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Evaluation Criteria for Implementation of a Sustainable Sanitation and Wastewater Treatment System at Jiuzhaigou National Park, Sichuan Province, China

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Abstract The administration of Jiuzhaigou National Park in Sichuan Province, China, is in the process of considering a range of upgrades to their sanitation and wastewater treatment systems. Their case history involves an ongoing series of engineering design flaws and management failures. The administration of the Park identified sustainability, environmental protection, and education goals for their sanitation and wastewater treatment system. To meet the goal of sustainability, environmental and economic concerns of the Park's administration had to be balanced with socio-cultural needs. An advanced reconnaissance method was developed that identified reasons for previous failures, conducted stakeholder analysis and interviews, determined evaluation criteria, and introduced innovative alternatives with records of successful global implementations. This evaluation also helped the Park to better define their goals**.** To prevent future failures, the administration of the Park must commit to a balanced and thorough evaluation process for selection of a final alternative and institute effective long-term management and monitoring of systems. In addition, to meet goals and achieve energy efficient, cost-effective use of resources, the Park must shift their thinking from one of waste disposal to resource recovery. The method and criteria developed for this case study provides a framework to aid in the successful implementation of sanitation projects in both underdeveloped and developed areas of the world, incorporating socio-cultural values and resource recovery for a complex group of stakeholders.

Keywords China · Evaluation criteria · Park management · Residuals reuse · Resource recovery · Sanitation · Tourism · Wastewater treatment

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Introduction

Jiuzhaigou translates as the "valley of nine villages" for the nine Tibetan villages originally located within Jiuzhaigou National Park (hereafter referred to as the Park). The Park is located at the transition of the Tibetan Plateau, Qiang Plateau and Sichuan Basin in the northern region of Sichuan Province, China (location in Fig. 1, statistics in Table 1). The Park is characterized by mountainous and karst topography and a series of crystal clear, blue-green lakes, pools, and waterfalls resulting from carbonate calcified dikes. To protect this unique natural environment, visitors have access to the Park through a tourist shuttle bus system and are restricted to walking on 55 km of boardwalks. Visitation to the Park has increased rapidly following regional road improvements in 1997 and construction of an airport in 2004, and was highlighted at the 2008 Olympic Games as one of China's premier parks. It is the only park in China to have the combined certifications of UNESCO World Heritage Site, World Biosphere Reserve, and Green Globe 21,

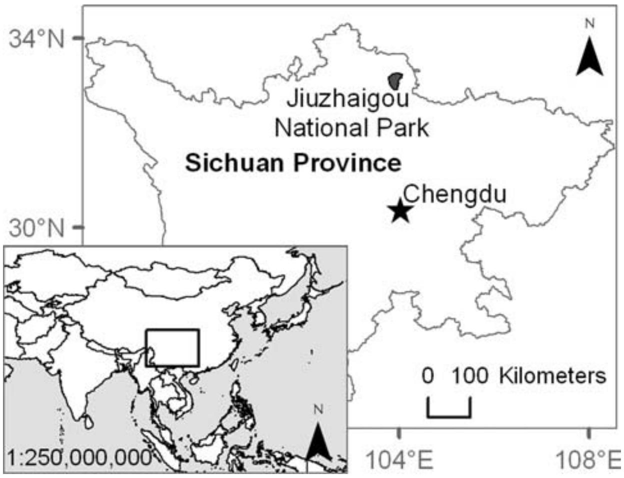


Fig. 1 Location of Sichuan Province and Jiuzhaigou National Park within China

Table 1 Relevant Jiuzhaigou National Park statistics

Area	730 km^2
Elevation	1,996–4,764 m
Temperature	2.5°C January average
	17°C July average
Precipitation	43 mm January average
	104 mm July average
Residents	1,200 in four villages
Staff	470 permanent employees
	350 high season employees
Visitation	2,000,000 (60% of visitation in July–October)

Resident, staff and visitation numbers are for the year of 2006

representing a model for ecological protection and sustainability in China (IUCN 2006).

The administration of the Park is currently in the process of upgrading sanitation and wastewater treatment systems throughout the park. The determination and implementation of appropriate solutions, which will provide adequate protection of natural resources and habitats, presents a challenge due to the Park's unique hydrologic environment, location, popularity, inclusion of an indigenous Tibetan population, and a history of previous system failures. These concerns also need to be matched with the administration's goal of being a model of environmental park management and sustainability in China. The administration of the Park has identified three goals for a sanitation and wastewater collection and treatment system: (1) implementing a sustainable system that is uniquely matched to their needs and status; (2) assuring the ecological and hydrological balance of the entire the Park environment; and (3) educating the Park visitors about environmental protection.

The value the administration of the Park places on the protection of park resources and education allows them to consider more expensive options than would otherwise be considered as cost-competitive. As a result, the administration has expended significant capital in attempts to meet their goals, but have historically experienced a succession of poor engineering decisions and designs. In an effort to prevent an ongoing series of failures, the administration of the Park requested an evaluation from a collaborative, multi-disciplinary project that included the Park, Sichuan University and the University of Washington. As noted by Ludwig and others (2005), a reconnaissance study prior to environmental impact analysis and feasibility studies for new projects is frequently beneficial in preventing later failures in project design (including institutional, economic, and financial, as well as engineering aspects). The "advanced reconnaissance" approach developed here takes Ludwig and others's (2005) approach further to incorporate a thorough analysis of these aspects as well as additional environmental and socio-cultural aspects that are important to the Park. A structured framework for future, more detailed engineering analyses will be important for the Park to reach an integrated solution that satisfies their goals, and is a cost-effective, long-term solution. The goal of this project was to build a criterion based framework that would better enable the Park to consider innovative approaches. To aid the Park administrators in their consideration of proposed solutions, the developed criteria were then applied to alternative technologies in the literature to identify examples of successful global implementations for their consideration.

