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PROFILE

Wildland Recreation and Human Waste: A Review of Problems, Practices, and Concerns

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ABSTRACT / Proper disposal of human waste is an important concern for the appropriate management of wildlands. This paper reviews the state of knowledge regarding pathogens and human waste disposal in dispersed backcountry recreation areas in the United States. Of concern is the impact of travelers, such as backpackers, backcountry skiers, and mountaineers, in areas where toilets are not provided. At this time, the magnitude of problems related to human waste disposal in wildlands is unclear. Aesthetics and water contamination with the resultant potential for disease transmission are the predominant issues. Few studies have analyzed the aesthetics of human waste disposal. In wildlands, contamination of water sources primarily originates from surface soil. The fate of enteric pathogens on or in soils is highly variable and dependent on the complex interactions of many factors, most importantly soil type, moisture, and temperature.

It is difficult to make general recommendations that apply to all ecosystems. There is still a relative dearth of studies that allow the manager or visitor to come up with specific practices that are the best for their area. The preferred method of disposal remains to dig a small hole (cat hole) and bury the waste. Other site specific methods are also discussed.

Treatment of drinking water has become standard practice for most backcountry travel. With such treatment, there is little evidence currently to suggest that the health hazard to humans is great enough to impose further regulation in areas currently using cat holes.

Recreational use of backcountry areas in the United States has increased significantly in recent decades (Hammit and Cole 1998, Cole 1996) and is currently estimated to be approximately 20 million visitor-days per year (Hampton and Cole 1995). Accompanying this increase is a potential for disturbance and degradation of wildland areas and an ongoing need to monitor and address potential direct and indirect user impacts. Improper disposal and concentration of human feces is a recognized problem. Carothers and Johnson (1984) counted 108 piles of feces and accompanying toilet paper at a single beach camp in Glen Canyon National Recreation Area. At one campsite without facilities, Christensen and others (1978) counted 43 toilet tissues, with most of these located close to water. Excreta was generally not found with the tissue, and it was suggested that dogs, dung beetles, coyotes, or natural weathering possibly removed the fecal matter, increasing the chances of pathogen dispersal and possible contamination. Twenty-five percent of National Park Service managers reported that inadequate disposal of human waste was a common problem in many of their backcountry areas (Marion and others 1993).

Currently, there is little applied research on the effectiveness and accompanying problems of various human waste disposal methods. Many sources of information on the best practices for wildland visitation (e.g., Hampton and Cole 1995) suggest disposal techniques that include shallow burial in soil (cat holes), latrines, surface disposal, and carrying out of feces. In many cases, these suggestions have been based on observations and experience instead of experimental work.

There are two primary concerns with the disposal of human waste in the backcountry: human health problems as a consequence of either direct contact or contamination of drinking water, and aesthetic concerns of visitors who find improperly disposed human waste. Moreover, the transmission of disease-causing pathogens (bacteria, viruses, and protozoans) from human feces is a serious health concern.

Our study reviewed the relevant literature to arrive at the best suggestions for fecal disposal in various wildland environments. We examined topics that included basic microbiology and parasitology, soil processes, water quality, and the transport and fate of fecal pathogens. We consulted biological, government, and agricultural, expanded academic, and social science

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indexes. Most literature reviewed was from non-wildland–based research, since limited applied work has been done. Interviews were conducted with microbiologists and water quality and waste management specialists to clarify certain issues and problems. This review aims to summarize all direct and related research to provide a background for land managers, outdoor educators, and backcountry visitors who seek to determine the best practice of waste disposal for their specific site. It cannot replace thorough field examinations of levels of use, environmental concerns, and site-specific considerations.

Significance of the Problem

Over 100 bacteria, protozoans, and viruses are potentially present in human feces and capable of causing illness (Cowgill 1971). Common parasites include *Giardia lamblia*, *Cryptosporidium parvum*, and *Entamoeba histolytica*. Viral infections include hepatitis A, gastroenteritis caused by rotavirus, Norwalk-like agents, and viruslike particles (Singh and McFeters 1992). The pathogens most pertinant to backcountry travelers will be discussed in detail.

