5 Water

Among the various impacts of wildland recreation, its influence on aquatic ecosystems is seldom mentioned or understood, yet water quality is a major concern in recreation areas. It serves as both a medium for water-based activities, including body contact sports, and a drinking source for users. Thus, water-related impacts are somewhat unique, different from soil, vegetation, and wildlife impacts in that water quality is more directly related to human health.

Although water quality is sanctioned by law in highly developed recreation areas and has been researched fairly extensively at cottage-based lakes, far less is known about water-related impacts in remote wildland areas. Because of the lack of developed sanitation facilities in these areas, drinking water and human waste disposal are concerns. The problem is compounded by the concentration of backcountry users at alpine lakes and streams. This chapter reviews some of the major physical, chemical, and bacteriological problems of water sources in wildland recreation areas. Lake and river impacts related to high residential development (cottages) will not be considered. For additional review of the effects of recreation on water resources, see Kuss, Graefe, and Vaske 1990.

BASIC WATER ECOLOGY

Aquatic ecosystems, like terrestrial ecosystems, have many parameters that interact to determine water quality. Some of these impact parameters are *direct*, occurring on or in the water. Other impacts to water systems are *indirect*, characterized by inputs that originate from actions that occur on shore or in the watershed (Liddle and Scorgie 1980). Major impact parameters influencing water quality are (1) nutrients, (2) suspended solids, (3) amount of dissolved oxygen, (4) temperature and flow, (5) pH, (6) fecal bacteria and pathogens, (7) dissolved solids, and (8) transparency (Kuss, Graefe, and Vaske 1990). Recreation-related impact research has focused on (1) nutrient enrichment of the water, (2) suspended solids (turbidity), (3) reduced dissolved oxygen, and (4) bacterial contamination in the form of fecal waste. Water temperature and flow, as well as seasonal and site factors, influence the importance of each of the variables.

Water Temperature and Flow

Water impacts reach unacceptable levels commonly under the conditions of warm temperatures and low flow rate. Dissolved oxygen often reaches its lowest levels during warm summer evenings when water flow also is low. Warm temperatures tend to increase the growth of aquatic plants and bacteria, problems of warm water systems. Temperature also affects animal life. Recreational activities can indirectly increase the temperature of lakes and streams, affecting the species composition of fish populations. Some fish can tolerate temperatures as high as about 30°C, whereas trout can survive an absolute maximum of 25°C to 26°C for only a short period of time. As a rule of thumb, trout waters should never exceed 20°C. Removal of stream bank foliage may increase the temperature of trout streams above acceptable levels. In lakes, depletion of oxygen at lower depths (the hypolimnion) forces trout to move to upper layers with sufficient oxygen but higher temperatures, which may be fatal.

Water flow is related to dilution capacities, influencing the concentration of pollutants in water sources at any particular time. Restricted bays and inlets to lakes, as well as slow-flowing springs and streams, often contain the highest bacterial counts and lowest oxygen supplies. In water systems that show a rapid flushing rate or a high flow rate, the danger of poor water quality appears to be minimized. Precipitation patterns and the dilution capacity of a water system can greatly influence the degree of recreation-caused impacts. However, the influence of storms is mixed. The rapid flushing rate of storms can help in removing suspended and dissolved nutrients from streams, but at the same time storms are a major agent at flushing nutrients and soil from disturbed watersheds into lakes and streams. Nutrient influx and coliform bacteria are sometimes most prevalent just following a storm.

Nutrients

Nutrients in lakes are directly related to the aging of these water systems, a process known as eutrophication. The addition of nutrients, primarily nitrogen and phosphorus, stimulates the net productivity of water bodies. A lake normally undergoes natural succession from a young, nutrient-deficient, unproductive lake with high oxygen levels (oligatrophic) to increased nutrient levels, higher production, greater deposits of organic matter, and low oxygen levels (eutrophic). Eutrophication can be accelerated by recreational activities and actions that increase the rate at which nutrients are added to lakes. The additional nutrients increase the rate and amount of plant growth and, if excessive, lead to undesirable weed growth, algal blooms, or the replacement of sport fish by less attractive species. The excessive vegetation also leads to a depletion of the dissolved oxygen supply during decay of the organic plant materials.

For most recreational use, high water quality means low productivity so that lakes are clear, cool, and deep—suitable for swimming, boating, and good habitats for sport fish (Wall and Wright 1977). In alpine lakes even minute changes in nutrients can cause increases in algae populations. Heavy shoreline use of such lakes and streams accelerates soil erosion, leading to an influx of nitrates into these water bodies. Lake edge and stream bank erosion not only accelerate the rate of nutrient influx, but they influence water clarity, an important indicator of water quality for recreation purposes. Water clarity is conditioned by many factors, including productivity levels of the water as influenced by phytoplankton densities, turbidity, and water color.

