The Impact of Implementation of Chemically Enhanced Primary Treatment on the Furnas Reservoir in Brazil

by

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ABSTRACT

The increasing population growth and demand for water resources in many Latin American countries has lead to the construction of many man-made multi-use reservoirs for hydroelectricity, potable water, and industrial uses. Due to the lack of widespread water treatment facilities, these water bodies may be subject to increasing amounts of raw sewage discharges. The Furnas Reservoir serves as an example. This study examines how much the water quality in the Furnas Reservoir might improve due to the use of Chemically Enhanced Primary Treatment (CEPT) for treating wastewater discharges in Brazil.

This study focuses on wastewater discharges from Alfenas; a city located in the province of Minas Gerais, Brazil, and about 300 km north of São Paulo. It is one of approximately 140 cities that use the reservoir for potable water. First, through testing, the bacterial and nutrient levels in the reservoir are determined and compared with the reduced levels that are expected through CEPT treatment. Second, a mathematical model is developed to quantify the bacterial and nutrient concentrations in the reservoir. The model is used to predict concentrations in the reservoir, using annual water quality data and measurements obtained from field studies for a section of the reservoir directly adjacent to the city. The results show that substantial decreases in fecal coliform, phosphorus, and biochemical oxygen demand (BOD) can be obtained through CEPT use, followed by chemical disinfection, at the wastewater streams. Also, due to the reduction in BOD, dissolved oxygen (DO) concentrations increase, which can prevent anoxic conditions from developing in the reservoir.

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1 INTRODUCTION

People remove water from various sources for domestic, commercial, industrial, and agricultural uses. They also oftentimes return the used water or wastewater to the same water source. Because bacteria and other microorganisms can survive in natural waters for considerable amounts of time, water use can become a health hazard as well as a necessity. If the water ingested is not safe to consume, serious health problems and possibly death can occur. Thus, access to safe drinking water is important, particularly for the more sensitive members of the population.

Water can act as a carrier in the transmission of many diseases. Transmitters of disease that arise from polluted water include bacteria, viruses, and other potentially harmful organisms. The ability of water to carry diseases raises the level of concern over public health impacts when polluted water is used to supply drinking water. Widespread outbreaks of waterborne diseases are associated with the use of untreated water, or deficiencies in existing treatment systems. (McGhee, 1991). Although all classes and ages are affected by waterborne epidemics, children under the age of five are especially at risk. (PAHO, 1991). Diarrheal diseases are an important cause of mortality and morbidity in Latin American countries. This is particularly true in rural areas. (PAHO, 2001). Disease prevention is possible if water is treated.

Diseases that can be transmitted by water include bacterial, viral, and protozoal infections. (McGhee, 1991). Notable bacterial waterborne diseases include typhoid fever, shigellosis, bacillary dysentery, and cholera. Traveler's diarrhea also falls into this category, even though the source of infection is not known; but it is suspected that transmission may be similar to bacillary dysentery and that the causative agent could be a pathogenic *Escherichia coli* (*E. coli*). (Keller et al, 1992). Hepatitis A is a notable viral disease associated with water. Other diseases such as shistosomiasis predominate in tropical climates, such as Brazil. The above diseases can occur when fecal matter is exposed to the water supply, causing serious outbreaks. These diseases are especially a serious problem in developing nations.

Waterborne disease outbreaks are usually widely distributed across populations within an area, but can be traced back to a single source of contamination. These same diseases could also be transmitted though contaminated food and personal contact by infected persons. (Keller et al, 1992). If drinking water is adequately disinfected and there is an adequate sewage treatment system, the likelihood of infection through the drinking water supply would remain at a minimum.

Organisms that cause serious infectious diseases are normally spread through fecal and urinary discharges of sick persons and carriers. (McGhee, 1991). Thus, water supply protection against these agents is usually a matter of preventing the discharges of inadequately treated wastewater into the sources of potable water.

Many organisms are found in water, most having no adverse impact on human health. Testing for specific disease-causing species, whether viral, bacterial, or protozoal, is difficult. Since these organisms are transmitted primarily through feces and urine of infected persons, water which shows evidence of extensive contamination is considered to be unfit for consumption. Contamination is usually assessed by determining the number of coliform bacteria in a sample of water. *E. coli* is excreted in numbers up to 4×10^{10} organisms per person per day. (McGhee, 1991). The presence of coliforms is not necessarily proof that water is dangerous. However, it does indicate that the water could be contaminated with harmful pathogens.

The purpose of water quality management has historically been aimed at preventing waterborne disease outbreaks. However, only a relatively few nations, namely developed ones, have treatment systems in place for treating both wastewater and drinking water. Due to the short supply of drinkable water accessible to most of the world's population, access to water is sometimes uncontrolled, and drinking water is taken from a contaminated source. (McGhee, 1991). Because drainage can include human and animal waste, these waters are oftentimes polluted.

The population that is most likely to be threatened by waterborne diseases is young children, especially in poor communities. Diarrheal diseases are important contributors to malnutrition in children under five years of age. Children under the age of five are usually at a greater risk. Water-related diseases result in various forms of diarrhea. Because diarrhea weakens the body through dehydration, effects of other health conditions such as malnutrition are enhanced. In worst situations, 50% of all children die before age five, and approximately 70% of the deaths are related to environmental sanitation. (Tchobanoglous et al, 1985).

Annually, at least 1.5 billion episodes of diarrhea occur in children under the age of five. (CEPIS website). An estimated 4 million children die each year as a result. (PAHO, 1991). More than 2.5 million infants and young children die each year from diarrheal diseases related to unsafe and poor sanitation. (PAHO, 1991). Diarrhea removes essential body fluids and vital nutrients, producing dehydration and malnutrition. Difficulty in obtaining an adequate quantity of clean water and safe food, and the lack of basic sanitation, are major causes of diarrhea in young children.

Water disinfection has been recognized as one of the most important barriers for human protection. There appears to a large disparity of coverage between urban and rural areas. Brazil reported that less than 10% of its rural population was supplied disinfected water. (PAHO, 2001). Thus, there is little access to safe drinking water in rural areas in the country.

To ensure watershed and reservoir protection against contamination, these areas should be protected to ensure that the water supply is not contaminated in a way that would render it unfit for use.

2 BACKGROUND

2.1 Objective

The purpose of this project is to predict the level of improvement in the water quality within the Furnas Reservoir as a result of Chemically Enhanced Primary Treatment (CEPT) implementation at the city of Alfenas. The city is located on the banks of the Furnas Reservoir in the province of Minas Gerais, Brazil within the continent of South America, as shown in Figure 2-1 and Figure 2-2. The city is about 300 km north of the city of São Paulo.
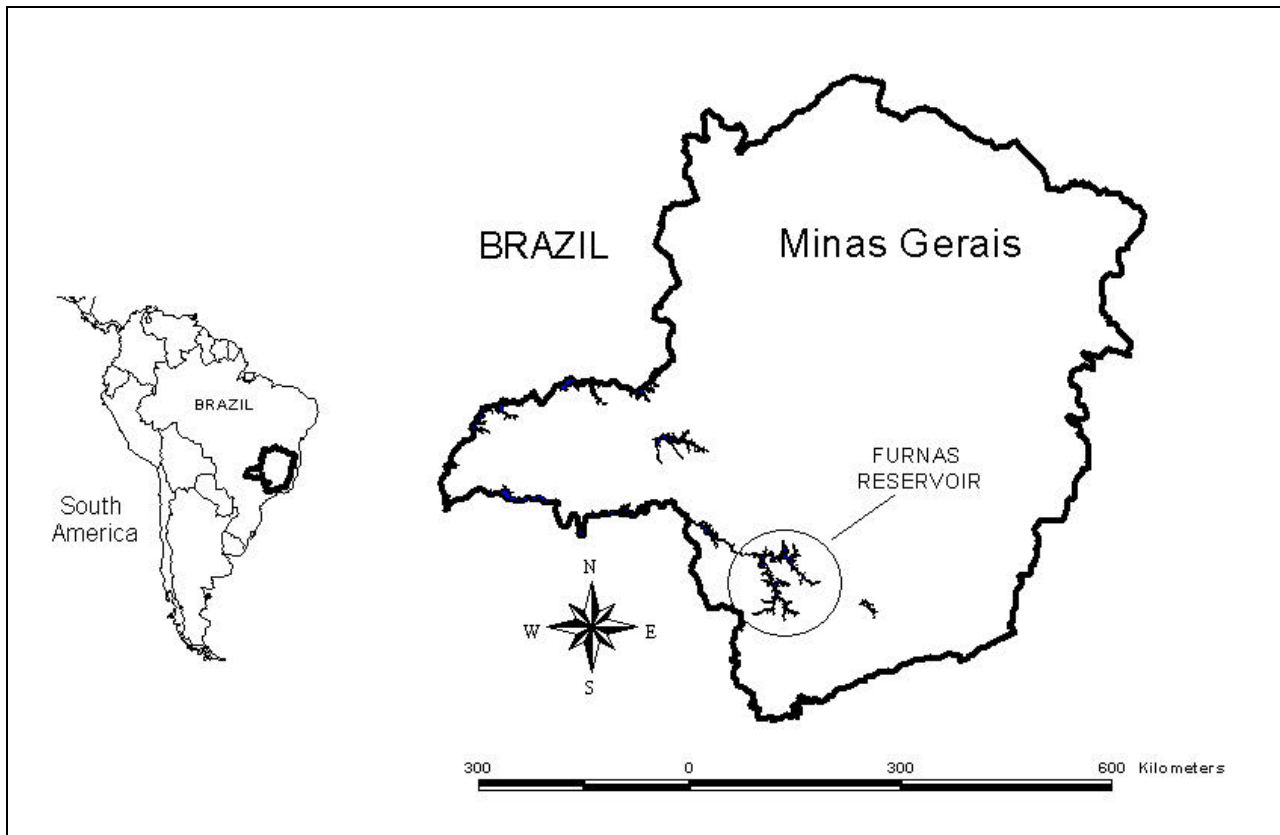
Figure 2-1: Location of the Furnas Reservoir

This project examines the reduction in bacterial and nutrient concentrations that is expected in the reservoir due to CEPT reductions of these concentrations in the

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wastewater discharged from Alfenas and into the reservoir. The location of the city of Alfenas in relation to the Furnas Reservoir is shown in Figure 2-2.
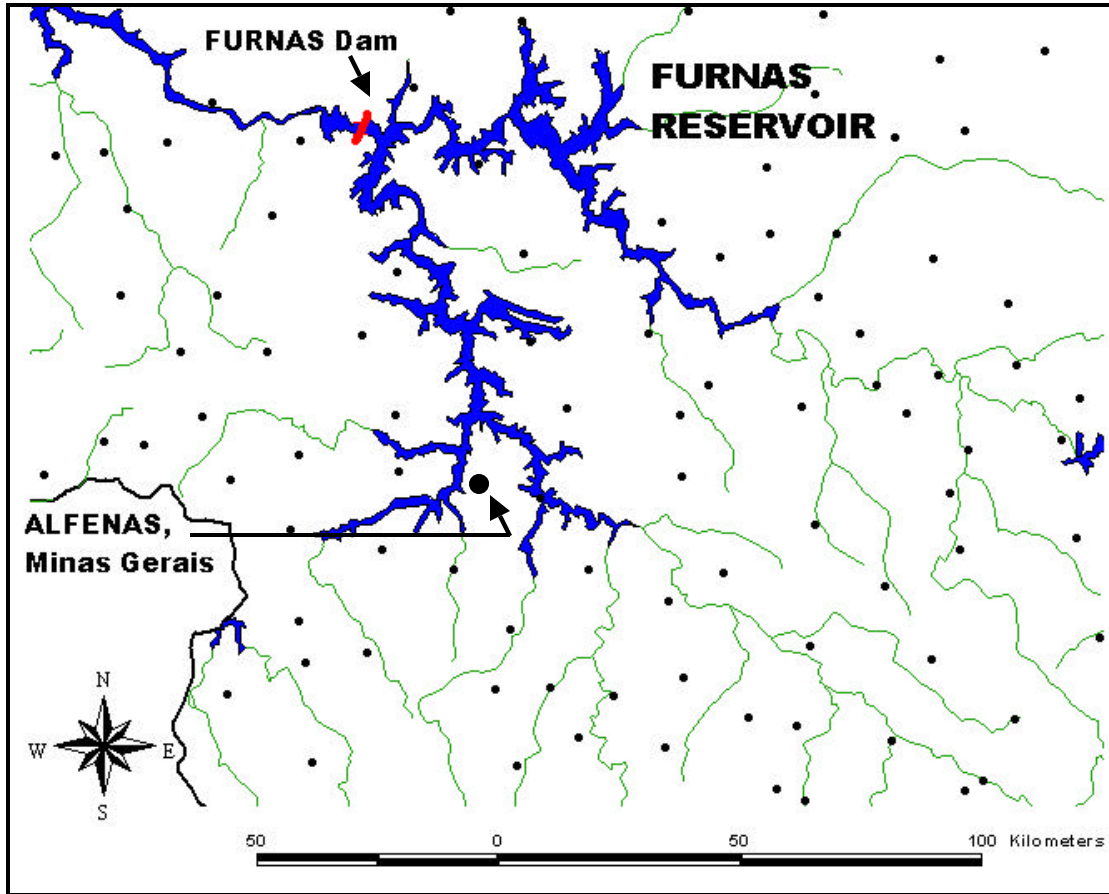
Figure 2-2: Location of Alfenas, and surrounding cities, with respect to the Furnas Reservoir

The objective of this project was accomplished in two ways. First, the existing nutrient and bacterial concentrations were determined in the reservoir. Using the expected reductions of these concentrations due to CEPT use at Alfenas, as well as historical data about the water quality in the reservoir, the improvements in contaminant concentrations were predicted using a mathematical model. The model was applied to a section of the reservoir where wastewater from Alfenas was discharged.

Reductions in biochemical oxygen demand (BOD), fecal coliform, and phosphorus were examined. Since reductions in BOD concentrations could lead to

increases in dissolved oxygen (DO) concentrations, improvements in DO concentrations were also examined. Decreases in DO concentrations can potentially lead to anoxic conditions in the reservoir, causing eutrophication to occur.
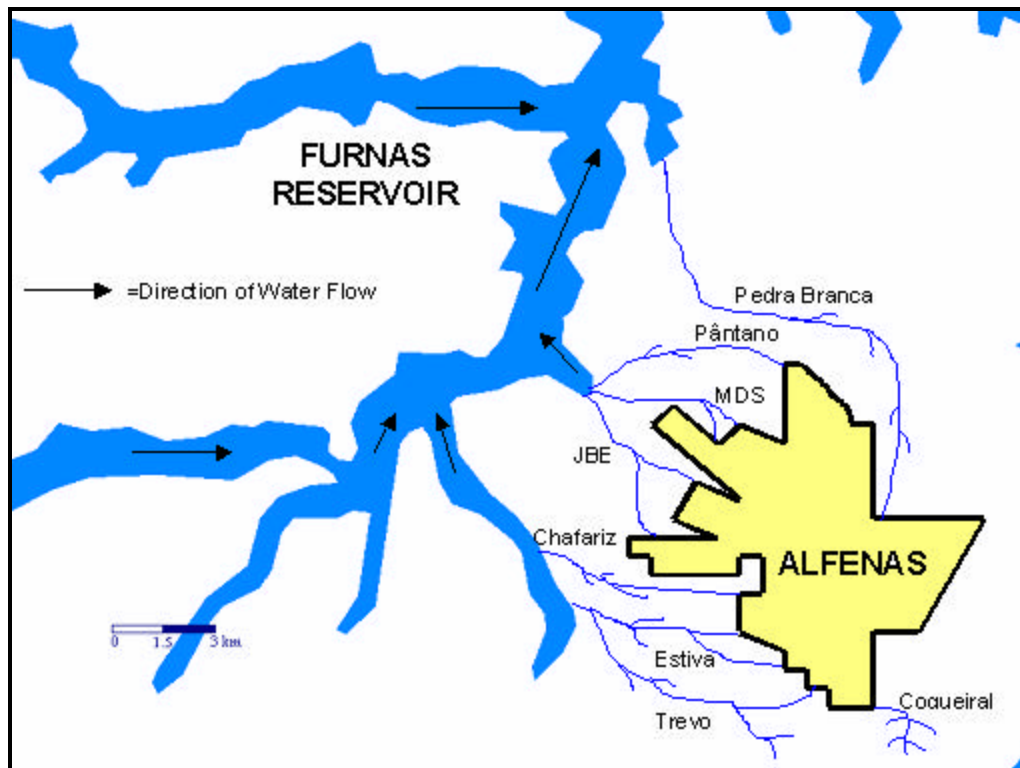
Figure 2-3: Open-channel streams from Alfenas discharging into the Furnas Reservoir

A combination of options was examined. A mathematical model was used to predict concentrations when the reservoir was at its highest and lowest volume, as well as situations where CEPT was or was not implemented. The data used for the model was based reservoir measurements from onsite analyses in Brazil. Annual water quality data from the University of Alfenas, located in the city of Alfenas, was also used.

