Identification of Causes and Sources of Pollution and Estimation of Pollutant Loads Report

Nonpoint Source Protection Program CWA §319(h)

Prepared for the Texas Commission on Environmental Quality

and the U.S. Environmental Protection Agency

Region VI

The River Systems Institute

Texas State University – San Marcos

Andrew Sansom

Executive Director

601 University Drive

San Marcos, Texas 78666

(512) 245-9200

as22@txstate.edu

Acknowledgements

The Identification of Causes and Sources of Pollution and Estimation of Pollutant Loads Report is the second in a series of documents that detail the Spring Lake Watershed Characterization Project. This report is the result of collaboration and cooperation between many groups and individuals which have played important roles in the planning, activities, and support for the Spring Lake Project.

The characterization of the Spring Lake Watershed is an ongoing project. The primary authors of this report – Dr. Weston Nowlin and Dr. Benjamin Schwartz - would like to recognize several individuals for their invaluable input, assistance and support. We would like to recognize Philip Ramirez, Gaby Timmins, Benjamin Hutchins, Kerstin Hoesel, and Jesse Becker for their hard work in the field, lab and at the computer. We would also like to thank Mary Van Zandt, Hayat Qurunful, Jason Pinchback, Vanessa Lavender, Andy Sansom, Dr. Thom Hardy, and Emily Warren of Texas State University-San Marcos and the River Systems Institute.

The Spring Lake Project would also like to thank the following groups for providing expertise and input: Texas Commission on Environmental Quality, Texas Parks and Wildlife, U.S Environmental Protection Agency, U.S Geological Survey, and the Edwards Aquifer Authority.

We are especially grateful to the partnership with the Texas Commission on Environmental Quality (TCEQ). Funding provided through the TCEQ and the U.S. Environmental Protection Agency supported the development of the Spring Lake Project and its continuing efforts.

Contents

LIST OF ACRONYMS AND ABBREVIATIONS

CAFO	Concentrated Animal Feeding Operation
EMC	Event Mean Concentration
EPA	Environmental Protection Agency
ET	Evapotranspiration
GIS	Geographic Information Systems
IH	Interstate Highway
LULC	Land Use-Land Cover
MRLC	Multi-Resolution Land Characteristics Consortium
N	Nitrogen
NCDC	National Climate Data Center
NH_4^+	Ammonium
NLCD	National Land Cover Database
NO_3^{2-}	Nitrate
NO_2^-	Nitrite
NOAA	National Oceanographic and Atmospheric Administration
NPS	Nonpoint Source
OSSF	On-Site Sewage Facility
P	Phosphorus
PO_4^{3-}	Phosphate
RSI	River Systems Institute
SOW	Scope of Work
SWAT	Soil and Water Assessment Tool
TDP	Total Dissolved Phosphorus
TDS	Total Dissolved Solids
TKN	Total Kjeldahl Nitrogen
TN	Total Nitrogen
TP	Total Phosphorus
TCEQ	Texas Commission on Environmental Quality
TSS	Total Suspended Solids
TXSTATE	Texas State University
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
USMR	Upper San Marcos River
USMRCG	Upper San Marcos River Coordinating Group
WPP	Watershed Protection Plan

List of Figures

List of Tables

Overview of the Identification of Causes and Sources of Pollution and Estimation of Pollutant Loads Report

The San Marcos River is an ecologically unique spring-fed ecosystem located along the margin of the Edwards Plateau in central Texas. Spring Lake, located in the City of San Marcos, is the headwaters of the San Marcos River where artesian spring water from the Edwards Aquifer emerges into the lake from approximately 200 openings. Water from these springs support the overwhelming majority of the annual discharge of the upper San Marcos River, but the importance of the springs has become evident during recent droughts. During portions of the 1996 drought, San Marcos Springs and nearby Comal Springs combined accounted for 70% or more of flows in the Guadalupe River reaching Victoria and nearly 40% of flows that reached the San Antonio Bay.

Spring Lake is a horseshoe-shaped water body with two main regions: the Spring Arm and the Slough Arm. Most of the hydrological inputs to Spring Lake occur from spring openings in the Spring Arm. Sink Creek, the lake's only significant surface water tributary, discharges into the Slough Arm of the lake. Due to the relatively large spring water influence, Spring Lake and the upper river reaches are characterized by clear water, abundant and productive macrophytes and a relatively large number of endemic and native species. Spring Lake and the upper sections of the river exhibit nearly constant seasonal flows and water temperatures of ~22^{o}C; this relative environmental constancy has led to a high number of endemic species in the headwaters. However, the potential sensitivity of the headwaters to environmental perturbation, and the limited geographic range of many of the spring-adapted organisms, have led to the designation of a large number of federally- and state-listed taxa in the headwaters of the San Marcos River.

In addition to the high ecological value of the San Marcos River headwaters, the area also has substantial economic and cultural value for central Texas. Spring Lake and the upper river lie within the Texas State University campus and serve as a focal point for the campus and the City of San Marcos. Thousands of people visit the upper San Marcos every year for recreational activities such as swimming, tubing and kayaking, and glass bottom boat rides in the headwaters. While the exact number of recreational users of the San Marcos River and its headwaters is unknown, approximately 125,000 people per year take part in the various programs at the Aquarena Center on Spring Lake, and the City of San Marcos also estimates that two city parks in the upper section of the river receive more than 600 recreational visitors per day on a typical summer day (e.g., not 4th of July weekend). In addition, there have been major archeological finds of prehistoric human artifacts and animal remains in Spring Lake. Further downstream from Spring Lake, the San Marcos River supplies drinking water for a number of communities in the San Marcos – Guadalupe River drainage, including the cities of San Marcos (49,000 residents) and the City of Victoria (60,000 residents). Water quality and quantity is of principle concern to communities below the San Marcos River – Guadalupe River confluence because they are highly dependent upon the San Marcos River contribution to river flows, especially during relatively dry periods.

Texas State University and the City of San Marcos have taken significant measures to protect the water quality of Spring Lake. The University, a public institution currently owns the land the lake sits on and acts as a steward to protect the lake's current state. The city has put in place special ordinances to ban swimming and boating in the lake to protect the endangered species habitat in the lake. Additionally, the city partners with the university to monitor water quality in the lake (bacterial testing). The City has acquired and will preserve 251 acres of land from a developer who had planned to build a conference facility immediately upstream of Spring Lake. The stormwater from this property flows directly into Spring Lake and Sink Creek just upstream of the lake. The most current plans for local action include a Watershed Protection Plan that will begin in the next few years. At this time, the City of San Marcos and Texas State University are funding a half-time watershed planner position.

To date, there has been a limited attempt to obtain data on nutrient inputs to Spring Lake. Despite the system's high ecological, economic and cultural value, Spring Lake and the upper San Marcos River have recently experienced increased turbidity and major algal blooms following substantial rainfall events and the associated increases in surface and subsurface flows. While there is an obvious and sometimes persistent deterioration of water quality during and after periods of high surface and ground water inputs to the lake, the relative pollutant load contributions of these sources in the watershed is unknown. Thus, determination of the relative nutrient and sediment inputs to the lake from the various hydrological sources is critical for the management and preservation of the lake. In order to determine the influence of various sources of water on algae and turbidity in the lake, storm event-based data which are collected at a high-temporal resolution and are quality-assured are required. In particular, determination of inputs of phosphorus (P) are of greatest concern because productivity of the lake is extremely phosphorus limited due to the low levels of immediately bioavailable phosphorus (<5 µg orthophosphate - P/L) relative to the high levels of bioavailable nitrogen (~1600 µg NO_3^{2-} - N/L) (Groeger et al. 1997).

One of the largest concerns of a potential source of nutrient perturbation to the lake is through hydrological inputs from the Sink Creek watershed. Currently, portions of the Sink Creek watershed are experiencing land use changes or have been proposed for future development. Sink Creek is historically an ephemeral stream that drained ranching and agricultural areas. However, rapid urban development along the IH-35 Austin-San Antonio corridor has led to a substantial increase in impervious cover and urban land use in many watersheds in the region; there is concern that increased development in the region may lead to increased levels of human development in the Sink Creek watershed that may deteriorate water quality of Sink Creek, Spring Lake and the Upper San Marcos River. Most of the land within the Sink Creek watershed is privately owned; however, the City of San Marcos recently purchased approximately 250 acres within the watershed as part of a "greenbelt" and the uppermost headwaters of Sink Creek are located on Freeman Ranch, a property owned by Texas State University. Because Sink Creek discharges into the relatively shallow and productive Slough Arm of Spring Lake, incidents of high precipitation and high surface waters inflows may function as a major contributor to deterioration of lake water quality because of the land use changes within the Sink Creek watershed.

The relative contribution of nutrients from the spring openings during periods of high discharge also remains unclear. During periods of low precipitation and surface flows (e.g., summer and early fall) groundwater dominates hydrological and nutrient inputs to the lake. However, groundwater discharges to the lake also increase with precipitation, but the relative contribution of these groundwater flows to nutrient loading during high flow periods is unknown. In addition, there are numerous spring openings in Spring Lake that vary in flow rate and groundwater sources. Some openings discharge water from largely local sources, while other openings can discharge water from regional sources that are much older. The relative contribution of these various groundwater sources and how they vary seasonally and with local precipitation patterns is also unclear.

Another potential nutrient source to Spring Lake and the upper San Marcos River is the Texas State University Golf Course. The course lies immediately adjacent to the middle portion of the Slough Arm of Spring Lake, and maintenance practices from the course may lead to nutrient and sediment inputs to the lake. Again, the relative contribution of nutrient runoff from the golf course to algal blooms in the lake remains unknown.

Given the recent substantial water quality issues and the ecological, economic and cultural value of the Spring Lake system, understanding the relative nonpoint source (NPS) contributions of nutrients and suspended materials to Spring Lake via groundwater, the Sink Creek watershed, and the Texas State Golf Course is critical to preserve the biota and water quality of the lake.

Executive Summary

The San Marcos River is an ecologically unique spring-fed ecosystem located along the margin of the Edwards Plateau in central Texas. Spring Lake, located in the City of San Marcos, is the headwaters of the San Marcos River where artesian spring water from the Edwards Aquifer emerges into the lake from approximately 200 openings. Water from these springs support the overwhelming majority of the annual discharge of the upper San Marcos River, but the importance of the springs has become evident during recent droughts. To date, there has been a limited attempt to obtain data on nutrient inputs to Spring Lake. Despite the system's high ecological, economic and cultural value, Spring Lake and the upper San Marcos River have recently experienced increased turbidity and major algal blooms following substantial rainfall events and the associated increases in surface and subsurface flows. While there is an obvious and sometimes persistent deterioration of water quality during and after periods of high surface and ground water inputs to the lake, the relative pollutant load contributions of these sources in the watershed is unknown. Thus, determination of the relative NPS nutrient and sediment inputs to the lake from the various hydrological sources is critical for the management and preservation of the lake.

The purpose of this report is to present information on calculated estimates of hydrological inputs, and sediment, nutrient, and bacteria loadings from the Sink Creek watershed to Spring Lake. Specifically, this report covers activities related to Objective 8 of the Scope of Work (SOW) (Tasks 8.2 through 8.5). In addition, this report represents Objectives 9 and 10 of the SOW in that this is a report providing the information, results, and analyses from the activities outlined in Objective 8. In this report, we provide the information on our estimates annual water yield from the Sink Creek Watershed top Spring Lake and the calculated nonpoint source pollution loads from land use types in the Sink Creek watershed using literature-based Event Mean Concentrations (EMCs).

In this portion of the Spring Lake Project, we estimated the loading of various NPS constituents including nutrients, heavy metals, and bacteria to Spring Lake and the local groundwater pool from the Sink Creek watershed. We also estimated the proportional loading of these NPS constituents from the various LULC types within the Sink Creek watershed. In general, we found that magnitude of the loads from the Sink Creek watershed to Spring Lake and the local groundwater from the various land use-land cover (LULC) types were largely a function of the proportion of each LULC type within the watershed. However, Residential areas, while being a relatively small portion of the watershed, had a somewhat greater than expected contribution to the loads of several NPS constituents. In addition, the results from calculations of per acre yield from the different land use types indicate that conversion of the dominant land use types in the watershed (Undeveloped/Open land use and to some extent Rangeland) generally had lower nutrient, bacterial and metal yields than land uses associated with more intense human impact land uses (Residential, Commercial, Cropland, and Industrial land uses). These findings provide a foundation for designing and implementing LULC-specific management measures to preserve or improve the current water quality of Spring Lake and the Upper San Marcos River and to reduce NPS pollutant loads from future human activities in the watershed. Finally, this work is an initial characterization of the potential loads from the Sink Creek watershed that can be used in the future Upper San Marcos River Watershed Protection Plan.

