IMPROVED WASTEWATER TREATMENT FOR THE MUNICIPALITY OF LAS VEGAS, HONDURAS

MASTER OF ENGINEERING PROJECT REPORT
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1 INTRODUCTION

Since 2005 MIT has been studying Lake Yojoa and the various stakeholders who contribute to the anthropogenic environmental impact on the lake. The chronology of the project can be found in Appendix A: Project Timeline. The Municipality of Las Vegas is one of these stakeholders and in January 2008, Dr. Eric Adams, Aridaí Herrera, Anne Mikelonis, and Matthew Hodge traveled to Honduras to work with the Municipality on its wastewater treatment system. While there, the team studied existing wastewater conditions, options for improvement, specifically through the use of chemically enhanced primary treatment, and options for the Municipality to expand treatment throughout the region. This report summarizes the findings of the group in these three areas and makes recommendations to the municipal government on how to reduce the Municipality's impact on Lake Yojoa.

2 DESCRIPTION OF LAS VEGAS

The Municipality of Las Vegas is located just west (14º 52' N, 88º 4' W) of the largest freshwater lake in Honduras, Lake Yojoa. Lake Yojoa is situated 125 kilometers northwest of Tegucigalpa. The region of Las Vegas gained the status of township on September 8th, 1987 and became a municipality formally on December 17, 1997 (Herrera 2006). Figure 1 shows the geographic location of Lake Yojoa, or Lago de Yojoa.

Figure 1 Location of Las Vegas, Santa Barbara, Honduras (Honduras 2007)

The Municipality has a total population of 30,000 with approximately 17,000 people in towns or neighborhoods and the remainder living in rural areas throughout the Municipality. The major urban areas are: Las Vegas, El Mochito Mocho Arriba (El Mochito), and San Juan. Figure 2 outlines the approximate extents of the Municipality and the location of the urban areas.

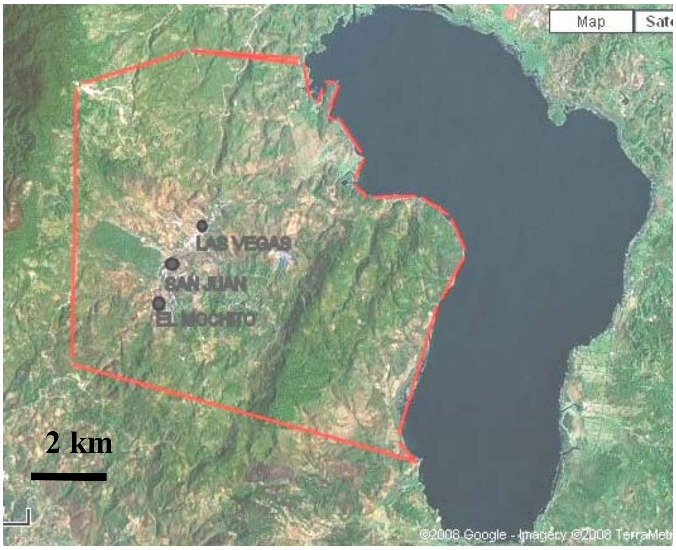


Figure 2 Aerial Image of the Municipality of Las Vegas [modified from (Google 2008a)]

The city of Las Vegas is located in the center of the region. All three urban areas are amongst the foothills and mountains that surround Lake Yojoa. The terrain in this region is increasingly mountainous as one moves away from the lake. Each urban area has a different cause for its concentrated population. The City of Las Vegas is the seat of the Municipality and the center of commerce for the region. El Mochito is home to the AMPAC Mine, the largest mine in Central America (Chokshi 2006). Finally, San Juan is largely a residential area providing labor to the AMPAC Mine.

As a part of an extensive program of development, the municipal government is expanding sanitation services throughout the region. One major thrust of this work is the conveyance of domestic wastewater in the urban areas away from homes. The source of domestic wastewater in Las Vegas is, predictably, private residences. The municipal staff provided information about the number of residences in each urban area. A schematic representation of this information is presented in Figure 3. Note that Las Vegas has been broken out into two sections because central Las Vegas already has primary wastewater treatment while the northern region of the city does not.

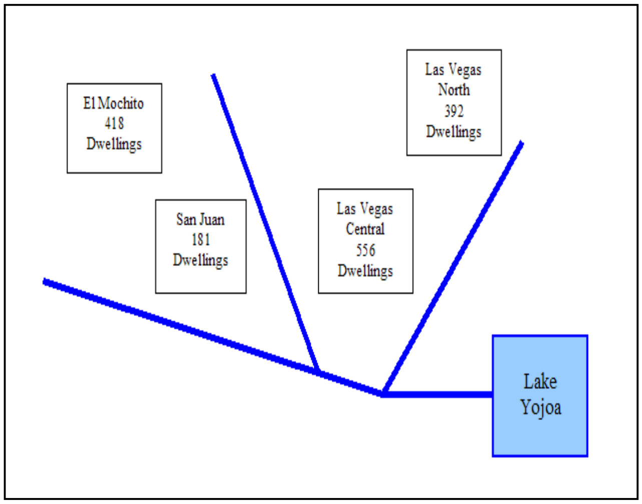


Figure 3 Schematic Diagram of Las Vegas Urban Areas

Figure 3 shows the number of official properties, either already connected to sewerage in the case of central Las Vegas or legally deeded properties in the other areas. According to the Municipality, the number of actual connections is somewhat larger in all cases because of illegal connections or non-deeded properties. For example, in central Las Vegas 556 legal connections have been made to the Imhoff tank that treats sewage from this region, but this number is augmented by an additional 40 to 50 illegal connections (Godoy 2008a). A similar unofficial need for sewerage is likely to exist in the other urban areas. Another valuable observation that is presented in Figure 3 is the system of creeks that pass by each urban center and eventually merge to form Raices Creek. All wastewater, treated and untreated, from the urban areas is currently discharged into these creeks and conveyed to Lake Yojoa.

3 EXISTING WASTEWATER TREATMENT

This section documents the existing wastewater treatment infrastructure in the Municipality of Las Vegas. For each system a brief history of the technology and the basic mechanisms of treatment are described. Site-specific history such as the circumstances of construction and dimensions are also included wherever known. The wastewater treatment infrastructure in the Municipality of Las Vegas consists of two Imhoff tanks in parallel. The Imhoff tanks service roughly 3,600 residents (600 homes x 6 people per home) in central Las Vegas. Community septic tanks are used in the neighborhoods of El Mochito, but in the case of San Juan wastewater is discharged directly into rivers. During January 2008 new sewerage was under construction for the area of North Las Vegas through a grant from the government of Taiwan.

3.1 Imhoff Tanks

3.1.1 Background

An Imhoff tank is a structure designed to provide primary wastewater treatment. Throughout its history Imhoff tanks have had a variety of designs but characteristic to all is a two-story construction of a sedimentation chamber above a sludge digestion chamber (Figure 4).

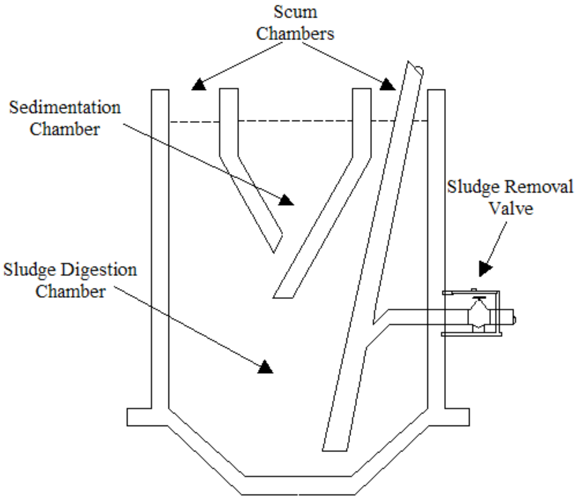


Figure 4 Imhoff Tank Schematic

Karl Imhoff invented and patented the Imhoff tank in Germany in 1906 (Herrera 2006). During the 1930's Imhoff tanks represented 50% of all wastewater treatment facilities in the United States (2006). While the majority of Imhoff tanks within the U.S. have since been abandoned or modified to adapt to changing treatment objectives and regulations, within Honduras, they continue to represent a significant portion of wastewater treatment infrastructure at approximately 40% of all documented facilities (SANAA 2000).

3.1.2 Mechanics

The tanks function on the premise that particulate matter will settle through the small opening in the base of the sedimentation chamber and into the sludge storage and digestion chamber below. The removed solids are anaerobically stabilized in the sludge storage chamber through natural biochemical and microbiological reactions until the chamber fills up. It is possible to empty the sludge storage chamber by gravity using valves located at the bottom of the tanks.

Expected treatment levels from a properly maintained Imhoff tank are the same as those for isolated sedimentation tanks without a sludge digester. Typically this will provide a very wide range of total suspended solids (TSS) removal rates (20% - 70%) and 10% - 40% for Biochemical Oxygen Demand (BOD) (Reynolds and Richards 1996). The actual removal rate for a specific tank is a function of influent water quality and hydraulic residence time. In the absence of additional treatment, sedimentation will not yield substantial reductions in other important water quality indicators such as total coliform counts or nutrient loading from phosphorus and nitrogen.

Immediately below the sedimentation tank is the sludge chamber, which includes a neutral zone between itself and the slot into the sedimentation chamber and a sludge-storage space. It is possible to empty the sludge storage chamber by gravity using valves located at the bottom of the tanks. Sludge is removed through pipes, which extend a short distance inside the hopper. Gas produced within the chamber is released through vents into a scum chamber. Differences of hydrostatic pressure may result in surges of septic sewage up through the slots (Metcalf 1935) therefore care must be paid to keep the water level in the system constant in order to avoid the reintroduction of solids into the sedimentation tank from the digestion chamber.

3.1.3 Advantages

Imhoff tanks remain a viable treatment option in certain situations for several reasons. An Imhoff tank is a low-maintenance low-cost option in comparison to many alternative technologies and they do not need large amounts of land. In the mountainous terrain of Las Vegas this advantage is significant. They also provide storage and gravity removal mechanisms for digested sludge that plain sedimentation basins do not. Furthermore, with proper planning Imhoff tanks may later be coupled with applicable forms of secondary and tertiary treatment.

3.1.4 Las Vegas

The Imhoff tanks in Las Vegas were built in 1992 with capital funds from the Honduran Fund for Social Investment (FHIS). The system consists of two tanks in parallel, shown in Figure 5.

Figure 5 Photograph of Parallel Imhoff Tanks, Las Vegas

The system was originally designed to serve 4,000 residents producing 250 liters/person/day of wastewater. They were designed by the SANAA engineer Pedro Ortiz and constructed under the supervision of the nongovernmental organization Agua Para el Pueblo (APP). According to the Executive Director of APP their construction was part of a program to create construction jobs in the area. Originally there were plans to build a large septic tank with a drainfield on land adjacent to the Imhoff tanks. However funds ran short and this was never completed (Nuñez 2008). A road now occupies this piece of land.

3.2 Septic Tanks

3.2.1 Mechanics

Similar to an Imhoff tank, a septic tank provides primary wastewater treatment. However, a septic tank consists only of a sedimentation basin, as shown in Figure 6.

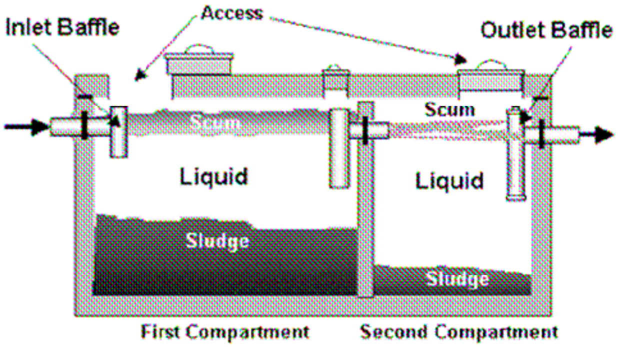


Figure 6 Tank Schematic (Seattle 2003)

A typical septic tank consists of one or two compartments and may be made of a variety of watertight materials such as concrete, fiberglass, or plastic. Tanks accept wastewater from a house or group of houses. Solids enter the tank and settle while scum floats to the top. Water exits the tank from the neutral zone below the scum and above the sludge, leaving it relatively solid-free. The U.S. Environmental Protection Agency recommends a detention time of 24 hours, which will remove roughly half of the solids and BOD_5 (EPA 2002). Sludge that is collected degrades anaerobically inside the tank. Eventually the tank will fill with sludge and must be pumped.

3.2.2 Las Vegas

Few details exist regarding the septic tanks in El Mochito. However, according to the Municipality one of the companies that owned the AMPAC Mine built a sewerage system for its employees in El Mochito. The system flows into septic tanks that serve anywhere from 4 to 30 homes (Godoy 2008b). In depth investigations were not made into the status of maintenance or the precise number of system but a brief visual inspection indicated that these tanks are in total disrepair. In the U.S. septic tanks are used in low-density areas with adequate space to construct a drainfield over which the septic tank effluent leaches through gravel from perforated pipes and is then further filtered by the natural soil. However, the septic tanks in El Mochito lack space for drainfields and therefore discharge directly into nearby creeks.

3.3 Natural Treatment

Immediately downstream of the Imhoff tank is Raices Creek. This receiving water body may be an important factor in assessing wastewater treatment options in Las Vegas. It is the way that most people in Las Vegas come in contact with effluent wastewater flows and is also the way that all wastewater is conveyed to Lake Yojoa. Some study of the creek was possible, specifically measuring the Chemical Oxygen Demand (COD) in the creek. Figure 7 highlights the flow path of the Raices Creek to Lake Yojoa.