Methodology

The following steps that were taken in the development of the advanced reconnaissance method that are presented in the methodology section include: (1) assess the applicability of existing methods of evaluation; (2) incorporate park demographics and institutional structure; (3) provide a critical review of historic and current systems and identify reasons for failures; (4) identify stakeholders; (5) conduct interviews with stakeholders; and (6) develop evaluation criteria based upon points 1–5. The criteria are illustrated and supported by placing them into a global context of successful examples in the results and discussion section.

Evaluate Applicability of Existing Methods of Evaluation

There are numerous examples of methods of evaluation in the literature, but none completely fit the needs of the Park. Many published methods rely on extensive data acquisition incorporating thousands of survey questionnaires (Cuesta and others 2006; Ngai and others 2007). Other methods have been developed for very specific situations such as disaster relief (Fenner and others 2007), or to evaluate only one component of a system such as point of use water filters (Ngai and others 2007). The Park needed an evaluation tool that was not too data intensive, and that could be applied to their entire system with their available resources.

Administrators of the Park identified “sustainability” as one of their most important goals. Sustainability is commonly accepted to be an integration of economic, social and environmental components to “meet the needs of the present without compromising the ability of future generations to meet their own needs” (United Nations General Assembly 1987). However, some scientists have argued that a finite state of sustainability can never actually be obtained, because by the nature of defining a closed box system it will always have energy and material flows in and out of it (e.g., solar, wind, water). For this reason, the Park’s goal of sustainability was interpreted to be “sustainable development” with the goal of reaching a “steady-state of sustainability” as described by von Hauff and Wilderer (2008).

To meet the goal of sustainability, environmental and economic concerns of the Park’s administration had to be balanced with socio-cultural needs. Most evaluation methods do not incorporate all three aspects of sustainability, and focus only on either environmental and/or economic considerations. Examples include exergy analysis, materials flow analysis, material intensity per unit service, economic analysis, life cycle assessment (LCA), and ecological footprint analysis (Flores and others 2008). LCA analysis has been applied to water treatment systems in order to consider the impacts of various alternatives on carbon footprints (Friedrich and others 2009). However, one of the greatest limitations of this approach is the limited availability of data specific to local environmental values and concerns that allow for data to be normalized for comparison to other regions or countries. In addition, other burdens and socio-cultural aspects associated with sanitation cannot be included in the LCA method for comparison. Most methods of evaluation leave out socio-cultural aspects of sustainability because of this difficulty in defining and quantifying it. However, there have been attempts to apply LCA methods for consideration of sustainability in water treatment systems (McConville and Mihelcic 2007), but the resulting method is labor intensive, with a multitude of stakeholder surveys combined with layers of matrices for compilation and evaluation of data. The approach requires long time periods and/or multiple interviewers, resulting in a scoring system that can be arbitrary depending on interpretations by different interviewers. Other evaluation methods have also evolved from industrial ecology to incorporate concepts of sustainability (von Hauff and Wilderer 2008). However, these still lack a method for the development of evaluation criteria to consider in the final quantitative analyses. The advanced reconnaissance method was developed for the Park to systematically incorporate multiple layers of sustainability, while utilizing and adapting the most applicable components of previous studies. In addition to traditional approaches, to ensure successful, long-term implementation, it was imperative to consider factors such as cultural significance, economic values, regional preferences, education, aesthetics and usability. These nontraditional approaches are all critical to enhance ownership, understanding, and client or stakeholder satisfaction, helping to ensure that all stakeholders will be invested in the success of the system.

Park Demographics and Institutional Structure

As summarized in Table 1, in 2006 there were 1,200 indigenous people living within the Park in four villages. In addition to the village populations there is a year-round park staff. At the peak season there are 820 staff members employed in 22 park offices (i.e., in addition to the administration office, there are computer services, construction and planning, guards, operations and maintenance, protection of forest health, ranger, science, etc. offices). Twenty percent of the employees are also residents of villages within the park. For the other 80 percent of park employees, housing is provided at the park’s accommodation block which is adjacent to the park. The park currently receives between 2,000,000 to 2,500,000 visitors each year. The park has experienced an extraordinarily rapid increase in visitation, with numbers increasing 10-fold over the last decade. It appears that the tourist visitation numbers will continue to increase, but at what rate cannot be predicted.

Review of Historic and Current Systems

Information was compiled from site visits throughout the Park and associated treatment facilities, interviews with the Park staff, interviews with project engineers, and review of Park technical documents. The following five distinct areas were defined within the Park by usage, location and type of treatment: (1) Park Entrance (visitor’s center and the Park offices); (2) Tibetan Villages (permanent indigenous communities within the park); (3) Nuorilang (restaurant and shopping complex); (4) Eco-tourism (multiple day backcountry hiking and camping trails); and (5) Main Tourist Route (tourist daytime visitation); these locations are shown in Fig. 2. The main focus of the review was the Main Tourist Route system as it is the one area where the administration of the Park has not yet started to determine upgrades.

