The Application and Performance of Urine Diversion to Minimize Waste Management Costs Associated with Remote Wilderness Toilets

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Abstract: The diversion of urine away from fecal matter, prior to contact, has the potential to improve a wide variety of public toilet systems managed at remote wilderness sites. In order to evaluate the reduction in mass, cost, and impact associated with human waste management at the Kain Hut, Bugaboo Provincial Park, British Columbia, Canada, we designed and tested three alternative waste treatment systems, all of which involved the diversion of urine with urinals and urine-diversion seats. By quantifying the mass of excreta deposited per toilet use, we were able to compare the baseline excreta mass collected per use in an unmodified barrel fly-out toilet system with that collected in a barrel toilet modified with urine diversion (urinals and urine diversion seats), urine diversion with solar dehydration, and urine diversion with 110V evaporation.

Introduction

Parks Canada is aiming to increase annual wilderness visitation to 22.4 million visits in 2015 from 20.7 million visits in 2008 (Parks Canada 2011). Total waste volume and waste management costs increase directly with increased visitation. In wilderness areas experiencing low usage, human waste may be adequately managed by pack out, cat holing (in areas with adequate soil structure; Cilimburg et al. 2000), or desiccation by smearing (dry/hot; Ells and Monz 2011). Under ideal conditions of low use as well as suitable environmental conditions, these standard methods of disposal should have little risk of ground or surface water pollution, pathogen transmission, or negative visitor experience (Cilimburg et al. 2000). However, should any of these criteria not exist, the risks associated with human waste outlined by Temple et al. (1982), Cilimburg et al. (2000), Moore et al. (2010), and Banerjee (2011) should stimulate the implementation of waste management plans.

Greg Hill conducting research in Bugaboo Provincial Park, British Columbia, Canada.

Human waste management in wilderness, and especially alpine wilderness, is very challenging. Remote sites frequently lack standard municipal infrastructure, including road access, sewerage, electricity, and water supply. Without these basic services the removal or treatment of human waste can become an expensive, intensive, offensive, and dangerous task. Additional challenges at alpine sites include short summers, large diurnal fluctuations, frequent freeze-thaw events, extreme weather, shallow and weak soils, limited vegetation, and challenging terrain (Weissenbacher et al. 2008).

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Nonetheless, the proper management of human waste is essential in order to prevent environmental contamination, ensure adequate user sanitation, and meet legal requirements.

There are two approaches to waste management programs in parks and wilderness areas: pack out or provision of toilets. Pack out involves the collection of fecal matter in bags, transport throughout the wilderness visit, and disposal at an approved septic waste disposal facility. Toilet provision involves the construction, maintenance, collection, and either on-site treatment and on-site disposal of end products or transport for off-site treatment.

Effective pack-out programs have a specific set of criteria (Robinson 2010 and White 2010). In all other wilderness areas, where annual visitation or intensity exceeds the loading rate manageable by open defecation and cat holing, toilets are generally provided. There are a variety of toilet systems used in North American remote wilderness areas, including pit toilets, barrel collection toilets (barrel fly-out), composting toilets, and dehydrating toilets. There is a wider selection of waste treatment technologies available in Europe, as wilderness travel in Europe is supported and serviced by large networks of popular and high-use huts, but many of theses require running water or power (Becker et al. 2007).

Human excrement is composed of urine and feces, the majority of which is urine. Urine, containing the majority of nutrients and much lower pathogen content than feces, could conceivably be treated on-site with minimal impacts by natural soil processes, assuming leachate to groundwater was not allowed. Feces, having high organic matter and pathogen content, is much more difficult to treat on-site, and in most cases – except where collected in pits – is removed for off-site treatment. The diversion of urine away from feces is commonly practiced in Scandinavian countries, primarily in order to capture and reuse uncontaminated nutrients in urine. However, there are a number of other beneficial uses of urine diversion, especially when applied to remote site waste management toilet systems.

The majority of urine can be diverted from fecal matter in barrel fly-out toilets, resulting in considerable operation and maintenance cost reduction.