Giardia

The protozoan *Giardia* sp. appears to be the most common animal parasite affecting humans in the United States, and some recognize it as such for the entire world (Hibler and Hancock 1990). Giardiasis, caused by *Giardia* sp., can be transmitted through fecal contamination of food and water or through direct fecal-oral contact. Though waterborne transmission of *Giardia* is believed to be the least common mode of transmission overall (Hibler and Hancock 1990), it is the primary concern of backcountry travelers because many *Giardia*-infected areas exist in the backcountry. Studies reviewed by Hibler and Hancock (1990) have found that in Colorado 40% to 45% of beaver were infected; 48% of muskrats and as many as 20% of cattle were shedding cysts. Beaver have been implicated most frequently as the major source of *Giardia* contamination (Cole 1990). Cows have also been shown to harbor the human-infective *Giardia* (Suk and others 1986). Dogs may be important reservoirs for the human *Giardia* sp. (Woo 1984); they can defecate in or near water and roll in feces, thus helping spread cysts (Davies and Hibler 1979). Wild animals may dig up and consume feces, possibly becoming infected. Most animals are believed to lose their infectivity over winter, and, overall, humans are considered the most important component in the epidemiology of giardiasis (Davies and Hibler 1979). One milligram of feces may contain 300 million cysts (Bemrick 1984), and ingestion of even a few cysts of *G. lamblia* is can lead to infection (Rendtorff 1954).

Suk and others (1987) found that human presence may play a significant role in and/or be a useful indicator of *Giardia* contamination of surface water. Likewise, Monzingo and Stevens (1986) have indicated that the intensity of human use may be a factor in *Giardia* contamination, with more contamination in higher use areas.

Though the recorded incidence of giardiasis among backcountry visitors increased from 123 reported cases in 1965 to 1058 in 1977 (Craun 1979), it is uncertain whether this is because of increased awareness and more accurate diagnosis by physicians or increased water contamination (Suk and others 1986). On surveying intestinal parasites in the United States, Kappus and others (1994) found that *Giardia* is increasingly identified, and its incidence may be on the rise. Most outbreaks of waterborne giardiasis are only reported if multiple individuals are infected from a common source. Backpackers and campers who become infected are generally not reported as ‘‘outbreaks’’ (Martin and others 1985).

Cryptosporidium

Another protozoan, *Cryptosporidium*, has been recognized as a potential waterborne disease-causing agent. Although several species of *Cryptosporidium* exist, only one, *C. parvum*, is known to be infectious to humans, and there is a question whether the many strains of *C. parvum* differ in virulence and infectious dose (Pontius 1995). A low dose of *C. parvum* oocysts can cause infection in healthy adults (DuPont and others 1995). In humans, *Cryptosporidium* is most commonly associated with profuse, watery diarrhea. Additional symptoms include abdominal pain, nausea, vomiting, and fever (Rose 1990a). Those infected may be asymptomatic, yet still transmit the disease (Pontius 1995). Currently there is no treatment available; the disease is self-limiting in all but those who are immunosuppressed (Rose 1990a, Pontius 1995).

Rose (1990a) notes that *Cryptosporidium* is similar to other enteric organisms; person-to-person contact, waterborne, and foodborne routes of transmission may all play a role. According to Rose (1980a), ‘‘sewage discharge may be a significant source of contamination of oocysts in the environment. This may not only be a potential risk for humans but also for animals’’ (p. 302). *Cryptosporidium* oocysts have frequently been isolated from a variety of surface waters throughout the United States (Madore and others 1987, Ongerth and Stibbs 1987, Rose 1990a), and infections are likely to be identified more frequently as laboratories adopt better diagnostic techniques (Kappus and others 1994). *Cryptosporidium* and *Giardia* can both originate from animals, so their presence in backcountry water supplies is common. Rose and others (1991) found that 24% of pristine waters tested contained *Cryptosporidium* oocysts, and 5% contained *Giardia* cysts; in contrast, 42% of polluted waters contained oocysts and 15% contained cysts. *Cryptosporidium* was detected more often than *Giardia* in every type of water; this may reflect the widespread occurrence of *Cryptosporidium* in a variety of animals (Rose and others 1991). Studies indicate a wide range of cross-species transmission. The most extensive studies indicate that oocysts from humans and cattle may infect many mammalian species, including dogs, mice, and sheep (Fayer and Unger 1986). This pathogen is known to be resistant to commonly used disinfection techniques, including iodine and chlorine (Conner and Seward 1993).