Phosphorus, in the form of phosphate, tends to be the limiting factor in aquatic plant growth. It has a strong affinity for soil particles and tends to be tied up in the bottom sediments of lakes. However, swimming, wading, boating, and other activities that stir the bottom sediments of streams and shallow lakes may release concentrations of phosphate and other nutrients. Phosphates contained in motor boat oil and in detergents find their way into aquatic systems, although not as much as in the past. Detergents, for example, now contain fewer phosphates than in the past.

The response of lakes to nutrients and their vulnerability to accelerated eutrophication are based on many site factors. Size of watershed or drainage basin, shoreline configuration, mean depth, elevational position, and present trophic status are important (Sargent and Zayer 1976). Shallow lakes with numerous bays and inlets at low elevations with warm temperatures will show the most impact to recreational activities. The type of soils and geology surrounding the lake, as well as type and extent of forest or vegetation cover, will also have an influence on rate of eutrophication.

Dissolved Oxygen

Dissolved oxygen is necessary in respiration of most aquatic organisms. When the depletion of oxygen by respiring organisms occurs at a faster rate than it is being diffused in from the atmosphere or produced by photosynthetic organisms, a deficit in oxygen level may develop. If plant growth and decomposition are excessive, the dissolved oxygen supply of the bottom layer of lakes (hypolimnion) will be depleted by the decay of organic matter. With the increased decay of organic matter, bacterial respiration is high. The depletion is most pronounced in warm lakes because oxygen solubility varies inversely with temperature.

The depletion of oxygen in aquatic ecosystems has several impacts on aquatic animals and plants. The minimal requirements of species vary and often limit the spatial distribution of certain forms in aquatic communities (Reid 1961). Cold-water fish such as trout need a minimum of 6 to 7 parts per million (ppm) of dissolved oxygen; warm-water fish such as bass need a minimum of 5 ppm. Fish kills resulting from oxygen depletion have occurred in lakes, ponds, and streams (Hynes 1970). Many species of aquatic insects are typically replaced by less oxygen-demanding species as an oxygen deficit develops, causing further changes in aquatic populations positioned higher on the food chain. Availability of oxygen affects plants in primarily two ways: species composition and nutrient uptake. Some submerged species of aquatic plants are sensitive to low levels of dissolved oxygen and are replaced by more tolerant species. In terms of nutrient levels, phosphate increases under anoxic conditions and becomes more readily available for plant production in the surface layers of lakes. Thus, nutrient level, plant production and decomposition, and dissolved oxygen supply are all intricately related. In relation to recreational use, the impact can be summarized as follows: with recreational use, production in lakes can be quickly altered from acceptable rates to excessive growth rates with associated changes in oxygen supply and species composition of aquatic organisms (Vander Wal and Stedwill, 1975).

Pathogens and Other Pollutants

The major concern with recreational aquatic impacts involves the presence of pathogens and pollutants that directly influence human health. Pathogens are disease-causing organisms that are transmitted by the feces of human and other warm-blooded animals. The major source is raw or inadequately treated sewage, a particular concern in remote recreational areas. Pathogens at unacceptable levels are a serious health hazard, making water sources unfit for body contact and drinking.

Human feces contain more than 100 viruses, bacteria, and protozoa that cause disease or death to infected humans (Cowgill 1971). The common indicator bacteria such as total coliforms, fecal coliforms (FC), and fecal streptococci (FS) are widespread in fecally contaminated environments and originate from diverse sources, including the intestinal tract of humans, other mammals, birds, and reptiles (Kabler and Clarke 1960; Kuss, Graefe and Vaske 1990). The presence of coliforms in a stream or lake usually indicates recent fecal pollution and the possible presence of enteric pathogens. Coliform bacteria themselves are nonpathogenic but are used as indicators because they are more easily measured than the pathogens with which they are associated.

The relationship of fecal coliform (associated with humans) to fecal streptococcus (associated with other animals) density (FC/FS ratio) is used to provide information as to sources of pollution.

> Based on per capita contributions of indicator bacteria from man and domestic livestock, FC/FS ratios greater than about 4:1 are usually indicative of man's body wastes. Ratios less than about 0.7:1 suggest contamination originated from livestock, wildlife, storm water runoff, and other nonhuman sources (Gary 1982, p. 5).

As will be documented later in this chapter, animal sources of coliform appear to be more prevalent in wilderness areas than are human sources.

Human wastes are also a source of nutrients. Feces of humans may contain as much as 1.5 g of phosphorus and 10.4 g of nitrogen per person per day (Liddle and Scorgie, in Kuss, Graefe, and Vaske 1990). In sterile, remote environments human and animal feces located around heavily used lakes can be two of the most common sources of bacterial influx to these aquatic systems (Merriam, Smith, Miller, Huang, Tappeiner, Goeckerman, Bloemendal, and Costello 1973).

