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.

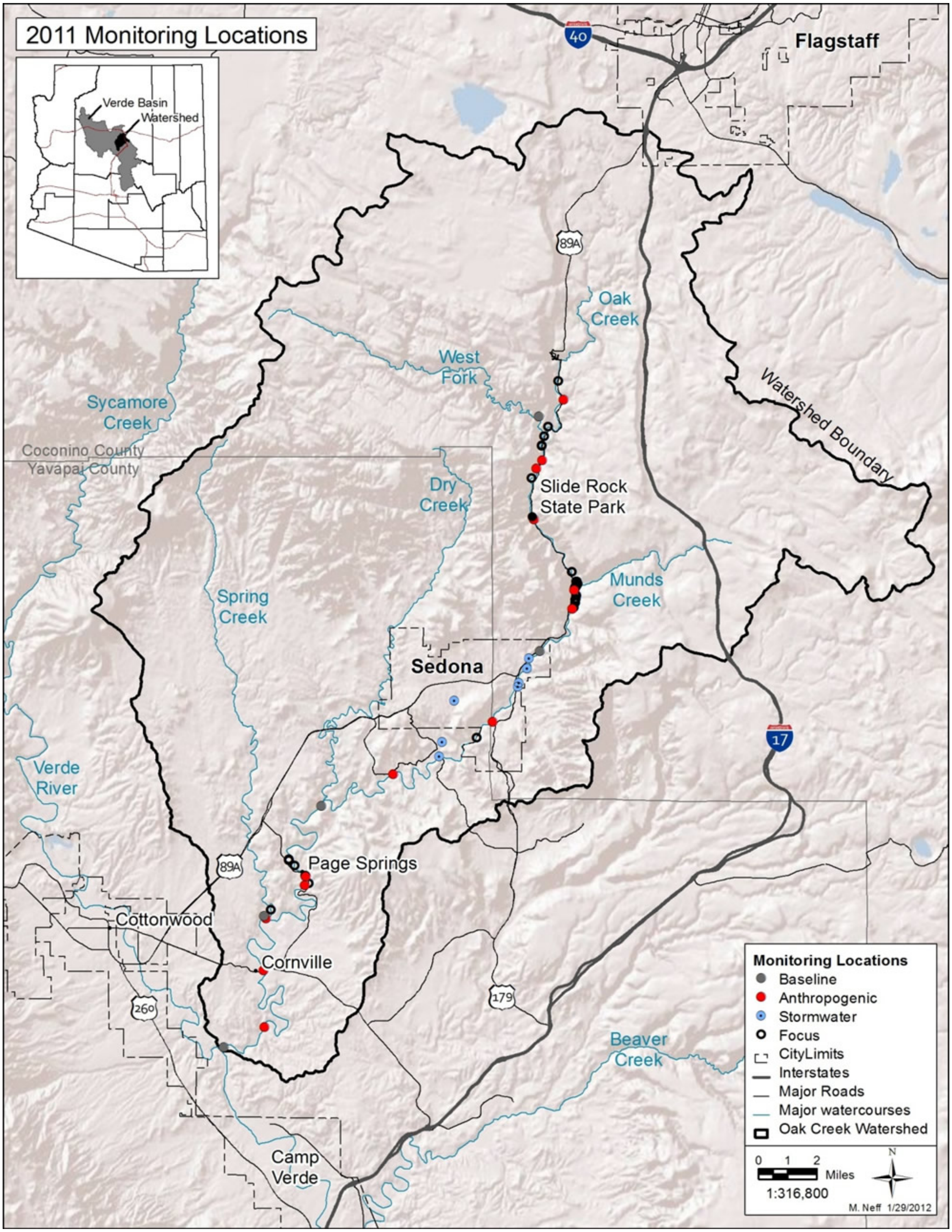

Figure 9. OCWIP monitoring locations, 2011

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).

