OPTIMIZATION OF WASTEWATER STABILIZATION POND SYSTEMS IN HONDURAS

by

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Submitted to the Department of Civil and Environmental Engineering
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ABSTRACT

During the academic year of 2008-2009, three Master of Engineering students from the Department of Civil and Environmental Engineering at the Massachusetts Institute of Technology (MIT) conducted a study of wastewater treatment systems in Honduras. Building upon previous research, this study assessed the state of centralized wastewater treatment facilities. The project included travel to Honduras in January 2009 for a field survey of these facilities. In addition, the students undertook more focused individual work on various facets of sustainable wastewater treatment. Robert McLean examined options for enhancing performance of an existing Imhoff tank. Mahua Bhattacharya investigated sludge handling practices and alternatives including a study of sludge resource value and potential reuse. Lisa Kullen studied flow behavior in waste stabilization ponds focusing on benefits to effluent quality attainable through operational modifications.

This thesis presents a summary of this investigation including a Honduran national and water sector background, and trends based upon site visits and observations. With the context of the sanitation sector thus defined, a detailed investigation of wastewater stabilization ponds follows. This study explores hydrodynamic changes and water quality improvements attainable through various modifications in maintenance and operation of these facilities. Extensive use of flow modeling is employed to demonstrate the quantifiable impact of the modifications discussed. Analytical calculations of ideal pond performance are compared to computer numerical flow modeling results, computed using the INTROGLLVHT modeling software. This comparison examines the sensitivity of pond performance to a number of variable factors including sludge accumulation and distribution, pond outlet geometry, and inlet flow symmetry. The largest effect and greatest sensitivity was found for unbalanced, asymmetric flows, yielding greatly reduced pond efficiency. Sludge accumulation had a significant effect on final effluent quality due to reduced pond volume and residence time. However, the distribution of a given volume of sludge and the spacing of pond outlets both had minimal effect on effluent quality. Recommendations for pond maintenance developed from this analysis include a careful balance of pond flow and strict adherence to a scheduled desludging routine.

ACKNOWLEDGEMENTS

I would like to thank the people who contributed to this thesis in innumerable ways.

First and foremost I am grateful to my research teammates. Dr. Eric Adams, Aridaí Herrera, Mahua Bhattacharya, and Robert McLean offered camaraderie in Honduras and support through the project phases preceding and following the trip. In particular, Eric was instrumental in shaping my investigation, providing constructive and encouraging feedback, and addressing my knowledge gaps by pointing me in the right direction every time. With Ari as our skillful liaison, our team functioned as though we were all at home in his home country. And Mahua, the other Muchacha, served as a field assistant, idea sounding board, and a source of moral support without which this work might have been possible, but it certainly would not have been fun.

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I’d like to thank my academic community, including the many teachers and classmates who have shaped my education. From my earliest teachers to the professors who more recently spurred me on, I’ve enjoyed numerous insights and the development of a true love of learning. My professors here at MIT have broadened my curiosity into aspects of environmental engineering that I had never considered. My time at MIT has been filled with academic challenges and a collaborative student community to match. It is the spirit of teamwork, fundamental to our MEng class, which has made every challenge surmountable.

Finally, to my family - my parents, brothers, sisters-in-law, aunts, uncles, and cousins - and to my friends, I thank you for your tireless support. You called when I wasn’t accepting calls, send cards when I needed a smile, visited when I had a spare moment, and reminded me every step of the way that I was not alone with such a team behind me. I truly could not have done this if not for you.

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1.0 INTRODUCTION

1.1 Project Background

Wastewater stabilization ponds are a common form of primary and secondary wastewater treatment throughout Honduras. A wastewater stabilization pond is a large constructed body of water through which wastewater flows. During the residence time in the pond, generally on the order of days, water quality is improved through natural processes such as sedimentation and biodegradation. A typical wastewater stabilization pond system consists of multiple ponds configured to achieve various treatment goals. By one account, wastewater stabilization ponds comprise 50% of the centralized treatment systems reported in Honduras, while Imhoff tanks, an alternate technology involving a sedimentation tank over a sludge digestion chamber, comprise another 40% of Honduran centralized systems (SANAA, 2000).

1.2 Purpose of this Study

This thesis is part of a larger effort to evaluate wastewater treatment throughout Honduras, paying particular attention to several existing wastewater stabilization ponds. Waste stabilization ponds are ideally suited to the local context of Honduras in their ability to meet national discharge criteria with limited capital investment. Additionally, these ponds require minimal technical staffing, which is critical given the shortage of technically trained personnel throughout Honduras. The tropical climate in Honduras is well suited to ideal pond function as certain natural attenuation processes are enhanced by consistent warm temperatures and/or sunlight. Pond systems require minimal input with regard to electricity or chemical additives, making them an ideal low-maintenance technology. However, if a pond’s minimal maintenance needs are not met or if it is poorly designed, then performance efficiency will suffer resulting in poor quality of wastewater discharges.

Responsibilities regarding the operation and maintenance of wastewater treatment systems are in the process of being passed over from the National Autonomous Water and Sanitation Service (SANAA), to the respective municipalities. The national Regulator of the Potable Water and Sanitation Sectors (ERSAPS) handles regulation of this sanitation sector. In order to address the political and technical challenges associated with this transition, SANAA and ERSAPS have been collaboratively involved in a government-sponsored initiative, performing a comprehensive review of the current state of centralized wastewater treatment systems including both Imhoff tank and waste stabilization pond systems.

Previous work has set the stage for the current research in Honduras. In 2006, MIT graduate researchers studied pollution at Lake Yojoa, the largest inland lake in Honduras. Among several pollution sources, upstream contributions were identified from a poorly functioning Imhoff tank in the city of Las Vegas (Trate, 2006 and Chokshi, 2006). In that same year, a University of Texas graduate researcher studied this underperforming system, reporting on its current malfunction and designing a rehabilitation and maintenance program for the system (Herrera, 2006). Two years later, MIT graduate researchers were again in Las Vegas experimenting with enhancements to the system through chemically enhanced primary treatment (Mikelonis, 2008) and exploring expansions of treatment for current and projected future needs (Hodge, 2008). These studies concluded that the tanks were not functioning properly due to lack of adequate capacity, tank maintenance and sludge removal. Consequently, the “treated” wastewater was not complying with the required effluent criteria prior to discharge into the environment.

The current report and the study herein were undertaken in response to a request for assistance in reviewing centralized wastewater treatment in Honduras. In the fall of 2008, MIT was approached for assistance by ERSAPS and SANAA. In response to this request, three students from the MIT Masters of Engineering (MEng) Program in Environmental Engineering studied Honduran wastewater treatment in general and specific ways. Mahua Bhattacharya, Robert McLean, and Lisa Kullen completed a study of wastewater treatment in the nation through a literature review, as well as travel to Honduras for interviews, observations, and field data collection. As a group these students developed Evaluating Wastewater Treatment Options for Honduras (Bhattacharya et al., 2009), an overview of wastewater treatment as evidenced in ten facilities in Honduras. Selections from this report are summarized in Chapters 2, 4 and 8 of this thesis. Each student also undertook a more focused investigation of one facet of wastewater treatment; accordingly Lisa Kullen performed a study of waste stabilization pond systems which forms the basis of the pond analysis and assessment presented here.

The purpose of this project is to contribute to this nationwide study through the assessment of facility trends as observed in prototypical centralized wastewater treatment systems throughout this Central American nation. Building upon previous research, this work then examines the hydraulic function of four existing ponds. Potential design modifications for existing and future systems are explored with the goal of improving the quality of treatment effluent. Through computer numerical modeling, this investigation of maintenance routines seeks to offer insight into the impacts attainable through no- or low-cost maintenance modifications. From this assessment, recommendations for improving system performances have been developed. In particular this research intends to demonstrate the impact that routine maintenance has on pond efficiency, thereby underscoring the importance of adhering to a regular maintenance schedule.

2.0 HONDURAS BACKGROUND

Portions of this section originally appeared in Evaluating Wastewater Treatment Options for Honduras (Bhattacharya et al., 2009).

2.1 Honduras - General

The Republic of Honduras is the second largest country in Central America. With a population of 7.7 million people, Honduras covers an area of 112,000 square kilometers, roughly the area of the state of Tennessee. A map depicting the location of Honduras can be found in Figure 2-1.

Figure 2-1: Overview Map of Honduras
Source: Center for Disease Control, 2008

Honduras is a Spanish-speaking nation comprised of 18 departments or political territories, which are further divided into a total of 298 municipalities. The nation is democratic, with universal mandatory voting by all citizens over the age of 18 years (U.S. CIA, 2008). The country's capital of Tegucigalpa is also its largest city, where 12% of the population resides. Overall the country's population is divided into 43% urban dwellers and 57% rural (WHO, 2001).

Honduras has one of the highest levels of poverty in the Central American region, with 65% of the population living on less than two dollars a day (Water for People, 2006) and a nominal per capita GDP of $1,635 (FCO, 2008). Literacy rates in the nation were reported at 80% on the 2001 census. The median age in the country is 20 years, with a life expectancy at birth of 69 years (U.S. CIA, 2008).

2.2 Honduras – Water and Sanitation

Poverty reduction, through the provision of essential services such as adequate water and sanitation, has been a primary development initiative in Honduras (Mikelonis, 2008). However, poverty levels have also been a factor in the historical lack of sewerage fee collection, with current service providers facing cultural and economic challenges in levying rates or tariffs on sanitation services. As a result, sanitation is largely inadequate throughout the country; in urban areas, 41% of all residences lacked sanitation services as of 2001. Rural sanitation connection rates were reportedly below 20% (WHO, 2001). Similar investigative work performed by the organization Water for People five years later (Table 2-1) found improvement in these numbers but found services still lacking across both urban and rural populations.

Table 2-1: Sanitation Coverage
Source: Water For People, 2006

Population Groups	2001 Population	Population with Sewerage Service	Population with Latrines	Total Population Served	Coverage %
Rural	3,113,304	Unknown	1,541,085	1,541,085	49.5
Urban	2,895,776	1,538,440	1,006,947	2,545,387	87.9
Global	6,009,080	1,538,440	2,548,032	4,086,472	68

Inadequate sanitation holds severe consequences for the Honduran population with regards to water-related diseases. With a high infant mortality rate of 42 out of 1000 births, the leading cause of infant mortality is reported as intestinal infectious diseases. For children under the age of 5, the second leading cause of death is diarrheal diseases. Water-related diseases include waterborne (e.g. bacterial diarrhea, hepatitis A, typhoid fever) as well as vector-borne illnesses (e.g. malaria and dengue fever) whose transmission is exacerbated by unsanitary conditions. Cholera, a waterborne illness previously eradicated from Honduras, re-emerged with an outbreak in 2001. Proper sanitation is critical to raising the standards of health in the nation (WHO, 2001).

2.3 Regulatory Framework for Water and Sanitation

Multiple agencies attempt to work across several layers of government in the oversight, regulation, administration, and promotion of water and sanitation provision within Honduras. Unfortunately coordination gaps between agencies have led to difficulties in changing regulation, obtaining necessary permitting for new projects, and successfully maintaining existing systems. There has been an internal drive within Honduran water and wastewater agencies, as well as external encouragement from aid organizations, to reorganize regulatory responsibilities. This restructuring aims to improve the efficiencies of communication between agencies and to improve the water and sanitation infrastructure of the country. Descriptions of these agencies are provided within this section and are summarized in Table 2-2.

ERSAPS

Compliance and enforcement in the sanitation sector is handled by the Regulator of Potable Water and Sanitation Sector, or ERSAPS (Herrera, 2006). This agency is charged with the task of acting as a regulatory overseer for municipalities of all sizes with regard to water and sanitation. The agency disseminates knowledge about the laws governing water and sanitation to local authorities through regional workshops and online manuals. These technical manuals are provided through their website which include guidelines for meeting regulatory requirements (Mikelonis, 2008)

SANAA

Historically, the oversight responsibility for sanitation in Honduras fell to the National Autonomous Water and Sanitation Service (SANAA), which was charged with all aspects of sanitation including planning and construction as well as operation of facilities. A legislative change in 1990 created the Law of Municipalities, granting Honduras' 298 municipalities the independent responsibility for sanitation services within their borders. A subsequent legislative change in 2003 created the Framework Law for the Water and Sanitation Sector of Honduras. This new law detailed the procedure for the implementation of the restructuring guidelines in the Law of the Municipalities requiring the decentralization of the water and wastewater services from SANAA to each municipality.

This transference of responsibility from SANAA to the municipalities was set to be completed in 2008. Progress in implementing the change in jurisdiction has been slow, and SANAA's position is that some municipalities are not ready to manage these responsibilities. SANAA still operates roughly half of all urban water sanitation services, despite the mandate to terminate this function by 2008; the remainder of these services is provided by a combination of municipalities and private utility ventures. In the current configuration, SANAA's role is as technical secretary to CONASA, described below (Water for People, 2006).

CONASA

The agency of CONASA was created by the Honduran government to assist in implementing the changes mandated by the Law of the Municipalities and encouraged by the UN Millennium Development Goals and Poverty Reduction Goals set by the national government. As specified in the Framework Law for the Water and Sanitation Sector of Honduras of 2003, the National Water and Sanitation Council (CONASA) was created to set policy for the sector. CONASA seeks to expand sanitation coverage to 95% by the year 2015 (WHO, 2001).

SERNA and CESCCO

Approvals and permitting for wastewater treatment systems are mainly carried out by SERNA, the Department of Natural Resources and the Environment. The agency is specifically involved in the formulation and evaluation of policies pertaining to water resources, renewable energy sources including geothermal power and hydropower, and mining. CESCCO, the Center for the Study and Control of Contaminants, is the technical research arm of SERNA. Its responsibilities include the assessment of pollutant impact on human health and ecosystems, providing laboratory analysis assistance and services to communities, as well as monitoring air pollution in major urban centers (SERNA, 2009).

FHIS

Funding for many water sanitation projects is channeled through the Honduran Social Investment Fund (FHIS), an agency designed to mitigate the economic effect of governmental restructuring on local communities. This agency selects priority projects and transfers funds to municipalities to support those projects with funding from both the Honduran government and international aid agencies. The capital funding provided by

FHIS is critical for the implementation of a large portion of Honduras' wastewater facility projects (Water for People, 2006).

RAS-HON

The Honduran Network of Water and Sanitation (RAS-HON) facilitates the efforts of the various entities in the water sanitation sector. This non-governmental organization (NGO) consists of a group of advising environmental engineers and others with technical expertise in the field of sanitation who work with the various agencies listed above in providing technical support and exchange of ideas within this sector (Sistemas de Información, 2007).

Juntas

The provision of services in rural areas falls almost exclusively to the Water Boards or the *Juntas Administradoras de Agua* (Water for People, 2006). Many of these Juntas are organized into a national association, the Honduran Association of Water Boards, which lobbies for the interests of the rural water boards and allows for pooling of technical knowledge (RAS-HON, 2008).

Table 2-2: Summary of Agency Roles

Agency	Role
SANAA	Releasing authority as urban service provider
	Becoming technical secretary to CONASA
CONASA	Establishment of Policy
FHIS	Channels national and international funds for infrastructure projects
RAS-HON	NGO allows for exchange of ideas and technical support
Juntas	Regional water boards charged with providing rural sanitation services
ERSAPS	Compliance and enforcement in the sanitation sector
SERNA	Approvals and permitting for water resources projects
CESCCO	Technical branch of SERNA providing research and laboratory services

3.0 WASTEWATER STABILIZATION PONDS

3.1 General Description

Among the options for wastewater treatment in Honduras, there has been widespread support for the use of wastewater stabilization ponds. The typical pond design includes a large pond cavity partially excavated from level soil, with embankments formed from the removed material (Figure 3-1). In these ponds natural processes involving algae, bacteria, and photolysis degrade wastewater with relatively little human intervention, as seen in Figure 3-2 (Mara, 2003). Due to their simplicity, pond systems are widely recommended for use in Central America. In his case study on stabilization ponds in Honduras, Oakley states “Waste stabilization pond systems have long been promoted… to help solve the devastating problem of excreta-related disease transmission at an affordable cost,” (2005). The low operating cost and low technical intervention required by ponds systems make them ideally suited to wastewater treatment in Honduras.

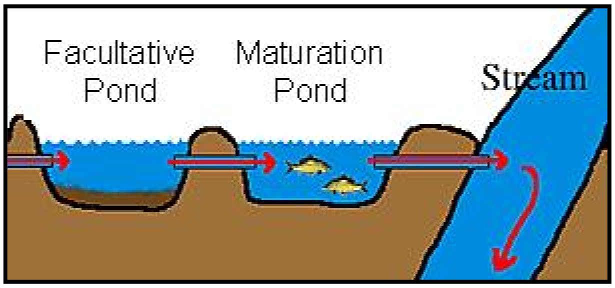

Figure 3-1: Basic Wastewater Stabilization Pond
Source: www.water.me.vccs.edu

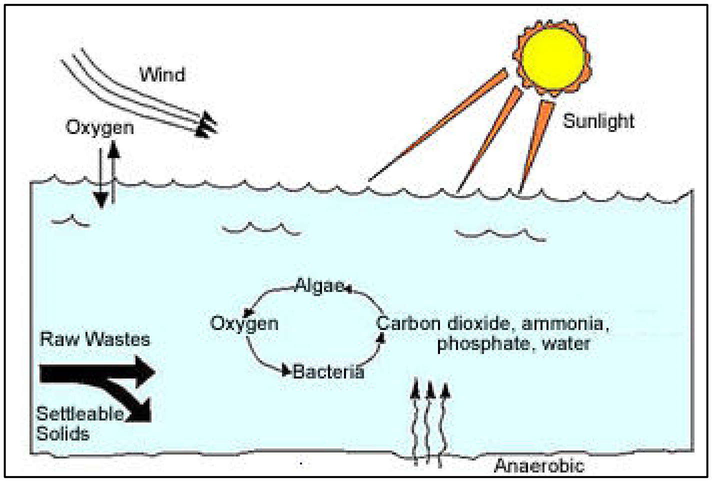

Figure 3-2: Algae, Bacteria, and Settling Processes Occurring in Facultative Ponds
Source: www.stabilizationponds.sdsu.edu

Honduras is faced with limited capital available for building or maintaining wastewater infrastructure. The historical lack of fees collected for water and wastewater services leads to reliance on limited local funding, sporadic funding from the national government distributed by FHIS, and international aid; thus, limiting operational costs is key to system performance. Additionally, a lack of maintenance is often cited as the cause for poor treatment system performance, so minimizing dependence on technically knowledgeable staff allows for more reliable function of a treatment system. Given these circumstances, waste stabilization ponds offer the ideal combination of low capital cost, very low operating costs, and limited technical maintenance requirements.

As ERSAPS plans for system improvement and expansion, waste stabilization ponds are under consideration as one ideal technology. However, previous research found a wide range of performance with many systems drastically underperforming. Many pond systems investigated fell well below established effluent discharge standards (Oakley, 2005). This is of concern for the health of the human population and the aquatic life in receiving waters, as well as being a public relations concern. The perception that ponds are unnecessary or ineffective has historically led to abandonment of some ponds in Latin America. Mara (2003) observes that “cities and towns can be ‘turned off’ WSP by a bad experience with them - sometimes resulting from poor operation and maintenance, or allowing them to become seriously overloaded.” For this technology to be viable in Honduras, improvements to pond performance must be identified and carried out.

3.2 Ideal Pond Design

Fundamental to an assessment of existing pond systems is an understanding of ideal stabilization pond performance. Pond systems in Honduras are typically comprised of two or more facultative ponds followed by one or more maturation ponds (Oakley, 2008). Table 3-1 details the recommendations put forth by Mara (2006) for pond design in developing countries. Table 3-2 lists recommendations for routine maintenance. These guidelines are general in nature and may not take into account specific constraints at a particular site. However they provide a basic framework for understanding ideal design and maintenance requirements of stabilization pond systems in Honduras.

Table 3-1: Recommended Waste Stabilization Pond Facility Characteristics

Recommended WSP Facility Characteristics	
Characteristic	**Benefit**
Anaerobic Ponds - Depth 2-5 Meters	Preserve Anaerobic Conditions in Deep Water
Anaerobic & Primary Facultative - Length : Breadth is 2-3:1	Wider Design Prevents Sludge Banks Near Inlet
Facultative Ponds - Depth 1-2 Meters	Sunlight & Photosynthesis at all Depths
Secondary Facultative Ponds - Length : Breadth is 10:1	Plug Flow
Inlet/Outlet at Opposite Corners, or Baffled to Approximate	Plug Flow
Single Inlet and Outlet	Gravitational Pipe Settling Disrupts Design Flows
Inlet Below Surface	Minimize Short Circuiting
Outlet Below Surface	Below Scum, Below Algae, Well Above Sludge
Weeds Kept Out of Pond & Back From Edges	Discourage Mosquitos, Preserve Photosynthesis
Security: Locked Fence/Gate	Ensure Public Safety; Discourage Tampering/Wildlife
Operator Booth, Rest Room	Operator Comfort Supports Pond Maintenance
Storage Shed: Protective Gear, Rakes, Wheelbarrow, Boat	Tools Needed for Performing Maintenance
Monitoring and Sampling	Monthly Routine To Identify Failures
Sludge Less Than 1/3 Pond Volume	Sludge Decreases Pond Volume & Retention Time

Source: Mara, 2003

Table 3-2: Recommended Waste Stabilization Pond Facility Maintenance Routines

Recommended WSP Maintenance Routines	
Task	**Benefit**
Remove Screenings from Bar Racks	Prevent Flow Obstructions
Remove Grit from Grit Chamber	Prevent Flow Obstructions
Mow Embankments Back from Water	Control Mosquitoes, Aid Photosynthesis (Remove Shade)
Anaerobic: Spray Scum with Water or Wastewater	Control Mosquitoe Breeding
Facultative/Maturation: Remove Scum/Plants	Control Mosquitoes, Aid Photosynthesis (Remove Shade)
Remove Solids From Inlet/Outlet Area	Remove Disruption to Intended Flow Pattern
Repair Animal Damage/Erosion To Embankments	General Maintenance
Repair Damage to Fences/Gates	Site Security
Regularly Check Sludge Depth; Remove at 1/3 Pond Volume or Every 1-5 Years	Increase Effective Volume; Can Partially Desludge Annually (Convenience of Planning & Coordinating Task Annually)

Source: Mara, 2003

3.3 Ideal Pond Function

Honduran guidelines for wastewater effluent have been criticized as arbitrary and unattainable. Accordingly there has been inconsistent enforcement of these guidelines throughout the nation. However, with proper pond sizing, the literature shows that a well functioning waste stabilization pond system would be expected to achieve effluent quality standards mandated by these regulations.

Table 3-3: Honduras Effluent Guidelines

Effluent Guidelines	
Parameter	**Requirement**
Total Suspended Solids	100 mg/L max
Ammonia Nitrogen	20 mg/L max
pH	6.00 – 9.00 range
Fecal Coliforms	5,000 CFU/100 mL max
BOD	50 mg/L max

Source: ERSAPS, 1996

Table 2-1 presents a partial listing of Honduras effluent discharge requirements as listed by ERSAPS. Given proper sizing and loading, waste stabilization ponds in Latin America have been able to attain these levels of effluent quality. For example, a study of ponds in Northeast Brazil at 25 degrees Celsius showed secondary maturation pond effluent with fecal coliform colonies measuring 550 to 1600 colony-forming units (CFU) per 100 mL, unfiltered biochemical oxygen demand (BOD) at 22 to 26 mg/L, and ammonia nitrogen at 7 to 17 mg/L (Mara, 2003). This climate is similar to that of Honduras and pond efficiency approximating that of Brazil should be attainable. However, final effluent monitoring of pond systems in Honduras found mean values for fecal coliforms at 54,700 CFU/100 mL, and suspended solids ranging as high as 135 mg/L (Oakley, 2005).

