Small Flows Quarterly
JURIED ARTICLE

The Need for Wastewater Treatment in Latin America:

A Case Study of the Use of Wastewater Stabilization Ponds in Honduras

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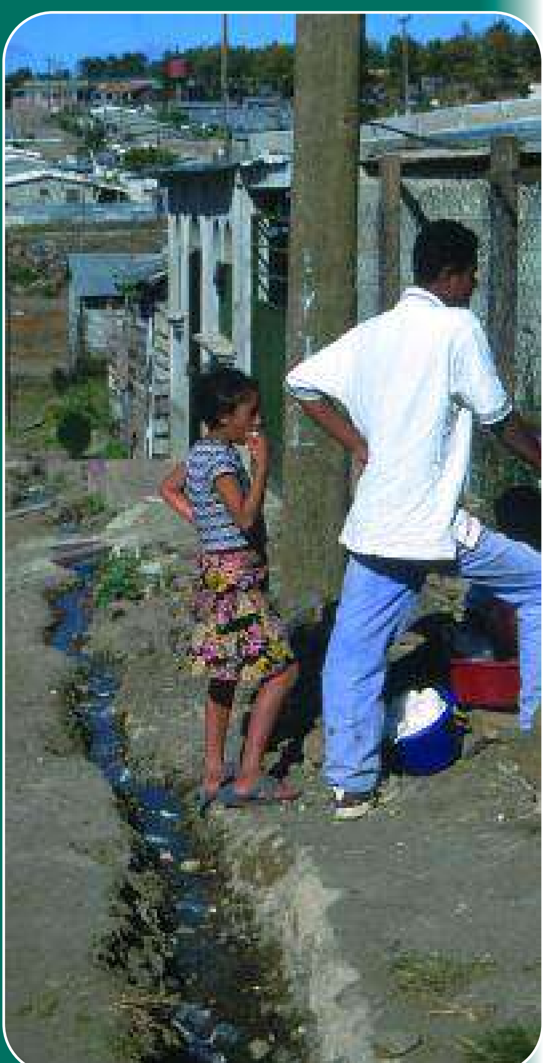

A common scene in Latin America: raw sewage flowing down a street in an urban development near Tegucigalpa, Honduras.

Abstract

This paper discusses the issue of wastewater treatment in developing countries, especially in Latin America, and presents a detailed case study of the use of stabilization pond systems in Honduras. Ten pond systems in Honduras were monitored during dry and wet seasons to develop a database for performance, improving designs, and developing more appropriate effluent standards based on local conditions. The pond systems were monitored for flow rates, helminth eggs, *Shigella* species, *Escherichia coli*, fecal coliforms, and conventional parameters, including BOD_5 and suspended solids (SS). Pond sludges were also monitored for helminth eggs, and percent total solids, volatile solids, and fixed solids. Results show that the majority of ponds have higher flow rates (with lower hydraulic retention times) and much higher organic loading rates than those assumed by designers. Nevertheless, all of the systems monitored removed 100 percent of the influent helminth egg concentrations and satisfy the World Health Organization microbiological guidelines for Category B irrigation with wastewater effluents. *Shigella* species were not detected, and *Escherichia coli* and fecal coliform removal were highly variable. The removal of BOD_5 and SS was typical for stabilization pond systems, and organically overloaded ponds did not exhibit significant difference from underloaded ones. Sludge analyses showed that all pond sludges are heavily contaminated with helminth eggs and that several ponds are in need of desludging. Planning for system expansion, and adequately financing operation and maintenance, including pond desludging, are major issues within municipalities for long-term sustainability. The study concludes that at this time treatment objectives in municipalities should focus on helminth removal, with the objective of using pond effluents for agricultural and aquaculture reuse to enhance long-term sustainability of pond systems

Author's Note: *The perspective presented in this paper is far removed from the technical and regulatory context of wastewater treatment as practiced in the U.S. The paper's purpose is to present to the readers of the* Small Flows Quarterly *the problem of excreta-related infections in developing countries and the goal of effective wastewater treatment as a public health imperative using a natural system technology in a way distinct from the U.S. experience.*

While there is much interest on natural systems for wastewater treatment (WEF, 2001) or decentralized wastewater management systems (Crites and Tchobanoglous, 1998), and while lagoon or waste stabilization pond systems are subsumed within these categories, it is clear that in the U.S., pond systems have long fallen out of favor as a treatment option for municipalities. This is principally a result of increasingly stringent discharge requirements (Metcalf and Eddy, 2003). Although the U.S. Environmental Protection Agency (EPA) has recently published revised editions of its constructed wetlands and onsite wastewater design manuals (EPA, 2000 and 2003), it is doubtful that the waste stabilization pond design manual published over 20 years ago (EPA, 1983) will ever be revised.

Outside the U.S. it is a quite different story. Waste stabilization pond systems have long been promoted in developing countries as the only viable option to help solve the devastating problem of excreta-related disease transmission at an affordable cost (Cairncross and Feachem, 1992; CEPIS/OPS, 2000; Egocheaga and Moscoso, 2004; Feachem, et al., 1983; León and Moscoso, 1996; Mara, 2004; Rolim, 2000; Shuval and Fattal, 2003; and Shuval, et al., 1986). Pond systems in developing countries are typically designed for pathogen removal and agricultural reuse using epidemiologically-based guidelines, such as the World Health Organization's (WHO) microbiological guidelines for wastewater use in agriculture and aquaculture (WHO, 1989). This approach for wastewater treatment is distinct from that taken historically in the U.S. and Europe and is especially distinct from the current focus of U.S. regulation at the state and federal level.

The purpose of this paper is to discuss the issue of wastewater treatment from the perspective of developing countries in Latin America and to present a detailed case study, including extensive monitoring results, of stabilization pond use in Honduras—one of the poorest countries in the Western Hemisphere with typically high prevalence rates of excreta-related infections.

Wastewater Treatment Issues Outside the U.S.

Global Status of Excreta-Related Infections and Wastewater Treatment

The provision of drinking water supply, sewerage, and wastewater treatment for communities throughout the world has been a major component of development projects financed over the last 20 years. This effort started with the International Drinking Water Supply and Sanitation Decade movement (1981 to 1990), which was spearheaded by the World Bank (Cairncross and Feachem, 1993). During the 1990s, the WHO and the United Nations Children's Fund (UNICEF) formed the Joint Monitoring Program for Water Supply and Sanitation, whose overall aim was to improve planning and management within countries by support in monitoring the water supply and sanitation sector (WHO/UNICEF, 2000). The WHO/UNICEF Joint Monitoring Program has presented four assessment reports (1991, 1993, 1996, and 2000). The findings of the latest report (WHO/UNICEF, 2000) can be summarized, in part, as follows with additional information cited from other sources:

- Worldwide approximately 1.1 billion people lack access to improved water sources.
- Approximately 2.4 billion people have no access to any form of improved sanitation.
- Excreted-related infections are a major cause of morbidity and mortality worldwide.
- There are approximately 4 billion cases of diarrhea each year, causing 2.2 million deaths, mostly among children, from diseases associated with lack of safe drinking water, inadequate sanitation, and poor hygiene.
- Intestinal worms (helminths) infect at least 10 percent of the population of the developing world (WHO/UNICEF, 2000), and likely infect up to 24 percent of the world's population (Chan, 1997).
- Protozoan infections probably exhibit a similar prevalence to helminths, and *Entamoeba histolytica* infection is one of the 10 most common infections in the world (Savioli, L. et al., 1992).
- Lack of wastewater treatment is a health hazard in all developing countries. With the exception of the U.S., Canada, and some European countries, the median percentage of urban wastewater treated worldwide is very low as seen in **Table 1**.
- The discharge of untreated wastewater is especially a health hazard where receiving waters are used for drinking water sources, bathing, washing, irrigation, and fisheries.
- Conventional wastewater treatment methods as practiced in the U.S. and Europe are not affordable in developing countries (which is the main reason why they don't exist), nor do they necessarily provide the requisite degree of pathogen removal for the protection of public health, especially parasitic infections.

