two may carry sediment from high-slope areas in the north and contribute to higher sediment levels at RR12 north. The largest increase in median sediment concentrations occurs between RR12 north and Blue Hole (Figure 6.9). There is one major tributary that joins the main creek between these two sites that may contribute large volumes of sediment during high flows, and Blue Hole being a prime recreation area may contribute to sediment in the creek here during low flows.

A time series of target maximum (5.0 mg/L) and observed sediment concentrations reveals that there are a cluster of exceedances that occurred from spring 2005 through fall 2006 (Figure 6.10). A major roadway, Winters Mill Parkway, was under construction from October 2005 to July 2007 in the southeastern portion of the watershed. Some of the highest relative exceedances in the spring of 2006 may be associated with the construction of this road, although RR12 downtown and the confluence both had exceedances in the spring of 2005 before work started. Instream dredging operations were documented in 2005. In addition exceedances occur at all sites during this period, including those above the influence of bypass construction. Other construction activities along RR12 and Jacob's Well Rd. could contribute excess sediment to the creek as well, if proper stormflow mitigation measures are not employed.

Stormflow monitoring results for TSS indicates occasionally very high sediment loads carried in the creek during rainfall events. Samples of stormflows were taken every 30 minutes for the first three hours of each storm and every hour thereafter until flows subsided and analyzed for sediment concentrations. The maximum concentration measured during the five events was 63.3 mg/L and the minimum was 0.5 mg/L, but 22% of discrete samples registered at or above 5.0 mg/L. At the Dry Cypress site above Jacob's Well, TSS concentration for the one storm sampled started high at 10.0 mg/L and gradually dropped to 2.0 mg/L.

In general, BMPs that act to retain sediment on the uplands will help to maintain sediment concentrations at acceptable levels in the creek. The focus should be on retaining sediment in the three major tributaries that join the creek between Jacob's Well and Blue Hole, and on reducing sediment tracked into and stirred up in the creek during very low flows. In addition, trapping sediment may also help to reduce the concentrations of other pollutants in the water, since many substances are accumulated on the land surface and travel with sediment during runoff events.

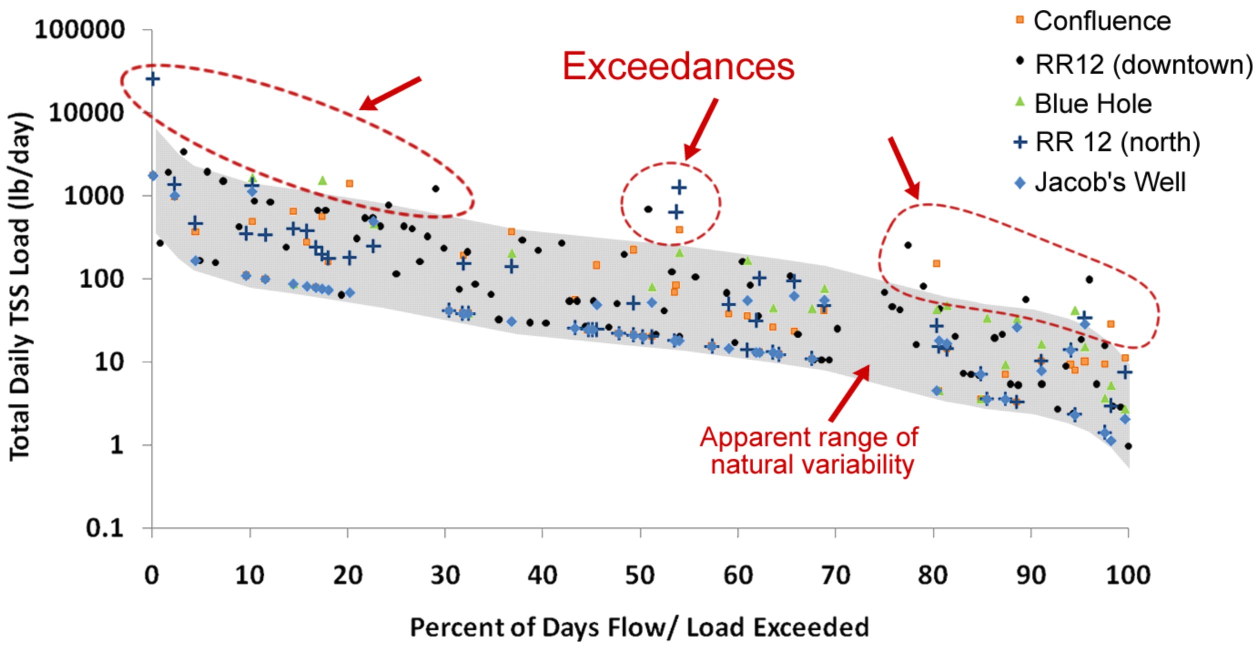


Figure 6.8. Load duration curve of total suspended solids (sediment) at five sites along Cypress Creek.

There appears to be a natural range of variability between 0.5 and 5.0 mg/L across all flow levels (grey shaded area). Dots represent loads calculated for observed conditions. Values above the shaded area indicate times of excess sediment loading.

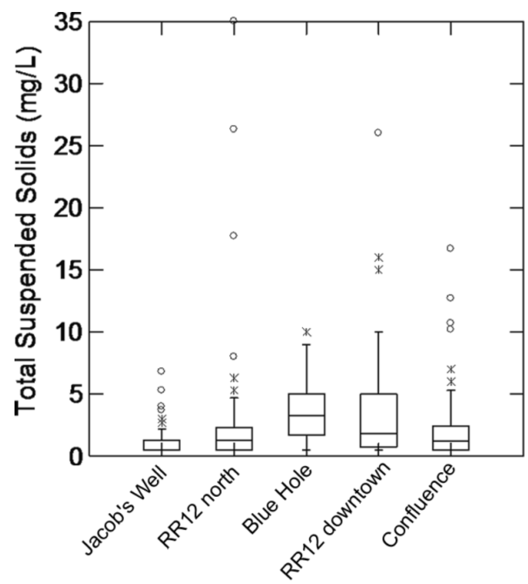


Figure 6.9. Box-and-whisker plot showing the variability of total suspended solids (mg/L) measured at five sites along the Cypress Creek.

Lines through the center of boxes represent the median value, bottom and top of boxes represent the 25th and 75th percentiles, respectively, and whiskers show the 5th and 9th percentiles. Dots are outlying values.

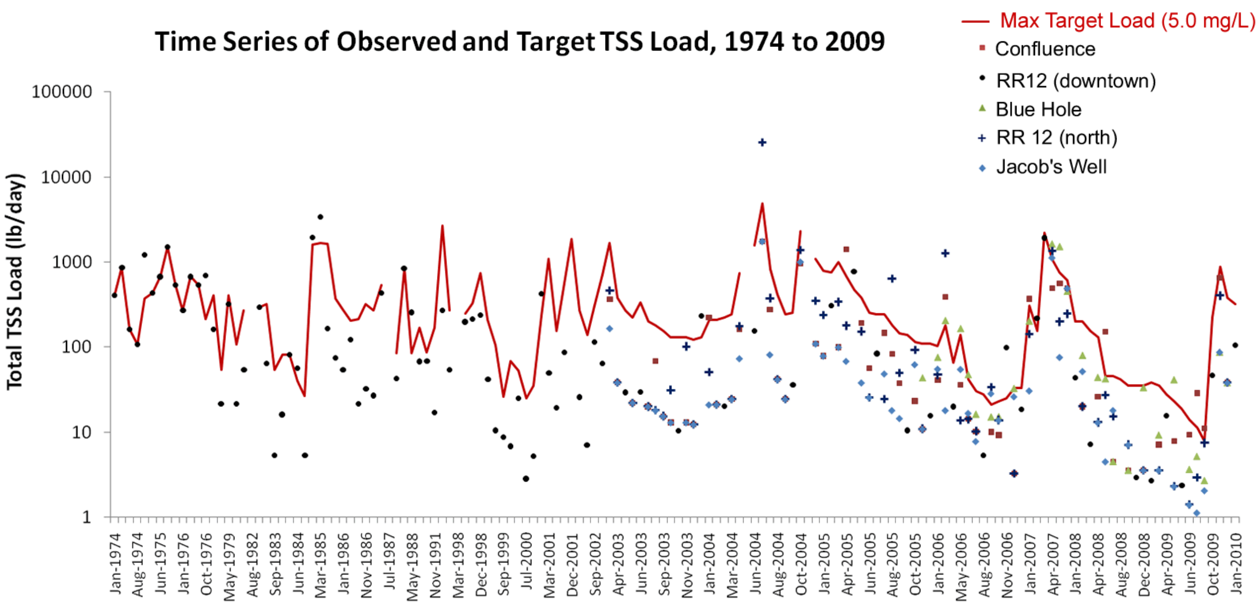


Figure 6.10. Time series of observed and target maximum sediment load for five sites along Cypress Creek.

Samples are taken monthly (CRP sites) or quarterly (TCEQ site). The red line indicates target loads calculated based on available flow estimates and 5.0 mg/L concentration. Points above this line represent exceedances of the target load.

6.2 Dissolved Oxygen and Aquatic Life

Dissolved oxygen (DO) is a very important indicator of a stream's ability to support aquatic life. TCEQ standards for DO in the Cypress Creek require that 24-hour mean values do not go below 6.0 mg/L, and that individual grab samples do not fall below 4.0 mg/L. Factors influencing DO levels include flow, the physical conditions of a given reach, water temperature, sediment and dissolved solids. During higher flows, rushing water is aerated by bubbles as it churns over rocks and down waterfalls, causing DO to be relatively high. As water slows down behind small dams and becomes more stagnant, oxygen only enters the top layer of water, and deeper water is often low in DO concentration due to decomposition of organic matter by oxygen-depleting bacteria that live on or near the bottom. Colder water can hold more dissolved oxygen, so spring-fed streams such as Cypress naturally have very high levels. As flow decreases and channels widen and are exposed to more sun, temperature can increase and cause DO to drop. During rainy seasons, oxygen concentrations tend to be higher because the rain interacts with oxygen in the air as it falls. Higher levels of sediment and dissolved solids can also decrease DO in the stream. Higher nutrient levels can also affect DO by allowing for greater algae or plant growth, which generate oxygen during photosynthesis. This can cause the stream to become super-saturated with oxygen during the day (due to photosynthesis) and drop sharply at night (due to respiration). Algal blooms can also cause eutrophication as they decompose, severely reducing oxygen necessary to support aquatic life.

Water quality data for the Cypress Creek indicate that the greatest influences on DO levels are flow and mean air temperature. Although water temperature can influence DO, the temperature varies relatively little through the course of the stream because of the constant inflow of spring water. Although water temperatures have been recorded up to 52.6 ^{o}C, the majority of readings fall in a relatively narrow range between 17 and 24 ^{o}C. Mean and maximum daily air temperature, however, were found to be statistically significant predictors of DO levels. The Cypress Creek was placed on the 303d list for impaired water bodies in 2000 due to low DO concentrations. This impairment coincided with the first time in recorded history that flow at Jacob's Well Spring was reduced to zero. Although the segment was later delisted, DO impairment remains an issue of primary concern for the continuing health of the aquatic ecosystem.

Dissolved oxygen varies considerably from site to site (Figure 6.11), with springflow coming out of Jacob's Well at a lower DO concentration (median=5.88 mg/L; n=62), rising slightly as it travels to the upper RR12 crossing (median=6.76 mg/L; n=60), then dropping sharply again at Blue Hole (median = 4.90 mg/L; n=27). By the lower RR12 crossing through downtown Wimberley, dissolved oxygen is generally excellent, with 98% of samples taken equaling or exceeding 6.0 mg/L (median=8.40 mg/L; n=132). Dissolved oxygen then drops slightly between downtown and the confluence (median=7.6; n=63). At the confluence, only 84% of samples exceed (are below) the target of 6.0 mg/L for exceptional aquatic life use. DO saturation levels at Jacob's Well are relatively consistent, with concentrations between 5.0 and 7.0 mg/L, and provide a steady flow of cold water into the creek. As the water travels downstream, it picks up some oxygen through mixing with air and biological processes along its course. The RR12 north site seems to be susceptible to lower flows and higher temperatures, with a wider range of DO values recorded that are correlated with temperature. Shortly downstream, flow is reduced and the creek forms a large, relatively deep swimming hole at Blue Hole. There is anecdotal evidence of numerous small springs and seeps contributing cold groundwater into the creek at this point. DO drops dramatically, and only exceeds 6.0 mg/L in 37% of samples. It is likely that this combination of decreasing flow velocity and groundwater input acts to reduce DO levels here. Downstream of Blue Hole, the stream gains oxygen and by the RR12 downtown site it is consistently high with only two values below 6.0 recorded here, in August 1994 and July 1996. The drop in DO between downtown and the confluence could be due to increased water temperature or to increasing microbial activity from an excess of organic material.

A multivariate linear regression was performed to identify variables most highly correlated with DO values at each location. Stepwise (backward) regression was used with sample collection time, water temperature, flow, N, P, TSS, *E. coli*, daily maximum temperature, and daily average temperature. This type of analysis starts by relating all the variables to DO, then starts to drop out variables as it determines that their effects are less significant (below a given threshold, in this case 0.15). The result is a selection of variables that are most highly correlated to the variable of interest. The resulting models were significant ($p < 0.05$) at all but the Jacob's Well site ($p=0.39$) which was better predicted by a constant value. For the three upstream sites, the most significant variables were water temperature, air temperature, and flow. Air temperature and TSS are most strongly correlated with DO at RR12 downtown, while air temperature and flow are strongest at the confluence. In the majority of cases temperature and flow are primary factors. Water temperature is more highly correlated at the upper sites, while at the lower sites air temperature (and thus solar radiation) plays a bigger role in determining DO concentrations.

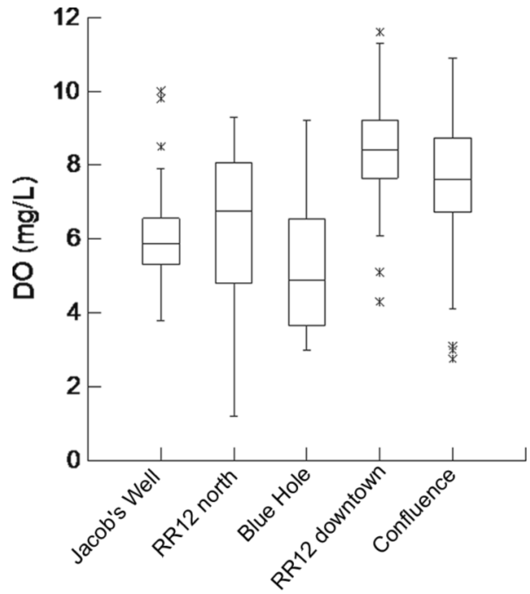


Figure 6.11. Box-and-whisker plot of dissolved oxygen (mg/L) measured at five sites along the Cypress Creek.

Lines through the center of boxes represent the median value, bottom and top of boxes represent the 25th and 75th percentiles, respectively, and whiskers show the 5th and 9th percentiles. Dots are outlying values.

More evidence that flow plays a primary role in dissolved oxygen concentrations is seen by examining plots of dissolved oxygen across a range of flow levels. 10th, 20th, 30th, etc. percentiles were calculated for flows estimated at the confluence from 2000 to 2009 and DO observations plotted at each level (Figure 6.12). For all sites, a flow level between 1.31 and 4.1 cfs appears to be sufficient to sustain DO levels above 4.0 mg/L at least 75% of the time. 6.0 mg/L is a minimum 24 hour standard for maintaining adequate conditions for aquatic ecosystems. Between 4.11 and 5.1 cfs, DO exceeds 6.0 mg/L at least 75% of the time, which is a target level for maintaining a healthy aquatic community.