Pit toilets are one of the least expensive toilet systems to build and operate, as they function both as collection and on-site treatment by relying on natural soil to attenuate pathogens and nutrients (Gunn and Odell 1995). Despite research indicating that >20 m (65.6 ft.) unsaturated soil must exist below a pit toilet in order to effectively remove viral pathogens from water 50 m (160 ft.) horizontally away (Moore et al. 2010), common practices frequently either place the pit into groundwater (McCrumb, pers. comm. 2012) or require only 1–2 m (3.3–6.6 ft.) of vertical separation from seasonal-high groundwater (Gunn and Odell 1995). Horizontal separation to surface water is reported by Gunn and Odell (1995) to be 10–20 m (32.8–65.6 ft.), depending on soil type, but with more recent concerns over enteric virus survival and transport, these distances may be as high as 1,000–3,000 m (3,280–9,842 ft.), depending on soil type and depth of unsaturated soil below the pit. Moore et al. (2010) provide an in-depth summary and calculation templates for separation distances and risk tolerance. In light of the likely impacts of pit toilets on water quality, they may no longer be a reasonable choice except where proof of vertical and horizontal separation from groundwater and surface/well water is suitable for soil type and seasonal flux in water table. It may be possible to eliminate the pollution risk associated with pit toilets if urine is diverted away from the pit, and the pit sealed with an impermeable liner.

North American mixed latrine-style composting toilets propose to employ aerobic bacteria and microorganisms to decompose excrement to the point at which end products are "safe" for on-site discharge, making them an attractive alternative for pit-toilet sites. However, the body of literature on mixed latrine-style composting toilets, especially from field studies, indicates that they are unreliable in the production of compost suitable for discharge into a public park environment (Matthews 2000; Redlinger et al. 2001; Holmqvist and Stenstrom 2002; Guardabassi et al. 2003; Jenkins 2005; Jönsson and Vinnerås 2007; Tonner-Klank et al. 2007; Jensen et al. 2009; Hill and Baldwin 2012; Hill et al. 2013). Moreover, this style of composting toilet is expensive and hazardous to maintain as material must be removed annually (Hill and Baldwin 2012). With the diversion of urine away from feces, the feces become a viable feedstock for invertebrate-driven decomposition (vermicomposting) and the source of odor is eliminated (ammonia from urea), making them far superior in performance and hazard reduction (Hill and Baldwin 2012). However, there are currently no commercially available public-utility urine-diversion systems available in North America. Urine-diversion seats and urinals, commonly used in residential Scandinavia, require testing in a public environment to prove their worth.

In rare circumstances, dehydrating toilets and incinerating toilets can be found, but there is limited data on these systems in North American wilderness environments, and their ability needs to be evaluated prior to greater market uptake.

Alpine sites, generally not suitable for pit toilets (lack of soil) or composting toilets (too cold), are frequently serviced with barrel fly-out collection toilets in Canada. Barrels are transported annually by helicopter for off-site treatment. However, the expense and intrusion of helicopters to regularly remove barrels from wilderness destinations is large and can cost thousands of dollars per year at high-use sites (Hanson, pers. comm. 2011). By diverting urine, which constitutes 75% of daily excreta mass per capita, away from the collection barrel into a shallow septic field or wetland, considerable expense, intrusion, and risk associated with helicopter removal of excreta could be minimized. The remaining fecal matter, high in moisture, could be further minimized through desiccation.

The performance of urine diversion by urine-diversion seat and urinal would be most effectively evaluated at a barrel fly-out toilet site because of the simplicity in quantifying excrement collected in easily managed drums. In order to evaluate and enumerate the reduction in excreta associated with each mass reduction treatment, we established each treatment at a high-use backcountry wilderness site and periodically measured the change in mass collected per average toilet use under each toilet treatment system. Based on the reduction in mass, potential cost savings were estimated using available financial data.

