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.

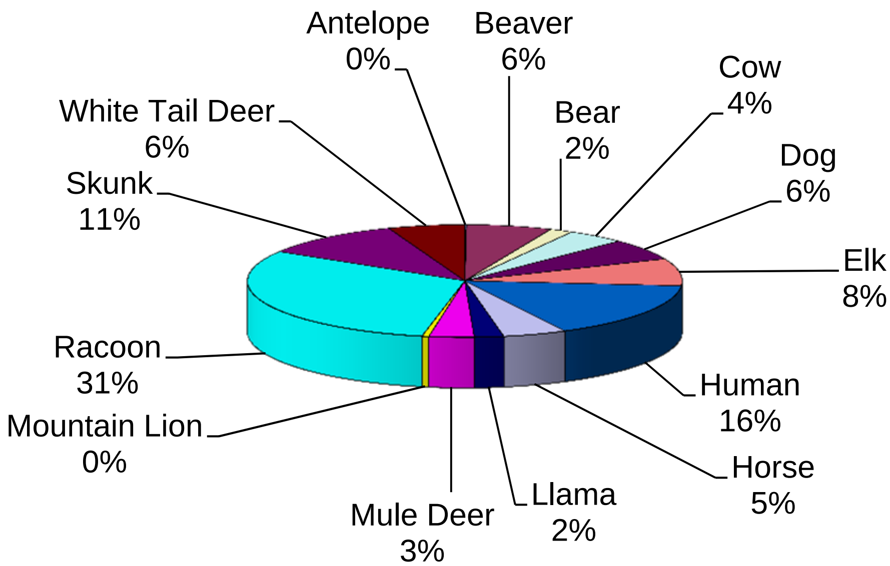

Figure 1. Distribution of *E. coli* by species compiled from Oak Creek Canyon as a whole (OCCTF 2002).

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.