1.0 General Watershed Information and Issues in the Upper San Marcos River

Spring Lake is the headwaters of the San Marcos River where artesian spring water emerges into the lake from >200 spring openings; this spring system is the second most hydrologically productive in the state. Water from these springs originates from the Edwards Aquifer (Figure 1.0). The Edwards Aquifer is a large, complex limestone karst aquifer spanning a substantial portion of the central Texas region. A more detailed discussion of the flow paths of Edwards Aquifer waters to Spring Lake are provided in a previous report associated with this project (see the Spring Lake Watershed Initial Characterization Report).

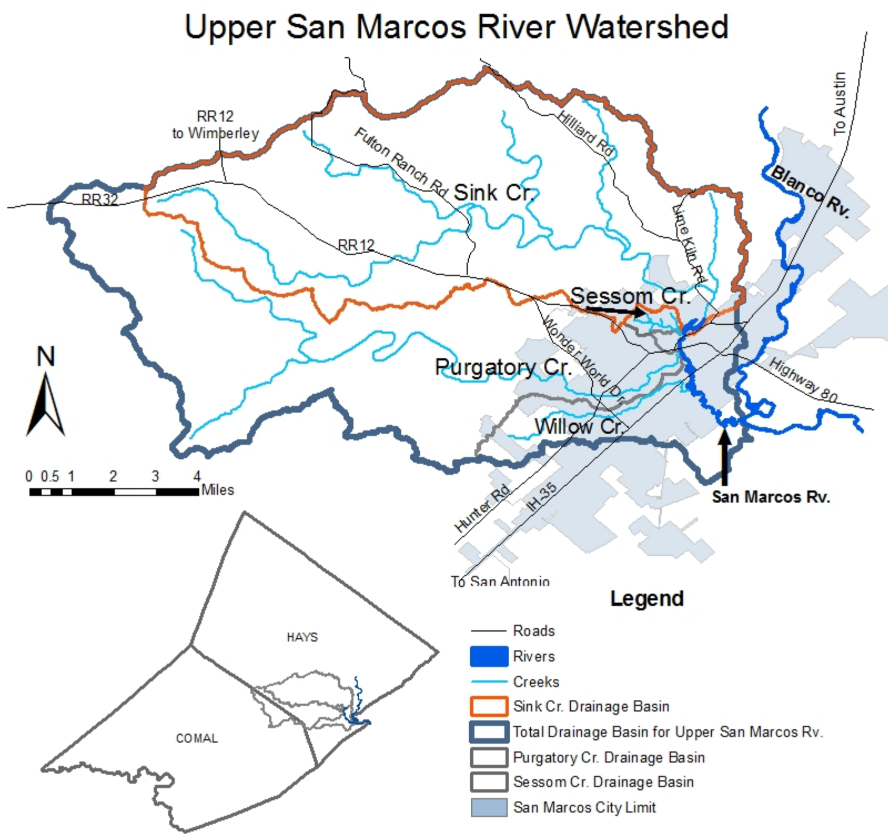

Figure 1.1. The Upper San Marcos River Watershed and its four main sub-basins - Sink Creek, Sessom Creek, Purgatory Creek, and Willow Creek. The upper most contributing sub-basin (Sink Creek) enters the San Marcos River near the headwater artesian springs located in Spring Lake. The City of San Marcos is shown in the south eastern corner of the map. Note that these watershed boundaries are only for surface drainage, and that they do not define the much larger groundwatershed contributing flow to San Marcos Springs.

Although Spring Lake receives most of its annual hydrological inputs from groundwater sources, Sink Creek discharges into the Slough Arm of the lake. Flows from Sink Creek originate more than 15 stream miles upstream to the northwest near the city of Wimberley. Much of the time, Sink Creek is dry and experiences little to no flow. However, during strong rain events or in relatively wet years (e.g., El Niño years), Sink Creek flows and appears to discharge substantial loads of sediments and nutrients into Spring Lake and the upper river. As the name implies, water in the creek also "sinks" and presumably provides some recharge to local groundwater sources (Johnson and Schindel 2008). However, the extent of this groundwater recharge from the creek is not known. There are also several flood retention structures (dams) upstream from Spring Lake on Sink Creek, with the largest of these structures located on Freeman Ranch. Presumably, these flood retention structures also provide some opportunity for surface waters to recharge the aquifer.

Typically, the strong spring water influence on Spring Lake and the upper San Marcos, the upper river exhibits high water quality with low turbidity, low suspended sediment loads, and low phosphorus (P) concentrations. Spring Lake and the upper San Marcos River have recently experienced increased turbidity and declines in water quality rainfall events, presumably from inputs by Sink Creek. However, the relative pollutant load contributions of these ground- and surface water sources to Spring Lake and the upper San Marcos River currently remain unknown.

The purpose of this report is to present information on calculated estimates of hydrological inputs, and sediment, nutrient, and bacteria loadings from the Sink Creek watershed to Spring Lake. Specifically, this report covers activities related to Objective 8 of the Scope of Work (SOW) (Tasks 8.2 through 8.5). In addition, this report represents Objectives 9 and 10 of the SOW in that this is a report providing the information, results, and analyses from the activities outlined in Objective 8. In this report, we provide the information on our estimates annual water yield from the Sink Creek Watershed top Spring Lake and the calculated nonpoint source pollution loads from land use types in the Sink Creek watershed using literature-based EMCs. The analyses in this report will be presented to the Upper San Marcos Coordinating Committee for review and comment. Ultimately, the goal of the activities reported here are to identify potential causes and sources, or groups of similar sources of NPS loading that may need to be controlled to achieve the load reductions estimated in the Sink Creek watershed.

2.0 Causes and Sources of Pollution and Estimation of Loads

2.1 Pollution Inputs to Aquatic Systems

A pollutant is defined as a substance that is present in concentrations that may cause harm to plants and animals (including humans) or exceed an environmental quality standard (United Nations 1997). Point sources of pollution to a waterbody are defined as individual, identifiable sources such as the effluent from an industrial outfall or the discharge from a wastewater treatment plant. Point sources of pollutants are regulated under State of Texas law and the Federal Clean Water Act and are therefore subject to permit requirements. Permitted point sources have specific effluent limits, monitoring requirements, and enforcement mechanisms. Within the Spring Lake/Sink Creek watershed there are no identified point sources of pollution, thus, there are currently no concerns about loading from these kinds of sources to the Spring Lake and the headwaters of the San Marcos River.

In contrast to a point source of pollution, NPS pollution is not associated with known individual sources. Nonpoint source pollution inputs to a waterbody are associated with diffuse contributions to the site of interest, such as nitrogen (N) inputs through atmospheric deposition (Vitousek 1998). Pollutants associated with hydrologic inputs (e.g., nutrients, bacteria, and sediments carried in water) are the most common nonpoint sources. However, the pollutant loads to a waterbody from nonpoint sources can exhibit substantial temporal and spatial variability. As such, NPS loads to a waterbody can be a function of human activity and/or the naturally-occurring background pollution.

In the upper San Marcos River Watershed, NPS pollution is a substantial source of concern due to multiple anthropogenic activities in the watershed, including land use intensity and land use patterns, and alteration the hydrologic regime. In the Sink Creek watershed, NPS inputs from changing land use patterns (e.g., an increase in urban land use and impervious surface) and alteration of the hydrologic regime (e.g., changes in the timing and magnitude of hydrologic inputs) are likely to play an important role in determining nutrient and sediment NPS loads to Spring Lake. In particular, exports of nutrients such as N and phosphorus (P), sediments, and bacteria from surrounding landscapes can have substantial impacts on the water quality and subsequent suitability of waters as recreational resources, drinking water sources, and quality habitat for organisms. Given the high water quality in Spring Lake and the Upper San Marcos River (Groeger et al. 1997), determination of the potential sources of NPS constituents in the watershed and the magnitudes of the externally-derived loads these constituents are critical for future protection and management of the ecosystem.

Two landscape types that are frequently associated with NPS pollution are urban- and residential-dominated areas and agriculture-dominated areas. Urban and residential NPS pollution is often associated with surface runoff containing increased suspended and dissolved solids, nutrients, metals, bacteria, biological and chemical oxygen demand, petroleum-derived hydrocarbons, herbicides, and pesticides. Nonpoint pollution sources in landscapes dominated by these land use types can include vehicles, construction, fertilizer and pesticide application, erosion, animal wastes, and local atmospheric deposition. In addition, low-density residential areas that do not utilize waste water service (i.e., sewer service) will have on-site sewage facilities (OSSF's; septic systems). These systems, if not properly installed or maintained, can contribute NPS loadings of bacteria. Nonpoint source pollutant loads from agricultural landscapes include suspended and dissolved solids, nutrients, herbicides, pesticides, and animal wastes. All of these NPS constituents from urban/residential- and agriculture-dominated landscapes can be transported in solution, suspended in surface runoff, or adsorbed on soil particles. In the Sink Creek watershed (and the Upper San Marcos River watershed), residential, urban, and agricultural NPS issues are likely to be the most relevant.

In the Spring Lake watershed, the intimate connectivity between surface- and ground-water likely makes any NPS loading to waters within the recharge zone in the Edwards Aquifer relevant to the NPS dynamics in Spring Lake. Urban and agricultural development, septic systems, irrigation systems, fertilizer, herbicide, and pesticide application, and leaking petroleum storage tanks within this larger defined area have potential to affect NPS loads to Spring Lake. Changes in the intensity and composition of LULC practices in the larger recharge area will increase the potential for water quality impairment and may place further strain on groundwater inputs to the lake by the lowering of aquifer levels through groundwater extraction.

2.2 Nonpoint Source Pollution Loading

Estimation of pollutant loads from surrounding landscapes to a water body and from upstream to downstream points within a flowing water system is an extremely insightful process that can be critical for the identification of sources and types of NPS pollution. Estimated pollutant loads can then be used as a basis for understanding which portions of a watershed or specific practices within a watershed need to be further examined or managed. Spring Lake and the USMR are considered to exhibit relatively high water quality (see the Spring Lake Watershed Initial Watershed Characterization Report for a review of existing water quality data), but the influence of the Sink Creek watershed on loads of nutrients, sediments, and bacteria has not been examined. As a part of the Spring Lake Watershed Characterization Project, empirical data on nutrient, suspended sediment and bacteria loads from the Sink Creek watershed to Spring Lake are being collected and will be presented in subsequent reports. For this report, we utilize an approach in which we estimate the potential load of various pollutants (i.e., nutrients, sediments and bacteria) from the Sink Creek watershed to Spring Lake using calculated surface water runoff and aquifer recharge, literature-based values of pollutant concentrations, LULC patterns in the watershed, and estimated densities of houses, septic systems, people and animals in the watershed. Other watershed characterizations have utilized similar approaches to estimate NPS pollutant loads from watersheds (Berg et al. 2008; RSI 2010). When this analytical approach to determine pollutant loads from a watershed is used, it can be a particularly powerful when estimated loads are eventually coupled with empirically-based data on actual pollutant loads. As stated previously, the estimated loads presented here will be explicitly coupled with empirical estimates of pollutant loads in subsequent reports.

3.0 Estimation of Pollutant Sources in the Sink Creek Watershed

For our estimates of pollutant loads from the various LULC types and various potential pollution sources in the Sink Creek watershed, we focused on two main groups of pollutants: (1) nutrients and sediments and (2) bacteria. For calculations of potential loads of nutrients, sediments, and bacteria to Spring Lake we used an approach in which we coupled our values for LULC types in the Sink Creek watershed to literature-based estimates of concentrations of pollutants coming off various LULC types. For the purposes of our loading estimates, we utilized a 'whole watershed' approach instead of dividing the watershed into the subcatchments. This decision was made for several reasons. First, soils in the Sink Creek watershed are thin and porous (Battle 1984), leading to potentially rapid losses of surface water to the deeper aquifer pool that supplies springs in Spring Lake. Thus, groundwater-surface water interactions are not well known and water from the various portions and subcatchments of the watershed are likely mixed to some extent within the larger regional groundwater pool that emerges from the lake. Second, there are likely to be substantial flow losses to groundwater within the stream bed itself, leading to aquifer recharge and mixing of runoff from various subcatchments within the watershed. Third, there are three flood retention structures located within the Sink Creek watershed (Figure 3.0) which function as hydrological integration points in the watershed. The flood retention structure farthest downstream in the watershed (SI-1 in Figure 3.0) integrates approximately 75% of the watershed area. Flood retention structure SI-2 is the largest in the watershed and integrates the entire western portion of the watershed, and structure SI-3 integrates the contributions from the northern Hilliard/Lime Kiln Road portion of the watershed. In addition to these structures retaining surface water during times of high runoff, these sites serve as potentially important groundwater recharge sites (e.g., Ockerman 2002). Again, groundwater recharge occurring at these structures, if substantial, can lead to some homogenization of the hydrological and pollutant inputs from the various subcatchments. Therefore, we chose to express the hydrological inputs and pollutant loads from the entire Sink Creek watershed rather than from smaller scale subcatchments.