In a system typical of Honduras, design criteria will specify ideal BOD surface loading for facultative ponds rather than specifying volume loading. This is because facultative ponds require a robust algae population, as photosynthesis generates most of the oxygen required for degradation of wastewater, and therefore surface loading is specified in order to ensure the solar exposure required at the pond surface is provided. In order to maintain this algae population, surface loading of BOD should range from 100 to 400 kg/ha-day in facultative ponds, as determined by Equation 1 suggested by Mara (2003):

$$\text{Surface Loading [kg/ha day]} = 0.1 * \text{BOD Inflow [g/day]} / \text{Pond Area [m}^2\text{]}$$

Equation 1

Pond area and volume are fundamental design variables determined from requirements regarding retention time and BOD loading. Retention time is specified by removal rates for BOD, helminth eggs, and *Escherichia coli* (*E. coli*). Factors considered in the sizing of both facultative and maturation ponds include population served, BOD contribution per person, volumetric wastewater flow rate per person, temperature, pond liquid depth, pond evaporation, BOD removal rate constant, and the specified effluent BOD; Mara (2003) suggests a series of formulae for determining pond area and volume considering all these factors. Design of existing ponds in Honduras may have been based on inaccurate assumptions of these factors. For example, the volumetric loading historically assumed is 100 to 120 liters per person per day (Lppd); however calculations performed by Oakley (2005) found a range of 92 to 514 Lppd in existing systems. Use of accurate flow data would have suggested larger pond systems in many cases. The problem of excess flow was corroborated in the city of Las Vegas by Mikelonis (2008).

Ideal pond design seeks to create plug flow conditions, or what might be considered a “first in, first out” flow regime, as depicted in Figure 3-3. Ideally the condition of plug flow involves no mixing in the longitudinal direction, the direction of flow. The presence of lateral or vertical mixing is generally assumed to be complete although it is unimportant to this flow regime.

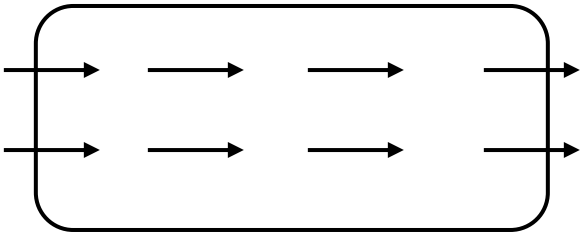

Figure 3-3: Plug Flow Schematic

The reason plug flow is advantageous can be seen by examining a treatment processes that occurs with a first-order rate, meaning that the process occurs as an exponential function of time. A first-order decay process is generally represented by:

$$C_{out} = C_{in} * e^{-kt}$$

Equation 2

where C_{out} is final concentration, C_{in} is initial concentration, k is a decay constant specific to the constituent and conditions present, and t is residence time in pond. To illustrate first order kinetics, and thus this exponential function of time, the reader is asked to consider that sedimentation of solids occurs in proportion to the concentration of suspended solids. Likewise bacterial breakdown of organic matter will effectively reduce the biochemical oxygen demand (BOD) in proportion to its concentration. While the process of decay could continue indefinitely, the rate drops with time as the concentration is reduced. Due to the finite volume of a wastewater stabilization pond, a mean residence time t* exists such that

$$t^* = V/Q$$ **Equation 3**

where V is pond volume and Q is volumetric flow rate. Thus it can be considered that, for any water parcel A retained longer than time t*, another parcel B of water has had its residence time shortened commensurately. With a first-order decay process, the benefit of a longer retention time for parcel A is not enough to offset the loss of benefit in reducing the retention time of parcel B. Thus there is a net loss of efficiency as systems deviate from plug flow. Figure 3-4 illustrates this point. For a parcel of water leaving at t = t*, the water body's average retention time, removal efficiency is marked by the pink line for the whole parcel. If instead this parcel of water ranged in residence time, it would follow the pink curve to experience some improved benefit in the slower-to-leave water. This improved benefit is indicated by the lower concentration marked by the right hand triangle. But it would also suffer some lost benefit in the water which leaves first, indicated by the left hand triangle. This lost benefit exceeds the gained benefit, demonstrating the plug-flow is more advantageous than a mixed flow regime overall.

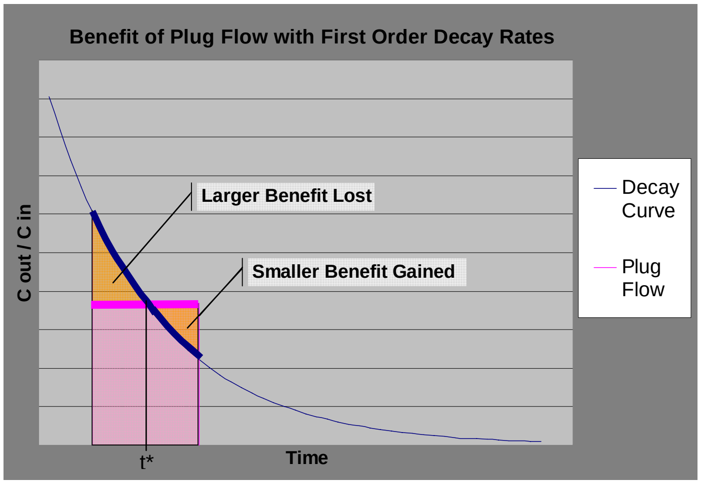

Figure 3-4: Plug Flow Net Benefit

An argument can be made that purely plug flow conditions are marked by risks which could outweigh their benefits. For example, by virtue of its limited longitudinal mixing, plug flow offers little dilution to sudden temporary spikes in constituent concentrations. Thus contaminants which are harmful to the microbial population of treatment systems could enter the system in high concentrations unmitigated by dilution. In the ponds studied in Honduras, the frequency of such events is expected to be low due to wastewater originating from domestic sources, and due to the overall lower consumption rates of chemical cleaning products and personal care products in the developing world. Additionally, idealized plug flow is never attained in built systems due to the impossibility of eliminating longitudinal mixing. This is due to the influence of chemical dispersion, friction and irregular flow patterns based on the effect of inlet and outlet geometry on mixing behavior. As Mara (2003) states, "Due to their long hydraulic retention time, (wastewater stabilization ponds) are more resilient to both organic and hydraulic shock loads than any other wastewater treatment process.” Thus plug flow, as much as it can be attained in built systems, is generally regarded as a desirable flow regime in wastewater stabilization ponds.

In light of the ideal pond criteria discussed, an exploration of pond performance in Honduras is both relevant and important. There is a striking range in performance of pond systems throughout the country, with removal efficiencies for BOD and SS ranging from 70 to 95% and 55 to 95% respectively (Oakley, 2005). These removal rates, combined with actual effluent data, indicate that the ponds may be underperforming or undersized for the communities they serve; these limitations impact not just the quality of the water receiving the discharge but also the reputation of the pond system, increasing the risk of system abandonment. These issues suggest the need for investigation of modifications to improve system efficiency. Therefore this research explores maintenance-based causes for observed limitations to pond performance.

Since plug-flow conditions (in which longitudinal dispersion is absent) represent an ideal case, it is worthwhile to consider the effects of some longitudinal dispersion in so called “dispersed flow reactors”. The magnitude of longitudinal dispersion can be characterized by the Peclet number, given by $Pe = UL/E_L$ where U is the average water velocity, L is the pond length, and E_L is the longitudinal dispersion coefficient. E_L is generally unknown, but may be calibrated by graphical comparison of the pond’s effluent concentration with that predicted for an idealized pond with various values of Pe. This process may be dubbed a “Peclet number analysis,” and it considers a conservative tracer introduced as a step input at time t=0, for which the analytical solution is given by

$$\frac{C_o}{C_i} = 0.5\{[erfc\,\frac{\mathrm{L - Ut}}{\sqrt{\mathrm{4Et}}}] + \exp(\mathrm{Pe})\,[erfc\,\frac{\mathrm{L - Ut}}{\sqrt{\mathrm{4Et}}}]\} \qquad \textbf{Equation 4}$$

where C is effluent concentration, L is distance traveled to outlet, U is water velocity, t is time, E is longitudinal dispersivity, and Pe is Peclet number. A graph of Equation 4 is plotted in Figure 3-5. It is noteworthy that the Peclet number for any water body is the velocity times length divided by the longitudinal dispersivity, or Pe = UL/E. Thus a lower Peclet number indicates greater mixing in the water body. In theory a completely mixed tank would have a Peclet number of zero, and a tank with no longitudinal mixing would have a Peclet number approaching infinity. This framework of a Peclet number analysis is employed throughout the literature, with many researchers referring to an alternative dispersion number d which is equivalent to the inverse of the Peclet number. The terms Pe and 1/d are interchangeable, and so the current study will refer to the Peclet number in all cases.

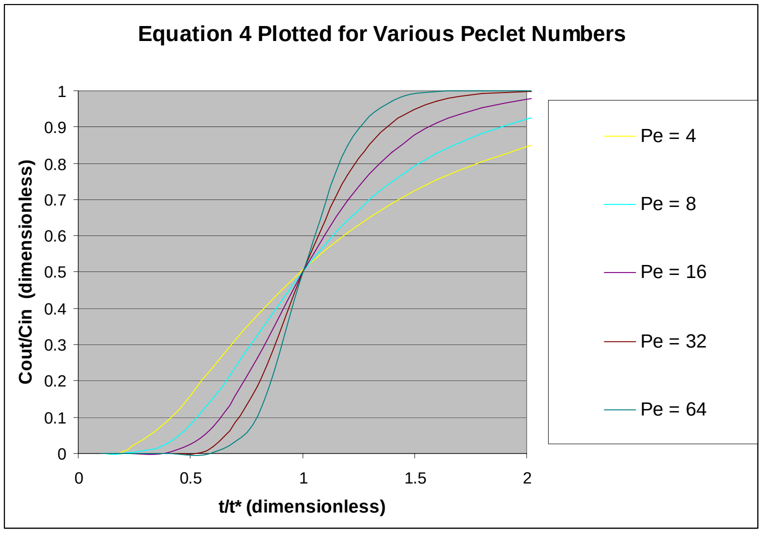

Figure 3-5: Equation 4 Plotted for Various Peclet Numbers

In a dispersed flow reactor with steady flow and first order decay, Wehner and Wilhelm (1956) showed that the ratio of outlet to inlet concentration is given by Equation 5:

$$C_{out}/C_{in} = (4\,a * \exp\{Pe/2\}) / [(1+a)^2 * \exp\{Pe*a/2\} - (1-a)^2 * \exp\{-Pe*a/2\}]$$

Equation 5

where $\alpha = [1+(4kt^*/Pe)]^{0.5}$. The results of this equation for a series of Peclet numbers are plotted in Figure 3-6.

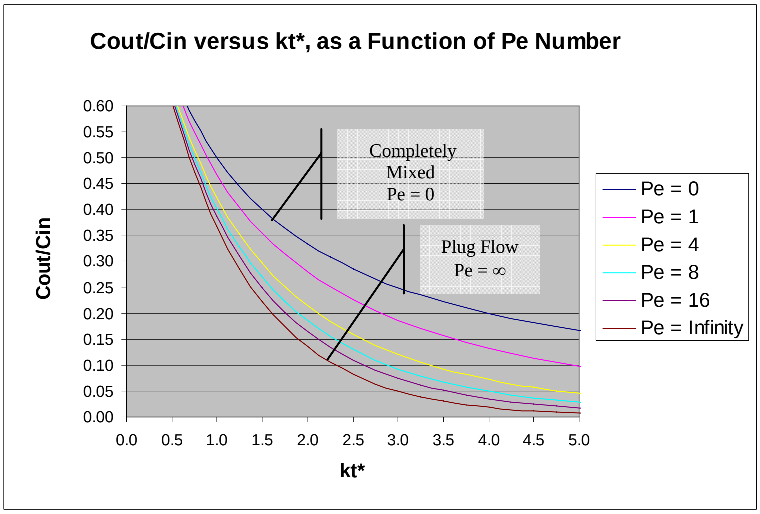

Figure 3-6: Cout/Cin vs. kt*, as a Function of Peclet Number (General)

As is depicted in the graph, for any given Peclet number an increase in mean residence time will serve to decrease the final effluent concentrations. It is also seen that, when time is fixed along with influent concentration and decay rate, a higher Peclet number leads to lower effluent concentrations. For a completely mixed reactor, this model predicts behavior indicated by the curve for a Peclet number of 0, whereas perfectly plug flow conditions are depicted by the curve for a Peclet number approaching infinity.

3.4 Previous Studies

To provide a context for the current research, previous studies were consulted. Von Sperling (2003) studied several empirical equations from the literature for estimating a Peclet number in order to evaluate waste stabilization ponds as one dimensional dispersed flow reactors. While the Peclet number was found to be intrinsic to a calculation of effluent constituent concentrations, a sensitivity analysis in that study found that a simple formulation of Peclet number was no less accurate than one derived from a more complex equation. This is due in part to the uncertainty in many of the terms of these and other pond design equations. Accordingly, it was determined that a simple equation is valid for estimating a Peclet number:

$$Pe = L/B$$ **Equation 6**

where L is pond length and B is breadth (von Sperling 2003).

Various Peclet values are found through the literature for existing waste stabilization ponds. For example, in Brazil the Peclet number of an existing pond was reported to be between 0.3 and 1.25, and in Portugal as between 0.3 and 2.0 (Marecos do Monte and Mara, 1987). These real ponds exhibit a wide variability in dispersive behavior.

To address this gap between analytical solutions and actual pond behavior, Lloyd et al. (2003) studied modifications to an existing pond system in Colombia. These modifications included changing the effective geometry of the ponds in an attempt to mitigate short circuiting in these ponds. The impact on final effluent quality was examined in an attempt to understand how such modifications could be made to real systems in order to improve substandard pond performance. The results of this study support the value of enhancing plug flow-like conditions for increasing pathogen removal in existing systems.

Other researchers have questioned the validity of using a dispersed flow approximation at all, since analytical calculations of pond performance based on pond length and breadth alone do not account for complex hydrodynamic behavior caused by many other factors. Agunwamba (1991) cites limitations incurred by failing to account for factors such as depth to breadth ratio, wind effects, dead zones in flow, and sampling time elapsed since tracer release. Further, it is demonstrated that the use of empirical equations for computing analytical solutions often introduces great error due to imprecision in the terms of these equations. Thus the removal of wastewater constituents predicted analytically may not be achieved in real systems.

While effluent quality is heavily influenced by geometric complexities such as inlet and outlet locations and dimension ratios, typical pond design currently takes these factors into consideration only minimally. Shilton and Harrison (2003) conducted an extensive investigation of pond response to modifications in geometry, in an effort to develop guidelines for waste stabilization pond hydraulic design. The study indicated the need for further research to broaden the body of knowledge regarding geometric impacts on pond performance.

The variability in Peclet numbers observed in real ponds, along with the debate over the limitations of analytically determined pond performance, suggests there is value in using numerical modeling to characterize pond behavior. This modeling has advantages over simple analytical calculations for assessing performance in cases where a dispersed flow reactor is a poor approximation of a real system. Further, numerical modeling enables analysis of performance improvements attainable through complex modification to the geometry of existing and future waste stabilization ponds.

3.5 Introduction to Subject Ponds

In order to examine complex geometric effects on pond behavior, this study conducted detailed investigation of two wastewater stabilization pond systems in Northern Honduras. Pond characteristics are summarized in Table 3-4. The first system was in the city of La Lima, serving a population of 3,500 people. After the headworks, the system divides into two parallel circuits each consisting of a facultative pond and a maturation pond in series. The final effluent is released to Rio Chamelecon, which then drains to the Caribbean Sea. The facility occupies 14 hectares of land. This study focused on the facultative ponds, which are each 40 meters wide, 80 meters long, and 1.2 meters deep. The residence time of these ponds is approximately 3.4 days, with a flow rate of 0.0105 m^3/s to each pond, or a flow rate of 0.021 m^3/s to the overall facility. At the time of the visit some dead zones were apparent in the corners of the ponds along with evidence of recirculation and an accumulation of scum in pond corners. The facility reports that desludging is pending, although it is not clear when this will be carried out.

The second system studied was in the city of Puerto Cortés. The wastewater treatment facility is located on a strip of land between the Alvarado Lagoon and the Caribbean Sea. The total facility occupies 22 hectares. The population served by this facility is approximately 50,000. After the headworks the system divides into two parallel circuits, each consisting of an anaerobic and a facultative pond in series; both circuits then join and flow into two maturation ponds in series. Effluent quality at this facility is reportedly high, exceeding the water quality of the receiving waters on measures such as *E. coli* count. Desludging has not been undertaken yet as this is a newer system. Facility operators anticipate desludging the anaerobic ponds during 2009, and desludging the facultative ponds on a five year interval. This study focused on the anaerobic ponds at Puerto Cortés, which are each 40 meters wide, 108 meters long, and 4 meters deep. The residence time of these ponds is approximately 2.5 days, with a flow rate of 0.05 m^3/s for each pond or 0.1 m^3/s for the overall facility.

Table 3-4: Characteristics of Subject Ponds

Pond Characteristics		
Characteristic	**La Lima Facultative 1 & 2**	**Puerto Cortés Anaerobic 1 & 2**
Width (m)	40	40
Length (m)	80	108
Depth (m)	1.2	4.0
Volume (m^3)	3000	10,300
Mean Residence Time (d)	3.4	2.5
Population Served	3,500	50,000
Receiving Waters	Rio Chamelecon	Alvarado Lagoon

4.0 OBSERVED STATE OF WASTEWATER TREATMENT

Portions of this section originally appeared in Evaluating Wastewater Treatment Options for Honduras (Bhattacharya et al., 2009). Over the course of the project a variety of sites was visited, representing a sample of the different treatment systems found throughout Honduras. The facilities visited are listed in Table 4-1. These facilities were found to range greatly on measures involving adequacy of design as well as operation and maintenance. Some facilities observed routine water quality sampling and maintenance protocols while others were found to be less maintained or completely abandoned. The trends discussed below are generally drawn from the ten facilities visited, with an emphasis on observations from waste stabilization ponds. While this survey presents an informative glimpse into typical wastewater management systems, it may not be fully representative of the wider state of wastewater treatment throughout the country.

Table 4-1: Treatment Facilities Visited & Technology Used

Sites Visited & Technology Used			
ID No.	**Location**	**Date Visited**	**Treatment Type**
1	Guaimaca	10-Jan-09	Imhoff Tank and Constructed Wetland
2	Talanga	10-Jan-09	Waste Stabilization Ponds
3	Villa Linda Miller	10-Jan-09	Imhoff Tank and Anaerobic Filter
4	Amarateca	11-Jan-09	Package Plants
5	Teupasenti	11-Jan-09	Anaerobic Treatment & Constructed Wetland
6	Las Vegas	7-Jan-09	Imhoff Tank
7	Puerto Cortés	20-Jan-09	Waste Stabilization Ponds
8	Choloma	19-Jan-09	Waste Stabilization Ponds
9	La Lima	17-Jan-09	Waste Stabilization Ponds
10	Tela	18-Jan-09	Waste Stabilization Ponds

4.1 Design

Many instances of wastewater treatment facility design oversight were observed. A striking example of this involves a geoliner failure at the waste stabilization ponds at Puerto Cortés. It was suggested that the site of this facility was poorly chosen as it was previously a wetland. Thus this site experiences biological activity leading to methane generation with subsequent entrapment beneath the ponds. Due to a high water table, this methane is entrapped, causes the geoliner to blister above the pond surface as depicted in by satellite in Figure 4-1 A. Figure 4-1 B is a photograph detailing one such blister, inhabited by ground nesting birds which offer a sense of scale in this image. Additional site investigations may have revealed the site as inappropriate or suggested mitigating measures to address the issue of methane accumulation beneath the geoliners.

The city of Talanga also experienced a design oversight as their pond system appeared oversized for the flows currently received. Talanga reported connection of only 15% of the incorporated city after two and a half years in operation. Thus one of two facultative ponds was unused and required filling with river water to prevent desiccation cracking of the clay liner. In other locations, illegal connections from storm drains and industrial wastewater sources were of concern. For instance, Puerto Cortés reported high flows and shortened residence times during rainfall events due to illegal storm sewer connections. Overall, of the ten visited systems currently on line, only 80% were assumed to be properly sized, as illustrated in Figure 4-2.

Figure 4-1: Geoliner Failure at Puerto Cortes: A) Satellite View, B) Photographed with Nesting Birds Source: A) Google Earth and B) the Author

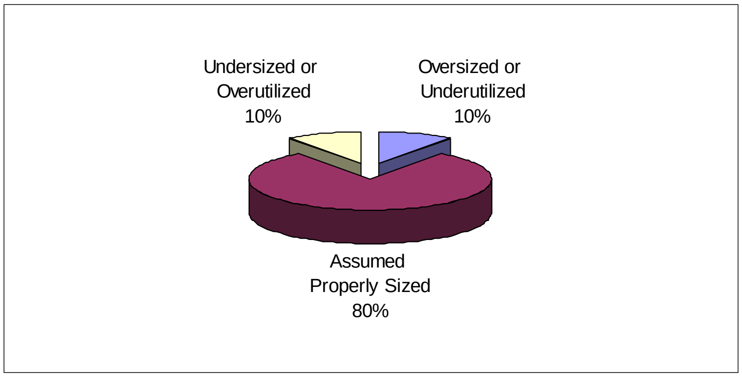

Figure 4-2: System Sizing Efficiencies

Other observations of systems include a lack of bar screens at 50% of the on line facilities. Some of these were misplaced, perhaps due to a lack of permanent installation, while others were not a part of the original facility design. Bar screens are valuable in keeping large obstructions out of the systems preventing unintended flow patterns or clogs which these can cause.

4.2 Operation and Maintenance

Several important aspects of operation and maintenance were identified over the course the study. These are crucial to ongoing system performance and broadly fall under the categories of general maintenance, water quality monitoring, and sludge management.

4.2.1 General Maintenance

General maintenance activities include routine tasks such as surface scum removal, cleaning of bar screens, clearing of flow obstructions, and groundskeeping. Overall half of the facilities visited were maintained to some degree and appeared to be in good operating condition. The extent of general maintenance conducted varied from site to site. At four facilities, scum and bar screenings were removed daily and disposed of in onsite pits or in sanitary landfills and the site grounds were well maintained.

By contrast, flow irregularities were observed at the pond system in Tela. In this system the second of three ponds was filled to the top of its berm with seepage over one side. The outlet pipe exiting this pond could be seen to flow only half full where it flowed by gravity into the next pond, although the pipe was completely submerged where it exited the flooding pond uphill. Though this was likely due to a flow obstruction, none was immediately visible so the cause cannot be confirmed.

4.2.2 Water Quality and Flow Monitoring

Flow monitoring practices were reported at at least four locations. Flow measurement devices were present at several other facilities; however, these were not found to be used (Figure 4-3). In addition, irregular flow patterns were observed in several cases. At the pond system in Talanga, flow into the maturation pond was visibly unbalanced between two inlet pipes. When this issue was brought to the operator’s attention, it was found that the system valves were not capable of completely balancing this flow. Further, the facility operator and director did not appear concerned with balancing the flow. Since flow balance is linked to pond performance, it could be reasonably speculated that this imbalance negatively impacts the effluent quality at this pond.

