Douglas A. Ducey, Governor

Henry R. Darwin, Director

Watson Lake TMDL: Total Nitrogen, DO, pH & Total Phosphorus Targets

Arizona Department of Environmental Quality
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List of Abbreviations

A.A.C.	Arizona Administrative Code
A.A.R.	Arizona Administrative Register
ADEQ	Arizona Department of Environmental Quality
AF	acre-feet
AFWS	Arizona Flood Warning System
AgI	Agricultural-Irrigation
AgL	Agricultural-Livestock
A&Wc	Aquatic and Wildlife-coldwater
A&Ww	Aquatic and Wildlife-warmwater
cfs	cubic feet per second
CGP	Construction General Permit
EPA	United States Environmental Protection Agency
^{o}F	degrees Fahrenheit
ft.	feet
ft. msl	feet above mean sea level
FC	Fish consumption
FBC	Full Body Contact
GIS	Geographic Information System
g/day	grams per day
HUC	Hydrologic Unit Code
in.	inches
LA	Load Allocation
lbs/day	pounds per day
Ma	million years ago
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
mi.	miles
mi.^{2}	square miles
MOS	Margin Of Safety
MS4	Municipal Separate Storm Sewer System Permit
MSGP	Multi-sector General Permit
NPDES	National Pollution Discharge Elimination System
NCDC	National Climate Data Center
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
ppb	parts per billion
TMDL	Total Maximum Daily Load
USFS	United States Department of Agriculture- Forest Service
USGS	United States Geological Survey
WIP	Watershed Implementation Plan
WLA	Waste Load Allocation
WRCC	Western Region Climate Center
µg/L	micrograms per liter
YPIT	Yavapai-Prescott Indian Tribe

EXECUTIVE SUMMARY

Located within the Granite Dells rock formation, Watson Lake near Prescott, Ariz., has a colorful history. The waterbody is one of the oldest reservoirs in Arizona. The initial dam was constructed in 1914. Nearby, there was a swimming area and clubhouse, providing a popular 'spa' destination for locals and travelers. With growing population and irrigation needs, the dam was raised in 1937 to provide additional storage for the Chino Valley Irrigation District (Wells, date unknown). By the 1950s, storage was being supplemented by discharge of treated effluent from the City of Prescott's Sundog Wastewater Treatment Plant.

With development of the Clean Water Act and need for surface water protection, the Arizona Water Quality Control Board promulgated nutrient standards for the Verde River basin in 1981, including Granite Creek and Watson Lake. By 1983, Watson Lake was ranked "most eutrophic lake in Arizona" (Towler, 1983; Towler, 1986). Although the City of Prescott ceased discharge from Sundog to Granite Creek in 1989, high productivity and associated issues have continued. In 2000, the Arizona Game and Fish Department (AGFD) investigated a fish kill in which a large number of Golden Shiners (a small minnow) died. These fish are known to be "extremely sensitive to environmental stresses" (Dahlberg, AGFD). Watson Lake was included in the ADEQ lake monitoring rotation starting in 2002. Water Quality data collected between 2000 and 2004 led to the EPA listing Watson as impaired in 2004 for high nitrogen, high pH, and low dissolved oxygen (DO). TMDL development has extended the pollutants of concern to include phosphorus loading to the lake.

The Watson Lake TMDL was initiated in 2007 and developed concurrently with the CWA Section 319-funded *Improvement Plan for the Upper Granite Creek Watershed* (Prescott Creeks Association, 2012). The urbanized creek segments have been channelized and separated from their natural floodplains, increasing the risk of flooding to nearby properties. The majority of natural riparian vegetation has been replaced by walls or other structures and cannot adequately perform biological filtration functions. Stormwater drainage from roads and neighborhoods is directed into the nearest waterway. The data indicate that the primary factors leading to water quality impairments in the project area are nonpoint source pollutants, increased runoff volumes due to impervious surfaces, and a lack of stormwater detention and infiltration/filtration.

The TMDL takes a combined watershed and in-lake approach to determining nutrient loading that will meet the applicable Verde River nutrient water quality standards. The TMDL incorporates modeling of nutrient inputs using a software package developed by the Corps of Engineers (COE) called FLUX/PROFILE/BATHTUB, which diagnoses and predicts lake response (Walker, 1999). The model was supported by a lake bathymetry study. Based on the model's mass balance of nutrients, it will be necessary to reduce total nitrogen (TN) inputs by 34 percent and total phosphorus (TP) inputs by 32 percent; with consideration of background and a margin of safety, the overall reduction is 47 percent for total nitrogen and 49 percent for total phosphorus.

In meeting the Verde River nutrient criteria through a combination of watershed and in-lake loading reductions, average peak season chlorophyll-a in Watson Lake is expected to be reduced from an average of 28 ug/L to 10 ug/L, a 55 percent improvement based on mass balance nutrient reductions and corresponding chlorophyll-a levels from literature. pH is expected to meet the 9.0 SU standard in Segment 2 (deeper areas). Growth of submerged aquatic vegetation must be managed in order to meet the 9.0 pH standard in the shallow section of the lake. With lower biomass and active lake management, the DO standard of 6.0 mg/L in the top meter is expected to be met year-round and oxygen depletion rates in deeper waters should improve. Additional studies included sediment coring and limnocorral (mesocosm) investigation to inform lake management.

ADEQ will work with stakeholders to update the 2012 Watershed Improvement Plan, identify and prioritize watershed sampling for source determination, identify and prioritize locations for application of best management practices, and support development of a lake management plan to include ongoing lake monitoring and in-lake management strategies for lake improvement.

Table ES-1 Existing Loads, Loading Capacity, and Allocations

Conditions/Allocations	Annual Loading to the Lake	
	TN (lbs/yr): lbs/day	**TP (lbs/yr): lbs/day**
Existing Conditions	10,888/365 = 29.83	2,228/365 = 6.12
Loading Capacity (LC) 34% TN Reduction 32% TP Reduction	7,186/365 = 19.69	1,515/365 = 4.15
Background 10% of LC for TN 15% of LC for TP	1.97	0.62
Margin of Safety (10% of LC)	1.97	0.42
Available Capacity (LC – NB – MOS)	15.75	3.11
Waste Load Allocation	2,874/365 = 7.88	568/365 = 1.56
Load Allocation	2,874/365 = 7.88	568/365 = 1.56
% reduction from existing:	47%	49%

Table ES-2. Breakdown of WLA and LA based on Jurisdiction/Ownership

Ownership Categories	Watershed Area (%)	Watershed Area(sq mi)	Permits	WLA TN (lbs/day)	WLA TP (lbs/day)	Nonpoint LA TN (lbs/day)	Nonpoint LA TP (lbs/day)
Unallocated WLA Reserve 10% of WLA ADOT MS4 Other TBD				0.80	0.16		
City of Prescott	39	17.56	MS4 MSGP CGP	5.66	1.12		
Yavapai County (unincorporated)	10	4.46	MS4 MSGP CGP	1.42	0.28		
Total WLA	49	22.02		7.88	1.56		
Unallocated LA Reserve 15% of LA TBD						1.18	0.23
Prescott National Forest	40	18.11				5.90	1.17
State Trust	5	2.24				0.74	0.015
Military	0.2	0.08				0.06	0.001

Total LA	45.2	20.43				7.88	1.56

Initially, compliance with the TMDL will be established as a concentration-based target that supports the TMDL mass-based determinations so that all jurisdictions and permits will be held to the same water quality endpoint. Percentage reductions in nutrients are expected to be greater during the occurrence of wetter years, as the model year 2011 was a relatively dry year.

1.0 SETTING

1.1 Geography and Land Ownership

Watson Lake and its tributaries are located in the upper portion of the Verde Watershed. The watershed is approximately 40 square miles, varying in elevation from 7,000 feet in the upper watershed to 5,162 feet at the lake. Granite Creek and its tributaries drain south to north through the city of Prescott to Watson Lake, approximately three miles north of town.

Figure 1 shows the boundaries of the City of Prescott, Prescott National Forest-Bradshaw District, State Trust lands, Yavapai-Prescott Indian Reservation, and Military (Veteran's Hospital). Since the 1960s, the population of Prescott has more than doubled from less than 20,000 to more than 43,000. Currently, land ownership in the Watson Lake watershed is 40 percent City of Prescott, 40 percent Prescott National Forest, 10 percent Yavapai County, five percent State Lands, and five percent a combination of military and reservation (WIP, 2013). The creeks shown in red have been determined to be impaired for *E. coli.*

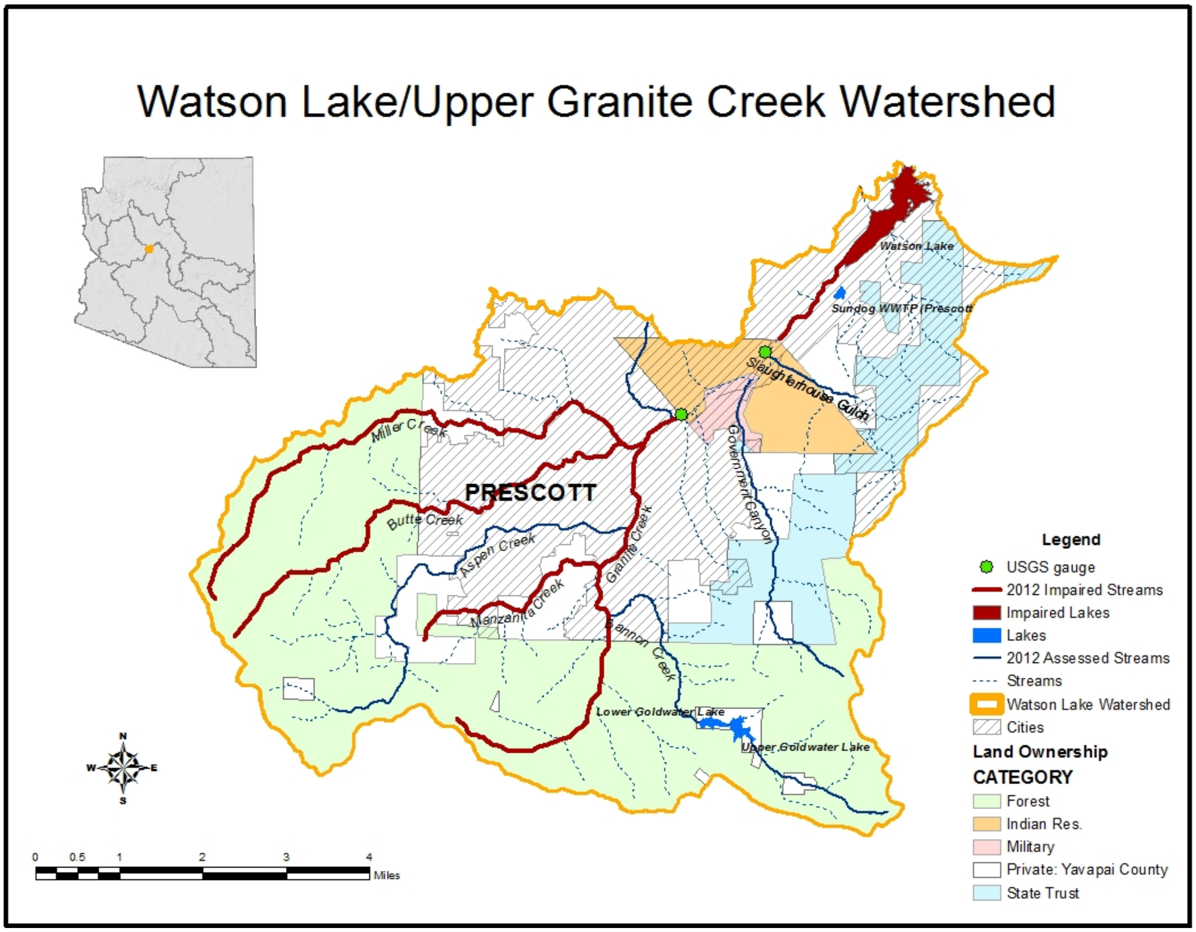

Figure 1. Location of the Watson Lake Watershed

A small percentage of land (less than five percent) in the Watson Lake TMDL Watershed is owned by the Yavapai-Prescott Indian Tribe (YPIT). The location of the Yavapai-Prescott Indian Tribe land is depicted on Figure 1 as “Indian Reservation”. ADEQ must consider federal Tribal Trust responsibilities in the Watson Lake Watershed since TMDLs are subject to the approval of the U.S. Environmental Protection Agency (EPA). The United States has a trust responsibility to protect and maintain rights reserved by, or granted to, federally recognized tribes and individual Indians, by treaties, statutes, and executive orders. The trust responsibility requires that federal agencies take all actions reasonably necessary to protect trust assets, including the fishery resources of the Indian tribes in the Watson Lake Watershed. ADEQ will assist USEPA in fulfilling tribal trust responsibilities by adopting a TMDL that restores and maintains pollutant levels that are protective of fish and other beneficial uses related to the YPIT to the degree that natural conditions allow.

1.2 Land Use

Land uses in the watershed include light industrial, urban commercial and residential, low-density residential, recreation, public purpose (e.g., cemeteries, V.A. Hospital), and special uses such as the wastewater treatment plant. Historically there was some lode and placer mining, but most occurred east, south, and west of the watershed divide. Grazing was common historically but currently only the YPIT grazes 40 head of cattle in a pasture along a two-mile section of lower Granite Creek. There is a range management schedule for these cattle and they are not grazed along the creek full time. Active timber management and controlled burning is ongoing for reduction of fuels near the wildland-urban interface. Currently, Prescott National Forest land is managed primarily for recreation.

1.3 Climate and Hydrology

The Prescott area is known for its ideal four-season climate. Average summer temperatures range from 52^{o} F to 89^{o} F; average winter temperatures range from 23^{o} F to 60^{o} F (The Weather Channel web site). Storms in July, August, and September deliver brief but intense precipitation; the average precipitation range for these months is approximately 1.7 inches to 4.41 inches (Western Regional Climate Center web site). The overall average annual precipitation for the area varies from as low as 13.5 inches to as much as 19 inches without snowfall. Winter storm season runs from December through April, with an average total snowfall of 20 or more inches (Prescott Chamber of Commerce web site; Wirt et. al, 2004). A second rainy season occurs during the winter months (December through March). In general, the winter events are less intense, but longer in duration and larger in extent.

Figure 2 shows the distribution of precipitation in the watershed as it relates to topography and corresponding stream gradients. Nearly 47 percent of the watershed land area has a slope greater than 15 percent; 33 percent of the land area has a slope between zero and 5 percent; and the remaining 20 percent of the land area has a slope between 5 and 15 percent (WIP, 2012; ALRIS gradient cover).

In general, the precipitation falling in the Prescott area and Chino basins, does not leave the Upper Verde as surface flow; the water not captured and utilized for irrigation or stored in reservoirs, evaporates and only about five percent recharges the alluvial aquifer (Wirt, 2004). Granite Creek and its tributaries are intermittent in the winter months and ephemeral in summer months.

Watson was originally impounded for irrigation between 1912 and 1915. Water rights were held first by the Arizona Land and Irrigation Company, then by the Hassayampa Alfalfa Farms in 1914 (later became the Chino Mutual Water Users Association) and eventually in 1925, the Chino Valley Irrigation District (CVID). The capacity of the storage right is 4,600 acre-feet. In the early 1990s, the City of Prescott began efforts to acquire both Watson and neighboring Willow Creek Reservoir. Working with the CVID, Salt River Project, and the Arizona Department of Water Resources, the City acquired the real property and water rights associated with both lakes in 1988.

Currently most runoff from Granite Creek to Watson Lake is stored under an agreement between the City and the Arizona Department of Water Resources for surface water supply and recharge credits, and for recreational purposes. The City manages lake levels and water is periodically released from the dam for irrigation and recharge downstream. Under the Watson and Willow Lakes Master Plan (Logan Simpson Design, Inc. 1999), the City strives to maintain a recreational pool of no less than 7 feet below the spillway whenever possible. Water from the lakes is also delivered to the recharge facility in an effort to augment the aquifer. The Water Resources and Management Report for Prescott, 2010, states that “complex legal restrictions and variable surface water flow as well as the city’s desire to maintain sufficient volume for recreation, limit the amount of and time periods during which lake water that can be delivered to the aquifer”.

The lake is stocked for recreational fishing and no-wake boating is allowed. The City of Prescott does not allow swimming, posting signs at ramp and dock areas. Above a certain elevation, water can also be shunted from Watson Lake to nearby Willow Creek Reservoir using the gravity-fed "cross cut ditch."

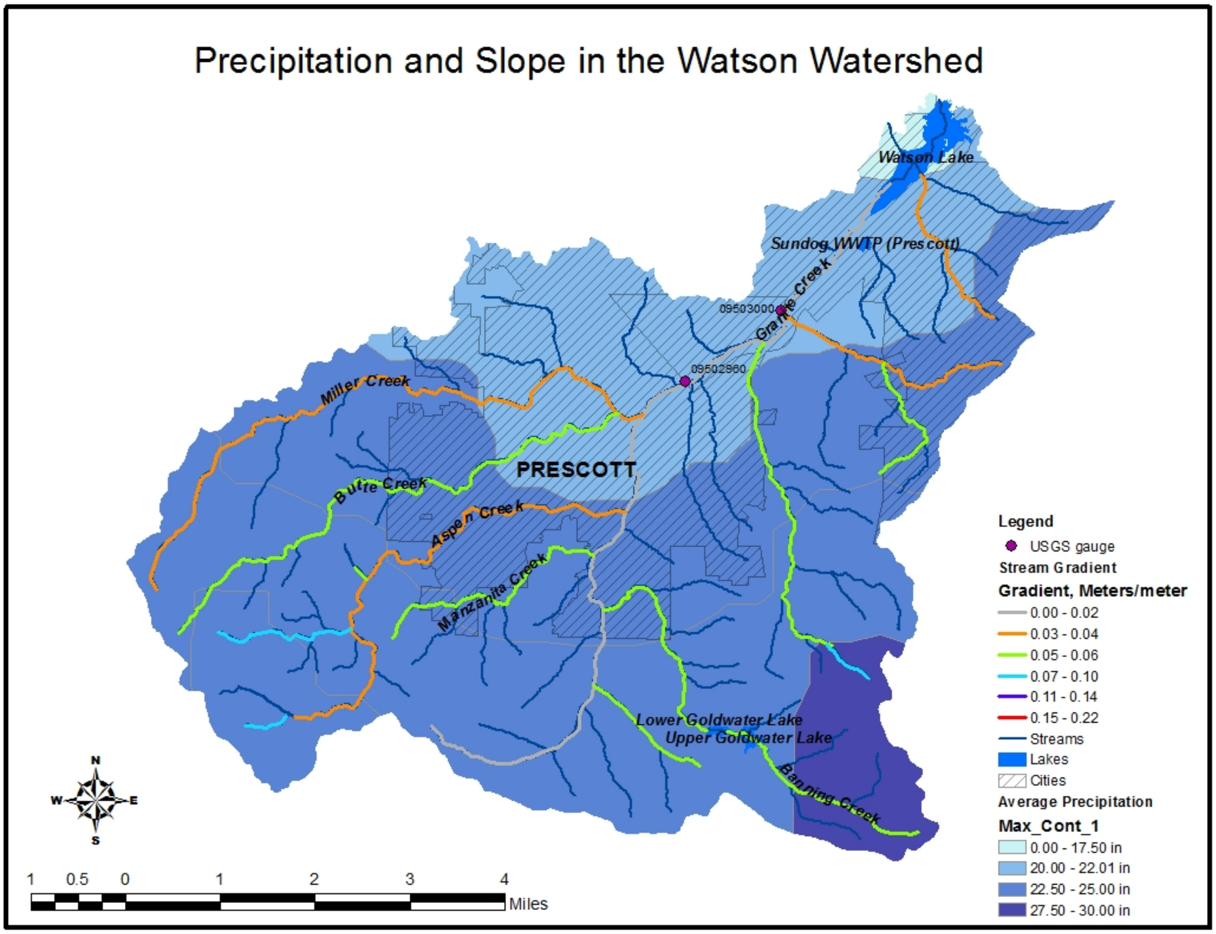

Figure 2. Precipitation and Watershed Slope

There are two USGS gauges located above Watson Lake (shown in Figure 2), and one gauge located below the lake. Figure 3 illustrates seasonal variability in surface flow in response to precipitation, showing sustained flow only during winter months at the USGS gauge at Prescott (09502960). Consequently, Watson Lake water levels vary seasonally and from year to year (Figure 4 shows the lake level fluctuations over the same 3-year period shown in Figure 3). Further discussion on inflows and lake levels is presented in Section 7.2 of this report.

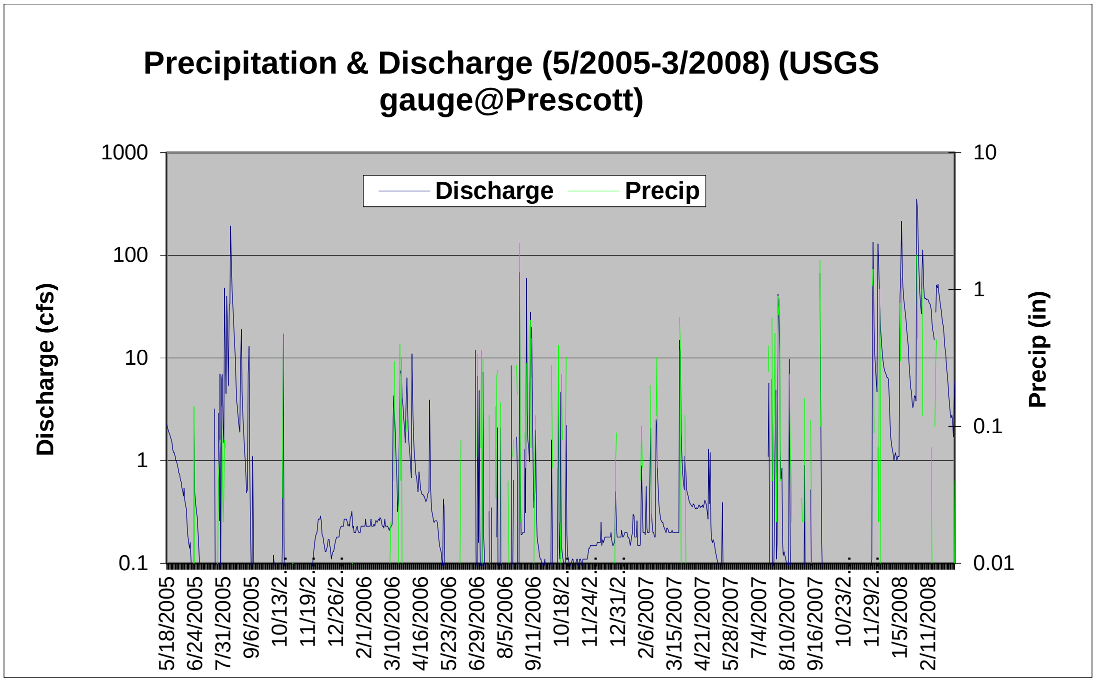

Figure 3. Rainfall and Runoff for Prescott USGS Gauge (5/2005-3/2008)

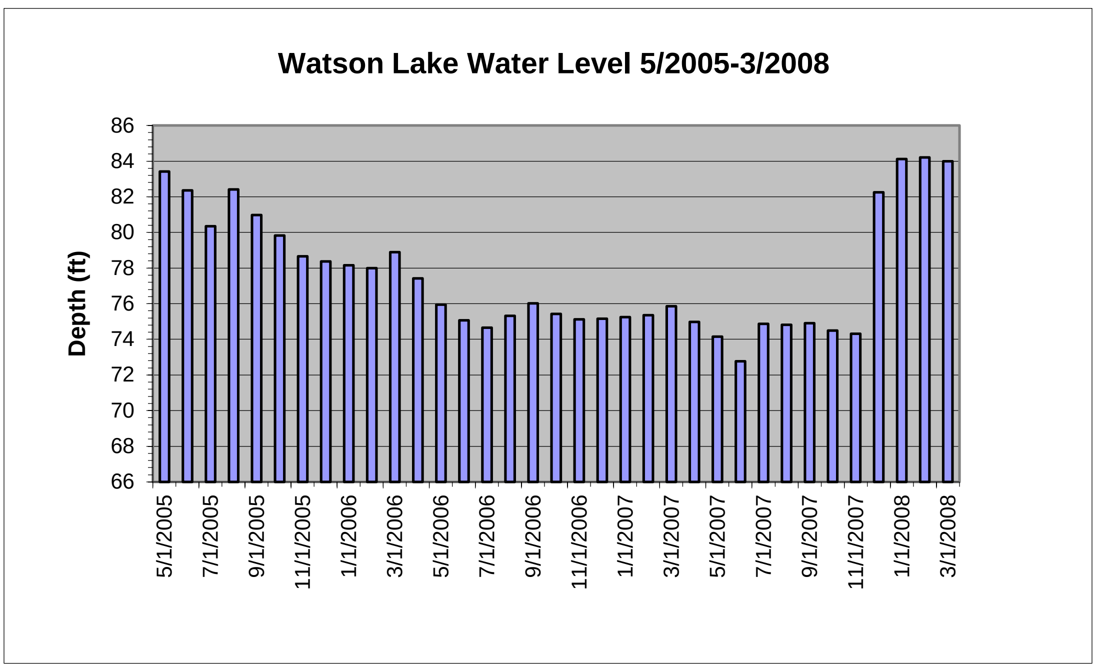

Figure 4. Fluctuations in Watson Lake Levels (5/2005-3/2008)

1.4 Geology, Soils, Vegetation, and Fire Impacts

Figure 5 shows the surface geology of the watershed. Most of the Watson Lake watershed, except the upper part of the Banning Creek watershed, falls into a soil erosion category that is moderate to high. In order of abundance, granitic geology dominates, followed by sedimentary, basalt, and volcanic.