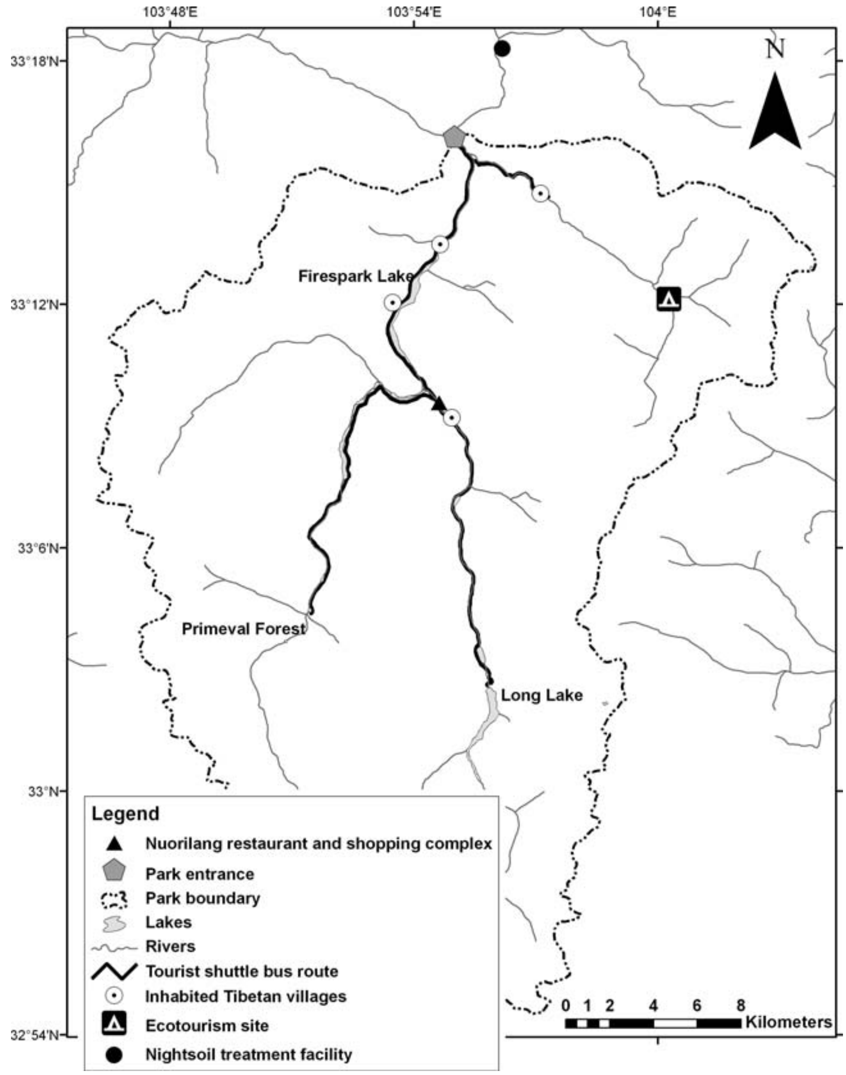


Fig. 2 Location of facilities within Jiuzhaigou National Park

Identification of Stakeholders

Stakeholder analysis was carried out in order to ensure that socio-cultural, economic, and environmental resources would all be considered in shaping future sanitation projects to meet the Parks sustainability goals. From a review of Park demographics and institutional structure, as well as the systematic evaluation of historic and current sanitation systems, key stakeholders were identified by a multi-disciplinary and institutional team for interviews. Who would be impacted by sanitation systems, and the impacts that stakeholders could have on a system, were considered in the determination of stakeholders. The multidisciplinary project team consisted of experts in anthropology, environmental education, forest ecology, environmental engineering, and the Park science staff. Key stakeholders that were identified for interviews included both socio-cultural and institutional representatives:

- socio-cultural – indigenous village residents, tourists, residents of neighboring valley, and Park employees responsible for cleaning and maintaining toilets and treatment facilities
- institutional – administrators from the Park ranger, science, operations and maintenance, and construction and planning departments, and the director of the Park

It was also determined that additional environmental and economic stakeholder concerns would be taken into account through the expertise of the multidisciplinary team.

Stakeholder Interviews

Open-ended, semi-structured interviews were selected to allow the interviewees to contribute candid, unsolicited opinions to interviewers (Schouw and Tjell 2003). In addition, direct observations by researchers at the time of interviews could be incorporated into the interview (e.g., tourists washing hands in a lake and emptied toilet contents being loaded into transfer trucks by hand). The topics of interviews included:

- type of stakeholder and association within the organization of the Park
- methods of sanitation
- problems identified with current system (e.g. public health, environmental, economic, and socio-cultural concerns)
- opinions and/or thoughts in regards to different methods
- beneficial use and value of end resource products
- characterization and history of previous failures

Interviews were held to ensure adequate coverage of identified stakeholders. Interviews were conducted until it was obvious that a clear convergence of stakeholder opinion had been reached. However, in some cases (e.g., administrators), there was only one person available to interview.

Development of Criteria

Results of stakeholder interviews, reasons for previous failures, and goals of the Park were evaluated employing the expertise of the multidisciplinary team to identify high priorities for sanitation and wastewater treatment systems. A mixture of brainstorming and an iterative building, team- and stakeholder-critiquing, and rebuilding criteria lists were used to arrive at the final set of evaluation criteria. The resulting list of stakeholder concerns and justifications were compiled into the final ten criteria.

The ten developed criteria were used as higher level guidance criteria to evaluate alternative technologies from the literature. Potential design options were identified for the Park that met all ten criteria. The resulting options are all viable alternatives that can now be evaluated by more specific and measurable criteria, for example the Integrative Sustainability Triangle proposed by von Hauff and Wilderer (2008).