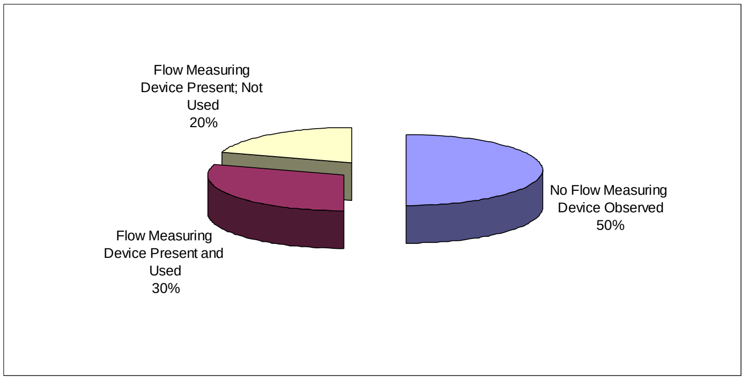

Figure 4-3: Examination of Flow Measurement Device Distribution and Usage

Routine water quality monitoring was directly observed in two cities. The final effluent from these facilities was reportedly compliant with regulatory requirements. Two other facilities reported that quality testing is routinely performed. Five facilities confirmed that they were not performing water quality testing, and a sixth site did not report such testing. In the case of the ponds in Choloma, the plant director is currently seeking guidance regarding water quality parameters and testing protocols, and no testing is being performed at this time. Quality monitoring observations are summarized in Figure 4-4.

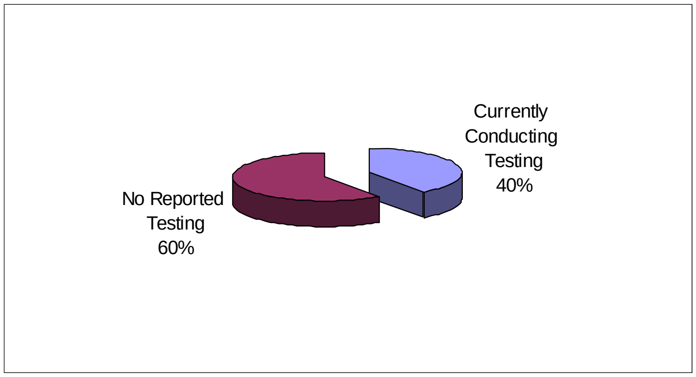

Figure 4-4: Water Quality Monitoring Distributions

Testing need not be difficult, but should be implemented routinely in order to monitor system function and ensure discharge quality standards are met. Mara (2003) states that:

> Effluent quality monitoring programmes should be simple and the minimum required to provide reliable data. Two levels of effluent quality are recommended:
>
> 1. *Level 1*: representative samples of the final effluent should be taken regularly (at least monthly) and analysed for those parameters for which effluent discharge or re-use requirements exist.
> 2. *Level 2*: when Level 1 monitoring shows that a pond effluent is failing to meet its discharge or re-use quality, a more detailed study is necessary.

While effluent discharge quality requirements are mandated by law and posted on the ERSAPS website, this research was unable to determine whether testing protocols are mandated by law, or whether guidelines regarding those protocols have been made available to this facility director who voiced an interest in learning about recommended testing protocols.

4.2.3 Sludge Management

Of the facilities visited, a number were recently brought into operation and have not yet needed to carry out desludging (Figure 4-5). Facilities such as La Lima and Puerto Cortés have been monitoring sludge depth and are reportedly in the process of developing a sludge management plan. Puerto Cortés anticipates desludging its anaerobic ponds at some point in 2009.

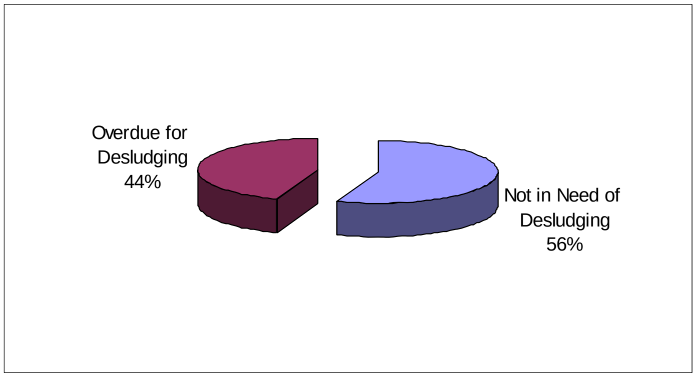

Figure 4-5: Distribution of System Time Horizons for Desludging

The systems at Tela, Teupasenti, and Las Vegas reportedly have been desludged although not necessarily on a routine basis (Figure 4-6). Sludge at Tela was dried and buried onsite in 2007. Drying beds were used for sludge management at Teupasenti. None of the facilities surveyed has been successful in implementing or marketing sludge for beneficial reuse.

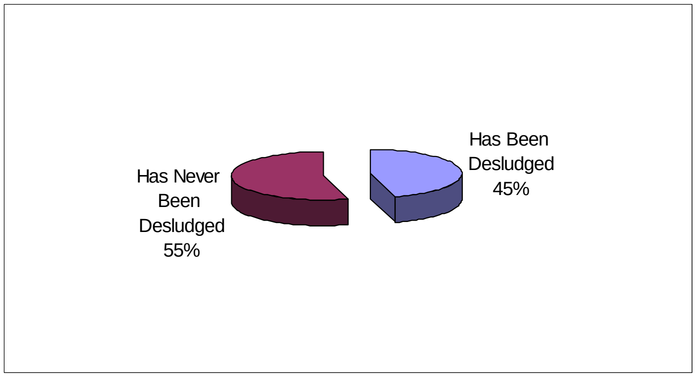

Figure 4-6: Distribution of Systems Which Have Been Desludged

5.0 DATA COLLECTION AND METHODOLOGY

The current project included a study of waste stabilization pond system performance including computer flow simulation and performance calculation. As a part of this study, data was collected from several ponds on sludge accumulations and information was gathered on the history of the systems. Data was also collected on several water quality indicators. The intent of this data collection was to enable an examination of current pond performance in comparison to idealized behavior.

5.1 Sludge Depth Measurements

One major removal mechanism in waste stabilization ponds is the settling of solids. Over time this process leads to sludge accumulations which compromise pond performance. Sludge occupies a portion of the pond, reducing the effective volume available for wastewater treatment. Since residence time is proportional to volume, this leads to a shorter interval of treatment. Theoretically pond performance would be compromised by the presence of any sludge accumulation at all, but at lower accumulations this effect would be minimal. This study sought to understand the impact of this effect with larger sludge accumulations.

Besides reducing available volume, sludge accumulations can have other impacts on pond performance. Uneven deposition of sludge can influence hydraulic behavior of ponds, potentially causing deviations from a plug flow regime. As previously stated, plug flow can be viewed as “first in, first out” flow without any recirculation, providing the ideal condition of a uniform residence time in waste stabilization ponds. It is speculated that uneven sludge accumulations could cause deviations from plug flow, leading to behaviors like stagnating or recirculating water in some areas, or short circuiting in other areas as inflowing water skims across the surface from inlet to outlet.

For the purposes of this analysis it was necessary to measure the depth of the water column to the sludge over a grid. Water depth was calculated through measurements of the depth of the sludge itself, from pond bottom to top of sludge layer. This, combined with information on the shape of the pond walls and bottom, allowed for the indirect calculation of the depth of the water column on a grid.

Measurements were taken by sludge stick while traveling in a boat over a grid for two facultative ponds in La Lima and two anaerobic ponds in Puerto Cortés. At the La Lima facility this sludge stick consisted of a long wooden stick wrapped in a white towel. At the Puerto Cortés ponds the wooden sludge stick was too short, so the sludge stick used consisted of a 6 meter length of PVC pipe which was graduated with hand-sawn hatch marks at one end. This sludge stick was the tool used for routine measurements by the operators of the Puerto Cortés facility. The stick was lowered at each point on the grid until it penetrated the sludge and reached pond bottom. Raising the stick, entrapped particles were evident in the white towel or in the hatchings up to the level of the sludge blanket depth. By subtracting the sludge depth from the pond depth, an assessment could be made of water depth on this grid.

The grid was demarcated with flags on all sides of the pond, and field assistants coordinated with boat operators by sighting between the flags to center the boat on each point in the grid.

The first ponds studied were the two facultative ponds at La Lima. The facultative ponds were chosen due to their greater accumulation of sludge in comparison to the maturation ponds. The later ponds receive wastewater which has already undergone settling to a great extent. This, combined with the ponds' short time of three years in operation, led to a much lower sludge accumulation in the maturation ponds.

The facultative ponds both measured 80 meters long by 40 meters wide by 1.2 meters deep. The grid for measurements in Pond 1 was laid out by placing flags at 9.5-meter intervals along the sides and 9 meter intervals across the top and bottom, with an alignment which placed a flag at the center of each long and short side. Due to rounding of the pond corners, each corner had a point which is omitted. See Table 5-1 for grid spacing and sludge depth recorded in La Lima Facultative Pond # 1.

Table 5-1: La Lima # 1 Sludge Depth

LA LIMA FACULTATIVE POND #1 SLUDGE DEPTH (m)					
		DISTANCE ACROSS POND WIDTH (m)			
		11	20	29	38
DISTANCE ACROSS POND LENGTH (m)	11.5	0.11	0.13	0.64	0.05
	21.0	0.16	0.13	0.19	0.11
	30.5	0.09	0.1	0.09	0.07
	40.0	0.13	0.07	0.07	0.12
	49.5	0.08	0.06	0.09	0.06
	59.0	0.08	0.12	0.03	0.08
	68.5	0.1	0.13	0.1	0.05
	78.0	0.13	0.18	0.12	N/A

Pond 2 was laid out similarly. However irregularities in the alignment of one side of the pond placed multiple data points too close to the pond's edge. This row of data was deemed irrelevant and was eliminated from this study. See Table 5-2 for grid spacing and sludge depths observed in Facultative Pond # 2.

Table 5-2: La Lima # 2 Sludge Depth

LA LIMA FACULTATIVE POND #2 SLUDGE DEPTH (m)						
		DISTANCE ACROSS POND WIDTH* (m)				
		2	11	20	29	38
DISTANCE ACROSS POND LENGTH (m)**	2.0	N/A	0.16	0.23	0.27	N/A
	11.5	0.11	0.13	0.14	0.28	0.16
	21.0	0.08	0.11	0.13	0.29	0.15
	30.5	0.06	0.09	0.11	0.26	0.18
	40.0	0.13	0.09	0.12	0.13	0.13
	49.5	0.12	0.09	0.12	0.16	0.13
	59.0	0.11	0.15	0.12	0.17	0.1
	68.5	0.05	0.13	0.15	0.14	0.1
	78.0	N/A	0.16	0.15	0.14	N/A

At the facility of Puerto Cortés the deep anaerobic ponds were chosen for study because of their placement as the first ponds in the circuit, and subsequent greater sludge deposition than that experienced by ponds later in the system. Additionally, these ponds are nearly three times as deep as the other four ponds at Puerto Cortés, so the accumulation is more substantial than it would be for a shallower pond with an equivalent volume. With a relatively short time in operation, the facility engineer advised us that sludge accumulation in the later facultative and maturation ponds was minimal.

The grid layout for these ponds consisted of three longitudinal columns spaced at seven meter intervals and nine lateral rows spaced at 9.5 meter intervals. The decision to shorten the lateral interval and to eliminate data collection nearer all sides was made due to the long sloping sides in the geometry of these deep ponds. With a three-to-one slope and a depth of four meters, these walls extended inward 12 meters from the water's edge at the point where they leveled off into the pond bottom. The facility engineer reported insignificant sludge accumulation on the pond walls as it slid down the slope to the flat bottom. This information coupled with difficulties in taking measurements over the sloped sides led to the decision to shrink the grid interval toward the center in the lateral dimension. See Table 5-3 & Table 5-4 for grid spacing and depth values recorded in Puerto Cortés Anaerobic Ponds # 1 and 2.

Table 5-3: Puerto Cortés # 1 Sludge Depth

PUERTO CORTES ANAEROBIC POND #1 SLUDGE DEPTH (m)				
		DISTANCE ACROSS POND WIDTH* (m)		
		14	21	28
DISTANCE ACROSS POND LENGTH (m)**	14	0.58	0.6	0.35
	24	0.64	0.64	0.46
	34	0.63	0.51	0.42
	44	0.29	0.48	0.32
	54	0.21	0.18	0.23
	64	0.13	0.15	0.23
	74	0.11	0.21	0.23
	84	0.18	0.26	0.18
	94	0.21	0.18	0.18

Table 5-4: Puerto Cortés # 2 Sludge Depth

PUERTO CORTES ANAEROBIC POND #2 SLUDGE DEPTH (m)				
		DISTANCE ACROSS POND WIDTH* (m)		
		14	21	28
DISTANCE ACROSS POND LENGTH (m)**	14	1.00	1.00	0.96
	24	1.00	1.00	1.00
	34	0.98	1.00	0.91
	44	0.98	0.94	0.76
	54	0.26	0.49	0.35
	64	0.03	0.23	0.42
	74	0.03	0.23	0.26
	84	0.03	0.06	0.03
	94	0.03	0.03	0.10

5.2 Water Quality Testing

Water samples were collected in order to evaluate pond performance. Laboratory measurements made include chemical oxygen demand (COD) and *E. coli*. Samples were collected at three facilities: La Lima, Puerto Cortés, and Choloma. Plans to study sludge bathymetry in Choloma were abandoned due to the presence of several large crocodiles in these ponds coupled with the invasive nature of this data collection. Specifically, the research team determined that methodically probing the pond bottom over a grid from a boat would be unsafe in a pond inhabited by crocodiles. However water samples were safely collected in this pond system.

In all cases grab samples were taken from the end of the system and in a progression against the direction of flow to prevent cross contamination of the samples. Thus grab samples were taken at the final effluent, at the outflow of each pond in progression, and at the headworks to the facility.

Samples were taken by submerging a plastic container into the flowing water where it exits each stage of treatment, and pouring approximately 50 mL into a Whirl-Pak storage bag. Whirl-Pak bags are pre-equipped with a sodium thiosulfate tablet for chlorine removal. This study involved non-chlorinated water, and sodium thiosulfate interferes with one of the laboratory tests utilized on these samples. Accordingly, the sodium thiosulfate tablets were discarded from all bags as per the *E. coli* testing instructions.

Samples were transported back to a field laboratory where testing was conducted. It should be noted that these samples were not refrigerated and the interval from collection to testing ranged from 2 to 24 hours. Thus these test results are informative for this research but should not be considered valid for purposes of assessing either system function or legal compliance.

COD testing was done using the Hach COD2 tubes and the Hach Method 8000 incubation and spectrophotometer analysis method. *E. coli* was measured using 3-M Petrifilms and the AOAC Official Method 991.14 including 24 hour incubation to obtain a most probable count. In all cases three tests were conducted from each sample to verify results. Three blanks were also run using tap water alongside each batch test that was performed. All water quality lab test results can be found in Appendix B.

Finally, data collection included an interview with facility operators and engineers to better understand the performance history of each facility, and to identify any particular issues that each facility may be facing. These interviews were documented in the Facility Checklists, which can be found in Appendix C. Pond dimensions were obtained from as-built drawings when available. When drawings were not available, depth was determined in the interview and other pond dimensions were obtained by digitally scaling off of satellite images of these systems found on Google Earth. Pond wall slope in La Lima was visually estimated to be three-to-one. Since this is the slope found in the as-built drawings of Puerto Cortés, this estimate was deemed adequate for the purposes of this study.

6.0 FLOW MODELING

For the purposes of studying flow behavior in the subject wastewater treatment ponds, a computer hydrodynamic model was used. Ponds were represented spatially and flow was simulated through these ponds under a variety of conditions. This chapter provides a description of the modeling process including model software overview, file setup including the bathymetry (shape) file and input file, and a discussion of the variables manipulated for the various executions of the model.

6.1 INTROGLLVHT Program

The program used for modeling pond flow was INTROGLLVHT, the Introductory Generalized Longitudinal, Lateral, Vertical Hydrodynamic Transport model developed by J. E. Edinger Associates Inc. This model is available along with its workbook Waterbody Hydrodynamic and Water Quality Modeling by John Eric Edinger, published by the ASCE press (Edinger, 2002). This software is a simplified version of the full GLLVHT model, which in turn is the precursor to the GEMSS model which is commonly used by industry for many current modeling applications. Like these related models, INTROGLLVHT uses numerical modeling of transport and transformation processes to simulate water quality as influenced by inputs selected by the user. Several water quality models are available within the program; this study conducted all simulations using the Temperature, Salinity, First-Order Decay Constituent (TSC) model.

6.1.1 Governing Equations

The development of the INTROGLLVHT model, as with any model of hydrodynamic behavior, depends upon many assumptions and the selection of several governing equations to guide the numerical simulation. A full explanation of this numerical basis and its justification can be found in Edinger & Buchak (1980, 1985). A selection of these equations and assumptions will be presented here, all taken from Edinger (2002).

For the modeling of momentum in each direction, a balance is found through the total transport derivative, which includes local change, advection, dispersion, momentum balance, continuity, and constituent transport in the following equation:

$$\frac{\partial U}{\partial t} = g\frac{\partial z'}{\partial x} - \frac{g}{\rho}\int_{z}^{z'}\frac{\partial \rho}{\partial x} - \frac{\partial UU}{\partial x} - \frac{\partial VU}{\partial y} - \frac{\partial WU}{\partial z} - fV + \frac{\partial A_x(\frac{\partial U}{\partial x})}{\partial x} + \frac{\partial A_y(\frac{\partial U}{\partial y})}{\partial y} + \frac{\partial A_z(\frac{\partial U}{\partial z})}{\partial z}$$

Equation 7

where U, V and W are x, y and z direction velocity, $\partial U / \partial t$ is the transport derivative, g is gravitational acceleration, ρ is density, z is water depth, and z' is water surface elevation. With momentum balanced as such, the model uses a continuity equation which is integrated vertically:

$$\frac{\partial z'}{\partial t} = \int_z^h \frac{\partial U}{\partial x} dz + \int_z^h \frac{\partial V}{\partial y} dz$$ **Equation 8**

where the waterbody bottom is represented by z = h. Changes in concentration of constituents with time are computed as:

$$\frac{\partial C}{\partial t} = \frac{\partial UC}{\partial x} - \frac{\partial VC}{\partial y} - \frac{\partial WC}{\partial z} + \frac{\partial (D_x \frac{\partial C}{\partial x})}{\partial x} + \frac{\partial (D_y \frac{\partial C}{\partial y})}{\partial y} + \frac{\partial (D_z \frac{\partial C}{\partial z})}{\partial z} + H$$ **Equation 9**

where C is constituent concentration and H is a source/sink term. The model's computation is constrained by the Torrence condition requiring that (UΔt/Δx, VΔt/Δy <1). This dictates the maximum time step size allowable in the model.

In order to account for dispersion and shear, the model incorporates both the Von Karman relationship and the Richardson number Ri:

$$A_z = \frac{\kappa Lm^2}{2} \left(\frac{\partial U}{\partial z}^2 + \frac{\partial V}{\partial z}^2 \right)^{\frac{1}{2}} \exp\{-1.5Ri\}$$ **Equation 10**

where κ is the Von Karman coefficient and Lm, the mixing length, is a function of depth and/or cell thickness. Dispersion is then scaled to the cell size by using Equation 11 with m-k-s units as per Okubo (1971):

$$Dx,Dy = 5.84 * 10^{-4} (\Delta x, \Delta y)^{1.1}$$ **Equation 11**

where Dx,Dy is the lateral or longitudinal dispersion coefficient and Δx, Δy is the lateral or longitudinal cell dimension.

6.1.2 Model Limitations

This model has several limitations to its applicability, its computational procedure, and its capabilities. Some limitations are borne of the simplification of the GLLVHT model into this introductory program. Others are constraints imposed by the computational process and the underlying logic of the software. Limitations include:

- When defining a waterbody shape, the software is bound by a relatively small grid size of 50 x 50 x 30 cells. The cell size is variable, but in the z direction the cells cannot span less than 1 meter.
- Where an inlet enters a waterbody, discharge momentum is not considered. Thus a rapid jet and a slower stream are both modeled as a source within a given cell. Thus flow emanates outward from the modeled cell without considering effects such as entrainment and subsequent recirculation. This is not a significant

limitation in the current application, with inlet momentum relatively small due to small flow rates. But this effect could become significant with larger flows.

- The calculation of dispersion under the Von Karman/Okubo scheme can introduce error when scaling a waterbody, which may be required by constraints imposed on cell size and dimension.
- Model outputs are presented as tabulated numerical results rather than a graphic presentation. In order to generate a graphical presentation, results must be further manipulated in another program such as Matlab or Excel.

6.1.3 Input & Output Files

Each model run requires setup of two files before execution, the bathymetry file and the input file. The bathymetry file represents water body shape, and includes a numerical grid representing water depth at each of a number of cells of a chosen dimension. The input file specifies a number of terms such as volumetric flows, constituent concentration and decay rate, a Chezy coefficient which determines frictional impacts on flow velocity and mixing, and a variety of parameters specifying the desired output data.

Once the bathymetry and input files have been created, the model is executed, writing several output files as it progresses. This study focuses primarily on the Time Series Output (TSO) file, representing concentrations of a constituent at a specified position at each time step through the model run, based upon conditions specified in the input file.

6.2 Pond Bathymetry

In creating bathymetry files, a basic as-built approximation of each pond was developed in Microsoft Excel; modifications were made to represent base topography for various observed and hypothetical sludge distributions.

For the as-built ponds, water body dimensions were chosen based on several sources including construction drawings, measurements taken on-site, and dimensions taken from Google Earth images. In particular, Google Earth was valuable in determining the relative locations of outlets which are different at the otherwise similar ponds in La Lima. Ponds sides were all given a 3:1 slope until they reached maximum depth. This slope was chosen because it was evidenced in the Puerto Cortés drawings, and was cited elsewhere in the literature, so it provided a reasonable assumption for slope stability and design convention in La Lima. Maximum pond depth was modeled as six meters in Puerto Cortés, and a depth of 1.4 meters was modeled in La Lima.

Next, a bathymetry was developed for the condition of observed sludge depths. As noted previously, sludge depth measurements were taken in all four ponds over a grid. An assumption was made so that sludge would not accumulate on the sloped walls, as this claim was made by one engineer at the facilities and as it was a reasonable assumption. While this may not be the case in all ponds, or it may not be true in the "greater friction" case of a cement-lined pond, this assumption was carried through all calculations of sludge location, depth, and volume for these simulations. Thus all sludge depth measurements were taken over the flat bottom and not over the sloped walls of all ponds.

In order to develop a bathymetry for the conditions observed, the as-built bathymetry was modified to reflect the decrease in depth of water column over these measured points. That is, the depth value was modified by subtracting the measured depth of sludge. Next the grid was populated using bilinear interpolation. By this process columns were interpolated bilinearly in Excel.

In order to visualize the shape of the water body created by this process, graphs were developed representing water depth at each point in this newly created, higher resolution grid. The first graph, Figure 6-1, displays in plan view the shape of the shell within which water flows as sludge occupies the bottom of the pond. The legend displays the depth represented by each color, and the contours of depth can be seen as the contours between these colors. The second graph, Figure 6-2, represents a cutaway side view of the same data. Here the sludge contours are evidenced not just in colors but in the height of the pond base over the chart base.