Other major sources of pollutants in wildland aquatic areas fall into the categories of oil products, solid wastes, and sediments. All three of these water quality impacts are greatly associated with motor boating. Muratori (1968) suggests that 500 million liters of unburned outboard fuel are discharged every year into the navigable waters of the United States. Litter, in the form of bottles and cans, finds its way to the bottom of lakes and streams. Finally, turbidity of streams and lakes, which is due to boat propeller action and aquatic activities, can influence light penetration through water and reduce photosynthesis.

IMPACTS ON WATER QUALITY

Nutrient Influx

Nutrients, primarily nitrogen and phosphorus, enter wildland water systems mostly as a result of shoreline and campsite erosion. However, seasonal data to indicate that wildland recreation activities are a major impact on nutrient balance in lakes and streams are generally lacking (Gosz 1982). Studies in campgrounds usually fail to show increased nutrient levels in associated waters (Brickler and Utter 1975; Gary 1982; Segall and Oakley 1975). In some cases moderately eutrophic conditions are found in streams in campgrounds, but analyses upstream indicate that the nutrients are primarily from natural sources. Potter, Gosz, and Carlson (1984) list natural sources to include precipitation, run off, bottom sediments, decomposing plankton, transient waterfowl, falling tree leaves, bedrock type and natural soils.

Gary (1982) surveyed over a three-month period the nutrient balance of a Colorado stream as water entered and left a small commercial campground. Levels of NO_3-N did not exhibit any definite seasonal trend, and concentrations at three study sites were not significantly different. Other chemical and physical properties remained unchanged and were not significantly increased by campground use. Similar results have been obtained for campgrounds that are equipped with modern sanitation facilities (Gosz 1982).

In mountainous backcountry areas where lakes are normally oligotrophic and are popular recreation areas, the impact of nutrient influx is a particular concern. Algae populations in oligotrophic lakes respond to only small changes in nutrients. Shoreline and campsite erosion and water contamination by campers are potential sources of nutrients in these systems. Silverman and Erman (1979) studied two lake basins, one receiving high visitor use and the other low use, in Kings Canyon National Park, California, for differences in water quality. Visitor use was found not to affect the condition of the lakes; however, there were extreme differences between the basins because of natural sources. The basin lakes receiving low use had about 60 times more nitrates than the high-use lakes early in the summer. Phosphate concentration was similar for all lakes. Background levels and natural sources of nutrients are a major problem when relating recreational use to nutrient influx. In many cases natural sources contribute the largest quantities of nutrients, making comparative studies difficult to interpret (Barton 1969). Baseline studies of conditions before and after recreation occurs in an area are needed, rather than studies that compare areas of high and low visitor use. However, this procedure may not be the complete solution. Stuart, Bissonnette, Goodrich, and Walter (1971) found that a closed watershed, when opened for "limited recreation and logging," actually decreased in bacterial contamination.

Phosphate appears to be more of a nutrient input in wildland areas than nitrogen. Water quality studies carried out at nine campground sites and controls in the Boundary Waters Canoe Area, Minnesota, indicated that recreational use increased phosphate concentration and coliform bacteria in the lake water near campsites. Flushing of the bare, campsite impact zones and of fire pits is a common occurrence with each rainstorm and contributes to the nutrient input of the lakes (Fig. 1). Even though phosphate and coliform levels increased at the BWCA campsites, other water quality parameters, including temperature, dissolved oxygen, pH, specific conductance, nitrate concentration, and nitrogen were not affected by recreational use.

Dickman and Dorais (1977) found that human trampling of the shoreline and steep-sided basin of a semiwilderness lake in Canada led to an exceptionally high phosphorus loading of the lake. Over a 20-year period (1956–1976) recreational use of the small lake increased tenfold, significantly reducing plant cover in the lake basin and increasing erosion on its steep slopes. The trampling and resulting erosion caused a phosphorus loading of 854 mg/m^2 of lake surface, placing Pinks Lake among the most eutrophic lakes of North America (Dickman and Dorais 1977). However, the lake receives no municipal, agricultural or rural effluent discharge because of its location in a semiwilderness, forested watershed. A significant portion of the dissolved phosphorus is entering the eutrophic zone of the lake from apatite-rich rock, which has eroded following the destruction of ground cover as a result of human trampling. The causal link between human trampling and the high phosphate concentrations was further corroborated by leachate tests of the eroded apatite rock material near the edge of the lake. The tests independently supported the hypothesis that apatite-derived, dissolved phosphorus was the principal factor responsible for the high concentrations of phosphorus in the spring.