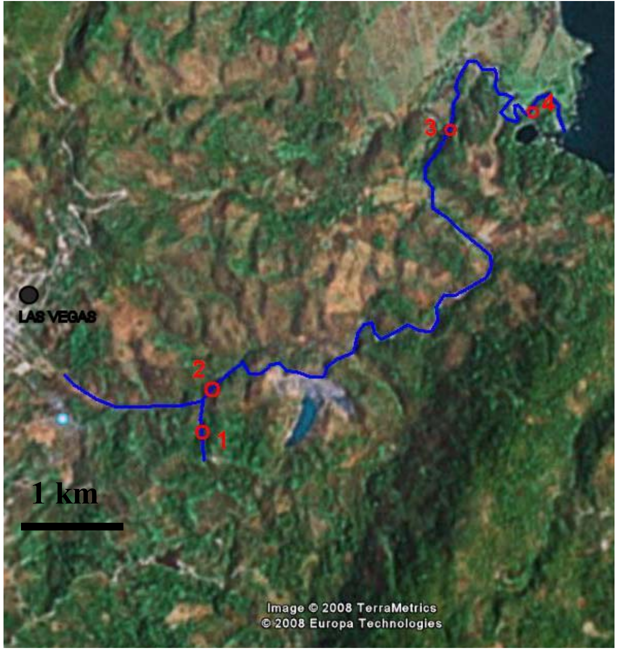


Figure 7 Flow Path of Raices Creek [Modified from (Google 2008b)]

The creek receives flows from creeks that pass through El Mochito, San Juan, and Northern Las Vegas. Currently this creek is not only accepting semi-treated effluent from the Imhoff tank, but also receiving untreated wastewater from each of these other areas. Locals who live near the creek have another name for Raices Creek that loosely translated means Feces Creek. The local community is aware of the poor water quality in the creek. All of the creeks that eventually join to form Raices Creek are steep and have relatively turbulent flow. Figure 8 is typical of the creeks.

Figure 8 Representative Section of Raices Creek

Substantial turbulent flow is to be expected given that the creek must achieve an elevation drop of approximately 250 meters in the span of only four to five kilometers. Many cascades exist in the creek as well as small areas of ponding. Both reaeration and sedimentation of BOD may be helping to naturally treat the effluent that is discharged to the creek. In an effort to understand what affect this has on the water quality of the creek COD samples were taken at various points along the creek.

Returning to Figure 7, each red circle represents a sampling location. Point 1 is immediately upstream of where the flow from the Imhoff tank joins Raices Creek. Point 2 is immediately downstream of where the flow joins the creek. Point 3 is approximately 75% of the length of the creek between the Lake Yojoa and Las Vegas, but it is still in the portion of the creek where the flow is entirely from the system of creeks. Point 4 is at the mouth of the creek where it joins Lake Yojoa. The total flow in the Creek at points 1, 2, and 3 are roughly equivalent, but at point 4 the flow is substantially mixed with the lake water. A sample of water was taken from each point and analyzed for COD. Table 1 presents the results of these tests.

Table 1 COD Concentration at Creek Sampling Points

Location	COD (mg/L)
Point 1	19
Point 2	32
Point 3	15
Point 4	1

In the results from the Imhoff tank, BOD correlated to COD with a factor of approximately 0.5 (see Appendix C). If the relationship between COD and BOD in the Imhoff tank is assumed to be valid in the creek as well, then the concentration of BOD decreases substantially prior to reaching Lake Yojoa. Three things may be responsible for the reduction in BOD concentration. They are: dilution, settling, and aerobic digestion in concert with reaeration from the atmosphere.

If the goal of treatment is to prevent organic loading from reaching the lake only, both settling and aerobic digestion would constitute treatment. Dilution on the other hand is not reducing the total mass of BOD reaching the lake. From looking at the aerial photography presented in Figure 3 and Figure 7 it is reasonable to think that there is substantial inflow from surface runoff entering Raices Creek as it approaches Lake Yojoa. From the COD measurements immediately upstream and downstream of the Imhoff tank discharge point, a mass balance of COD indicates a factor of 10 dilution upon entering the creek. The Imhoff discharge point is approximately half way along the total length of Raices Creek, so an additional factor of two dilution is expected from diffuse inflow along the remaining length of Raices Creek.

Given that the travel time to Lake Yojoa is on the order of hours and typical digestion rates for BOD range between 0.3 and 0.6 d^{-1} (Reynolds and Richards 1996), it is unlikely that aerobic processes play a substantial role in changing BOD concentrations. While the relatively substantial elevation drop from Las Vegas to Raices Creek may increase the availability of dissolved oxygen by increasing the reaeration coefficient, it also creates more turbulent flow that will prevent BOD settling from taking place. In summary, the changes in BOD concentration are most likely due to substantial dilution and to a much lesser extent settling of BOD. Aerobic processes are likely to have only a very small influence on the level of BOD in the creek. It is likely that the organic loading to the lake is reduced, but only to a small degree.

4 WASTEWATER QUALITY

Due to time constraints it was not possible to directly measure the quantity and makeup of the wastewater in all three urban areas. A study of wastewater quantity and quality was conducted for the Imhoff tank that treats the wastewater of central Las Vegas. The results of this study were assumed to apply to the other urban areas in Las Vegas, but should be validated before any detailed design for expanded treatment.

4.1 Flow

In his 2006 thesis, Herrera found and reported a study by Experco International, a Canadian environmental consulting firm. Experco conducted both water quality testing and continuous flow monitoring for a 24-hour cycle in April 2003. The results of that flow study are re-presented in Figure 9.

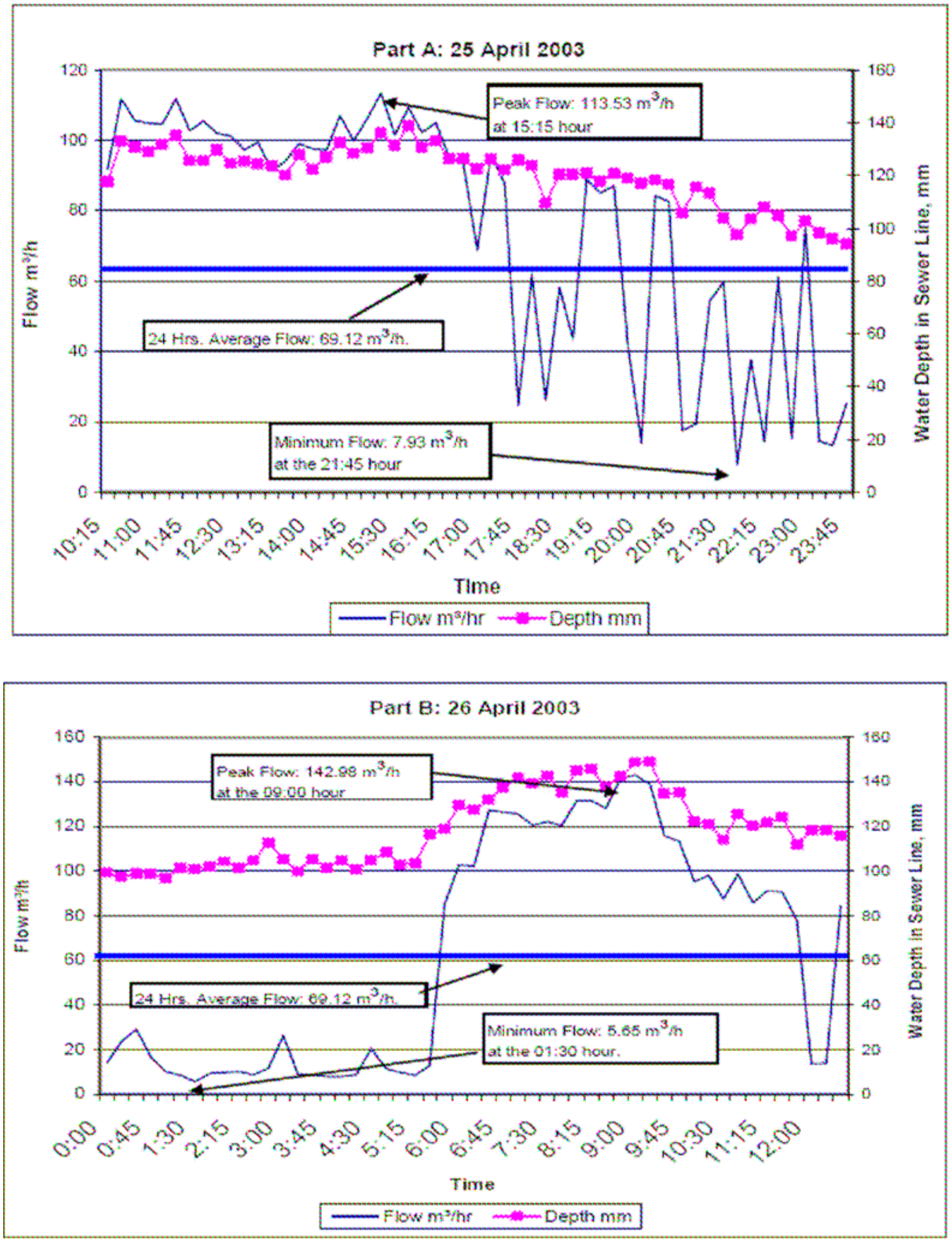


Figure 9 Diurnal Flow for Las Vegas Imhoff Tank (Herrera 2006)

From these plots, it is clear that even in 2003 the tank was overloaded. The reported peak flow from this data is 143 m^3/hr, and the daily average flow is 69 m^3/hr. Based on the original design drawings, it is clear that the flow to the tank should be substantially less than this flow (Ortiz 1991).

During the site visit in January 2008 flow data was collected and this data matches well to the Experco International data. The flow was monitored periodically between January 14 and January 25.

In the absence of a flow meter, the flow rates were collected utilizing a cross-section and velocity method. Immediately upstream of the tank, the wastewater passes through a long stretch of circular 0.305 m (12") diameter concrete pipe. At each end of this 50 m pipe is a box opening and approximately 20 m from the upstream box is a break in the top of the concrete pipe that allows for depth measurements. The velocity was measured by dropping a buoyant brightly colored object into the water (a tangerine with an approximate diameter of 5 cm) at the upstream box and timing how long the object took to arrive at the downstream box. At the same time the depth of water at the 20 meter location was measured. From this depth the area could be calculated. The velocity multiplied by the cross-sectional area is equal to the flow. Since the object is buoyant, velocity is being measured at or near the free surface where velocity will be at a maximum. Friction along the pipe wall will reduce velocity near the pipe walls. Thus it is recognized that flow measurements with this method would be an upper bound for actual average flow, but from visual inspection it is clear that there is substantial debris in the pipe and the flow is very turbulent. It was concluded that the flow as measured was a serviceable approximation of actual flow in the pipe. Table 2 presents the resulting flow rates from this monitoring

Table 2 Collected Flow Data from Imhoff Tank

Date	Time	Flow Rate
		m^3/hr
1/16/2008	09:30	191
1/16/2008	14:30	191
1/17/2008	04:30	103
1/17/2008	10:00	173
1/19/2006	14:00	161
1/20/2008	10:00	180
1/21/2008	09:30	164
1/25/2008	15:00	145
1/29/2008	10:45	170
1/29/2008	12:00	156
1/29/2008	12:30	149
1/29/2008	13:00	153

From these flow measurements, it can be concluded that the average peak flow to the tank during the day was approximately 180 m^3/hr. Given that only a single data point was collected during low flow times it is not possible to say that 103 m^3/hr represents an average value for low flow periods. It is, however, clearly an indication that there is substantial flow in off peak hours. Based on visual observation of the tank during the site visit and analysis of the data collected by Experco International, it is appropriate to consider the tank to have a two-stage diurnal flow. This two-stage flow is composed of a daytime flow that varies between 190 m^3/hr and 160 m^3/hr and a nighttime flow that varies between 60 m^3/hr and 100 m^3/hr. Assuming 18 hours of daytime flow and 6 hours of nighttime flow and 6 people per residence, this flow is equivalent to approximately 1,000 L/person/day. To give a frame of reference for this value, typical values for design of wastewater treatment in Western Europe are on the order of 200 L/person/day. Wastewater production in Las Vegas on a per capita basis is extremely high and warranted further investigation. In talking with municipal staff some potential sources of non-domestic wastewater emerged.

Potential additional sources of influent water include: infiltration of groundwater and storm-water, cross-connects with storm-water piping, non-domestic water usage, and illegal connections. It was observed that TSS on off peak hours is very low. This suggests that relatively clean water is entering the sewerage system in Las Vegas. Evidence is also available that supports the idea of non-domestic wastewater production. Figure 10 is a photograph taken of the scum chamber of the Imhoff tank.

Figure 10 Photograph of Coffee Beans Present in Wastewater

De-pulped coffee can clearly be seen in the wastewater. This region of Honduras grows coffee commercially. The municipal engineering staff indicated that in de-pulping coffee, water is allowed to run over the picked beans for upwards of 24 hours (Godoy 2008a). It appears from this photograph that the de-pulping of coffee is an activity that may be carried out in the home. Depending on the extent of in home de-pulping, this may represent a substantial portion of clean water inflow. Finally, illegal connections are a known, but un-quantified source of flow in the Municipality. It is not uncommon for an existing residence to illegally plumb its own connection to a sewer main in order to avoid paying initial connection and monthly charges for service. The cumulative effect of these sources explains the substantial wastewater production in Las Vegas.

4.2 Contaminants

In order to assess the performance of the Imhoff tank and to understand the characteristics of wastewater in Las Vegas, wastewater samples were taken from the influent and effluent channels of the tank. Four measures of water quality were used: TSS, COD, BOD, and total coliforms (TC). Details of this testing can be found in Appendix B.