Raw sewage discharged from Alfenas is collected in open-channel streams. Open-channel flow occurs in these streams, where the surface of the flowing liquid within the streams is at atmospheric pressure. There are eight wastewater streams emanating from Alfenas, seven of which discharge directly into the reservoir and are the subject of this study.

The seven streams that discharge to the Furnas Reservoir are called Pedra Branca, Trevo, Estiva, Chafariz, Jardim Boa Esperança (JBE), Morada do Sol (MDS), and Pântano. The specific locations of the streams are shown in Figure 2-3. Each stream contributes a percentage of the total wastewater flowing from the city, according to Table 2-1.

Table 2-1: Wastewater percentages from Open-channel streams

Stream	Percent of Total Wastewater from Alfenas (%)
Pedra Branca	32
Trevo	4.1
Estiva	11
Chafariz	16
JBE	11
MDS	5
Pântano	16

Source: Engesolos Report, 2001

CEPT implementation is expected to result in a 90% reduction in phosphorus and a 60% reduction in BOD in wastewater. (Olive, 2002). Following CEPT treatment with disinfection of the effluent is expected to reduce fecal coliform concentrations from approximately 10^7 MPN per 100 ml to 10^2 MPN per 100 ml.

2.2 The Furnas Reservoir

The Furnas Reservoir is located in Minas Gerais, in southeast Brazil as shown in Figure 2-1. As shown in Figure 2-2, several cities lie along the banks of the reservoir, relying on it as a source of potable water. The reservoir has a variety of uses. It is used to generate hydroelectric power and as a major source of drinking water, as well as for recreational purposes such as fishing and swimming. The reservoir is also constantly

subject to discharges of untreated wastewater from the many cities residing along its banks.

Table 2-2: Operating parameters of the Furnas Reservoir

Maximum Length	Maximum Storage Level	Maximum Flood Level	Minimum Operating Level	Flooded Area	Total Volume	Useful Volume
220 km	768 m	769 m	750 m	1440 km^2	23 bil m^3	17 bil m^3

Source: FURNAS Centrais Elétricas S.A. website

The reservoir is a highly dendritic. Its shape resembles several branching tributaries that flow toward its center, like a "dendrite". This also means that it does not act like a lake, which is created over geologic time while reservoirs are man-made.

The Furnas Reservoir is part of the Paraná river basin. The Paraná river basin within the Brazilian territory has a total area of 877,000 km^2 and an average flowrate of 11,000 m^3/s. (ANA website). The basin occupies southern and southeastern Minas Gerais. Several sub-basins comprise the Paraná basin, in which the Furnas Reservoir is part of the sub-basin called the Rio Grande basin. The Furnas Reservoir basin, as shown in Figure 2-4, occupies a total drainage area of 46,450 km^2. (GIS, ANA website). Table 2-2 shows some of the characteristics that affect the flow of water through the reservoir.

Most of the land along the reservoir is rural, and used for agriculture. Corn, coffee, and potatoes farms are localized on the banks of the reservoir. A large majority of these farms use chemical fertilizers on the farmlands.

The cities along the reservoir discharge domestic waste, which is composed of untreated sewage, industrial waste, and stormwater, into the reservoir. These streams contribute tremendous amounts of biological activity to the water body.
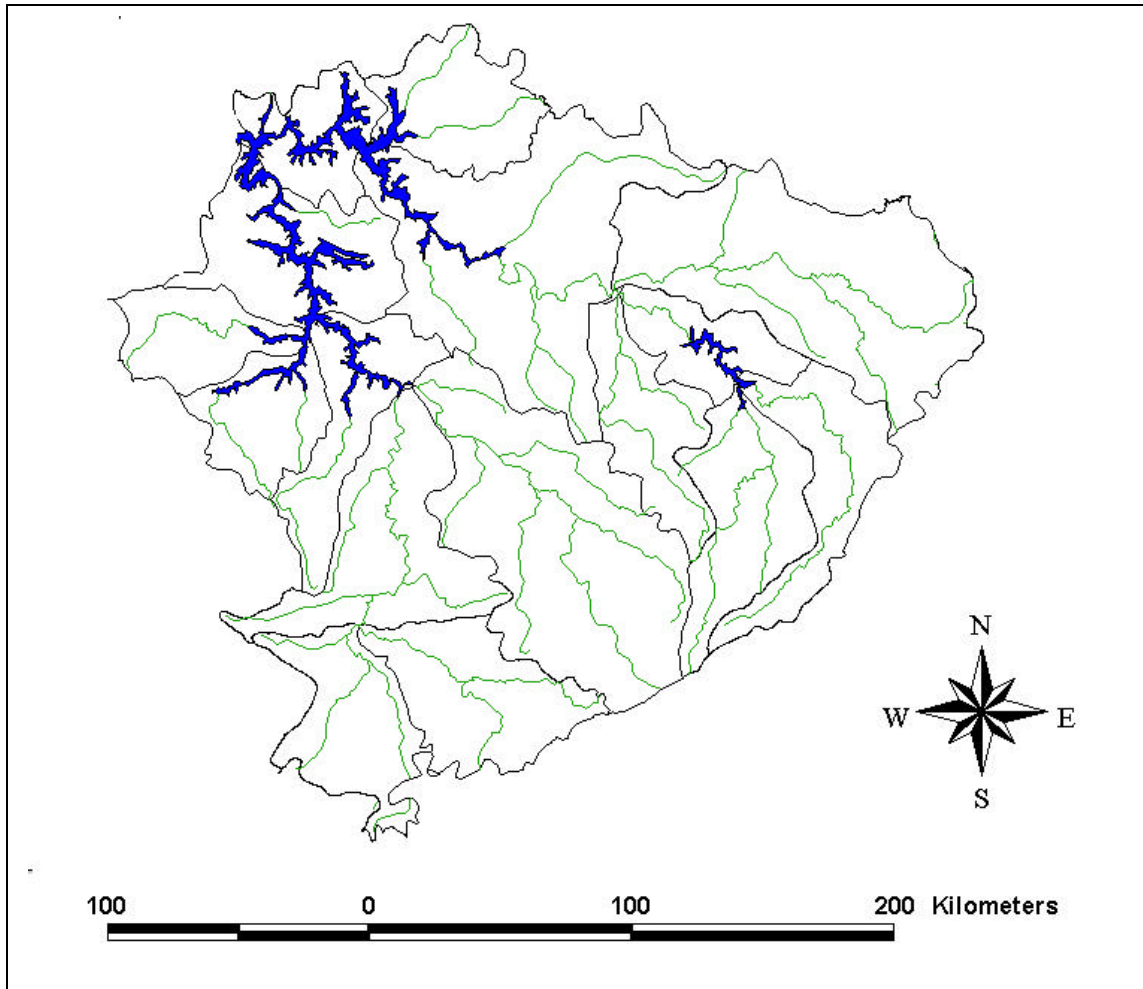
Figure 2-4: Furnas Reservoir drainage basin

Alfenas is one of the largest cities residing along the reservoir. Alfenas lies within a sub-basin, as shown in Figure 2-5, within the Furnas Reservoir basin. This sub-basin occupies a total drainage area of 1,537 km^2. (GIS, ANA website). The city has been experiencing a sharp economical growth, making it one of the fastest growing mining cities in the country. The water quality of this watershed is main concern of this study.
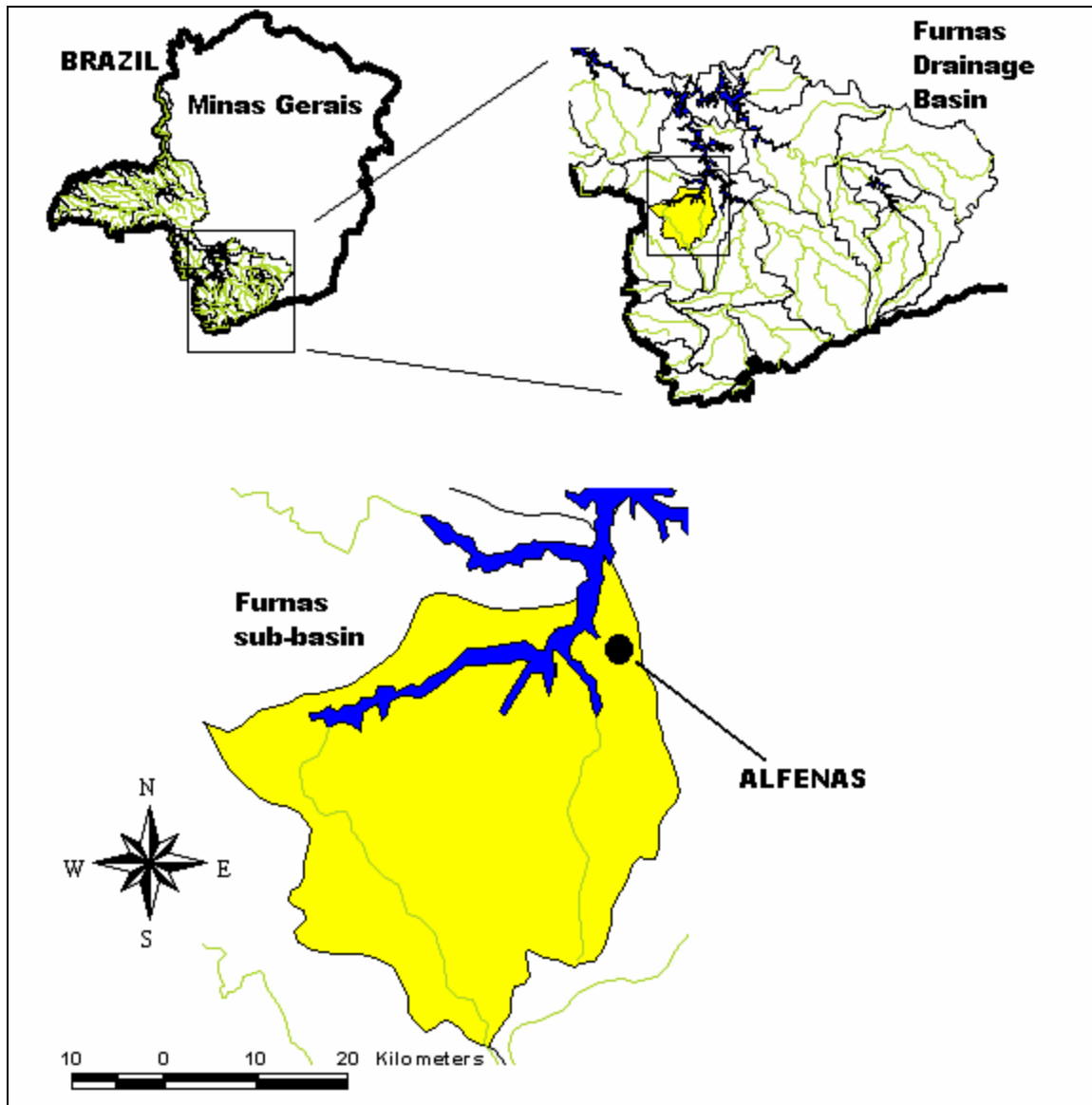
Figure 2-5: Furnas sub-basin, subject of reservoir study

2.3 Water and Sanitation

Untreated wastewater is released into the reservoir on a regular basis from the same cities using it as a source of potable water. This leads to adverse public health and welfare, since the wastewater is not treated.

A constant flow of sewage discharge to the reservoir allows harmful microorganisms from feces to dwell, which can cause waterborne diseases to occur. Over 100 virus types are known to occur in human feces, and a person infected with a water-related disease may excrete as many as 10^6 infectious particles in 1 gram of feces. (Tchobanoglous et al, 1985).

Waterborne diseases affect mostly children under five years of age. Table 2-3 shows disease incidence and deaths due to water-related diseases in children in Alfenas. Table 2-4 shows a comparison of the total deaths to the deaths due to incidences of diarrhea for children under age 5 in Minas Gerais.

Table 2-3: Childhood morbidity and mortality due to diarrheal-related illnesses in Alfenas

Year	Total Incidences of Diarrheal-Related Illnesses				Total Deaths due to Diarrheal-Related Illnesses			
	less than 1 year	1 to 4 years	Total (All ages)	% of Total	less than 1 year	1 to 4 years	Total (All ages)	% of Total
1998	13,520	10,850	42,430	57%	2	2	14	29%
1999	18,041	14,685	72,549	45%	1	0	3	33%
2000	22,111	16,210	70,474	54%	0	0	8	0%
2001	13,068	17,685	54,487	56%	1	2	3	100%

Source: Ministério da Saúde, DATASUS website

Table 2-4: Childhood morbidity due to diarrheal illnesses in Minas Gerais

Year	Total Deaths of Children less than 5 years of Age in Minas Gerais	Mortality of Children less than 5 years of Age related to diarrheal illness, Deaths by year and age range in Minas Gerais	Percent of Total Deaths
1994	11232	817	7%
1995	10364	680	7%
1996	9283	548	6%
1997	8551	322	4%
1998	7999	321	4%

Source: Ministério da Saúde, DATASUS website

2.4 Furnas Reservoir Water Level

The reservoir is part of a hydroelectric system. The location of the FURNAS Dam is shown in Figure 2-1. FURNAS Centrais Elétricas S.A, one of the largest electric utilities in Brazil, owns and operates the FURNAS Dam, which is used to supply hydroelectric power to many areas in the country. The FURNAS Dam was completed 1962. The hydroelectric plant generates electrical energy through the use of the hydraulic potential at the dam. The 1,606-sq km reservoir includes large hydroelectric facilities and is the center of an extensive regional electrical grid serving the industrial centers of São Paulo, Rio de Janeiro, and Belo Horizonte. (Columbia Encyclopedia, 2001). FURNAS Centrais Elétricas S.A also operates several other hydroelectric dams in Brazil.