FIGURE 1. Rainstorms flush nutrients and pollutants from campsites and fire pits directly into the nearby lake, Boundary Waters Canoe Area, Minnesota. (*Photo*: W. E. Hammitt.)

Coliform Bacteria and Other Pathogens

The major controversy over recreational use of water is based on a sanitation concern. Many studies suggest that recreational activity is a significant source of bacterial contamination. Likewise, many studies fail to show significant water quality degradation because of wildland recreation. Many results are site specific, and in a number of cases, conflict with each other. Thus, there is a divergence of opinion on the question of recreational impact on bacterial water quality levels (Aukerman and Springer 1975; Gosz 1982; Kuss, Graefe, and Vaske 1990; Wall and Wright 1977).

Studies conducted in wildland areas show that while sewage-flow rates may be the most significant source of bacterial contamination in developed recreational areas, this is not the case with wildland recreation. Campgrounds and other use areas in wildlands often have little or no water directly associated with sewage disposal (pit, vault privies, or no facility), as well as lower production (i.e., fewer individuals, as well as per capita production of sewage wastes in terms of laundry, dish water, etc.). The primary source of bacterial contamination in wildlands is from surface soil, a result of both background levels of microorganisms and those associated with human and domestic animal waste products (Gosz 1982). Regardless of the presence or absence of humans, natural bacterial densities in soils are high enough so that precipitation can be expected to increase the bacterial counts in nearby streams and lakes. No natural water source could consistently meet potable water standards, because of the normal influx of bacteria (Potter, Gosz, and Carlson 1984; Silverman and Erman 1979).

One of the first backcountry studies to indicate that recreational use affects coliform bacteria was the work of King and Mace (1974) in the Boundary Waters Canoe Area, Minnesota. They found that coliform bacteria populations of water at canoe campsites were significantly higher than at control points (Table 1). The average coliform levels at the campsites were above the maximum (2.2 organisms/100 ml) considered safe for drinking water. The difference between campsites and controls was larger for the high- and medium-use campsites, suggesting a relationship between use level and coliform bacteria density. High bacterial counts were found only adjacent

TABLE 1. Coliform Populations for the Various Use Classes of Campsites: University of Minnesota, BWCA Campsite Study, 1970

	(Number of Coliform/100 ml) Use Categories		
Location	High[a]	Medium	Low
Campsite	4.61	6.63	5.83
Control	0.28	1.95	4.68
Difference	4.33	4.68	1.15

Source: Merriam, Smith, Miller, Huang, Tappeiner, Goeckermann, Bloemendal, and Costello 1973.

[a] High-use sites had over 1100 visitor days total use, medium-use sites had over 500 visitor days total use, and low-use sites had under 300 visitor days total use.

to the campsites, indicating that the effect on the lakes is generally small. Effluent from the pit toilet on each campsite was determined as the probable source of the bacteria (Fig. 2). Because the soils are shallow, effluents reach bedrock quickly and drain into lake basins. Shoreline activities at the campsites such as swimming, washing dishes, cleaning fish, and boat launching are other probable causes (King and Mace 1974). Such activities stir bottom sediments, shown to be a microbial habitat where the organisms from the fecal matter of warm-blooded animals can persist and concentrate (Van Donsel and Geldreich 1971).

In the heavily used backcountry areas of the White Mountains of the northeastern United States, coliform levels have been a problem near shelters and huts. In untreated water supplies at shelters or major trails, the presence of fecal and total bacteria was found to vary seasonally for most lakes, springs and streams. Highest counts occurred in late July, with some counts in excess of recommended public health standards. However, by late August most waters sampled were nearly clear of bacteria.

At developed campgrounds in wildland recreation areas, Varness, Pacha, and Lapen (1978) and Johnson and Middlebrooks (1975) reported significant increases of coliform bacteria associated with recreational use. Varness, Pacha, and Lapen (1978) found higher bacteria densities downstream from heavily used camping areas without sanitary facilities, and Johnson and Middlebrooks (1975) found that sharp increases in fecal coliform counts coincided with peak recreational use at areas having toilets. The peak use levels of bacteria dropped sharply at the end of the recreation season.

Where water quality problems have been identified with recreational activities, most appear where use is concentrated and density dependent. Bacterial pollution resulting

FIGURE 2. Pit toilets, if located on shallow soils and near water, can be a source of coliform bacteria and associated pathogens. (*Photo:* W. E. Hammitt.)

from recreation use appears to be more closely related to the total number of people visiting an area during a given seasonal period than to total length of stay. "These impacts relate to: 1) effects that are highly density dependent, such as peak season, holiday, or weekend use versus weekday use; 2) location of sites that concentrate use; 3) the number of sites within the watershed; 4) the frequency with which the sites are used; and 5) the condition of available facilities" (Kuss, Graefe, and Vaske 1990, p. 124).