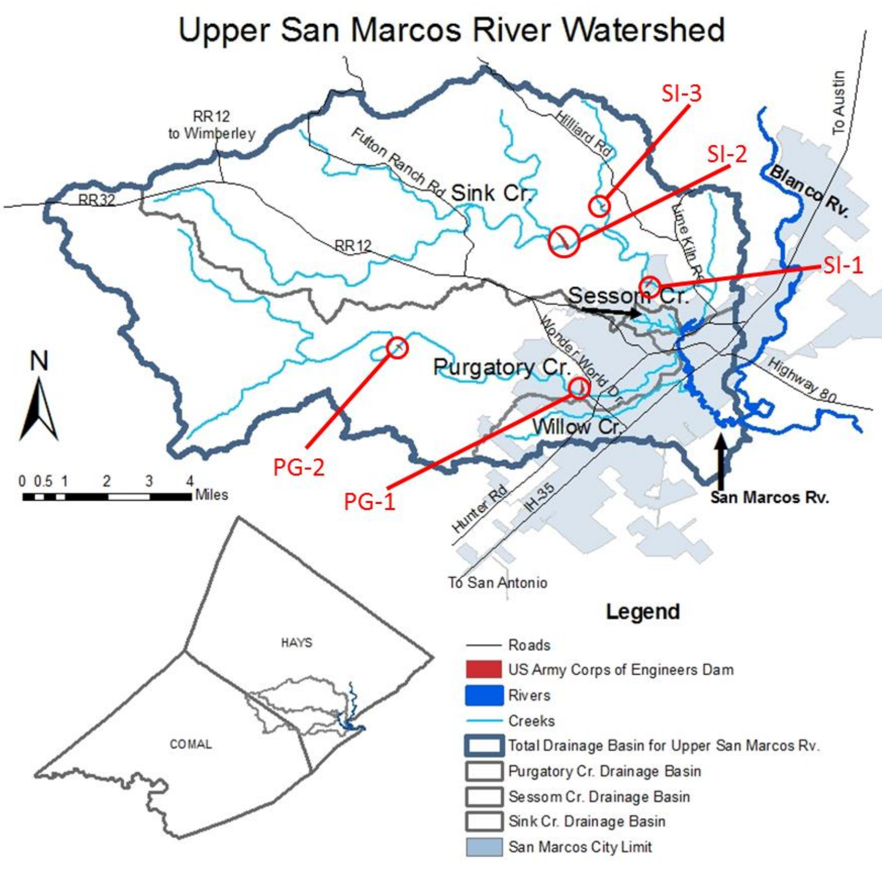

Figure 3.0. The Upper San Marcos River Watershed, with the major flood retention structures indicated in red. The City of San Marcos is shown in the south eastern corner of the map.

3.1 Nutrient and Sediment Loading Methods

A diversity of analytical methods can be used to estimate pollution exports from the various LULC categories in watersheds, including several spatially-explicit modeling approaches. For example, the Soil and Water Assessment Tool (SWAT) can be used to model hydrological, sediment, and nutrient export from watersheds. For the purposes of this report, we did not utilize a spatially explicit modeling approach (i.e., SWAT) for several reasons. First, the majority of the focus of this project is on the empirical monitoring of inputs from Sink Creek and the water quality in Spring Lake. Second, SWAT modeling can be problematic in the central Texas Edwards Aquifer Recharge area because the model does not allow for rapid percolation of water to deep aquifer storage (Afinowicz et al. 2005), a potentially important process in the Sink Creek watershed. SWAT assumes that water moving through a soil profile will affect the volume of base flow in a stream rather than allowing water to be lost to a deeper regional aquifer system without being expressed in local baseflow return (Afinowicz et al. 2005). As the name "Sink Creek" implies, there are substantial hydrologic losses from the creek when flows are present. Finally, a substantial spatially explicit modeling effort will be conducted as a part of the future WPP for the Upper San Marcos River watershed. Therefore, we elected to utilize and approach in which we calculated the hydrological exports and potential loads from the entire Sink Creek watershed using literature-based estimates of runoff and concentrations of pollutants coming off various LULC types. The approach utilized in this study provides helpful preliminary information to stakeholders prior to the development of the larger WPP, particularly with regard to potential impacts through land use changes in the watershed and any preliminary actions that might be taken to address potential water quality concerns.

Estimating Annual Water Yield

We first estimated the annual water yield from the Sink Creek watershed in order to determine the amount of water leaving the watershed via channelized flow. A variety of studies have examined water yields in the central Texas region and have concluded that annual water yields in creeks range from approximately 5 – 25% percent of mean annual precipitation (Arnold et al. 1999; Ockerman 2002; Alllen et al. 2005; Afninowicz et al. 2005; Allen et al. 2011). For this report, we selected an annual water yield for surface water of 10% of annual precipitation (after Afninowicz et al. 2005). This value is on the lower end of the range of values in the literature, but given the losing stream nature of Sink Creek and the presence of multiple small flood retention/recharge structures in the watershed, this estimate is likely to be more relevant for the Sink Creek watershed.

Mean annual precipitation in the Sink Creek watershed is 945 mm per year (0.945 m/yr) (see the Spring Lake Watershed Initial Watershed Characterization Report), which yields 9.45 mm of precipitation that will end up in the main stream channel. When mean annual precipitation (0.945 m/yr) is multiplied by watershed area (125,124,956 m^2), the result is the total rainfall volume deposited on the watershed (118,243,083 m^3/yr). Given a 10% water yield from the watershed, then 11,824,308 m^3 is potentially exported from the Sink Creek watershed in the stream channel on average per year. We also assumed that approximately 65% of annual precipitation was lost from the watershed as evapotranspiration (ET) (Ockerman 2002; Afinowicz et al. 2005). Obviously, there is likely to be substantial year-to-year variation in precipitation and thus water yield from the watershed. In addition, water yield from a landscape can vary with drought conditions which affect soil properties and vegetative cover (Allen et al. 2011). Therefore, the water yield value presented here should be viewed as the hypothetical water yield from the watershed during an average precipitation year.

In addition of the water yield of the watershed to the main stream channel, a portion of precipitation also ends up being exported to the groundwater pool. Again, literature estimates for the central Texas region on groundwater recharge vary from 6 – 28% of annual precipitation, with most estimates around 20-25% (Ockerman 2002; Afinowicz et al. 2005). Given the high potential groundwater recharge capacity of the Sink Creek watershed, we assumed 25% of annual precipitation ended up as recharge, yielding a mean annual groundwater input of 29,560,771 m^3/yr. Of this volume moving into the aquifer, we assumed 57% of the total volume came from direct infiltration, 36% came from inputs from stream flows (stream flow loss inputs) and 7% came from recharge associated with flood retention structures (based on estimates from Ockerman 2002).

The watershed annual water yield estimate was coupled with event mean concentrations (EMC) of various NPS pollution constituents from several literature sources (Baird et al. 1996; Ockerman et al. 1999; Ockerman 2002; City of Austin 2006). The EMCs from Baird et al. (1996) are not from the central Texas region, whereas the EMCs from Ockerman et al. (1999) and Ockerman (2002) are for streams in the central Texas Edwards Aquifer region. In addition, the watersheds in the City of Austin (2006) report EMCs for small watersheds for a variety of LULC types, but do not have data for cropland or rangeland LULC types. Thus, the EMCs from Ockerman (1999 and 2002) and the City of Austin (2006) are more likely to be representative of the Sink Creek watershed and we primarily utilized these EMCs in calculations. However, if an EMC for a constituent of interest or LULC type was provided by the three aforementioned studies, we utilized EMCs from Baird et al. (1996). Furthermore, both City of Austin (2006) and Baird et al. (1996) report bacterial loadings from different LULC types as total fecal coliform. Because the focus of this project is on *Escherichia coli* (*E. coli)* loading rather than loading of all fecal coliform bacteria, we converted fecal coliform densities to *E. coli* densities by multiplying the fecal coliform EMC by 0.63, a commonly used conversion factor used by the TCEQ in previous projects.

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 NPS 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 Spring Lake/Sink Creek watershed. The EMCs and their literature sources are presented in Table 3.1.1. These NPS constituents include various forms of N, P, and sediments. We also estimated loads of several heavy metals, biological oxygen demand (BOD), chemical oxygen demand (COD), and *E. coli*.

Constituent	Units	Residential	Commecial	Industrial	Cropland	Rangeland	Undeveloped/Open
TN	mg/L	1.98*	1.93*	1.59*	4.4‡	0.7‡	0.9*
TKN	mg/L	0.9§	0.7§	1.11*	1.7‡	0.2‡	1.02§
Nitrite + nitrate - N	mg/L	0.28†	0.32†	0.535*	1.6‡	0.4‡	0.56†
Ammonia - N	mg/L	0.06§	0.1§	0.207*	0.102θ	0.102θ	0.0468*
TP	mg/L	0.165§	0.19§	0.354*	1.3	0.01	0.124§
TDP	mg/L	0.169*	0.203*	0.108*	0.124θ	0.124θ	0.03*
TDS	mg/L	54†	52†	116‡	1225‡	245‡	119†
TSS	mg/L	53†	114†	184.92*	107‡	1‡	48†
Total Pb	ug/L	15.96*	31.50*	23.2*	1.5‡	5‡	3.63*
Total Cd	ug/L	0.569*	0.638*	0.73*	1‡	0‡	0.534*
Total Cu	ug/L	9.98*	11.42*	11.92*	1.5‡	0‡	5.04*
Total Zn	ug/L	55.50*	135.62*	112.54*	16‡	6‡	20.25*
BOD	mg/L	11.14*	11.68*	7.04*	4‡	0.5‡	3.64*
COD	mg/L	55.81*	66.42*	53.92*	57.09θ	57.09θ	42.16*
Fecal coliform	colonies/100 mL	61252.91*	33912.5*	36057.4*	25852.40‡	37θ	16205.6*

Table 3.1.1. List of NPS constituents used in this study, indicating the units and the EMCs for the various LULC types. Specific sources for the EMCs are indicated by the following symbols: † = Ockerman (2002), § = Ockerman et al (1999), * = City of Austin (2006), ‡= Baird et al. (1996), and ϑ = no EMC available and the value is a mean of the EMCs from the other LULC types for this constituent. Fecal coliform EMC values are multiplied by 0.63 to provide E. coli estimates.

Land Use and Land Cover Analysis

The Land Use-Land Cover (LULC) analysis was performed in the Sink Creek watershed was performed as a part of the Spring Lake Watershed Initial Watershed Characterization Report. Thus, we will briefly discuss them here. We utilized the National Land Cover Datasets (NLCD) database and the LULC data was downloaded from the USGS seamless server (http://seamless.usgs.gov/nlcd.php). NLCD data for the Sink Creek/Spring Lake watershed from 2006 were projected and clipped and analyzed for the entire watershed.

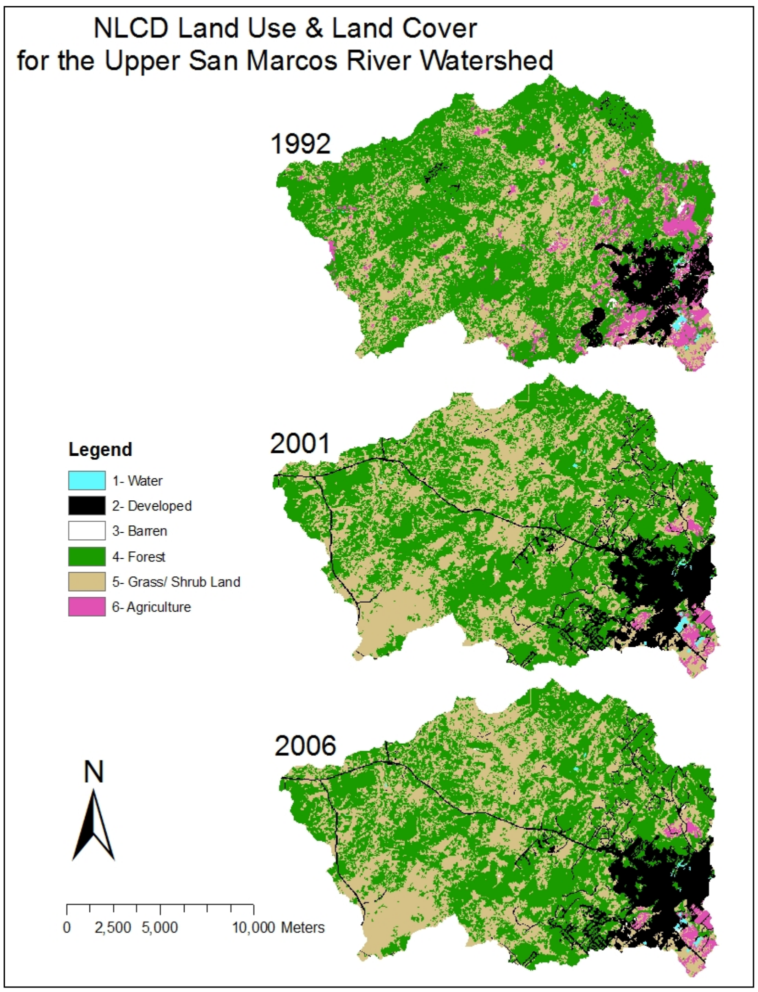

Figure 3.1. Patterns in LULC characteristics in the Sink Creek Watershed across three time intervals (1992, 2001, and 2006). The major LULC types are indicated by the various colors.