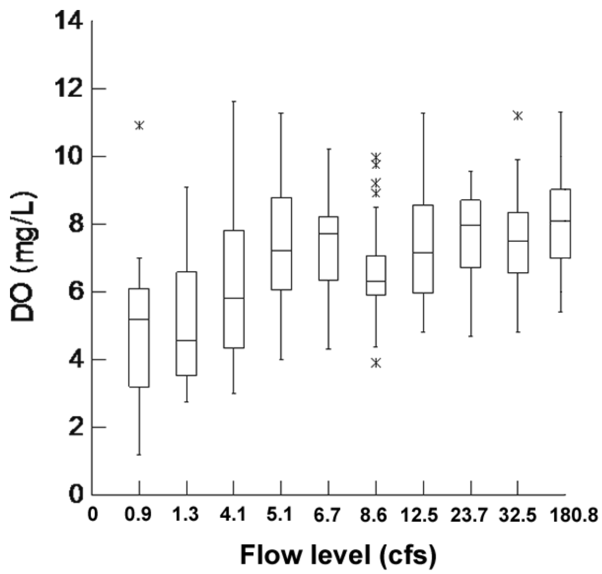


Figure 6.12. DO concentrations by flow level.

Flow levels (given in cubic feet per second) correspond to the 10th, 20th, 30th, etc. percentile of flows estimated at the Cypress Creek confluence, 2000-2009. In this chart, a flow level of 0.9 reflects DO concentrations measured when flow is ≤ 0.9 cfs, 1.3 indicates flow from 0.91 to 1.3 cfs, etc.

Plots of DO concentrations by flow level were also compiled for each site, and flow statistics were calculated for DO measurements ≥6.0 and <6.0 mg/L (Table 6.1). In addition, percent exceedance curves for DO concentrations were developed for all sites by season (Figure 6.13). These curves show the percent of time that observations meet or exceed given levels of DO. The following is a summary of these findings by site:

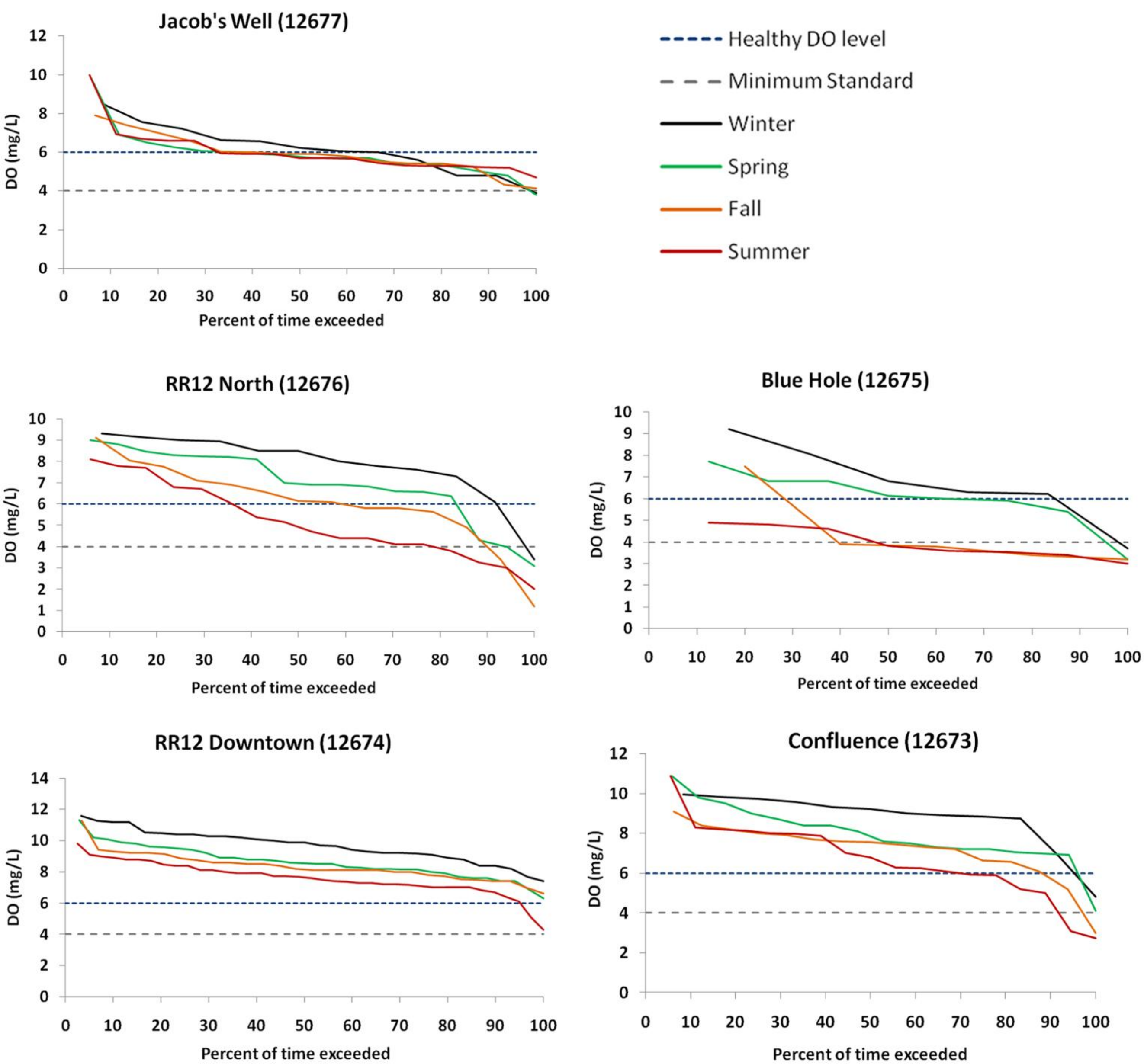


Figure 6.13. Percent exceedance curves for Dissolved Oxygen by season.

Fall and Spring consistently show decreased DO, likely due to reduced flows and increased temperatures.

Table 6.1. Comparison of flows at high and low oxygen levels.

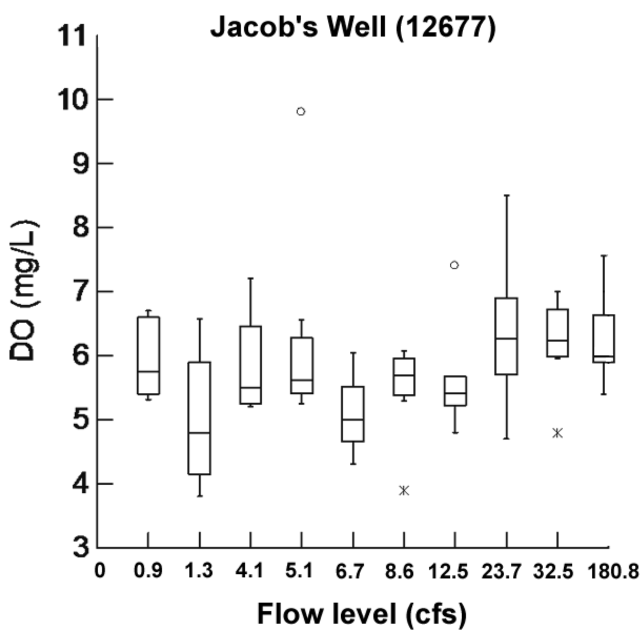
Flows estimated at confluence (a) and measured at Jacob's Well (b) calculated for DO measurements above and below the target threshold of 6.0 mg/L. For all stream segments, mean flow is much lower when DO <6.0 mg/L. For Jacob's Well, the opposite is true, indicating that maintaining adequate flow throughout the length of the creek is critical for maintaining its historical condition as a spring-run creek.

a)	RR12 north 12676		Blue Hole 12675		RR12 downtown 12674		Confluence 12673	
	DO <6.0	DO ≥6.0	DO <6.0	DO ≥6.0	DO <6.0	DO ≥6.0	DO <6.0	DO ≥6.0
N of cases	21	36	17	10	N/A	50	10	50
Flow Min (cfs)	0.30	0.86	0.30	3.82	N/A	0.71	0.30	0.52
Flow Max (cfs)	9.50	180.76	28.33	39.45	N/A	82.8	6.71	180.76
Flow Mean (cfs)	3.17	23.35	4.28	12.89	N/A	13.9	1.65	19.05

b)	Jacob's Well 12677	
	DO <6.0	DO ≥6.0
N of cases	24	9
Flow Min (cfs)	0.00	0.01
Flow Max (cfs)	26.00	9.90
Flow Mean (cfs)	5.28	3.28

12677 Jacob's Well

DO at Jacob's Well is not as strongly affected by air temperature as the downstream sites. Unlike all other sites, DO actually increases when there are lower flow rates (Figure 6.14). Average flow measured at Jacob's Well when DO ≥6.0 mg/L is 3.3 cfs, while average flow when DO <6.0 mg/L is 5.3 cfs (Table 6.1). This indicates that DO is primarily determined by the oxygen saturation of groundwater coming out of the aquifer. When spring flows are reduced, water remains in the pooled area around the spring longer and so has a longer time exposed to the air and other biological processes that increase DO locally. This could also be reflecting increased levels of plant photosynthesis during the day, indicating algae growth in stagnant waters during low flows. If this is the case, these higher values during the day would be offset by plummeting DO values at night due to plant respiration. The seasonal percent exceedance curves for this site show that while concentrations do tend to be highest in winter, seasonality plays less of a role here than at the other sites. DO exceeds 4.0 mg/L nearly 100% of the time, and it exceeds 6.0 mg/L only about 70% of the time (Figure 6.14).

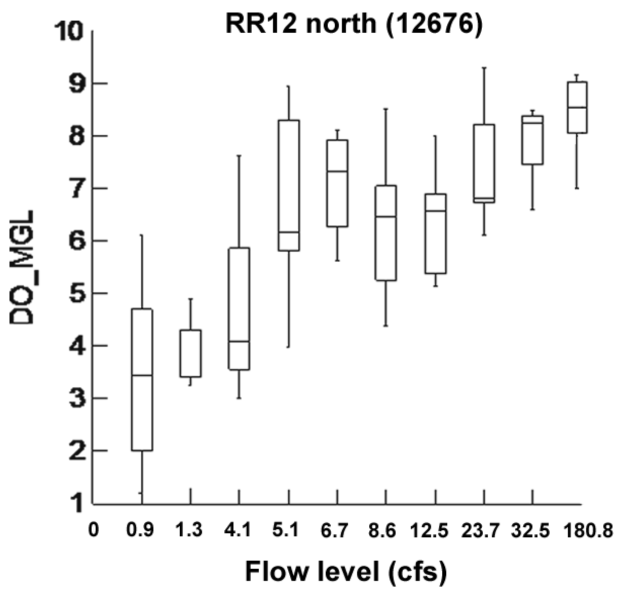


Flow levels (given in cubic feet per second) correspond to the 10th, 20th, 30th, etc. percentile of flows estimated at the Cypress Creek confluence, 2000-2009. In this chart, a flow level of 0.9 reflects DO concentrations measured when flow is ≤ 0.9 cfs, 1.3 indicates flow from 0.91 to 1.3 cfs, etc. At this site DO is more affected by the amount of groundwater flow coming out of Jacob's Well Spring than by streamflow at the surface.

Figure 6.14. DO concentrations at Jacob's Well by flow level.

12676 RR12 North

This site is located 4.5 km downstream from Jacob's Well and generally has a higher DO concentration, indicating that the water has mixed with air and picked up oxygen on the way. The exception here is in the summer months, when DO generally declines from Jacob's Well to RR12 north. Average estimated flow when DO ≥6.0 mg/L is 23.4 cfs, while average flow when DO <6.0 mg/L is 3.2 cfs (Table 6.1). In the summer months, DO falls below the target of 6.0 mg/L 65% of the time, while in other seasons it falls below 6.0 only 23% of the time. Percent exceedance curves by season show that summer and fall are consistently times of low DO at this site (Figure 6.13), and values are correlated to both maximum daily temperature and flow levels. Median DO concentrations increase significantly at the 4.11 - 5.1 cfs level and above (Figure 6.15). Therefore, it is critical to maintain flow and shading in the reach above this site to maintain DO at optimal levels.



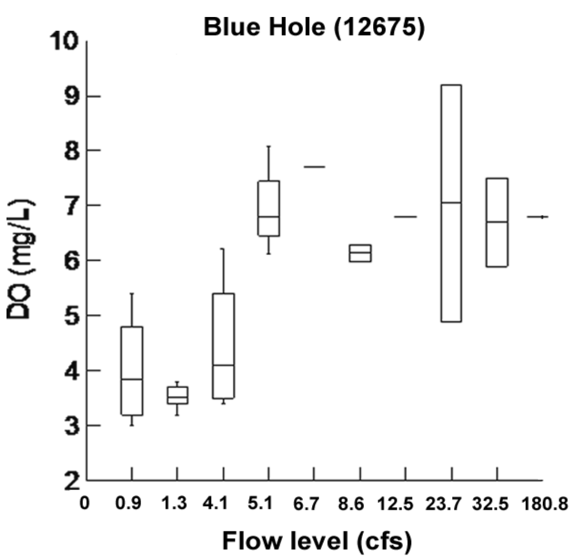
Flow levels (given in cubic feet per second) correspond to the 10th, 20th, 30th, etc. percentile of flows estimated at the Cypress Creek confluence, 2000-2009. In this chart, a flow level of 0.9 reflects DO concentrations measured when flow is ≤ 0.9 cfs, 1.3 indicates flow from 0.91 to 1.3 cfs, etc. At this site the median DO concentration increases significantly at the 5.1 cfs flow level.

Figure 6.15. DO concentrations at RR12 north by flow level.

12675 Blue Hole

This site has the lowest average DO of all monitoring sites. Blue Hole Park is a very popular recreation area, so stream conditions are likely affected by recreational use, especially in the summer months. The stream channel deepens and flow slows down at this point, and during wetter periods there is likely some input of oxygen-depleted groundwater through numerous small springs and seeps. DO concentrations are lowest in the summer and fall, and are below the minimum 4.0 mg/L target about half the time. Levels only rarely exceed 6.0 mg/L in the fall, and never in the summer months (Figure 6.16). Estimated flow when DO <6.0 mg/L is 4.3 cfs, versus 12.9 cfs when DO is ≥6.0 mg/L. Low flow appears to exacerbate the tendency toward low DO levels at this site, but overall the 4.0 mg/L minimum standard is violated in about 40% of all samples. However a plot of observed DO by flow levels shows that there is a significant improvement in DO concentrations above the 4.11 - 5.1 cfs flow level, the same as is seen at the RR12 north site (Figure 6.16).

Potential causes for low DO at this site include the input of oxygen-depleted groundwater and decreasing flow as water pools in the area. However the high degree of shading in this area and the cooler water should increase DO concentrations, but recreation activities may make it difficult for plants to establish and produce DO through photosynthesis during the day. In addition, increased suspended sediments due to human activities and increased dissolved solids due to groundwater inflows can both act to decrease the potential for DO saturation. However DO levels in groundwater as measured at Jacob's Well tend to fall between 5.0 and 7.0 mg/L, indicating that groundwater in the area is not so depleted in oxygen as to explain the very low levels found at this site. Very low DO values may reflect an excess of organic matter entering the stream above Blue Hole, which can result in a flourishing of oxygen-depleting bacteria.

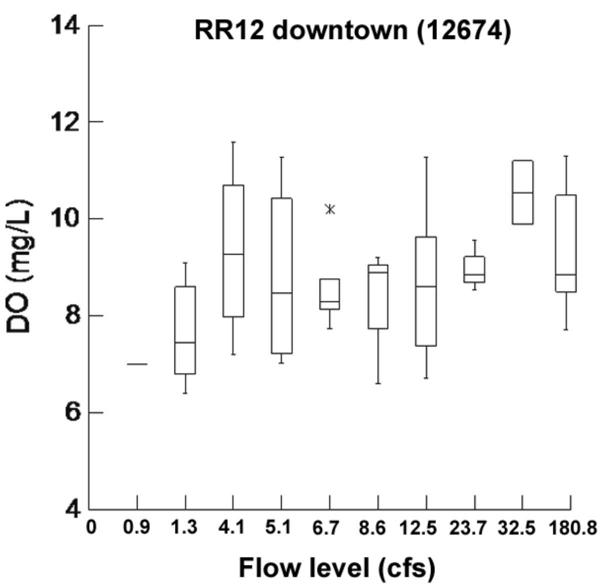


Flow levels (given in cubic feet per second) correspond to the 10th, 20th, 30th, etc. percentile of flows estimated at the Cypress Creek confluence, 2000-2009. In this chart, a flow level of 0.9 reflects DO concentrations measured when flow is ≤ 0.9 cfs, 1.3 indicates flow from 0.91 to 1.3 cfs, etc. At this site the median DO concentration also increases significantly at the 5.1 cfs flow level.