Methods

We chose the Conrad Kain Hut, Bugaboo Provincial Park, British Columbia, elevation 2,100 m (6,890 ft) above sea level, as a site to test three

Figure 1 – Alternative toilet waste management treatments at Kain Hut, Bugaboo Park, BC Canada. (A) Urine diversion toilet seat. (B) Urinal with 1-inch braided drain pipe to collection barrel. (C) Lower toilets with UD12V solar hot-air panel (i) above a 5W PV panel (ii). (D) Upper Kain Hut toilet insulated basement, 110V heater, and 110CFM exhaust fan positioned around a 200 L plastic barrel with double garbage bags to collect solids.

alternative waste treatment technologies. The hut sits 5 km (3.1 miles) from and 700 m (2,297 ft) above the trailhead, 45 km (28 miles) west of Brisco, British Columbia. Accommodating 40 overnight occupants, it is used principally in the summer by hikers, climbers, and guides. It is one of the more popular destinations in the Canadian alpine and is serviced with propane for cooking and lighting. Water from above the hut is piped directly to plumbing in the hut for cooking and drinking. Gray water is gravity fed to a solids-separating tank or direct to disposal field in a natural sedge meadow overlying solid granitic parent material 30 m (98 ft.) below the hut. There are three outdoor toilets: one close to the hut and two down a short flight of stairs. Prior to our experimental manipulations, the toilet close to the hut was used as a urine-only toilet; a mesh grate just below the toilet surface dissuaded fecal matter additions. Urine from the urine-only toilet was diverted into the gray-water disposal pipe. The hut and toilets sit on a small bedrock knoll with unobstructed solar exposure until mid-afternoon when Snowpatch Spire interrupts direct incoming solar radiation. This site was chosen for research as it was representative of other moderate to high-use alpine sites, was guaranteed to have adequate visitation to accumulate necessary excrement for measurement, and provided attractive sanitation amenities, including running water for hand washing and bathing – important for researchers and assistants conducting this biohazardous research.

We designed and assessed three alternative toilet waste management systems that could be retrofitted into any standard barrel fly-out toilet (BFO). The simplest system was urine diversion (UD), which included both a men's urinal and urine-diverting seat from EcoVita (Bedford, MA) (see Figures 1A and 1B). The second involved the urine-diversion system plus solar dehydration (UD12V). This system transfers incoming solar radiation to sensible heat inside a thin, flat, transparent panel; the hot air is then driven through ducting by a fan and photovoltaic panel to the surface of the excrement pile. The $0.5 m^2$ solar hot-air panel, 100-cubic-feet-minute (CFM) fan, and 5W photovoltaic panel were purchased from Clear Dome Solar (San Diego, CA). We designed our own solar dehydrating toilet system based on Arnold's (2010) design (see Figure 1C). The third system combined urine diversion with a 110V 800W heater and a 110V 110 CFM blower and exhaust fan inside an insulated chamber (UD110V) (see Figure 1D). The toilet closest to the Kain Hut was chosen for UD110V due to its proximity to 110V outlets. The basement chamber at this toilet was insulated with 4-cm (1.6 in.) thick Styrofoam boards. Data were collected during two sample periods, August 15–17 and September 3–5, during which time access to the other toilets was restricted so as to account for all toilet uses. BFO, UD, and UD12V treatment systems were established at the lower two toilets for three-to-six-day periods, according to following schedule: BFO/BFO, August 14–18; BFO/UD12V, August 18–20; UD/UD12V, September 4–10; BFO/UD, September 14–19. During these sample periods, access to the UD110V upper toilet was restricted as much as possible without creating lines so as to maximize the use in the lower toilets and ensure no preference or bias was occurring in toilet selection (e.g., upper toilet for urination, lower toilets for defecation). In addition, hut visitors were instructed to use all available toilets equally during their stay so as to ensure an even and unbiased distribution of toilet use (e.g., potential preference for left vs. right).