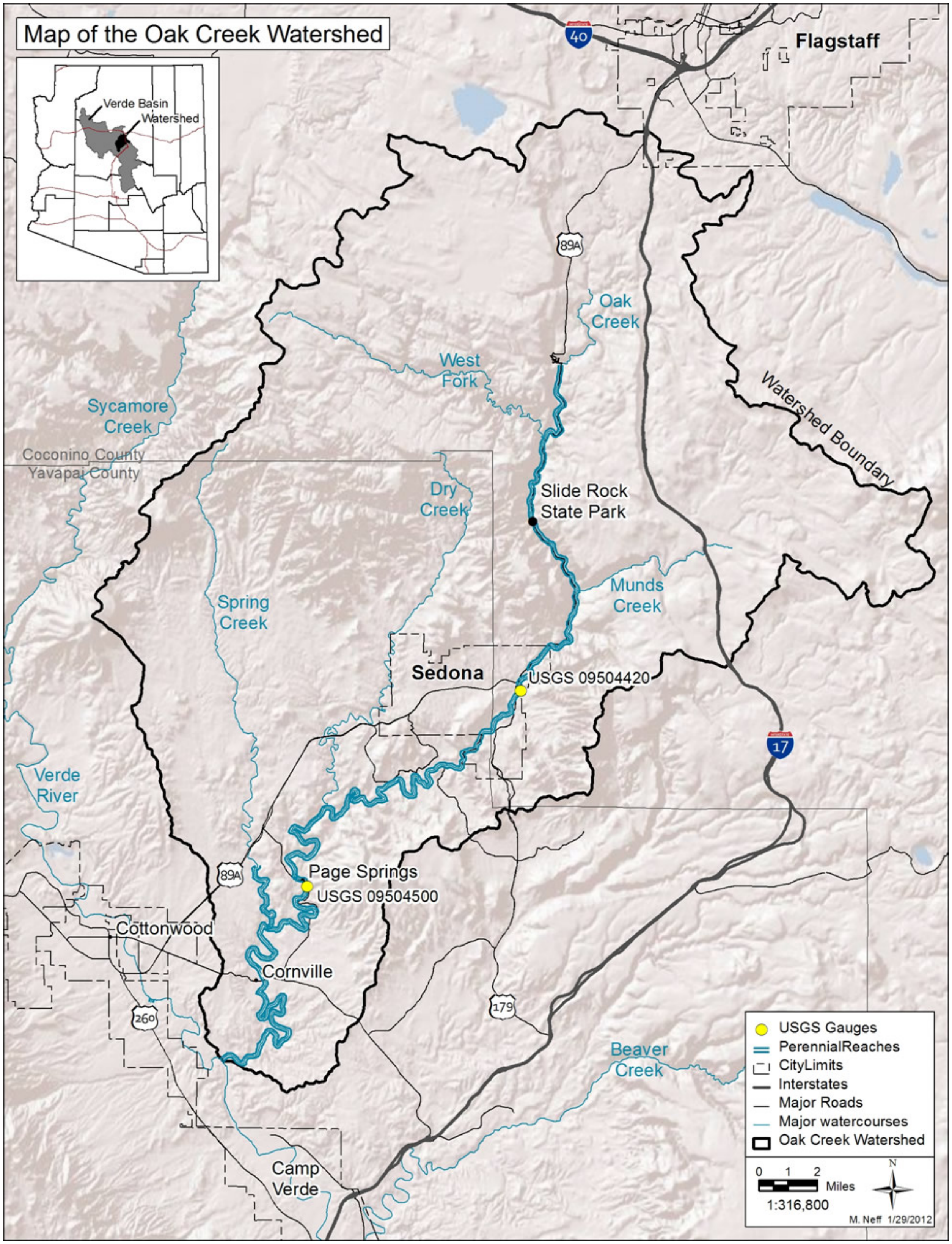

Figure 2. Oak Creek Watershed.

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.