As a result of the above situation, the professional community concerned with sanitation and public health in developing coun-

Geographic Region	Asia	Latin America & Caribbean	Africa	North America	Europe
Population in yr. 2000, billions	3.68	0.52	0.78	0.31	0.73
Median percentage of wastewater discharges that receive any form of treatment	35	14	0	90	66

TABLE 1 Wastewater Treatment Worldwide

tries has long concluded that the principal objective of wastewater treatment in areas where excreta-related infections are endemic should be the removal of pathogens using low-cost appropriate technologies, and that generally the most appropriate technology is a waste stabilization pond system (Cairncross and Feachem, 1992; CEPIS/OPS, 2000; Egocheaga and Moscoso, 2004; Feachem, et al., 1983; León and Moscoso,1996; Mara, 2004; Rolim, 2000; Shuval and Fattal, 2003; Shuval, et al., 1986; and WHO/UNICEF, 2000). The pathogen removal efficiencies of various treatment processes as generally cited in the literature are shown in **Table 2**.

Process	Removal, %		Removal, Cycles $\log_{10}$			
	BOD_5	SS	Virus	Bacteria	Helminth Eggs	Protozoan Cysts
Primary Sedimentation	25—40	40—70	0—1	0—1	0—1	0—2
Activated Sludge[1]	55—95	55—95	1—2	0—2	0—1	1—2
Trickling Filters[1]	50—95	50—90	1—2	0—2	0—1	1—2
Disinfection with Chlorine	---	---	0—4	2—6	0—1	0—3
Stabilization Ponds in Series[2]	70—95	55—95[3]	2—4	2—6	2—4 (100%)	2—4 (100%)

1. Preceded and followed by sedimentation
2. Depending on the number of ponds in series, hydraulic retention time, and physical design
3. Pond effluents typically have higher SS concentrations in the form of algae although the removal of the influent SS is greater than 90%

Sources: Feachem *et al.*, 1983; Mara, 2004; Scott, 2003

TABLE 2 Removal of Pathogens and Conventional Parameters in Various Treatment Processes

This focus on pathogen removal with stabilization pond systems is distinct from the historical objectives of wastewater treatment in developed countries and is especially far removed from current focus on more stringent effluent regulations with the use of increasingly more costly and complicated technologies in the U.S. Nevertheless, the sheer magnitude of the problem of public health and wastewater treatment in developing countries necessitates a different approach (**Figure 1** graphically shows the gap in per capita gross national product among the U.S. and various countries of Latin America, which underscores the need for low-cost solutions not used in the U.S.). In fact, the focus on stabilization ponds for developing countries is within the same spirit of the interest in natural systems for wastewater treatment in the U.S., with emphasis on natural environmental components to provide the desired treatment, and the benefits of fewer operational personnel, less energy consumption, and less sludge production than conventional mechanical systems (WEF, 2001). In this context, it is worthwhile to quote from the classic text, *Sanitation and Disease*, published over twenty years ago and still relevant today for the problem of wastewater treatment in developing countries:

> *"Those whose job is to select and design appropriate systems for the collection and treatment of sewage in developing countries must bear in mind that European and North American practices do not represent the zenith of scientific achievement, nor are they the product of a logical and rational design process. Rather, treatment practices in the developed countries are the product of history, a history that started about 100 years ago . . .. Conventional sewage works were originally developed in order to prevent gross organic pollution in European and North American rivers; they were*

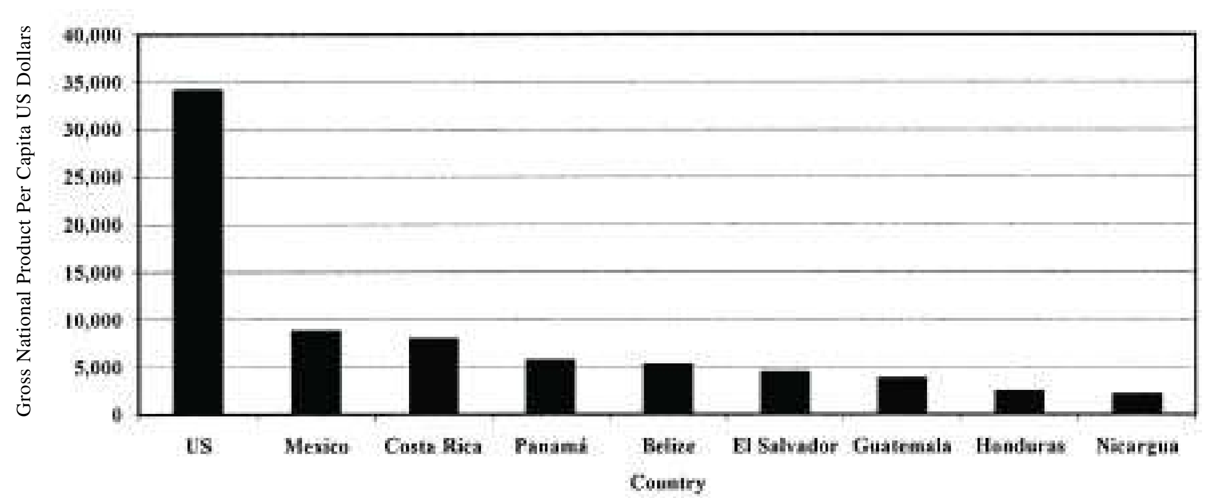


FIGURE 1 Per Capita Gross National Product for the United States, Mexico, and Central America in US Dollars - Year 2000

Raw sewage contaminates the streets of Latin America. This photo was taken in the town of Danlí, Honduras.

never intended to achieve high removal of excreted pathogens. Their use in tropical countries in which excreted infections are endemic is only justifiable in special circumstances, for there is an alternative treatment process much superior in obtaining low survivals of excreted pathogens—the waste stabilization pond system."
(Feachem, et al., 1983, pp. 63–64)

The Situation in Latin America

It is estimated that the urban population of Latin America, with approximately 340,000,000 persons connected to sewers, generates 52,000,000 m^3/day of wastewater (Egocheaga and Moscoso, 2004; WHO/UNICEF, 2000). It is further estimated that only 3,100,000 m^3/day of this wastewater, or 6 percent of what is generated, receives secondary treatment before being discharged into surface waters or reused directly in agriculture or aquaculture (Egocheaga and Moscoso, 2004). Of all the capital cities from Mexico City to Buenos Aires, the vast majority do not treat their wastewaters, to say nothing of the thousands of smaller cities throughout the region. Surface waters—rivers, streams, lakes and coastal areas—are widely contaminated with raw wastewater discharges throughout Latin America.

The problem of wastewater treatment is exacerbated by severe shortages in water quantity for agriculture. Throughout Latin America, there has been an historical tendency to use either raw or diluted wastewaters for irrigation and aquaculture, and it is estimated that at least one million hectares are irrigated with these contaminated sources (Egocheaga and Moscoso, 2004). The effects on public health of excreta-related infections have been devastating and have even had deleterious effects on disease morbidity within the U.S. The following examples are typical and illustrate how the magnitude of the problem is not only local, but also affects populations throughout the hemisphere:

- The cholera epidemic, which began in Peru in 1991, produced 1,199,804 cases with 11,875 deaths between 1991—1997 in 20 countries including the U.S.; it is estimated that the epidemic cost the country of Peru one billion U.S. dollars in tourism and exportation of agricultural products in only 10 weeks (OPS, 1998). The epidemic was caused by the consumption of drinking water and food products contaminated with raw sewage. Cholera, which had not been present in the Western Hemisphere for over 100 years, is now endemic in various countries in Latin America.
- Five outbreaks of cyclosporiasis from 1995 to 2000 in the U.S. and Canada caused by the emerging protozoan pathogen, *Cyclospora cayetanensis*, have been linked to raspberries imported from Guatemala (Bern, et al., 1999; Ho et al., 2002). It is assumed that the raspberries were irrigated or washed with either raw sewage or sewage-contaminated water. The principal route of transmission of *Cyclospora* infections in Guatemala is the water-borne route (Bern, et al., 1999).
- The largest epidemic of hepatitis A in the history of the U.S. occurred in 2003, with more than 700 cases in 4 states, all linked to green onions imported from two farms in Mexico (Fiore, 2004). It is assumed the onions were contaminated with the virus through irrigation or washing with either raw sewage or sewage-contaminated water (Fiore, 2004).