In general, most of the land within the Sink Creek watershed in 2006 is classified as Forested (49.1%) and Grassland/Shrubland (37.7%) (Figure 3.1). Developed areas constitute a much smaller portion of the watershed (11.5%), with Agriculture (1.4%), Water (0.12%) and Barren Land (0.08%) composing only a small fraction of the watershed. Based upon these LULC patterns, it can be concluded that the Sink Creek watershed does not exhibit intense human development patterns in the watershed.

The NLCD data includes a greater number of LULC types than the LULC types provided by the literatures-based EMCs (14 *versus* 7), thus we needed to reduce the number of LULC types from the NLCD so that there was concordance in LULC types in the EMC analyses. Event Mean Concentration values were reported for Residential, Commercial, Industrial, Cropland, Rangeland, and Undeveloped/Open areas (Table 3.1.1). Thus, we assigned all LULC types reported by the NLCD into the seven categories for EMCs (Table 3.1.2).

Original NLCD LULC Classification	Reclassified LULC	m^2 in Watershed	% of Watershed
Open Water	Undeveloped/Open	130,268.31	0.10%
Developed, open space	Residential	4,827,114.62	3.86%
Developed, low intensity	Residential	804,069.90	0.64%
Developed, medium intensity	Commecial	485,137.15	0.39%
Developed, high intensity	Industrial	116,792.28	0.09%
Barren Land	Undeveloped/Open	52,107.32	0.04%
Deciduous Forest	Undeveloped/Open	17,894,373.53	14.30%
Evergreen Forest	Undeveloped/Open	50,654,607.03	40.48%
Mixed Forest	Undeveloped/Open	55,700.93	0.04%
Shrub/ Scrub	Rangeland	29,764,960.81	23.79%
Grassland/Herbaceous	Rangeland	19,588,759.94	15.66%
Pasture/Hay	Cropland	652,239.94	0.52%
Cultivated Crops	Cropland	64,684.95	0.05%
Woody Wetlands	Undeveloped/Open	34,139.28	0.03%

Table 3.1.2. Conversions of 2006 NLCD LULC types to LULC types given in the list of literature-based EMCs. The original NLCD LULC type, the LULC type it was reclassified as, the number of m2 in the Sink Creek watershed that were of the LULC type, and the % area in the watershed that is in the LULC type are provided. Percentages add up to 100% of the watershed.

After this conversion of LULC types, the Sink Creek watershed was dominated by Undeveloped/Open (55%) and Rangeland (39.4%) LULC types, with Residential (4.5%), Cropland (0.57%), Commercial

(0.39%), and Industrial (0.09%) LULC types composing a smaller percentage of the land cover in the watershed (Table 3.1.2).

Calculations for Annual Pollution Loads

The mean annual water yield was converted to runoff volume ($\frac{m^3}{yr}$) by converting to meters and multiplying by the total area of the watershed. NPS loadings for each constituent are calculated as the sum of EMCs for each land use type multiplied by runoff volume and scaled by the relative area of the watershed in each land use type:

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

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

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

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

a_1 = percent of watershed area in land use type 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 (lbs/acre/year).

3.2 Nonpoint Source Pollution Loadings

Potential sources of NPS pollution in the watershed are varied and are likely to include residential landscaping activities, on-site septic treatment (septic tanks), fertilizer and pesticide application, land clearing for new construction or cedar removal, deposition of pet and livestock wastes, surface runoff from parking lots and roads, grazing activities associated with livestock, atmospheric deposition, and some limited recreational use of the green space along Sink Creek.

NPS pollution sources associated with residential/urban areas includes on-site septic treatment, which remains the primary method of wastewater treatment in most of the watershed. Indeed, all of the residential development in the eastern portion of the watershed along Lime Kiln and Hilliard roads utilizes on-site septic systems. It is not known how future developments will treat wastewater, but an increase in septic systems is likely because much of the watershed is unincorporated. Nonpoint source pollution associated with residential land use includes fertilizer and pesticide application. In addition, native vegetation removal and land clearing can increase runoff and erosion. Residential and urban areas will have associated transportation networks which increase runoff and are associated with higher levels of suspended and dissolved solids and heavy metals. According to EMC estimates (Baird et al. 1996; Ockerman et al. 1999; Ockerman 2002; City of Austin 2006), residential land use is among the highest source of N, P, and thus biological and chemical oxygen demand. Commercial and Industrial land uses are associated with higher levels of heavy metals, such as Pb, Cd, Cu and Zn. Impervious surface cover surface in urbanized areas can also result in pollutant loadings being delivered to Sink Creek faster and in greater concentrations than in areas with natural drainage systems (Novotny and Olem, 1994).

More rural areas within the Sink Creek watershed also have the potential to contribute NPS loads more indicative of these kinds of LULC types. Rangeland can generate suspended and dissolved solid loads which can end up in streams and downstream lakes (Table 3.1.1). Animal waste can contribute nutrients and bacteria and grazing can increase soil erosion through compaction and vegetation removal. Agricultural land use (Cropland) is often associated with higher N loads and higher levels of eroded sediments and dissolved solids.

In the Sink Creek watershed, Rangeland and Undeveloped/Open areas contribute the largest calculated loads of N to Spring Lake (Figure 3.2.1). Our calculated estimates indicate that in total, the Sink Creek watershed exports 0.75 lbs of total nitrogen (TN) per acre of total watershed area per year. Most of this is exported N is in the form of NO_3^{2-} + NO_2^--N and total Kjeldahl-N (the sum of both organically-bound N and NH_4^+); however, most of the TKN-N is organically-bound because NH_4^+ exports from the Sink Creek watershed are low (Figure 3.2.1). These results indicate that most of the N loading to Spring Lake is in the dissolved form, in particular in the form of NO_3^{2-} + NO_2^{-}N.

In contrast to N loading from the Sink Creek watershed, total phosphorus (TP) exports from the Sink Creek watershed are much lower (0.07 lbs TP/acre/year; Figure 3.2.1), but most of this P (~87%) is predicted to be in a soluble form (TDP) that is relatively more bioavailable to algae and bacteria.

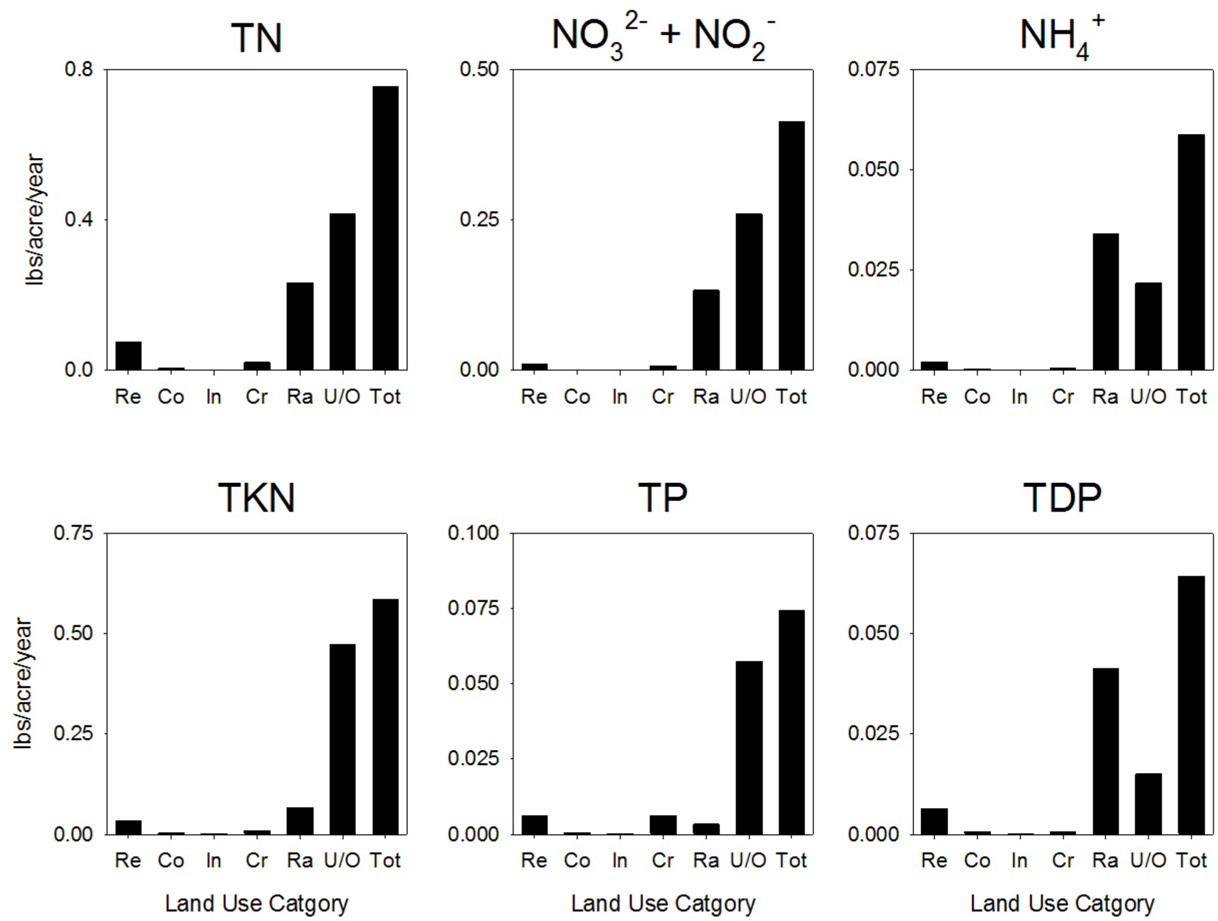

Figure 3.2.1. Estimated annual loads of nutrient NPS constituents from the Sink Creek watershed to Spring Lake from the various LULC types in the watershed as well as the watershed as a whole. Re = Residential, Co = Commercial, In = Industrial, Ra = Rangeland, U/O = Undeveloped/Open, and Tot = Total Watershed Load.

Other NPS parameters exhibited similar loading patterns (Figure 3.2.2). TDS, TSS, BOD, and COD exhibited total annual exports of 145, 26, 2.3, and 41 lbs/acre/year, respectively. For these NPS constituents, Rangeland and Undeveloped/Open areas were the largest contributors to the annual load. However, Residential areas exhibited an increased contribution to these loads, especially in the estimated annual BOD. Total loading of *E. coli* loading from the watershed was equivalent to 6,373 cell/100mL/acre/year, with Undeveloped/Open areas contributing the highest portion of this load; however, Residential areas were the second highest contributor of *E. coli* loading.

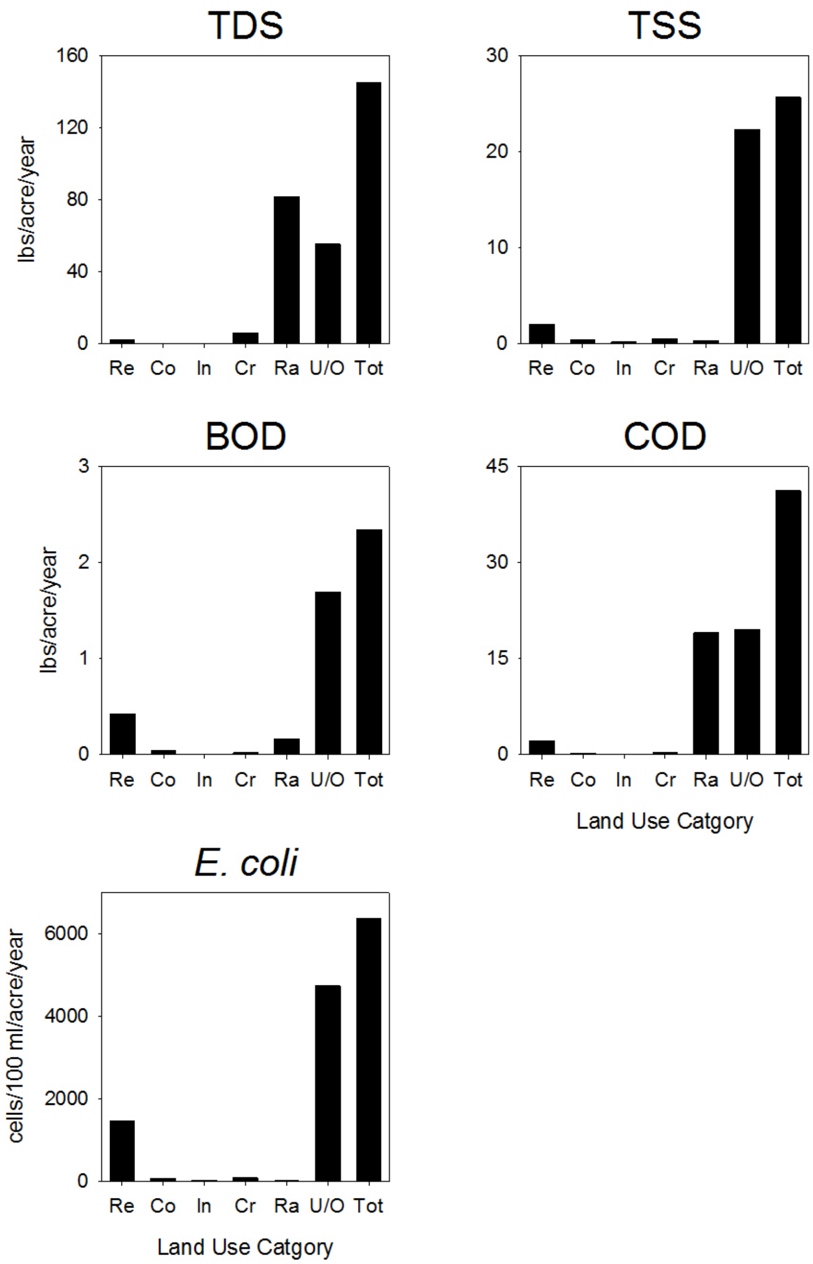

Figure 3.2.2. Estimated annual loads of dissolved and suspended solids, biological and chemical oxygen demand, and* E. coli *NPS constituents from the Sink Creek watershed to Spring Lake from the various LULC types in the watershed as well as the watershed as a whole. Re = Residential, Co = Commercial, In = Industrial, Ra = Rangeland, U/O = Undeveloped/Open, and Tot = Total Watershed Load.