Additional Pathogens

Other main pathogens passed via feces include the bacteria *Salmonella* sp., *Shigella* sp., *Campylobacter jejuni*, and *Yersinia enterocolitica*. These bacteria are all responsible for waterborne gastroenteritis. *Salmonellae* appear to be ubiquitous and are shed in the feces of infected wild and domestic animals (Stuart and others 1976). *Salmonella* was isolated from pristine Colorado streams that contained a low number of coliforms (Fair and Morrison 1967). The four species of *Shigella* are among the most common causes of diarrhea in humans, and humans are always the source (Stelma 1990). *C. jejuni* has only recently been recognized as a relatively common cause of diarrhea, and untreated water is believed to be a source of transmission. A number of animal hosts are known to carry this pathogen (Stelma 1990). Taylor and others (1983) isolated *C. jejuni* from 23% of individuals with diarrheal disease acquired in the mountains of northwestern Wyoming. *Campylobacter*-induced enteritis was found to be three times more common than giardiasis; 2% of the water samples and 3% of animal fecal specimens contained *C. jejuni*. Waterborne gastroenteritis can also be caused by *Y. enterocolitica*, with symptoms similar to those presented by *Salmonella* and *Shigella*. It is possible that wild and or domestic animals are a reservoir of this pathogen, as it was found in lakes and streams infrequently visited by campers (Harvey and others 1976).

Human enteroviruses number over 100 and are extremely diverse, though they are often discussed collectively (Rose 1990b, Gerba and Rose 1990). Enteroviruses that cause illness in humans originate only from other human beings (Gerba and others 1997).

Pathogens in Soils

Evaluating the potential hazard resulting from fecal disposal involves examining the fate of pathogens within the soil regime and the likelihood of their entry into water systems. Zyman and Sorber (1988) conclude that ‘‘pathogen fate in soil is a function of survival in soils and retention by soil particles’’ (p. 2105). Backcountry recreation areas encompass a wide range of environments, and each contains soils with extremely different biological, physical, and chemical characteristics. The survival and transport of pathogens in soils are controlled by many factors, including climate, soil type, and type of pathogen (Bitton and Harvey 1992). The relationship between these factors is complex, difficult to pinpoint, and varies over time (Van Donsel and others 1967, Fuller and Warrick 1985a).

There have only been two studies that looked directly at the rate of pathogen decline following fecal burial using the cat hole disposal technique. These studies addressed the persistence of bacteria, but not that of protozoans or viruses. Temple and others (1982) buried bacterial-laden fecal samples sandwiched between soil layers in various environments within the Bridger Mountains of central Montana, USA. Differences in elevation, soil, moisture, exposure, vegetation, and depth of burial did not significantly affect bacteria survival rates. Some organic materials in feces may actually protect bacteria; therefore, it was suggested that a mixture of soil and feces could result in a more rapid decline of the pathogen. Reeves (1979) also studied the fate of fecal matter after deposition in catholes. The feces were placed in the porous, granitic soils of the Sierra Nevadas, California, USA, and were dug up after 1 year. Bacteria were present at most sites at least 1 year later, though it was less prevalent in dry environments. Decomposition was not measurably affected by depth of burial, except for shallow deposits in moist duff, which tended to decompose more rapidly (see Table 1).

There have been a number of studies that have examined the land application of sewage sludge as a method for waste disposal. (Edmonds 1976, Johnson and Urie 1976, Liu 1982, Fuller and Warrick 1985a, 1985b). Results from these studies highlight potential consequences for backcountry human waste disposal. These sewage studies generally report significant variation in pathogen survival relative to the variety of environmental conditions (Table 2).

Soils are an effective pathogen filter, with a number of studies indicating that the majority of bacteria and / or viruses are removed in a relatively short distance. The Environmental Protection Agency (1981) notes that fecal coliforms are generally removed after sewage wastewater percolates through 1.5 m of soil. After the

Table 1. Principal findings relating shallow burial (cat hole) to bacteria survival

Summary of finding	Citation
Differences in elevation, soil, moisture, exposure, vegetation, and depth of burial did not significantly affect bacteria survival rates.	Temple and others (1982)
Bacteria were present at most sites at least 1 yr later. Decomposition not affected by depth of burial, except for shallow deposits in moist duff which tended to decompose more rapidly.	Reeves (1979)

Table 2. Principal findings relating to the influence of sewage sludge application on microorganism survival