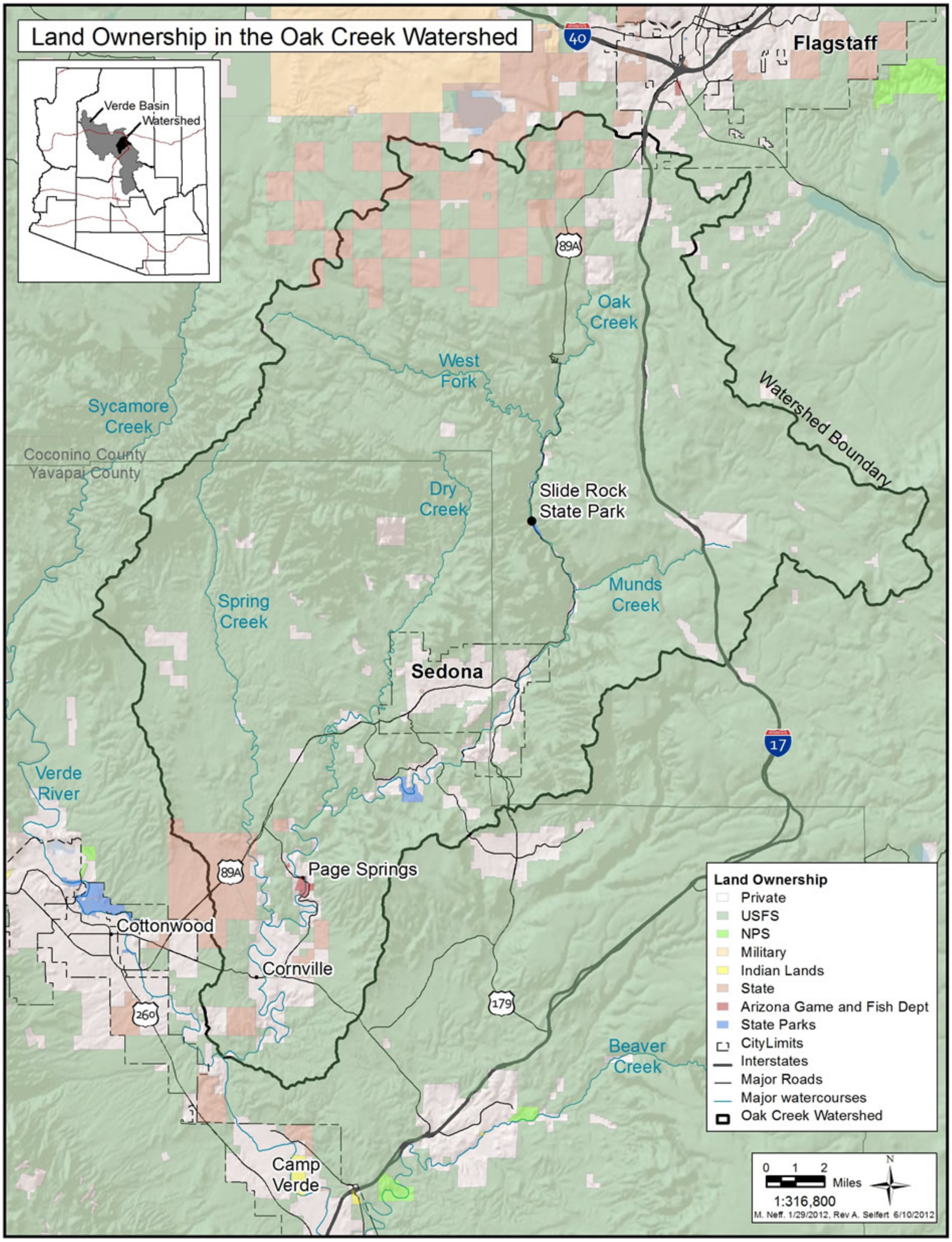

Figure 3. Land ownership in Oak Creek Watershed

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.

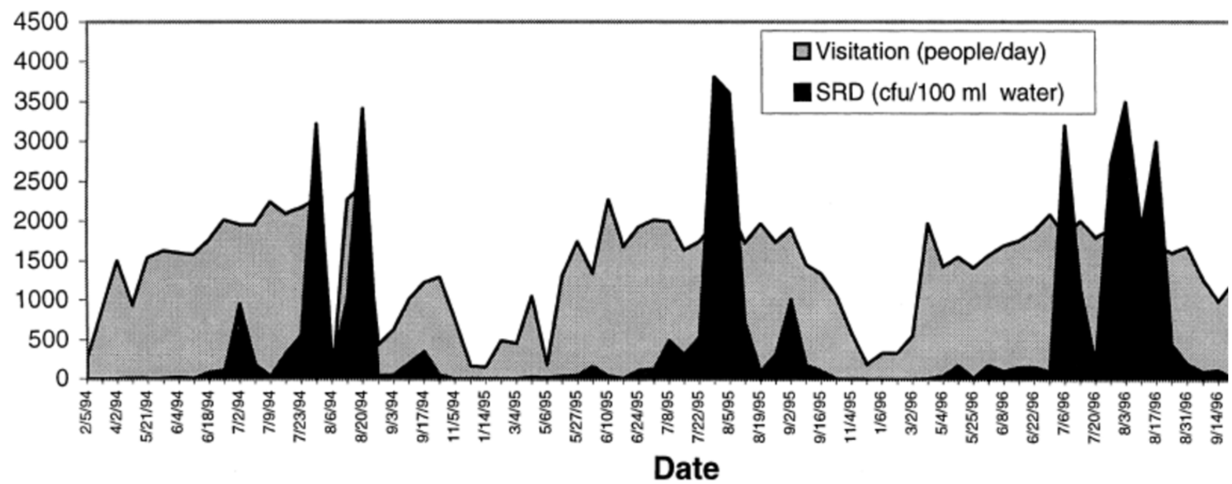

Figure 4. Visitors at site Slide Rock State Park from 1994 to 1996 compared to fecal coliform counts of cfu/100 ml at the Slide Rock downstream (SRD) site. Note the convergence of visitors and fecal coliform during the late summer months during all 3 years. Also, note the improvement of water quality 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.