In order to determine mass reduction performance with respect to the standard BFO, we recorded the number of door counts at 6 to 24 hour intervals over the course of the 3-to-6-day sample periods. The interval and period length depended on the intensity of hut visitation; we increased sampling intensity with increased visitation. We targeted 10–30 toilet uses per interval in order to maximize the number of intervals, while minimizing differentiable mass change at the collection barrel below each toilet. Change in barrel mass was determined by weighing the collection barrel with a veterinary pet scale before and after each sampling. Door counters were EPC-MAG1 model made by Inter-Dimensional Technologies, Inc. (Hop Bottom, PA). A 10-second delay function was employed in order to eliminate erroneous readings caused by wind or door-closing errors. We subtracted the unit's final count from its initial and divided the difference by two in order to obtain the total toilet uses. Dividing the change in barrel mass by toilet use eliminated the effect of variable sampling interval length and established a robust quantifiable baseline in the assessment of remote site waste treatment performance. A simple mass balance equation was used to quantify performance. Temperature and humidity sensors connected to data loggers (HOBO U12, Onset Computer Corp.) were used to collect ambient and treatment system air temperature and relative humidity data. Wind speed at the outlet of the ducting above the barrel was measured with a Kestrel 4500 (Nielsen Kellerman).

All three alternative treatment systems were tested twice. BFO was tested three times. Combined, there were nine treatment runs conducted between August and September 2010. Each run was divided into three to six sample periods. Measurements with fewer than five toilet uses per sampling period were not used in order to reduce variability.

JMP 9 (SAS Institute) was used to analyze our data. For all statistical tests, the alpha value was set at 0.05. One outlier was removed from the BFO treatment dataset after it was discovered that a dysfunctional door latch caused an overestimation of toilet use. No other alterations or transformations were made or required for the data analysis.

Results

The installation of the urine-diversion seat and urinal required one hour (see Figures 1A and 1B). The solar hot-air system was tested prior to installation on August 16 on an exposed meadow adjacent to the Kain Hut. The sky was cloudless and winds were calm over the course of the day. The solar hot-air panel consistently raised the air temperature and reduced the relative humidity for eight and a half hours by an average of +10ºC and –14%, respectively, with a maximum heating of +15ºC and drying of –19%. Wind speeds at the outlet of the vent varied from 0–3 m/second (0-9.8 ft/ second) . The solar hot-air system required eight hours to plan and install at the lower toilet site (see Figure 1C). Over the course of two sample periods spanning four days, the treatment consistently raised the air temperature and reduced the relative humidity for 6.8 hours per day. The hot-air panel produced a maximum of 3 m/second (9.8 ft/second) air flow, heating of +7ºC, and drying of –18%.

UD110V system assembly and testing required 15 days. During a representative 20-hour sample interval, the system increased the average basement temperature and reduced the relative humidity by an average of +24.7ºC and –44%, respectively, up to a maximum of +30.5ºC and –63%. The system averaged an actual temperature of 31ºC and 17% relative humidity.

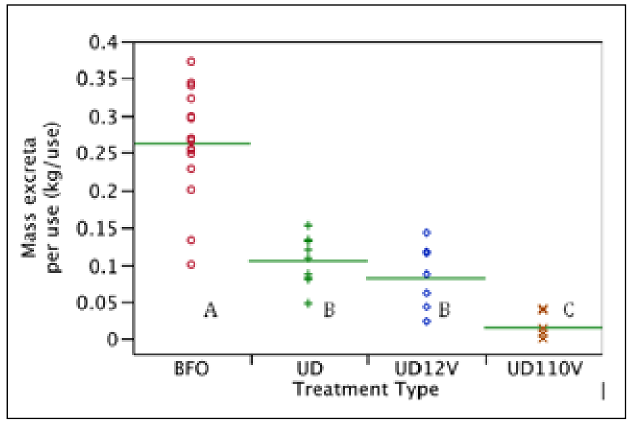

Figure 2 – Mass of excreta mass per toilet use by treatment type (kg/use) (wet solids). Data are measurements from each 24-hour interval over the summer. Significantly different treatments denoted with different letters (A, B, C) as determined by pair-wise comparisons using the Wilcoxon method (a=0.05).