Summary of finding	Citation
Groundwater contamination from vertical movement of potential pathogens appears unlikely, hazards from surface runoff and direct handling in the first year may arise.	Edmonds (1976)
Disease outbreaks have occurred when crops grown on soils receiving raw sewage were eaten raw, or when an area was grazed shortly after waste application.	Elliott and Ellis (1977)
Soil microflora are a well-established ecological unit resistant to invasion of new microorganisms not indigenous to the habitat.	Fuller and Warrick (1985a)
Microorganisms, embedded within sludge or in an individual excreta, are likely to be retained within the solid.	G. Bitton (personal communication)
Liquid sewage injected below the surface caused increased nitrogen levels to groundwater, but no fecal coliforms were detected.	Johnson and Urie (1976)
After 4 yr of heavy sludge application 92–98% of microorganisms had died.	Liu (1982)
In sludge-amended soils where moisture was maintained, less inactivation of viruses was observed in clay loam than in sandy loam.	Straub and others (1992)
Bacteria deposited on soil via feces are immobilized and subject to the ecology of a specific site.	Van Donsel and others (1967)

application of dewatered sludge to gravely soils believed to offer little resistance to pathogen movement, Edmonds (1976) found few viable fecal coliforms penetrated to soil depths greater than 5 cm beneath the surface. In a study by Liu (1982), after 4 years of sludge application greater than 90% of the surviving microorganisms remained in the top 20-cm layer of soils. Unfortunately, bacteria are not considered good indicators of viral transport since viruses are smaller and less easily strained in soil (Bitton and Harvey 1992).

The main factors specific to controlling enteric bacteria survival (Table 3) are temperature, moisture content, sunlight, pH, organic material, bacterial type, and antagonistic and/or competitive microorganisms (Elliott and Ellis 1977, Bitton and Harvey 1992), with temperature, moisture, and organic material most critical (Bitton and Harvey 1992). If the soil system is saturated and water moves too slowly, anaerobic conditions result, increasing pathogen longevity (Hurst and others 1980; Potter and others 1984). Freeze-thaw conditions are particularly lethal (Kibbey and others 1978).

The survival patterns for protozoans may differ from that of other pathogens. According to Hibler and Hancock (1990) *Giardia* cysts are resistant to adverse environmental conditions (drying and desiccation) for a short period of time. The *Cryptosporidium* oocysts are known to be robust and are resistant to various environmental stresses that cause death in other infectious species. A study by Robertson and others (1992) revealed that although desiccation was 100% lethal, a small proportion of *Cryptosporidium* oocysts survived for at least 32 days at −22°C, though they could not say if infectivity was retained. On the soil surface high temperature, dessication and ultraviolet radiation can be lethal to pathogens (Menzies 1977).

Soil properties can play a significant role in the survival of pathogens in backcountry areas (Table 4). Soils that consist predominantly of clay-size particles can be problematic if used for human waste disposal. They crack with wetting and drying or freezing and thawing and may pool water, establish water tables, and encourage runoff, thereby allowing pathogens to readily enter the water system (Fuller and Warrick 1985a). However, Zyman and Sorber (1988) found that ‘‘in soils with a high proportion of clay, adsorption plays an important role in virus removal’’ (p. 2105). The size of soil particles, the nature of the soil and the rate of flow through soil are all important in filtering microbes. Percolating waters carrying pathogens can move through bedrock fractures to shallow groundwater supplies, and

Table 3. Factors affecting longevity of pathogens

Summary of finding	Citation
Pathogens generally survive best in moist soils under low (not frozen) temperature.	Bitton and Harvey (1992); Kibbey and others (1978); Yeager and O'Brien (1979); Straub and others (1992)
Viruses have been shown to persist for up to 170 days in sandy soils at temperatures of 3 to 10°C.	Bagdasar'yan (1964) as cited in Elliott and Ellis (1977)
At 4°C with constant moisture, viruses persisted for up to 180 days.	Yeager and O'Brien (1979)
The main effect of temperature on virus survival may be its influence on evaporation rates.	Yeager and O'Brien (1979)
Desiccation decreases pathogen survival.	Van Donsel and others (1967); Elliott and Ellis (1977); Zyman and Sorber (1988); Bitton and Harvey (1992); Robertson and others (1992)
Anaerobic conditions result in increased pathogen longevity.	Potter and others (1984); Hurst and others (1980)
Virus survival appeared to decrease as soil moisture content increased up to the soil saturation point. After saturation, virus survival increased as more liquid was added.	Hurst and others (1980)
Adsorption of viruses to soil increases survival.	Hurst and others (1980)
Coliform organisms were found to persist in soil for long periods, enterococci were found to die out rapidly in soil.	Mallmann and Litskey (1951)
Higher organic content in soil resulted in an increased survival of fecal coliforms.	Bitton and Harvey (1992); Elliott and Ellis (1977); Mallmann and Litskey (1951); Tate (1978)
Soil organic matter may decrease virus adsorption.	Bitton and Harvey (1992)
Viral adsorption increased as pH decreased.	Hurst and others (1980)