Figure 6.16. DO concentrations at Blue Hole by flow level.

12674 RR12 at Downtown Wimberley

By the time Cypress Creek reaches downtown Wimberley, it generally has very high DO levels. There are only two DO values below 6.0 mg/L recorded here, in August 1994 and July 1996. Unfortunately there are no flow readings for those days, but the fact that these were recorded in the summer means that temperatures were likely high. This site has the longest record of water quality starting in 1973, and is the only site for which total suspended solids was correlated with DO concentrations in the stepwise linear regression described above ($p=0.074$). Besides TSS, air temperature had the strongest relationship with DO values ($p<0.001$). Flow may also play an important role here, but is less strong of a predictor than for the other sites. Nonetheless, median DO concentrations show a slight increase at about the 1.31 - 4.1 cfs flow level, a slightly lower level than at the upper sites (Figure 6.17). Percent exceedance curves by season show that the same reduction in DO occurs in the summer and fall as it does at the other sites, but the difference is not as great (Figure 6.13). However no 24-hour DO data were available for this study. DO concentrations measured during the day may be very high due to adequate mixing of the water with air and overall healthy conditions. However very high DO values in the daytime may also indicate an excess of photosynthetic activity, which can cause large swings in available oxygen between day and night. 24-hour measurements of DO would be useful to have for this site, to determine if concentrations remain adequate throughout the night as well.

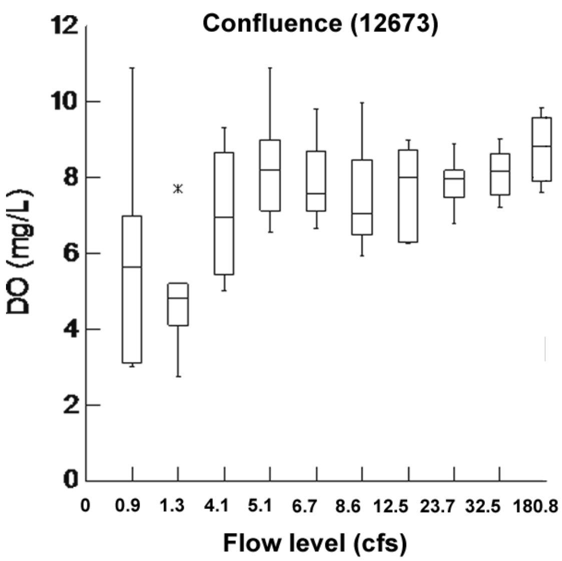


Flow levels (given in cubic feet per second) correspond to the 10th, 20th, 30th, etc. percentile of flows estimated at the Cypress Creek confluence, 2000-2009. In this chart, a flow level of 0.9 reflects DO concentrations measured when flow is ≤ 0.9 cfs, 1.3 indicates flow from 0.91 to 1.3 cfs, etc. At this site, DO concentrations tend to increase above the 4.1 cfs flow level.

Figure 6.17. DO concentrations at the downtown Wimberley site by flow level.

12673 Confluence with Blanco River

DO concentrations at the confluence tend to be lower than at the RR12 downtown site. DO at the confluence is strongly correlated with both temperature and flow. The time of sample collection also had a significant (p=0.05) and positive effect, indicating that DO levels increase due to photosynthetic activity throughout the day. Average flow when DO <6.0 mg/L is only 1.65 cfs, versus 19.05 cfs when DO ≥6.0 mg/L. At this site DO concentrations improve markedly above the 1.31 - 4.1 cfs flow level, and always exceed 6.0 mg/L at 4.11 - 5.1 cfs and above (Figure 6.18). Excess organic matter contributed to the stream between downtown Wimberley and the confluence may also contribute to lower dissolved oxygen here. It is critical that flow be maintained and nutrient levels managed to ensure that oxygen concentrations remain adequate here to support aquatic life.



Flow levels (given in cubic feet per second) correspond to the 10th, 20th, 30th, etc. percentile of flows estimated at the Cypress Creek confluence, 2000-2009. In this chart, a flow level of 0.9 reflects DO concentrations measured when flow is ≤ 0.9 cfs, 1.3 indicates flow from 0.91 to 1.3 cfs, etc. At this site DO concentrations improve markedly above the 4.1 cfs flow level, and always exceed 6.0 mg/L at 5.1 cfs and above.

Figure 6.18. DO concentrations at the Blanco confluence by flow level.

Dissolved oxygen records dating back to December 1973 at the downtown Wimberley site (12674) allow for comparison of long-term trends in water quality (Figure 6.19). Comparison of DO values from 1973-1999 to 2000-2009 shows that although seasonal patterns of DO remain similar, concentrations have generally increased in the winter, fall, and spring, and decreased in the summer. Median instantaneous flows recorded at the site have generally decreased, but overall flow has become more variable. This is likely related to the increasing variability seen in rainfall since 2000 (see Section 4.2.1 for a discussion of climate records). Urbanization can also act to increase the variability of flows by altering natural hydrologic properties of a watershed that act to delay flow recession rates. However the fact that DO levels measured during the day are increasing for most seasons and decreasing in summer could be explained if the stream is experiencing increasing loading of nutrients and other organic matter that act to increase DO levels when conditions are hospitable and to decrease it when flow is reduced and temperature increases in the summer. However 24-hour DO data would be necessary to see if the increased DO levels observed are only present during the day (which would support this conclusion) or if they remain relatively constant through both day and night (which would indicate an alternative explanation). In general, oxygen levels are clearly influenced by flow and temperature at all sites, and particularly in the stream segments below Jacob's Well.

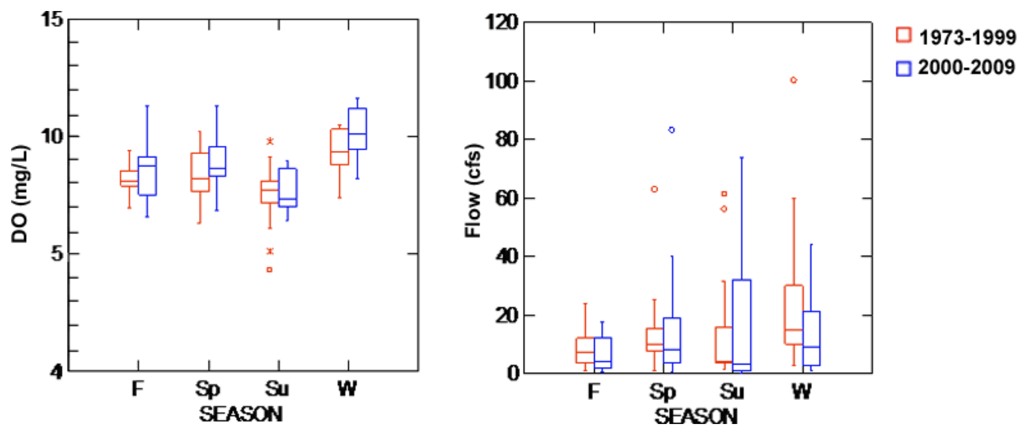


Figure 6.19. Box-and-whisker plots of DO and instantaneous flow (1973-1999 and 2000-2009)

For RR12 downtown site (12674), box & whisker plots of dissolved oxygen and instantaneous flow measured for 1973-1999 (n=81) versus 2000-2009 (n=51). Dissolved oxygen concentrations are lower in the summer and higher in other seasons during the later period, while median flows are slightly reduced for all.

6.3 Recreation and Bacterial Impairment

Figure 6.20. E.coli, courtesy of The Guardian, UK

E. coli is a type of fecal coliform bacteria that comes from human and animal waste. Bacteria strongly impacts contact recreation in the creek. Disease-causing bacteria, viruses and protozoans may be present in water that has elevated levels of *E. coli*, so this is used as a screening test to identify times when it is unsafe for contact recreation. Very high bacteria levels have been seen at all sites during medium to high flows (Figure 6.21). A cluster of very high values is found under the highest flow conditions, indicating a nonpoint source that washes *E. coli* in with higher surface or shallow sub-surface flows. These tend to be in the summer and fall when high temperatures favor the growth of bacteria and large flow events wash these bacteria into the creek. At median flow levels, all sites show exceedances at various times, including at Jacob's Well. These median flows tend to occur in the spring and fall, and exceedances here are often associated with elevated sediment and nitrogen levels entering the creek.

At lower flows (below about 2 cfs), *E. coli* exceedances occur primarily at RR12 downtown. Because there would be very little surface flow during these dry periods, *E. coli* must be contributed by shallow subsurface flow from septic systems in the local area or pet/animal waste placed directly in the stream and riparian area. Two of the four low-flow *E. coli* exceedances at RR12 downtown are associated with elevated ammonia; however many times the two are not closely correlated. Higher *E. coli* values are correlated with elevated TSS levels at all sites except at Jacob's Well, which tends to have the lowest bacteria concentrations due to the influence of spring flow (Figure 6.22), but also has the greatest variability of observed concentrations.

Stormflow monitoring recorded *E. coli* levels as high as 3,110 mpn/100mL at the confluence and 680 mpn/100mL above Jacob's Well. These high values occurred during a time of periodic rain events with no more than 4 days between storm events. Smaller events that followed nearly two weeks of no rainfall had lower *E. coli* levels, between 160 and 280 mpn/100mL at the peak. However because data are available for such a short period of time in the spring only (six storms at confluence, one above Jacob's Well; February to March 2010), it is important to continue stormflow sampling for at least one year to be able to draw more accurate conclusions about sources and stormflow concentrations of bacteria.

Fecal coliform bacteria like *E. coli* indicate contamination due to untreated sewage, manure, or pet waste in contributing areas. High *E. coli* values during high and median flows, and their association with elevated sediment and nitrogen levels, mean that BMPs that help to retain sediment and organic matter on the upland areas will help to reduce bacteria entering the creek during these times. High *E. coli* levels at very low flows, however, tend to indicate a problem with malfunctioning septics near the creek or animal waste deposited directly into the stream. BMPs including proper septic maintenance and education regarding picking up pet waste and limiting animal access to the creek will help to mitigate these low-flow problems. Birds, both aquatic and otherwise, can also be a source of direct fecal matter input to the creek. A bacterial species analysis would be helpful to determine the relative contribution of fecal matter from different species of wild and domestic animals and to help decide on appropriate mitigation measures.

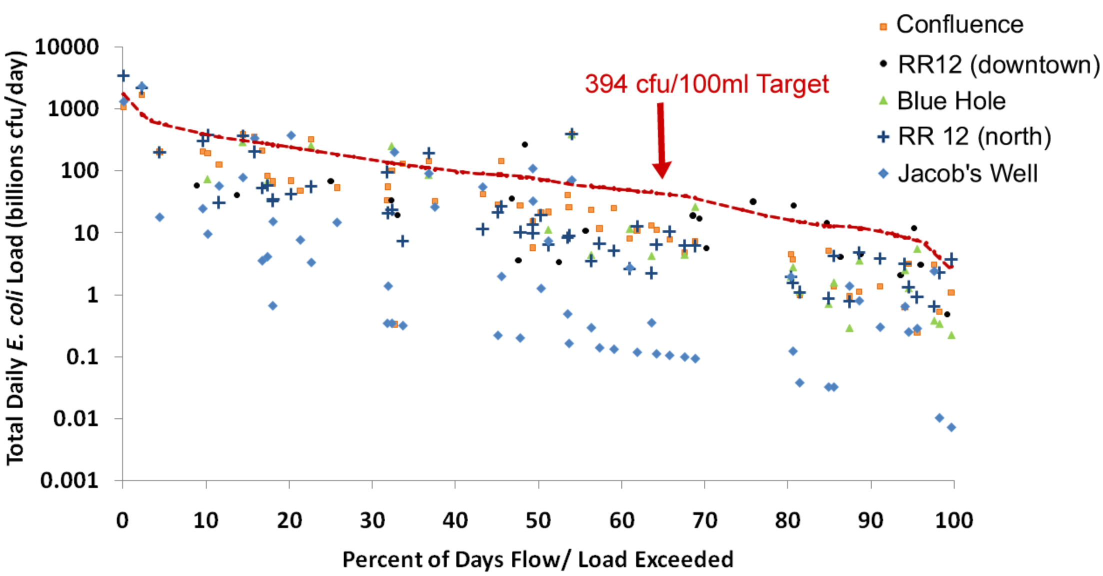


Figure 6.21. Load duration curve of E. coli at five sites along Cypress Creek.

The red dashed line represents E. coli loads at a target concentration of 394 cfu/100ml, and dots represent loads calculated for observed conditions.

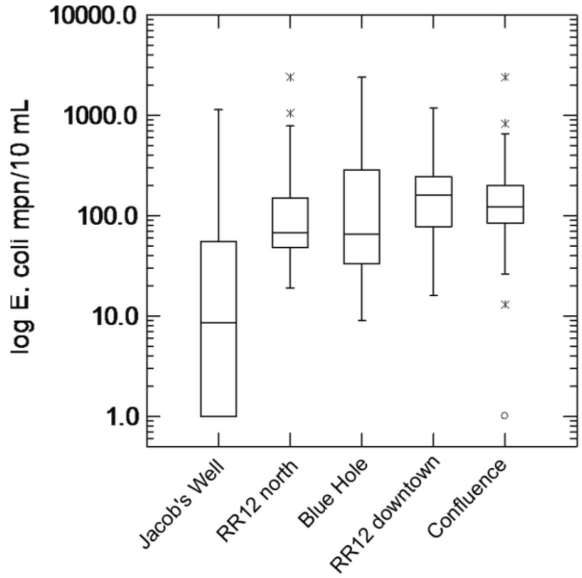


Figure 6.22. Box-and-whisker plot of E. coli (cfu/100 ml) measured at five sites along the Cypress Creek.

Lines through the center of boxes represent the median value, bottom and top of boxes represent the 25th and 75th percentiles, respectively, and whiskers show the 5th and 9th percentiles. Dots are outlying values.

6.4 Wastewater Treatment Plants in the Watershed

There are two Wastewater Treatment Plants (WWTP) that serve the watershed. The Village of Wimberley and Guadalupe-Blanco River Authority have a permit for the Blue Hole Wastewater Treatment Facility in Wimberley. The plant and disposal site are located one mile northeast of the intersection of RR12 and RR2325. The plant is authorized to dispose of effluent at a maximum volume of 0.050 MGD by land application on 19 acres of land that is not available to the public. Application rates are not to exceed 2.96 acre-feet per year per irrigated acre. No discharge of pollutants into water is allowed by the permit. Currently, the wastewater is shipped to the WWTP in Lockhart for treatment. There is no land application of wastewater in the Cypress Creek watershed from this WWTP at this time, but plans show it may take place in the future.

The other WWTP is located in the City of Woodcreek. Aqua Wastewater Management, Inc. (AquaTexas) services a large number of households and businesses in the area. AquaTexas has a permitted WWTP located approximately 1,200 feet south southeast of the intersection of RR2325 and Jacob's Well Road, approximately 4 miles north of Wimberley. This WWTP is located outside of Cypress Creek watershed boundaries and the treated waste is pumped back into the watershed for dispersal. The plant is authorized to dispose of the treated wastewater at a maximum volume of 0.375 MGD by land applying on 175 acres of land. This acreage is the Woodcreek golf course. Application rates cannot exceed 2.4 acre-feet per year per acre irrigated. No discharge of pollutants in to water is allowed by this permit.

There have been numerous complaints against this plant, including leaking pipes, overflowing lift stations, exceedance of flow limits, overflowing manholes, overflowing effluent ponds, and complaints of odors. There should not be any runoff of effluent from the golf course into Cypress Creek, but given the number of complaints, onsite testing is needed to verify that requirement is being met. While applying treated effluent to golf courses (as indicated in permits) is considered safe, there are cases where this use becomes a problem. Inadequate soil depth, high counts of nitrogen, *E.coli*, and Phosphorus in the effluent and runoff can contribute to pollution in nearby streams. There is insufficient information at this time to determine if this is the case in the Cypress Creek watershed, therefore monitoring of runoff from the golf course area is recommended to verify that no net loading is occurring to surface streams.

Land application of treated effluent is increasing for the use in irrigation of golf courses. The TCEQ has designated this type of reclaimed water use as a Type I, which includes irrigation areas where the public may be present during the irrigation or the public may be in contact with the reclaimed water. Thus, standards for this type of land applying are stricter than other approaches for managing treated effluent.

