BACTERIOLOGICAL WATER QUALITY TREND ANALYSIS IN OAK CREEK CANYON, ARIZONA

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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 is one of the most beautiful and picturesque landscapes in the Southwest. It 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 Slide Rock State Park have been monitoring the creek running through the park for bacteriological contaminants since 1995. Stream water sample analyses at various times have shown the amount of bacteria in the stream to be rising well above acceptable levels. There are a number of possible sources for the contamination, including livestock and wildlife grazing in the forests above the creek, 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. Even though it is not possible to determine how much each one of these possible sources contributes to the *E. coli* concentration without comprehensive sampling from each source and tracing and typifying work, our analysis of the available data shows some correlation between the number of visitors and *E. coli* counts at Slide Rock Park.

The Natural Setting of the Study Area

Oak Creek originates about 10 km 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 m and is joined by Fry Canyon Creek, the West Fork of 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 located primarily within the Coconino National Forest and encompasses an area of 1200 km^2, which falls from an elevation of 2580 m in the east to about 970 m above sea level in the south. The canyon's part of the watershed is about 460 m deep and relatively narrow for roughly 20 km, before opening up to about 1.5 km wide downstream. As the creek flows southward, it is flanked by colorful cliffs of Kaibab Limestone and Coconino Sandstone. 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 Department of Water Resources 1990). The Natural Resources Conservation Service classifies soils into four types—A, B, C, and D—based on the potential to produce runoff. All four are recognized, with types C and D, which have a high proclivity to produce runoff, forming the majority of the soils present above the canyon rim and below the city of Sedona (ADEQ 1999).

Baseflow near the headwaters of Oak Creek is approximately 6.8 m^3/min. 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

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average precipitation in the northern part of the watershed is about 44.5 cm. About 60% of this precipitation comes 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 Cypress-Juniper Woodland. The riparian communities consist of mostly alder, box elder, and ash in the northern part and sycamore, 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, handles a large volume of visitors, mostly between Memorial Day and Labor Day weekends (ADEQ 1999). The number of visitors has been steadily increasing 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 pets in the canyon. Recreation includes full-body contact water use (swimming, sliding etc.), wading, fishing, and hiking. All of these activities affect the water quality of the creek (multiple conversations with Slide Rock State Park rangers, 1999). But at the moment, we do not know how much the visitors contribute to the water quality problem, and to what extent other factors may be contributing to the pollution. However, this question will be answered for the most part by a study currently being carried out by Northern Arizona University.

There are 545 structures within the canyon. These structures, which are mostly summer homes, are located primarily on the 176 hectares of private land. The only access to and through the canyon is Highway 89A, which carries about 7 million visitors per year to Oak Creek and Sedona. One million of these visitors stop and utilize the publicly owned recreation sites, and 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 of 1999 (Slide Rock State Park 1999). This is a considerable increase compared to just over a thousand during a single day in June of 1974 and 20 in June of 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 segments of State Route 89A (ADEQ 1999). A Coconino County ordinance in 1982 specified that all development of private lands within Oak Creek Canyon is 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 stream flow measured by the USGS at Oak Creek gauging station 09504420 and the number of visitors, as well as the *Escherichia coli* (*E. coli*) count recorded by Arizona State Park personnel and designated agents. The *E. coli* database for this paper is based on grab samples collected from five locations daily during the summer months when visitation is high. The summer visitation season begins on Memorial Day weekend in the first week of June and lasts through 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 *E. 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 five 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 near 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. *E. coli* counts from each of the sites are analyzed for their monthly distributions, spatial distributions across the sampling sites, and 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 primarily to protect the health and safety of the public using the swimming area for full-body contact activities. The plan, issued by the Arizona Department of Environmental Quality, is made available to the U.S. Forest Service Sedona Ranger District, the Coconino County Department of Health Services, and other regulatory agencies that monitor and manage 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 EPA guidelines adopted by the Arizona Department of Environmental Quality on April 24, 1996.