Table 4. Factors affecting retention of pathogens in soils

Summary of finding	Citation
Presence of clays and other minerals, such as hematite and magnatite, increases virus retention.	Bitton and Harvey (1992)
"Bacterial adsorption to soils is favored in the presence of cations, minerals, low concentrations of soluble organics and at low pH" (p. 106).	Bitton and Harvey (1992)
Adsorption plays an important role in virus removal in soils with high proportion of clay.	Zyman and Sorber (1988)
Loamy soils consisting of a balance of silt, sand, and clay help in the breakdown of human waste contaminants.	Fuller and Warrick (1985b)
Soils and rock formations with fissures or underground channels may permit rapid flow and carry pollutants long distances with little opportunity for inactivation.	Potter and others (1984)

insufficient microbial filtration occurs in or along these fractures. The transport of bacterial populations through porous aquifers is possible. Allen and Morrison (1973) studied the movement of bacteria in waters percolating through fractured bedrock in mountains in Colorado. The tracer bacteria traveled over 30 horizontal m, and the researchers suspect the distance could exceed 100 m.

It is often incorrectly assumed that a visible humus layer is necessary for fecal decomposition, and if this soil type is absent, as in arid or high alpine soils, there is little value in burying the feces. There is, however, significant pathogen attenuation in mineral soils. Arid soils are not microbiologically inactive but "teem with an abundant and varied microbial population which is as adequate as that in other soils for biodegradation and transformation of matter when energy sources and moisture become available" (Fuller and Tucker 1977, p. 473).

Heavy rainfall has been shown to allow significant vertical migration of indicator organisms (Zyman and Sorber 1988) and can be important in the transport of viruses within the soil profile (Bitton and Harvey 1992). In one study, Johnson and Urie (1976) injected liquefied human wastes 15 cm below the surface in an area of highly permeable sandy soils and shallow water tables. Immediately after artificial rain, fecal coliforms were found 4.6 m down the groundwater gradient, though counts were low. The bacteria were filtered from the effluent by the somewhat finer soils. After 1 year, fecal coliforms had decreased significantly, and no fecal coliform organisms were detected in groundwater samples. The main limiting factor of pathogen migration through soils (and ground water) is pathogen life span.

Water Quality

An overriding concern with human waste disposal in the backcountry is the potential for contamination of water systems and the resultant potential for disease transmission. In wildlands, bacterial contamination of surface water sources primarily orginates in the surface soil which contains background levels of microorganisms and those originating from human, domestic, and wild animal waste products (Silsbee and Larson 1982, Cole 1990).

Viral contamination of drinking water probably causes more illness than is recognized, probably due to a lack of facilities and methods for analysis and because agencies do not request testing (Gerba and Rose 1990). Once viruses have entered a water system, they cannot multiply (Gerba 1987), but they may survive for weeks or months depending on climatic conditions (Hurst 1990).

A number of studies have been initiated to assess the impact of human waste disposal on water quality (Table 5). Conclusions from these studies are variable and at times contradictory.

Table 5. Principal findings relating to the influence of recreational use on fecal pathogens in water systems

Summary of finding	Citation
Potential positive correlation between human use and bacteria densities.	Christensen and others (1978)
Recreationally derived pollution was observed, but not human body waste contamination.	Flack and others (1988)
Recreation use had little effect on bacterial densities.	Gary and Adams (1985)
Fecal coliform counts increased in unvisited areas as recreational use levels increased in adjacent areas.	McDowell (1979)
Visitors did not seem to be major contributors to bacterial contamination.	Silsbee and Larson (1982)
Fecal coliforms increased by the end of summer; the source of the pollution was unknown.	Skinner and others (1974)
A closed watershed was found to have high levels of fecal coliforms even when compared to a similar watershed that was used by humans.	Stuart and others (1976)
44.9% of samples collected at sites downstream from high recreational use areas and 17.2% of samples collected downstream from low recreational use areas contained *Giardia* cysts.	Suk and others (1987)
Findings indicate that waterborne health hazards could exist due to human use.	Varness and others (1978)

Indicator Bacteria

To assess water quality, researchers have generally analyzed the prevalence of specific indicator bacteria in water systems. Which bacteria to measure and what conclusions can be drawn from their abundance is not well understood (Berg 1978, Cabelli 1982, Tunnicliff and Brickler 1984, Kuss and others 1990). The fecal coliform (FC) group is a commonly measured water quality indicator. These microorganisms are known to be short-term survivors in aquatic ecosystems, and their presence serves to indicate recent fecal contamination. These bacteria are relatively convenient and simple to detect (Singh and McFeters 1992).