Surface waters obviously play a significant role in the continued transmission of excreta-related infections, since they are commonly used for bathing, washing, drinking water supply, crop irrigation, and the consumption of fish and shellfish. Professional judgment regarding the principal objective of wastewater treatment in the region dictates the removal of fecal pathogens as the first priority of wastewater treatment. This conclusion has been reached many times, and most recently by an exhaustive study of wastewater pollution, treatment, and reuse throughout Latin America published by the Pan American Center for Sanitary Engineering and Environmental Science (Egocheaga and Moscoso, 2004). The study concludes that the proper management of domestic wastewater in Latin America should focus on public health as a first priority, with the removal of pathogens as the principal objective of wastewater treatment. The study also concludes that in order to resolve the problem of agricultural demand for water and the sustainability of wastewater treatment in impoverished cities, treatment of wastewater focusing on pathogen removal should be integrated with the productive reuse of the treated wastewater (Egocheaga and Moscoso, 2004; CEPIS/OPS, 2000). The study concludes that the best available technology for accomplishing this goal is wastewater stabilization pond systems, which can most easily meet the WHO guidelines for wastewater reuse in agriculture than any other technology. The WHO guidelines are shown in **Table 3**.

Category	Reuse Conditions	Exposed Group	Intestinal Helminths[b] (Arithmetic Mean Number of Eggs per Liter[c])	Fecal Coliforms (Geometric Mean Number per 100 mL[c])	Wastewater Treatment Expected to Achieve the Required Microbiological Guideline
A	Irrigation of crops likely to be eaten uncooked, sports fields, public parks[d]	Workers Consumers Public	≤ 1	≤ 1,000	A series of stabilization ponds designed to achieve the microbiological quality indicated, or equivalent treatment
B	Irrigation of cereal crops, industrial crops, fodder crops, pasture, and trees[e]	Workers	≤ 1	No standard recommended	Retention in stabilization ponds for 8—10 days or equivalent helminth and fecal coliform removal
C	Localized irrigation of crops in Category B if exposure to workers and the public does not occur	None	Not applicable	Not applicable	Pretreatment as required by irrigation technology but not less than primary sedimentation

a. In specific cases, local epidemiological, sociocultural and environmental factors should be taken into account and the guidelines modified accordingly.
b. *Ascaris* and *Trichuris*, species and hookworms.
c. During the irrigation period.
d. A more stringent guideline limit (≤ 200 fecal coliforms/100mL) is appropriate for public lawns, such as hotel lawns, with which the public may come into direct contact.
e. In the case of fruit trees, irrigation should cease two weeks before fruit is picked, and no fruits should be picked off the ground. Sprinkler irrigation should not be used.

Source: WHO, 1989.

TABLE 3 World Health Organization Recommended Microbiological Guidelines for Wastewater Use in Agriculture

Case Study of Honduras

Background

The provision of water supply and sewerage services for Honduras has been a major component of development projects financed over the last 15 years. Approximately 81 percent of the estimated total population of 6.7 million has access to drinking water, and 70 percent has access to sanitation services (OPS, 2002). In spite of these efforts in the public health sector, however, excreta-related infections are still a major cause of morbidity and mortality. The cholera epidemic, with over 15,378 cumulative cases during 1991 to 2000, and the continued high morbidity of intestinal protozoan and helminth infections as shown in **Table 4**, underscore the persistent public health problems (Girard de Kaminsky, 1996; OPS, 1998, 2002). Surface waters play a significant role in the continued transmission of excreta-related infections, since the vast majority are polluted with wastewater discharges and are commonly used for bathing, washing crop irrigation, and fish and shellfish harvesting. In an attempt to ameliorate the problem, all internationally financed sewerage projects within Honduras now require wastewater treatment as a necessary component.

It has been generally assumed by the professional community in Honduras that waste stabilization ponds are the treatment option of choice because of their effectiveness in pathogen removal and their low operation and maintenance costs (Oakley, et al., 2000).

Parasite	Range of Prevalence in Select Locations 1986—93
Protozoans	
Entamoeba histolytica	2.0–19.5%
Giardia lamblia	2.8–61.0 %
Criptosporidium spp.	3.6–15.0%
Helminths	
Ascaris lumbricoides	5–70%
Anquilostomas	2–6%
Trichuris trichiura	1–32%

TABLE 4 Prevalence of Excreta-Related Parasites in Honduras

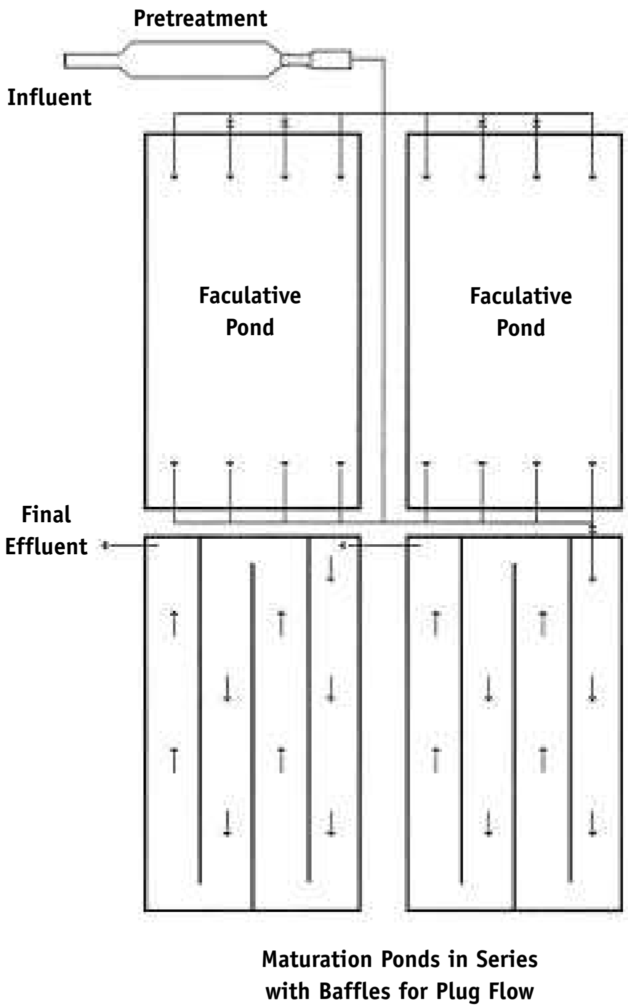
Approximately 21 waste stabilization pond systems have been constructed in the last 10 years. The majority of the pond systems were funded by USAID-Honduras through its Municipal Development Project. This program, which has as its primary goal the institutionalization of more responsive and effective municipal government, works with 34 municipalities representing 50 percent of the Honduran population. **Figure 2** shows a typical design of a pond system, which consists of two facultative ponds in parallel (so one can be taken out of service for desludging), followed by one or two maturation ponds in series.

Issues With Effluent Guidelines

The environmental protection agency for the government of Honduras has promulgated effluent standards for municipal wastewater discharges that are shown in **Table 5**. The standards, which are arbitrary, focus on fecal coliforms and do not address specific pathogen removal, which is much more important where excreta-related infections are endemic (Feachem, et al., 1983; Mara, 2004). It is difficult to meet fecal coliform standards more stringent than 10,000/100mL with stabilization ponds (Oakley, et al., 2000) unless four or five ponds are designed in series (Mara, 2004), which is an added capital and operational expense that should be technically justifiable in poor communities. Because no local data have been available showing specific pathogen removal in pond systems, there has been much confusion among professionals and the public in Honduras as to what type of design is most appropriate for local conditions.

Parameter	Maximum Permissible Concentration
Fecal Coliforms, MPN/100mL	5,000
BOD_5, mg/L	50
SS, mg/L	100

TABLE 5 Effluent Standards Promulgated in Honduras



A typical pond system design, with a bar screen and horizontal grit chamber for pre-treatment, with a battery of two facultative ponds in parallel followed by two maturation ponds in series. Facultative ponds are designed in parallel so one can be taken out of service for desludging every 5 to 10 years.

FIGURE 2 Typical Pond System Design

Manually cleaned horizontal grit chambers—a technology no longer in use in the U.S.—are used for pretreatment because of high grit loads in sewer systems that can prematurely fill ponds. (León, Nicaragua)

Issues With Operation and Maintenance and Sustainability

The responsibility for operation and maintenance of pond systems lies with the municipalities. In an attempt to avoid the problem of abandoned systems that has frequently occurred in other countries, USAID-Honduras has sponsored numerous workshops on waste stabilization pond design, monitoring, and operation and maintenance for professionals, operators, and the general public. This is a continuing process that requires a long-term commitment. There are many institutional factors that cannot be changed easily, such as the ability and political resolve of the municipal governments to charge fees for sewerage and wastewater treatment, and to maintain adequately trained personnel on staff. As an example of the difficulties involved in what would appear to be a simple task, at present, there is not one pond installation in Honduras where an operator measures flow rates at all—let alone on a routine and documented basis.