Samples are taken and evaluated in accordance with these guidelines and are 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 to 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 mean drops consistently to safe limits.

According to the above guidelines, three management plan levels have been set for Slide Rock State Park: low risk, water quality alert, and high risk. 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 of whether or not visitors want to engage in full-body recreational activities in the creek becomes the responsibility of the visitor, although park personnel warn sternly and conspicuously 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 for the Slide Rock swimming area, in accordance with Arizona State Park policy.

Findings

Testing for *E. coli* in Oak Creek Canyon began in the late 1970s with samples taken mostly 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 improvement in the water quality in Oak Creek. 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, with a mean of 332, and 15 occurrences of 800 cfu or higher (Towler 1984). In 1983 samples from the latter location had values that ranged from 2.5 to 1200 and a mean of 289 cfu, whereas other samples taken 1 mile further downstream had values averaging only 42 cfu (Towler 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 1984). The mean values for samples over the last 5 years, 1995–1999, are considerably lower (see Table 1). However, the higher frequency of samples taken during these years might have

Table 1: Annual trends of summer months: *E. coli* count means for samples taken from March to November, where data were available. Samples taken from just below Slide Rock (under highway bridge):

Years	*E. coli* counts (cfu)
1977–81	332
1983	289
1995	192
1996	85
1997	56
1998	38
1999	62

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, and an increased environmental consciousness in the visiting public may all be 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, August, and September (see Figures 1 and 2).

Figure 1 shows the monthly mean distribution of *E. coli* counts for 1999 in five 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 is high.

The condition is corroborated by Figure 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 both 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. How-

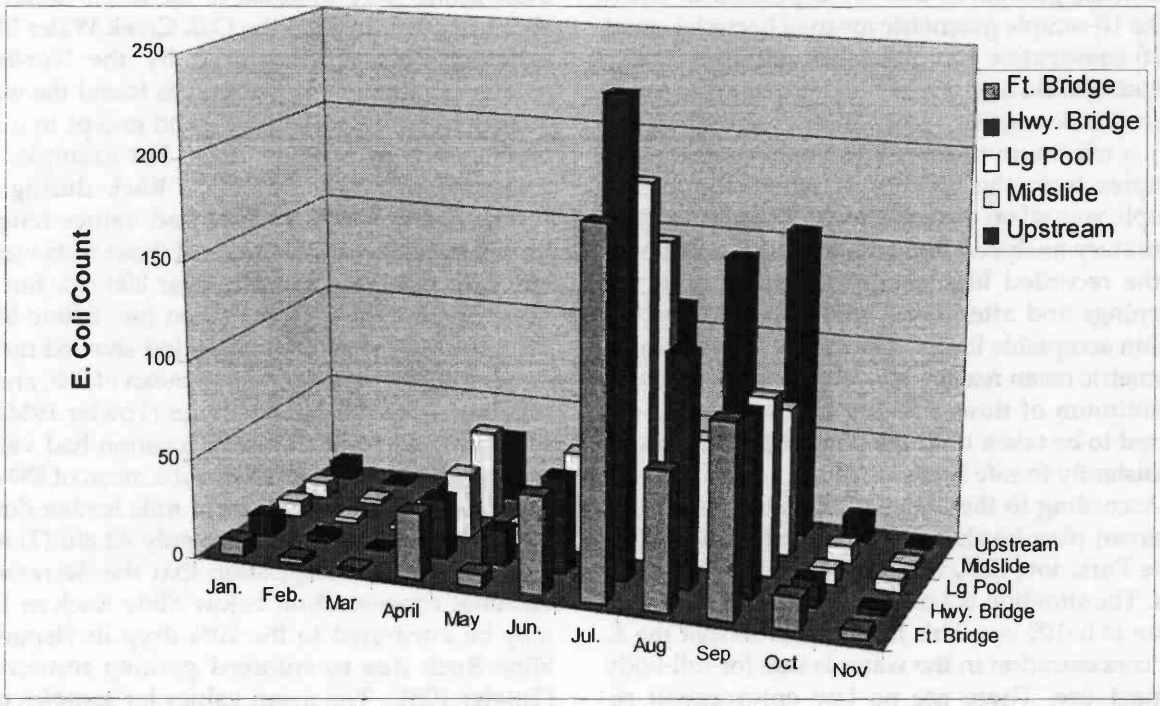

Figure 1. Monthly average *E. coli* values for 1999. Increased values at all testing locations can be noticed for July, August, and September.

