A Community-based Ecological Greywater Treatment System in Santa Elena-Monteverde, Costa Rica

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Abstract

Research at the Monteverde Institute into alternative, low-cost wastewater treatment systems has resulted in the development of an ecological greywater treatment system servicing four households in nearby Santa Elena. The system became operational in April 2001 and is currently being monitored in terms of input and output water quality parameters, plant species performance, seasonal variation, cultural acceptance and maintenance issues. Of particular interest is the concept of establishing an "environmental services contract" for the system which will allow the owner to receive payment for the provision of a service from her neighbours. Such a contract is currently being formulated and will represent a first in Costa Rica in terms of a private wastewater treatment service provider.

Introduction

Costa Rica has whole-heartedly embraced eco-tourism as a source of much-needed foreign exchange and which until recently was the nation's number one industry in terms of financial turnover. While the country is famous for its enlightened approach to conservation and its sheer biological diversity, the impacts of unlimited ecotourism, population growth and a lack of any national master plan are being felt. In particular it is widely recognised that the pollution of water and water bodies, in hand with diminishing fresh water supplies, is now a real threat to the health and livelihood of all species. The state of Costa Rica's national water and wastewater treatment and supply systems has come under intense scrutiny in recent months following a series of significant diarrhea outbreaks linked to contaminated water supplies, as well as on-going media coverage of the gross pollution resulting from the discharge of untreated sewage to the environment. Years of ineffectual political administration, ineffective legal mechanisms and prevailing cultural values have all been blamed as contributing to the current scenario [1]. While Costa Rica has achieved relatively high levels of coverage in terms of water and sanitation in comparison to all other Central American countries it faces significant challenges in the years ahead if this is to be sustained. It is worth noting that in Latin America as a whole, 98% of all sewage is discharged completely untreated [2].

Monteverde, in northwest Costa Rica, has experienced significant unregulated growth in the last two decades due to eco-tourism which stemmed from biological interest in the area in the 1960s and 70s. For example, visitor numbers to the world famous Monteverde Cloud Forest Preserve which consists of some 10,500 hectares of tropical montane cloud forest which is one of the world's most threatened ecosystems, have risen from some 300 individuals in 1982 to over 55,000 in 1999 [3]. The name 'Monteverde' (or 'The Zone') is generally used to describe the three communities of Monteverde, Cerro Plano and Santa Elena which are all adjacent to cloudforest vegetation on the Cordillera de Tilaran at an altitude of 1200-1600m. The Monteverde zone is a legal political entity known as District 10 of the canton (county) of Puntarenas in the province of Puntarenas.

Development has proceeded in an ad-hoc fashion and local planning for the region has been virtually non-existent with little, if any, enforcement of national planning codes and regulations. The associated environmental impact, principally in the rapidly urbanising town centres has been considerable [4]. The disposal of domestic wastewater, principally the greywater component, will be discussed here.

Climate and terrain

The climate in Monteverde consists of three seasonal types: Wet (May-October), Transitional (November-January) and Dry (February-April). Approximately 80% of the annual average 2519mm of rain falls in the wet season and temperature varies between 9.0^{0}C and 27.0^{0}C with an average of 18.5^{0}C. Soil in the Zone typically consists of a porous and free draining A horizon with high organic content overlying less permeable B and C horizons which represent relatively young volcanic geological formations [3].

Prevailing 'water and sanitation' culture:

The prevailing wastewater disposal paradigm in the Monteverde Zone, which is also widespread throughout the country, consists principally of a septic tank for household blackwater (70% of households in Costa Rica [5]) while all greywater is disposed of directly onto the ground surrounding the dwelling and/or directed to the nearest stream or street. Run-off of this greywater is reasonably rapid due to the region's steep terrain and thus one potential health risk - that of disease associated with stagnant and ponding water - is fortunately avoided. Many of the coastal areas, however, not only in Costa Rica but in greater Central America, with flatter terrain and higher temperatures are much more susceptible to mosquito-borne disease risks such as dengue fever and malaria associated with stagnant water. The public perception of greywater (*aguas grises*) appears largely to be only one of nuisance value due to the odour and visual component and this is further diminished during the wet season months when daily rainfall tends to dilute and flush away greywater. The nuisance value of greywater however is most marked in the dry season months not only due to lack of rainfall but the fact that the dry season is the most popular time for tourism when water demand and hence also greywater discharge is greatest. Concerns pertaining to environmental degradation as well as health impacts associated with the greywater discharge have also been expressed in the community, particularly by those residents who have experienced the development of the zone first-hand. It is one of these concerned residents who proposed that the greywater system described in this paper be located on her property.