The loading of the heavy metals Pb, Cd, Cu and Zn exhibited much lower absolute annual loads than other NPS constituents (ranging from x10^{-6} to x10^{-9} lbs/acre/year; Figure 3.2.3). Lead, Cu and Zn were estimated to have much greater exports than Cd from the Sink Creek watershed, with

Undeveloped/Open areas contributing a higher fraction to the load. Again, Residential areas were estimated to contribute a slightly higher portion of the total load of these heavy metals to Spring Lake.

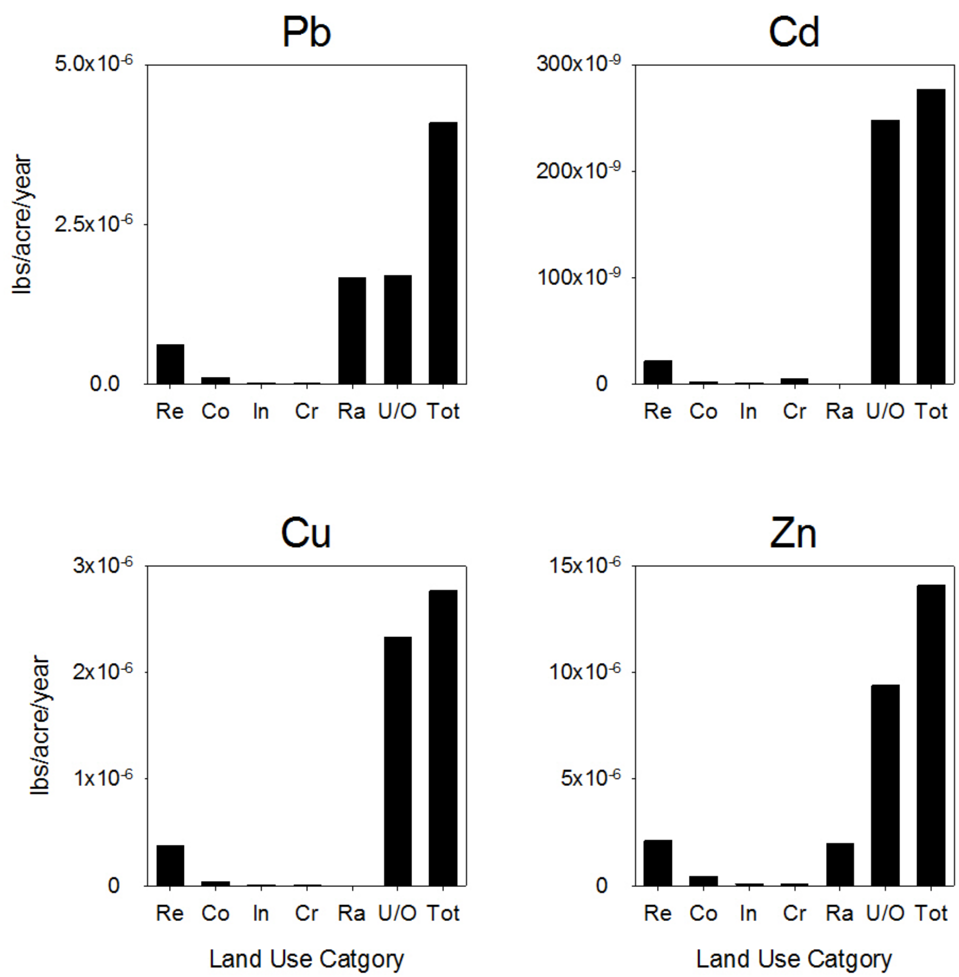

Figure 3.2.3. Estimated annual loads of heavy metal NPS constituents from the Sink Creek watershed to Spring Lake from the various LULC types in the watershed as well as the watershed as a whole. Re = Residential, Co = Commercial, In = Industrial, Ra = Rangeland, U/O = Undeveloped/Open, and Tot = Total Watershed Load.

In our modeling efforts, we assumed 10% of the annual runoff ended up being exported out of the watershed and into Spring Lake. However, we also assumed that 25% of the annual runoff went into recharge for the aquifer. Because we assumed this constant percentage of runoff went to groundwater recharge, all NPS constituent loads to the aquifer were 2.5x higher than the loads to Spring Lake (Figures 3.2.4, 3.2.5, and 3.2.6). Thus, the estimated annual loads of NPS constituents to the groundwater are much greater than the loads to the lake, but the proportional contribution of each LULC type to the annual load is the same in both the Spring Lake and groundwater loading estimates.

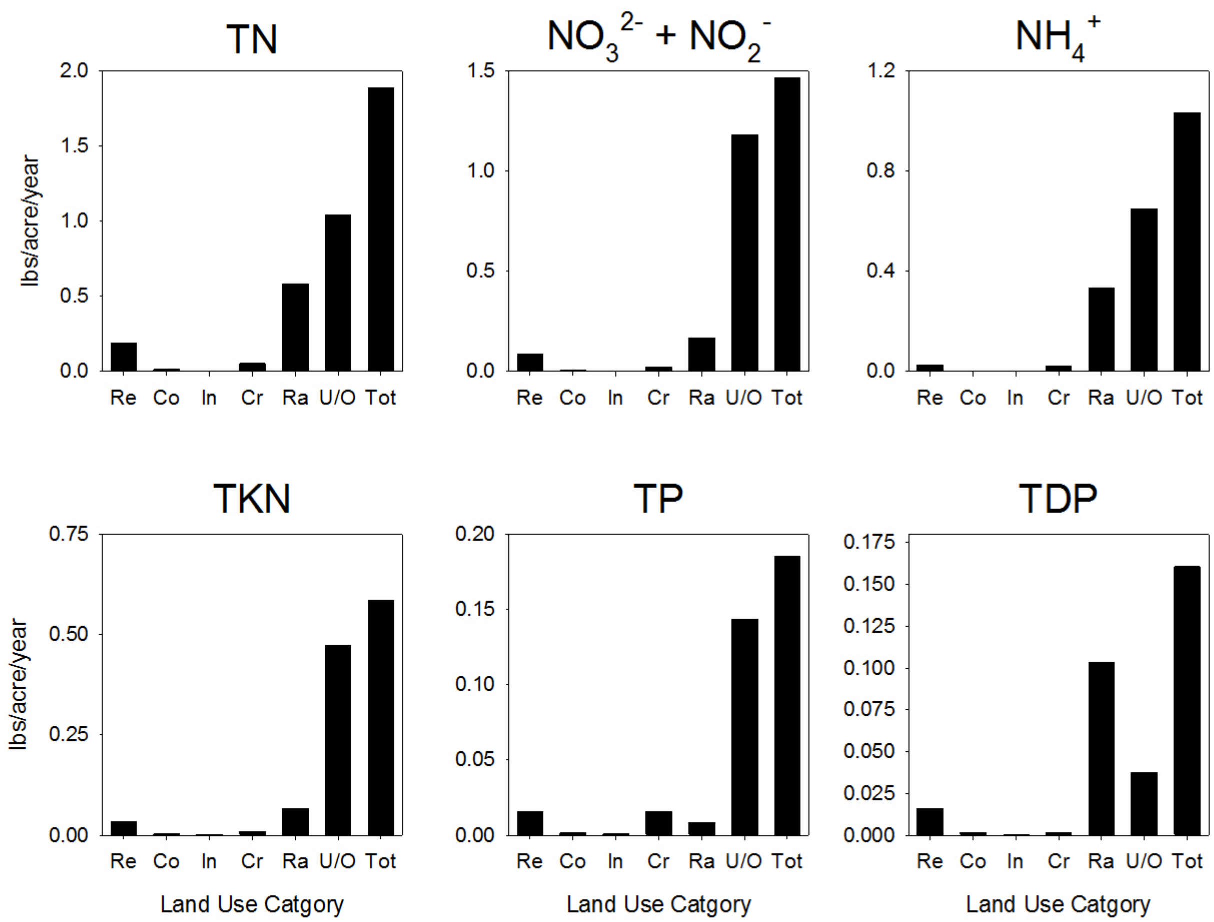

Figure 3.2.4. Estimated annual loads of nutrient NPS constituents from the Sink Creek watershed to the local groundwater pool from the various LULC types in the watershed as well as the watershed as a whole. Re = Residential, Co = Commercial, In = Industrial, Ra = Rangeland, U/O = Undeveloped/Open, and Tot = Total Watershed Load.

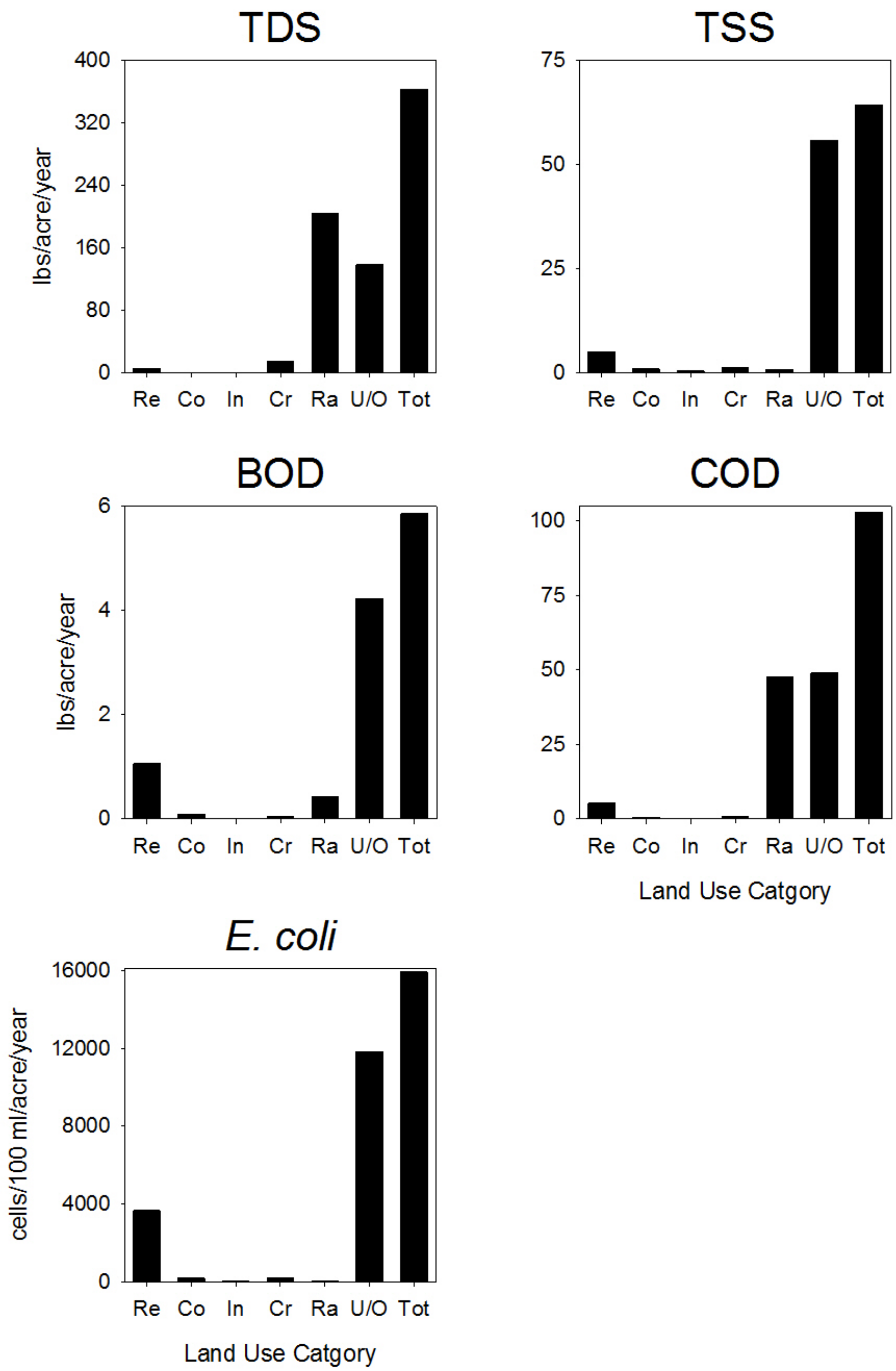

Figure 3.2.5. Estimated annual loads of dissolved and suspended solids, biological and chemical oxygen demand, and **E. coli** ***NPS constituents from the Sink Creek watershed to the local groundwater pool from the various LULC types in the watershed as well as the watershed as a whole. Re = Residential, Co = Commercial, In = Industrial, Ra = Rangeland, U/O = Undeveloped/Open, and Tot = Total Watershed Load.***