Source: Furnas Lake Users Association, 2002
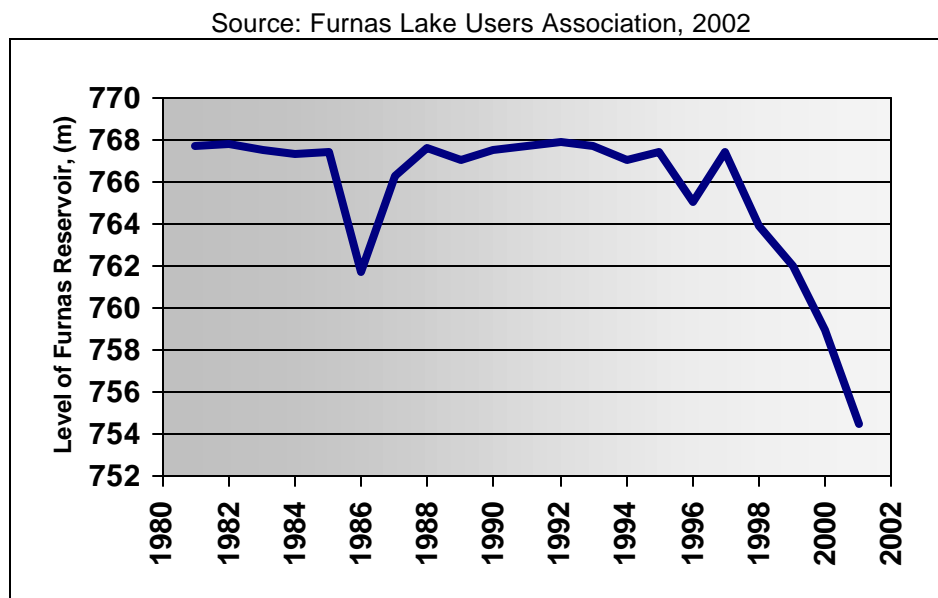
Figure 2-6: Change in water level in the reservoir height over time

Due to greater energy demands, the company has been drawing more water from the reservoir for longer periods of time. This has resulted in a dramatic decline in the water height. Figure 2-6 shows a dramatic decline between the years 1996 and 2001. Starting in 1996, hydroelectric power was in peak demand. The reservoir water level dropped about 12 meters during the period between 1996 and 2001. The

maximum height in the reservoir is 16 meters. (FURNAS Centrais Elétricas S.A. website).

The decline in the reservoir level also resulted in a simultaneous decline in its volume. The cross-sectional area of flow in the Furnas basin is approximately triangular. As shown in Figure 2-7, large decreases in the water height in the reservoir could result in a substantial decline in its volume. By 2001, the volume had dropped about 90%, in which only 10% to 11% of the water volume was available to the cities in the Furnas region. Along with the untreated sewage that is normally discharged to the reservoir, the reduced volume can increase the contaminant concentrations in the reservoir and exacerbate bacterial and viral disease outbreaks.
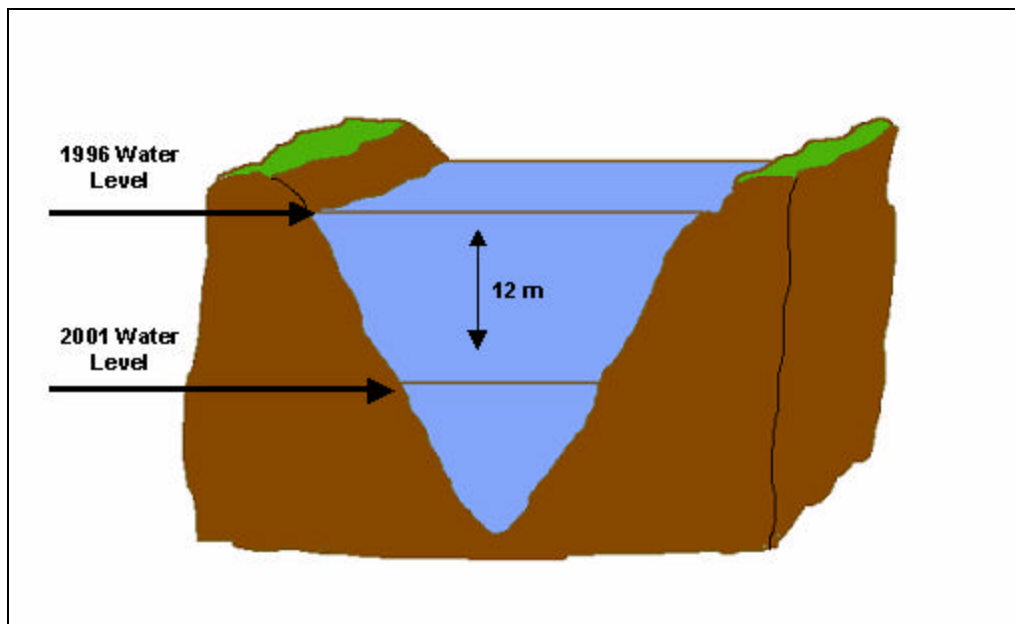
Figure 2-7: Schematic Drawing of Furnas Reservoir Cross-section

2.5 Eutrophication

Eutrophication is a clear environmental concern. This can occur when the wastewater discharging into the reservoir is rich in dissolved nutrients, such as phosphates and nitrates, encouraging the growth of oxygen-depleting algae and other

plant life in the reservoir. This causes anoxic conditions to develop, which can kill fish and other organisms in the water body.

Natural waters can be classified as one of three trophic states: oligotrophic, mesotrophic, and eutrophic. The classification is based on the ability for the water body to support life. Oligotrophic waters are usually clear, containing low concentrations of essential nutrients such as nitrogen, phosphorus, iron, and life forms are present in small amounts. When natural processes such as growth, death, and decay as well as input nutrients from runoff increase result in the gradual increase in nutrient concentrations, the water body becomes more productive. Mesotrophic and eutrophic are used to describe this phenomenon. The process in which a freshwater body moves from oligotrophic to mesotrophic to eutrophic conditions is called eutrophication.

Although nutrient concentrations were measured in the reservoir, algal growth and other analysis for other biota were not examined. Thus, the existing trophic state of the reservoir was not examined.

2.6 Climate

According to Table 2-5, about 50% of the precipitation occur in the summer months, which commences in December each year for Brazil and other countries located in the southern hemisphere. The evaporation in this area averages between about 800 and 1300 mm/yr, according to the Brazilian National Institute of Meteorology (Instituto Nacional de Metorologia) website.

The regional climate is connected with the state and uses of the reservoir. The reservoir was originally formed for generating hydroelectric power. Table 2-5 shows the annual precipitation in the area between 1973 and 2000. The area received an average precipitation of 1390 mm/yr between those years.

Table 2-5: Seasonal Precipitation in the Furnas Region

Season	Average Precipitation between 1973 and 2000 (mm)	Percentage
Summer	683	49%
Fall	289	21%
Winter	61	5%
Spring	350	25%

Source: Furnas Lake Users Association, 2002

Beginning in 1996, a combination of excess power production and severe drought has led to a severe drop in the reservoir elevation. These conditions potentially increased contaminant concentrations in the reservoir.

Source: Furnas Lake Users Association, 2002
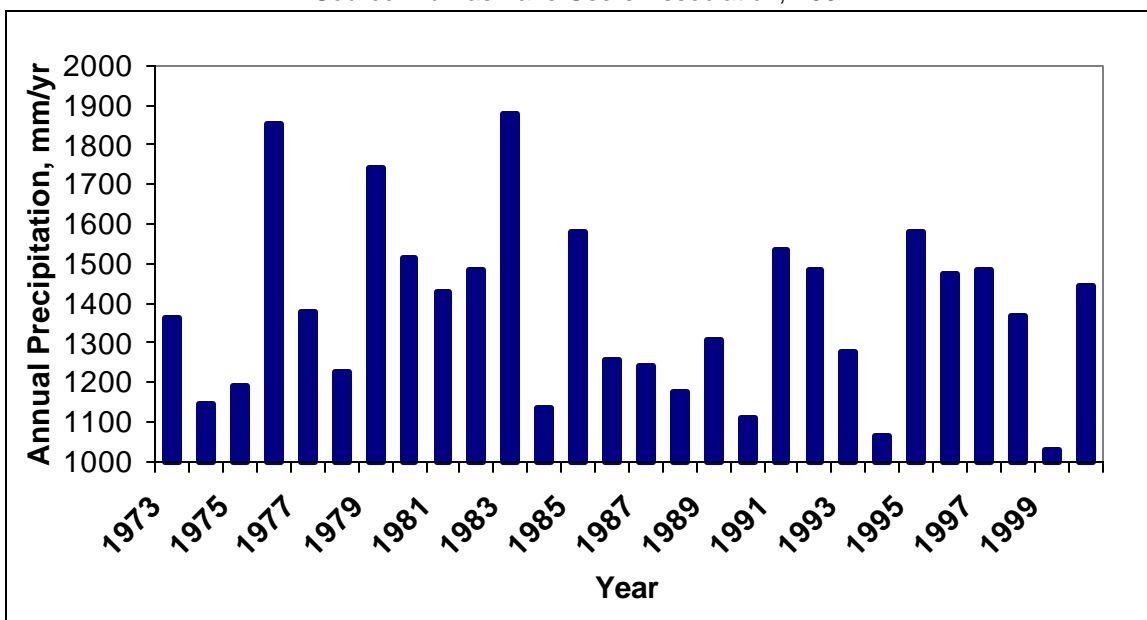
Figure 2-8: Annual Rainfall in the Furnas Region

2.7 CEPT Proposal at Alfenas

CEPT is the proposed solution for treating wastewater from the cities along the reservoir. CEPT is a process in which untreated wastewater is drawn through a

treatment process where chemicals are used to enhance coagulation and flocculation of contaminants for removal from wastewater. This process allows these contaminants to aggregate and settle out of the wastewater, leading to a cleaner effluent that is discharged to the reservoir. Initially, CEPT is considered for treating wastewater flowing from Alfenas. But this treatment technology can be extended for use at other cities residing along the reservoir.

CEPT is effective in reducing harmful bacteria, BOD, and phosphorus in wastewater. In order to predict the effectiveness of CEPT in reducing these concentrations in the reservoir, water samples are taken from the reservoir and analyzed to determine the existing concentrations. These samples are used to understand the physical, chemical, and biological characteristics of the water. The CEPT plant design is presented by Olive (2002) and a proposal for sludge management is examined by Stout (2002).

The need for treatment is necessary for the long-term because any existing health and environmental problems may dramatically increase in the future. The population and industry in the area have been growing at a substantial pace. The city is becoming a major metropolitan area, with a significant rise in tourism during the summer months. Therefore, one of the city's main goals is mitigating the adverse effects of untreated wastewater released into the reservoir. Achieving this goal will help to preserve the local environment, improve possibilities of recreational use, and most importantly, improve the standard of living of the citizens of Alfenas.

3 WATER QUALITY CHARACTERISTICS

Several water quality parameters were examined in the reservoir and in the waste streams. Among these parameters were dissolved oxygen (DO), temperature, pH, phosphorus, nitrates, ammonia, chemical oxygen demand (COD), and total and fecal coliforms. Water quality is highly variable over time due to both natural and human factors. Water temperature, photosynthetic activity, and flows vary with season. Nutrient and bacterial loads also vary with season and flow, as well as human management.

3.1 DO and Temperature

DO and temperature were both examined in the reservoir. DO was measured because the BOD, a component of wastewater, consume DO. If large amounts of BOD are discharged into a water body, anoxic conditions could develop, threatening the lives of fish and other species. The main focus of wastewater treatment plants is to reduce the BOD in the effluent discharged to natural waters. The excess bacteria grown in the system are removed as sludge, and this "solid" waste is then disposed of on land.

DO is the volume of oxygen contained in water. Oxygen enters the water by photosynthesis of aquatic biota and by the transfer of oxygen across the air-water interface. (Tchobanoglous et al, 1985). The solubility of oxygen in water is dependent upon the partial pressure of oxygen in the air, the temperature of the water, and the mineral content of the water.

Both the partial pressure and the degree of saturation of oxygen change with altitude. Gas solubility decreases as pressure decreases. Thus, the amount of oxygen absorbed in water decreases as altitude increases because of the decrease in relative pressure. (Tchobanoglous et al, 1985). According to the Brazilian Institute of Geography and Statistics (IBGE), the altitude of Alfenas is 881 meters. Thus, DO saturation concentration calculations are adjusted for the altitude of the city. At a given temperature, DO concentrations are calculated using the formula in Equation 3-1.

$$DO_{sat} = \frac{DO_{sea\,level} \times 90}{100} \, mg/L$$

Equation 3-1: Equation for Finding DO concentration at Saturation

DO_{sat} is the DO concentration at saturation, $DO_{sea\,level}$ is the DO saturation concentration at sea level at a given temperature, and the value $\frac{90}{100}$ represents the altitude correction for Alfenas. (YSI 58 Operations Manual, 1999).

DO and water temperature were also measured to determine whether the reservoir was stratified with respect to DO concentrations and water temperature in the reservoir. This phenomenon is called stratification and is more likely to occur in temperate climates. Stratification is the result of the water's temperature-dependent density. As water temperatures increase, the density decreases. Thus, the sun-warmed water will remain at the surface of the water body, forming the epilimnion. At the same time, the denser, cooler water sinks to the bottom, forming the hypolimnion. The layer separating the two layers is called the thermocline. (Tchobanoglous et al, 1985). This condition is less severe in tropical climates, such as in Brazil.

Water temperature also affects the rate of chemical reactions, biological activity, conductivity, dissolved oxygen, and pH. Metabolic rate and the reproductive activities of aquatic life are also controlled by water temperature. Metabolic activity increases with a rise in temperature, thus increasing a fish's demand for oxygen. (Tchobanoglous et al, 1985).

3.2 pH

The water pH of the reservoir and waste streams was measured. The pH of a sample of water is a measure of the concentration of hydrogen ions. The pH was measured to examine changes in the water column with respect to this parameter. pH can be used to determine the solubility and biological availability of chemical

constituents such as nutrients like phosphorus, nitrogen, and carbon and heavy metals like lead, copper, and cadmium. Solubility is the amount of a substance that can be dissolved in the water, and biological availability is the amount that can be utilized by aquatic life. (Tchobanoglous et al, 1985). Generally, natural water bodies have pH values between 4 and 10, and the average value for river water lies between 6 and 8. (Keller et al, 1992).

3.3 *Chemical Oxygen Demand (COD)*

In this study, COD was used as a surrogate for BOD. COD is defined as the oxygen equivalent of the organic portion of the sample that is susceptible to oxidation by a strong chemical oxidant. COD does not distinguish between refractory or "inert" organic matter.

BOD is a measure of the amount of oxygen that bacteria will consume while decomposing organic matter under aerobic conditions. BOD is usually determined by incubating a sealed sample of water for five days; the oxygen loss from the beginning to the end of the test is measured after five days. Samples are usually diluted prior to incubation or the bacteria will deplete all of the oxygen in the bottle before the test is complete. (Tchobanoglous et al, 1985).

COD does not differentiate between biologically available and inert organic matter, and it is a measure of the total quantity of oxygen required to oxidize all organic material into carbon dioxide and water. COD values are always greater than BOD values, but COD measurements can be made in a few hours while BOD measurements take five days. (Metcalfe and Eddy, 2002).

3.4 *Nutrients*

Phosphorus (in the form of orthophosphate), ammonia, and nitrates were examined to determine the relative amounts of these constituents in the reservoir and in

the waste streams. Nutrients such as phosphorus and nitrogen are essential for the growth of algae and other plants. Aquatic life is dependent upon these "photosynthesizers", which usually occur in low levels in surface water. Excessive concentrations of nutrients, however, can overstimulate aquatic plant and algal growth. Bacterial respiration and organic decomposition consume DO, depriving fish and invertebrates of available oxygen in the water, and leading to eutrophication.

Fertilizers, failing septic systems, and wastes from pets and farm animals are typical sources of excess nutrients in surface waters. In aquatic ecosystems, because phosphorus is normally available in the lowest amount, it is usually the limiting nutrient for plant growth. This means that excessive amounts of phosphorus in a system can lead to an abundant supply of vegetation and cause low DO concentrations in the water body. (McGhee, 1991).

3.5 Total and Fecal Coliforms

Bacteria and viruses from human and animal wastes carried to streams can cause disease. Fecal coliform bacteria are normally present in water and it is their concentration that is significant with respect to potential disease transmission. Fecal coliform, found in the intestines of warm-blooded animals, is the bacteria for which many surface water quality standards are written. Fecal coliform bacteria do not cause disease but are used as an indicator of disease causing pathogens in the aquatic environment. (McGhee, 1991).

