Temperature Analysis for Lake Yojoa, Honduras

By

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ABSTRACT

Lake Yojoa is the largest freshwater lake in Honduras, located in the central west region of the country (14°5' N, 88° W). The lake has a surface area of 82 km^2, a maximum depth of 26 m. and an average depth of 16 m. The locals believe that the anthropogenic activities around the lake for the past 25 years have impacted the water quality of the lake. Temperature analysis of the lake helps to understand the seasonal changes in the thermal structure of the lake, and it also indicates the seasonal changes in the water quality of the lake. The lake is marginally stratified most of the year, with a maximum difference of 4°C between the water surface and the lake bottom. The temporal changes in the thermal structure of the lake are studied using the lake stability analysis and a temperature model CE-THERM. The two analyses confirm that the lake overturns once a year. However, they differ on the onset of the overturn event and the seasonal changes in the stratification depth. The stability analysis indicates an overturn in November and for some years less stable lake conditions in June. The CE-THERM model was run for year 2005 and it indicates a possible overturn in June, and the lake remaining mixed until December. Further analysis using additional data is recommended to improve the temperature model predictions. Higher wind speeds, and lower air temperature were observed during the October and November time period, their combined effect appears to be mixing the lake. The inflow water is about 3 °C colder than the lake surface for most of the year, and it tends to sink in the bottom of the lake water column. Poor quality of inflow water settling in the bottom of the lake during a sudden overturn event can cause negative consequences on the dissolved oxygen of the lake, and thus the aquatic processes depending on it. Further studies are recommended to study the transport of the inflowing waters and their circulation in the lake water column, especially during the periods of low stability. Additionally, the thermal analysis can be extended to analyze other water quality constituents, and ultimately leading to the study of eutrophication.

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Table of Contents

List of Figures

List of Tables

1. Introduction

Lake Yojoa is the largest freshwater lake in Honduras, with spectacular beauty and remarkable ecological diversity around the lake. It is located in the central west region of Honduras, 125 kilometers northwest of Tegucigalpa, the capital of the country, and 75 kilometers south of San Pedro Sula, the industrial center of the country (Figure 1.1). Geographically, it is located between 14°45' and 14°57' north latitude, and 87°53' and 88°07' west longitude. It has an elevation of 632 meters above the mean sea level.

Figure 1.1: Map of Honduras (Honduras, 2006)

2. Purpose of Study

The purpose of this study is to analyze the changes in the thermal structure of Lake Yojoa. The water quality in Lake Yojoa is of great interest to the local communities, industries, and municipalities. The locals believe that anthropogenic activities have had an impact on the lake's water quality in the past 25 years. Anthropogenic activities that could have major water quality impacts were identified as untreated wastewater, agriculture, aquaculture, and mining. The natural process of physical, chemical, and biological changes ("aging") associated with nutrient, organic matter, and silt enrichment of a lake is known as "eutrophication". The anthropogenic activities around the lake may accelerate its eutrophication, thus diminishing its aesthetic beauty, recreational value, water quality, and habitat suitability (Garn et al., 2003). The biological, chemical and physical processes occurring in a lake are strongly influenced by its temperature. Thus the knowledge of the changes in the thermal structure of the lake will point to the changes in the water quality of the lake. In the future, it can be used to evaluate the processes defining the water quality of the lake, and thus determine the trophic status (i.e. health) of the lake. Additionally, there were two known incidents of possible sudden lake overturn (Section 5.1) in the past, affecting the aquaculture industry severely (Section 4.1). The study of the thermal structure of the lake will also help identify the factors that cause such overturn occurrences.

A field study was conducted in January 2006 for three weeks to obtain comprehensive information on various stakeholders. The practices for small and large-scale industries were observed and are explained in the next chapters. Temperature and water quality data was measured at various locations in and around the lake. Additionally, historical data on Lake Yojoa's temperature and water quality was collected from various sources. This data was used to analyze the seasonal changes in the thermal structure of the lake.

3. Background Information

3.1. Topography

The Lake Yojoa region is not a single geographic unit that can be delineated with precision. There are two large natural reserves: the National Parks of Santa Barbara on the northwest of the lake and Cerro Azul Meambar on the southeast of the lake. These two natural preserves form the boundaries of the contributing watershed of the Lake Yojoa, with a large part of these preserves outside the watershed. Figure 3.1 shows a map of Lake Yojoa with surrounding natural reserves.

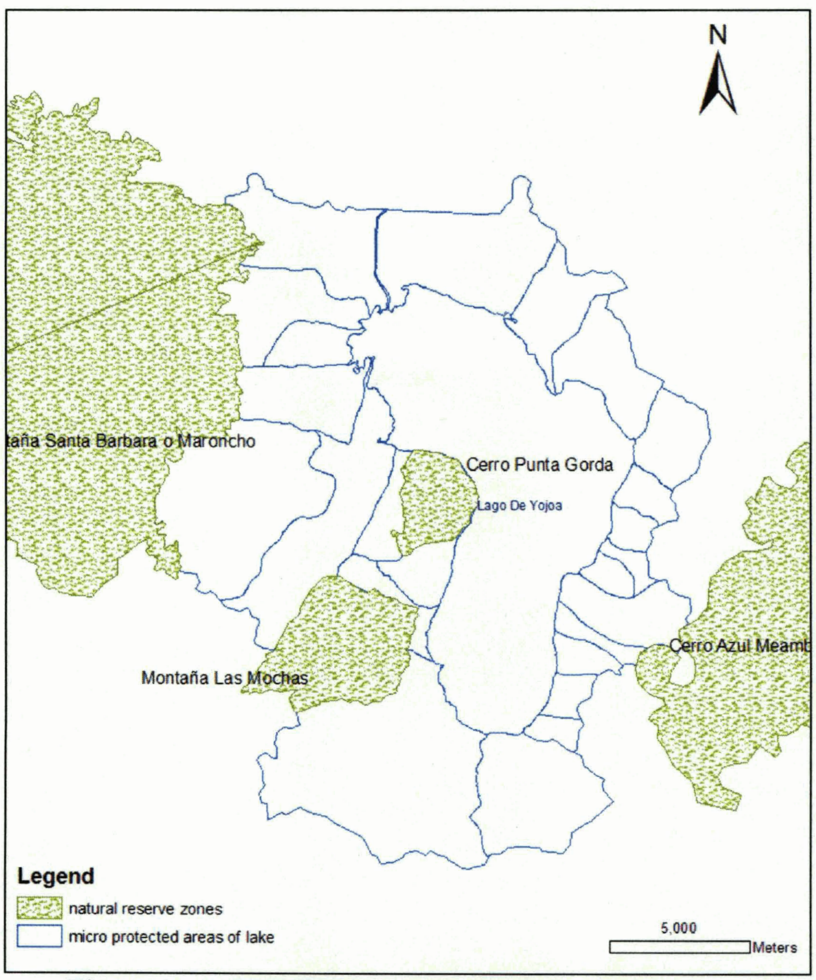

Figure 3.1: Natural reserves surrounding Lake Yojoa

The topography of the river basin in the northern sector of the lake is flat. On the east and the west sides of the lake, the topography changes from undulating to mountainous, with steep slopes as it approaches the two national forests. In the northwestern and southeastern regions around the lake, the topography is undulating.

3.2. Bathymetry

The Lake Yojoa is 16.2 km in length (maximum) and 6.2 km in width (maximum), with surface area of 89 square km, and perimeter of 54 km. The average depth of the lake is 16 m, and depending on the water level the maximum depth of the lake ranges from 26 to 29 m. (Vaux et al., 1993). Bathymetry is defined as the measurement of the depth of the bottom surface of a water body. Besides providing navigational information, bathymetric data is useful for modeling purposes. Refer to Section 7.2.1 for additional information.

3.3. Meteorology

The annual average temperature recorded for the region around the lake is 22.7°C. The monthly average temperature is the lowest in December and January (20°C), and highest in May and June (24.8°C) (Betancourt, 1981). The two natural reserves of Azul Meambar and Santa Barbara on either side of Lake Yojoa form a micro-climate for the region. Partially cloudy conditions persist all year round. Refer to Section 7.3.2 for additional information on meteorological data used in connection with lake thermal analysis.

3.4. Hydrology

Six major rivers and tributaries flow into the lake with significant quantities of runoff. These are: Helado, Varsovia, Balas, Raices (El Cianuro), Yure, and Cacao. The natural outlet of the lake was historically in the south (near Varsovia), however with the establishment of a hydroelectric dam on the northern end, the water was diverted to the dam via a constructed drainage canal in the north (Drainage Canal ENEE). The flow rate in this canal is controlled to meet the flow requirements for hydroelectric power generation. Refer to Section 7.3.3 for additional information.

4. Stakeholders

Figure 4.1 represents various stakeholders around Lake Yojoa. The term "stakeholders" includes industries discharging directly or indirectly into the lake, people depending on the lake for their water needs and livelihood, and individuals and organizations with general interest in the lake's water quality.

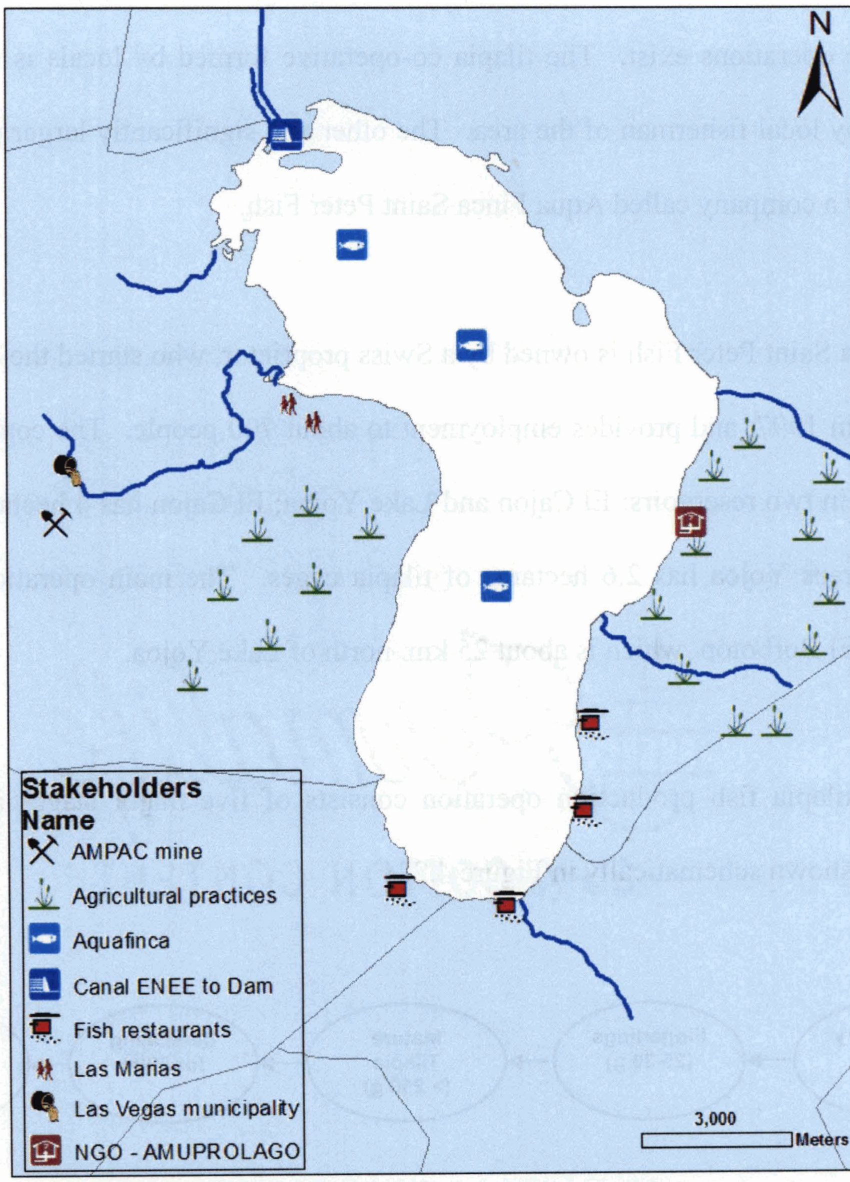

Figure 4.1: Various stakeholders in and around Lake Yojoa.

4.1. Fish Farms

Lake Yojoa is used extensively for commercial production of tilapia fish, which is a significant part of the lake ecosystem. Additionally, some locals fish tilapia and largemouth bass using nets and harpoons. The catches of the local fisherman average about 150 pounds per day, a majority of which is tilapia. These fish are then sold to local people and fish restaurants along the lake periphery. In addition to local fisherman, two large scale operations exist. The tilapia co-operative formed by locals is operated and managed by local fisherman of the area. The other and significantly larger production is handled by a company called Aqua Finca Saint Peter Fish.

Aqua Finca Saint Peter Fish is owned by a Swiss proprietor, who started the operations in Honduras in 1997, and provides employment to about 700 people. The company has its operations in two reservoirs: El Cajon and Lake Yojoa; El Cajon has 4 hectares of tilapia cages whereas Yojoa has 2.6 hectares of tilapia cages. The main operations center is located in El Borbotón, which is about 25 km. north of Lake Yojoa.

A typical tilapia fish production operation consists of five major stages as explained below and shown schematically in Figure 4.2.

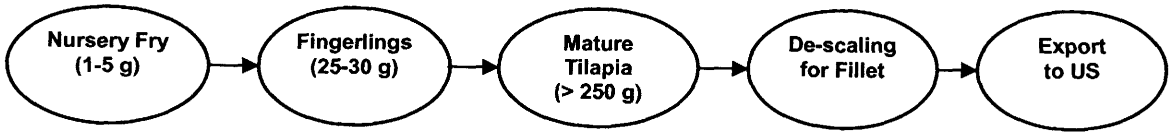

Figure 4.2: Different stages of tilapia fish production at Aqua Finca.

Nursery Fry: The tilapia fish are cultured in an indoor temperature-controlled room at the El Borbotón plant. When the fish grows to about 1-5 g. in weight, it is transferred to the next production stage.

Fingerlings: Fingerlings are juvenile fish that are fed in baffled open channels at the El Borbotón operation center. The water in the open channels is aerated regularly. The fingerlings mature when they attain a weight of about 25-30 g, at which time they are transferred to open cages in Lake Yojoa or El Cajon reservoirs.

Mature Tilapia: Tilapia are raised to full maturity in floating cages in Lake Yojoa and El Cajon. Aqua Finca uses Norwegian-type circular cages, each of 250 m^2 area and 6m depth, which are constructed on-site. Lake Yojoa has three cables of about 15-18 cages each. The total area of all cages is about 2.6 hectare, which is within the permitted 4.0 hectare limit. Present production in Lake Yojoa is about 4000 tonnes/year with about 1300 tonnes of standing crop at any given time. Tilapia are harvested when they weigh about 250 g.

Tilapia require proteins, lipids, vitamins and minerals in their diet for efficient growth. Alcon, a Honduran feed company, produces this feed with ingredients like animal tissue, dried powdered solid waste recycled from the descaling operation, by-products from vegetable farming like maize, soya, wheat, etc. (Snir et al., 2006). The feed is extremely efficient and environmental friendly: 100% of it floats so there is no settling. The tilapia fish production cycle generally has a duration of eight months, where 2.2 pounds of feed produces about 1000 grams of fish (Schmittou, 2003).

Descaling/Cleaning: The mature fish are descaled and cleaned to produce fillet at the El Borbotón operations center. The company indicates they provide a very high level of quality control, plant safety, and hygiene. The solid waste is completely reused for biofuel, feed production and other purposes.

Export: The fillet is transferred from the Yojoa region to San Pedro Sula airport on a daily basis, and it is exported to the U.S. under the brand of Regal Springs.

Aqua Finca monitors the water quality of Lake Yojoa on regular intervals and reports the results on a quarterly basis. Physical water quality parameters including temperature, pH, DO, and conductivity are monitored at three sampling locations at a depth interval of 1 m. Chemical and biological parameters including nitrogen, phosphorus, total sediment, BOD, COD, and algae are sampled at larger depth intervals at the same locations.

During October 2003 and October 2005, the fishing industry (Aqua Finca and the co-operative) observed sudden fish kills at Lake Yojoa and El Cajon reservoirs. In October 2005, the incident occurred overnight, and Aqua Finca lost up to 260 tonnes of fish in the two reservoirs combined and suffered a major financial blow (Snir et al., 2006). Aqua Finca believes that a sudden overturn in the lake caused the poor quality anoxic water from the bottom to move to the surface in a short time period, depleting the dissolved oxygen (DO) from the top region. The water in the top layers could not absorb sufficient atmospheric oxygen in this short period to sustain the fish, thus resulting in massive fish kills. Refer to Section 5.1 for additional explanation on the lake overturn event. Aqua Finca had measured the DO at one of their monitoring sites, in fact near one of their fish cages, at frequent intervals in October 2003. Figure 4.3 shows the DO profile for the top 10 m of the lake. The figure clearly shows a drop in DO on 16th and 17th October by about 2 mg/L from the DO measurements taken three days earlier.

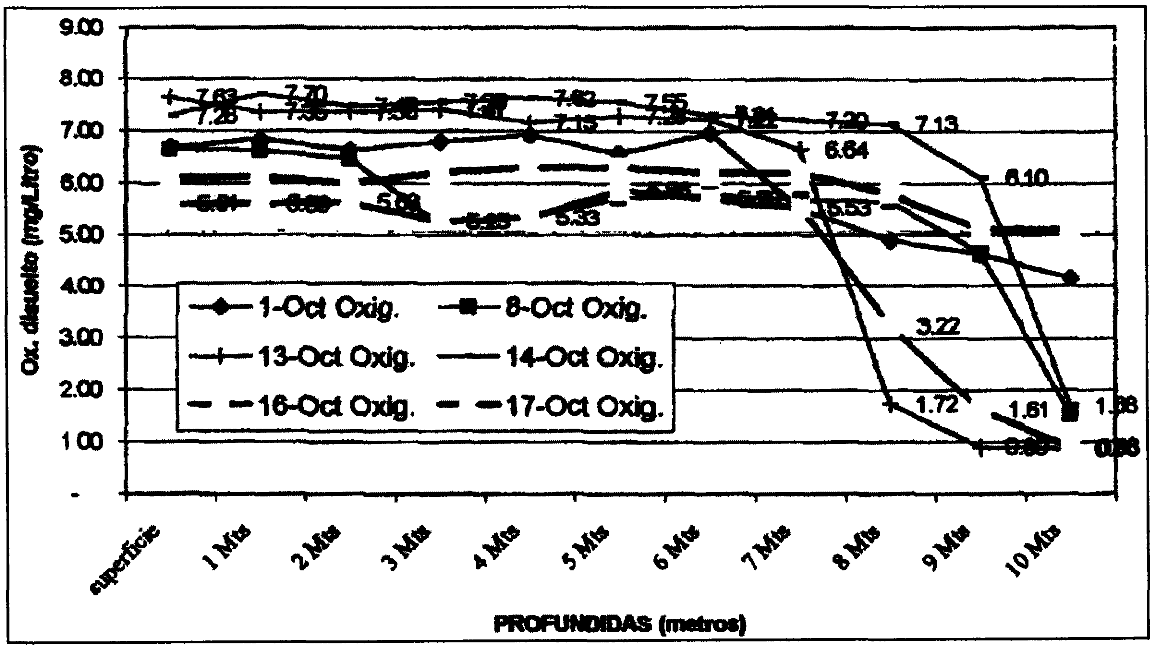

Figure 4.3: Dissolved oxygen at the Proyecto Piscicola site at Lake Yojoa
(Aqua Finca Saint Peter Fish, October 2003)

4.2. Mines

AMPAC mine is located in the El Mochito region, northwest of Lake Yojoa. The mine's operations began in 1948; it was acquired by American Pacific Mining Corporation in

1987, and by a trans-Canadian organization, Breakwater, in 1990. It is the biggest mine in Central America and provides employment to more than 200 people from the neighboring village of Las Vegas, one of the largest villages close to the mine. The AMPAC mine currently produces zinc, lead and trace quantities of silver. It mines about 1850 tonnes/day of ore, from which 6.94% is zinc, 1.7% is lead and 0.0087% is silver (AMPAC Mine Operations, 2006).

The different stages of the mining operation were observed during the field visit as illustrated in Figure 4.4.

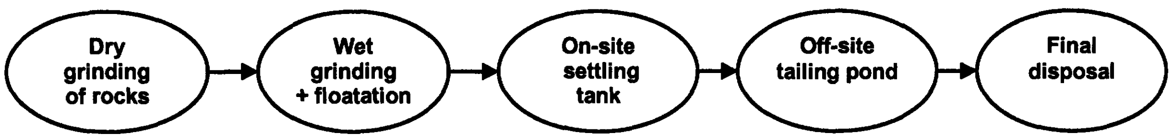

Figure 4.4: Different operation stages at the AMPAC mine.

Dry grinding: The first stage of production involves dry grinding of large sized rocks extracted from the quarry to produce small size pellets.

Wet grinding: The next stage involves grinding of the pellets with water to form a wet slurry. Next, chemical compounds, including, copper sulfate, sodium isopropionate, isobutyl carbinol, calcium oxide, sodium cyanide and zinc sulfate are added. These additives cause the metals to rise at different rates, thus allowing mechanical skimmers to separate them from the slurry. Skimmed metals are further processed for export; residual slurry is taken to next stage.