For a 30 day average, per TCEQ (1997), Type I reclaimed water shall have a quality of:

BOD_5 or $CBOD_5$	5 mg/l
Turbidity	3 NTU
Fecal coliform or *E. coli*	20 cfu/100 ml*
Fecal coliform or *E. coli*	75 cfu/100 ml**
Enterococci	4 cfu/100 ml*
Enterococci	9 cfu/100 ml**

**30 day geometric mean*
*** maximum single grab sample*

7.0 Discussion and Recommendations

The characterization of Cypress Creek shows the state of current water quality remains within state standards, although elevated pollution and bacteria levels and depressed dissolved oxygen have been observed under a variety of conditions and indicate that the stream is experiencing some water quality impairments. The watershed will continue to experience additional stress on the water system due to development, associated NPS pollutants, and declining aquifer levels. However, the characterization of a watershed is not only based on background information, data, and analysis but also on developing an understanding of how potential pollution might impact waters and habitat of the creek, groundwater, and residents of the watershed. The following sections address implications of potential NPS pollution and how such water degradation might impact the overall watershed. Possible impacts are evaluated through assessment of vulnerable areas in the watershed, pollutant potential, and economic assessment of land values under water degradation indexing.

7.1 Areas of Vulnerability

7.1.1 Vulnerable Tributaries

Much of the focus on pollution sources and best management practices (BMPs) has been on impacts to the perennial Cypress Creek itself. However management of pollution loads from upland areas and along major tributaries will also help to maintain water quality in the main creek. Based on analysis of water quality, potential pollutant loadings, land cover, and current and future patterns of development, **three groups of tributaries are recommended for priority attention to buffers and other BMPs** that will help to keep the creek clean and clear (Figure 7.1*)*. Group A is considered priority due to current and near future developments, group B due to potential future development, and group C due to high potential runoff and sediment yields.

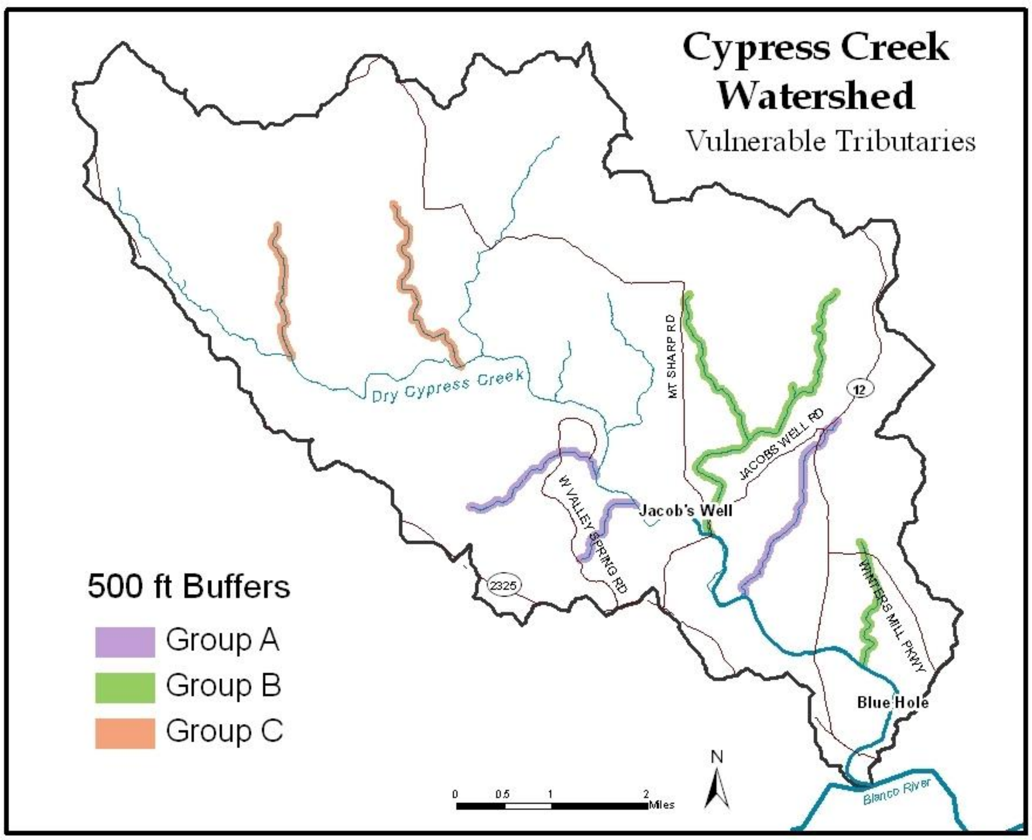


Figure 7.1. Vulnerable areas recommended for BMPs.

Group A tributaries drain areas where high-intensity residential development is already in place or platted for the near future. One of these (Hog Creek) also drains much of the area around RR12, where new residential and commercial development is likely to occur. Along these tributaries, riparian buffers and other BMPs will be very important for new construction.

Education of existing riparian landowners regarding riparian management and restoration of disturbed buffers is recommended.

The concern for Group B tributaries is for potential future developments. If large-lot inholdings and ranches are further subdivided, riparian buffers will be very important for maintaining water quality. Development along the western side of RR12 and Jacob's Well Road may impact the western tributary in this group in terms of both water quality and peak flows. Slopes are high in the upper reaches of the western tributary, which will make BMPs to retain flow and sediment in the uplands very important there. In addition, the southernmost tributary near the confluence with the Blanco may impose a flooding risk on downstream segments of the stream if stormflows are not properly managed with appropriate BMPs.

Finally, Group C tributaries drain predominantly agricultural areas that also have very high slopes in the uplands and relatively low vegetative cover to retain sediment. Preliminary modeling results show that these areas could have high erosion and flows if they are not managed properly. The contributing area to these tributaries would be recommended as priority for rangeland management BMPs, stormwater detention, and riparian buffers. In addition this area drains the land surrounding upper Ledgerock Road and CR 218, both of which Hays County identified as major transportation corridors in its 2025 plan and which may therefore experience near- future developments.

7.1.2 Flooding

As with many regions in the Hill Country, flooding within the Cypress Creek watershed occurs during and after high rainfall events. The immediate impacts of flooding are temporary high waters on roadways and potential flooding of structures in low-lying areas. However, the swiftly moving high water is also a runoff mechanism that transports and disperses NPS pollutants along its path. While data collection and analysis from the sampling and testing of stormflow events are still ongoing, it is recognized that when flooding occurs, the turbulent waters can contribute to pollutant and sediment loadings. Without implementing a suite of prevention techniques, flooding is likely to increase with land use development. Hays County is initiating a flood study in the Blanco River Basin. These results will be available to the watershed protection planning effort upon their completion.

7.1.3 Groundwater Vulnerability

Karst features in the watershed are recognized conduits with regard to groundwater vulnerability and NPS pollution. Where faults, fractures, sinkholes, and/or caves are connected from the land surface to the hydrologic strata of aquifer levels, the potential exists for NPS pollutants to migrate within infiltrating waters through the subsurface. In the case of the Hill Country region, an additional factor to consider is thin to non-existent soil layers. Substantially thick soils can slow the infiltration of certain pollutants by providing a substrate onto which the pollutants adsorb, albeit at differing concentrations and rates of adsorption. However, the thin, predominately calcareous soils of the Hill Country tend to provide little adsorption for infiltrating pollutants. Because of the potential for rapid subsurface flows to reemerge down-gradient, such contamination may impact water quality in streams as well.

Groundwater wells in the watershed are also a factor of vulnerability to consider. Many wells have been installed over the years into various levels of the Trinity aquifer system. According to the Hays-Trinity GCD report, at least 924 wells exist in the watershed (HTGCD, 2008). Due to state rules and regulations, wells may have been drilled but not always located or logged. A well may not necessarily be protectively cased down to the level of the pump but typically is cased from tens of feet below land surface up to the elevation of the protective well cover. This type of installation is known as "open hole;" it reduces well installation costs to take advantage of groundwater entering the well hole under some variation in aquifer levels over time. NPS pollutants infiltrating the subsurface may enter open hole wells below their protective casing. In such cases, the vulnerability of groundwater increases due to the vertical conduit provided by the well. Additionally, wells that are improperly abandoned or capped provide another level of uncertainty with regard to vertical migration of NPS pollutants. Additionally, raw water tests for *E.coli* contamination have been conducted by a local water provider. Some of these tests are revealing concentrated *E.coli* in the raw water extracted from the aquifer. Positive *E.coli* tests from primary water supply wells indicate current contamination from unknown sources.

7.2 Pollutant Potential in the Watershed

A composite index map was created to demonstrate the areas that have high loading potential for the various pollutants evaluated in this study. For each pollutant of concern the best estimate was used for the composite index: organic nitrogen, organic phosphorus and sediment were taken from SWAT model results, BOD and oil/grease were taken from the land use loading model, and the *E.coli* – surface and OSSF were taken from the SELECT model (Table 7.1). For each individual pollutant and subwatershed, loadings were scored 1 to 5 using an equal interval method such that a score of 1 represents values up to 20% of the maximum, a score of 2 represents 21 to 40% of maximum, 3 represents 41 to 60% of maximum, etc. Scores for each subwatershed were averaged and weighted 1 to 5 using the above method to produce the composite index (Figure 7.2). On the composite, a score of 1 means that the subwatershed scored relatively low for many pollutant loadings, and a score of 5 means that it scored highly for many pollutant loadings.

Table 7.1. Data used for Pollution Potential Index:

Pollutant	Source(s) of estimate SWAT model	 Land use loading model	 SELECT loading model
Organic nitrogen	X		
Organic phosphorus	X		
Sediment	X		
Biochemical Oxygen Demand (BOD)	X	X	
Oil and grease	X	X	
E. coli from pets and wildlife (surface sources)			X
E. coli from OSSF (subsurface sources)			X

The composite index map for the Cypress Creek watershed shows the areas that have the greatest potential to produce nonpoint source pollutants. Because these pollutants may impact water quality in the creek, they are important to quantify and understand within the watershed.

To reduce these potential nonpoint source pollution loads, **three areas are prioritized for immediate attention to BMP implementation**.

- Areas in the upper and western portions of the watershed that are primarily agricultural lands have generally low composite index scores, however subwatersheds with high water yield scored high for sediment and nutrient loads that are associated with high flows. Nonpoint source pollution concerns are nitrogen, Phosphorus, BOD, and *E. coli* resulting from livestock and animal waste untreated at the land surface. BMPs, such as stormwater detention and riparian buffers, that reduce the amount of surface runoff entering creek channels will be of primary importance in these areas. Much of the surface flow generated in these upper watershed areas is lost to rapid infiltration through fractures and sinks, however this still presents a concern for high nutrient loading to groundwater resources.

- The second priority nonpoint source pollution management area is in the lower portion of the watershed around Woodcreek and Wimberley where much commercial and residential development is located along the perennial Cypress Creek, RR12 and downtown Wimberley. Potentially high contributing sources are nitrogen and Phosphorus from fertilizer use and pet/animal waste; oil, grease, and suspended solids from the many major and minor roadways in the area; and *E. coli* from pet, livestock, and wildlife waste as well as untreated human waste from failing septic systems. Hog Creek and the subwatershed just downstream are ranked highly due to occurrence of runoff from much of the commercial and residential development along RR12 and RR2325.

- The third area includes the Woodcreek North subdivision and areas just upstream to the north and west. Although these areas did not score as highly as the more densely developed watersheds to the southeast, this area is of primary concern because of the high likelihood for rapid future development to medium to high density residential. Residential land uses are the highest contributor to BOD, oil and grease, phosphorus, and surface runoff, which means that there is a high potential for increased loading from this area in the near future. The primary contributors to the index scores here are sediments, nutrients, and *E. coli* from the roadways and residential development in the area, associated with increased impervious cover, high flow potential, and pet/animal waste.

In addition, many areas with the highest composite scores are within the areas serviced by AquaTexas and Wimberley Water Supply waste-water treatment, meaning that nonpoint source potential is not necessarily highest where homes and businesses rely only on septic systems for wastewater treatment. Contributions from septic systems therefore do not seem to be of highest concern when compared to the magnitude of potential nonpoint source pollution from pet/animal waste and washoff of particulates and nutrients from dense residential, commercial development, or poorly managed rangelands. There is still the potential for *E. coli* loading from malfunctioning septic systems in close proximity to the creek during times of low flow, as suggested by water quality observations in the downtown area. Although proper septic maintenance is critical, particularly for those systems located in close proximity to creek channels, the effects of these failures may be swamped by pet, livestock, and/or wildlife waste if it is consistently left untreated on the surface. Priority BMPs should therefore be education for local residents with regard to pick up and disposal of pet waste, limiting animal access to the creek, and limiting the populations of nuisance wildlife such feral hogs and deer.

An overlay of potential pollutant loadings with karst features, faults, and riparian areas reveals that the areas of highest potential loading often have additional environmental sensitivities that must be considered when managing new developments (Figure 7.2). Faults and caves in the upper parts of the watershed are likely places of localized aquifer recharge. There is anecdotal evidence that these features can act as major sinks during rainfall events. Faults and karst features in the mid to lower portions of the watershed are more likely to produce springs and seeps where subsurface flow is redirected back to surface channels, particularly during wet periods when the water table in the shallow aquifer rises.

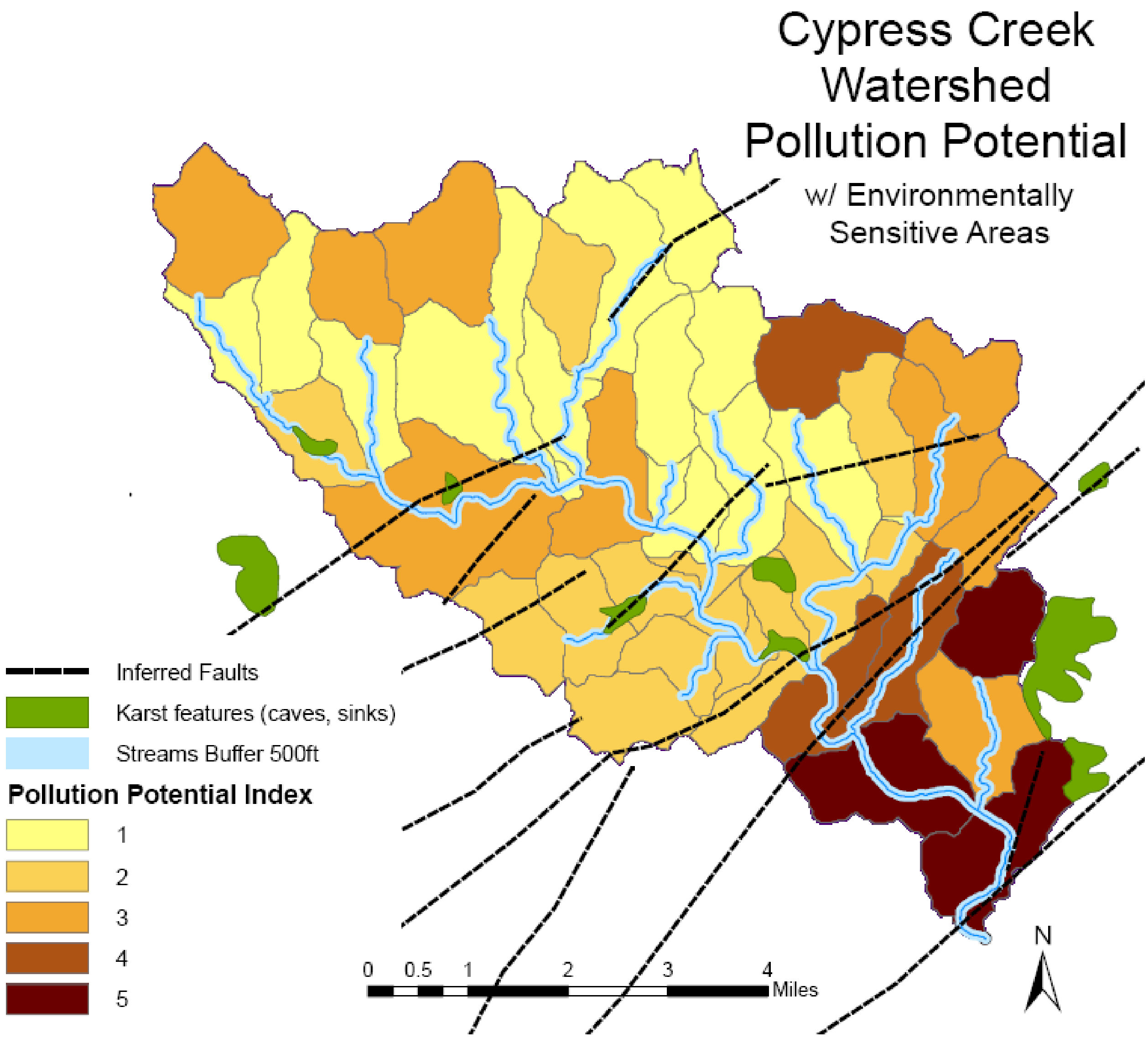


Figure 7.2. Composite subwatershed map of potential pollutants.