Results and Discussion

Review of Historic and Current Systems

Originally all of the toilets in the Park were keng (traditional, shallow-pit latrines), with 30 tourist facilities in 1990. Since then, the Park has implemented a range of treatment technologies from pit latrines to centralized wastewater treatment facilities (WWTFs). A summary of historic treatment methods and planned changes for the Park Entrance, Tibetan Villages, Nuorilang Complex, and Zharu Valley Ecotourism areas are provided in Table 2, with locations shown in Fig. 2. The proposed changes for parts 1 through 3 will all meet Class 2 of the Chinese Integrated Wastewater Discharge Standard (equivalent to U.S. secondary treatment).

In 1994, for the Main Tourist Route area, the Park constructed western-style, flush toilet facilities at the most highly visited locations. However, an associated WWTF was not constructed until 1999, at which time two biological attached-growth secondary WWTFs were constructed (Yan and Mei 2005). The system did not function properly because of intermittent electricity, low winter-time operating temperatures, and inadequate water pressure. As a result, both the toilet and treatment facilities were closed (Yan and Mei 2005). In 2001, the Park instituted a new system of dry toilets together with an off-site night soil treatment facility (NSTF). The system is still in use today and handles 6,000 t of toilet waste annually. Toilet waste is captured in 10 m long plastic bags that wrap around toilet seats; each time the toilet is used a motion sensor initiates a mechanism to move the bag down, replacing the plastic seat cover for the next user and transporting the plastic

Table 2 Location, description and type of sanitation and wastewater treatment for identified areas at Jiuzhaigou National Park

Location	Description	Historic treatment	Current and/or planned changes
Park entrance	Visitor's center and park offices	Primary treatment (septic tank), discharge directly to Baihe River, solids taken off site	Connection via new sewer main to new Jiuzhaigou County Municipal waste water treatment facility[a]
Inhabited Tibetan Villages[b]	Four villages with 1,200 total inhabitants	Keng toilets (shallow pit latrine), untreated solids used in agriculture, no grey water treatment	125 m^3 d^{-1} underground wastewater treatment facilities at each village, effluent and biosolids trucked off site
Nuorilang Complex[c]	Restaurant and shopping complex, seating capacity >2,000	Grey water storage in tanks, grey water and food waste trucked off-site	500 m^3 d^{-1} underground grey water wastewater treatment facility
Zharu Valley Ecotourism	New multiple day hiking trails, $\leq$500 people km^{-1}	None	Pit latrines

The Main Tourist Route area is covered in body of text. [a] Municipal wastewater treatment facility started operation in 2007; [b] villages are located on the valley floor of Jiuzhaigou park; [c] historic, current and planned operations of the toilets and associated treatment at Nuorilang are the same as those described for the Main Tourist Route

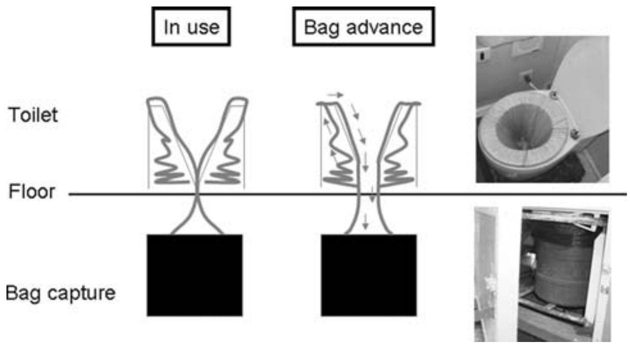


Fig. 3 Main Tourist Route toilet system. Schematic shows movement of plastic bag prior to and following each use. Plastic bags in toilet and bucket for capture are shown in photos

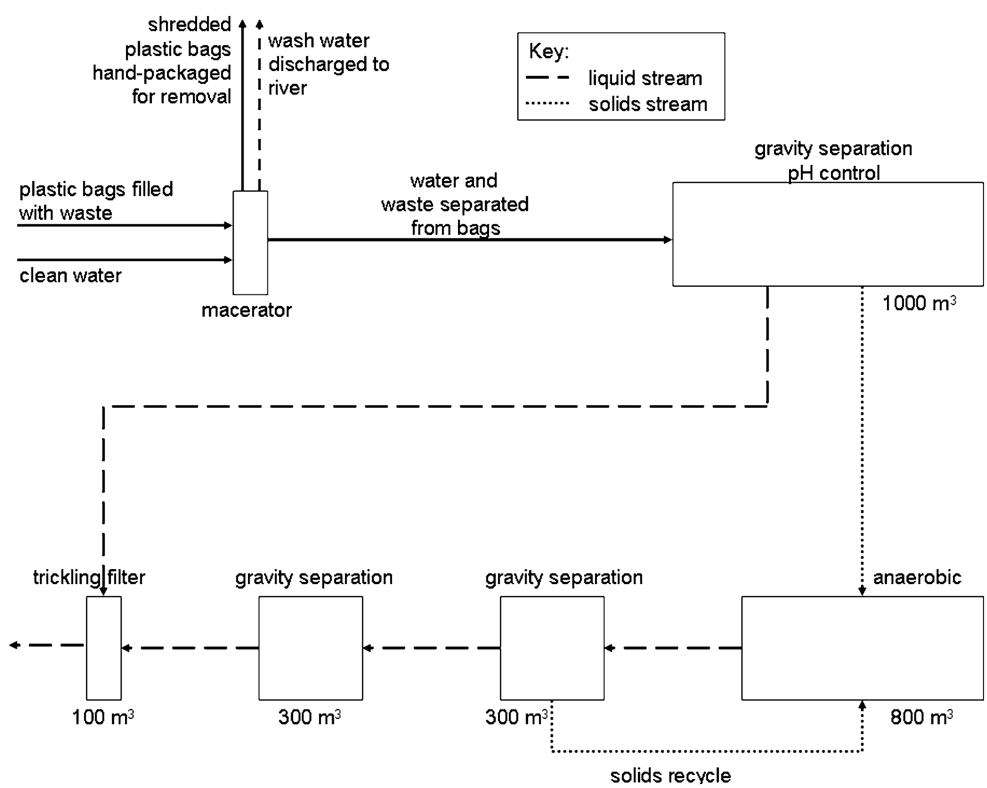
containing waste into a bucket located below the toilet bowl (Fig. 3). The toilets are maintained by Park employees that replace the 10 m long bags when they are full and carry them to the road where they are collected by truck. The trucks then transport them to the NSTF which is located 5 km outside the park entrance. In 2006, this system used approximately 24 t of plastic bags.