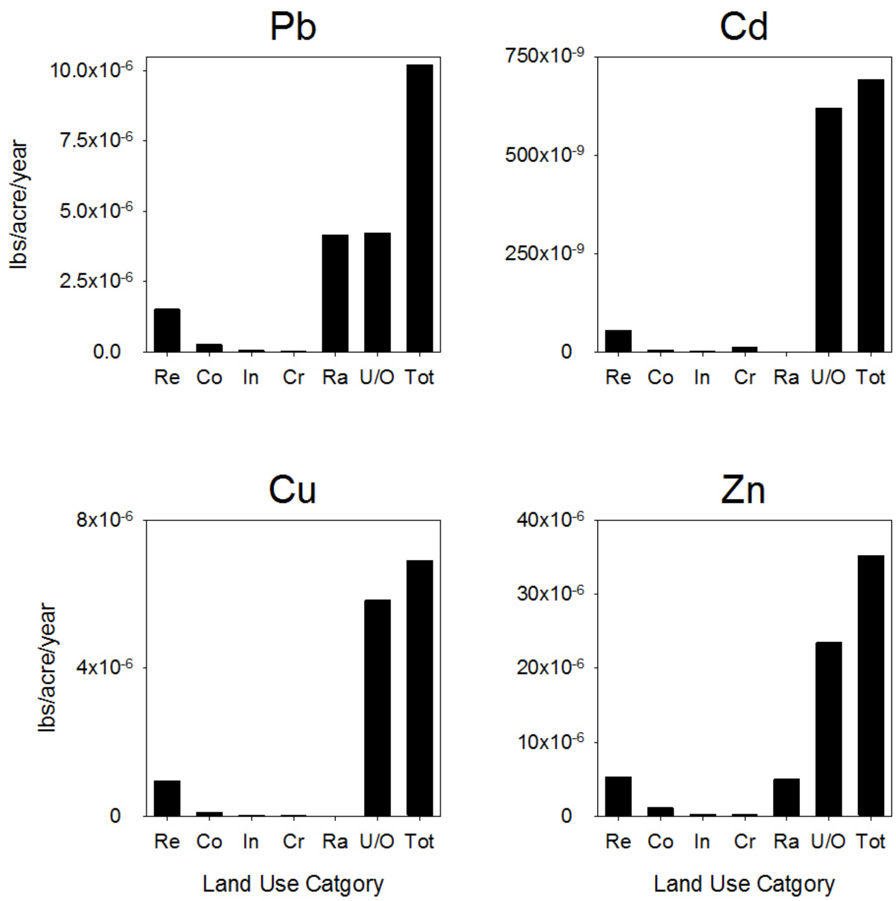

Figure 3.2.6. Estimated annual loads of heavy metal NPS constituents from the Sink Creek watershed to the local groundwater pool from the various LULC types in the watershed as well as the watershed as a whole. Re = Residential, Co = Commercial, In = Industrial, Ra = Rangeland, U/O = Undeveloped/Open, and Tot = Total Watershed Load.

In addition to examining the calculated load of the watershed and each LULC, we explicitly examined the proportional or percent contribution of each LULC type to the calculated annual load in order to assess the relative importance of each LULC type to NPS loading to Spring Lake and the aquifer. Through determining the percent contribution of each LULC type in the Sink Creek watershed, we can potentially highlight different areas of the watershed may be targeted for various pollution mitigation strategies. In addition, we can examine which LULC types should be avoided in order to preserve or improve water quality of the lake and Upper River. For example, if Residential area in the watershed accounts for a non-proportional contribution of the TP load to the lake and groundwater (e.g., their contribution to the TP load is greater than would be expected based solely upon the Residential percent cover of the watershed) then stakeholders may want to caution against future residential developments in the watershed without explicit management measures to mitigate against the TP loading. Furthermore, stakeholders can use this information to target existing LULC types in the watershed that should have management measures installed or initiated in order to improve or lessen the loading of NPS constituents from these LULC types.

For the various estimated loads of nutrients examined by this analysis (TN, TKN, NO_3^{2-} + NO_2^{-}, NH_4^{+}, TP, and TDP) to the lake and groundwater, Rangeland and Undeveloped/Open areas cumulatively accounted for 82 – 95% of the total annual load (Figure 3.2.7).

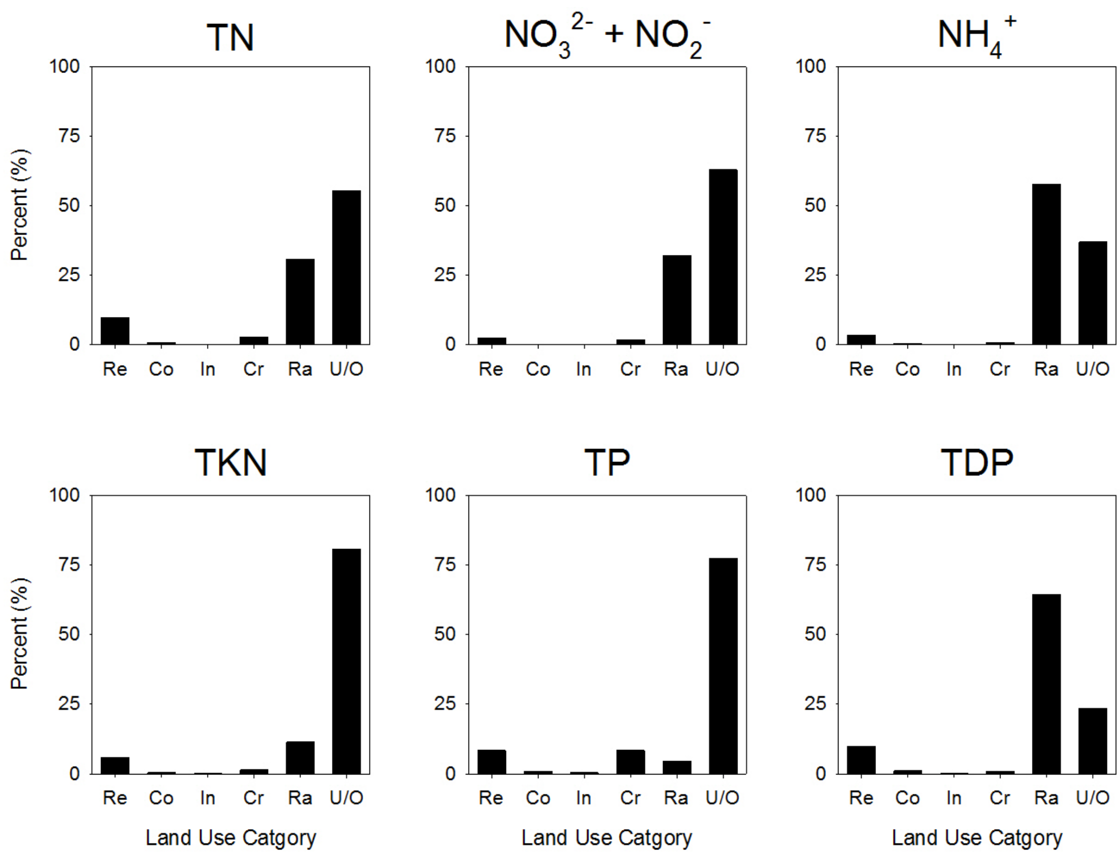

Figure 3.2.7. Percent contribution of the each LULC type to the annual loads of nutrient NPS constituents to Spring Lake and the local groundwater pool. Re = Residential, Co = Commercial, In = Industrial, Ra = Rangeland, U/O = Undeveloped/Open, and Tot = Total Watershed Load.

Given that these two LULC types account for 94% of the watershed, this finding is not surprising. Indeed, the overwhelming proportional contribution of combined Rangeland and Undeveloped/Open areas was consistent across the other NPS constituents examined by this study, accounting for 79 – 94% of the annual loads (Figures 3.2.8 and 3.2.9).

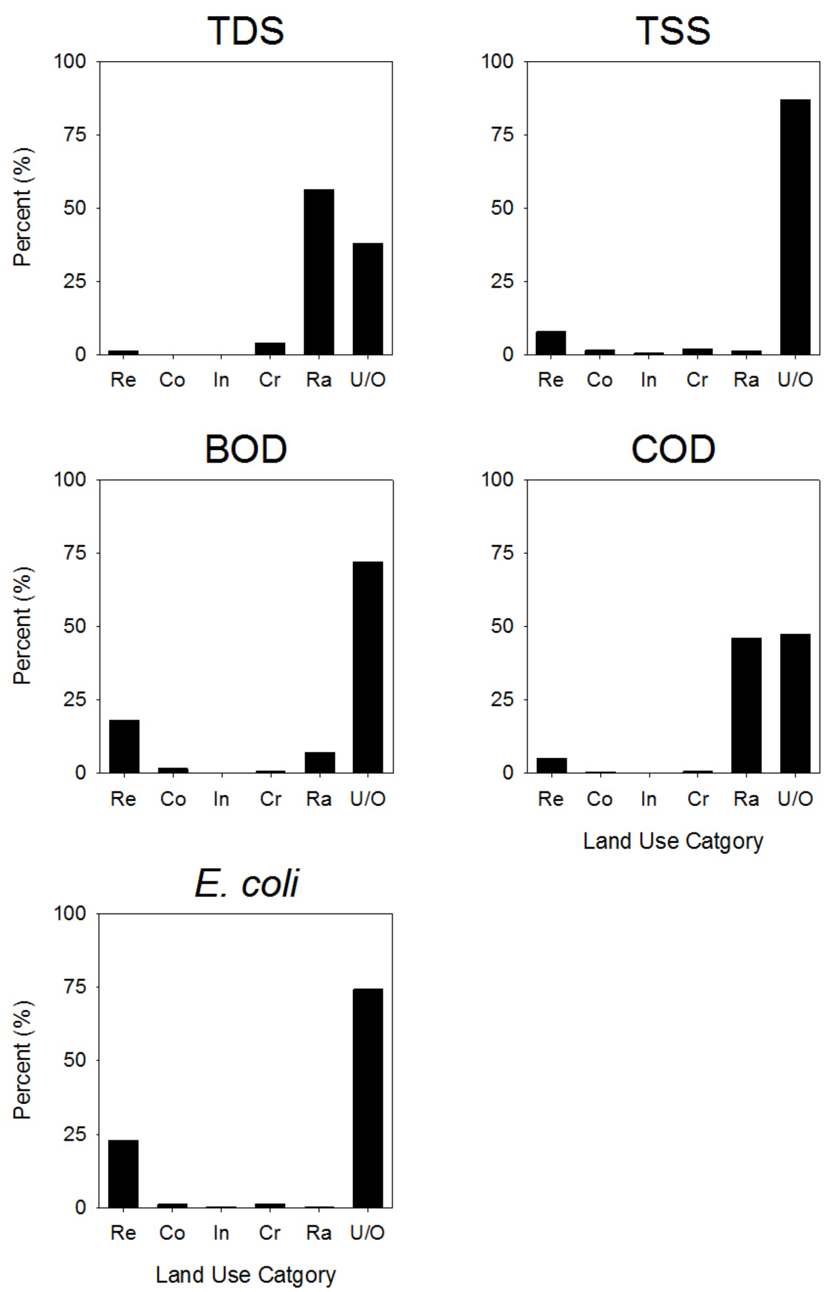

Figure 3.2.8. Percent contribution of the each LULC type to the annual loads of dissolved and suspended solids, biological and chemical oxygen demand, and* **E. coli** *to the Spring Lake and the local groundwater pool. Re = Residential, Co = Commercial, In = Industrial, Ra = Rangeland, U/O = Undeveloped/Open, and Tot = Total Watershed Load.