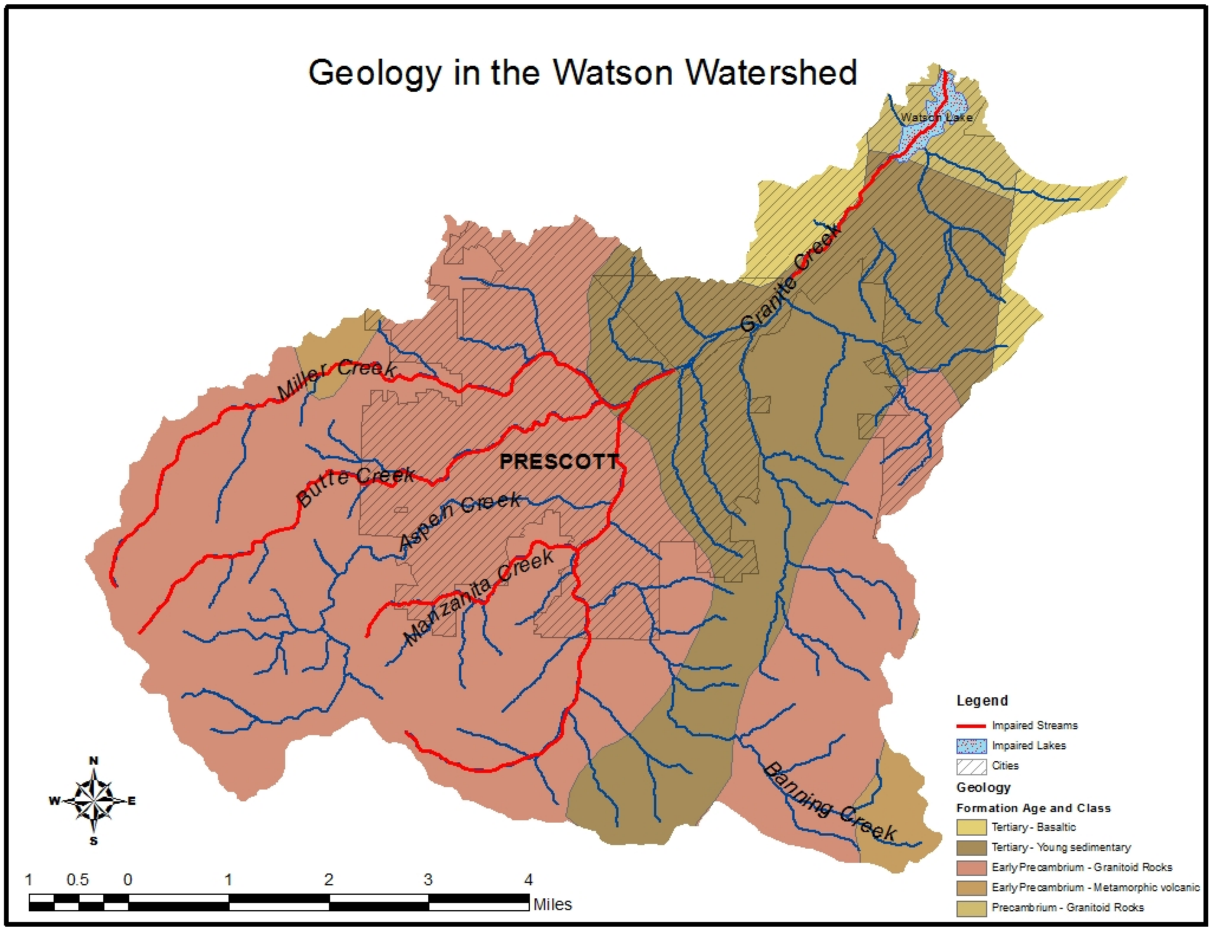

Figure 5. Surface Geology of the Watson Lake Watershed

The area is defined as a structural trough that trends northwest for a distance of about 25 miles from the southern part of the Upper Agua Fria sub-basin to the northern part of the Little Chino sub-basin near Del Rio Springs. The trough appears to have developed in late Tertiary time, 10 million years ago to the present, due to crustal extension in central Arizona and in the Basin and Range province to the south (Wirt et. al., 2004). Sub-surface geology consists of three hydro-stratigraphic units with similar hydrologic properties (Corkhill and Mason, 1995).

Vegetation within the Verde watershed varies with elevation, from desert shrub at the lower elevations through grassland, chaparral, canyon hardwoods, pinion and juniper woodlands, vast ponderosa pine forests and occasional stands of white fir and Douglas fir. The Watson watershed contains all these biomes except the desert shrub. The 2012 WIP mentions a 2011 Forest Service “Watershed Condition Framework”, which characterized the Upper Granite Creek watershed as “functioning properly” (healthy). However, geographic modeling by the University of Arizona’s Nonpoint Education for Municipal Officials (NEMO) program’s Watershed Based Plan for the Verde Watershed classified the Granite Creek subwatershed at moderate risk for sediment and extreme risk for organics. Mobilization of sediment and organics is exacerbated by the need to conduct controlled burns to stabilize the “wildland-urban interface”, the area or zone where structures and other human development meet or intermingle with undeveloped wildland or vegetative fuels (USFS, 2006). Figure 6 shows these burn locations (between 1 and 10 acres), as well as the 2002 Indian Fire (3,100 acres) and the 1950 Ruth Fire (1,200 acres) which burned across the watershed divide.

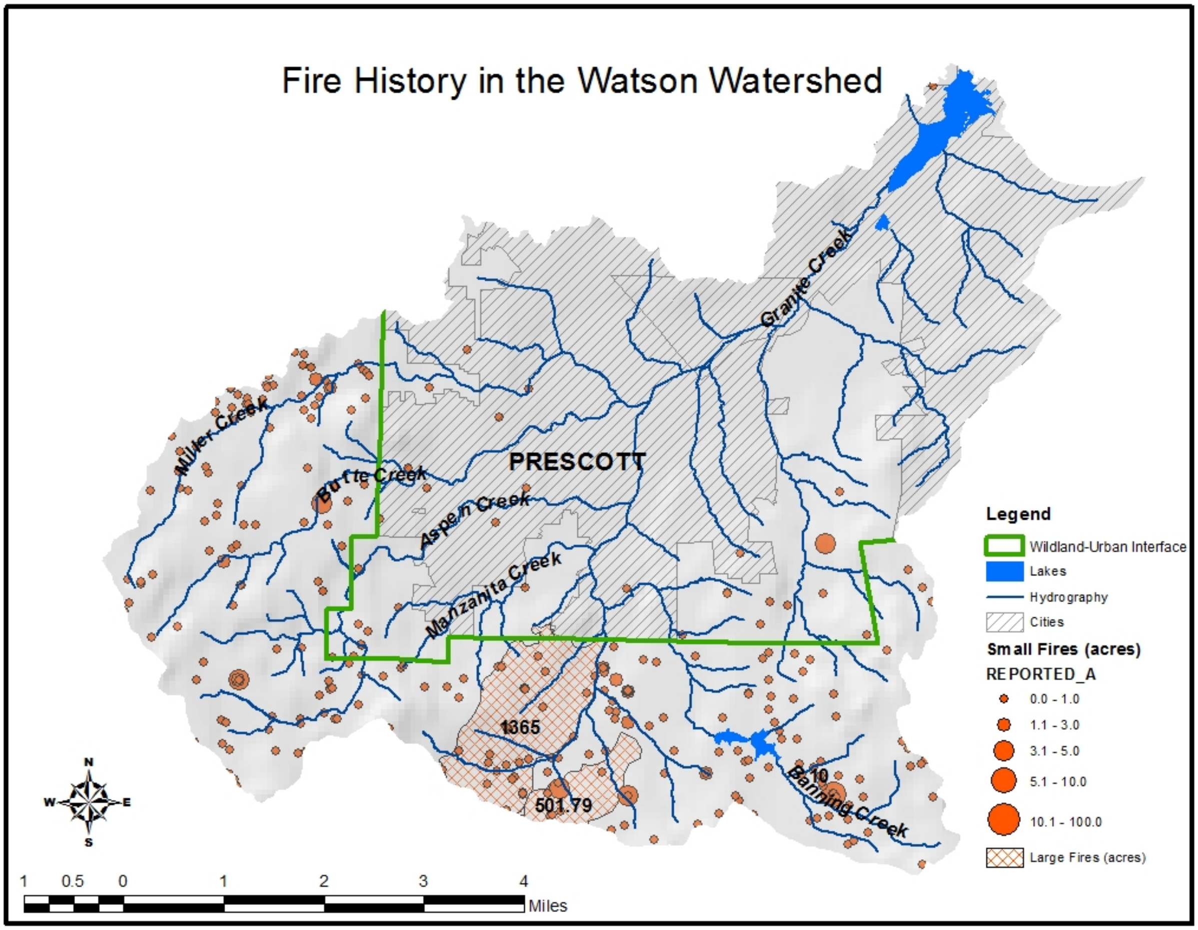

Figure 6. Fire History in the Watson Lake Watershed (USFS, 2006)

2.0 SOURCES OF WATER QUALITY DATA

2.1 Federal Monitoring

Prior to 2002, stream water quality data were collected by the USGS at the Prescott gauge station and by EPA and/or the U.S. Fish and Wildlife Service (USFWS) during superfund-related studies, e.g., Veteran's Hospital, Whipple Barracks, and a lumber treatment facility. USGS collected basic parameter suites in the 1980s and 1990s as well as one round of priority pollutant samples. The EPA and USFWS sampling concentrated on particular heavy metals and organic compounds that bioacummulate, such as mercury or polychlorinated biphenyl.

2.2 State Monitoring

Shortly after Watson Lake reached full pool for the first time after purchase by the City in 1999, the Arizona Game and Fish Department (AGFD) responded to a fish kill on Watson Lake during the summer of 2000. The AGFD reported that the kill was restricted to shad (small minnows) and the algal bloom responsible for the oxygen crash was the Cyanophyte *Aphanozomenon*.

The Verde River basin was a monitoring priority for ADEQ in 2003, the ADEQ Lakes Program collected four quarters of lake data at Watson Lake and three quarters of data at Willow Creek Reservoir. The ADEQ Fixed Station Network Program collected four quarters of stream data from Granite Creek above Watson Lake. TMDL sampling began in the summer of 2007 and was completed in 2013.

2.3 Prescott Creeks Preservation Association

Prescott Creeks Preservation Association (Prescott Creeks) is a local 501(c)(3) nonprofit organization with the mission "to achieve healthy watersheds and clean waters in central Arizona for the benefit of people and wildlife through protection, restoration, education and advocacy". The group has been committed to restoration of Watson Woods, the riparian area just above Watson Lake, since the mid-1990s. Beginning in 2006, ADEQ began providing funding support to Prescott Creeks through Clean Water Act 319 grants. During the development of the Watson Lake TMDL, Prescott Creeks received funding for restoration work in Watson Woods, baseline water quality monitoring, education and outreach, and development of a Watershed Improvement Plan (WIP) and demonstration project. ADEQ worked collaboratively with Prescott Creeks to collect surface water data on Granite Creeks and its tributaries to support both the WIP and the TMDL. Further discussion of stream data can be found in Section 7 of this report.

2.4 Northern Arizona University (NAU)

In 2011, ADEQ contracted with Northern Arizona University (NAU) to construct a bathymetric map of Watson Lake and to collect and analyze two deep sediment cores for depositional history. The results of this study will be discussed in Section 6 of this report.

2.5 University of Arizona (UA)

In a separate contract with the UA, two sets of two mesocosms (or limnocorrals) were installed in Watson Lake in the summer of 2011 to measure lake response to 1) nutrient addition and 2) aluminum sulfate (ALUM) application for nutrient removal. A follow-up study was conducted in the summer of 2012 to assess the impact of periphytin growth on phytoplankton biomass. The City of Prescott Public Works Department, Wastewater Division, assisted UA in collection of data from 8/2012 to 10/2012 by collecting samples and shipping to the specified lab. The results of this study are discussed in Sections 6 and 9 with additional detail in Appendix B.

3.0 LISTING HISTORY

3.1 Clean Water Act Section 303(d) List

Section 303(d) of the Clean Water Act requires states to compile a list, the 303(d) List, of surface waterbodies that do not meet applicable water quality standards. TMDLs must be developed for waterbodies on the 303(d) List. TMDLs set the amount of the given pollutant(s) that the waterbody can withstand without creating an impairment of that surface water's designated beneficial use(s).

3.2 Data used for original Watson Lake 2004 Listing on Arizona's 303(d) List

The 2004 ADEQ Water Quality Assessment included data collected up through October 2002. Listing data for Watson Lake were based on a fish kill investigation by AGFD in the summer of 2000 and follow-up data collected by ADEQ from 2002 through 2004. Listing data for Granite Creek included samples collected by AGFD above Watson Lake and data collected by the USGS from 1998 to 2001 at the upper USGS gauge (09502960) in Prescott. ADEQ assessed both the lake and creek as "inconclusive", but EPA "over-filed" and listed both as impaired by low DO and Watson Lake as also impaired by high total nitrogen and high pH.

3.3 Assessment of Watson Lake and Granite Creek since 2004

Watson Lake and Granite Creek were added to the 2004 Water Quality Impaired Waters List (303(d)). Watson Lake was listed for low DO, high pH, and nitrogen in excess of the Verde Water Quality Standards; these listings have continued through subsequent assessments. Although Granite Creek and Watson Lake have not been assessed as impaired for phosphorus, based on subsequent data collection and lake response modeling, phosphorus reductions will also be required to achieve target chlorophyll-a levels.

Following the 2004 listing, TMDL sampling (2007 – 2012) of Granite Creek and its tributaries shows few DO samples below the standard of 7.0 for cold water streams, all but two lower values occurred below 1 cubic feet second (cfs) during short intense summer storms or first flush events when organic material washes in from overland flow (Figure 7). ADEQ intends to develop a separate report in late 2014 that demonstrates the streams are not impaired by low DO based upon recent data.

The 2010 Integrated 305(b)/303(d) Report identified Granite Creek (excluding the segment through the YPIT) and Miller Creek as impaired for *Escherichia Coli* (*E. coli)*. Most tributaries have shown exceedances of *E. coli* under storm conditions. The latest draft 2012 Integrated 305(b)/303(d) Report adds Butte Creek and Manzanita Creek to the impairment list for *E. coli*. A separate TMDL is being prepared for *E. coli*, expected to be released in December of 2014 for public comment. Based upon ADEQ assessment methodology, no streams within the Watson watershed meet the criteria for nutrient impairment.

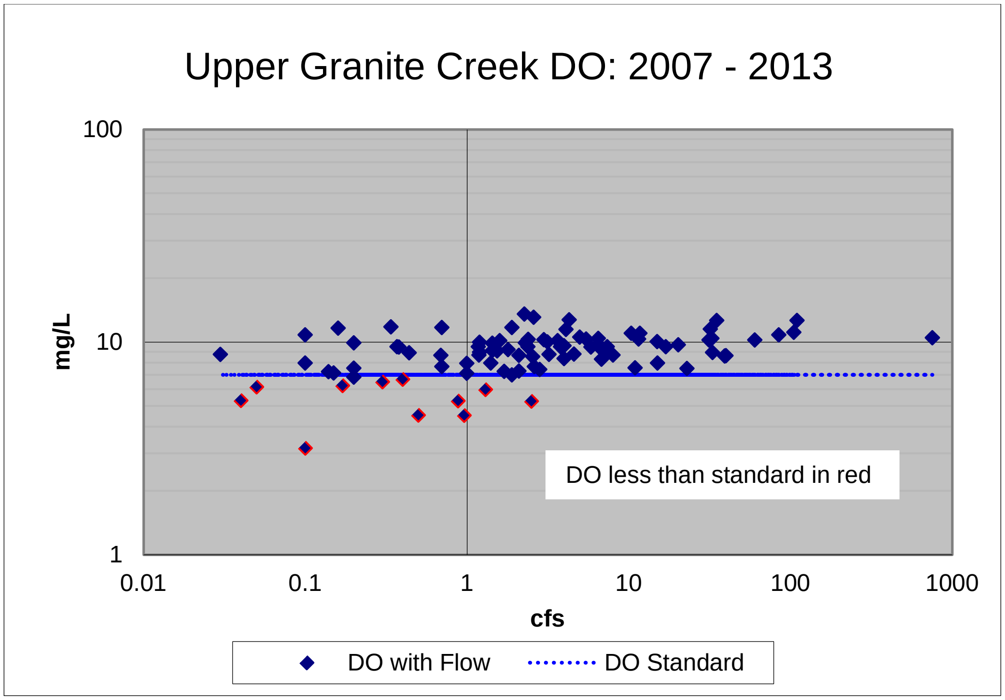

Figure 7. Granite Creek and Tributary DO values

4.0 TMDL NUMERIC TARGETS

4.1 Beneficial Use Designations

ADEQ codifies surface water quality standards in the Arizona Administrative Code (A.A.C.), Title 18, Chapter 11. Designated beneficial uses, such as fish consumption, recreation, agricultural uses, and support of aquatic and wildlife, are described in A.A.C. R18-11-104 and are listed for specific surface waters in Appendix B of A.A.C. R18-11. Designated uses for Watson Lake and Granite Creek and its tributaries are shown in Table 1. Granite Creek tributaries above the reservoir are intermittent and carry the Aquatic and Wildlife–cold water (A&Wc) designation based on elevation (above 5,000 feet), in addition to Full Body Contact (FBC) and Fish consumption (FC). Watson Lake is located around 5,000 feet and is designated as warm–water, as are the creeks downstream of the reservoirs. Granite Creek below Watson is also intermittent for approximately two miles and then it goes subsurface or is diverted to the recharge basin.

Table 1. Designated Uses

WATERBODY	DESIGNATED USES
Watson Lake	A&Ww, FBC, FC, AgI, AgL
Granite Creek above Watson Lake*	A&Wc, FBC, FC, AgI, AgL
Granite Creek below Watson Lake	A&Ww, FBC, FC, AgI, AgL

A&Ww: aquatic and wildlife-warm water   AgL: agriculture livestock watering
AgI: agriculture irrigation
*Arizona Surface water quality standards are not applicable on tribal land; Granite tributaries carry only A&Wc, FBC and FC

4.2 Current Water Quality Standards (WQS)

The State of Arizona's surface water quality standards for nutrients are listed in A.A.C. R18-11-108 and 109. Numeric criteria for TN and TP apply to all streams in the Verde River Watershed. Numeric nutrient criteria were derived for single sample maximum, 90th percentile, and annual mean values. DO criteria differ depending on whether the waterbody is designated as cold-water or warm-water. The criteria for pH are consistent between warm and cold water and between reservoirs and streams. Primary applicable WQS are summarized in Table 2. The TMDL is written to meet the annual mean Verde River nutrient standards at Watson Woods above the lake and within the lake itself.

Table 2. Water Quality Standard Targets for Watson Lake, Granite Creek and their Tributaries

Analyte	**Verde River and its tributaries**	**A&Wc**	**A&Ww**	**FBC**	**AgI**	**AgL**
Total Nitrogen (mg/L) Single Sample Max Annual Mean	 3.0 1.0					
Total Phosphorus (mg/L) Single Sample Max Annual Mean	 1.0 0.1					
Dissolved Oxygen (mg/L)		7.0	6.0			
pH (SU)		6.5-9.0	6.5-9.0	6.5-9.0	4.5-9.0	6.5-9.0
Narrative Standard	"A surface water shall not contain pollutants in amounts or combinations that cause the growth of algae or aquatic plants that inhibit or prohibit the habitation, growth, or propagation of other aquatic life or that impair recreational uses"					

ADEQ is updating and refining the Narrative Nutrient Standards for lakes and reservoirs (A.A.C. R18-11-108.03). If and when those criteria are formally accepted by the EPA, ADEQ will make revisions based on the EPA accepted in-lake targets.

5.0 SOURCE IDENTIFICATION

5.1 Watershed Information Resources

Numerous data sets were analyzed in an effort to understand the origins and nature of the pollutants in Watson Lake and Granite Creek. In addition to water quality and sediment sample results, field observations, physiographic data, hydrologic data, and meteorological data were evaluated. The physiographic, hydrologic, and meteorological information were taken primarily from published references and websites, as listed in the references.

5.2 Point Source Loading

Point source loadings represent a discharge directly entering a waterbody via a discrete conduit such as a pipe which impacts the overall pollution loading of the waterbody. The discharge may be characterized as having a positive or negative impact, depending upon whether the inflow decreases or increases the concentration of the pollutants in the waterbody.

Historically (1950s to 1988), the Sundog Wastewater Treatment Plant discharged secondary treated effluent to Granite Creek about one-fourth mile upstream of Watson Lake. With initiation of the Verde River nutrient standards in the early 1980s, and in response to subsequent pressure from EPA to meet its National Pollution Discharge Elimination System (NPDES) permit, the City of Prescott commissioned a study to explore management implications for Watson Lake (Sommerfeld and Ellingson, 1984). At that time, it was estimated that 53.8 kg P/day (118 lbs P/day) and 199 kg N/day (438 lbs N/day) entered Watson Lake, approximately 66 percent of the total nutrient load (remaining 33 percent non-point source). The Northern Arizona Council of Governments *Watson Lake Water Quality Management Plan* (Towler, 1986) states that effluent made up as much as 40 percent of the flows to Watson Lake (1,960 acre feet per year of 4,830 acre feet total lake volume) during winter months when effluent was not diverted for irrigation of golf courses.

The City's application for a Nutrient Waiver was ultimately denied by the Water Quality Control Council, precursor to ADEQ. By 1989, the City of Prescott had lined the effluent ponds and constructed a bypass around the lake to recharge excess effluent near the Prescott Airport. The City no longer has a wastewater discharge permit; the 2009 Annual Water Use and Withdrawal Report states that the City distributed the 4,019 acre-feet (AF) of reclaimed water for direct reuse at Antelope Hills Golf Course (1,419 AF), Prescott Lakes Golf Course (458 AF), Hassayampa Golf Course (212 AF), and Commercial/Other 958 AF), with the remaining 2,430 AF being recharged.

However, while the bypass has certainly improved the situation for Watson Lake, there have been occasional storm-induced upsets. According to the WIP, 2012, p17):

> *"With some of this infrastructure as old as 90 years (City of Prescott, 2010) and even recent infrastructure in need of upgrades, sewer overflows are not entirely uncommon. During a heavy winter storm in January 2010, stormwater inundated aging sewer lines, resulting in sewer overflows from five manholes along Granite Creek and Miller Creek. The cumulative effect of the inflow and infiltration forced the sewage treatment plant to discharge three million gallons of partially treated effluent into nearby Granite Creek just above Watson Lake (Dodder, 2010)".*

In response to this unintended discharge, the City of Prescott has made further efforts to prevent sewer overflows by 1) surveying all manholes in waterways, replacing manhole covers that were ripped off, locking all covers that currently have the locking ability, and identifying manhole lids that will be upgraded. A manhole insert program is also being implemented to reduce the amount of inflow water that enters manholes from the streets (WIP, 2012).

Currently, there are two general Municipal Separate Storm Sewer Systems (MS4) permits held by the City of Prescott and Yavapai County and one individual MS4 stormwater permit held by the Arizona Department of Transportation. General Construction Permits (CGP) are numerous and of relatively short duration. There are also several Multi-sector General Permits (MSGP) issued by ADEQ. A complete list of permits relevant to Watson Lake can be found in Table 10 in Section 8.3.2 of this TMDL.

5.3 Nonpoint Source Loadings

Nonpoint source loadings represent a diffuse form of water pollution from various natural and anthropogenic sources that accumulate in a watershed and are most often transported to the waterbody via precipitation runoff. The following are possible sources of nutrients identified within the Watson Lake watershed:

- Golf course fertilizer
- Lawn fertilizer
- Effluent reuse on golf courses
- Illicit discharges to creeks
- Septic leach fields
- Water reclamation plant
- Aerial deposition
- Breakdown of vegetation
- Burned vegetation and ash from fires
- Domestic and wild animal waste
- Historic dumping
- Historic landfills

The WIP contains a thorough review of these potential non-point sources (WIP, 2012). A brief summary of WIP findings provides insight into potential nonpoint sources, although none could be directly quantified:

- There are approximately 5000 customers of the City's water service (combination of City and County parcels) that are not connected to the sewer system and rely on septic systems for wastewater disposal
- As a rough estimate, there are 166 residential parcels likely to have one or more septic systems that are within the 100-year floodplain; a reasonable estimate for septic discharges is a total load of 19 lbs/yr of nitrate and 0.4 lbs/yr of orthophosphate.
- There are 55 acres of golf courses that receive treated effluent at Grade B+, which does not have a nitrogen management requirement
- Gray water reuse occurs in the watershed, requiring a Type 1 Reclaimed Water General Permit (for less than 400 gallons per day); some nutrients and pathogens may be present
- Five acres are zoned for horses or boarding stables; the only known grazing within the project area is on Yavapai-Prescott Indian Tribe property and on private and State Trust Lands off of Prescott Lakes Parkway
- Numerous residences of the upper watershed keep animals on their property: a few hundred horses, no more than a few dozen cattle, chickens, ducks, geese, turkeys, sheep, goats, and pigs
- Wildlife include mountain lion, bobcat, mule deer, squirrels, wild turkeys and other avian species, skunks, raccoons, and javalina
- Pet waste from domestic dogs and cats or boarding facilities; there are no designated dog parks within the Watson Lake drainage
- Runoff from wildfires; The Indian Fire of 2002 burned a total of 1300 acres including the upper reaches of several tributaries and Upper Granite Creek. Areas of wildfire and controlled burning within the wildland-urban interface likely contribute nitrate and phosphorus to creeks during storm events
- Impervious cover within the Watson watershed is 5,310 acres or 18.6 %, which increases the volume and velocity of runoff; EPA (2009) rates a subwatershed with between 10 – 25 % impervious cover as "degraded"; impervious cover in all but the headwater subwatersheds are well above 10% - in some cases over 50% - indicating serious degradation in most of the Watson Lake watershed. Annual phosphorus, nitrogen, chemical oxygen demand, and metal loads increase in direct proportion with increasing impervious area.
- In all, Prescott has 400 miles of streets and storm sewers (conveyances other than wastewater)
- High recreation within the watershed is considered a source of *E. coli* but not nutrients

- The Microbial Source Tracking data collected through the Watershed Improvement Planning project found bacteria from bovine sources during a January 2010 storm so it is likely the cattle may be contributing nutrients to Granite Creek under storm conditions.