On-site settling tank: The mining operations have primary setting ponds at the main center in El Mochito, where the residual slurry is pumped. Approximately 40% of the effluent from the settling tank is used to backfill the mine, while the remaining 60% is pumped to a tailings pond located a few miles from the central mining operations.

Off-site tailing pond: The first tailings retention pond was built in 1960's. It was replaced with a new one in 1971, and the newest tailings pond will be opened in 2006. The old tailings ponds are vegetated and regularly monitored.

Final disposal: The residual from the tailings pond is discharged to the Raices River about 8 km upstream of Lake Yojoa. The water quality in the Raices River is monitored on a monthly basis at several points upstream and downstream of the discharge point by Dirección de Fomento a la Minería (DEFOMIN). DEFOMIN is the department of the government of Honduras responsible for administration of the country's mineral resources (AMPAC Mine Operations, 2006). The comprehensive water quality tests include manganese, zinc, copper, aluminum, arsenic, silver, cadmium, nickel, total chromium, iron, mercury, lead and cyanide. Additionally, DEFOMIN also reports the pH and temperature at these monitoring points (Lago, 2006).

No communication was established with DEFOMIN during the field visit to obtain the water quality reports on the heavy metals listed above.

4.3. Wastewater

One of the major problems plaguing most developing countries is water and wastewater treatment, and Honduras is no different. The largest municipality surrounding the lake is Las Vegas. The municipality discharges its waste to an Imhoff tank, a system that includes primary settling and a septic tank (Figure 4.5). The Las Vegas treatment plant, however, is ineffective, and the wastewater of 600 families is discharged essentially untreated to Raices River about 8 km upstream of Lake Yojoa (Flores, 2006). Discharge of raw wastewater into a river contributes nutrients to the system, thus having an impact on water quality.

Figure 4.5: Wastewater treatment facility, Municipality of Las Vegas

4.4. Fish Restaurants (Las Casetas)

The fish restaurants (known as Las Casetas) are a tourist attraction, serving approximately 15,000 tourists per month. There are approximately 50 fish restaurants along the south-eastern periphery of the lake. Wastewater from these restaurants, which includes cooking oil, sanitary wastewater and grey water, is directly discharged into the lake (Santos, 2006). Figure 4.6 shows pipes leading from one of these restaurants directly to the lake.

Figure 4.6: Discharge pipe from La Casetas

4.5. ENEE Dam – Hydroelectric power generation

The Empresa Nacional de Energía Eléctrica (ENEE) is the organization in charge of generating and transmitting 1,392 MW of electricity throughout Honduras (Descripción del Sistema Interconectado, 2006). One of the hydroelectric generation plants is located at Cañaveral, at a capacity of 29 MW (AMUPROLAGO, 2003). Cañaveral is located about 5 miles north of Lake Yojoa. The water that is used at this hydropower generation plant is withdrawn from Lake Yojoa through the Drainage Canal ENEE (known as the Artificial Canal). Since the flow rate in this canal is controlled by water requirements at the ENEE plant, the lake water levels in the past have fluctuated between 631m. to 638 m

(ENEE, 2006). Varying lake levels can cause periodic wetting and drying of the lake shoreline, which can induce release of nutrients.

4.6. Agricultural Practices

There are several types of agricultural land uses surrounding the lake, including animal husbandry and crop production. About 60 percent of the area of the Lake Yojoa watershed is occupied by farming activities (Congreso Investiga las Causas de Contaminación en Lago de Yojoa, 2006). The most common types of crops planted in the region are coffee, yucca, pineapple, and sugar cane (Coello and Pineda, 2006). The types of fertilizers used and application rates for the crops in this region could not be determined as a part of this study. However, rainfall runoff entering Lake Yojoa contains fertilizers used on these plantations. Slash and burn farming is a common agricultural practice for the sugar cane plantations. A possible effect of slash and burn farming on the lake's water quality is increased sedimentation (Gafur et al., 2003). Additionally, cattle and chickens are raised on land adjacent to the lake. Manure from these animals can also find its way into the lake water via rainfall events. Overgrazing of pastures can also lead to increased sedimentation.

4.7. Lake Residents

Residents of the surrounding towns and villages have a vested interest in the water quality of Lake Yojoa, as well. Although Yojoa is not a drinking water source for the residents, the locals take pride in the aesthetics of the lake. Additionally, locals use the lake for recreational purposes like swimming and boating. Locals also fish the lake for its bass and tilapia. The local economy is highly dependent on the lake and many locals are employed by the fish farms, hotels, restaurants, etc.

4.8. Non-profit Organizations

The Asociación de Municipios para la Protección del Lago de Yojoa (AMUPROLAGO) is a non-profit organization supporting the environmental quality of Lake Yojoa. AMUPROLAGO is directed by the mayors of the lake's surrounding municipalities. The goal of the organization is to conserve the natural resources in the Lake Yojoa watershed.

4.9. Additional activities around the lake

In the absence of adequate wastewater collection systems, other villages in the area discharge waste to septic systems with subsurface wastewater disposal. These septic systems are very old and most likely have never been pumped. It is possible that these systems are leaking into the lake through groundwater infiltration. Additionally, septic tanks are used by a number of resort hotels along the lake (Boesch, 2006).

Open land disposal of solid waste and use of tributary water for washing and bathing are a few examples of the lack of general environmental awareness, lack of infrastructure, and general poverty of the community around Lake Yojoa. Since the infrastructure does not support weekly trash collection and appropriate disposal, small open landfills have been created on the outskirts of villages and towns. For example, the landfill in Figure 4.7 was found outside of the village of Peña Blanca near the ENEE Canal during the field visit. It is not uncommon to see garbage along the sides of the road. Since there are not proper disposal methods, this is a common way to get rid of garbage. The garbage piles may contain liquid wastes that were improperly disposed. The liquid wastes, as well as leachate from these garbage piles, can easily enter nearby surfaces waters, possibly impacting those waters. Also, villagers around Lake Yojoa wash their clothes and bathe in the tributaries to the lake. Detergents used for clothes washing may contain phosphorus, thus contributing nutrients to the lake.

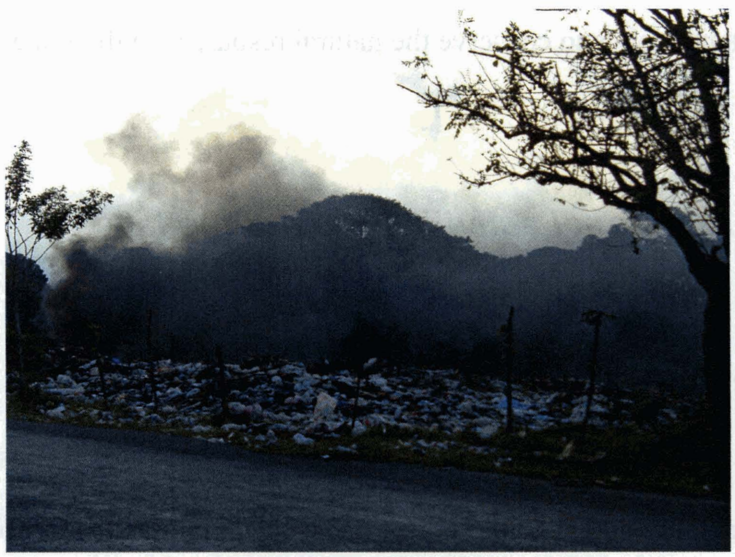

Figure 4.7: Burning of solid waste outside Peña Blanca

5. Temperature Dynamics of a Lake

5.1. Introduction

The surface of a lake is exposed to the sunlight, and is warmer than the bottom, which gets little or no sunlight. The density of water increases with a decrease in its temperature. Therefore, the colder bottom region of the lake is denser than the upper region, and it requires significant work to move this water up. Meanwhile, wind-generated eddies tend to mix the surface water with the underlying water. When the upper and the lower regions have thermally distinct properties, and the wind effects are not strong enough to penetrate beyond the upper region, the lake is called thermally stratified. The upper region is nearly isothermal and is called the epilimnion. The colder and denser bottom region is called the hypolimnion, and the region between them is called the metalimnion. The level within the metalimnion that has the strongest temperature gradient is called the thermocline.

Dissolved oxygen (DO) is an important water quality parameter affecting many aquatic processes. The dissolved oxygen in a lake is replenished at the water surface through a process of reaeration and is slowly diffused to the bottom of the lake, and it is consumed during the decomposition of organic matter in the lake. Particulate organic matter flowing into the lake, being denser than water, settles to the bottom of the lake. During stratification, the thermal barrier limits the diffusion of oxygen into the hypolimnion, and the continuous decomposition of organic matter can eventually lead to anaerobic conditions in the hypolimnion. Anoxic waters have poor quality and bad odors. Figure 5.1 illustrates a thermally stratified lake and its temperature and dissolved oxygen profile.

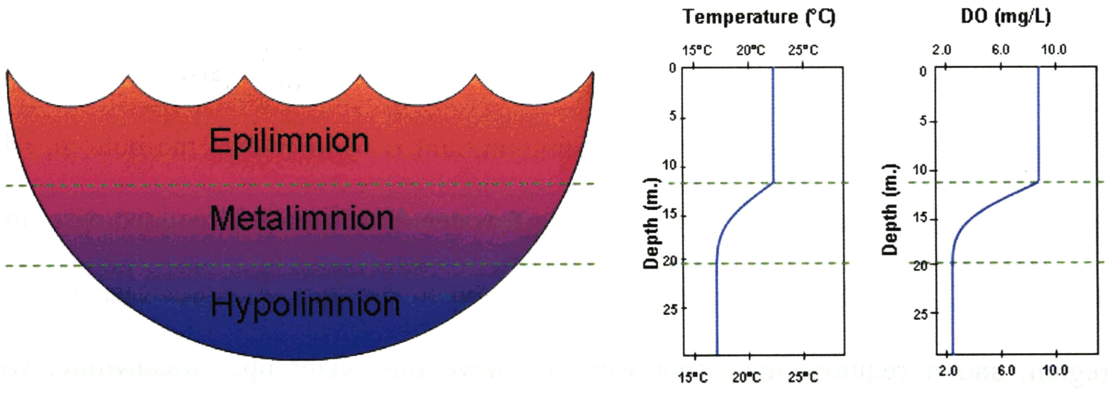

Figure 5.1: Temperature and DO profile of a thermally stratified lake.

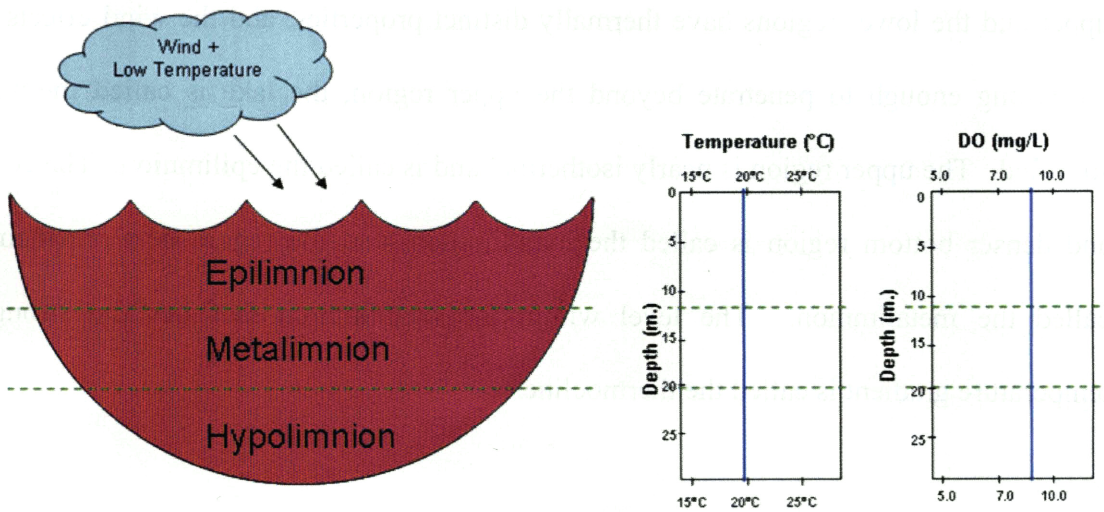

Figure 5.2: Temperature and DO profile of a mixed lake.

Seasonal changes in air temperature and other meteorological variables can reduce the temperature difference between the epilimnion and the hypolimnion. Strong winds can induce water currents (mean and turbulent) that can penetrate the thermal barrier, and can mix the two regions. These two factors separately but often combined can vertically mix the lake, resulting in one isothermal region. Such an event is called an overturn or a mixing event. Figure 5.2 illustrates a vertically mixed lake and its temperature and dissolved oxygen profile.

5.2. Dynamics of a Tropical Lake

The seasonal pattern of stratification and mixing occurrences are different for lakes in different geographical area. Based on the frequency of stratification, a thermal classification system was introduced by Hutchinson and Löffler (1956). Table 5.1 shows this classification system tabulated for various geographical areas (Schmid-Araya, 2006).

Table 5.1 Thermal Classification of Lakes (Schmid-Araya, 2006)

LAKE TYPE	CHARACTERISTICS	GEOGRAPHICAL AREA
AMICTIC LAKES	No vertical mixing, sealed off perennially by ice.	Antarctica, altitude mountains.
HOLOMICTIC LAKES	Complete vertical mixing at least once a year.	
COLD MONOMICTIC	Water temperatures never greater than 4°C and with one circulation in the summer at or below 4°C.	Arctic and high mountains lakes.
WARM MONOMICTIC	Water temperatures never drop below 4°C, they circulate freely in the winter at or above 4°C and stratified in summer.	Coastal areas of Northern Europe and North America.
DIMICTIC	Two periods of mixing, one spring and one autumn.	Cool temperate regions, high elevations in sub-tropical regions.
OLIGOMICTIC	Tropical, with rare circulation at irregular interval, and temperatures above 4°C	Equatorial regions with high humidity
POLYMICTIC	Lakes with frequent or continuous circulation.	Shallow lakes

Given the tropical climate of Lake Yojoa, it could either be a warm monomictic or an oligomictic lake. The reduced seasonality of the tropical environment makes it difficult to predict the occurence of the mixing cycles in tropical lakes (Lewis, 1983). Tropical lakes typically also tend to have a small vertical temperature gradient, which makes it difficult to identify the epilimnion (Lewis, 1987). Additionally, tropical lakes are more vulnerable to changes resulting from wind and heat than temperate lakes. This is primarily because of the minimal Coriolis effect, low maximum stability, and high response of stability to changes in heat content. Tropical lakes should be viewed as less stable than temperate lakes because of large, unpredictable, and biotically potent changes in the size of the epilimnion (Lewis, 1987). The Lake Yojoa region has mild variations in air temperature (i.e. reduced seasonality) and the lake itself has small temperature gradients most of the year. Therefore, studying a tropical lake like Lake Yojoa is a challenging task.

5.3. Purpose of Temperature Analysis

The primary purpose of conducting the temperature analysis reported in this thesis is to understand the seasonal changes in the thermal structure of the lake. This study also tries to identify the conditions that caused the overturns in October 2003 and 2005 and led to large fish kills. Secondly, this study can help explain the effect of thermal changes on other water quality processes such as eutrophication in the lake. It also provides the groundwork for conducting water quality modeling in the future. As explained in Chapter 6 and 7, two complementary analyses are employed to analyze the temporal and spatial variations in temperature. Since understanding a tropical lake is a challenging task, the purpose of conducting two different analyses is to understand the lake dynamics from two different perspectives and compare the results from both studies. The two analyses are:

Stability Analysis: Stability analysis examines the historical data on lake temperature structure and its effect on lake density and lake stability. It evaluates the mixing frequency of the lake and the seasonal variations of the depth of the thermocline.

Temperature Modeling: This method uses a numerical model, CE-THERM, to understand the effect of external factors such as wind, air temperature, advection and latitude on the mixing frequency of the lake. It also confirms the results obtained from the stability analysis.

6. Stability Analysis of Lake Yojoa

6.1. Introduction

In order to evaluate the mixing frequency and the seasonal changes in the depth of the thermocline of the lake, three different sub-analyses were conducted. The three sub-analyses were:

1. Temperature Analysis
2. Density Analysis
3. Stability Index Analysis

The data required for the temperature analysis were a set of temperature profiles over frequent intervals. The data required for density and stability index analysis were the temperature data. Historical data on temperature profiles were collected during the previously mentioned field trip conducted during January 2006. In addition, limited field temperature observations were made during this time, but they were of insufficient duration to be useful for the analysis. Therefore, historical data were utilized for the analysis. Detailed temperature profiles were available for two separate time periods: 1.) 1979 to 1982, and 2.) 2001 to 2002.

6.2. Temperature Analysis

Figure 6.1 is a graph of temperature (°C) from September 1979 to October 1982 recorded from the water surface to a depth of 21 m (Goldman and Vaux, 1984). The data were measured at a station that is located in the center of the lake and has a depth of 23 m. In years 1979 and 1980, the lake overturned in November; in the year 1981, the lake overturned in early December; and in the year 1982, the lake overturned in October. In the year 1980 and 1982, the lake had reduced thermal stratification (i.e. less stability) around June, though it appears that the lake did not mix completely. The average depth of the thermocline during the stratification period was 6.5 m.

Figure 6.2 is a graph of temperature (°C) from March 2001 to November 2002, recorded from the water surface to a depth of 21 m (Sandoval, 2003). The temperature data were monitored at station Indice, located in the center of the lake with a depth of 22 m. In the year 2001, the lake overturned in early December. After the overturn event, it remained vertically mixed until March 2002. In the year 2002, the lake overturned in November; however due to the lack of data for the year 2003, it was not possible to evaluate the length of the period during which it remained mixed. The average depth of the thermocline during thermal stratification was 7 m.

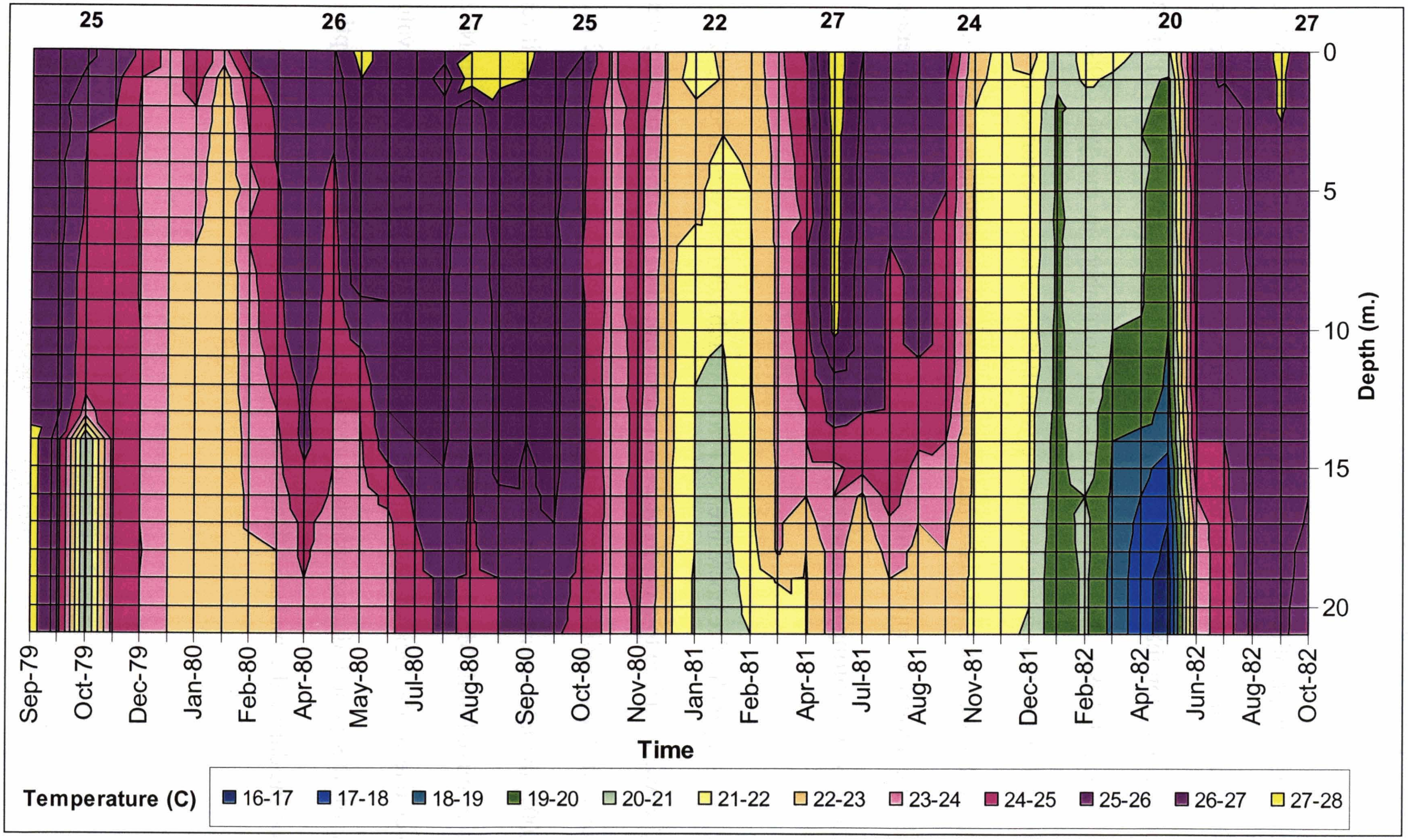

Figure 6.1: Temporal variations of temperature profile for year 1979 to 1982

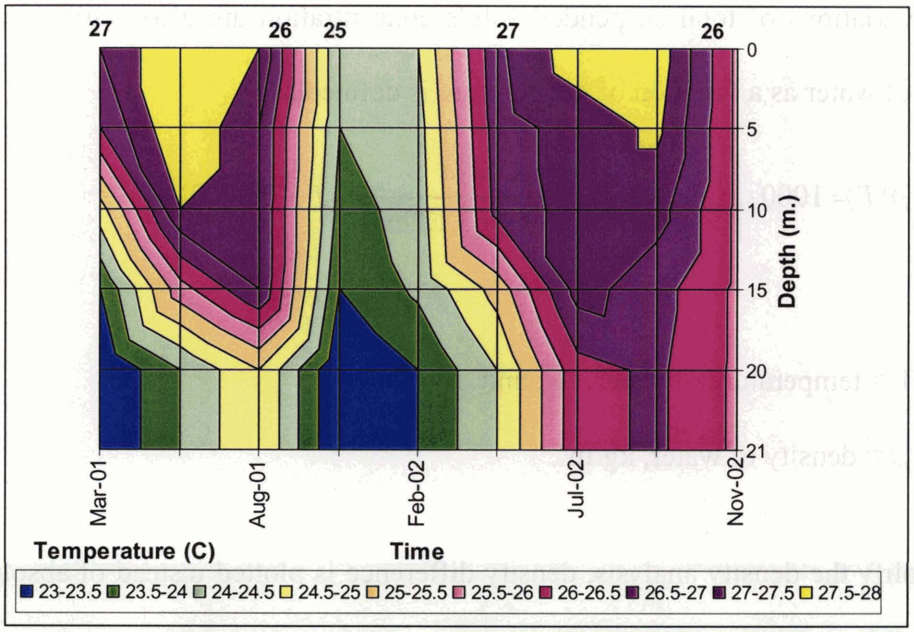

Figure 6.2: Temporal variations of temperature profile for year 2001 and 2002

From the temperature profiles for the two separate time periods, it is clear that the lake overturned once a year usually around November. The lake appeared to be less stable around June with a relatively weak thermal stratification. The average depth of the thermocline during the thermal stratification is about 6.5-7 m.