Other investigations in both remote backcountry areas and at developed facilities in wildland recreation areas support the argument that recreational use has *no* significant adverse impact on the bacterial quality of water. Aukerman and Springer (1975) found no significant increases in coliform bacteria at heavily used developed campgrounds or at remote backcountry campsites in Colorado. In fact, they found an inverse relationship between cases of bacterial density increases and levels of campground utilization. The study is significant in that it involved three types of camping (i.e., campgrounds off paved roads, campgrounds off unpaved roads, and roadless backpacking sites), a number of campgrounds, and a heavily used recreational area. The authors concluded that "although campers are contributing to the bacterial pollution of the Cache la Poudre River watershed, the amount contributed at each campground is insignificant in terms of established water quality standards."

Similar results showing insignificant levels of coliform bacteria have been reported for alpine lakes in Kings Canyon National Park, California (Silverman and Erman, 1979), for water sources in Great Smoky Mountains National Park (Silsbee, Plastas, and Plastas 1976), and for developed campgrounds in Colorado (Gary 1982) and Wyoming (Skinner, Adams, Richard, and Beetle 1974). In Kings Canyon National Park only 10 percent of the water samples had positive total or fecal coliform, and at most two per sample. Fecal streptococci levels were somewhat higher than coliform (52 percent positive samples and a maximum count of eight colonies per sample), indicating wildlife as the source. Skinner, Adams, Richard and Beetle (1974), studying a natural watershed open only to hikers and wildlife, found yearly means for fecal coliform in 1970, 1971, and 1972, to be 1.2, 0.6, and 0.2 organisms/100 ml, respectively. The fecal streptococci bacteria counts for the same years were 22, 2, and 3/100 ml.

An important issue concerning recreational areas that contain hazardous levels of bacteria is the source of the contamination. Many studies that have identified the source report the contamination to be from nonhumans. Livestock is responsible in some cases (Marnell, Foster, and Chilman 1978; Silsbee, Plastas, and Plastas 1976), and in many instances wildlife contaminate the water (Potter, Gosz and Carlson 1980; Silsbee, Plastas, and Plastas 1976). In the Great Smoky Mountains National Park, European wild boars that root and wallow in springs and other water drinking sources are a major source of fecal streptococci bacteria. Bacteria in the feces of wildlife are as much a health hazard as those of humans. Therefore, reducing or managing the number of recreation users to an area may not necessarily reduce the bacterial levels to within safety limits. Moreover, drinking and cooking water may need to be boiled even in areas receiving little or no recreational use.

There are some instances that suggest that in remote wildland areas light recreational use will improve the bacteriological quality of water sources because wildlife will avoid the areas (Stuart, Bissonnette, Goodrich, and Walter 1971; Walter, Bissonnette, and

Stuart 1971). Walter and Bottman (1967) compared a closed watershed and one open to recreational use. They found that bacterial counts (fecal coliforms and fecal streptococci) were higher for the closed watershed than for the open watershed, which in 1970 had been opened for "limited recreation and logging." Bacterial contamination decreased in the streams after the watershed had been made available for human use. The authors concluded that human activities had resulted in a reduced wildlife population, which had contributed substantially to the previous bacterial pollution.

Little is currently known about the accumulation of bacterial organisms and nutrients in the bottom sediments of wildland water sources. Most studies of bacterial contamination examine only the surface waters when, in fact, the bottom sediments may contain the larger concentrations of organisms and nutrients. Brickler and Tunnicliff (1980) found fecal coliform densities in bottom sediments to be significantly higher than in surface water of rivers and tributaries in Arizona. Surface water FC densities ranged from 2.1 to 8.0/ml in the Colorado River, whereas densities in bottom sediment reached 48,000/ml. Forty-three percent of the sediment samples exceeded 500/ml, and 34 percent of them exceeded 1000/ml. Bacterial levels in bottom sediments are of considerable importance since several recreational activities such as swimming and boating cause suspension of bottom sediments and direct contact of the microorganisms with recreationists. As more bottom sediment analyses are conducted, they may modify considerably our thinking about the status of water quality as represented by analyses of surface water alone (Gosz 1982).

Backcountry Camping and Drinking Sources

The previous discussion on coliform bacteria dealt with levels found in lakes and streams, with no specific attention devoted strictly to drinking sources in backcountry camping areas. Because water is not chemically treated in these areas and is often taken from springs or very small tributaries, bacterial contamination is a concern. Giardiasis, hepatitis, and other diseases are a constant potential threat in these situations (Fig. 3).