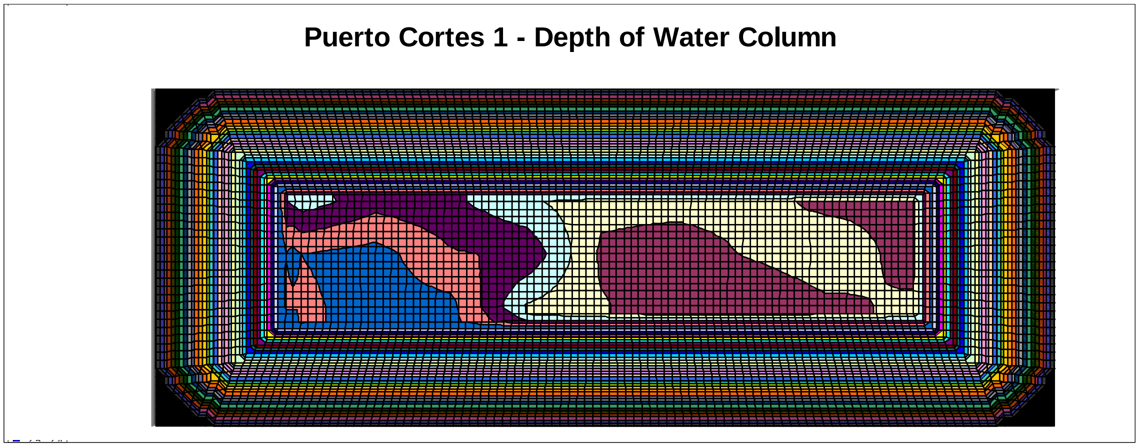

Figure 6-1: Puerto Cortés #1 Water Body Shell, Plan View

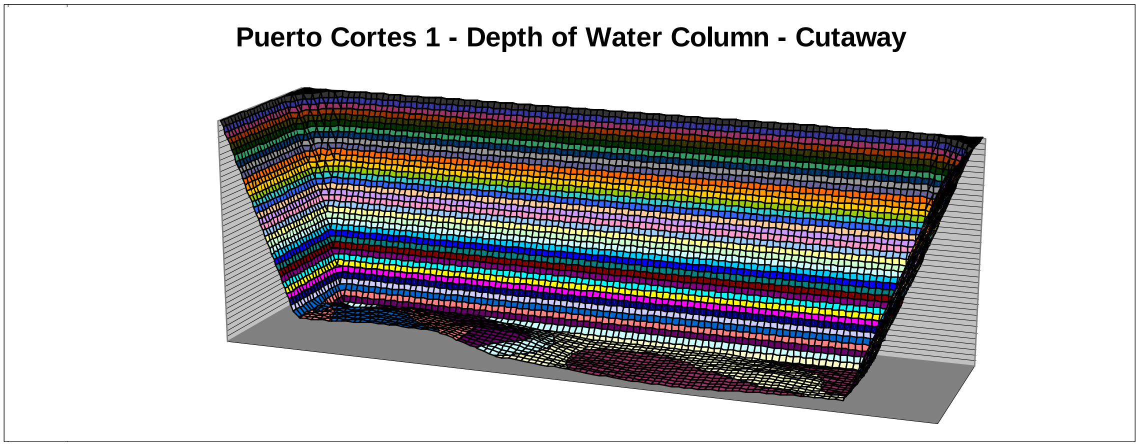

Figure 6-2: Puerto Cortés #1 Water Body Shell, Elevation Section

As an exploration of alternate sludge volumes and distributions, several other bathymetries were developed. One such case involved the same sludge volume observed, but distributed evenly to create a level pond bottom. This bathymetry was developed for each pond by calculating the equivalent depth of the volume of sludge interpolated from the depth measurements. This equivalent depth was entered in the spreadsheet over the pond base, again extending to a first legitimate value at the margins.

Next projections were made for the ponds with increased sludge. This was carried out for just one pond at each location, and included various assumptions of sludge accumulation. In the shallower ponds at La Lima, sludge was increased to 20% and then to 40% of pond volume. In the deeper ponds of Puerto Cortes, the sludge was increased to 10% and then to 20% of pond volume. This was computed for even and uneven sludge distribution. In order to compute water column depths for an uneven sludge distribution, an attempt was made to preserve but exaggerate the uneven distribution observed in field measurements. Attempts were made to maintain a consistent effective volume between even and uneven sludge distributions in each case, although minor fluctuations in the effective volume were accounted for and offset in the analysis which followed these simulations.

To develop the bathymetries into the format required by the INTROGLLVHT program, these excel bathymetries required condensing. The INTROGLLVHT program specifies a maximum grid size of 50 x 50 x 30 cells in the x, y, and z directions. With the larger ponds at Puerto Cortés being 108 meters in length, the grids were condensed by eliminating roughly two out of three rows and columns. In order to preserve symmetry, a cell size was chosen as $\Delta x = \Delta y = 2.4$ meters. This choice of a cell size may have introduced minor distortion over the sloped walls, but this distortion is expected to be insignificant in comparison to the overall sensitivity of this model.

The creation of useful bathymetry grids in La Lima posed a greater challenge due to the decreased sludge depth. Resulting from the smaller flow rate and smaller pond depth at La Lima, the ponds had a sludge depth much lower than that at the Puerto Cortés ponds. This led to variations in sludge on the order of centimeters, whereas these variations were in tens of centimeters in Puerto Cortés, a full order of magnitude greater. However, due to limitations of the model, bathymetry depth could only be entered to one decimal place. Additionally the model was found to have a limitation that cell depth be one meter or more (Δz must be equal to or greater than one). By extension, the resolution of bathymetry could go no more precise than a tenth of a meter, which would mask the detail of uneven sludge distribution in both La Lima ponds. Thus it was decided to scale these models up by a factor of roughly 10 in all spatial dimensions. This was successful in preserving some of the resolution of the bathymetry data and keeping the box shape approximately constant, without violating the model's precision or minimum values.

It is possible that this scaling introduced some error with regard to minimizing dispersion, and all model outputs for La Lima should be interpreted in light of this possibility. Scaling also has the potential to introduce error in behavior regarding gradients in density. This is due to the relationship between buoyancy and momentum as represented in the densimetric Froude number. This constant can be described as F_o:

$$F_o = U/\mathrm{Sqrt}\,(g\triangle\rho_o h/\rho)$$ **Equation 12**

where U is velocity, g is the gravitational acceleration, ρ is water density, $\triangle\rho_o$ is the density difference, and h is a characteristic depth (Adams, 2008). A rigorous application of scaling should hold the Froude number constant, where a Froude ratio is equal to 1:

$$\mathrm{F_r} = 1 = \frac{U_r^2}{L_r \frac{\Delta\rho}{\rho}}$$ **Equation 13**

where the subscript r denotes a scaling ratio. Since $\Delta\rho/\rho$ is usually equal to one, this leaves a velocity scaling factor of

$$U_r = \sqrt{L_r}$$ **Equation 14**

and a time scaling factor of

$$T_r = \frac{L_r}{U_r}$$ **Equation 15**

With the length scale used in this case, that would entail scaling lengths by a factor of 10, volumes by a factor of 1000, velocities by the square root of 10, times by the square root of 10, and volumetric flows by 100 times the square root of 10.

However density effects were not expected to be significant because gradients in temperature and dissolved and suspended solids were modest. Thus the risk of rounding error was determined to outweigh the benefit of holding the Froude number constant, and so a decision was made to intentionally violate Froude scaling. Thus all lengths were scaled up by a factor of ten, including scaling areas by a factor of 100 and volumes by a factor of 1000. Accordingly, velocities were scaled by a factor of 10 and volumetric flows were scaled by a factor of 1000. No other dimensions (e.g., time, decay rate) were scaled. Because length was scaled and dispersion is calculated in the model with a length-based scaling factor, the model's computation of dispersion may be impacted by the decision to scale this waterbody. All results of the numerical modeling are presented non-dimensionally.

6.3 Input File

In addition to the bathymetry file, execution of the model requires an input file specifying a number of conditions which govern transport and transformation processes, and other conditions which govern the presentation of the model output. Table 6-1 presents the terms called for by the model, a description of each term including units, and the inputs used for all four ponds in the basic simulation presented here.

Table 6-1: INTROGLLVHT Input File Terms

Input Files: Calls, Description, & Value Used																					
Term	Description	LL1					LL2					PC1					PC2				
$1.nwqm	Identifies water quality model used		1					1					1					1			
$2.Inflow Conditions																					
$ninflows	Number of inflows to water body		2					2					1					1			
$qinflow,iinflow,jinflow,kinflow	Volumetric flow (m^3/s),i, j,& k inflow location																				
$intake,inintake,jintake,kintake	For coupled inflow/intakes only (none)																				
$temp saln const	Temp, salinity, constituent concent. of influent																				
		5.25	7	3	5		5.25	7	3	5		0.05	14	8	2		0.05	14	8	2	
		0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0	
		0	0	100			0	0	100			0	0	100			0	0	100		
		5.25	12	3	5		5.25	12	3	5											
		0	0	0	0		0	0	0	0											
		0	0	100			0	0	100												
$3. Outflow Conditions																					
$noutflows	Number of outflows from water body		2					2					1					1			
$qoutflow,ioutflow,joutflow,koutflow	Volumetric flow (m^3/s), i, j,& k loc. of outflow																				
		5.25	8	30	2		5.25	8	30	2		0.05	4	32	2		0.05	4	32	2	
		5.25	11	30	2		5.25	11	30	2											
$4.Elevation Boundary Conditions																					
$nelevation kts	Number of elevation bounds (none);																				
	value of k at water surface		0	2				0	2				0	2				0	2		
$iewest,ieeast,jesouth,jenorth	Spatial description of elev boundaries (none)																				
$zmean,zamp,tmelag,tideper	Tidal data pertaining to elev boundaries (none)																				
$k temp saln const	TSC data pertaining to elev boundaries (none)																				
$5.Initialize Water Quality Profiles																					
$ninitial	Option to initialize, 1 = yes or 0 = no		1					1					1					1			
$k temp saln const	TSC data pertaining to each cell layer,																				
	as prompted by k value	2	0	0	0		2	0	0	0		2	0	0	0		2	0	0	0	
		3	0	0	0		3	0	0	0		3	0	0	0		3	0	0	0	
		4	0	0	0		4	0	0	0		4	0	0	0		4	0	0	0	
		5	0	0	0		5	0	0	0		5	0	0	0		5	0	0	0	
		6	0	0	0		6	0	0	0		6	0	0	0		6	0	0	0	
		7	0	0	0		7	0	0	0		7	0	0	0		7	0	0	0	
		8	0	0	0		8	0	0	0		8	0	0	0		8	0	0	0	
		9	0	0	0		9	0	0	0											
		10	0	0	0		10	0	0	0											
		11	0	0	0		11	0	0	0											
		12	0	0	0		12	0	0	0											
		13	0	0	0		13	0	0	0											
		14	0	0	0		14	0	0	0											
		15	0	0	0		15	0	0	0											
		16	0	0	0		16	0	0	0											
$6.External Parameters																					
Chezy,Wx,Wy,CSHE,TEQ,Rdecay,Lat.	Chezy coefficeint ($m^{1/2}$/s), wind speed in x &																				
	y direction (m/s), coefficient of surface																				
	heat exchange (Watts/m2/deg C), equilibrium																				
	temperature (C), decay rate (per day), lattitude	35	0, 0	20, 0	0	15.5	35	0, 0	20, 0	0	15.5	35	0, 0	20, 0	0	15.9	35	0, 0	20, 0	0	15.9
$7.Output Profiles																					
$nprofiles	Number of output profiles desired		2					2					2					2			
$ipwest,ipest,jpsouth,jpnorth	Spatial description of slice to analyze in output																				
$u-vel, v-vel, w-vel	Selection of velocities to be printed;																				
	0 = no and 1 = yes for each																				
$nconstituents	Number of const. for which output data desired																				
$I-const(1),I-const(2), I-const(3), etc	Code identifying constituent(s); 3=concent.																				
		7	12	5	5		7	12	5	5		13	13	6	10		13	13	6	10	
		0	0	0			0	0	0			0	0	0			0	0	0		
		1					1					1					1				
		3					3					3					3				
		7	12	28	28		7	12	28	28		5	5	30	34		5	5	30	34	
		0	0	0			0	0	0			0	0	0			0	0	0		
		1					1					1					1				
		3					3					3					3				
$8.Output Surfaces																					
$nsurfaces $nconstituents	Number of surfaces for which output desired;																				
	0 = none, 1 = top, 2 = top & bottom;																				
	number of const. for which output data desired		2	1				2	1				2	1				2	1		
$U-vel V-vel			1	1				1	1				1	1				1	1		
$I-const(1), I-const(2), I-const(3), etc.	Code identifying constituent(s); 3=concent.	3					3					3					3				
$9.Output Time Series																					
$ntimser	Number of time series locations for output		1					1					1					1			
$nconst, iconst, jconst,kconst	Code identifying constit.(s), i, j & k location	3	8	30	2		3	7	30	2		3	5	32	2		3	5	32	2	
$10.Simulation time conditions																					
$dtm tmend	Model time step (sec); simulation length (hrs)	300	196				300	196				600	192				600	192			
$tmeout tmeserout	Frequency of surface output (hours);																				
	freq. of time series output (hrs)	6	3				6	3				6	6				6	6			
$11.Internal Boundary Locations																					
$nintbnd	Number of internal boundaries (none)		0					0					0					0			
$ibwest,ibeast,jbsouth,jbnorth,ktop,kbot	Spatial description of internal bounds (none)																				
$12. Constituent Averages																					
$nconarv	Number of constit. for which averaging desired		1					1					1					1			
$nconstarvs	Code identifying constituent(s); 3=concent.		3					3					3					3			
$13. Groundwater Inflow																					
$ngrndwtr	Presence of groundwater infiltration,																				
	1 = yes or 0 = no		0					0					0					0			

The values shown in this table were entered into the command window when prompted by the input file setup program. These inputs governed the execution of the model in most cases, including each variation on the bathymetry due to sludge volume and distribution. Minor changes were made to these basic input files as will be noted below.

Several assumptions informed the choice of entries to the input file. Based on the scaled up volume of the La Lima models, volumetric flow was scaled up similarly by 10 in each spatial dimension, or by 1000 overall. Flow is assumed to be equal at each pond, as well as at each inlet and each outlet in ponds with double inlets and outlets, unless otherwise specified. This flow to each pond comprised half of the overall average flow rate reported by each facility as each facility routed flow to two presumably equal circuits. Temperature and salinity information was not entered as it was not relevant to the focus of this study. Constituent concentration in the influent was input as 100 µg per liter in all cases. Water profiles were all initialized to zero, meaning that water bodies were described as having no constituent concentration at time t = 0. For external parameters, a Chezy coefficient of 35 was chosen as typical of the frictional impact of a sediment surface approximating the sludge surface which lines these ponds after any appreciable period of operation. The coefficient of surface heat exchange and the equilibrium temperature were both irrelevant to this study. Wind in the x and y directions was zero, as was decay of the conservative tracer. The latitude was entered accurately for each pond system.

Modifications were made to the input files to simulate variations in conditions. In order to simulate unbalanced flow at La Lima, flow was doubled through one inlet and eliminated through the other. When computing all models which involved decay, the decay rates were changed from 0 to 0.5 day^{-1}.

Outputs were generated for constituent concentration adjacent to one of the outlets at each pond at each time step. The model assumed no groundwater infiltration or appreciable evaporation or precipitation.

6.4 Confirming Compliance with the Torrence Condition

As stated previously, the model computations are bounded by the Torrence condition ($U\Delta t/\Delta x<1$). The files run in the simulations were checked for compliance with this condition. In the general case, the highest flow velocities occur with the smallest effective volume, or the half-full sludge case. Since local velocities vary from average velocity, a conservative approach would allow for a cushion by having $U\Delta/\Delta x << 1$.

In the half full case at the scaled ponds of La Lima, cross sectional area is:

$$A = Y * Z = 400 \text{ m} * 6 \text{ m} = 2400 \text{ m}^2$$

Overall flow in the pond is Q = 10.5 m^3/s (scaled up from an actual pond flow rate of 0.0105 m^3/s). Thus the average water velocity is:

$$U = Q/A = 10.5\ \mathrm{m}^3/\mathrm{s} \ /\ 2400\ \mathrm{m}^2 = .0044\ \mathrm{m/s}$$

The time step in the simulations was t = 300 s. The cell size is 28.57 m in the x and y directions. Thus:

$$U\Delta t/\Delta x = 0.0044\ \mathrm{m/s} * 300\ \mathrm{s} \ /\ 28.57\ \mathrm{m} = 0.046 \ll 1$$

This satisfies the Torrence condition. To be certain this condition is not violated close to the inlets and outlets, the above computation was again performed considering the cross sectional area of a single cell. Since the model does not consider momentum at the inlet, the simulation effectively treats the inlet as a source with flow spreading out from there. Due to the pond outer boundary, water cannot flow backwards from the inlet. Likewise, in consideration of surface and bottom constraints, a conservative assessment would not consider flow transported in the vertical dimension. Thus this computation calculated flow in one direction as overall flow divided by three.

$$A = \Delta Y * \Delta Z = 28.57\ \mathrm{m} * 1\ \mathrm{m} = 28.57\ \mathrm{m}^2$$
$$U = {}^{1}/_{3}\ Q \ /\ A = 1.75\ \mathrm{m}^3/\mathrm{s} \ /\ 28.57\ \mathrm{m}^2 = 0.061\ \mathrm{m/s}$$
$$U\Delta t/\Delta x = 0.061\ \mathrm{m/s} * 300\ \mathrm{s} \ /\ 28.57\ \mathrm{m} = 0.64 < 1$$

Again this satisfies the model constraint. Finally this was repeated for the Puerto Cortés ponds in the half full case. Presenting just the extreme case of flow adjacent to the inlet and outlet, with a time step of 600 s:

$$A = \Delta Y * \Delta Z = 2.4\ \mathrm{m} * 1\ \mathrm{m} = 2.4\ \mathrm{m}^2$$
$$U = 1/3\ Q \ /\ A = .0017\ \mathrm{m}^3/\mathrm{s} \ /\ 2.4\ \mathrm{m}^2 = 0.00071\ \mathrm{m/s}$$
$$U\Delta t/\Delta x = 0.00071\ \mathrm{m/s} * 600\ \mathrm{s} \ /\ 2.4\ \mathrm{m} = 0.17 \ll 1$$

Again, the simulations conducted in this case are compliant with this model limitation.

7.0 ANALYSIS

In studying the hydrodynamic behavior of the ponds in La Lima and Puerto Cortés, simulations were run for all four ponds under investigation. As indicated in Sections 6.2 and 6.3, these simulations were repeated with a number of variations from the initial case in order to understand the impact of modified maintenance routines on effluent quality.

The initial run of all simulations was with a conservative tracer, giving insight into the mixing behavior of ponds. This was followed by simulation with the tracer exhibiting first-order decay. By repeating the simulation under this condition, the model shed light on the predicted final effluent quality and how it has changed based upon the manipulations to shape and flow.

In order to determine a decay rate for use in these simulations, field data were examined. This inquiry looked at decay of two constituents in six ponds to determine the rate evidenced at sites under investigation in Honduras. This identified a plausible range for a decay rate to use in numerical modeling of these real ponds.

The results of these simulations are presented below. Modeled performance is compared with analytical computations for these water bodies, and is followed by a discussion of the behavior represented in those results.

7.1 Decay Rate Calculation

The collection of field water quality data allowed for selection of a plausible decay rate for pond simulations. Water samples were collected and quality tested on several parameters as previously noted. This information was evaluated in terms of average value of constituent concentration at the end of each stage of treatment at each facility.

These relative concentrations are charted for La Lima in Figure 7-1 depicting COD, and in Figure 7-2 depicting *E. coli*. Since this facility was laid out with two pond circuits in parallel, the two graphed lines trace removal in those two circuits as indicated by the legend. The horizontal axis indicates the stage in treatment with Location 1 referencing the headworks, Location 2 the facultative pond effluent, and Location 3 the maturation pond effluent. The vertical axis indicates the concentration as a percentage of original influent concentration.

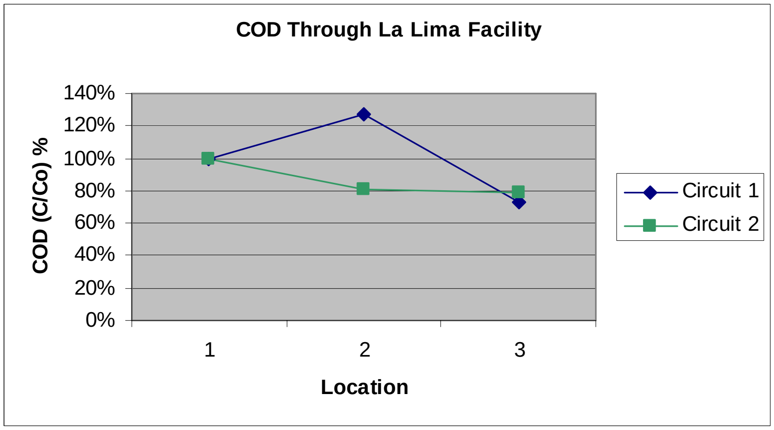

Figure 7-1: COD Removal Through La Lima Facility

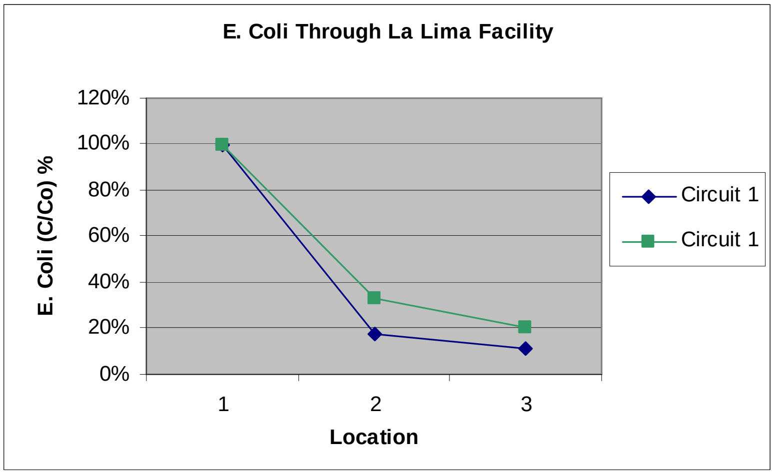

Figure 7-2: *E. coli* Removal Through La Lima Facility

It should be noted that the spike in Circuit 1 COD to above-headworks levels is unexpected and is likely due to a flaw in this data collection. The activity of collecting sludge depth measurements created significant agitation in the ponds, and was seen to resuspend some sediment. It is not unreasonable to suspect that this may have occurred more at one pond than the other, nor that the resuspended organic matter could account for the some or all of the inflated COD found in those samples.

This same analysis was carried out with field lab results from Puerto Cortés with the chart in Figure 7-3 depicting COD and Figure 7-4 depicting *E. coli*. This facility had an unusual configuration of series and parallel ponds. Thus along the horizontal axis, Location 1 is the headworks, Location 2 is after the anaerobic pond in each circuit as noted in the legend, Location 3 is after the facultative pond in each circuit, Location 4 is after flow circuits have joined and passed through Maturation Pond # 1, and Location 5 is after Maturation Pond # 2.