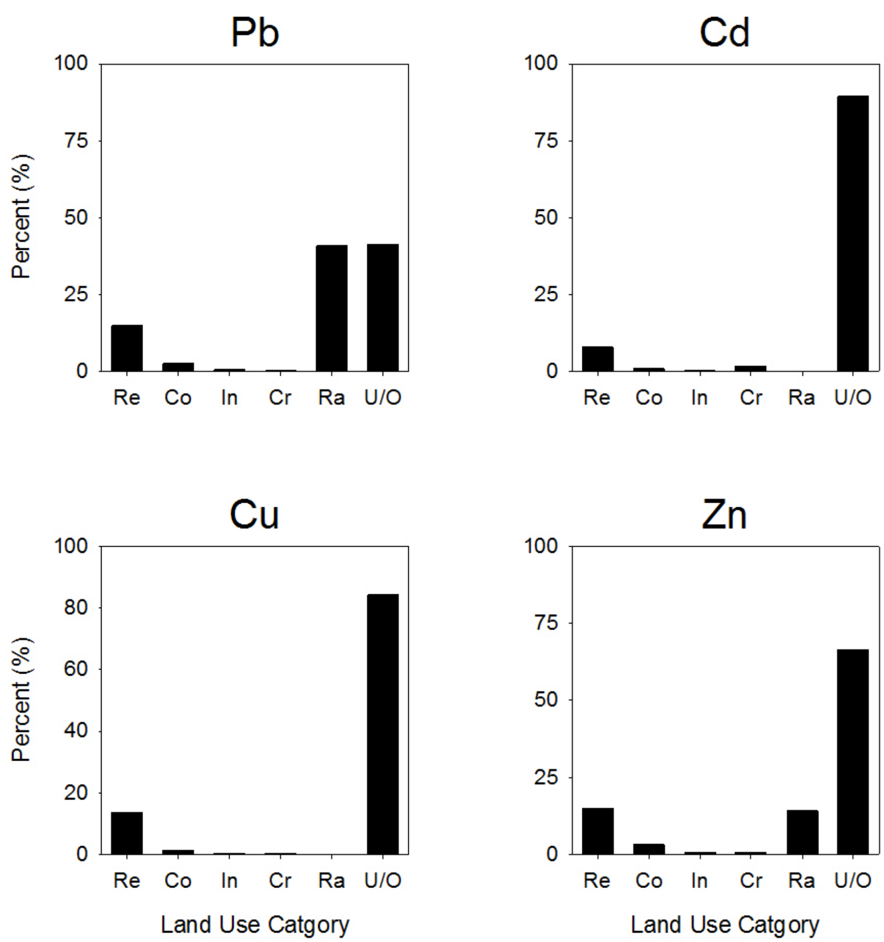

Figure 3.2.9. Percent contribution of the each LULC type to the annual loads of heavy metals to the Spring Lake and the local groundwater pool. Re = Residential, Co = Commercial, In = Industrial, Ra = Rangeland, U/O = Undeveloped/Open, and Tot = Total Watershed Load.

Residential land use, which accounts for 4.5% of the watershed area, was the next highest contributor to annual loads, accounting for 3 – 10% of the annual load of nutrients to the lake and the groundwater. However, Residential land use in the Sink Creek watershed was estimated to contribute a greater proportion of the annual load for BOD (18%) *E. coli* (23%), Pb (15%), Cu (14%), and Zn (15%). These higher proportional loadings provide insight to the importance of residential areas to loadings of some NPS constituents to Spring Lake and the local groundwater.

4.0 Summary and Recommendations

In this portion of the Spring Lake Project, we estimated the loading of various NPS constituents including nutrients, heavy metals, and bacteria to Spring Lake and the local groundwater pool from the Sink Creek watershed. We also estimated the proportional loading of these NPS constituents from the various LULC types within the Sink Creek watershed. In general, we found that magnitude of the loads from the Sink Creek watershed to Spring Lake and the local groundwater from the various LULC types were largely a function of the proportion of each LULC type within the watershed. However, Residential areas, while being a relatively small portion of the watershed, had a somewhat greater than expected contribution to the loads of several NPS constituents. In addition, our findings provide a foundation for designing and implementing LULC-specific management measures to preserve or improve the current water quality of Spring Lake and the Upper San Marcos River and to reduce NPS pollutant loads from future human activities in the watershed.

Results of our modeling and calculation efforts indicate that conversion of one land use type to another leads to changes in the yields of various NPS constituents from the landscape. When EMCs from the different land use and land cover types are converted to annual aerial yields (e.g., lbs/acre/year or cells/100 mL/acre/year) irrespective of the percent cover of the land use type in the Sink Creek watershed, there is a relatively consistent pattern of increasing loads of NPS constituents with the presence of human activities. Calculation of an aerial yield on a per acre basis allows for the direct comparison of the yield of different NPS constituents from one acre of each land use type. In terms of the NPS annual yield of nutrients, Undeveloped/Open land use has lower TN, TP and TDP yields than Residential, Commercial and Industrial land use types (Fig. 4.1). In contrast, Cropland generally exhibits the highest N and P aerial yields of all the LULC types. In addition, annual aerial yields of TSS, BOD, COD, and *E. coli* when compared Residential, Commercial and Industrial land use types (Fig. 4.2). Rangeland exhibits the lowest annual yields of TSS, BOD, and *E. coli*. Finally, yields of metals (Pb, Cd, Cu, and Zn) were lowest in Rangeland and Undeveloped/Open land use types (Fig. 4.3). The results of these calculations indicate that the annual aerial yield of most nutrients, oxygen demanding substances, *E. coli*, and metals will increase if an acre is converted from Undeveloped/Open land use to a land use type that is more intensively utilized by humans.

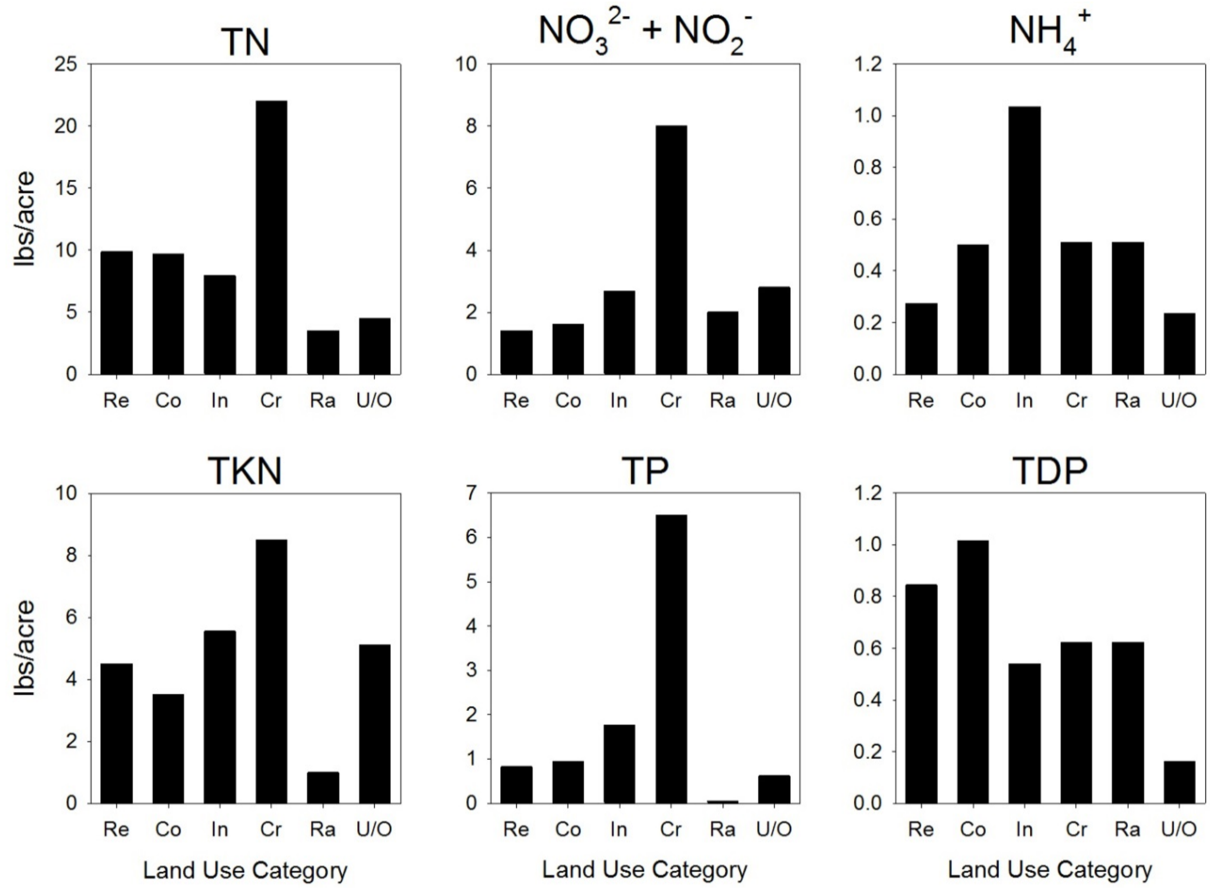

Figure 4.1. Annual per acre aerial yield of nutrients from different land use types found in the Sink Creek watershed. Re = Residential, Co = Commercial, In = Industrial, Ra = Rangeland, and U/O = Undeveloped/Open.

In the Sink Creek - Spring Lake watershed, the intimate connectivity between surface- and groundwater is highly likely to make any NPS loading to Sink Creek relevant to the nutrients and water quality dynamics in Spring Lake. Although NPS loads from human activities such as the presence of faulty septic systems and fertilizer application can run off into Sink Creek and be exported to Spring Lake via surface waters, it is highly likely that a substantial portion of the runoff ends up as recharge to the local groundwater pool. In this study, we assumed that 25% of annual water yield ended up as recharge; however, this percent contribution is likely higher than this value and changes seasonally with the hydrodynamic properties of the aquifer. Given the connectivity between the Sink Creek watershed and the groundwater emerging into Spring Lake, changes in the intensity and composition of LULC practices in the Sink Creek watershed have the potential to affect water quality in Spring Lake and the Upper San Marcos River. Subsequent and ongoing data collection efforts of this overall study involve the collection of high temporal resolution water quality data from multiple spring openings in Spring Lake, which may provide information on the responsiveness of springs to localized rainfall and recharge events.

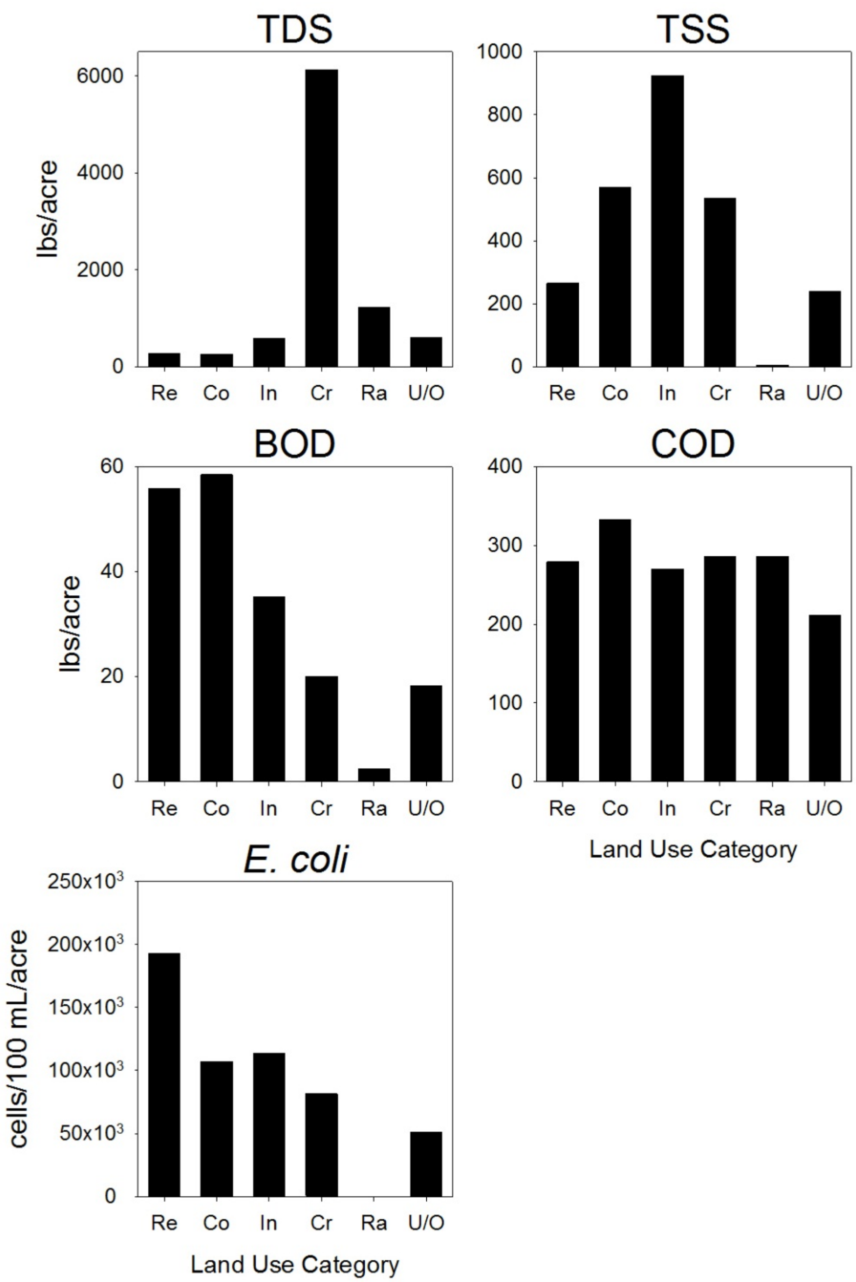

Figure 4.2. Annual per acre aerial yield of dissolved and suspended solids, biological and chemical oxygen demand, and* E. coli *from land use types found in the Sink Creek watershed. Re = Residential, Co = Commercial, In = Industrial, Ra = Rangeland, and U/O = Undeveloped/Open.