A summary discussion of watershed data collected within the context of the TMDL is offered in Section 7 of this TMDL, with additional detail provided in Appendix A.

6.0 TMDL DEVELOPMENT

6.1 Conceptual Model

This TMDL incorporates available information and combines empirical data for watershed analysis, load duration curves, and the use of a software package developed by the Corps of Engineers (COE) called FLUX/PROFILE/BATHTUB, which diagnoses and predicts lake response (Walker, 1999). The TMDL incorporates modeling of nutrient inputs from both external (watershed) and internal (in-lake cycling) sources. The primary external loading site to Watson Lake has been set at Watson Woods near the USGS Sundog Road gauge (09503000), as this site captures the largest portion of watershed loading to Watson Lake. Relative loads from background forest and the bottom of each of the major tributaries were also estimated to guide further source identification and TMDL implementation.

A TMDL is the total amount of a pollutant that can be assimilated by the receiving water while still achieving surface water quality standards. TMDLs can be expressed in terms of mass per time or by other appropriate measures (i.e. pounds per day or grams per day). TMDLs are comprised of the sum of individual wasteload allocations (WLAs) for point sources, and load allocations (LAs) for nonpoint sources and natural background. In a lake or reservoir TMDL, internal cycling of pollutants is also a crucial consideration. The TMDL must include a margin of safety (MOS), either implicitly or explicitly, that accounts for the uncertainty in the relationship between pollutant loads and the quality of the receiving water body. This definition is expressed as:

$$\text{TMDL} = \sum \text{WLA} + \sum \text{LA} + \text{MOS}$$

To develop TMDLs for Watson Lake, the following approach was taken.

1. Collect and review recent and historic data
2. Select model(s) and associated inputs
3. Define TMDL endpoints
4. Simulate existing conditions through a range of seasons and flows
5. Assess source loading alternatives
6. Determine the TMDL and source allocations

Watson Lake is a monomictic lake, indicating that the lake stratifies into two layers (the shallower epilimnion and the deeper hypolimnion) once during the summer, and the entire lake mixes during the rest of the year. Stratification has a strong influence on nutrient balances, algal productivity, and dissolved oxygen concentrations within the growing season. Characteristics of the lake that affect the degree of impairment include watershed nutrient loading, submerged aquatic vegetation (SAV), algal production, lake depth and volume, and the composition of bed sediment. Nutrient loading, light, and warm temperatures stimulate the growth of primary producers (algae, plankton, SAV, etc.).

External sources of nutrient loading include urban stormwater runoff, nonpoint wastewater sources, atmospheric deposition directly to the lake, and other nonpoint sources, including runoff from undisturbed natural land cover. Lake levels affect the surface area of the substrate available for SAV growth as well as the volume of water conducive for algal and plankton growth.

Internal sources of loading include die-off of algae, plankton, SAV, and other organisms, which results in either the release of dissolved nutrients from decomposition or the storage of organic matter in bed sediments, which can later be released as dissolved nutrients through longer-term decomposition and chemical processes. These dissolved nutrients represent the internal nutrient loading in the lake that can further stimulate productivity. Excessive productivity can lead to algal blooms and low dissolved oxygen. Low dissolved oxygen is of particular concern in the deeper hypolimnion layer that is not exposed to the atmosphere during stratification. Fish and other organisms that require oxygen will be forced to avoid deeper depths, which can severely limit their optimum habitat and even lead to death.

Increased toxicity is also a potential concern with excessive productivity. As primary producers consume dissolved carbon dioxide, the pH of the water column increases. Elevated pH can lead to increased concentrations of dissolved, unionized ammonia ($NH3$), with is potentially toxic to aquatic life. In addition, some algal species can directly produce substances toxic to both humans and aquatic life.

6.2 Overview of Watson Lake Studies in Support of the TMDL

ADEQ collected samples from three sites within Watson Lake from 2002 to 2012. Data on nutrient species, chlorophyll-a, organic carbon, and field parameters were used in model development.

Tetra Tech, Inc. was contracted to evaluate nutrient loading to Watson Lake and in-lake response. The BATHTUB model (Walker, 2004), a well-known and nationally applied model, was selected based on its relevance to the study questions and applicability to the data sets available. The model simulates steady-state water and nutrient mass balances in a spatially segmented hydraulic network that accounts for advective transport, diffusive transport, and nutrient sedimentation. Empirical relationships previously developed and tested for reservoir applications (Walker, 1999) form the basis for model simulation of eutrophication-related water quality conditions (expressed in terms of growing season average TP, TN, chlorophyll-a, transparency, organic nitrogen, non-ortho-phosphorus, and hypolimnetic oxygen depletion rate). This model was chosen for Watson Lake because it does not require extensive watershed or lake input data and it provides a simulation of lake sedimentation rates, which are important for considering the effect of internal loading on lake nutrient concentrations (Tetra Tech, 2012).

A number of model assumptions were required to develop inputs to BATHTUB, including setting the growing season as May through October and dividing the lake into two segments with separate model inputs (Tetra Tech, 2012). ADEQ provided Tetra Tech with daily mean flow data interpreted by FLUX (BATHTUB loading program) as well as independent analysis of monthly mean flows. As BATHTUB requires monthly loading data, Tetra Tech evaluated both monthly/seasonal and annual time steps to calculate nutrient loading to Watson Lake.

Dr. Paul Gremillion from NAU collected bathymetry data in June 2009. Bathymetry is necessary for lake modeling, as it provides the data to calculate lake volume, surface area, and water retention time. In the summer of 2011, Gremillion extracted two long sediment cores from Watson for analysis of deposition rates over time as well as isotopic analysis of nutrients. Discussion of coring results can be found in Section 6.3.5 of this report.

Dr. David Walker from the University of Arizona Environmental Research Lab (ERL) conducted in-situ analysis of algal response to nutrient loading using two sets of paired mesocosms, or limnocorrals. Walker also tested the efficacy of dosing the lake with ALUM to reduce nutrients available to algae. The Walker study ran two summers, the first in late 2011 and the second in late 2012 (Walker, 2013). Discussion of the results can be found in Section 9 and Appendix B of this report.

The results from the Gremilion and Walker studies were provided to Tetra Tech. Unfortunately, the chlorophyll-a data collected by ADEQ and by Walker did not provide a good calibration with nutrients due to the unique character of the dominant alga (clumping cyanobacteria with high biovolume but lower chlorophyll-a). Walker conducted a Phase II study to evaluate the impact of algal growth on rocks, as this phenomenon appears to be contributing significantly to overall biomass. However, in the absence of a robust nutrient-chlorophyll relationship, Tetra Tech defaulted to a nutrient mass-balance approach for establishing nutrient targets in Watson that would meet the annual mean Verde River nutrient water quality standards.

6.3 BATHTUB Modeling

Model development focused on the years of 2010 and 2011 because these years provided the most nutrient and chlorophyll-*a* data for calibration. The year 2007 was also modeled and served as a model validation year. 2010 represents a relatively wet year and 2007 represents a relatively dry year in terms of inflow to Watson. The primary model calibration year of 2011 was determined to be much dryer than 2010 and much more similar to 2007 (Figure 8).

6.3.1 Inflow Records and BATHTUB Calibration

Loading to the lake occurs during runoff and precipitation events which in effect reloads the in-lake nutrient cycling system. The Yavapai County Flood Control Alert System has several precipitation gauges within the watershed. Figure 9 shows the distribution of precipitation across the watershed from southeast to northwest across the time frame when most lake data were collected (2007 – 2013) and explains why inflow records are so variable.

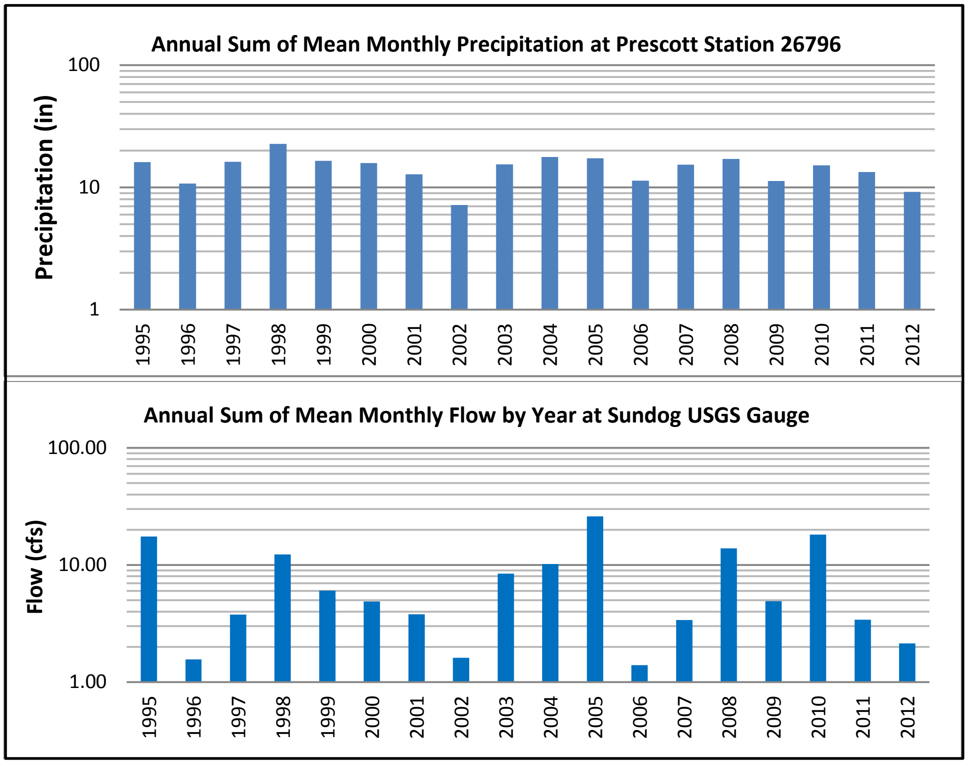

Figure 8. Variation in Annual Precipitation and Flow above Watson

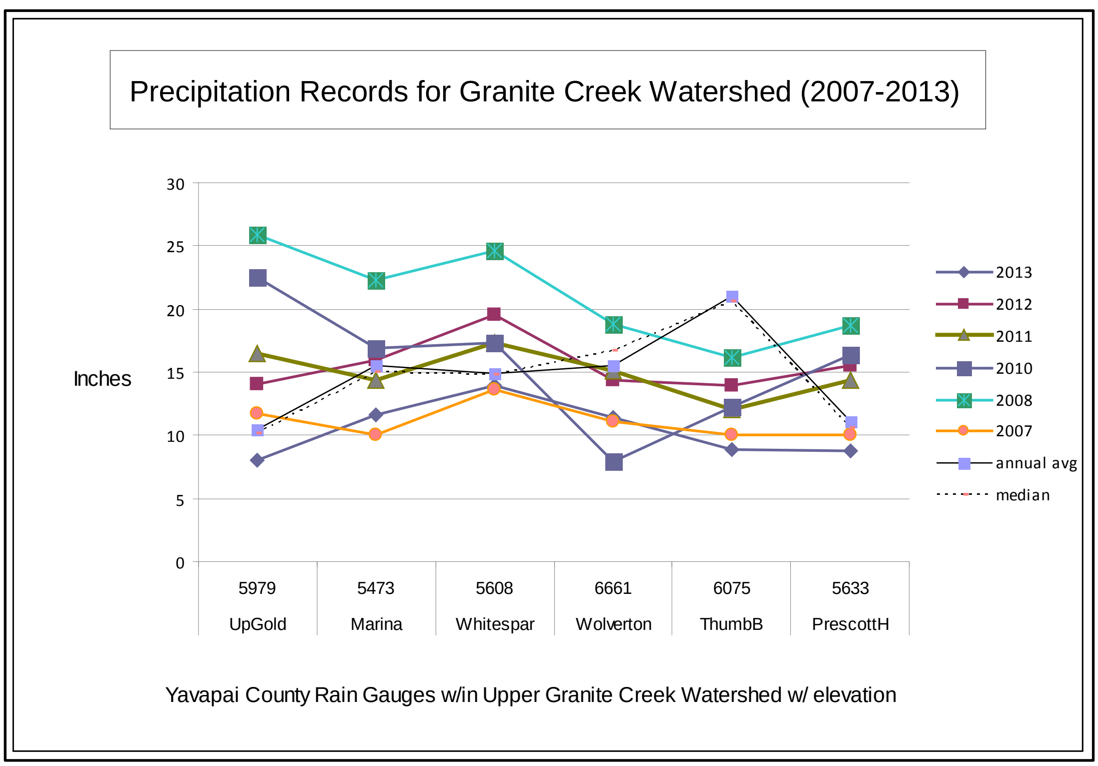

Figure 9. Granite Creek Watershed Precipitation Data (2007-2013)

In 2008 and 2010, precipitation was highest in the southeast section of the watershed (Upper Goldwater/Upper Government) and corresponded with higher flows at the lower Granite Creek gauge. Those years represent the higher end of the last 15-year period of flow records, as indicated by monthly mean and annual mean flow statistics (Table 3).

Higher flows in 2008 and 2010 produced a flushing effect for Watson Lake, in that more water flowed through the lake and was released than in an average year, diluting and displacing part of the nutrient load downstream.

In-lake response (productivity) is linked to precipitation and runoff, lake level, and internal nutrient cycling. The BATHTUB model requires mean monthly inflow data. From flow records, ADEQ estimated monthly loading rates to Watson Lake for TP, TN, inorganic nitrogen (TIN), and ortho-phosphorus from grab sample data collected at the Watson Woods site above Watson Lake. Monthly loads were annualized for 2010 and 2011, and validated with data from 2007.

To account for hydrologic variation, BATHTUB model runs were developed for 2007, 2010, and 2011; model calibration was based on 2011 data when in-lake water quality resolution was greatest (Figure 10).

Table 3. USGS Mean Monthly and Mean Annual Flow Statistics (cfs) for Sundog Gauge

USGS Stats	Monthly Mean (cfs)												Annual Mean (cfs)	
Calendar Yr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yr	ranked high to low
1995	3.55	2.39	2.57	0.69	0.67	0.17	0.45	1.84	3.35	0	0.16	0.31	2005	33
1996	0.14	1.46	0.59	0.03	0	0.29	4.46	0.3	2.13	0.37	0.59	0.4	2010	17.6
1997	3.2	1.69	0	1.18	0.27	0.15	0.32	2.8	3.95	0.14	0.25	2.24	1995	17.4
1998	0	3.12	3.17	1.24	0.45	0	5.66	4.24	2.08	1.09	1.05	0.6	2008	13.5
1999	0.15	0.35	0.84	0.95	0.38	1.08	5.4	2.92	4.45	0	0	0	1998	12.3
2000	0.26	1.2	2.13	0.24	0	1.48	1.06	3.71	0	5.18	0.51	0.05	2003	8.26
2001	1.2	1.15	1.55	0.6	0.42	0.38	0.9	3.81	0.5	1.08	0.56	0.66	2009	6.94
2002	0.03	0	0.23	0.39	0	0	1.99	0.11	2.38	0.79	0.69	0.56	1999	6.23
2003	0.53	3.43	1.95	0.26	0.03	0.01	3.32	2.77	0.97	0	1.52	0.64	2001	5.37
2004	0.47	1.1	0.38	2.11	0	0	2.47	1.56	1.16	3.45	2.64	2.44	2011	3.96
2005	4.45	3.87	1.46	1.39	0	0.29	1.15	3.51	0.19	0.94	0.03	0	1997	3.37
2006	0.14	0	1.78	0.8	0.06	0.61	1.56	2.79	2	1.34	0.01	0.29	2000	3.36
2007	0.36	1.03	1.28	0.12	0.26	0	4.74	1.78	1.92	0.03	0.02	3.85	2004	2.81
2008	3.87	2.17	0.08	0	0.58	0	2.94	1.75	0.64	0.03	1.55	3.47	2012	2.29
2009	0.19	2.16	0.06	0.83	0.9	0.11	2.09	0.79	1.35	0	0.09	2.71	2002	1.59
2010	5.6	2.04	1.8	0.44	0	0	1.51	3.34	0.1	1.41	0.44	3.01	1996	1.55
2011	0	3.24	0.59	0.63	0.4	0	1.8	0.55	1.82	0.9	1.08	2.33	2006	1.39
2012	0.23	0.26	2.07	0.78	0	0	3.19	1.8	0.85	0.04	0	0.79	2007	1.39

Light Shading = TMDL sampling years
Dark Shading = Modeled years

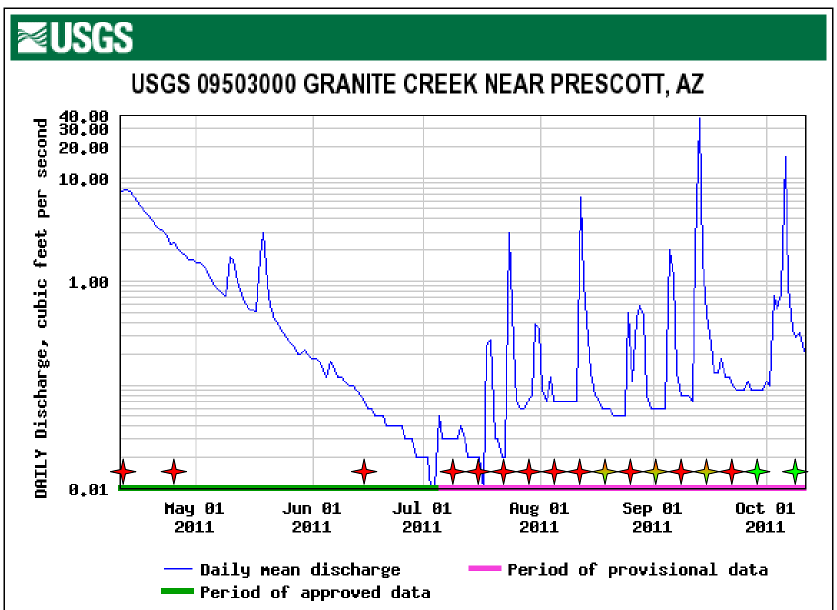

Figure 10. Lake Sampling (stars) and Flows in 2011

Based on the calibration results, the 2011 model provided a more reliable estimate of lake level and retention time compared to the 2010 model and is likely more representative of the typical water and nutrient balance of the lake. Lake elevation in August 2011 was close to the median at 5155 feet (large star) as opposed to August 2007 and August 2010 (small stars), which is the City's target elevation for the recreational pool (Figure 11).

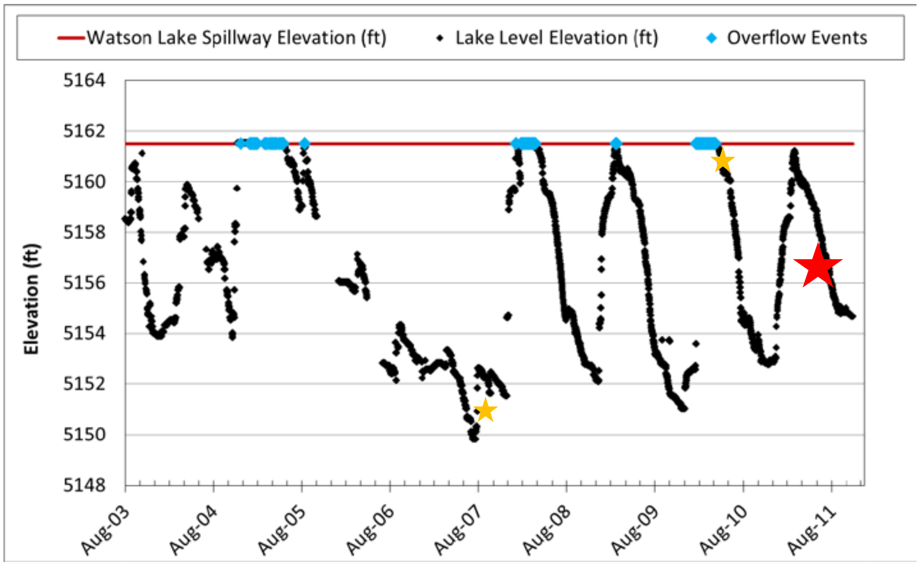

Figure 11. Lake Level Fluctuations within the TMDL Study Period
★ Lowest and highest lake level sampled ★ Conditions modeled

6.3.2 Lake Segmentation

To capture the variation in water quality and morphology between the upper and lower portions of the lake, Tetra Tech divided Watson Lake into two model segments. The first segment, identified in the model as Segment 1, is the upstream portion of the lake that is greatly influenced by the growth of submerged aquatic vegetation (SAV) (Figure 12). The second segment, identified in the model as Segment 2, represents the remaining downstream portion of the lake, from near the boat ramp north to the dam. Segment areas were selected by Tetra Tech based on what appeared to be an obvious and natural division within the lake. Segment 1 includes very shallow areas with depths ranging from 0 to 4.5 meters and is predominantly covered by SAV throughout the growing season. Segment 2 was predominantly open water throughout the year with depths ranging from 0 to 14.9 meters with greatest depths recorded near the dam.

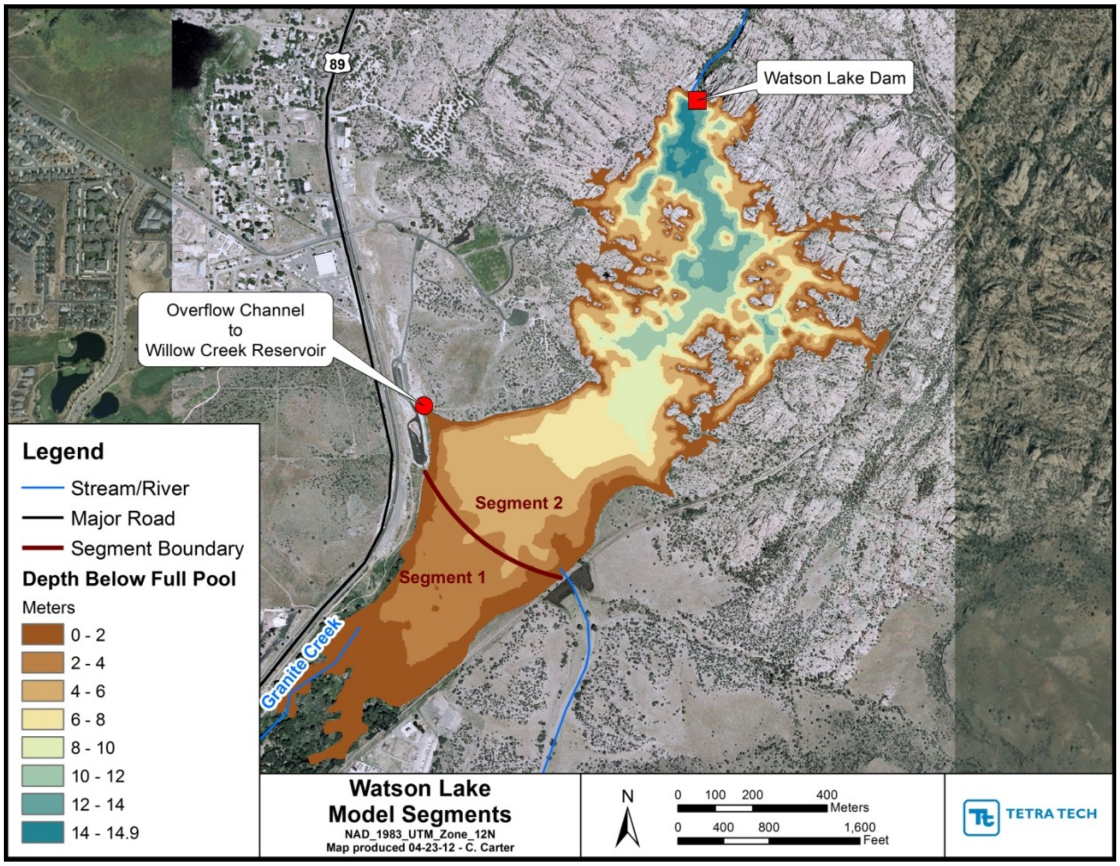

Figure 12. Watson Lake Model Segmentation (Gremillion and Tetra Tech)

6.3.3 Watershed Segmentation

To account for loading to the lake from tributaries and direct drainage, Tetra Tech divided the Watson Lake watershed into three sections (Figure 13). The first and largest section, covering approximately 26,400 acres (36.3 square miles), includes the Granite Creek drainage area upstream from Watson Lake and is identified in the model as Tributary 1. The second section, covering approximately 247 acres, includes land area directly draining to Segment 1 of the lake and is identified in the model as Tributary 2. The third and final section, covering approximately 1,980 acres, includes land area directly draining to Segment 2 of the lake and land drained by an unnamed tributary and is identified in the model as Tributary 3. Model inputs for flow rate for Tributaries 2 and 3 were estimated as a proportion of the flow rate calculated for Tributary 1 based on differences in drainage areas between Tributaries 2 and 3 and Tributary 1.

Model inputs for nutrient concentrations from the tributaries were calculated as flow-weighted concentrations of observed data from Tributary 1 at Watson Woods near the lower USGS gauge. Because these concentrations were calculated as flow-weighted, the same concentrations were used as model inputs for the other tributaries. BATHTUB performs a calculation of watershed nutrient loading from each tributary using the flow-weighted nutrient concentrations and the estimated area-weighted flow rates.