Due to the foresight of the North American Quakers who settled in the area in the 1950s and protected some 500 hectares of the cloud forest to protect their water supply (which provided the basis for the Monteverde Cloud Forest Preserve) all the Zone's water is now provided by natural spring sources within this protected area. Water of sufficient quality and quantity at a low price has largely been taken for granted, which in hand with a seeming abundance of 'water' in the wet season, have not conspired to create an ethic of water conservation or awareness. For example, the current water tariff of 740 colones (US$2.25) for the first 15 kilolitres/house/month means that water is used frequently for washing vehicles, wetting down roads and driveways in the dry season and the like. In the home, dishes are almost invariably washed one by one under running cold water. Flushing toilets are standard in most dwellings except in some of the more rural or isolated areas where pit toilets are occassionally found. The local water authority's, Acueductos y Alcantarillados (AyA) design figure for domestic water supply is 150 litres/person/day [4]. While estimates for the percentage of greywater/blackwater range between 60 and 80% of the total water consumption [5,6], given the above information and the prevailing Costa Rican culture for high levels of personal hygiene and cleanliness it is suspected that in Monteverde the percentage of total water consumption discharged as greywater is towards the higher figure. Further research is proposed to more accurately determine this greywater/blackwater ratio for the design of future greywater treatment systems.

The pre-existing culture of domestic wastewater separation at the source raises interesting and less problematic treatment options than in the conventional mixed-source disposal systems. For example, septic tank and leach fields can be significantly smaller than would be permitted were greywater and blackwater to be combined. While laws do exist regarding the disposal of untreated greywater into the street or stream, the fines are so small as to be insignificant, the likelihood of enforcement remote and the practice so widespread that any change to this situation is unlikely in the forseeable future.

Ecological sanitation and ecological engineering

The terminology "ecological sanitation" or "ecosan" for short is used to describe an "alternative sanitation concept which represents a more holistic approach towards ecologically and economically sound sanitation" [7,8]. This ecosan approach emphasises water conservation, nutrient capture and reuse, the prevention of pollution, biological rather than chemical/mechanical processes and aims to close the loop on the water cycle as occurs in nature. Ecological engineering has been defined as the "design of ecosystems for the mutual benefit of humans and nature" [8]. Both ecological sanitation and ecological engineering have formed the underlying design basis for this work.

Community-based Ecological Greywater Treatment System

Attention has primarily been given to potential ecological treatment systems for greywater, rather than blackwater, due to the perceived need in the Zone resulting from the 'nuisance' value of the current practice. While the 'nuisance' value (odour and unsightliness) of untreated greywater flowing down the streets and streams of an 'eco-touristic' town may be the main motivator for many local residents to take action, it nevertheless provides the incentive to tackle a problem which in fact has implications beyond simply 'nuisance' ones: in terms of public health, biological diversity and environmental impacts. For example, a continuing water quality sampling program of local rivers initiated by Scheffe in November 1999 at the Monteverde Institute and in collaboration with scientists from Smith College has revealed a rapid deterioration in stream water quality immediately downstream of the local towns. Some of the typical water quality parameters for some local streams are given below in Table 1. High levels of fecal coliform particularly downstream of Santa Elena are also indicative of contamination from septic tank and leachfield effluent, which will be investigated in further studies, however, the majority of contamination in terms of volume can be considered to be a result of directly visible greywater discharge. The data presented here represents the results from fortnightly water sampling which took place from January to June 2001 when rainfall was minimal. The results indicate most noticeably the deterioration in water quality in terms of turbidity, biological oxygen demand (BOD), dissolved oxygen (DO) and fecal coliform.

Table 1: Typical water quality parameters of streams upstream and downstream of Santa Elena taken during January to June 2001.

Parameter	Upstream (Typical values)	Downstream (Typical values)
Turbidity (cm)	60+	16.5-60+
Phosphate (mg/l)	0	na
Nitrate Nitrogen (mg/l)	0	0-0.22
BOD (mg/l)	0.25-1.4	1.4-6.9+
TDS (mg/l)	20-30	40-80
pH	6.5-7.0	6.2-6.9
Temperature (degrees C)	14.0-17.4	17.0-19.0
Dissolved Oxygen (mg/l)	7.2-8.7	5.0-8.0
Fecal coliform (colonies/100ml)	100-330	300-8000

Note: 'Upstream' represents streams emanating from undisturbed catchments. 'Downstream' represents stream sites immediately downstream of the Santa Elena township.

Initial research into the suitability of reedbeds to treat greywater was carried out at the Monteverde Institute's Community Art Centre which was undergoing renovation in early 2000. As part of this renovation it was decided to implement environmentally-friendly wastewater disposal systems, and as a result, a composting toilet and reedbed system to biologically treat the Centre's greywater were installed. The main philosophy behind this demonstration project was to provide low-cost, non-polluting, sanitation alternatives to the typical flush-and-discharge systems, one which conserves and reuses water, and is open to the general public.

