BACTERIOLOGICAL WATER QUALITY TREND ANALYSIS IN OAK CREEK CANYON, ARIZONA

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ABSTRACT: The purpose of this paper is to analyze the temporal and spatial distribution of bacterial contamination at Slide Rock State Park in Oak Creek Canyon, Arizona. Oak creek Canyon has a magnificent landscape, highly diversified riparian fauna and flora and an invigorating climate, that attracts several thousand visitors each week. Recreational activities include hiking, mountain biking, rock climbing, camping, fishing, and swimming. These activities have led to water quality concerns in the creek. Arizona State Park employees at the Slide Rock State Park have been monitoring the stream running through the park for bacteriological contaminants since 1995. Stream water sample analyses at various times have indicated the amount of bacteria in the stream rising well above acceptable levels. There are a number of sources for the contamination, including livestock and wildlife grazing in the forests above the creek, domesticated and wild animals, as well as residential homes inside the canyon, the large number of tourists visiting Oak Creek Canyon for recreational purposes, and the different facilities catering to the needs of the tourists. Our analysis of the available data shows some correlation between the numbers of visitors and E. coli counts at Slide Rock Park.
KEY TERMS: Oak Creek Canyon

THE NATURAL SETTING OF THE STUDY AREA

Oak Creek originates about 10 kilometers southwest of Flagstaff, Arizona, near the southern rim of the Colorado Plateau and runs through Oak Creek Canyon in a southwestern direction to become a part of the Verde River some 33 km downstream. Along this distance the creek drops 760 meters and is joined by Fry Canyon Creek, West Fork Oak Creek, Munds Creek, and Spring Creek as tributaries. A number of springs, such as those near Indian Gardens also add to the waterflow in the creek. The entire Oak Creek watershed is primarily located within the Coconino National Forest and encompasses an area of 1200 km^2, which falls from an elevation of 2580 meters in the east to about 970 meters above sea level in the south. The canyons part of the watershed is about 460 meters deep and relatively narrow for roughly 20 km, before opening up to about one-and-a-half kilometers across downstream. Kaibab Limestone and Coconino Sandstone cliffs flank the creek as it flows southward. The red sandstone, which holds the series of pools at Slide Rock State Park, is the Supai Formation

The soils of the watershed, which are derived from these formations and others, vary greatly along the entire elevation gradient of the watershed (Arizona Dept. of Water Resources, 1990). The Natural Resources Conservation Service classifies soils into four types A, B, C, and D on the potential to produce runoff. All four are recognized within the watershed. Types C and D, which have a high proclivity to produce run-off, form the majority of the soils present above the canyon rim and below the city of Sedona (ADEQ, 1999a).

Baseflow near the headwaters of Oak Creek is approximately 6.8 m^3/minute. The upper part of Oak Creek is a gaining stream and by the time it reaches Slide Rock State Park its baseflow increases to nearly 30.6 m^3/min. With the aid of tributaries and ground water contributions in the form of springs, the baseflow continues to rise steadily downstream until the average baseflow becomes 40.8 m^3/min. in Sedona. Like any other streams in the Southwest, Oak Creek experiences occasional flash floods during abnormally high precipitation events, which occur mostly during the "monsoon season" in July, August and September. There is also some flooding from rapid snowmelt and rain on snow in the spring. The annual average precipitation in the northern part of the watershed is about 44.5 cm. About 60% of this precipitation occurs as snow. In the southern section of the creek the annual average precipitation, which consists mostly of rainfall, decreases to 35 cm.

The vegetation pattern in the Oak Creek watershed is reflective of the area's climate. From north to south the vegetation type in the watershed changes from Ponderosa Pine-Douglas-Fir Forest to Chaparral to Pinyon-Pine Woodland to Oak Woodland (consisting of Gamble and Arizona Oak, from which the canyon's name is derived), and to a Cypress-Juniper Woodland. The riparian communities consist of mostly alder, box elder and ash in the northern part and sycamore,

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cottonwood and walnut in the southern part. However, just before joining the Verde River, the watershed cover becomes dominated by a semi-desert grassland.