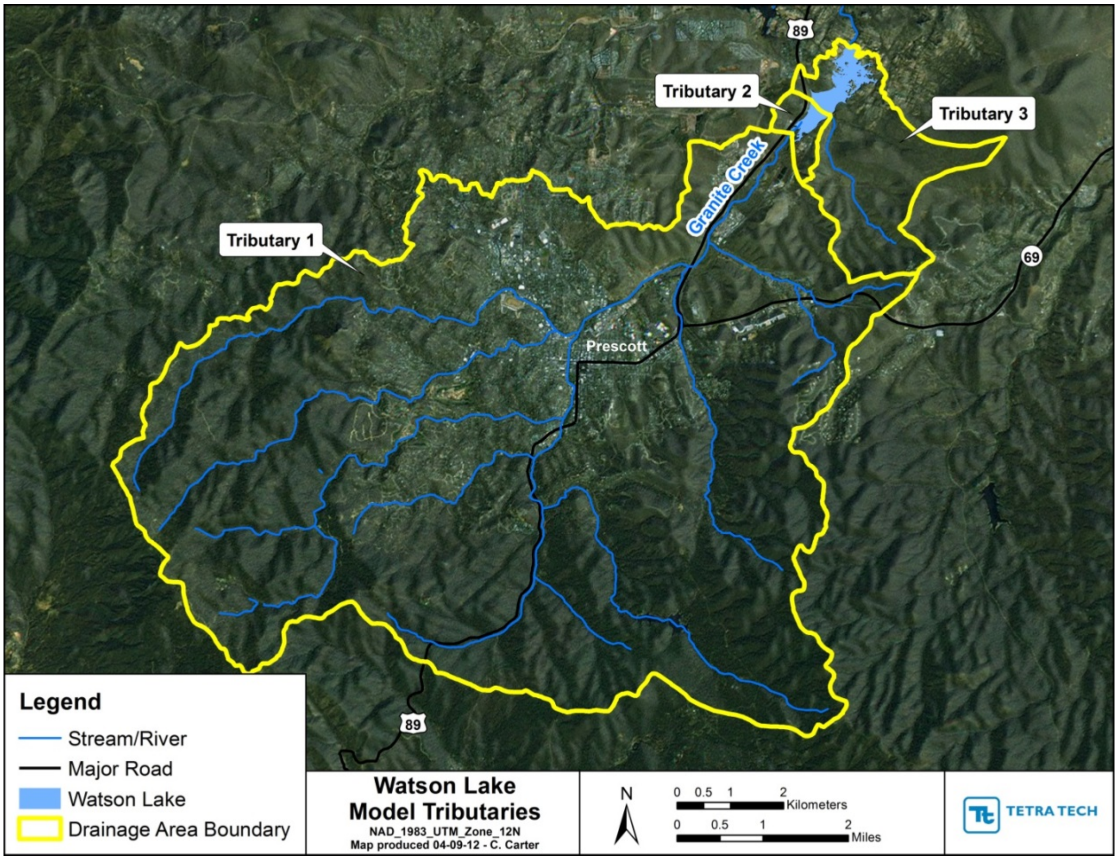

Figure 13. Watson Lake Model Tributaries for (Tetra Tech, 2012)

6.3.4 Model Assumptions

Nutrient modeling incorporates atmospheric deposition of nitrogen in establishing a mass balance for nitrogen in lakes and reservoirs. Tetra Tech used a deposition rate of 2.27 kg-N/ha (227mg/m^2), found by averaging available data. This value was used for model input for both TN and total inorganic nitrogen (TIN) loading from atmospheric deposition, a generalization sufficient for modeling purposes because the Watson Lake surface area is small compared to the watershed area.

Tetra Tech assumed loading of TP and ortho-phosphorus from atmospheric deposition to be zero throughout model development. Data for atmospheric deposition of TP and ortho-phosphorus were not readily available to estimate accurate values for the study area, and Tetra Tech found no evidence to suggest that TP and ortho-phosphorus contributions from atmospheric deposition would be considerable proportions of total load to the lake.

Tetra Tech considered several options for the model averaging period, including full year, growing season (May through October), and February through September. Based on BATHTUB model guidance, the appropriate averaging period for each model year was the annual averaging period (one year). In the Tetra Tech analysis, Watson Lake was not found to be phosphorus limited; the calculations to estimate the appropriate averaging period were based on an evaluation of the turnover ratio for nitrogen under growing season and annual loading conditions.

Tetra Tech estimated normal pool elevation for 2007 (5,152 feet), 2010 (5,160 feet), and 2011 (5,155 feet) from an assessment of frequency distribution plots of daily lake level elevation for each year. For 2007, there was a clear unimodal frequency distribution peaking at 5,152 ft. above sea level. Both 2010 and 2011 frequency distributions for lake level elevation were bimodal. Best professional judgment and knowledge of the lake level seasonal patterns were used to estimate normal pool elevation for both 2010 and 2011. Normal pool elevation was used to calculate surface area, mean depth, hypolimnetic thickness, and volume for model inputs and diagnostic variables.

6.3.5 BATHTUB Nutrient Mass Balance

BATHTUB was applied to calculate the mass balance of phosphorus and nitrogen, which accounted for inflow, uptake, transformations, and deposition to sediment (Walker, 1999). The model adjusted for inflow phosphorus partitioning to sediment and in-lake nitrogen partitioning through the effective sedimentation rate coefficient. Because the sedimentation models selected for both TP and TN have been empirically calibrated using the reservoir dataset, effects of internal loading from bottom sediments are inherently reflected in the model output parameter values and error statistics (Walker, 1999).

6.3.6 Results from Sediment Coring

Lake sediment cores captured the time period from approximately the mid-1940s to 2011. Analysis showed a relatively high sedimentation rate within the reservoir. The cores showed a predominance of terrestrial inputs with high magnetic resonance, as well as the historical account of regular lake drying due to irrigation withdrawals (Gremillion, 2012). During years that Watson received treated effluent with high concentrations of TN and TP, the lake received storm loads which largely overshadowed the wastewater signature; never-the-less, isotopic analysis suggested the presence of wastewater inputs.

Since the late 1990s, when the City acquired Watson Lake, cores reflect the fact that water level has been more consistently maintained. Isotopes of carbon and nitrogen indicate a growing influence of methane production in sediments which reflects increasing algal growth and deposition, particularly cyanophytes (Gremillion, 2012). There is a lack of corresponding increase in sediment phosphorus compared to carbon and nitrogen, which indicates sediments as a supply of phosphorus (phosphate) and ammonia that are released to the water column under strongly reducing conditions. Therefore, hypolimnetic anoxia strongly influences water column processes and improving oxygenation of bottom waters may help improve water quality.

7.0 GENERAL SUMMARY OF WATERSHED DATA

7.1 Sample Locations

ADEQ collected water quality data across a spectrum of flow conditions. Water quality samples were collected at various locations throughout the watershed during different flow events: summer monsoons, winter storms, and snowmelt. Tributary sample sites were selected with the intent of capturing the cumulative effects of the watershed, identifying the source(s), amount (load) of pollutants delivered at various locations within the watershed, and the amount (load) entering or leaving receiving water (lakes). The natural topography and hydrology, 150 years of anthropogenic influence, and a growing urban population dictated a practical approach to estimating loads and allocations by considering key locations such as the bottom of each tributary or through bracketing land use changes.

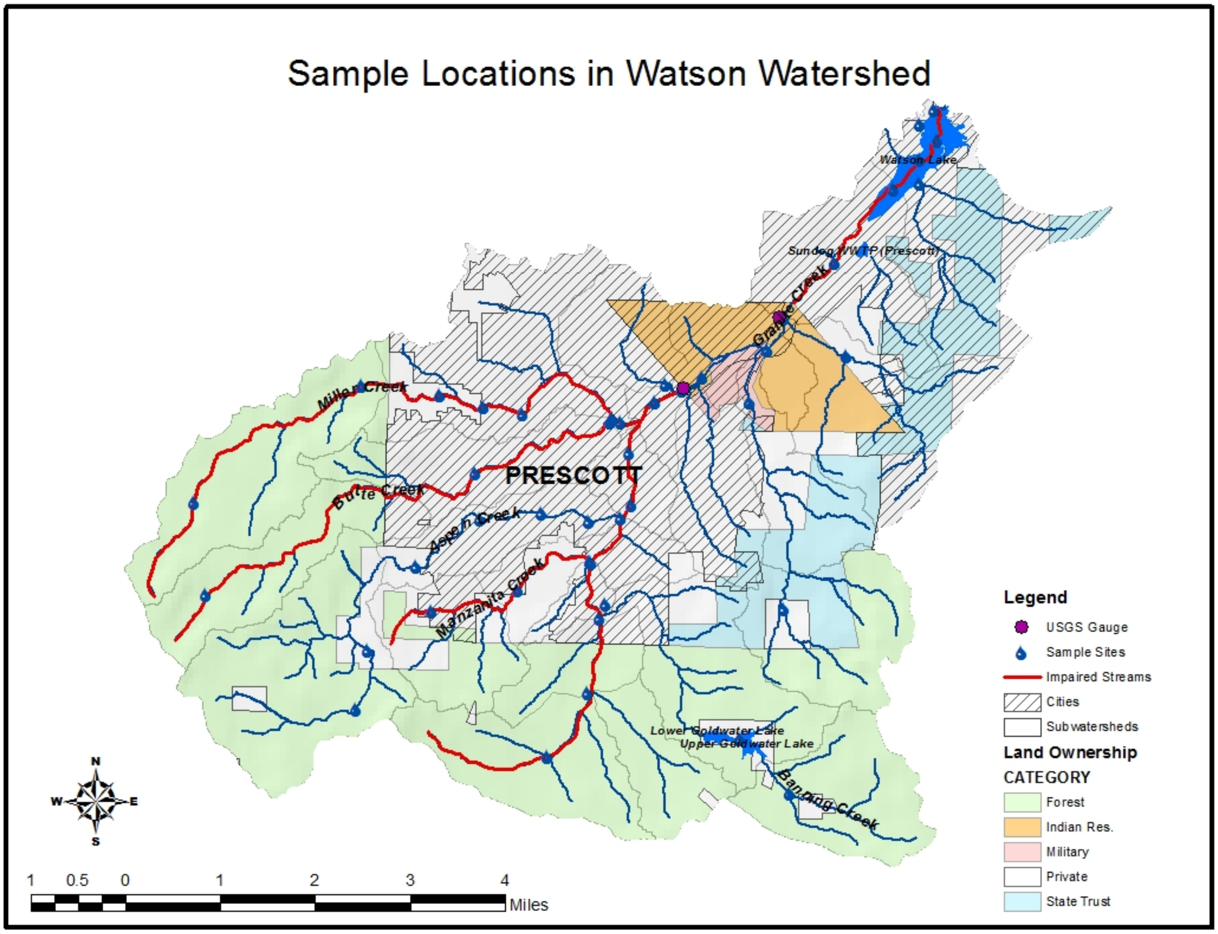

Figure 14. Sample Locations

7.2 Flow Characterization in Determination of Critical Conditions

TMDLs must include consideration of critical conditions and seasonal variation to ensure protection of the designated uses of the waterbody at all times. ADEQ interprets "critical condition" as a combination of environmental factors during which an exceedance of a water quality standard occurs and is predicted to occur in the future; the exceedance would not occur absent the environmental factors. Examples of a critical condition may include stream flow, seasonal periods, weather conditions, or anthropogenic activities, and can be localized to a specific site (A.A.C. R18-11-601).

Critical conditions for nutrient impaired lakes typically occur during the warm summer months when water temperatures are elevated and algal growth rates are high. Excessive rates of algal growth may cause large swings in DO, elevation pH, odor, and aesthetic problems. Loading of nutrients to lakes during winter months are often biologically available to fuel growth in summer months. The recommended loading capacity accounts for summer season critical conditions by using BATHTUB to calculate possible annual loading rates consistent with meeting the selected growing season nutrient endpoint ranges.

The upper USGS gauge (09502960) is close to downtown Prescott and captures inflows from Upper Granite Creek, Banning Creek, Manzanita Creek, Aspen Creek, Butte Creek, Miller Creek, and the North Fork of Granite Creek (approximately 30 square miles). The upper gauge was used to approximate the relative flow interval for samples collected on upper Granite Creek and its tributaries. The lower USGS gauge (09503000) is located about one mile upstream of Watson Lake at Sundog Ranch Road on YPIT land. Additional flows from Government Wash and Slaughterhouse Gulch, as well as runoff from Acker Park and Fort Whipple sub-watersheds are captured at the lower gauge, resulting in a total of 36.3 square miles. Approximately four square miles is ungauged above Watson Lake. A third gauge (09503300) is located approximately three-fourths mile downstream of the Watson Lake dam on Granite Creek and will be referenced to indicate flows leaving Watson Lake.

Using the lower Granite Creek gauge (09503000) flow duration curve, nutrient sample results from Watson Woods were plotted to determine the critical flow percentiles for exceedances of the TN and TP annual mean standards (Figures 15 and 16). The graphs show actual grab sample results in relation to the annual mean water quality standards. Critical loading for both TN and TP has been captured in the top 25 percent of flows (greater than 8 cfs). TN and TP samples collected at Watson Woods near the lower gauge span flows from five cfs to 800 cfs.

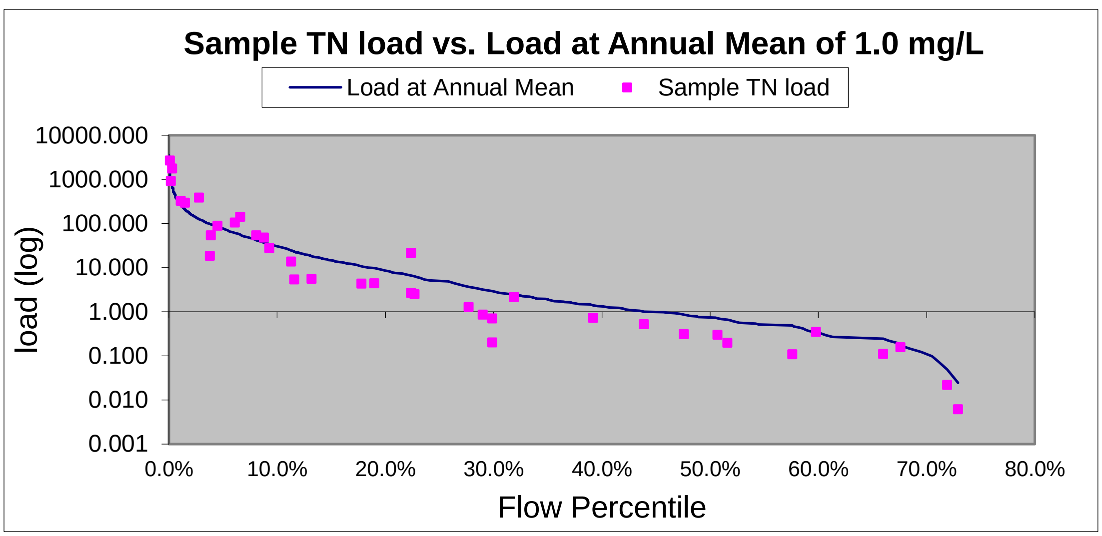

Figure 15. Critical Loading Conditions for TN

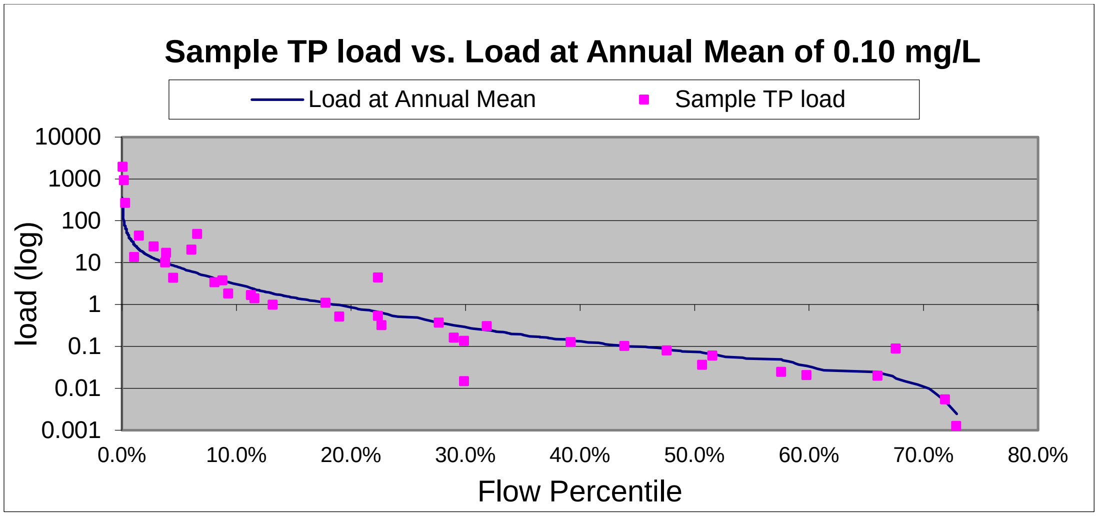

Figure 16. Critical Loading Conditions for TP

For purposes of this project, data will be divided into two flow categories, storm flow and stable flow. To define these two conditions, data were analyzed in conjunction with flow durations worksheets for the period of record flow history for the two USGS gauges above Watson Lake. The worksheets used base flow recession coefficients (BFRC) to determine whether a day's flow was to be characterized as storm flow or stable flow based upon comparison to the previous day's flow (ADEQ, 2013).

7.3 Nutrient Concentration in Relation to Water Quality Benchmarks and Flow Category

7.3.1 Total Nitrogen

Figures 17 and 18 show the distribution of results for all TN samples collected in the watershed under both stormflow and stable flow conditions between 2007 and 2012. By flow category, there is a slight left-skew for stable flow samples and an expected right-skew for stormflow samples. Under stable flow, there was approximately an equal number of TN values at or below (23) and above (27) the value of 1.0 mg/L (Verde River annual mean WQS), whereas stormflow conditions produced almost six times as many TN values above the benchmark (45 vs. seven).

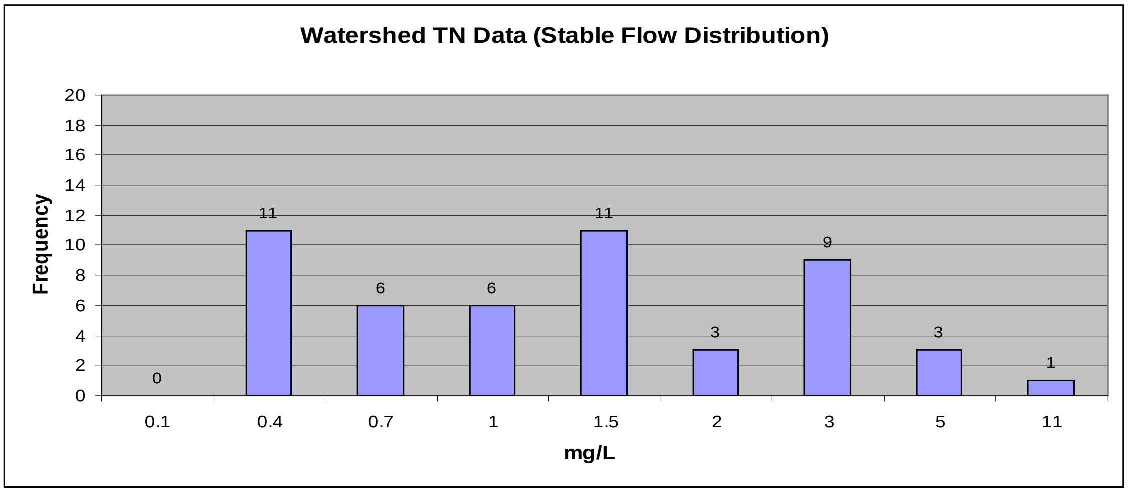

Figure 17. Watershed TN Data (Stable Flow Distribution) in Relation to Verde Annual Mean

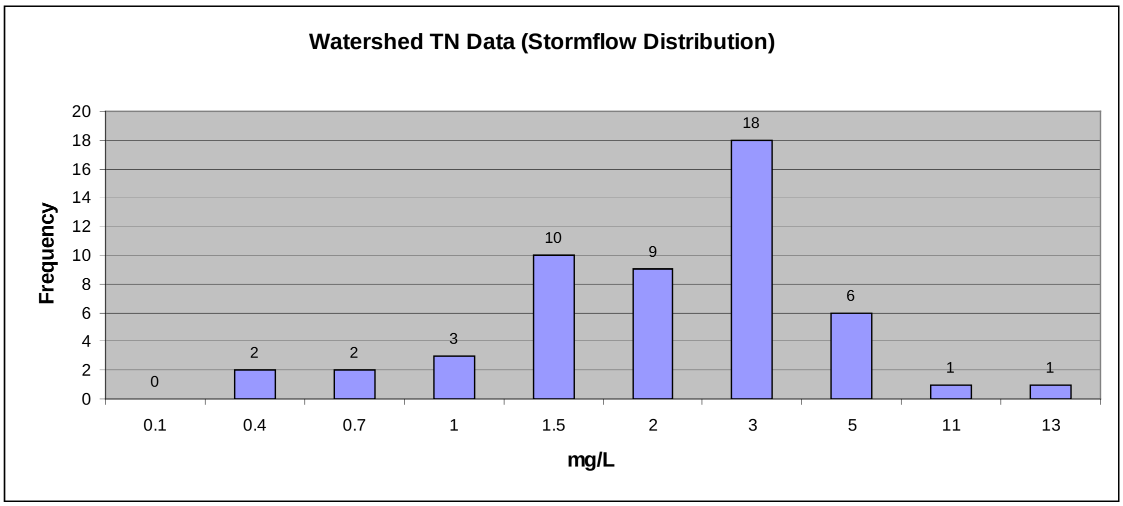

Figure 18. Watershed TN Data (Stormwater Distribution) in Relation to Verde Annual Mean

Shown another way, Figure 19 shows the TN results relative to flow as a log-log plot; the annual mean and single sample maximum standards are plotted for comparison. For TN, there isn't a clear relationship of concentration to flow.

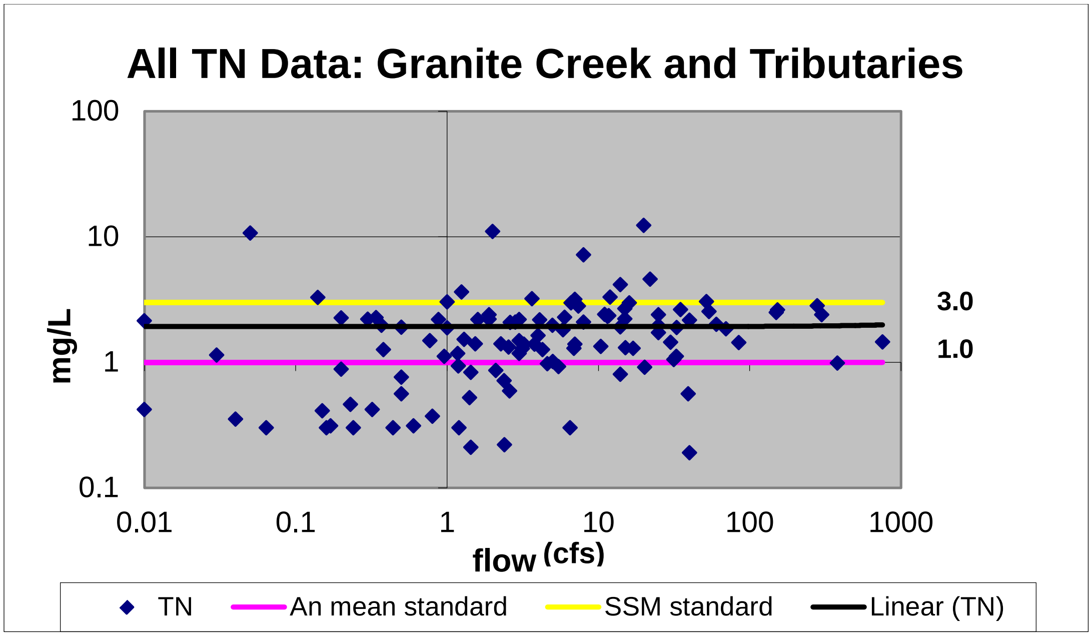

Figure 19. Bivariate (log-log) Plot of TN Data from Granite Creek and Tributaries

7.3.2 Total Phosphorus

Figures 20 and 21 show the distribution of results for all TP samples collected in the watershed. TP distribution, broken out by flow category is largely left-skewed, but concentrations tend to increase under high flow conditions and associated with suspended sediment. Under stable flows, more samples met the 0.01 mg/L annual mean WQS (30) than exceeded (20).

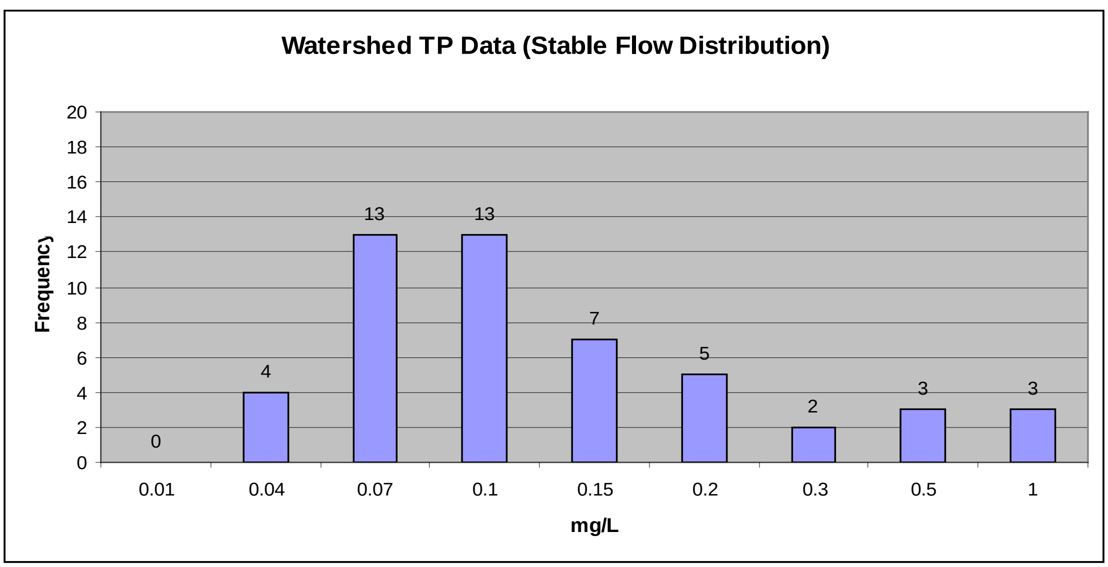

Figure 20. Watershed TP Data (Stable Flow Distribution)

Under storm flow conditions, like TN, there were six times as many TP values above the benchmark of 0.1 mg/L but up to 50 times the concentration.