Several months after the construction of the Art Centre's greywater reedbed, the first author was contacted by a resident of Santa Elena, Mrs Jimenez, who was anxious to establish a similar system in Santa Elena where the need for greywater treatment is more pressing. After several weeks of discussion a grant proposal was developed to seek funding for the construction of a project on Jimenez's private property in Santa Elena to treat the greywater from four households. The proposal was submitted to the first Ford Motor Company Environmental Awards to be held in Costa Rica and was successful with funding received in January 2001 for the project.

The greywater treatment system consists of two submerged-flow (subsurface-flow) reedbeds in series followed by a pond and a drainage/soakage area after which any surplus, treated water can overflow to a nearby stream. The design was based upon the submerged-flow reedbed type for wastewater treatment [9] and furthered the design trialed at the Community Art Centre described previously. Factors which contributed to this decision were:

- Water level is always maintained at least 10 cm below the reedbed's surface level (crushed rock). This avoids the potential for mosquito breeding and odours as no surface water is present.
- Relative low cost. Costa Rican labour costs typically are low (approximately 500 colones/hour [US$2.10]). The single most expensive component was the crushed rock at US$20/m3.
- Ease of construction.

The combined flows of the owner's house and the three neighbouring households was estimated to be approximately 3,000 litres per day maximum. This figure was based on the previous 12 months of water supply meter readings which were made available by AyA and then factored on the basis of 75/25% for greywater and blackwater components respectively. Further research and data collection to better understand both the quality and quantity of greywater discharged from a typical Costa Rican household is required and is one of the long term goals of this project.

Further, while information exists on the use of reedbeds and constructed wetlands for the treatment of wastewater (both grey and black water), little information exists on 'greywater only' reedbed systems in tropical areas. This project will serve as a site for the gathering of this information as it is monitored in the years ahead. Reedbeds for the treatment of both grey and black waters will also be trialed at the Institute in the near future.

Reedbed System

Work on the reedbed system commenced in February with the first household connected in April 2001. While the site was challenging in terms of its steep terrain slope (1:6), the relatively soft soil type typical of the region made manual digging 'along contour' reedbeds relatively straightforward. The first reedbed is approximately 14m long, 1.8m wide and 0.6m deep, the second approximately oval in shape (6m by 4m and 0.6m deep) and both are lined with two layers of black building plastic. The second oval-shaped pond has internal plastic baffle walls to extend the flow path to approximately 12m. Prior to filling of the reedbeds with crushed rock (*piedra cuarta*) which was obtained locally, some 40-50mm of soil was placed on the bottom of the beds to avoid puncturing the plastic liner. As mentioned earlier this crushed rock was the most expensive component of the system and alternatives including non-recyclable plastic (PET) drinking water bottles cut up into sections have also been trialed at the Art Centre site with success in terms of providing an inert media and structural support for the plant roots. This locally available crushed rock was determined to have a porosity of 50% which allows an effective storage volume of 15 m3 (15,000l) or 5 days retention for this system.

Due to the region's steep topography, wetlands - and native wetland plants - are non-existent. However several non-native reed species were located in a few isolated areas and were identified with the assistance of local botanists [10]. The reedbed was planted with "Job's Tears/Lagrima's de San Pedro" (*Coix lacryma-jobi*), a member of the Tripsaceae family and the species considered to be the most suitable and yet non-invasive. Recent research however suggests that mixed resident vegetation may in fact prove to be more effective at nutrient stripping than monoculture systems such as this and some experimentation with this will be attempted [8].

After passing through the reedbeds, the treated greywater flows into a shallow pond containing fish (tilapia) to consume mosquito larvae, and floating aquatic plants including water hyacinth (*Eichornia crassipes)*, water lettuce (*Pistia stratiotis*) and local 'patita' (*Heteranthera reniformis*) for additional water treatment. It then flows into a soakage basin planted with useful phreatophyte species such as banana, bamboo, sugarcane, taro and lemongrass [11]. All connections between the reedbeds, pond and drainage area consist of plastic-lined, rock-filled drains and not piped connections, for simplicity of construction. Only greywater from the houses is piped in 75mm diameter pvc pipe to a 750l concrete compensation/settling tank prior to entering the reedbed.