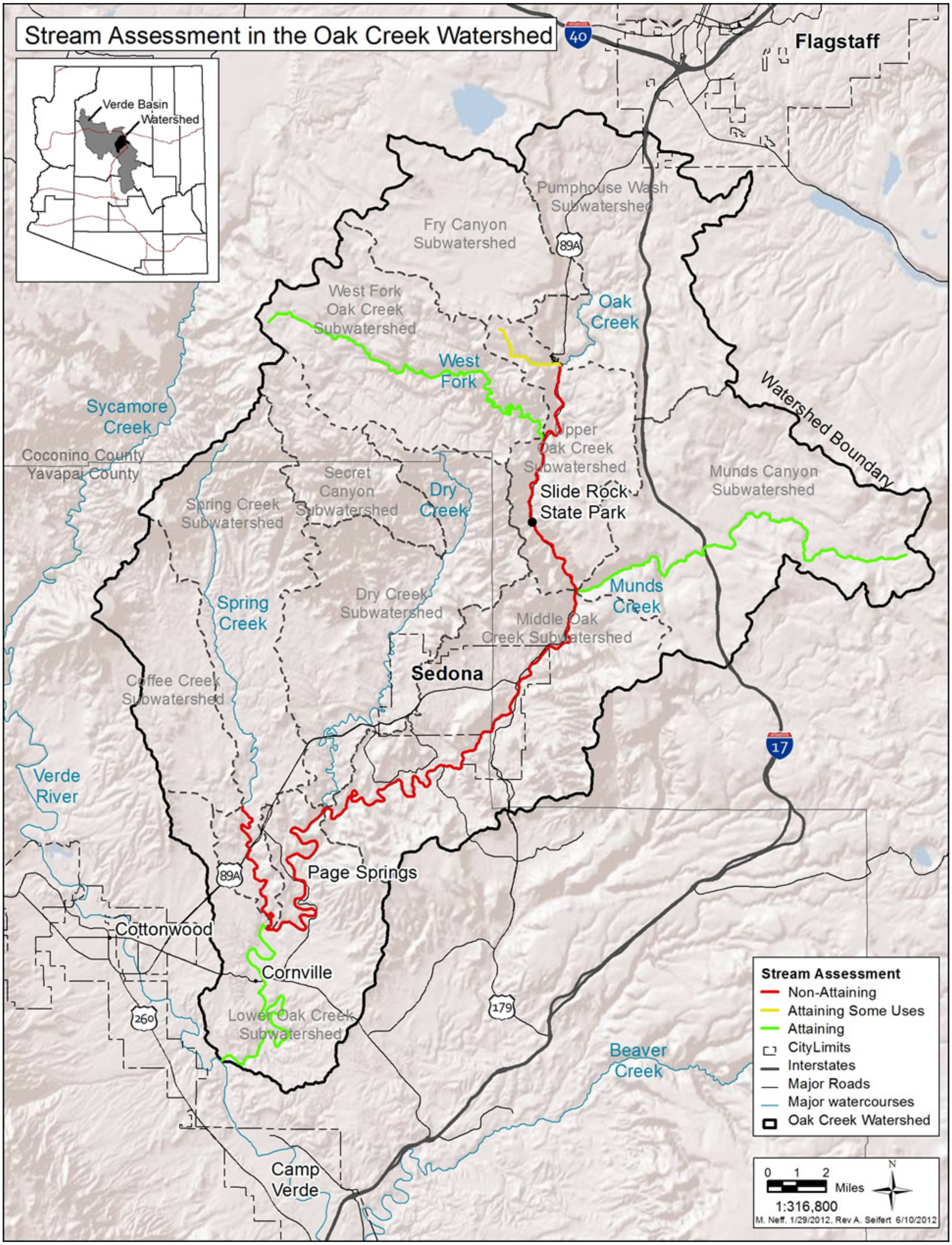

Figure 5. Nonattaining reaches in Oak Creek Watershed

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.