However, there is a divergence of opinion regarding the usefulness of measuring coliforms to indicate water quality. Unfortunately, there are no ‘‘ideal’’ indicators (Berg 1978; Singh and McFeters 1992). Standard coliform indicators of water quality do not reliably assure a safe water supply with respect to *Giardia* (Lippy 1978, Jakubowski 1984). For example, Kunkle and Cowdin (1985) found no discernible correlation between bacterial counts and the presence of *Giardia* in waters of Rocky Mountain National Park, Colorado. There is also no consistent relationship between number of fecal coliforms and number of viruses in water or sediments (Melnick 1987). Coliform populations in streams fluctuate dramatically, apparently in response to daily and seasonal environmental changes. These fluctuations need to be considered when comparing data, interpreting results, and designing studies (Bohn and Buckhouse 1985). The absence of an indicator does not ensure the absence of pathogens, and infection is still possible (Elliott and Ellis 1977, Berg 1978, Perrine and Mah 1979).

Fecal streptococci, including the group enterococci best satisfies the requirement for a water quality indicator (Cabelli 1982). Fecal streptococcus (FS) is found in the intestinal tract of warm-blooded animals. Some believe that the ratio between the numbers of fecal coliforms and the numbers of fecal streptococci can differentiate contamination of human origin ($FC/FS > 4$) from that of animal origin ($FC/FS < 0.7$) (Kuss and others 1990, Hammitt and Cole 1998). Van Donsel and others (1967) found that testing for fecal coliforms and fecal streptococcus together indicates the degree of pollution and whether the source is of human or animal origin.

The quality of water systems can vary significantly over time and between watersheds. Impacts from human waste are generally believed to be localized, temporary, and dependent on environmental variables (Varness and others 1978, Kuss and others 1990). Interpreting water quality results can be problematic when the desirable systems to analyze are remote; there may be an unacceptable lag time between collection and analyses (Kuss and others 1990). A number of studies have concluded that moderate recreational use has little or no effect on water quality (Werner and others 1985, Gary and Adams 1985). Cole (1990) found that ''where level of bacterial contamination has been related to amount of recreational use, no evidence shows that areas receiving more recreational use present higher health hazards than lightly used areas'' (p. 435).

Most water quality studies have been conducted on highly developed or easily accessible recreation sites or on municipal water reservoirs (McDowell 1979). Kuss and others (1990) conclude that, overall, such studies have found that the adverse effects on water quality have primarily affected areas receiving high use at peak periods of time (activities such as boating, fishing, and swimming). Fewer studies have analyzed remote wildland water systems; the results of these studies have often been inconclusive and of diverging opinions. A thorough review of water quality studies in wildlands is found in Hammit and Cole (1998).

The survival time of fecal bacteria and pathogens in water systems is influenced by water temperature, chemical and physical parameters, predation, and available nutrient concentrations (McFeters and Stuart 1972, Davenport and others 1976, Stephenson and Street 1978). Fecal bacteria generally are short-lived in the nutrient-poor waters characteristic of mountain environments, and therefore the bacterial analysis of wildland waters can only detect relatively recent fecal pollution. However, indicator bacteria are evidence of recent fecal pollution and indicate the potential presence of enteric pathogens which have similar origins and survival characteristics. (McDowell 1979).

Studies designed to determine the cause of possible waterborne disease outbreaks are complicated by factors such as ''1) the low numbers and transient nature of the fecal pathogens in drinking water, 2) difficulties in detecting pathogens in water due to interference by natural competing flora and 3) the fastidious nutrient requirements of pathogenic bacteria'' (Stelma 1990, p. 249). It follows that dispersed water use and resulting illness would be even more difficult to link to a specific pathogenic culprit.

Herrmann and Williams (1986) summarize the reasons for the scant research on water quality in wildland areas, attributing this to problems with access, difficulties discriminating between background water quality levels and imputs from nonhuman sources, perceived severity of consequence of input (consequence perceived as insignificant, immediate hazard perceived as minimal to visitor or ecosystem), and the difficulty of conducting controlled experiments in the wilderness.

Two studies indicate that bacteria numbers in stream sediments are much higher (10–100 times) than would be expected from the bacteria counts in overlying waters; the bacteria in sediments can survive for extended periods and are slowly added from the water above (Hendricks 1971, Tunnicliff and Brickler 1984). Under certain conditions growth of bacteria can occur on or in bottom sediments (Hendricks and Morrison 1967, McFeters and others 1978). Animal and human disturbances of bottom sediments may increase the release of indicator bacteria (Varness and others 1978, Gary and Adams 1985, Kuss and others 1990).