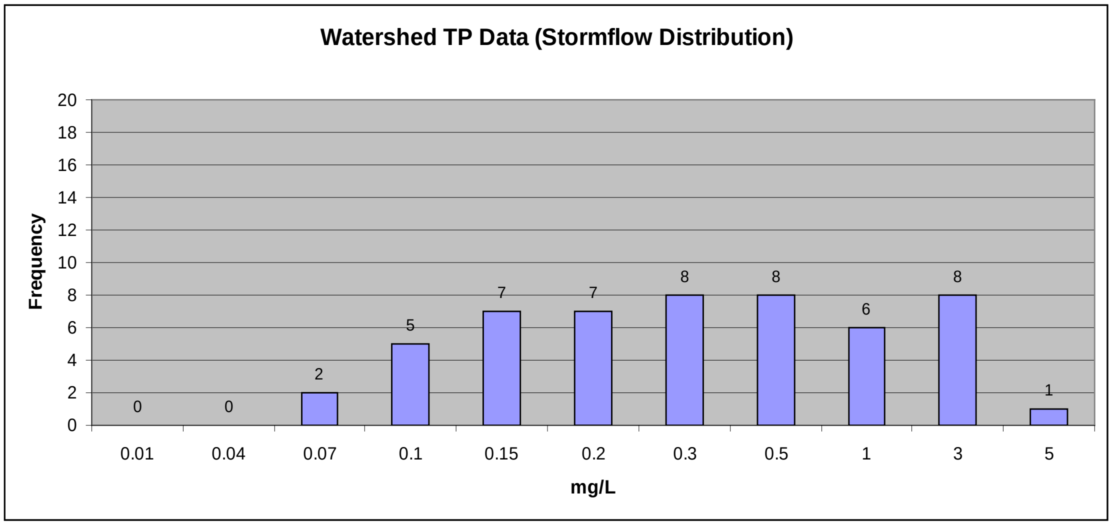

Figure 21. Watershed TP Data (Stormwater Distribution)

The log-log bivariate plot for TP vs. flow shows a stronger relationship, with TP increasing as flow increases, particularly in the higher flow categories (Figure 22).

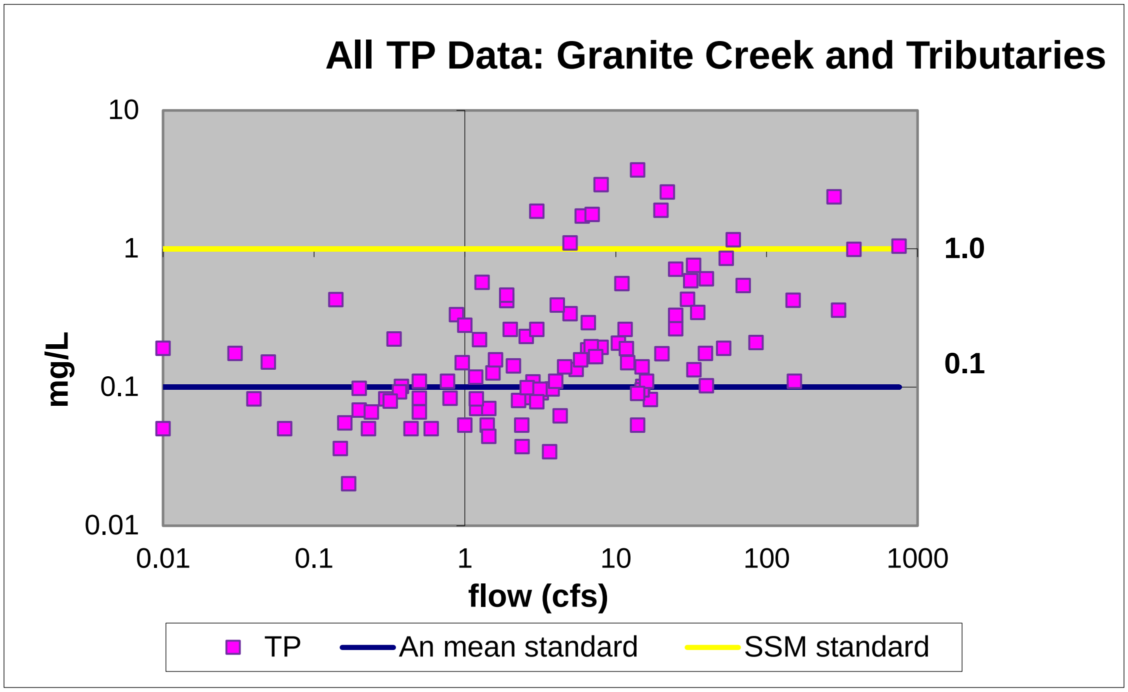

Figure 22. Bivariate (log-log) Plot of TP Data from Granite Creek and Tributaries

7.3.3 Determination of Background

The weathering and erosion of native geology and mobilization of terrestrial sediments can introduce pollutants into a stream system once a mechanism for transport has been established. Most of the upper watershed is made up of highly friable granite and outcrops are common. Natural erosion rates and overall sediment delivery to a water body are increased by increasing the surface area exposed.

The Watson Lake watershed has a mean gradient of approximately four percent, with higher elevations reaching 10 percent. Thus, runoff of precipitation from the land surface (overland flow) is routed directly to the creeks and loading is cumulative. Antecedent conditions, such as the time since the last storm, along with storm intensity, are both important drivers of nutrient and sediment loading to Granite Creek and Watson Lake.

Storm events and snowmelt sufficient to produce runoff and transport of sediment to the creeks occur most often from December to May, although intense storms of short duration occur from July through September. Loading occurs from both disturbed and relatively undisturbed land uses. A GIS-based study conducted by the University of Arizona Cooperative Extension NEMO program demonstrates the overall picture of loading potential in the Watson Lake watershed. Modeling showed that water yield is highest in developed portions of the watershed, largely based on the extent of impervious surfaces. In contrast, sediment yield is highest in the upper, forested portions of the watershed (WIP, 2012). Nutrients yield was not modeled, but based on the NEMO analysis, could be expected to reflect aspects of both sediment and water yield. Following dry conditions, intense storms of short duration (summer) will mobilize surface sediment and nutrients; snow and rainstorms in the winter will saturate the ground and promote leaching of nutrients from the subsurface.

Generally, a natural forest condition would be considered “background.” However, the national forest above Prescott was harvested aggressively in the late nineteenth century and grazed as well. Prescott National Forest Service maintains an active presence, conducting controlled burning at the wildland-urban interface. According to the Prescott National Forest web site, there have been two major wildfires in the Watson Lake watershed, the 1950 1,200-acre Ruth fire and most recently, the larger 2002 3,100-acre Indian Fire in the upper Granite Creek drainage. One to three acre controlled burns are common, with a few between five and 10 acres.

Recreational activities are popular in the forest and unpaved roads crisscross the upper watershed. The organic soils within the forest contain relatively high levels of nitrogen, phosphorus, and total organic carbon (TOC) which may be mobilized during heavy rains. Thus, the upper watershed forested areas are best categorized as "least impacted" from a development point of view, but impacted to some degree by fire and recreation from the standpoint of "background" nutrient levels. Although the sample size is small, Table 4 shows a range of nitrogen, phosphorus, and carbon found in upper watershed soils as compared to lower down the watershed in creek sediments.

Table 4. Comparison of Nutrients in Soils

UPPER SITES (NATIONAL FOREST)	**TOC % ORG C**	**AMMONIA MG/KG-N**	**TKN MG/KG-N**	**NO2+NO3-N MG/KG-N**	**TP MG/KG-P**
Upper Banning (above Goldwater)	**9.29**	41	**2800**	**5**	**4560**
Upper Granite (Indian Fire area)	**5.39**	99	**2240**	**5**	4480
Upper Aspen (near FS boundary)	**10.2**	119	**1580**	<1	1790
Upper Miller (burn area)	2.48	**130**	1400	<1	3140
Upper Miller (non-burn area)	3.01	69	1460	**5**	1550
LOWER SITES (URBAN/ DEVELOPED)					
Government blw Oak Knoll	2.77	**145**	580	<1	**8120**
Lower Manzanita	1.94	**351**	980	**13**	**7490**
Lower Miller	2.07	54	960	**2**	1820
Lower Butte	2.53	126	1340	1	3080
Granite at Granite Park	1.01	119	670	<1	2670

*** Bold indicates the top three (highest) concentrations found**

It appears that the upper watershed soils have the potential to contribute significant amounts of organic carbon (TOC), organic nitrogen (TKN), and total phosphorus. Although these are not the most bio-available forms, once transported to the creeks and lake, they may become bioavailable. Looking at the top three highest values, two lower watershed sites showed higher nutrient values than the forest sites for ammonia, nitrate and phosphorus: Lower Manzanita and Government Wash below Oak Knoll. TP includes phosphate, which is highly mobile, as are ammonia and nitrate. Communities directly upstream of these sites utilize onsite septic systems which may be pollutant sources.

Mention has been made that upper watershed sites on Prescott National Forest land may contribute a significant background nutrient load, most likely associated with sediment, but also associated with natural breakdown of organic matter. The latter may be exacerbated by wildfire or controlled burns. In addition, there may be a portion of the loads arising from roads and recreational facilities/activities. ADEQ evaluated the per-event TN and TP loads, comparing forested sites with associated sites on the same creek that are outside Prescott National Forest boundaries (Appendix A). Eleven of the 14 events showed upstream contributions at 10 percent or less for TN and 15 percent or less for TP. The TMDL will include an allowance of 15 percent for forest TP load and 10 percent for forest TN load. Table 5 shows the three subwatershed areas that are considered “background” but have shown loads greater than the 10 and 15 % background levels.

Table 5. Upper Watershed Results in Relation to Assigned Background

Headwater Sub-watershed	**TP above the 15% background**	**TN above the 10% background**
Upper Granite	NA	11% - 16%
Upper Aspen	16% - 27%	NA
Upper Miller	24% - 43%	11% - 16%

When sampling events are evaluated by type of precipitation/runoff, it appears that first-flush storms (following a dry period) and rain-on-snow events, create the highest upper watershed loading for both TP and TN.

7.4 Analysis in Support of Watershed Improvements

For purposes of guiding the prioritization of water quality improvements within the watershed, ADEQ has provided data analysis by site, by event, and by sub-watershed location (Appendix A: Supporting Documentation: Watershed Data Analysis). Summary points from data analysis conducted by the WIC (WIP, 2012) correspond to those by ADEQ in Appendix A and include the following:

- Levels of nitrogen and phosphorus and *E. coli* exceed state water quality standards during high stream flow and runoff from precipitation; although there were sample results above the annual mean and single sample nitrogen and phosphorus Verde standards, no nutrient listings on the creeks have resulted based on the assessment criteria
- Low dissolved oxygen levels in Granite Creek (originally believed to indicate nutrient loading) occur only during lower flows – not when nutrients or bacteria exceed standards
- When exceedances occur during high flows, nutrients and bacteria appear to be the result of many sources, with impervious surfaces generating a greater volume of stormwater runoff
- Riparian degradation is sufficient that excess nutrients and pathogens are not being intercepted and filtered out
- 91 percent of the 46 samples collected across 23 sites were positive for the human genetic marker, meaning that human bacteria were present in those samples. 22 samples at 14 sites are considered to be strong positives (three out of three) (WIP, Appendix B)
- Testing for human-health pharmaceuticals, artificial sweeteners, personal care products, and other emerging contaminants that would suggest sewer or septic pollution was conducted at 13 sites in April 2012; results reveal strong anthropogenic influences in lower Manzanita, middle and lower Miller, lower Butte, and the N. Fork of Granite Creek .
- Aging wastewater sewer infrastructure and I&I problems occasionally contribute to nutrient and bacteria exceedances
- Bacterial pollution appears to be widespread and exceedances of the bacteria standards occur more frequently than exceedances of the nutrient standards
- Although there is some overlap, from the top to bottom of the watershed, total nitrogen appears to elevate in the residential areas, whereas *E. coli* concentrations increase in urban areas
- Forest “background” levels for total phosphorus and TKN were high under first flush and rain on snow storm conditions with overland sheet flow; nitrate was high in areas impacted by fire
- Forest snowmelt nutrients levels were very low
- Lower Manzanita above Granite and Lower Miller above Butte had the most persistently high nutrient levels
- Some nutrient attenuation (loss downstream) is occurring between Granite Park and Watson Woods, although there appear to be contributions from the North Fork of

Granite, the Acker Park subwatershed, the Government Wash subwatershed, and the Slaughterhouse Gulch subwatershed, all of which need more data to ascertain their overall impact on loading to Watson Lake

- Use of bioretention and other forms of Green Infrastructure would be beneficial overall, but based on sampling, should be prioritized for Upper Granite, Lower Manzanita, Lower Miller, Lower Butte, and the North Fork of Granite

8.0 MODEL RESULTS, TMDL REDUCTIONS, and MARGIN of SAFETY

As mentioned in Section 6.3 of this report, Tetra Tech ran BATHTUB for 2010 (relatively wet year) and 2011 (moderately dry year with average lake level) and 2007 (dry year with low lake level) for model validation.

There were only two in-lake sampling events in 2010 and the 2010 model scenario overpredicted nutrient levels, most likely due to the effect of lake flushing. For 2007 when lake level was below average, the 2007 model scenario overpredicted phosphorus in Segment 1 (likely tied up in SAV) and underpredicted phosphorus in Segment 2 (likely due to increased sediment release).

8.1 Lake Model Targets

ADEQ provided Tetra Tech with lake data collected from July 2000 through October 2011 at the sites shown in Figure 23. Data sources included ADEQ (2002, 2003, 2007-2011), AGFD (2000), the City of Prescott (2005-2006), ASU (1984), NAU (2009, 2011), and UofA (2011). Growing season coverage occurred in the summer of 2011.

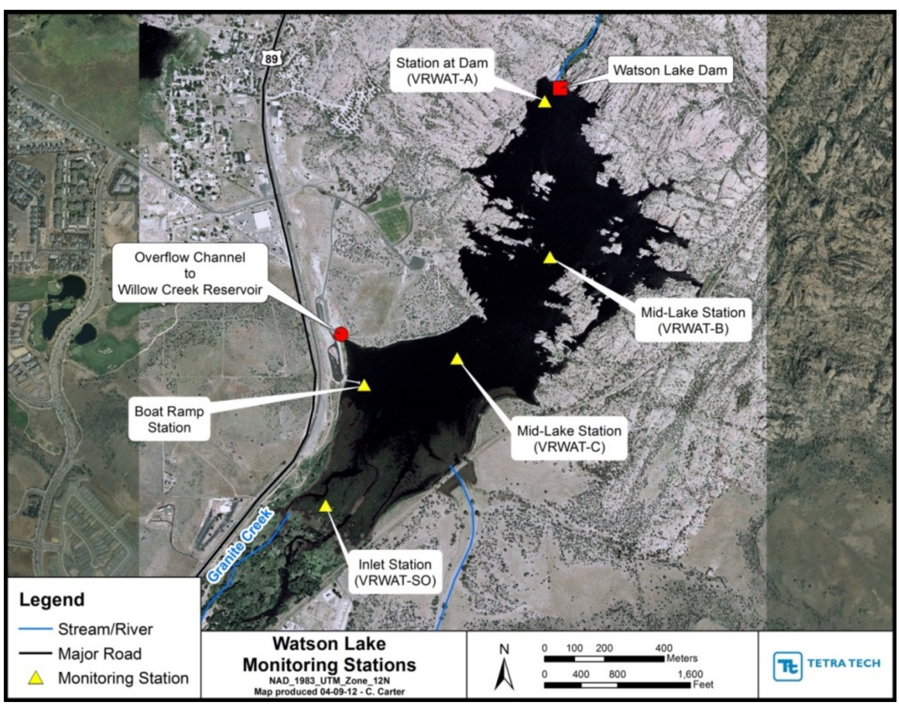

Figure 23. Watson Lake Sampling Sites

To be protective of downstream conditions, annual average nutrient endpoints of 1 mg/L TN and 0.1 mg/L TP were selected based on the applicable Verde River numeric water quality standards. Based on the literature search (Tetra Tech, 2012, Table 4), TN concentration recommendations ranged from 0.3 to 1.8 mg/L, and TP concentration recommendations from 0.0125 mg/L to 0.140 mg/L. The following ranges were selected by Tetra Tech based on reference ranges for use in determining loading capacity to Watson lake in order to attain the Verde River nutrient standards downstream and to minimize risk of impairment, particularly nuisance algal blooms within the lake:

- TN growing season endpoint range: 0.3 to 0.8 mg/L
- TP growing season endpoint range: 0.03 to 0.06 mg/L

Targets for both DO and pH will be the applicable water quality standards. As shown previously, the 2011 model was calibrated to observed growing season median concentrations for in-lake TN and TP. The growing season for Watson Lake is defined as May through October, which represents the typical time period during which productivity increases are observed. In-lake stratification typically begins in June and early July and has been observed to continue into October. Lake Segments 1 (shallow area near the inlet) and 2 (remainder of the lake) were calibrated separately for both TN and TP for the 2011 model year. Calibration of TN and TP models for the Watson Lake 2011 model year were performed by adjusting sedimentation coefficients within the ranges recommended for application of the model to improve the agreement between observed and predicted nutrient concentrations (Walker, 1999).

The BATHTUB model calibrations for years 2007, 2010, and 2011 suggest positive overall retention for both nitrogen and phosphorus (Tetra Tech, 2012). Recycling of nutrients from lake sediments is expected to occur within Watson Lake (algal uptake, death, decay, and re-release). The model suggests that the net effect of watershed loading, internal loading, nutrient uptake, settling, denitrification, and other processes leads to a net retention of nutrients in the lake. Net retention of nutrients means that Watson Lake is acting as a sink; more nutrients are retained than leave the system. This concept is separate from nutrient cycling, in which phytoplankton and aquatic plants take in nutrients for growth and ultimately release them upon death and decomposition. Outside of a flushing event, these results are expected; the estimated flow weighted concentrations entering the lake (0.23 mg-L TP and 1.13 mg/L TN in 2011) are greater than the in-lake area-weighted concentrations (0.06 mg-L TP and 1.04 mg/L TN in 2011). The BATHTUB results confirm Gremillion's sediment coring analysis; watershed loading appears to overwhelm the load contribution from sediment release, however, in-lake nutrient cycling by primary producers ensures a steady supply of nutrients, whether they settle and are re-released during stratification, or simply settle and contribute to net retention of the nutrient load.

External loading results were confirmed for TP with independent calculations of internal load using empirical equations, one from Welch and Jacoby (2004) and one from Nurnberg (1984) (Tetra Tech, 2012). To account for hydrologic variation, BATHTUB model runs were developed for 2007, 2010, and 2011; model calibration was based on 2011 data when in-lake water quality resolution was greatest (Figure 10). Internal loading was calculated separately with two equations using the following variables: outflow rate, volume, flushing rate, mean depth, lake or segment TP concentration, and inflow TP concentration.

8.2 Modeling Scenarios and Linkage Analysis

The BATHTUB model for the year 2011 was applied to the model scenarios and resulting TMDL calculations. Based on the calibration results (Tetra Tech, 2012), this model provides a more reliable estimate compared to the model for 2010. Although 2011 was a relatively dry year in terms of inflows, lake volume was average. Compared to 2010, 2011 is likely more representative of the typical water and nutrient balance within the lake. The BATHTUB application provides a basis for evaluating the relative impact of management scenarios on nutrient balance. This approach assumes that nutrient reduction will improve algal conditions and that adaptive management will be needed to ensure restoration of designated uses.

Several model scenarios were developed to test the load reductions that can be achieved by watershed and lake management options. The scenarios provide an indication of which management options would provide significant load reductions towards addressing lake impairments and also provide an estimate of the maximum technically achievable reductions in nutrient loads. Table 6 displays the nutrient concentrations and oxygen depletion rate results for each scenario (Tetra Tech, 2012). Oxygen depletion (HOD and MOD) are separate but related to nutrient levels. Lower numbers for deep lake oxygen depletion (HOD) and mid-depth (MOD) oxygen depletion numbers are preferable, as they reflect a higher level of dissolved oxygen present for support of aquatic life. A 100 percent watershed load reduction may not be achievable, but the scenario demonstrates that in-lake recycling must also be addressed to achieve the TMDL/WQS.

Table 6. Scenario Results: TN and TP Segment Concentration, (HODv) and (MODv)

Scenario	Segment 1		Segment 2			
	TN (mg/L)	**TP (mg/L)**	**TN (mg/L)**	**TP (mg/L)**	**HODv (mg/L-day)**	**MODv (mg/L-day)**
Existing Conditions	1.08	0.105	1.04	0.053	0.760	0.168
100% Watershed Load Reduction	0.80	0.081	0.79	0.045	0.682	0.150
In-lake percent reduction	26%	23%	24%	15%	10%	11%
Lake Dredging to 1.14m	1.10	0.121	1.03	0.045	0.721	0.159
In-lake percent reduction	0%	0%	1%	15%	5%	5%
Lake Dredging to 4.5m	1.05	0.084	1.00	0.035	0.660	0.145
In-lake percent reduction	3%	20%	4%	44%	13%	14%
Lake Level, Lower (2007 levels)	1.13	0.214	1.03	0.056	1.282	0.171
In-lake percent reduction	0%	0%	1%	0%	0%	0%
Lake Level, Higher (2005 levels)	1.03	0.068	1.01	0.043	0.495	0.150
In-lake percent reduction	5%	35%	3%	19%	35%	11%
Alum Treatment	1.08	0.023	1.04[1]	0.018	0.478	0.105
In-lake percent reduction	0%	77%	0%	66%	37%	37%
Watershed and Alum Treatment	0.80	0.018	0.79[1]	0.015	0.421	0.093
In-lake percent reduction	26%	83%	24%	72%	45%	55%

Figure 24 compares the scenario loading results for lake inflow, flow between segments, and lake outflow and shows that the watershed load reduction and alum treatment scenarios appear to be the most promising management options for reducing nutrient loading to and from the lake as well as in-lake concentrations and DO depletion rates. The dredging and lake level scenarios provided some promising results for reduction of TP and lowered oxygen depletion but provided only a small degree of TN reduction, if any. The combined watershed load reduction and in-lake alum treatment scenario represents the estimate of maximum technically achievable reduction in nutrient loads to the lake. Although modeling did not indicate nitrogen reduction with use of Alum, the Limno-corral study did find a reduction in the TKN form of nitrogen. Additional in-lake treatment options such as aeration would also assist in achieving target goals.

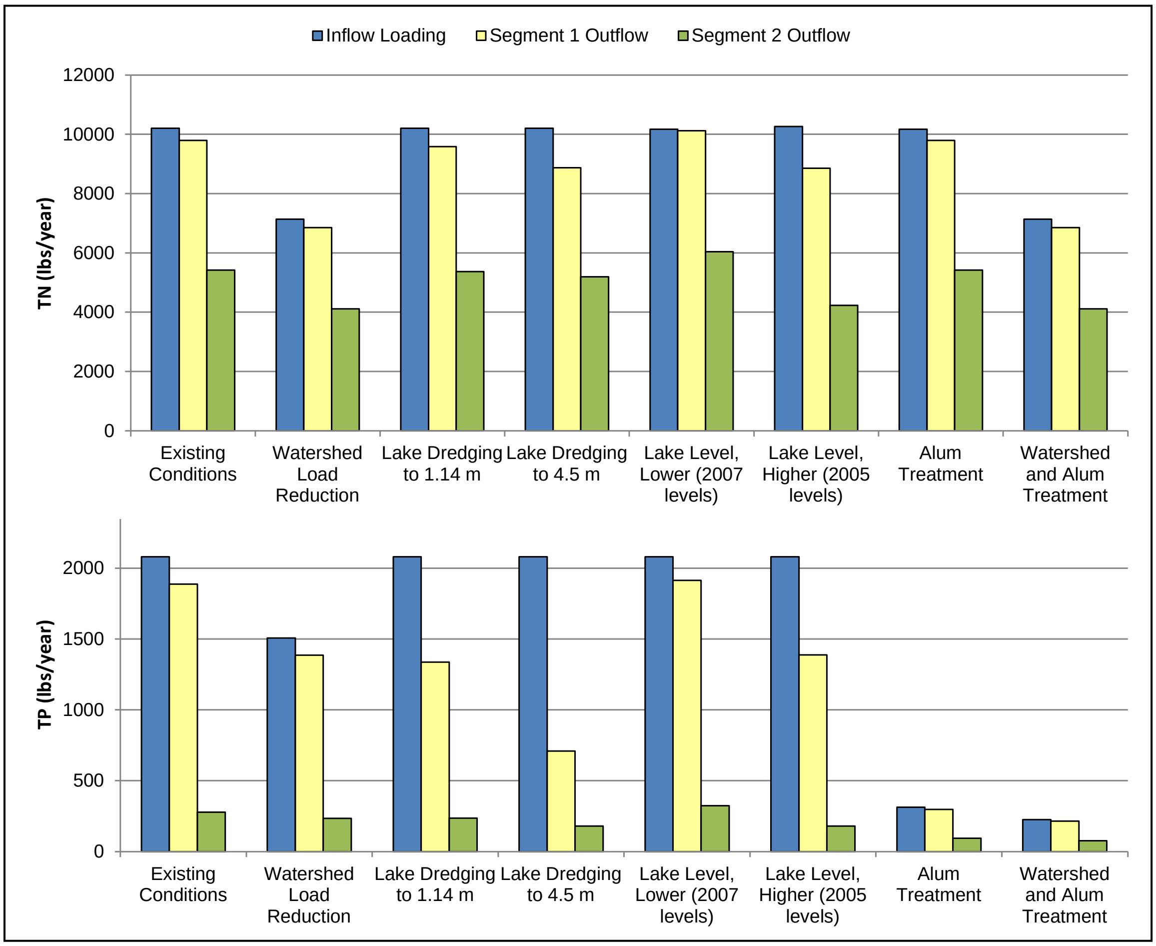

Figure 24. TN and TP Loading Scenario Result (Tetra Tech, 2012)

Based on the 2011 modeled scenarios, in-lake concentrations can be reduced to within the nutrient endpoint ranges if loading to the lake is reduced by 34 percent for TN and 32 percent for TP (assuming the addition of in-lake treatment). This analysis was based on the watershed load reduction scenario in which all loads from urban lands were treated; however, the reductions could be achieved in a variety of ways. It is anticipated that opportunities exist to reduce nutrient loading from aging sewer infrastructure, septic leach fields, and other wastewater sources as well as from streambank erosion and other nonpoint sources.

