Improvement Plan for the Oak Creek Watershed, Arizona

Prepared by the Oak Creek Watershed Council
For Arizona Department of Environmental Quality
In partial fulfillment of
CWA § 319H contract no. EV09-0035, Project 11T03

August 31, 2012

Acknowledgements

The development of this plan was funded by the **Arizona Department of Environmental Quality** (ADEQ) Water Quality Improvement Grant (WQIG) program. The WQIG program awards funding to water quality projects focused on nonpoint source pollution throughout the state. Funding for this program is provided by the US EPA pursuant to Section 319(h) of the Clean Water Act.

Oak Creek Watershed Council
Plan development oversight was provided by Oak Creek Watershed Council in conjunction with the Oak Creek Watershed Improvement Commission (WIC). Oak Creek Watershed Council is a 501(c)(3) nonprofit organization that exists to protect the Oak Creek Watershed environment as well as the integrity of Oak Creek and its tributaries.

Oak Creek Watershed Improvement Commission
The WIC is a voluntary group of watershed stakeholders including local and state government and land management agencies, as well as local residents and community groups. Individuals and organizations represented on the WIC include:

Amina Sena, USDA Forest Service
Josh Myers, Yavapai County
Steve Pawlowski, Sierra Club
Charles Mosley, City of Sedona
Ken Beller, Cathedral Vista POA
Cindy Dunn, Arizona Game and Fish Dept.
Lee Luedeker, Arizona Game and Fish Dept.
Paul Lindberg, Consulting Geologist
Ryan Matson, Slow Water Team
Jeanmarie Haney, The Nature Conservancy
Steve Estes, Verde Valley Land Preservation
Sharon Masek Lopez, Northern Arizona University
Gail Clement, Consulting Geologist

Technical support

Arizona Department of Environmental Quality (ADEQ)
Non-point Education for Municipal Officials (NEMO)
University of Arizona Soil, Water, and Environmental Science Department
Master Watershed Stewards (MWS)
Arizona Cooperative Extension
Oak Creek Watershed Council (OCWC)

Abstract

Previous research and monitoring in Oak Creek have found *Escherichia coli* (*E. coli)* bacteria concentrations exceeding Arizona Water Quality Standard for full body contact of 235 colony forming units per 100 ml water. Efforts have been made to try to reduce human-caused sources of *E. coli*, yet *E. coli* exceedances remain a problem especially where there is concentrated recreation in the creek, such as at Slide Rock State Park, and during storm events that deliver additional *E. coli* to the creek. The Oak Creek Watershed Council conducted a field investigation during summer 2011 to try to identify *E. coli* source areas. Water samples were collected repeatedly before and during summer monsoon at several locations along the entire stream length, from tributary flow, and from springs that discharge to Oak Creek. All samples were tested for *E. coli* bacteria. Some of these samples were also tested for turbidity and nutrient concentrations. A limited number of samples were tested to determine the presence of human, bovine and dog DNA. Results showed that *E. coli* exceedances were greatest in and below the City of Sedona with very few exceedances in Oak Creek Canyon. Exceedances often corresponded with storm flow events, were strongly related to turbidity, and may sometimes be associated with septic leakage, especially from larger commercial systems, that may be intercepted by groundwater and transported through spring discharge to the creek. The findings of the 2011 investigation support earlier studies some of which call for investigation of sediment *E. coli* reservoirs because they appear to be a primary means by which *E. coli* causes exceedances when reservoirs are disturbed either by recreation activity or turbulence caused by storm events. A series of best management practices projects regarding recreational, agricultural, residential and commercial activities in the watershed is recommended, as are continued investigations into potential contaminant pathways including septic system leakage, dog feces concentrations, and sediment reservoir development and disturbance with emphasis on tracking and reducing sediment sources as a means of reducing the *E. coli* bacteria that are harbored in sediment.

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Abbreviations

303(d)	Arizona's Impaired Waters List
319(h)	Clean Water Act Section 319(h), a source of funding for nonpoint source pollution prevention
A&W	Aquatic and wildlife – a designated use for water quality standards
ADEQ	Arizona Department of Environmental Quality
AGFD	Arizona Game and Fish Department
AIS	Anthropogenicly Influenced Site
AUW	Arizona Unique Waters
AZPDES	Arizona Pollution Discharge Elimination System
BMP	Best Management Practices
cfu/100ml	colony forming units per 100 milliliters, a measure of *E. coli* concentration
CNF	Coconino National Forest
E. coli	*Escherichia coli*
EPA	United States Environmental Protection Agency
FBC	Full body contact – a designated use for water quality standards
HUC	Hydrologic Unit Code
NAU	Northern Arizona University
NEMO	Nonpoint Education for Municipal Officials
NPDES	National Pollution Discharge Elimination System
OAW	Outstanding Arizona Waters
OCCTF	Oak Creek Canyon Task Force
OCWC	Oak Creek Watershed Council
OCWIC	Oak Creek Watershed Improvement Commission
PBC	Partial body contact – a designated use for water quality standards

SAP	Sampling and Analysis Plan
SRSP	Slide Rock State Park
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
TMDL	Total Maximum Daily Load
WIP	Watershed Improvement Plan
YCFCD	Yavapai County Flood Control District

Chapter 1 – Background

Pollutant of Concern

Oak Creek is not attaining water quality standards for *E. coli* because for many years water samples have repeatedly exceeded the state water quality standard single sample maximum of 235 colony-forming units per 100 milliliters (235 cfu/100ml) for full body contact. The purpose of the Oak Creek Watershed Improvement Plan is to identify sources that contribute to *E. coli* impairment/standards exceedances and recommend actions to reduce human- and wildlife-related contamination so that the creek may attain the water quality standard.

Since 1973, *Escherichia coli* (*E. coli*) bacteria in the water of Oak Creek have been a concern. Previous DNA testing of water and sediment from Oak Creek has indicated that wild sources of *E. coli* bacteria include raccoon, skunk, elk, beaver, white tail deer, mule deer, bear, and mountain lion, antelope in descending order (Southam et al. 2000, OCCTF 2002) **(**Figure 1). Southam collected scat for genotyping standards and water and sediment samples and conducted genetic analysis using Amplified Fragment Length Polymorphism (AFLP). Samples were collected midweek during baseflow conditions at Pumphouse Wash, Pine Flats, West Fork, upstream and downstream of Slide Rock State Park and Grasshopper Point in Oak Creek Canyon on 11 dates in 1998 and 1999.

Southam et al. (2000) found that human-related sources [ie. from human waste and that of their pets and livestock, including human (16%), dog (6%), horse (5%), cow (4%), and llama (2%)] accounted for about 33% of *E. coli* found in waters of Oak Creek on average. It is important to note that Southam's 33% attributed to human activity is an average; human contribution to *E. coli* in Oak Creek water on individual days ranged from 0 to 70%. It is also important to note that Southam (2000) found single fecal release events, indicated by low *E. coli* diversity index, suggest that a single animal (or human) can cause a direct impact to *E. coli* reservoirs in stream sediments, which in turn may contaminate water when sediment is disturbed. The highest amount of *E. coli* concentration attributed to human source in a sediment reservoir was 125,020 cfu/100ml downstream of Slide Rock State Park on September 6, 1999.

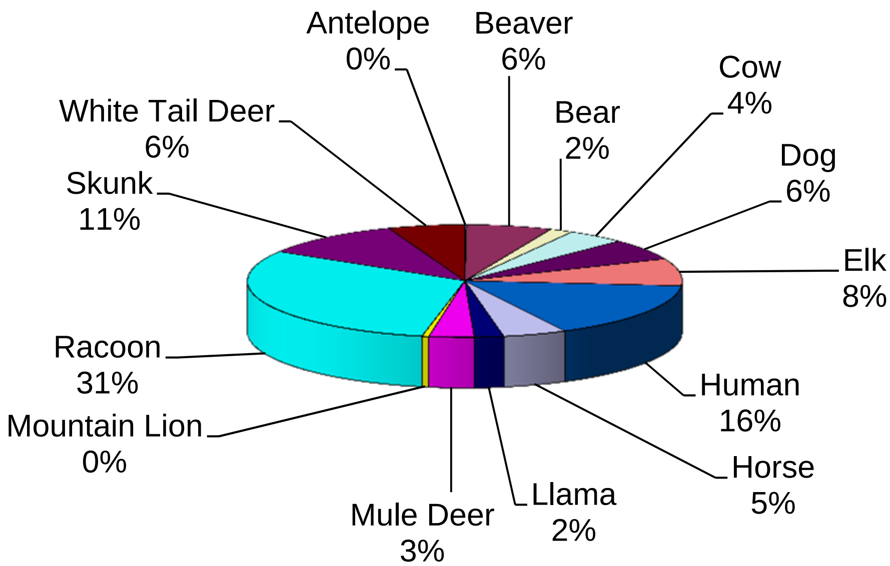

Figure 1. Distribution of *E. coli* by species compiled from Oak Creek Canyon as a whole (OCCTF 2002).

Most strains of *E. coli* are harmless and live in the intestines of warm-blooded mammals, but some strains produce a powerful toxin and can cause severe illness (EPA 2011a). These strains are called pathogens *E. coli* O157:H7 is an example of a pathogenic strain that can cause serious illness and even death, but it is uncommon. While not generally a health threat in itself, *E. coli* is used to indicate the possible presence of potentially harmful bacteria and viruses (EPA 2011b). Testing for *E. coli* is an inexpensive and practical way of monitoring potential fecal pollution. Other fecal contaminants include fecal streptococci, enterococci, *Cryptosporidium spp.*, *Giardia spp.*, *Shigella spp.*, norovirus, total coliforms, fecal coliforms and *E. coli* 0517:H7, which may cause human health problems that include skin, ear, eye, gastrointestinal, urinary tract, respiratory, neurologic and wound infections (EPA 2011c).

Watershed Description

Oak Creek watershed is a sub-watershed of the Verde River Watershed in north central Arizona at the northern edge of the Transition Zone between the Basin and Range Province and the Colorado Plateau (Figure 2). The headwaters are in ponderosa pine forest of the Coconino National Forest at a maximum elevation of 7,629 feet, and the stream flows 50 miles in a southwesterly direction to the confluence with the Verde River at 3,180 feet elevation while passing through pinyon-juniper, high desert and riparian vegetation types. Annual precipitation in the headwaters is about 18 inches, whereas Sedona receives 12 inches per year (YCFCD 2011). Tributary ephemeral washes descend from the pine forest to Oak Creek Canyon providing streamflow primarily during snowmelt and summer monsoon storms. Oak Creek Canyon is a narrow (1 to 3 miles breadth) canyon extending from the Mogollon Rim thirteen miles downstream to the northern limit of the City of Sedona.

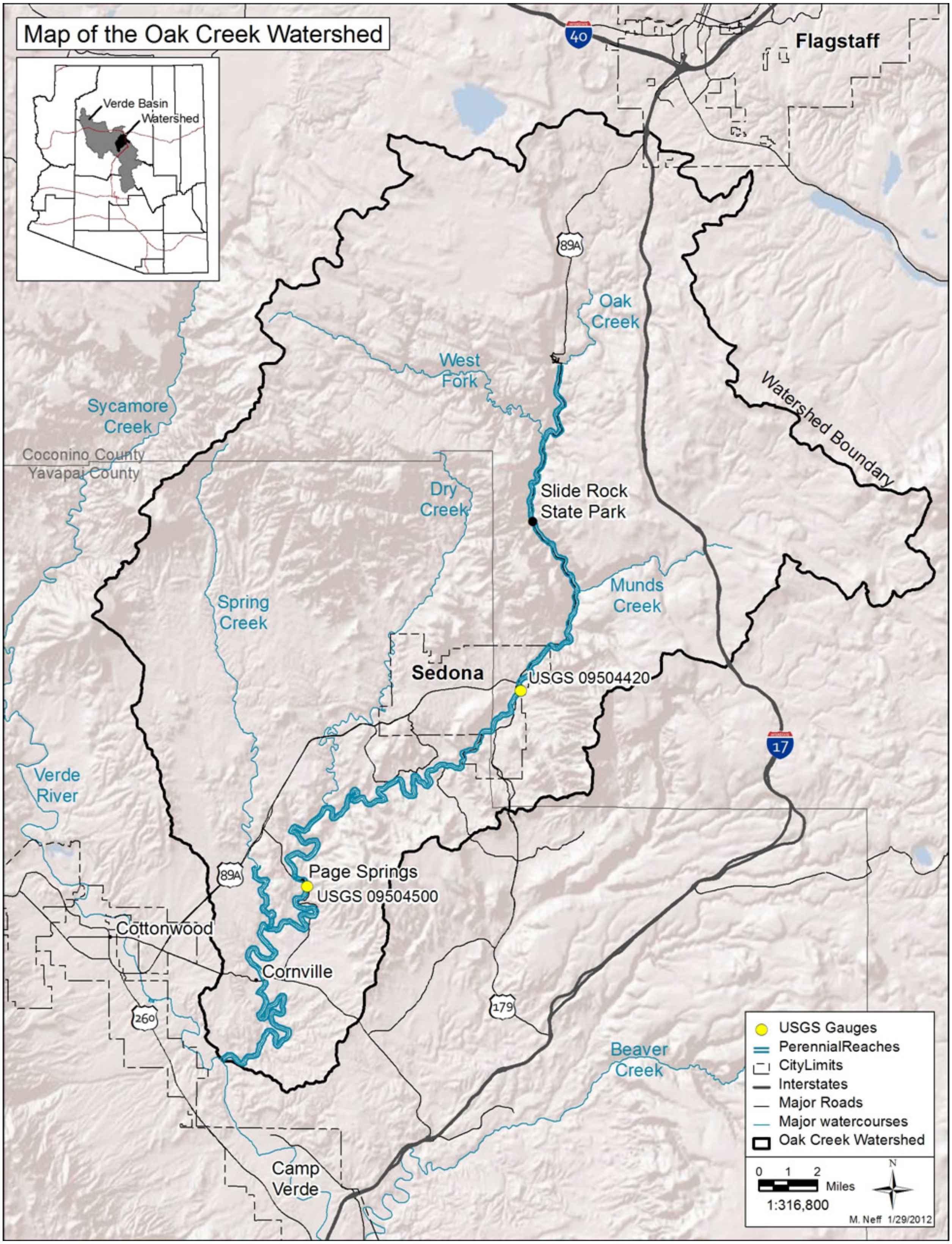

Figure 2. Oak Creek Watershed.

Springs provide perennial flow to Oak Creek. Perennial streamflow begins in Oak Creek Canyon from springs just above Sterling Springs Fish Hatchery. Numerous springs within Oak Creek Canyon issuing from the Coconino Aquifer, which includes the Coconino Sandstone, Supai Formation, and Redwall Limestone (Dryden 1998), provide base flow that increases from ~3-5 cfs near the headwaters, to 18 cfs at Slide Rock State Park and 24 cfs at the Sedona gage (OCCTF 2002). In the Page Springs area springs issuing from the Verde Formation add approximately 20 cfs to streamflow, as measured by Arizona Game and Fish Department at the Page Spring Fish Hatchery (Cindy Dunn, personal communication). Oak Creek is characterized by gaining reaches where springs are located and losing reaches between each major set of springs (Pool 2011). Baseflow at the USGS Oak Creek near Cornville gage is about 21 cfs (OCCTF 2002). Major tributaries include West Fork Oak Creek, Munds Canyon and Spring Creek which all have perennial stream flow in their lower reaches and Pumphouse Wash and Dry Creek which flow only during snowmelt and storm events. Where spring discharge sites correspond with residential development, potential exists for contamination of shallow groundwater by improperly installed or maintained septic systems, which may allow fecal contaminants to be carried to Oak Creek via spring flow (Keswick et al. 1982, Bitton and Harvey 1992).

Oak Creek watershed is situated in Coconino and Yavapai Counties. Land use within the watershed includes forestry, grazing, recreation, agriculture, residential and commercial. In Oak Creek Canyon, 54.5 acres are used by Scenic Highway 89A; 123 acres are developed as campgrounds, parking lots, picnic areas, and scenic views. Houses and homes account for 245 acres (OCCTF 2002). In 1996, 304 permanent residents were reported to live along Oak Creek (Snelling 1996). The largest land owners are public, including national forest and Arizona state lands, parks, and fish hatcheries (Figure 3). The uppermost part of Oak Creek watershed in the Pumphouse Wash subwatershed hosts a population of about 4,000 in the communities of Forest Highlands, Kachina Village and Mountainaire adjacent to Flagstaff and 630 at Munds Park (2010 Census). Numerous small residential lots are situated in the valley floor of Oak Creek canyon, some of which have full time residents and many of which are vacation homes. The city of Sedona and surrounding areas within the watershed have the largest concentration of population with 10,192 residents (U.S. Census 2010). This population swells during periods of high tourism. In Sedona a generous availability of national forest land within the developed area combined with stunning vistas translates into heavy recreational use in this reach also. Going downstream from Sedona agricultural land use is found on acreages adjacent to Oak Creek in the Red Rock Loop, Page Springs and Cornville areas. The population in the Pages Springs and Cornville area is about 3,335. Impaired reaches of Oak Creek include Oak Creek Canyon down to Spring Creek confluence and the perennial reach of Spring Creek.

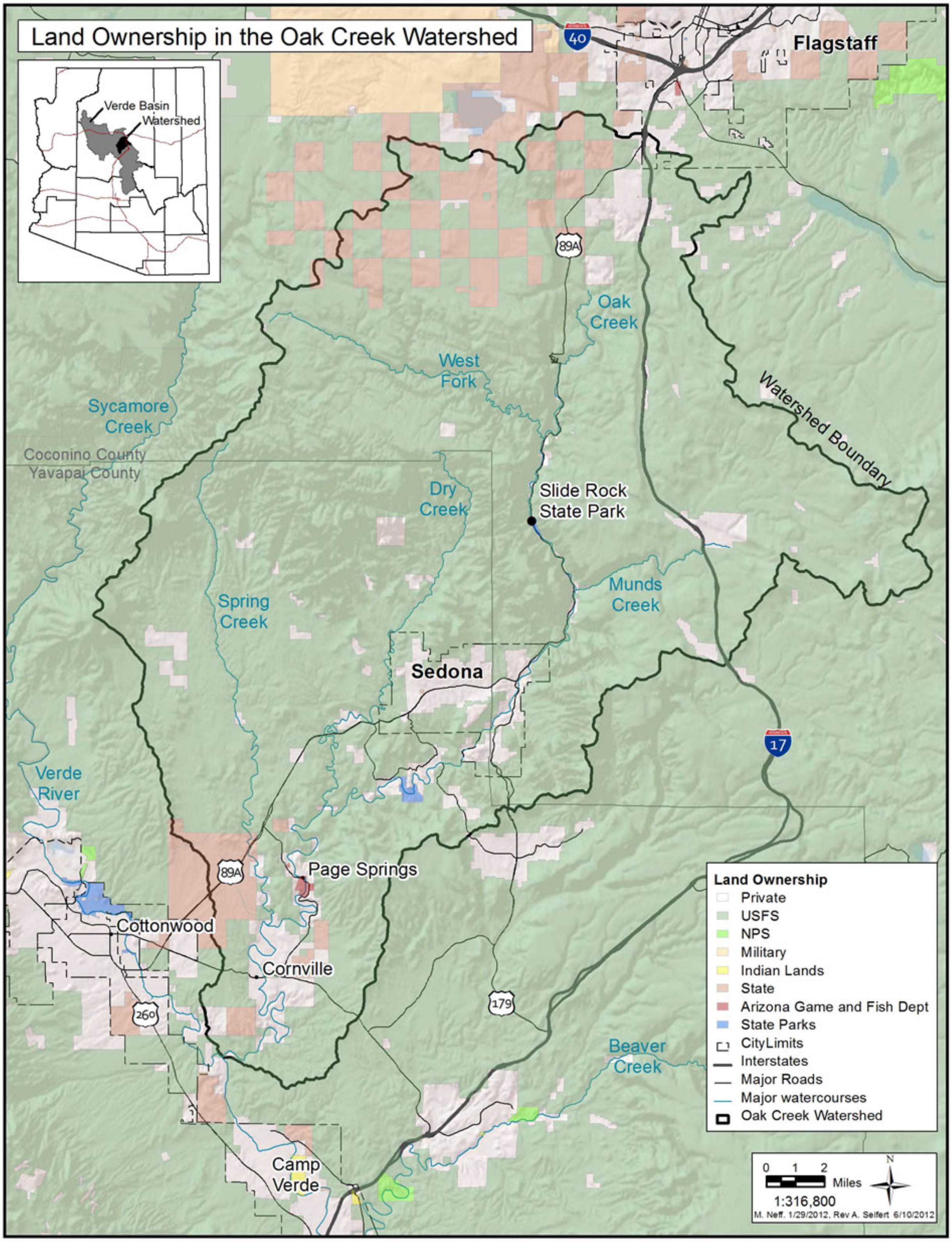

Figure 3. Land ownership in Oak Creek Watershed

Water Quality Concerns

Evidence of Impairment

Repeated exceedance of the *E. coli* standard in Oak Creek lead Arizona Department of Environmental Quality (ADEQ) to list Oak Creek as an impaired water and to develop a Total Maximum Daily Load (TMDL) as described below (ADEQ 2010). Seasonal deterioration in bacteriological water quality, due to impacts attributed to fecal pollution, has been observed in Oak Creek since 1973 (Obr et al. 1978). Subsequently, numerous studies and monitoring efforts have confirmed the results of the initial study and discovered the predominant mechanisms by which *E. coli* enters the water column (Jackson 1981, Rose et al. 1987, Hansen and White 1992, Southam et al. 2000) (Table 1). Water quality is impaired during periods of peak recreational use (summer months and especially holiday weekends) (Figure 4), which is to say that concentrations of *E. coli* exceed the water quality standard for the designated uses of full body contact (swimming). This is partly due to recreationalists as a source of fecal bacteria, but largely due to the disturbance of stream sediments by swimmers and waders as well by increased streamflow during storm events.