At the NSTF the bags are manually loaded into a chute where they drop into a macerator (Fig. 4), with river water added to aid in the separation of the chopped up plastic from excreta. The diluted excreta then drops into a series of underground tanks where it is treated by gravity separation and anaerobic biological treatment. The effluent is treated by contact media filtration (stones) before discharge to the Baihe River. The chopped up plastic bags exit the macerator onto a concrete pad at ground level, still containing a significant amount of excreta. They are then hosed off for further separation (Fig. 5), with the water draining directly into the NSTF effluent and the Baihe River. The system for separation of plastic from excreta is not effective with pieces of plastic bags contaminating every step of the process (Fig. 5). The chopped up bags are packaged by hand into new plastic bags and reportedly taken by truck to Chengdu for recycling (Fig. 5).

Concerns with Current System

Concerns with the Park sanitation and wastewater treatment include reliance on an expensive, labor intensive approach that does not provide adequate levels of environmental and health protection. At the time of installation in 2001, 32,000 Renminbi (RMB) was paid for each toilet (20 million RMB total or 2.4 million U.S. Dollars [USD]). Operations and maintenance costs in 2006 were 2,000,000 RMB (250,000 USD) annually, with plastic bags contributing 5 RMB per use (0.60 USD in 2006, currently 0.75 USD) if everything operates optimally. Based on tank size at the NSTF and an estimate of the Park population equivalent, using values in Zeeman and others (2000) solids are most likely being washed out in the effluent to the Baihe River. Hand-washing facilities are not provided

Fig. 4 Process flow diagram for night soil treatment facility



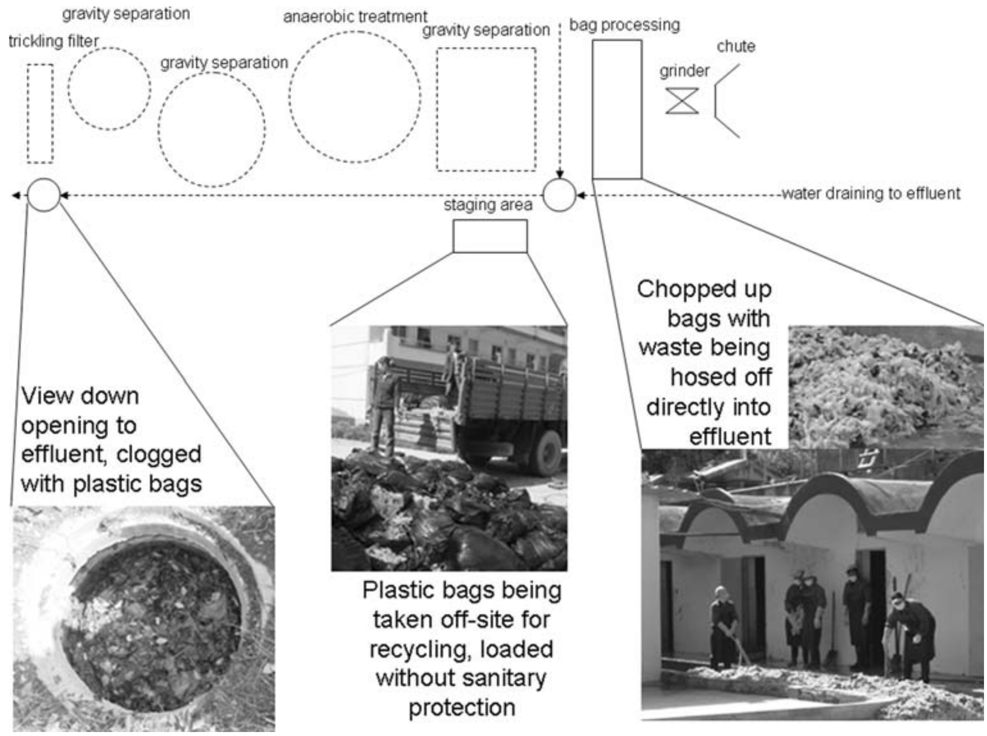


Fig. 5 Photos illustrate operating concerns at night soil treatment facility shown in location of treatment process, including: processing area (*left*); plastic bags being loaded for off-site recycling (*middle*); and opening to effluent (*right*). Dashed lines are below grade, solid lines above grade

for tourists, employees of the Park who maintain the toilets, or the people that handle the plastic bags at the NSTF. Other operational problems include cultural problems associated with the western-style toilets, for example seat breakage when users stand on the seat, and disposal of non-human waste in the toilets (e.g. batteries) that result in breakage or clogging at the NSTF. Also of concern is poor implementation of operation, maintenance, and monitoring, including inadequate staff and lack of adequately trained operators to maintain Village and Nuorilang WWTFs, low operating temperatures for biological processes, no pathogen reduction treatment for biosolids and inadequate environmental protection associated with backcountry hiking and camping in the Zharu Valley Ecotourism area.