Although there is still a great deal of uncertainty and local heterogeneity regarding subsurface fractures and flow paths, several lines of evidence converge to show that baseflow at Jacob's Well originates from the Cow Creek geologic formation and is dependent on regional aquifer levels and flow from the northwest. However, the spring also has a component of flow that rises and falls with more local rainfall and results from recharge to the shallow aquifer within the lower Glen Rose formation (HTGCD, 2008). Jacob's Well spring levels show a rapid response to rainfall events which suggests that water is infiltrating into the lower Glen Rose aquifer, travelling southeasterly through the subsurface, and re-emerging at springs along the Cypress Creek, its tributaries, and potentially along the Blanco River as well. Whereas the surface flow contribution from the upper Dry Cypress may be negligible during all but the largest storm events, the potential remains for pollutants such as nutrients and bacteria to be carried through these rapid subsurface flows and to impact water quality in the Cypress Creek and Blanco River. Although it is critical to manage those subwatersheds that scored highly in the composite index, upper watershed areas should not be ignored in future considerations of water quality assessments and BMP implementation. These areas are also subject to potential nonpoint source pollution due to the potential for land use changes. Such changes may alter the partitioning of rainfall across the watershed, thereby increasing surface flows while decreasing infiltration and thus affecting potential recharge to the aquifer and Jacob's Well spring.

In addition, flow appears to be a critical factor for maintaining adequate oxygen levels and a highly functioning aquatic community. For all sites, observed DO levels show improvement at flows above 1.3 cfs. At 4.1 cfs and above, oxygen levels are generally excellent. At these low levels, spring flow rather than surface runoff is the primary contributor to streamflow. Therefore to keep the Cypress Creek flowing and an exceptional aquatic community, it is imperative that Jacob's Well flow be maintained at or above a minimum level of ±4.1 cfs. Due to uncertainties in the methods of estimation, the flow estimates used in this study contain a degree of error (15-25%), and so should be taken as a starting point for setting goals rather than an absolute prescription. In addition, HTGCD (2008) estimated that pumping for municipal supply wells averages to about 1 cfs. This pumping has been shown to directly affect spring flow at Jacob's Well; therefore any flow target should add 1 cfs as a margin of safety (MOS) as well as account for uncertainties in estimates. Therefore, a target flow level can be calculated as:

*4.1 cfs DO target + 1 cfs pumping MOS ± 25% error ≈ **3.8 to 6.4 cfs.***

It is important to note that the pollutant loadings estimated for this report are for loadings based on average runoff, known land uses, and the physical properties of the subwatersheds. The actual loading values could be higher or lower depending on the amount of runoff generated due to rainfall amount and intensity throughout a given year and the mitigation measures already in place to retain water and sediment in the uplands. A survey of existing BMPs and continued monitoring is recommended to refine loading estimates. This analysis is intended primarily to provide relative nonpoint source loadings from different parts of the watershed to characterize the general patterns of loading and to prioritize areas for watershed management and BMP implementation.

7.3 Assessment of Water Quality and Economic Conditions

A significant understanding of potential water degradation can be achieved through economic analysis specific to a watershed. Towards that goal, an economic evaluation of the possible effects that water quality degradation might have on land values was conducted by the Economic Subcommittee (see Appendix A). Business and land owners within the watershed worked with the Subcommittee to determine economic effects that an impaired creek might have on Wimberley. The group utilized county appraisal data, real estate figures, and information from Wimberley business owners.

In Figure 7.3, ‘Q’ represents Water Flow, while ‘S’ represents the water quality of the creek. Using Hays County Appraisal data and the percentages determined by the Subcommittee, predicted losses resulting from the degradation of the creek in quantity and quality were determined. It was found that in the upper dry segment of Cypress Creek, market land/home values would not be affected by a decrease in water flows or quality because land values in that part of the watershed were not based on their proximity to the flowing creek. The Economic Subcommittee data suggest the greatest economic effect of a degraded creek would be to the wet/adjacent portion of the watershed where decreased flows would cause a 25-45% drop in market values while decreased water quality would result in a 20-30% decline in market values. This would potentially reduce the market values of this portion (wet/adjacent) of the watershed by nearly half.

In economic terms, combined decreased flows in the wet portion of the watershed would create significant losses in land values. In addition, the Subcommittee estimated that an impaired Cypress Creek would have a dramatic effect on Wimberley’s tourist businesses. For more discussion on this evaluation, please refer to Appendix A.

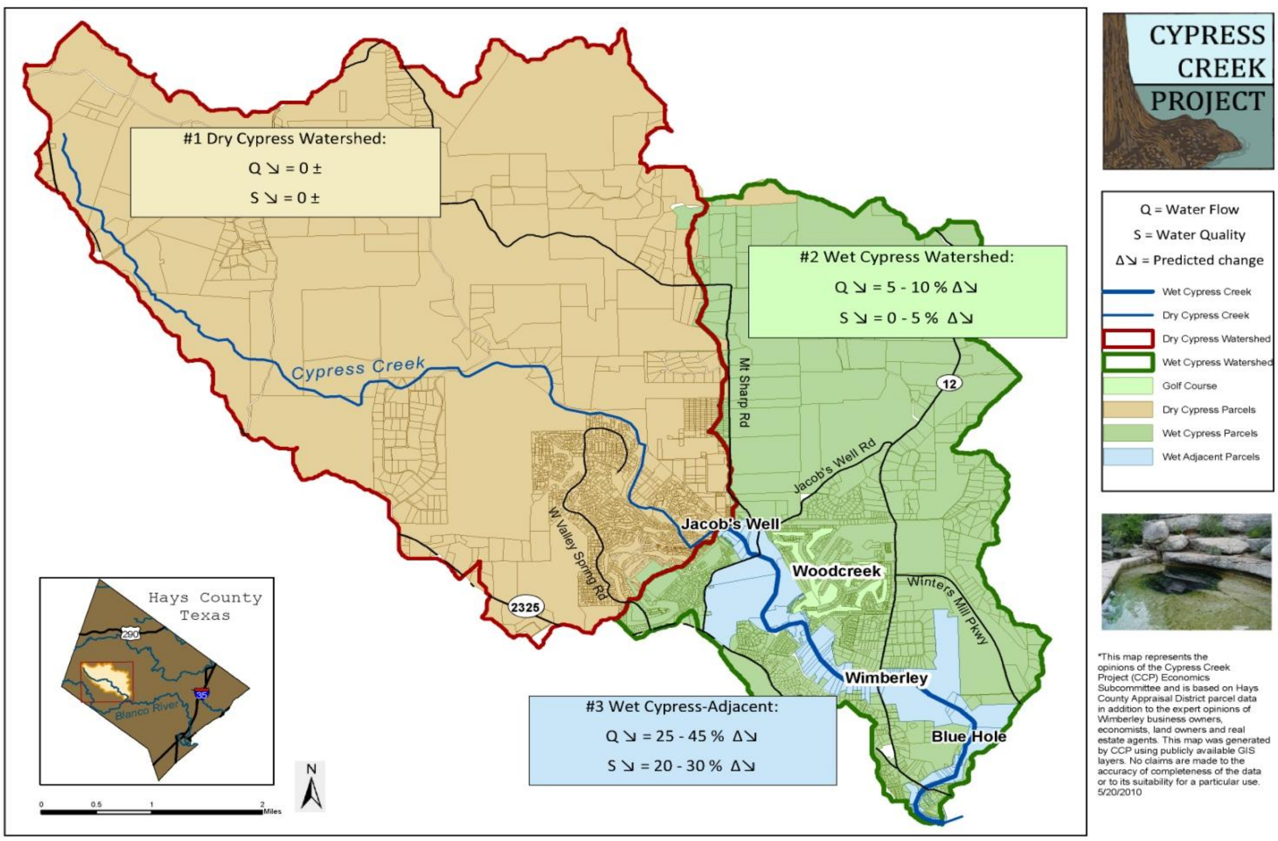


Figure 7.3. Predicted economic effects of water quality degradation.

7.4 Summary of Watershed Characterization and Recommendations

This water quality characterization report shows that the Cypress Creek, as a whole, is in adequate condition when assessments are based on State water quality standards. Spatial and temporal analysis show natural and anthropogenic activities impact water quality, quantity, land use, and land cover. There are indications that healthy Cypress Creek watershed functions are negatively impacted by land use change. The lower portion of the watershed benefits from the relatively low development activities in the mid and upper portions. These positive benefits currently protect surface and groundwater baseflow, water quality and quantity, as well as habitat and biodiversity. As land use in this area continues to shift from open space and ranching to residential and commercial, increasing adverse impacts are likely to occur as additional loadings impact water quality, and as increased pumping impacts spring flows. Impacts on spring flows may be mitigated if additional sources of water supply are secured, including distributed low-capital investment solutions such as rainwater harvesting.

Impervious cover was estimated at 6% in 1996. By 2005, impervious cover increased to 9% total in the Cypress Creek watershed (Carter, 2008). A recent USGS study (Cuffney et al., 2010) demonstrates that healthy watershed functions are impacted at impervious cover rates as low as 10%. As impervious cover increases throughout the watershed, likely impacts include: increased flooding frequency and magnitude; increased NPS pollutant potential; increased streambed scouring and erosion; increased rate of habitat loss; decreased biodiversity; and decreased aesthetic value. In addition impervious cover can impact hydrology by increasing the volume and speed of surface runoff, decreasing the potential for groundwater infiltration and impacting baseflow in the creek. Once impervious cover rates are in the 15 – 20% range, resource managers may begin to focus efforts more on flood and erosion prevention and much less on maintaining clear, clean, and flowing water conditions. It is pertinent to address local and county regulation and market incentives in order to fully manage impervious cover for the entire watershed.

Nitrogen levels in the creek reflect conditions typically observed in karst systems where artesian springs produce the majority of baseflow. Background levels are typically higher at Jacob's Well and decrease as nitrogen is assimilated and utilized as it moves downstream. However, there are times when elevated nitrogen levels are observed and this occurs during moderate to high flow conditions. This could indicate NPS pollution from runoff during rainfall events. Potential sources for these elevated nitrogen levels could be lawn fertilizers, decomposing vegetation and animal wastes, and other sources. It is likely this trend will increase over time.

Phosphorus levels are low and indicate Cypress Creek is a phosphorus limited system. When phosphorus is freely available in the stream it is quickly assimilated by plants. However, data show that phosphorus levels from Cypress Creek at RR12 (downtown Wimberley) are elevated during low to moderate flow periods. This could indicate a steady source of phosphorus inputs from localized activities. At this location, elevated ammonia and *E. coli* levels are also observed during low to moderate flow conditions.

Ammonia levels are low and below the detection limit at most sites with the exception of the Cypress Creek at RR12 (downtown Wimberley) location. Elevated ammonia levels are observed at moderate to high flow conditions. Low flow ammonia levels could indicate recent fecal input into the stream from animal or malfunctioning septic systems.

Elevated sediment loads are observed during low, moderate, and high flow conditions. The primary area where sediment is chronically problematic is the stretch of creek from RR12 north to the confluence with the Blanco River. There are two major tributaries that join the main creek from the north between Jacob's Well and RR12 north. These two creeks may carry sediment from high-slope areas in the north and contribute to higher sediment levels at RR12 north. The largest increase in median sediment concentrations occurs between RR12 north and Blue Hole. There is one major tributary that joins the main creek between these two sites that may contribute large volumes of sediment during high flows, and Blue Hole being a prime recreation area may contribute to sediment in the creek during low flows. The construction of Winters Mill Parkway starting in 2005 coincides with observed elevated readings in the 2005 to 2007 period. As observed in the 2005 data, instream dredging is also impacting the stream (Figure 7.4). It is important to consider managing sediment throughout the entire watershed and not just in the riparian areas.

Figure 7.4. High sediment flow during a storm event, 2005. Photo by Jason Pinchback.

E.coli levels are elevated at all sites, including Jacob's Well, during median and high flow periods. A cluster of very high values is found under the highest flow conditions, indicating nonpoint source pollutants that wash *E. coli* in with higher surface or shallow sub-surface flows. These tend to be in the summer and fall. During low flow conditions, high *E.coli* levels are observed in Cypress Creek at RR12 downtown Wimberley location. These are also observed in conjunction with elevated ammonia and phosphorus levels. Groundwater and surface water resources are vulnerable to *E.coli* contamination due to the karst system and interconnectedness of shallow water aquifers, subsurface flows, fault systems, and stormwater runoff.

Dissolved oxygen varies considerably from site to site with flow and air temperature predominantly influencing these changes. Evidence that flow plays a primary role in dissolved oxygen concentrations is seen by examining plots of dissolved oxygen across a range of flow levels. For all sites, a flow level between 1.3 and 4.1 cfs may be sufficient to sustain DO levels above 4.0 mg/L at least 75% of the time. 6.0 mg/L is a minimum 24 hour standard for maintaining adequate conditions for aquatic ecosystems. At flows between 4.1 and 5.1 cfs, DO exceeds 6.0 mg/L at least 75% of the time, which is a target level for maintaining a healthy aquatic community. Given a margin of safety for uncertainties in flow estimates and known impacts from a water supply well nearby, a flow target of 4 to 6 cfs is recommended to maintain the historic nature of the creek as a spring-run stream.

This watershed characterization and associated analysis highlights significant findings from the available information and points out there are still numerous data gaps and the need for additional data. This characterization report also provides the basis for the watershed protection plan and will help to craft an appropriate education and outreach strategy that targets the appropriate audience with the corresponding information and actions that can bring improvements. With that being said, this watershed is under a constant state of change. Land use changes, new developments and water resource infrastructure are continually being proposed. These changes will impact watershed functions. With a more comprehensive understanding of how these impacts can be mitigated, it is entirely possible to sustainably manage Cypress Creek to remain clear, clean, and flowing. This can only occur with the support of the community, its decision makers, and stakeholders.

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Appendix A. Watershed Subcommittees Overview

Within a watershed protection planning process, it is important to understand the priorities, perspectives, and culture of the community and its stakeholders. A watershed stakeholder includes anyone who lives, works, or shares an interest in protecting the watershed. Stakeholder involvement is an essential component for a successful watershed protection plan because it enhances cooperation, collaboration, and community participation. Stakeholders provide local insight about public concerns and values that help bridge scientific research and community-driven efforts.

A Watershed Protection Plan is a coordinated effort that provides assessment and management information to address water quality and restoration objectives within a watershed. This holistic approach identifies potential sources and causes of impairments to local ground and surface water resources.

Diverse stakeholder representation is essential to the success of the Cypress Creek Project. In order to represent these diverse interests, the River Systems Institute indentified a comprehensive list of key stakeholders that represented a broad range of perspectives. Initially, 20 stakeholders were selected based on their background, expertise, and community involvement. The first Cypress Watershed Committee meeting convened on June 3, 2009 and was successful in securing commitment from the stakeholders, identifying topics, and chairs for various subcommittee groups, and nominating a Committee chair, Scott Johnson.

Quarterly Cypress Watershed Committee meetings have been held to provide a forum for subcommittee groups to discuss their progress, findings, and hear suggestions from the entire Committee. Membership within the Cypress Watershed Committee has changed throughout this yearlong process, yet current members remain committed to the preservation of the Cypress Creek.