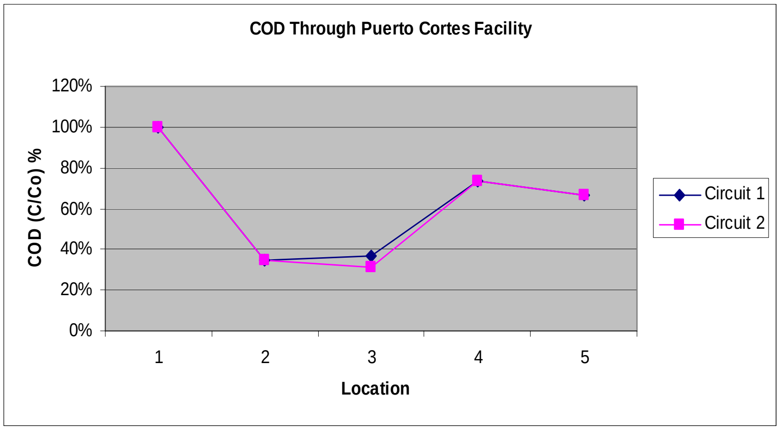

Figure 7-3: COD Removal Through Puerto Cortés Facility

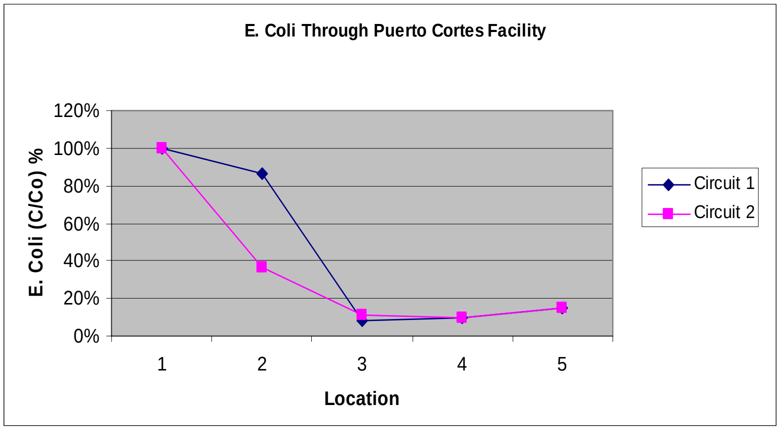

Figure 7-4: *E. coli* Removal Through Puerto Cortés Facility

Again some readings were found to be suspect and may indicate irregularities in the data collection. The COD level was found to step up significantly in effluent from Maturation Pond # 1, and it does not lower appreciably after Maturation Pond # 2. There was no stirring activity through sludge depth measurements in the implicated ponds, and the pattern is consistent through several ponds. Additionally, this pattern is sustained through the three tests run on each water sample at each location. This may be indicative of increased algal cell growth on the hot, sunny afternoon when sample collection was conducted, the first such day after an overcast and rainy week. Further investigation would be necessary to fully understand the cause for this spike in COD.

Similarly, this analysis of relative constituent concentrations was repeated for the field data collected at Choloma as indicated by Figure 7-5 and Figure 7-6. At this facility, a lack of sludge depth measurements and associated churning activity may have led to more representative and reliable effluent sample lab results. As with La Lima, this facility was laid out with two pond circuits in parallel, and again the two graphed lines trace removal in those two circuits as indicated by the legend. Thus, Location 1 corresponds to the headworks, Location 2 to the effluent from the facultative ponds, and Location 3 to the effluent from the maturation ponds.

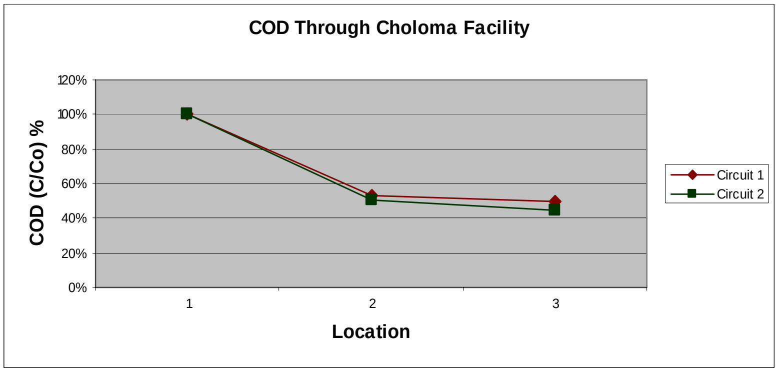

Figure 7-5: COD Removal Through Choloma Facility

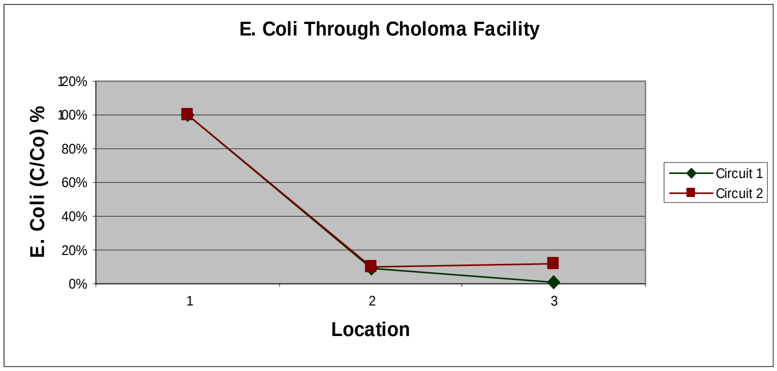

Figure 7-6: *E. coli* Removal Through Choloma Facility

This information on relative constituent concentrations was used to calculate an ideal decay rate for the ponds studied at these facilities. This calculation assumes as a decay time the mean residence time, as calculated from the effective volume for each pond. In the case of Choloma, the decay time used was the residence time reported for the facultative ponds. These calculations used the first-order decay equation previously described in Equation 2, rearranged as

$$k = -\ln (C_{out} / C_{in}) / t^* \qquad \textbf{Equation 16}$$

This equation assumes plug flow conditions, and therefore is anticipated to underestimate the decay as seen in these ponds. An alternate decay constant calculation could be performed assuming dispersed flow conditions and a particular Peclet number; however this analysis was limited to a single formulation of the decay constant k. The relative constituent concentrations and calculation of decay rates are summarized for La Lima in Table 7-1, for Puerto Cortés in Table 7-2, and for Choloma in Table 7-3.

Table 7-1: La Lima Decay Rates

La Lima Ballpark Decay Rates (Using t*)		
	LL1	**LL2**
COD C/C$_o$	128%	81%
Decay k$_{(COD)}$	**(Bad Data)**	**0.091**
E. Coli C/C$_o$	17%	33%
Decay k$_{(E.Coli)}$	**0.715**	**0.470**

Table 7-2: Puerto Cortés Decay Rates

Puerto Cortes Ballpark Decay Rates (Using t*)		
	PC1	**PC2**
COD C/C_o	35%	35%
Decay $k_{(COD)}$	**0.432**	**0.446**
E. Coli C/C_o	86%	37%
Decay $k_{(E.Coli)}$	**0.059**	**0.422**

Table 7-3: Choloma Decay Rates

Choloma Ballpark Decay Rates (Using t*)		
	CH1	**CH2**
COD C/C_o	53%	51%
Decay $k_{(COD)}$	**0.315**	**0.341**
E. Coli C/C_o	9%	10%
Decay $k_{(E.Coli)}$	**1.208**	**1.162**

The decay rates found through this process were considered in determining a decay rate for the model simulations. The value of $k = 0.5\ d^{-1}$ was selected for all simulations as being reasonably within the range evidenced by these ponds, fitting with anticipated values, and offering decent sensitivity to the changes being made in the various model runs.

7.2 Modeled and Analytical Evaluation of Pond Behavior

The first suite of simulations considered all four ponds in varying conditions with a virtual dye (conservative tracer) in order to study mixing behavior in the ponds. The model was run with a stepped input into water initialized with a zero concentration of the conservative tracer. The effluent concentrations were divided by the influent concentration, and model running times were divided by the mean residence time, and the resulting non-dimensional values were plotted. Along with the model output data, a series of curves for various Peclet numbers were plotted for the same c_{out}/c_{in} over time/t* graph using Equation 4. An approximate Peclet number was determined for each case by visually interpolating between the curves as graphed. One such graph can be found in Figure 7-7. For the purposes of understanding the conservative tracer simulation graphs, the reader's attention is brought to the Peclet curves which form a backdrop to the model data. Smooth curves are charted with a Peclet number rising by powers of two, and are indicated by the legend in each graph. The model output data points are marked by boxes and joined by a curve, and are also defined in the legend. This analysis was performed for all cases of even sludge, where waterbody behavior could be approximated as a dispersed-flow reactor. From this analysis, a Peclet number was estimated in each such case for use in comparing analytical and numerical results. The model numerical solution could then be compared to various analytical solutions for final effluent quality assuming this and other values for the Peclet number given the water body’s geometry as discussed below.

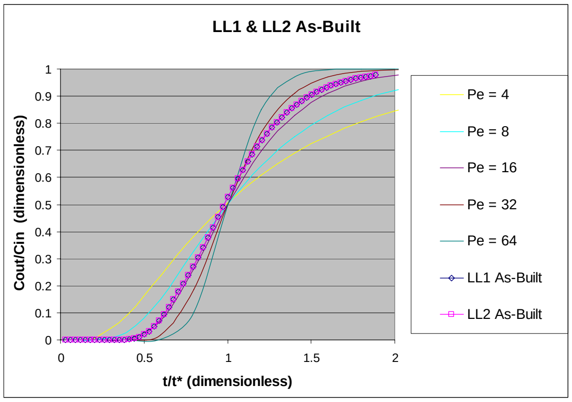

Figure 7-7: Peclet Number Estimation Per Equation 4

The selection of a decay rate allowed for analysis of pond behavior, and of the effect of shape and flow modifications on effluent quality. For numerical analysis, the INTROGLLVHT model was run again under several conditions involving constituent decay. All decay simulations were run until the output concentrations approximated a steady state. All of the simulations used bathymetry shape files and input files identical to those used for a conservative tracer, only this time the tracer had a decay rate of 0.5 d^{-1}.

Finally, the modeled decay output was compared to analytical solutions for decay under a number of conditions as previously stated, with results summarized in Table 7-4. In cases of the evenly distributed sludge, an analytical solution was computed for four cases. The first case used a Peclet number of infinity, for a completely plug flow estimation. The second analytical solution used a high Peclet number selected as described above, by visual analysis of the graph of the conservative tracer's numerical results. A third analytical solution used a low Peclet number estimated by Equation 6 (von Sperling, 2003). A fourth analytical solution was computed with a Peclet number of zero to represent the completely mixed case. While Peclet numbers of zero and infinity provide the context of the outer bounds, the numerically inferred and von Sperling estimates are more realistic for these ponds. The analytical solution using the numerically inferred Peclet number can be compared to the numerical solution to verify model validity. However The solution using the von Sperling Peclet number more closely predicts the anticipated behavior of the real ponds, given additional mixing from factors such as wind which are not accounted for in this model.

7.2.1 As-Built Ponds

This examination of pond behavior begins with the as-built pond bathymetries. As-built conditions were simulated by the model, representing pond behavior with zero sludge accumulation. By examination of the graphs such as in Figure 7-7, it is estimated that the virtual ponds at La Lima have a Peclet number of 18, while the Puerto Cortés ponds have a Peclet number of about 6. These Peclet values are approximations which may or may not reflect true conditions at the real ponds, since this numerical model's representation of dispersion may not be representative of these ponds. Additionally this Peclet number is derived from model results and does not account for factors omitted by the model such as wind. These results can, however, shed light on the differential impact of pond geometry.

Table 7-4: Summary of Analytical and Numerical Predictions of Concentration Ratios

Predicted C_{out}/C_{in} Under Various Conditions								
Condition			Pond	Num. Sol'n	Analytical Sol'n			
				Model Result	Plug Flow Pe = ∞	Inferred Numerical Peclet Estimate [Pe Bracketed]	Von Sperling Peclet Estimate [Pe Bracketed]	Completely Mixed Pe = 0
As-Built			LL1	0.13	0.12	0.14 [18]	0.23 [2]	0.32
			LL2	0.13	0.12	0.14 [18]	0.23 [2]	0.32
			PC1	0.26	0.23	0.28 [6]	0.32 [2.7]	0.40
			PC2	0.26	0.23	0.28 [6]	0.32 [2.7]	0.40
Real Sludge	Uneven Dist		LL1	0.15	X	X	X	X
			PC2	0.27	X	X	X	X
	Even Dist		LL1	0.15	0.14	0.17 [18]	0.25 [2]	0.34
			PC2	0.26	0.23	0.28 [6]	0.32 [2.7]	0.41
Varying Sludge	Increased Sludge	Uneven Dist	LL1 - 20% Sludge	0.19	X	X	X	X
			PC1 - 10% Sludge	0.30	X	X	X	X
		Even Dist	LL1 - 20% Sludge	0.19	0.18	0.21 [19]	0.29 [2]	0.37
			PC1 - 10% Sludge	0.28	0.26	0.31 [6]	0.34 [2.7]	0.42
	Greatly Increased Sludge	Uneven Dist	LL1 - 40% Sludge	0.28	X	X	X	X
			PC1 - 20% Sludge	0.34	X	X	X	X
		Even Dist	LL1 - 40% Sludge	0.28	0.29	0 .31 (20)	0.38 [2]	0.44
			PC1 - 20% Sludge	0.33	0.31	0.36 [6]	0.39 [2.7]	0.46
Varying Flow Balance	As-Built	Unbal	LL1	0.18	X	X	X	X
		Bal	LL1	0.13	0.12	0.14 [18]	0.23 [2]	0.32
	Real Sludge	Unbal	LL1	0.22	X	X	X	X
		Bal	LL1	0.15	X	X	X	X

Notes: All numerical and analytical solutions assume a decay of 0.5 d^{-1}
X indicates values that could not be computed analytically
Inferred Numerical Estimate of Peclet Number is estimated from graphical results
Von Sperling Estimate of Peclet Number is from Equation 6 (von Sperling, 2003)

These Peclet numbers indicate more mixing in the ponds at Puerto Cortés as contrasted with those at La Lima. This is not a surprising finding, as the Puerto Cortés design involved much deeper ponds with a roughly similar footprint. Additionally the presence of a single inlet and outlet in the corners at Puerto Cortés might less effectively achieve a plug flow regime than the pair of inlets and outlets at opposing ends of the ponds at La Lima. As expected, the Puerto Cortés pond curves coincided exactly with one another, while the curves for the La Lima ponds were slightly different. La Lima pond number one performed slightly better with slightly less mixing as evidenced in the numerical model output. The only difference between the virtual ponds, as with the real constructed ponds, was the wider placement of outlets in La Lima Pond 1, as can be seen in the satellite image shown in Figure 7-8. Figure 7-9 depicts a satellite image of the Puerto Cortés ponds with the corner placement of inlet and outlet clearly visible.

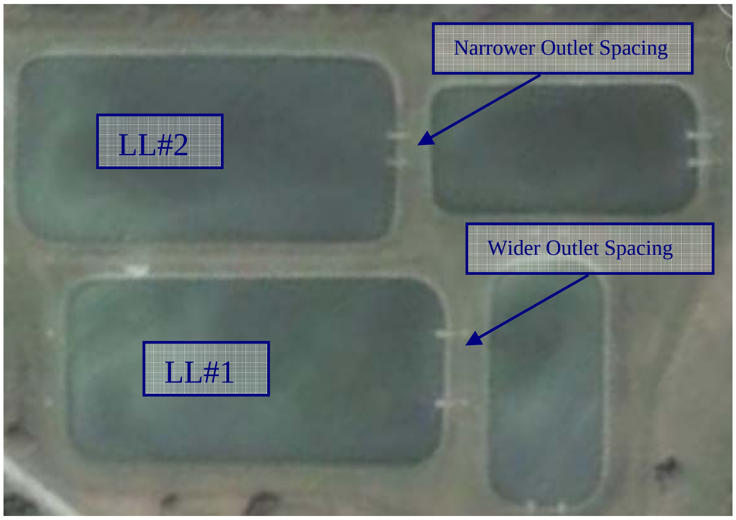

Figure 7-8: Satellite Image of La Lima Ponds
(Source: Google Earth)

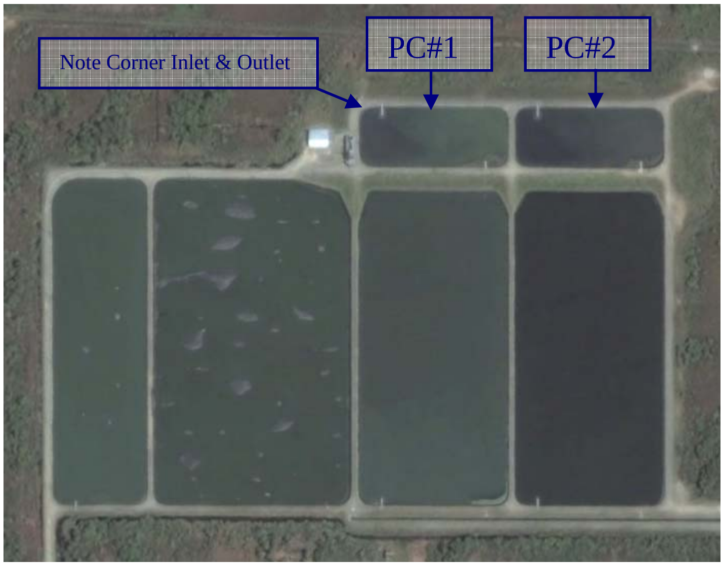

Figure 7-9: Satellite Image of Puerto Cortés Ponds
(Source: Google Earth)

The model was then run with decay. Figure 7-10 portrays the behavior of the La Lima as-built ponds, with no sludge accumulation. The presentation of this data places t/t* on the horizontal axis once again, while the vertical axis of C_{out}/C_{in} is shown in percentages for clarity. Since models were run to steady state, the ongoing performance of the pond (beyond startup) is seen in the eventual steady state concentration, or the level C_{out}/C_{in} percentage which stabilizes after a sufficiently long time. The pond achieves an effluent concentration that is 13% of the influent concentration. Again, it is interesting to note that the two ponds do not perfectly coincide. Although the difference is trivial, it is still noteworthy that simply widening or narrowing the space between symmetrically located outlets is capable of impacting virtual concentrations in the final effluent.

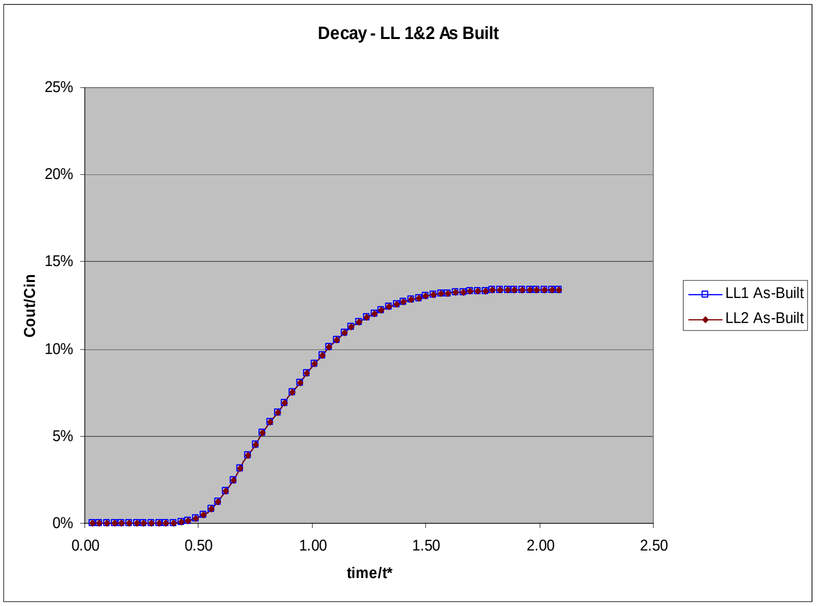

Figure 7-10: La Lima As-Built, With Decay

As stated previously, the final steady-state concentration is of greatest interest in the decay case, as this represents the ongoing condition of the pond in operation. Comparing the simulation effluent quality to analytical solutions for steady state concentration provides for a check on model function and a context of model performance within the anticipated range. Following across the As-built La Lima row on Table 7-4, a comparison of the numerical solution to analytical solutions can be made for all four Peclet number estimations.

As cited in the work of von Sperling (2003), an analytical solution for the Peclet number in La Lima is Pe = L/B = 80/40 = 2, whereas the model simulation suggests a value of 18. Considering these values in light of Equation 5, the simulated La Lima ponds are expected to have a kt* value of 2.1 and to achieve a final effluent concentration of 14% (Pe = 18) to 23% (Pe = 2) of the influent concentration. At the outer bounds a Peclet number of zero may be considered for a well-mixed tank and a Peclet number of infinity for a perfectly plug-flow tank. In this case the effluent concentration ranges from 12% (Pe = ∞) to 32% (Pe = 0). By comparison, the numerical solution predicted removal to

13% of influent concentration, showing good agreement with the analytical solution within inferred Peclet number of 18, as expected. A more realistic final effluent may be represented by the Von Sperling estimate, as this equation was empirically derived from real ponds data, and considers reel factors such as climate not accounted for in the computer numerical simulation.

While the Von Sperling results have real world validity, the numerical model of results are useful for internal comparison to the same results under different conditions. Intricate changes in geometry such as uneven sludge deposition or unbalanced flow cannot be accounted for an analytical calculations of pond behavior. Thus numerical modeling offers insight in these cases, by comparison to numerical modeling and simple cases such as the La Lima as-built ponds. This insight is informative for investigating the optimization of real ponds.

As in La Lima, a von Sperling estimate for the Peclet number in Puerto Cortés is found through Pe = L/B = 108/40 = 2.7, whereas the simulation suggests a value of 6. With a kt* value of 1.5, these ponds are expected to achieve a final effluent concentration in the range of 23% (Pe = ∞), 28% (Pe = 6), 32% (Pe = 2.7), and 40% (Pe = 0). The model performance gives a final effluent concentration of 26%, again similar to that predicted by the inferred numerical Peclet number. Figure 7-11 depicts the anticipated performance for each system based on various Peclet number assumptions.

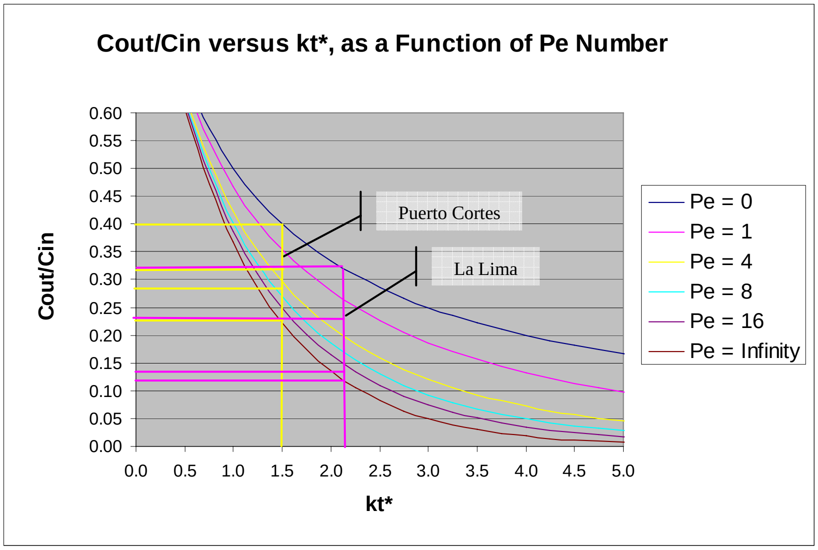

Figure 7-11: La Lima and Puerto Cortés C_{out} vs. C_{in}

To demonstrate how the flow patterns were distributed in modeled ponds, Figure 7-12 shows a vector field for water velocities in La Lima Pond # 1 after reaching steady state. The left hand image depicts surface water velocities, while the right hand image shows velocities at the bottom of this pond. These vector fields indicate localized variations in water speed, but these variations are only extreme close to the inlets and outlets, as expected.