An adaptive management approach to TMDL implementation is proposed. As more data become available on the extent of loading due to individual sources, the load allocations could be revisited based on the potential to reduce these individual loads. Stormwater treatment would provide opportunities for additional load reduction if the load allocations cannot be met through MS4 and nonpoint source management. One proposed idea is the use of macro-rainwater harvesting (MRH), suggested as one way to maximize both water quality and sustainability of water resources (McMillan, 2014).

8.3 TMDL Loads and Allocations

The TMDL or loading capacity and the resulting load reductions necessary to meet the TMDL have been calculated from modeled results based on nutrients loading at the Watson Woods (lower Granite Creek gauge) location using the TMDL equation:

$$TMDL = \sum WLA + \sum LA + NB + MOS$$

In order to calculate the load in grams per day (g/day) from discharge in ft^3/sec (cfs) and concentrations in mg/L a conversion factor is first calculated:

$$ft^3/sec * 28.32L/ft^3 * 86400sec/day * mg/L * kg/1{,}000{,}000mg = 2.447\ kg/day$$

The conversion factor of 2.447 was used in the following equation:

$$\text{Existing Load} = cfs * [nutrient] * 2.447 * 365 = kg/yr$$

To convert to lbs/yr, multiply by 2.206

From Tetra Tech (2012), Table 7 presents the existing loads and recommended loading capacity and allocations. The loading capacity that corresponds with in-lake nutrient, DO and pH targets, represents a reduction in loading to the lake of 34 percent for TN and 32 percent for TP. An implicit margin of safety is provided through conservative assumptions used throughout the model and scenario development. In addition, a 10 percent explicit margin of safety (MOS) is provided to account for uncertainty in the loading estimates that has not already been accounted for by conservative model assumptions. Accounting for the MOS and background conditions, the waste load allocation (WLA) and load allocation (LA) represent reductions of 47 percent for TN and 49 percent TP

The watershed load reduction scenario (100 percent watershed nutrient reduction plus ALUM) from which the 34 percent reduction in TN loading and 32 percent reduction in TP loading was derived, produced TN and TP concentration reductions that were within and close to the high end of the target ranges for both TN (0.3 to 0.8 mg/L) and TP (0.03 and 0.06 mg/L) concentrations when compared to analyses performed on other management scenarios, therefore in-lake load reductions are also required to meet the TMDL. Tables 8 provides the TMDL equations.

Table 7. Existing Loads and Loading Capacity

Conditions/Allocations	**Annual Loading to the Lake**	
	TN (lbs/yr): lbs/day	**TP (lbs/yr): lbs/day**
Existing Conditions	10,888/365 = 29.83	2,228/365 = 6.12
Loading Capacity (LC) 34% TN Reduction 32% TP Reduction	7,186/365 = 19.69	1,515/365 = 4.16
Background 10% of LC for TN 15% of LC for TP	1.97	0.62
Margin of Safety (10% of LC)	1.97	0.42
Available Capacity (LC – NB – MOS)	15.75	3.11
Waste Load Allocation	**2,874/365 = 7.88**	**568/365 = 1.56**
Load Allocation	**2,874/365 = 7.88**	**568/365 = 1.56**
% reduction from existing:	**47%**	**49%**

Table 8. Watson Lake Nutrient TMDL Equations

TN TMDL =	7.88 lbs/day (LA $_{\text{Non-point source}}$) + 7.88 lbs/day (WLA $_{\textbf{Point source}}$) + 1.97 lbs/day (NB) + 1.97 lbs/day (MOS) = 19.69 lbs/day
TP TMDL =	1.56 lbs/day (LA $_{\text{Non-point source}}$) + 1.56 lbs/day (WLA $_{\textbf{Point source}}$) + 0.62 lbs/day (NB) + 0.42 lbs/day (MOS) = 4.16 lbs/day

8.3.1 Summary of Mass Based Loads

Urban area accounts for 14 percent of the watershed but approximately 50 percent of the TN and TP load (Tetra Tech, 2012). Mass based load targets are divided 50:50 for point source and nonpoint source inputs based on jurisdiction; the allocations are shown in Table 9 (including a reserve under each category). The YPIT is not included in the TMDL.

Table 9. Breakdown of WLA and LA based on Jurisdiction/Ownership

Ownership Categories	Watershed Area (%)	Watershed Area(sq mi)	Permits	WLA TN (lbs/day)	WLA TP (lbs/day)	Nonpoint LA TN (lbs/day)	Nonpoint LA TP (lbs/day)
Unallocated WLA Reserve 10% of WLA ADOT MS4 Other TBD				0.80	0.16		
City of Prescott	39	17.56	MS4 MSGP CGP	5.66	1.12		
Yavapai County (unincorporated)	10	4.46	MS4 MSGP CGP	1.42	0.28		
Total WLA	49	22.02		7.88	1.56		
Unallocated LA Reserve 15% of LA TBD						1.18	0.23
Prescott National Forest	40	18.11				5.90	1.17
State Trust	5	2.24				0.74	0.015
Military	0.2	0.08				0.06	0.001
Total LA	45.2	20.43				7.88	1.56

Initially, compliance with the TMDL will be established as a concentration-based target that supports the TMDL mass-based determinations so that all jurisdictions and permits will be held to the same water quality endpoint. Percentage reductions in nutrients are expected to be greater during the occurrence of wetter years since the model year of 2011 was a relatively dry year.

8.3.2 Waste Load Allocations (WLA) and Load Allocations (LA)

As of the fall of 2014, there were two general MS4 permits (City of Prescott and Yavapai County) and one individual stormwater permit (ADOT) located within the Watson Lake watershed, the ADOT MS4 is a statewide permit. Collectively, the permitted point sources (MS4, MSGP, and CGP) are assigned a concentration based WLA equal to 1.0 mg/L total nitrogen and 0.10 mg/L TP. This WLA is applied, as a water quality based effluent limit (WQBEL), to all existing and future AZPDES (individual and general) permittees within the Watson Lake watershed. The WLA applies to discharges that occur in response to precipitation events and is applicable for each separate discharge that may issue from the permitted entity or site. The exception is for MS4 permits where the WLA is expressed as a system-wide requirement. Permittees can demonstrate compliance with the WLA by either direct sampling of outfall discharges or demonstrate that best management practices quantitatively reduce the discharge of pollutants to a level that meets the WQBEL. Since the WLA is based upon annual mean Verde nutrient water quality standards, the mean value of permit discharge data will determine if the WLA allocation is being met. However, if single grab samples exceed the WLA permittees should evaluate the effectiveness of BMPs, modify or implement new BMPs, or provide additional measures to improve water quality.

Compliance with the concentration based WLA will be determined during ADEQ's review of the annual permit monitoring reports. Additional SWMP requirements may be imposed based upon monitoring results and would be evaluated in future reviews.

Specific reductions from each permittee are not quantifiable at this time due to a lack of discharge monitoring data. As this permit requirement is met, ADEQ will review the monitoring data and develop specific load reduction targets. ADEQ will incorporate these updated WLAs and reductions into future revisions of the Watershed Improvement Plan (as discussed in Section 9.0) and SWMP reviews and requirements.

In addition to the three MS4 permits, there are five Multi-sector General Permits (MSGP) and several Construction General Permits (CGP) located within the Watson Lake watershed (Table 10 and Figure 25). Sanitary sewer system overflows do not receive a load allocation or waste load allocation. Spill from the sewage collection system to waters of the United States are a violation of Section 301(a) of the CWA and are prohibited.

Compliance with the concentration based LA will be determined through cooperative monitoring and assessment with nonpoint source entities.

Table 10. MS4 and MSGP Permits in the Granite Creek Watershed

FID No.	Permit No.	Issue Date	Permit Type	Permittee Name
Citywide	AZMS4-2002-30	2002	MS4	City of Prescott: Storm Water
Unincorp	AZMS4-2002-40	2002	MS4	Yavapai County: Storm Water
Corridors	AZS000018	2000	MS4	AZ Dept. of Transportation: Storm Water
5	AZMSG-60156	5/27/11	MSGP	Fann Contracting Inc.: Trucking
6	AZMSG-60592	7/19/11	MSGP	Lamb RV Storage: Transit
2	AZMSG-68954	3/29/12	MSGP	City of Prescott: Sundog Treatment Works
3	AZMSG-68974	3/29/12	MSGP	City of Prescott: Transfer Station & Service
20	AZMSG-83190	11/24/14	MSGP	Yavapai Block Company, Inc.

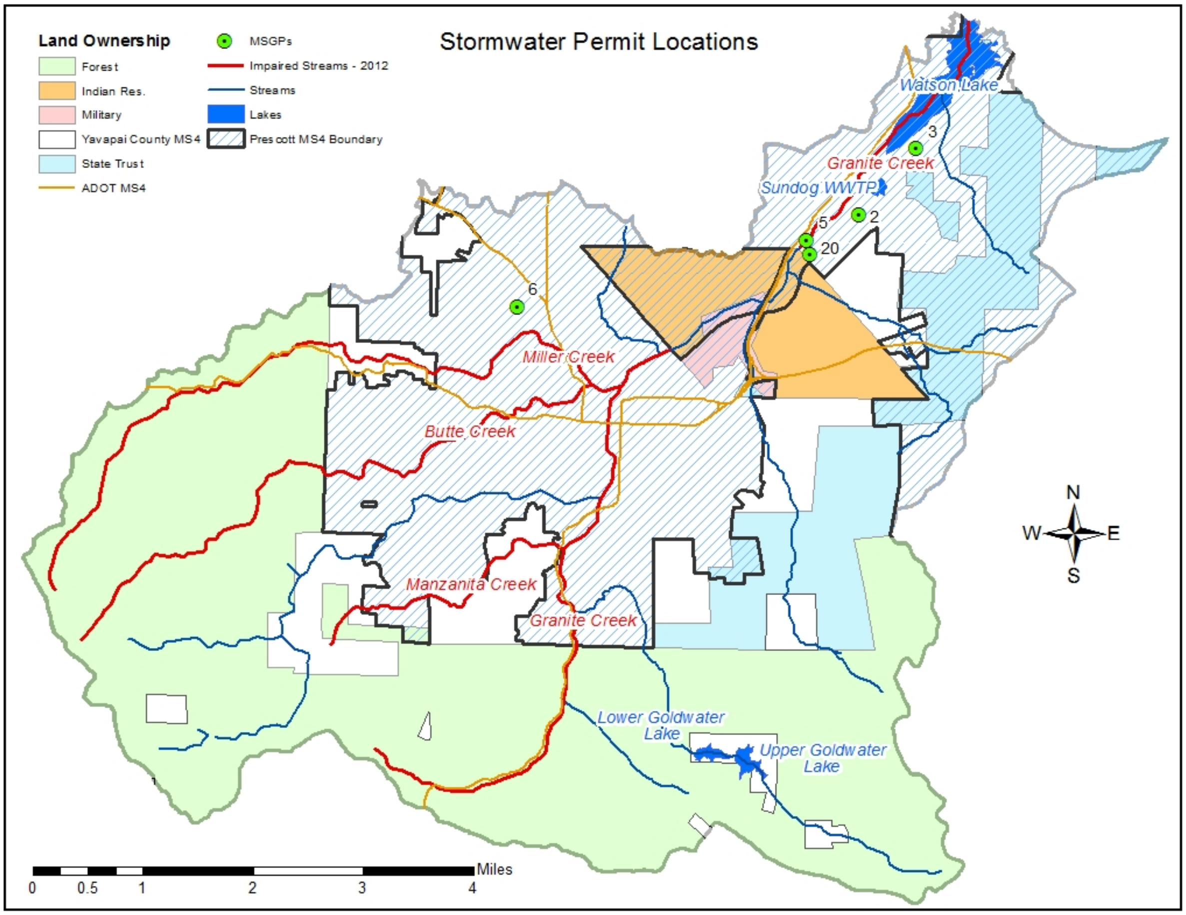

Figure 25. Jurisdictional Boundaries and Locations of MS4 and MSGP Permits

8.3.3 Review of all Relevant Water Quality Targets

The annual mean TN and TP targets are linked to in-lake targets, as shown in Table 12. The in-lake targets will be achieved through a combination of watershed reductions and reductions in lake internal nutrient cycling. Using empirical relationships of nutrient concentrations to chlorophyll-a (Walker, 1999), average peak season chlorophyll-a in Watson Lake is expected to be reduced from the current growing season mean of 28 ug/L seen in Watson to a mean of 10 ug/L (an approximately 54 percent improvement). With lower biomass and active lake management in Segment 2 of Watson (deeper area), the DO standard of 6.0 mg/L in the top meter is expected to be attained, Hypolimnetic Oxygen Demand (HOD) is expected to improve by 45 percent during thermal stratification, and the upper pH standard of 9.0 SU is expected to be met year-round. Attainment of the pH standard in Segment 1 (shallow area) will require management specific to reducing SAV biomass.

Table 12. Standards and Water Quality Targets

Granite Creek & Tribs Nutrient Targets: Annual Mean Verde Standards applied to stormflow (mg/L)		**Watson Lake Nutrient Targets: modeled targets to meet Verde Annual Mean Standards (mg/L)**		**Watson Lake Chlor-a Target (ug/L)**	**Watson Lake pH Standard (SU)**	**Watson Lake Surface DO Standard (mg/L)**	**Watson Deep DO Target (mg/L)**
TN	TP	TN	TP	Mean of 10	6.5 – 9	6.0	2.0
1.0	0.1	0.8	0.06				

8.4 Impact of TMDL on Downstream Waters

Under average conditions, Granite Creek below Watson flows on the surface for approximately one-fourth mile below the USGS gauge 09503300. A significant portion of the dam release is held behind another dam at the gauge site and diverted into an irrigation canal and/or the pipeline that recharges treated effluent and storage water at the Airport Recharge Basin. The creek is dry for approximately 12 miles until it surfaces approximately one-half mile above the Verde. Studies have shown that Granite Creek contributes less than five percent of the flow to the Upper Verde River. The quality of the water in Granite Creek where it meets the Verde River is high and to date there is no indication of negative impact on the Verde River.
No nutrient samples have been collected by USGS at the gauge below Watson Lake (09503300). ADEQ collected one downstream sample on April 3, 2008 during a period when the lake was in a mixed condition and found the following nutrient levels: 0.8 mg/L TN and 0.19 mg/L TP. Two additional downstream samples were collected during the summer when the lake was stratified: 1.62 mg/L TN with 0.60 mg/TP, and 1.20 mg/L TN with 0.44 mg/L TP. These data suggest release of TN and TP approximately doubles during summer months. However, further sampling should be designed to confirm the character of the dam discharge versus possible groundwater or other influences.

ADEQ recommends collection of additional samples of water released from Watson dam during peak summer conditions to further evaluate potential impacts below Watson. Samples obtained approximately one half mile below the dam may reflect the influence of groundwater and confuse evaluation of impacts below Watson. Sampling should be conducted to characterize both potential groundwater influence in addition to the water released from the dam. However, meeting TMDL targets within the lake will improve water quality for uses downstream of the lake and continue to ensure no degradation of the Verde River system.

9.0 DISCUSSION OF MANAGEMENT OPTIONS for REDUCTION of TN and TP

The Watson Lake watershed has been identified as a “targeted watershed” by ADEQ. Watersheds with this designation receive priority ranking when applying for 319 grant funds to implement projects recommended in the WIP to address nonpoint sources and increased support from ADEQ water monitoring and permitting programs. Urban stormwater activities that directly implement an AZPDES permit are considered to be point source in nature, and are not eligible for 319 funding per federal guidelines. Much of the Granite Creek/Watson Lake watershed falls under MS4 permit regulation, which does limit the activities that can be funded by 319 monies. However, projects outside of the MS4 boundaries and projects that take place on and address pollution coming from private property within an MS4 are eligible for 319 funding and will receive prioritization. ADEQ continues to coordinate efforts with local stakeholders to implement priority projects, update the WIP, and improve water quality throughout the watershed. In addition to directly reducing source loading, management practices best suited to mitigate nutrient loading from the upper watersheds are in-stream sediment controls/stabilization and off-creek retention basins that could reduce loads to the creeks.

Upon completion of the Watson Lake and Granite Creek TMDLs, ADEQ will work with the WIC and additional stakeholders to update the WIP, incorporating the results of the TMDL studies. Watersheds that were shown as significant sources in both the original WIP and TMDLs will be identified and prioritized for additional investigation. While the 2012 WIP identified green infrastructure and bioretention basins as the primary implementation projects, ADEQ continues to pursue projects that remove sources rather than treat their symptoms. The ADEQ CWA programs will continue to coordinate sampling, permitting and compliance efforts in order to improve water quality within the watershed by reviewing water quality data, annual permit reporting requirements and tracking compliance schedule implementation. ADEQ will initiate the WIP revision process in the fall of 2014, completing it within a year.

9.1 Recommendations from the Watershed Improvement Plan (WIP), excerpted from Prescott Creeks et. al, 2012

Watershed investigations as part of the WIP comprised of volunteer water quality monitoring, a watershed field survey, watershed residents' survey, and riparian buffer assessment. Water quality monitoring was conducted between 2009 and 2012 for physical parameters including pH, dissolved oxygen, and temperature; chemical parameters like TN, TP, Total Kjeldahl Nitrogen (TKN), and ammonia; and biological parameters including *E. coli* and *Bacteroides* for Microbial Source Tracking (MST). Monitoring also included testing for pharmaceuticals with the Arizona Lab for Emerging Contaminants (ALEC). Both the ALEC monitoring and MST testing revealed strong anthropogenic influences on lower Manzanita Creek, lower Butte Creek, North Fork of Granite Creek, and lower Miller Creek with the North Fork of Miller Creek possibly contributing significantly to water quality problems downstream. Data for the North Fork of Miller Creek to-date is limited.

In a 2010 watershed field survey, Creek Crew volunteers systematically walked 16.5 miles of stream to document sources and causes of excess nutrients and *E. coli.* Of the sources/causes documented, the majority of them were related to stormwater drainage, followed by impacts to the riparian buffer. Miller, Butte, Granite, and Aspen Creeks had the most observations per mile of creek surveyed. These data point towards urban pollutants carried in stormwater, exacerbated by a lack of adequate riparian buffers along the urban creek reaches.

A 2010 rapid vegetation assessment and physical survey of the Upper Granite Creek Watershed was undertaken to assess the current functionality of the watershed channels in terms of their ability to filter pollutants from runoff. Results indicate that riparian impacts are scattered across the watershed and are not isolated to a specific land use. Urban reaches of Miller, Butte, and Granite Creeks had the lowest riparian scores, signifying that these reaches had little to no vegetation, other disturbances, and/or limited width due to human activities or structures.

A Watershed Residents' Survey was mailed to approximately 40,000 households between December 15, 2009 and March 15, 2010. The survey was designed to gather information about watershed residents' knowledge of watershed and water quality issues; perceptions of water quality; attitudes and values about protection and restoration of local water ways; and environmental behaviors. Nearly 1,500 survey responses were received. Survey results demonstrate that there is general public support for protecting and restoring our waterways, yet there are large gaps in public knowledge about watersheds and sources of pollutants.

Through these data collection activities and local knowledge of the watershed, potential sources of pollution were identified as: aging and degraded municipal sewer infrastructure; failing or ill-maintained septic systems; water reuse; horses, cattle, and other livestock; and pets. Background sources such as wildlife and forest fires also contribute to nutrient loading. The lower subwatershed areas are highly urbanized. Therefore, the types of potential bacteria and nutrient sources are greater than in the mostly undeveloped upper subwatersheds. The urbanized creek segments have been channelized and separated from their natural floodplains, increasing the risk of flooding to nearby properties. The majority of natural riparian vegetation has been replaced by walls or other structures and cannot adequately perform biological filtration functions. Stormwater drainage from roads and neighborhoods is directed into the nearest waterway untreated. The data indicates that the primary factors leading to water quality impairments in the project area are nonpoint source pollutants, increased runoff volumes due to impervious surfaces, and a lack of stormwater detention and infiltration/filtration.

GI is the primary WIP recommendation for addressing stormwater and associated pollutants in the watershed. GI is a broad term for features that rely on natural processes such as soil, water, and plants to provide ecosystem services such as clean air, clean water, and temperature regulation. GI encompasses existing forests and green spaces as well as constructed bio-retention features such as rain gardens, wetlands, and filter strips. Many of these practices were originally developed in temperate climates but are gaining popularity in municipalities in the arid Southwest as a way to manage urban stormwater at a lower cost than the traditional grey-water infrastructure (pipes and culverts) while providing other economic, social, and environmental benefits (USEPA, 2009). The WIP recommends that GI be integrated with traditional grey infrastructure to the maximum extent possible within the watershed to effectively reduce stormwater quantity before it enters the already overburdened stormwater system and discharges to the nearest water body.

Because a watershed-aware citizenry is key to improving surface water quality, the WIP also recommends a variety of education and outreach activities to engage the community and raise awareness to targeting different audiences and community groups. Public workshops, mailings, educational articles, and expanding the existing creek signage and storm drain marker programs are recommended.

As part of a comprehensive strategy, the WIP also includes BMP recommendations for golf course turf management, manure management, green waste, forest protection and restoration, and invasive vegetation management. Specifically, the WIP identifies four priority BMP projects which are described in detail in Appendix H of that document and listed below:

- Bioretention and Sediment Basins at Prescott Rodeo Grounds
- Whipple Street Bioretention Basins*
- Green Infrastructure Demonstration at Prescott Community/Adult Center*

- Green Industrial Site Practices at the APS Construction Yard

  * projects since funded through Non-point Source (CWA Section 319) Grant awarded by ADEQ

To ensure continued investments in watershed health, the WIP recommends that continuous, local funding sources be investigated. In addition to federal, state, and private grant programs, an example of such funding is a “watershed protection fee” levied on municipal utility customers. The Watershed Residents’ Survey of 2010 found that the majority of respondents supported a fee to address local water quality and watershed issues in addition to supporting protection and restoration efforts within the watershed. The fee would be a property-based charge calculated, for example, on the amount of impervious area on a property. In return, the fee would provide an incentive to reduce impervious cover, disconnect downspouts, and install rainwater harvesting features.

9.2 Recommendations from the Watson Lake Modeling Report (excerpted from Tetra Tech, 2012)

Management of stormwater and wastewater loading, collectively, is likely to address the majority of the anthropogenic nutrient loading from the watershed. The ideal stormwater treatment facilities would provide large reductions in both nitrogen and phosphorus. More dense urban areas within the City of Prescott may be constrained by space and steep slopes. While wet detention ponds (commonly-used stormwater facilities) provide moderate nitrogen and phosphorus reduction, these facilities may be difficult to site in the more dense urban areas. Even in low density urban areas, steep slopes may constrain the ability to site wet detention ponds or other large, centralized stormwater facilities. Smaller, more distributed stormwater facilities would likely provide more promising options for stormwater treatment throughout the developed watershed areas. Bioretention areas were chosen as the representative distributed stormwater treatment facility for the purpose of this scenario.

Bioretention areas are relatively small depressions filled with sandy soil and planted with vegetation that receive stormwater runoff and slowly infiltrate the runoff into the underlying soil. Where native soils do not provide sufficient infiltration rates, a gravel underdrain can be constructed underneath the sandy soil layer. These facilities can be incorporated into existing landscaping, parking medians, and other small areas available for retrofits. Filter strips or other pretreatment devices should be used to remove sediment from runoff before it enters a bioretention area, as these the sandy soil layer can become clogged with sediment. The maximum recommended drainage area is five acres. Bioretention areas can be expensive to implement, but provide multiple advantages in addition to nutrient reduction, including landscaping amenities, control of downstream flow, and potential for groundwater recharge.

Hirschman et al. (2008) suggests that load reductions of 64 and 55 percent can be achieved by treating stormwater runoff with bioretention. Greater reductions have been measured from bioretention, but these values provide a conservative estimate of load reductions that can be achieved, given that bioretention has not been studied directly within the watershed. Urban land uses accounted for 14 percent of watershed area and approximately 50 percent of TP or TN load, but bioretention could be universally applied to any land use.

9.3 Lake Management Plan

9.3.1 Recommendations from the 1986 Watson Lake Management Plan (William Towler for the Northern Arizona Council of Governments)

The state Verde nutrient standards were promulgated In the early 1980s. As a result, Prescott was faced with the necessity of adding nutrient removal to their wastewater treatment process at the Sundog Ranch plant. The City applied for a nutrient waiver in January of 1984 and subsequently hired Dr. Milton Sommerfeld of ASU to study nutrient loading to Watson. In conjunction with this study, EPA Region 9 provided funding for the Northern Arizona Council of Governments to develop a Lake Management Plan for the lake. The work program for the Watson Lake Study contained several elements:

- Review of existing water quality data
- Background sampling
- Gross Nutrient Budget
- Intensive survey design
- Sediment study assistance
- Lake restoration feasibility study
- Public participation

If discharge of effluent to Watson was to continue, the draft NPDES permit contained limits for phosphorus and nitrogen which were 98 percent and 96 percent less than the existing loadings, respectively. Alternatives considered included the following:

- No Action (Water Quality Control Board would have to approve nutrient waiver)
- Complete nutrient removal
- Total effluent reuse
- Use of ‘ponds’/wetlands in Granite Creek for nutrient removal by plants
- Diversion of effluent to a different location
    - Granite Creek below the lake
    - Directly to the CVID ditch
    - Willow Lake
    - A different watershed

Ultimately, a nutrient waiver was not approved and the City opted to build a diversion structure to carry the secondary-treated effluent around the lake for irrigation and recharge. Over time, much of the effluent has been used in reuse applications on golf courses during summer months. There was discussion of retaining or removing the full body contact (FBC) designated use, but renewed interest in recreation at Watson led the City to obtain a grant to upgrade park facilities on an easement known as Watson Lake Park. Upgrades included paved roads, picnic ramadas, restrooms, parking areas and a campground. The grant was contingent upon boating use and the development of a ramp. The FBC use was retained, although the City has continued to post the lake as “no swimming”.