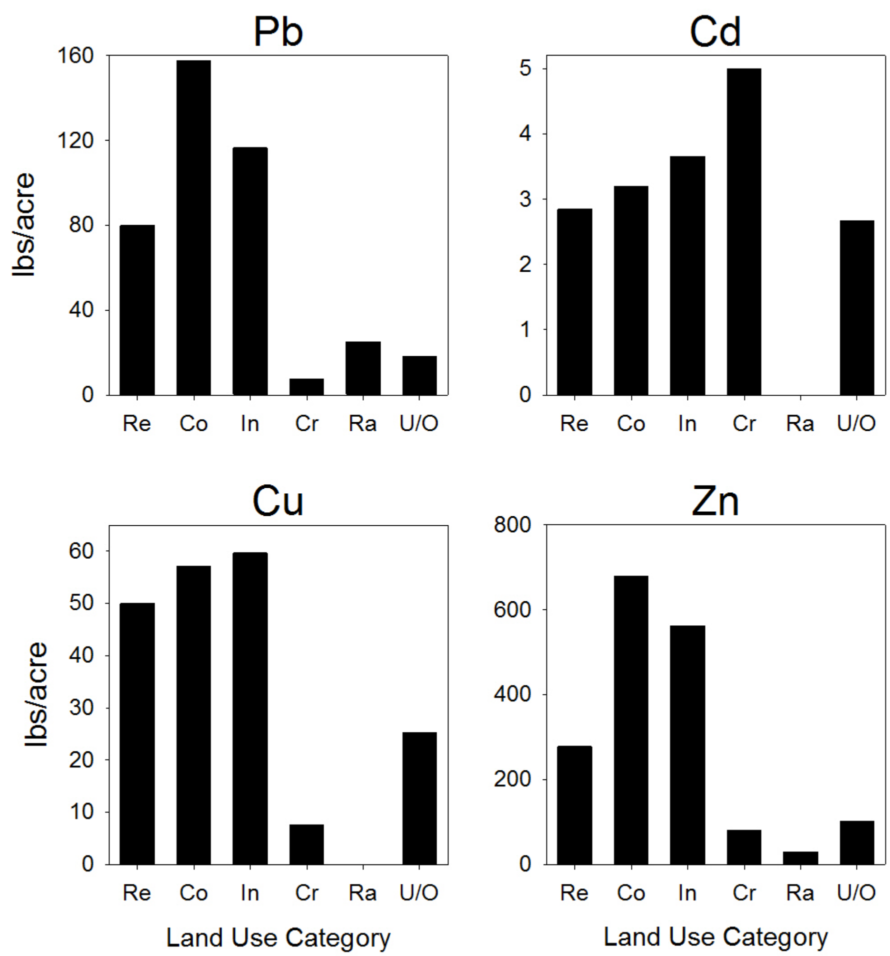

Figure 4.3. Annual per acre aerial yield of metals from land use types found in the Sink Creek watershed. Re = Residential, Co = Commercial, In = Industrial, Ra = Rangeland, and U/O = Undeveloped/Open.

Results of our analyses indicate that the Sink Creek watershed is dominated by Rangeland and Undeveloped/Open areas and that these areas are the largest contributors to NPS loadings to Spring Lake and the local groundwater. These findings show that most of the watershed (based upon 2006 NLCD data) is relatively undisturbed by human activities and that potential future management measures should take this into account. Our estimates of annual aerial yields also indicate that conversion of land use from Rangeland and Undeveloped/Open to other more intensively-occupied land use types will lead to larger exports in many NPS constituents to Sink Creek and the groundwater pool. Specifically, future management measures could obtain conservation easements in areas and to preserve areas which are currently classified as Undeveloped/Open. Indeed, we suggest that future NPS management efforts should strongly consider these land conservation efforts as a part of their overall waters quality management plans.

Rangeland in the Sink Creek watershed is an important LULC type both in terms of its percent coverage in the watershed and its percent contribution to the annual NPS loads. It is important to note that in this analysis the literature-based EMCs for various NPS constituents for Rangeland were relatively low (Table 3.1.1), especially for most nutrients, BOD, and *E. coli*. This result highlights some of the consequences of assumptions made during modeling efforts such as this report. Cattle and livestock practices can potentially have large effects on nutrient loading and water quality; however, the magnitude of these effects are likely a function of the density of livestock in an area and the specific management practices involved with the livestock operation. In the Sink Creek watershed, there are no concentrated animal feeding operations (CAFOs) and cattle densities are relatively low (~1 cow/25 acres), thus the lower EMCs for Rangeland used by this study are likely to be reflective of conditions in the watershed. In addition, the actual loadings from Rangeland activities are likely to be dependent upon specific management practices within the watershed, such the timing and duration of grazing in locations, cattle access to the stream bed and/or the riparian zone.

Our results also highlight that Residential area within the Sink Creek watershed, although a small percentage of the watershed area can have a substantial contribution to the loading of some NPS constituents, such as BOD, *E. coli*, and some heavy metals. Given that residential areas within the watershed are dominated by septic systems, wastewater and stormwater management measures are likely to be important in order to reduce the loads coming from Residential –dominated areas. Indeed, calculation of the per acre aerial yield of NPS constituents indicates that Residential land use has higher per acre yields in some nutrient forms, BOD and COD, *E. coli*, and metals than Rangeland and Undeveloped/Open land uses. Future development within the watershed is likely to be a conversion of Undeveloped or Rangeland to Residential area; thus, our results clearly suggest that stakeholders need to plan management measures accordingly if areas are converted to Residential land use. In particular, the Windmere Ranch Development has a high likelihood of impacting water quality in the lake and the upper river because it will be located along Sink Creek near Spring Lake and will be positioned downstream from the farthest downstream flood retention structure. It is recommended that future development activities should be carefully examined and best management practices (BMPs) should be applied to maintain water quality.

Based upon these findings, we generated a map indicating several areas within Sink Creek – Spring Lake watershed which should be considered for maintaining or improving current and future water quality of Spring Lake and the Upper San Marcos River (Figure 4.4). Within the figure, several areas are highlighted to illustrate issues related to the current and future NPS loadings. Area 1 is largely a residential area that sits within San Marcos city limits. Residents use city sewer systems so septic loading is not much of a concern; however, there is substantial impervious cover and management of application of lawn materials, pet waste management, and stormwater runoff should be a priority. Area 2 on the map is relatively low density residential area located along Lime Kiln and Hilliard area. These residents are on septic systems and often have several trailer homes on a single lot. Management measures associated with septic systems, application of materials to lawns, and pet waste are of concern. Area 3 is again largely residential and contains a mix of high- and low-density housing. Like Area 1, lawn materials, pet waste management, and stormwater runoff should be a priority management issues. The final area, Area 4, is located in the western portion of the watershed and contains relatively large houses on large (>2 acre) lots. There is a low density of houses and although issues such as septic systems, application of materials to lawns, and pet waste are of concern, this portion of the watershed is likely to be the area of lowest priority.

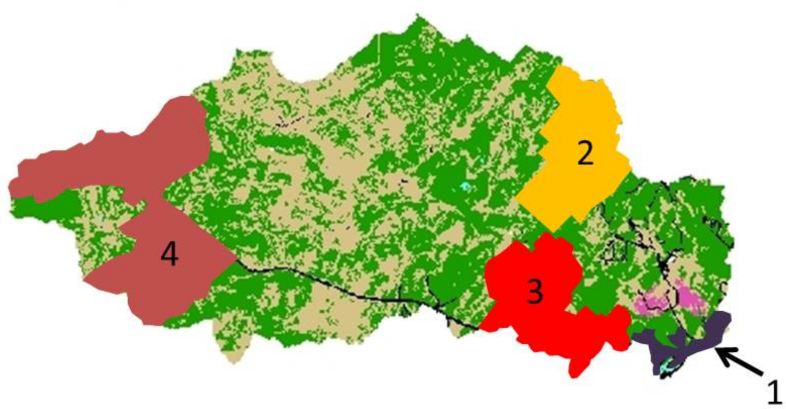

Figure 4.0. Highlighted areas within the Spring Lake - Sink Creek watershed which should be considered for improving or maintaining current and future water quality in Spring Lake and the Upper San Marcos River. Detailed explanation of the different areas indicated by the coloring and numbers is provided in the report text.

Preservation of water quality and quantity in Spring Lake and the Upper San Marcos River requires an integrated management plan that incorporates both surface- and groundwater, spans agency jurisdictions, allows for stakeholder involvement, and maintains the sometimes difficult balance between natural resource management and economic development. Future portions of the Spring Lake Watershed Characterization and Recommendations Project, including the periodic collection of water quality data and the determination of NPS loads associated with storm events from the Sink Creek watershed will play a vital role in initiating the generation of such a management plan. These loading estimates also provide an foundation for the future WPP for the entire Upper San Marcos River watershed.

References

Afinowicz, JD., CL. Munster, and BP Wilcox. 2005. Modeling Effects of Brush Management on the Rangeland Water Budget: Edwards Plateau, Texas. JAWRA. 41:181-193.

Allen, PM, RD Harmel, JA Dunbar, and JG Arnold. 2011. Upland contribution of sediment and runoff during extreme drought: A study of the 1947–1956 drought in the Blackland Prairie, Texas. J Hydrology. 407:1-11.

Allen,PM, RD Harmel, J Arnold, B Plant, J Yelderman and K King. 2005. Field data and flow system response in clay (vertisol) shale terrain, north central Texas, USA. Hydrol Process 19:2719–2736.

Arnold, JG, R Srinivasan, R, TS Ramanarayanan, and M DiLuzio, M. 1999. Water resources of the Texas Gulf Basin. Water Sci Tech 39:121-133.

Baird, C, M Jennings, D Ockerman, and T Dybala. 1996. Characterization of nonpoint sources and loadings to the Corpus Christi Bay National Estuary Program study area. Texas Natural Resource Conservation Commission CCBNEP-05. Austin, TX.

Batte, CD. 1984. Soil Survey of Comal and Hays Counties, Texas. United States Department of Agriculture Soil Conservation Service.

City of Austin. 2006. Stormwater runoff quality and quantity from small watersheds in Austin, TX. Water Quality Report Series COA-ERM/WQM 2006-1.

Groeger AW, Brown PF, Tietjen TE, Kelsey TC (1997) Water quality of the San Marcos River. Texas Journal of Science 49:279–294.

Johnson, S, G Schindel, and J Hoyt. 2009. Water quality trends analysis of the San Antonio Segment, Balcones Fault Zone Edwards Aquifer, Texas. Edwards Aquifer Authority Report No. 09-03.

Novotny, V. and H. Olem. 1994. Water quality: prevention, identification and management of diffuse pollution. Van Nostrand Reinhold. New York, NY.

Ockerman, DJ. 2002. Simulation of Runoff and Recharge and Estimation of Constituent Loads in Runoff, Edwards Aquifer Recharge Zone (Outcrop) and Catchment Area, Bexar County, Texas, 1997–2000. USGS. Water-Resources Investigations Report 02–4241.

Ockerman, DJ, BL Petri, and RN Slattery. 1999. Stormwater Runoff for Selected Watersheds in the Edwards Aquifer Recharge Zone, Bexar County, Texas, 1996–98. USGS. USGS Fact Sheet FS–172–98.

RSI. 2010. Cypress Creek Watershed Watershed Characterization Report. Prepared for the Cypress Creek Watershed Protection Plan for the TCEQ and EPA.