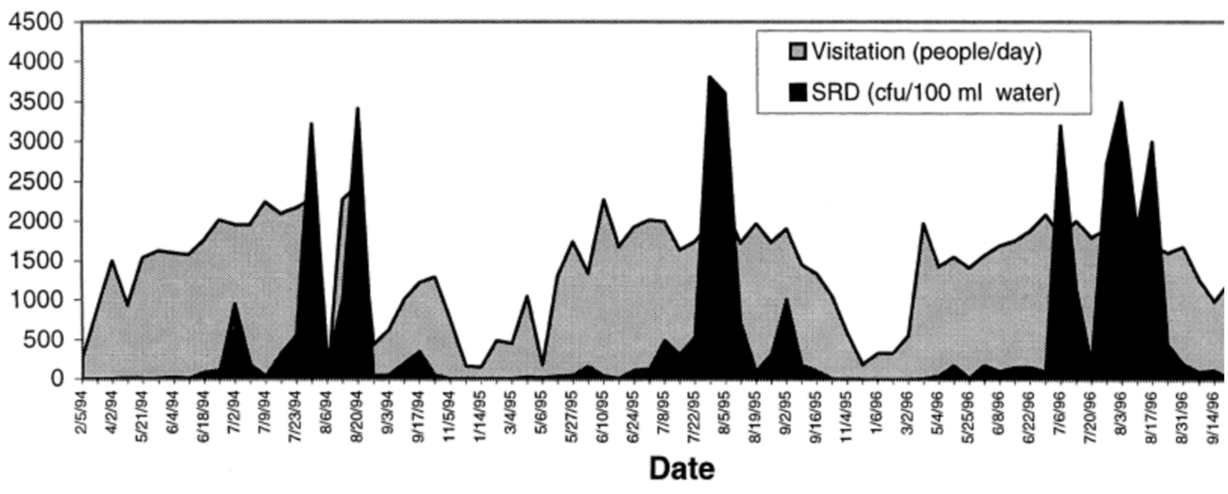

Figure 4. Visitors at site Slide Rock State Park from 1994 to 1996 compared to fecal coliform counts of cfu/100 ml at the Slide Rock downstream (SRD) site. Note the convergence of visitors and fecal coliform during the late summer months during all 3 years. Also, note the improvement of water quality after site closure due to a forest fire (early August, 1994) (Crabill et al. 1999). The largest exceedances occurred during late July and early August when there were not any stormflow events to stir the sediment, so the effect is seen to be due to sediments being disturbed by recreators.

Table 1. Summary of relevant water quality studies and monitoring in Oak Creek Watershed.

Years	Location tested	Parameters	Timing	Findings	Source
late 1960s	Banjo Bill, Slide Rock, Indian Gardens, Chavez Crossing, Page Springs	fecal coliform			cited in ADEQ 1999
1967-1978	Oak Creek near Cornville	biological data, nutrient, organic, inorganic, physical properties, stream flow, sediment			USGS (per TMDL 2010)
1970s		fecal coliform	summer; after heavy runoff		Obr et al. 1978, Segall 1976
1975-1979	31 sites along Oak Creek	Fecal coliform, fecal streptococci		Four sites above 235 cfu/100 ml. Concluded that creek has ability to recover from bacterial loading. Wastewater sources present, but system capable of self-mitigation.	cited in ADEQ 1999
1978-1980	Oak Creek near Sedona	biological data, nutrient, organic, inorganic, physical properties, stream flow, sediment			USGS (per TMDL 2010)
1978-2002	Oak Creek at Red Rock Crossing	biological data, nutrient, organic, inorganic, physical properties, stream flow, sediment			USGS (per TMDL 2010)
1980	Slide Rock and Grasshopper Point swim areas	water quality	Summer	Fecal coliform not correlated with swimmers or rain events.	Jackson 1981

1982	Slide Rock, sampled by US Forest Service	fecal coliform		Two samples above 800 cfu/100 ml; Five samples above 150 cfu/100 ml. General trend of increasing coliforms with increasing visitors.	cited in ADEQ 1999
1982-1984	Pine Flat, Slide Rock, Indian Gardens, Grasshopper Point, Red Rock, Tlaquepaque, Chavez Crossing, Page Springs	physical and chemical parameters , total coliform, fecal coliform, fecal streptococci, rotavirus, enterovirus, visitor numbers	June – August	Fecal coliform not correlated with swimmers.	Rose et al. 1987
1985 + 1988	31-38 sites along the creek	Fecal coliform, fecal streptococci, chemical parameters		Higher values at storm water sites & locations below Sedona. Westview Motel: 6,000 cfu/100 ml, Dry Creek blw Hwy. 89A: 30,000 cfu/100 ml Hwy. 179: 12,000 cfu/100 ml, Red Rock Crossing: 11,000 cfu/100 ml, Chipmunk Lodge: 500 cfu/100 ml; 3/15 sites Slide Rock sites blw 120 cfu/100 ml, above Slide Rock: >200 cfu/100 ml, Cave Springs: 260 cfu/100 ml, abv West Fork: 208 cfu/100 ml	cited in ADEQ 1999
1987-1988	Seven alluvial wells, 15 deep regional wells	Fecal coliform		Detected low levels of *E. coli* (10 cfu/100 ml) in two shallow wells in Canyon and one resort well in Sedona	cited in ADEQ 1999
1987-1988	Oak Creek Near Sedona	biological data, nutrient, organic, inorganic, physical properties, stream			USGS (per TMDL 2010)

		flow, sediment			
1993	Pine Flats	physical and chemical parameters , fecal coliform	December		Lightner 1994
1993	Three alluvial wells	Fecal coliform		One well showed 300 total coliform (~60 fecal coliform). Ground water at 10 feet below land surface; aquifer connected to stream	cited in ADEQ 1999
1994-1998	Pine Flats campground, Pine Flats residence area, SRSP, Manzanita campground, Trailer Park residence area, Grasshopper point	physical and chemical parameters, fecal coliform	throughout the year	Slide Rock had highest values and showed 14 exceedances; Grasshopper Point showed two exceedances; campgrounds relatively low. Pine Flats Subdivision (1994 MS Thesis). Pattern corroborated earlier results. Sediment reservoir builds at Slide Rock over summer months. No significant difference after 1996 BMPs	Dryden 1998
1994-1996	Four upstream, four downstream locations	physical and chemical parameters, fecal coliform	throughout the year	Sediment agitation by recreational activity and storm surges associated with the summer storm season are responsible for the impact to water quality and not recreational users directly.	Crabill et al 1999
Since 1996	5 sites: Upstream, Midslide, Large Pool, Foot Bridge, Highway Bridge	*E. coli*	Weekly Oct-Apr, 5 times per week May-Sept., twice daily during water quality exceedances		Slide Rock State Park (per TMDL 2010)

1997-1999	various locations	*E. coli*	throughout the year		Keys 2001
1998-1999	Pump House Wash, West Fork, upstream and downstream of SRSP, Grasshopper Point	*E. coli*, DNA	throughout the year	Water fecal pollution is a sum of the material transported from upstream. Most of the fecal pollutions comes from natural animal populations with sporadic and seasonal impacts from human, cattle, horse and llama sources. Fecal pollutions in Oak Creek is not a regrowth phenomenon.	Southam et al. 2000
Since April 1998	Above SRSP, Grasshopper Point, Ladders, Mormon Crossing, Crescent Moon, Spring Creek	*E. coli*, air and water temperature	weekly (usually Wednesday) April - September	Frequent elevated *E. coli* concentrations at high recreational use areas.	Friends of the Forest for Coconino National Forest
1998	18 sites	fecal coliform, *E. coli*, inorganics, nutrients, physical parameters, turbidity			ADEQ TMDL Unit
2003-2008		TMDL Phase II monitoring			ADEQ
July 1, 2008-June 30, 2009		*E. coli*, physical parameters, metals, nutrients, and stream flow	Quarterly		ADEQ Monitoring Unit
2011	14 sites on Oak Creek from Pine Flats to Verde confluence, 2 perennial and 5 ephemeral tributaries, 22 springs in Oak Creek Canyon and 4 springs at Page Springs	*E. coli*, streamflow, pH, conductivity, dissolved oxygen, turbidity, nutrients, DNA – human, bovine and dog	July 5 to September 22, baseflow and stormflow	*E. coli* and turbidity were related. *E. coli* was greater during/after storm events, especially from Sedona down. Large amounts of sediment and *E. coli* enter Oak Creek from Sedona-area washes. Some springs appeared to be affected by septic leakage based on *E. coli* and human DNA results.	Oak Creek Watershed Council – the study reported here

Sediment in Oak Creek supports 10 to 17,000 times more *E. coli* than creek water, acting as a bacteriological reservoir (Southam 2000). In 1995, Crabill et al. (1999) found that water quality violations in Oak Creek only occurred when sediments were found to have high fecal coliform counts (a sediment reservoir in place).When sediment is disturbed, either by recreation or by turbulent, higher-velocity storm flows, the sediment is lifted into the water column where increased contact between sediment particles and water causes entrainment of *E. coli* in the water, thereby increasing aqueous *E. coli* concentrations. Southam et al. (2000) used DNA fingerprinting to identify the relative contributions of *E. coli* from source mammals (Figure 1). Human-related sources (from humans, pets, livestock, septic system effluent) accounted for only about 33% of all *E. coli* found in Oak Creek, with perhaps a few more percentages attributable to wild animals that are present near the creek foraging on human food waste. The remainder of *E. coli* in Oak Creek was attributed to wildlife including: raccoons (31%), skunks (11%), elk (8%), white-tailed deer (6%), beaver (6%), and other mammals. Because 2/3 of *E. coli* in Oak Creek appears to be attributed to something other than human influence, it is challenging to address dispersed nonpoint source pollution with comprehensive and complete measures that could reduce *E. coli* loads below the TMDL. Stakeholders may have to settle for "improvement, rather than perfection", i.e. reducing the risk of human contact with fecal pathogens in Oak Creek water with the understanding that under certain conditions, such as storm events or heavy recreational visitation, exceedances are likely to occur. The Oak Creek Watershed Improvement Plan and future Best Management Practices should result in water quality improvement as well as prevention of fecal contamination and protection of the watershed from future degradation.

Crabill (1999) found that the correlation between the summer rains and the fecal coliform buildup upstream of Pine Flats, near where Oak Creek perennial flow begins, suggested fecal material from the abundant elk, deer and cattle populations on the surrounding plateau impact the creek and are transported there with the runoff. In contrast, downstream at Slide Rock State Park (SRSP) the occurrence of fecal pollution in the sediments prior to the summer rain season suggested that the source of fecal pollution must be close to the creek because a long-distance transport mechanism, i.e. summer storms, is not in place; this implicated a human (recreational and/or residential) source of fecal pollution near SRSP. Crabill's conclusions were largely supported by DNA analysis conducted by Southam et al. (2000), although higher concentrations of human DNA were not found at SRSP as Crabill suspected. Southam had the following conclusions:

1. Oak Creek fecal pollution came from multiple sources based on high temporal and spatial variability of *E. coli* in water and sediment,
2. Fecal pollution in Oak Creek is not a regrowth phenomenon,
3. Most of the fecal pollution in Oak Creek Canyon comes from natural animal populations with sporadic impacts from human, dog, cattle, horse and llama sources,

4. *E. coli* concentrations in water generally do not reflect the sediment profile at the sample sampling site but rather demonstrate that pollution is a sum of material transported from upstream,
5. Single animals (or humans) can cause pollution events in sediment and water, for example Southam's results indicated contamination at Pine Flats by a single raccoon (This is an important message for the outreach program; a single diaper, human waste pile, or dog waste pile could cause water pollution that could affect human health),
6. *E. coli* populations can overwinter but winter populations did not contribute to fecal pollution measured during the following season. (This indicates that there may be a renewal of the creek's water quality each winter.)

To reduce *E. coli* pollution in Oak Creek Southam recommended the following:

1. Increase toilet facilities,
2. Educate the public about dog droppings, provide signage and baggies/disposal containers on critical trails,
3. Implement locally approved grazing modifications that decrease the inflow of sediment carrying fecal material, and
4. Continued water quality monitoring.

In addition to the issues mentioned above, septic effluent contamination is particularly a concern in Oak Creek Canyon where soils may not be sufficient for onsite sewage treatment. Percolation rates in Oak Creek Canyon vary from adequate to exceedingly rapid (50 to 4 minute per inch) (Segall 1976). In 1993, about 150 homes in Oak Creek Canyon utilized septic leach field systems (Stafford 1993) some of them likely on lots with rapid percolation. According to long-time Oak Creek Canyon resident Morgan Stine, prior to the the use of backhoes, septic drainfield leachlines were usually hand dug and shallow, which allowed for adequate separation between effluent and underlying "spring beds" for soil organisms to treat septage and eliminate pathogens. However, from about 1965 to 2001 septic drainfields tended to be installed using backhoes, placing leachlines too close to "spring beds" and unsuitable soils (coarse gravels and sands) to allow for treatment. One of the objectives of the current study has been to identify such places where untreated septic effluent may be intercepted by spring flow. New data will be presented in this report indicating possible contamination of springs by septic effluent. (See the following sections: Water Quality Monitoring Methods and Focus, Preliminary Monitoring Survey Findings and Findings Unique to this Study.

Application of Water Quality Standards

The presence of *E. coli* in stream water is a concern because it is an indicator of the likely presence of fecal contamination. When surface waters contain fecal contaminants, people can come in contact with pathogens such as *Cryptosporidium spp.*, *Giardia spp.*, *Shigella spp.*, norovirus and *E. coli* 0517:H7 when recreating in the stream, which may cause human health problems that include skin, ear, eye, gastrointestinal, urinary tract, respiratory, neurologic and wound infections. Because of this risk and *E. coli* concentrations found at Slide Rock State Park, a one-mile segment of Oak Creek was designated as "impaired" in 1998 by ADEQ. Based on Arizona Unique Waters status (AUW), specific water quality standards were designated for Oak Creek , including an *E. coli* standard of 580 colony forming units per 100 milliliters (cfu/100ml) to meet the Total Maximum Daily Load (TMDL, see TMDL Findings section below) (ADEQ 1999a). In 2003 the statewide *E. coli* standard for full body contact was lowered to 235 cfu/100 ml, including Oak Creek (ADEQ 2010). Subsequently, The ADEQ 2006/08 305(b) Assessment Report listed five segments of Oak Creek and one segment of Spring Creek as impaired for exceeding the *Escherichia coli* (*E. coli*) water quality standard for a total of 47.4 stream miles (Table 2 and Figure 5). Since a TMDL was approved in 2010 these reaches are no longer considered impaired, but are instead considered "non-attaining".

Table 2. Reaches in Oak Creek watershed impaired in 2008 due to *E. coli*, now considered nonattaining.

Reach	HUC	Length (miles)	Year designated
Oak Creek from headwaters to West Fork Oak Creek	15060202-019	7.4	2006
From West fork Oak Creek to tributary	15060202-018A	5	2006
Oak Creek from tributary to boundary of Slide Rock State Park	15060202-018B	1	1992
Oak Creek from Slide Rock State Park to Dry Creek	15060202-018C	20	2006
Oak Creek from Dry Creek to Spring Creek	15060202-017	10	2006
Spring Creek	15060292-22	4	2006

Oak Creek and the West Fork of Oak Creek were renamed from Arizona Unique Waters (AUW) to "Outstanding Arizona Waters" (OAW) during the 2009 Triennial Review of the Arizona Surface Water Quality Standards (ADEQ 2010). However, this was simply a name change and did not affect the standards. Site-specific numeric nitrate and phosphate standards still apply to Oak Creek (Arizona Administrative Code R18-111-9(F)). As an OAW, Oak Creek and West Fork are classified as a Tier 3 waters under the antidegradation language included in the Water Quality Standards (A.A.C. R18-11-106 and 107), which calls for maintaining and protecting the existing water quality and no new or expanded point source discharge directly to an OAW. Any upstream discharge or discharge to a tributary needs to demonstrate that it will not degrade water quality. Temporary discharges are allowed under the 401/404 program which is administered by the U.S. Army Corp of Engineers and allows for limited “dredge and fill” disturbance of stream channels. Under a grandfather clause, some excavation of irrigation diversion works in Oak Creek by irrigation associations is allowed without a 404 permit.

ADEQ has recently adopted new biocriteria standards (Jan 2009) and has drafted an associated bioassessment implementation guidance document (ADEQ draft, 2008. However, because the final guidance document is not complete, implementation procedures have not been adopted and the standard cannot be used for assessment purposes. Once the new biocriteria standards are implemented, they will be used to assess biological integrity of perennial wadeable streams across Arizona. See the link to ADEQ’s webpage: http://www.azdeq.gov/environ/water/standards/index.html.