DEVELOPMENT AND USE OF THE AREA

Oak Creek Canyon in general, and Slide Rock State Park in particular, handle a large volume of visitors, most of which come in the period between Memorial Day and Labor Day weekends (ADEQ, 1999b). The number of visitors has steadily been increasing ever since the Canyon became settled in the late 1870s (Sedona Westerners, 1968, West, 1975, Stafford, 1993). One undesirable consequence of the canyon's development and use as a recreation site is pollution of the creek water, which probably reached its peak in the 1970s (West, 1975). Since then, public education has resulted in higher awareness of the pollution problem, leading to some control of the pollutants. However, there still remains an increasing threat from microbial contaminants, which seems to grow with the increasing number of visitors, residents and their pets in the Canyon. Recreation includes full body contact water use (swimming, sliding etc.), wading, fishing and hiking. All these activities affect the water quality of the creek (Multiple conversations with Slide Rock State Park Rangers, 1999 and 2001).

There are 545 structures within the canyon. These structures, which are mostly summer homes, are primarily located on the 176 hectares of private land. The only access to and through the canyon is Highway 89-A, which carries about 7 million visitors a year to Oak Creek and Sedona. One million of these visitors stop and utilize the publicly owned recreation sites, while 300,000 visit Slide Rock State Park (Stafford, 1993). The maximum number of visitors during a single day to Slide Rock was 4056 in June 1999 (Slide Rock State Park, 1999). This is a considerable increase compared to just over a thousand during a single day in June 1974 and 20 in June 1959 (West, 1975). The main recreational experiences people have include camping, picnicking, fishing and swimming. The bulk of the land use in the canyon consists of forest land (52%), range allotments (38%), and urban development (2%), including Sedona. The remaining land is shared by state land (including the Park), scattered private developments, and the segments of the State Route 89A (ADEQ, 1999a). A Coconino County ordinance in 1982 specified that all development of private lands within Oak Creek Canyon are restricted to single family homes at a density not to exceed one unit per "net developable acre."

DATA COLLECTION AND ANALYSIS

The data used in this study include streamflow measured by the USGS at Oak Creek gauging station 09504420, the number of visitors, as well as the Escherichia coli (E. coli) count recorded by Arizona State Park personnel and/or designated agents. The E. coli data for this paper is based on grab samples collected from 5 locations daily during the summer months when visitation is high. The summer visitation season begins on Memorial Weekend in the first week of June and lasts through the Labor Day weekend in early September. Whenever peak readings occur additional samples are taken. During the winter and other off-season months samplings are made rather intermittently. Water quality samples to determine Escherichia coli counts are generally measured and analyzed on-site at the Slide Rock State Park laboratory (licensed by the Arizona Department of Health Services) according to Colony Forming Units (cfu) of bacteria. The samples are processed in the laboratory within 6 hours. The results are logged for public information within 30 hours (including a 24-hour incubation period) after sampling. The 5 sampling locations are "upstream," where Oak Creek enters the State Park, "midslide", the location of the actual sliding area within the rock bed of the creek, the "large pool" at the bottom of the slide, by the "foot bridge", which crosses the creek at the bottom of the large pool and under the "highway bridge", where highway 89A crosses Oak Creek. These sites are located meters apart downstream from each other along the reach of the creek within the State Park. Information on the amount of E. coli counts from each of the sites are analyzed for their monthly distributions, spatial distributions across the sampling sites and their relationship with the number of visitors to the State Park.

SURFACE-WATER QUALITY MANAGEMENT PLAN

The Slide Rock State Park 1999 Surface Water Quality Management Plan was designed to primarily protect the health and safety of the public using the swim area for "full-body contact" activities. The plan, issued by Arizona Department of Environmental Quality, is made available to U.S. Forest Service Sedona Ranger District, Coconino County Department of Health Services and other managing and/or regulatory agencies for monitoring and managing recreational activities within Oak Creek Canyon and Slide Rock State Park. The plan uses bacterial standards for surface waters permitting full-body contact as the basis for management in accordance with the Arizona Administrative Code, Title 18, Chapter 11-109.C. and E.P.A. guidelines adopted by the Arizona Department of Environmental Quality on April 24, 1996.

Samples are taken and evaluated in accordance with these guidelines and expressed in terms of the 10-sample geometric mean of bacterial count in 10 consecutive samples taken within a 30-day period. Should any one of the daily samples result in an unsafe reading (equal or greater than 580 cfu), a minimum of three additional confirmation samples from the vicinity of

where the unsafe sample was taken, are expected to be collected and laboratory analyzed immediately within 24 hours of the recorded high reading - preferably in the mornings and afternoons, until the readings fall within acceptable limits. Likewise, if the 10-sample geometric mean reaches a level at or above 130 cfu, a minimum of three running evaluations are expected to be taken until the geometric means consistently drop to safe limits.