Giardiasis, an intestinal disease caused by the protozoan pathogen *Giardia lamblia*, has been reported with increasing incidence by recreationists utilizing sources of water that drain forested and mountain areas. In recent years, cysts of *Giardia* have been reported in surface waters of Rocky Mountain, Olympic, Sequoia, and Yosemite National Parks as well as several national forests and wilderness areas (Monzingo, Kunkle, Stevens, and Wilson 1986; Cole 1990). As stated by Cole, it is not clear whether incident of *Giardia* is increasing because contamination is spreading or whether the disease is being more frequently and accurately diagnosed. Nevertheless, giardiasis infections have caused almost 50 percent of the reported waterborne disease outbreaks in the country since 1971 (Martin, Kunkle, and Brown 1986).

The disease is transmitted through fecal contamination of food and water or through direct fecal-oral contact. Beaver, muskrat, rodent, elk, domestic cattle, and dogs have been linked as major vectors of waterborne giardiasis. Symptoms of the disease include diarrhea, abdominal cramps, flatulence, greasy and foul-smelling stools, abdominal bloating, fatigue, weight loss, anorexia, and nausea (Monzingo and Stevens 1986).

FIGURE 3. Bacterial contamination is a constant concern with drinking sources in the backcountry. (*Photo*: W. E. Hammitt.)

It has been established that where large numbers of outdoor recreationists concentrate, as many as one in ten animals may be carriers of *Giardia* cysts (Monzingo, Kunkle, Stevens, and Wilson 1986). For example, examination of several watersheds in Rocky Mountain National Park has led to the conclusion that the risk of ingesting viable *Giardia* cysts from contaminated water is high in areas where beaver are active, moderate in high human-use areas or where marginal beaver habitat occurs, and low in areas of limited human use and poor beaver habitat. Kuss, Graefe, and Vaske (1990, p.114) recommend that "because of the rising incidence of the disease and the number of vectors, however, all surface water should be suspect and sterilized by boiling."

Silsbee, Plastas, and Plastas (1976) surveyed the fecal coliform and streptococci concentrations in four types of water sources in Great Smoky Mountains National Park: flowing springs, seepage springs, spring-fed streams, and tributary-fed streams. A flowing spring is a spring that flows from a localized source and can be sampled directly as it comes from the ground. A seepage spring seeps from the ground over a wide area and after it has flowed over the ground surface for some distance, drinking water can be obtained from it. Spring-fed or primary streams are fed mainly by a spring or by seepage. A tributary-fed or secondary stream is one fed by various tributaries.

Flowing springs tended to be the best drinking water sources, giving consistently low coliform counts (Table 2). Seepage springs were highly variable, giving both low and high counts. Small spring-fed streams also tended to be variable and gave high counts at times. Larger tributary-fed streams generally gave consistent levels of contamination although somewhat higher than flowing springs. These results indicate that following springs are the best drinking sources, followed by secondary streams. However, even in the secondary streams the coliform levels average in the danger zone.

Sources of bacteria in the four drinking sources were primarily wildlife. Most of the FC/FS ratios indicated animal sources of contamination. Data collected from above and below campsites and outhouses showed that they did not have a major effect on the bacteriological quality of the water in the areas tested. The backcountry staff of Great Smoky Mountains National Park strongly recommend that campers boil all drinking water used in the backcountry.

Solid Waste and Foreign Materials

Solid waste in the form of litter tends to accumulate at the bottom of streams and lakes. The amount of solid waste carried into backcountry areas is potentially greater for watercraft activities than for backpacking since the materials are more easily transported. During the summer of 1969, solid waste left behind by recreational users of the Boundary Waters Canoe Area, Minnesota, totaled an estimated 360,000 lbs of bottles, cans, and other nonburnable refuse (King and Mace 1974). This averages to about 3 lbs per recreation user. Barton (1969) estimates that the solid waste figure of 360,000 lbs is equivalent to 1 ton of phosphates and 13 tons of nitrogen. In addition, decomposition of the material provides an abundant supply of trace elements as well as some major ions (Barton 1969). Since the 1970s the Boundary Water Canoe Area and other areas have prohibited bottles and cans on the backcountry lakes (Fig. 4).

TABLE 2. Comparison of Different Types of Backcountry Water Sources and Fecal Coliform Densities

	Range of Fecal Coliform Counts (Percent)					Number of Samples
Source Type	0	1–10	11–30	31–100	>100	
Primary stream	32	20	20	24	4	21
Secondary stream	15	77	7	1	0	72
Flowing spring	72	28	0	0	0	32
Seepage spring	33	40	15	8	4	21
All streams	20	62	10	7	1	93
All springs	57	32	5	4	2	53

Source: Silsbee, Plastas, and Plastas 1976.