Change in barrel mass per toilet use data were compared between sampling periods within treatment type with robust, rank sum, nonparametric Wilcoxon Kruskal-Wallis tests; not one of the treatment runs was significantly different. Therefore, in order to increase sample sizes, we grouped treatment runs into treatment types (see Figure 2). The relationship between mean change in excreta mass per toilet use by treatment type was significant ($p<0.0001$), with largest mass associated with BFO toilets (median = 0.27 kg/use; 0.60 lb./use), followed by UD (median = 0.11 kg/use; 0.24 lb./use), UD12V (median = 0.086 kg/use; 0.19 lb./use), and UD110V (median = 0.009 kg/use; 0.02 lb./use).

Discussion

The median values of urine mass/toilet use (feces mass/toilet use subtracted from excreta mass/event), feces mass/toilet use (UD mass/use), and excreta mass/toilet use (BFO mass/use) were found comparable to values from other locations (see Table 1). Urine volume reported here was slightly lower than for other studies, but this could be explained by the remote location. All site visitors are required to ascend >1000 m (3,280 ft.) in elevation to access the facility, and the main activities include hiking and mountaineering, both of which are likely to induce dehydration. Fecal mass reported here is on par with fecal mass of the average European/North American (see Table 1). The fecal mass we reported might also be slightly elevated due to the assumption that all matter collected in the UD treatment was fecal matter; it is likely that a small fraction of urine bypassed the urine-diverting seat and urinal. If the efficiency of urine diversion was 90%, the fecal mass/toilet use would drop to 99 g/use (3.5 ounces/use) and the urine mass/use would increase 176 g/use (6.2 ounces/use), bringing our values closer into the middle range of these studies.

Our results indicate that with the addition of a urine-diversion seat and urinal, up to 0.16 kg (0.35 lb.) per use of excreta can be eliminated from the barrel fly-out system. This equates to a 60% reduction in barrel fly-out mass. Equipped with urine-diversion equipment, each barrel will hold 2.5 times as many excrement deposits as compared with standard all-in-one barrel collection systems, greatly reducing the total numbers of barrels filled at each site.

A urine-diversion seat and plastic urinal costs less than $200CDN and is simple and quick to install. The urinal was easier to maintain than the urine-diversion seat, which occasionally became clogged with toilet paper. After such events the toilet was inoperable and posed a health hazard for other toilet users and required cleaning, which was done by the on-site hut custodian. More research and development are needed to develop low maintenance public-utility urine-diversion systems (Shiskowski 2009). There are two commercial urine diversion products that are likely to require less regular maintenance: an inclined foot-operated treadmill (Ecosphere Technologies, France) and the adhesion and gutter systems (NatSol Ltd., Wales), but neither is available commercially in North America. We have filled the need for public-utility urine-diversion technology in North America by designing two system: the TTS-Basic and the TTS-Mechanical (Toilet Tech Solutions, Squamish, BC), but testing is required to verify long-term performance.

Urine could be diverted into preexisting gray-water systems for dilution and to reduce the chance of struvite precipitation and potential flow constriction. Sites without a preexisting gray-water treatment system would need to design and construct a leach field according to local septic field codes to ensure sufficient soil surface area to attenuate nutrients and low levels of pathogens given estimate flows of urine (Steinfeld 2007). For sites that generate more than three barrels of excrement per year (the max load of a Bell 407), installing a UD system could reduce the total cost of barrel removal from $180 to $72CDN per barrel.

With nonsignificant differences between UD and UD12V, we are unable to conclude whether solar dehydration is a viable waste reduction treatment. Given labor and capital costs to set up and take down the dehydrating equipment and variable weather conditions that would reduce the efficacy of the dehydrating system, we do not think dehydration through this type of retrofit is likely to be a reliable solution for these alpine areas. More effective commercial toilet systems maximize the surface area of fecal matter and the time it is exposed to a desiccating environment; the best example of this is the cloth bagging carousel systems developed by Ecosphere Technologies where a urine-diverting treadmill moves fecal matter onto the surface of a rotating carousel (where cloth bags hang), ensuring subsequent fecal deposits do not cover up the most recent additions, and even those buried can desiccate through the cloth fabric.