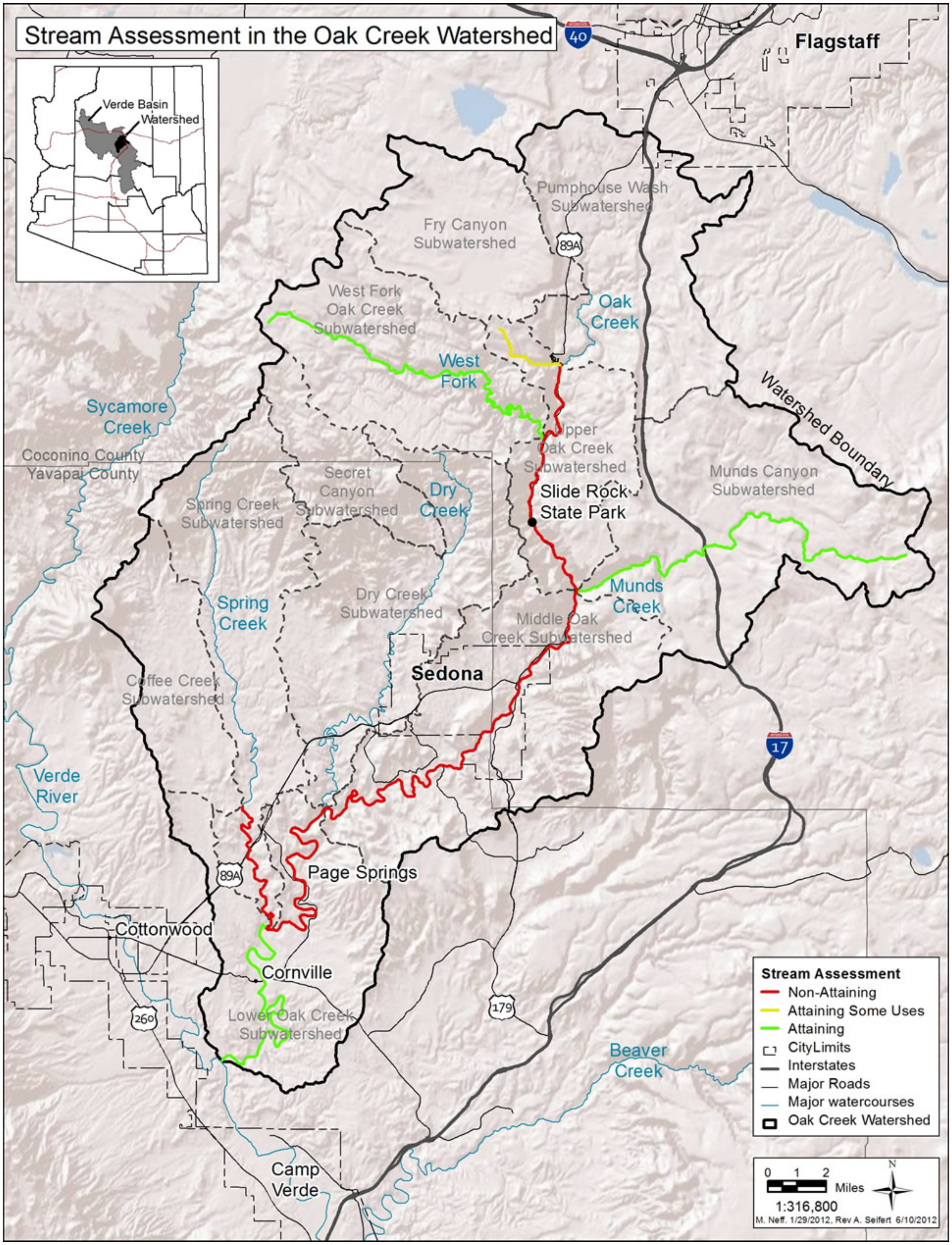

Figure 5. Nonattaining reaches in Oak Creek Watershed

Critical Conditions

Exceedances of *E. coli* are likely in Oak Creek under the following conditions:

1. Multiple sources from wildlife, livestock, pets and humans provide *E. coli* to Oak Creek, especially during storm events.
2. Temperatures are conducive to persistence of *E. coli* in sediment reservoirs, generally from late spring through early fall.
3. Concentrated recreational activity disturbs sediment reservoirs of *E. coli*, whereby sediment particles mix with the water column and *E. coli* is released into the water column.
4. Storm events deliver fecal material to Oak Creek from surrounding uplands and increase streamflow causing *E. coli* in sediment reservoirs to mix with the water column.
5. Springs intercepting inadequate septic systems deliver *E. coli* to Oak Creek in concentrations greater than creek water
6. In rare circumstances, inadequate and/or overloaded commercial septic systems discharge seepage water to Oak Creek that exceeds the *E. coli* standard.
7. Inappropriate animal waste management (eg. horse manure) may introduce *E. coli* to Oak Creek.

TMDL Findings

A Total Maximum Daily Load (TMDL) is defined by the EPA as "a calculation of the maximum amount of a pollutant that a waterbody can receive and still safely meet water quality standards" (EPA 2011). Since a TMDL determination for Oak Creek and Spring Creek has been completed and approved, both ADEQ and EPA consider the Oak Creek and Spring Creek segments to be "not attaining", rather than "impaired", and were removed from the 303(d) impaired waters list (ADEQ 2010). This means a TMDL has been completed but water quality standards are still not being attained. Prior to TMDL completion, a water may be considered "impaired" that does not meet water quality standards. The Slide Rock State Park segment was first designated as impaired in 1999, whereas the other segments were designated in 2006. In the 1999 TMDL, probable *E. coli* pollution sources causing impairment in the Slide Rock State Park (SRSP) segment of Oak Creek were previously listed as sediment, wildlife, recreational uses and rangeland grazing.

In 1999, ADEQ's pathogen TMDL recommended a 30% reduction of the summer's recreational season to achieve a reduction in fecal coliform loads to Oak Creek at SRSP to attain the standard of 580 cfu/100ml. The TMDL identified the following strategies to be implemented, which were meant to improve water quality at SRSP but are applicable to the watershed as whole:

- Reduce sediment loading to Oak Creek, as bacteria were associated with the sediment;
- Identify failing septic systems and repair or replace these systems;
- Reduce recreation impacts on water quality (e.g., improved public restroom and shower facilities, improved trash management); and

- Reduce animal waste impacts on water quality (e.g., control drainage from pastures and trails, control litter and other wastes that attract skunk and raccoons).

Water quality standards changed in 2003; the previous single sample maximum for fecal coliform bacteria of 580 cfu/100 ml was reduced to 235 cfu/100 ml *E. coli*. Also in 2003, ADEQ started a revision of the 1999 TMDL due to continuing exceedances of *E. coli* water quality standards and because *E. coli* had become the standard, rather than fecal coliform. ADEQ initiated an investigation in 2004 to measure the effectiveness of the implemented strategies, further delineate the extent of the contamination, and identify sources and loadings.

In 1999, ADEQ completed a nutrient TMDL for Oak Creek. The single sample maximum standard for total nitrogen and total phosphorus are 1.5 and 0.25 mg/L respectively and the annual mean values are 1.00 and 0.10 mg/L respectively (ADEQ 1999c). Nutrient concentrations (phosphorous and nitrogen) were found to be low and only a few nutrient standard violations were predicted. Improvements to wastewater treatment systems on Munds Canyon were effective in eliminating nutrient exceedances; no new nutrient limits were needed for septic system loadings on Oak Creek. ADEQ determined that Oak Creek's status as an Outstanding Arizona Water and the existing discharge limits were sufficient protection against nutrient contamination. In 2002, fecal coliform bacteria, nitrogen and phosphorus were removed from the 303(d) impaired waters list (first listed in 1994) for the 17 mile stretch of Munds Creek to Oak Creek. Wastewater effluent reaching Munds Creek no longer led to impairments.

The 2010 TMDL for *E. coli* in Oak Creek uses Load Duration Curves that display the relationship between stream flow, loading capacity, and water quality data to determine if a reduction in pollutant concentration is needed under a certain flow condition. Table 3 represents the findings of this assessment and defines the stream segments that need reductions in *E. coli* loads. For the purposes of the TMDL, hydrograph separation techniques are used to identify storm flows. Flow frequency zones correspond to the percentage of time that flow exceeds a given level as follows:

High flows: 0-10 percent of flows exceed (ie. rare flow event)

Moist conditions: 10-40 percent of flows exceed

Midrange flows: 40-60 percent of flows exceed

Dry conditions: 60-90 percent of flows exceed

Low flows: >90 percent of flows exceed (ie. common flow volume)

Table 3. Summary of percent E. coli load reductions for Oak Creek.

“meets” = existing load meets TMDL, SRSP = Slide Rock State Park (ADEQ 2010 TMDL).

Segment	High Flows	Moist Conditions	Midrange flows	Dry Conditions	Low Flows
Headwaters to West Fork	96%	Meets	42%	meets	Meets
West Fork to Slide Rock	meets	21%	meets	meets	Meets
SRSP	meets	62%	meets	2%	12%
SRSP to Dry Creek	93%	5%	68%	meets	9%
Dry Creek to Spring Creek	94%	Meets	51%	34%	25%

Figure 6 from the 2010 TMDL report demonstrates how *E. coli* concentrations can be strongly related to streamflow, with the higher concentrations corresponding with high flow events, (although the example is from a stream not in Arizona). This is consistent with studies in the Oak Creek watershed which have found that high flows create turbulence that disturbs sediment on the stream floor and increases contact between sediment particles and water so that *E. coli* is released from the sediment into the water (Southam 2000, Crabill 1999). Some increased *E. coli* during high flow events may also be due to flushing of fecal matter from upland surfaces through overland flow. Figure 6, which is used as an example, is a load duration curve from another state. The solid red line on the graph in Figure 6 is the geometric mean of fecal coliform concentrations while the dashed red is the single daily maximum allowed by Arizona water quality standards (Arizona has a geometric mean *E. coli* standard [126 cfu/100 ml] but it is not exceeded enough to cause impairment). Figure 7 is a load duration curve for the reach Slide Rock to Dry Creek in which *E. coli* concentrations that plot above the curve indicate exceedances of the water quality standard.

Table 3 shows that the relationship between flow magnitude and *E. coli* concentration is not static but varies by stream segment (eg. Slide Rock State Park has greater *E. coli* loading at low flow than most reaches and greater loading during moist conditions than at high flows; this is because exceedances at Slide Rock are correlated more with recreation than with streamflow, which is not the case in most segments of Oak Creek.). This indicates that, while some BMPs are applicable throughout the watershed, in some stream segments BMPs to reduce *E. coli* loading must be tailored to address the particular bacterial sources and processes. According to the 2010 TMDL, the critical conditions when exceedances are likely to occur are as follows: 1. during the summer months, 2. in places where recreational activity is concentrated and 3. when storm events rapidly increase streamflow.

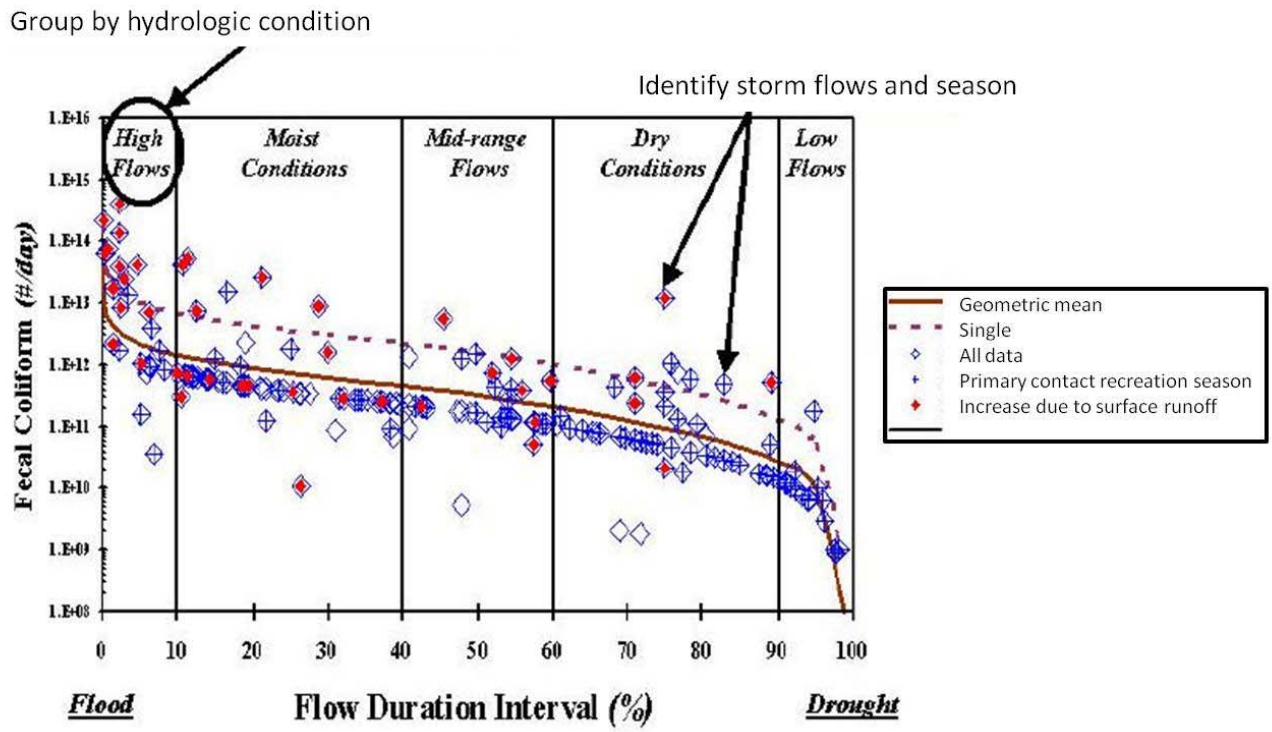

Figure 6. Sample load duration curve (Cleland 2003).

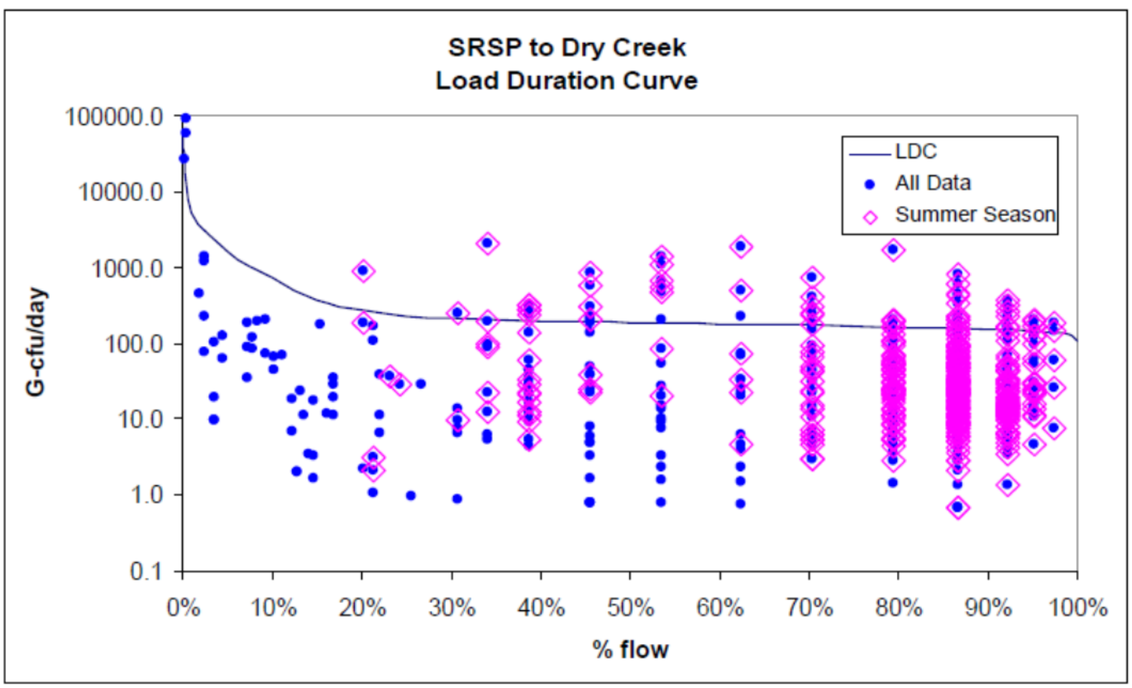

Figure 7. *E. coli* load duration curve, Slide Rock Sate Park to Dry Creek (ADEQ 2010)

Point sources are regulated by ADEQ, but non-point sources are not regulated in the same way and rely on voluntary efforts to control their pollution potential. ADEQ (2010) identified water treatment facilities, fish hatcheries, and storm water related discharges as the main point sources in the Oak Creek watershed. The main non-point sources were identified as wildlife, domesticated animals, humans, and urban development.

Past Efforts to Reduce *E. coli* Loading

Based on strategies recommended in ADEQ's 1999 TMDL, the Oak Creek Canyon Task Force and other organizations implemented several projects that were funded by Clean Water Act §319(h) Water Quality Improvement Grants and other funding sources. Table 4 and the map in Figure 8 summarize these projects that implemented Best Management Practices (BMPs) in an attempt to reduce *E. coli* loading in Oak Creek. General permit BMPs normally applied in the Oak Creek watershed include: public education, public involvement, illicit discharge detection and elimination, pollution prevention and good housekeeping (EPA 2012). It has been difficult to determine the effectiveness of these measures, since a continuous monitoring program is not in place in the watershed, except at Slide Rock State Park (SRSP). Southam (2000) reported that there were 19 *E. coli* exceedances at SRSP from 1994 to 1997, or an average of 4.75 per year. In 2011 SRSP had 4 exceedances, so perhaps there has been a slight improvement, but evaluation of SRSP's *E. coli* records shows no significant trend. While past BMP projects have all been appropriate and admirable efforts, they probably have not been extensive enough to significantly decrease nonpoint source *E. coli* contamination in Oak Creek. Later in this document we will discuss our investigation results and priority BMPs that could help to reduce *E. coli*.

Plan Development

The goal of the Oak Creek Watershed Improvement Plan (OCWIP) is to define practical projects whose implementation will reduce *E. coli* and related fecal contamination in Oak Creek. The general methods used to develop this plan were:

1. Review past studies,
2. Conduct a field investigation to collect *E. coli* data, other water quality parameters, and DNA evidence in Oak Creek, its tributaries, and springs that supply Oak Creek to try to identify potential sources of fecal contamination,
3. Conduct a social survey to determine watershed residents' knowledge and attitudes about fecal contamination of Oak Creek, and
4. Based on field investigation and social survey findings, propose BMPs to reduce fecal contamination, including on-the-ground projects and a significant education and outreach component, and
5. Provide projections of reduced *E. coli* loading due to implementation of recommended BMPs.

Past efforts to reduce *E. coli* loading in Oak Creek have not succeeded in attainment of the water quality standard. Our approach differs from previous projects in that we used baseline, anthropogenicly influenced sites (AIS), stormwater and focused sampling to target locations in the watershed where *E. coli* contamination is problematic and identify management measures that are technically appropriate as well as fitting within the local culture. Chapter 2 will describe the methods by which we collected and analyzed relevant data and the conclusions drawn from our results. Chapter 3 and Appendix B will lay out in detail the management practices and projects that we propose to reduce *E. coli* contamination in Oak Creek.

Table 4. Historic water quality improvement projects in Oak Creek Watershed.