Objectives

As a result of the problems mentioned above, USAID-Honduras decided to fund a monitoring study for wastewater stabilization pond installations. The objective of this study was to monitor 10 wastewater stabilization pond systems from different climates throughout Honduras during the dry season (March, April, May) and wet seaon (September, October, November) to develop a local database for improving design parameters and operation and maintenance requirements and to assess the long-term sustainability of systems in the municipalities. It was also planned that this study would help contribute to the development of effluent standards for specific pathogen removal rather than fecal coliform removal, and that concrete recommendations based on the results could be made for the minimum number of ponds that should be designed in series to remove specific pathogens, with the goal that the final effluent could be used for agriculture or aquaculture to help foster sustainability. It was hoped that the conclusions would more adequately address the serious public health issues facing financially-strapped municipalities with populations from 1,000 to over 100,000 persons.

A barefoot boy spearfishing in sewage-contaminated water near Iquitos, Peru.

Methodology

Project Design

Ten pond systems were selected at varying locations throughout the country. Eight systems were facultative-maturation pond configurations, one an anaerobic-facultative pond configuration, and one an anaerobic-facultative-maturation pond configuration. All systems were visited for five consecutive days during the dry and wet seasons. Two days were used for the collection of support information, which included age of the system, original design population, physical condition, estimation of accumulated sludge volume using bathymetric methods, level of operation and maintenance, and an evaluation of the long-term sustainability based on municipal support. Each system was then monitored diurnally for three consecutive days.

The influent flow rate was continuously monitored using an ISCO area-velocity flow meter, which allowed an accurate measurement of peak, minimum and mean flow rates. The influent and effluent of each pond within the system were sampled for helminth eggs, *Shigella* species, *Escherichia coli*, fecal coliforms, suspended solids (SS), five-day biochemical oxygen demand (BOD_5), pH, and temperature; dissolved oxygen was also measured at various points within facultative ponds. Sludge samples at the entrance to each primary pond system, whether anaerobic or facultative, were taken with a dredge and analyzed for helminth egg concentrations and percentage total, fixed, and volatile solids.

Rationale for Parameter Selection

A major objective of the project was to monitor pathogens endemic in Honduras using the capabilities of local laboratories, with the idea that routine monitoring could be continued in the future. Fortunately, one national laboratory within the Secretary of Natural Resources and Environment has the capabilities to analyze water and sludge samples for helminth eggs on a routine basis using a methodology originally developed in Mexico; they cannot, however, distinguish viable from nonviable eggs. Unfortunately, the only other analyses in water samples that could be performed within the limits of this study on a routine basis by local laboratories were *Shigella* species (presence-absence test), and the nonpathogenic indicators *Escherichia coli* and fecal coliforms. While it would be highly desirable to monitor for a protozoan pathogen, there are no laboratories in Honduras able to perform the analyses in water samples at this time.

The final selected parameters

for pathogens were, therefore, helminth eggs in water, sludge samples, and *Shigella* species (presence-absence) in water. *Escherichia coli* and fecal coliforms were also chosen, despite their limitations for indicating pathogen removal, because they could be easily monitored routinely in water samples and used for comparison with other studies in the literature. It was also hoped that *Escherichia coli* would be more representative of bacterial removal than fecal coliforms.

The conventional parameters of SS, BOD_5, pH, temperature and dissolved oxygen were selected to assess system performance in terms of organic loadings. Sludge samples at the entrance to each primary pond system, whether anaerobic or facultative, were taken with a dredge and analyzed for helminth egg concentrations and percentage total, fixed, and volatile solids. The objective of sludge sampling was to estimate degradation and accumulation rates, the extent of grit entering the system, and the public health risks of sludge handling due to helminth egg concentrations.

Sampling and Analytical Methods

With the exception of the helminth analyses, all samples were analyzed according to *Standard Methods* (APHA, 1995). The samples for helminth eggs, SS, and BOD_5 were 24-hour flow-weighted composites, while those for *Shigella* species, *Escherichia coli* and fecal coliforms were grab samples taken at different times throughout a 24-hour period. The sludge samples were taken daily with the dredge (approximately 1.0 L) over the three-day period at the entrance to each pond where sludge depth was estimated to be greatest; this method is limited and was meant only to give a rough idea of sludge characteristics since sludge cores give a much more accurate account of deposition and decomposition processes and helminth survival rates (Nelson, et al., 2004).

Results

Flow rates, Hydraulic Retention Times, and Organic Loading Rates

Table 6 presents the results of pond flow rate monitoring, calculated hydraulic retention times, mean influent BOD5 concentrations, and organic surface loading rates. Basing the measured influent flow rate on the original design populations, the calculated per capita flow rates ranged from 92 to 514 liters per person per day (Lppd), and the majority are much higher than the typical design assumption of 100 to 120 Lppd. The higher flows are likely due to increased connections due to population growth, illegal connections from commercial and industrial sources, and inflow and infiltration into the sewer system. The increase is significant from what was originally assumed in the design and exemplifies the resiliency of pond systems for developing countries—mechanical systems such as activated sludge could never handle such an increase over the original design flow.

As a result of the higher measured flow rates, the calculated hydraulic retention times are shorter and the organic surface loading rates higher than anticipated from the original designs. Only two facultative pond systems satisfied the

Pond System	Mean Influent Flow Rate m^3/day	Original Design Population	Per Capita Flow Based on Design Population Lppd	Area of Primary Pond Ha	Hydraulic Retention Time, Days				Mean Influent BOD_5 mg/L	Organic Surface Loading Rate kg BOD_5/Ha-day	Organic Volumetric Loading Rate g BOD_5/m^3-day
					F/A[1]	F/M[2]	M	Total			
Catacamas East[3]	2,580	5,350	482	1.02	5.0	3.7		8.7	400	1,011	80
Catacamas West	945	3,400	278	1.38	23.0	4.2		27.1	437	300	
Moroceli	218	705	309	0.12	7.0	7.0		14.0	220	410	
Tela[3]	2,726	5,306	514	0.42	2.6	4.3	2.6	9.5	114	737	44
Catacamas East[3]	2,639	5,350	493	1.02	4.9	3.6		8.5	296	765	60
Catacamas West	902	3,400	265	1.38	24.1	4.4		28.4	294	193	
Danli[3]	5,150	10,000	515	0.99	2.4	4.8		7.2	205	1,066	85
Juticalpa[4]	3,510	11,422	307	1.23	6.1	3.4		9.5	177	505	
El Progreso[4]	2,932	23,000	127	2.83	20.9	13.9		34.8	71	74	
Tela[3]	2,121	5,306	400	0.42	3.3	5.5	3.4	12.2	62	313	19
Trinidad	1,816	6,108	297	0.98	7.8	6.2		14.1	76	141	

*The systems at Pajuiles and Villanueva are not included because of difficulties measuring flow rates.

1 F/A: facultative or anaerobic. The systems at Danli and Tela consist of an anaerobic pond followed by a secondary facultative pond. Tela has a third maturation pond in series.

2 F/M: Facultative or maturation pond.

3 The hydraulic retention time was calculated using the net volume of the primary ponds (design volume minus volume of accumulated sludge).

4 Only one battery of two in parallel was monitored.

TABLE 6 Results of Measured Flow Rates, Hydraulic Retention Times, and Loading Parameters for Monitored Pond Systems

WHO guideline of an eight- to 10-day minimum detention time for helminth egg removal; nevertheless, as will be discussed below, all of the systems met the WHO guidelines for 100 percent helminth egg removal.

The mean influent BOD_5 was found to vary greatly among systems, ranging from 71 to 437 mg/L. As a result of higher than expected flow rates and influent BOD_5 values, the organic surface loading rates of the majority of facultative ponds exceeded the estimated maximum loadings for the latitudes and climates of Honduras, which is estimated to be between 280 to 350 kg BOD_5/ha/day as shown in **Figure 3**. In spite of this, the overall BOD_5 removal was about what would be expected for normally loaded stabilization pond systems as discussed below. Once again this shows the resiliency of pond systems to handle widely varying loading rates and still maintain adequate treatment levels.