Typical sources of bacteria are sewage from septic system failure and stormwater overflows, poor pasture management and animal-keeping practices, pet waste, and urban runoff. (McGhee, 1991). High bacterial levels limit the uses of water for swimming or contaminate drinking water in groundwater wells. The presence of excessive bacteria also may indicate other problems, such as low DO concentrations.

4 WATER QUALITY SAMPLING

4.1 *Reservoir Sampling by the University of Alfenas*

Water sampling conducted by the University of Alfenas is separate and distinct from the field studies associated with the CEPT wastewater treatment plant project. The University has been monitoring the water quality in the Furnas Reservoir since 1996. The University, in partnership with FURNAS Centrais Elétricas S.A., has been tracking bacterial, nutrient, and metals concentrations in the reservoir.

The specific areas that are monitored are of two types. The first type includes recreational areas that are used primarily for fishing and swimming, as well as other recreational uses. The second type includes wastewater in open-channel streams and tributaries, which flow from nearby cities and discharge stormwater runoff and raw sewage into the reservoir. Water samples are collected from a combined total of approximately 48 areas ('swimmable' areas and wastewater streams).

These efforts are part of an initiative called Projecto Furnas. There are three stages of this initiative. In the first stage, the University collected samples each month between July 1996 and August 1997. Sample collection for the second stage started in July 1998, with the last sample being collected in August 1999. Sample collection for the third stage commenced in July 2001, is expected to be completed during the summer of 2002.

Each water sample taken from the reservoir and waste streams are collected in two-liter bottles. The samples are analyzed in a laboratory for bacterial, nutrient, and metals content usually during the same day. The samples are refrigerated at a temperature of 4°C and below this level to preserve the bacterial content of the water. This is done for performing bacterial and chemical analysis at a later time. The university did little to no testing directly in the field, and it was routine procedure for any testing to be performed in a chemical or biological laboratory.

4.2 Lake Sampling and Field Measurement Techniques
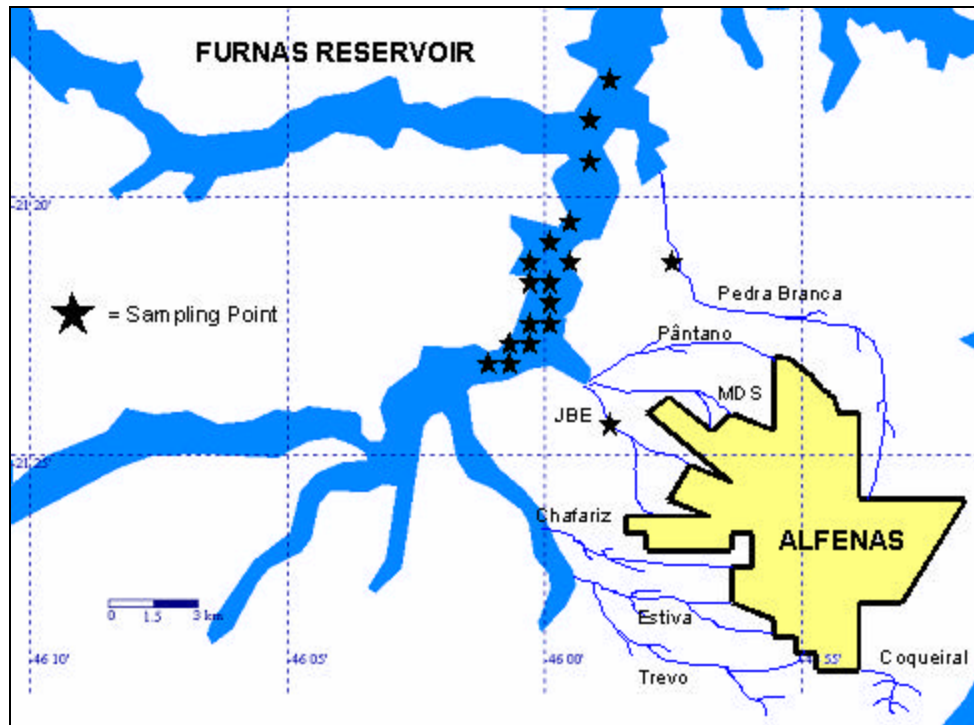
Figure 4-1: Sampling Points in the Furnas Reservoir

During the month of January 2002, samples were collected from the Furnas Reservoir and in two open-channel waste streams that flowed from Alfenas. The specific sampling points are indicated in Figure 4-1. The specific sampling coordinates, which were obtained using a global positioning system (GPS) device, are listed in Table 4-1. Water samples were collected on January 17th, January 18th, January 21st, and January 24th. The particular section of the reservoir was selected because of the open-channel waste streams from Alfenas flowed into this section. This location appeared to be the best area where representative samples could be collected. Various sampling points were selected within the reservoir. Generally, samples were collected in the centerline of the reservoir section, which is usually the deepest point in the section.

Measurements of water temperature and DO concentration were made on-site at each sampling point. Depth measurements were also made at each sampling point. A

"grab" water sample was taken at each sampling point in either a heat-sterilized bottle or a sampling bag containing a sterilization capsule. Bacterial and nutrient analysis was performed in a laboratory. These analyses included COD, nitrate, ammonia, orthophosphate and total and fecal coliforms.

Table 4-1: Reservoir Sampling Point Coordinates

	January 17, 2002		January 18, 2002	
Sample Point	Latitude, S	Longitude, W	Latitude, S	Longitude, W
Point 1	21°23.213'	46°00.937'	21°22.912'	46°00.937'
Point 2	21°22.819'	46°00.532'	21°21.816'	46°00.532'
Point 3	21°21.730'	46°00.184'	21°21.506'	46°00.184'
Point 4	21°20.786'	45°59.940'	21°18.593'	45°59.940'
	January 21, 2002		January 24, 2002	
Sample Point	Latitude, S	Longitude, W	Latitude, S	Longitude, W
Point 1	21°23.051'	46°00.163'	21°22.715'	46°00.409'
Point 2	21°21.716'	46°00.651'	21°22.021'	46°00.320'
Point 3	21°19.506'	45°59.508'	---------	---------
Point 4	21°18.115'	45°58.946'	---------	---------
Point 5	21°22.687'	46°00.103'	---------	---------
Point 6	21°23.589'	46°00.892'	---------	---------
Point 7	21°23.729'	46°01.133'	---------	---------

On January 17th and January 18th, water samples were collected from the surface of the reservoir. On January 21st and January 24th, water samples were collected from the surface and at various depths below the surface. The samples taken at various depths below the reservoir surface were first collected using a Van Dorn horizontal water bottle and then transferred to a heat-sterilized bottle or sterile Whirl-Pak bag, as shown in Figure 4-2. A Van Dorn water bottle was used to collect water samples from discrete depths. Usually 2 to 3 samples were collected in one water column at various depths, and analyzed to determine differences in water quality between surface

and deep water. The water samples collected in the sterilized bags had elevated pH and COD measurement levels, which may have been due to a sodium thiosulfate preservative.

Simultaneous field measurements of DO and temperature were taken at different depths in the reservoir using a portable YSI model 57 DO meter, equipped with a YSI model 5329 DO Probe which are shown in Figure 4-3 and Figure 4-4. The probe was attached to a 50-foot cable, which was very practical for taking depth profile measurements of DO and water temperature. The DO meter was calibrated by Winkler titration.

The probe was immersed directly into the reservoir at depths between 1 meter and 11 meters, depending on the depth of the part of the reservoir being measured. Measurements were taken at 1- and 2-meter intervals. Depth profiles were taken over the course of the 4-day period.

Source: Nasco website

Figure 4-2: Whirl-Pak Bag with Sodium Thiosulfate Preservative

4.3 Stream Sampling

Water samples collected from the open-channel wastewater streams required the use of waterproof boots and gloves, as well as the use of a safety mask for sample collection. The streams that were sampled include Pedra Branca and JBE, as shown in Figure 4-1. The specific sampling coordinates, using a GPS device, were located at 21°21.531' South, 45°57.472' West and 21°23.924' South, 45°58.900' West, respectively.

Source: YSI Incorporated website

Source: YSI Incorporated website

Figure 4-3: Portable DO and Temperature meter

Figure 4-4: Dissolved Oxygen Field Probe

The streams contained various domestic wastes, consisted of mostly raw sewage. The water in the streams clearly had rapid velocities, and the water looked murky and emitted a sewage odor. Water samples were collected from two wastewater streams discharging from Alfenas to the Furnas Reservoir. Samples were collected over a 3-day period, in which no samples were collected on January 24th due to time constraints. Some samples were collected during the day before 11:00 am and others after 2:00 pm.

4.4 Testing Methods

DO, water temperature, pH, COD, orthophosphate, ammonia and nitrate were measured. HACH test kits were used for the chemical analyses to measure the amount of nitrate, orthophosphate, ammonia, and COD. DO and water temperature was measured in the field as noted in the section above. pH was measured in the laboratory using a pH meter provided by the University of Alfenas.

HACH color disc test kits were used for measuring nitrate, ammonia, and orthophosphate concentrations. Each kit provides two vials, one for a blank sample with no reaction and the other for mixing a reagent into the sample. Depending on whichever test kit was used, each vial for a kit required 5 to 20 ml of sample. When the applicable reagent was mixed into a sample, there may be a color change. This color change was compared to the blank non-reacting sample, as a reference, using the color disk as shown in Figure 4-5. The value on the scale of the color disc, where the color change in the reacting vial is the same as the color on the color disc using the blank sample, was used. This value was multiplied by 4.4 to obtain mg nitrate per liter for nitrate concentrations and divided by 50 to obtain mg phosphate per liter for orthophosphate concentrations. The ammonia concentration was read directly from the scale on the color disc for the ammonia kit. Accuracy for color disc kits is typically ± 10% or ± the smallest increment, subject to individual color perception. (HACH website).

Source: HACH website   Source: HACH website

Figure 4-5: HACH Color-Based Test Kits   **Figure 4-6: COD reagent test tubes**

COD was also measured using a HACH COD test kit. The kit provided prepared COD reagents in test tubes as shown in Figure 4-6. However, the reagents contained hazardous material, so the test tubes were always capped. A 2-ml volume of water sample was added to a COD vial. Then the vial was capped and shaken to allow the sample to react with the reagent. After this mixing step, the vial was added to a COD reactor to allow the reagent to digest the sample contents at 150 °C for two hours.

Total and fecal coliforms, were measured using the standard method for Multiple-Tube Fermentation Analysis. Figure 4.7 shows this process, which is used to analyze for coliforms. Digestion mediums were inoculated with a drop of sample, with dilution ranging from 10^{-3} to 10^{-7} and left to digest in an oven set at 34.5 °C for 48 hours. Tubes showing positive reaction, evidenced by bubbling, were re-inoculated in fecal coliform mediums and heated in water bath at 44.5 °C for 24 hours, after which a second reading was taken.
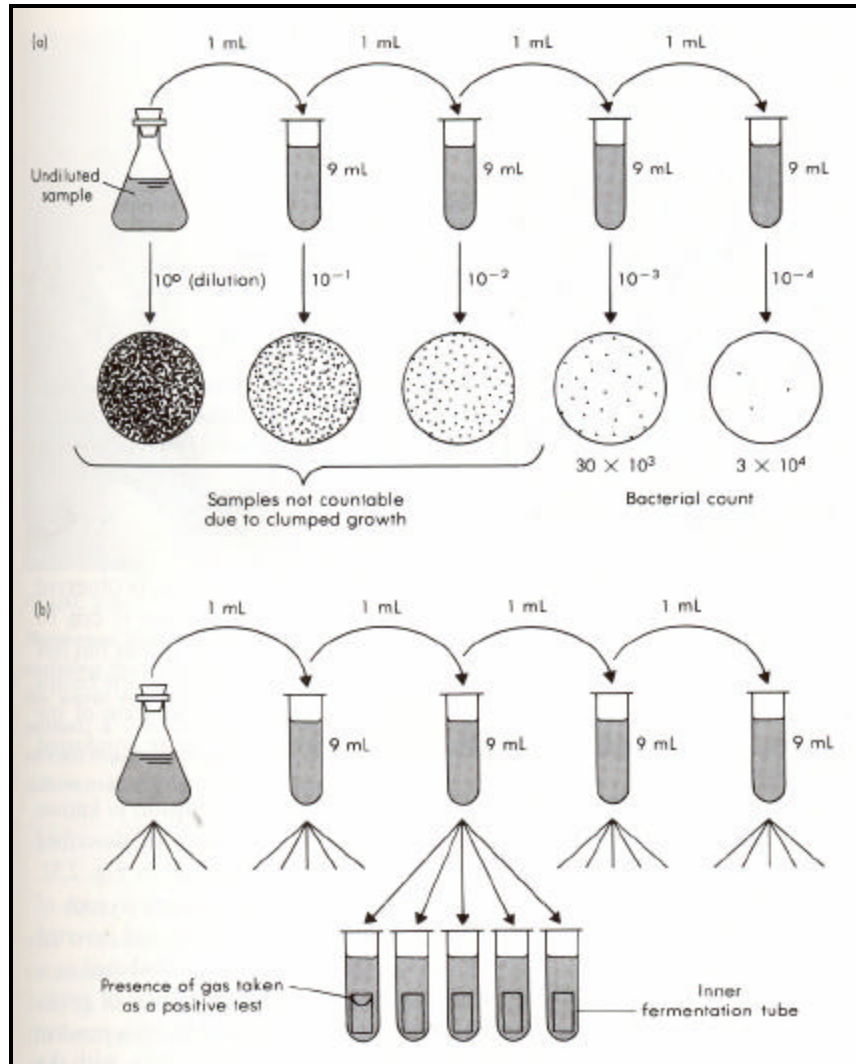
Figure 4-7: Multiple-tube Fermentation Analysis for Coliform Determination (McGhee, 1991)

5 WATER QUALITY MEASUREMENTS

5.1 DO and Temperature

Depth profiles for temperature and DO concentrations in the reservoir are shown in Appendix A. These profiles show little to no stratification with respect to DO and temperature. Also, the measurements of DO concentrations and temperature were consistent because the concentrations measured at different locations in the reservoir were approximately the same, as shown in Appendix A. This means that the section of the reservoir studied could be described as a well-mixed system.

DO concentrations ranged from 4 mg/L to 8 mg/L. The lowest DO concentrations occurred at the lowest depths in the reservoir and the higher values were found at the reservoir surface. The temperature ranged between 24°C and 30°C. If fact, there was little variation in temperature throughout the depth of the reservoir. Based on the depth profiles, the section of the reservoir that was studied appeared to be weakly stratified with respect to temperature and DO concentration.

The DO concentration appeared to be highest at the surface of the reservoir and lowest at the reservoir bottom. The concentration was above saturation at times due to the daytime algal production of oxygen. The highest concentration was 123% more than the saturation value. DO saturation concentrations appeared to drop at deeper levels in the reservoir. At the lowest depths, the concentrations are about 50% of the saturation concentration.

5.2 pH

The pH of the reservoir samples for the first two days of sampling ranged between 7.5 and 8.2, as shown in Table 5-1. On the third day, more sampling points were selected and more water samples were collected. Samples were collected at

discrete depths, as well as near the surface of the reservoir. On the third day, all of the samples were collected in Whirl-Pak bags containing a sodium thiosulfate capsule to keep the sample sterile. The pH values ranged between 8.8 and 9.3, as shown in Table 5-2.