6.3. Density Analysis

Density of water is a function of temperature, salinity and total suspended solids present in the water, as defined by the equation (Gill, 1982; Martin and McCutcheon, 1999):

$$\rho = \rho(T) + \rho(S) + \rho(TSS) \tag{6.1}$$

Since this is a freshwater lake, variations in salinity are negligible. Further, temporal and spatial variations of total suspended solids concentration are also neglected. Thus the density of water as a function of temperature is defined as:

$$\rho(T) = 1000 \cdot \left[1 - \frac{T + 288.9414}{508929.2 \cdot (T + 68.12963)} \cdot (T - 3.9863)^2 \right] \qquad (6.2)$$

where,

T = temperature of water, °C; and

ρ = density of water, kg/m^3.

To simplify the density analysis, density difference is plotted instead of absolute density values. Density difference is given by:

$$\Delta\rho = \rho_r - \rho \qquad (6.3)$$

where,

ρ = density of water, kg/m^3; and,

ρ_r = reference density (density of freshwater at 4°C), kg/m^3.

The density difference profile follows the same pattern as temperature profile, indicating a once-a-year overturn event occurring sometime around November (Figure 6.3 and 6.4).

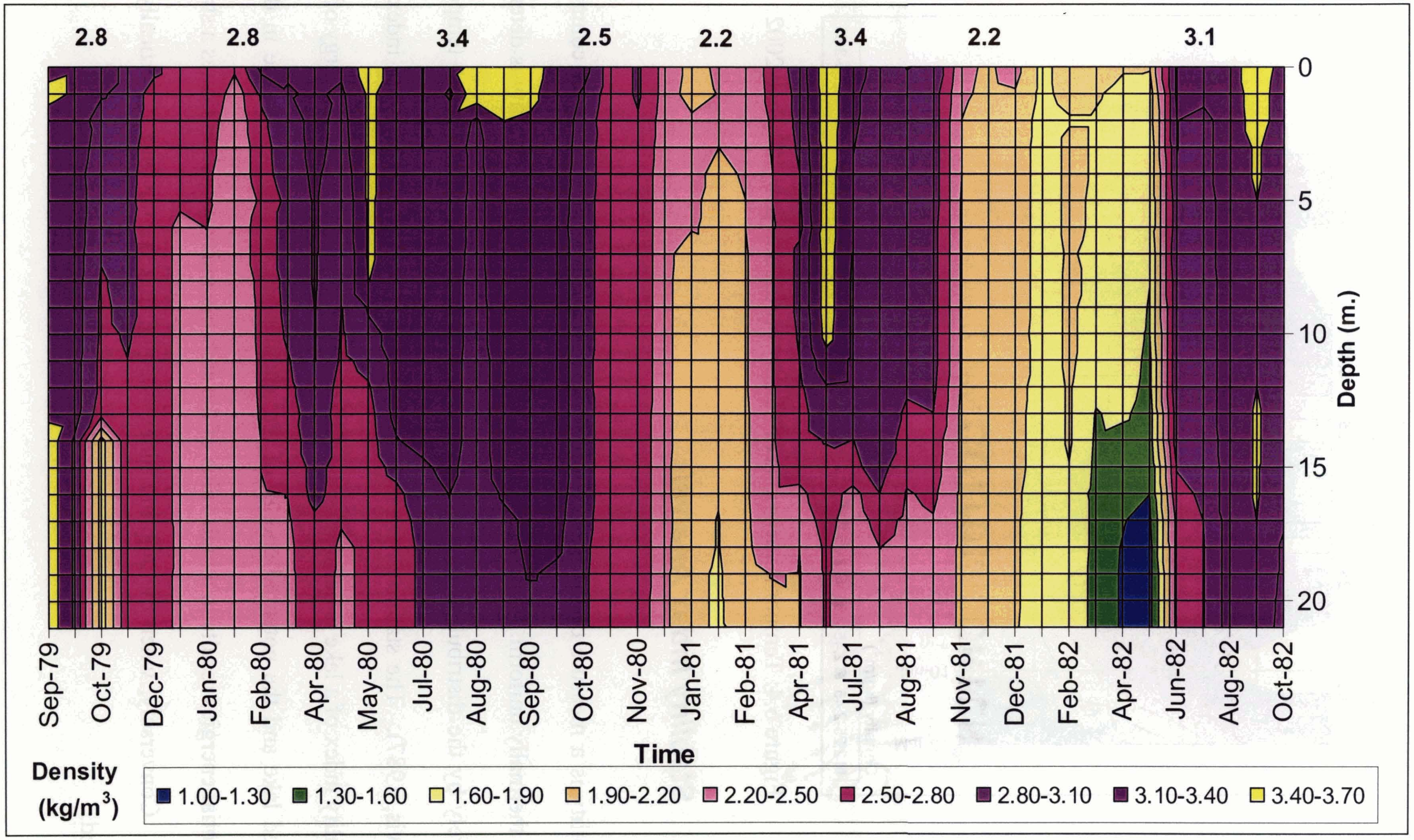

Figure 6.3: Temporal variations of density profile for year 1979 to 1982

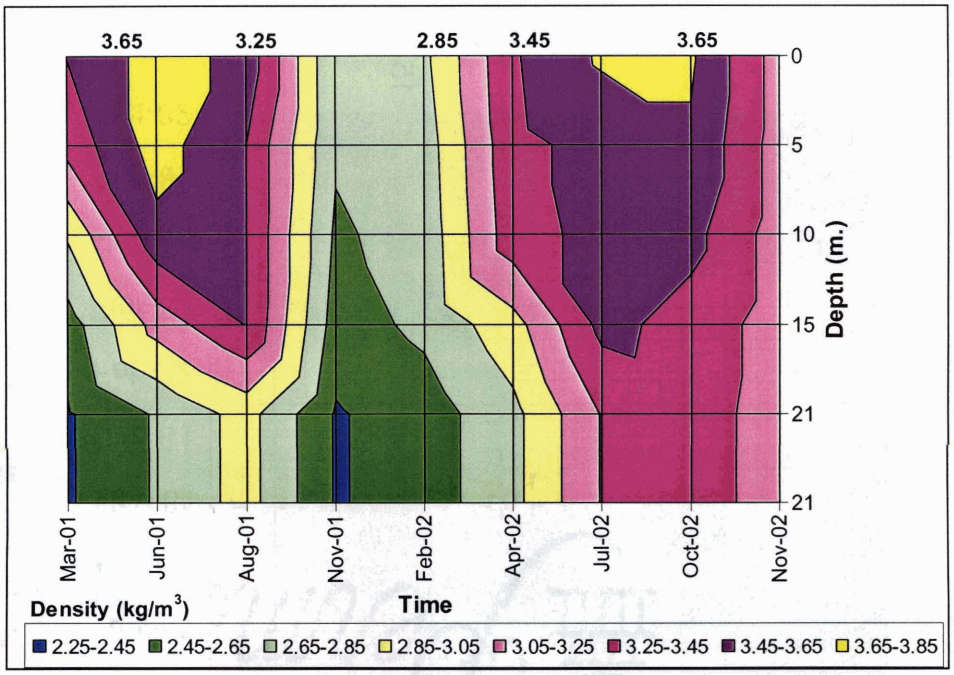

Figure 6.4: Temporal variations of density profile for year 2001 and 2002

6.4. *Stability Index Analysis*

Stability is a measure of the amount of work required to render the water column of a lake thermally uniform. For a lake of given shape and dimensions, stability is determined entirely by the distribution of water densities, which are related in turn to temperature (Lewis, 1987). The stability of a lake is measured in terms of a stability index. The stability index of a lake is defined as the difference between the potential energy of a well mixed lake and the potential energy of the actual lake. A large difference in the two potential energies results in a high value of the stability index, which indicates a stratified lake. Conversely, when the stability index is equal to zero, the lake is vertically well-mixed.

Potential energy is a function of density ρ, surface area of the lake A, acceleration due to gravity g, and depth of the lake z. Mathematically the stability index is defined as (Adams, 2006, pg. 8-34):

Stability Index = P.E. (well mixed) – P.E. (actual)

$$\text{S.I.} = \int_0^h [\overline{\rho} - \cdot\rho(z)] \cdot [z - \overline{z}] \cdot A(z) \cdot g \cdot dz \qquad (6.4)$$

where

z = depth of the lake, m;

$\overline{z}$ = depth of the center of mass of the lake, kg/m^3;

$A(z)$ = surface area of the lake at depth z, m^2;

$\overline{\rho}$ = density of the water at the center of mass of the lake, kg/m^3;

$\rho(z)$ = density of the water at depth z of the lake, kg/m^3;

g = acceleration due to gravity, m/s^2; and

P.E. = potential energy, kg m^2/s^2.

Since the temperature, density and surface area at different depths of the lake are known, the stability index values are computed for the two separate time periods (1979-1982, and 2001-2002). The temperature profiles for the two time periods were measured to a depth of 21 m, which was used as the datum for the equation 6.4. As the stability index calculation for the two periods start at the same depth, the potential energies for the two periods are comparable. For the period of 1979 to 1982, the stability index of the lake was minimal during November for 1979, 1980 and 1981 (Figure 6.5). The stability index for the year 1982 was minimal from August through October. Also, for the year 1980 and 1981 the stability index reduced during June. This indicates that the lake was less stable during summer, and thus was most sensitive to the factors causing an overturn.

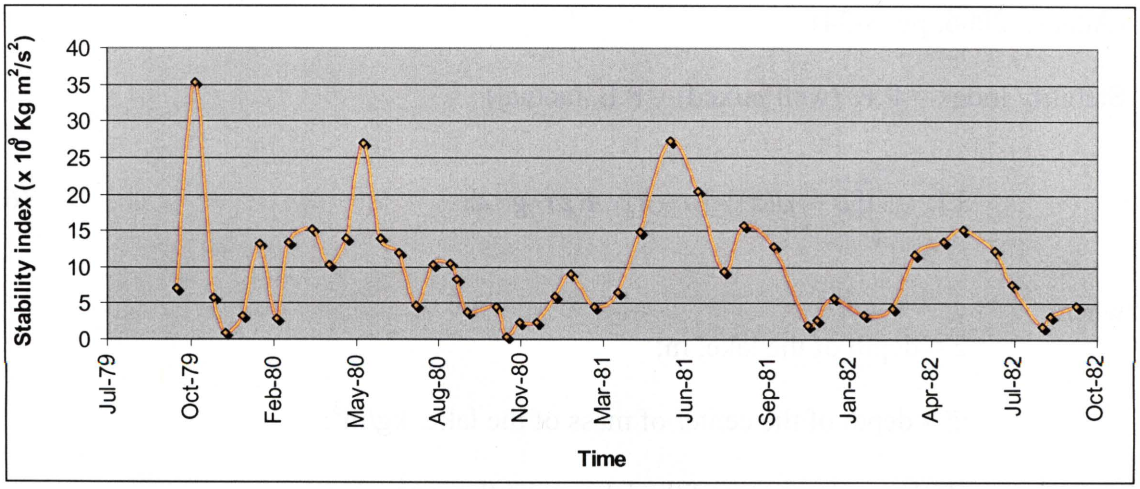

Figure 6.5: Temporal variations of stability index for year 1979 to 1982.

For the period of 2001 to 2002, the stability index of the lake was minimal during the period of November 2001 to February 2002, which is consistent with the previous conclusions that the lake overturned once a year (sometime around November). (Figure 6.6)

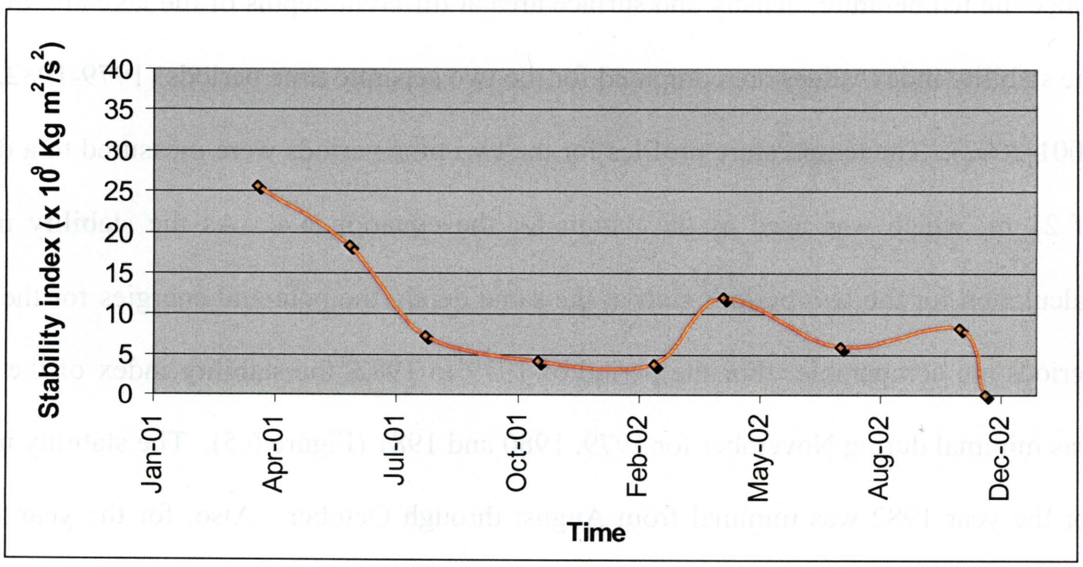

Figure 6.6: Temporal variations of stability index for year 2001 to 2002.

A lake can overturn due to the changes resulting from wind and temperature. The wind has a shearing effect on the water surface; it creates turbulence that circulates the water from the surface to the underlying layers. In this process, the kinetic energy of the wind is translated into an increase in potential energy experienced as the layers become mixed. Similarly, a decrease in air temperature induces surface cooling, which causes an increase in density. The cooler surface water being denser than the underlying warmer layers, moves down, and warmer layers move up, the layers thus readjusting their potential energy to attain stability.

To assess the effect of these two factors on lake stability, the daily wind speed and air temperature are plotted for the time period of 2001 to 2002. The wind speed and temperature data are averaged from the daily measurements at three weather stations as described in Section 7.3.2. As seen in Figure 6.7, the daily wind speed increases frequently around November, and the daily temperature decreases during the same time. The combination of high wind speed and low temperature around November can easily overturn this marginally stratified lake. The figure also shows monthly averaged wind speed and temperature data. The monthly averaged wind speed values do not increase significantly during the November period, but the daily wind speed values have higher variations. Higher wind speeds for a few consecutive days can create enough turbulence to overturn a weakly stratified lake during this time.

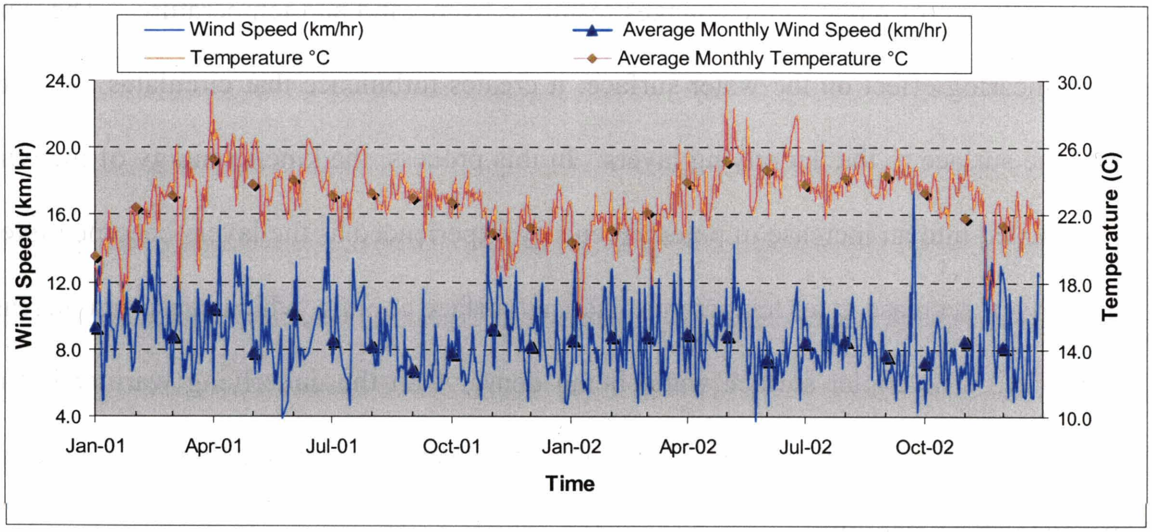

Figure 6.7: Temporal variations of wind speed and temperature for year 2001 and 2002.

6.5. Conclusion Regarding Lake Stability

From the three different sub-analyses for the two historical time periods as discussed above, it appears that the lake mixed once a year, generally around November. Also, the lake was less stable sometime around June for some of the years analyzed. During the stratification period, the average stratification depth was about 7 m. The lake overturn appeared to occur due to the combined effects of high wind speed and low air temperature.

7. Temperature Modeling for Lake Yojoa

7.1. Introduction

Temperature profiles were observed during the field visit from 01/17/2006 to 01/22/2006 at seven different sampling locations. The data were observed to a depth of 16m., which is also the average depth of the lake. Figure 7.1 shows the seven sampling locations and their corresponding temperature profiles. It can be inferred from the profiles that there is negligible horizontal variation of temperature within the lake (i.e. the temperature in the lake on any horizontal plane is nearly the same). Therefore, a horizontally averaged model is adequate to analyze the thermal structure of the lake.

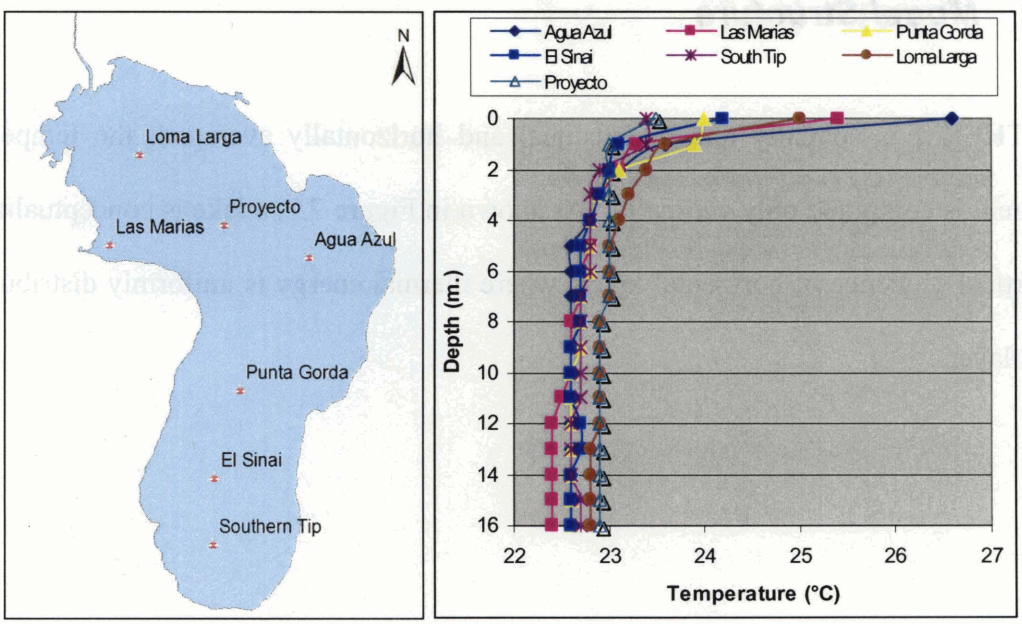

Figure 7.1: Temperature profiles at seven locations at Lake Yojoa.