Table 6 also shows that those ponds that were designed as anaerobic ponds (Danlí and Tela) were operating below the range of optimum volumetric loading rates for anaerobic ponds of 100 to 300 g BOD_5/m^3/day, and that one overloaded facultative pond (Catacamas East), was approaching the volumetric loading of an anaerobic pond. Nevertheless, none of these ponds exhibited odor problems, and their performance was similar to the other, lesser loaded ponds, again demonstrating the resiliency and wide margin of safety typical of pond systems.

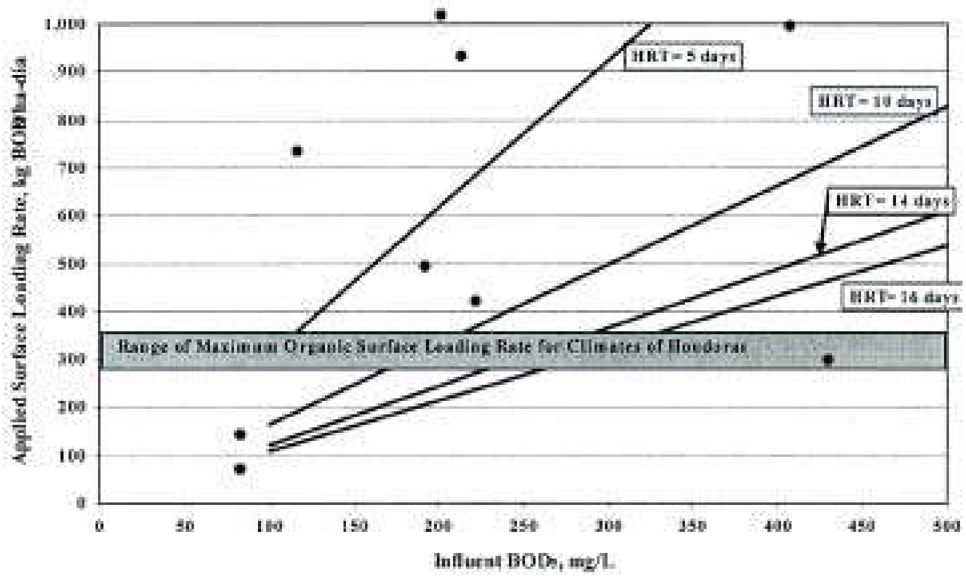


FIGURE 3 Organic Surface Loading Rate Versus Influent BOD_5 for Various Hydraulic Retention Times (HRT)

Pond System	Arithmetic Mean Helminth Egg Concentration Eggs/L (Range of Values in Parentheses)			Arithmetic Mean Helminth Egg Concentration in Facultative Pond Sludges[1]
	Influent Wastewater	Facultative Pond Effluent[1]	Maturation Pond Effluent	Eggs/gram dry weight (Range in Parentheses)
Catacamas E. Dry Season	13 (9–18)	0	0	53 (13–84)
Wet Season	33 (24–48)	0	0	308 (247–356)
Catacamas W. Dry Season	84 (42–133)	0	0	303 (282–499)
Wet Season	29 (24–48)	0	0	674 (520–960)
Danlí[1] Wet Season	45 (30–58)	2 (0–7)	0	467 (30–1,164)
Azacualpa Wet Season	9 (0–20)	0	0	35 (8–53)
Morocelí Dry Season	15 (0–24)	0	0	189 (126–295)
Pajuiles Dry Season	744 (720–792)	29 (22–42)	0	4,473 (3,720–5,299)
El Progreso Wet Season	6 (3–9)	0	0	62 (15–141)
Tela Dry Season	9 (4–16)	0	0	1 (1–2)
Wet Season	2 (0–4)	0	0	50 (18–108)
Trinidad Wet Season	6 (4–8)	0	0	15 (0–20)
Villanueva Dry Season	55 (18–72)	3 (0–16)	0	738 (228–1,875)

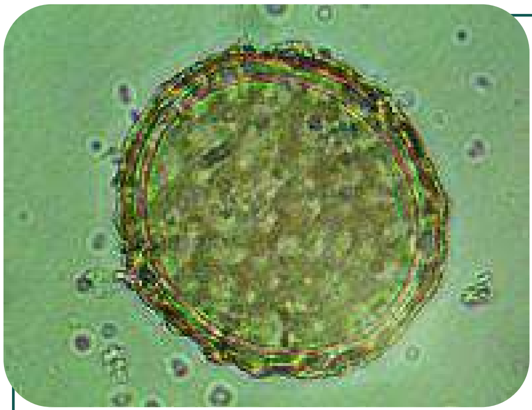
1. The system in Danlí was designed as an anaerobic pond followed by a facultative pond.

TABLE 7 Helminth Egg Removal Wastewater Stabilization Pond Systems in Honduras

Helminth Egg Removal

Table 7 shows the results of helminth egg monitoring. The arithmetic mean concentration of helminth eggs in raw wastewater ranged from 9 to 744 eggs/L. The helminths found in raw wastewater and sludges were, in order of abundance, *Ascaris lumbricoides*, *Trichuris trichiura*, and Anquilostomas (hookworm), and reflect the prevalence of helminth infections found in the general population. (Examples of eggs found in raw wastewater are shown in **Plate 1**.) With the exception of three ponds (Danlí, Pajuiles, and Villanueva), all of the facultative ponds removed 100 percent of the influent helminth eggs.

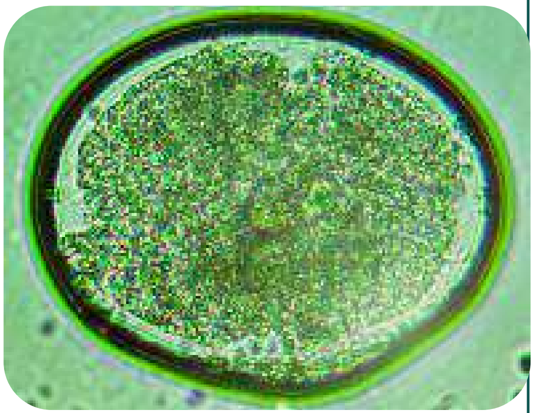
The ponds at Danlí and Villanueva were anaerobic and likely



a) *Ascaris lumbricoides* (fertile)

b) *Ascaris lumbricoides* (fertile and unfertile)

c) *Trichuris trichiura*



d) Anquilostomas

PLATE 1: Examples of helminth eggs found in all of the raw wastewaters sampled throughout Honduras, which illustrates the widespread problem of infections. Because there is no immunity to parasitic infections, as long as the environment is contaminated transmission will continue to occur. Eggs are approximately 50 µm in diameter, a size that can easily be removed by sedimentation in facultative ponds.

Photos courtesy of Dr. Gilberto Padilla

At least four maturation pond systems have crocodiles, which feed on turtles and birds. Frogs are also abundant in several maturation pond systems. (Santa Cruz de Yojoa, Honduras.)

did not achieve 100 percent removal as a result of insufficient hydraulic detention time or resuspension with rising gases from anaerobic digestion. The carryover of helminth eggs in the facultative pond at Pajuiles could have been due to the burrowing activity of turtles or crocodiles observed in the pond.

Table 7 also shows the results for helminth egg concentrations in facultative or anaerobic pond sludges. The concentrations ranged greatly among systems, from a mean of one egg per gram dry sludge at Tela to 4,473 eggs per gram dry sludge at Pajuiles. Although no differentiation was made between viable and nonviable eggs, the results in **Table 7** leave no doubt that pond sludges pose a serious health risk with helminth eggs and need to be properly managed during pond desludging operations and ultimate disposal.

Shigella Species

The presence of *Shigella* species was not detected throughout the study. One of the problems with measuring bacterial pathogens is that they are likely present in wastewater only during an outbreak or epidemic episode; after the episode passes they are only present in asymptomatic carriers in very small concentrations that are difficult to detect in wastewater.

Fecal Coliforms and *Escherichia coli*

The results of fecal coliform and *Escherichia coli* $\log_{10}$ removal are shown in Table 8 and

Figures 4 to 7. For facultative ponds it appears that it may be possible to achieve a 2.0 $\log_{10}$ removal of both fecal coliforms and *E. coli* if the hydraulic detention time is greater than 10 days. The maturation pond results (**Figures 6 and 7**) are much more inconsistent and do not show a correlation between hydraulic detention time and bacteria removal. These results exemplify the difficulty in using fecal coliforms or *Escherichia coli* as indicators of bacterial pathogens for wastewater as has been reported in the literature (Feachem, et al., 1983; and Mara, 2004.)