Reasons for Failures

Adequate capital, goals and innovative solutions on their own have not been enough to solve the Park's problems. The administration of the Park has lacked a consistent process to evaluate and determine alternatives that meet established sustainability goals, resulting in poor engineering decisions and designs. The administration of the Park has goals in place that voluntarily set high sanitation and wastewater treatment standards for environmental protection that are not currently being met, as outlined in the "concerns with current system" section above. As these goals are voluntary and higher than those required by Class 2 of the Chinese Integrated Wastewater Discharge Standard, to achieve them the administration must also make a commitment to being the responsible agency for their enforcement. The administration of the Park has many measures in place to protect the natural resources of the Park from human impact. However, in regards to sanitation and wastewater treatment, they have lacked a strict management system to implement and oversee monitoring, training of staff, operations, preventative and routine maintenance, and appropriate failure response capabilities. In addition, previous decisions were made and implemented from the top down by the Park administration without consideration of socio-cultural impacts to stakeholders. Implementation and management of a sanitation and wastewater treatment system is currently the administration's largest hurdle in achieving sustainable management.

Evaluation Criteria

Many of the evaluation criteria that resulted from the advanced reconnaissance method stem more from an ecological or multidisciplinary approach than traditional engineering, but will help to ensure success of the final implementation by increasing factors such as ownership, benefit, understanding and satisfaction of stakeholders, in addition to improved levels of management. The proposed and used criteria are not as readily quantifiable as conventionally considered engineering criteria, but can be used as higher level guidance criteria when selecting alternatives, and can also be considered in quantitative evaluations designed to incorporate sustainability (von Hauff and

Wilderer 2008). The ten criteria and their explanations are as follows:

I. Provide for sanitation and hygiene. A high standard of sanitation and hygiene that is not currently being met must be achieved. Any solution must include hygienic facilities and provide protection for users, processors, and maintainers of all phases of the system. This includes sufficient pathogen reduction for end products to protect people that could come into contact with them, either in the environment or through handling, and providing for hand washing or other types of sanitation facilities.

II. Protect environment of the Park. To protect the unique aquatic environment of the Park, systems must minimize water usage, energy consumption, land area, impacts to water quality, and have a high reliability with low risk of consequences due to failure. Effluent should only be discharged to the environment of the Park if it is treated to an exceptionally high standard. Dry or low-flush toilets with zero discharge to the environment should be considered as they will provide more affordable treatment, conserve water resources, and have been shown by previous experience at the Park to be more successful than flush toilets and WWTFs.

III. Implement economical system. Systems must be reasonably priced including initial capital expenditure, continuing operation and maintenance, and make efficient use of existing and available facilities, materials, equipment and workforce. A cost benefit analysis must be carried out to balance goals of sustainability with performance, but ultimately, a well-designed, ecological, reuse-based system will be more economical than other alternatives that have been previously considered and implemented.

IV. Provide for the needs of indigenous populations. Obtain feedback from villagers within and external to the Park prior to implementing technological changes that may remove resources and result in unintended social, economic, or environmental consequences. For example, the removal of keng toilets within the Park will eliminate a source of soil conditioner and fertilizer that villagers rely on for subsistence farming.

V. Require ongoing commitment. The initial and long-term success of systems will require a commitment by the administration of the Park to management including education, human resources, support, training, operations, monitoring, and preventative and routine maintenance. The ongoing performance of systems will need to be dynamically managed with changes implemented as problems arise. Technologies that are the most easily and readily maintained by the Park will be more sustainable in the long-term.

VI. Take account of aesthetics and usability. Odors, appearance, and overall nature of toilets are critical to ensure usage as evidenced by previous failure of keng toilets. Toilets need to be culturally-appropriate, convenient, and straightforward to use to ensure successful implementation with large, easy to understand pictures for proper use. An adequate number of facilities for disabled people should also be provided.

VII. Provide environmental education. Technological implementations that involve changes in common practice require education to inform users of proper use. This is especially important for transient populations such as the tourists to the Park that otherwise do not have a vested interest in the resource, as is evidenced by failure of previous foreign technologies such as western-style toilets. Education for visitors, villagers and the Park staff should also highlight the positive environmental aspects of the system. As discussed in Gaulke and others (2008), models of successful educational opportunities for ecological waste management abound (e.g., CK Choi Building, University of British Columbia, Canada [Cole 1996], and the Living Machine at IslandWood, Washington, U.S. [Todd and Todd 1993]). Increased knowledge of benefits will increase commitment and dedication to proper use of the system. Interviews suggested acceptance and enthusiasm for these ideas and is further supported by the long history of waste reuse in China.

VIII. Provide for beneficial reuse. To meet the Park's sustainability goals they need to shift their thinking from one of waste disposal as demonstrated by the current plastic bag and NSTF system, to one of resource recycling. Waste streams must be used for the generation of beneficial and valuable end-products, for example biosolids used as soil conditioners and fertilizers or generation of methane gas for cooking fuel or energy production. Markets for end products are already in place, villagers in and around the Park have demonstrated an acceptance and desire for end products. Wherever possible, resources should be used within the Park, as the greatest benefit will also be realized by minimizing transportation and energy.

IX. Evaluate park capacity. It is a requisite that the system be designed for seasonal and daily fluctuations of number of tourists. Currently there is no maximum level for the Park visitation. This should be considered to ensure an adequate design that matches infrastructure to visitor capacity. Information for waste quality and quantity could then be more accurately estimated for the design of a new system.