A computer model, CE-THERM, was selected to analyze the seasonal changes in the thermal structure of the lake. CE-THERM is a standalone model created from the temperature component of the CE-QUAL-R1 water quality model (US Army Corps of Engineers, 1995). The advantages of using a numerical model to analyze the temperature structure are:

- A numerical model can predict stratification or overturn events, and the seasonal changes in the stratification depth.
- The impact of mild variations in weather conditions on lake overturn could be studied using a numerical model.
- Since CE-THERM is a part of a water quality model (CE-QUAL-R1), it lays the foundation for running a water quality model in the future.

7.2. Model Structure

CE-THERM is spatially one dimensional and horizontally averaged; the temperature gradient is computed only vertically. As shown in Figure 7.2, a lake is conceptualized as a vertical sequence of horizontal layers where thermal energy is uniformly distributed in each layer.

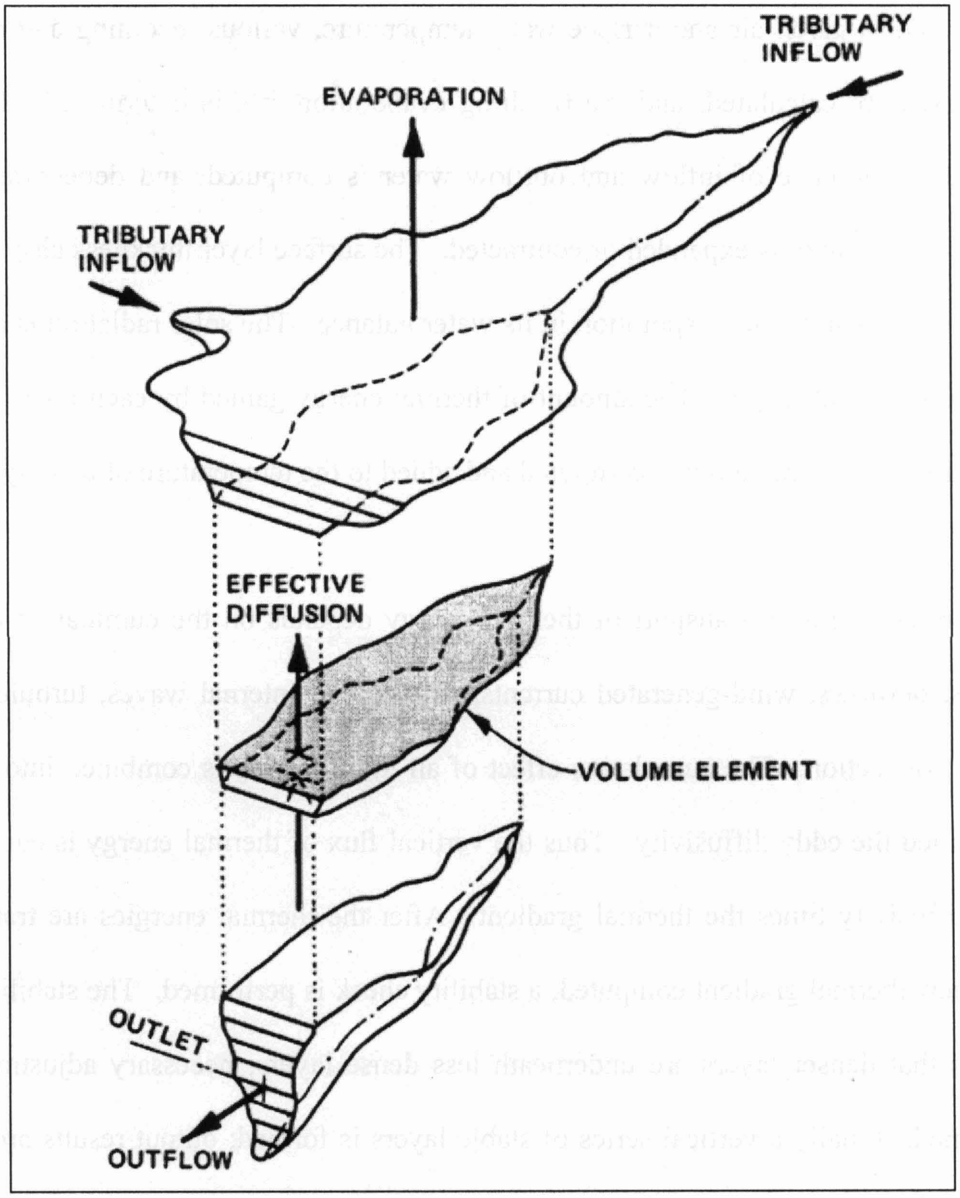

Figure 7.2: Geometric representation of a stratified lake and mass transport mechanisms. (US Army Corps of Engineers, 1995)

CE-THERM computes the temperature at a given time through a series of computational steps. For each time interval, the density of inflowing water is calculated and the inflowing water is distributed evenly among the horizontal layers with similar density. Depending on the outlet location, the withdrawals of outflow water from the horizontal layers and their release quantities are computed. The next step computes a heat and water budget. For a given air and surface water temperature, various incoming and outgoing heat fluxes are calculated, and the resulting evaporation rate is determined. For each layer, the difference of inflow and outflow water is computed, and depending on the difference, the layer is expanded or contracted. The surface layer thickness also accounts for the water lost due to evaporation in its water balance. The solar radiation is absorbed exponentially with depth. The amount of thermal energy gained by each layer from the absorption of solar radiation is computed and added to the temperature of that layer.

The vertical diffusive transport of thermal energy depends on the cumulative effect of inflows, outflows, wind-generated currents, surface and internal waves, turbulence and natural convection. The cumulative effect of all these factors is combined into a single term called the eddy diffusivity. Thus the vertical flux of thermal energy is equal to the eddy diffusivity times the thermal gradient. After the thermal energies are transported and a new thermal gradient computed, a stability check is performed. The stability check ensures that denser layers are underneath less dense layers; necessary adjustments are performed. Finally a vertical series of stable layers is formed; output results are printed and the next time interval is analyzed (US Army Corps of Engineers, 1995). Appendix A shows the conceptual flow chart of various subroutines of the CE-THERM model, with a brief description of each subroutine.

7.3. Model Construction

The input data required for the CE-THERM model are as follows:

7.3.1 Bathymetric Data

The CE-THERM model requires coefficients of a power law function that define the lake surface area against depth relationship. This information was derived from a bathymetric study previously conducted (Vaux et al., 1993). Using ArcGIS 9.1 (ArcScan), the bathymetry was digitized into a GIS format from the paper format. A GIS format of the bathymetry allowed efficient calculations for surface area at various lake depths. The GIS data was projected in the North America Albers Equal Area Conic projection, which minimizes area distortions (Figure 7.3).

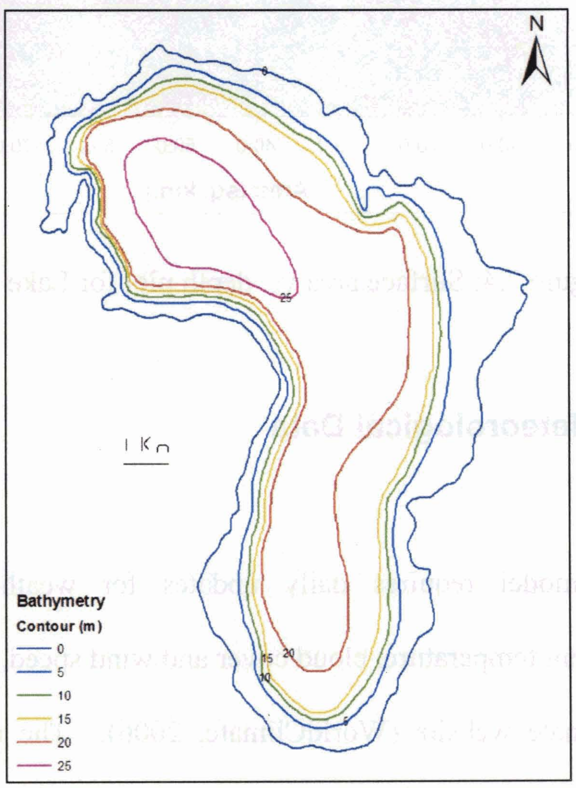

Figure 7.3: Bathymetry for Lake Yojoa
(Vaux et al., 1993)

Figure 7.4 below represents the relationship between depth and surface area of the lake. The input parameters to the CE-THERM model are coefficients of a power law function that define this curve. Refer to Appendices B and C for the calculations of these coefficients.

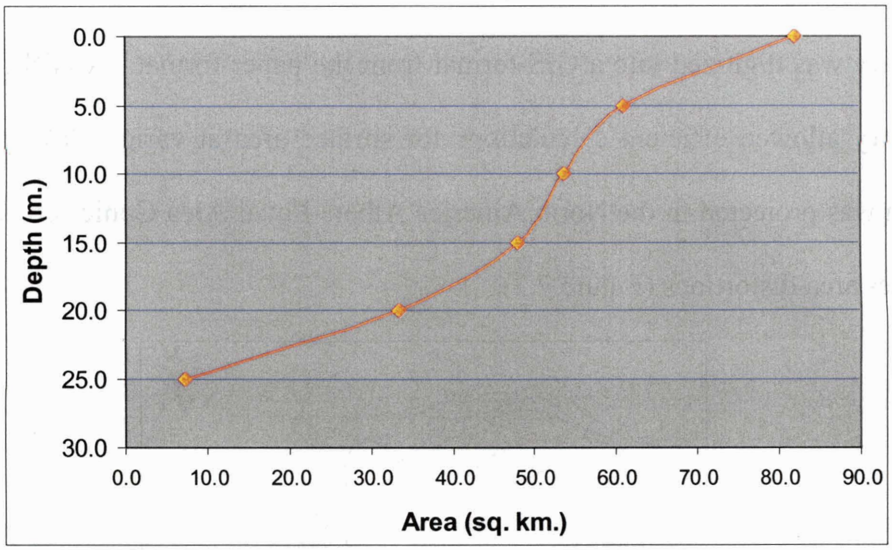

Figure 7.4: Surface area vs. depth plot for Lake Yojoa.

7.3.2 Meteorological Data

The CE-THERM model requires daily updates for weather conditions like air temperature, dew point temperature, cloud cover and wind speed. This data was obtained from the WorldClimate website (WorldClimate, 2006). The meteorological data are collected on a daily basis at the weather stations around Lake Yojoa. Since the closest weather station is about 60 km from Lake Yojoa, taking the weather data from one particular station may not be the best representation of weather conditions at Lake Yojoa.

Figure 7.5 shows five weather stations (Santa Rosa De Copan, Nueva Ocotepeque, Yoro, San Pedro Sula, and La Esperanza) that were analyzed to select the weather stations that best represented weather conditions at Lake Yojoa.

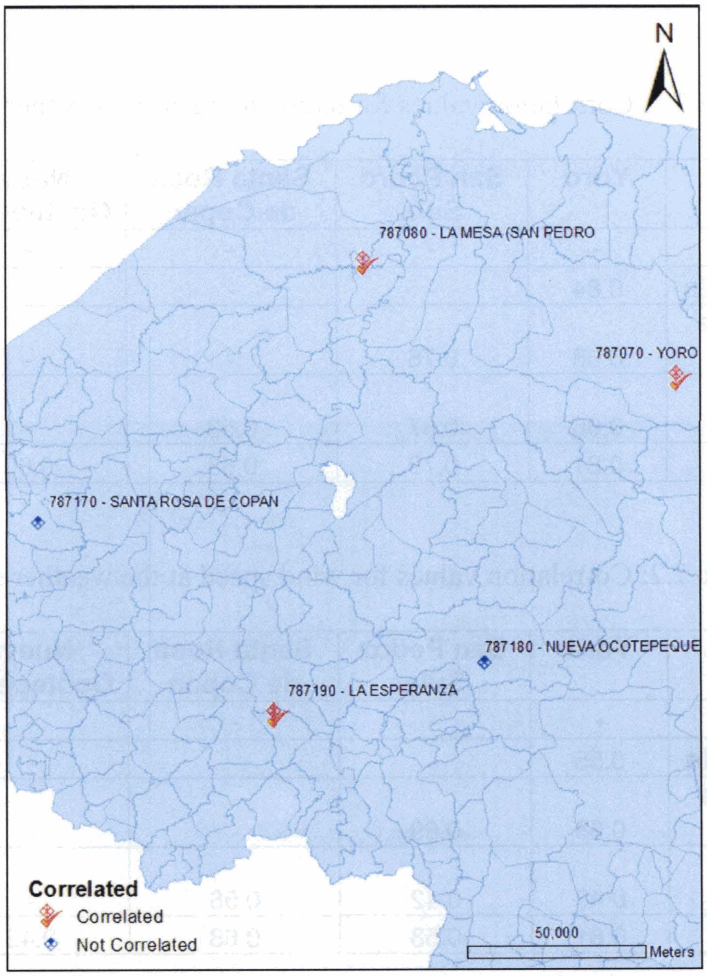

Figure 7.5: Weather stations around Lake Yojoa

Three weather stations (Yoro, San Pedro Sula and La Esperanza) were eventually selected for the following reasons:

- The temperature and wind speed conditions at these three weather stations had better correlations than the surrounding stations. Table 7.1 and 7.2 shows the correlation values for temperature and wind speed at the five stations.

Table 7.1: Correlation values for temperature at the weather stations.

	Yoro	San Pedro Sula	Santa Rosa de Copan	Nueva Ocotepeque	La Esperanza
Yoro	-	-	-	-	-
San Pedro Sula	0.84	-	-	-	-
Santa Rosa de Copan	0.68	0.76	-	-	-
Nueva Ocotepeque	0.66	0.67	0.53	-	-
La Esperanza	0.81	0.79	0.68	0.60	-

Table 7.2: Correlation values for wind speed at the weather stations.

	Yoro	San Pedro Sula	Santa Rosa de Copan	Nueva Ocotepeque	La Esperanza
Yoro	-	-	-	-	-
San Pedro Sula	0.55	-	-	-	-
Santa Rosa de Copan	0.68	0.69	-	-	-
Nueva Ocotepeque	0.43	0.42	0.56	-	-
La Esperanza	0.81	0.53	0.68	0.45	-

- These three weather stations surround the lake region, and therefore their average would give a good representation of the weather conditions for the lake region.

- These three weather stations bracket the elevation of Lake Yojoa. Table 7.3 shows the elevation of Lake Yojoa and the three correlated weather stations. Yoro has the same elevation as Lake Yojoa, but San Pedro Sula and La Esperanza have respectively lower and higher elevation than the lake. San Pedro Sula and La

Esperanza were included on the basis that the weather conditions at lower and higher elevation when averaged will represent the weather conditions at the middle elevation (i.e. Lake Yojoa).

Table 7.3: Elevation of Lake Yojoa and weather stations

Location	**Elevation (above msl)**
Lake Yojoa	632 m.
Station Yoro	670 m.
Station La Esperanza	1030 m.
Station San Pedro Sula	31 m.

Refer to Appendix D for formats and units of the weather data.

7.3.3 Inflow and Outflow Temperature and Flow Rate

The CE-THERM model requires daily updates for the inflow and outflow temperature and flow rate. As previously mentioned, there are six rivers and tributaries flowing into the lake and one artificial canal flowing out of the lake. Figure 7.6 shows a map of all inflows to and the outflow from Lake Yojoa.

Aqua Finca monitors temperature, flow rate and other water quality parameters in the inflow tributaries and outflow canal. There are two problems with the data provided by Aqua Finca: firstly the data was reported on a monthly basis and secondly it was provided for the year 2005 only. This would limit running the model for the year 2005 only and interpolating the monthly data to daily values, thus using less accurate daily values to drive the model. An alternate method (equilibrium temperature calculation) was considered for substituting the temperature data.

Figure 7.6: Inflow (rivers and tributaries) and outflow (canal)

Equilibrium temperature is the temperature of a water body at which it is in equilibrium with the atmosphere (i.e. net surface heat transfer is zero). It is a function of parameters like dry bulb temperature, dew point temperature, cloud cover, wind speed, latitude of the location and day of the year (i.e. the same meteorological variables used as input to CE-THERM). Most of these parameters were averaged on a daily basis from the three weather stations (Yoro, San Pedro Sula, and La Esperanza).

Equilibrium temperature calculations require balancing incoming and outgoing heat fluxes (Figure 7.7). The incoming fluxes include solar shortwave radiation and atmospheric longwave radiation. The outgoing fluxes are back radiation, evaporation and convection. The three outgoing fluxes are dependent on water surface temperature, which is approximately equal to the equilibrium temperature when the outgoing fluxes balance the incoming fluxes. Thus the procedure for calculating equilibrium temperature is iterative. The empirical equations for calculating the five heat fluxes for equilibrium temperature differ slightly from the heat flux equations in CE-THERM.

The heat fluxes for equilibrium temperature are calculated as follows (Shanahan, 1984):

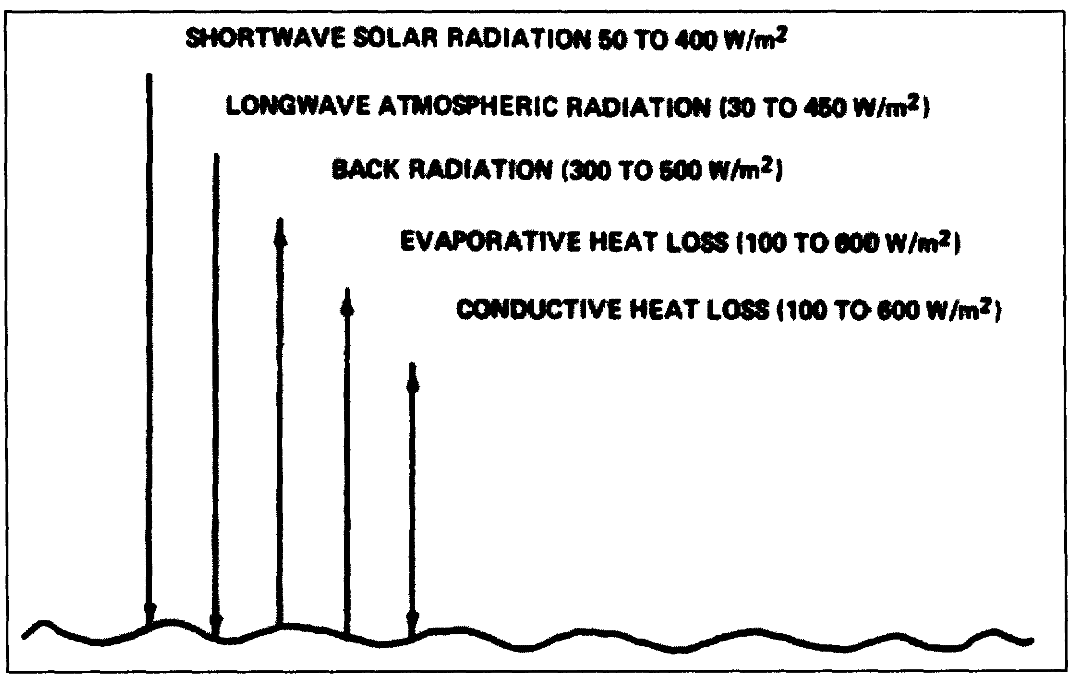

Figure 7.7: Incoming and outgoing heat fluxes.
(US Army Corps of Engineers, 1995)

The net heat flux at the water surface is given by:

$$\phi_n = \phi_{sn} + \phi_{an} - \phi_{br} - \phi_e - \phi_c \quad (7.1)$$

where

ϕ_n = net heat flux into the water surface, W/m^2;

ϕ_{sn} = net solar (short-wave) radiation into the water surface, W/m^2;

ϕ_{an} = net atmospheric (long-wave) radiation into the water surface, W/m^2;

ϕ_{br} = back (long-wave) radiation from the water surface, W/m^2;

ϕ_e = evaporative heat flux from the water surface, W/m^2; and

ϕ_c = conductive heat flux from the water surface, W/m^2.

Solar Radiation: The net solar radiation into the water surface is the incoming radiation from the sun, less that absorbed or scattered in the atmosphere, blocked by clouds and reflected at the water surface.

$$\phi_{\mathrm{sn}} = 0.94 \cdot \phi_{sc} \cdot (1 - 0.65 \cdot C^2) \tag{7.2}$$

where,

ϕ_{sc} = clear sky solar radiation, W/m^2; and

C = fraction of the sky covered by clouds.

Atmospheric Radiation: Atmospheric longwave radiation is the major source of heat to a lake on warm cloudy days. Its magnitude depends primarily on air temperature, relative humidity and cloud cover.

$$\phi_{an} = 2.89 \times 10^{-8} \cdot (1 + 1.29\sqrt{e_a}) \cdot (T_a + 273)^4 \cdot (1 + 0.17C^2) \tag{7.3}$$

where,

e_a = vapor pressure 2 meters above the water surface, Mb; and

T_a = air temperature 2 meters above the water surface, °C.