Funding Source	Year completed	Organization	Location	Completed Activities
319(h) – 2 related grants	2001	Oak Creek Canyon Task Force and Coconino County Environmental Health	Oak Creek Canyon	Installation of 14 residential waste system upgrades along Oak Creek.
319(h)	2002	Coconino Nat'l Forest & Slide Rock State Park	West Fork Oak Cr., upstream of SRSP, SRSP, other locations?	Installation of three restroom facilities at popular trailheads to eliminate potential for fecal coliform contamination. Stabilization and restoration of a total of 10 acres of bare ground at 5 sites to reduce erosion and improve soil stability. Sediment traps were installed at SRSP just upstream of the swim area, just north of SRSP and at Encinosa Day Use Area. The sediment traps filled rapidly and were not maintained.
ADEQ Water Quality Improvement Grant	2004	Oak Creek Canyon Task Force	Oak Creek Canyon	Designed, constructed and installed four trailhead signs that conveyed the concept of reducing litter and promoted using restrooms instead of the forest and creek area.
ADEQ Water Quality Improvement Grant	2004	Oak Creek Canyon Task Force	Indian Gardens Oak Creek Canyon	Installation of toilets and a wastewater treatment system at Indian Gardens Visitor Center. Providing sediment control structures throughout Oak Creek Canyon. As of 2012 these sediment traps are filled. Sediment traps at Half Way CG, a borrow pit upstream of SRSP on the east side of the Hwy 89, Manzanita CG. Expansion of the campaign to increase waste disposal by summer holiday visitors. Installation of showers waste system at Cave Springs Campground. Keep Oak Creek Canyon Beautiful - volunteers visited campgrounds and day use areas giving away trash bags to visitors. A ten-ton dumpster was placed at Indian Gardens to encourage visitors to drop off their trash rather than leave it behind in the Canyon

Funding Source	Year completed	Organization	Location	Completed Activities
	2004	AZ Game & Fish Dept.	where?	Exclusion of livestock from riparian areas
			where?	Control of off-road vehicle travel to reduce sediment loads and enhance bank stability.
319h	2002	AZ State Parks	Slide Rock State Park	
319h	2009	Pender Engineering & Oak Creek Canyon Task Force	Oak Creek Canyon, Sedona	Education grant to teach high school students from Sedona how to be Trailhead Ambassadors and pass along their knowledge to Oak Creek Canyon visitors.
University of Arizona Cooperative Extension	2011	University of Arizona & Oak Creek Watershed Council	Oak Creek Watershed, Sedona	Master Watershed Steward program - volunteers are taught how to become stewards of a watershed. The first course began in March 2011. 12 Master Watershed Steward Associates graduated in June, 2011

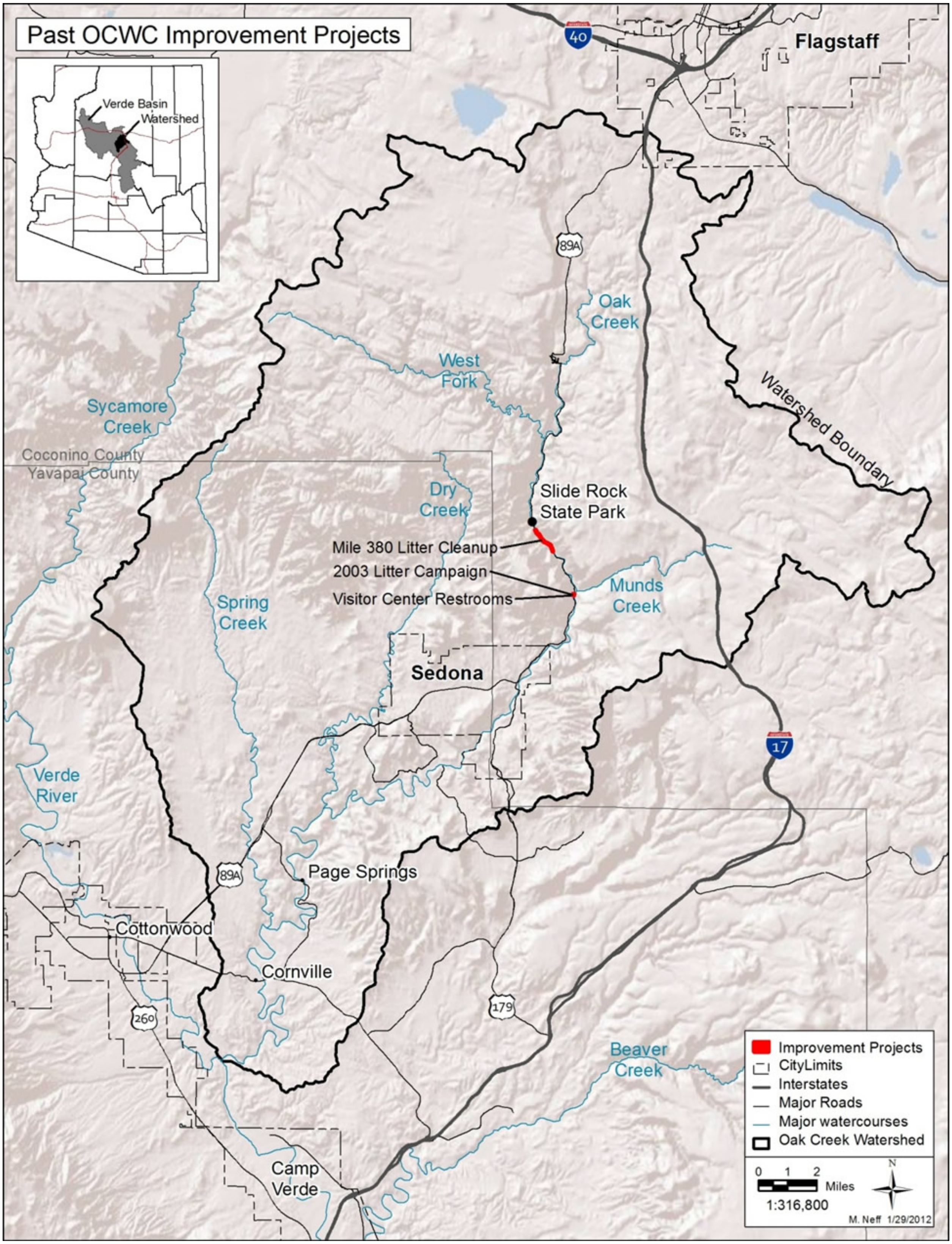

Figure 8. Best Management Practices (BMP) projects in the Oak Creek Watershed

Chapter 2 – Watershed Investigation

Field survey methods & findings

Water Quality Monitoring methods and focus

Water quality was assessed at 56 sites in the watershed including 5 baseline, 11 anthropogenicly influenced (AI), 7 stormwater and 33 focus sites, of which 27 were springs (Figure 9, Table 5). These sites were selected by the monitoring team leaders in consultation with the Oak Creek Watershed Improvement Commission (OCWIC), a technical advisory group with extensive knowledge of current and historic watershed conditions. Baseline sites were selected to reflect more or less natural conditions within Oak Creek. AI sites were places with suspected effects from human influences such as human waste, dog waste, livestock waste, trash, and sediment disturbance during recreation. Stormwater sites were selected in the Sedona urban area to evaluate the degree to which stormwater delivers *E. coli* to Oak Creek. These sites were sampled during one storm event August 1, and on two other occasions (September 6 and 11) pools in the washes were sampled the morning after storm events, since for safety reasons the washes were not sampled during nighttime storm events and by morning flow had ceased. Oak Creek was sampled on mornings following storm events to further characterize impacts. An attempt was made to sample tributary washes outside of the urban area, but due to a shortage of time and confusion about the location of access points, no washes outside of Sedona were sampled during storm events. Focus sites are those where specific impacts on Oak Creek water quality were suspected, such springs that discharge from underneath developed land with septic systems, perennial flow adjacent to waste treatment ponds, or where a concentration of dogs or livestock may impact water quality.

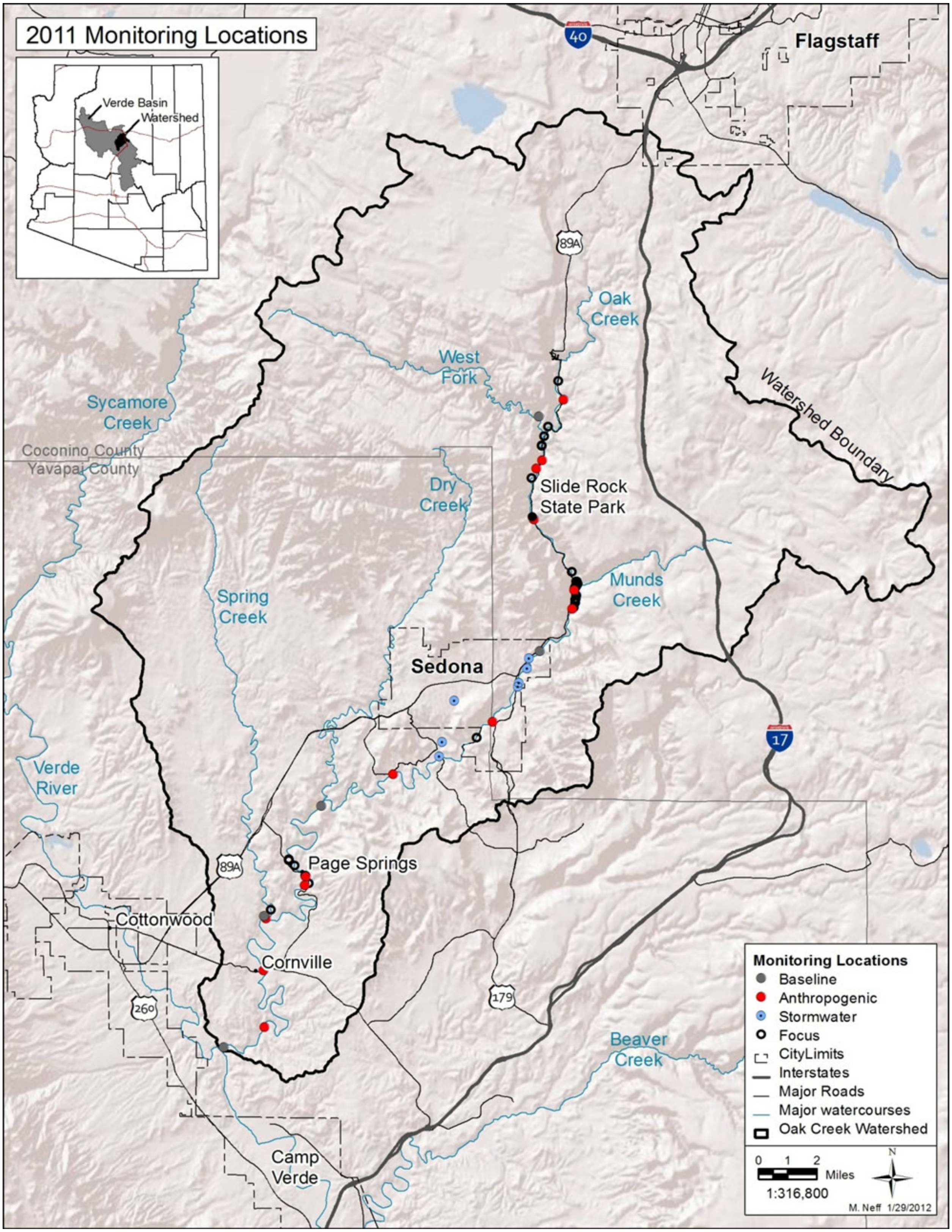

Figure 9. OCWIP monitoring locations, 2011

Table 5. OCWIP sampling location types and locations, 2011

Site	Testing Rationale	Testing Parameters	# times tested
Baseline Data			
M13 - West Fork, one mile upstream from mouth	Baseline/Reference/ control site	pH, DO, temp, conductivity, TDS, *E. coli*, turbidity, flow, nitrate (field test), nitrogen suite and phosphate (lab analysis)	8 samples total; 2-3 background samples prior to monsoon stormflow; 5-6 samples during stormflow
M45 - Lomacasi, ADEQ site 36.97, control site	Baseline		
M32 - Dry Creek confluence	Baseline		
M39A - below Spring Creek confluence	Baseline		
M43 - above Verde River confluence	Baseline		
Anthropogenicly Influenced Sites(AIS)			
M08 - below Pine Flat subdivision	Septics concentration	All of the above, but nitrogen suite only if field test is >0.8 mg/L	8 samples total; 2-3 background samples prior to monsoon stormflow; 5-6 samples during stormflow
M09, M09A - below Forest Houses	Septics concentration		
M44 - Slide Rock State Park (below bridge)	Recreation		
M17 - Indian Gardens	Septics concentration		
M18 - below Living Springs	Septics concentration		
M25 - Chavez Ranch	Urban runoff		
M29 - – below Red Rock State Park	Ag, septics & recreation		
M36 - Page Springs (below bridge)	Septics and agriculture		
M39 - Spring Creek	Sewage treatment ponds		
M40 - Cornville Bridge	Septics and agriculture		
M41 - below Cornville Estates	Septics and agriculture		
Stormwater			
M49 - Jordan Pump	Urban runoff	Turbidity, *E. coli*, DNA, virus	Washes sampled at first flush (August 1, 2011) and mornings after 2 other storm events.
M48 - Arroyo Roble	Urban runoff		
M47 - Tlaquepaque Bridge	Urban runoff		
M46 - Soldier Wash	Urban runoff		
M26 - Carol Canyon, Shelby Road	Urban runoff		
M27 - Carol Canyon, Chavez Ranch Road	Urban runoff		
M51 - Carol Canyon, confluence	Septics concentration		

Site	Testing Rationale	Testing Parameters	# times tested
Focus			
S1, S3, S9, S16, S35, S36, S39, S41, S42, S45, S45A, S45B, S48, S49, S49A, S52, S58, S67, S70, S71, S75, S77, S78, S98, S100, S107, S109, F5, F6, F7	Spring beds may intercept septic effluent due to mounding and/or soil saturation	Nitrogen suite, basic water quality, TDS, DNA, *E. coli*, phosphate	Once, unless *E. coli* or nutrients were elevated, then repeat sampling
F1	Concentrated dog-walking area		
F3	sewage treatment ponds		
F4	Spring outfall with wildlife concentration		

At all sites *E. coli*, geographic coordinates and photographs were collected. In addition, at baseline and AI sites the following parameters were measured or noted in the field using methods and equipment described in table 6:

- date, start and stop time of data collection
- time of sample collection
- current weather and weather in past 7 days
- signs of flushing
- air and water temperature
- dissolved oxygen (mg/L) and oxygen saturation (%)
- conductivity (µS)
- total dissolved solids (mg/L)
- pH
- streamflow (cfs)
- crew initials
- designated water uses (eg. FBC, A&W, PBC, Ag)
- samples collected (*E. coli*, nutrients, DNA)
- notes

Table 6. Field data collections methods

Parameters	**method/equipment**
Total dissolved solids, conductivity, pH and water temperature	ExTech pH/Conductivity meter - model EC500
Dissolved oxygen, percent dissolved oxygen and water temperature	ExTech dissolved oxygen meter - model DO600
Air temperature	a glass and alcohol thermometer in a protective metal case
Streamflow	Rapid method - Channel width and maximum depth where measured. A float was timed as it flowed a distance of 10 feet along the channel thalweg. For channels with a rectangular profile the resulting velocity was multiplied by the width and depth, whereas for most channels the flow was divided by 2 to account for the channel shape.

E. coli samples were collected in sterile 100ml bottles using gloves by lowering the bottle into the stream inverted, removing the lid, turning the bottle upright under water and capping it under water. Over the course of the study 144 samples, including six duplicate samples, were collected. No blank samples were collected. Of the 5 duplicate samples that had *E. coli* concentrations greater than 10 cfu/100 ml, the average log difference from the original sample was +/- 10.8%, with values greater than 200 cfu/100 ml being more consistent (+/- 1.7%) than values between 10 and 200 cfu/ml (+/- 16.8%). Samples were transported in coolers to the laboratory within a 6 hour hold time window. In the laboratory samples were handled using nitrile gloves and analyzed using a IDEXX Colilert® system and QuantiTrays® using a 24-hour incubation period. *E. coli* in samples was analyzed according to manufacturer instructions. Both the *E. coli* lab at Slide Rock State Park and a lab set up at NAU with equipment borrowed from ADEQ were used to test *E. coli*.

Many, but not all, sites were sampled for nutrients including phosphate, nitrite, nitrate, and ammonium (see data summary table in Appendix A). In the latter half of the sampling season we tested nutrient concentrations as personnel was available and if samples were not too sediment laden. Nutrient samples were collected in Nalgene bottles that were previously washed in the laboratory and rinsed with distilled water. Because the bottles were not acid washed to destroy any residual nutrients, in the field at each site the bottles were filled and emptied 5 times before filling with sample. Samples were transported in a cooler on ice, then kept in a refrigerator and analyzed within 48 hours. A Machery-Nagel Nanocolor ® model 500D photometer (unit N500D 0730) was used to measure phosphate, nitrite, nitrate and ammonium. Samples were first allowed to come to room temperature before analysis.

Turbidity was measured in nephalametric turbidity units (NTUs) in the lab using either a Hach 2100P turbidimeter (SN:010200027859) or a Hach 2100Q portable turbidimeter (SN:10110C005972). Sample was shaken to resuspend sediment particles and poured into glass vials that were inserted into the turbidimeter and results were read according to manufacturer instructions.

DNA testing was used to discriminate between human, bovine and other sources of *E. coli* contamination through Microbial Source Tracking (MST). A total of 43 samples were collected across 29 sites in 2 sterile 1-liter HDPE bottles for MST analysis. Prior to sampling bottles were washed using laboratory soap, rinsed 6 times with tap water and 3 times with distilled water, air dried and heat sterilized in an autoclave for 20 minutes at 140 degrees. Samples were shipped on ice to Dr. Channah Rock's laboratory (hereafter the Water Quality Laboratory) at the Maricopa Agricultural Center in Maricopa, Arizona for DNA analysis. MST performed by the Water Quality Laboratory differentiated among three categories of *bacteroides* bacteria: human, bovine and total. Bacteria belonging to the genus *Bacteroides* have been suggested as alternative fecal indicators to *E. coli* or fecal coliform. This is due to the fact that they make up a significant portion of the fecal bacteria population, have little potential for re-growth in the environment, and have a high degree of host specificity that likely reflects differences in host animal digestive systems. The use of fecal bacteria to determine the host animal source of fecal contamination is based on the assumption that certain strains of fecal bacteria are associated with specific host animals and that strains from different host animals can be differentiated based on genotypic markers. One of the most widely used approaches utilizes a method called polymerase chain reaction (PCR) to amplify a gene target that is specifically found in a host population. PCR enables researchers to produce millions of copies of a specific DNA sequence in relatively short amount of time. *Bacteroides*-based methodologies are designed to target specific diagnostic sequences within the *Bacteroides* 16S rRNA gene (which is vital for protein synthesis and therefore present in all bacteria) present in feces from different animals. Testing used microbial detection methodologies and molecular source tracking, in conjunction with microbial genotyping techniques. See the Oak Creek Watershed Council Sampling Analysis Plan for a complete description of DNA testing methods. Combining two methods (testing DNA of *bacteroides* and bacteriophages) allowed for a better understanding of the system dynamics to identify potential non-point source impacts within impaired watersheds.

Preliminary Monitoring Survey Findings

The following are some of the early findings and adaptations that were made based on findings:

1. With 3 sampling teams, each including a sampling team leader and one or two volunteers, it was not possible to sample more than about 12 sites in one day. Therefore it took 2 days to complete a background sampling of all baseline and AI sites.
2. In the lowest reach around Cornville, it was difficult to sample more than 3 sites and stay within the 6 hour hold time for *E. coli*, because of travel time. Therefore the daily sampling total was sometimes reduced to 11 sites.
3. Each site takes about 1 hour to sample and take measurements. This does not account for travel time between sites.
4. Streamflow estimates were not improved with greater detail in measurements, so we use the simplest method.
5. We discovered greater *E. coli* concentrations in the middle and lower watershed prior to monsoon, which appeared to be associated with greater non-storm-related turbidity.
6. The difference in *E. coli* concentrations became even more abrupt with the onset of stormflow. Above Sedona in Oak Creek Canyon *E. coli* concentrations elevated very slightly in response to stormflow but did not exceed the standard. However, from Sedona downstream to Page Springs, *E. coli* concentrations increased dramatically in response to stormflow and exceeded the standard greatly following the large storm event on August 1st, which might be considered the first flush.
7. A relatively low *E. coli* count at Cornville on August 2nd may indicate that it takes greater than 19 hours for *E. coli*-laden stormwater to travel downstream from Sedona to Cornville. This may be a kinematic wave effect in which cleaner water is pushed ahead of water that has been mixed with surface pollutants, delaying the arrival of pollutants. The delay might allow for warning recreationalists to not swim in turbid waters that may have elevated fecal contamination.
8. Turbidity during storm events seems directly related to the sediment input that increases going downstream (Figure 10).

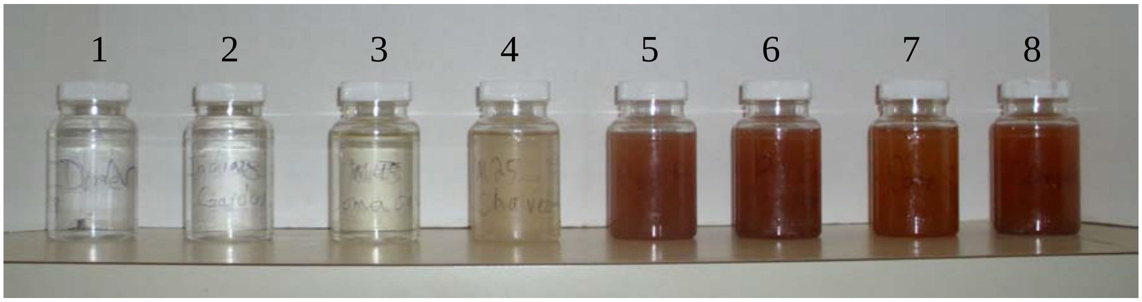

Figure 10. Oak Creek water samples September 15, 2011 following a storm event the night before.