Table 3 presents the removal rates for the water quality characteristics that were monitored during the site visit. For all test data refer to Appendix C.

Table 3 Treatment Performance of Imhoff Tank Without Remediation

Characteristic	Influent	Effluent	Percent Change
TSS	190 mg/L	140 mg/L	- 26%
BOD	150 mg/L	120 mg/L	- 19%
COD	320 mg/L	260 mg/L	- 19%
TC	500×10^6	1800×10^6	+ 260%

The results of the assessment of the performance of water quality for the influent and effluent flow to the Imhoff tank are comparable to the values that would be theoretically expected for an undersized sedimentation tank (Reynolds and Richards 1996). The only abnormal result that was found was the substantial increase in TC passing out of the Imhoff tank. While sedimentation is not considered an effective method for coliform removal, it is an effective method for solids removal. It is expected that a large portion of bacteria, especially fecal coliforms would be attached to the fecal matter (solids). Therefore it is logical to expect at least some reduction in TC concentrations.

A potential reason for this situation was found through visual inspection. It was observed that methane gas is released from the digestion chamber through the central sedimentation tank as well as the scum chambers. At times this gas carries up to the surface large masses of partially digested solids. These solids, which would likely be very high in bacteria, do not immediately descend to the bottom of the chamber when the methane bubble breaks. Instead they float on the surface. When this occurs close to the outlet of the Imhoff tank they become part of the effluent water. This bubbling and solids reintroduction is a regular occurrence and may explain the increase in TC concentrations. Imhoff tanks are actually designed to prevent just this situation, so it is possible that the Imhoff tank in Las Vegas was not correctly built and remediation may be necessary. This is likely a result of a mistake in design or in construction and can only be remedied by actual modification to the bottom of the sedimentation chamber.

5 MAINTENANCE

Las Vegas has already invested substantial capital into the construction of Imhoff and septic tanks: however without proper maintenance the systems will not provide the treatment of which they are capable (up to 70% removal of TSS and 40% removal of BOD_5). In fact, without maintenance certain water quality parameters may even worsen as the wastewater flows through the systems (i.e. total coliforms). Regular maintenance of the systems is not a complex or expensive proposition. This section describes the history of maintenance to-date on the systems, several proposed solutions, and outlines the tasks that a designated operator should perform on a regular basis.

5.1 Imhoff Tank Maintenance

5.1.1 Sludge Removal

The Las Vegas Imhoff tanks did not receive maintenance until December 2007 when the municipality cleaned the digestion chambers for the first time since 1992. The procedure took three men two days. Sand and other compacted solids clogged the valves at the base of the tank that were constructed for sludge removal. This resulted in several of the discharge pipes needing replacement after the cleaning. The sludge was emptied from the digestion chamber by rope and bucket. After removal it was buried along side of the Imhoff tanks. The simplest forms of sludge disposal are incineration, land application, or burial. For future disposal of sludge, it will be necessary to dewater the sludge so it can be handled more easily. Therefore the construction of a sludge drying bed is perhaps the most important step towards regular maintenance that the Municipality can take. A sludge drying bed is an open area with a porous media (typically sand over gravel) as a base and some form of walls to contain the sludge. Despite lack of sludge removal for 16 years, the tanks are in good structural condition.

Recommendations:

- Semiannually, remove sludge (approximately 40 m^3).
- Design and build a sludge drying bed adjacent to the Imhoff tanks.

5.1.2 Flow

Flow between the two Imhoff tanks is not evenly distributed. This results in unequal residence times and less than optimal removal of solids. There are several correctable causes of uneven flow distribution. The first is poor quality and improperly utilized flow gates. A flow gate is a wooden board placed in the channel along the periphery of the Imhoff tanks. It is designed to prevent influent wastewater from circumventing treatment by flowing through the channel to the outlet instead of through the tank. Flow gates should be located in eight positions in the bypass channel that surrounds the sedimentation chambers (Appendix D). The flow gates should be used to bypass the sedimentation chambers during cleaning. They should also be used to periodically reverse the flow so that solids will be deposited along the entire length of the digestion chamber rather than primarily in the effluent end.

An effort to install flow gates was made in January 2008. Wooden gates were put in place, but many of the gates short-circuited because the boards did not create a good seal with the concrete channel. The plumbers of Las Vegas came up with the idea of using bags of sand as further means to block the flow behind each wooden flow gate. The bags are easier to remove and did a better job than the wooden flow gates alone.

Recommendations:

- Maintain eight flow gates consisting of wooden planks and bags of sand (Figure 11).
- Monthly, use the gates to reverse the flow through the system (directions in Appendix D).

Figure 11 Wooden + Sand Bag Flow Gate

The inlets into the sedimentation chambers do not facilitate even flow distribution between and within the two Imhoff tanks. Wooden baffles with two rows of holes were implemented during January 2008 to even out the flow (Figure 12).

Figure 12 Wooden Baffles

Approximately 13 holes per row were installed using a hand drill. They were approximately one inch in diameter and spaced one inch apart. The positioning and size of the holes was done through trial and error. An operator should continue to balance the flow through whatever means available. The ultimate goal is to have even flow in both Imhoff tanks and for that flow to spread across the entire width of the sedimentation chambers. While the baffles do help to even out the flow distribution they also clog very easily because there is no grit chamber prior to the sedimentation chambers. Plastic bags and large pieces of fecal matter block the holes after several hours. Once the holes are blocked the water flows over the top of the baffles, but even when this occurs the flow distribution is still better than without the baffles in place. Cleaning the baffles requires poking a stick in the holes and removing plastic bags. It was observed that this transforms the influent channel into a grit chamber where many more solids are deposited. An effort must also be taken to clean this out more frequently.

Recommendations:

- Daily cleaning of the influent channel and baffles.
- Daily examination and equalization of flow.

5.1.3 Scum

Gases generated during sludge digestion produce bubbles that rise to the surface of the tank carrying with them partly digested solids. The majority of the gas and solids rise in the scum chamber portion of the tank. As a result a layer of solid crust forms in the scum chambers (Figure 13).

Figure 13 Scum Chamber Filled with Digested Solids

This layer must be routinely broken up in each of the four scum chambers to allow gas to escape easily from the digestion chamber. A simple tool like a shovel can be used to remove scum from the scum chambers. The operator can construct a scraper similar to the one shown in Figure 14 that is used by the operator in Marcala, La Páz, Honduras.

Recommendation:

- Bi-weekly removal of scum from all scum chambers and sedimentation chambers.

5.1.4 Sedimentation Chamber

In order to achieve the highest possible levels of solids removal from the sedimentation chamber an operator needs to routinely clean the tanks. A rubber squeegee can be used along the sloping walls of the settling compartment to remove any solid material. This can be preformed while the tanks are full of water. This prevents scouring and deposits the material into the lower chamber where it can be properly digested. Secondly, the operator should ensure that the slot between the sedimentation chamber and digestion chamber remains free of obstruction. Dragging a chain and prodding with a long metal stick are two possible methods.

Figure 14 Operators Equipment in Marcala, Honduras

Recommendations:

- Weekly removal of solids from sloped sides of sedimentation chamber.
- Bi-Weekly inspection that slot to sludge digester remains open.

5.1.5 Records

Keeping accurate and updated records of the conditions at the Imhoff tanks is crucial to further optimization of the system and fixing any problems that may arise. The operator should document each day which of the tasks described above were performed and any difficulties that arose during the maintenance.

Recommendations:

It is also advised to record the following statistics:

- Daily, flow into the system
    - Consider constructing a weir, but at least perform a calibrated velocity-area flow measurement as follows:
        - Drop a tangerine or other small piece of fruit into the straight portion of the influent channel.
        - Record the distance traveled, time to travel this distance, and depth of water in the pipe.
        - Calibrate the measurements by measuring the flow rate leaving the tank.
        - From these numbers flow can be calculated from area and velocity.
        - Record the date and time of measurement.

- Monthly, height of sludge in the digestion chamber

  - Insert a long rod into the tanks until the bottom of the digestion chamber is hit.
  - Remove the rod and record the length of the rod that is covered in sludge.
  - Repeat at the influent and effluent ends of each tank.

- Semi-annually, measure the quantity of sludge removed from system. This could be measured in the number of buckets manually removed or if using the sludge valves as a flowrate accompanied by the length of time of removal.

5.2 Septic Tank Maintenance

Sludge needs to be removed from septic tanks as well. The time between removals depends on the size of the system and loads entering the tanks but will probably be several times a year. A detailed survey of the septic tanks in El Mochito should be performed. At a minimum the survey should measure the quantity of flow into each system, the size of the tanks, and the state of maintenance. After completion of this survey, a detailed maintenance plan such as the one just described for the Imhoff tanks can be developed.

5.3 Sludge Drying Beds

A sludge drying bed is an open area with a porous media (typically sand over gravel) as a base and some form of walls to keep sludge in the specified area. Figure 15 provides a schematic diagram of a typical sludge drying bed.

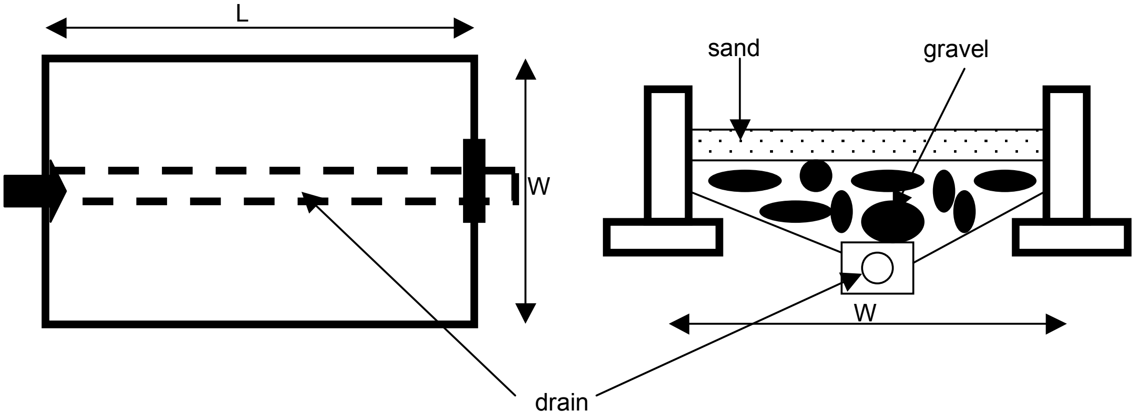


Figure 15 Typical Design for Sludge Drying Bed

After digested sludge is removed from a wastewater treatment installation, it is composed mostly of water. The solids content of digested sludge typically ranges from 10% to 15% (Reynolds and Richards 1996). As such, it is not easily handled. If the sludge is dried, then the solids content can reach as high as 40% (Reynolds and Richards 1996). Once this process has been completed, sludge can be handled much more easily and can be moved for final disposal in a landfill, incineration, or agricultural applications.

A sludge drying bed achieves the removal of water by both drainage of water through the porous media and by evaporation of water to the atmosphere. The required maintenance is minimal and typical sizing is usually in the range of 6 m – 9 m by 8 m – 38 m, for an individual bed. In the case where more drying area is needed, multiple beds can be built side by side. In dryer environments appropriate drying typically occurs in 2 to 4 weeks (Reynolds and Richards 1996). In the case of Las Vegas it will be important to include a roof or other cover structure to prevent rain from diluting and rewetting the sludge in the drying bed. Sludge removal and processing is a critical step in any wastewater treatment system that generates sludge. It is necessary in both a centralized system design and a decentralized system design. For detailed calculations of appropriately sized sludge drying beds for Las Vegas, see Appendix F.

6 EXPANDED WASTEWATER TREATMENT

The Municipality of Las Vegas is committed to reducing the impact that it has on Lake Yojoa. It was clear in meeting with the Mayor, Carlos Fuentes, and other stakeholders around the lake that there is a perception that Las Vegas is one of the major polluters of Lake Yojoa. In addition to having a perception as a polluter, the Municipality is also engaged in an extensive program of development, which includes expansion of electricity services, expansion of paved roads, and expansion of sewerage. As of December 2007 the Municipality had already secured funding from the government of Taiwan to expand and improve wastewater collection in the area. Whether motivated by public perception or by development goals, the Municipality has committed to expanding sewerage and wastewater treatment. The question becomes, what will be the best system for Las Vegas? This depends on the level of treatment that the municipality wants to achieve and what limitations it faces for new projects.

In Honduras, there are many levels of treatment that Las Vegas may aspire to achieve. One potential set of objectives are the national wastewater effluent standards, presented in Table 4.

Table 4 Honduras National Effluent Standards(Sanamiento 2005)

Effluent Regulations	
Parameter	*Max Permitted*
BOD_5	50 mg/l
COD	200 mg/l
Total Kjeldahl Nitrogen	30 mg/l
Ammonia as Nitrogen	20 mg/l
Total Phosphorous	5.0 mg/l
pH	6.0 – 9.0
Sulfates	400 mg/l
Aluminum	2.00 mg/l
Settleable Solids	1.0 ml/l/h
Suspended Solids	100 mg/l
Total Fecal Coliforms	5000/100 ml

These standards apply across all of Honduras. These standards, however, are very demanding given that few municipalities in Honduras have treatment systems that are more advanced than primary treatment. An alternative framing of treatment goals was suggested by Pedro Ortiz of SANAA. In an interview at the SANAA headquarters in Tegucigalpa, he indicated that it would make more sense for municipalities to focus on prioritizing wastewater treatment instead of trying to achieve unrealistic national standards. Ortiz pointed out that many of the receiving water bodies in Honduras have substantial elevation change over short distances, which leads to the entrainment of oxygen in the water. He believes that it is better to focus on solids removal in primary treatment and particularly focus on methods to remove pathogens from effluent water in secondary treatment (Ortiz 2008).