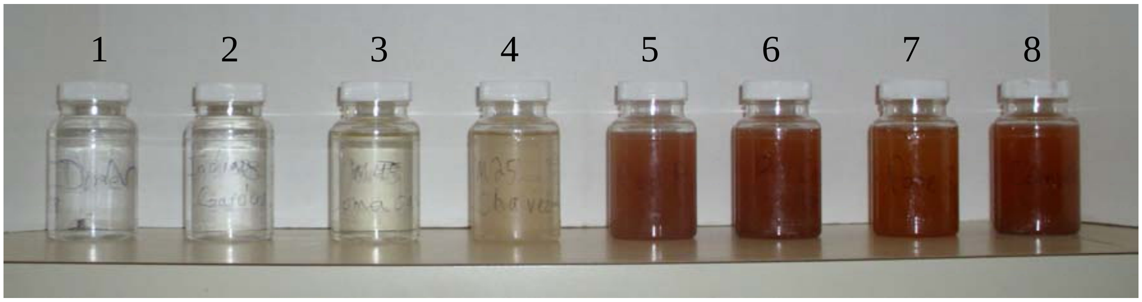

Figure 10. Oak Creek water samples September 15, 2011 following a storm event the night before.

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.).

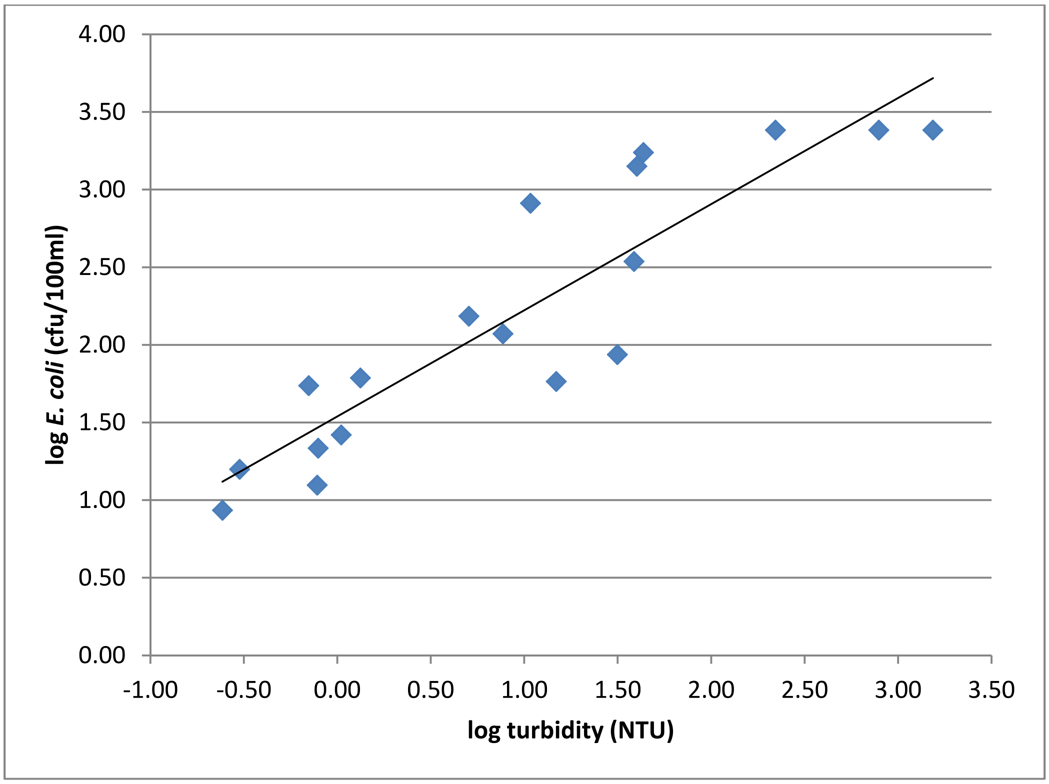

Figure 11. Log *E. coli* concentrations as response to log turbidity, Oak Creek August 2, 2011, $R^2 = 0.87$.