Conventional Wastewater Constituents

The conventional wastewater constituent analyses of BOD_5 and SS (**Table 8**) show that each pond system is functioning as would be expected in terms of performance and removal efficiencies, in spite of being loaded above their original designs. Dissolved oxygen analyses and visual inspection showed that four as-designed facultative ponds (Catacamas East, Morocelí and Villanueva) were not facultative and were functioning as anaerobic ponds. In spite of being anaerobic, however, the ponds performed well in terms of removal of BOD_5, SS, fecal coliforms, *Escherichia coli* and helminth eggs, and they did not have any serious odor problems.

Solids Analyses in Facultative Sludges

Desludging of ponds has been found to be a significant expense for poor municipalities if it is not planned for and budgeted years in advance (Oakley, et al., 2000). Pond sludge analyses were therefore performed to develop parameters on sludge accumulation rates, including grit loads. The facultative pond sludge analyses summarized in **Table 9** show that the percent total solids ranged from 11.6 to 15.5 percent, volatile solids from 23.9 to 31.4 percent, and fixed solids from 68.0 to 76.1 percent. The high percentage of fixed solids is a result of the effect of inorganic solids entering the ponds from lack of grit chambers.

The volume of sludge in each facultative pond was measured by taking soundings on a grid from a launch. Sludge accumulation rates were then calculated by using the measured flow rates and the number of years the pond system had been in operation. Grit accumulation rates were then estimated from the results of the sludge solids analyses by assuming that pond sludge without grit should have a volatile solids content of approximately 50 percent after digestion (Metcalf and Eddy, 2003).

The results in **Table 9** show that sludge accumulation rates per 1,000m^3 of wastewater treated are

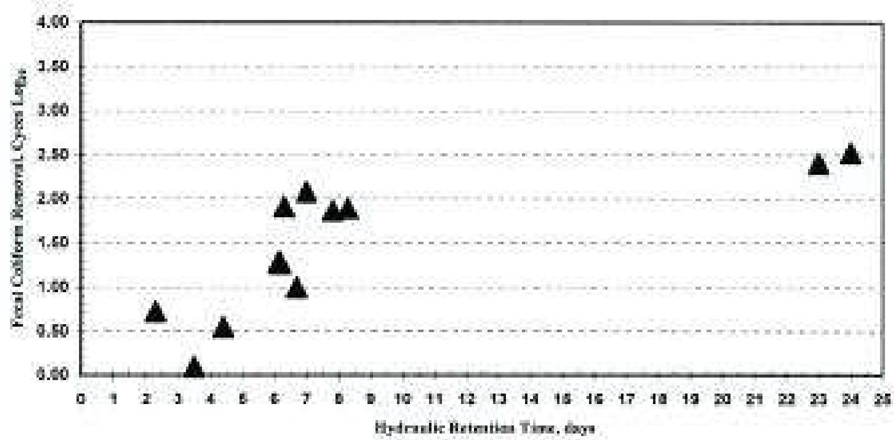


FIGURE 4 Fecal Coliform Removal in Faculative Ponds in Honduras

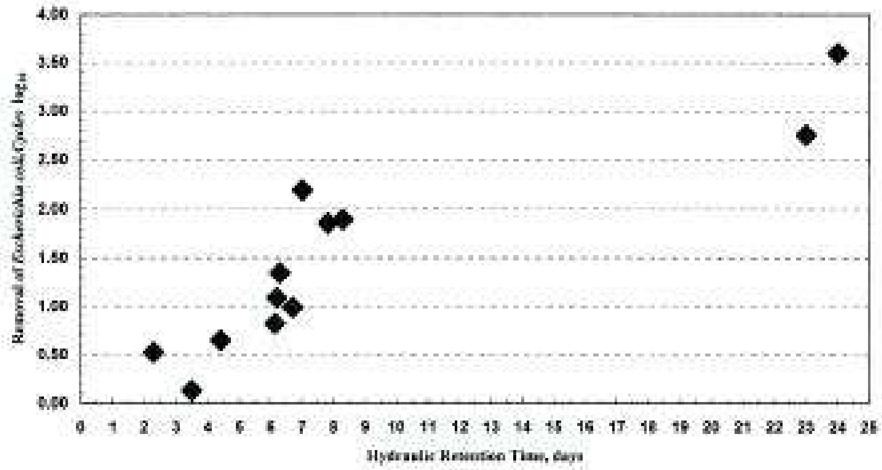


FIGURE 5 Removal of *Escherichia coli* in Facultative Ponds in Honduras

Parameter	Mean[1] (Range of Values)	
	Influent	Final System Effluent
Escherichia coli, NMP/100mL	2.71E+07 (1.22E+06—8.96E+08)	2.89E+04 (2.71E+02—1.17E+07)
Fecal Coliforms, NMP/100mL	4.7E+07 (2.84E+06—2.01E+09)	5.47E+04 (6.21E+02—1.47E+07)
BOD_5, mg/L	206 (62—438)	56 (19—93)
Filtered BOD_5, mg/L	------	37 (11—91)
SS, mg/L	207 (66—383)	72 (24—135)

1. Fecal coliform and *Escherichia coli* concentrations are geometric means. All others are arithmetic means.

TABLE 8 Summary of Monitoring Results for *E. coli*, Fecal Coliforms, BOD_5, and SS for all Systems Monitored, Wet and Dry Seasons

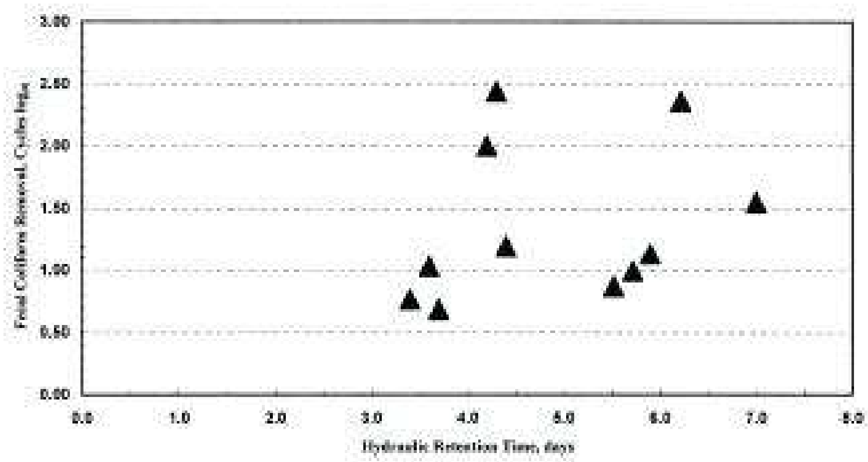


FIGURE 6 Fecal Coliform Removal in Maturation Ponds in Honduras

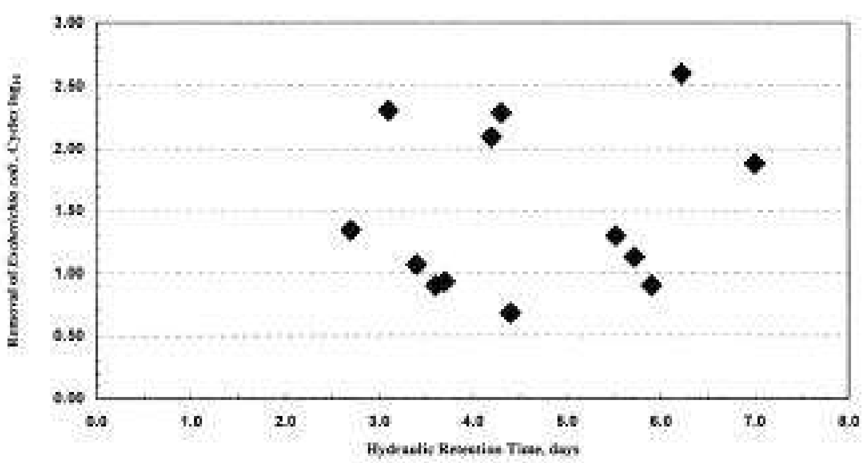


FIGURE 7 Removal of *Escherichia coli* in Maturation Ponds in Honduras

Parameter	Range of Values
Total solids, %	11.6—15.5
Volatile solids, %	23.9—31.4
Fixed solids, %	68.0—76.1
Estimated grit accumulation in primary ponds, $m^3/1{,}000m^3$	0.010—0.085
Measured sludge accumulation in primary ponds, $m^3/1{,}000m^3$	0.224—0.548

TABLE 9 Summary of Results for Primary Pond Sludges

an order of magnitude lower than accumulation rates from conventional processes (Metcalf and Eddy, 2003), which is another advantage of stabilization ponds since sludge handling is kept to a minimum. If facultative ponds are not overloaded, a pond with a 10-day detention time can most likely operate up to 10 years or more without the need for desludging.