While the recommendation to focus on solids removal and pathogen removal are well reasoned and apply generally to wastewater treatment across Honduras, a third approach that Las Vegas can pursue is to prioritize its own wastewater treatment needs. In Las Vegas, at present, there is only limited exposure to wastewater. Once wastewater enters the system of creeks that conveys the water to Lake Yojoa, there is only one community that comes into regular contact with the contaminated water. Immediately downhill of the Imhoff tank that treats wastewater from central Las Vegas, there is a community of approximately 25 families that cross through Raices Creek every day as they walk the road between their residences and central Las Vegas. Other than that, no measurable portion of the population comes into contact with the stream until it reaches Lake Yojoa. The lake can act like an enormous detention pond where natural die off rates of microorganisms will eliminate nearly all pathogens. It may in fact make sense for Las Vegas to focus exclusively on the removal of solids from wastewater.

In addition to the goals for treatment, the available resources of Las Vegas will play a role in determining the best wastewater treatment options for Las Vegas. Las Vegas has substantial financial resources from multiple sources, including: the AMPAC Mine, the government of Taiwan, and the United States Agency for International Development. This is likely atypical of municipalities in Honduras, but Las Vegas does face limitations regarding land, technical expertise, and political processes.

Las Vegas is a large area, but it is also in the center of Honduras, which is a mountainous region. There is very little flat land available for large infrastructure projects. Similarly, there is very little clear land and thick vegetation and trees cover any undeveloped land. Any large-scale infrastructure project would require enormous amounts of earthwork. The one exception to this is the area that was cleared during the construction of the Imhoff tank. This area is approximately 20,000 m^2 (determined from aerial photography). This number can serve as the upper limit for the footprint of any additional wastewater treatment facilities.

In addition to limited availability of land, Las Vegas is constrained by available technical expertise. The Municipality has one civil engineer on staff that is responsible for everything from wastewater treatment, to road construction, to maintenance of government buildings. The technical capabilities of the Municipality does not include the kind of expertise necessary to operate modern wastewater treatment facilities like what is found commonly in the United States. An added problem with any modern system is the availability of materials. There are hardware stores in Las Vegas, but anything that must be imported can take months to arrive in Las Vegas.

Politics play a role in everything in Honduras, including public services like wastewater collection and treatment. The entire staff of a municipality is changed when a new mayor is elected. This is especially true when the new mayor is from a different political party. The complete changeover of staff calls into question whether any of the improvements that are made during the current mayor's term of office will be maintained. Las Vegas is limited by project horizons. Long term planning is nearly impossible in this political situation. Any wastewater treatment design should take into account all of these factors.

Maintenance is clearly an important part of improving wastewater treatment in Las Vegas. Maintaining the existing facilities will provide treatment to those residences that are already connected to sewerage. A substantial portion of the population in Las Vegas is not connected to a treatment system of any type. Las Vegas will need to expand treatment to reduce the overall impact on Lake Yojoa. This will require the construction of new infrastructure. An alternative for Las Vegas is to increase the capacity of existing infrastructure, specifically the Imhoff tank. The options for this alternative are somewhat limited, but one worthy of investigation is the use of chemically enhanced primary treatment.

6.1 Chemically Enhanced Primary Treatment (CEPT)

Chemical treatment of wastewater involves the use of coagulants such as metal salts to bind together suspended solids. The larger conglomerations of suspended solids produce increased particle removal through gravitational settling. Due to the higher suspended solids removal rates of chemical treatment (commonly around 80%) there is also an increased removal of BOD (around 40-60%). Examples of chemical additives to wastewater are aluminum sulfate (alum), ferric chloride, ferric sulfate, and lime. Adding chemicals to wastewater is not a new treatment process. As early as the 1870s there are reports of its use in England. In fact during the early 1900s it was also commonly utilized in the United States. This was before the development and widespread adaptation of biological treatment (Parker 2001). Adding coagulants to Imhoff tanks in Honduras is a new concept.

Realistically there are long lead times associated with obtaining funding and for the construction of new infrastructure. Therefore, bench scale and pilot testing of CEPT within the Imhoff tanks was performed during January 2008. The goal of the investigations was to determine if CEPT is an immediate interim solution towards meeting national effluent regulations using existing structures. An additional goal of the study was to determine if, with CEPT, the Imhoff tanks could handle surface overflow rates such that the Imhoff tanks might also be able to accommodate modest service area expansions. The recommendations are based on the following:

1) Available local coagulants
2) Potential TSS and COD removal efficiencies
3) Dosage of coagulant and cost
4) Additional sludge production
5) Feasibility of chemical injection

6.1.1 Available Coagulants

Choice of coagulant in Honduras is very limited. The only readily available coagulant is solid alum, which is widely used in water treatment plants in Honduras. Attempts to obtain iron based metal salts were futile. Wastewater is a complex substance. Depending on local conditions, such as pH, different chemicals are more or less effective. Having only one option limits the optimization process of CEPT. The alum used during January 2008 was in powdered form and obtained as a gift from Aguas de San Pedro to Las Vegas. The bags indicated it was imported from the Chilean company Fábricas Arteaga. Fábricas Arteaga sells solid alum as $Al_2(SO_4)_3 \cdot 14H_20$ (17% as Al_2O_3). This would be 90,020 mg/kg of total Al. Laboratory analysis of the alum used during January 2008 indicate 78,000 mg total Al/kg dry sample.

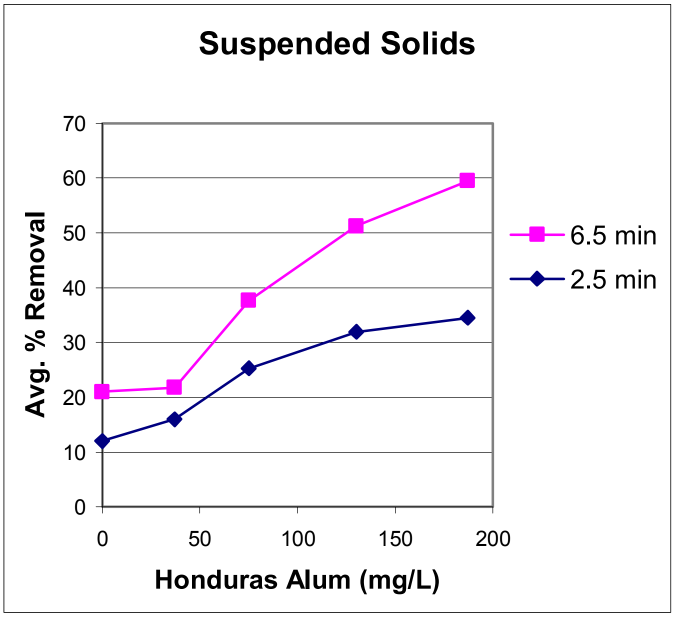
6.1.2 Potential TSS and COD Removal Efficiencies

Bench Scale

Jar testing was performed during January 2008 using a mechanical stirring apparatus with 2 L beakers. A standard mixing and settling regime was utilized. Before chemical addition the jars were stirred to suspend any solids that had settled during the set up of the experiment. Afterwards various dosages of chemicals were injected into the jars and the samples were stirred for 30 seconds at 100 rpm. Samples were taken after the jars had settled for 2.5 minutes and 6.5 minutes and tested for suspended solids, and COD. A retention time of 2.5 minutes in the jars corresponds to a surface overflow rate (SOR) of 0.06 m/min. A retention time of 6.5 minutes in the jars is a SOR of 0.02 m/min. The results are displayed in Figures 16 and 17.

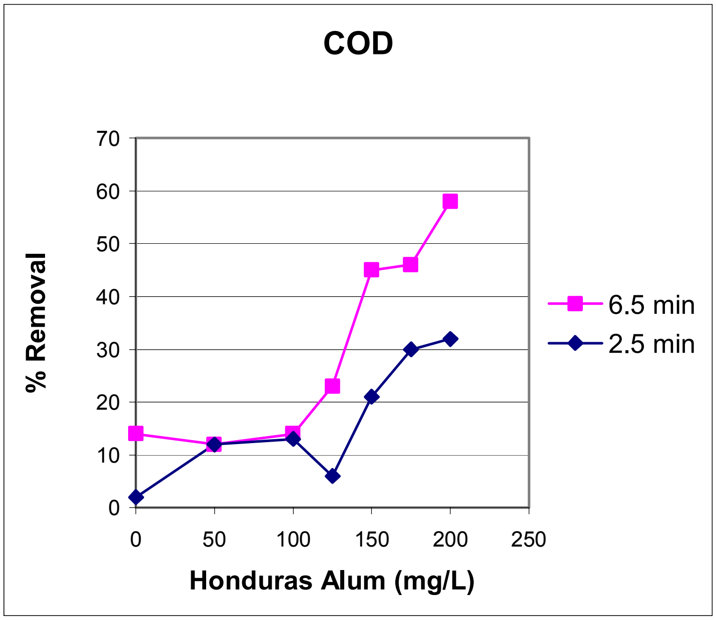
The jar tests were repeated several times for many of the different chemical dosages. The graph in Figure 15 was produced first by averaging the results of these various trials at each dosage and then taking these values and averaging across a range. For example the point at 75 mg/L represents the average of the values for 60, 70, 80, 90, and 100 mg/L. Due to a limited supply of COD reagents COD was only tested once, after the range of dosages had been determined.

The SOR for the Imhoff tanks in Las Vegas varies throughout the day. The lowest observed flow was 103 m^3/h at 4:30 am and the peak flow was observed to be 191 m^3/h at 9:30 am. The surface area available for sedimentation is (2.33 m width) x (10.5 m length) x (2 tanks) = 49 m^2. Therefore the corresponding peak SOR is 0.06 m/min and low flow SOR is 0.035 m/min. It is expected that the Imhoff tanks in Las Vegas would behave somewhere between the 2.5 min and 6.5 min settling in the jar testing.



Range (mg/L)	Dosage (mg/L)	#pts. 2.5 min	#pts. 6.5 min
0	0	13	13
37	25	1	1
	50	2	2
75	60	2	2
	70	1	1
	75	1	1
	80	2	2
	90	4	4
	100	6	6
130	110	5	5
	120	2	2
	125	3	3
	130	2	2
	140	1	2
	150	3	2
187	175	2	2
	200	1	2

Figure 16 Suspended Solids Results



Number of Samples: 1
per data pt.
Initial SS: 138
Initial COD: 290
Initial NTU: 134
Initial pH: 8.1

Figure 17 COD Results

Pilot Test

A pilot test of CEPT was run for 1.5 hours (approximately 3 times the residence time of the Imhoff tanks) with alum dosed at approximately 150 mg/L starting at 11:30 am. Flow rate and influent and effluent samples were taken every 30 minutes after the alum was introduced. Using the flow rate, the measured TSS and COD values were adjusted to account for the residence time. This data is presented in Table 5.

Table 5 Pilot Test Results

Time	Flow (m^3/h)	Residence Time (min)	Influent (mg/L)	Influent (Time Adjusted)	Effluent (mg/L)	% Removal	*% Avg. Removal*
			TSS				
10:30 am	169.2	35	200	-	-	-	53
12:00 pm	156.2	38	210	206	110	47	
12:30 pm	149.8	40	320	209	100	52	
1:00 pm	153.0	39	130	286	115	60	
			COD				
10:30 am	169.2	35	407	-	-	-	57
12:00 pm	156.2	38	493	456	185	59	
12:30 pm	149.8	40	221	484	120	75	
1:00 pm	153.0	39	286	302	187	38	

Looking carefully through Table 5 one should immediately notice that during the pilot test the influent was experiencing an above average slug of COD. The authors recall that the water looked substantially more concentrated with feces on the morning of the pilot test than other mornings working at the Imhoff tanks. Therefore for the purpose of comparison with the bench scale jar testing the conditions at 1:00pm will be used and the corresponding 38% removal. For a dosage of 150 mg/L bench scale testing predicted COD removal of 21% for a SOR of 0.06 m/min and 45% for a SOR of 0.02 m/min. Bench scale testing also predicted a suspended solids removal of 34% for a SOR of 0.06 m/min and 55% for a SOR of 0.02 m/min. The average SOR for the Imhoff tanks on the day of the pilot test was 0.053 m/min; however both the suspended solids and COD removal more closely resembles the predictions for the smaller SOR of 0.02 m/min. This confirms that the jar testing curve of 6.5 min corresponds more closely to the actual conditions in the Las Vegas Imhoff tanks.

A primary goal of the use of CEPT is to meet the national effluent regulations of 200 mg/L for COD and 100 mg/L for TSS. All of the COD effluent samples taken while using CEPT achieved this goal while the baseline sample taken at 10:30am did not. TSS only achieved the regulation for one of the three samples, but was close for the other 2.

6.1.3 Dosage of Coagulant and Cost

At 190 mg/L average influent of TSS and 320 average influent values for COD, the loads on the Las Vegas Imhoff tank are not particularly concentrated for typical domestic sewage. However, they still need 38% removal rates for COD and 47% removal rates of TSS in order to meet Honduran regulations of 100 mg/L TSS and 200 mg/L COD. The bench scale testing suggests that this cannot be achieved for the surface overflow rate of 0.06 m/min, but for 0.02 m/min a dosage of around 150 mg/l would be appropriate. The pilot test supports this dosage. However this is a very costly solution even if run for only 18 hours a day (at night the levels of contaminants are not likely to exceed regulations). The company Tecno Quimica is the largest chemical supplier in Honduras and has offices in both Tegucigalpa and San Pedro Sula. They sell alum in 50 kg bags at 500 Lempiras per bag. (there are approximately 20 Lempiras to the dollar). The cost of chemicals alone would be: 10 Lempira/kg x 180 m^3/h x 18 h/day x 1000 L/m^3 x 150 mg/L x 1kg/1,000,000mg = 4,860 Lempira/day ~ $243/day.