The overall objective of this process is to identify management measures and areas we can improve to ensure long-term integrity of Cypress Creek. Final recommendations from the Watershed Protection Plan will be implemented by Cypress Watershed Committee, Subcommittee members, and additional watershed partners. Watershed Committee and Subcommittee membership is comprised of stakeholders from Wimberley and Woodcreek city council, Hays County Commissioners, Hays Trinity Groundwater Conservation District Board, Texas Parks and Wildlife, Texas Commission on Environmental Quality, Texas Farm Bureau, The Nature Conservancy, local landowners, Texas Agrilife Extension, Wimberley Valley Watershed Association, Wimberley Independent School District , GBRA, Texas State Soil and Water Conservation Board, Keep Wimberley Beautiful, Wimberley Water Supply Company, Wimberley Institute of Cultures, and more. In addition, serving on the Committee and Subcommittees are local realtors, lawyers, environmental consultants, developers, local business owners, professors, various board members, retired teachers, master naturalists, rainwater collection experts, and local citizens.

Subcommittee groups were created to target various issues of concern within the watershed. Subcommittee focus topics were selected by the Watershed Committee at the initial meeting. These groups include Water Quantity, Water Quality, Land Stewardship, Economic, Education and Outreach, and the Decision Support System. Membership was comprised of Cypress Watershed Committee members and concerned citizens within the watershed. Each Subcommittee chair presents recommendations and suggested management measures at the quarterly Cypress Watershed Committee meetings. Subcommittee meetings were held monthly at various locations throughout the watershed and were facilitated by the Subcommittee chair and River Systems Institute staff liaison.

Subcommittee group assignments were structured based on components of the EPA's nine elements of a successful Watershed Protection Plan. While suggested subcommittee tasks addressed the EPA's 9 guidelines, each subcommittee also identified additional tasks that they felt were pertinent to the watershed and public outreach. These supplemented tasks included an assessment of the economic impact Cypress Creek has on residential and commercial property values; cost and benefit analysis of alternative sources of water: rainwater, surface water transfers, drilling additional wells; water budget to help citizens understand the finite nature of their water resources; and structuring relevant education and outreach efforts. These tasks will help strengthen the outreach component of the Watershed Protection Plan as they are intended to draw support and educate the community on issues affecting the Cypress Creek Watershed. The following are summaries provided by the individual subcommittees:

Decision Support System Subcommittee

Chair: David Baker (WVWA, HTGCD)

Members: Doug Wierman (HTGCD), Debbie Magin (GBRA), Gordon Linam (TPWD), Jason Pinchback (RSI), Aaron Wendt (TSSWCB), Sally Caldwell (Woodcreek), Matt Heinemann (WVWA), Vicente Lopes (TX State University-San Marcos), Phil Lebkuecher (Developer and local landowner), Jack Higginbotham (TCEQ)

Staff Liaison: Adrian Vogl, Watershed Science Lab, Texas State

Surface- and ground-water resources in the Hill Country area are threatened by intense urbanization and increasing demand for water resources. There are increasing concerns about the impacts of this development on nonpoint source pollution to local surface waters, compounded by potential reductions in spring flows due to declining aquifer levels. The Cypress Creek Project recognizes that planning in the area would greatly benefit from a decision support system that provides stakeholders and regulatory agencies with a watershed-scale analysis of these potential impacts to determine which areas are most sensitive to development pressure, and where BMPs and other conservation measures may be sited most effectively.

Planning and assessment in land and water resource management are evolving from simple, local-scale problems toward complex, spatially explicit, regional ones. Such problems have to be addressed with distributed models that can compute runoff and erosion at different spatial and temporal scales. The extensive data requirements and the difficult task of building input parameter files, however, have long represented an obstacle to the timely and cost-effective use of such complex models by resource managers. The U.S. EPA Office of Research Development and the USDA-ARS Southwest Watershed Research Center have developed a tool to facilitate this process. The Automated Geospatial Watershed Assessment (AGWA) tool uses widely available standardized spatial datasets that are used to develop input parameter files for two watershed runoff and erosion models, including both an event-based hydrologic model and a continuous simulation model. These two models allow for examination of hydrologic and NPS impacts of changing land use at both storm-event and long-term scales.

AGWA was developed under the following guidelines:

- Provide simple, direct, and repeatable method for hydrologic model parameterization
- Use only basic, easily obtainable GIS data
- Be compatible with other geospatial watershed-based environmental analysis software
- Be useful for scenario and alternative futures simulation work at multiple scales

The Cypress Creek Project, in association with the Watershed Science Lab at Texas State University, is developing a Decision Support System for the Cypress Creek watershed

(CCP-DSS) based on the AGWA program. The DSS is developed to assist stakeholders and regulatory agencies with jurisdiction in the area to generate scenarios, evaluate outcomes, and ultimately to develop a Watershed Protection Plan based on these analyses. The DSS consists of a database management system to integrate available data, a set of integrated hydrologic and water quality simulation models, and a user interface that allows for the analysis of potential development scenarios.

The CCP-DSS is based on the AGWA software package. In addition, it incorporates a scenario evaluation tool, Facilitator, also developed by USDA-ARS Southwest Watershed Research Center, and is populated with all the relevant GIS, climate, and hydrologic data in an associated database. This initial product will be delivered Aug 2010 along with all necessary documentation. Training sessions were held Jul 2010 for subcommittee members to learn to generate and evaluate scenarios using the tool.

Stakeholder involvement has been critical throughout the DSS development process. The DSS/Technical Subcommittee was recruited during initial Steering Committee meetings, and consists of representatives from HTGCD, GBRA, WVWA, TX Parks and Wildlife, RSI, TSSWCB, TX State University-San Marcos, City of Woodcreek, TCEQ, local developers and landowners. A series of meetings was held with the subcommittee from Sep 2009 to May 2010 to develop objectives for how the DSS will be utilized, identify additional data to include in the watershed planning process and the DSS, develop evaluation criteria for ranking alternative watershed management strategies, and determine how the model output should be structured so as to be most useful to decision makers.

Specific items addressed by the subcommittee are:

- DSS purpose and potential end-users
- Watershed conceptual models, inputs and outputs in the AGWA system
- Additional outputs desired for the CCP-DSS
- Which BMPs are appropriate for Cypress Creek? Which BMPs may be evaluated using the CCP-DSS?
- How can the results inform WPP elements A and B? (identify NPS causes/sources and estimate load reductions)
- Numeric criteria for scenario evaluation
- Simulation results in preliminary DSS and how their display could be improved
- Future of CCP-DSS in Project Phase II and beyond
- Scheduling initial training sessions

In the Cypress Creek Project Phase II, work will continue on the CCP-DSS and will include continuing calibration based on data obtained from the stormflow monitoring program and refinement of functions to increase understanding of assimilative capacity and load allocation in the watershed. In addition it is anticipated that evaluating alternative scenarios using the DSS will help the Steering Committee to make recommendations for the final Watershed Management Plan.

Economics Subcommittee

Chair:	Scott Johnson (Cypress Watershed Committee Chair)
Members:	David Glenn (Wimberley Planning and Zoning Commission, VAG), Jackie Maloy (Keller Williams Realty), Jim Henderson (Jim Henderson Real Estate), Gary Weeks (Gary Weeks Furniture), Eddie Gumbert (Developer)
Staff Liaison:	Hayat Qurunful (RSI); Emily Warren (RSI)

It is evident that the economic health of the Wimberley Valley will be negatively affected if Cypress Creek becomes polluted or ceases to flow. Since the health of the creek and business in the community is inter-related, most businesses will feel the negative consequences of the environmental degradation of Cypress Creek. Using Hays County Appraisal data and the percentages determined by the Subcommittee, predicted losses resulting from the degradation of the creek in quantity and quality were determined.

The Economic Subcommittee is tasked with:

- Economic assessment of the Cypress Creek to the community. For example:
  - Assess Development
  - Assess Property values along water
- Show water's economic impact through various means
- Work with Education and Outreach Committee to convey economic value assessment of Cypress Creek to the community
- Recommend goals for Economic Development in the community

The resulting map and information generated by the Economic Subcommittee can be found in section 7.3 of the characterization.

Education and Outreach Subcommittee

Chair:	Matt Heinemann (WVWA, Texas State)
Members:	Karen Ford (Hays County), Melinda Gumbert, Jackie Maloy, Cindi Thomas, Debbie Magin, Jackie Mattice, Linda Lang, Gina Fulkerson, Cathy Howell
Staff Liaison:	Drue Koegler, Matt Heinemann (WVWA, Texas State)

The overall goal of the Education and Outreach Subcommittee is to increase the involvement of the community in watershed protection activities through awareness, education and action. Outreach and education tools include bumper stickers, electronic newsletters, special events and workshops, outdoor roadside signs, public service announcements, blogs, published reports, flyers, and many more.

Education and Outreach Subcommittee tasked with:

- Consider other stakeholders/individuals that should be part of subcommittee and recruit members of the community
- Identify causes of water quality/quantity problems from education/outreach perspective
- Identify existing outreach and education activities and how we can improve
- Provide information about the Watershed Committee activities to the local media
- Develop an Outreach and Education plan to meet the goals of the Cypress Creek Project.

The Education and Outreach Component can be found at www.cypresscreekproject.org.

Land Stewardship Subcommittee

Chair:	Rachel Ranft (The Nature Conservancy)
Members:	Seth Terry (Texas Farm Bureau), Carolyn Vogel (Vogel Environmental Consulting), Malcolm Harris (Wimberley Parks and Recreation Board), Dell Hood (Master Naturalist, Wimberley Parks and Recreation Board), Chuck Curtis (Master Naturalist), Sam Rivers (Rancher), Ryan McGillicuddy (TPWD), Kasey Mock (Texas AgrliLife Extension: Hays County)
Staff Liaison:	Hayat Qurunful (RSI); Mary Van Zandt (RSI)

Land Stewardship is an essential part of caring for the Cypress Creek; activities on land directly affect the quality and quantity of the water in the creek. The committee researched activities connected with small landowners, large (non-agricultural) landowners, and large (agricultural) landowners, in addition to conservation practices.

Land Stewardship Subcommittee Tasks:

- Consider other stakeholders/ individuals that should be part of subcommittee and recruit members of the community.
- Identify areas of concern within watershed
- Identify Best Management Practices that will help improve or maintain water quality/quantity.
- Feasibility of implementation of Best Management Practices
- Work with Outreach and Education subcommittee

The list of BMP's generated by the Land Stewardship Subcommittee are as follows:

1. Renters / Small Land Owners (less than 2 acres)
    a. Avoid Fertilizer, Pesticide and Insecticide Use
        i. Need to educate citizens on the effects that chemical fertilizers, pesticides and insecticides have on groundwater and what organic alternatives exist.
        ii. What are local golf courses using on the grass?
            1. Can we have sustainable golf courses?
    b. Maintain Septic Systems
        i. Home septic systems should be checked for leaks/maintenance
    c. Pick-Up Pet Waste
        i. Pet waste should be collected and thrown away, not left on the ground to join surface water/ storm water/ groundwater

d. Disposing of Pharmaceuticals
    i. Pharmaceuticals should be thrown away, and not flushed down the toilet.
e. Benefits of Rainwater Harvesting
f. Impervious Cover and how it affects the environment
    i. Need to educate citizens on the direct connections between increased impervious/impermeable cover and increased storm water and flooding rates
g. Plant Education
    i. Which aquatic plants are invasive? Which plants are native?
h. Erosion Control
i. Habitat Conservation
    i. Certain properties meet the specifications for critical Golden Cheeked Warbler Habitat. If so, the county/state will buy those properties from landowners for conservation.
j. Brush Control
    i. There are appropriate ways to clear brush with a controlled burn without harming the topsoil
k. 5 minute timers for showers, turn off water when soaping or scrubbing
l. replace leaking pipes, faucets, sprinklers, etc.
m. Install low flow toilets
n. Use watering schedule
o. Install grey-water system
p. Encourage removal of water intensive plants like St. Augustine & Crepe Myrtle
q. Plant native grasses within recharge areas to enhance recharge

2. <u>Large Non-Agricultural Land Owners</u>
    a. Septic
    b. Pet Waste
    c. Hazardous Waste Pick-Up
    d. Illegal Dumping
    e. Recycling
    f. Brush Control
        i. There are appropriate ways to clear brush with a controlled burn without harming the topsoil
    g. 5 minute timers for showers, turn off water when soaping or scrubbing
    h. Replace leaking pipes, faucets, sprinklers, etc.
    i. Install low flow toilets
    j. Use watering schedule
    k. Install grey-water system
    l. Encourage removal of water intensive plants like St. Augustine & Crepe Myrtle
    m. Plant native grasses within recharge areas to enhance recharge

3. <u>Large Agricultural Landowners</u>
    a. Livestock management
        i. Livestock waste
            1. Need to educate people on hazards of animal waste in water
        ii. Overgrazing
            1. Need to educate people on the proper range management techniques
        iii. Wildlife management
    b. Fertilizer, Pesticide and Insecticide
    c. Rainwater Harvesting
    d. Pervious vs. Impervious Cover
        i. Need to educate citizens on the direct connections between increased impervious/impermeable cover and increased storm water and flooding rates
    e. Brush Control
        i. There are appropriate ways to clear brush with a controlled burn without harming the topsoil
    f. Habitat Conservation
    g. Erosion Control
    h. Plant Education
        i. Which aquatic plants are invasive? Which plants are native?
    i. 5 minute timers for showers, turn off water when soaping or scrubbing
    j. Replace leaking pipes, faucets, sprinklers, etc.
    k. Install low flow toilets
    l. Use watering schedule
    m. Install grey-water system
    n. Encourage removal of water intensive plants like St. Augustine & Crepe Myrtle
    o. Plant native grasses within recharge areas to enhance recharge

CONSERVATION

Various practices that can be adopted by anyone to help conserve energy and natural resources

-Vegetation/Riparian Buffers
-Native Plant Use
-Rainwater Collection
-Low Flow Toilets
-Energy Efficient Appliances
-Organic fertilizing and pest control
-Replace impervious cover w/ pervious cover
-Use pervious cover in new constructions

Potential BMP's and Water Conservation Measures

- World Water Day – March 22
- Cypress Creek Blessing
- Work with Elementary Schools
  - Wimberley Outdoor Educators, WIC, GBRA
  - Older classes start a water blog
- Newspapers include a water conservation tip of the week
- Workshops on rainwater harvesting, xeriscaping, etc.
- Cypress Flow Display in town showing level of discharge (like burn ban signs)
- Watershed Model at the Visitor Center or Wimberley Community Center
- Signs saying "Entering Cypress Creek Watershed"
- Display charts showing patterns of dry and wet periods

Water Quality Subcommittee

Chair:	Debbie Magin (GBRA)
Members:	Tracey Bratton (Loomis Environmental Consulting), Don Ferguson (City of Wimberley Administrator), David Baker (WVWA, HTGCD), Pete Anderson (Wimberley), Pat Bohannon (TCEQ), Glenn Longley (TSU), Eddie Gumbert (Developer), Gordon Linam (TPWD)
Staff Liaison:	Vanessa Lavender (RSI, Texas State); Mary Van Zandt (RSI)

Clean water is vital to the health of Cypress Creek, and to the cities of Wimberley and Woodcreek. The quality of the water in Cypress Creek is currently high, and the goal of this project is to maintain a clean, clear and flowing creek. Clean water is essential not only to the health of the creek, but also to business owners, local citizens, swimmers, aquatic life, and plants in and of the creek. This region will undoubtedly see an increase of up to 50% in population over the next generation. An increase in population will lead to an increase in water consumption, an increase in urban runoff, and quite possibly, pollution. The Water Quality Subcommittee was formed to identify potential sources of pollution in the watershed, and develop practices in how best to deal with them.

Water Quality Subcommittee Tasks:

- Consider other stakeholders/ individuals that should be part of subcommittee and recruit members in community
- Set long term goals/standards for water quality parameters to guarantee "clean, clear, and flowing"
- Identify areas of concern
- Identify causes and sources of water quality problems
- Identify standards in place to protect, what we can improve, or new management measures
- Identify Best Management Practices that can be implemented

It was determined that there is no point source pollution going in to Cypress Creek. The Water Quality Subcommittee identified many possible causes of nonpoint source pollution in the watershed. These include:

- increased impervious cover
- construction in the watershed
- effluent on the golf course
- personal behaviors
- lawn care

- agricultural practices
- leaking septic systems
- leaking oil pipelines
- improper storm water management
- grandfathered developments
- lack of enforcement of existing regulations
- improper wildlife controls (e.g. feeding deer)
- pet waste
- improper riparian management
- improper garbage disposal
- illegal dumping of sewage.