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.

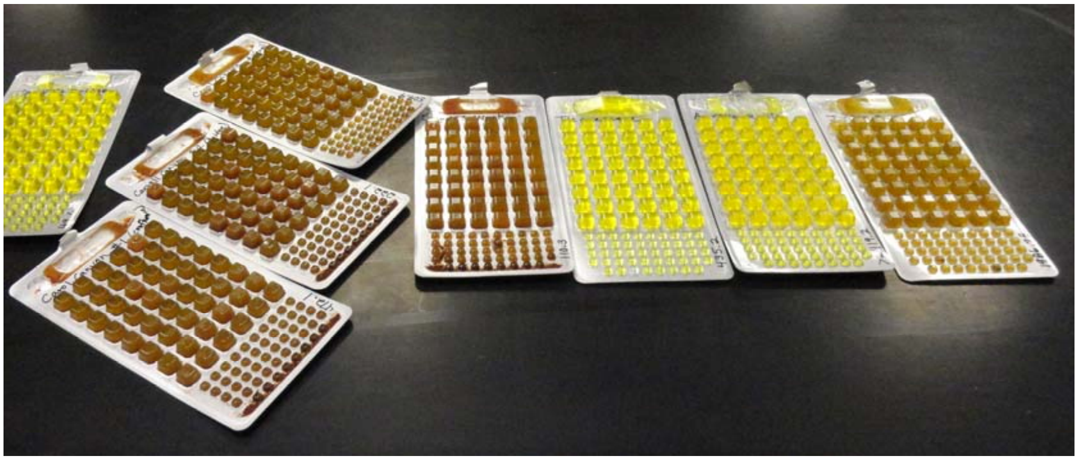

Figure 12. Quanti-trays showing variation in sediment yield among stormwater flow collected from Sedona's washes on August 1. The darker brown the sample is, the more sediment it holds. From left (downstream) to right (upstream) are Carroll Canyon 1, 2, and 3, Soldier's Wash, Tlequepaque, Arroyo Roble 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.