In addition to point source control of nutrients, the document discusses several in-lake restoration alternatives (dredging, nutrient precipitation, flushing, chemical treatment of algae, biological control, and weed harvesting . The document also suggests the control of non-point sources and erosion/ lake sedimentation through retention of native vegetation, enactment and enforcement of a grading and excavation ordinance, prohibition or severe limitation of construction on slopes in excess of 25 percent, replanting of excavated slopes, and replacement of disturbed or removed vegetation with native plant materials or other similar vegetation.

The document recommends ongoing sampling (Intensive Survey Design) within the lake, above the lake in the watershed, and below the lake, as well as a “sediment study” (bathymetric measurements) to determine lake sedimentation and changes in storage capacity. In addition, there were three recommendations for future research;

- Release of nutrients by bottom sediments
- Uptake of nutrients by riparian vegetation
- Edibility of fish species

9.3.2 Recommendations from the Phase II Limno-corral Study, excepted from Walker, 2013

Based on the combined results of Phase I and Phase II, ALUM application proved very efficient in reducing TP by 86 percent, with the secondary effect of reducing TKN. The study suggests that, even in the presence of various forms of nitrogen, that phosphorus can be made a limiting nutrient to algal growth.

Estimating the impact of phytoplankton algal biomass reduction proved difficult, due to lack of adequate size fractionation in the plankton nets used and the patchy nature of the dominant algae. Periphyton biomass, on the other hand, clearly showed a significant reduction of 67.5 percent.

Walker asserts, “Periphyton occupies a different ecological role than phytoplankton, however, the manner in which either periphyton or phytoplankton responds to nutrient limitation should be similar and total P reduction should result in a similar drop in biomass. For example, if phytoplanktonic chlorophyll *a* levels are 30 ug/L and total P levels are 0.5 mg/L, then lowering the total P levels to 0.07 (86 percent reduction) should result in a decrease of chlorophyll a levels to 9.75 ug/L”. Dr. Walker included several recommendations in his Phase II report, strongly emphasizing the need for a lake management professional:

- Develop a lake management plan that clearly lays out priorities and establishes a long-term comprehensive lake monitoring program and strategy for ongoing assessment of water quality improvements.

- Manufacture a tiered plankton sampler, each tier with its own flow meter, to capture overlapping size classes.

- Severe seasonal anoxia and reducing conditions leads to release of phosphorus and ammonia from lake sediments. Aeration may be the treatment capable of most benefit by helping to prevent fish kills, decreasing the amount of potentially toxic cyanobacteria, increase algal diversity and zooplankton biomass favoring the fishery, and mediate phosphorus inactivation.

- As preferred first treatment method, Watson would benefit from a combination of both hypolimnetic (deep) and shallow (direct) aeration.

- As secondary treatment, ALUM or dredging should be considered. Deep dredging would remove nutrient-rich sediments, whereas, dredging in the shallow segment may minimize growth of submerged aquatic vegetation.

- If ALUM is chosen for treatment, application needs to be repeated; it is best used early in the spring and repeated throughout the summer in smaller doses to prevent toxicity and loss of oxygen at depth. Dissolved and total aluminum should be carefully monitored.

9.4 Watershed Monitoring Strategy as Part of an Updated WIP

The ADEQ Watershed Protection Unit and Stormwater Permit Unit will work with stakeholders to develop a comprehensive and complimentary watershed monitoring strategy. Sample plans will follow ADEQ QAPP/SAP requirements and clearly state spatial and temporal monitoring objectives and reporting. ADEQ recognizes that permitted entities may have specific objectives that differ from non-permitted entities. Each monitoring entity will contribute a chapter to an appendix of the updated WIP, identifying site locations, sample parameters, collection methods, labs used, data reporting requirements, and quality assurance/quality control measures. It will be important to update the strategy on a regular basis so that source characterization and TMDL implementation are timely noted. The list of entities identified to date include:

- Prescott Creeks and volunteers (Nonpoint Source)
- Prescott College and volunteers (Nonpoint Source)
- Prescott National Forest (Nonpoint Source)
- State Lands (Nonpoint Source)
- YPIT (Nonpoint Source)
- Private entities TBD
- City of Prescott (MS4)
- Yavapai County (MS4)
- ADOT MS4 facilities

9.5 WIP as TMDL Implementation

There are several objectives in reconvening the WIC and updating the WIP. ADEQ will use this forum to coordinate outreach and education efforts and stakeholder involvement in source identification, monitoring efforts, BMP identification, and project implementation and tracking. ADEQ acknowledges that plans will be considered working documents, subject to refinements or adjustments as needed. It will be important to update the WIP on a regular basis so that source characterization and TMDL implementation are timely noted. Table 13 identifies key milestones for implementation of the TMDL.

Table 13. Milestones for TMDL Completion and Implementation

Milestone	Responsible Party	Target Date
Reconvene WIC	Watershed Protection Unit	February 2015
Incorporate TMDL findings in WIP	Watershed Protection Unit	March 2015
Lake and creek monitoring to identify BMPs • Miller Creek and creeks data gaps • Watson Lake • Ongoing	Watershed Protection Unit	 Being January 2015 Begin March 2015 TBD
Update data analysis with recent data	Watershed Protection Unit	April 2015
Incorporate WIC goals and objectives in WIP	Watershed Protection Unit and stakeholders	May 2015
Incorporate a means to track and compile discharge monitoring results and nonpoint source monitoring results in the WIP	Watershed Protection Unit	May 2015
Incorporate lake monitoring strategy	Watershed Protection Unit and City of Prescott	May 2015
Incorporate timeline for lake management plan development	Watershed Protection Unit and City of Prescott	June 2015
Complete updated WIP	Watershed Protection Unit	June 2015
Public review of WIP	Watershed Protection Unit	June 2015
Implement water quality improvement projects	Watershed stakeholders	Ongoing
Annual review of stormwater monitoring data	Stormwater Permits Unit and Watershed Protection Unit	Annually
Effectiveness monitoring of BMPs	Watershed Protection Unit	TBD
Determine load reductions	Watershed Protection Unit	Annually

10.0 PUBLIC and STAKEHOLDER INVOLVEMENT

Public involvement included 1) collaboration with Prescott Creeks, 2) several presentations to the City of Prescott Water Issues Committee, and 3) two formal public meetings held at the City of Prescott Council Chambers. Public notice of the availability of the draft documents was made via a posting in a newspaper of general circulation -*The Prescott Daily Courier*; via email notifications; via phone calls; and via webpage postings. Representatives of the City of Prescott and their contractor, AMEC, met with ADEQ to discuss the draft documents (Watson Lake

Modeling Report, TETRA TECH, 2012; Sediment Coring Report, Gremillion, 2012; Phase I and II Limno-corral Report. These meetings took place on June 13, 2013 and October 29, 2013. Responses to questions and comments received during the 30-day public comment period that ran from April 1 to May 1, 2014, have been addressed in a public notice posted in the Arizona Administrative Register (A.A.R.) in January 2015 that will run for 45 days.

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APPENDIX A
Watershed Data Analysis

INTRODUCTION:

This appendix contains the results of various data analyses conducted in support of the TMDL as well as the Prescott Creeks Association WIP. Table A-1 shows the single sample maximum Verde River water quality standards exceedances for TN and TP by sample site and date. Table A-2 shows the TN and TP monthly mean results by site and date that are greater than the annual mean Verde River water quality standards. Figure A-1 is a map of the sample locations cited in Tables A-1 and A-2.

The following sections covers TN, TP, and flow distribution, sub-watershed nutrient concentration by flow category, watershed nutrient load comparison by site, and watershed nutrient load comparison by event.

Evaluation of Watershed Nutrient Data in Relation to Surface Water Quality Standards

Table A-1. Sites with Number of Single Sample Maximum (SSM) Standard Exceedances

Map No.	Site Location (top to bottom)	Date	Result	SSM Standard TN	Date	Result	SSM Standard TP
		m/y	mg/L	(> 3.0 mg/L)	m/y	mg/L	(> 1.0 mg/L)
2	Granite at Ponderosa Rd	12/07 01/08	10.7 4.14	2	01/08	3.70	1
5	Manzanita at White Spar Rd	01/08 12/08 12/09 01/10	4.57 2.96 2.90 3.30	4	01/08	2.56	1
4	Aspen at Forest Service Boundary				01/08	1.86	1
6	Aspen at Rancho Vista Rd	01/08	7.16	1	01/08	2.89	1
16	Aspen at Park Rd	01/08	12.27	1	01/08	1.89	1
25	Butte at Lincoln Rd	03/12	5.05	1			
33	Miller at Thumb Butte Park				01/08	1.72	1
31	Miller at Pine Rd	01/10	2.97	1			
24	Miller at Lincoln Rd	03/10	3.21	1	01/08 08/13	1.16 1.50	2
26	Granite at Granite Park	10/10	3.02	1			
29	North Fork Granite at 6th St	01/10 03/12	3.63 2.88	2			
9	Government below Oak Knoll	01/08	3.16	1	01/08	1.76	1
30	Government abv Granite	08/13	3.52	1	08/13	3.40	1
39	Granite at Watson Woods	01/10	3.03	1	01/08	1.04	1

Table A-2. Sites with Number of Monthly Means* Greater than Annual Mean (AM) Standard

Map No.	Site Location (top to bottom)	Date	Result	AM Standard TN	Date	Result	AM Standard TP
		m/y	mg/L	> 1.0 mg/L	m/y	mg/L	> 0.10 mg/L
2	Granite at Ponderosa Rd	12/07	4.38	1	12/07	0.12	1
4	Aspen at Forest Service Boundary	12/07	1.19	1			
19	Aspen at Middlebrook Rd	08/13	1.06	1	8/13	0.16	1
7	Banning above Granite				02/10	0.16	1
14	Manzanita at White Spar Rd	12/07 01/08 12/09 02/10 10/10 08/13	1.60 2.98 2.78 1.42 1.69 1.08	6	12/07 01/08 12/09 02/10 10/10 08/13	0.13 1.36 0.19 0.13 0.18 0.44	6
16	Aspen at Park Rd	01/08	6.57	1	01/08	1.02	1
20	Granite at Leroux Rd				08/13	0.25	1
25	Butte at Lincoln	12/07 01/08 10/10	1.07 1.45 1.21	3	12/07 01/08 10/10 08/13	0.30 0.28 0.27 0.26	4
27	Miller at Oregon Rd	01/08	2.06	1	01/08	1.28	1
26	Miller at Lincoln Rd	12/07 01/08 02/10 08/13	2.09 2.29 1.53 2.21	4	12/07 01/08 08/13	0.48 0.38 1.14	3
29	Granite at Granite Park	10/10 08/13	1.60 1.07	2	10/10 08/13	0.33 0.28	2
34	North Fork Granite at 6th St	02/10 08/13	2.38 1.41	2	02/10 08/13	0.13 0.35	2
32a	Acker at Moeller St or EZ St	08/13	1.99	1	08/13	0.60	1
32b	Acker at Whitlow St	08/13	1.48	1	08/13	0.43	1
37a	Slaughterhouse above Granite			0	08/13	0.15	1
39	Granite at Watson Woods	12/07 01/08 12/09 02/10 08/13	1.15 1.19 2.38 1.13 1.39	5	12/07 01/08 12/09 08/13	0.35 0.48 0.26 0.43	4
44a	Granite below Watson Lake	08/13	1.39	1	08/13	0.52	1

*Monthly mean = mean of at least two samples collected within a one month period

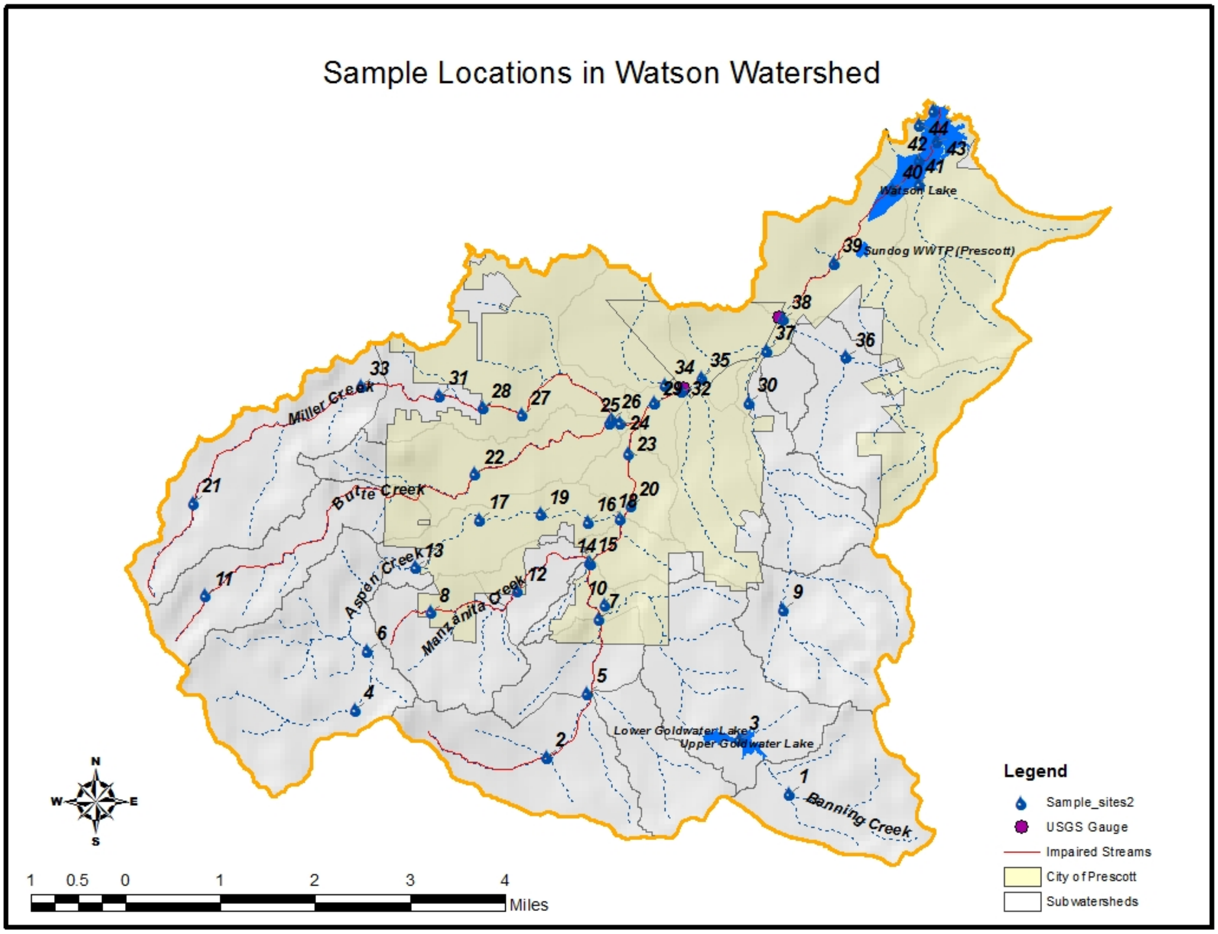


Figure A-1. Watershed Sample Sites

Watershed Nutrient Data Distribution and Relation to Flow

Environmental data are seldom '"normally distributed"; they do not follow a typical bell-shaped curve. Figure A-2 shows the distribution of TN and TP data collected throughout the watershed. TN appears to be relatively normally distributed, whereas, TP data are left-skewed (based on a sample size of 100). The lower graph shows a weak overall relationship of either TN or TP to associated flow measurements.

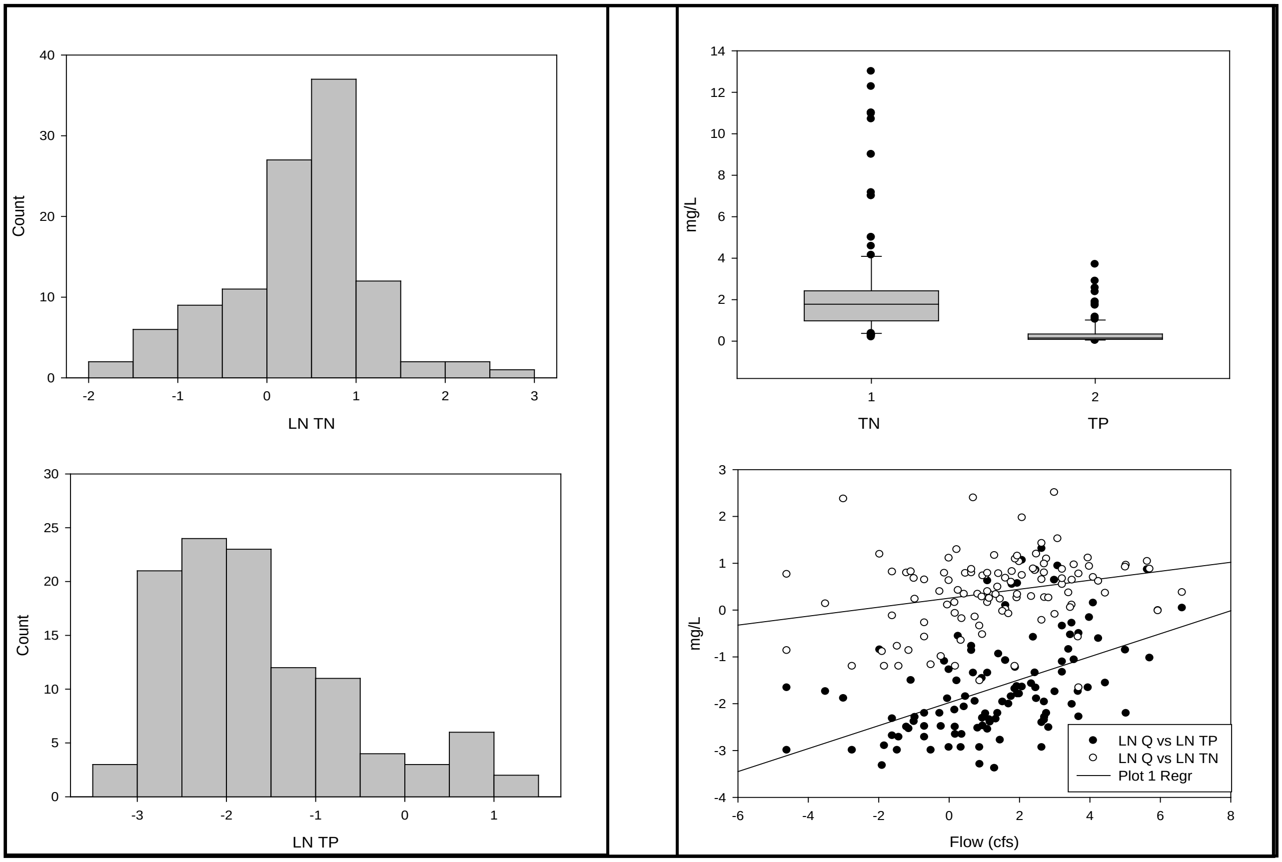


Figure A-2. Distribution of TN and TP in Watershed Samples and Relation to Flow

Although the scatter is broad for both TN and TP, there is a more defined increase in TP with increase in flow. Phosphorus tends to bind with sediment, so in storm events that mobilize sediment, higher TP can be expected. Nitrogen is more closely associated with organic material and appears to be mobilized under both stormflow and stable flow. The statistical breakdown of flow history at the two USGS gauges above Watson Lake can be seen in Table A-3.

Table A-3. Statistics of Monthly Mean Data for Period of Record (POR), by Water Year (WY)

Upper Granite Creek USGS Gauge (09502960) POR: 1994 - Present

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Mean	2.38	3.13	5.00	14.3	21.7	15.6	4.61	0.80	0.23	4.01	6.02	4.12
Max	14.0	29.4	44.5	101	128	74.1	31.6	3.92	1.15	24.4	20.5	14.0
(WY)	(2005)	(2005)	(2005)	(2005)	(2005)	(1995)	(1998)	(1998)	(1999)	(1999)	(2005)	(1997)
Min	0.02	0.08	0.18	0.09	0.09	0.20	0.24	0.03	0.00	0.00	0.25	0.25
(WY)	(2008)	(2006)	(2006)	(2002)	(2002)	(2002)	(2002)	(1996)	(2002)	(1997)	(2002)	(2001)

	Water Years 1995 - 2008	Year	Month
Annual total			
Annual mean	5.99		
Highest annual mean	30.0	2005	
Lowest annual mean	0.79	2002	
Highest daily mean	940	1995	Mar 6
Lowest daily mean	0.00	1995	Jul 11
Annual seven-day minimum	0.00	1995	Jul 22
Annual runoff (ac-ft)	4,340		
Annual runoff (cfsm)	0.200		
10 percent exceeds	11		
50 percent exceeds	0.21		
90 percent exceeds	0.00		

Lower Granite Creek USGS Gauge (09503000) POR: 1932 – 1947; 1994 - Present

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Mean	1.66	1.78	4.60	10.1	21.4	21.7	7.00	1.02	0.26	3.14	5.02	3.15
Max	15.2	30.0	48.1	109	159	79.2	67.2	7.03	1.59	32.0	24.9	17.1
(WY)	(2001)	(2005)	(2005)	(2005)	(1937)	(1941)	(1941)	(1941)	(1999)	(1999)	(2005)	(1999)
Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(WY)	(1933)	(1933)	(1933)	(1934)	(1934)	(1934)	(1934)	(1935)	(1933)	(1934)	(1947)	(1932)

	Water Years 1995 - 2008	Year	Month
Annual total			
Annual mean	6.70		
Highest annual mean	33.0	2005	
Lowest annual mean	0.37	1935	
Highest daily mean	1450	1937	Feb 7
Lowest daily mean	0.00	1932	Jul 1
Annual seven-day minimum	0.00	1932	Jul 4
Annual runoff (ac-ft)	4,850		
Annual runoff (cfsm)	0.184		
10 percent exceeds	12		
50 percent exceeds	0.3		
90 percent exceeds	0.0		

* from USGS web site: http://waterdata.usgs.gov/nwis/rt

Sub-watershed Nutrient Concentration - by Flow Category

When broken down by sub-watershed, it can be seen that Lower Miller Creek and Lower Manzanita Creek had the highest number of elevated TN values, both creeks under stable flow and Miller Creek also under stormflow (Figures A-3 and A-4). The Watson Woods location also shows elevated TN, reflecting accumulation from upstream sources. The highest number of elevated TP values under stable flow was Lower Miller. Under stormflow conditions, the greatest number of elevated TP occurred at the Watson Woods site, which again reflects accumulation from upstream (Figures A-5 and A-6). Relatively higher concentrations of nutrients found under stable flow may indicate septic influence or other point source input. Though not conclusive, these findings dovetail with the results from Prescott Creeks sampling for chemicals frequently found in wastewater (WIP, 2012).