Table 5-1: pH Measurements for 1st and 2nd Day of Reservoir Sampling

Sample number	Depth of Sample	pH Measurement	
		January 17, 2002	January 19, 2002
Point 1	Near surface	7.5	7.4
Point 2	Near surface	8.2	7.6
Point 3	Near surface	7.6	7.5
Point 4	Near surface	7.7	7.8

Table 5-2: Measurements for 3rd Day of Reservoir Sampling

January 21, 2002		
	pH Measurement	
Sample number	Near surface	7 ft below surface
Point 1	9.2	--
Point 2	9.3	9.0
Point 3	9.3	9.1
Point 4	9.2	9.2
Point 5	9.3	--
Point 6	9.2	--
Point 7	8.8	--

The pH values for the fourth, and final, day of sampling ranged from 7.8 and 9.1, as shown in Table 5-3. Water samples were taken at various discrete depths of 1, 2, 4, and 7 meters.

Table 5-3: pH Measurements for 4th Day of Reservoir Sampling

January 24, 2002							
Sampling Point	**Depth (m)**	**pH Measure #1**	**pH Measure #2**	**pH Measure #3**	**Average [H+] (mol/L)**	**Average of pH Measurements**	**Average pH**
Point 1	1	8.8	8.9	--	1.43E-09	8.8	8.7
	2	9.1	9.0	--	8.37E-10	9.1	
	4	8.8	9.0	--	1.33E-09	8.9	
	7	7.8	7.9	7.8	1.60E-08	7.8	
Point 2	1	9.0	8.7	--	1.51E-09	8.8	8.8
	2	9.0	9.1	--	9.64E-10	9.0	
	4	9.0	8.7	--	1.59E-09	8.8	
	7	8.7	8.7	8.7	2.08E-09	8.7	

The average pH was calculated by converting the pH values to hydrogen concentrations, [H+]. The [H+] concentrations were then averaged for each day; and the average hydrogen concentration(s) was converted to the pH. The pH is equal to negative logarithm of the hydrogen concentration.

The pH was not reported for the water sample collected from Pedra Branca on January 17th. Samples were not collected from either stream on January 24th due to time constraints. The pH values are listed in Table 5-4 for the waste streams.

Table 5-4: pH for Waste Streams

Stream pH Measurements			
Waste Stream	**January 17, 2002**	**January 18, 2002**	**January 21, 2002**
Pedra Branca	Not Reported	7.5	7.0
JBE	7.7	7.5	7.1

5.3 Orthophosphate

The orthophosphate concentrations in the reservoir and waste streams are listed in Tables 5-5 and 5-6, respectively. Although water samples were collected from the reservoir on January 24th, nutrient analyses were not conducted on these samples.

Table 5-5: Orthophosphate concentrations in the Reservoir

Samplin g Point	Orthophosphate (mg Phosphate/L)			
	January 17, 2002	January 18, 2002	January 21, 2002	January 24, 2002
Point 1	0.02	0.19	0.07	Not Reported
Point 2	0.02	0.03	0.05	Not Reported
Point 3	0.03	0.03	0.04	--
Point 4	0.03	0.03	0.05	--
Point 5	--	--	0.04	--
Point 6	--	--	0.04	--
Point 7	--	--	0.05	--

Table 5-6: Orthophosphate concentrations in waste streams

Sampling Point	Orthophosphate (mg Phosphate/L)		
	January 17, 2002	January 18, 2002	January 21, 2002
Pedra Branca	0.20	0.06	0.23
JBE	0.20	0.30	0.44

5.4 Nitrate and Ammonia

All nitrate concentrations measured in the reservoir water samples were less than 0.01 mg/L. Also, ammonia concentrations were not detected in any of water samples collected from the reservoir. The ammonia and nitrate concentrations in the open-channel waste streams are listed in Table 5-7.

Table 5-7: Ammonia and nitrate concentrations in the waste streams

Sampling Point	January 17, 2002		January 18, 2002		January 21, 2002	
	Ammonia (mg/L)	Nitrate (mg/L)	Ammonia (mg/L)	Nitrate (mg/L)	Ammonia (mg/L)	Nitrate (mg/L)
Pedra Branca	1.3	0.001	1.3	0.001	2.4	0.001
JBE	2.5	0.001	2.5	0.002	2.5	0.002

5.5 COD

The COD concentrations in the reservoir are listed in the tables below. The samples collected from the reservoir on January 21st were collected in Whirl-Pak sampling bags that contained a sodium thiosulfate capsule that is used to keep the sample sterile. All other samples taken from the reservoir, as well as samples taken from the streams were collected in heat-sterilized bottles provides by the University of Alfenas.

Table 5-8: COD in the reservoir for January 17th and 18th

Sample number	COD (mg/L)	
	January 17, 2002	January 18, 2002
Point 1	23.3	23.1
Point 2	15.5	7.8
Point 3	25.8	22.7
Point 4	21.6	23.7

The reservoir samples show elevated COD levels, which may be due to the chemical capsule in the sampling bag. Thus, due to the uncertainty in these results, the COD measurements for January 21st were not used in any further analysis.

The average COD concentration in the reservoir for January 17th is 28.8 mg/L, 19.33 mg/L for January 18th, and 7.2 mg/L for January 24th. The average COD concentration of the three days is 18.4 mg/L.

Table 5-9: COD measurements for January 21, 2002

Sample number	COD (mg/L)	
	Near surface	7 ft below surface
Point 1	36.5	--
Point 2	21.9	78.3
Point 3	125.3	78.4
Point 4	101.1	30.9
Point 5	39.5	--
Point 6	88.1	--
Point 7	33.4	--

Table 5-10: COD measurements for January 24, 2002

Sampling Point	Depth (m)	COD (mg/L)
Point 1	1	10.8
	2	14.4
	4	7.2
	7	3.6
Point 2	1	7.2
	2	3.6
	4	7.2
	7	3.6

Table 5-11: COD Concentrations in the waste Streams

Waste Stream	January 17, 2002	January 18, 2002	January 21, 2002
Pedra Branca	12.2	54.4	11.8
JBE	37.8	148.4	36.5

5.6 Fecal Coliform

Table 5-12 shows the fecal coliform concentrations in the reservoir and the waste streams. Points 1 through 7 represent the fecal coliform concentrations in the reservoir. The average fecal coliform concentration in the reservoir for January 21st is 335.8 MPN/100 ml. The average concentration over January 17th, January 18th, and January 21st in the reservoir was 568.6 MPN/100 ml.

Table 5-12: Fecal Coliform Concentrations in MPN per 100 ml

Sampling Point	January 17, 2002	January 18, 2002	January 21, 2002
Point 1	--	--	--
Point 2	--	--	--
Point 3	--	--	45
Point 4	170	1200	93
Point 5	--	--	700
Point 6	--	--	--
Point 7	--	--	460
Pedra Branca	1.7×10^4	2.2×10^5	2.0×10^3
JBE	2.2×10^6	1.6×10^8	4.5×10^5

6 WATER QUALITY MODELING

In this section, a mathematical model is used to predict the level of improvements of the ambient concentrations in the reservoir due to CEPT implementation. This study will focus on two cases: (1) predicting the reservoir concentrations at high and low water volume in the reservoir, and (2) predicting concentrations in the reservoir due to the use of CEPT and the case in which CEPT is not used to treat the wastewater in Alfenas. Only BOD, fecal coliform, phosphorus, and dissolved oxygen concentrations are predicted.

For examining concentrations at high and low reservoir volumes, annual water quality data gathered by the University of Alfenas was used. At high volume, 1996 data is used to estimate concentrations. At low volume, 2001 data was used, since the reservoir dropped to its lowest level in this year. This examination looks at the impact of how the changing reservoir levels will impact the concentrations in the reservoir and how effective CEPT will be in reducing these concentrations.

The concentrations in the reservoir are predicted using a well-mixed model for the section of the reservoir studied during January 2002. There is little variation in this section based on depth profiles conducted on the reservoir, in which the sampling points are shown in Figure 4-1. Therefore a well-mixed model is used to predict the ambient concentration for local use of CEPT in Alfenas.

6.1 Well-Mixed Model

6.1.1 Theory

The well-mixed model, or completely mixed system, is a system in which the concentration is the same throughout the volume of the system. Figure 6-1 shows an example of a well-mixed system.
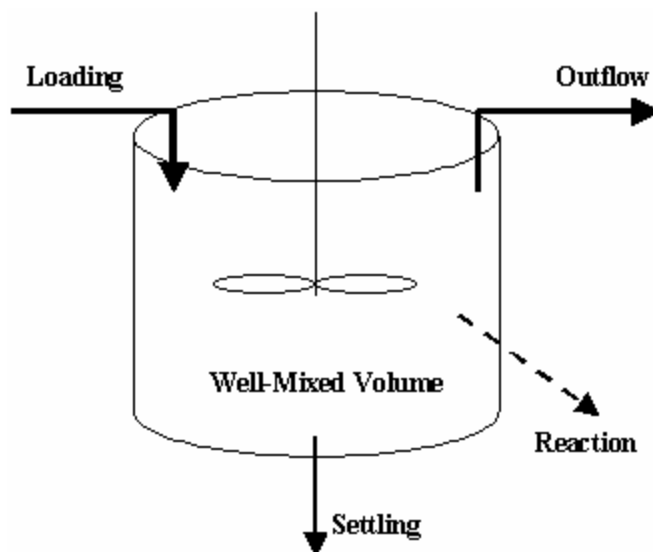
Figure 6-1: Well-Mixed System

The arrows in the figure represent the major sources and sinks of a contaminant in the system. The dashed arrow represents a sink due to reaction. It is used to distinguish it from the other sources and sinks which are transport mechanisms. For this study, a section of the reservoir is taken to represent a well-mixed system. The inputs to the system include loading from Alfenas, as well as other tributaries. Losses in the system include contaminant decay due to reaction and settling.

The mass balance for the system is expressed as the following:

Accumulation = Mass in – Mass out + Production – Sinks

The accumulation term represents the change in mass over time. If mass is being removed from the system, the accumulation term is negative. If the system gains mass, the accumulation term is positive.

$$\text{Accumulation} = \frac{dM}{dt}$$

In the above equation, M represents mass. M can be expressed as C*V, where C is concentration in mg/L and V is the volume in Liters. At constant volume,

$$\text{Accumulati on} = V\frac{dC}{dt}.$$

The mass entering the system represents the loading. The total loading is the sum all the loadings. For a specific input, the loading is represented by the product of the concentration of contaminant in the input and its flowrate. The loading can be expressed as the following, where C_i is the concentration in mg/L of input i and Q_i is its flowrate in L/d:

$$\text{Mass in} = \sum C_i Q_i$$

The mass exiting the system is the concentration of the contaminant in the outflow multiplied by its flowrate. The concentration at the output is also the same as the average concentration within the system, due to well-mixed conditions. The outflow is represented by the following equation in which Q_{out} is the total flow leaving the well-mixed system in units of liters per day:

$$\text{Mass out} = CQ_{out}$$

Other losses in the system include reaction decay and settling. These losses are normally characterized by the way in which they occur. For example, the reaction decay is normally represented by mass multiplied by a decay constant. Settling depends on the settling velocity of the particle and the surface area available for falling particles. Reaction decay and losses due to settling can be expressed by the following, where k_d is the decomposition rate in day^{-1}, u is the apparent settling velocity in m/s, and As is the surface area of the sediments in m^2:

$$\text{Reaction} = k_d * V * C$$

$$\text{Settling} = u * A_s * C$$

The most common representation for reaction decay that purges contaminants from natural waters is kVC. Settling losses can be formulated as a flux of mass across the surface of the sediment-water interface, as shown in figure 6-2. (Chapra, 1997).
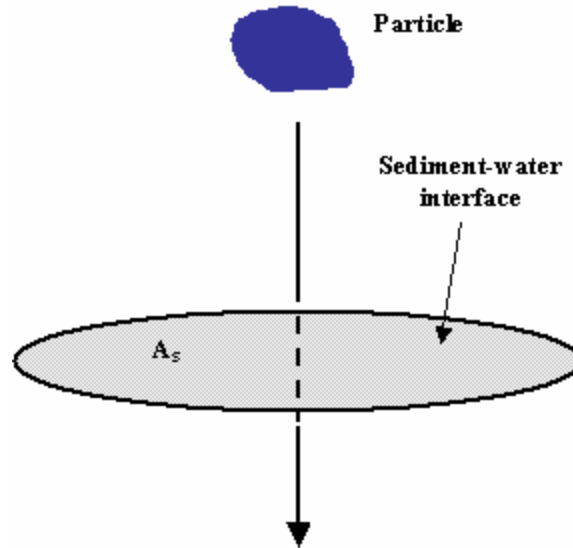
Figure 6-2: Particle falling to a sediment surface

The product of the flux and the area gives the settling term in the mass balance. Since the volume is equal to the average depth, H, and the reservoir surface area, the settling equation can be formulated into the first-order reaction:

$$\text{Settling} = k_s VC$$

where k_s is the settling rate of the contaminant, which is equal to $\dfrac{u}{H}$. Often, the settling rate and the reaction decay rate are considered together. Thus, the terms k_s and k_d are combined as shown in the following:

$$k = k_s + k_d$$

in which k represents the total removal rate (day^{-1}) of the contaminant, which includes both decay and settling.

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Therefore, the complete equation is $V\dfrac{dC}{dt} = \sum C_i Q_i - CQ_{out} - kVC$. At steady state $\dfrac{dC}{dt} = 0$ and rearranging the equation to solve for C gives:

$$C = \frac{\sum C_i Q_i}{Q_{out} + kV}$$

The concentration C within the well-mixed volume represents the average concentration. Therefore, $\overline{C}$ is used to represent C. So, the equation becomes:

$$\overline{C} = \frac{\sum C_i Q_i}{Q_{out} + kV}$$

$$\text{where, } Q_{out} = Q_{Alf} + Q_{in}$$

C_i is the concentration input in mg/Liter; $\overline{C}$ is average concentration in the control volume in mg/Liter; Q_i is the flowrate of input stream i in Liters/day; Q_{out} is total the flowrate leaving the control volume in Liters/day; k is the decay constant in day^{-1}; and V is the volume of the section in Liters. The above equation applies to BOD, phosphorus, and fecal coliform concentrations.

Dissolved oxygen concentrations in the reservoir decrease as BOD concentrations increase in the reservoir. This can lead to detrimental anoxic conditions in the water body. CEPT may actually improve DO concentrations in the reservoir because it reduces BOD concentrations. The calculations for predicting changes in DO concentrations in the reservoir are shown in Figure 6-3.

$$\text{Reaeration} = k_a * (C_s - \overline{C}) * A_s$$

$$\text{Inflow} = \sum C_i * Q_i \longrightarrow \boxed{\begin{array}{c} \text{FURNAS} \\ \text{RESERVOIR} \end{array}} \longrightarrow \text{Outflow} = \overline{C} * Q_{out}$$

$$\text{DO Consumption} = k_d * L * V$$
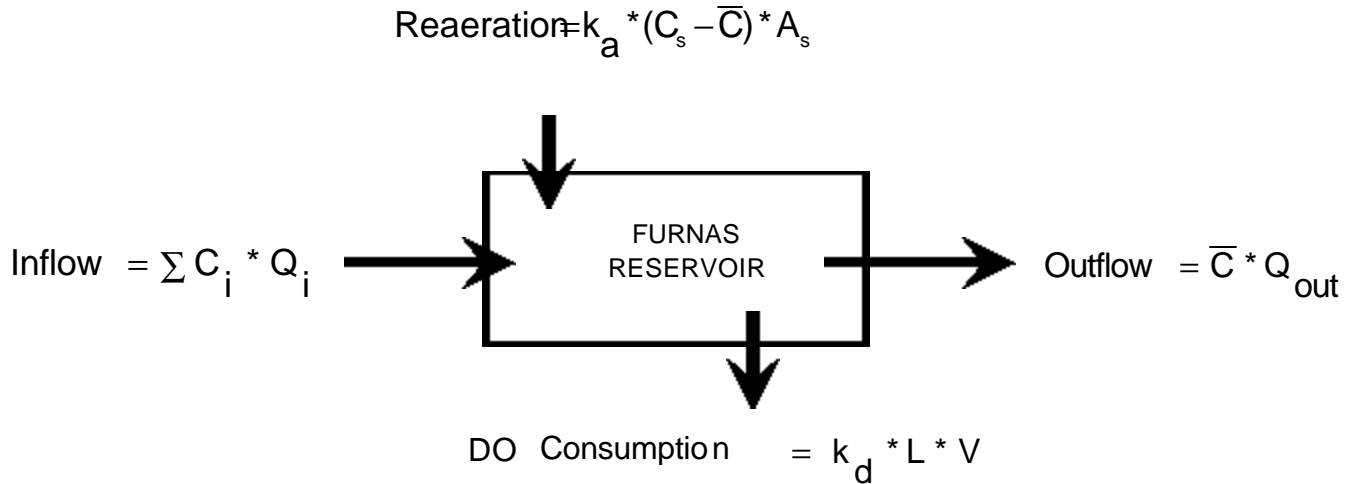
Figure 6-3: Schematic of DO Concentrations in the Reservoir

The parameters C_i and $\overline{C}$ are the inflow and average DO concentrations in the reservoir; k_a is the reaeration constant; C_s is the DO concentration at saturation; V is the reservoir volume; A_s is the surface area; Q_i and Q_{out} are the inflow and outflow flowrates; and k_d and L are the decay constant and concentration of BOD. The mass balance around the reservoir section leads to the following equation:

$$\overline{C} = \frac{C_{in}Q_{in} + k_a C_s A_s - kLV}{Q_{out} + k_a A_s}$$

Equation 6-1: Equation for Predicting the Average DO Concentration

The removal rate k for BOD as calibrated for Equation 6-1, is used in place of the decay rate k_d for BOD, although this may result in an underestimation in the predicted DO concentration.