Grit accumulation is estimated to be approximately 5 percent of total sludge accumulation as shown in **Table 9**. While this does not appear to be significant, during storm events, significant quantities of grit can enter primary ponds and cause blockages at inlets, and even prematurely fill a pond (Oakley, et al., 2000). For this reason it is recommended that grit chambers be installed in all systems.

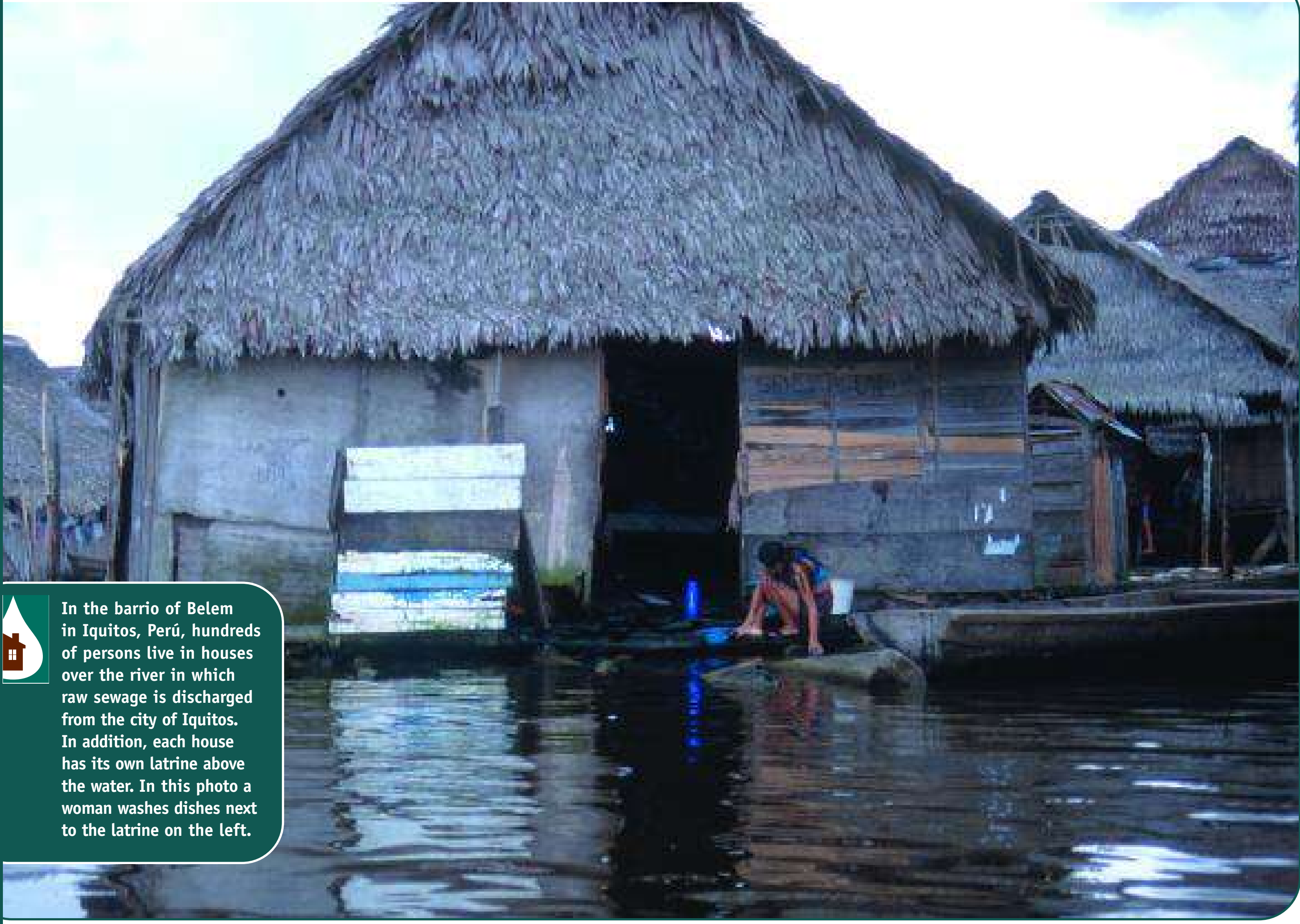
Physical Condition, Monitoring, Operation and Maintenance, and Sustainability Issues

Table 10 presents a summary of the physical conditions, monitoring, operation and maintenance, and sustainability issues encountered in the systems assessed in this study. Most installations are physically well maintained, but many are hydraulically and organically overloaded without accurate flow measuring devices and grit chambers. At least three installations are in urgent need of desludging.

Monitoring in all installations is nonexistent, and nowhere are flow rates measured or samples taken for laboratory analysis. The few installations where attempts were made to measure sludge ac-

Physical Condition	Routine Monitoring	Maintenance	Personnel	Plans for Expansion and Sludge Removal	Sustainability
Most systems are hydraulically and organically overloaded, without accurate flow measurement devices and grit chambers. Several systems are in urgent need of desludging.	None of the systems monitored measure flow rates or have sampling programs. Only a few have attempted to monitor accumulation of sludge in primary ponds.	Most of the systems have adequate physical maintenance of the installation.	While most systems have permanent operators assigned to operate and maintain the installation, all lack training in measurement of flow rates, sampling, and measurement of sludge accumulation.	None of the municipalities have plans for installation expansion, even though many are arriving at their hydraulic and organic limits. No municipality has planned, let alone prepared a budget, for the desludging of primary ponds.	Most installations have technical and financial support for maintenance, and most have public acceptance. The major problem in all municipalities is long-term planning for plant expansion and sludge removal.

TABLE 10 Summary of Physical Condition, Operation and Maintenance, and Sustainability Issues in Monitored Systems



In the barrio of Belem in Iquitos, Perú, hundreds of persons live in houses over the river in which raw sewage is discharged from the city of Iquitos. In addition, each house has its own latrine above the water. In this photo a woman washes dishes next to the latrine on the left.

cumulation had sludge depths approaching the water surface at the inlets! Adequate operator training is a key issue to help resolve these problems.

The wherewithal of the municipality to properly manage the installation and plan for the future, though, is the key to sustainability. The majority of installations have rudimentary technical support to train and pay an operator to physically maintain the system, and the public generally accepts pond systems as a public health benefit. None of the municipalities, however, adequately plan for system expansion, nor measure increased loads (nor how to manage them) as growing populations continuously connect to the sewer systems. As primary ponds reach levels where desludging is imperative, there is a real possibility that an installation could be abandoned because of operation and maintenance costs, which, unfortunately, is a common problem throughout Latin America.