Table 1—Range/Median Urine, Feces, and Excreta Mass Per Toilet Use. Modified from Schouw et al. (2002)

Location	Urine range (g/toilet use)	Feces range (g/toilet use)	Excreta range (g/toilet use)	References
Vietnam	164–240	87–93	198–267	Polprasert et al. (1981) in Schouw et al. (2002)
Developing nations	240	87–347	290–310	Feachem et al. (1983) in Schouw et al. (2002)
Europe/ North America	240	67–133	270	Feachem et al. (1983) in Schouw et al. (2002)
Thailand	120–240	80–267	188–306	Schouw et al. (2002)
Canada backcountry	160*	110*	270	This study

*Assumes UD efficiency was 100%.

Table 1 – Range/median urine, feces, and excreta mass per toilet use. Modified from Schouw et al. (2002) by dividing reported generation rate of urine, feces, and excreta per person per day by the average number of urination events per person per day (5), average number of fecal deposits per day (1.5), and estimated average number of excreta events per day (5).

The UD110V treatment had the lowest mean excreta mass per toilet use but is the most inappropriate system for most wilderness toilets due to its reliance on electrical power and constant maintenance. This toilet also had the greatest degree of sampling error, being closest to the hut and likely used most frequently for quick urination trips at night and the lowest number of sample intervals. These factors lead us to place low confidence in the data from this treatment and the practicality of this waste management system. Instead, we suggest further research should be conducted on commercially available dehydrating toilet systems, which reportedly can dry material with only solar energy, to the point at which it can be burned on-site (Neau, pers. comm. 2012).

Fecal matter must have <15% moisture content before it is easily burnable (Pretzsch, pers. comm. 2010); applying this to the average wet fecal deposit measure here of 110 g/toilet use (3.9 ounce/use), the estimated desiccated end product would need to be <16.5 g/toilet use (0.58 ounce/use), which is slightly higher than the result obtained in the UD110V of 8.6 g/toilet use (0.3 ounce/use). However, we attempted to burn the end product of the UD110V treatment on-site with a portable SmartAsh cyclonic incinerator by Elastec without success, casting doubt on the ability to burn desiccated fecal matter. More research is needed to verify the claims that this material can be incinerated on-site. If validated, this treatment would result in the lowest mass/toilet use, management exposure, and off-site transport cost.

Diverting urine away from the collections barrel resulted in a much thicker residual material, which did not slosh when dragged out from under the toilet. This is an important aspect of waste management, as park visitors are required to exchange full barrels for empty ones at many wilderness sites managed by the Alpine Club of Canada. Full barrels of conventional excrement are predominantly urine and are difficult and hazardous to handle but easier for the septic truck to evacuate. The evacuation of the urine-diverted barrel took four times as long (20 minutes as opposed to a standard 5 minutes) and required an equal volume of added water to waste. The success of this step was critical in proving the benefits of urine diversion in this context. Septic truck costs ($225CDN/hr.) are much lower than helicopter costs ($2,000CDN/hr). Many septic trucks carry water tanks. Nevertheless, until a reliable urine-diversion system becomes available, urine should be diverted only from urinals to prevent toilet-seat clogging issues.

Discharged urine will have a plant fertilization effect favoring grasses, sedges, and deciduous shrubs and is not likely to enhance invasive species (Bowman et al. 1995; Wang et al. 2010; Ells and Monz 2011). Competition for nutrients found in urine – by both microbes and plants – is strong, and risk of leaching nitrogen into water bodies is low if unsaturated soil is discharged into, even in alpine and Arctic soils (Brooks et al. 1996; Jones and Murphy 2007). Nitrogen loading rates should be kept below 430 kg/ha (384 lbs./acre) in grassland soils to ensure ammonia does not build up in the soil, thereby inhibiting microbial processes as occurs with high concentrations of cattle urine (Orwin et al. 2010). These findings come from experimental studies simulating the effects of climate change, snow-cover change, or land-use change. To the best of our knowledge, no studies on the impacts of human urine diversion have been conducted, and more research on this topic is necessary before urine diversion becomes common practice.