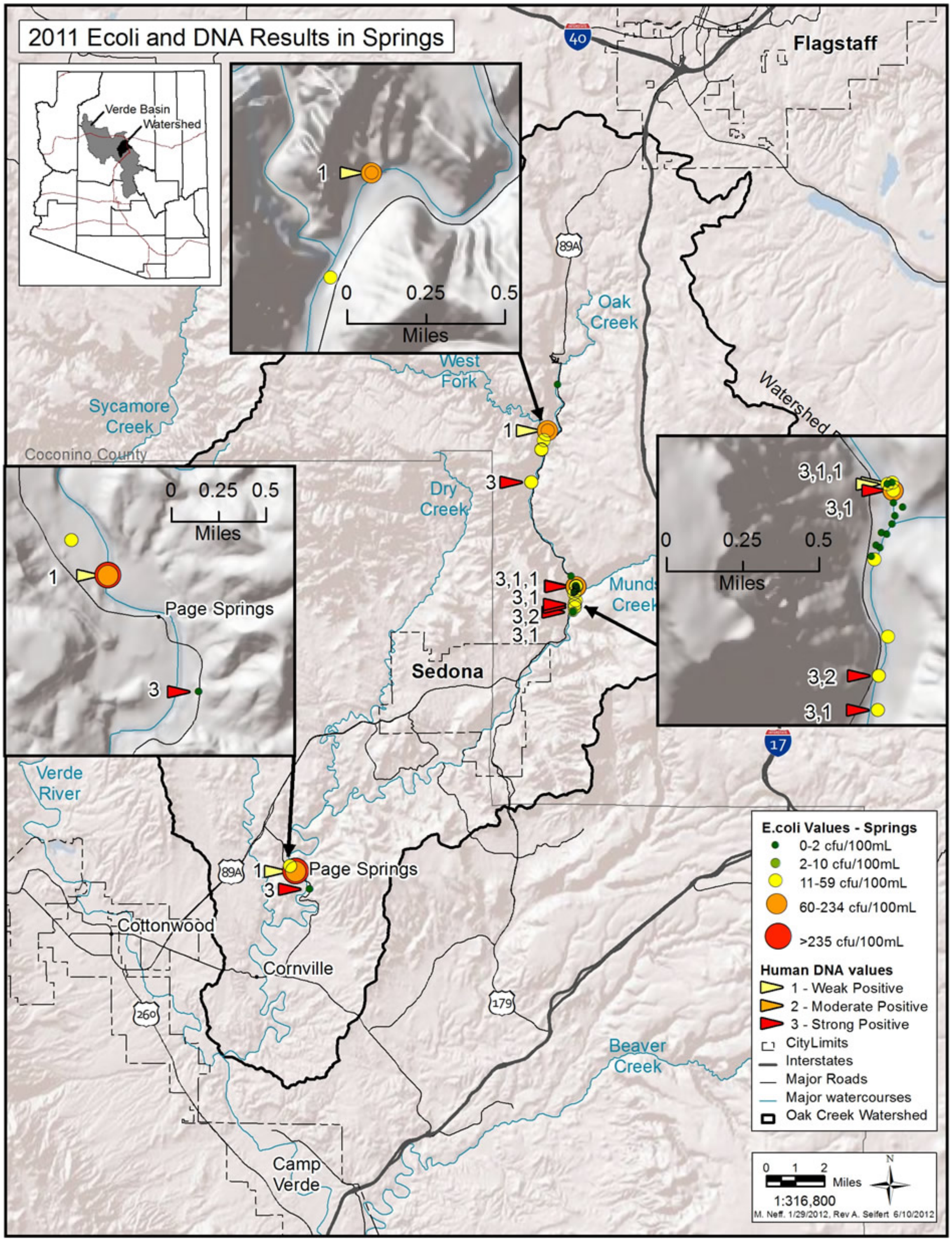

Figure 13. *E. coli* and human DNA test results at springs in Oak Creek watershed. 3= strong positive, 2 = medium positive, 1 = weak positive result for Human DNA.

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.