Site	Stream mile	*E. coli* (cfu/100 ml)
1. Pine Flats	49.0	0
2. Indian Gardens	40.5	65.4
3. Lomacasi	37.4	426
4. Chavez Crossing Campground	33.9	1,354
5. below Red Rock State Park	27.9	2,489
6. Dry Creek Confluence	22.7	5,794
7. Page Springs Bridge	17.2	506
8. Cornville Bridge	8.9	7,270

9. We set up a Colilert system (on loan from ADEQ) at the NAU lab to allow for stormwater sampling late in the day, since the Slide Rock Lab was not available after the park closed at 7:00 p.m.
10. Coordinating volunteers for rapid response to sample stormwater flow was challenging. We missed July 4th and July 18th stormwater flow in the Sedona washes. Each event occurred in the late afternoon on a day when we did not have baseline sampling planned and before specific volunteers had made commitments to stormwater sampling. July 5th was our first sampling day, and the *E. coli* results downstream of Sedona were not noticeably different than those on other dates that were not preceded by a storm event. Therefore, although the July 4th and 18th storms did result in stormflow in the Sedona washes, the magnitude might not have been great enough for either to be considered "first flush". See hydrograph in figure 15 (page 55) for magnitude of storm events.
11. We did capture a large storm event on August 1st, which was a 10- to 50-year flow event, ie. there is a 2 to 10 percent chance of a storm of a similar intensity and duration occurring in a given year (Charles Mosley, personal communication). The resulting *E. coli* concentrations were very elevated in Sedona's stormwater runoff and in the creek water downstream of Sedona the following day. The August 1st event might be considered the "first flush". Unfortunately we were only able to grab *E. coli* samples for this event and did not collect DNA samples to determine the relative sources of *E. coli*.
12. September 6th and 11th we collected stormwater the day after rainstorms from pools of water in washes. Although this was not optimal, we felt it was better than no sample. DNA was sampled in the washes on Sept. 6 and analyzed at the Rock Lab for human

and bovine DNA and Real-Time Quantitative Polymerase Chain Reaction (qPCR) DNA Analytical Technology for dog DNA.

13. The strongest single relationship we found was between *E. coli* concentrations and turbidity in Oak Creek on August 2, 2011 following the storm event on August 1st with an R^2 of 0.87, n = 10 (Figure 11). For all creek samples that have both *E. coli* and turbidity data the R^2 is 0.82, n = 18. Unfortunately we did not have access to a turbidimeter for the first part of the sampling program, but greater turbidity was visually observed at sites where more *E. coli* was found. This was especially true from Page Springs down to the Verde River confluence, even in the absence storm flow. Investigation of turbidity sources is needed in this reach (eg. irrigation return flows, livestock in stream, low water crossings, etc.).

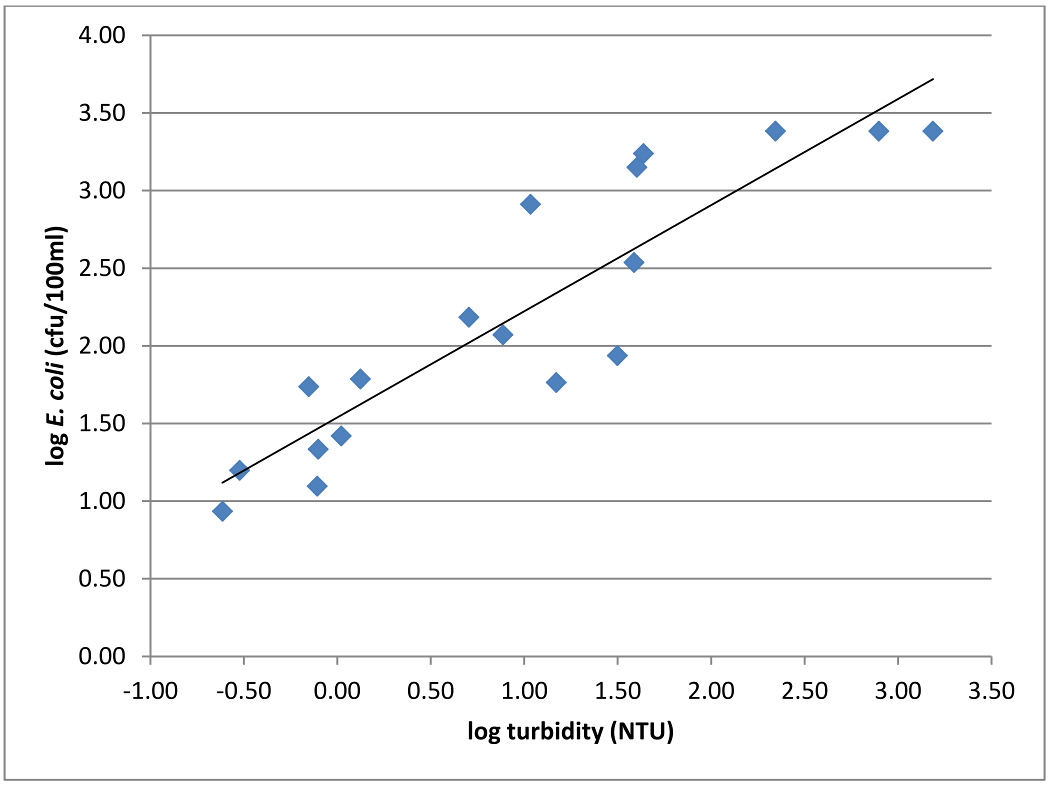

Figure 11. Log *E. coli* concentrations as response to log turbidity, Oak Creek August 2, 2011, $R^2 = 0.87$.

14. Curiously, on August 1st, *E. coli* and turbidity did not seem to be significantly related in Sedona stormwater runoff, though turbidity of stormwater samples was not measured that day. Arroyo Roble which had the highest *E. coli* count (>2,419.2 cfu/100ml) had the lowest turbidity (nearly clear) while Carroll Canyon Wash samples were extremely turbid but had *E. coli* counts ranging from just 222 to 509 cfu/100 ml (Figure 12.). (Sediment in the Carroll Canyon samples clogged the bottom row of small cells, displacing water and probably causing them to not fluoresce. However, when we made an assumption that all those cells would have fluoresced, the result was within 10% of what was reported.) Because *E. coli* is strongly correlated with sediment in the creek but not with sediment in the tributary

washes, it appears that the washes, rather than harboring sediment reservoirs themselves, simply provide the raw materials (sediment & *E. coli*) for the *E. coli* sediment reservoirs in the creek. These reservoirs are then mixed with the water column during storm events or recreational use to elevate the water *E. coli* concentrations.

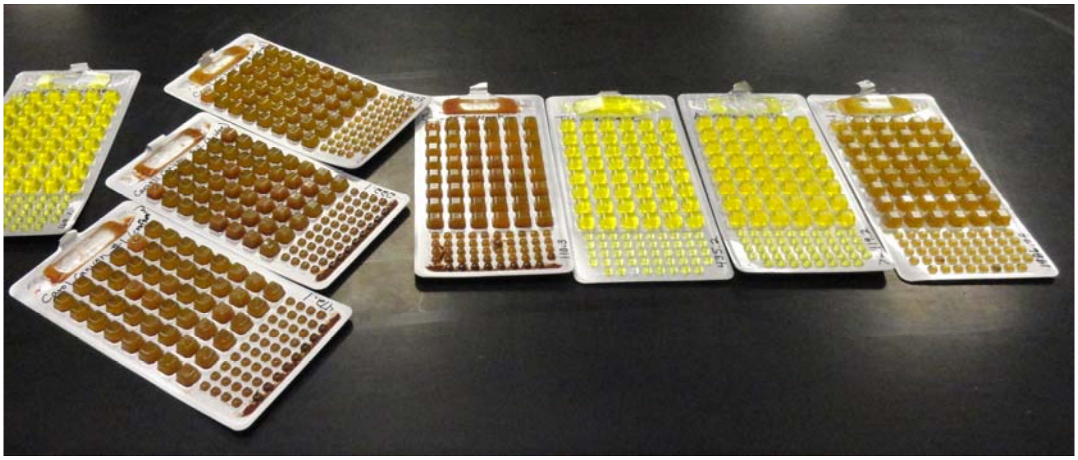

Figure 12. Quanti-trays showing variation in sediment yield among stormwater flow collected from Sedona's washes on August 1. The darker brown the sample is, the more sediment it holds. From left (downstream) to right (upstream) are Carroll Canyon 1, 2, and 3, Soldier's Wash, Tlequepaque, Arroyo Roble and Jordan Wash. (The sample on the far left is from Cornville Bridge, where the storm pulse had not reached yet.)

15. The capacity of the Colilert system was exceeded (>2419.2 cfu/100ml) for one sample from the August 1st stormwater sampling (Arroyo Roble) and 3 of the samples from the followup August 2nd creek sampling (below Red Rock State Park, Dry Creek Confluence and Page Springs bridge). This means we do not know how high the *E. coli* concentration actually was at these locations. In subsequent sampling we analyzed 1/10 dilutions of samples when we suspected we would find very high *E. coli* counts.
16. Monsoon activity in the watershed was sporadic in July and most of August. Some storm events did not generate enough stormwater flow to collect a sample or to elevate creek flow significantly, even though briefly in isolated places rainfall was intense. We were not able to collect samples from as many storm events as we would have liked.
17. Focus site sampling was largely inconclusive. In the first round of spring sampling a few sites appeared to have somewhat elevated *E. coli* counts, but none exceeded the FBC standard. Likewise some sites had very slightly elevated nutrients, but there were no statistically significant relationships between nutrient concentrations and *E. coli* concentrations as we has hoped, so it does not appear that nutrients could be used as a proxy indicator for septic contamination of springs.
18. No nutrients tested (nitrite, nitrate ammonium or phosphate) appear related to *E. coli* concentrations in creek water.
19. Total Dissolved Solids and conductivity are the only other water quality parameters that appear to perhaps have a direct relationship with *E. coli* concentrations in Oak

Creek water. Hypothesizing that they are probably associated with greater turbidity and contact between the water column and *E. coli* in the stream's sediment reservoir, regression analyses were done to see if TDS or conductivity are related to turbidity, but this does not seem to be the case.

20. Dissolved oxygen and pH had no apparent relationship to *E. coli*.
21. Most springs were very low in both nutrients and *E. coli.* with no significant relationships found among nutrients and *E. coli*.
22. Although no focus sites exceeded the *E. coli* FBC standard, except the spring ditch in the Page Springs area (272 cfu/100ml), and most concentrations were less than 100 cfu/ml, some focus sites might merit further monitoring (Table 7), because they had *E. coli* elevated above concentrations in the Oak Creek and/or tested positive for human DNA. [Three replicates for DNA analyses were completed for each sample. A weak positive was one in which one out of three tests was positive for human DNA. A medium positive had two out three tests positive. A strong positive was one in which all three tests were positive for human DNA.] The presence of a strong positive for human DNA, especially along with elevated *E. coli,* indicates a possible septic or sewage source of *E. coli.* Such sources may "charge" sediment reservoirs that produce water quality exceedances when disturbed.
23. Some sites tested positive for human DNA but did not raise concern about septic system influence because they were either far from septic systems (Zane Grey's cabin spring) or they were surface water affected by stormflow that likely delivered human DNA from distal locations (Table 8). It is important to note, however, that several *E. coli* exceedances coincided with human DNA detections in and downstream of Sedona (Chavez Crossing Campground, Carroll Canyon 2, and below Red Rock State Park), so future monitoring should endeavor to pin point sources of human DNA in surface water of the Sedona area in order to locate possible sources of fecal contamination.

Table 7. Three spring locations in Oak Creek Canyon with suspected septic leakage, based on *E. coli* and DNA results.

0 = negative, 1 = weak positive, 2 = medium positive, 3 = strong positive for presence of human DNA.

Site, general location	Date	*E. coli* cfu/100ml	Human DNA	Notes
S41, stream mile 44.4	8/24/11	47.1	3	Commercial septic system
S49, stream mile 41.0	8/24/11	202.4	1	Residential septic system(s)
S49, stream mile 41.0	9/16/11	2	1	Residential septic system(s)
S49, stream mile 41.0	9/20/11	15.5	3	Residential septic system(s)
S71, stream mile 40.1	9/20/11	22.8	1	Commercial septic system
S70, stream mile 40.1	9/20/11	18.6	3	Commercial septic system
S109, stream mile 40.1	9/21/11	0	3	Commercial septic system
S71, stream mile 40.1	9/22/11	27.8	3	Commercial septic system
S70, stream mile 40.1	9/22/11	25.6	1	Commercial septic system
S109, stream mile 40.1	9/22/11	8.5	2	Commercial septic system

Table 8. Other sites that tested positive for human DNA and may warrant further monitoring.

0 = negative, 1 = weak positive, 2 = medium positive, 3= strong positive for presence of human DNA. Bolded values are *E. coli* exceedances.

Site, location	Date	*E. coli* cfu/100ml	Human DNA	Note
Oak Creek Canyon				
M08, Pine Flats	9/11/11	15.8	2	Following storm event
S16, Zane Grey's cabin	8/24/11	100.5	1	High recreation area
M17, Indian Gardens	9/11/11	152.9	3	Following storm event
M45, Lomacasi	9/11/11	117.8	2	Following storm event
Sedona area				
M25, Chavez Crossing CG	9/11/11	**1,413.6**	2	Following storm event
M27, Carroll Canyon 2	9/6/11	**>2,419.2**	3	Following storm event
M29, below Red Rock SP	9/11/11	**2,419.17**	2	Following storm event
Downstream of Sedona				
M32, Dry Cr. confluence	9/11/11	**344.8**	1	Following storm event
M36, Page Springs bridge	9/11/11	**816.4**	3	Following storm event
S107, Page Springs	9/20/11	116.9	1	Septic leakage suspected
F6, Page Springs	9/20/11	**272.3**	0	Septic leakage suspected
M39, Page Springs	9/16/11	**687.7**	1	Leaking sewer pond suspected
M41, Cornville Estates	9/11/11	58.1	1	Following storm event

Summary of Findings

Findings supportive of past studies

Past studies and past monitoring data show that *E. coli* levels in Oak Creek are usually low but occasionally rise above the single sample maximum of 235 cfu/100ml, the water quality standard set by the Arizona Department of Environmental Quality for full body contact (FBC). Exceedances have usually occurred during periods of high recreational use or during or shortly after stormflow events. Our results are consistent with these past findings. Our sampling data revealed exceedances of the FBC standard only associated with stormwater flow in the washes of Sedona and in Oak Creek downstream of these washes following stormflow events, with the exception of Spring Creek. Spring Creek had an *E. coli* exceedance that coincided with a weak positive human DNA result, which indicates possible leakage from a sewage treatment pond adjacent to Spring Creek. Although we did not find any exceedances apparently associated with recreation, twice daily monitoring at Slide Rock State Park revealed an exceedances on four dates in summer 2011 (Sun. 6/19, Sun. 7/13, Mon. 7/4, Sun. 7/31), wherein all the Sunday dates saw heavy visitation and Monday July 4th the park closed to protect against *E. coli* contact. Because no storm events had occurred around the time of the Slide Rock exceedances, and because the Slide Rock *E. coli* concentrations were much greater (mostly >2,419 cfu/100 ml) than Oak Creek Canyon concentrations associated with storm flow (77 cfu/100 ml average), it may be assumed, as it has been in past studies, these exceedances were associated with heavy recreational use that may have contributed *E. coli* source and/or disturbed sediments sufficiently to mix *E. coli* into the water column from the sediment reservoir.

Recreational use or high streamflow disturb stream sediments and mix them with the water column transferring *E. coli* from sediment particles to the water (Crabill et al. 1999, Southam et al. 2000). Crabill et al. (1999) found that average fecal coliform concentrations (which included *E. coli*) in Oak Creek Canyon were 2200 times greater in the top 10cm of sediment than in the overlying water column. Southam et al. (2000) found sediment *E. coli* concentrations at some sites were >10,000 times greater in than in the water column. The findings are consistent throughout the literature which indicates the majority of enteric bacteria in aquatic systems are associated with sediments and that these associations influence their survival and transport characteristics (Jamieson et al. 2005). Fecal bacteria can persist in the sediment for up to 12 weeks, hence the term "sediment reservoir" of *E. coli* (Lightner 1994). Because *E. coli* concentrations in Oak Creek water appear strongly related to disturbance of sediment reservoirs, more work is needed to identify specific sources of sediment in order to reduce habitat that sustains *E. coli* in the stream system. The University of Arizona may help to determine sediment source areas using sediment loss modeling. Sediment sources might include streambank or upland erosion by recreationalists, construction sites, inappropriately engineered or maintained road crossings, or construction and erosion of irrigation diversion dams, such as this example:

Considerable sediment was observed at site M39A below the Spring Creek confluence. About ½ mile upstream is an irrigation diversion dam that can be seen on aerial photo with streamflow eroding down through the dam. An irrigation association in the Page Springs area builds up the dam each year to pump water from the pool, sometimes higher than permitted by Army Corp of Engineers and disturbs considerable sediment in the process (Mariann Speare, Oak Creek Valley HOA, personal communication).

Sediment sources such as this need to be investigated and appropriate BMPs implemented to reduce sediment loads that contribute to *E. coli* sediment reservoirs.

Most of the basic water quality parameters or physical stream properties did not yield any significant relationship with *E. coli* concentrations. Table 9 shows some of the possible significant relationships as found through statistical analysis of the 2011 data. R^2 is an expression of the goodness of fit of a trend line; R^2 ranges from 0 to 1 with higher numbers expressing a closer fit of data points along a trend line. The strongest relationship we found was between turbidity and *E. coli* concentrations, supporting the results of past studies that point to disturbance of stream sediments and contact between sediment particles and the water as the primary means of Oak Creek water becoming contaminated with *E. coli*. Another strong relationship was between ranked streamflow (order from upstream to downstream) and *E. coli* as measured at baseline conditions. What this says is that *E. coli* appears to accumulate going from upstream to downstream. However, lower *E. coli* concentration in the upper reaches (Oak Creek Canyon) may also be due to the creek having better "self cleaning" properties where gradients are higher and aeration is greater. Well-aerated streams, such as in Oak Creek Canyon, have an assimilative capacity that can aerobically treat fecal contamination, essentially through a "fixed-film media system" that has to do with the presence of biofilms and the amount of surface area of rocks (Fitch et al. 1998, Neu and Lawrence 1997). Oak Creek, in Oak Creek Canyon, has demonstrated this aerobic treatment ability, as evidenced in past monitoring, by significantly reducing *E. coli* concentrations from exceedance-level at SRSP to below exceedance-level one mile downstream (Morgan Stine, personal communication).

A possibly significant relationship between *E. coli* in spring samples and the nutrient phosphate merits further investigation to determine if phosphate may be used as indicators of septic effluent impacts on springs. Total dissolved solids (TDS) and conductivity also had a possibly significant relationship to spring *E. coli*. However, given the low R^2 on the TDS and conductivity regressions, it appears that it may be necessary to use multiple lines of water quality evidence for inferring septic system influence. The use of monitoring wells and fluorescent dye or other tracers may be necessary to positively identify the effluent contamination of Oak Creek for specific sites.

Table 9. 2011 Oak Creek water quality sampling positive relationships of water quality and physical environment to *E. coli* concentrations according to linear regression

Statistically significant relationships are ranked from strongest to weakest.
Flow rank is the order of the sampling location from headwaters to mouth.
(AI = anthropogenicly-influenced).