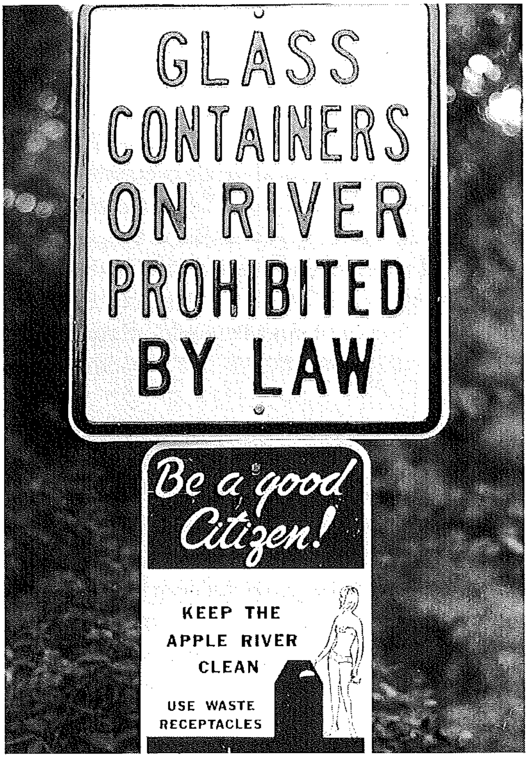

FIGURE 4. Some heavily used water resource areas prohibit the use of bottles and cans in the backcountry. (*Photo*: D. W. Lime.)

Much concern has been expressed over the potential harm of oil and gasoline from outboard motors in aquatic ecosystems. Because outboard motors are two-stroke engines, the engine lubricant oil is mixed directly with the gasoline. The exhaust discharged into water by outboard engines contains oil and gasoline residues. Muratori (1968) and Stewart and Howard (1968) report that "as much as 4 gal of gasoline mixture out of every 10 may be discharged into the water from outboard motors." Modern motors should usually discharge between 10 to 20 percent of their fuels into the water. Besides the gasoline and oil being discharged into the water, the use of leaded gasolines has the potential of ejecting tetraethal leads into the water, which accumulate in bottom muds and may affect aquatic organisms (Barton 1969). English, Surber, and McDermott (1963) reported that outboard motor exhaust-water contains an average of 105 g/gal of nonvolatile oil, 57 g/gal of volatile oil, 0.53 g/gal of lead, and 0.60 g/gal of phenols.

The primary ecological effect of outboard motors is the deposition of oil on aquatic organisms. Oil in water attaches to the surface of unicellular plankton and other plants to interfere with air-gas exchange. Oil films also inhibit the growth of many forms of algae, disturbing the food chain of fish and other aquatic organisms. In addition to coating the surface of floating plants to interfere with gas exchange, oil can lead to oxygen depletion. One gram of oil in water requires 3.3 g of oxygen for complete oxidation (Barton 1969). Oil extracts can also stimulate bacterial growth, which is significant in that these organisms are competitors with algae for oxygen and nutrients found in water.

Phosphates and other chemicals contained in fuel-oil mixtures can also affect aquatic organisms, although little conclusive data exist (Jackivicz and Kuzminski 1973; Liddle and Scorgie 1980). Tainting of fish flesh occurs at a fuel-usage level of 8 gal of outboard motor fuel per million gal of lake water per season (English, Surber, and McDermott 1963). Oil also has an adverse effect on fish growth and longevity. However, in experimental ponds, Lagler, Hazzard, Hazan, and Tomkins (1950) found no effects on population of fish or plants that could be attributed to outboard motor exhaust.

Suspended Matter and Turbidity

Suspended matter may be the single most common factor influencing alterations in water quality in recreation areas. Anderson, Hoover, and Reinhart (1976) estimate that 80 percent of the deterioration in water quality is due to suspended solids. While in suspension, such solids cause waters to be turbid; reduced light penetration may restrict the photosynthetic activity of plants and the vision of animals. These finely divided materials at high concentrations are known to interfere with the feeding of filter feeder organisms and are abrasive to sensitive structures such as the gills of fish (Warren 1971). Reproduction of fish, particularly trout, and fish food are affected as these materials settle out. Perhaps most important for recreation purposes, increased loads of suspended solids greatly reduce the clarity of water and the public's desire to enter it.

Turbidity, related to recreation, can originate in water bodies from primarily three zones: bottom sediments, shorelines and adjacent banks, and the surrounding watershed. The disturbance of stream and lake sediments by boats and swimmers has been reported. Liddle and Scorgie (1980) report numerous aquatic plants that are uprooted by the wash and turbulence resulting from outboard motor propellers in shallow waters. Narrow channels are particularly sensitive because of the repeated use of such areas. Boats propelled by oars and/or paddles impart relatively little impact to stream bottoms, except in shallow stream riffles where canoes commonly scrape periphyton from rocks. Although boating may increase turbidity in selected high use areas, there seems to be little quantitative evidence that it is a major impact factor (Hansen 1975; Lagler, Hazzard, Hazan, and Tomkins 1950; Liddle and Scorgie 1980). For example, Lagler and colleagues found no recordable increase in turbidity because of outboard motors in their experimental ponds, even though there was considerable movement of the bottom sediments. There was some redistribution of benthic invertebrates, but no damage was recorded.