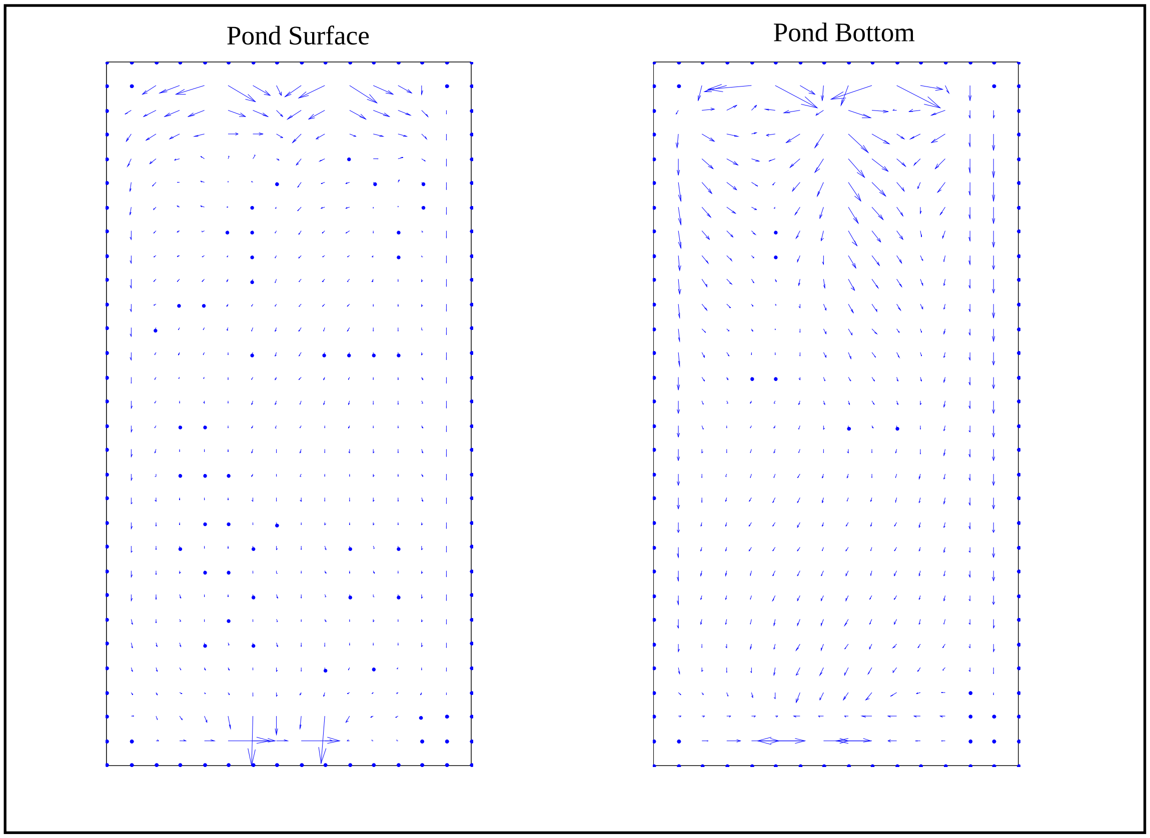

Figure 7-12: La Lima As-Built Flow Velocities

7.2.2 Current Sludge Volumes

Next simulations were carried out to approximate the real volumes of sludge observed at the ponds, in both the observed current distribution and in an evenly distributed layer. In this case, the even pond base associated with an even sludge surface induced slightly less mixing than the uneven sludge surface, as indicated by visual inspection of a conservative tracer (not depicted), and by nominally increased effluent concentrations in the unevenly distributed case. In La Lima the final effluent was 15.2% in the uneven case and 14.9% in the even case, with a slight penalty of 0.3% due to the uneven sludge distribution. In Puerto Cortés, the final effluent was 27% in the uneven case in 26% in the even case, with a penalty of 1% for uneven sludge distribution. By comparison, a von Sperling estimate of final concentration is 25% in La Lima and 32% in Puerto Cortés for the case of even sludge distribution. Other comparisons can be made by examination in Table 7-4. These resluts generally indicate that an uneven sludge distribution causes a decrease in pond performance, but a minimal decrease at that.

7.2.3 Increased Sludge

Exaggerating the pond bottom topography with greater sludge depths allowed for speculation of changes to pond performance if sludge accumulations are allowed to continue to and beyond the recommended desludging level. It should be noted that the mean residence time t* is effectively decreased as effective volume decreases with the presence of sludge. Thus this analysis considers the t* value specific to each bathymetry in analyzing the results of each trial.

This exaggeration of sludge had the anticipated effect of increasing the Peclet number in La Lima, which rose to Pe = 19 when sludge filled 20% of the pond and rose to Pe = 20 when sludge occupied 40% of the pond. These Peclet numbers were found by visual inspection as previously described, and as such are approximations. In Puerto Cortés a visual inspection of Peclet number did not reflect a change with increased sludge volume, perhaps due to the much deeper nature of these ponds.

One concern with uneven sludge is the uneven flow patterns it can affect and the subsequent potential for short circuiting. The notion of short circuiting in an uneven sludge distribution is supported by the velocity vector fields for the La Lima pond. Figure 7-13 depicts the La Lima pond water velocities for surface and bottom when sludge fills 40% of the pond volume. Channels of larger arrows indicating more rapid streamlined flow are seen in the sidelines and center of the pond, most dramatically on the pond floor.

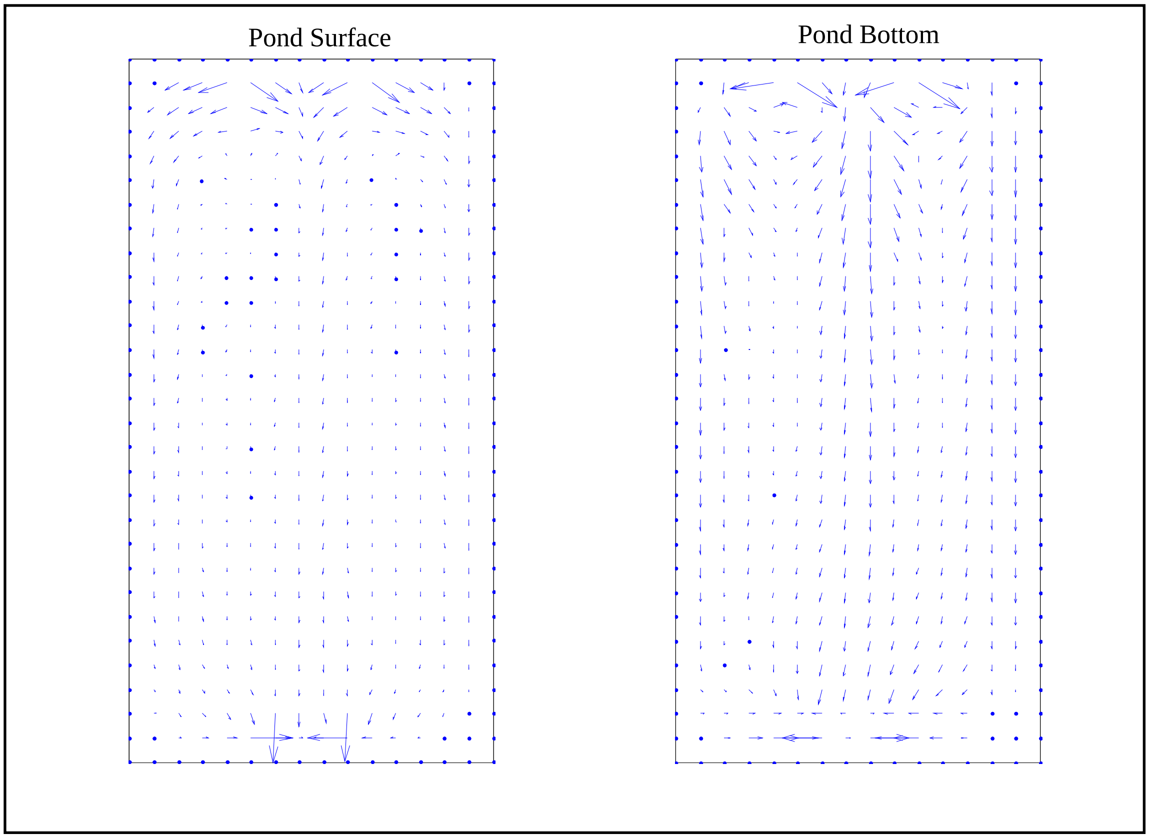

Figure 7-13: La Lima 40% Sludge Flow Velocities

It should be noted that the reduction in effective pond volume with increased sludge will reduce pond performance regardless of the impact on mixing or plug flow conditions, and due to decreased mean residence time. This is evidenced in the analytical calculations and simulations involving decay, particularly with regard to these sludge depths and distributions.

Modeling with first-order decay confirms the analytical solution for final effluent concentrations. When the La Lima pond was modeled with sludge at 20% of pond capacity, effluent concentrations climbed from 13% (no sludge) to 19% in both the even and uneven cases. When the Puerto Cortés pond was modeled with sludge occupying a quarter of the pond volume, effluent concentrations climbed slightly from 26% (no sludge) to 28% in the even distribution case, and climbed even more to 30% in the uneven case. Thus the Puerto Cortes pond demonstrates that an even sludge distribution is preferable in its benefits for the effluent quality, while this effect was not present in La Lima.

This comparison was repeated with these sludge bathymetries doubled. In La Lima, pond performance decreased further with the presence of sludge from 13% (no sludge) to 28% when sludge occupied 40% of the pond in even and uneven distributions. In Puerto Cortés, sludge was increase to 20% of pond volume, and as was seen in the 10% full bathymetries, the even sludge pond outperformed the uneven pond, again suggesting that an even sludge distribution may be optimal. Again, pond performance decreased from 26% (no sludge) to 33% for even sludge and 34% for uneven sludge. Generally speaking, these results confirm the assumption that pond performance decreases significantly with increasing sludge accumulation, once again demonstrating that reduced effective volume leads to reduced performance.

7.2.4 Unbalanced Flow

Another variable manipulated in this study was the balance of flow at La Lima, where each pond was equipped with two inlets. The analysis of unbalanced flow offers insight into conditions actually observed in Honduras, as one pond visited had a noticeably different flow rate in each of its two inlets. This simulation was conducted by doubling flow in one inlet and eliminating it in the other. Outlet flow was not manipulated as flow is directed by gravity into a drop basin on each side, and not controlled by valves as inlet distribution is. While it is conceivable that an obstruction could reduce flow partially or completely at one outlet, this condition was not simulated as a part of this study. In simulated conditions, an unbalanced flow led to strikingly different behavior indicating a short circuiting flow regime, with high concentration water escaping the outlet before the ambient water level has built up.

To represent the short circuiting, the INTROGLLVHT model outputs for surface and bottom velocities are presented as vector fields in Figure 7-14. Upon examination, the vector fields support the hypothesis of short circuiting flow, showing large pockets of unmoving water (indicated by dots instead of arrows). The vector fields also depict distinct channels of more rapidly moving water represented by arrows which align down the sidelines of the surface and base of the pond. This trend for short circuiting of unbalanced flow was observed in vector fields for all sludge depths and distributions, and became exaggerated with sludge accumulation.

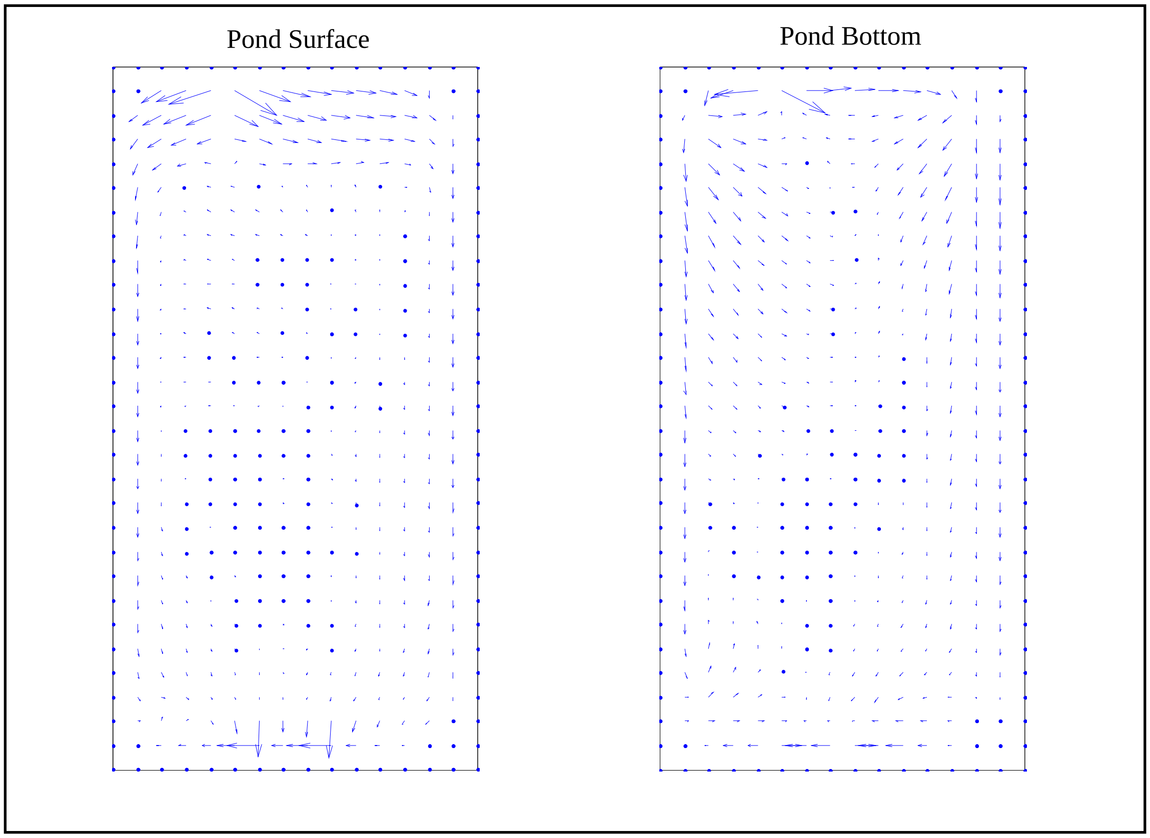

Figure 7-14:La Lima As Built Flow Velocities - Unbalanced Flow

Unbalanced flow cannot be accurately incorporated into an analytical solution based on dispersed flow (i.e., there is no Peclet number than can be used to reproduce the observed build up of a conservative tracer introduced as a step). In this case, the options are limited to relying upon the model to illuminate the effect of flow balance on effluent quality.

Simulating decay in La Lima pond #1, the model gives an output which is presented in Figure 7-15 under two scenarios. This analysis was expanded to include unbalanced flows. The lower blue and red curves represent the as-built and measured sludge bathymetries respectively, with a simulation involving balanced flow. The upper blue and red curves represent the same bathymetries once again with the single variation of an unbalanced flow. As stated previously, an unbalanced flow consisted of doubling the flow through one inlet while eliminating the flow through the other.

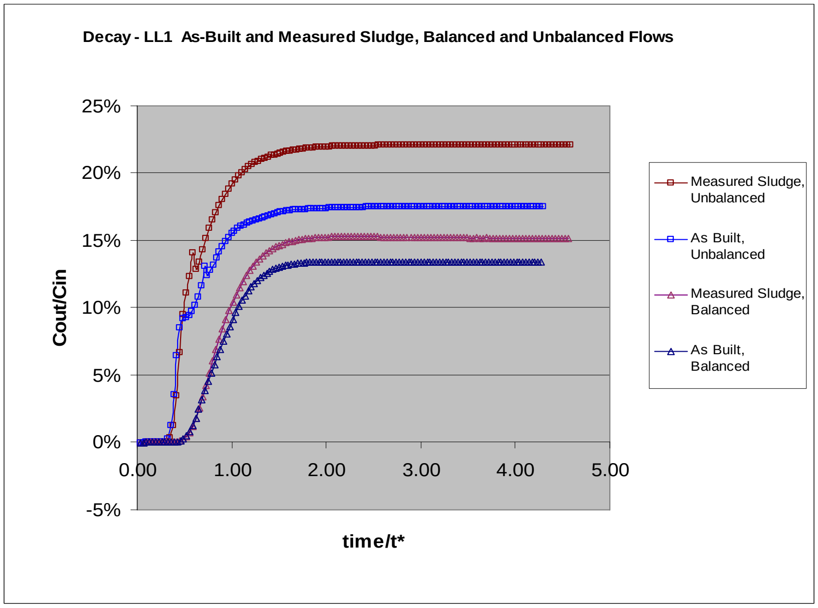

Figure 7-15: La Lima # 1 - Balanced vs. Unbalanced Flow

The results in this chart are striking. As an anticipated effect, the as-built pond outperforms the measured sludge pond, attributable in part to increased mixing and more significantly to decreased retention time in the measured pond. It may have also been anticipated that the ramp up interval would exhibit erratic behavior as demonstrated in this chart with unbalanced flows, similar to the erratic ramp up seen in the non-decay case. But most striking is the deterioration of pond performance at steady state with unbalanced flows, and the antagonistic effect that uneven sludge has on this deterioration. Whereas the presence of sludge led to a cost of two percentage points in removal efficiency with balanced flows (13.4% to 15.2 %), this cost was nearly five points in the unbalanced flow case (17.5% to 22.1%). And in the comparison within a single bathymetry, simply balancing the flow could net about four percentage points of further improved performance in the as-built case (17.5% to 13.4%), growing to a six percentage point gain if sludge is present (22.1% to 15.2%). The specific percentages are unique to the set of assumptions that inform this model, but the trend indicated by these percentage distributions is instructive for pond operation generally. As stated previously, all model concentrations are summarized in Table 7-4. These factors point to the importance of maintaining symmetric and balanced flows within a system.

8.0 RECOMMENDATIONS AND CONCLUSIONS

Portions of this section originally appeared in Evaluating Wastewater Treatment Options for Honduras (Bhattacharya et al., 2009). As previously outlined, there are trends pertinent to design, operation and maintenance, and community issues that have been shown to hinder the performance of wastewater treatment including wastewater stabilization pond performance in Honduras. Addressing these concerns has the potential to improve the current infrastructure and to support adequate development of new systems.

As indicated by the computer numerical modeling of ponds under many variations, maintenance modifications have the capacity to significantly impact the performance of ponds, at little to no cost. Most significantly, the evidence suggests that there is great value in a rigorous effort to balance flows in all ponds. As witnessed by this research group, flow control is often neglected at systems in Honduras. When unbalanced flow was brought to one facility operator's attention, he responded by adjusting the flow diverter valve slightly, resulting in a visible lessening of flow imbalance. However, it is not clear if there was any follow-up. This indicates the need for improved technical training of operators, and/or the importance of including flow balance benefits in such training.

Secondary to the issue of flow balance is the impact of sludge removal on effluent quality. Historically the recommendation was to desludge on the interval of roughly once per decade (Mara, 2003). The length of this interval is a perceived benefit of ponds, with the slow accumulation of sludge analogous to a long fuse, with no precipitous failure as sludge accumulates. However there are dangers in this presumption. While the 10 year interval used to be the standard procedure for ponds, newer recommendations presented by Mara (2003) call for desludging as a function of volume, when sludge occupies 1/3 pond, and not less frequently than once every five years. This limits the loss of effective volume and hydraulic residence times due to accumulated sludge. The results found in this study were for individual ponds which were each a part of a larger pond system, so final effluent quality was not considered by this analysis. Still, interpolation of this study's results for projected sludge accumulations indicates that pond performance will drop significantly before sludge reaches half of a pond's capacity.

These simulations underscore the importance of controlling sludge volume. As sludge accumulates, effective pond volume and thus residence time is reduced. Desludging effectively increases pond volume. One suggestion put forth by Mara (2003) is that partial desludging be completed on an even shorter interval than the current recommendations, perhaps once a year. The argument for this is not that the frequency is critical, but that it is easier to successfully plan for the staffing, equipment, and facility needs of this task if it falls at the same point in the calendar each year. Whether this or another strategy is employed, the importance of appropriate and timely desludging is clear.

A third finding of this modeling study is that an even sludge distribution may indeed outperform uneven sludge, but the effect is minimal. In well-functioning systems, the efforts required to control sludge distribution are probably not warranted. But in critical performance circumstances, such as when a system's demand approaches its design capacity or when desludging is overdue but pending logistical delays, it may be advantageous to level out the sludge distribution in order to gain a performance edge with respect to effluent quality. It is believed that this could be achieved by dragging a wide metal rake or screen behind a boat, although the design of such an implement is beyond the scope of the current study. One factor influencing sludge distribution is flow distribution. In addition to the benefits already discussed, balanced pond flows can be beneficial in more evenly distributing sludge

Generally speaking, operation and maintenance concerns could be mitigated through appropriate regulatory and community involvement. The enforcement of water quality monitoring protocols along with effluent discharge requirements holds the power to improve overall performance, indirectly ensuring that proper operation and maintenance procedures are followed.

The involvement of regulatory agencies such as SANAA or SERNA in mandating proper water quality monitoring and reporting could serve to enforce effluent compliance. Where proper water quality monitoring protocols have not been developed such agencies could provide guidance in creating procedures to achieve regulatory wastewater standards. A system of periodic reporting to regulatory agencies could act to sustain plant performance and identify areas of concern on a regional scale. Implementation of a discharging permit regime could establish penalties for non-compliance with regulatory requirements. While the Technical Standards for Discharge put forth by the Ministry of Health (1996) and published on the ERSAPS website allude to penalties for violation of discharge standards, this research group never learned of these penalties being applied at the dysfunctional systems visited.

Many of the issues encountered in this survey pertained to technical obstacles which could be preempted by the active involvement of oversight agencies such as SANAA. Detailed technical considerations should be included in the design approval process to ensure that systems are technically sound. These could include examining the appropriateness of facility site location, sizing, and technology employed. The inclusion of performance clauses within consulting or vendor contracts could also act to guarantee appropriateness of technologies by creating a system of accountability, ensuring consistent performance. In addition vendors and consultants should provide proper operations and maintenance procedural manuals to be kept onsite for facility operator reference at any new facility.

Successful management of wastewater systems requires adequate involvement of the communities which they serve. This could be established in a number of ways. During the selection and approval phase of designs, active participation and feedback from community leaders could ensure involvement and identify critical issues such as potential odor problems or lack of maintenance funds needed to sustain certain types of systems.

Additionally, this early involvement could develop a community sense of ownership for its wastewater management system. This sense of ownership could preemptively tackle future issues such as lack of ongoing maintenance funding. This is particularly important at this critical phase of water sector reform as management responsibilities are decentralized within Honduras.

To improve the upkeep of wastewater treatment facilities, an external measure that might be undertaken involves the creation of a circuit rider position. A person in this role could disseminate technical information, assisting various facilities in resolving their issues based upon lessons learned elsewhere. For instance, a lack of flow control was observed at several waste stabilization ponds and Imhoff tank systems. Uneven flow distribution has been shown to have a significant impact on treatment efficiency in simulated cases in this study. This lack of flow control may be overcome by operators obtaining insight on possible methods used in other municipalities to better control flow. Additionally, understanding the importance of flow control through active dialogue with a circuit rider could lead operators to better managed flow control valves, gates, and other devices where such devices do exist.

The circuit rider could also provide technical guidance where needed. Based on this survey, two locations where such guidance could be useful are Choloma and Talanga. In Talanga, the operator and the director of the municipal water division were not aware that their Parshall flume could be used for flow measurement. And at Choloma, no water quality monitoring is currently being carried out since the operations staff is unsure of which parameters to test. Both these issues could be resolved through the provision of adequate technical guidance. In the brief tour of facilities conducted by this research group, the SANAA engineer traveling with the group used these and other circumstances to initiate technical discussions about facility operational improvements, in effect serving as an ad hoc circuit rider. The expansion of this role into a full time position would appear to be a beneficial and worthy investment for the improvement of wastewater treatment in Honduras.

Given the pattern of system abandonment seen in Honduras, optimization of existing systems holds real value not just for improving performance, but for keeping systems on line and operational. Some optimizations require capital investment or political involvement such as the creation of a circuit rider position, the enforcement of discharge standards, and the expansion of undersized systems. But many improvements can be achieved through modification of maintenance routines. Such changes, including the balance of flow and the adherence to a regular desludging schedule, hold the potential to improve system performance at a nominal cost. These maintenance-based changes present an opportunity for adding value to existing infrastructure as one step towards addressing the gap in wastewater treatment in Honduras.