Sample type	**Dependent variable**	**Independent variable**	**N**	**R^2**	**F ratio**
Baseline + AI	*E. coli*	turbidity	17	0.604	0.0001
Focus spring	*E. coli*	phosphate	38	0.483	0.0001
Baseline + AI	*E. coli*	ammonium	17	0.505	0.0010
Baseline + AI	*E. coli*	flow rank	15	0.498	0.0022
Focus spring	*E. coli*	total dissolved solids	42	0.247	0.0007
Focus spring	*E. coli*	conductivity	42	0.235	0.01

Statistical results in Table 10 compare and contrast two conditions. The strongest relationship found was that *E. coli* concentrations from Sedona downstream were higher associated with stormflows than with baseflow. The contrast between stormflow and baseflow was also strong for Oak Creek as a whole, but was weak or possibly insignificant in Oak Creek Canyon where *E. coli* concentrations did not elevate much during storm events. There was a significant contrast between *E. coli* concentrations in Oak Creek Canyon and from Sedona downstream, with concentrations being significantly higher from Sedona downstream. In Table 10 statistically significant relationships are ranked from strongest to weakest.

Table 10. T-test significant differences in *E. coli* concentrations by baseflow vs. stormflow and by location.

Location	**condition 1**	**condition 2**	**F-ratio**
Sedona down	Baseflow	Stormflow	<0.0001
all of Oak Creek	baseflow	Stormflow	0.0002
all of Oak Creek	OC canyon	Sedona down	0.0082
Oak Creek Canyon	baseflow	Stormflow	0.0586

Given the strong relationship between stream sediments and *E. coli* in the water, the next practical step is to ask where the *E. coli* comes from that resides in the sediments. As discussed in chapter 1, the sources of *E. coli* contamination Oak Creek Canyon's water column have been identified using DNA analysis. The top five contributors to *E. coli* pollution in Oak Creek water accounted for 84% of the pollution, including raccoons (31%), humans (16%), skunks (11%), elk (8%), and beaver, dogs, and white-tailed deer (each 6%) (Southam et al. 2000). In July, prior to flushing monsoon rains, Southam found a greater proportion of *E. coli* was attributed to humans, often around 30% and sometimes nearly 50%. Southam also identified that the top 6 sources of *E. coli* in the Oak Creek Canyon sediment accounted for 88% of sediment *E. coli*; these sources were similar but not the same as water column sources – horse (16%), humans (12%), raccoons and white-tailed deer (both 11%), elk and skunk (10%) and cows and mule deer (both 9%).

Crabill et al. 1999 concluded that the occurrence of fecal pollution in the sediments at Slide Rock State Park (SRSP) prior to the summer rain season suggested that the source of fecal pollution must be close to the creek because a long-distance transport mechanism, i.e. summer storms, was not in place. This implicated a human (recreational and/or residential) source of fecal pollution at SRSP or just upstream.

We sampled a spring (S41) approximately 0.8 miles upstream of SRSP 3 times and found somewhat elevated *E. coli* counts (47.1, 19.5 and 16.4 cfu/100 ml) in comparison to average (non-storm-event) concentrations of *E. coli* in creek water in Oak Creek Canyon (11 cfu/100 ml) and typically low *E. coli* concentrations in Oak Creek Canyon springs (0 to 2 cfu/100 ml). One of two DNA samples of S41 tested positive for human DNA (strong positive), indicating that the resort's leach field might be exceeding its capacity and/or mixing with spring water and contributing fecal contamination that could impact water quality in the park downstream. Another source could be defective sewer pressure or gravity pipes located near springs or Oak Creek. Discharge from this resort and possibly other upstream leaking septic systems may be loading *E. coli* into sediments that are then disturbed by park visitors causing entrainment in the water column. There is also likely direct contribution of fecal matter from swimmers and waders and from feces left near the stream, as has been observed through feces counts in other streams with heavy recreation use (Madigan 1997).

Findings unique to this study

Many of our monitoring results were supportive of previous studies' conclusions, particularly the correlation between sediment reservoirs and *E. coli* in Oak Creek Water, since turbidity and *E. coli* had the strongest statistical relationship of any two parameters in our study ($p = 0.0001$, $R^2=0.604$). However, we were able to investigate potential sources of *E. coli* more specifically than previous studies. Our findings fit into 2 main focus areas:

1. Septic effluent interception by springs and
2. Stormwater delivery of *E. coli* and sediment to Oak Creek.

Focus 1: Septic effluent interception by springs

To investigate the possibility that septic systems in residential and commercial sites with shallow groundwater are contaminating springs that provide water to Oak Creek, we collected 25 samples from spring, spring channels and spring ditches in Oak Canyon and the Page Springs area and tested for *E. coli*, nutrients and *Bacteriodes* DNA (Table 11). Sampling sites were selected because they had elevated *E. coli* and/or nutrients levels that indicated possible septic influence due to proximity of septic systems. A spring sample was considered elevated in *E. coli* concentration if the concentration was noticeable higher than typical baseline concentration in nearby Oak Creek. Most natural springs have *E. coli* concentrations (0-2 cfu/100 ml) that are much less than creek water at baseline (~10 cfu/100 ml in Oak Creek Canyon, ~50 cfu/100 ml Sedona down).

DNA samples were analyzed for *Bacteriodes* DNA and bacteriophages at the University of Arizona water quality lab in Maricopa, AZ. The use of fecal bacteria to determine the host animal source of fecal contamination is based on the assumption that certain strains of fecal bacteria are associated with specific host animals and that strains from different host animals can be differentiated based on phenotypic or genotypic markers (Layton 2006). One of the most widely used approaches utilizes polymerase chain reaction (PCR) to amplify a gene target that is specifically found in a host population (Shanks 2010). *Bacteroides*-based methodologies are designed to target specific diagnostic sequences within the *Bacteroides* 16S rRNA gene (which is vital for protein synthesis and therefore present in all bacteria) present in feces from different animals. Katherine Field and colleagues, in particular, have performed extensive research into the use of *Bacteroides* 16S rDNA-based PCR assays for MST (Field and Bernhard 2000, Field et al. 2003, Field and Dick 2004). Bernard and Field developed 16S rRNA gene (rDNA) makers from *Bacteroides* to detect fecal pollution and to distinguish between human and ruminant (e.g., bovine, goat, sheep, deer, and others) sources by PCR (2004). Targeting this gene along with PCR primers will allow differentiating between human- and ruminant-associated *Bacteroides*, therefore identifying the possible source of contamination.

Bacteriophages are viruses that infect bacteria and have also been recommended as alternative indicators to fecal contamination. These organisms are of particular significance due to the fact that they more accurately mimic pathogenic virus survival and fate in the environment. While bacteria may tend to die off or degrade at a rapid rate, viruses tend to be more stable in environmental conditions.

Human DNA results for 43 samples were that nine were a strong positive (3/3), 5 were a medium positive (2/3), 10 were a weak positive (1/3) and 19 were negative. The samples included 25 spring samples for which 14 were positive for human DNA, of which 10 samples had elevated *E. coli* (15.5 - 116.9 cfu/100 ml, average 61.6 9 cfu/100 ml) and 4 samples did not have elevated *E. coli* but could have contained viruses or bacteriophages associated with septic effluent. These results indicate that interception of septic effluent by groundwater flowing to springs is likely a source of *E. coli* in some springs. Figure 13 is a map showing springs that tested positive for human DNA. Some of these are suspected to have septic influence.

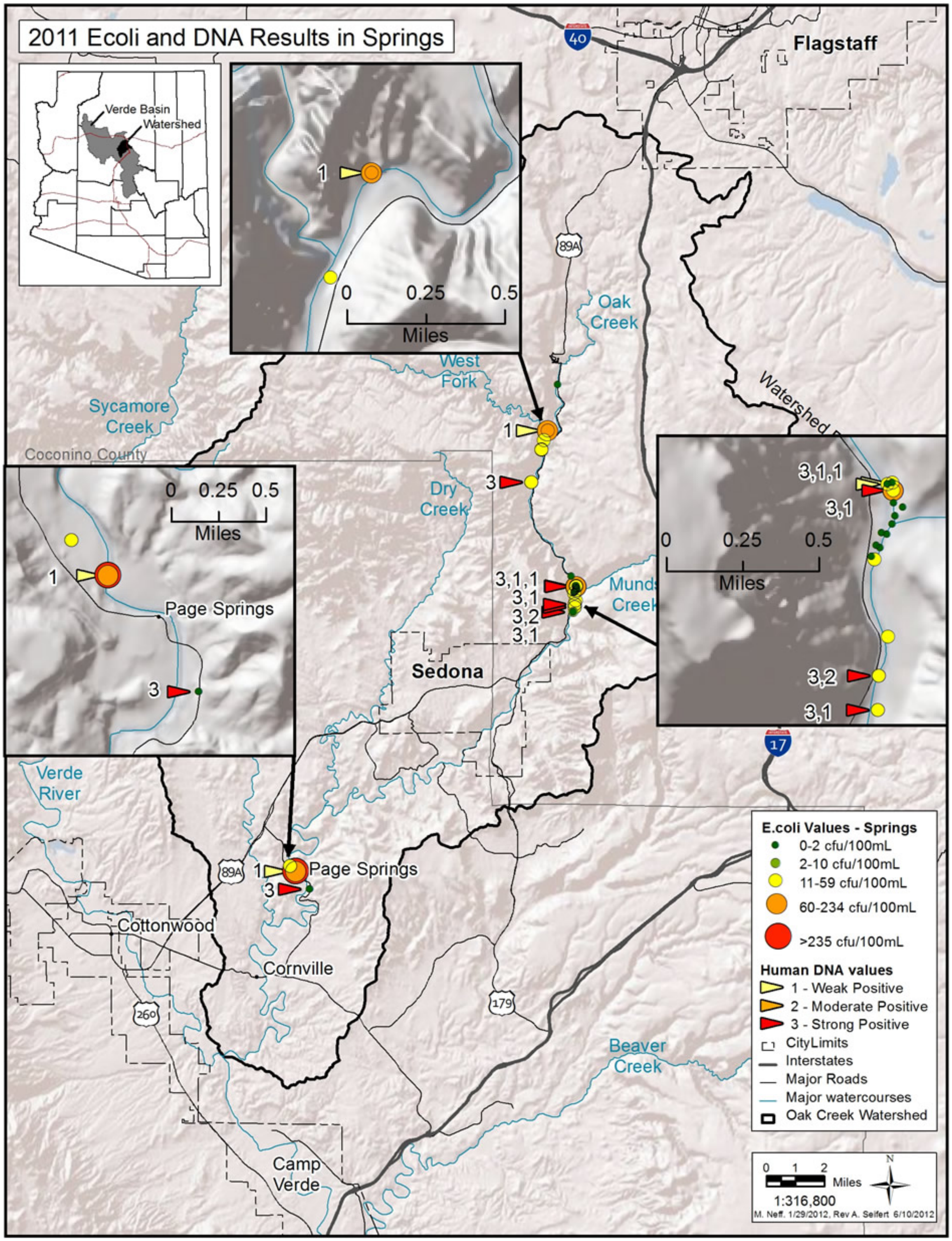

Figure 13. *E. coli* and human DNA test results at springs in Oak Creek watershed. 3= strong positive, 2 = medium positive, 1 = weak positive result for Human DNA.

Identification of contaminated springs is not always straight forward and requires repeat sampling. Whereas *E. coli* concentrations at springs where human DNA was detected are at concentrations below the FBC standard, and the *E. coli* from these source may be quickly diluted by creek water, the more-or-less steady flow of elevated *E. coli* may "charge" sediment reservoirs with *E. coli* that can later be disturbed to cause exceedances in the water column. This concept could possibly be validated by measuring *E. coli* concentrations in sediment below spring discharge points relative to other creek sediment. More sampling is recommended to develop a clearer understanding of the relationship between *E. coli* and human DNA in springs that may be under the influence of septic effluent. With the possible exception of phosphate, nutrient levels showed no obvious relationship with *E. coli* concentrations where human DNA was present (Table 11), so it is not advised to use nutrients as a possible indicator of septic influence, unless further investigations using a large sample size can establish nutrient/*E. coli* relationships with greater confidence.

Table 11. Spring focus site results and interpretation of septic influence.

Grey highlights indicate interpreted background levels. Human DNA: number of detections out 3 tests.

Date	Description	*E_coli* cfu/100 ml	Phosphate mg/L	Nitrite mg/L	Nitrate mg/L	Ammonia mg/L	Human DNA positive	Suspected Septic Influence
8/24/2011	Spring 16, Zane Grey's cabin	105	0.10	<0.002	0.02	0.03	1	No
8/24/2011	Spring 41, upstream of SRSP	19.5	0.07	0.002	0.06	0.02	3	Yes
8/24/2011	Spring 52, Indian Gardens	0	0.05	<0.002	<0.02	0.01	1	Uncertain
8/24/2011	Spring 49, Indian Gardens	202.4	0.06	<0.002	<0.02	0.01	1	Yes
8/24/2011	Page Springs Source	0	0.04	<0.002		0.02	3	Uncertain
8/24/2011	Bubbling Ponds Spring	25.6	<0.04	<0.002	0.06	0.02	0	No
8/24/2011	Bubbling Ponds Outfall	14.6	1.0	0.006	0.11	0.05	0	No
9/16/2011	Spring 52, Indian Gardens	16.1	Nd	nd	nd	nd	0	Uncertain
9/16/2011	Spring 49, IG, source	2	Nd	nd	nd	nd	1	Yes
9/16/2011	spring ditch, AGFD	2419.17	Nd	nd	nd	nd	0	Uncertain
9/16/2011	spring ditch, Crawford	>2419.2	Nd	nd	nd	nd	0	Uncertain
9/16/2011	Bubbling Ponds Spring	19.9	Nd	nd	nd	nd	0	No
9/16/2011	Bubbling Ponds outfall	147	Nd	nd	nd	nd	0	No
9/16/2011	Page Springs Source	0	Nd	nd	nd	nd	0	No
9/20/2011	Spring 41, upstream of SRSP	16.4	<0.04	0.002	<0.02	0.04	0	Uncertain
9/20/2011	Spring 49 source	20.1	0.05	<0.002	<0.02	0.01	0	Uncertain
9/20/2011	Spring 49 near source	15.5	0.05	<0.002	0.02	0.03	3	Yes
9/20/2011	Lower Indian Gardens, midway	22.8	0.05	0.003	<0.02	0.05	1	Yes
9/20/2011	Lower Indian Gardens, nr runs	18.5	0.08	0.010	0.08	0.15	3	Yes
9/20/2011	Spring ditch, AGFD	272.3	0.10	0.002	0.03	0.03	0	Uncertain
9/20/2011	Spring ditch, Crawford	116.9	0.04	0.003	0.03	0.05	1	Yes
9/21/2011	Lower Indian Gardens, lower	0	0.07	0.009	0.07	0.07	3	Yes
9/22/2011	Lower Indian Gardens, midway	27.8	0.06	0.002	0.05	0.01	3	Yes
9/22/2011	Lower Indian Gardens, nr runs	25.6	0.05	0.008	0.13	0.08	1	Yes
9/22/2011	Lower Indian Garden, lower	8.5	0.08	0.009	0.15	0.08	2	Yes

It should be noted that not all property owners allowed us to sample springs on their property. One commercial property with a large septic system in proximity to a spring denied access for sampling, but human DNA and elevated *E. coli* were found downstream in the spring ditch samples. Water sampled twice in September 2011 from 2 locations on a ditch downstream of the this spring revealed elevated *E. coli* (116.9 to >2419.2), with the water quality standard greatly exceeded on 9/16/11 and human DNA detected 9/20/11. A commercial property owner in Oak Creek Canyon where septic issues have been a concern in the past was also reticent at first to have springs sampled, but did eventually allow sampling in September. *E. coli* levels were slightly elevated but there were no exceedances. However, a neighbor anonymously reported a sewage smell emanating from the property in August and human DNA was detected in all of the September samples. It is recommended that these and other commercial properties with septic systems is close proximity to springs should be monitored in the future.

Water quality was also sampled in Spring Creek upstream and downstream of a residential area's wastewater treatment plant (WWTP) evaporative ponds adjacent to the spring-fed creek. There were two *E. coli* exceedances on Spring Creek below the WWTP ponds. Water sampled from Spring Creek on 8/24 upstream of the WWTP ponds had an *E. coli* concentration of 46.7 cfu/100 ml, whereas below the WWTP ponds the concentration was 249.5cfu/100 ml, exceeding the water quality standard. On 9/16 Spring Creek samples had *E. coli* concentrations of 579.3 and 686.7 cfu/100ml above and below the WWTP ponds respectively. Human DNA was detected (weak positive) in Spring Creek below but not above the WWTP ponds on 9/16/11. There was clearly some *E. coli* traveling down Spring Creek in perennial flow from above the waste water treatment ponds on 9/16/11, so the *E. coli* below the treatment ponds on that date cannot be fully attributed to the ponds. However, the large difference in *E. coli* concentrations above and below the ponds on 8/24, combined with the positive human DNA result on 9/16 below the ponds, is cause for concern. Inspection of the ponds is recommended to determine if leaks are a problem, as they have been in the past, as reported by the HOA manager.

Focus 2: Stormwater delivery of *E. coli* to Oak Creek

2011 was a very hot, dry year for Sedona. For the month of August a new record was set for average daily temperature of 83 degrees Farenheit. Perhaps the heat affected the formation of monsoon storms, since there were few that resulted in stormflow during July and August. Figures 14 and 15 show the rainfall record and hydrograph for the Oak Creek near Sedona gage. The first 2 storms of the season caused stormwater flow in the washes and increased streamflow of Oak Creek slightly, but we were not able to grab samples because our volunteer sampling team was not yet organized. Never-the-less the 3rd storm on August 1st which we captured appears to have been the "first flush" of the watersheds with sufficient flow to move fecal material from the uplands.