According to the above guidelines, three management plan levels have been set for Slide Rock State Park. They are low risk, water quality alert and high-risk levels. The situation is "Low Risk" when the geometric mean is 0-109 cfu. This level indicates that the E. coli concentration in the water is safe for full-body contact use. There are no law enforcement requirements at this level. A level 2 "Water Quality Alert" is declared when either the geometric mean of the E. coli concentration is within the range of 110 -129 cfu or the amount of E. coli in a single test equals or exceeds 580 cfu. At this level the decision whether or not visitors want to engage in full body recreational activities in the creek becomes the responsibility of the visitor, although park personnel sternly and conspicuously warns against such activities. When the geometric mean of E. coli counts is greater than 130 cfu, or the value for a single sample is greater than 580 cfu, the E. coli concentration is classified as "High Risk". This level indicates substantially unsafe water quality standards for swimming, sliding and other full body contact. This condition warrants an emergency closure order of the Slide Rock Swim Area, in accordance with Arizona State Park Policy.

FINDINGS

Testing for E. coli in Oak Creek Canyon began in the late 1970s with samples mostly taken intermittently. The procedure continued in the same fashion until 1995. Since then it has become more regular. In either case, there appears to be some noticeable trends of improvement in the water quality in Oak Creek. Out of 31 samples taken at Slide Rock in 1978 by the U.S. Forest Service, 13 samples (or 42%) exceeded acceptable state limits (Barnett, 1978). These limits were 800 cfu for a single reading or a geometric mean of 200 cfu (ADEQ, 1992). These limits were updated to the levels described above in 1996. In 1983 the Oak Creek Water Management Plan administered by the Northern Arizona Council of Governments found the water quality in Oak Creek to be good except in a few places, such as at Slide Rock. For example, 125 measurements taken at Slide Rock during the summers from 1977 to 1981 had values ranging from 0 to 1220 cfu. The mean of those tests was 74 cfu with only two samples over 800 cfu. But the same number of samples taken just below Slide Rock during the same time period showed results ranging from 0 to 3300 and with a mean of 332 and 15 occurrences of 800 cfu or higher (Towler and Sedona Oak Creek Task Force, 1984). In 1983 samples from the later location had values that ranged from 2.5 to 1200 and a mean of 289 cfu, while other samples taken 1 mile further downstream had values averaging only 42 cfu (Towler and Sedona Oak Creek Task Force, 1984). There is a suggestion that the decrease in bacterial concentration below Slide Rock in 1983 may be attributed to the 20% drop in visitors at Slide Rock due to enforced parking restrictions (Towler and Sedona Oak Creek Task Force, 1984). The mean values for samples over the last seven years, 1995-2001, are considerably lower (See Table 1). However, the higher frequency of samples taken during these years might have some effect on the findings. It is possible that measurements in previous years might have been taken mostly during high visitation periods. Also, the presence of full-time rangers, providing guidance since the summer of 1979 (Eaker, 1980), the establishment of a State Park in 1984, as well as an increased environmental consciousness in the visiting public may be the reasons behind the improvement in the E. coli concentration around Slide Rock. Taking a closer look at the seasonal and annual trends in E. coli counts, we noticed that the highest average values occurred in July through September (Fig. 1 & 2).

Table 1. Annual trends of summer months E. coli count means for samples taken (Mar. to Nov. where data was available) **From just below Slide Rock (or under Hwy. Bridge)**

Years	E. Coli Counts (cfu)
1977-81	332
1983	289
1995	192
1996	85
1997	56
1998	38
1999	62
2000	109
2001	138

Figure 1 shows the monthly mean distribution of E. coli counts for 1999 in 5 different sampling locations in Slide Rock State Park. In all locations, without exception, the monthly mean E. coli counts are significantly higher during the summer months of July, August and September, when the number of visitors to the area are high.