Back Radiation: Water emits radiation as an almost perfect black-body. Its magnitude can be determined from:

$$\phi_{br} = 5.44 \times 10^{-8} \cdot (T_s + 273)^4 \tag{7.4}$$

where

T_s = water surface temperature, °C.

Evaporation: Evaporative heat flux is directly proportional to the rate of evaporative water loss.

$$\phi_e = \left(1.01 - 9.1 \times 10^{-4} \cdot T_s\right) \cdot f(W) \cdot (e_s - e_a) \tag{7.5}$$

where,

e_s = saturation vapor pressure of the air at the water surface temperature, Mb;

e_a = vapor pressure at 2 meters above the water surface, Mb;

$f(W)$ = wind speed function, W/m^2/Mb.

Conduction: Conduction occurs by a heat diffusion process similar to the moisture diffusion that drives evaporation. The conductive heat flux is given by:

$$\phi_c = 0.6 \cdot f(W) \cdot (T_s - T_a) \tag{7.6}$$

Linearized Heat Exchange method: In the linearized heat exchange concept, the net heat flux is assumed to be a linear function of the surface water temperature:

$$\phi_n = K \cdot (T_S - T_E) \tag{7.7}$$

where,

K = surface heat exchange coefficient, W/m^2/°C; and

T_E = equilibrium temperature, °C.

The results for equilibrium temperature were compared to the observed inflow data for year 2005. Figure 7.8 shows the daily values of calculated equilibrium temperature and observed inflow, outflow and lake surface temperatures. Table 7.4 shows the annual averages for these temperatures. Unfortunately, the observed inflow temperatures were about 6°C lower than the computed equilibrium temperatures. Analyzing the basin hydrology, the residence time of the water in the inflowing rivers was found to be approximately 10 hours, which is too short to allow the water in these rivers to equilibrate with its surrounding atmosphere. The equilibrium temperature could not substitute for the inflow temperature to drive the model; therefore the observed monthly data were used for model simulation.

Table 7.4: Annual average (inflow, lake & outflow) temperature

Station	**Annual Average (°C)**
Equilibrium temperature	27.5
Inflow (average of 6 rivers)	21.5
Lake water surface	24.6
Outflow	24.5

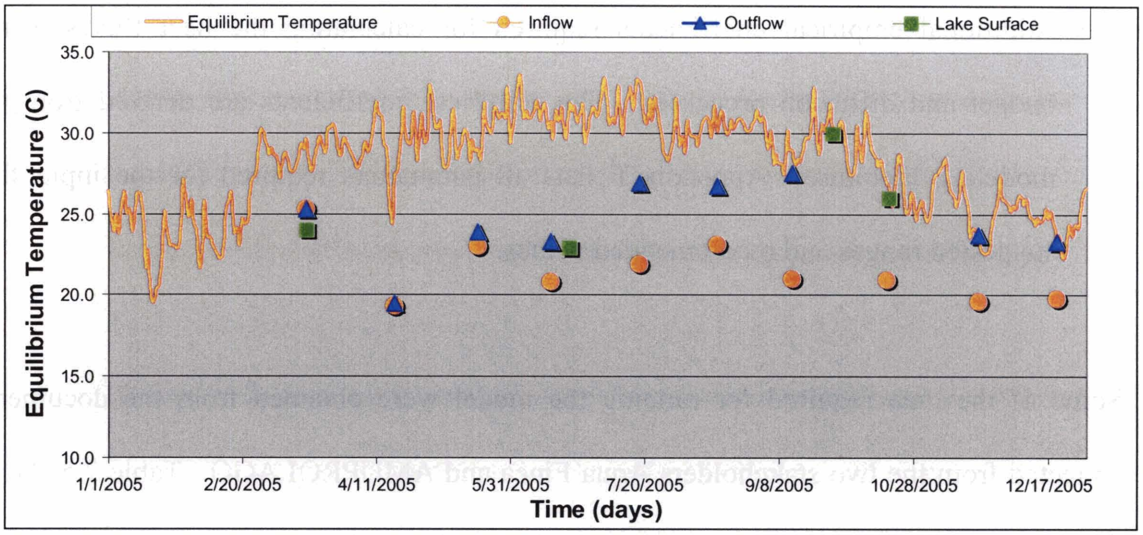

Figure 7.8: Equilibrium temperature comparison

From the Figure 7.8, it is evident that the observed inflow temperature is about 3°C colder than the observed outflow and the lake surface temperature, which means that this colder and denser inflow water will tend to settle in the bottom of the lake. The organic matter transported with the inflow water will also settle in the bottom, increasing the demand for oxygen and exacerbating the anaerobic conditions in the hypolimnion.

7.3.4 Additional Coefficients

Additionally, the CE-THERM model requires a few calculated and empirical coefficients such as:

- The coefficients required for calculating the solar energy absorbed in each horizontal layer. Appendix E explains the equations and calculations.

7.4. Model Calibration

The CE-THERM model is calibrated extensively for temperate lakes, and thus the empirical coefficient values recommended in the CE-QUAL-R1 manual are for temperate lakes. The model was calibrated to observed data collected on a quarterly basis by Aqua Finca during 2005. The observed data are available only up to a depth of 10 m; therefore the model simulations were calibrated to a depth of 10 m only. The model was found to be relatively sensitive to the following coefficients: CDIFF, a coefficient to capture the effect of advection on diffusion; CDIFW, a coefficient to capture the effect of wind on diffusion; AA and BB, coefficients in the wind speed function.

7.4.1 Eddy Diffusion Coefficients (CDIFW, CDIFF)

The empirical coefficients CDIFW and CDIFF are used to calculate the eddy diffusion coefficient, which governs the vertical mixing in the lake. The vertical eddy diffusion coefficient DC (m^2/sec) at a layer interface I is given by:

$$DC(I) = \Delta t^2 \left\{ \left[\frac{CDIFW \times DISW}{1 + Ri} \right] + \left[\frac{CDIFF \times (DISF(I) + DISF(I+2))/2}{1 + \left(\frac{1}{Fr} \right)^2} \right] \right\} \quad (7.8)$$

where

Δt = time interval of computation, sec;

DISW = dissipation of energy (wind) per unit mass, m^2/sec^3;

CDIFW = calibration coefficient due to wind;

Ri = Richardson number;

Fr = Froude number;

DISF(I) = dissipation of energy (advection) per unit mass for layer I, m^2/sec^3;

CDIFF = calibration coefficient due to advection.

The Richardson number is defined as:

$$Ri = \frac{\frac{g}{\rho_w}\frac{\partial \rho}{\partial Z}}{\left(\frac{u_*}{KD}\right)^2} \tag{7.9}$$

where,

D = depth of layer from surface, m;

u_* = shear velocity, m/sec;

g = acceleration due to gravity, m/sec^2;

ρ_w = density of water, kg/m^3;

$\frac{\partial \rho}{\partial Z}$ = local density gradient, $kg/m^3/m$; and,

K = von Kármán's constant (0.4).

The densimetric Froude number is defined as:

$$Fr = \frac{u}{\left(\frac{\Delta \rho}{\rho_w} g \Delta Z\right)^{1/2}} \tag{7.10}$$

where,

u = longitudinal velocity, m/sec;

$\Delta\rho$ = local density change, kg/m^3; and

ΔZ = layer thickness, m.

The equation 7.8 shows that the coefficient CDIFW governs the eddy diffusion coefficient due to wind effects. The CDIFW value was calibrated during the periods of high wind speed and low advection (i.e. the diffusion was primarily due to wind effects), until the simulated stratification depth was similar to the observed stratification depth. Similarly, the CDIFF value was calibrated during the period of low wind and high advection (i.e. diffusion is primarily due to advection – inflow and outflow). The recommended range for CDIFW in the CE-THERM documentation is 1.0×10^{-5} to 1.0×10^{-4}, but the model calibrated best with a value of 0.5×10^{-2}. Using the upper bound value from the recommended range for CDIFW, the model simulated no overturn and unrealistically high difference between the top and bottom layers of the lake. This indicated that using a CDIFW value higher than the suggested upper bound will induce more diffusion of thermal energy to the hypolimnion, smaller temperature difference between the top and bottom layers of the lake, thus the simulated profiles being similar to observed profiles. Use of a higher hypolimnetic diffusion coefficient than recommended suggests that hypolimnetic mixing plays a greater role in tropical lakes than in temperate lakes, and therefore it needs further study (Alvaro, et al., 1989). The recommended range for CDIFF is 1.0×10^{-6} to 1.0×10^{-5}, and the model calibrated best with a value of 0.5×10^{-6}. While the results with the higher diffusivity coefficients look better than those with the lower diffusivity coefficients, due to insufficient data for lower depths, this model cannot be considered as adequately calibrated. Wind Function Coefficients (AA, BB)

The empirical coefficients AA and BB are used in the wind speed function, *f(W)*, for calculating the two outgoing heat fluxes, evaporative heat loss and conductive heat transfer. The wind speed function *f(W)* ($W/m^2/Mb$), used in Equations 7.5 and 7.6, is dependent on the coefficients AA and BB:

$$f(W) = AA + BB \cdot W \qquad (7.11)$$

where,

AA, BB = empirical coefficients; and

W = wind speed, m/sec.

For high wind speeds, the wind speed function *f(W)* and thus the two outgoing (evaporative and convective) heat fluxes are higher, resulting in lower surface water temperature. The coefficient values were varied until the simulated results for the surface water temperature were similar to the observed data. The suggested values of AA and BB in the CE-QUAL-R1 manual are derived from modeling experiences with lakes in Colorado, Maryland, Russia, Canada and Australia. The recommended range for AA is 2.21×10^{-9} to 4.18×10^{-9}, while the model calibrated best with a value of 5.0×10^{-9}. The recommended range for BB is 0.95×10^{-9} to 1.51×10^{-9}, while the model calibrated best with a value of 1.26×10^{-9}.

For the first observation on 3/16/2005, the simulated temperature is about 2°C warmer than observed temperature (Figure 7.9). The figure shows a stratified lake, with the depth of the thermocline as 12 m. The second observation on 6/22/2005 shows simulated temperatures much higher (5°C) than the observed temperatures. The depth of the simulated thermocline is about 21 m. The observed data are for the top 10m only, thus it is not possible to compare the simulated and observed thermocline depth. The high difference in the surface water temperature for these profiles is possibly due to a large disparity in the weather data and the observed weather conditions during this period. For the last two profiles (9/28/2005 and 10/19/2005), the simulated and observed data are quite comparable. The simulated results show that the lake is mixed to almost 21 m depth. Unfortunately, not having temperature observations to the bottom of the lake is a major drawback for model verification.

7.6. Discussion of Results

Lake Yojoa is a marginally stratified lake, in which the average temperature difference between the water surface and lake bottom is approximately 4°C. High wind speeds and/or low temperatures for a short period can cause the lake to mix. When simulating the thermal conditions for a lake that is extremely sensitive to the input weather data like wind speed and temperature, it is crucial that such short-term local fluctuations of weather conditions are accurately recorded and reported. The weather data employed to drive the model reported here is a spatial average of three weather stations with different elevations. The lake is surrounded by natural reserves on either side (Figure 3.1); it is

- Additional empirical coefficients required for calculating the heat fluxes, water budget and diffusion processes. The empirical coefficients are derived from the modeling literature. Appendix F lists all parameters required for the input file, suggested ranges and recommended values.

Some of the data required for running the model were obtained from the documents collected from the two stakeholders Aqua Finca and AMUPROLAGO. Table 7.5 shows the input data matrix used to select the best dataset for model simulation. The year 2005 has all the data required for CE-THERM, and therefore the model will simulate thermal structure for 2005 only.

Table 7.5: Input data matrix

YEAR	2005	2004	2003	2002	2001	Source
Temperature Profiles	Y	Y	Y	Y	Y	Aqua Finca, 2005
Bathymetry Data	Y	Y	Y	Y	Y	Vaux et al, 1993
Meteorological Data						
Dry bulb (air) temperature	Y	Y	Y	Y	Y	WorldClimate, 2006
Dew point temperature	Y	Y	Y	Y	Y	WorldClimate, 2006
Cloud cover	Y	Y	Y	Y	Y	WorldClimate, 2006
Wind speed	Y	Y	Y	Y	Y	WorldClimate, 2006
Inflow/Outflow Data						
Flow rate	Y	N	N	N	N	Aqua Finca, 2005
Temperature	Y	N	N	N	N	Aqua Finca, 2005

Appendices G and H show the template required for the input file (CQT.dat) and the final input file CQT.dat used for running the model respectively.

7.5. *Model Results*

The lake conditions were simulated for 365 days during the year 2005. To specify initial conditions, temperature values at different depths were required for the first day (1/1/2005) of simulation. Since Aqua Finca reports its monitoring data on a quarterly basis, the initial conditions were obtained by interpolating between the data recorded on 12/15/2004 and 3/16/2005. The simulated output was printed at an interval of every 15 days. The results were graphed and compared for four dates (3/16/2005, 6/22/2005, 9/28/2005 and 10/19/2005), during which temperature was measured over varying depths by Aqua Finca. Aqua Finca monitors water quality parameters at three different locations in the lake; observations for the deepest point (Loma Larga) were plotted, as the model simulates conditions at the deepest part of the lake.

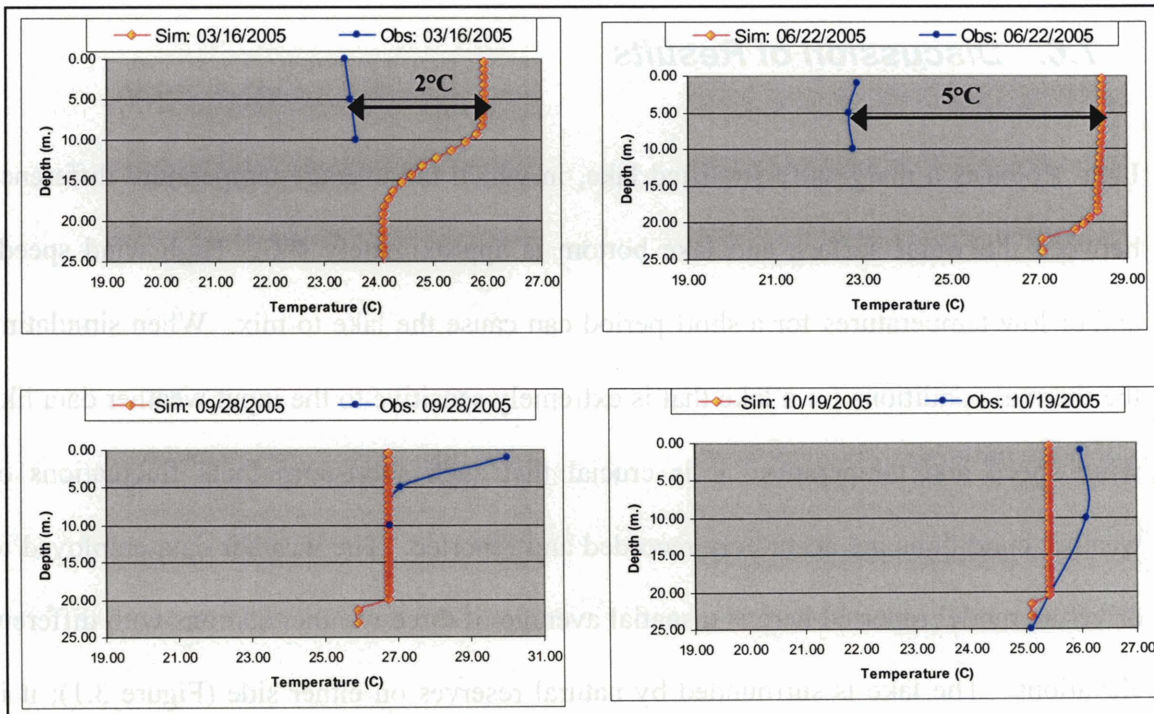

Figure 7.9: CE-THERM simulation results compared with observed data.

likely that it has its own micro-climate. Thus, it is possible that the averaged weather data may not accurately represent the climactic conditions at the lake. To understand the effect of spatial averaging of weather data from three different stations on the model results, a simple graphical analysis is performed.

As previously mentioned, equilibrium temperature is a measure of atmospheric forces which integrates the effects of weather data like air temperature, dew point temperature, cloud cover and wind speed. Thus, for the three stations (Yoro, San Pedro, La Esperanza), using their individual weather data, daily equilibrium temperature is calculated. Finally, equilibrium temperature is calculated using the average of the data from the three weather stations, which essentially is the weather data input to the model. Figure 7.10 shows a graph of equilibrium temperatures for individual and average weather data, whereas Table 7.6 shows annual averages of each temperature plot. From the graphical and tabular information, it is evident that the equilibrium temperatures at

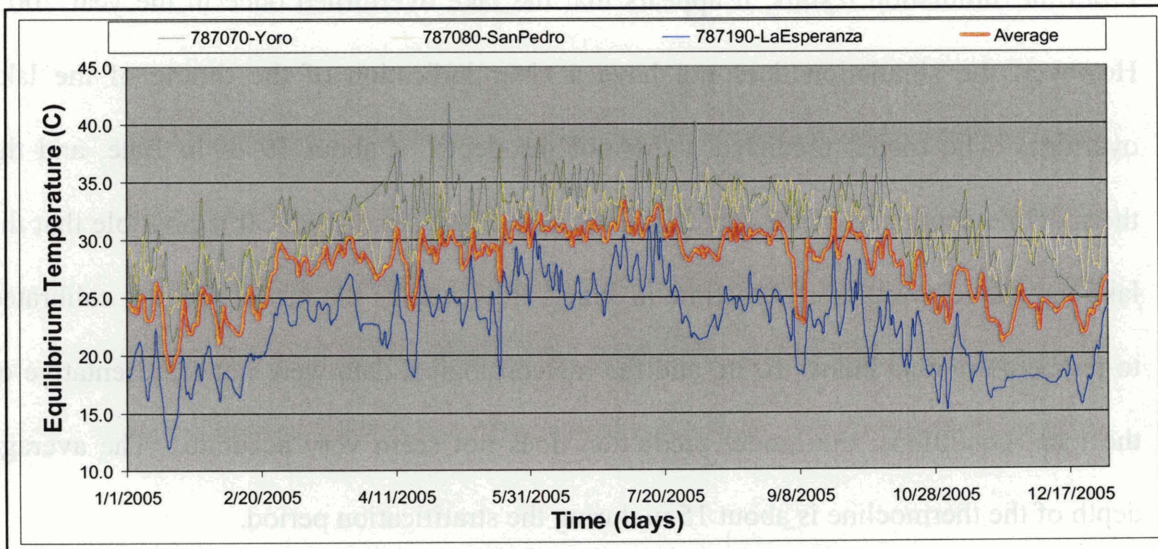

Figure 7.10: Equilibrium temperatures for selected weather stations.

individual weather stations vary significantly (±5°C) from the average equilibrium temperature.

Table 7.6: Annual average equilibrium temperature

Station	Annual Average (°C)
787070 – Yoro	31.3
787080 – San Pedro	30.8
787190 – La Esperanza	22.3
Average for 3 Stations	27.5

Since the actual weather conditions at Lake Yojoa can be much higher or lower than the conditions represented by the averaged weather data, significant differences between simulated and observed temperature values are likely. This analysis provides a plausible explanation for the higher temperatures predicted by the model.

7.7. Conclusion Regarding Temperature Model

From the simulation results, it appears that the lake overturned once in the year 2005. However, the simulation does not have a clear indication of the timing of the lake overturn. The model predicted a thermocline depth of about 19 m in June, and the thermocline depth stayed the same until the end of the simulation. It is possible that the lake may have overturned sometime in June. However, as the model was not calibrated to temperature data below 10 m, and the meteorological data were not representative of the local conditions, the model prediction does not seem very accurate. The average depth of the thermocline is about 15 m during the stratification period.

The knowledge of the onset of thermal stratification in the lake and the depth of the thermocline can be used to predict the general water quality of the lake. An important indicator of the lake's water quality is the dissolved oxygen: its concentration in the deep water of tropical lakes is a critical matter for their protection and management. Three factors work against the retention of oxygen in the deep waters of tropical lakes: 1) the long duration of stratification in tropical lakes; 2) the poorer ability of water to hold oxygen at high temperatures than at low temperatures; and 3) higher rates of microbial metabolism at the high temperatures characteristic of the deep water of tropical lakes. Together, these three factors magnify the influence of any organic enrichment of deep waters. Therefore, undesirable effects associated with anoxia caused by eutrophication or direct organic enrichment of waters will be more serious and more quickly realized in tropical lakes than temperate lakes. An extension of the duration, severity, or spatial distribution of the anoxia within the hypolimnetic zone may have strong negative consequences for the biota and the usefulness of the lake as a water supply or fishery (Lewis, 2000). Though the concentration of dissolved oxygen in the hypolimnion cannot be predicted by CE-THERM, the volume of hypolimnetic water at various times in the year can be calculated using the model results. Figure 7.11 shows a plot of the thermocline (stratification depth) for the simulation period of 2005.