Many wilderness destinations in the Canadian Rocky Mountains are used for winter travel. Fortunately, nutrient uptake even occurs in winter in both alpine and Arctic tundra under snowpacks (Bilbrough and Welker 2000; Schimel et al. 2004). There is some concern with frozen urine causing blockages in pipes or at the discharge point, but pilot projects have demonstrated this concern is limited when plumbing runs are short, piping is of appropriate diameter, and discharge occurs under snow (insulating) (Neau, pers. comm. 2012).

Conclusion

The majority of urine can be diverted from fecal matter in barrel fly-out toilets, resulting in considerable operation and maintenance cost reduction. Further reduction in moisture content by dehydration was not efficient, but further research on commercial dehydration systems may prove otherwise. Urine diversion can also benefit the other common toilet systems. If pit toilets were modified to isolate fecal matter from groundwater and urine were diverted and discharged to surface aerobic soil, the risk of pathogen transmission to groundwater would be eliminated without much increase in operation and maintenance costs. Urine diversion can also render feces into a suitable feedstock for vermicomposting (Yadav et al. 2010) and presumably other forms of invertebrate decomposition. Vermicomposting is a low-temperature process that requires very little management, making it suitable for treatment of fecal matter at wilderness locations, reducing total mass, volume, pathogen content, and handling risk (Yadav et al. 2010; Hill and Baldwin 2012). However, urine-diversion seats proved unreliable as a public utility.

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References

Arnold, J. 2010. Solar dehydrating toilets in Rocky Mountain National Park. Paper presented at the Exit Strategies: Managing Human Waste in the Wild Conference, Golden, Colorado.

Banerjee, G. 2011. Underground pollution travel from leach pits of on-site sanitation facilities: A case study. *Clean Technology and Environmental Policy* 13: 489–497.

Becker, W., M. A. Schoen, and B. Wett. 2007. Solar-thermic sewage sludge treatment in extreme alpine environments. *Water Science and Technology* 56(11): 1–9.

Bilbrough, C. J., J.M. Welker and B. Bowman. 2000. Early spring nitrogen uptake by snow-covered plants: A comparison of arctic and alpine plant function under the snowpack. *Arctic, Antarctic, and Alpine Research* 32(4): 404–411.

Bowman, W. D., T. A. Teodose, M. C. Fisk. 1995. Physiological and production responses of plant growth forms to increases in limiting resources in alpine tundra: Implications for differential community response to environmental change. *Oecologia* 101: 217–227.

Brooks, P.D., Williams, M.W., and Schmidt, S., 1996. Microbial activity under alpine snowpacks, Niwot Ridge, Co. *Biogeochemistry* 32 (2): 93-113.

Cilimburg, A., C. Monz, and S. Kehoe. 2000. Wildland recreation and human waste: A review of problems, practices, and concerns. *Environmental Management* 25(6): 587–698.

Ells, M. D., and C. A. Monz. 2011. The consequences of backcountry surface disposal of human waste in an alpine, temperate, and arid environment. *Journal of Environmental Management* 92(4): 1334–1337.

Guardabassi, L., A. Dalsgaard, and M. Sobsey. 2003. Occurrence and survival of viruses in composted human feces. *Sustainable Urban Renewal and Wastewater Treatment* 23. Danish Environmental Protection Agency, Danish Ministry of the Environment.

Gunn, I. and Odell, A. 1995. *Wastewater servicing for remote area recreational facilities.* Masters thesis, School of Engineering, the University of Auckland, NZ.

Hill, G. B., and S. A. Baldwin. 2012. Vermicomposting toilets, an alternative to latrine style microbial composting toilets, prove far superior in mass reduction, pathogen destruction, compost quality, and operational cost. *Waste Management* 32: 1811–1820.

Hill, G.B., Baldwin, S.A., Vinnerås, B. 2013. Composting toilets a misnomer: Excessive ammonia from Urine inhibits microbial activity yet is insufficient in sanitizing the end-product. *Journal of Environmental Management*. (in press).