Recommendations and Conclusions

Waste Disposal

Given the available literature, there is a relative dearth of information that allows the land manager or visitor to come up with specific practices that are the best for their area. There is a need for more applied research. Temple and others (1982) studied cat hole burial in a mountain environment. Reeves (1979) studied surface deposits, cat holes, and Iatrines, also in a mountain environment. However, there is a lack of work done in alpine environments, deserts, and coastal areas. The following recommendations are based on a philosophy of minimum impact realizing that the only way to have no impact would be to pack out all human waste. Though carry-out practices are an effective means of disposal in specific settings, there is little current evidence to suggest that sufficient hazards exist to recommend this for wider application.

Where soil is available, sequestering feces in cat holes appears to be the best practice (Reeves 1979, Temple and others 1982). The reasons for a burial type of disposal are threefold: (1) the negative impact on visitor experience when encountering feces and or toilet paper in the backcountry; (2) possibility of animal and insect transmission of pathogens; and (3) possibility of water contamination after rainfall. The few studies that have been conducted show no clear evidence to indicate that there is an optimal burial depth for bacterial mortality (Temple and others 1982). However, as long as the feces are sufficiently buried to avoid being uncovered by animals yet not buried so deeply as to affect the water table, the actual depth appears incidental. Given the readily available capabilities and accepted practice of field treatment of drinking water, hazards to human health can easily be mitigated.

Many land management agencies and outdoor education groups commonly recommend depositing wastes in cat holes 30–60 m (100–200 ft) from lakes and streams. Based on the research reviewed here, there is no compelling evidence to alter such recommendations, except to standardize the distance to 60 m. Given the possibility that distances are underestimated, there would be no adverse effects with the greater distance. In addition, a recommendation to stay 60 m from potential water courses, including dry ravines and water-logged areas, would reduce chances of wastes entering water systems. To avoid concentrating feces, dispersing widely away from the campsites is prudent.

The recreationist should choose a site with the greatest amount of soil, both horizontally and vertically. A small trowel to facilitate digging is recommended. Fifteen to twenty centimeters (6–8 in) is a common recommended depth to ensure that the feces are covered sufficiently. After use, and before covering the hole, mix some soil into the cat hole with a stick to further promote decomposition (Temple and others 1982). It has not been determined how many individuals can overnight at a site lacking facilities without causing unacceptable degradation. Cole (1990) acknowledges that when the cat hole method results in visitors frequently uncovering fecal matter, a toilet facility may be necessary. The addition of toilets to areas that otherwise appear pristine might alter their wilderness character (Cole 1990), and managers will likely need to make decisions regarding problem areas on a site-by-site basis. Though beyond the scope of this article, toilets are an important part of the solution in many high-use areas; various types, including composting toilets, have been used effectively in a wide range of environments (e.g., Fay and Walke 1977, Leonard and others 1980, Plumley and Leonard 1981, Weisburg 1988, Lachapelle and Clark 1999).

The digging and use of temporary latrines by backcountry visitors is almost always an inappropriate method for disposal. The larger the concentration of feces, the more time needed for decomposition (Reeves 1979), which increases both the likelihood that feces will be discovered by other visitors and that pathogens will come into contact with ground water. However, with young children who may not be able to properly locate and dig cat holes, it may be best to dig a small latrine. A shallow trench or the equivalent of a series of cat holes is recommended (Hampton and Cole 1995).

Surface disposal is a commonly used technique and is advocated under certain conditions (Hampton and Cole 1995). Little research has been done to assess potential hazards or the efficacy of decomposition of this method, but aesthetic concerns have been raised. In high alpine environments where there is predominately rock or marginal soil supporting fragile plant communities, surface disposal may be appropriate. Technical rock and mountain climbers travel, camp, and bivouac on terrain that lacks soil for burial, and surface disposal may be the preferred method for these recreationists provided they are not in a drainage or in a high-use area. This technique is appropriate only in remote, infrequently visited locations and dry weather patterns are necessary. Surface disposal should only be taught to and practiced by those willing to perform the technique properly. It is based on the premise that desiccation decreases pathogen survival (Van Donsel and others 1967, Elliott and Ellis 1977, Zyman and Sorber 1988, Bitton and Harvey 1992, Robertson and others 1992). Feces should be deposited where they will be exposed to the greatest amount of sunlight and smeared with a rock to establish a thin layer with the greatest possible surface area.