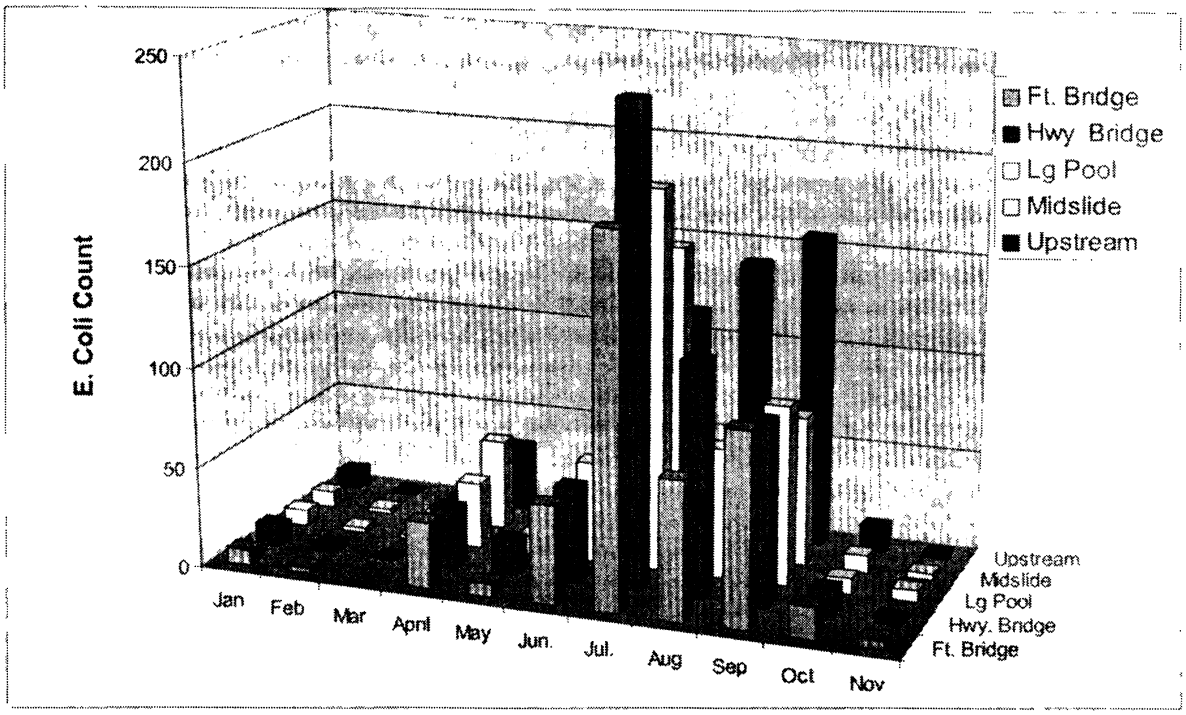

Figure 1: Monthly average E. coli values for 1999. Increased values at all testing locations can be noticed for July. August and September.

The condition is corroborated by Fig 2, which shows the mean monthly E. coli counts for the 1995-1999 summer months. The highest average E. coli counts tend to occur just below Slide Rock under the highway bridge. Also note that the field laboratory operated by the Arizona State Park Service at Slide Rock State Park can only count up to 2419 E. coli at the maximum. This underestimates the mean E. coli counts as shown in Figures 1 and 2, as well as other values so obtained, and does affect the geometric mean and consequently the closure decisions made on this basis. Determination of the absolute number of E. coli counts for each sample analyzed is, therefore, important in order to make better and safer decisions.

Figure 3 shows the number of visitors to the park increasing dramatically during the summer months. This should, theoretically, explain the high E. coli counts for the same time period. However, in spite of the simultaneous high occurrences of visitors and E. Coli counts during the summer months, there is no good statistical correlation between daily number of visitors and E. coli counts. Some possible reasons for this include the intermittent nature of the recreational activities at Slide Rock (Eaker, 1980), and the way the E. coli count and number of visitors data are collected and analyzed.

People are not using the area for the whole 24-hour period each day, but only for a small part of each day. Therefore, if bacteria are being added through recreational activities, it would happen during those hours when people are present and not continuously, as in a sewage outfall. Further, Slide Rock does not only appeal to visitors seeking full body water contact. Besides wading, swimming and sliding the park provides opportunities to picnic, BBQ, play ball games, hike etc., attracting visitors in all age categories, with or without pets. Still others may decide to stay overnight at campsites in different locations along the creek at a camping site or in one of the motels. These different uses are expected to have different environmental effects on the Oak Creek water and identifying the types, levels and duration of use may be helpful to see the relationships between the number of visitors and E. coli counts.

Another factor possibly contributing to the low correlation between the number of visitors and the E. coli count is the delayed effect of the first on the second. It takes some time for bacteria introduced by campers, local motel and eatery patrons, hikers, and even users of water based recreation to reach points of sampling. The direct contributions from visitors and their pets may take days before reaching their peaks. However, visitors recreating in the water may also have an indirect, but important effect on E. coli counts, by stirring the bottom sediment that harbors the bacteria and distributing the later along the entire water column, which ultimately shows up in the samples. One other factor contributing to the lower correlation between visitors and E. coli counts is park closure. Due to the delayed effect described above, samples taken during park closure may show high E. coli counts at a time when there are actually few or no visitors.