The City of Wimberley conducted a study of the downtown businesses and roughly 75% of the septic systems are not permitted. The building of downtown Wimberley has not had much oversight.

Woodcreek has ordinances against feeding deer and not picking up pet waste. Both violations can result in a $100 fine. However, these violations require written affidavits from witnesses and enforcement has not been adequate.

Water Quantity Subcommittee

Chair:	Jack Hollon (HTGCD)
Members:	David Baker (WVWA, HTGCD), Sally Caldwell (Woodcreek City Council), Clifton Ladd (Loomis Environmental Consulting), Andy Grubbs (Hays County Environmental Consulting), Harvey Mabrey (Wimberley H20), Anne Mabry (Wimberley H20), Dell Hood (Master Naturalist, Wimberley Parks and Recreation Board)
Staff Liaison:	Kristina Tower (RSI, Texas State)

Water Quantity Subcommittee Tasks:

- Consider other stakeholders/individuals that should be part of subcommittee and recruit members of the community
- Set long term goals to ensure “clean, clear, and flowing”
- Gather data to identify areas of concern
- Identify causes and sources of water quantity problems
- Identify standards in place and areas we can improve
- Identify Best Management Practices and water conservation measures that can be implemented

Groundwater is the primary source of drinking water for residents living within the Cypress Creek Watershed. Pressure from periods of prolonged drought and a burgeoning population have strained this area’s diminishing water resources. The Cypress Water Quantity Subcommittee was formed to help provide insight and address these issues through a local perspective. Their overall objectives include identifying areas of concern or sources of impairment and selecting appropriate management measures to mitigate current and potential threats to water resources within the watershed. Water quantity concerns include limited availability of water to meet current and future demands, water-intensive landscaping, development within recharge areas, leaking infrastructure, unregulated wells, and lack of water conservation awareness. The group unanimously identified education and outreach as the primary means to instill change within the community and help protect resources for future generations. Educational pamphlets and reports are being generated to help promote awareness pertaining to water quantity issues/concerns.

Various stakeholders have noted a need for a comprehensive water budget to assess the current and projected consumption effect upon the underlying aquifer levels. Variables to be assessed include: the amount recharged; the amount pumped by water utility companies; estimated pumping by residential wells; and the amount saved through rainwater harvesting and other water conservation methods. The board of the Hays Trinity Groundwater Conservation District has been assisting the Subcommittee in this effort. The finished product will be user-friendly and help stakeholders understand the complex hydrologic cycle of the Cypress Creek Watershed. In addition to increased awareness of the variables affecting water quantity, citizens will learn the amount of water they can save through various water conservation methods such as rainwater harvesting.

As this region experiences projected periods of drought and population growth, it becomes increasingly important to consider alternative sources of water. Since the majority of citizens that live within the Cypress Watershed rely upon wells, their main source of water may dwindle in the coming years due to increased and unregulated pumping. The Subcommittee will assess the general costs and benefits of surface water transfers, rainwater harvesting, and additional drilling. The Wimberley Water Supply Company is currently assessing the feasibility of allocating surface water from various sources and transporting it to the Wimberley Valley. This analysis will help provide general information to stakeholders regarding the average cost per customer and the long term benefits of all three sources of water.

The Subcommittee identified potential causes of impairment and compiled a comprehensive list of practices that could be implemented to reduce their impact. Best management practices (BMPs) are techniques or mechanisms used to mitigate or reduce the impact of nonpoint source pollution. Listed below are potential BMPs that can be used at various levels to help ensure sufficient flows for Cypress Creek and Jacob's Well:

1.) Community/Educational:
    - Celebrate World Water Day with Cypress Water Day
    - Cypress Creek Blessing
    - Work with Elementary schools
        - Wimberley Outdoor Educators, WIC, GBRA
        - Older classes start a water blog
    - Newspapers: include water conservation tip of the week
    - Workshops: Rainwater harvesting, Xeriscaping, Monitoring your Well, etc.
    - Cypress Flow display in town showing level of discharge (similar to burn ban signs)
    - Watershed model at Visitor Center or Wimberley Community Center
    - 5 minute timers for showers; cut water off while soaping and scrubbing
    - Signs that say "Entering Cypress Creek Watershed"
    - Display charts showing patterns of dry and wet periods
    - Provide charts showing the correlation between pumping and Jacob's Well discharge

2.) Homeowners:
    - Xeriscaping: encourage removal of water-intensive plants such as Saint Augustine and Bermuda grasses
    - Replace leaking pipes, faucets, sprinklers, etc
    - Install efficient showerheads, faucet aerators, toilet flappers
    - Low-flow toilets
    - Rainwater harvesting
    - Use watering schedule (evenings/mornings)
    - Install grey-water systems

3.) Land Management
- Native plants and grasses within recharge areas to enhance recharge
- Terracing hills to catch rainwater
- Staged removal of Ash Juniper in dense areas
- Recharge enhancement features: clearing sinkholes and recharge caverns and put filters to catch debris
- Rain Gardens: small depressions to catch rainwater
- Preservation of recharge areas: Conservation easements

4.) Water Supply Companies
- Tiered rate structure (similar to Wimberley Water Supply)
- Water bills should include graphs of personal usage in gallons, individual usage compared to average use, a water conservation tip or hotline to report leaks.
- Monitor and repair leaking pipes

Appendix B. SWAT Model Calibration

Watershed modeling of the Cypress Creek contributing area was performed using the Cypress Creek Decision Support System (CCP-DSS), a modeling and results visualization package based on the Automated Geospatial Watershed Assessment (AGWA2) tool. AGWA is an interface for ESRI's ArcGIS jointly developed by the U.S. Environmental Protection Agency, U.S. Department of Agriculture (USDA) Agricultural Research Service, and the University of Arizona to automate the parameterization and execution of two commonly-used hydrologic models, SWAT and KINEROS (Miller et al., 2007). The CCP-DSS is based on the AGWA2 system and has been populated with all the relevant local data to perform scenario analyses on the Cypress Creek watershed.

The Soil and Water Assessment Tool (SWAT) was used to modelflow, sediment, and nutrients across the watershed and stream channels. This model uses information on soils, topography, land cover, rainfall, and temperature to simulate hydrologic processes on the land surface that create surface flow, infiltration and subsurface flow, and routes these flows, sediment and nutrients through stream channels (Neitsch et al., 2002). Daily data from 2000 to 2009 were used to run the model and to compare the simulated outputs to observations.

Parameters

The SWAT model was parameterized using the SSURGO soils geodatabase from NRCS, a 10-m resolution digital elevation model from USGS, and the 2009 baseline land cover developed for this study (See Section 4.3). The parameterizer tools in AGWA2 were used to determine initial parameter values for the model based on the above datasets. A comprehensive survey of existing BMPs within the watershed does not exist and was not within the scope of this project to obtain. Therefore existing BMPs such as detention structures were not input into the model. Instead the modeled watershed was based on topography, soils, and land cover.

Inputs

Observed daily rainfall data from two NCDC and one LCRA station (Wimberley, Fischer's Store, and Dripping Springs 5 SSW) and daily temperature data from Dripping Springs were used to drive the model. The period 2000-2004 was used for calibration, and 2005-2009 for verification. Daily springflows at Jacob's Well for 2000-2009 were estimated using USGS flow records for Jacob's Well spring, the Blanco River at Wimberley, and Cypress Creek confluence streamflow. Total springflows were then used, along with an automated baseflow separation program (Abscan), to estimate baseflow (flow from the deep aquifer that is not influenced by local subsurface flow). Base springflows were injected into the modeled stream in order to provide a realistic baseflow for calibration of total flows at the confluence.

Calibration

Calibration was performed using annual and daily mean flow estimated at the creek's confluence (see Section 4.2.4 for description of flow estimation methods). Flow on any given day was not very well simulated by the model, and in general peak flows simulated were higher than observed peak flows. However due to the lack of observed flow data and the methods used to estimate daily flow, it is likely that "observed" flows are understated under high flow conditions and nonexistent for the highest peaks. Peak flows above a certain level were not estimated because of the high degree of uncertainty and poor fit between Cypress and Blanco observed stages above 6.4 ft. Therefore it was not possible to reliably calibrate peak flows for most high-flow days.

Instead model calibration focused on achieving a reasonable approximation of the overall flow regime. Flow duration curves of estimated and simulated daily flows are relatively similar, showing that the overall flow regime is adequately simulated by the model (Figure B.1). Discrepancies at the highest flows are due to the fact that those flows are missing from the estimated time series used to develop the “observed” flow duration curve (refer to Section 4.2.4 – Streamflow). Actual peak flows at the outlet are likely higher than what has been estimated but may be lower than simulated. Reliable measurements of peak flows would be necessary to further calibrate modeled peak flows.

Sediment and organic nitrogen were simulated by the model and the range of values compared to observations using load duration curves (Figures B.2 and B.3). Load duration curves for simulated sediment and organic nitrogen were constructed using model outputs for the stream reach at the watershed outlet. This reach extends from the confluence of the last major tributary, between the RR12 north and the Blue Hole sampling sites, to the confluence with the Blanco River. Three CRP sites are located along this reach, Blue Hole (12675), RR12 downtown (12674), and the Confluence (12673), so data on total suspended solids and total nitrogen for these three sites were plotted along with the simulated load duration curves to compare observed to simulated values. Overall sediment and organic nitrogen are simulated within a reasonable range when compared with observed values. However the estimates for both parameters are less reliable at the lowest flow levels: the model tends to underestimate sediment and overestimate nitrogen loads at the lowest flows. Therefore model results for sediment yields should be taken as conservative estimates, whereas estimates of total nitrogen loading may be overestimated or may indicate that the stream exhibits a high degree of assimilative capacity for nitrogen.

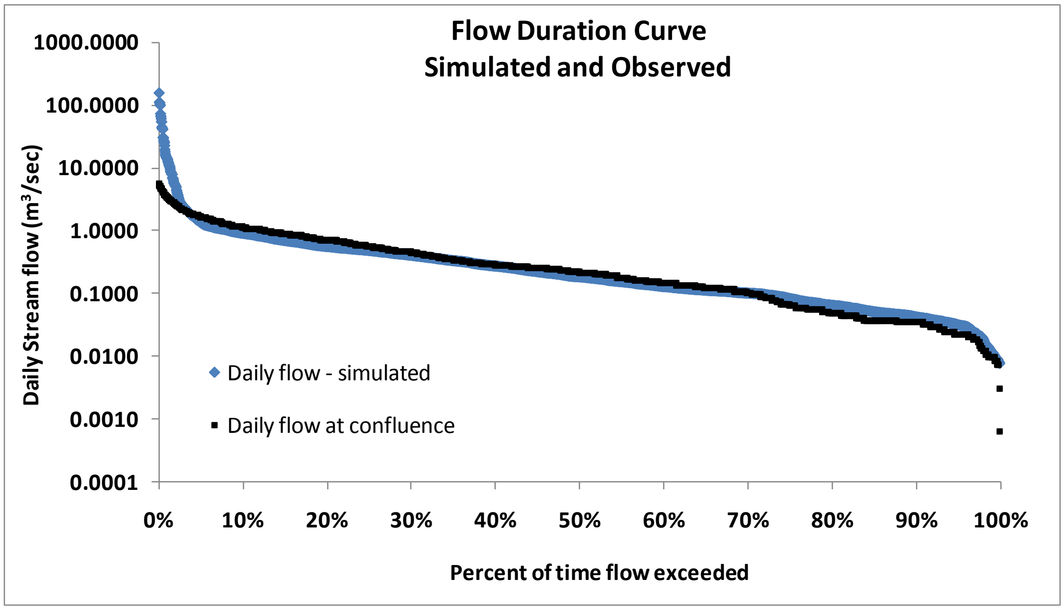

Figure B.1. Simulated and Observed Flow Duration Curves for the Cypress Creek watershed. Daily flows (m^3/sec) were simulated using the SWAT2000 hydrologic model.

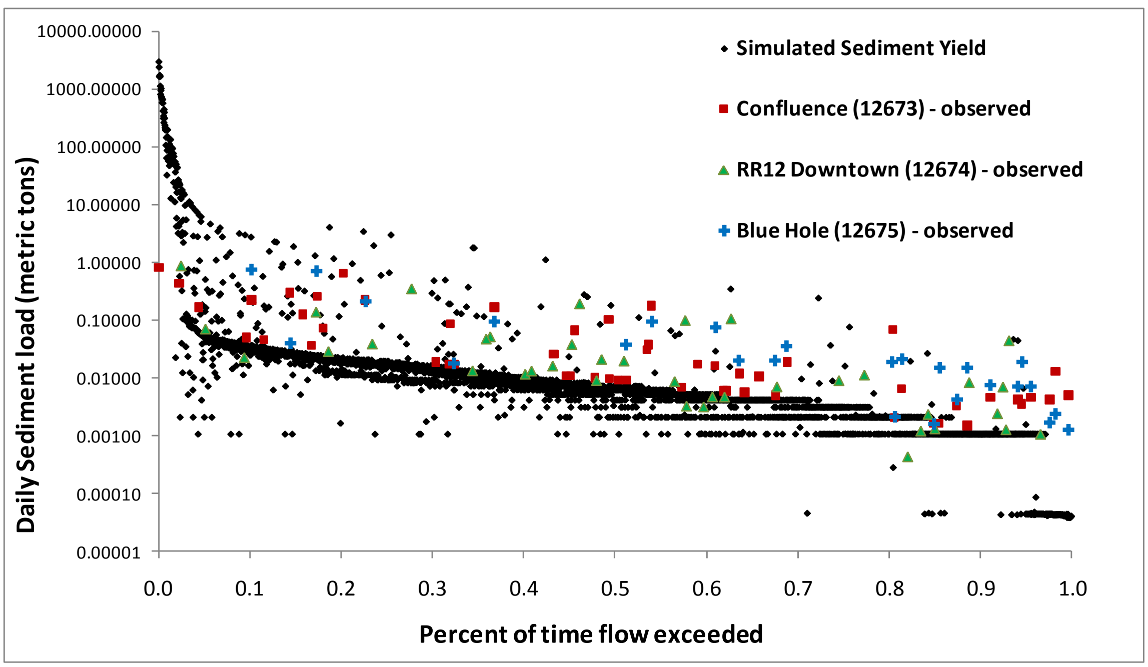

Figure B.2. Simulated and Observed Load Duration Curves for sediment (metric tons). Overall the simulated sediment loads are within the same range as observed, although at the lowest flows the model tends to underestimate sediment loads.

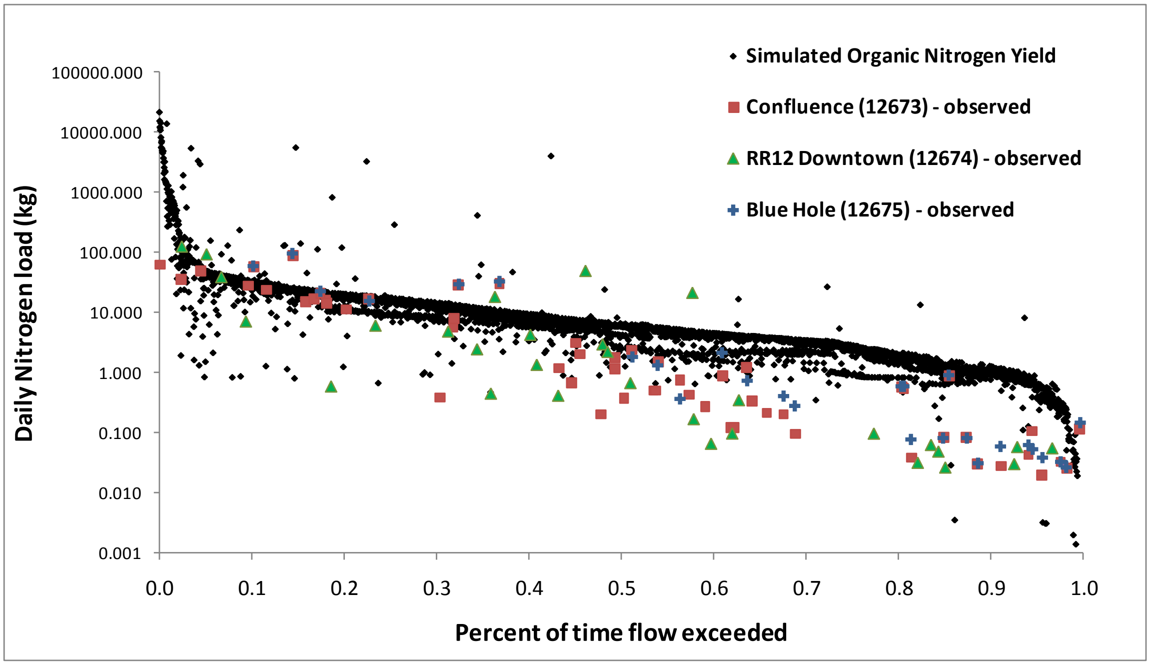

Figure B.3. Simulated and Observed Load Duration Curves for organic nitrogen (kg). Overall the simulated nitrogen loads are within the same range as observed, although at the lowest flows the model may overestimate nitrogen.