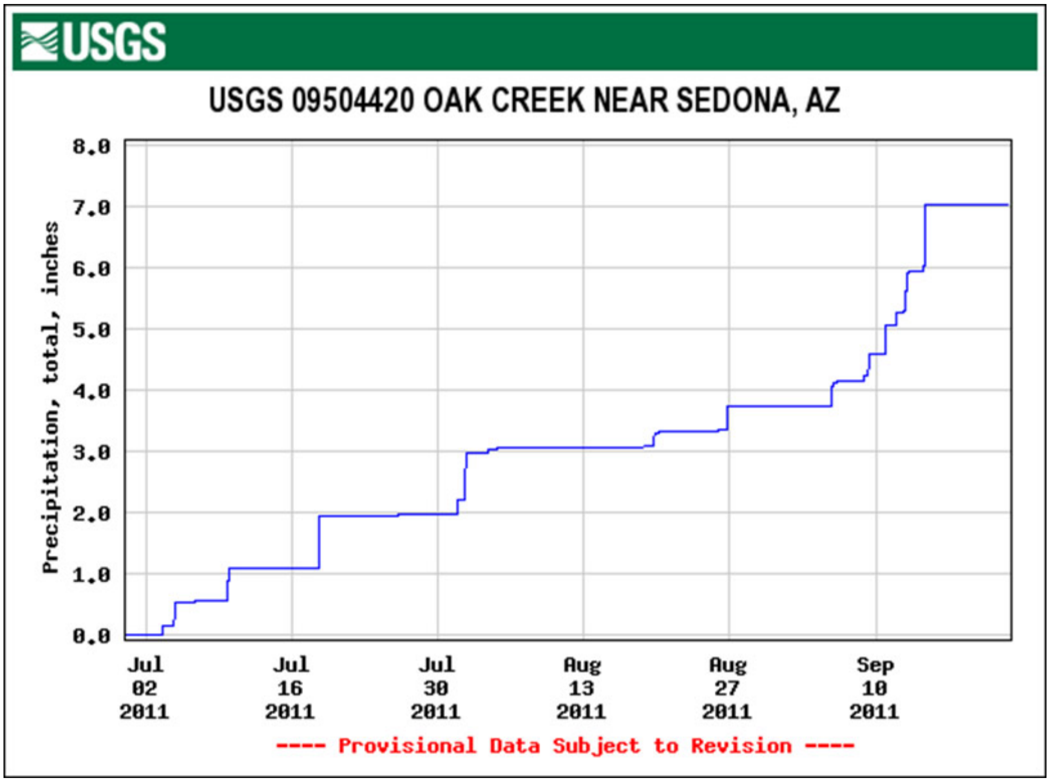

Figure 14. Rainfall July 1 through September 22, 2011 at Oak Creek near Sedona, USGS gage no. 09504420

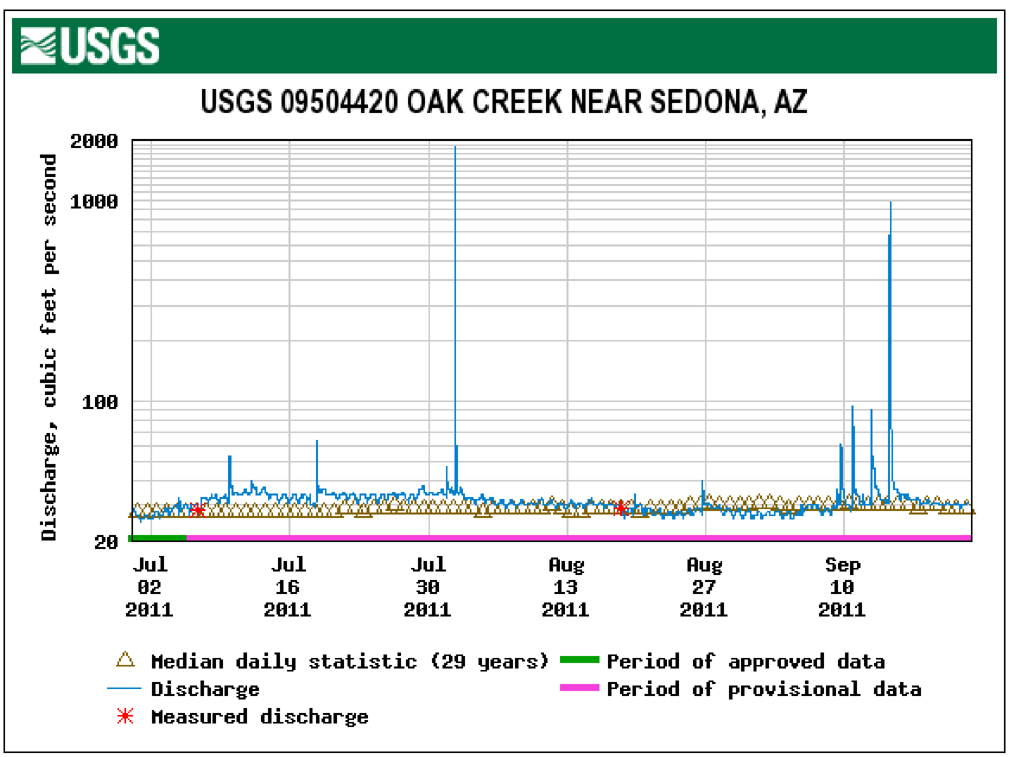

Figure 15. Rainfall July 1 through September 22, 2011 at Oak Creek near Sedona, USGS gage no. 09504420

Stormwater in the Sedona area was sampled on three occasions and found to have very high concentrations of *E. coli*. Sedona washes sampled August 1st had *E. coli* concentrations ranging from 110.3 to >2419.2 cfu/100 ml with an average >879.3 cfu/100 ml. On 9/6/11, with the exception of Jordan Pump (172 cfu/100 ml), all pools in Sedona washes sampled the morning following a storm showed had >2419.2 cfu/100 ml *E. coli*. Dilutions of 9/11/11 samples collected from pools the morning following a storm event were tested for *E. coli* and showed that concentrations in Sedona's stormwater ranged from 1,563.1 to >8,200.7 cfu/100 ml. Sedona's urban runoff is a huge episodic contributor of *E. coli* to Oak Creek. This is evidenced by the high *E. coli* concentrations in stormwater draining from urban areas (>2,157.5 cfu/100 ml average) contrasted with concentrations in Oak Creek upstream of Sedona following storm events (143.1 cfu/100 ml). A concerted effort should be made within Sedona to identify stormwater pollution sources and ameliorate them. OCWC will need to work closely with the City of Sedona, Coconino National Forest and other interested parties to address this concern. A pilot program survey and cleanup of dog and human feces at the urban/recreation interface may assist in affecting a change in habits of hikers in these areas.

Oak Creek was sampled throughout its length on August 2nd to see how stormwater flow impacted the creek. Although the whole watershed received considerable rainfall on August 1st (City of Sedona Engineer Charles Mosley described the 1+ inches of rainfall in Sedona as a 10- to 50-year event), the average *E. coli* concentration the following day upstream of Sedona was only slightly higher than background (28.9 cfu/100ml versus the 10.5 cfu/100ml baseline average for Oak Creek Canyon), while concentrations in Sedona downstream to Page Springs were extremely high (1,733 cfu/100ml to >2,419 cfu/100ml) compared with average background (47.1 cfu/100 ml for this reach). Curiously, the *E. coli* concentration at Cornville Estates (86.5 cfu/100 ml) were comparatively not much higher than previous concentrations (37 and 13.4 cfu/100 ml), leading to the conclusion that the bulk of the *E. coli* pulse from the August 1st event took longer than 19 hours to arrive downstream at Cornville. This type of delay may be useful for warning recreationalists via radio public service announcements to avoid swimming in Oak Creek when water is turbid following storm events, since *E. coli* levels are likely to be high. OCWC could work with Yavapai County Flood Control District, who provides flood warning, to develop a water quality warning system.

Social Survey Findings

On February 9, 2012 the Oak Creek Watershed Council mailed 1,224 social surveys to randomly selected residences in the Oak Creek watershed. The purpose of this survey was to ascertain resident's knowledge, understanding, attitudes and behaviors with regards to fecal contamination of Oak Creek to inform priorities for the education and outreach programs. The survey recipients represented a 10% random sample of residential property owners, using parcel data provided by Coconino and Yavapai Counties. From 14,802 properties OCWC subtracted those properties with out of state mailing addresses and obvious nonresidential properties (commercial, government, school, church, etc.) for a final "population" of 12, 241 residences. The 10% sample was selected by numbering each entry, generating 1,224 random numbers from 1 to

12,241 and selecting the properties with those numbers. On March 20, 2012 OCWC ended receipt of the surveys and entered response data in a spreadsheet. There were 265 replies or 21.6% of those sent out, which is generally considered a good response rate for a mail survey, meaning that the sample results are representative of the attitudes of the residential population as a whole.

The mailed social survey included a one-page introductory letter and a two-sided page with multiple choice questions on which respondents checked boxes, wrote comments, folded, taped or stapled, and mailed back to OCWC using postage that was pre-affixed. The survey was publically announced in the local newpaper and on a local radio station about one week prior to it being sent out. The social survey and its results may be found in Appendix B. Insights from the survey are presented below.

Highlights of the results from Questions 1 – 14, regarding knowledge, perceptions, behaviors and demographics, include the following through direct answers and extrapolation:

- 95% of property owners have some concern about the health of the Oak Creek Watershed.
- On average each property owner visits/recreates along the Creek between 7 and 10 times per year.
- Hiking is almost 3 times as popular an activity as swimming.
- Personal observation & the newspaper were the choice of 74% as sources of information.
- Human feces, litter, baby diapers & septic systems were thought to be biggest contributors to creek contamination.
- Half of watershed property owners have pets & 90% of the pets go outside.
- 90% of watershed property owners with pets clean their yard of pet waste.
- 45% own a dog therefore there are at least 5400 dogs in the watershed.
- 45% of those who own a dog walk it (them) in the watershed, extrapolating to almost 2500 dogs walked in the watershed annually.
- 64% of dog owners who walk their dog(s) always pick up their dog's waste. Approximate quantification of dog feces left behind in the watershed is around 500 feces per day, just from dogs owned by residents of the watershed, not counting dogs of visitors. Each gram of dog feces has 20 million *E. coli* bacteria colonies in it.
- 95% of dog owners who pick up the feces throw them into the trash.
- 89% of dog owners would use dog waste stations if provided.
- 93% of respondents were over 45 years old, and 47% were over 65 years old.
- 80% have 1 or 2 people living in the household
- For 62% there property in the watershed is their primary home.

Question 15 on the second page of the Survey had multiple choice answers to several questions regarding how much the respondents think various potential pollution sources threaten Oak Creek's water quality, with the choices being, "not sure", "not a problem", "slight problem" "moderate problem" and "large problem". Percentages below are for responses that included some concern about the problem (slight problem, moderate problem and large problem):

- Responses to recreation problems were the most significant of all categories. Respondents ranked recreation threats to Oak Creek in this order:

  - Trash 84%
  - Lack of public toilets 79%
  - Lack of trash receptacles 79%
  - Baby diapers 75%
  - Human feces 67%
- There seems to be a consistency in these answers to those in Question 6 regarding which sources respondents thought were the biggest contributors to creek contamination that can cause human illness.
- 69% believe that dog feces are a problem to some degree, and 48% wildlife feces.
- Almost 2/3 thought that wildlife attracted to water by human food waste threatens the water quality of Oak Creek.
- More than twice as many people thought Jeep/ORV trails cause erosion and sedimentation which affects water quality of Oak Creek than any other reason.
- 60% thought there was some problem with stormwater runoff: lawn fertilizers & pesticides 71%, pet feces in yards 66%.
- For wastewater, respondents saw the following threats: residential septic systems 68%, and commercial septic systems, 66%, inadequately maintained sewer system 62%.
- 54% saw disturbance of sediment as a threat.
- 51% felt lack of riparian buffers was a threat.

Potential Future Projects

Based on the findings of the field investigation, especially where we found elevated *E. coli* concentrations, *E. coli* exceeding the water quality standard, and evidence of human sources or *E. coli* (eg. human DNA indicating possible septic contamination of springs), we developed 15 potential Best Management Practices projects to address contamination. Tables 12 and 13 outline these projects. Appendix C provides complete project descriptions and may be used as guide for project planning. The projects in Table 12 are the highest priority projects, based on based on findings from previous studies and our data collection and analysis. Table 13 outlines a second tier of projects that are based on inference through observation and some data collection, but more data is needed to confirm the project need and/or direction. The subject areas are in order of priority. Within each subject the projects are in order of priority based on current and previous findings.

Project prioritization was developed by the principal investigator with advice and approval from the Oak Creek Watershed Improvement Commission. Outreach projects were given the highest priority, because reducing *E. coli* contamination in Oak Creek relies largely on changes in human behavior that will hopefully follow outreach and education. Also, every project has an outreach component, all of which will be coordinated under the umbrella of the Oak Creek Community Outreach Program (OCCOP), which will appeal to various audiences – residents, visitors, hikers, pet owners, jeep users, swimmers, fishermen, commercial property owners, farmers, livestock owners, etc. Within the outreach category, the highest priority projects are those that address critical pollution pathways as identified through observation, past research, and 2011 data collection and analysis.

Commercial septic system issues are the second priority after education and outreach, because there are a number of commercial septic systems that appear to be exceeding their capacity and causing septic effluent to be intercepted by springs that deliver elevated *E. coli* and human DNA to Oak Creek. Effluent mounding during high use periods in the summer may be responsible for this effect. Although the indicator *E. coli* was not always very high in spring discharge, it was often elevated above typical spring levels and the presence of human DNA is of concern, since septic effluent can deliver other pathogens (such as viruses) in which the human DNA is detected. The potential for human health risk to recreators in Oak Creek due to septic discharge makes the commercial septic system project a high priority. Working collaboratively with commercial property owners to evaluate and address this situation is vital. Because there is a less certain connection between residential septic systems and spring contamination, and because the loading from individual systems is small, a project to address residential septic systems is relegated to Tier 2 as displayed in Table 13.

Stormwater issues are the third priority category. Tremendous amounts of sediment and *E. coli* were detected in stormwater in Sedona's washes, and *E. coli* concentrations in Oak Creek indicate the Sedona washes are probably the biggest sources of sediment and *E. coli* to the creek during storm events. To what extent these pollutants arise due to natural geology and wildlife fecal sources or are due to recreational activities and the feces of pets and humans is uncertain. Observation of heavy deposits of dog feces along trails in and around Sedona suggests that pet feces are a significant source, but DNA testing of stormflow was inconclusive, probably due to lack of sensitivity of the test or due to sampling or analysis error, since all test results were negative. The projects in this category are aimed at continued and expanded monitoring of *E. coli*, human DNA, erosion and sedimentation in the catchment areas of Sedona's washes both in and outside city limits. Monitoring findings will guide focused efforts to decrease *E. coli* and sediment sources. Working with neighborhood groups such as the Elf Neighborhood Association, will help facilitate community involvement and proactive solutions. Physical improvements will include erosion control work, and the installation and maintenance of dog waste stations to the extent that funding allows. Partners will work together with the U.S. Forest Service to seek permits and cooperative agreements for these activities.

Recreation is a major activity in the watershed and a potential source of water pollution. This has been evidenced by the cleanup days where volunteers have picked up huge amounts of litter (which may draw scavenging wildlife to the creek and often includes used baby diapers) and observed prodigious dog waste. Projects in the recreation category will address tangible infrastructure needed to facilitate changes in human behavior that can improve water quality. The placement of toilets, trash receptacles, and signage will aid visitors in keeping Oak Creek beautiful and reduce fecal matter in Oak Creek. Also, evaluating the impact of specific recreation activities is needed, such as erosion along jeep trails or social trails to the creek.

Second tier projects include those that would benefit from further data collection and analysis to support the project need and to focus the activities. Outreach related to stormwater can be informed by results from additional stormwater monitoring described above. Outreach related to animal waste dumping from farmlands in the lower watershed may be informed by a survey of current animal waste management practices that was outside the scope of the 2011 investigation. Projects to address erosion in the lower watershed due to road crossings and irrigation diversion structures also require inventory of such sites to determine the extent of the problem, before developing workable solutions.

Table 12. Oak Creek WIP top priority project recommendations.

The need for these projects is supported by finding from this and/or previous investigations as well as observations.

Project Number	Reach	Findings	Recommendations	Potential Collaborators
		Education and Outreach		
EO-2	Oak Creek Canyon	High recreation use of Oak Creek Canyon in the Summer contributes to *E. coli* contamination through several pathways: 1. dog feces, 2. used baby diapers, 3. human feces, 4. food waste that attract wildlife that defecates near the stream, 5. soil disturbance and erosion that contributes sediment to *E. coli* sediment reservoirs, and 6. disturbance of sediment reservoirs by swimmers and waders causing *E. coli* to enter the water column.	Conduct a pre-summer and early summer media campaign that is tiered to both residents and visitors with a public health awareness focus that includes public service announcements, kiosks, and volunteer contact with recreators at campground and day use areas to get the message out. The message should include health effects of fecal contamination, symptoms of infection due to fecal contamination, pictures of dirty diapers in the woods and blown up pictures of the germs that cause illness. Involve local businesses in an incentives/reward programs such as free frozen yogurt certificates or Red Rock day passes that volunteers hand out to visitors who pick up dog waste.	Coconino County Health Department, OCWC
EO-5	Throughout the watershed	Recreators often do not grasp the consequences of their actions. Even one fece (dog, diaper or dump) can cause contamination of Oak Creek.	Conduct a public outreach program to get the "Even one" message across that even one deposit of human or pet feces can cause contamination that threatens human health.	Coconino and Yavapai County Health Departments, OCWC
EO-6	Throughout the watershed	An umbrella outreach coordination is needed	Oak Creek Community Outreach Program (OCCOP)	OCWC, Verde River Basin Partnership?

Septic System Issues				
SS-1	Oak Creek Canyon and Page Springs commercial sites	Some commercial property owners are resistant to water quality monitoring, but anecdotal evidence as well as *E. coli* testing and human DNA analysis results point to possible contamination from commercial septic systems. Because these systems have large loads, mounding is possible that increases the potential for septic effluent to be intercepted by springs and carried to the creek.	Use soil surveys and county environmental health records for septic system installation to identify areas of high potential for septic leakage to groundwater. Consider use of fluorescent dye or other tracers to identify effluent migration to Oak Creek. Monitor the spring channels downstream of commercial septic systems. Work along with county environmental health departments to build a collaborative relationship with property owners. Provide incentives to improve septic system.	Coconino and Yavapai County Health Departments, OCWC
Stormwater Issues				
SW-1	Sedona as a whole	Washes deliver considerable *E. coli* and sediment to Oak Creek during storm events, which raise *E. coli* levels in Oak Creek and provide source materials for sediment reservoirs of *E. coli* that contribute to later exceedances during storm events or recreation when sediment reservoirs are disturbed. Along with *E. coli* a tremendous amount of sediment is discharged from Carroll Canyon during storm events. This sediment adds to *E. coli* sediment reservoirs in Oak Creek that, when disturbed, are a leading cause of *E. coli* exceedances in the water column.	Establish a monitoring program in city washes for *E. coli* and sediment. Conduct DNA testing to determine what portion of *E. coli* is from humans, dogs and wildlife or livestock as a baseline and repeat sampling after BMPs are in place to see if they are effective at reducing *E. coli*. Test sewer system for leaks at wash crossings and repair any leaks. Establish and maintain dog waste stations. Conduct outreach program. Evaluate erosion problems in the Carroll Canyon watershed through field surveys and modeling to identify critical sites. Implement best management practices to reduce erosion on both private and public lands. These may include riparian area protection, improved rangeland health, and corral maintenance.	City of Sedona, Yavapai County Health Department, ADEQ Stormwater & General Permits Unit, OCWC, Coconino National Forest, Little Elf Neighborhood Group

Recreation Issues				
RC-1	Oak Creek Canyon	There is a shortage of public restrooms in the canyon, especially access that does not require a Red Rock Pass, since many people will park along the highway and hike into the creek rather than pay the fee.	Establish restrooms at intervals that will help ensure the public accesses them rather than defecating near the stream. Post signs along the highway indicating public restrooms. Establish collaborative agreements and funding to maintain restrooms. This is a high priority, which was identified in the past and has not had enough action.	Coconino National Forest, business owners, ADOT, OCWC
RC-3	Oak Creek Canyon and national forest access adjacent to Oak Creek in Sedona	Trash receptacles are lacking, leading visitors to litter including used diapers that contribute to *E. coli* pollution and food waste that attracts wildlife whose feces add to *E. coli* in the creek.	Place trash receptacles at convenient locations. Work out collaborative agreements and funding to maintain trash receptacles.	Coconino National Forest, business owners, Arizona State Parks, OCWC

Table 13. Oak Creek WIP second tier project recommendations.

These projects are supported by some findings of the current and/or past investigations, but more data collection and analysis are needed to determine the scope of these projects and priority locations.