6.2 Application of Model to Furnas Reservoir
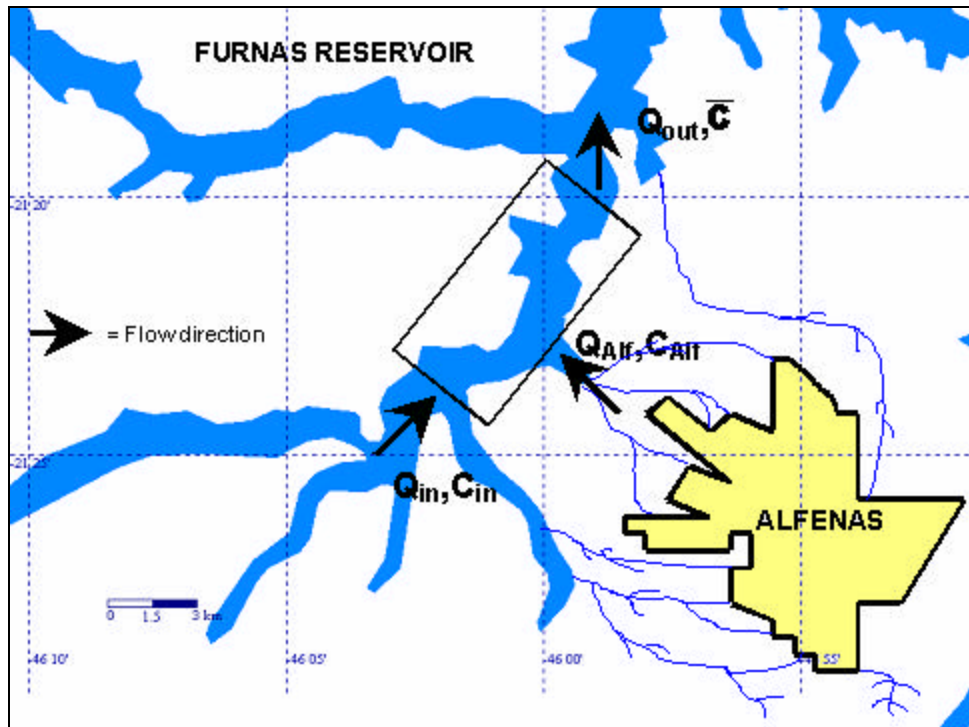
Figure 6-4: Section of Furnas , subject of modeling exercise

The principles for the well-mixed model, discussed previously, were applied to a section of the Furnas Reservoir to predict BOD, fecal coliform, and phosphorus. Concentration predictions for DO are handled somewhat differently. Due to the drop in the reservoir volume between 1996 and 2001, data from these years are used to predict ambient concentrations in the reservoir at high volume (1996) and at low volume (2001).

The loading entering the section from Alfenas is based on a rate of sewage production from the city of 180 L/day-inhabitant and the percentage of the total population that the wastewater streams serves. (Metcalf and Eddy, 2002).

A population of 58,963 inhabitants for the city is used for 1996. (IBGE website). The census population for 2000 is used for the concentration prediction of 2001. The 2000 population is reported to be 66,957 inhabitants. (IBGE website). To simplify the

calculations, a rounded number of 67,000 is used for 2001, and 59,000 is used for 1996. There are three wastewater streams flowing from Alfenas directly into the control volume in the reservoir. These streams are called Pântano, MDS, and JBE. Altogether, these streams represent raw sewage from a total of 32 % of the total population of Alfenas. (Furnas Lake Users Association, 2001).

COD is used as a surrogate for BOD. Based on the BOD to COD correlation for the raw sewage, the ratio of BOD to COD is estimated to be 0.6. The COD concentration in of the raw sewage, based on field studies, is 494 mg/L. Thus, the BOD concentration is approximately 60 % of the COD concentration or 296 mg/L. (Olive, 2002)

The fecal coliform concentration in the raw sewage was measured. This concentration was determined to be 8×10^6 MPN per 100 ml. This value varies in comparison to the fecal coliform concentrations in the two streams reported in Chapter 5. The fecal coliform concentration in the raw sewage will fluctuate.

The fecal coliform and BOD concentrations are based on field studies conducted by the project team at the JBE wastewater stream in Alfenas. For this study, these concentrations are assumed to be the same as the concentrations in the other wastewater streams.

6.2.1 Reservoir and Stream Flowrates

The flowrates can be estimated using rainfall data or using information about the total flow in the reservoir as shown in Equations 6-3 and 6-4.

Equation 6-3 is used to estimate the flowrates using rainfall data. In the equation, P is the precipitation, ET is the evapotranspiration, and DA is the area of the drainage basin. Q_{Alf} is the flow contribution from Alfenas, and Q_{in} is the other stream flows. Q_{out} is the total flow from the system, as shown in Figure 6-4. Groundwater flow into and out of

the system is assumed to be the same. Thus, groundwater flow is assumed to be negligible or zero. The evapotranspiration is estimated using the Thornwaite and Mather method for estimating potential evapotranspiration. (Thornwaite and Mather, 1957). Estimates for evapotranspiration assume a soil moisture storage of 50 mm. This value may be higher. Higher values of soil moisture storage result in decreased flow calculation. The total rainfall was 1445 mm/yr for 2001 and 1473 mm/yr for 1996. (Furnas Lake Users Association, 2002). The estimated evapotranspiration is 882.7 mm/yr for 2001 and 916.2 mm/yr for 1996. (Thornwaite and Mather, 1957).

$$Q_{out} = (P - ET) * (DA)$$
$$Q_{out} = Q_{Alf} + Q_{in}$$

Equation 6-2: Flowrate Calculation using Rainfall Data

Equation 6-4 is used to estimate the flowrates using total flow in the reservoir at the Dam. In the equation, Q is the total flow in the reservoir, DA_i is the drainage basin area of our control volume, and DA is the area of the entire drainage basin for the Furnas region. The total flow, Q, into the reservoir can be described by the following equation, where Q_{dam} is the total flow through the turbines at the dam and $\dfrac{dV}{dt}$ is the change in water storage over time in the reservoir.

$$Q = Q_{dam} + \frac{dV}{dt}$$

Both Q_{dam} and $\dfrac{dV}{dt}$ are known. (Furnas Lake Users Association, 2002). Due to unavailability of some data, 2000 data is used for calculations for dates beyond 2000. So, the total average reservoir flows for both years 876 m³/s for 2001 and 957 m³/s for 1996. (Furnas Lake Users Association, 2002). The area for the drainage basin for the well-mixed system is 1,537 km² and the drainage basin area for the Furnas region is 46,450 km². (IBGE, 1997).

$$Q_{out} = Q * \frac{DA_i}{DA}$$

Equation 6-3: Flow calculation using Total Reservoir Flow

The loading from Alfenas is based on the raw sewage discharged from the city. The flow from Alfenas for both years is calculated below.

Q_{Alf}=180 L/day-inhab * 67,000 inhab * 0.32 ≈ 4 mil L/d   (2001)

Q_{Alf}=180 L/day-inhab * 59,000 inhab * 0.32 ≈ 3.4 mil L/d   (1996)

The flowrate for Q_{out} is estimated using both methods and the average is used in further calculations of the average concentrations in the reservoir.

Estimated Q_{out} for 2001:

Rainfall: $(1445 - 883)\frac{mm}{yr} * \frac{1}{365\,days} * \frac{m}{1000\,mm} * 1537 * 10^6 m^2 * \frac{1000\,L}{m^3} = 2367\,mil\frac{L}{day}$

Total Flow: $876\frac{m^3}{sec} * \frac{1000}{m^3} * \frac{86400\,sec}{day} * \frac{1537\,km^2}{46450\,km^2} = 2504\,million\frac{L}{day}$

Average: $\frac{(2367 + 2504)\,million}{2} = 2436\,million\frac{L}{day}$

Estimated Q_{out} for 1996:

Rainfall: $(1473 - 916)\frac{mm}{yr} * \frac{1}{365\,days} * \frac{m}{1000\,mm} * 1537 * 10^6 m^2 * \frac{1000\,L}{m^3} = 2194\,mil\frac{L}{day}$

Total Flow: $957\frac{m^3}{sec} * \frac{1000}{m^3} * \frac{86400\,sec}{day} * \frac{1537\,km^2}{46450\,km^2} = 2736\,million\frac{L}{day}$

Average: $\dfrac{(2194 + 2736)\text{ million}}{2} = 2465\text{ million }\dfrac{L}{day}$

Since the 1996 and 2001 flows are so close, we can assume that the total flow for both years is the average of the flows for both years, or 2450 mil L/d. The flowrate Q_{in} is simply the difference between Q_{out} and Q_{Alf}.

6.3 Calibration of Existing Conditions in 2002
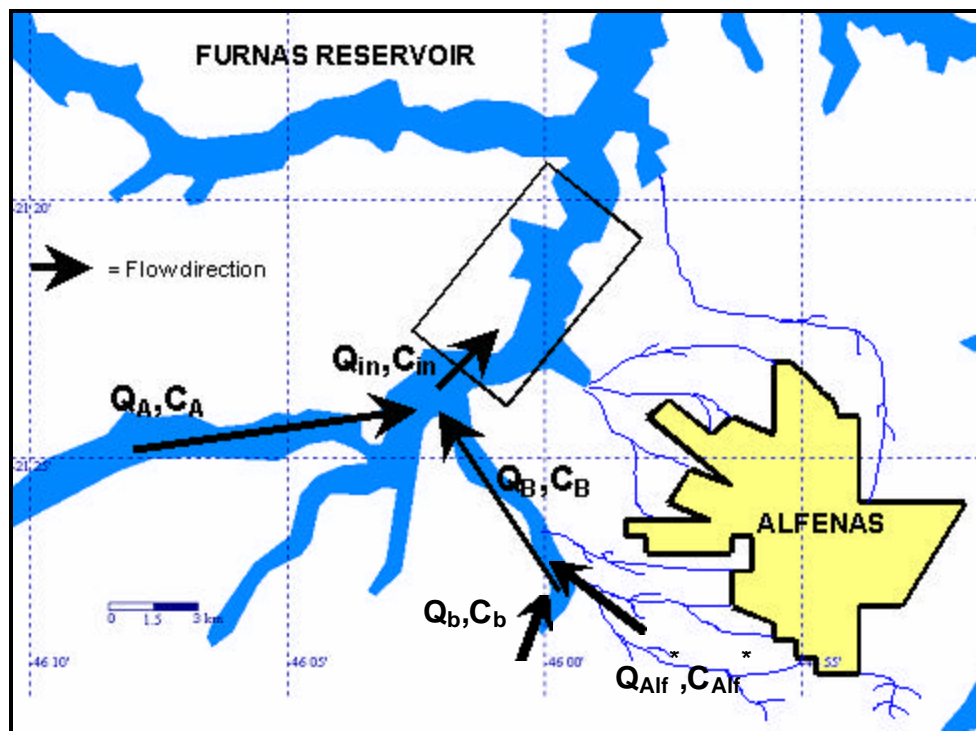
Figure 6-5: Schematic of flows contributing to C_{in}

Calibration of k involves using three equations. Equations 6-6 and 6-7 are used to estimate upstream concentrations, and Equation 6-5 is used to perform the final calculation of the removal rate, k, for BOD, fecal coliform, and phosphorus. k is estimated using data from the field studies during January 2002 in Brazil, and water quality data obtained from the reservoir by the Hydric Resources Research Laboratory at the University of Alfenas.

$$k = \frac{C_{Alf}Q_{Alf} + C_{in}Q_{in}}{\overline{C}V} - \frac{Q_{out}}{V}$$

Equation 6-4: Equation for estimating the removal rate, k

Figure 6-5 describes the flow regime for used for the well-mixed system. Concentration C_{in} is found by the following method:

$$C_{in} = \frac{C_AQ_A + C_BQ_B}{Q_A + Q_B}$$

Equation 6-5: Equation for C_{in}

C_A, C_B, Q_A, and Q_B are shown in Figure 6-5. C_A and C_B are based on water quality data collected during January 2002 by the University of Alfenas. Q_A and Q_B are based on flow estimates based on the local watershed. C_B requires estimation using Equation 6-7, where C_{Alf}^* and Q_{Alf}^* represent contaminant concentrations and flow in the waste streams discharged from Alfenas. C_b represents the water quality concentrations measured in the reservoir by the University of Alfenas, and Q_b represents the water flow rate, which is derived from watershed data. C_b and Q_b are upstream of inputs C_{Alf}^* and Q_{Alf}^*, as indicated in Figure 6-5.

$$C_B = \frac{C_{Alf}Q_{Alf} + C_bQ_b}{Q_{Alf} + Q_b}$$

Equation 6-6: Equation for upstream concentration

The specific flow rates are listed in the tables below. The volume of the well-mixed section is approximately 36 billion liters, also derived from watershed data and an average depth of 8 meters. These values are based on 2002 estimates.

Table 6-1: Flow rates in Furnas

Parameter	Flow rates (Liters per day)
Q_{out}	2450 million
Q_{Alf}, Q_{Alf}^* (1996)	3.4 million
Q_{Alf}, Q_{Alf}^* (2001)	4 million
Q_{in}	2446 million
Q_A	2203 million
Q_B	243 million
Q_b	239 million

The reaeration constant determines the rate in which dissolved oxygen is replenished in the reservoir. The reaeration constant, k_a, is predicted using Equation 6-8.

$$k_a = \frac{\overline{C}Q_{out} + kLV - C_{in}Q_{in}}{(C_s - \overline{C}) * SA}$$

Equation 6-7: DO Reaeration Equation

Neglecting the impact of the BOD concentrations from the waste streams discharging from Alfenas, the DO concentrations in C_B and C_{in} are estimated below.

$$C_B = \frac{C_b Q_b + k_a C_s SA_B - kLV_B}{Q_B + k_a SA_B} \quad \text{and} \quad Q_{in} = \frac{C_A Q_A + C_B Q_B}{Q_A + Q_B}$$

The surface area for section B, SA_B, is 6 million m^2; C_b is 8 mg O$_2$/L; C_s is 7.4 mg O$_2$/L; k is 0.043/day, as derived in the Section 6.3.1; V_B is 30 billion liters; and C_A is 4.6 mg O$_2$/L. Plugging these values into the above equations, and solving for k_a by trial-and-error leads to a value of 0.85 meters per day.