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APPENDIX A: EQUIPMENT AND MATERIALS LISTING AND COST

Laboratory Equipment & Supplies for Wastewater Research in Honduras
January 2009

	Microbial Indicator Testing Supplies	Mft.	item #	unit price	shipping	Ext.
100	Whirlpack bags (case of 10 boxes, 100paks/box = 1000 total)	VWR	11216-759	$238.10		$23.81
100	Petrifilm (50/pk)	3M	6404	$75.00		$150.00
100	1 ml pipettes-sterile, plastic, graduated, individ wrapped (500/pk)	Evergreen Scientific	2222-1580-021	$37.00		$7.40
2	Petrifilm Spreaders					
1	Cooler					
	HACH					
100	pH strips 50/pk	HACH	27456-50	$9.19		$18.38
100	Ammonia Nitrogen NH3 Strips (25/pk)	HACH	27553-25	$17.39		$69.56
100	COD2 Digestion Vials, Mercury-Free (250/pk)	HACH	25651-15	$199.00	$36.95	$116.55
1	Portable Turbidity, Suspended Solids, & Sludge Level System	HACH		$2,200.00		$2,200.00
	Lab Equipment					
1	Graduated cylinder-glass, 10 ml,	VWR-Nalgene				
1	Graduated cylinders - Polypropylene 100 mL, (12/pk)	VWR-Nalgene	24744-692	$51.88		$4.32
1	Gloves- Evolution LTX SM, (100/pk)	VWR	32916-532	$73.63		$73.63
	Fieldwork Supplies					
4	Lab marking pens, extra fine tip (4/pk)	Sharpie		$3.44		$3.44
1	Extension Cord					
1	Reel-Type Measuring Tape, 200'					
1	Roll Duct Tape					
1	Measuring Tape, 16'					
					Total:	$2,667.09

APPENDIX B: DATA

Field Lab Data – La Lima

La Lima		**Sampling Location**					
Constituent	**Sample**	**Influent**	**Facultative 1 Effluent**	**Facultative 2 Effluent**	**Maturation 1 Effluent**	**Maturation 2 Effluent**	**Blank**
COD	**A**	281	333	208	214	213	0
	B	257	345	215	193	204	0
	C	258	338	219	175	210	0
	Average	265	339	214	194	209	0
pH	**A**	9	8	9	9	9	9
	B	9	9	9	9	9	9
	C	9	8	9	9	9	8
	Average	9	8	9	9	9	9
Ammonia Nitrogen	**A**	5	4	3	4	2	0
	B	5	3	4	5	2	0
	C	4	3	2	4	1	0
	Average	5	3	3	4	2	0
E. Coli	**A**	124	36	59	24	30	9
	B	134	29	36	20	36	10
	C	(Bad Data)	29	54	28	38	14
	Average	129	31	50	24	35	11
Note: E. coli tests were all done with a 1:1000 dillution in tap water. Thus results were read, then subtracted the average E.coli count for tap water blank, then multiplied by 1000 to obtain MPC.							
E. Coli	**A**	113000	25000	48000	13000	19000	9
	B	123000	18000	25000	9000	25000	10
	C	(Bad Data)	18000	43000	17000	27000	14
	Average	118000	20333	38667	13000	23667	11
Note: Removal Efficiencies were calculated for each pond, as (1-(C/C_o))							
COD C/C_o		100.00%	127.64%	80.65%	57.28%	97.66%	
Ammonia Nitrogen C/C_o		100.00%	71.43%	64.29%	130.00%	55.56%	
E. Coli C/C_o		100.00%	17.23%	32.77%	63.93%	61.21%	
COD Removal Efficiency			-27.64%	19.35%	42.72%	2.34%	
Ammonia Nitrogen Removal Efficiency			28.57%	35.71%	-30.00%	44.44%	
E. Coli Removal Efficiency			82.77%	67.23%	36.07%	38.79%	
Notes:							
COD spiked in Facultative 1, presumably due to excessive paddling and stirring during sludge depth measurements.							
Ammonia Nitrogen spiked in Maturation 2, for unknown reason.							
Charts: C (pond effluent)/C(Headworks) %							
COD C/C_o		100%	128%	81%	73%	79%	
Ammonia Nitrogen C/C_o		100%	71%	64%	93%	36%	
E. Coli C/C_o		100%	17%	33%	11%	20%	
La Lima Ballpark Decay Rates (Using t*)							
	LL1	**LL2**					
COD C/C_o	128%	81%					
Decay $k_{(COD)}$	**(Bad Data)**	**0.091**					
E. Coli C/C_o	17%	33%					
Decay $k_{(E.Coli)}$	**0.715**	**0.470**					

Field Lab Data – Choloma

Choloma		Sampling Location					
Constituent	**Sample**	**Influent**	**Facultative 1 Effluent**	**Facultative 2 Effluent**	**Maturation 1 Effluent**	**Maturation 2 Effluent**	**Blank**
COD	**A**	240	135	135	133	103	0
	B	271	161	152	147	148	0
	C	324	149	135	133	121	0
	Average	278	148	141	138	124	0
pH	**A**	8	8	8	8	8	9
	B	8	8	8	8	8	9
	C	9	9	8	8	8	8
	Average	8	8	8	8	8	9
Ammonia Nitrogen	**A**	4	4	3	4	1	0
	B	4	4	4	4	1	0
	C	5	2	3	4	1	0
	Average	4	3	3	4	1	0
E. Coli	**A**	92	20	23	11	17	9
	B	93	20	17	14	24	10
	C	83	14	16	11	20	14
	Average	89	18	19	12	20	11
Note: E. coli tests were all done with a 1:1000 dillution in tap water. Thus results were read, then subtracted the average E.coli count for tap water blank, then multiplied by 1000 to obtain MPC.							
E. Coli	**A**	81000	9000	12000	0	6000	9
	B	82000	9000	6000	3000	13000	10
	C	72000	3000	5000	0	9000	14
	Average	78333	7000	7667	1000	9333	11
Note: Removal Efficiencies were calculated for each pond, as (1-(C/C_o))							
COD C/C_o		100.00%	53.29%	50.54%	92.81%	88.15%	
Ammonia Nitrogen C/C_o		100.00%	76.92%	76.92%	120.00%	30.00%	
E. Coli C/C_o		100.00%	8.94%	9.79%	14.29%	121.74%	
COD Removal Efficiency			46.71%	49.46%	7.19%	11.85%	
Ammonia Nitrogen Removal Efficiency			23.08%	23.08%	-20.00%	70.00%	
E. Coli Removal Efficiency			91.06%	90.21%	85.71%	-21.74%	
Notes:							
E. Coli was unusually high in Maturation 2, for unknown reason. Possibly wildlife activity such as the presence of crocodiles in pond, or otherwise a contaminated sample.							
Ammonia Nitrogen data spiked in Maturation 1 for unknown reason.							
Charts: C (pond effluent)/C(Headworks) %							
COD C/C_o		100%	53%	51%	49%	45%	
Ammonia Nitrogen C/C_o		100%	77%	77%	92%	23%	
E. Coli C/C_o		100%	9%	10%	1%	12%	

Choloma Ballpark Decay Rates (Using t*)		
	CH1	CH2
COD C/C_o	53%	51%
Decay $k_{(COD)}$	**0.315**	**0.341**
E. Coli C/C_o	9%	10%
Decay $k_{(E.Coli)}$	**1.208**	**1.162**

Field Lab Data – Puerto Cortes

Puerto Cortes		Sampling Location							
Constituent	Sample	Influent	Anaerobic 1 Effluent	Anaerobic 2 Effluent	Facultative 1 Effluent	Facultative 2 Effluent	Maturation 1 Effluent	Maturation 2 Effluent	Blank
COD	**A**	504	185	194	208	191	150	120	0
mg/L	**B**	755	209	210	213	187	154	136	0
	C	513	219	210	227	171	147	154	0
	Average	591	204	205	216	183	150	137	0
pH	**A**	8	7	8	9	9	9	8	9
	B	9	8	8	9	8	8	8	9
	C	9	8	8	9	9	9	9	8
	Average	9	8	8	9	9	9	8	9
Ammonia Nitrogen	**A**	5	5	4	4	3	4	3	0
	B	5	5	4	4	3	4	3	0
	C	4	6	3	4	3	4	1	0
	Average	5	5	4	4	3	4	2	0
E. Coli	**A**	158	123	60	28	31	25	55	9
	B	167	136	51	23	34	30	34	10
	C	(Bad Data)	167	89	20	19	22	17	14
	Average	163	142	67	24	28	26	35	11
Note: E. coli tests were all done with a 1:1000 dillution in tap water. Thus results were read, then subtracted the average E.coli count for tap water blank, then multiplied by 1000 to obtain MPC.									
E. Coli	**A**	147,000	112,000	49,000	17,000	20,000	14,000	44,000	9
Colonies/mL	**B**	156,000	125,000	40,000	12,000	23,000	19,000	23,000	10
	C	(Bad Data)	156,000	78,000	9,000	8,000	11,000	0	14
	Average	151,500	131,000	55,667	12,667	17,000	14,667	22,333	11
Note: Removal Efficiencies were calculated for each pond, as (1-(C/C_o))									
COD C/C_o		100.00%	34.59%	34.65%	105.71%	89.41%	75.36%	90.91%	
Ammonia Nitrogen C/C_o		100.00%	114.29%	78.57%	75.00%	81.82%	114.29%	58.33%	
E. Coli C/C_o		100.00%	86.47%	36.74%	9.67%	30.54%	98.88%	152.27%	
COD Removal Efficiency			65.41%	65.35%	-5.71%	10.59%	24.64%	9.09%	
Ammonia Nitrogen Removal Efficiency			-14.29%	21.43%	25.00%	18.18%	-14.29%	41.67%	
E. Coli Removal Efficiency			13.53%	63.26%	90.33%	69.46%	1.12%	-52.27%	
Notes:									
COD spiked in Facultative 1, for unknown reason.									
Ammonia Nitrogen spiked in Maturation 1, for unknown reason.									
E. Coli was unusually high in Anaerobic 1, possibly due to heavier loading, greater sludge accumulation, and lower retention time. **Other possible explanations include contamination of sample due to very large bird population observed at facility.**									
Charts: C (pond effluent)/C(Headworks) %									
COD C/C_o		100%	35%	35%	37%	31%	74%	67%	
Ammonia Nitrogen C/C_o		100%	114%	79%	86%	64%	86%	50%	
E. Coli C/C_o		100%	86%	37%	8%	11%	10%	15%	

Puerto Cortes Ballpark Decay Rates (Using t*)		
	PC1	**PC2**
COD C/C_o	35%	35%
Decay $k_{(COD)}$	**0.432**	**0.446**
E. Coli C/C_o	86%	37%
Decay $k_{(E.Coli)}$	**0.059**	**0.422**

APPENDIX C: FACILITY ASSESSMENT CHECKLIST

Ficha De Campo de Plantas Depuradoras (Wastewater Treatment Plant Data Sheet)

Informacion General (General Information)

Fecha (Date): 20-Jan-09
Ciudad (City): Puerto Cortés
Departamento (State): Cortés
Pais (Country): Honduras
ID de Proyecto (Project ID): #7
Nombre del Entrevistador (Interviewer Name): Lisa Kullen
Coordenadas GPS (GPS Coordinates): 15.85770, -87.92467
Altitud (Elevation), m:
Resumen del Sitio (Summary of Site):

Puerto Cortés has a sophisticated, well-designed system of lagoons handling large flow volume for a large city. The system has a very good removal efficiency, with effluent quality meeting WHO guidelines for swimming waters (80 CFU). This is a very well managed system.

System is suffering a critical failure of the geoliner. System is built over a marsh with a high water table, and methane generation has strained the geoliner. The facultative and especially the maturation ponds have large bubbles in the membrane, many emerging above the surface of the pond. The liner has broken & failed in several places. The city is searching for solutions and is concerned about funding and about the success of the alternatives considered. Among the options are a geodrain (gravel bed and pipes laid beneath ponds) or concrete liners for ponds. Both solutions involve reconstructing ponds at great expense. Problem will get worse, and must be addressed soon.

Informacion de Contacto y Personal de Planta (Contact Information and Plant's Personnel)

Nombre del Entrevistado (Name of Person Interviewed): Ing. Sara Canales
Posicion del Entrevistado (Interviewee's Position): Engineer in charge of facility
Departamento Laboral del Entrevistado (Interviewee's Department): Wastewater Treatment Plant (Aguas de Puerto Cortes)
Nombre de Planta (Name of the Plant): Alcantarillado Sanitario
Ubicacion de Planta (Plant's Site Location): Puerto Cortés
Director de Planta (Plant Director): Ing. Sara Canales
Operador de Planta (Plant Operator): Denis Contreras & Enrique Bardales
Correo Electronico del Director de Planta (Director's e-mail): scanales75@hotmail.com
Direccion de la Oficina del Director (Plant's Director's address): 9 Calle Este, Entre 4 y 6 Calle, Primer Nivel Estadio Excelsior
Numero de Telefono (Telephone Number): 665-6870 or 665-2794

Detalles de Construccion de Planta Depuradora (Construction Details of WWTP's Construction)

Fecha de Construccion (Construction Date): 2005
Poblacion Servida (Population Served): 40,000 to 60,000 people
Capacidad de Planta (Plant's Capacity), m3/dia: Unknown
Terreno Requerido (Land Required), Hectareas: 22 Hectares
Consultor Internacional del Proyecto (International Consultant): Hazen & Sawyer
Consultor Nacional del Proyecto (National Consultant): None
Costo de Construcion (Construction Cost): $21,500,000
Planos Disponibles del Diseno de la Planta (Available Drawings)?: Unknown
Organismo(s) Financiero (s) (Funding Agency or Agencies): Inter-American Development Bank Loan, city will repay

1. Proceso de Tratamiento Existente (Existing WWT Technology - check all that apply):

___ Tanques Imhoff (Imhoff Tanks)
X Lagunas de Oxidacion (Waste Stabilization Ponds)
- ___ Anaerobio (Anaerobic) # 2 (will expand to 3)
- ___ Facultativa (Facultative) # 2 (will expand to 3)
- ___ Maduarcion (Maturation) # 2 (will expand to 3)

___ Lagunas Aereadas (Aerated Lagoons)
___ Aeriacion Mechanizada (Mechanical Aeration)
___ Planta Paquete (Package Plant)
___ Upflow Anaerobic Sludge Blanket (UASB)
___ Aeriacion Mechanizada (Mechanical Aeration)
___ Filtro Percolador (Biofilters)
___ Lodos Activados (Activated Sludge)
___ Otro(s) (Others): Anaerobic digester; constructed wetland

Tú Dibujas de Configuración del Sitio:
(Sketch Site Configuration):

2. Descripcion General de Instalaciones Fisicas y Pre-Tratamiento (General Description of Physical and Pre-Treatment Facilities)

Epoca (Season): ____ Seca (Dry) X Lluviosa (Rainy)

1) A que distancia se encuentran la planta depuradora de las casas de habitacion mas sercanas?
(How far is the treatment plant form the nearest residence?)
50 Meters (residences were relocated by city, but some moved back)

2) Se encuentra cercado actualmente las instalaciones de la planta depuradora (cerac, portones, y candados?
(Is the treatment plant site currently enclosed (fences, gates, locks)?
Yes

3) Que tipo de cerco presenta? (What type of fence was used)
Chain Link Fence & Guard at Gate

4) Como se encontro el cercado al momento de la visita a la planta?
(What was the condition of the site's fence at the time of the visit?)
X Bueno (good)
☐ Regular (regular)
☐ Malo (poor)
☐ Ninguna (none)

5) Cual es el tiempo de residencia con el cual se diseno el sistema de tratamiento? Actual de tiempo de residencia?
(What is the residence time for which the system was designed? Actual operating residence time?)
9 - 13 days (depending on rain; many illegal storm drain connections exist, so system gets large flows in frequent rain storms)

6) Personal que labora permanentemente en el la planta depuradora?
(Permanent personnel working at the plant?)
X Vigilante (Guard) # 1
X Operador (Operator) # ~4
X Ingeniero supervisor (Supervising Engineer) # 1

7) Indicar las herramientas de operacion y mantenimiento que son propiedad y utilizadas por el personal de planta?
(Indicate the maintenance and operation tools at the site that belong and are used by plant's personnel?)
X Guantes de hule (rubber gloves)
X Botas de hule (rubber boots)
X Capotes (rain coats)
X Botiquin (first aid kit)
☐ Uniforme de campo (field uniform)
☐ Casco (hard hat)
X Rastrillo para rejilla (bar screen rake)
X Pala (shovel)
X Piocha (pick)
X Carreta de mano (wheelbarrow)
X Podadora de cesped (lawn mower)
X Martillo (hammer)
X Serrucho (hand saw)
X Escoba (broom)
X Desnatador (scum remover)
X Lancha (boat)
X Manguera (hose)
X Machete (machete)
X Desatornillador (screw driver/drill)
X Llave Stilson 12" (12" pipe wrench)
X Extractor de natas (scum remover)
☐ No visto (None seen)

8) Indique la condicion de las herramientas de operacion y mantenimiento de la planta?
(Indicate the condition of the maintenance and operation tools?)
X Buena (good)
☐ Regular (regular)
☐ Mala (poor)
☐ No es aplicable (not applicable)

9) Con que instalaciones de limpieza cuentan en la casa de operacion (si existe alguna) en la planta de tratamiento?
(What cleaning facilities exist at the plant's operation room (if any exist)?)
X Agua potable (potable water)
X Jabon (soap)
X Cloro (bleach)
X Toallas desechables (disposable towels)
X Bañera (bathroom/shower room)
X Llave spita simple (simple faucet/spigot)
X Alcohol (alcohol)
☐ Ninguna (none)

10) Con que equipo cuenta el botiquin de primeros auxilios (si existe alguno)?
(List first aid kit equipment (if any exist)
X Tela adhesive (gauze)
X Algodon (cotton)
X Alcohol (alchohol)
☐ Mercurio cromo (Chromium mercury)
X Detergente desinfectante (desinfecting detergent)
X Tijeras (scissors)
X Pinzas (tweezers)
☐ Repelente (repellent)
☐ No cuenta con botiquin (no first aid kit available)

11) Existe una lancha disponible para el matenimiento de la planta? Si la respuesta es no, pasar a la pregunta No. 14).
(Is thera a boat available for the maintenance of the plant? If there is no boat, go to question No. 14).
X Si (yes)
☐ No (no)
☐ No es aplicable (not applicable)

12) Si una lancha existe, cual es la condicion de la lancha?
(If a boat exists, what is its condition?)
X Buena (good)
☐ Regular (regular)
☐ Mala (poor)

13) Cuales son las dimensiones de la lancha o la capacidad de esta? (what are the boat's dimensions or capacity?)

Capacidad? (Capacity?)	Dimensiones (dimensions):
5 Personas (Persons)	____ Length, m
☐ No es aplicable (not applicable)	____ Width, m
	____ depth, m

14) Cual es el nombre, ubicacion y condiciciones del cuerpo receptor del agua tratada?
(What is the name, location and condition of the body of water receiving the treated effluent?)
Nombre (name): Laguna de Alvarado
Ubicacion (location): Puerto Cortés
Tipo de cuerpo receptor (description of receiving water body):
____ Quebrada (Stream)
____ Rio (River)
____ Oceano (Ocean)
X Otro (Other): Lagoon
Tributario a que cuerpo mayor (tributary to what major water body): Caribbean Sea
Distancia del cuerpo de agua mayor (Distance to major water body): Immediately adjacent

15) Existen rejiallas en el sistema? (si la respuesta es no, pasar a la pregunta No. 20)
(Do bar screens exist as part of the treatment system? (if not, go to question No. 20)
X Si (yes)
☐ No (no)

16) Describir el tipo de rejillas. (material, dimensiones, separaciones, ect.)
(Describe the type of bar screens (material, dimensions, opening size, ect.)
Metal rails in sophisticated headworks. 1 cm space between rails.

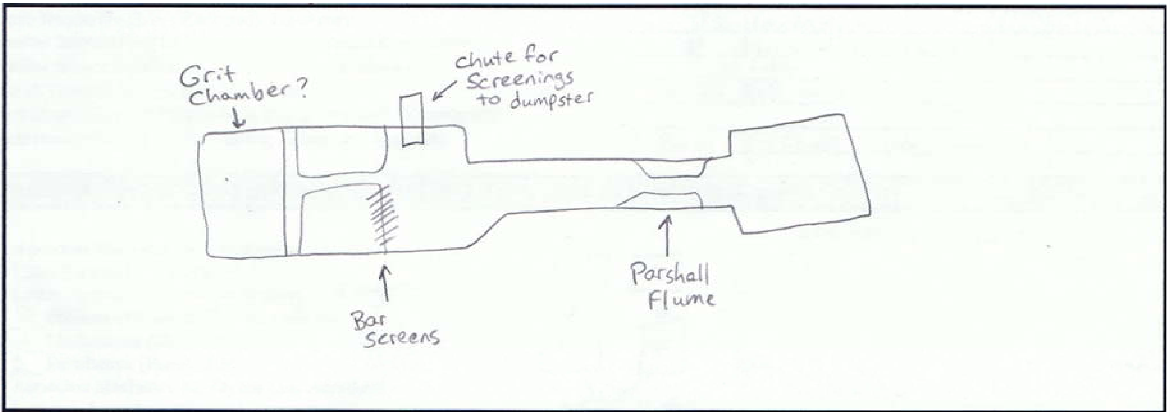
17) Cual es la frequencia de limpieza de estas rejillas?
(How frequent are bar screens cleaned?)
X A diario (daily)
☐ Cada 2 dias (every 2 days)
☐ Cada 3 dias (every 3 days)
☐ Cada semana (every week)
☐ Otro (other) Screens were cleaned mechanically, but system is currently not operating so they are hand cleaned.

18) Que disposicion se le da la material removido de las rejillas?
(How is the material removed from bar screens disposed off?)
☐ En la basaura (in the trash)
☐ En la calle (on the street)
☐ En el cuerpo receptor (in the recieivng water body)
☐ Enterrado (buried)
X Otro (other) Sanitary Landfill

19) En cuanto se estima el costo de la construccion de las rejillas en un lugar cercano a la planta?
(What is the estimated construction cost for the bar screens, if built in a nearby shop?)
Unknown Lempiras (Lps.)

20) Posee desarenador la planta de tratamiento? (si su respuesta es no, pasar a la pregunta No. 25)
(Is there a grit chamber as part of the treatment plant? If your answer is no, go to question No. 25)
X Si (yes)
☐ No (no)

21) Dibujar el desarenador (sketch of the grit chamber)



20) ¿Qué registros se mantienen y qué pruebas se realiza en la instalación?
(What records are kept and what testing is performed at the facility?)
Very good records, including testing influent and effluent 2x/week. Tests are performed at Jordan Labs every month.

21) ¿Con qué frecuencia se limpia systema?
(How often is the sludge cleaned out?)
Not yet - 3 years in anaerobic, and 5 years in facultative pond.

22) ¿Qué se hace con los lodos removidos?
(What do you do with the sludge that is removed?)
Drying bed will be built on premises. After dry, unsure where sludge will be disposed of.

23) Se han reutilizado los lodos en granjas o jardines?
(Has there been reuse of sludge for farms or gardens?)
Not yet, but under consideration.

24) ¿Existe interes en la utilización de los lodos en las granjas o jardines?
(Do you think anyone in town would be interested in using sludge for farms or gardens?)
Yes.