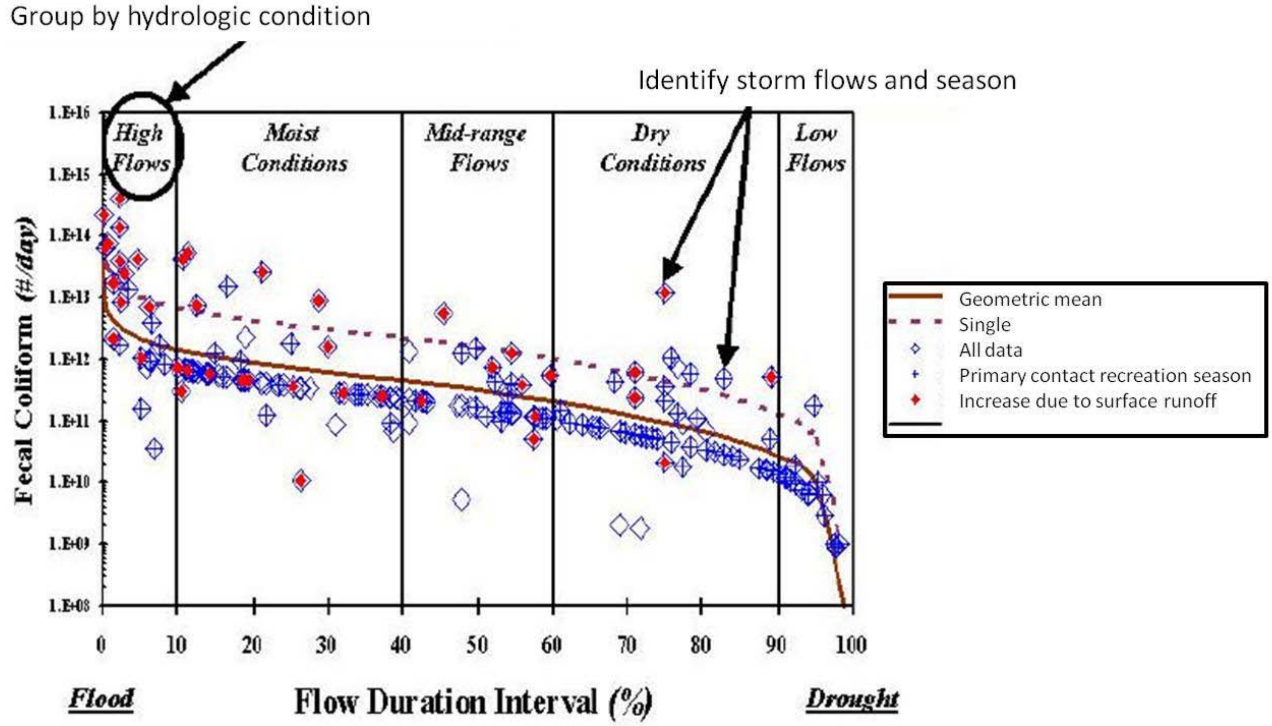

Figure 6. Sample load duration curve (Cleland 2003).

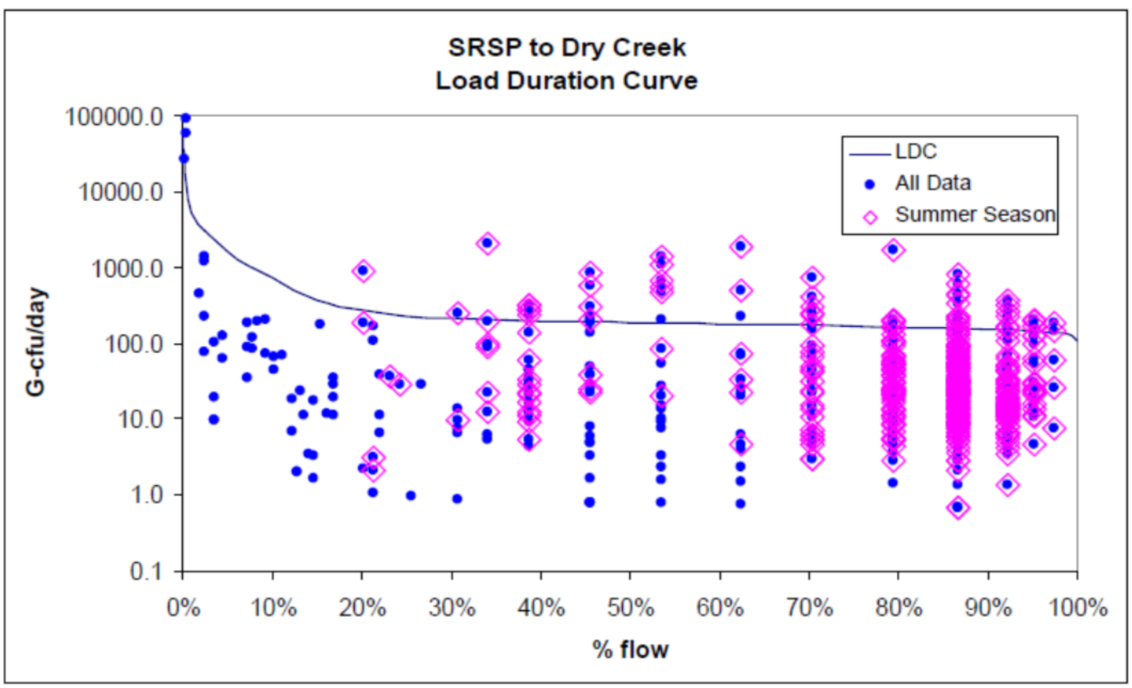

Figure 7. *E. coli* load duration curve, Slide Rock Sate Park to Dry Creek (ADEQ 2010)