To ensure the system can meet future needs, increasing visitation would then require a deliberate process that included appropriate upgrades to infrastructure.

X. Protect environment external to the Park. To implement a truly sustainable system, the administration of the Park must also consider its environmental impacts external to the park. 75% of the Park boundaries are shared with other protected areas. If the protected areas do not take responsibility for their impacts on unprotected areas outside of their boundaries, the ramifications on environmental protection and resource limitations on these areas will be disproportionately high. This will eliminate alternatives with a high environmental impact outside of the Park boundaries such as heavy use of non-biodegradable plastic bags and insufficient treatment at the NSTF.

Alternatives for Consideration

The experience of the Park in dealing with their sanitation and wastewater treatment requirements illustrates the difficulty of applying technologies across wide-ranging regions and cultures. Western concepts of centralized WWTFs have only been in place for around 100 years, but due to their success in protecting public health, they have become firmly ingrained by many as the only or best solution. However, in addition to other sustainability considerations, frequently they fail in different regions for reasons including lack of expertise for operations and maintenance, consistent supply of energy, and replacement parts that are not locally available. To determine the most appropriate and sustainable solution for diverse global locations, other innovative technologies must be considered. Provided here are a few examples of alternative technologies with a record of successful global implementations that have not previously been considered for the Park, and that meet all ten criteria. The evaluation process considered all ten of the criteria equally to ensure that the decision making process would not favor one criteria and/or one stakeholder above others to alleviate previous problems associated with top down management decisions. Alternatives are discussed under the framework of: (1) Collection; (2) Capture; and (3) Treatment. A summary of the alternatives and how they meet criteria are presented in Table 3. A relative value of two was assigned by the project team if the criteria were exceptionally met, a one if it was adequately met, and zero if it was not met at all. Central to all of these technologies is a shift in

Table 3 Summary of the alternatives reviewed for Juizhaigou National Park that met all ten of the evaluation criterion

Criteria	Collection		Capture	Treatment			
	Food	Urine/excreta	Storage tanks	Com-post	Anaero-bic	Night soil	Urine
I. Sanitation and hygiene	2	2	2	1 (path)	2	2	2
II. Protect environment	2	2	2	2	2	2	2
III. Economical system	2	2	2	2	1 (invest)	1 (invest)	2
IV. Indigenous populations	2	2	2	2	2	2	2
V. Ongoing commitment	2	1 (educat)	1 (empty)	1 (O&M)	1 (O&M)	1 (O&M)	2
VI. Aesthetics/usability	2	1 (concern)	2	1 (odor)	2	1 (odor)	2
VII. Environ. education	2	2	1 (out of sight)	2	2	2	2
VIII. Beneficial reuse	2	2	2	2	2	2	2
IX. Park capacity	2	1 (critical)	1 (critical)	1 (critical)	1 (critical)	1 (critical)	2
X. External environment	2	2	2	2	2	2	2

A score of 2 was assigned if the criteria was exceptionally met, 1 if it was adequately met, and 0 if not met at all. Brief explanations are provided for alternatives that received a ranking of "adequately met"

path = ability to achieve complete pathogen kill without regrowth

invest = higher initial investment

educat = user education critical to success

empty = emptying tanks regularly before they are full

O&M = commitment to ongoing operations and maintenance

concern = concern that users are not familiar with system

odor = odor potential

out of sight = less opportunity for education because the tanks are buried out of sight

critical = design for future park capacity is critical thinking from one of waste disposal to resource recycling, ultimately translating to more cost and energy efficient treatment and reclamation methods. Further examples of integrated sustainable systems in Australia, the Philippines, Thailand, and Western Africa are described by Polprasert (2007).

Collection

Although not commonly employed, the separate collection of waste streams more readily provide for energy efficiency with subsequent simplified levels of treatment necessary to capture benefits of end products. Considered here are separate collection for food waste, and for urine and excreta.

Food waste produced in the Park that is currently trucked off-site (Table 2) could be incorporated into a treatment and reuse plan increasing opportunities for beneficial uses and producing a high quality end product. The food waste from Nuorilang and the Tibetan Villages could be collected and treated, either at a central facility or at each location. Separate collection of municipal waste streams (e.g. food, recyclables) has been successful in Germany, Japan, Sweden, and the United States and is starting to be implemented in Chongqing, China (Hui and others 2006).

The separate collection of urine and excreta can be accomplished through the use of urine diverting toilets, which work by having two separate collection areas. Urine typically contributes 87% of the total nitrogen and 50% of the total phosphorus to the combined toilet waste stream (Otterpohl and others 2004). Separate collection of these nutrients facilitates their beneficial reuse and increases energy efficiency by eliminating the need for their removal from combined treatment facilities (Matsui and others 2001). Technologies for urine diverting toilets include dry toilets that are already mass produced in China (Winblad and Simpson-Hebert 2004) to low-flush technologies being developed in Hamburg, Germany (Otterpohl and others 2004). Important considerations when employing urine diverting toilets are that they are comfortable for the user (Pahl-Wostl and others 2003), urine and excreta are collected without cross contamination (Hoglund and others 1998; Schonning and others 2002), and they drain well to the separate capture areas (Otterpohl and others 2004). Although at present source separation is a novel alternative, there has actually been a long history of separate collection and reuse in China (Winblad and Simpson-Hebert 2004) as well as more recent implementations in Germany, The Netherlands and Sweden. Numerous studies have shown that users are interested and accepting of such toilets if sufficient information is provided about their use and the toilets are well-designed (Hanaeus and others 1997; Otterpohl and others 2004; Berndtsson 2006).