6.1.4 Additional Sludge Production

A major concern with chemical addition is the effect on sludge production both in terms of quantity and quality. Sludge from chemical precipitation of alum is more gelantinous than primary sludge lacking chemical addition. This may lead to sludge that is more difficult to dewater.

Sludge production was calculated for three scenarios. Scenario A) No Maintenance (26% removal TSS) results in 184 kg/day of sludge. Scenario B) With Maintenance (40% removal TSS) results in 283 kg/day of sludge. Scenario C) With CEPT results in 469 kg/day of sludge. It is important to note that while the amount of sludge markedly increased in the CEPT scenario about half of this increase is due to the increased removal of solids, which is the goal of the treatment. Only 18% of the sludge produced in the CEPT scenario is due to chemical precipitation. An added bonus of CEPT is that it helps to remove phosphorus. Phosphorus removal represents 2% of the CEPT sludge. Figure 18 shows the full breakdown of the sludge produced due to the CEPT scenario.

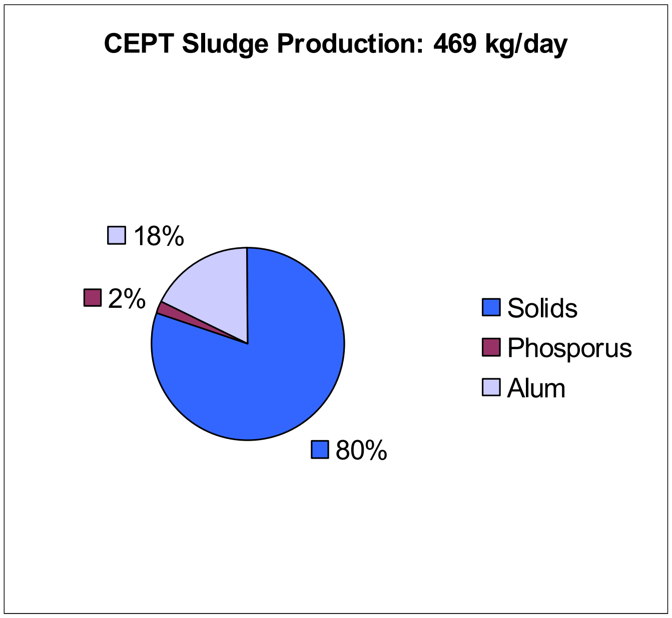


Figure 18 CEPT Sludge production

6.1.5 Feasibility of Chemical Injection

Currently, injecting chemicals is not an easy task in Las Vegas. Regular injection of chemicals would require the construction of a feed system that can maintain a constant but adjustable flow. Additionally the chemicals would be added in solution not solid form, which requires a water supply near the Imhoff tanks. This is not currently available.

6.1.6 Conclusion

The final recommendation is that CEPT is costly and that through improved maintenance and water conservation the Municipality of Las Vegas may greatly increase their level of wastewater treatment for a fraction of the cost. A more detailed overview of the methods and an in-depth discussion of the results of the CEPT bench and pilot scale studies are fully documented in Anne Mikelonis' thesis "Chemically Enhanced Primary Treatment of Wastewater in Honduran Imhoff Tanks" (Mikelonis 2008).

6.2 New Infrastructure Expansion

While CEPT serves to improve primary treatment, the cost of chemicals makes it somewhat prohibitive for Las Vegas. It will be more cost effective for them to expand basic treatment throughout the Municipality instead of incremental improvements for a portion of the population. After determining the goals and limitations for the situation in Las Vegas, it is possible to consider the technology options available to Las Vegas, but prior to that, it is instructive to review the basic principles that are relevant to wastewater treatment.

6.2.1 Background

The treatment of wastewater has two stages. The first stage is the removal of contaminants from water and the second stage is the final elimination of these contaminants. There are three types of processes that can be used to achieve both removal and elimination of contaminants. These processes are: physical, chemical, and biological. Physical processes are used principally in the removal stage of wastewater treatment while biological and chemical processes are used in both the removal and the elimination stage of the treatment. Most treatment systems will incorporate more than one process to effectively reduce the environmental impact of wastewater. A description of each process is supplied here to enhance understanding of the actual technology options available in designing a wastewater treatment system.

The dominant physical process used in wastewater treatment is sedimentation. Sedimentation takes advantage of the fact that much of the contamination in wastewater is in a solid form. If these solid particles are denser than water they will tend to sink and settle out of the water column. For Reynolds numbers less than 0.3, according to Stoke's Law (Tchobanoglous et al. 2003), the velocity at which a particle will settle out of the water column can be calculated with Equation 1.

$$v_s = \frac{2}{9}\frac{r^2 g(\rho_p - \rho_F)}{\mu} \qquad (1)$$

where:

v_s = settling velocity
r = radius of the particle
g = constant of gravity
$\rho_{P,F}$ = density of the particle or fluid
μ = dynamic fluid viscosity

This process of settling can be utilized to remove "settleable" contaminants by forcing wastewater into a tank whose dimensions are such that particles will fall to the bottom of the tank before they exit the tank. By calculating the vertical settling velocity and the horizontal flow velocity of the water, it is possible to size a tank to remove a large portion of contaminated particles from wastewater. The key parameter in the sedimentation of solids from wastewater is hydraulic residence time (equation 2). The hydraulic residence time is the average time that a parcel of water spends in a tank.

.

$$\tau = \frac{V}{Q} \qquad (2)$$

where:

Q = Flow to Sedimentation Tank
V = Volume of Sedimentation Tank
τ = Residence Time

As has already been mentioned, chemical processes can be used in the removal of contaminants from wastewater or for the elimination of contaminants. In the case of removal of contaminants, chemical processes are most commonly used to enhance sedimentation, but can also be used to disinfect, as in the case of chlorination (for further discussion the see Chlorination later in Appendix E).

Finally, biological processes are used in the removal and elimination of contaminants in wastewater, but are most commonly used in digestion (elimination) of contaminants. Biological processes eliminate many types of contaminants ranging from chemical, such as nitrogen, to microorganisms and pathogens. The process of eliminating all of these contaminants is known as digestion. Generally speaking digestion is the consumption of contaminants by living bacteria and microorganisms to fuel growth and reproduction. The individual agents and interactions that are involved in digestion are complicated and varied, but the processes can be understood in two forms: aerobic digestion and anaerobic digestion. Aerobic digestion occurs in the presence of oxygen. Conversely, anaerobic digestion occurs in the absence of oxygen. Equation 3 (Aerobic digestion) and Equation 4 (Anaerobic digestion) (Reynolds and Richards 1996) provide generic equations to represent these biological processes.

$$OrganicMatter + Free\_O_2 \rightarrow New\_Cells + NH_3 + 3CO_2 + H_2O + Solids \qquad (3)$$

$$OrganicMatter + Combined\_O \rightarrow New\_Cells + CH_4 + CO_2 + Solids \qquad (4)$$

These processes remove approximately 99.8% of fecal coliforms present in the sludge (Reynolds and Richards 1996) as well as a substantial fraction of volatile solids. Each biochemical reaction described above is catalyzed by microbes that thrive in the particular environment (e.g. aerobic microbes in aerobic digestion and anaerobic microbes in anaerobic digestion). Wastewater treatment technologies utilize at least one of these three types of processes and often utilize combinations of all three to achieve removal and elimination of contaminants.

6.2.2 Screening of Technologies

There are many types of wastewater treatment technologies for the Municipality of Las Vegas to choose from. Appendix E provides a description of many forms of conventional wastewater treatment technology that have not been described previously. Prior to actual design it makes sense to determine which technologies can be screened out by the goals and limitations of Las Vegas.

The best wastewater treatment system for Las Vegas is a low maintenance, small footprint, gravity driven, and highly durable system. This will enable whatever system is put into place to overcome the limitations of technical expertise and availability of land as well as potential changes in municipal governance. To determine which technologies meet these criteria, Table 6 presents each of the conventional wastewater treatment technologies available to Las Vegas. For a full description of these technologies see Appendix E.

Table 6 Conventional Wastewater Treatment Technologies

Technology	Removal of Contaminants	Elimination of Contaminants
Sedimentation Tank	Physical (settling)	None
Septic Tank	Physical (settling)	Biological (anaerobic digestion)
Imhoff Tank	Physical (settling)	Biological (anaerobic digestion)
Waste Stabilization Pond (Anaerobic)	Physical (settling)	Biological (anaerobic digestion)
Waste Stabilization Pond (Facultative)	Physical (settling)	Biological (anaerobic digestion)
Waste Stabilization Pond (Maturation)	None	Biological (aerobic digestion)
Trickling Filter	None	Biological (aerobic digestion)
Upflow Anaerobic Sludge Blanket	Physical (settling)	Biological (anaerobic digestion)
Activated Sludge	None	Biological (aerobic digestion)
Latrine	Containment	Biological (aerobic digestion)
Chemically Enhanced Primary Treatment	Chemical	None
Constructed Wetlands	Physical (settling)	Biological (aerobic digestion)
Aeration	None	Biological (aerobic digestion)
Chlorination	None	Chemical (disinfection)

Each technology has a substantial cost either in the form of installation or operation or both. The cost of a technology comes in three forms: land, electricity, and chemical supplements. Depending on the location of a wastewater treatment facility, the monetary value attached to each of these types of cost will vary and in combination with the required level of treatment will be the deciding factor in selecting an appropriate technology for wastewater treatment. Table 7 groups the technologies by the type of cost they incur (need for land, need for electricity, or need for chemical supplies) and ranks them within each type in order of ascending cost.

Table 7 Grouping of Wastewater Treatment Options by Cost

	Land	**Electricity**	**Chemical Supplements**
order of increasing resource demand ↓	Latrine	Aeration	CEPT
	Septic Tank	Activated Sludge	Chlorination
	Sedimentation Tank	UASB	
	Imhoff Tank		
	Trickling Filter		
	Waste Stabilization Ponds		
	Constructed Wetlands		

Beyond the cost of a facility it is important to evaluate the capacity and technical expertise required to conduct maintenance. Figure 19 plots all of the technologies on axes that represent technical expertise and a qualitative measure of residents served (capacity).

		Capacity		
		Low	**Medium**	**High**
Technical Requirements	**Low**	Latrine	Septic Tank Sedimentation Imhoff Tank	Waste Stabilization Pond
	Medium		UASB CEPT Trickling Filters	Constructed Wetlands
	High		Aeration	Activated Sludge Chlorination

Figure 19 Relative Technical Requirements and Capacity of Treatment Technologies

Now with an understanding of the form and relative cost of conventional wastewater technologies as well as an understanding of the technical requirements for maintenance and the capacity of each technology, it is possible to look at the case of Las Vegas and make preliminary recommendations about the best options for the Municipality.

6.2.3 Discussion

An analysis of the conventional technologies available to Las Vegas reveals that there are multiple tradeoffs involved with each option. This section detailed the relative positions of the various technologies so recommendations can be made to Las Vegas to provide the most economical means to achieve their wastewater treatment goals. The perfect technology for Las Vegas exists in the upper right corner of Figure 18. The optimal technology is also in the land category of Table 8 and preferably as low as possible in that list.

Waste Stabilization Ponds (WSPs) are the best technology when considering the tradeoff of capacity and technical expertise. But WSPs do not score well in total cost. The amount of land necessary to construct a system of WSP for Las Vegas would be approximately 70,000 m^2 for existing flow conditions and 17,000 m^2 if the amount of wastewater production per capita can be cut by 75% (for details of this calculation see Appendix F). Unless tremendous gains are made reducing non-wastewater inflow to the wastewater system, WSPs are not a viable option for Las Vegas.

A technology that reaches a compromise between land use, capacity, and technical expertise is some form of combination system like an Imhoff tank, septic tank, or UASB. The one risk of a UASB is the likely need for flow regulation so as to not upset the sludge blanket. This will require a pumping system. Additionally, a UASB is not particularly durable because if the suspended sludge bed becomes damaged or eliminated, it cannot easily be remediated. This leaves Imhoff tanks and septic tanks. When appropriately sized and maintained, both forms of tank can supply appropriate levels of primary treatment and do not violate any of the limitations of Las Vegas. They are gravity driven, small footprint, low maintenance, and durable technologies. They have the added advantage of being familiar to the municipal staff of Las Vegas.

The only shortcoming of Imhoff and septic tanks is that they do not provide pathogen removal. While it is debatable whether or not pathogen removal should really be a concern of Las Vegas, it is worth considering what options are available to them. The primary treatment provided by sedimentation in an Imhoff or septic tank can be augmented by some form of secondary treatment to remove pathogens. There are two ways to achieve pathogen removal. The first way is disinfection with chlorination or other comparable technology. The second way is through the use of natural die off rates to remove pathogens them from effluent water. Maturation ponds are one example of a technology that eliminates pathogens through their natural die off. Of the two technologies, maturation ponds violate fewer of the limitations faced by Las Vegas and with a hydraulic residence time of approximately 5 days, a maturation pond can achieve 99% reductions in TC (Mara 2004). So, if pathogen removal is a concern of the Municipality, a combination of primary treatment from an Imhoff tank and secondary treat from a maturation pond will achieve the goals of wastewater treatment without violating any of the limitations.