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

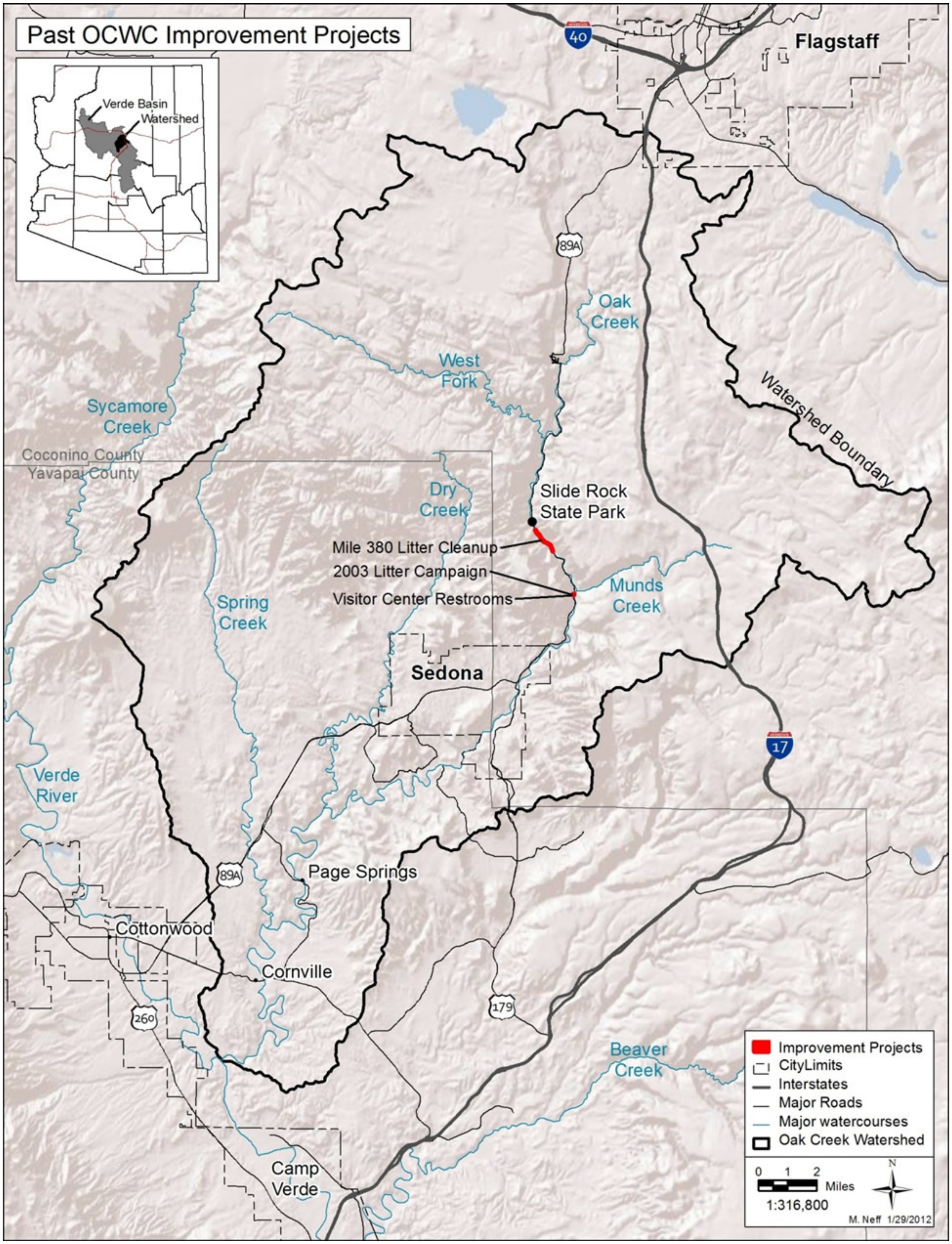

Figure 8. Best Management Practices (BMP) projects in the Oak Creek Watershed