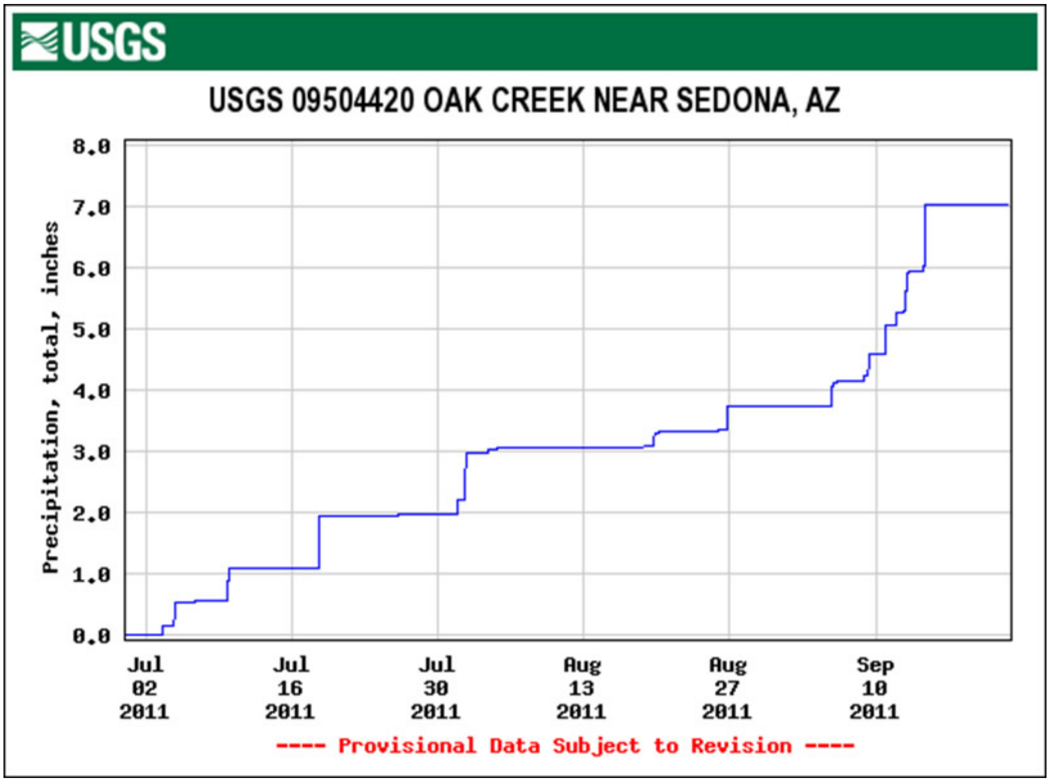

Figure 14. Rainfall July 1 through September 22, 2011 at Oak Creek near Sedona, USGS gage no. 09504420

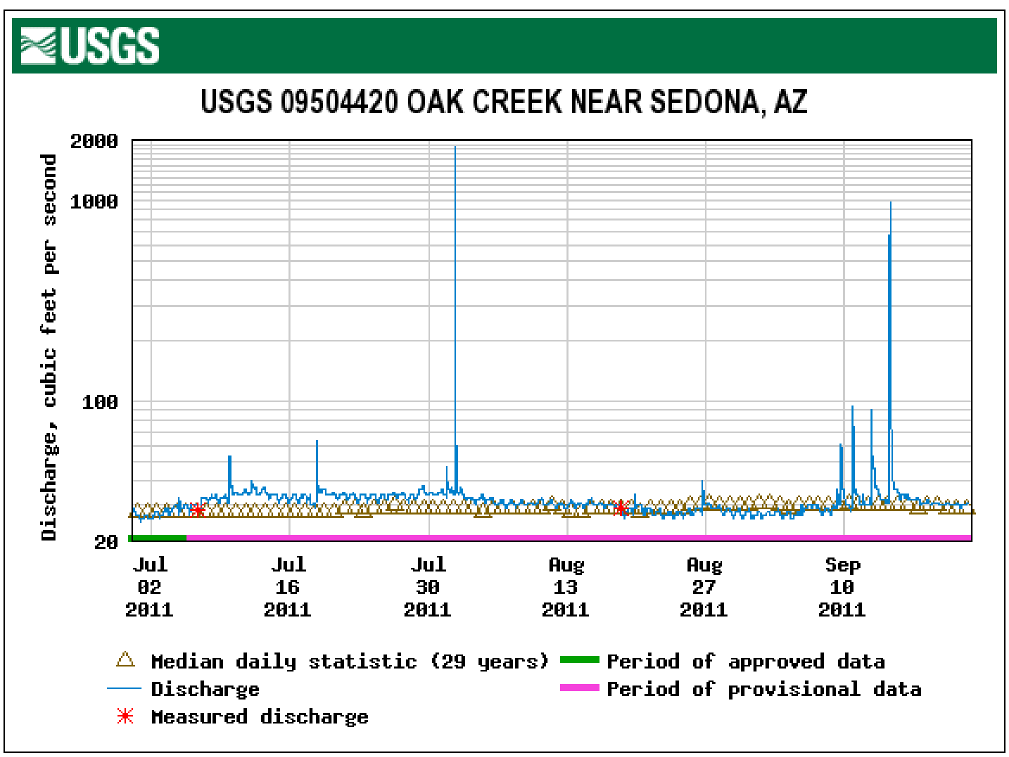

Figure 15. Rainfall July 1 through September 22, 2011 at Oak Creek near Sedona, USGS gage no. 09504420

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