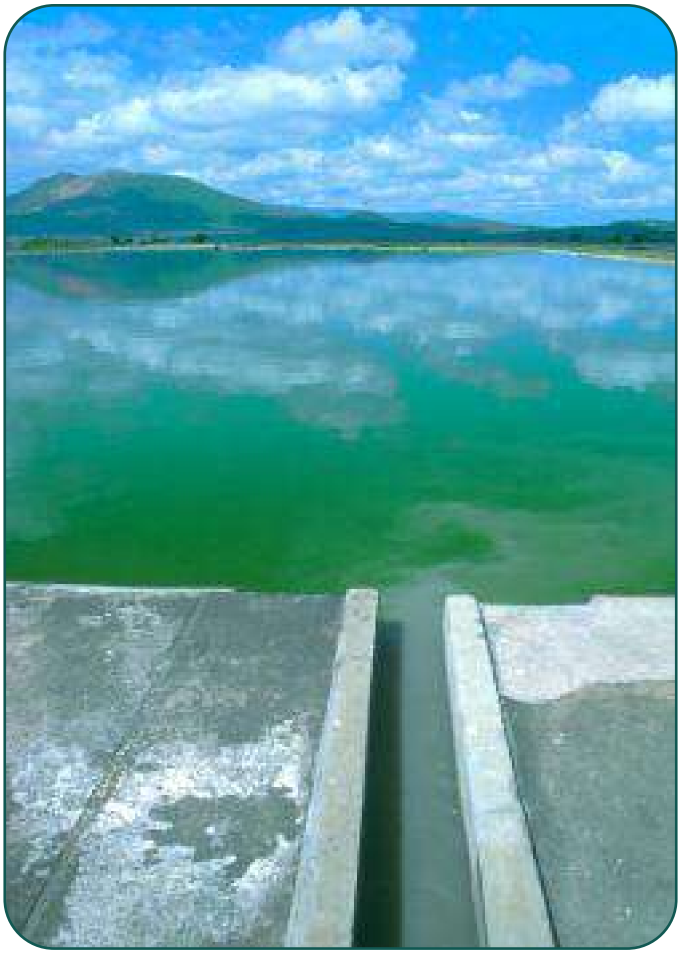
Discussion and Conclusions

In a country such as Honduras, where wastewater treatment essentially does not exist, the only realistic option that has a possibility of success in helping solve serious public health problems is the introduction of wastewater stabilization pond systems. Even these simple resilient pond systems, however, will fail if their design, implementation, operation and maintenance, planning, and municipal commitment are not suited to local needs and conditions. The results of this project have enabled the following observations and conclusions to be drawn.

Effluent Standards and Wastewater Reuse

Parasitic infections, such as helminth infections, are the major public health problem related to excreta-related infections as indicated in the ubiquitous presence of helminth eggs in raw wastewaters throughout the country. Since the project results dramatically showed that every pond system removed 100 percent of influent helminth eggs, and since helminth eggs can be routinely monitored in local laboratories, it makes more sense to initially orient treatment objectives and effluent standards on helminth egg removal rather than on an arbitrary level of fecal coliform concentration that has no demonstrated relation to problem pathogens, and which is difficult to achieve without designing numerous ponds in series. Using this conceptual framework, wastewater treatment in municipalities using two ponds in series can easily meet WHO´s Category B requirements for restricted irrigation, transforming what was once a serious public health problem into a potential resource for agriculture. This, in poor municipalities, is much more preferable than proposing more lagoons in series at a greater cost, or more complex technologies using disinfection, which are beyond the technical and financial capabilities of the municipalities.

As far as concern for bacterial pathogens, the literature shows that



A well-designed and maintained facultative pond. (Masaya, Nicaragua)

they typically exist in concentrations 3 or 4 orders of magnitude lower than fecal coliforms (Feachem, et al., 1983). Studies performed in Latin America have shown that a 3-cycle $\log_{10}$ removal of fecal coliforms removes essentially all of the bacterial pathogens of concern (León and Moscoso, 1996; Mara and Cairncross, 1989). As an example, **Figure 8** shows the results of removal of *Vibrio cholerae* 01 as compared to fecal coliforms in the waste stabilization pond system of San Juan in Lima, Perú at the height of the cholera epidemic in 1991 (León and Moscoso, 1996). The highest concentration of *Vibrio cholerae* 01 measured in raw sewage was only 2,700 MPN/100mL as compared to 5.2 E+08 MPN/100mL for fecal coliforms. The first facultative pond essentially removed the vast majority of *Vibrio cholerae* 01, and no significant concentrations remained in the effluents of the first or second maturation ponds. Until further studies can show more detailed survival of various bacterial pathogens in pond systems, in would seem that two ponds in series that remove at least 3, $\log_{10}$ cycles of fecal coliforms should remove the vast majority of bacterial pathogens.

Pathogenic protozoa pose another concern, but at present they cannot be analyzed for in wastewater treatment systems on a routine basis. Various studies have suggested, however, that they are effectively removed in stabilization pond systems (Scott, 2003).

System Design for Pathogen Removal

The results of this study suggest the following recommendations for systems design:

- All systems should be designed using flows measured in the field instead of assuming per capita flow rates. Because there is no historical record of flows and their increase with time, much caution needs to be used in the design and useful life of systems.
- Horizontal grit chambers should be designed for all systems to ensure that primary ponds do not prematurely fill with grit.
- It is best to avoid anaerobic ponds since their increased loadings require desludging more frequently (at least every three years), which is an added expense and risk for the municipality.
- Two facultative pond systems in parallel with at least a 10-day detention time followed by one maturation pond with at least a 5-day detention should remove 100 percent of helminth eggs, satisfy WHO's Category B for restricted irrigation, and reasonably ensure removal of bacterial and protozoan pathogens. This design also allows for the maximum interval of desludging and hence the minimum need for sludge handling.
- All designs should incorporate agricultural (or aquaculture) reuse as an integral part of the system using the WHO guidelines. This, hopefully, would help municipalities look at wastewater treatment in a more positive light than they have in the past and foster sustainability.

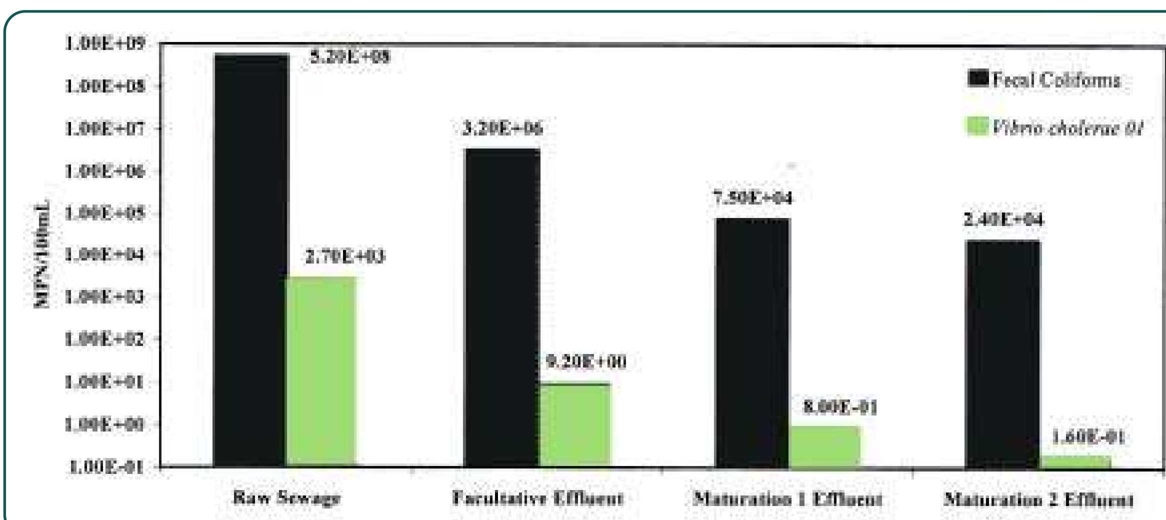


FIGURE 8 Removal of Fecal Coliforms and *Vibrio cholerae 01* in San Juan Pond System, Lima, Peru, in 1991. Source: Leon and Moscoso, 1996.

A girl collects polluted water for domestic water supply-a serious problem throughout Latin America. (Flores, Guatemala)

A well-designed pond system for a community of approximately 10,000 persons in the valley of Amarateca, Honduras.

Sustainability

Sustainability is by far the most important issue for wastewater treatment in Honduras. It makes little sense to argue over technological details and removal efficiencies if the municipalities themselves do not have the infrastructure and the financial capabilities to adequately operate, plan for expansion, and desludge their systems. Latin America has historically had serious problems making drinking water systems sustainable, and the median ratio of urban drinking water tariff to unit cost of production is less than one for the Region (WHO/UNICEF, 2000). If there is difficulty in making drinking water systems sustainable, it is obvious that wastewater treatment will be even more formidable a task. It is for this reason that waste stabilization pond systems integrated with agricultural or aquaculture reuse offer the best promise to help address some of this hemisphere's most serious public health problems.

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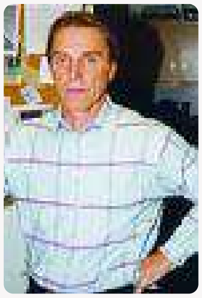

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