6.3.1 Removal Rate Constant for BOD

C_{Alf} and C_{Alf}^* are 296 mg/L, assuming that the raw waste in all of the waste streams in Alfenas has the same BOD concentration. (Olive, 2002). C_b is 3.8 mg/L, based on water quality measurements taken by the University of Alfenas in January 2002. (Tanure, 2002).

$$C_B = \frac{C_{Alf}^* Q_{Alf}^* + C_b Q_b}{Q_{Alf}^* + Q_b} = \frac{296 * 4 * 10^6 + 3.8 * 239 * 10^6}{243 * 10^6} = 8.6 \text{ mg/L}$$

C_A was assumed to be the average of water quality measurements taken between the months of December 1998 and March 1999, since water quality data was not taken after this time. Therefore, C_A is 1.8 mg/L. (Tanure, 1999).

$$C_{in} = \frac{C_A Q_A + C_B Q_B}{Q_A + Q_B} = \frac{1.8 * 2203 * 10^6 + 8.6 * 243 * 10^6}{2446 * 10^6} = 2.5 \text{ mg/L}$$

COD concentrations measured in the reservoir are used as a surrogate for estimating BOD concentrations. Using historical water quality data from the University of Alfenas, a BOD to COD ratio of 0.1 is used to estimate BOD concentrations using COD measurements. BOD to COD ratio of treated wastewater, which is comparable to ambient conditions in water bodies, is between 0.1 and 0.3. (Metcalf & Eddy, 2002).

The average concentration for $\overline{C}$ measured in the reservoir was 18.4 mg/L COD (See Chapter 5). Therefore, the BOD concentration is 0.1 multiplied by 18.4 or 1.84 mg/L.

$$k = \frac{C_{Alf} Q_{Alf} + C_{in} Q_{in}}{\overline{C}V} - \frac{Q_{out}}{V} = \frac{296 * 4 * 10^6 + 2.5 * 2446 * 10^6}{1.84 * 36000 * 10^6} - \frac{2450 * 10^6}{36000 * 10^6} = 0.043/\text{day}$$

6.3.2 Removal Rate Constant for Fecal Coliform

C_{Alf} is 8 million MPN/100 ml, with the same raw waste assumption as that for BOD concentrations. (Olive, 2002). C_b is 27 MPN/100 ml, based on water quality measurements taken by the University of Alfenas in January 2002. (Tanure, 2002).

$$C_B = \frac{C_{Alf}{}^* Q_{Alf}{}^* + C_b Q_b}{Q_{Alf}{}^* + Q_b} = \frac{8 * 10^6 * 4 * 10^6 + 27 * 239 * 10^6}{243 * 10^6} \approx 131{,}700\, \text{MPN/100 ml}$$

The same assumptions for BOD above also apply here for C_A, which was assumed to be the average of water quality measurements taken between the months of December 1998 and March 1999, since water quality data was not taken after this time. Therefore, C_A is 81 MPN/100 ml. (Tanure, 1999).

$$C_{in} = \frac{C_A Q_A + C_B Q_B}{Q_A + Q_B} = \frac{81 * 2203 * 10^6 + 131714 * 243 * 10^6}{2446 * 10^6} \approx 13{,}200\, \text{MPN/100 ml}$$

The average concentration for $\overline{C}$ in the reservoir was 568 MPN/100 ml. (See Chapter 5).

$$k = \frac{C_{Alf} Q_{Alf} + C_{in} Q_{in}}{\overline{C} V} - \frac{Q_{out}}{V} = \frac{8 * 10^6 * 4 * 10^6 + 13158 * 2446 * 10^6}{568 * 36000 * 10^6} - \frac{2450 * 10^6}{36000 * 10^6} = 3.1/\text{day}$$

6.3.3 Removal Rate Constant for Phosphorus

C_{Alf} and $C_{Alf}{}^*$ are 7.5 mg/L, with the same raw waste assumptions as that for BOD and fecal coliform concentrations. (Olive, 2002). Since no nutrient water quality measurements were taken in the reservoir by the University of Alfenas, C_b and C_A were assumed to be negligible or zero.

$$C_B = \frac{C_{Alf}{}^* Q_{Alf}{}^* + C_b Q_b}{Q_{Alf}{}^* + Q_b} = \frac{7.5 * 4 * 10^6 + 0 * 239 * 10^6}{243 * 10^6} = 0.12\, \text{mg/L}$$

$$C_{in} = \frac{C_A Q_A + C_B Q_B}{Q_A + Q_B} = \frac{0*2203*10^6 + 0.12*243*10^6}{2446*10^6} = 0.012\,\text{mg/L}$$

The average concentration for $\overline{C}$ in the reservoir was 0.01 mg/L (See Chapter 5).

$$k = \frac{C_{Alf}Q_{Alf} + C_{in}Q_{in}}{\overline{C}V} - \frac{Q_{out}}{V} = \frac{7.5*4*10^6 + 0.012*2446*10^6}{0.01*36000*10^6} - \frac{2450*10^6}{36000*10^6} = 0.015/\text{day}$$

6.3.4 Rate Constants

Table 6-2 shows the removal rate constants for BOD, fecal coliform, and phosphorus, and the reaeration constant for DO. The reaeration constant is 0.85 meters per day or 0.11 day^{-1} for the control volume, which has an average depth of 8 meters. The removal rate constant for BOD is expected to be much higher than the estimated value of 0.043 day^{-1}, especially since the reservoir is located in a tropical climate. BOD decay occurs at a rate that increases with increasing temperature. (Bowie et al, 1985). Phosphorus and fecal coliform rate constants appear to be within the range of expected values.

The estimated rate constants neglect temperature variations. These values are used to predict the concentrations for high volume (1996) and low volume (2001) in the reservoir.

Table 6-2: Rate Constants

Parameter	Constant	Value	Units	Effect
BOD	k	0.043	day^{-1}	Total removal rate
DO	k_a	0.11	day^{-1}	Reaeration constant
Fecal Coliform	k	3.1	day^{-1}	Total removal rate
Phosphorus	k	0.015	day^{-1}	Total removal rate

6.4 CEPT Implementation at 3 Streams
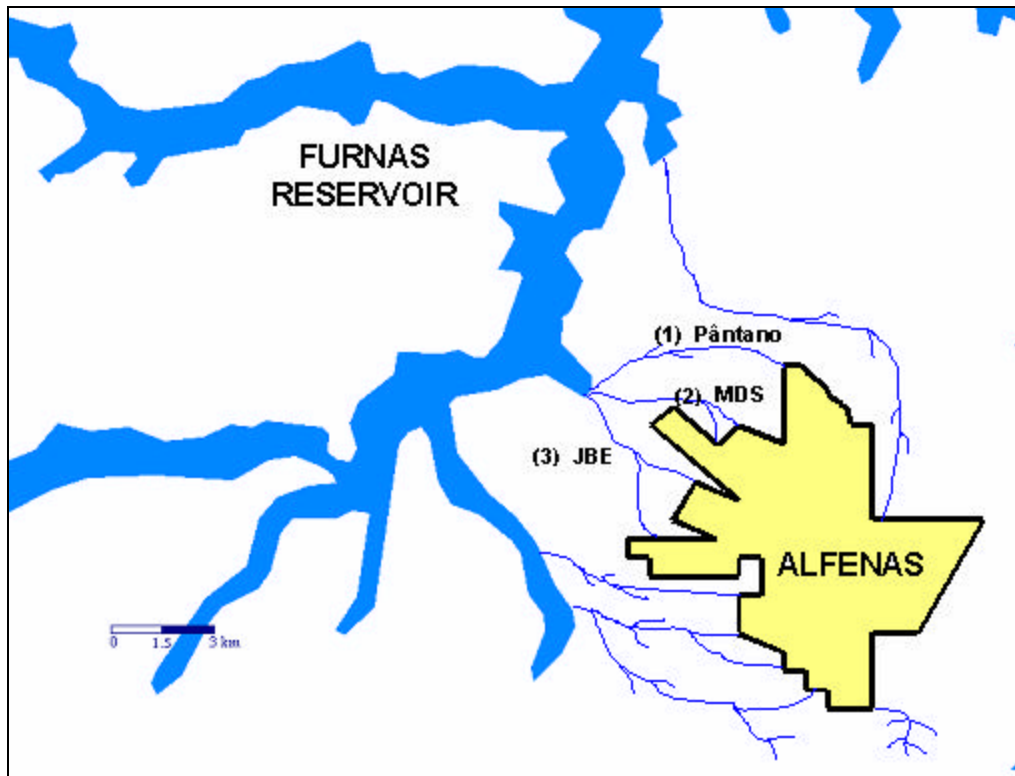
Figure 6-6: CEPT use at 3 waste streams

Assuming CEPT use on the wastewater streams JBE, MDS, and Pântano, as shown in Figure 6-6, the BOD, phosphorus, and fecal coliform concentrations are found using Equation 6-1, and the decay rates, shown in Table 6-2.

The average concentration $\overline{C}$ is predicted for low (2001) and high (1996) water volumes in the reservoir. Equations 6-6 and 6-7 are used to first calculate C_B and C_{in}. Using the same assumptions as used to calculate the decay and reaeration constants, C_B is based on water quality data collected by the University of Alfenas and waste stream data based on field measurements collected in January 2002. C_A is derived from water quality measurements taken by the University. Tables 6-3 and 6-4 show the values for C_B and C_{in} for BOD and fecal coliform. Phosphorus concentrations are shown

in Table 6-5. Phosphorus measurements were not collected in the reservoir so the only phosphorus contribution to the reservoir is assumed to come from the waste streams discharging from Alfenas. Table 6-6 shows the DO concentrations for C_A, C_B, and C_{in}.

Table 6-3: BOD Concentrations for C_{in} Considering CEPT at 3 Streams

BOD (mg/L)			
Year	C_A	C_B	C_{in}
High Volume (1996)	0.9[a]	5.6	1.4
Low Volume (2001)	1.6 [a]	6.3	2.1
January 2002	1.8 [a]	8.6	2.5

[a] Source: University of Alfenas, Projecto Furnas I, II, and III

Table 6-4: Fecal Coliform Concentrations for C_{in} Considering CEPT at 3 Streams

Fecal Coliform (MPN/100 ml)			
Year	C_A	C_B	C_{in}
High Volume (1996)	356 [a]	112047	11543
Low Volume (2001)	510 [a]	131712	13544
January 2002	81 [a]	131714	13158

[a] Source: University of Alfenas, Projecto Furnas I, II, and III

Table 6-5: Phosphorus Concentrations for C_{in} Considering CEPT at 3 Streams

Phosphorus (mg/L)			
Year	C_A	C_B	C_{in}
High Volume (1996)	0.0	0.105	0.01
Low Volume (2001)	0.0	0.124	0.012
January 2002	0.0	0.124	0.012

Table 6-6: DO Concentrations for C_{in} Considering CEPT at 3 Streams

DO (mg/L)			
Year	C_A	C_B	C_{in}
High Volume (1996)	7.1 [a]	6.6	7.1
Low Volume (2001)	5.7 [a]	6.2	5.8
January 2002	4.6 [a]	5.3	4.7

[a] Source: University of Alfenas, Projecto Furnas I, II, and III

Using the values in Table 6-3 through Table 6-6, the average concentrations for BOD, fecal coliform, DO, and phosphorus are predicted for the situation in which CEPT is used at the highlighted waste streams shown in Figure 6-6. These predictions are compared to the situation in which CEPT is not used to determine the level of reduction expected in the reservoir due to CEPT use on the waste streams discharging from Alfenas. The expected reductions are 60% for BOD, 90% for phosphorus, and a 10^4 to 10^5 reduction in fecal coliform if CEPT is followed by chemical disinfection.

Table 6-7: Volumes of Well-Mixed Section of Reservoir for Various Years

Year	Volume (Liters)
High volume (1996)	112.5 billion
Low volume (2001)	11.25 billion[a]
January 2002	36 billion[b]

[a] Estimate based on reservoir losing 8 meters of height between 1996 and 2001
[b] Based on reservoir gaining 5 meters (Furnas Lake Users Association, 2002)

The results for BOD, fecal coliform, DO, and phosphorus are shown in Table 6-8 through Table 6-11.

Table 6-8: Average Reservoir BOD Concentrations, CEPT at 3 Streams

BOD (mg/L)			
Year	Without CEPT	With CEPT	Percent Reduction
High Volume (1996)	0.6	0.5	17%
Low Volume (2001)	2.1	1.9	10%
January 2002	1.8	1.7	9%

Table 6-9: Average Reservoir Fecal Coliform Concentrations, CEPT at 3 Streams

Fecal Coliform (MPN/100 ml)			
Year	Without CEPT	With CEPT	Percent Reduction
High Volume (1996)	159	81	49%
Low Volume (2001)	1762	896	49%
January 2002	568	285	50%

Table 6-10: Average Reservoir Phosphorus Concentrations, CEPT at 3 Streams

Phosphorus (mg/L)			
Year	Without CEPT	With CEPT	Percent Reduction
High Volume (1996)	0.021	0.011	45%
Low Volume (2001)	0.024	0.014	45%
January 2002	0.024	0.014	45%

Table 6-11: Average Reservoir DO Concentrations, CEPT at 3 Streams

DO (mg/L)			
Year	Without CEPT	With CEPT	Percent Improvement
High Volume (1996)	7.41	7.45	0.6%
Low Volume (2001)	6.73	6.75	0.3%
January 2002	5.88	5.92	0.7%

6.5 CEPT Implementation at 6 Streams
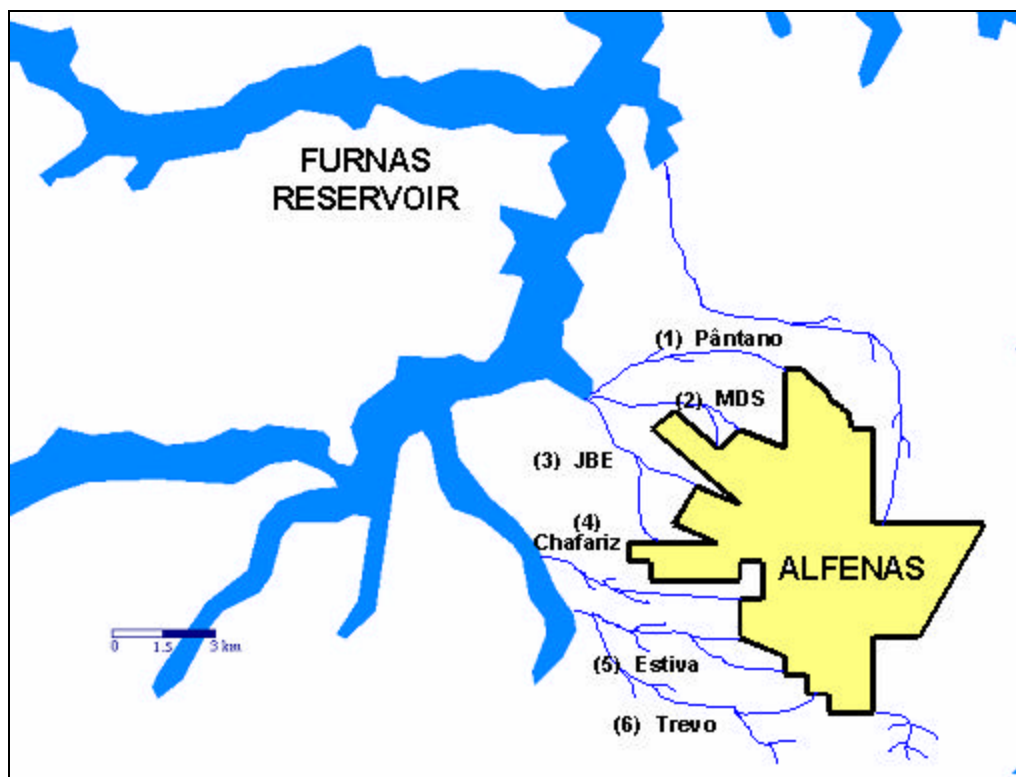
Figure 6-7: CEPT use at 6 waste streams

CEPT becomes somewhat more effective in reducing bacterial and nutrient concentrations if used at more than three waste streams. It can also be more effective in raising DO concentrations in the reservoir. The concentration predictions for expanding CEPT use to a total of 6 wastewater streams are listed below. The streams include Trevo, Estiva, and Chafariz, as well as JBE, MDS, and Pântano, all of which are shown in Figure 6-7. In obtaining the average concentrations in the reservoir, the reductions discussed previously for BOD, phosphorus, and fecal coliform are applied to all six streams, instead of three. The same assumptions and calculations for 3 streams are used for predicting the concentrations for 6 streams. The estimates for C_{in} are in Table 6-12 through Table 6-15. The results for BOD, fecal coliform, DO, and phosphorus are shown in Table 6-16 through Table 6-19. Table 6-16 through Table 6-19 show the predicted average reservoir concentrations with and without CEPT usage.