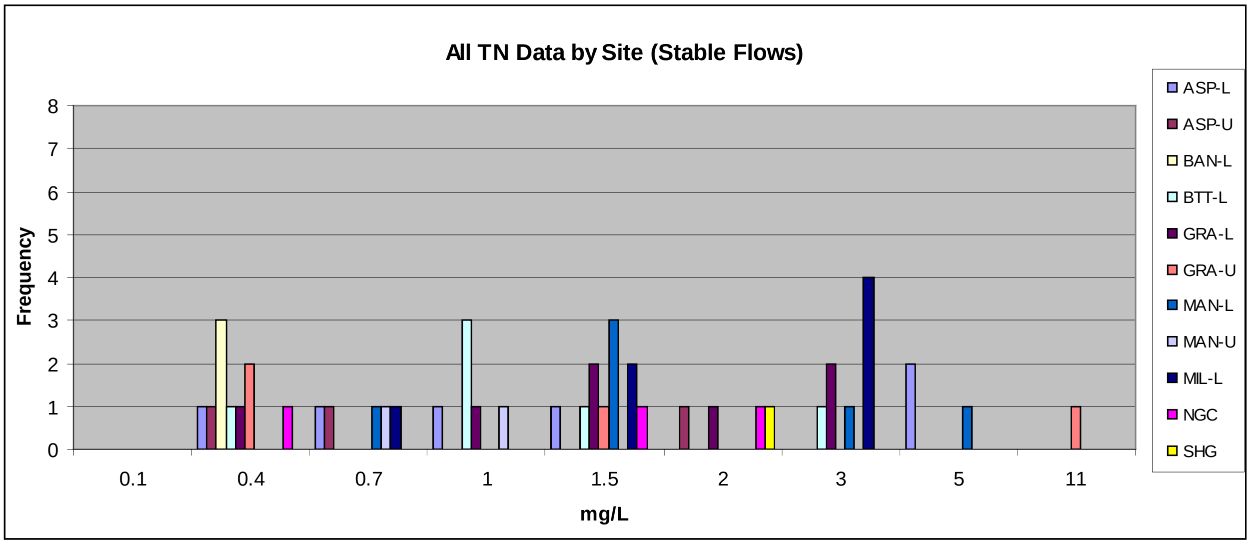


Figure A-32. All TN Data by Site (Stable Flows)

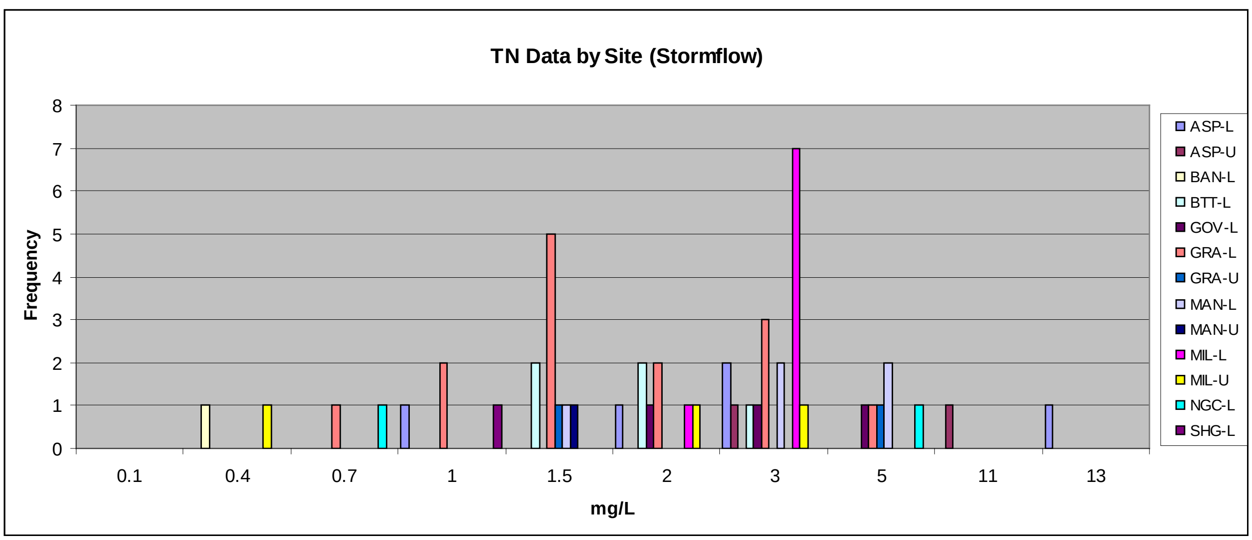


Figure A-4. All TN Data by Site (Stormflows)

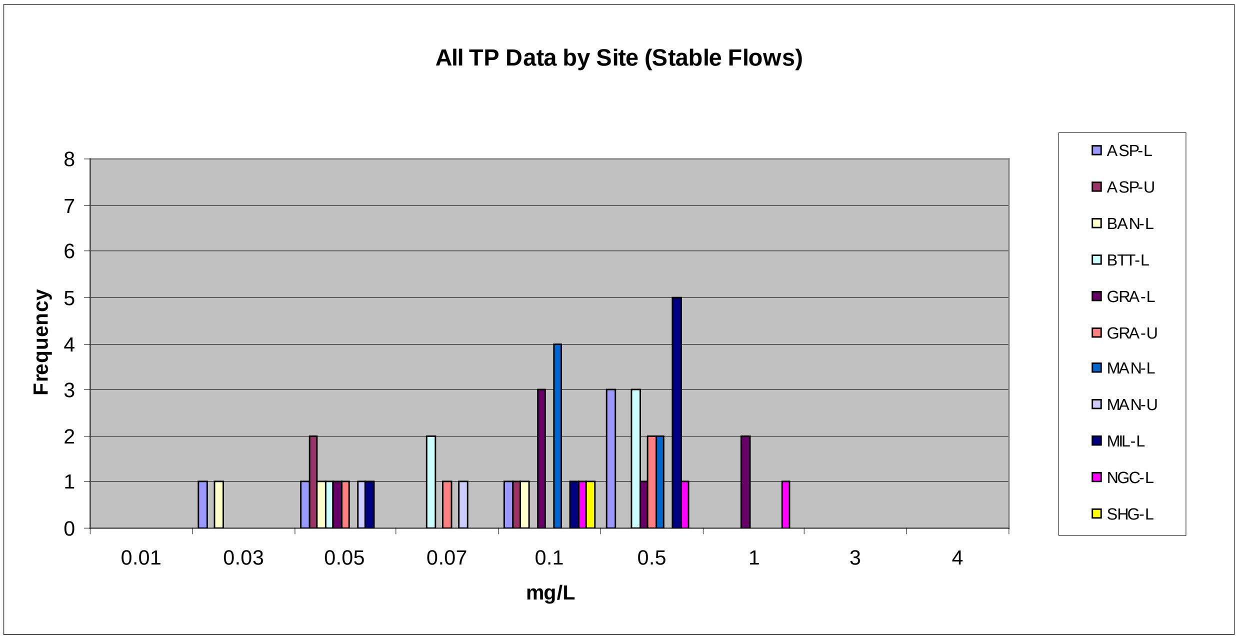


Figure A-5. All TP Data by Site (Stable Flows)

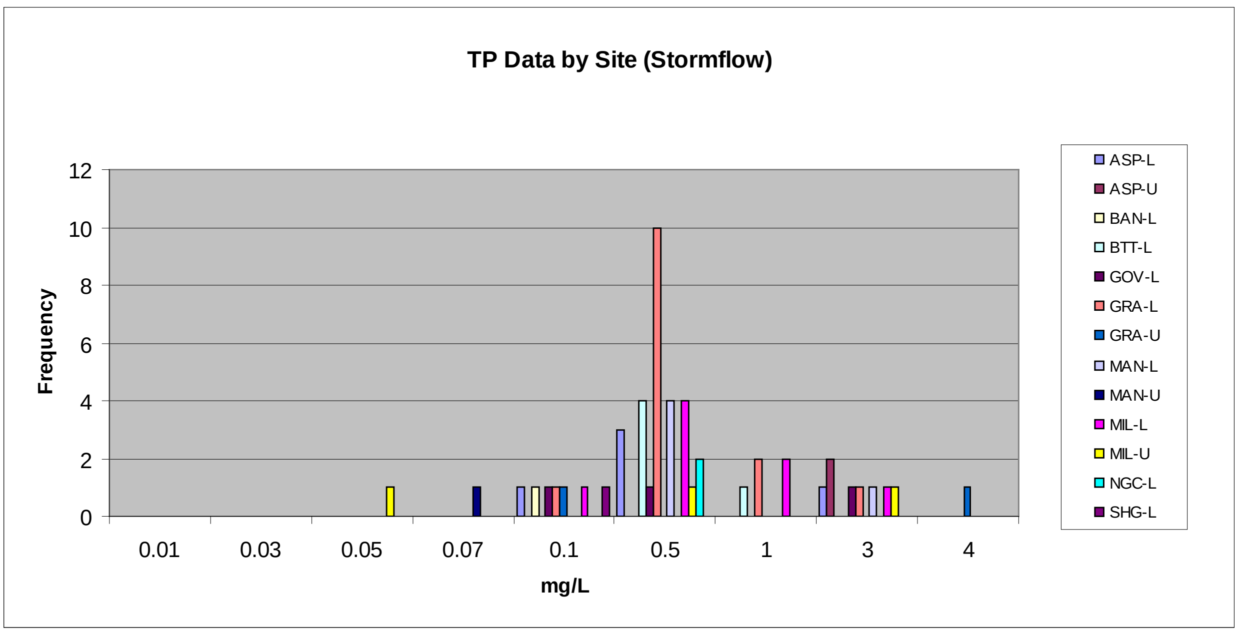


Figure A-6. All TP Data by Site (Stormflows)

Watershed Nutrient Load Comparison - By Site

Table A-4 shows TN and TP loads calculated using flow-weighted analysis. All "upper" sites are on Forest Service land, except for Upper Government, which is located at the base of the Oak Knoll residential community. "Lower" sites are all within city, county, tribal, or state boundaries (refer back to Figure 12 for site locations). Daily loads have been ranked from highest to lowest, showing a consistent subset of locations where higher loads are present. Note that Lower

Banning load is quite low, reflecting the fact that much of the watershed is regulated by Upper and Lower Goldwater Lake. Note also, in this analysis, the two sites on Lower Granite Creek show the lowest daily loads, reflecting the effects of dilution and the fact that the load is spread out over a greater area. The highest load per square mile was found at the Upper Granite location (Ponderosa Rd.), which may reflect the influence of the 2002 Indian Fire. To a lesser extent, Upper Aspen, Upper Manzanita, and Upper Miller also fall into the top eight loads calculated; in terms of "background load", the forest load is an important consideration. Figure A-7 presents the data compiled by subwatershed.

The subwatersheds with the highest loadings will be revisited in the 2015 updated WIP and prioritized for additional source determination and possible BMP applications.

Table A-4. Flow-weighted Analysis by Watershed Site (cumulative area)

Watershed Position	TN Load Ranked		Watershed Position	TP Load Ranked
	(lbs/day/square mi)			(lbs/day/square mi)
Upper Granite	**13.30**		***Upper Granite***	**11.64**
Lower Aspen	**8.60**		***Upper Government***	**4.12**
Lower Manzanita	**7.63**		***Lower Manzanita***	**3.31**
Upper Government	**7.41**		***Upper Aspen***	**2.71**
Lower N. Fork Granite	**6.15**		***Lower Aspen***	**1.81**
Upper Manzanita	**5.56**		***Lower N. Fork Granite***	**1.61**
Upper Aspen	**3.26**		**Slaughterhouse Gulch**	**1.54**
Lower Government	**2.80**		**Upper Miller**	**1.48**
Slaughterhouse Gulch	2.32		Lower Miller	0.66
Upper Miller	2.27		Lower Butte	0.57
Lower Butte	1.90		Lower Government	0.46
Lower Miller	1.90		Upper Manzanita	0.22
Upper Butte	1.23		Upper Butte	0.13
Lower Banning	0.51		Granite at Watson Woods	0.11
Granite at Granite Park	0.46		Lower Banning	0.09
Granite at Watson Woods	0.20		Granite at Granite Park	0.07
Median	**2.56**		**Median**	**1.06**
First Quartile	1.72		First Quartile	0.20
Third Quartile	6.48		Third Quartile	2.03

Bolded sites have calculated daily load above median of all sites

Italics **indicate the same locations showing higher loads for both TN and TP**

Watershed Nutrient Load Comparison - By Event

Perhaps most convincing is analysis of TN and TP loads by sampling event. Figure A-7 and Table A-5 show a rank of the sites from highest to lowest where calculated flow-weighted loads were one or two times greater than the standard deviation of the mean of the data set for each event. Lower Manzanita and Lower Miller top the list for both TN and TP, with Lower Butte, Middle Miller, Lower Aspen, North Fork Granite, and Granite Park all showing at least one event.

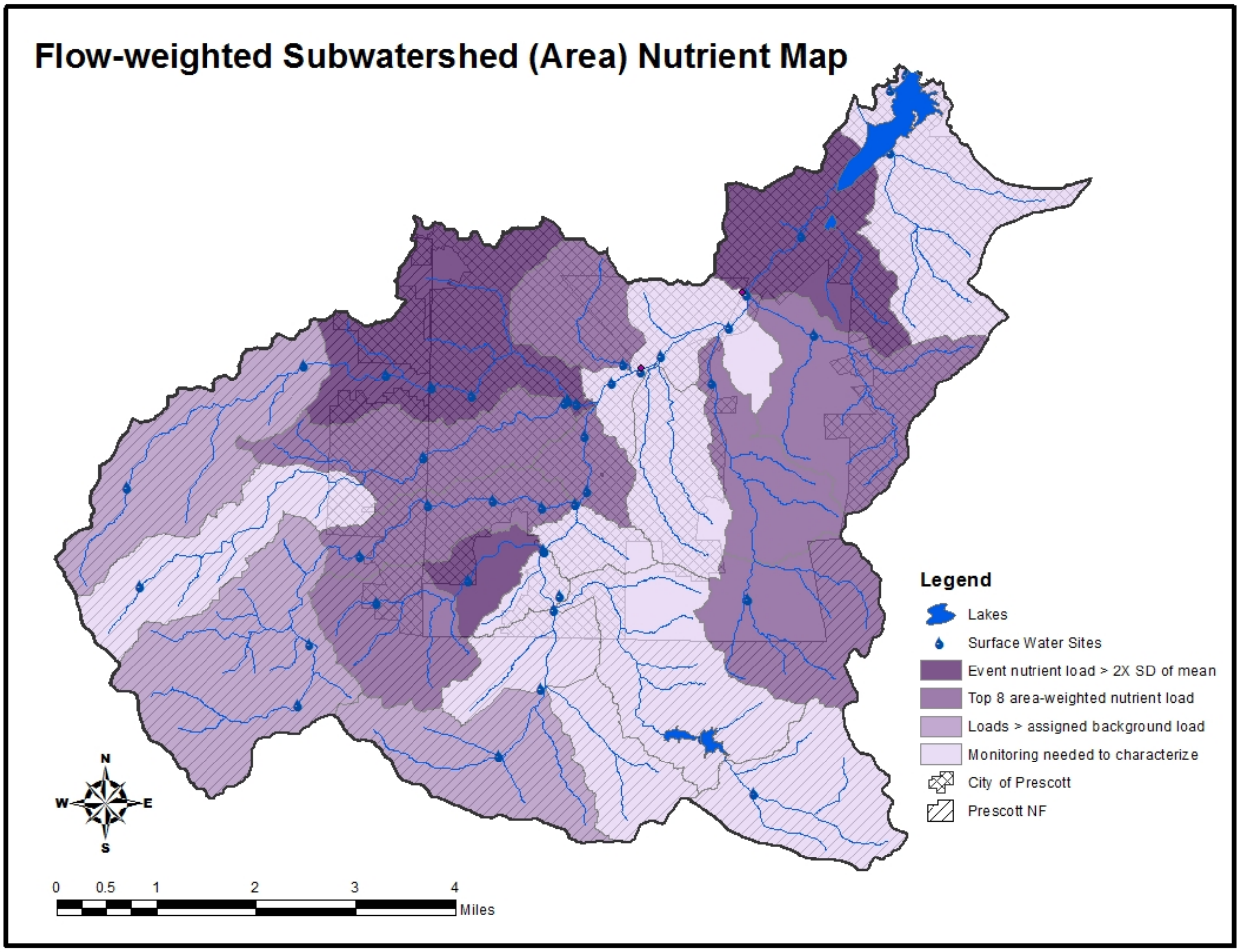


Figure A-7. Subwatershed Area Nutrient Loading Status

Table A-5. Per-event Analysis by Watershed Site

		12/12/2007	12/12/2007	1/6/2008	1/6/2008	1/7/2008	1/7/2008	1/11/2008	1/11/2008	1/27/2008	1/27/2008	1/28/2008	1/28/2008	2/7/2008	2/7/2008	12/18/2008	12/18/2008	2/14/2009	2/14/2009	12/7/2009	12/7/2009	1/26/2010	1/26/2010	5/13/2010	5/13/2010	10/5/2010	10/5/2010
#	***TOTAL NITROGEN LOAD***	*> 2 SD*	*> 1 SD*	*> 2 SD*	*> 1 SD*	*> 2 SD*	*> 1 SD*	*> 2 SD*	*> 1 SD*	*> 2 SD*	*> 1 SD*	*> 2 SD*	*> 1 SD*	*> 2 SD*	*> 1 SD*	*> 2 SD*	*> 1 SD*	*> 2 SD*	*> 1 SD*	*> 2 SD*	*> 1 SD*	*> 2 SD*	*> 1 SD*	*> 2 SD*	*> 1 SD*	*> 2 SD*	*> 1 SD*
9	***Lower Manzanita***	***1***		***1***				***1***		***1***				***1***		***1***		***1***				***1***					*1*
7	***Lower Miller***		*1*				*1*					***1***			*1*		*1*		*1*	***1***							
4	***Watson Woods***					***1***						***1***									*1*					***1***	
4	***Lower Butte***		*1*									***1***									*1*						*1*
3	*Middle Aspen*										*1*												*2*				
3	***Middle Miller***														*1*							***1***	*1*				
2	*Upper Granite*								*1*		*1*																
2	***Lower Aspen***							***1***		***1***																	
2	***North Fork Granite***																							***1***			*1*
1	*Middle Granite*												*1*														
1	***Granite Park***											***1***															
1	*Slaughterhouse*						*1*																				
0	*Upper Manzanita*																										
0	*Upper Butte*																										
0	*Upper Miller*																										
0	*Lower Banning*																										
0	*Upper Aspen*																										
0	*Upper Gage*																										
0	*Upper Government*																										
0	*Lower Government*																										

#	TOTAL PHOSPHORUS LOAD	> 2 SD 12/12/2007	> 1 SD 12/12/2007	> 2 SD 1/6/2008	> 1 SD 1/6/2008	> 2 SD 1/7/2008	> 1 SD 1/7/2008	> 2 SD 1/11/2008	> 1 SD 1/11/2008	> 2 SD 1/27/2008	> 1 SD 1/27/2008	> 2 SD 1/28/2008	> 1 SD 1/28/2008	> 2 SD 2/7/2008	> 1 SD 2/7/2008	> 2 SD 12/18/2008	> 1 SD 12/18/2008	> 2 SD 2/14/2009	> 1 SD 2/14/2009	> 2 SD 12/7/2009	> 1 SD 12/7/2009	> 2 SD 1/26/2010	> 1 SD 1/26/2010	> 2 SD 5/13/2010	> 1 SD 5/13/2010	> 2 SD 10/5/2010	> 1 SD 10/5/2010
8	**Lower Manzanita**	**1**		**1**				1			1				1	**1**		**1**				**1**					
6	**Lower Miller**		1				1	**1**				**1**						**1**		**1**							
6	**Watson Woods**					**1**						**1**					1				1			**1**		**1**	
3	**Middle Aspen**									**1**												**2**					
3	Lower Butte	1										1									1						
3	**Middle Miller**													**1**								**2**					
2	Lower Aspen								1									**1**									
2	North Fork Granite																								1		1
2	Upper Miller								1		1																
1	**Upper Granite**									**1**																	
1	**Middle Granite**											**1**															
1	**Granite Park**											**1**															
1	Slaughterhouse						1																				
0	Upper Manzanita																										
0	Upper Butte																										
0	Lower Banning																										
0	Upper Aspen																										
0	Upper Gage																										
0	Upper Government																										
0	Lower Government																										
	Total Results Per Event	3	3	2	0	2	4	4	3	4	4	9	1	2	3	2	2	4	1	2	4	7	3	2	1	2	4

Bold indicates sites with one or more high values greater than 2x the standard deviation of the mean

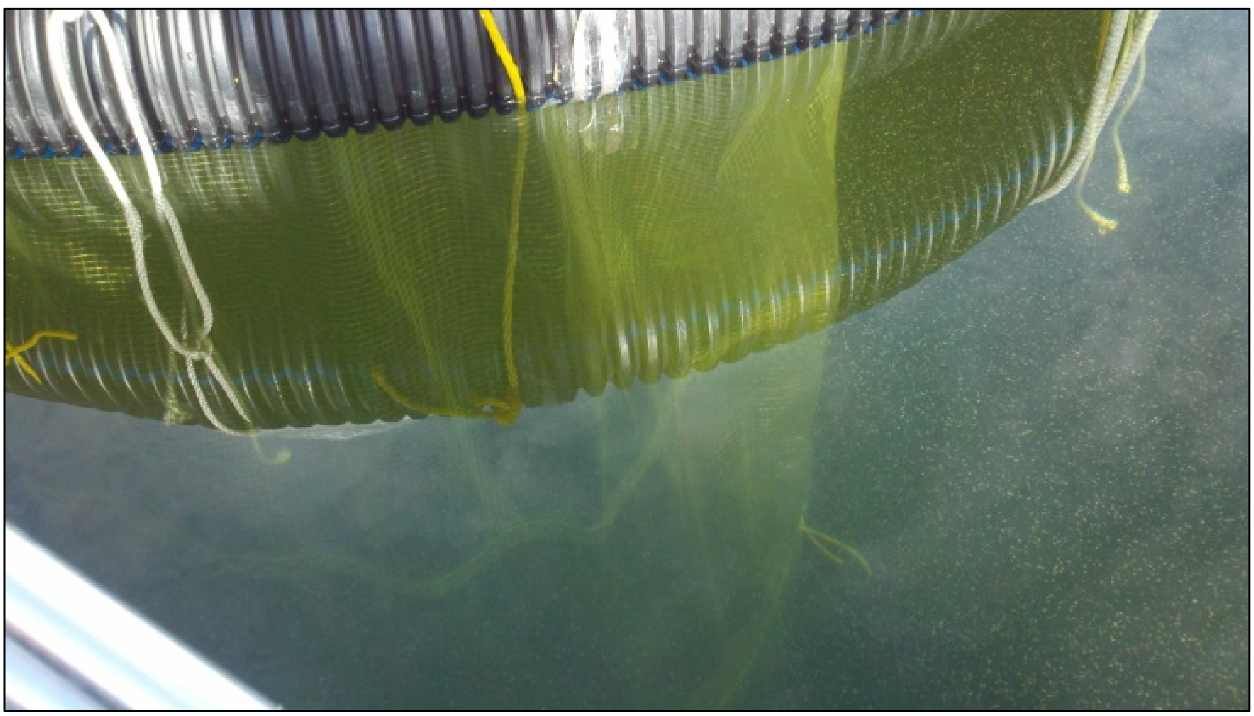
APPENDIX B

Limno-corral Study

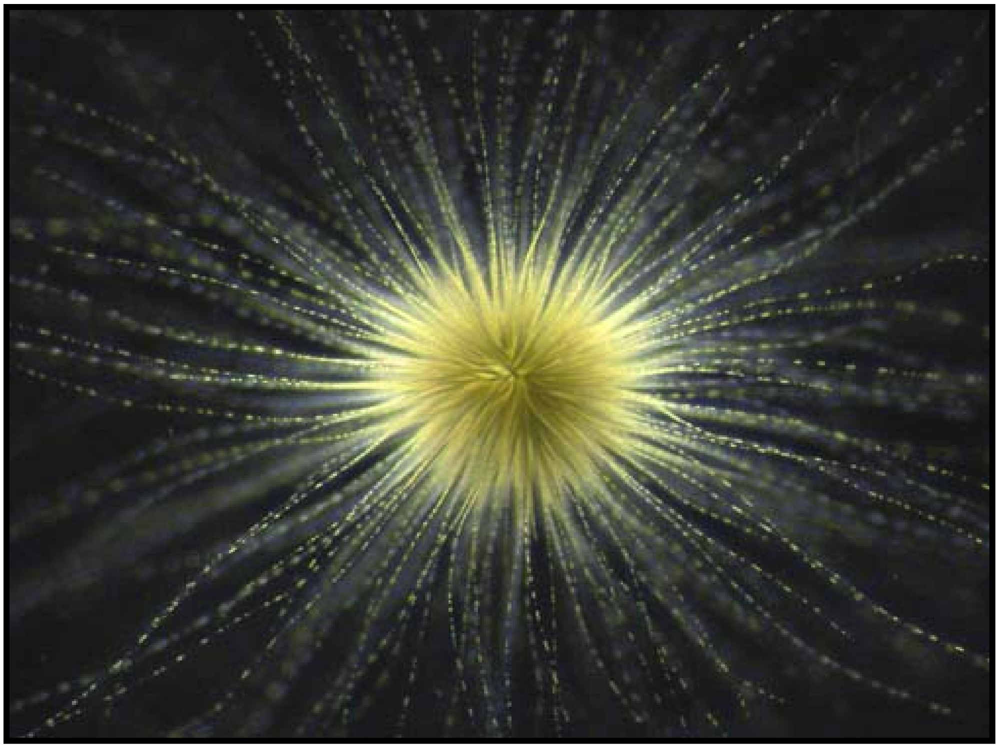
Phase I: Summer of 2011

Highlights from the Phase I study conducted in August through September of 2011 include close reproducibility between replicates and response to algal nutrient levels following treatment(s). Phosphorus was significantly reduced following addition of ALUM, with secondary reduction in TKN. The algal assemblage shifted from cyanobacteria to predominantly chlorophyta.
Less successful was the measured planktonic algal biomass and biovolume response to fertilization and algal treatments; Walker (2012) suggested that one reason for this was perhaps insufficient time given for the algal response, as the project was only run from mid-August through mid-October rather than over the entire summer. In addition, the periphytic (attached algae) growth that occurred on the surface of the limno-corrals was not expected so sampling for periphytin had not been included in the sample plan.

The poor relationship of nutrient levels to algal biomass (chlorophyll-a) not only occurred in the Phase I study, but also was revealed in the open water lake samples collected by ADEQ. Walker attributes this poor relationship to the dominance of *Gloeotrichia,* a cyanophyte that grows in clumps and is heterogeneously distributed in the water column (seen below). This is a highly heterocystous species capable of fixing atmospheric nitrogen.



Clumps of *Gloeotrichia* outside Limno-corral



Photomicrograph of *Gloeocystis*, a similar alga

Walker states:
"Given the total biovolume observed *in situ* within the lake, but not necessarily reflected in collected samples, we could assume there is a relatively large degree of nitrogen fixation occurring within the lake. The presence or absence, or speciation, of nitrogen within the lake and the presence of an abundance of species capable of N_2 fixation leads to the potential for a few scenarios. Before N_2 can be incorporated into biological molecules, it must be converted to NH_3. The biological reduction of N_2 is catalyzed by a multimeric enzyme complex, nitrogenase. This enzyme is irreversibly inhibited by molecular oxygen. The specialized heterocystous cells where nitrogen fixation occurs, walls off oxygen from NH_3 in surrounding cells. The presence of such a highly heterocystous species such as *Gloeotrichia* indicates the possibility of nitrogen limitation in the surrounding water, giving it a decisive advantage over other phytoplanktonic species.

Upon the introduction of nitrogen and phosphorous during the fertilization treatment, the advantage *Gloeotrichia* had over other species was removed. This resulted in smaller-bodied algal cells such as flagellated chlorophytes becoming dominant. This new assemblage requires not only light but also oxidized forms of nitrogen such as NO_3 and to a much smaller degree, NO_2. The new nutrient ratios and levels favored an abrupt and total assemblage shift in a relatively very small period of time. This assemblage shift not only occurred in the phytoplankton, but also in the amount of periphytic biomass which was readily observed growing inside the limno-corrals. This sudden growth (primarily of filamentous *Spirogyra*) and overall biomass of periphyton was un-expected given the relatively short duration of the experiment." (Walker, November 2012 Draft)

Phase II: Summer of 2012

The limno-corral material is approximately 85 percent light-transparent. In Phase II, Dr. Walker re-sampled the limno-corrals (after cleaning them) over the same season (August through October) of 2012; the objective was to assess the influence of opacity on the growth of attached algae (periphytin) vs. floating algae (phytoplankton) biomass. Phase II of Walker's study showed that ALUM is not only effective in reducing nutrients, but also effective in reducing periphytin biomass (see Tukey's significant difference test below). This finding has important implications because Watson has a large surface area of granitic rocks within the lake photic zone conducive to periphytin growth. Walker provides a discussion of various lake management options in his Phase II report (Walker, August 2013).