Overall, generalizations regarding the fate of pathogens within soils are difficult to make because soil conditions and soil depths are extremely varied. Meaningful soil surveys are cost prohibitive, and information gained from a study done in one area is not necessarily transferable to other sites (Leonard and Plumley 1979). Finally, most of the studies involve fecal bacteria or viruses, and these organisms do not necessarily behave in the same manner as protozoans.

Winter backcountry travel poses unique problems because with snow and frozen ground, it is generally not possible to bury feces below the soil surface. When the snow melts the feces remain on the surface. There are organizations that promote bagging and carrying out of feces in popular areas (Cashman 1994), and this may be a reasonable option, especially since sleds are often available for hauling and odors in winter are minimal.

Human waste disposal on glaciers is also a concern because free water is a component of all glaciers. A small percentage of melt water runs on the surface, some water flows through conduits englacially, and the largest percentage is carried subglacially (Benn and Evans 1998). Wastes can easily enter the water system and, depending on the drainage system, travel quickly out the terminus of the glacier. With dispersed travel on large glaciers, wastes are likely to be significantly diluted. Wastes may be successfully deposited in crevasses above the uppermost firn line (the area of the glacier remaining snow-covered throughout the year) on these expansive, remote glaciers. The wastes will likely become further embedded in the glacier, and microbial breakdown will occur via physical disintegration (Dreeger, personal communication). On these large glaciers, below firn line options include surface disposal, burial in soils off the glacier, or a pack-out system.

Resource managers of glaciers in popular locations such as Mt. Rainier National Park, Washington, USA, require visitors to bag and carry out wastes on highly traveled routes. Collection sites and toilets are located at high camps and at the base. Visitor compliance using the bags can be a problem. They also advocate surface disposal in remote locations (Samora, personal communication).

Because rivers funnel boaters along established routes and it is often difficult to hike out of the drainages, recreationists are encouraged or required to pack out all solid waste. With continued education and the increased availability of user-friendly containers, it is likely that all river runners will adopt waste removal systems. Since 1993 most disposal methods of human waste in landfills have been prohibited, and commercial river users must obtain toilet systems that can be emptied at RV dump stations or disposal sites at the take out (Williams and Monz 1994, Hampton and Cole 1995).

In most coastal areas, since decomposition and attenuation of pathogens are likely to occur relatively fast in the ocean (Dawe and Penrose 1978), direct ocean disposal has been suggested in infrequently visited areas (Hampton and Cole 1995). After defecating onto a flat rock, feces are thrown into the ocean, preferably far from camp and into deep waters and/or waters with strong wave action or currents. If no rocks are available, a beach at low tide can be used. In some cases it is possible to pack out feces and dispose of them at sewage disposal sites (Hampton and Cole 1995). There is no definitive study on whether pathogens retain their infectivity while in sea water. In looking at the survival of *Cryptosporidium* oocysts, Robertson and others (1992) found that ‘‘the diluting effect of the sea is enormous, but the risk of contracting cryptosporidosis from accidentally ingesting oocysts while swimming in coastal areas contaminated with sewage cannot be dismissed’’ (p. 3499). Hampton and Cole (1995) stress that little is known about sea disposal and therefore caution needs to be used when disposing of human waste in an ocean environment: ‘‘Potential ecological problems with [the direct disposal] method include introduction of pathogens and toxins into the marine environment . . . [and] ingestion if visitors use salt water for cooking’’ (p. 129).

Areas of Future Research

No literature was found that studied social impacts of human waste disposal in wildlands. Specific researchable topics include: (1) visitor perception of each disposal method; (2) the impact on visitor experience when encountering feces in the backcountry; and (3) rates of compliance of each of the different methods.

Another area in need of research is the breakdown of microorganisms in site-specific locations. Studies which examine pathogen decomposition in a variety of ecosystems would help in making site-specific management decisions.

Conclusion

Following the above guidelines for proper waste disposal will not eliminate health hazards, but will go a long way toward eliminating the aesthetic concerns of encountering feces in the backcountry. Educating visitors about the prevalence of contamination and the necessity of water treatment is the most important step managers can take to mitigate health concerns (Cole 1990). Due to the difficulty and high variability in assessing waterborne pathogens in backcountry situations, the best practice is to disinfect all drinking water in the backcountry. Three methods of field water disinfection are widely available: heat, filtration and chemical treatment and all three can be safe and highly effective if proper procedures are followed (Backer 1994). After reviewing the studies involving *Giardia* and *Cryptosporidium*, it seems prudent to encourage backcountry users to follow the aforementioned techniques for waste disposal to keep cyst/oocyst concentrations and cross-transmission to a minimum.

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