The plant and fish species used in such biological treatment systems need to be carefully assessed, particularly non-native invasive species which may have the capacity to invade local water bodies to the detriment of native species (Kivaisi). The emergent *coix lacryma-jobi* being used here has been described as having 'naturalised' [10], and while thriving thus far in its role as an plant for greywater treatment its capability to spread beyond the reedbed is being monitored. Similarly the use of the floating macrophyte - water hyacinth (*Eichornia crassipes*) for wastewater treatment in developing countries has been described as controversial [8] due to its highly invasive nature. In Costa Rica this non-native plant is readily seen in some of the larger water bodies including Lake Arenal on the Pacific side and the Tortugero waterways on the Atlantic side. Similar arguments apply to the use of the non-native tilapia fish, however, suitable hardy wetland plants and fish for these wastewater treatment systems are largely non-existent in the type of terrain, altitude and climate experienced in Monteverde.

Performance

Since the system was planted in early April it was left to mature, rather than subjecting the recently transplanted reeds to a full loading of greywater, only one house was connected initially. The remaining three houses are currently being connected which has allowed the reeds and their roots to become established, bacteria to develop throughout the system and pond water to stabilise. Water quality data collected to-date is presented below in Table 2.

Table 2: Water quality parameters of the Santa Elena greywater reedbed's inlet and outlet compared with data from other studies.

Greywater Parameter	Various studies*	Inlet	Outlet (pond)
Volume (l/pp/day)	76-224	112	na
Ratio of total water %	53-81	75	
Turbidity	20-140 NTU	12.5-15cm	60+cm
Phosphate (mg/l)	1.4-35	0-0.14	0-0.14
Nitrate Nitrogen (mg/l)	0-4.9	0	0
Suspended Solids (mg/l)	20-1500	na	na
BOD (mg/l)	33-620	20-25	0.4-4.0
TDS (mg/l)	420-1700	130	80-90
pH	5-8.7	6.2-6.7	6.5-6.8
Temperature (degrees C)	na	20-21	19.3-21.6
Dissolved Oxygen (mg/l)	na	1.6	2.4-4.8

* source [6], greywater characteristics as reported by various studies conducted in the USA. Range of values given.

The total cost of the system described here including all plumbing materials, transport, crushed rock, plastic liner and labour, but excluding system design and supervison, was approximately US$1,000 which represents a cost of US$250/household. For comparison purposes, the cost locally for the installation of a typical and very basic septic tank and small drainage field is approximately US$250-300. Maintenance costs are as yet unknown but it is envisaged that after the first year of operation this will be known, and that this cost will be reflected in the terms of payment of the environmental services contract.

Environmental Services Contract

The concept of environmental services contracts (ESC) as a tool for the protection of natural resources on private land in Costa Rica was established in 1992 [12]. It was initiated by CEDERANA (Environmental and Natural Resources Law Center) with a philosophy based on the understanding that "conservation of the existing biodiversity in Latin America is a vital component for the future sustainable development of the region". Todate it has been used effectively to ensure the protection of existing forests on private lands. In this instance we are endeavouring to establish an ESC which will allow the owner of the land, Mrs Jimenez, to receive payment for the provision of a service (treatment of her neighbours greywater on her property) from her neighbours. This is reasonably complicated due to the following factors:

- no such pre-existing ESC exists in Costa Rica
- no tariff exists at present for the treatment of greywater (current tariff for main sewerage connection in the capital, San Jose is an additional 25% of the monthly water bill)
- annual maintenance costs are so far unknown
- willingness to pay (while the neighbouring residents have agreed 'in principal' to the scheme it is to be seen if they will in fact sign a contract when it has been formulated)
- collection of fees and who will be responsible for this task

Such a contract is currently being formulated and if successful will represent a first in Costa Rica in terms of a private wastewater treatment service provider.

Conclusions

While it is premature to conclude that the system is a success it has demonstrated the 'in principal' suitability for this type of biological greywater treatment systems in terms of viability and reproducibility in the mountainous tropics. Clearly other technological options exist [13] and long term considerations which will need to be examined include maintenance, cultural acceptance and affordability. Other factors such as free-land availability, topography, soil type and nuisance control (mosquitoes, odour etc) have been described by others [8]. Opportunities for reuse of the treated water also exist [14]. In the low lying coastal areas of the tropics the performance of such systems is likely to be enhanced due to the warmer climate however the increased annual rainfall may tend to reduce this advantage.

It is to be expected that the performance, in terms of the treated water quality, will vary with the seasons and therefore at least one full year of monitoring will be required to accurately determine the system's efficiency. However as no national standards exist in Costa Rica as to the acceptable limits on domestic wastewater discharge in terms of quantity or quality, it may be that the system's performance will be relative, that is, any treatment is 'better' than none. It is envisaged that by trialing and monitoring this real scale, ecological greywater treatment system, flaws can be overcome and design parameters achieved which will optimise the cost, size and efficiency for future installations.

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