Capture

Based on criterion II, installing treatment systems within the Park was ruled out to minimize impacts to water quality and required land area. Hence, an important component of an integrated system will include methods of storing waste that provide adequate environmental and health protection, and minimize energy resources in transfer. The only option that met all ten criteria was storage in underground tanks that could be used for capture of either separate or combined waste streams. Wastes from either dry, low-flush or pour-flush toilets can be collected in underground tanks via drop shafts from the toilets and emptied with a vacuum truck. Storage tanks and vacuum trucks are commonly employed around the world to empty septic tanks (Polprasert 2007). The Park already owns vacuum trucks, with the need for additional trucks to be evaluated. If a dry toilet system with separate urine collection is employed a more powerful, blower type of vacuum truck would have to be used for collection (e.g. types used for clearing storm drains) (Harada and others 2006).

Treatment

Unconventional treatment alternatives can ultimately maximize the beneficial reuse of nutrients and reduce energy consumption. Considered here are composting, anaerobic treatment, a NSTF, and the treatment of separately collected urine.

Composting harnesses the natural processes of decomposition and stabilization, requiring low energy inputs and resulting in significant pathogen reduction. Benefits to treatment by composting include an end product which can be safely used in agriculture, and a facility that is easier to build and maintain than many other options. Composting processes can be located at individual toilet facilities or a centralized facility. Concerns with individual composting systems include consistently reaching high enough temperatures for pathogen reduction, relying on time and adverse conditions. Experiences in Denmark with pathogen reduction and regrowth in individual systems that incorporate separate urine collection have been documented by Tønner-Klanka and others (2007). Thermophilic temperatures for pathogen reduction would be more readily accomplished and monitored at one centralized facility. Malmén and others (2004) present a successful example of thermophilic composting of low flush toilet waste together with grey water sludge and organic waste in Sweden.

The treatment of biowaste by anaerobic digestion is well documented with tens of thousands of applications in South East Asia (Otterpohl 2002) and 2.7 million domestic installations in India (Raheman 2002). In addition to pathogenic reduction rendering a safe to use, stabilized end product, this process allows for capture of methane gas that can be used in applications from cooking, to fuel and electricity production, depending on the scale and complexity of implementation. The decision of source collection (i.e. food waste, combined or separate toilet waste) will determine the optimum anaerobic treatment method (Zeeman and Lettinga 1999; Steiner 2000; Krzystek and others 2001). Biosolids from the village WWTFs could also be incorporated in the treatment process for stabilization and pathogen reduction. The cold wintertime climate at the Park could present operational problems associated with the anaerobic process. This could be addressed by insulation, subsurface burial, or heating the influent waste stream utilizing biogas production (Polprasert 2007). However, a requirement for heat could reduce the benefits of methane production for power generation and increase operational complexity.

Replacing the current NSTF with an adequately designed facility could potentially provide the highest level of environmental protection. There are 1,185 NSTF in Japan serving 37 million people (Gaulke 2006). These NSTF, unique to Japan, could be used as models of successful implementations. Night soil treatment typically employs activated sludge together with advanced technologies including nutrient removal and membranes for solid–liquid separation. NSTF systems in Japan have been shown to be more economical than conventional WWTFs (dependent on the scale of implementation) and have been proposed as a sustainable solution for developing countries (Harada and others 2006). Separate urine collection can also be incorporated into these systems, as well as treatment of food and municipal waste (Matsui and others 2006). A centralized NSTF in cooperation with the protected areas surrounding the Park would also provide a way to increase sustainable treatment, reducing the impact to the environment from all of the protected areas. Vacuum trucks could be shared for parks that are close together, with relay stations to transfer night soil from smaller holding facilities to a larger centralized facility.

Urine is relatively sterile and needs little treatment for pathogen reduction before reuse. Treatment technologies require little energy input, being as simple as storage in tanks for six months for pathogen die off (Hoglund and others 1998; Otterpohl 2002). Nitrogen in urine is in a plant available form, hence, the separate collection and reuse of urine can also save energy over commercial fertilizers if the urine is not transported long distances (e.g. less than 22 km) (Jönsson 2002).

Conclusions

The separate collection of waste streams can facilitate resource recovery by simplifying treatment. The alternatives that received the highest rankings in Table 3 were the collection and onsite reuse of food waste, and treatment of separately collected urine. Both of these alternatives were ranked higher due to the simplicity of treating waste streams for resource recovery that have minimal risk of exposure to pathogens, obviously there will always be an increased risk when resource recovery includes excreta. Alternatives that received slightly lower rankings were all associated with the collection and treatment of excreta. For these alternatives, the ten criteria were all still adequately met, and potential concerns were identified.

The developed advanced reconnaissance method provides the administration of the Park with evaluation criteria to ensure that alternatives that are considered in a more detailed engineering selection and design process will incorporate their goals of sustainability, environmental protection, and environmental education. The criteria will help to avoid previous failures resulting from decision making, management, operations and maintenance, and socio-cultural concerns. The criteria are also applicable to existing Park systems to aid in prevention of future failures. Lessons learned through this case history are transferable to other implementations throughout the world in both underdeveloped and developed areas, where concepts of sustainability are considered in the evaluation of sanitation solutions. The ten evaluation criteria can be directly employed in similar situations, for example parks and nature reserves where socio-cultural needs of tourists and local residents are to be considered. The criteria developed for the Park can also be used for guidance in situations where the developed advanced reconnaissance method is employed to develop site specific evaluation criteria that incorporate socio-cultural values and resource recovery for complete systems with a complex group of stakeholders.

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