An added advantage of this system is that it can easily be built in stages or broken up into a decentralized system. As has been shown, Raices Creek provides some treatment of organic matter and it is assumed that the other creeks that convey wastewater from San Juan and El

Mochito will also provide some treatment as well as conveyance. If these streams are incorporated into the overall wastewater treatment design then each urban area can have its own wastewater treatment facility providing substantial savings in terms of the cost of constructing and maintaining many kilometers worth of sewage mains. To give an idea of how much area is needed for each region, Table 9 shows the results of preliminary sizing of the Imhoff tank, maturation pond system for both the existing wastewater flow levels and a 50% reduction in wastewater flow (for details on these calculations see Appendix F). The necessary surface area of the Imhoff tank for each area is shown as well as its relative size (the numbers in parentheses show area compared to the existing facility in Central Las Vegas).

Table 8 Necessary Dimensions for a Decentralized Wastewater Treatment System

		Dimensions	
Urban Area	**Treatment Technology**	**Existing Flow Size**	**Reduced Flow Size**
Central LV	Tank	110 m^2 (2.1)	55 m^2 (1.0)
	Maturation Pond	17640 m^2	8820 m^2
North LV	Tank	77 m^2 (1.5)	39 m^2 (0.7)
	Maturation Pond	12350 m^2	6180 m^2
San Juan	Tank	37 m^2 (0.7)	19 m^2 (0.3)
	Maturation Pond	5880 m^2	2940 m^2
El Mochito	Tank	83 m^2 (1.6)	42 m^2 (0.8)
	Maturation Pond	13230 m^2	6620 m^2

6.2.4 Centralized vs. De-Centralized Systems

As well as selecting specific technologies, Las Vegas has a more general decision to make. The Municipality can either have a centralized system for treating all of the wastewater in a single location and piping to transport wastewater to this location or it can have a decentralized system with smaller treatment facilities near each urban area. A centralized system for Las Vegas would have to be located at an elevation that is lower than all of the urban areas so that it can be a gravity driven system. This leaves only the area immediately downhill of the existing Imhoff tank. A decentralized system of wastewater treatment would provide a local treatment facility for each urban area. This system can then take advantage of the existing system of creeks to convey the water and provide some natural treatment. The disadvantage of system is that it requires the use of space in each urban area and it would also mean more locations within the municipality that are exposed to the harm and risk of wastewater treatment.

The Municipality of Las Vegas has multiple options to treat wastewater. These options range from latrines to waste stabilization ponds to activated sludge systems. Given the specific situation of Las Vegas, treatment technologies that have a small footprint are preferable. This leads to the conclusion that septic tanks and Imhoff tanks will provide more economical treatment for the Municipality. To improve pathogen removal, these primary systems should be coupled with secondary treatment in the form of maturation ponds. Finally, central to any expansion should be the inclusion of sludge drying bed for dewatering of sludge produced in wastewater treatment.

Recommendations:

- Imhoff tanks should be installed for each urban area in Las Vegas.
- If secondary treatment is needed, maturation ponds will provide adequate pathogen removal.
- Reduction in per capita wastewater production must be achieved for treatment to effective.

7 SUMMARY

7.1 Maintenance

The following maintenance tasks need to be consistently preformed in order to optimize wastewater treatment in Las Vegas:

7.1.1 Imhoff tanks

- Maintenance of eight flow gates.
- Daily recording of flow, maintenance, and sludge.
- Daily cleaning of the influent channel and inlet baffles.
- Daily equalization of flow.
- Bi-Weekly inspection that slot to sludge digester remains open.
- Bi-weekly removal of scum.
- Weekly removal of solids from sloped sides of sedimentation chamber.
- Monthly reversal of flow.
- Semiannual removal of sludge (approximately 40 m^3).
- Design and construction of a sludge drying bed adjacent the Imhoff tanks.

7.1.2 Septic Tanks

- Investigation of the status:
    - Quantity of flow into each system.
    - Size of the tanks.
    - State of maintenance.

7.2 Conservation

Flows to the Imhoff tanks are considered excessive as they can be eliminated more cheaply than they can be treated. The system was designed for a per capita wastewater production of 250 L/day. However, the residents of Las Vegas are currently producing 1,000 L/person/day of wastewater. It is suspected that these large quantities stem from in-home de-pulping of coffee, which involves leaving the tap open all night. The water from this activity should not be discharged to the Imhoff tanks and would be better off released into the ground or streams. Additionally, it is recommended that the Municipality undertake serious measures of water conservation such as educating residents on how to fix leaky faucets, installing low flow toilets and showerheads, and metering water usage. In the long run this will actually save the municipality treatment costs and protect precious natural resources. In order to start these initiatives a deeper understanding of water use practices is necessary.

Recommendation:

- A household survey consisting of questions similar to the following should be conducted:
    - How many people are in each house?
    - How many faucets in each house?
    - How many faucets are leaking/broken?
    - What type of activities is water used for?
    - Do the households use the water for industrial purposes (i.e. de-pulping coffee)?

7.3 Wastewater Treatment Expansion

The Municipality of Las Vegas has multiple options to treat wastewater. These options range from latrines to waste stabilization ponds to activated sludge systems. Given the specific situation of Las Vegas, treatment technologies that have a small footprint are preferable. This leads to the conclusion that septic tanks and Imhoff tanks will provide more economical treatment for the Municipality. To improve pathogen removal, these primary systems should be coupled with secondary treatment in the form of maturation ponds. Finally, central to any expansion should be the inclusion of sludge drying bed for dewatering of sludge produced in wastewater treatment.

Recommendations:

- Imhoff tanks should be installed for each urban area in Las Vegas.
- If secondary treatment is needed, maturation ponds will provide adequate pathogen removal.
- Reduction in per capita wastewater production must be achieved for treatment to effective.

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APPENDIX A: PROJECT TIMELINE

MIT Involvement with Lake Yojoa, Honduras

Time	Activity
Fall 2005	MIT Master of Engineering Program in Civil and Environmental Engineering identifies Lake Yojoa as a potential thesis project for students completing their MEng Degree in Environmental Engineering.
Winter 2005-2006	Dr. Eric Adams, Tia Trate, Mira Chokshi, and Aridaí Herrera conduct on site study focused on stakeholder identification and lake water quality (nutrients and thermal profile).
Spring 2006	Tia Trate and Mira Chokshi complete report on stakeholders and lake water quality. The report quantifies nitrogen levels in the water as well as the thermal profile of the lake. Additionally, Trate and Chokshi identify 7 stakeholders that have interest in environmental health of lake. These stakeholders are: Aquafinca, AMPAC mine, Las Vegas, Las Marias, a hydropower plant, and a restaurant association. Reports are available from: http://dspace.mit.edu/handle/1721.1/35495 http://dspace.mit.edu/handle/1721.1/35078
Summer 2006	Aridaí Herrera returns to Lake Yojoa to study the wastewater treatment facility of Las Vegas, a potential source of pollution cited by Chokshi and Trate.
Winter 2006	Herrera completes report that describes the existing wastewater treatment facility in Las Vegas, an Imhoff tank. The report also recommends remediation approach for existing wastewater treatment in Las Vegas.
Fall 2007	Herrera recommends follow-on project working with Las Vegas to examine options for improving the existing wastewater treatment in Las Vegas. This project is accepted by MEng students Anne Mikelonis and Matt Hodge.
Winter 2007-2008	Dr. Adams, Mikelonis, Hodge, and Herrera return to Honduras to assess options for improved wastewater treatment in Las Vegas. While in Las Vegas, the Municipality requests comprehensive preliminary study of options for wastewater treatment throughout Las Vegas.

Spring 2008	Mikelonis and Hodge complete preliminary assessment of wastewater treatment options for Las Vegas.

On Site Activities of Team January 2008

Date	Activity
January 7	Team of Aridaí Herrera, Anne Mikelonis, Matt Hodge, and Dr. Eric Adams arrive in Honduras. Team meets with Diana Betancourt from NGO Water for People and Manuel Lopez, an independent consultant to Aguas de San Pedro.
January 8	Team meets with Municipality of Las Vegas leadership including Mayor Carlos Fuentes and Chief Engineer Alexis Rodriguez. During the meeting, project goals are explained and refined.
January 9	Team meets with Aquafinca Manager Israel Snir to update him on project and request assistance in finding lab equipment. Aquafinca agrees to supply the use of an analytical balance during the team's time in Honduras.
January 10	Team meets with Ramon Cordona, Infrastructure Director for the Honduran Social Investment Fund (FHIS) and Hugo Chavez, an engineer for FHIS, to discuss wastewater treatment in Honduras and the goals of the Las Vegas project.
January 11	Team examines another Imhoff tank in Marcala, Honduras. Team returns to Las Vegas to have second meeting with the Mayor and indicate the questions they will answer while on site. The questions they specify are: 1) Removal efficiency of the existing tanks 2) Downstream water quality analysis 3) Options for sludge handling 4) Identification of local sources of coagulants 5) CEPT testing (bench and/or pilot scale) 6) Conceptual design of a full scale system for CEPT application

January 12	Team visits El Progreso and La Lima at the recommendation of FHIS to see good examples of popular treatment technology, waste stabilization ponds. Aridaí Herrera and Dr. Eric Adams return to the United States.
January 15– 22	Team collects influent and effluent water samples, measures flow and conducts jar tests to determine appropriate dosing of chemicals for CEPT pilot test on Imhoff tank. Hodge begins to collect necessary information for preliminary design of wastewater treatment system for Las Vegas. Mikelonis designs pilot test for CEPT.
January 23	Team travels to Tegucigalpa and meets with original contractor that built Imhoff Tank in Las Vegas, Agua Para el Pueblo (APP) and acquires original design drawings of tank. Team also meets with Pedro Ortiz, a senior manager for the National Agency of Water Supply and Sewerage (SANAA) to discuss wastewater treatment in Honduras.
January 24-28	Matt Hodge conducts preliminary screening of appropriate wastewater treatment technologies for Honduras and Anne Mikelonis prepares to conduct pilot test of CEPT in Imhoff Tank.
January 29	Team conducts pilot test of CEPT in Imhoff tank.
January 30	Team visits other Imhoff tanks in the department of Santa Barbara
January 31	Team makes final presentation to Mayor and municipal staff of Las Vegas.
February 1	Team meets with AMPAC mine and presents findings to engineering staff of mine at the request of the Mayor of Las Vegas.
February 2	Anne Mikelonis and Matt Hodge return the United States.

APPENDIX B: TESTING PROTOCAL

Total Suspended Solids

TSS is a measure of the particle matter that exists in the water column. TSS is a contaminant of concern because it can limit the penetration of sunlight into a receiving water body. If the solids are denser than water they can settle out of the water column and be deposited on the sediment of a water body. When particles settle onto the sediment they can have a detrimental effect on invertebrates that inhabit the water body floor and can also harm aquatic life by limiting growth rates and reducing resistance to disease (Viessman and Hammer 2005). Typical municipal wastewater has a TSS of between 450 and 1250 mg/L (Reynolds and Richards 1996).

TSS is measured by filtering a water sample under a partial vacuum. The filter is weighed prior to and after the filtering of the water sample. The difference in weight is the measure of total solids in the sample. This mass divided by the volume of the water sample yields the concentration of TSS. The methodology used in testing TSS is the “Total Suspended Solids Gravimetric Method Standard Method 2540.”

Chemical and Biochemical Oxygen Demand

COD and BOD are in and of themselves not directly a pollutant of concern. However, the presence of dissolved oxygen (DO) is one of, if not the, most important water quality indicators. Typically, a DO concentration of 5 mg/L is necessary to maintain healthy aquatic life in water bodies (Viessman and Hammer 2005). As potential sinks of dissolved oxygen, BOD and COD become important water quality indicators as well. BOD is a measure of the oxygen used by microorganisms in order to biodegrade contaminants in receiving water bodies. COD on the other hand is “the oxygen equivalent of the organic matter susceptible to oxidation by a strong chemical oxidant” (Viessman and Hammer 2005).

Typically, BOD is of greater interest for domestic wastewater, but BOD testing is time consuming typically consisting of either a 5 day or 28 day measurement of water samples. COD can be correlated to BOD so a common practice is to take limited BOD readings and many COD readings and then estimate BOD from COD. That procedure was followed in this project. The method used to measure COD was the “HACH Chemical Oxygen Demand Colorimetric Method 8000” and for BOD the “Biochemical Oxygen Demand Method 5210” method was used.

Total Coliforms

TC is not a wastewater contaminant in and of itself either. It is used as a surrogate for measuring the presence of microbes, viruses, and bacteria that can cause sickness in humans. Testing for individual pathogens requires many complicated testing procedures. In lieu of such intensive testing, TC has been adopted as a good indicator of the potential presence of pathogens. Coliforms originate in the intestinal tract of warm-blooded animals including humans. Therefore, if coliforms are present, it is reasonable that other fecal matter may be present. Non-human coliforms are indistinguishable from human coliforms so utilizing coliform counts to assess the risk of pathogens requires knowledge about contributing waters, sources and destinations.

TC counts are typically performed by incubating a sample of water in a nutrient rich environment and then applying a dye to the background media that reacts with the coliforms to produce a different color. From there, the coliforms can be counted and this number divided by the volume of the water sample to determine the concentration of coliforms. The approved method for measuring coliforms is the “Membrane Filter Technique for Members of the Coliform Group Standard Method 9222.” Due to limitations of onsite laboratory equipment, another testing method was utilized in place of the standard method. 3M E.Coli/Coliform Count Plates were used to measure TC in Las Vegas.

While for the most part, on site investigations went very smoothly, there were some complications that had a direct effect on the availability and accuracy of water quality data. The first complication was the lack of an analytical balance. While on site, the investigators were able to use an analytical balance at the laboratory of the Aqua Finca fish farm. However, this balance only had an accuracy to 0.001 grams. Since the difference of pre and post weights of TSS samples were often less than 0.01 grams only two significant digits were recorded for these readings. A second complication arose when the 3m E. Coli/Coliform Plates were stolen from the Las Vegas laboratory facility. For this reason, TC counts are only available from early sampling.