Ficha De Campo de Plantas Depuradoras (Wastewater Treatment Plant Data Sheet)

Informacion General (General Information)

Fecha (Date):	19-Jan-09
Ciudad (City):	Choloma
Departamento (State):	Cortés
Pais (Country):	Honduras
ID de Proyecto (Project ID):	#8
Nombre del Entrevistador (Interviewer Name):	Lisa Kullen
Coordenadas GPS (GPS Coordinates):	15.593364, -87.925003
Altitud (Elevation), m:	

Resumen del Sitio (Summary of Site):

System has been online 2 years. The director is in process of developing testing protocols, and municipality is interested in recommendations of what to test and to monitor. Facility handles municipal domestic wastewater and some indstrial from machilladoras. Sludge levels have not been measured. Site is well maintained. System does have several large crocodiles (up to 4 meters in length) which pose a safety hazard as well as the potential to damage ponds when burrowing and when entering and exiting over birms. One facultative pond was much greener than the other, indicating dissimilar algael activity between the two ponds. This site is Lagunas Sector Centre; municipal ponds at Lagunas Sector Norte are also online but are reportedly in bad shape.

Informacion de Contacto y Personal de Planta (Contact Information and Plant's Personnel)

Nombre del Entrevistado (Name of Person Interviewed):	Ing. Julio Hernandez & Jose Cecilio Valle
Posicion del Entrevistado (Interviewee's Position):	Julio Hernandez: Technical Assistant
Departamento Laboral del Entrevistado (Interviewee's Department):	Dimach
Nombre de Planta (Name of the Plant):	Lagunas de Oxidacion Sector Centro
Ubicacion de Planta (Plant's Site Location):	Choloma
Director de Planta (Plant Director):	Ing. Julio Hernandez (Technical Assistant) & Fernando Moncada (Technical Director)
Operador de Planta (Plant Operator):	Eduardo Caballero
Correo Electronico del Director de Planta (Director's e-mail):	Hernandez: jicea@yahoo.com; Moncada: fermoncadam@yahoo.es
Direccion de la Oficina del Director (Plant's Director's address):	Bo. El Centro, 2da. Avenida, 2 y 3 Calle, Choloma, Cortés
Numero de Telefono (Telephone Number):	504-669-3223

Detalles de Construccion de Planta Depuradora (Construction Details of WWTP's Construction)

Fecha de Construccion (Construction Date):	Aug-05
Poblacion Servida (Population Served):	50,000 Persons
Capacidad de Planta (Plant's Capacity), m3/dia:	?(2 Facultative: 82*390 meters; 2 Maturation: 75*366 meters)
Terreno Requerido (Land Required), Hectareas:	10 hectares (ponds); 30 hectares (total)
Consultor Internacional del Proyecto (International Consultant):	None
Consultor Nacional del Proyecto (National Consultant):	Unknown
Costo de Construcion (Construction Cost):	Unknown
Planos Disponibles del Diseno de la Planta (Available Drawings)?:	Unknown
Organismo(s) Financiero (s) (Funding Agency or Agencies):	Unknown

1. Proceso de Tratamiento Existente (Existing WWT Technology - check all that apply):

____ Tanques Imhoff (Imhoff Tanks)
X Lagunas de Oxidacion (Waste Stabilization Ponds)
  ____ Anaerobio (Anaerobic) # ____
  X Facultativa (Facultative) # 2
  X Maduarcion (Maturation) # 2
____ Lagunas Aereadas (Aerated Lagoons)
____ Aeriacion Mechanizada (Mechanical Aeration)
____ Planta Paquete (Package Plant)
____ Upflow Anaerobic Sludge Blanket (UASB)
____ Aeriacion Mechanizada (Mechanical Aeration)
____ Filtro Percolador (Biofilters)
____ Lodos Activados (Activated Sludge)
____ Otro(s) (Others): ____________

Tú Dibujas de Configuración del Sitio:
(Sketch Site Configuration):

2. Descripcion General de Instalaciones Fisicas y Pre-Tratamiento (General Description of Physical and Pre-Treatment Facilities)

Epoca (Season): ____ Seca (Dry) X Lluviosa (Rainy)

1) A que distancia se encuentran la planta depuradora de las casas de habitacion mas sercanas?
(How far is the treatment plant form the nearest residence?)
200 Meters

2) Se encuentra cercado actualmente las instalaciones de la planta depuradora (cerac, portones, y candados?
(Is the treatment plant site currently enclosed (fences, gates, locks)?
Yes

3) Que tipo de cerco presenta? (What type of fence was used)
Barbed Wire

4) Como se encontro el cercado al momento de la visita a la planta?
(What was the condition of the site's fence at the time of the visit?)
X Bueno (good)
☐ Regular (regular)
☐ Malo (poor)
☐ Ninguna (none)

5) Cual es el tiempo de residencia con el cual se diseno el sistema de tratamiento? Actual de tiempo de residencia?
(What is the residence time for which the system was designed? Actual operating residence time?)
Reportedly 72 hours

6) Personal que labora permanentemente en el la planta depuradora?
(Permanent personnel working at the plant?)
X Vigilante (Guard) # 1
X Operador (Operator) # 5
☐ Ingeniero supervisor (Supervising Engineer) #

7) Indicar las herramientas de operacion y mantenimiento que son propiedad y utilizadas por el personal de planta?
(Indicate the maintenance and operation tools at the site that belong and are used by plant's personnel?)
X Guantes de hule (rubber gloves)
X Botas de hule (rubber boots)
X Capotes (rain coats)
X Botiquin (first aid kit)
☐ Uniforme de campo (field uniform)
☐ Casco (hard hat)
X Rastrillo para rejilla (bar screen rake)
X Pala (shovel)
X Piocha (pick)
☐ Carreta de mano (wheelbarrow)
☐ Podadora de cesped (lawn mower)
X Martillo (hammer)
X Serrucho (hand saw)
☐ Escoba (broom)
X Desnatador (scum remover)
X Lancha (boat)
X Manguera (hose)
X Machete (machete)
☐ Desatornillador (screw driver/drill)
☐ Llave Stilson 12" (12" pipe wrench)
X Extractor de natas (scum remover)
☐ No visto (None seen)

8) Indique la condicion de las herramientas de operacion y mantenimiento de la planta?
(Indicate the condition of the maintenance and operation tools?)
X Buena (good)
☐ Regular (regular)
☐ Mala (poor)
☐ No es aplicable (not applicable)

9) Con que instalaciones de limpieza cuentan en la casa de operacion (si existe alguna) en la planta de tratamiento?
(What cleaning facilities exist at the plant's operation room (if any exist)?)
X Agua potable (potable water)
X Jabon (soap)
☐ Cloro (bleach)
☐ Toallas desechables (disposable towels)
X Bañera (bathroom/shower room)
X Llave spita simple (simple faucet/spigot)
☐ Alcohol (alcohol)
X Ninguna (none)

10) Con que equipo cuenta el botiquin de primeros auxilios (si existe alguno)?
(List first aid kit equipment (if any exist) X Other: Asprin, Alka Seltzer
X Tela adhesive (gauze)
☐ Algodon (cotton)
X Alcohol (alchohol)
☐ Mercurio cromo (Chromium mercury)
☐ Detergente desinfectante (desinfecting detergent)
☐ Tijeras (scissors)
☐ Pinzas (tweezers)
☐ Repelente (repellent)
☐ No cuenta con botiquin (no first aid kit available)

11) Existe una lancha disponible para el matenimiento de la planta? Si la respuesta es no, pasar a la pregunta No. 14).
(Is thera a boat available for the maintenance of the plant? If there is no boat, go to question No. 14).
X Si (yes) *Boat is missing, but the municipality has a boat which is borrowed when needed
☐ No (no)
☐ No es aplicable (not applicable)

12) Si una lancha existe, cual es la condicion de la lancha?
(If a boat exists, what is its condition?)
X Buena (good)
☐ Regular (regular)
☐ Mala (poor)

13) Cuales son las dimensiones de la lancha o la capacidad de esta? (what are the boat's dimensions or capacity?)

Capacidad? (Capacity?)	Dimensiones (dimensions):
? Personas (Persons)	____ Length, m
☐ No es aplicable (not applicable)	____ Width, m
	____ depth, m

14) Cual es el nombre, ubicacion y condiciciones del cuerpo receptor del agua tratada?
(What is the name, location and condition of the body of water receiving the treated effluent?)
Nombre (name): Chaparro Quebrado & Quebrada San Augustin (Agua Prieta)
Ubicacion (location): Choloma
Tipo de cuerpo receptor (description of receiving water body):
X Quebrada (Stream)
____ Rio (River)
____ Oceano (Ocean)
____ Otro (Other): ____
Tributario a que cuerpo mayor (tributary to what major water body): Unknown
Distancia del cuerpo de agua mayor (Distance to major water body): Unknown

15) Existen rejiallas en el sistema? (si la respuesta es no, pasar a la pregunta No. 20)
(Do bar screens exist as part of the treatment system? (if not, go to question No. 20)
X Si (yes)
☐ No (no)

16) Describir el tipo de rejillas. (material, dimensiones, separaciones, ect.)
(Describe the type of bar screens (materila, dimensions, opening size, ect.)
Metal Screen with handles for removal

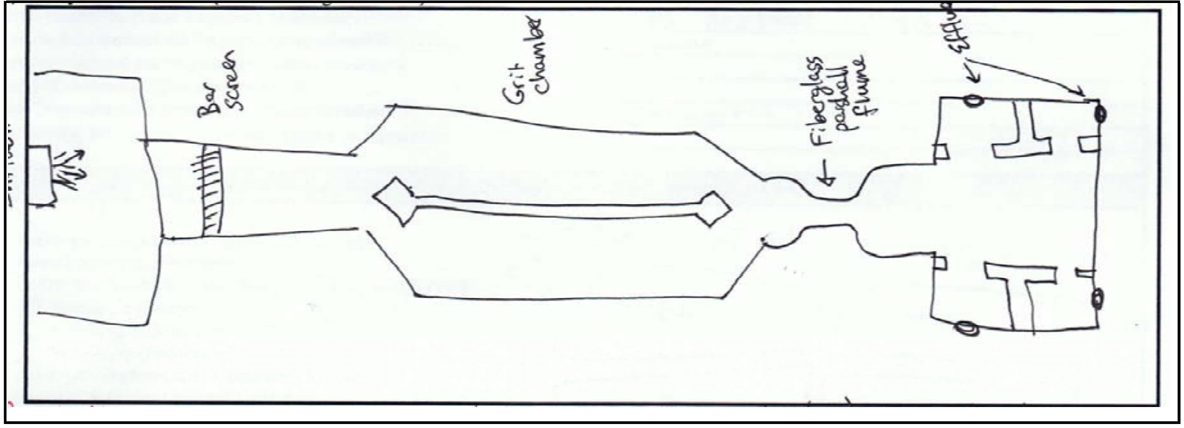
17) Cual es la frequencia de limpieza de estas rejillas?
(How frequent are bar screens cleaned?)
X A diario (daily)
☐ Cada 2 dias (every 2 days)
☐ Cada 3 dias (every 3 days)
☐ Cada semana (every week)
☐ Otro (other) ____

18) Que disposicion se le da la material removido de las rejillas?
(How is the material removed from bar screens disposed off?)
☐ En la basaura (in the trash)
☐ En la calle (on the street)
☐ En el cuerpo receptor (in the recieivng water body)
X Enterrado (buried)
☐ Otro (other) ____________________

19) En cuanto se estima el costo de la construccion de las rejillas en un lugar cercano a la planta?
(What is the estimated construction cost for the bar screens, if built in a nearby shop?)
Unknown Lempiras (Lps.)

20) Posee desarenador la planta de tratamiento? (si su respuesta es no, pasar a la pregunta No. 25)
(Is there a grit cahmber as part of the treatment plant? If your answer is no, go to question No. 25)
X Si (yes)
☐ No (no) ____________

21) Dibujar el desarenador (sketch of the grit chamber)



20) ¿Qué registros se mantienen y qué pruebas se realiza en la instalación?
(What records are kept and what testing is performed at the facility?)
No testing is currently performed. Flow monitoring is done through use of fiberglass Parshall flume in grit chamber.

21) ¿Con qué frecuencia se limpia systema?
(How often is the sludge cleaned out?)
Every 5-6 years (hasn't happened yet)

22) ¿Qué se hace con los lodos removidos?
(What do you do with the sludge that is removed?)
Take off site to a drying bed

23) Se han reutilizado los lodos en granjas o jardines?
(Has there been reuse of sludge for farms or gardens?)
Not yet

24) ¿Existe interes en la utilización de los lodos en las granjas o jardines?
(Do you think anyone in town would be interested in using sludge for farms or gardens?)
Yes, there is interest

Ficha De Campo de Plantas Depuradoras (Wastewater Treatment Plant Data Sheet)

Informacion General (General Information)

Fecha (Date):	17-Jan-09
Ciudad (City):	La Lima
Departamento (State):	Cortés
Pais (Country):	Honduras
ID de Proyecto (Project ID):	#9
Nombre del Entrevistador (Interviewer Name):	Ari Herrera
Coordenadas GPS (GPS Coordinates):	15.453206, -87.919711
Altitud (Elevation), m:	

Resumen del Sitio (Summary of Site):

Well maintained facility keeps very good records. Two facultative ponds and two maturation ponds. Routine maintenance is performed including grounds keeping, scum removal, raking bar screens, documenting flow measurements, and periodically measuring sludge. Some dead zones and were apparent in the corners of ponds. (more?)

Informacion de Contacto y Personal de Planta (Contact Information and Plant's Personnel)

Nombre del Entrevistado (Name of Person Interviewed):	Osmin Aguirre Dubon
Posicion del Entrevistado (Interviewee's Position):	Encaryado de Lagunas (Personnel and Plant Manager)
Departamento Laboral del Entrevistado (Interviewee's Department):	Alcantarillado (Wastewater)
Nombre de Planta (Name of the Plant):	Colonia La Meza / Rodas
Ubicacion de Planta (Plant's Site Location):	Colonia La Meza / Rodas
Director de Planta (Plant Director):	Osmin Aguirre Dubon
Operador de Planta (Plant Operator):	Marcos Ramires, Jose Vaquedano, Jose Luis Martinez
Correo Electronico del Director de Planta (Director's e-mail):	n/a
Direccion de la Oficina del Director (Plant's Director's address):	Municipalidad de La Lima
Numero de Telefono (Telephone Number):	668-2400

Detalles de Construccion de Planta Depuradora (Construction Details of WWTP's Construction)

Fecha de Construccion (Construction Date):	Jun-05
Poblacion Servida (Population Served):	Total capacity 10,000 people, currently serves 3,500 people
Capacidad de Planta (Plant's Capacity), m3/dia:	Unknown
Terreno Requerido (Land Required), Hectareas:	14 Hectares
Consultor Internacional del Proyecto (International Consultant):	Codecon / Puerto Cortés
Consultor Nacional del Proyecto (National Consultant):	N/A
Costo de Construcion (Construction Cost):	18,000,000 Lempiras
Planos Disponibles del Diseno de la Planta (Available Drawings)?:	Yes
Organismo(s) Financiero (s) (Funding Agency or Agencies):	USAID / FHIS

1. Proceso de Tratamiento Existente (Existing WWT Technology - check all that apply):

____ Tanques Imhoff (Imhoff Tanks)
____ Lagunas de Oxidacion (Waste Stabilization Ponds)
  ____ Anaerobio (Anaerobic) # ____
  X Facultativa (Facultative) # 2
  X Maduarcion (Maturation) # 2
____ Lagunas Aereadas (Aerated Lagoons)
____ Aeriacion Mechanizada (Mechanical Aeration)
____ Planta Paquete (Package Plant)
____ Upflow Anaerobic Sludge Blanket (UASB)
____ Aeriacion Mechanizada (Mechanical Aeration)
____ Filtro Percolador (Biofilters)
____ Lodos Activados (Activated Sludge)
____ Otro(s) (Others): ____________

Tú Dibujas de Configuración del Sitio:
(Sketch Site Configuration):

2. Descripcion General de Instalaciones Fisicas y Pre-Tratamiento (General Description of Physical and Pre-Treatment Facilities)

Epoca (Season): ____ Seca (Dry) X Lluviosa (Rainy)

1) A que distancia se encuentran la planta depuradora de las casas de habitacion mas sercanas?
(How far is the treatment plant form the nearest residence?)
1 Kilometer

2) Se encuentra cercado actualmente las instalaciones de la planta depuradora (cerac, portones, y candados?
(Is the treatment plant site currently enclosed (fences, gates, locks)?
Yes

3) Que tipo de cerco presenta? (What type of fence was used)
Barbed Wire

4) Como se encontro el cercado al momento de la visita a la planta?
(What was the condition of the site's fence at the time of the visit?)
X Bueno (good)
☐ Regular (regular)
☐ Malo (poor)
☐ Ninguna (none)

5) Cual es el tiempo de residencia con el cual se diseno el sistema de tratamiento? Actual de tiempo de residencia?
(What is the residence time for which the system was designed? Actual operating residence time?)
7-10 days

6) Personal que labora permanentemente en el la planta depuradora?
(Permanent personnel working at the plant?)
X Vigilante (Guard) # 1
X Operador (Operator) # 3
X Ingeniero supervisor (Supervising Engineer) # 1

7) Indicar las herramientas de operacion y mantenimiento que son propiedad y utilizadas por el personal de planta?
(Indicate the maintenance and operation tools at the site that belong and are used by plant's personnel?)
X Guantes de hule (rubber gloves)
X Botas de hule (rubber boots)
X Capotes (rain coats)
X Botiquin (first aid kit)
☐ Uniforme de campo (field uniform)
☐ Casco (hard hat)
X Rastrillo para rejilla (bar screen rake)
X Pala (shovel)
X Piocha (pick)
X Carreta de mano (wheelbarrow)
X Podadora de cesped (lawn mower)
X Martillo (hammer)
☐ Serrucho (hand saw)
X Escoba (broom)
X Desnatador (scum remover)
X Lancha (boat)
X Manguera (hose)
X Machete (machete)
☐ Desatornillador (screw driver/drill)
☐ Llave Stilson 12" (12" pipe wrench)
X Extractor de natas (scum remover)
☐ No visto (None seen)

8) Indique la condicion de las herramientas de operacion y mantenimiento de la planta?
(Indicate the condition of the maintenance and operation tools?)
X Buena (good)
☐ Regular (regular)
☐ Mala (poor)
☐ No es aplicable (not applicable)

9) Con que instalaciones de limpieza cuentan en la casa de operacion (si existe alguna) en la planta de tratamiento?
(What cleaning facilities exist at the plant's operation room (if any exist)?)
X Agua potable (potable water)
X Jabon (soap)
☐ Cloro (bleach)
☐ Toallas desechables (disposable towels)
X Bañera (bathroom/shower room)
X Llave spita simple (simple faucet/spigot)
X Alcohol (alcohol)
☐ Ninguna (none)

10) Con que equipo cuenta el botiquin de primeros auxilios (si existe alguno)?
(List first aid kit equipment (if any exist)
☐ Tela adhesive (gauze)
X Algodon (cotton)
X Alcohol (alchohol)
☐ Mercurio cromo (Chromium mercury)
☐ Detergente desinfectante (desinfecting detergent)
X Tijeras (scissors)
☐ Pinzas (tweezers)
☐ Repelente (repellent)
☐ No cuenta con botiquin (no first aid kit available)

11) Existe una lancha disponible para el matenimiento de la planta? Si la respuesta es no, pasar a la pregunta No. 14).
(Is thera a boat available for the maintenance of the plant? If there is no boat, go to question No. 14).
X Si (yes)
☐ No (no)
☐ No es aplicable (not applicable)

12) Si una lancha existe, cual es la condicion de la lancha?
(If a boat exists, what is its condition?)
X Buena (good)
☐ Regular (regular)
☐ Mala (poor)

13) Cuales son las dimensiones de la lancha o la capacidad de esta? (what are the boat's dimensions or capacity?)

Capacidad? (Capacity?)	Dimensiones (dimensions):
2 Personas (Persons)	Length, m
☐ No es aplicable (not applicable)	Width, m
	depth, m

14) Cual es el nombre, ubicacion y condicisiones del cuerpo receptor del agua tratada?
(What is the name, location and condition of the body of water receiving the treated effluent?)
Nombre (name): Rio Chamelecon
Ubicacion (location): La Lima
Tipo de cuerpo receptor (description of receiving water body):
Quebrada (Stream)
X Rio (River)
Oceano (Ocean)
Otro (Other):
Tributario a que cuerpo mayor (tributary to what major water body): Carribean Sea
Distancia del cuerpo de agua mayor (Distance to major water body): 50 km

15) Existen rejiallas en el sistema? (si la respuesta es no, pasar a la pregunta No. 20)
(Do bar screens exist as part of the treatment system? (if not, go to question No. 20)
X Si (yes)
☐ No (no)

16) Describir el tipo de rejillas. (material, dimensiones, separaciones, ect.)
(Describe the type of bar screens (materila, dimensions, opening size, ect.)
PVC, 3 cm spacing, 1.5 meters tall, 1/2 meter wide

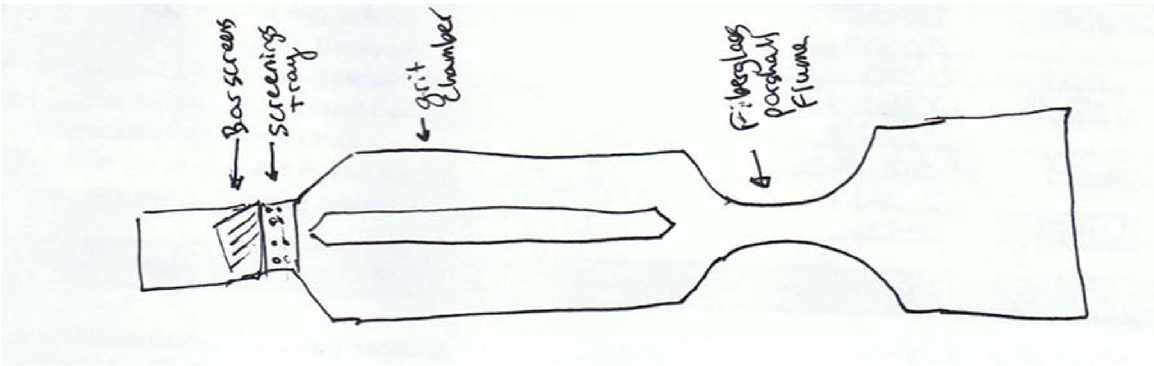
17) Cual es la frequencia de limpieza de estas rejillas?
(How frequent are bar screens cleaned?)
X A diario (daily)
☐ Cada 2 dias (every 2 days)
☐ Cada 3 dias (every 3 days)
☐ Cada semana (every week)
☐ Otro (other)

18) Que disposicion se le da la material removido de las rejillas?
(How is the material removed from bar screens disposed off?)
☐ En la basaura (in the trash)
☐ En la calle (on the street)
☐ En el cuerpo receptor (in the recieivng water body)
X Enterrado (buried)
☐ Otro (other) ________________

19) En cuanto se estima el costo de la construccion de las rejillas en un lugar cercano a la planta?
(What is the estimated construction cost for the bar screens, if built in a nearby shop?)
100 Lempiras (Lps.) (Made by municipality)

20) Posee desarenador la planta de tratamiento? (si su respuesta es no, pasar a la pregunta No. 25)
(Is there a grit chamber as part of the treatment plant? If your answer is no, go to question No. 25)
X Si (yes)
☐ No (no) ________

21) Dibujar el desarenador (sketch of the grit chamber)



20) ¿Qué registros se mantienen y qué pruebas se realiza en la instalación?
(What records are kept and what testing is performed at the facility?)
Flow monitoring with Parshall flume; sludge depth

21) ¿Con qué frecuencia se limpia systema?
(How often is the sludge cleaned out?)
De-sludging is pending

22) ¿Qué se hace con los lodos removidos?
(What do you do with the sludge that is removed?)
Have not removed sludge yet

23) Se han reutilizado los lodos en granjas o jardines?
(Has there been reuse of sludge for farms or gardens?)
Have not removed sludge yet

24) ¿Existe interes en la utilización de los lodos en las granjas o jardines?
(Do you think anyone in town would be interested in using sludge for farms or gardens?)
Unknown