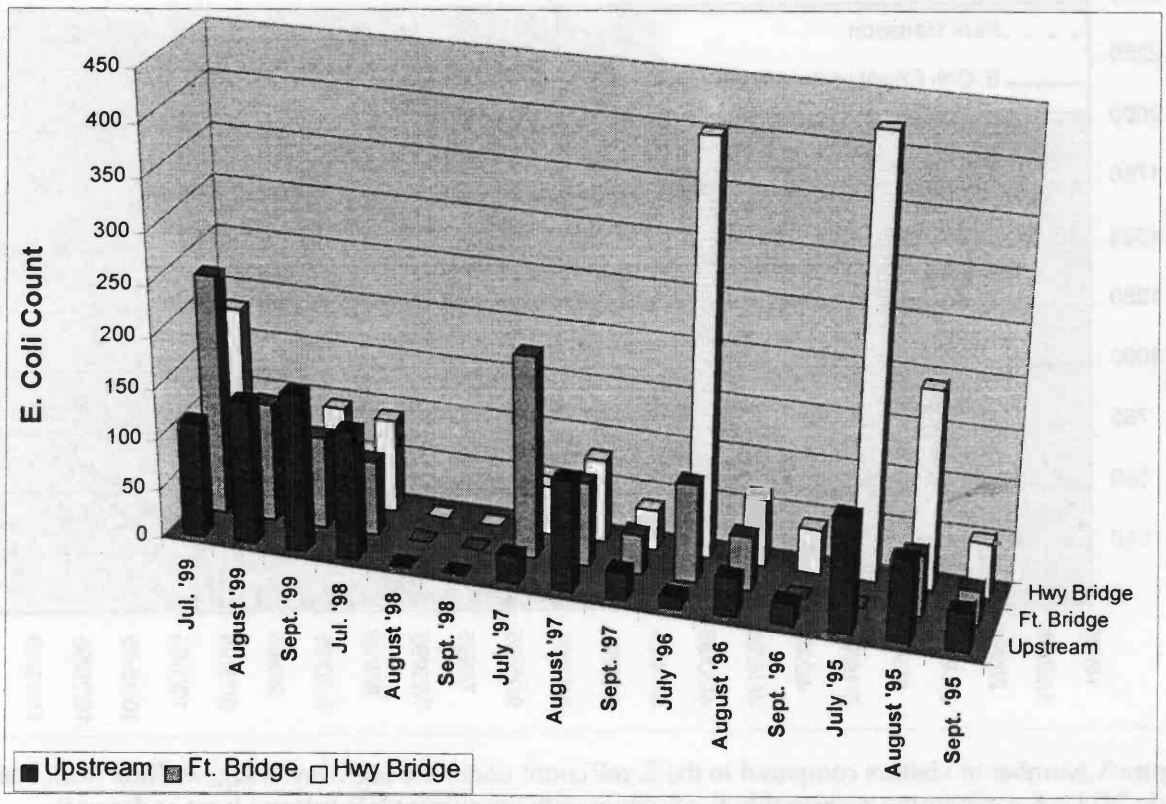

Figure 2. Monthly average *E. coli* values for July, August, and September 1995–99 at three sampling locations (no data available for August and September of 1998).

ever, 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 portion 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 appeal only to visitors seeking full-body water contact. Besides wading, swimming, and sliding, the park provides opportunities to picnic, BBQ, play ball games, hike, and so forth, thereby 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 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 in understanding the relationship 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 latter 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.