According to the ADEQ (2001) genotyping project water and sediment DNA profiles do not match up. 84% of the *E. coli* proportions in the water consisted of raccoons (31%), humans (16%), skunks (11%), elk (11%), beaver, dogs and white-tailed deer (6% each); whereas the *E. coli* proportions in the sediments showed to be horses (16%), humans (12%) raccoons and white-tailed deer (11% each), elk and skunk (10% each), cows and mule deer (9% each).

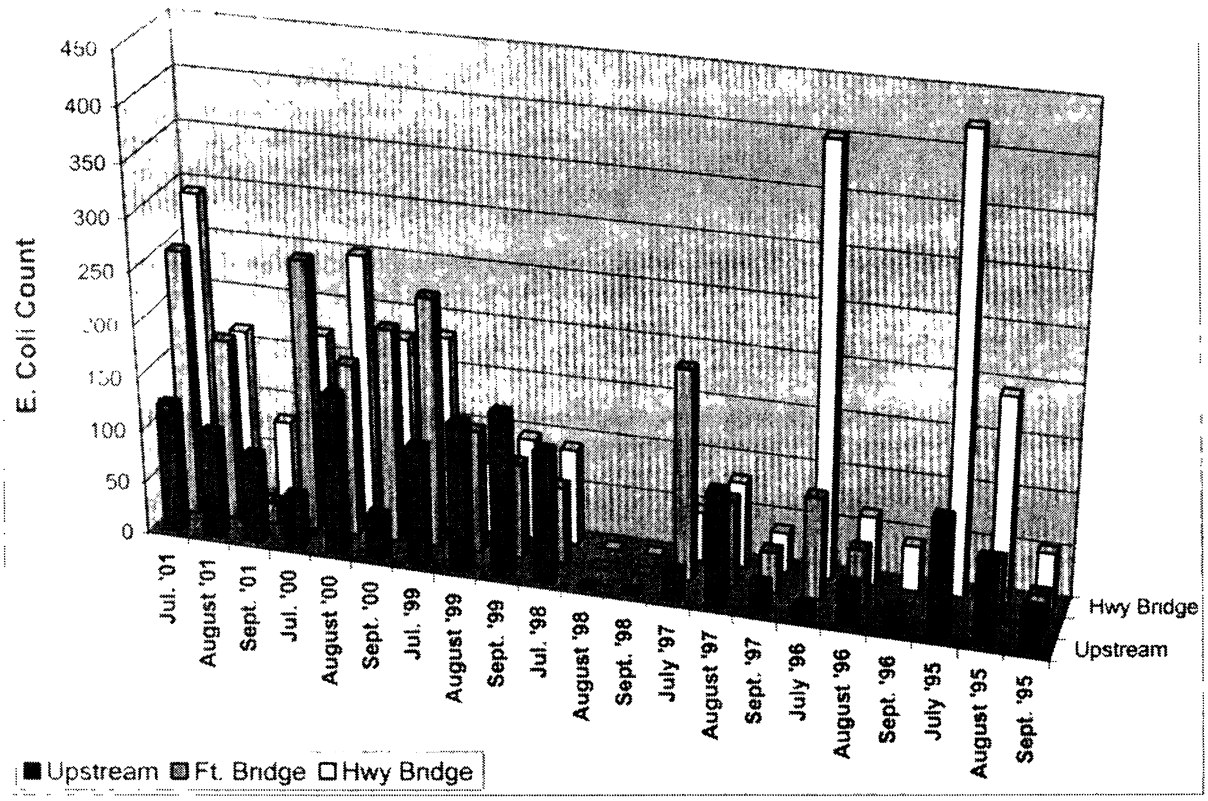

Figure 2: Monthly average E. coli values for July, August and September 1995-2001 at 3 sampling locations. (No data was available for August and September 1998.)