APPENDIX C: COLLECTED DATA

Flow

Date	Time	Depth (m)	Time (s)	Distance (m)	Flow (m^3/hr)
16-Jan	9:30AM	0.184	56	50	184
16-Jan	9:30AM	0.184	51	50	169
16-Jan	2:30PM	0.191	55	50	189
16-Jan	2:30PM	0.191	56	50	192
17-Jan	4:30AM	0.121	53	50	103
17-Jan	10:00AM	0.184	52	50	172
19-Jan	2:00PM	0.165	56	50	161
20-Jan	10:00AM	0.178	57	50	180
21-Jan	9:30AM	0.165	57	50	164
25-Jan	3:00PM	0.153	55	50	145
29-Jan	10:45AM	0.203	46	50	169
29-Jan	12:00PM	0.178	49	50	156
29-Jan	12:30PM	0.178	47	50	150

Notes:

Total Suspended Solids

Date	Time	TSS in (mg/L)	TSS eff (mg/L)
15-Jan	9:30AM	700	200
15-Jan	9:30AM	--	400
17-Jan	10:00AM	200	160
17-Jan	10:00AM	200	140
29-Jan	10:45AM	200	130
29-Jan	10:45AM	220	110

Notes:

- The only available analytical balance had three significant figures of accuracy (0.001g). This limited the accuracy of testing to 10 mg/L.
- For each set of two tests, the influent and effluent should be averaged and then compared to determine removal rates.

Chemical Oxygen Demand

Date	Time	COD in (mg/L)	COD eff (mg/L)
15-Jan	9:30AM	--	317
15-Jan	9:30AM	--	323
17-Jan	10:00AM	273	175
21-Jan	9:15AM	323	235
29-Jan	10:45AM	407	272

Notes:

- 15-Jan influent samples were found to faulty as they returned values well above 1000 mg/L and too close to the upper limit of the test to be reliable. Also, the sample was a distinct green color inconsistent with prescribed HACH method recommendations

Biochemical Oxygen Demand

Date	Time	BOD in (mg/L)	BOD eff (mg/L)
15-Jan	9:30AM	290	300
15-Jan	9:30AM	132	150
21-Jan	9:15AM	137.5	130
21-Jan	9:15AM	157	110

Notes:

- The results from 15-Jan did not meet the requirements of standard testing for BOD. There was not enough dissolved oxygen remaining in tested samples. The tests on 21 January did meet all requirements.

Coliforms

Date	Time	TC in (#/100 mL)	TC eff (#/100 mL)
15-Jan	9:30AM	--	6.00E+09
15-Jan	9:30AM	--	3.00E+09
17-Jan	9:15AM	5.00E+08	1.80E+09

Notes:

- The results from the tests on 15 January did not produce adequate influent results due to too many dilutions of sample water. While the tests were properly conducted they gave a non representative result of 0 TC/100 mL. While it is not representative, it does support the finding that effluent counts are higher than influent counts.

APPENDIX D: FLOW DIAGRAM

Changing the direction of flow helps to distribute the solids along the entire length of the digestion chamber. The locations of the flow gates are labeled in Figure 20. Table 9 contains the necessary arrangements for the flow gates to reverse the flow.

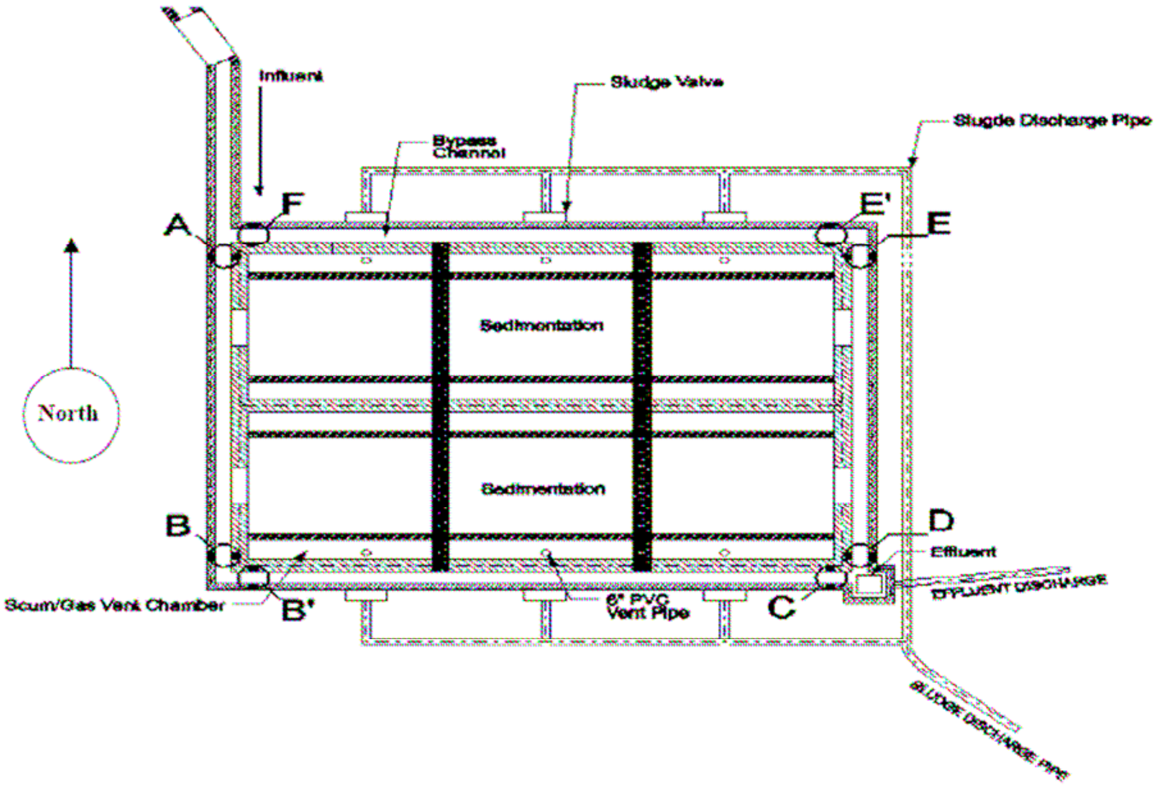
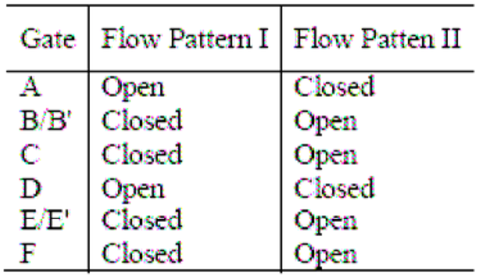


Figure 20 Flow Gate Locations (Herrera 2006)

Table 9 Flow Gate Arrangements (Herrera 2006)



Gate	Flow Pattern I	Flow Patten II
A	Open	Closed
B/B'	Closed	Open
C	Closed	Open
D	Open	Closed
E/E'	Closed	Open
F	Closed	Open

APPENDIX E: WASTEWATER TREATMENT OPTIONS

Sedimentation Tank

A sedimentation tank is a simple form of wastewater treatment that is always paired with a form of treatment to eliminate contaminants. Sedimentation tanks can take on many forms, but the basic function of a sedimentation tank is to provide a laminar flow environment to allow gravity to cause solids in the water to settle out of the water column and be deposited on the bottom of the tank. Hydraulic residence time is the key parameter in sizing sedimentation tanks. It is necessary for a parcel of water to spend enough time in the tank to allow settleable solids to be removed from the water column.

Waste Stabilization Pond

Waste stabilization ponds (WSPs) or oxidation ponds are a series of shallow open surface ponds that are fed by influent flows of wastewater. This technology is an increasingly popular form of wastewater treatment in Honduras (Chavez 2008). A 2000 publication by Oakley catalogued and explained many successful implementations of WSPs in Central America (Oakley et al. 2000). The results of this article were expanded and translated into a manual for the design, construction and maintenance of WSPs by USAID and FHIS.

A typical installation of a WSP will consist of an anaerobic pond and/or a facultative pond followed by a maturation pond. The system is built in series, but each unit is usually built with a parallel unit to allow for maintenance while still treating influent wastewater. An anaerobic pond removes BOD through sedimentation of organic solids in the wastewater. Anaerobic conditions are maintained by preventing aerobic bacteria such as algae from growing in the pond. According to Mara (2004), a properly designed anaerobic pond can achieve BOD removal of up to 60%. The sludge that is generated is digested anaerobically, just as was described for an Imhoff tank. Typical design parameters for an anaerobic pond are depths of 2-5 meters and an organic loading rate of greater than 100 g BOD/m^3-d (Mara 2004), high enough to prevent the presence of dissolved oxygen in the water column, yet still maintain a residence time of approximately 1 day.

While an anaerobic pond is often optional for a WSP system, facultative ponds are rarely omitted. A facultative pond also treats BOD, but this time it treats organic loading with aerobic processes. If a facultative pond is used as primary treatment, it will remove some BOD through sedimentation of solids; however, the main treatment mechanism is oxidation. Oxygen is provided to the water column through the prodigious growth of algae on the pond surface. Because the process is aerobic, loading to a facultative pond must be substantially less than an anaerobic pond. Typical design for a facultative pond includes a depth of 1.5 meters and a loading rate of 10-40 g BOD/m^2–d (Mara 2004) With this reduced flow an appropriate residence time is approximately 4 days.

Regardless of primary treatment, any WSP system will have a maturation pond for the removal of pathogens. The removal of viral pathogens through physical processes is not completely understood, but it is generally believed that sedimentation is again responsible for die-off rates for pathogens (Mara 2004). Similarly, for bacterial removal, not all processes are completely understood, but sedimentation and consumption by other bacteria and micro invertebrates contribute as well as increased bacterial die-off rates from elevated temperatures. In consideration of these various mechanisms, the key parameter for design remains residence time. A typical maturation pond has a maximum depth of 1 m to maintain both high levels of light intensity and reduce variations in dissolved oxygen through the depth of the pond. Given that a maturation pond is typically relatively well mixed, a residence time of 4.9 days will achieve a one log, or 90%, removal of pathogens (for details of this calculation see Appendix F).

Trickling Filter

A trickling filter is in fact not a filter at all. A trickling filter, or bio-filter is a porous media that is used as a structure to grow bacteria populations. Since the media is porous, a lot of surface area is generated for wastewater to come in contact with the bacteria that will digest organic matter in the wastewater. This aerobic digestion of bacteria is accomplished by periodically discharging wastewater onto the media and letting the water percolate to the bottom of the trickling filter where it is again collected for final disposal. By alternating between wastewater and exposure to the air, anaerobic conditions are prevented. Figure 21 demonstrates the processes that are occurring on the surface of a trickling filter.

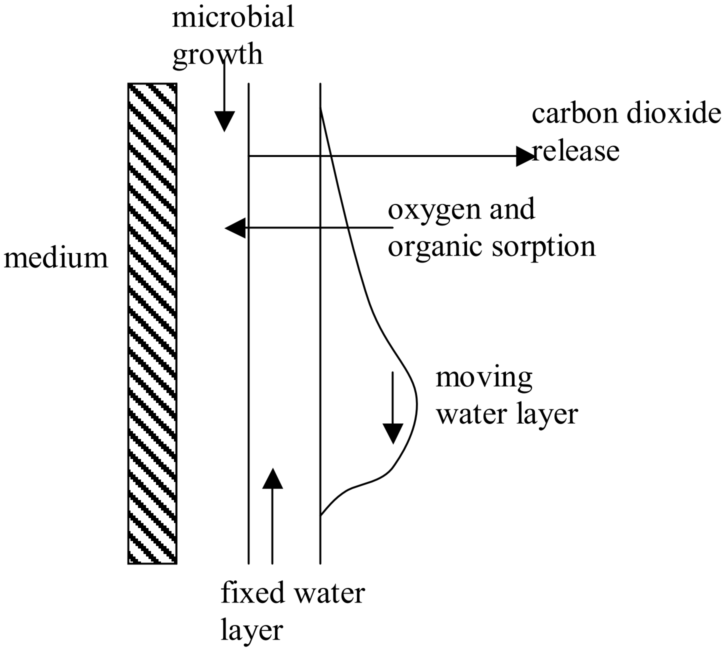


Figure 21 Organic Digestion in Trickling Filters (Reynolds and Richards 1996)

Trickling filters cannot provide primary treatment, but when they are properly maintained they do provide adequate secondary treatment. Low rate filters are typically loaded with a hydraulic rate of 1.8 L/min-m^2 and an organic loading rate of 0.2 kg BOD/m^3-d (Reynolds and Richards 1996).

In operating a trickling filter it is important to prevent the development of anaerobic conditions and to periodically flush the system so that as bacterial growth sloughs off of the media it does not clog pore space in the trickling filter. Another important consideration is the inclusion of methods to deal with the presence of flies which have been found to be nuisance in most low rate trickling filters (Reynolds and Richards 1996).

Upflow Anaerobic Sludge Blanket

Upflow anaerobic sludge blanket (UASB) systems provide primary treatment for the removal of solids through settling processes as well as digestion of solids through anaerobic processes. UASBs are concrete structures that allow influent wastewater to enter through the bottom of a tank. Either through hydraulic head or by pumping, water is forced upwards through a sludge layer (the blanket) allowing for contact between wastewater and anaerobic bacteria. As water passes upwards out of the blanket, the flow rate is maintained at a low rate so any solids that have passed through the blanket or organic material that may have come free from the blanket will again settle towards the bottom of the tank. Effluent channels are sloped upwards to promote this settling process.