Project Number	Reach	Findings	Recommendations	Potential Collaborators
		Education and Outreach		
EO-1	Sedona	Stormflow events in Sedona deliver large doses of *E. coli* to Oak Creek. Much of this *E. coli* may come from pet feces, since there are many pet owners and a great deal of dog-walking in these watersheds. Dog owners need to know the seriousness of leaving dog waste along trails and in yards where it can wash into tributaries of Oak Creek during storms. The need to be encouraged to pick up and properly dispose of dog feces.	Implement an outreach program that includes radio and newspaper stories, public service announcements, and presentations to civic groups. Use brief messages that get across 4 points: 1. the danger of *E. coli* and health effects on children, 2. causes of *E. coli* contamination, 3. how to change behaviors that cause *E. coli* contamination, 4. "Deputizing the World", i.e. encouraging residents to speak up when they see others leaving dog waste unattended.	City of Sedona, Yavapai County Health Department, OCWC
EO-3	Page Springs and Cornville	Dumping of animal waste into ditches or the creek may be increasing *E. coli.* Annual reconstruction of irrigation diversion dams may cause sediment deposition that contributes to *E. coli* sediment reservoirs.	Educate land owners about the impacts of animal waste dumping and provide technical assistance for implementing best management practices for animal waste management. Work with RV park owners to inform customers of the health effects of dumping waste and assure that they know where to properly dispose of waste according to pertinent waste management ordinances. Provide assistance with design, permitting, finances and construction for hardened irrigation diversion structures that will simultaneously reduce annual streambed disturbance and maintenance efforts by water users.	Cooperative Extension Service, Yavapai County Health Department, OCWC

EO-4	Throughout watershed	RV owners may be dumping "black water" an/or gray water into ditches or the creek, based on past observations and sewage odor observed near a creek-side RV park.	Work with RV park owners and the Forest Service to inform campers of the health effects of dumping waste and assure that they know where to properly dispose of waste. Evaluate the spacing and availability of waste dumping stations and determine if more stations or improved information about stations is needed. Provide information on website and pamphlets for distribution.	RV park owners and managers, Coconino National Forest, Arizona State Parks, OCWC
		Septic System Issues		
SS-2	Oak Creek Canyon residential sites	Two springs we tested appeared to indicate that residential septic systems contributed 0 to 202.5 (average = 42.7) cfu/100 ml *E. coli* at various times to Oak Creek by way of spring discharge. Although not exceeding the FBC standard, these supplies of *E. coli* during the summer months might inoculate sediment reservoirs that are later disturbed by recreation or storm events to cause exceedances of *E. coli* in the water column.	Continue to monitor springs that have shown elevated *E. coli* or/or DNA indication of septic influence. Using higher-density *E. coli* sampling of creek water and sediment in areas with springs and septic systems, identify neighborhoods where septic effluent interception by springs may be an issue and use targeted sampling to zoom in on possible sources. Conduct tracer dye or other tracer studies as practical to pinpoint improperly functioning septic systems. Establish an incentive program to upgrade septic systems where needed. Complete a hydrogeologic characterization by of springs in the vicinity of residential and commercial septic systems.	Coconino County Health Department, volunteer scientists, Northern Arizona University, neighborhood groups, OCWC

Recreation Issues				
RC-2	Slide Rock and Oak Creek Canyon	Past studies have noted that sediment reservoirs of *E. coli* build up at Slide Rock throughout the summer. This may be in part due to soil disturbance from people hiking into the park from upstream.	Evaluate erosion problems upstream of Slide Rock S.P., within the park, and throughout Oak Creek Canyon. Implement best management practices to reduce erosion. Post signs regarding importance of avoiding erosion to reduce *E. coli* problems that can close the park and/or contribute to illness.	Slide Rock State Park, Coconino County Rural Environmental Corp., Coconino National Forest, OCWC
RC-4	Throughout the watershed	Dog feces contribute to *E. coli* contamination.	Establish dog waste stations at ALL trailheads within 3 miles of Oak Creek. Conduct a public outreach program to encourage social pressure to pick up dog waste. Work collaboratively to secure funding for establishment and maintenance of dog waste stations.	Arizona State Parks, City of Sedona, Coconino National Forest, OCWC
Agricultural Issues				
AG-1	Throughout the watershed but especially downstream from Chavez Crossing.	Some livestock owners have reportedly dumped animal waste into irrigation ditches or Oak Creek. Also, a horse rehabilitation center uses as large pond adjacent to Oak Creek for physical therapy. Method of disposal of waste from this pond is unknown.	The location of all livestock owners should be determined and a focused outreach effort made to educate livestock owners on the water quality impacts of dumping animal waste into water. Distributed information should include local ordinances regulating setbacks from water for animal waste. A manure management brochure developed by Prescott Creeks may be modified for Oak Creek. Assistance should be provided to implement best management practices alternatives to dumping.	Cooperative Extension Service, livestock organizations in the watershed, OCWC

AG-2	Throughout the watershed but especially downstream from Chavez Crossing.	Annual earth moving activities to build or restore irrigation diversion structures may be introducing large quantities of sediment to creek and contributing to *E. coli* sediment reservoirs. Also, if irrigation tailwater is entering ditches, it may deliver sediment and/or *E. coli* to the creek.	Map all irrigation diversions and ditches. Have volunteers float/wade the creek with a GPS unit, camera, and notebook to inventory irrigation infrastructure. Engage local ditch associations. Identify problem areas and provide incentives to implement best management practices.	Cooperative Extension, ditch associations, Yavapai County GIS, ADWR, OCWC
AG-3	Cornville area	Reportedly there is a least one low water ford across Oak Creek downstream of Cornville that may be contributing sediment to the creek.	Investigate and map all fords, especially those that are not cement fords (can be combined with mapping effort above). Work collaboratively with property owners to explore implementation of improvements to reduce sediment inputs.	Yavapai County GIS, property owners, OCWC

Chapter 3 – Watershed Improvement Strategy

Best Management Practices Projects

As the result of the field investigation, social survey and review of past studies, OCWC is proposing 15 projects to reduce sources of *E. coli* and related fecal contamination in Oak Creek. These projects are outlined in detail in Appendix B. The project descriptions are intended to serve as a foundation for future funding proposals and project work plans. Table 14 provides the titles of the 15 projects. They are arranged by topic in order of priority, ie. Education and Outreach is the highest priority. The topics include Education and Outreach, Septic Systems, Stormwater, Recreation, and Agriculture. Priority ranking is based on knowledge from investigation results, past studies, observation, and anecdotal evidence. These priority rankings are subject to change following further review by the OCWC and OCWIC.

Table 14. Oak Creek WIP proposed BMP projects in order of priority

Project ID	**Project Name**
Top Priority Projects	
EO-2	Oak Creek Canyon Public Outreach Program
EO-5	"Even One" *E. Coli* Outreach Project
EO-6	Oak Creek Community Outreach Program (OCCOP)
SS-1	Oak Creek Commercial Septic System Improvement Incentive Project
SW-1	Sedona Area Stormwater Improvement Project
RC-1	Oak Creek Canyon Public Toilet Access Project
RC-3	Keeping Oak Creek Beautiful – Trash Receptacle Access Project
Second Tier Projects	
EO-1	Sedona Dog Waste Reduction Outreach Project
EO-3	Lower Oak Creek Watershed Outreach Project
EO-4	Recreational Vehicle Proper Waste Disposal Outreach Project
SS-2	Oak Creek Residential Septic System Improvement Project
RC-2	Oak Creek Canyon Sediment Source Reduction Project
RC-4	Oak Creek Watershed Dog Waste Station Installation Project
AG-1	Animal Waste BMPs for Oak Creek Watershed
AG-2	Oak Creek Irrigation Diversion Erosion Reduction Project
AG-3	Lower Oak Creek Erosion Reduction Project

Load Reduction

Through the implementation of Best Management Practices, over the course of several years, *E. coli* loading in Oak Creek may be expected to decrease considerably and the incidence of WQS exceedances should also decrease. However, evidence shows that it unlikely that exceedances can be completely eliminated, because storm events deliver large loads of *E. coli* to Oak Creek, much of which comes from wildlife sources. This loading, along with turbulent resuspension of *E. coli* from sediment reservoirs, causes *E. coli* counts in Oak Creek that far exceed the water quality standard but attenuate to background levels over 2 to 3 days following the storm event.

The University of Arizona estimated load reductions for each of the BMP projects using modeling techniques, pollutant loading values from the literature, and Oak Creek monitoring data. Table 15 is a summary of the estimated pollutant load reductions. The BMP project descriptions include explanations of UA's methods and findings.

Table 15. Pollution load reduction estimations for each Oak Creek BMP project

Project #	Project Title	Estimated Load Reduction	source
EO-1	Sedona Dog Waste Reduction Outreach Project	5.1×10^{13} CFU *E. coli* bacteria/year	dog feces
EO-2	Oak Creek Canyon Public Outreach Program	5.6×10^{12} CFU *E. coli* bacteria/year	human feces
		3×10^{10} CFU *E. coli* bacteria/year	diapers
		5.1×10^{13} CFU *E. coli* bacteria/year	dog feces
		7.02 tons of sediment/year	erosion
EO-3	Lower Oak Creek Watershed Outreach Project – Animal Waste Dumping	5.1×10^{11} CFU *E. coli* bacteria/year	horse feces
		9.7×10^{12} CFU *E. coli* bacteria/year	cow feces
EO-4	Recreational Vehicle Proper Waste Disposal Outreach Project	8.7×10^{11} CFU *E. coli* bacteria/year	human feces
EO-5	"Even One" *E. Coli* Outreach Project	5.6×10^{12} CFU *E. coli* bacteria/year	human feces
SS-1	Oak Creek Commercial Septic System Improvement Incentive Project	77.9 tons sediment/year	septics
		3,506.5 lbs nitrogen/year	septics
		601.6 lbs phosphorus/year	septics
SS-2	Oak Creek Residential Septic System Improvement Project	77.9 tons sediment/year	septics
		3,506.5 lbs nitrogen/year	septics
		601.6 lbs phosphorus/year	septics
SW-1	Sedona Area Stormwater Improvement Project	17×10^{12} CFU *E. coli* bacteria/year	dog feces
		4.75×10^{10} CFU *E. coli* bacteria/year	human feces
RC-1	Oak Creek Canyon Public Toilet Access Project	5.6×10^{12} CFU *E. coli* bacteria/year	human feces

RC-2	Oak Creek Canyon Sediment Source Reduction Project	7.02 tons per year	erosion
RC-3	Keeping Oak Creek Beautiful – Trash Receptacle Access Project	3 x 10^{10} CFU *E. coli* bacteria/year	diapers
RC-4	Oak Creek Watershed Dog Waste Station Installation Project	5.1 x 10^{13} CFU *E. coli* bacteria/year	dog feces
AG-1	Animal Waste BMPs for Oak Creek Watershed	5.1 x 10^{11} CFU *E. coli* bacteria/year	horse feces
		9.7 x 10^{12} CFU *E. coli* bacteria/year	cow feces
AG-2	Oak Creek Irrigation Diversion Erosion Reduction Project	10.2 tons sediment/year	erosion
		267.6 lbs nitrogen/year	
		30.2 lbs phosphorus/year	
AG-3	Lower Oak Creek Erosion Reduction Project	none; This project would provide information for development of future BMPs	

Reducing loads to meet standards is one of the objectives of the WIP. Reducing loads to meet standards necessarily entails eliminating human-related sources as much as possible to try to meet the TMDL reduction recommendation. Because eliminating all human sources would be extremely challenging, priorities should be set to reduce those sources that most affect *E. coli* exceedances during the summer months when there is high level of human contact with Oak Creek water. It is the finding of the OCWC that the greatest effort should be spent where the greatest opportunity exists to reduce human contact with pathogens, in other words where the greatest concentration of recreational water use occurs, with the acknowledgement that recreation in Oak Creek occurs throughout its entire length.

All of the proposed projects provide needed *E. coli* load reduction, but the largest reductions would most likely come from identifying sediment and *E. coli* sources in tributary wash watersheds in and around Sedona. Also the Oak Creek Canyon Public Toilet Campaign and the Commercial Septic System Improvement Demonstration Program would be important. Some reduction would occur immediately upon implementation, but total reduction is not likely to occur until there is comprehensive control of nonpoint source fecal pollution in the Oak Creek Watershed.

Cost-effectiveness comparison

Although an in-depth cost analysis was not completed for this report, generally the education and outreach projects are probably the most cost effective, since change in human behavior is necessary to reduce fecal contamination in Oak Creek. Also, outreach does not require permitting or pose technical challenges for the most part. Projects that physically support behavior changes, such as installation and maintenance of public toilets, trash receptacles and dog waste stations, are all expected to be cost effective in addressing pollution. Mitigation measures for septic systems may be very expensive, but should not be ruled out, since where needed these projects could have a significant effect on human health. Projects for some of the agricultural impacts in the lower watershed were ranked lower because the causation is not as directly attributable, fewer recreators may be impacted, and the cost in time and effort to address these concerns is considerable for an uncertain outcome.

Other resources and barriers considered

Several funding opportunities and potential collaborations exist to support proposed projects, including:

- Arizona Community Foundation
- Arizona Department of Environmental Quality
- Arizona Department of Water Resources/Arizona Water Protection Fund
- Arizona Public Service
- Bureau of Land Management
- Bureau of Reclamation
- Coconino County
- Coconino National Forest
- Clean Water Act Section 319(h) grants
- City of Sedona
- EQIP
- Kling Family Foundation
- Nina Mason Pulliam Charitable Trust
- National Science Foundation research grant related to *E. coli* in sediments
- Red Rock State Park
- Salt River Project
- Sedona Community Foundation
- Sedona New Frontiers
- Slide Rock State Park
- Udall Foundation
- United States Environmental Protection Agency
- Yavapai County
- The Walton Family Foundation
- Watershed Management Group
- WIFA

Land owners' desire and commitment to maintain improvements are important for project success. Considerations include the following:

- Agricultural land owners need to be engaged.
- Firm commitments are needed for maintaining dog waste collection stations.
- Septic system owners need to be approached in a non-threatening way, encourage collaboration and provide assistance.
- City of Sedona continued commitment to stormwater monitoring and public outreach.
- Elf Neighborhood desires to resolve flooding problems that may impact water quality

The Oak Creek Watershed is fortunate to have technical support available from several sources. Technical support may involve loaning monitoring equipment, providing technical advice, reviewing documents and outreach materials, providing student workers for assessment tasks, sharing historic data, providing technical expertise, collaborating on funding proposals, assisting with permitting processes, contributing to any needed environmental assessments prior to project implementation, entering into cost share agreements, and linking project activities to larger regional water management objectives. Sources of technical support may include:

- ADEQ
- City of Sedona
- Arizona State Parks
- Northern Arizona University
- University of Arizona
- OCWC volunteer experts
- The Nature Conservancy
- Sierra Club
- Verde Watershed Association
- Yavapai County Water Advisory Committee
- Coconino National Forest
- Bureau of Reclamation
- ADWR

Training and educational support available from:

- Northern Arizona University
- University of Arizona, Cooperative Extension Service
- NEMO
- OCWC volunteer experts

Several organizations may provide community involvement in implementation and maintenance, including:

- Home Owners Associations
- Friends of the Forest
- OCWC
- Master Watershed Stewards
- Spring Stewards

Some potential barriers to implementation include the following

- Absentee landowners
- It could be difficult to reach recreation users with information during the brief window they are in the watershed.

Other Recommendations

Water Quality Monitoring

Oak Creek Watershed Council should continue to monitor water quality in Oak Creek and perhaps enter into a collaborative relationship with Friends of the Forest who does regular *E. coli* monitoring. Beyond water quality monitoring, systematic testing of Oak Creek sediment should be conducted to see were *E. coli* sediment reservoir hot spots exists and to try to trace upgradient sources of *E. coli*. Coordinated sampling at various points along Sedona washes would be very beneficial to locate source areas of *E. coli* that is washed into Oak Creek during storm events. Turbidity testing may be another very useful way to locate erosion problems and sediment sources that contribute to *E. coli* sediment reservoirs.

Scientific investigations

Since Crabill published his results in 1999, we have known that a primary mode of *E. coli* contamination in Oak Creek is disturbance of *E. coli* sediment reservoirs by recreation or storm events. Southam (2000) repeated this finding and urged further investigation of Oak Creek sediment. Yet, only limited sediment testing (by ADEQ in 2004 and 2005) has been conducted in the past 12 years, and the methods and results differed from Southam's, so a both methods should be employed simultaneously to test the efficacy of each for monitoring *E. coli* sediment reservoirs. Also, testing of sediment up- and downstream of suspected *E. coli* sources should be done to determine the extent to which sources may "charge" reservoirs with bacteria. While many of the efforts to reduce *E. coli* have been well intentioned, none have proven effective. BMPs are not likely to be fully effective until sediment reservoir hot spots are identified and the *E. coli* stored in these reservoirs is traced back to its source. If Oak Creek contains more fine sediment than would naturally occur without human activity in the watershed, then identification of priority sediment reduction projects is in order. A geomorphic study of the bedload and bank deposits may be able to determine if sediment load in Oak Creek has changed over the past approximately 140 years since settlement by non-Indians. Forest restoration work in the upper watershed over the next 10 to 20 years is likely to generate additional sediment. Working with the Coconino National Forest, sediment and dissolved organic carbon discharge from the upper watershed should be monitored both because of potential to generate *E. coli* sediment reservoir and because of potential impacts on aquatic life.

The very obvious loading of *E. coli* into Oak Creek from washes in the Sedona area begs for a study of the washes in and around Sedona. Perhaps, as a City of Sedona's engineer asserts, a concentration of wildlife around the perimeter of Sedona is the primary source of *E. coli*. Or perhaps pet waste and human waste are also significant sources. Human DNA appeared in only 1 of 4 stormwater DNA samples (Carroll Canyon), but it was a strong positive (3 of 3). Dog DNA was negative in all 4 stormwater samples and 2 stormflow creek samples, which seem to be erroneous results due to a fairly high detection limit or perhaps degraded sample, since Southam's results regularly showed dog DNA is Oak Creek. A stratified stormwater sampling scheme should be devised with 1. high density *E. coli* and DNA sampling, 2. follow-up DNA testing where *E. coli* levels are high, and 3. systematic isolation of areas that appear as sources of *E. coli*, especially from human and dogs. This would require a high level of coordination and sufficient volunteer or paid personnel to accomplish, because storm events that produce stormwater flow are infrequent and unpredictable. Alternatively, automated samplers with cooling systems to preserve samples and cellular text messaging to alert investigators that a sample is available for pickup could be used, but such systems are expensive. In either case, ground surveys of fecal matter should be conducted throughout the tributary wash watersheds to determine where there are concentrations of human, pet or wildlife feces that may contribute to *E. coli* loading. Plots may be established along transects and feces found within a plot would be tossed outside the plot so that on subsequent outings only new feces are counted, to obtain an estimate of the human, pet or wildlife defecation rates in the area.

NPDES and MS4 Compliance Monitoring

Although tracking water discharge permits in the watershed would not necessarily rise to the level of a project, some sort of communication is needed between watershed advocates and the NPDES and MS4 Permit Units of ADEQ to see if resources can be pooled to facilitate regular compliance monitoring of wastewater treatment systems and stormwater systems in the watershed. These systems are self-monitoring and there is little independent monitoring of downstream water quality. Ongoing monitoring of *E. coli* concentrations in Oak Creek might be useful to identify wastewater discharges of concern. Discharge Monitoring Reports for the Sedona Ventures WWTP that discharges to Dry Creek and Pinewood Sanitary District that discharge to Munds Creek were viewed at ADEQ. No exceedances were found in Sedona Ventures records and in fact discharge effects flow down Dry Creek that reaches Oak Creek. Pinewood Sanitary District (Pinewood) reported one exceedance during January of 2011. During the period 2005-2011, Pinewood listed several emergency discharges, which are allowed under their permit (with monitoring) to avoid pond levels becoming too high on their dam. The most reasonable monitoring would be to keep tabs on when Munds Creek flows in the spring or during monsoon season and sample flow to see if any *E. coli* may be coming down from Munds Park.

Conclusion

The same actions recommended in 1999 by ADEQ's first TMDL report and by Southam in 2000 (see Chapter 1) are needed yet today to reduce *E. coli* and related fecal contamination in Oak Creek. Some have been implemented on a limited basis, but a more comprehensive effort is needed to educate the public and provide the means for healthy behaviors (eg. dog waste collection stations and adequate toilet access). The fact that our findings echo those of previous studies that were completed more than 10 years ago underscores the importance of translating science to the public through effective public outreach efforts. Science is not meant to sit on a shelf moldering in a forgotten professional journal or agency report. Scientific findings must be transformed into public knowledge that has the power to affect human behavior to improve the environment. That is why 5 out of 15 of the proposed projects are education and outreach projects, and the remaining 10 projects each have a key education and outreach element, all of which would fall under the umbrella of the Oak Creek Community Outreach Program (OCCOP). Although actions of the Oak Creek Watershed Council (previously Oak Creek Canyon Task Force), ADEQ, Coconino National Forest, Slide Rock State Park and others have tried to reduce *E. coli*, records of *E. coli* exceedances at SRSP show no trend in either frequency or severity. This lack of response may be because some key science-based recommendations of the past have not been acted upon. Our hope is that this WIP and the projects created from it will remedy this situation.

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Appendices

Appendix A. Oak Creek W.I.P. watershed investigation data

Appendix B. Oak Creek watershed social survey results

Appendix C. OCWIP Best Management Practices (BMP) Project Descriptions