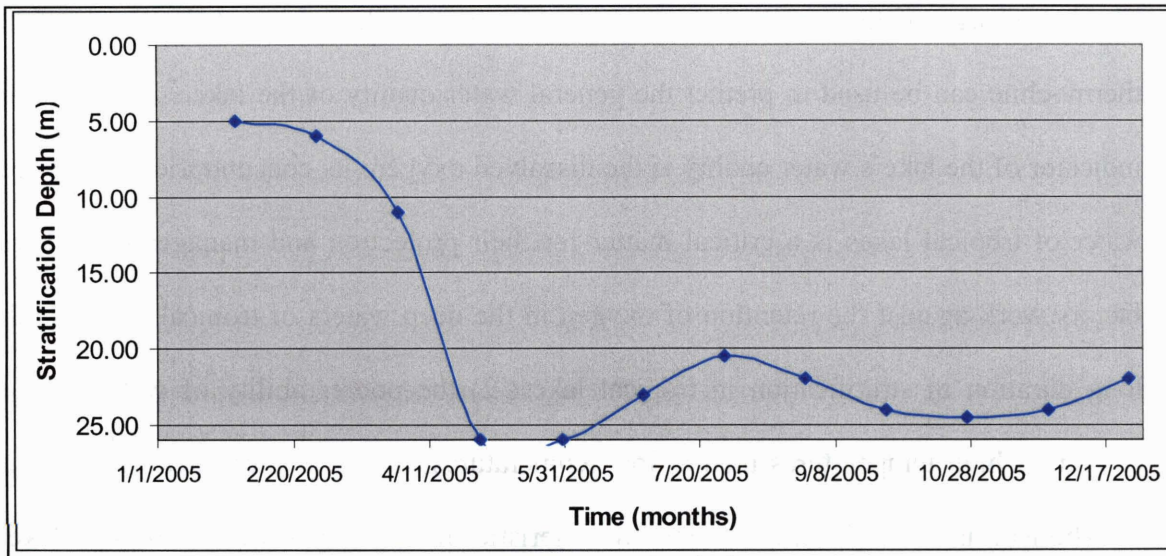

Figure 7.11: Stratification depth for year 2005

The volume of the lake (V_h) at a given elevation above the bottom of the lake can be calculated as:

$$V_h = \int_0^h A_h \cdot dh \qquad (7.12)$$

where,

h = elevation of the thermocline above the bottom of the lake, m; and

A_h = surface area of the lake at elevation h, m^2.

Using equation 7.12, the hypolimnion volume was calculated. The volume of the epilimnion was taken as the difference of the total volume of the lake and the hypolimnion volume. Figure 7.12 shows a plot of the computed hypolimnion and epilimnion volumes for the simulation period of 2005. From the plot, it is evident that most of the time the volume of poor quality hypolimnetic water is proportionally much less than the volume of epilimnetic water.

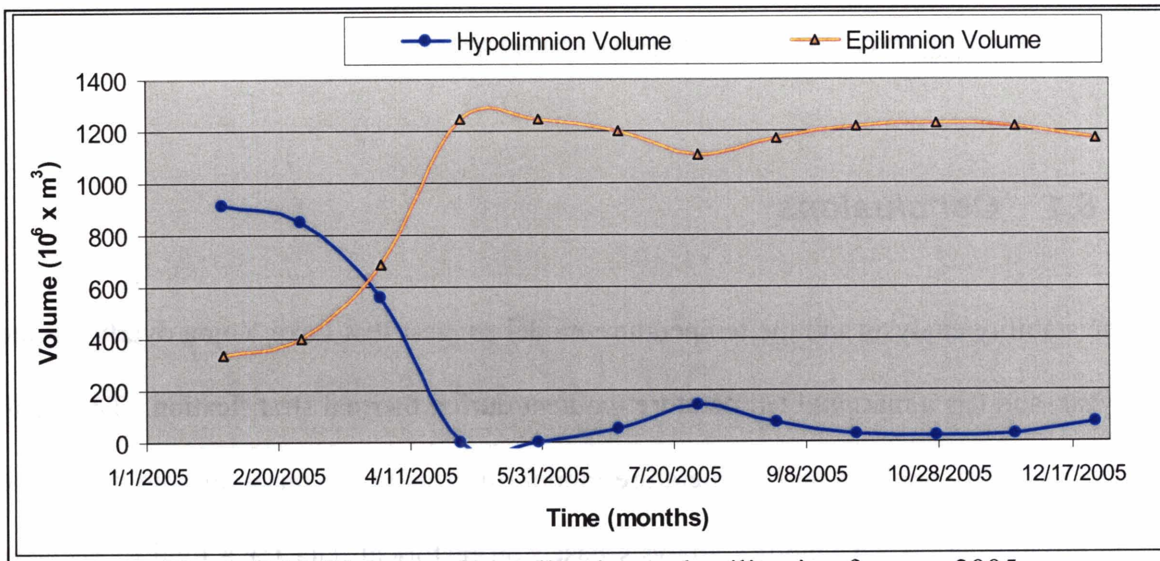

Figure 7.12: Volume of hypolimnion and epilimnion for year 2005

8. Conclusion and Recommendations

8.1 Conclusions

The stability analysis and the temperature model suggest that Lake Yojoa overturns once a year, and has a marginal temperature gradient during thermal stratification. The results of the stability analysis and temperature model differ as to the onset and the duration of the mixing period. A stability analysis based on historical data for a total of six years (1979, 1980, 1981, 1982, 2002 and 2002) found that the lake overturned usually in November. For some of the years (i.e. 1980, 1982), the lake appeared to have reduced stability sometime around June. The average depth of the thermocline is about 7 m during the stratification period. The temperature model was executed and the results were compared with data for a single year (2005); the results showed that the lake overturned in June and remained mixed until the end of the simulation in December. The historical data does indicate less stable lake conditions in June for some years, and thus it is possible that the lake may have actually overturned in June. However, due to the absence of temperature data below 10 m and meteorological data not representative of local weather conditions, the model predictions do not appear to be very accurate. The average depth of the thermocline was 15 m during the stratification period. The volume of poor quality hypolimnetic water calculated based on the model results was proportionally small. During October and November, the daily wind speed increased and the daily air temperature decreased. The combined effect of the wind and the cooling appears to overturn this marginally stratified lake. The advection (inflows and outflow) in the lake is higher during the period of June through November. The inflowing water is about 3°C colder than the lake surface, and tends to settle in the intermediate or bottom depths of the lake water column. The effect of the colder and higher inflow during the periods of low stability should be further analyzed.

The fish kills in October 2003 and 2005 occurred during the period of low stability that ranges from June to November, as indicated by the two analyses. Sustained periods of high wind speed and low temperature during October and November can cause a less stable lake to overturn suddenly. A sudden overturn causes the anoxic hypolimnetic water to move to the surface in a short time period: the result of the mixing of anoxic hypolimnetic water in the epilimnion could cause a sudden decrease in oxygen concentrations in the epilimnion. Respiration by phytoplankton blooms during cloudy conditions or at night, excessive fish feed, and nutrients in the surface runoff can further deplete the dissolved oxygen. In addition to the low dissolved oxygen affecting the fish survival, there are other constituents such as pesticides, metals, and nutrients carried by the inflow waters that are possibly toxic to the fish. Low DO in culture ponds is often associated with elevated levels of carbon dioxide (CO_2) and un-ionized ammonia (NH_3), both of which are toxic to fish (Water Quality Management for Fish Farmers, 2006). Table 8.1 shows a significant increase in the concentration of ammonia nitrogen (NH_3) in Lake Yojoa after the year 2001. Therefore, to identify the possible contaminants that could cause fish kills, detailed water quality monitoring on frequent intervals for constituents like dissolved oxygen, un-ionized ammonia, pesticides, and metals should be conducted.

Table 8.1: Nutrient concentrations in Lake Yojoa.
(Ramsar Sites Information Service, 2006)

Variable	Date			
	1979-1981	1995	2001	2004
Dissolved ortho –phosphate (mg/L)	3	-	80	8
Total phosphate	-	-	-	30
Nitrate-nitrogen (mg/L)	32	100	40	-
Ammonia-nitrogen (mg/L)	20	-	90	2000
Total nitrogen	-	-	-	530

8.2 Recommendations for Further Research

This thermal analysis of Lake Yojoa could be further improved for predictions of the changes in the thermal structure of the lake. The following recommendations are made to collect additional data that will lead to improved thermal analysis:

- The weather data driving the analysis were not accurate enough to represent the local weather conditions at the Lake Yojoa region. It is possible that the hydroelectric dam (ENEE) at Cañaveral may be recording weather conditions; further communication should be established to obtain these data. If no stations are found, a weather station should be built at Lake Yojoa

- Aqua Finca monitors temperature at 1 m intervals to the lake bottom on a bi-monthly basis. However, the data in Aqua Finca reports are summarized on a quarterly basis for three depths (to 10 m) only. Detailed in-lake temperature data as monitored should be requested from Aqua Finca. Alternatively, a series of thermistors could be set up in the lake for continuous (at least hourly) monitoring of temperature, and these data should be published in the public domain.

- From the observed inflow and outflow data, it appears that the colder inflow water tends to settle in the intermediate or bottom depths of the lake for most of the year. If poor quality inflow water is continuously settling in an anoxic hypolimnion, it can cause severe consequences to the biota and the overall health of the lake. Therefore, further field studies can be conducted to study the transport and distribution of the inflow water in the lake water column. For this purpose, tracer dye experiments can be conducted, or any tracer of opportunity if available can be utilized.

- In addition to the thermal analysis, water quality analysis using CE-QUAL-R1 can be conducted to assess the water quality and the trophic status of the lake. For this purpose, water quality data on the inflows to the lake and in-lake water quality profiles are required.

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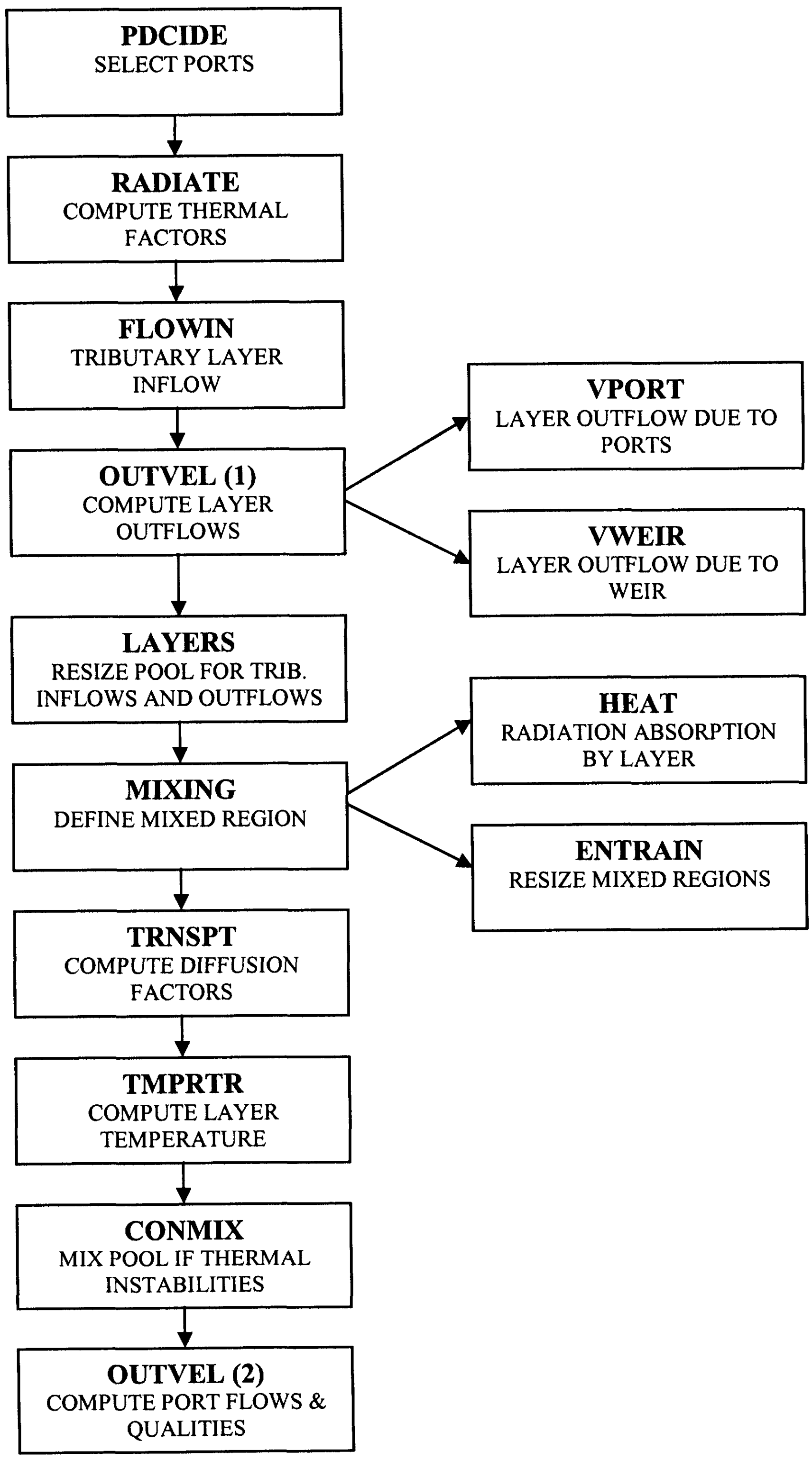
GIS Data Sources:

GeoCommunity http://data.geocomm.com/catalog/HO/datalist.html

The Municipality of Las Vegas

Appendix

Appendix A: CE-THERM Flow Chart



PDCIDE

Reservoir releases through multilevel ports can be specified or subroutine PDCIDE can be called to choose port flows in order to meet a release temperature objective. For purposes of temperature modeling of a lake with a single port, this subroutine is not required.

RADIATE

Subroutine RADIATE computes the principal components of the heat budget of a reservoir from meteorological data. These components include shortwave solar radiation, longwave atmospheric radiation, back radiation, convective heat loss and evaporative heat loss. The purpose of performing a heat budget is to calculate the evaporation rate from the reservoir, which is used to calculate the water budget of the reservoir. Refer to Chapter 7.3.3.

FLOWIN

Subroutine FLOWIN has three functions:

- **a.** Place the inflow at the correct level in the reservoir, depending on its temperature and density.
- **b.** Determine the thickness of the inflow zone, depending on inflow rate and existing density gradient over the inflow zone.
- **c.** Vertically distribute the inflowing water and accompanying materials in the reservoir.

OUTVEL

Subroutine OUTVEL is initially called to calculate the vertical distribution of outflow. After all new variable concentrations in the pool are calculated, it is again called to withdraw flow from layers and compute release quantities. It calls subroutine VPORT when port releases are involved, and/or subroutine VWEIR when weir flows are involved.

LAYERS

After the subroutine FLOWIN has partitioned the inflowing water among individual layers, and the subroutine OUTVEL has determined the composition of outflows from individual layers, subroutine LAYERS is called. This subroutine performs a water balance for each layer and adjusts layer geometry accordingly. When there is a net increase in water, layer volume expands as required; when there is a net decrease, layer volume diminishes. Beginning at the bottom with known elevation, each layer is examined and its new volume and thickness determined, and the elevation of its upper boundary is calculated. When all layers are resized, the sum of their heights is the surface water elevation.

MIXING

Subroutine MIXING determines the depth of the upper mixed region using an integral energy approach. It assumes that a lake is composed of two regions: a well-mixed surface region overlying a stable lower region. The depth of the mixed region is determined by comparing the turbulent kinetic energy (TKE) influx from wind shear and convective mixing in a time increment, to the work required (W_L) to lift a layer of metalimnetic water from its position at the bottom of the mixed region to the center of mass of the mixed region. If TKE is larger than W_L, entrainment occurs causing an increase in the depth and volume of the mixed region.

HEAT

Subroutine HEAT is called from subroutine MIXING and calculates solar radiation absorbed in each layer.

ENTRAIN

Subroutine ENTRAIN is called from subroutine MIXING when sufficient turbulent kinetic energy is available to entrain a layer into the mixed region and thereby increase the depth of the mixed region. The depth of the new center of mass of the upper mixed region is also calculated.

TRNSPT

Subroutine TRNSPT calculates diffusion coefficients and invariant transport matrix elements. Vertical mixing in reservoirs results from the cumulative effects of inflows, outflows, wind-generated currents, surface and internal waves, turbulence, natural convection, etc. Since the overall contribution of these phenomena to mixing is not completely understood, their cumulative effects are combined in an eddy diffusivity term. Eddy diffusivity assumes that the flux or transport of a variable concentration is equal to an eddy diffusivity coefficient times a concentration gradient.

TMPRTR

Subroutine TMPRTR calculates the vertical distribution of energy based on heat fluxes calculated in subroutines RADIATE and HEAT and the transport matrix calculated in subroutine TRNSPT.

CONMIX

Subroutine CONMIX examines the water densities layer by layer, beginning with the lowest, to detect if water in any layer is overlain by denser water. If such an unstable condition exists, densities in the unstable layers are averaged according to layer volumes.

OUTPT1, OUTPT2, OUTPT3, OBLOUT

All the above subroutines print output files with simulation results in standard formats that are readable by post-processing utility functions.

Appendix B: CE-THERM Input – Lake surface area vs. elevation coefficient calculations

ACOEF (1) and ACOEF (2)

The coefficients used to calculate the horizontal areas of the layers with respect to elevation are defined by the equation:

AREA (I) = ACOEF (1) * [Z (I) ^ ACOEF (2)] (B.1)

Since a power equation did not plot correctly, a log transformation was applied to solve the equation. The intercept is Log ACOEF1 and the slope is equal to ACOEF2 of the straight line curve. An inverse Log transformation is applied to get the value of ACOEF1.

A = ACOEF1 * Z^ACOEF2 (B.2)

Log A = Log ACOEF1 + ACOEF2 * LOG Z (B.3)

where:

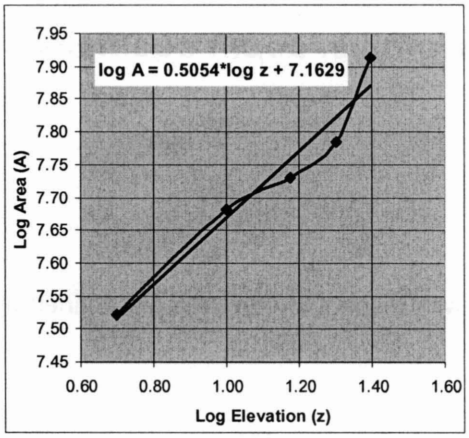
A = Area of horizontal layer in m^2; and

Z = Elevation of the layer in m.

Elevation z (m)	Area A (m^2)
0.1	7.3E+06
5	3.3E+07
10	4.8E+07
15	5.4E+07
20	6.1E+07
25	8.2E+07

Log transformation →

Log Elevation (z)	Log Area (A)
0.70	7.52
1.00	7.68
1.18	7.73
1.30	7.78
1.40	7.91



$\text{Log } A = 0.5054 * \log z + 7.1629$
$\text{Log (ACOEF(1))} = 7.1629$
$\text{ACOEF(1)} = 1.455 \times 10^{7}$
$\text{ACOEF(2)} = 0.5054$

Appendix C: CE-THERM Input – Lake width vs. depth coefficient calculations

WCOEF (1) and WCOEF (2)

The coefficients used to calculate the width of the layers with respect to elevation are defined by the equation:

WIDTH (I) = WCOEF (1) * [Z (I) ^ WCOEF (2)] (C.1)

A similar transformation was applied to the width and elevation dataset to derive the values of the coefficients.

W = WCOEF1 * Z^WCOEF2 (C.2)

Log W = Log WCOEF1 + WCOEF2 * LOG Z (C.3)

where:

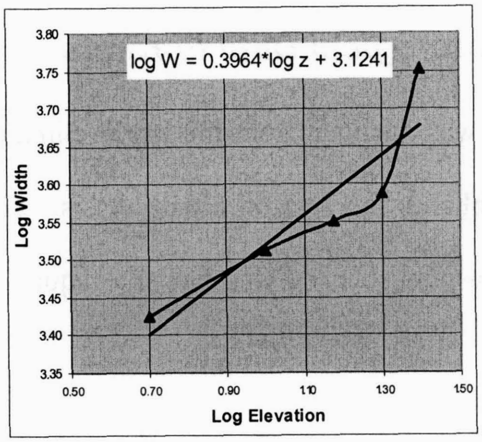
W = Width of horizontal layer in m; and

Z = Elevation of the layer in m.

Elevation (m)	Width (m)
0.1	1.81E+03
5	2.66E+03
10	3.26E+03
15	3.56E+03
20	3.87E+03
25	5.66E+03

Log transformation →

Log Elevation	Log Width
0.70	3.42
1.00	3.51
1.18	3.55
1.30	3.59
1.40	3.75



Log W = 0.3964 * log z + 3.1241
Log (WCOEF(1)) = 3.1241
WCOEF(1) = 1330.76
WCOEF(2) = 0.3964

Appendix D: CE-THERM Input – Meteorological Data Formats

The meteorological data required for CE-THERM was obtained from the world climate website (http://www.worldclimate.com), which publishes the data on a daily basis. To use this data as an input to CE-THERM, the data published on this website required format and unit conversion, as explained below:

CLOUD (Cloud Cover)

Cloud cover is the amount of the sky obscured by clouds when observed at a particular location. It is measured in OKTAS (eights of the sky covered in cloud). The cloud cover information available from the meteorological website was in descriptive format, rather than in OKTAS. The table below explains the various cloud cover codes, their descriptions and conversion to fractional value.

Cloud Cover Code	Description	Fraction
CLR	Clear	0
SCT	Scattered	0.31
BKN	Broken	0.75
OVC	Overcast	1
OBC	Obscured	0.6
POB	Partially Obscured	0.5

DPT (Dew point temperature)

Dew point temperature was available in °F, and converted into °C.