Holmqvist, A., and A. T. Stenstrom. 2002. Survival of *Ascaris suum* ova, indicator bacterial and *Salmonella typhimurium* phage 28B in mesophilic composting of household waste. *EcoSanRes,* Stockholm Environment Institute, Sweden.

Jenkins, J. 2005. *The humanure handbook*. White River Junction, VT: Chelsea Green Publishing.

Jensen, P. K. M., P. D. Phuc, F. Konradsen, et al. 2009. Survival of *Ascaris* eggs and hygienic quality of human excreta in Vietnamese composting latrines. *Environmental Health* 8: 57.

Jönsson, H. and B. Vinnerås. 2007. Experiences and suggestions for collection systems for source-separating urine and feces. *Water Science and Technology* 56(5): 71–76.

Jones, D.L. and Murphy, D.V. 2007. Microbial response time to sugar and amino acid additions to soil. *Soil Biology & Biochemistry* 39: 2178–2182.

Matthews, W. 2000. Waterless composting toilets in NSW. Australian Alps Best Practice Human Waste Management Workshop.

Moore, C., and Institute of Environmental Science and Research (N.Z.) staff. 2010. *Guidelines for Separation Distances Based on Virus Transport between On-Site Domestic Wastewater Systems and Wells.* ESR Communicable Disease Centre, Porirua, New Zealand.

Orwin, K. H., J. E. Bertram, T. J. Clough, et al. 2010. Impact of bovine urine deposition on soil microbial activity, biomass, and community structure. *Applied Soil Ecology* 44, 89–100.

Parks Canada. 2011. Parks Canada Agency Corporate Plan. Retrieved April 1, 2012, from www.pc.gc.ca/docs/pc/plans/plan2011-2012/sec01/index.aspx.

Redlinger. T., J. Graham, V. Corella-Barud, et al. 2001. Survival of fecal coliforms in dry-composting toilets. *Applied and Environmental Microbiology* 4036–4040.

Robinson, R. 2010. Evolution of Denali waste practices. Paper presented at Exit Strategies conference in Golden, Colorado.

Schimel J. P. et al. 2004. Increased snow depth affects microbial activity and nitrogen mineralization in two arctic tundra communities. *Soil Biology & Biochemistry* 36(2):217-227.

Schouw, N. L., S. Danteravanich, H. Mosbaek, and J. C.. 2002. Composition of human excreta – A case study from southern Thailand. *The Science of the Total Environment* 286: 155–166.

Shiskowski, D. 2009. Global nitrogen management – The role of wastewater management and urine separation as mitigation strategies. Paper presented at WCW Conference and Trade Show, Winnipeg, Manitoba.

Steinfeld, C. 2007. *Liquid Gold: The Lore and Logic of Using Urine to Grow Plants.* New Bedford, MA: EcoWaters Books.

Temple, K. L., A. K. Camper, and R. C. Lucas. 1982. Potential health hazards from human wastes in wilderness. *Journal of Soil and Water Conservation* 37(6): 357–359.

Tønner-Klank, L., Møller, J., Forslund, A., et al. 2007. Microbiological assessments of compost toilets: in situ measurements and laboratory studies on the survival of fecal microbial indicators using sentinel chambers. *Waste Management* 27: 1144-1154.

Wang, C., R. Long, Q. Wang, W. Liu, Z. Jing, and L. Zhang. 2010. Fertilization and litter effects on the functional group biomass, species diversity of plants, microbial biomass, and enzyme activity of two alpine meadow communities. *Plant Soil* 331: 377–389.

Weissenbacher, N., E. Mayr, T. Niederberger, C. Aschauer, S. Lebersorger, et al. 2008. Alpine infrastructure in Central Europe: Integral evaluation of wastewater treatment systems at mountain refuges. *Water Science and Technology* 57(12): 2017–2022.

White, E. 2010. The Mt. Shasta Human Waste pack-out system. Paper presented at Exit Strategies conference in Golden, Colorado.

Yadav, K. D., V. Tare, and M. M. Ahammed. 2010. Vermicomposting of source-separated human faeces for nutrient recycling. *Waste Management* 30, 50–56.

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