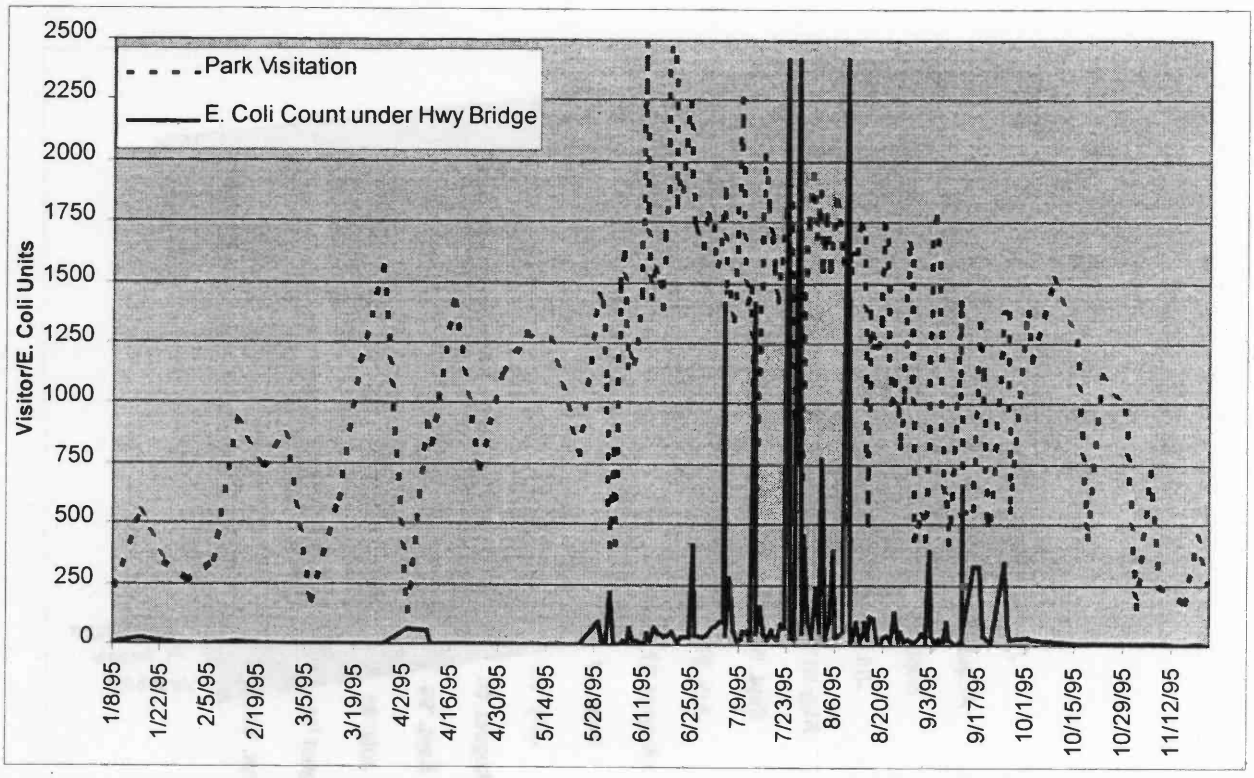

Figure 3. Number of visitors compared to the *E. coli* count under the highway bridge at Slide Rock State Park; 2419 is the maximum measurable *E. coli* count with the current laboratory set-up at the park.

Conclusion

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 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, which include wildlife and livestock grazing in the forest above the rim, and 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 m of the Oak Creek channel (ADEQ 1999). According to Bond and Dunikoski (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 percent becomes wastewater. Similar findings were made by Crabill et al. in 1999. These findings indicate that grazing, residential homes, and the business establishments along the creek probably generate more *E. coli* pollutants than the 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 feel strongly that there is a need for reliable and efficient clean-up procedures, appropriate protection, and timely maintenance of the waters in Oak Creek Canyon. This would require work to clearly identify the types, sources, and amounts of the *E. coli* polluting Oak Creek, as well as to find 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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