The recommended residence time for wastewater in a UASB is between 6 hours and 12 hours. Typical maximum capacities of UASBs are 4,000 m^3 per day, and for a properly maintained system BOD removal rates are on the order of 70% (Mara 2004). Dimensions of an UASB are limited by a typical maximum volume of 1,000 m^3 and are usually rectangular with a length to width ratio of less than 4:1. In designing an UASB, some of the important considerations are the ability to regulate flow and access to the digestion zone. Because flow is in the opposite direction of settling particles, a delicate balance between the upward advective force of the water and the settling force of gravity must be controlled. If flow is inconsistent or too high, the settling of particles will be stopped and an UASB will stop providing treatment. Just as flow must be actively controlled, sludge removal must be frequently managed as well. According to Mara (2004), sludge removal must occur as frequently as every 2 weeks. The byproducts of digestion are released to the atmosphere through a venting system that prevents gas bubbles from passing up through the sludge blanket and disrupting the bacterial growth.

Aeration

Aeration is the use of mechanical means to increase the presence of oxygen when organic matter in wastewater comes in contact with bacteria that will digest the material. This process is typically achieved by pumping oxygen in gas form into the bottom of a tank and letting that air rise through the water column. Oxygen will diffuse from the gas phase to the dissolved phase while the bubbles are in contact with water that is depleted of oxygen. Aeration can also be achieved by providing substantial mixing in the water column. In this form of aeration, the atmosphere acts as the source of oxygen and mixing helps to increase the rate at which this oxygen will diffuse into the water by constantly circulating the water and allowing water particles at all depths to come in contact with the surface. This process can be used in open air lagoons or ditches, but is most commonly used in activated sludge treatment processes.

Activated Sludge

Activated sludge is the most common form of treatment for urban areas in the developed world. The process requires a fluidized bed of microorganisms that are capable of digesting the organic material in wastewater in an aerobic environment. In this advanced process, influent wastewater is mixed with activated sludge prior to entering a reactor. Activated sludge is sludge that has been recycled from the effluent of the reactor. Prior to being joined with influent wastewater it passes through some form of aeration to reintroduce high levels of oxygen into the sludge. This is what makes it activated. Once in the reactor, solids from the influent wastewater quickly sorb to the activated sludge. Digestion occurs rapidly as well as rapid cell production. This means that the net gain in growth must be removed from the reactor and from the recycling stream to maintain a stable reactor environment. The operation of an activated sludge system is complicated and involves expertise in microbiology, chemistry, and physics. Without writing a full text book it is difficult to give a comprehensive understanding of an activated sludge treatment facility. While such facilities do tend to be complicated, they also provide high levels of treatment, achieving BOD removal rates of as high as 95% (Reynolds and Richards 1996).

Latrine

A latrine or pit latrine is the most basic form of wastewater treatment. It is simply an open hole or pit in the ground that collects domestic waste. The waste is then left to decompose. Ventilated improved pit latrines provide ventilation to the storage chamber to increase oxygen and provide a sink of gases that may cause odor problems (Ujang and Henze 2006). This form of aerobic digestion of waste is slow and is typically only used for a single residence. A latrine can be built for a single use and then filled with soil, or parallel containment tanks can be built and used in an alternating pattern to allow for full digestion and removal of waste from one while the other is in use. Latrines are a basic, but effective way to reduce the amount of contact between human waste, a health hazard, and humans.

Constructed Wetlands

Constructed wetlands depend on sedimentation and ecological metabolism to treat domestic wastewater. These are the same processes that are active in WSPs. A constructed wetland is typically a partially controlled natural environment of either free water surface or submerged media that creates an environment where treatment mechanisms can function. The EPA identifies constructed wetlands as a treatment method that can receive primary effluent and will treat water to secondary standards (EPA 2000). Given this limitation, any installation of a constructed wetland must be in coordination with a form of primary treatment. The EPA (2000) reports average values for constructed wetlands in the United States to be: 80% removal for BOD_5, 99% removal for total coliforms, and 82% removal for TSS.

Hydraulic residence time is once again the critical design parameter and just like a WSP, constructed wetlands can be designed for a specific water quality characteristic based on necessary residence times. Some other typical design guidelines are an average wetland depth of 1 m and a maximum organic loading rate of between 4.5 and 6.0 g BOD/m^2*day (EPA 2000).

APPENDIX F: EXAMPLE CALCULATIONS

Sludge Drying Bed [Based on Reynolds and Richards (1996)]

Sludge Density Calculation

Assumed Values:

% solids in sludge (P_s) = 15
% volatile solids (P_V) = 54

Variables:

S_s = Specific Gravity of Dried Solids Sludge
P_w = Percent Water = 1-P_s
S = Specific Gravity of Wet Sludge

Specific Gravity of Dried Solids Sludge

$$S_s = \frac{250}{100 + 1.5P_V} = 1.38$$

Specific Gravity of Digested Sludge in Imhoff tank

$$S = \frac{100S_S}{P_w S_S + 100 - P_W} = 1.043$$

$$\gamma_{sludge} = S\gamma_{water} = 1043 \, {}^{kg}\!/_{m^3}$$

Solids Deposition Calculation

Assumed Values:

% removal of TSS (R) = 40 %
TSS influent (TSS_{in}) = 200 mg/L
Daily Flow (Q) = 3600 m^3/day
Time Between Maintenance (T) = 183 days
Time for Anaerobic Digestion (T_{dig}) = 40 days (Reynolds and Richards 1996)
Typical Drying Bed Sludge Thickness (t) = 0.25 m

$$M_{sludge} = TSS_{in} R * Q = 288 kg/day$$

$$V_{sludge} = M_{sludge} / \gamma_{sludge} = 0.28 m^3/day$$

$$V_{sludge6month} = V_{sludge} T = 50.5 m^3$$

$$V_{digested} = V_{sludge6month} (T - T_{dig}) / T = 39.5 m^3$$

This final number is the sludge produced through settling that will have been digested in the last 183 days, 6 months. This is the sludge that can be safely removed from the Imhoff tank digestion chamber.

Necessary Area Calculation

Sludge drying beds are typically designed in terms of area considering a constant thickness of sludge in the bed. Typical thickness of sludge is 0.25 m.

$$Area = V_{digested} / t = 158 m^2$$

$$Area = \frac{TSS_{in} R Q}{t \gamma} (T - T_{dig})$$

Results:
Table 10 presents the same calculation just completed for various scenarios in Las Vegas. The scenario is presented on the far left, the critical characteristics of that scenario are presented in the middle and the far right column indicates the necessary area for a sludge drying bed.

Table 10 Appropriately Sized Sludge Drying Bed

Scenario	**Q (m^3/day)**	**TSS_{in} (mg/L)**	**Removal %**	**Area (m^2)**
Centralized				
Existing Imhoff tank, no flow change	3600	200	40	158
Existing Imhoff tank, 50% reduction in flow	1800	400	55	217
Additional Imhoff tank, no flow change	3600	200	60	237
Expansion for all Las Vegas, properly sized, no flow change	12000	200	60	790
Expansion for all Las Vegas, properly sized, 50% reduction in flow	6000	400	68	895
Decentralized				
El Mochito, properly sized, no flow change	2700	200	60	178
El Mochito, properly sized, 50% reduction in flow	1350	400	68	201
San Juan, properly size, no flow change	1200	200	60	79
San Juan, properly sized, 50% reduction in flow	600	400	68	90
North Las Vegas, properly sized, no flow change	2520	200	60	166
North Las Vegas, properly sized, 50% reduction in flow	1260	400	68	188

Waste Stabilization Ponds

Facultative Pond [Based on Mara (2004)]

Assumed Values

Water Temperature (T) = 18 deg C

Daily Flow (Q) = 3600 m^3/s

Concentration BOD (C) = 150 mg/L

Allowable Organic Loading (λ (kg/ha-day))

$$\lambda = 350(1.107 - 0.002T)^{T-25}$$

$$\lambda = 217 \tfrac{kgBOD}{ha-day}$$

Required Surface Area

$$A = \frac{CQ}{\lambda}$$

$$A = 25{,}000m^2$$

Results:

Table 11 presents the same calculation just completed for various scenarios in Las Vegas. The scenario is presented on the far left, the expected flow is presented in the middle and the far right column indicates the necessary area for a facultative pond given the limit of BOD loading and a depth of 1.5 m.

Table 11 Appropriately Sized Facultative Pond

Scenario	Q (m^3/day)	BOD (mg/L)	Area (m^2)
Centralized			
Central Las Vegas, no flow change	3600	150	25000
Central Las Vegas, 50% reduction in flow	1800	300	25000
Expansion for all Las Vegas, properly sized, no flow change	12000	150	83340
Expansion for all Las Vegas, properly sized, 50% reduction in flow	6000	300	83340
Decentralized			
El Mochito, properly sized, no flow change	2700	150	18750
El Mochito, properly sized, 50% reduction in flow	1350	300	18750
San Juan, properly sized, no flow change	1200	150	8340
San Juan, properly sized, 50% reduction in flow	600	300	8340
North Las Vegas, properly sized, no flow change	2520	150	17500
North Las Vegas, properly sized, 50% reduction in flow	1260	300	17500

Maturation Pond [Based on EPA (2000)]

Assumed Values

Well Mixed

Focus on Coliform Removal (EPA 2000)

Ambient Water Temperature (T) = 18 deg Celsius

% Removal of Total Coliforms (R) = 90

Depth of Pond (h) = 1 m

Daily Flow (Q) = 3600 m^3/day

Removal Efficiency, Independent of Influent Concentration

Coliform Die-off Rate

$$k_p = 2.6(1.19^{T-20}) = 1.8 day^{-1}$$

Necessary Residence Time

$$\theta = \frac{\frac{R}{(1-R)}}{k_p} = 4.9 days$$

Pond Surface Area Calculation

$$Volume = \theta Q = 17640 m^3$$

$$Area = Volume / h = 17640 m^2$$

$$Area = \frac{\theta Q}{h}$$

Results:

Table 12 presents the same calculation just completed for various scenarios in Las Vegas. The scenario is presented on the far left, the expected flow is presented in the middle and the far right column indicates the necessary area for a maturation pond to receive a 1 log (90%) removal of pathogens.

Table 12 Appropriately Sized Maturation Pond

Scenario	**Q (m^3/day)**	**Area (m^2)**
Centralized		
Existing Imhoff tank, no flow change	3600	17640
Existing Imhoff tank, 50% reduction in flow	1800	8820
Additional Imhoff tank, no flow change	3600	17640
Expansion for all Las Vegas, properly sized, no flow change	12000	58800
Expansion for all Las Vegas, properly sized, 50% reduction in flow	6000	29400
Decentralized		
El Mochito, properly sized, no flow change	2700	13230
El Mochito, properly sized, 50% reduction in flow	1350	6620
San Juan, properly sized, no flow change	1200	5880
San Juan, properly sized, 50% reduction in flow	600	2940
North Las Vegas, properly sized, no flow change	2520	12350
North Las Vegas, properly sized, 50% reduction in flow	1260	6180

Imhoff and Septic Tanks [Based on Tchobanoglous et al. (2003) and Herrera (2006)]

Assumed Values

Daily Flow (Q) = 3,600 m^3/day

Acceptable Overflow Rate (OFR) = 1.36 m/hr

Existing Tank Area ($Area_{Existing}$) = 2 x 2.3 m x 11.5 m = 53 m^2

Necessary Surface Area

$$Area = (Q / OFR) = 110 m^2$$

$$NoTanks = \frac{Area}{Area_{Existing}} = 2.1$$

Results:
Table 13 presents the same calculation just completed for various scenarios in Las Vegas. The scenario is presented on the far left, the expected flow is in the middle, and the last two columns present the necessary tank area as well a multiple. The multiple is the number of tanks of identical dimensions to the existing tank (which is a two chamber tank with each chamber having a surface area of 2.3 m x 11.5 m) that would be necessary to provide the total area required for adequate treatment.

The above calculation is for the scenario “Existing Imhoff tank, no flow change.” As has already been discussed the existing Imhoff tank is undersized. An appropriately sized Imhoff tank must be approximately twice as large as the existing tank. Therefore, if no reduction in flow can be achieved, another duplicate tank (with two chambers) can be added to the existing structure to provide adequate primary treatment. If a 50% reduction in flow can be achieved for Central Las Vegas, then no expansion would be necessary. The required area would be approximately 55 m^2, only slightly larger than the existing Imhoff tank.

For the areas of North Las Vegas, San Juan, and El Mochito, Imhoff tanks can be designed for a range of areas, but the multiple of the existing tank gives a good idea of how big the facility would have to be. For systems that can be small (as in the case of San Juan with reduced flow), the necessary area could be achieved with a one chamber tank, but this is not recommended. During times of maintenance wastewater would have to bypass all treatment and be discharged directly. Therefore, it is better to have a two chamber tank that is oversized to allow for cleaning and potentially increased use.

Table 13 Appropriately Sized Imhoff Tanks

Scenario	Q (m^3/day)	Area (m^2)	Multiple of Existing Imhoff Tank
Centralized			
Existing Imhoff tank, no flow change	3600	110	2.1
Existing Imhoff tank, 50% reduction in flow	1800	55	1.0
Expansion for all Las Vegas, properly sized, no flow change	12000	368	6.9
Expansion for all Las Vegas, properly sized, 50% reduction in flow	6000	184	3.5
Decentralized			
El Mochito, properly sized, no flow change	2700	83	1.6
El Mochito, properly sized, 50% reduction in flow	1350	42	0.8
San Juan, properly sized, no flow change	1200	37	0.7
San Juan, properly sized, 50% reduction in flow	600	19	0.3
North Las Vegas, properly sized, no flow change	2520	77	1.5
North Las Vegas, properly sized, 50% reduction in flow	1260	39	0.7