DBT (Dry bulb temperature)

Dry bulb temperature was available in °F, and converted into °C.

APRES (Barometric pressure)

Daily updates of barometric pressure were not available. Since fluctuations in the value of barometric pressure do not make significant differences in model operation, a constant value of 945 mb is used. (Recorded during the field visit)

WIND (Wind Speed)

Daily updates for wind speed were recorded in knots. A conversion factor of 1.85 was used to convert the wind speed from knots to km/hr.

1 knot = 1.85 km/hr

Appendix E: CE-THERM Input – EXCO & SURFRAC Calculations

EXCO (Extinction Coefficient) (1/m)

EXCO stands for extinction coefficient, which is utilized to determine the amount of solar radiation penetrating the water layers. It can be either be measured directly using a photometer or can be calculated if maximum Secchi disk depth is known.

$$\eta = 1.1\, Z_S^{-0.73} \quad \text{(E.1)}$$

where:

η = Extinction coefficient (1/m); and

Z_S=Secchi depth (m).

The Secchi depth of the lake ranges from 3.4 to 12.6 m, with an average of 7.1 (Vaux et al., 1993). Using a conservative value of 7.1 m, the extinction coefficient is 0.26.

SURFRAC

SURFRAC is the fraction of solar radiation absorbed in the 0.6-m surface layer. It can be calculated from EXCO, using Equation E.2.

$$\beta=0.27 \ln(\eta) + 0.61 \quad \text{(E.2)}$$

where:

β = SURFRAC; and

η = Extinction coefficient.

For EXCO = 0.26, the value of SURFRAC is calculated to be 0.25.

Appendix F: Parameter Description for CE-THERM Input File

Term	Units	Explanation	Range	Value
TITLE		Informational data		
IFIRST	day	First Julian day for which initial meteorological and update data are specified.		1
ILAST	day	Last inclusive Julian simulation day		365
NHOI	hour	Computation interval	1,2,3,4,6,8,12 or 24 hr.	24 hr
IPRT	hour	Interval in hours for tabular output	multiple of NHOI	24 hr
ISTART	day	First simulation day (Julian), greater than or equal to IFIRST		1
IYEAR	year	Last two digits of the simulation year		5
MODE		Refers to the way water is withdrawn from the reservoir.		NORMAL
STRUCT		Structure (PORT, WEIR, PORTWEIR) used to withdraw water		PORT
CHOICE		Variable used to show whether flow amounts are specified by port, or system selected		SPECIFY
CALBRAT		Indicates temperature profiles are available for calibration		YES
NTRIBS		Number of inflow tributaries.		1
NUME		Initial number of layers. It depends on minimum and maximum layer thickness.		26
XLAT	DD	Latitude of the project, expressed in decimal degrees.		14.85
XLONG	DD	Longitude of the project, expressed in decimal degrees.		88.00
TURB		Dust attenuation coefficient, represents the attenuation of solar radiation by dust due to scattering and absorption.	0.0 - 0.13	0.06
AA	m/mb-sec	Empirical coefficient used in the wind function to calculate evaporative and convective heat fluxes.	$2.21\text{-}4.18 \times 10^{-9}$	5.00-09
BB	1/mb	Empirical coefficient used in the wind function to calculate evaporative and convective heat fluxes.	$0.95\text{-}1.51 \times 10^{-9}$	1.26-09
ELEMSL	m	Elevation above sea level for the bottom of the pool		632
RLEN	m	Reservoir length		16200
SDZMIN	m	Minimum layer thickness, usually one-half the average layer thickness.	> 0.4	0.5

Term	Units	Explanation	Range	Value
SDZMAX	m	Maximum layer thickness, usually greater than twice SDZMIN		2
SDZ(I)	m	Each layer thickness, starting at the bottom of the reservoir, with I going from 1 to the number of layers (NUME)		1
NOUTS		Number of outlet ports.		1
ELOUT(I)	m	Elevation of Ith port numbered from the top downward.		23.0
PVDIM(I)	m	Vertical dimension of the port I		4.0
PHDIM(I)	m	Horizontal dimension of the port I		3.0
CURVE		The mathematical function used to predict the relationship between area and elevation.		POWER
ACOEF(1)		Coefficient used to calculate horizontal areas of the layers with respect to elevation.	Appendix B	14551240
ACOEF(2)		Coefficient used to calculate horizontal areas of the layers with respect to elevation.	Appendix B	0.5054
WCOEF(1)		Coefficient used to calculate width of the layers with respect to elevation.	Appendix C	1330.76
WCOEF(2)		Coefficient used to calculate width of the layers with respect to elevation.	Appendix C	0.3964
SHELCF		Sheltering coefficient. It is the fraction of the total water surface area exposed to the wind.	0 - 1	1.0
PEFRAC		Penetrative convection fraction, represents the fraction of total kinetic energy produced by natural convection, during cooling periods.	0.1 - 0.5	0.3
CDIFW		Calibration parameter for computing eddy diffusion coefficients representing the contributions of wind.	1.0×10^{-5} - 1.0×10^{-4}	0.5-02
CDIFF		Calibration parameter for computing eddy diffusion coefficients representing the contributions of advection.	1.0×10^{-6} - 1.0×10^{-5}	0.5-06
CDENS	kg/m^3	Critical density, to determine the placement of inflowing water.	0.01 - 2.0	0.3
EXCO	1/m	Extinction coefficient, estimated from maximum secchi disk depth.	Appendix E	0.26
SURFRAC		Fraction of solar radiation absorbed in a 0.6 m surface layer, dependent on EXCO.	Appendix E	0.25

Term	Units	Explanation	Range	Value
EXTINS	1/m * mg/l	Self-shading coefficient for suspended solids, which contributes to a concentration-dependent increment of the extinction coefficient.		
TSSETL	m/day	Suspended solids settling velocity.	0.86 - 860	1.0
NPOINT		Number of layers for which initial conditions are specified. At minimum, initial conditions must be specified for bottom and top layers.		6
ELEV	m	Elevation is specified from the bottom up to the surface.		
TEMP	°C	Temperature		
TDS	mg/L	Total dissolved solids		0
SS	mg/L	Suspended solids		0
FILNAM(1)		Name of the file containing predicted water column data		PLTWC
FILNAM(2)		Name of the file containing predicted outflow data		R1PLT04
FILNAM(3)		Name of the file containing tributary 1 inflow data		R1PLT11
FILNAM(4)		Name of the file containing tributary 2 inflow data, if tributary 2 is specified		R1PLT12
FILNAM(5)		Name of the flux file, if two tributaries are modeled		
FILID		Text to identify output from utilities		LAKE YOJOA HON 2005
INTMET	hour	Meteorological update interval, chosen as integral multiple of NHOI.		24
NCARDS		Number of records containing meteorological data		365
CLOUD	%	Cloud cover to compute shortwave and longwave radiation at every INTMET interval	Appendix D	
DBT	°C	Dry bulb temperature at every INTMET interval	Appendix D	
DPT	°C	Dew point temperature at every INTMET interval	Appendix D	
APRES	mb	Barometric pressure at every INTMET interval	Appendix D	
WIND	km/hr	Wind speed at every INTMET interval	Appendix D	
INTINT	hour	Update interval for outflows, generally chosen as an integral multiple of the computation interval, NHOI		24
NCARDS		Number of SOUTL2 records to be read		365

Term	Units	Explanation	Range	Value
LET		The outlets numbered from the top port down		1
QOT	m^3/sec	Flow out of each port		1.5
INT	hour	Update interval, an integral multiple of the computation interval NHOI		24
NCARDS		Number of records containing update values for current variable or variable group		41
DATA(I)		Update value, could be flow rate (m^3/s) for Q2, temperature (°C) for WQ TEMP.		
VERIFY		Boolean to confirming temperature profile		YES
NVRFY		Number of days for which confirmation data are specified		4
NVDAY		Julian day corresponding to a particular confirmation temperature profile		
NVTMPS		Number of depth-temperature pairs, provided for each temperature profile		
VELEV(I)		Depth-temperature pairs defining confirmation temperature profile		
VTEMP(I)		Depth-temperature pairs defining confirmation temperature profile		

Appendix G: Template for CE-THERM Input File

The table below explains the input file parameters required by the CE-THERM model. Since the program CE-THERM is written in FORTRAN, it requires the input parameters to be written in specific columns. Any error in entering a parameter in an incorrect column may result in unexpected results.

TITLE								
JOB	IFIRST	ILAST	NHOI	IPRT	ISTART	IYEAR		
MODE	MODE	STRUCT	CHOICE	CALBRAT				
PHYS1	NTRIBS	NUME	XLAT	XLONG	TURB	AA	BB	ELEMSL
PHYS2	RLEN	SDZMIN	SDZMAX					
PHYS2+	SDZ(I)							
OUTLET	NOUTS							
PHYS3	ELOUT(I)	PVDIM(I)	PHDIM(I)					
CURVE	CURVE							
AREAC	ACOEF(1)	ACOEF(2)						
WIDTHC	WCOEF(1)	WCOEF(2)						
MIXING	SHELCF	PEFRAC	CDIFW	CDIFF	CDENS			
LIGHT	EXCO	SURFRAC	EXTINS					
SSETL	TSSETL							
INIT0	NPOINT							
INIT2	ELEV	TEMP	TDS	SS				
FILES	FILNAM(1)	FILNAM(2)	FILNAM(3)	FILNAM(4)	FILNAM(5)			
FILID	FILID							
WEATH1	INTMET	NCARDS						
W2	CLOUD	DBT	DPT	APRES	WIND			
SOUTL1	INTINT	NCARDS						
SOUTL2	LET	QOT						
Q1	INT	NCARDS						
Q2	DATA(I)							
WQ TEMP	INT	NCARDS						
TEMP	DATA(I)							
WQ TDS	INT	NCARDS						
TDS	DATA(I)							
WQ SSOL	INT	NCARDS						
SSOL	DATA(I)							
VERIFY1	VERIFY							
VERIFY2	NVRFY							
VERIFY3	NVDAY	NVTMPS	VELEV(I)	VTEMP(I)				

Appendix H: CE-THERM Input File (CQT.dat)

```
TITLE               2005 LAKE YOJOA, HONDURAS
TITLE             FINAL RUN, VERSION MAY 28, 2006
TITLE
TITLE                        MAY 28, 2006
TITLE
JOB             1     365      24     360       1      05
MODE       NORMAL     PORT SPECIFY     YES
PHYS1           1      26   14.85    88.0     .20 5.00-09 1.26-09  632.00
PHYS2       16200     0.5     2.0
PHYS2+ 1      1.0     1.0     1.0     1.0     1.0     1.0     1.0     1.0   1.0
PHYS2+ 2      1.0     1.0     1.0     1.0     1.0     1.0     1.0     1.0   1.0
PHYS2+ 3      1.0     1.0     1.0     1.0     1.0     1.0     1.0     1.0
OUTLET          1
PHYS3       23.00     4.0     3.0
CURVE       POWER
AREAC    14551240  0.5054
WIDTHC    1330.76  0.3964
MIXING        1.0    0.30 0.50-02  0.5-06     0.3
LIGHT        0.26    0.25     0.1
SSETL         1.0
INIT0           4
INIT2         0.1    18.6
INIT2        16.0   18.48
INIT2        21.0   18.21
INIT2        26.0   18.11
FILES    PLTWC   R1PLT04 R1PLT11 R1PLT12
FILID     LAKE YOJOA HON 2005
WEATH1         24     365
W2 3STATNS 05  1     0.48    21.39    18.26  945.00    10.22
W2 3STATNS 05  2     0.55    24.17    21.56  945.00     9.37
W2 3STATNS 05  3     0.45    25.17    20.33  945.00    13.31
W2 3STATNS 05  4     0.45    23.94    18.64  945.00     8.41
W2 3STATNS 05  5     0.21    24.53    16.50  945.00    10.43
W2 3STATNS 05  6     0.26    23.04    16.17  945.00     8.66
W2 3STATNS 05  7     0.33    23.89    21.78  945.00     5.11
W2 3STATNS 05  8     0.45    27.61    23.00  945.00    22.14
W2 3STATNS 05  9     0.64    19.94    18.30  945.00    12.70
W2 3STATNS 05 10     0.45    23.89    18.33  945.00     8.84
W2 3STATNS 05 11     0.41    23.25    19.00  945.00     6.92
W2 3STATNS 05 12     0.33    23.85    16.57  945.00     7.66
W2 3STATNS 05 13     0.23    26.50    20.81  945.00     8.52
W2 3STATNS 05 14     0.48    24.83    21.94  945.00     7.98
W2 3STATNS 05 15     0.71    20.28    18.33  945.00     7.34
W2 3STATNS 05 16     0.64    19.00    17.72  945.00     4.26
W2 3STATNS 05 17     0.52    16.80    13.72  945.00    16.82
W2 3STATNS 05 18     0.49    16.48    14.54  945.00    17.24
W2 3STATNS 05 19     0.52    19.94    17.03  945.00    10.33
W2 3STATNS 05 20     0.71    19.81    17.22  945.00     8.94
W2 3STATNS 05 21     0.35    20.06    16.17  945.00     9.47
W2 3STATNS 05 22     0.45    21.48    15.28  945.00     7.38
W2 3STATNS 05 23     0.48    20.70    15.48  945.00    10.72
W2 3STATNS 05 24     0.35    22.61    16.08  945.00     7.34
W2 3STATNS 05 25     0.64    19.81    16.19  945.00    12.99
W2 3STATNS 05 26     0.52    20.76    15.15  945.00    10.86
W2 3STATNS 05 27     0.21    21.20    13.00  945.00    10.50
W2 3STATNS 05 28     0.23    23.75    17.78  945.00     9.15
W2 3STATNS 05 29     0.55    25.19    20.58  945.00     5.85
W2 3STATNS 05 30     0.37    26.06    23.06  945.00    10.64
W2 3STATNS 05 31     0.21    25.25    17.67  945.00    10.33
```

W2	3STATNS	05	32	0.26	22.85	15.59	945.00	9.30
W2	3STATNS	05	33	0.41	22.87	16.56	945.00	12.42
W2	3STATNS	05	34	0.41	24.36	17.75	945.00	9.05
W2	3STATNS	05	35	0.41	22.58	15.03	945.00	10.64
W2	3STATNS	05	36	0.45	19.20	14.70	945.00	14.76
W2	3STATNS	05	37	0.52	21.67	17.11	945.00	11.64
W2	3STATNS	05	38	0.41	23.50	18.25	945.00	11.28
W2	3STATNS	05	39	0.41	22.03	17.17	945.00	8.09
W2	3STATNS	05	40	0.28	24.39	16.67	945.00	11.07
W2	3STATNS	05	41	0.48	24.03	17.53	945.00	11.28
W2	3STATNS	05	42	0.48	23.44	17.58	945.00	12.03
W2	3STATNS	05	43	0.52	21.74	15.78	945.00	19.44
W2	3STATNS	05	44	0.10	23.11	16.89	945.00	12.35
W2	3STATNS	05	45	0.16	23.87	11.91	945.00	10.01
W2	3STATNS	05	46	0.23	23.97	18.25	945.00	7.34
W2	3STATNS	05	47	0.48	23.70	17.69	945.00	11.07
W2	3STATNS	05	48	0.26	24.04	15.17	945.00	15.47
W2	3STATNS	05	49	0.16	23.31	16.64	945.00	10.43
W2	3STATNS	05	50	0.33	24.36	15.83	945.00	13.20
W2	3STATNS	05	51	0.26	26.58	16.47	945.00	10.86
W2	3STATNS	05	52	0.41	24.13	15.04	945.00	13.13
W2	3STATNS	05	53	0.28	23.54	15.15	945.00	12.56
W2	3STATNS	05	54	0.35	25.53	19.14	945.00	9.37
W2	3STATNS	05	55	0.41	28.36	18.78	945.00	8.94
W2	3STATNS	05	56	0.43	26.41	17.39	945.00	10.57
W2	3STATNS	05	57	0.28	25.63	18.61	945.00	8.87
W2	3STATNS	05	58	0.33	27.69	18.93	945.00	8.80
W2	3STATNS	05	59	0.33	27.39	22.11	945.00	8.41
W2	3STATNS	05	60	0.39	28.44	20.56	945.00	7.93
W2	3STATNS	05	61	0.45	29.50	19.00	945.00	7.45
W2	3STATNS	05	62	0.55	25.09	19.94	945.00	9.58
W2	3STATNS	05	63	0.59	25.25	22.72	945.00	7.45
W2	3STATNS	05	64	0.55	25.75	20.78	945.00	7.45
W2	3STATNS	05	65	0.33	27.06	18.19	945.00	11.39
W2	3STATNS	05	66	0.33	27.86	19.36	945.00	10.01
W2	3STATNS	05	67	0.26	27.39	18.31	945.00	11.14
W2	3STATNS	05	68	0.26	29.33	19.08	945.00	10.54
W2	3STATNS	05	69	0.60	25.53	21.19	945.00	10.75
W2	3STATNS	05	70	0.59	25.56	19.11	945.00	8.09
W2	3STATNS	05	71	0.55	25.97	20.28	945.00	9.37
W2	3STATNS	05	72	0.33	27.06	21.61	945.00	12.99
W2	3STATNS	05	73	0.28	27.11	17.14	945.00	7.13
W2	3STATNS	05	74	0.28	27.72	18.94	945.00	8.52
W2	3STATNS	05	75	0.23	31.44	19.83	945.00	9.05
W2	3STATNS	05	76	0.33	30.75	19.11	945.00	12.24
W2	3STATNS	05	77	0.64	22.63	20.46	945.00	10.57
W2	3STATNS	05	78	0.58	25.78	21.67	945.00	7.66
W2	3STATNS	05	79	0.55	28.75	21.69	945.00	9.26
W2	3STATNS	05	80	0.48	30.22	20.61	945.00	8.84
W2	3STATNS	05	81	0.27	31.44	20.14	945.00	12.24
W2	3STATNS	05	82	0.43	30.22	20.92	945.00	13.41
W2	3STATNS	05	83	0.43	30.14	22.36	945.00	10.75
W2	3STATNS	05	84	0.48	27.39	20.22	945.00	9.58
W2	3STATNS	05	85	0.55	28.89	19.11	945.00	9.23
W2	3STATNS	05	86	0.41	32.67	18.75	945.00	11.18
W2	3STATNS	05	87	0.41	25.72	19.48	945.00	12.06
W2	3STATNS	05	88	0.48	25.72	24.00	945.00	12.13
W2	3STATNS	05	89	0.43	25.78	24.00	945.00	7.45
W2	3STATNS	05	90	0.37	26.08	23.38	945.00	10.22
W2	3STATNS	05	91	0.31	26.06	23.03	945.00	11.66
W2	3STATNS	05	92	0.38	27.30	23.02	945.00	13.80
W2	3STATNS	05	93	0.38	26.93	22.53	945.00	12.37
W2	3STATNS	05	94	0.45	27.00	21.50	945.00	18.52