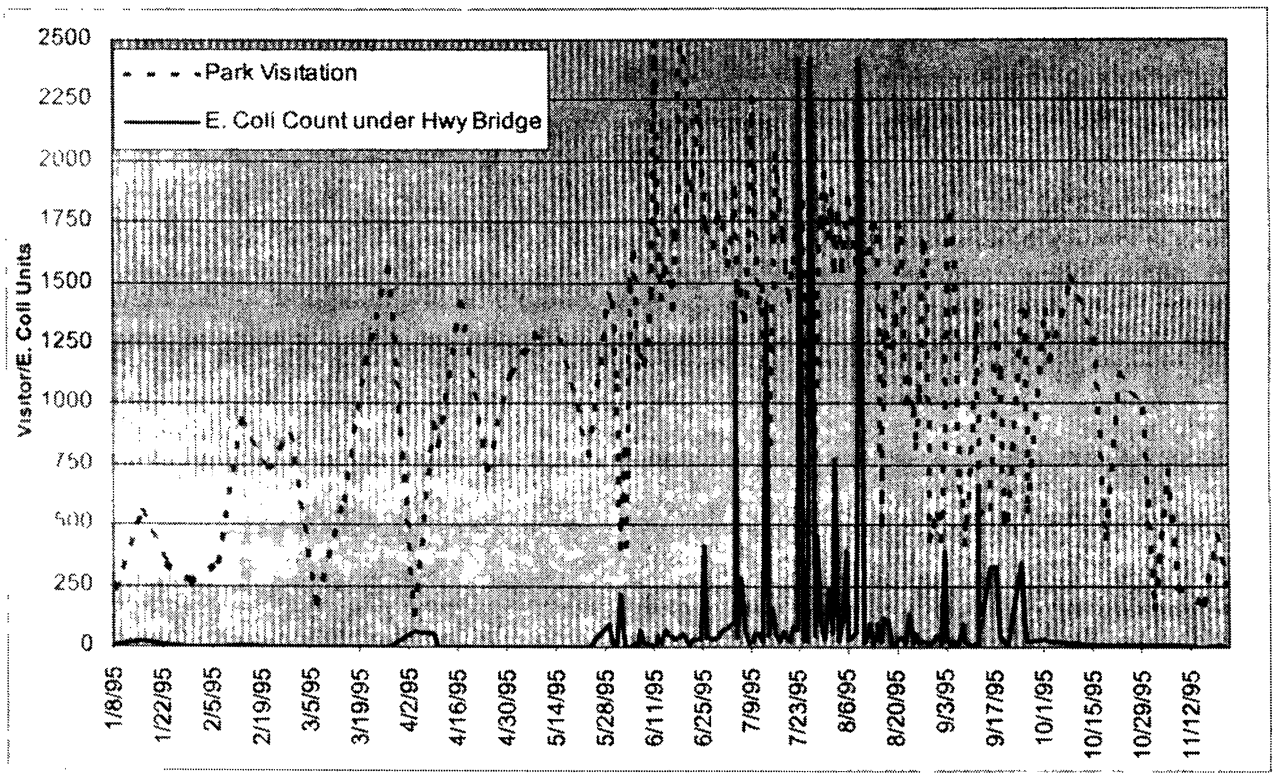

Figure 3: Number of visitors compared to the E. coli count under the highway bridge at Slide Rock State Park for 1999. (2419 is the maximum measurable E. coli count possible with current laboratory set-up at the State Park.)

CONCLUSIONS

Even though the water quality at Slide Rock and in Oak Creek has improved during the last 25 years, there is still some need for improvement. A health risk still exists here, due to the high Fecal Coliform bacteria concentration, especially during the months of high visitation, which is essentially from June to September. However, it is worth mentioning, that the literature and the data we analyzed indicate that recreational use alone was not a significant cause of bacterial pollution (Auckermann and Springer, 1976). Even though, there is a clear relationship between increased number of visitors and bacterial counts at the seasonal level, there seems to be little correlation between the two on a daily basis. For example, there is no recognizable relationship between the daily increases in levels of E. coli count and camper concentration in the campgrounds. This suggests the existence of other possible sources of bacterial pollution. Other sources include wildlife, businesses and private homes in the Canyon itself. The majority of the septic tanks between the confluence of West Fork Creek and Sedona are within 60 meters of the Oak Creek channel (ADEQ, 1999b). According to Bond (1977) 45.1 percent of the water consumption in second homes in North-Central Arizona occurs in June, July, and August, of which 86-96% become waste water. Crabill et al. (1999) made similar findings. These findings indicate that domesticated and wild animals, residential homes and the business establishments along the creek probably generate more E. coli pollutants compared to the number of visitors to Slide Rock State Park and other areas in Oak Creek Canyon.

Given Oak Creek's classification as a Tier III Unique Water body, and its important environmental, social, cultural, and recreational value to the State of Arizona and the local community, the authors strongly feel, that there is a need for developing a reliable and efficient clean up, appropriate protection and maintenance of the waters in Oak Creek Canyon. This would require finding a faster way of determining the extent of E. coli contamination of the waters to better safeguard visitors and other members of the community.

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