Swimming, wading, and fishing contribute to turbidity but only when concentrated in space and time. Gary (1982) recorded dramatic increases in suspended solids from waders near a small commercial campground on a few days when use was high. As soon as recreationists left the sampled area, suspended solid levels fell to almost predisturbance levels. Waders and swimmers in Great Smoky Mountains National Park also have an influence near campgrounds and heavy use segments of streams.

Streambank erosion and resulting suspended sediments are largely a result of trampling. Many wildland recreation activities concentrate at one time or another near the edges of water bodies. People walking in and out of water and up and down streambanks can quickly destroy the vegetation that protects shoreline soils from erosion (Fig. 5). Marginal vegetation and soils may also be damaged by those walking parallel to the water's edge but not directly engaged in water activities. Larson and Hammitt (1981) found that onlookers were a dominant source contributing to streambank impacts near family campgrounds. The crossing of streams by ORVs and horses also disturbs streambanks and bottom sediments, but again the impacts are usually quite isolated (Fig. 6).

Turbidity impacts from watershed disturbances are associated primarily with certain multiple-use land management practices (e.g., logging) and some recreation-caused erosion. Off-road vehicle and hiking trails in the southern Appalachian Mountains of the United States erode quickly where 80 to 90 in. of annual rainfall may be present. However, gravel roads, logging trails, and cutting practices in multiple-use recreational areas are probably a bigger contributor of watershed impacts than recreational use trails.

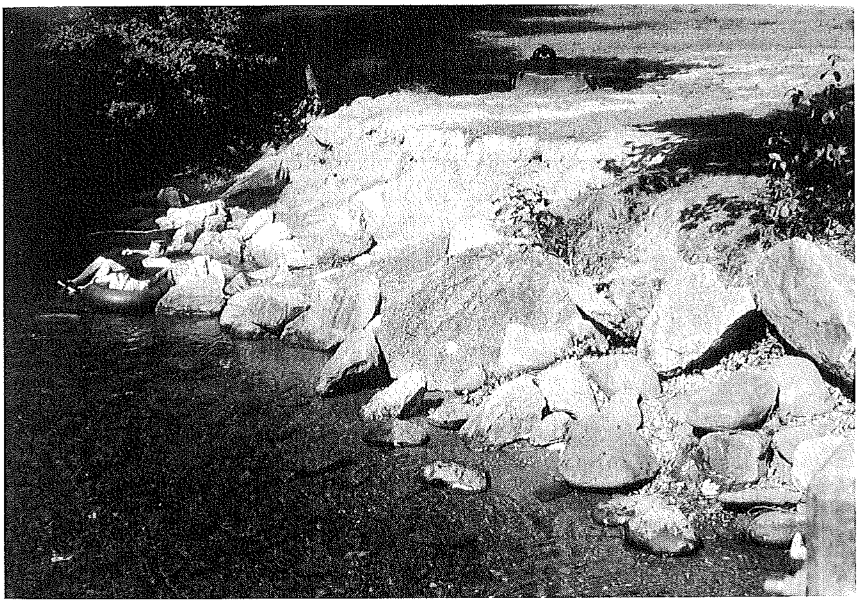

FIGURE 5. Swimmers and innertube floaters are causing streambank erosion at the put-in and take-out locations in Great Smoky Mountains National Park. (*Photo*: W. E. Hammitt.)

FIGURE 6. Off-road vehicles can greatly disturb streambanks and bottom sediments when crossing streams (*Photo*: W. E. Hammitt.)

SUMMARY

1. Water quality is a major concern, but not a frequent impact, in wildland recreation areas. It serves as a medium for body contact sports and as a drinking source for users. Thus, water-related impacts are unique in that they are more directly related to human health than soil, vegetation, and wildlife impacts.

2. Nutrient level, aquatic plant production and decomposition, and dissolved oxygen supply in aquatic ecosystems are all intricately related. With recreational use, plant production in warm lakes and streams can be quickly altered from acceptable rates to excessive growth rates with associated changes in oxygen supply and species composition of aquatic organisms.

3. Although coliform bacteria and quality of drinking water are obvious concerns in wildland recreation areas, there is conflicting research evidence that backcountry recreation drastically impacts water quality. More studies have failed than have shown significant increases in coliform counts as a result of recreational use. In several situations wildlife have been the dominant source of bacteria contamination in drinking water sources.

4. Suspended matter and turbidity may be the single most important water quality factor in the eyes of recreationists. Increased loads of suspended solids greatly reduce the clarity of water and the public's desire to use it.

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