W2	3STATNS	05 95	0.37	26.00	22.00	945.00	15.97
W2	3STATNS	05 96	0.41	31.00	23.00	945.00	20.22
W2	3STATNS	05 97	0.33	25.83	21.06	945.00	8.09
W2	3STATNS	05 98	0.48	25.89	18.19	945.00	12.56
W2	3STATNS	05 99	0.55	27.17	20.25	945.00	7.45
W2	3STATNS	05100	0.48	30.00	24.44	945.00	16.18
W2	3STATNS	05101	0.33	30.19	22.61	945.00	8.41
W2	3STATNS	05102	0.48	28.44	20.37	945.00	9.72
W2	3STATNS	05103	0.48	27.70	20.04	945.00	12.49
W2	3STATNS	05104	0.41	27.87	18.44	945.00	13.55
W2	3STATNS	05105	0.52	24.54	19.93	945.00	13.13
W2	3STATNS	05106	0.67	22.19	18.57	945.00	16.53
W2	3STATNS	05107	0.48	22.83	16.04	945.00	17.74
W2	3STATNS	05108	0.52	21.44	16.76	945.00	13.06
W2	3STATNS	05109	0.41	24.20	15.50	945.00	11.28
W2	3STATNS	05110	0.41	27.04	17.11	945.00	10.29
W2	3STATNS	05111	0.33	27.11	20.02	945.00	9.58
W2	3STATNS	05112	0.48	26.06	20.09	945.00	10.43
W2	3STATNS	05113	0.43	29.08	18.72	945.00	9.05
W2	3STATNS	05114	0.48	25.81	18.39	945.00	10.36
W2	3STATNS	05115	0.41	26.00	19.41	945.00	10.86
W2	3STATNS	05116	0.35	29.80	18.30	945.00	16.46
W2	3STATNS	05117	0.33	29.61	17.70	945.00	12.21
W2	3STATNS	05118	0.41	30.89	22.31	945.00	8.20
W2	3STATNS	05119	0.48	31.11	21.31	945.00	10.64
W2	3STATNS	05120	0.41	31.75	20.06	945.00	10.96
W2	3STATNS	05121	0.26	31.78	20.14	945.00	9.26
W2	3STATNS	05122	0.48	27.69	20.44	945.00	9.79
W2	3STATNS	05123	0.48	28.11	22.33	945.00	8.73
W2	3STATNS	05124	0.48	27.00	19.20	945.00	10.64
W2	3STATNS	05125	0.48	26.35	19.48	945.00	10.29
W2	3STATNS	05126	0.48	26.83	18.93	945.00	15.33
W2	3STATNS	05127	0.48	24.98	19.83	945.00	14.41
W2	3STATNS	05128	0.55	29.89	21.03	945.00	14.37
W2	3STATNS	05129	0.48	26.54	21.31	945.00	12.35
W2	3STATNS	05130	0.41	28.75	22.78	945.00	9.47
W2	3STATNS	05131	0.52	26.87	20.65	945.00	15.33
W2	3STATNS	05132	0.67	24.98	21.15	945.00	11.28
W2	3STATNS	05133	0.63	27.39	22.81	945.00	10.33
W2	3STATNS	05134	0.55	27.53	22.89	945.00	8.73
W2	3STATNS	05135	0.55	25.65	19.87	945.00	10.29
W2	3STATNS	05136	0.64	27.94	20.14	945.00	9.15
W2	3STATNS	05137	0.55	25.98	18.81	945.00	9.23
W2	3STATNS	05138	0.59	30.17	23.50	945.00	12.77
W2	3STATNS	05139	0.71	23.44	19.11	945.00	6.95
W2	3STATNS	05140	0.79	20.54	19.04	945.00	8.94
W2	3STATNS	05141	0.56	21.20	18.80	945.00	4.83
W2	3STATNS	05142	0.41	25.44	18.46	945.00	8.09
W2	3STATNS	05143	0.46	26.23	19.78	945.00	10.08
W2	3STATNS	05144	0.52	27.02	21.09	945.00	12.06
W2	3STATNS	05145	0.48	29.83	23.19	945.00	8.94
W2	3STATNS	05146	0.52	26.04	21.26	945.00	8.66
W2	3STATNS	05147	0.55	25.74	20.56	945.00	8.37
W2	3STATNS	05148	0.41	29.81	22.61	945.00	10.54
W2	3STATNS	05149	0.48	27.59	20.59	945.00	10.29
W2	3STATNS	05150	0.41	28.61	23.06	945.00	6.28
W2	3STATNS	05151	0.63	28.91	19.11	945.00	10.93
W2	3STATNS	05152	0.55	27.50	20.89	945.00	10.57
W2	3STATNS	05153	0.48	25.67	20.43	945.00	8.37
W2	3STATNS	05154	0.41	27.02	21.50	945.00	9.65
W2	3STATNS	05155	0.41	26.83	21.57	945.00	8.66
W2	3STATNS	05156	0.63	26.63	21.57	945.00	9.51
W2	3STATNS	05157	0.55	28.61	23.47	945.00	9.90

W2	3STATNS	05158	0.55	27.58	23.39	945.00	9.69
W2	3STATNS	05159	0.52	24.17	21.80	945.00	8.73
W2	3STATNS	05160	0.55	28.22	23.56	945.00	6.81
W2	3STATNS	05161	0.41	29.89	21.83	945.00	9.37
W2	3STATNS	05162	0.59	29.56	23.11	945.00	9.37
W2	3STATNS	05163	0.41	31.00	22.81	945.00	10.86
W2	3STATNS	05164	0.55	28.81	24.08	945.00	8.41
W2	3STATNS	05165	0.68	27.31	23.36	945.00	7.98
W2	3STATNS	05166	0.59	25.33	21.94	945.00	9.51
W2	3STATNS	05167	0.71	25.67	22.11	945.00	11.35
W2	3STATNS	05168	0.59	28.06	24.17	945.00	8.20
W2	3STATNS	05169	0.41	29.39	24.36	945.00	13.52
W2	3STATNS	05170	0.59	26.44	24.06	945.00	6.81
W2	3STATNS	05171	0.63	28.61	24.36	945.00	10.01
W2	3STATNS	05172	0.56	27.92	23.69	945.00	10.54
W2	3STATNS	05173	0.59	27.56	23.81	945.00	6.71
W2	3STATNS	05174	0.64	24.43	21.93	945.00	8.23
W2	3STATNS	05175	0.67	24.09	21.65	945.00	6.74
W2	3STATNS	05176	0.59	24.80	21.74	945.00	9.08
W2	3STATNS	05177	0.59	28.17	24.47	945.00	8.62
W2	3STATNS	05178	0.67	26.86	24.19	945.00	6.71
W2	3STATNS	05179	0.59	26.00	20.43	945.00	10.01
W2	3STATNS	05180	0.48	25.85	20.00	945.00	10.15
W2	3STATNS	05181	0.48	26.57	20.80	945.00	9.37
W2	3STATNS	05182	0.41	27.44	22.50	945.00	8.30
W2	3STATNS	05183	0.45	27.94	20.31	945.00	8.62
W2	3STATNS	05184	0.59	24.19	19.83	945.00	7.34
W2	3STATNS	05185	0.55	30.00	24.44	945.00	6.81
W2	3STATNS	05186	0.41	29.50	22.72	945.00	7.03
W2	3STATNS	05187	0.48	28.19	23.17	945.00	9.05
W2	3STATNS	05188	0.55	28.53	22.81	945.00	10.11
W2	3STATNS	05189	0.55	27.36	22.72	945.00	8.41
W2	3STATNS	05190	0.48	28.94	22.25	945.00	11.07
W2	3STATNS	05191	0.41	28.78	23.36	945.00	7.88
W2	3STATNS	05192	0.48	28.36	23.39	945.00	9.26
W2	3STATNS	05193	0.55	28.78	22.17	945.00	10.11
W2	3STATNS	05194	0.56	23.31	20.72	945.00	7.38
W2	3STATNS	05195	0.56	23.72	21.07	945.00	6.81
W2	3STATNS	05196	0.63	23.89	21.02	945.00	6.24
W2	3STATNS	05197	0.59	25.35	20.98	945.00	7.38
W2	3STATNS	05198	0.48	25.54	21.02	945.00	6.74
W2	3STATNS	05199	0.55	27.94	23.81	945.00	7.03
W2	3STATNS	05200	0.41	27.39	23.53	945.00	8.20
W2	3STATNS	05201	0.55	26.69	22.92	945.00	8.52
W2	3STATNS	05202	0.63	29.22	25.00	945.00	14.26
W2	3STATNS	05203	0.45	26.14	23.47	945.00	7.98
W2	3STATNS	05204	0.67	26.31	23.86	945.00	7.88
W2	3STATNS	05205	0.48	24.43	21.28	945.00	7.88
W2	3STATNS	05206	0.48	25.50	21.09	945.00	9.37
W2	3STATNS	05207	0.48	26.25	20.50	945.00	13.73
W2	3STATNS	05208	0.48	29.25	23.06	945.00	12.56
W2	3STATNS	05209	0.48	25.98	20.89	945.00	14.97
W2	3STATNS	05210	0.48	27.47	23.83	945.00	14.80
W2	3STATNS	05211	0.48	28.11	25.00	945.00	10.43
W2	3STATNS	05212	0.41	23.89	20.36	945.00	15.97
W2	3STATNS	05213	0.34	25.75	22.50	945.00	5.11
W2	3STATNS	05214	0.63	30.83	23.25	945.00	9.69
W2	3STATNS	05215	0.23	29.08	23.68	945.00	9.47
W2	3STATNS	05216	0.63	27.33	24.11	945.00	9.26
W2	3STATNS	05217	0.67	25.94	24.28	945.00	5.32
W2	3STATNS	05218	0.54	27.78	26.11	945.00	11.43
W2	3STATNS	05219	0.58	29.61	27.94	945.00	17.53
W2	3STATNS	05220	0.41	31.00	25.50	945.00	22.35

W2	3STATNS	05221	0.63	27.82	23.19	945.00	16.93
W2	3STATNS	05222	0.48	24.65	20.89	945.00	11.5
W2	3STATNS	05223	0.48	28.33	25.33	945.00	9.15
W2	3STATNS	05224	0.52	24.33	20.96	945.00	8.44
W2	3STATNS	05225	0.64	28.89	25.61	945.00	8.30
W2	3STATNS	05226	0.55	28.33	23.08	945.00	10.75
W2	3STATNS	05227	0.55	24.59	21.39	945.00	7.59
W2	3STATNS	05228	0.64	23.00	21.54	945.00	8.80
W2	3STATNS	05229	0.52	23.15	21.15	945.00	7.74
W2	3STATNS	05230	0.59	26.28	24.56	945.00	5.54
W2	3STATNS	05231	0.67	30.50	26.00	945.00	12.77
W2	3STATNS	05232	0.71	27.25	23.81	945.00	8.84
W2	3STATNS	05233	0.56	25.67	21.39	945.00	8.87
W2	3STATNS	05234	0.55	26.26	21.26	945.00	10.01
W2	3STATNS	05235	0.55	26.00	24.11	945.00	7.66
W2	3STATNS	05236	0.48	28.89	23.44	945.00	9.05
W2	3STATNS	05237	0.41	25.78	20.11	945.00	10.75
W2	3STATNS	05238	0.48	26.31	20.75	945.00	11.71
W2	3STATNS	05239	0.48	26.41	20.31	945.00	9.51
W2	3STATNS	05240	0.55	25.43	21.06	945.00	10.86
W2	3STATNS	05241	0.48	26.65	20.70	945.00	10.72
W2	3STATNS	05242	0.37	28.64	23.81	945.00	10.11
W2	3STATNS	05243	0.34	29.44	24.83	945.00	7.45
W2	3STATNS	05244	0.55	26.07	21.50	945.00	9.08
W2	3STATNS	05245	0.48	25.57	21.85	945.00	9.65
W2	3STATNS	05246	0.48	25.98	20.78	945.00	10.01
W2	3STATNS	05247	0.63	23.94	20.83	945.00	10.43
W2	3STATNS	05248	0.48	23.50	21.02	945.00	12.35
W2	3STATNS	05249	0.59	26.19	20.94	945.00	13.91
W2	3STATNS	05250	0.55	27.64	23.31	945.00	8.20
W2	3STATNS	05251	0.55	28.31	23.61	945.00	9.37
W2	3STATNS	05252	0.55	28.22	23.44	945.00	9.37
W2	3STATNS	05253	0.55	25.07	21.24	945.00	16.40
W2	3STATNS	05254	0.59	22.78	19.93	945.00	7.03
W2	3STATNS	05255	0.52	24.48	21.06	945.00	11.28
W2	3STATNS	05256	0.59	27.94	25.06	945.00	7.88
W2	3STATNS	05257	0.63	30.89	24.44	945.00	13.20
W2	3STATNS	05258	0.55	26.39	22.75	945.00	9.26
W2	3STATNS	05259	0.59	23.67	21.11	945.00	12.21
W2	3STATNS	05260	0.59	24.96	21.09	945.00	11.35
W2	3STATNS	05261	0.52	24.37	21.02	945.00	10.43
W2	3STATNS	05262	0.52	24.89	20.96	945.00	10.50
W2	3STATNS	05263	0.59	23.83	21.31	945.00	10.54
W2	3STATNS	05264	0.56	23.80	21.04	945.00	5.46
W2	3STATNS	05265	0.68	24.56	21.31	945.00	9.37
W2	3STATNS	05266	0.59	24.37	21.35	945.00	12.06
W2	3STATNS	05267	0.59	24.43	21.85	945.00	9.30
W2	3STATNS	05268	0.59	24.50	20.75	945.00	9.90
W2	3STATNS	05269	0.55	25.74	21.72	945.00	8.73
W2	3STATNS	05270	0.55	24.39	21.33	945.00	6.60
W2	3STATNS	05271	0.59	24.69	22.00	945.00	8.23
W2	3STATNS	05272	0.6	24.31	21.78	945.00	7.74
W2	3STATNS	05273	0.52	25.02	21.81	945.00	9.37
W2	3STATNS	05274	0.68	23.80	21.22	945.00	6.39
W2	3STATNS	05275	0.67	28.00	23.81	945.00	6.49
W2	3STATNS	05276	0.71	24.70	22.06	945.00	11.43
W2	3STATNS	05277	0.79	23.63	21.39	945.00	11.64
W2	3STATNS	05278	0.79	24.59	20.91	945.00	12.56
W2	3STATNS	05279	0.64	25.54	21.20	945.00	13.70
W2	3STATNS	05280	0.67	25.31	22.22	945.00	9.44
W2	3STATNS	05281	0.71	23.13	21.69	945.00	7.52
W2	3STATNS	05282	0.71	24.33	21.20	945.00	9.58
W2	3STATNS	05283	0.59	24.06	21.35	945.00	6.88

W2	3STATNS	05284	0.55	23.92	20.53	945.00	7.56
W2	3STATNS	05285	0.48	24.25	20.31	945.00	12.67
W2	3STATNS	05286	0.55	24.17	20.83	945.00	9.51
W2	3STATNS	05287	0.55	23.67	20.83	945.00	11.43
W2	3STATNS	05288	0.59	21.97	20.17	945.00	11.60
W2	3STATNS	05289	0.59	22.11	20.64	945.00	10.86
W2	3STATNS	05290	0.64	22.28	19.54	945.00	11.28
W2	3STATNS	05291	0.59	22.13	19.76	945.00	11.71
W2	3STATNS	05292	0.75	21.96	19.56	945.00	9.44
W2	3STATNS	05293	0.67	24.56	19.04	945.00	13.70
W2	3STATNS	05294	0.67	25.17	19.74	945.00	12.06
W2	3STATNS	05295	0.59	24.43	20.17	945.00	7.95
W2	3STATNS	05296	0.55	25.26	20.00	945.00	8.52
W2	3STATNS	05297	0.52	22.93	19.35	945.00	9.23
W2	3STATNS	05298	0.56	25.56	21.56	945.00	11.07
W2	3STATNS	05299	0.41	20.39	17.07	945.00	11.85
W2	3STATNS	05300	0.52	23.11	19.78	945.00	5.64
W2	3STATNS	05301	0.33	20.89	17.37	945.00	10.86
W2	3STATNS	05302	0.52	20.63	18.20	945.00	15.54
W2	3STATNS	05303	0.59	18.50	17.64	945.00	17.35
W2	3STATNS	05304	0.68	20.56	19.67	945.00	11.50
W2	3STATNS	05305	0.64	21.06	19.41	945.00	13.48
W2	3STATNS	05306	0.68	19.07	17.96	945.00	13.98
W2	3STATNS	05307	0.68	18.69	17.98	945.00	11.21
W2	3STATNS	05308	0.68	21.36	18.42	945.00	9.47
W2	3STATNS	05309	0.48	23.13	20.22	945.00	10.43
W2	3STATNS	05310	0.56	22.09	20.54	945.00	8.30
W2	3STATNS	05311	0.63	22.54	20.72	945.00	8.87
W2	3STATNS	05312	0.48	22.97	19.36	945.00	12.45
W2	3STATNS	05313	0.59	26.00	23.53	945.00	6.28
W2	3STATNS	05314	0.55	22.61	20.81	945.00	12.63
W2	3STATNS	05315	0.41	20.28	18.36	945.00	14.90
W2	3STATNS	05316	0.45	22.67	20.31	945.00	5.75
W2	3STATNS	05317	0.48	24.69	21.11	945.00	8.30
W2	3STATNS	05318	0.48	23.22	19.35	945.00	13.13
W2	3STATNS	05319	0.48	23.15	19.59	945.00	9.15
W2	3STATNS	05320	0.59	22.92	22.06	945.00	5.43
W2	3STATNS	05321	0.75	20.06	19.17	945.00	14.62
W2	3STATNS	05322	0.72	21.64	21.33	945.00	8.73
W2	3STATNS	05323	0.71	21.72	21.08	945.00	6.71
W2	3STATNS	05324	0.71	22.47	20.33	945.00	7.13
W2	3STATNS	05325	0.67	23.14	20.80	945.00	7.34
W2	3STATNS	05326	0.69	22.50	21.22	945.00	7.03
W2	3STATNS	05327	0.59	20.25	17.39	945.00	7.13
W2	3STATNS	05328	0.33	23.14	14.78	945.00	8.20
W2	3STATNS	05329	0.35	20.22	16.97	945.00	7.56
W2	3STATNS	05330	0.21	22.47	17.83	945.00	7.13
W2	3STATNS	05331	0.27	23.92	19.31	945.00	7.98
W2	3STATNS	05332	0.16	28.72	22.17	945.00	15.54
W2	3STATNS	05333	0.45	26.72	22.89	945.00	5.54
W2	3STATNS	05334	0.41	27.83	23.61	945.00	12.13
W2	3STATNS	05335	0.31	25.89	22.44	945.00	8.94
W2	3STATNS	05336	0.45	25.28	22.17	945.00	8.09
W2	3STATNS	05337	0.45	24.36	20.53	945.00	8.09
W2	3STATNS	05338	0.34	23.83	20.33	945.00	6.07
W2	3STATNS	05339	0.26	24.28	20.69	945.00	8.09
W2	3STATNS	05340	0.34	27.33	23.78	945.00	8.73
W2	3STATNS	05341	0.45	25.22	21.72	945.00	6.81
W2	3STATNS	05342	0.34	25.50	22.72	945.00	8.94
W2	3STATNS	05343	0.45	24.17	22.44	945.00	4.47
W2	3STATNS	05344	0.67	24.00	22.33	945.00	7.24
W2	3STATNS	05345	0.69	24.22	22.22	945.00	7.45
W2	3STATNS	05346	0.71	20.93	19.17	945.00	13.13

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W2 3STATNS 05347     0.56   21.98   18.41  945.00   13.13
W2 3STATNS 05348     0.52   24.83   21.83  945.00    6.81
W2 3STATNS 05349     0.41   27.22   22.78  945.00   10.64
W2 3STATNS 05350     0.53   25.56   23.39  945.00    5.54
W2 3STATNS 05351     0.64   26.39   23.28  945.00    7.88
W2 3STATNS 05352     0.42   21.03   18.08  945.00   10.01
W2 3STATNS 05353     0.45   24.50   23.50  945.00    9.58
W2 3STATNS 05354     0.71   24.11   22.33  945.00    5.96
W2 3STATNS 05355     0.70   22.61   22.00  945.00    4.47
W2 3STATNS 05356     0.71   18.43   17.83  945.00   12.42
W2 3STATNS 05357     0.70   21.78   20.56  945.00    7.66
W2 3STATNS 05358     0.42   26.33   20.94  945.00    8.30
W2 3STATNS 05359     0.59   24.56   22.44  945.00    5.32
W2 3STATNS 05360     0.70   22.67   21.22  945.00    6.81
W2 3STATNS 05361     0.42   22.33   20.22  945.00    6.39
W2 3STATNS 05362     0.64   24.56   20.39  945.00    8.73
W2 3STATNS 05363     0.64   22.14   18.92  945.00    7.98
W2 3STATNS 05364     0.53   21.86   19.50  945.00    6.49
W2 3STATNS 05365     0.34   28.44   23.17  945.00    8.52
SOUTL1        720       12
SOUTL2 YJA05  1          1    6.93
SOUTL2 YJA05  2          1    3.32
SOUTL2 YJA05  3          1    3.91
SOUTL2 YJA05  4          1    3.47
SOUTL2 YJA05  5          1    3.84
SOUTL2 YJA05  6          1    8.69
SOUTL2 YJA05  7          1   28.48
SOUTL2 YJA05  8          1   21.80
SOUTL2 YJA05  9          1   20.77
SOUTL2 YJA05 10          1   18.80
SOUTL2 YJA05 11          1   28.61
SOUTL2 YJA05 12          1   10.55
Q1  QIN       720        2
Q2 YJA05     6.93     3.32    3.91    3.47    3.84    8.69   28.48   21.80
20.77
Q2 YJA05    18.80    28.61   10.55    0.00    0.00    0.00    0.00    0.00
0.00
WQ TEMP       720        2
TEMP   1    21.00    23.00   25.30   19.30   23.00   20.80   21.90   23.10
21.00
TEMP  10    20.90    19.60   19.80    0.00    0.00    0.00    0.00    0.00
0.00
WQ TDS       8760        1
TDS            0.
WQ SSOL      8760        1
SSOL           0.
VERIFY1       YES
VERIFY2         1
VERIFY3     74    3 10.0      23.6  5.0      23.5  0.0      23.4
VERIFY3    170    3 10.0      22.8  5.0      22.7  0.0      22.9
VERIFY3    266    3 10.0      26.8  5.0      27.1  0.0      29.5
VERIFY3    287    3 25.0      25.1 10.0      26.1  0.0      26.0
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Appendix I: Contact Information

Name	Position	Organization	Address
Juan Carlos Sarto	Boatmen	AMUPROLAGO	
Mario Santos	President	Playas de Maria Patronata	
Antonio Lago	Engineer	Ampac Mine	
Gustavo Torres		DEFOMIN	
Javier Flores	Engineer	Municipality Las Vegas	
Angel Boesch	Owner	Agua Azul Hotel	
Hegel Velasquez	Engineer	ENEE	
Ricardo Pineda	Gerente de Procesamient o	USAID-RED	Apartado Postal 4766 San Pedro Sula Honduras
Antonio Coello	Sub-Director	USAID-RED	Apartado Postal 4766 San Pedro Sula Honduras
Peter A. Hearne	Oficial de Desastres y Medio Ambiente	USAID-Honduras	Avenida La Paz Frente a la Embajada Americana P.O. Box 3453 Tegucigalpa Honduras
Gregory Kimmet	Especialista en Produccion Mas Limpia	USAID-Honduras-MIRA	Colonia El Naranjal Calle La Ceiba, No. 172, La Ceiba Atlantida Honduras