References

Miller, S., Semmens, D., Goodrich, D., Hernandez, M., Miller, R., Kepner, W., and Guertin, D. P. 2007. The automated geospatial watershed assessment tool. *Environmental Modeling & Software* 22: 365-377.

Neitsch, S.L., Arnold, J.G., Kiniry, J.R., Williams, J.R., and King, K.W. 2002. Soil and Water Assessment Tool, Theoretical Documentation (Version 2000). Grassland, Soil and Water Research Laboratory, Agricultural Research Service, US Department of Agriculture. GSWRL Report 02-01. 506 pp.

Appendix C. EPA Nine Elements

EPA Element	Page Number(s)
1. Identification of Causes & Sources of Impairment	
a. Sources of impairment are identified and described	64-111
b. Specific sources of impairment are geographically identified	74-80
c. Pollution loads are attributed to each source of impairment and quantified	67-70
d. Data sources are accurate and verifiable, assumptions can be reasonably justified	64-80
e. Watershed-level estimates of necessary pollution control is provided	112-119
2. Expected Load Reductions	
a. Load reductions achieve environmental goal (ex TMDL)	Final WPP
b. Desired load reductions are quantified for each source of impairment	Final WPP
c. Expected load reductions are estimated for each management measure identified in Element 3	Final WPP
d. Data sources and/or modeling process are accurate and verifiable, assumptions can reasonably be justified	47,50, Appendix B
3. Proposed Management Measures	
a. Specific management measures are identified and rationalized	Appendix A
b. Proposed management measures are strategic and feasible for the watershed	Appendix A
c. Proposed management measures achieve load reduction goals	Appendix A
d. Critical/Priority implementation areas have been implemented	118-119
e. The extent of expected implementation is quantified	Final WPP
f. Adaptive management process in place to evaluate effectiveness of management measures	26
4. Technical and Financial Assistance Needs	
a. Cost estimates reflect all planning and implementation costs	BMP Report
b. Cost estimates are provided for each management measure	BMP Report
c. All potential Federal, State, Local , and Private funding sources are identified	Final WPP
d. Funding is strategically allocated- activities are funded with appropriate sources	Final WPP
e. Economic and environmental benefits are discussed and weighed against implementation costs	BMP Report
5. Information, Education, and Public Participation Component	
a. A Stakeholder outreach has been developed	Appendix A
b. All relevant stakeholders are identified and involved in the outreach process	Appendix A
c. Public meetings and forums have been/are scheduled to be held	Appendix A

d. Education/Outreach materials will be/have been disseminated	Appendix A, E&O Plan
6/7. Schedule and Milestones	
a. Implementation schedule includes specific dates and expected accomplishments	Final WPP
b. Implementation schedule follows a logical sequence	Final WPP
c. Implementation schedule covers a reasonable time frame	Final WPP
d. Measurable milestones with expected completion dates are identified to evaluate progress	Final WPP
e. A phased approached with interim milestones is used to ensure continuous implementation	Final WPP
8. Load Reduction Evaluation Criteria	
a. Proposed criteria effectively measure progress toward load reduction goal	Final WPP
b. Evaluation criteria are measurable and quantifiable	Final WPP
c. Interim WQ indicator milestones are clearly identified	Final WPP
d. Criteria include both: quantitative measures of implementation progress and pollution reduction; and qualitative measures of overall program success (including public involvement and buy-in	Final WPP
e. An Adaptive Management approach is in place, with threshold criteria identified to trigger modifications	Final WPP
9. Monitoring Component	
a. Monitoring plan includes an appropriate number of monitoring stations	49-50
b. Monitoring plan has an adequate sampling frequency	49-50
c. Monitoring plan will effectively measure evaluation criteria identified in Element 8	Final WPP

Appendix D. Data Inventory

Type	Description of Data	Dates (Gaps)	Data Format	Source	Projection	Coverage/Resolution	Data Quality
METEOROLOGY							
Precipitation	Daily, monthly, annual P for sites: Wimberley Henly Fischer's Store	03/1984-12/2009 03/1948-12/2009 01/1930-12/2009	MS Excel/Access	NCDC CDO: http://www7.ncdc.noaa.gov/CDO/cdo#TOP		3 sites outside watershed	High, some gaps
Air Temperature	Daily mean, min, max for station: Blanco San Marcos	05/1896-12/2009 11/1901-12/2009	MS Access	NCDC CDO: http://www7.ncdc.noaa.gov/CDO/cdo#TOP		2 sites outside watershed	
	Average monthly for station: Dripping Springs	01/2000-12/2009		LCRA: http://www.lcra.org/water/conditions/index.html			
Evaporation	Daily evaporation for station: Canyon Dam	06/1961-10/2007	MS Access	NCDC CDO: http://www7.ncdc.noaa.gov/CDO/cdo#TOP		1 site outside watershed	
Wind	24-hour wind movement for station: Canyon Dam	06/1961-10/2007	MS Access	NCDC CDO: http://www7.ncdc.noaa.gov/CDO/cdo#TOP		1 site outside watershed	
SURFACE WATER							
Quality & Quantity	Monthly or bi-monthly quality and inst. flow for sites: CC at Jacob's Well CC at RR 12 CC at Blue Hole CC at Blanco R. Blanco R. at CR 1492 Blanco R. at RR12 Blanco R. at CR 174	08/2002-12/2009 (Blue Hole begins 12/2005)	MS Excel	CRP/TCEQ : http://www.tceq.state.tx.us/compliance/monitoring/crp/data/samplequery.html		Cypress Ck from JW, Blanco R. above and below confluence	High, inconsistent data intervals
	Monthly or quarterly quality and inst. flow for CC at RR 12, downtown	12/1973-01/2010	MS Access/Excel	TCEQ : http://www.tceq.state.tx.us/compliance/monitoring/crp/data/samplequery.html		1 site on Cypress Ck	High, inconsistent data intervals
	Monthly or quarterly quality for sites: CC at Jacob's Well CC at Old Kyle Rd. CC at Blue Hole CC at CR 220	02/2001-03/2010 09/2007-03/2010 02/2007 12/1995-05/2007	MS Excel	Texas Stream Team River Systems Institute, Texas State University-San Marcos			

Type	Description of Data	Dates (Gaps)	Data Format	Source	Projection	Coverage/Resolution	Data Quality
SURFACE WATER (cont.)							
	Monthly quality and inst. flow at JW	08/2002-12/2009	MS Excel	TCEQ : http://www.tceq.state.tx.us/compliance/monitoring/crp/data/samplequery.html		1 site on CC	Medium, large gaps in data
	Hourly, daily quality and mean flow at JW	10/2006-04/2008		USGS Surface Water Data: http://waterdata.usgs.gov/nwis/sw			
	Daily water quality and mean flow for JW	04/2005-03/2010	MS Excel	USGS Surface Water Data: http://waterdata.usgs.gov/nwis/sw		1 site on CC	High
	Monthly fecal coliform monitoring at multiple sites on CC & Blanco R.	10/1971, 08/1984-04/2008	MS Excel	Wimberley Valley Watershed Association		CC from JW, Blanco R. above and below confluence	Medium, inconsistent data intervals
	Instantaneous (i.e. hourly or 15-min) flow for Blanco R. at Wimberley	12/1986-09/2008		USGS Instantaneous Data Archive: http://ida.water.usgs.gov/ida/available_records.cfm?sn=08171000		1 site on Blanco R. below confluence	High
	Daily mean flow for Blanco R. at Wimberley	8/1924-3/2010	MS Excel	USGS Surface Water Data: http://waterdata.usgs.gov/nwis/sw		1 site on Blanco R. below confluence	High
GROUND WATER							
Springs and Wells	Selected TX Springs	2005	GIS geodatabase shapefile	USGS: http://pubs.usgs.gov/of/2005/1351	NAD_1983_UTM_Zone_14N (re-projected)	Texas	High
	Hays Co. wells data	2007	MS Excel	TWDB: http://www.twdb.state.tx.us/publications/reports/GroundWaterReports/GWDatabaseReports/GWdatabaserpt.htm		Hays County	High, does not include all existing wells
		2008	MS Excel	HTGCD: http://www.haysgroundwater.com/		CC watershed	High
Subsurface geology	Subsurface geology and faults	2005	GIS shapefile	USGS: http://pubs.usgs.gov/of/2005/1351	NAD_1983_UTM_Zone_14N (re-projected)	Texas	High
Aquifers	Major aquifers	2006	GIS shapefile	TNRIS: http://www.tnris.state.tx.us/datadownload/download.jsp	GCS_North_American_1983	Texas	High

Type	Description of Data	Dates (Gaps)	Data Format	Source	Projection	Coverage/Resolution	Data Quality
DRAINAGE BASIN CHARACTERISTICS							
Watershed delineation	12 digit HUC		GIS shapefile	TPWD	NAD_1983_UTM_ Zone_14N (re-projected)	CC watershed	Medium
	AGWA delineation and subwatersheds discretization		GIS shapefile	AGWA delineation	NAD_1983_UTM_ Zone_14N	CC watershed	High, created using AGWA and NED data
Watershed Morphometry	DEM		GIS raster	USGS National Elevation Dataset: http://ned.usgs.gov/	NAD_1983_UTM_ Zone_14N (re-projected)	CC watershed, 10 m	High
	Slope		GIS raster	calculated (from NED data)	NAD_1983_UTM_ Zone_14N	CC watershed, 10 m	High
Soils	SSURGO tabular and spatial soils data	2007	GIS geodatabase shapefile	USDA NRCS: http://soildatamart.nrcs.usda.gov/	NAD_1983_UTM_ Zone_14N	Texas	High
Hydrology	National Hydrography dataset	2004	GIS geodatabase	USGS National Hydrography dataset: http://nhd.usgs.gov/	NAD_1983_UTM_ Zone_14N	Subregion 1210 (San Antonio-Guadalupe-Lavaca basins)	High
	Stream network		GIS shapefile	AGWA delineation	NAD_1983_UTM_ Zone_14N	CC watershed	High, created using AGWA and NED data
	Stream network, detailed		GIS shapefile	TXDOT	NAD_1983_UTM_ Zone_14N (re-projected)	Texas	High
	Curve numbers		GIS raster	TCEQ WAM modeling data	NAD_1983_UTM_ Zone_14N (re-projected)	San Antonio- Guadalupe basins. 0.5 km	Medium
	FEMA Q3 flood zones	2005	GIS geodatabase	TNRIS: http://www.tnris.state.tx.us/datadownload/download.jsp	GCS_North_American_1983	Hays County	High
Vegetation/Land Cover	National Land Cover datasets	1992 2001	GIS raster	MRLC: http://www.mrlc.gov	NAD_1983_UTM_ Zone_14N (re-projected)	CC watershed and surrounding area, 30 m	Medium, some discrepancy w/ aerials
	Modified NLCD land cover	2009	GIS raster	Cypress Creek Project generated	NAD_1983_UTM_ Zone_14N (re-projected)	CC watershed and surrounding area, 30 m	Medium, needs ground-truthing of veg types
	NLCD impervious cover	2001	GIS raster	USGS seamless server: http://seamless.usgs.gov/	NAD_1983_UTM_ Zone_14N (re-projected)	CC watershed and surrounding area, 30 m	High
	Digital orthophotography	1995 2002 2004 2005 2006 2008	GIS raster	CAPCOG: http://www.capcog.org/information-clearinghouse/geospatial-data/	NAD_1983_UTM_ Zone_14N (re-projected)	CC watershed and surrounding area, 1 m	High, satellite imagery

Type	Description of Data	Dates (Gaps)	Data Format	Source	Projection	Coverage/Resolution	Data Quality
HUMAN INFLUENCE							
Surface water use	Historical water use info, city, county, and major basins by sector: Wimberley Woodcreek Hays County Guadalupe Basin	 1990-1997 1990-2004 1974-2004 1974-2004	MS Excel	TWDB: http://www.twdb.state.tx.us/wushistorical/			High, estimates
Groundwater use	Hays Co. groundwater withdrawals, total by year	1975-2050 (decadal)	MS Excel	TWDB: http://www.twdb.state.tx.us/wushistorical/			Medium, inconsistent data intervals
	Historical groundwater pumpage estimates, state, county, aquifer by sector	Hays Co. GW-SW 1974-2004 Hays Co. by aquifer 1980-2003	MS Excel	TWDB: http://www.twdb.state.tx.us/wushistorical/		Texas Hays Co. Trinity aquifer	High, estimates
Population	Decadal population	1900-2000	MS Excel	TSDC: http://txsdc.utsa.edu/tpepp/txpopest.php		Hays County	High
	Census data	2000	GIS shapefile	TNRIS: http://www.tnris.state.tx.us/datadownload/download.jsp	GCS_North_American_1983	Hays County	High
	Population & water use projections	2010-2060		TWDB: http://www.twdb.state.tx.us/wrpi/data/pop.htm			High, projections
Infrastructure	Roads	2008	GIS shapefile	CAPCOG: http://www.capcog.org/information-clearinghouse/geospatial-data/			
	City boundaries	2008	GIS shapefile	CAPCOG: http://www.capcog.org/information-clearinghouse/geospatial-data/	NAD_1983_UTM_Zone_14N (re-projected)	Hays County	High
	Subdivision boundaries	2008	GIS shapefile	Hays Co. GIS Division: ftp://ftp.co.hays.tx.us/gis	NAD_1983_UTM_Zone_14N (re-projected)	Hays County	High
	Low water crossings		pdf	Hays Co. GIS Division: ftp://ftp.co.hays.tx.us/gis		Hays County	Medium, medium resolution
	2025 Transportation Plan	2025	pdf	Hays Co. GIS Division: ftp://ftp.co.hays.tx.us/gis		Hays County	High
	Building permits issued by year	2006-2009	pdf	Woodcreek POA: http://woodcreekpoa.org/html/permits.html		City of Woodcreek	High

Type	Description of Data	Dates (Gaps)	Data Format	Source	Projection	Coverage/Resolution	Data Quality
HUMAN INFLUENCE (cont.)							
	Vacant land inventory	2005	GIS geodatabase	CAPCOG: http://www.capcog.org/information-clearinghouse/geospatial-data/	NAD83_StatePlane_TX_Central	Hays, Travis, Williamson, Bastrop, Caldwell Counties	Medium, some missing fields
	Aqua Texas Inc Water/Wastewater lines	2005	pdf	Loomis Partners Consulting: http://www.loomis-partners.com	NAD_1983_UTM_Zone_14N (georeferenced)	Woodcreek/ Wimberley	High
Land use	Parcels data	2009	GIS geodatabase	Hays Central Appraisal District (HaysCAD): http://www.hayscad.com/Appraisal/PublicAccess/default.aspx [Modified/Updated by Cypress Ck Project]	NAD_1983_UTM_Zone_14N (re-projected)	Hays County	Medium, incomplete
	Tax appraisal data	2009	MS Excel	Hays Central Appraisal District (HaysCAD): http://www.hayscad.com/Appraisal/PublicAccess/default.aspx		Wimberly ISD	Medium, incomplete
	USDA common land units	2007	GIS geodatabase	NRCS Geospatial Data Gateway:	NAD_1983_UTM_Zone_14N	Hays County	High
	911 addressing points	2009	GIS shapefile	Hays Co. GIS Division: ftp://ftp.co.hays.tx.us/gis	NAD_1983_UTM_Zone_14N (re-projected)	Hays County	High