Table 6-12: BOD Concentrations for C$_{in}$ Considering CEPT at 6 Streams

BOD (mg/L)			
Year	C$_A$	C$_B$	C$_{in}$
High Volume (1996)	0.9[a]	3.1	1.1
Low Volume (2001)	1.6 [a]	3.4	1.8
January 2002	1.8 [a]	4.4	2.1

[a] Source: University of Alfenas, Projecto Furnas I, II, and III

Table 6-13: Coliform Concentrations for C$_{in}$ Considering CEPT at 6 Streams

Fecal Coliform (MPN/100 ml)			
Year	C$_A$	C$_B$	C$_{in}$
High Volume (1996)	356 [a]	115	332
Low Volume (2001)	510 [a]	26	462
January 2002	81 [a]	28	76

[a] Source: University of Alfenas, Projecto Furnas I, II, and III

Table 6-14: Phosphorus Concentrations for C$_{in}$ Considering CEPT at 6 Streams

Phosphorus (mg/L)			
Year	C$_A$	C$_B$	C$_{in}$
High Volume (1996)	0	0.011	0.001
Low Volume (2001)	0	0.012	0.0012
January 2002	0	0.012	0.0012

Table 6-15: DO Concentrations for C$_{in}$ Considering CEPT at 6 Streams

DO (mg/L)			
Year	C$_A$	C$_B$	C$_{in}$
High Volume (1996)	7.1 [a]	7.4	7.1
Low Volume (2001)	5.7 [a]	7.2	5.8
January 2002	4.6 [a]	6.6	4.7

Source: University of Alfenas, Projecto Furnas I, II, and III

Table 6-16: Average Reservoir BOD Concentrations, CEPT at 6 Streams

BOD (mg/L)			
Year	Without CEPT	With CEPT	Percent Reduction
High Volume (1996)	0.60	0.43	28%
Low Volume (2001)	2.13	1.65	23%
January 2002	1.83	1.40	24%

Table 6-17: Average Reservoir Fecal Coliform Concentrations, CEPT at 6 Streams

Fecal Coliform (MPN/100 ml)			
Year	Without CEPT	With CEPT	Percent Reduction
High Volume (1996)	159	2	98.5%
Low Volume (2001)	1762	31	98.3%
January 2002	568	2	99.7%

Table 6-18: Average Reservoir Phosphorus Concentrations, CEPT at 6 Streams

Phosphorus (mg/L)			
Year	Without CEPT	With CEPT	Percent Reduction
High Volume (1996)	0.021	0.0021	90%
Low Volume (2001)	0.024	0.0024	90%
January 2002	0.024	0.0024	90%

Table 6-19: Average Reservoir DO Concentrations, CEPT at 6 Streams

DO (mg/L)			
Year	Without CEPT	With CEPT	Percent Improvement
High Volume (1996)	7.41	7.50	1.2%
Low Volume (2001)	6.77	6.77	0.6%
January 2002	5.88	5.99	1.8%

7 DISCUSSION OF RESULTS

The results show that CEPT use at Alfenas results in reductions in BOD, fecal coliform, and phosphorus. It can also potentially increase DO concentrations in the reservoir. Reductions in nitrate and ammonia in the reservoir are not considered in this study, although these concentrations were measured in the water body. Fecal coliform concentration reductions will be achieved if CEPT is followed by chemical disinfection. Chemical disinfection would also kill other bacteria and pathogens as well.

BOD levels can be reduced by 17% at high water volume (1996) and 10% at low water volume (2001) in the reservoir for CEPT use at three streams. Fecal coliform concentrations can be reduced by 49% if CEPT is used at three streams for high and low water volume. Phosphorus concentrations can be reduced by 45% at high and low water volume also for CEPT use at three waste streams. Dissolved oxygen concentrations are predicted to increase from 0.3% at low volume to 0.6% at high volume 25% through CEPT use. Thus, it appears that significant reductions, especially for BOD and DO concentrations, can be attained at higher reservoir volumes. Reductions in all contaminant concentrations at higher water volume are due to the higher flows in the reservoir in 1996 than in 2001.

CEPT will to be more effective in reducing bacterial and nutrient concentrations if it is used at six waste streams. CEPT use can reduce BOD concentrations by 28% at high water volume and 23% at low water volume in the reservoir. It also increases DO concentrations by 1.2% at high water volume and 0.6% at low water volume. Reductions in phosphorus and fecal coliform concentrations are 90% and 98%, respectively, at low and high volumes. These reductions appear likely due to increased flows in the reservoir in 1996 than in 2001. As expected, CEPT is twice as effective at six waste streams than if it were used at only three waste streams.

8   CONCLUSIONS & RECOMMENDATIONS

The purpose of predicting the concentrations for CEPT use at three and six streams is to show the level of improvement expected in the Furnas Reservoir due to the use of CEPT. It is twice as effective at six streams as at three streams. Thus, by this reasoning, use of this technology at one stream would result in reductions that are a sixth of the reductions at sixth streams. However, the decision to use CEPT and the number of plants to be installed will ultimately depend on the decision-making authorities in Alfenas and on available funds for financing such a project.

CEPT implementation at six wastewater streams (Trevo, Estiva, Chafariz, JBE, MDS, and Pântano) would result in higher reductions of fecal coliform, BOD, and phosphorus concentrations discharged to the reservoir. This would lead to better water quality in the reservoir. However, these results apply only to the well-mixed section of the reservoir studied for this project. Concentration variations downstream of the control volume or for other cities in the region are not considered.

CEPT is more effective and efficient in reducing BOD concentrations in the reservoir at higher water volumes in the water body, due to increased water flow. Since reductions in BOD concentrations can lead to increases in DO concentrations in the reservoir, the improvement or increase in the DO concentrations were predicted. CEPT can increase DO concentrations from 0.6% to 1.2%. The greatest improvements in DO concentrations are likely to occur at higher water volumes. This improvement does not appear to be significant in the short-term, but may be in the long-term.

CEPT will improve the water quality in the reservoir. CEPT should be followed by chemical disinfection of the effluent to reduce fecal coliform concentrations. Based on the results of this study, CEPT is recommended for treating wastewater at Alfenas. CEPT technology is a viable option for reducing contaminant concentrations in reservoir for Alfenas, as well as for any city along the Furnas Reservoir to sustain good water quality in the water body.

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Appendices

Appendix A – Depth Profiles

A.1   January 17, 2002 Depth Profiles

Figure A-1: Temperature and DO Concentration Profiles within Reservoir

DO (mg/L), Temperature (°C)
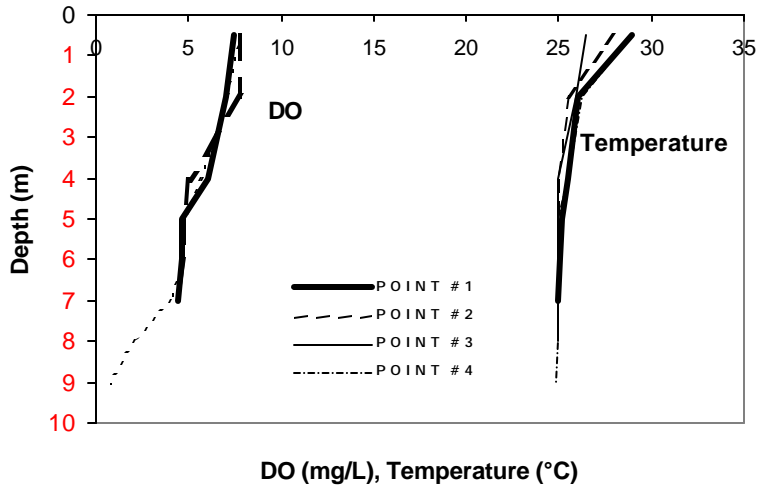
Figure A-2: Concentration Profiles for % Saturation of DO Concentrations

DO/Dosat*100%
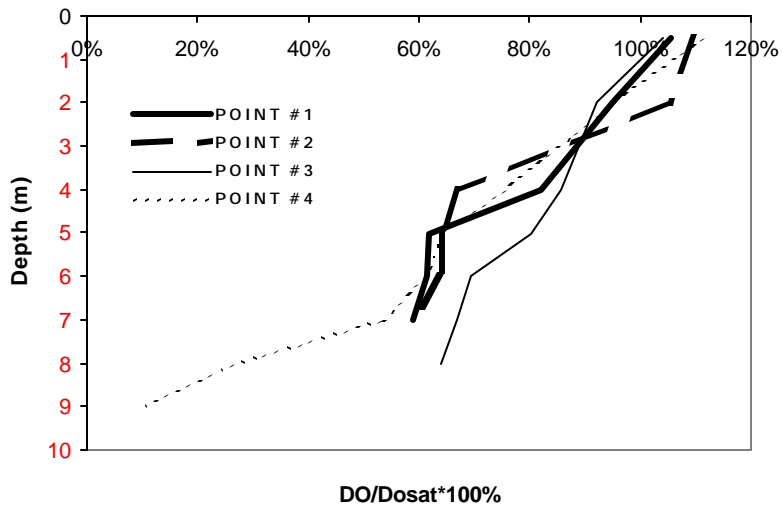
A.2   January 18, 2002 Depth Profiles

Figure A-3: Temperature and DO Concentration Profiles

DO (mg/L), Temperature (°C)
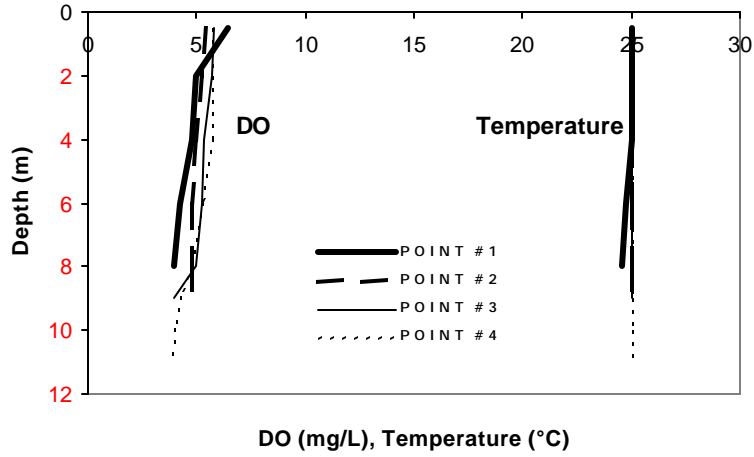
Figure A-4: Concentration Profiles for % Saturation of DO Concentrations

DO/Dosat *100%

73
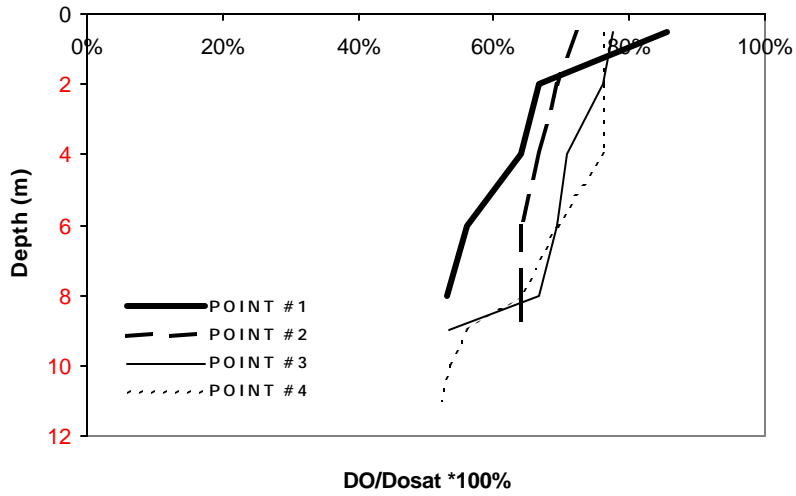
A.3 January 21, 2002 Depth Profiles

Figure A-5: Temperature and DO Concentration Profiles
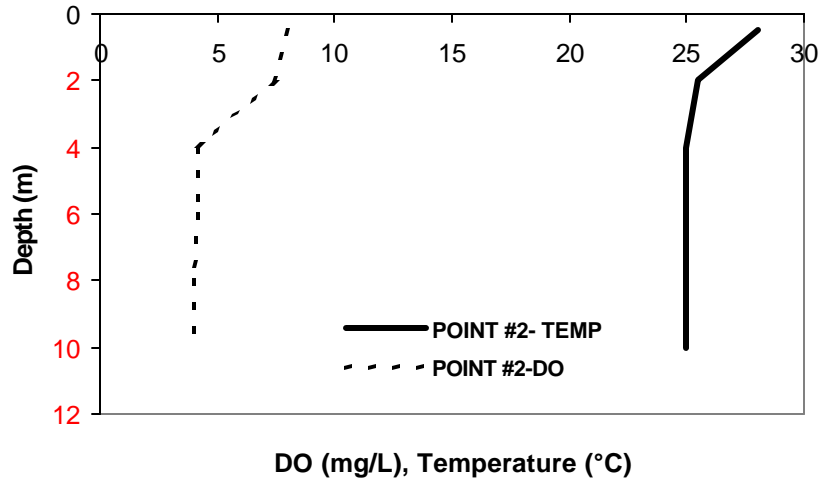
Figure A-6: Concentration Profiles for % Saturation of DO Concentrations
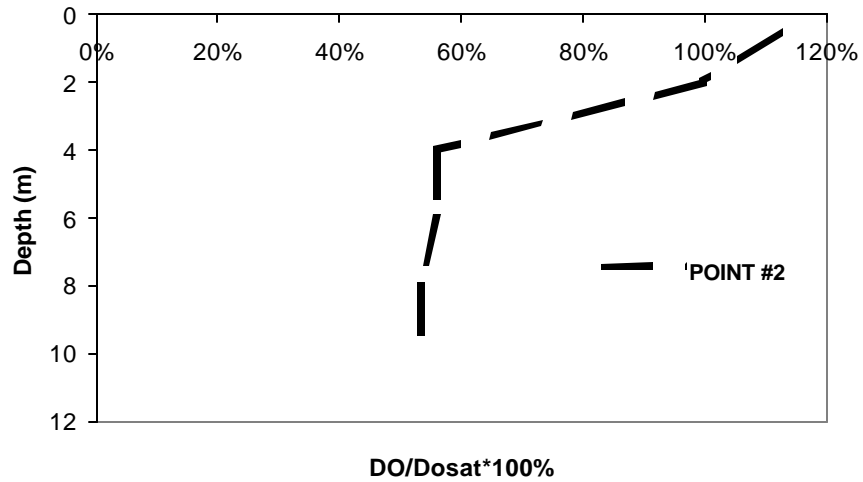
A.4 January 24, 2002 Depth Profiles

Figure A-7: Temperature and DO Concentration Profiles
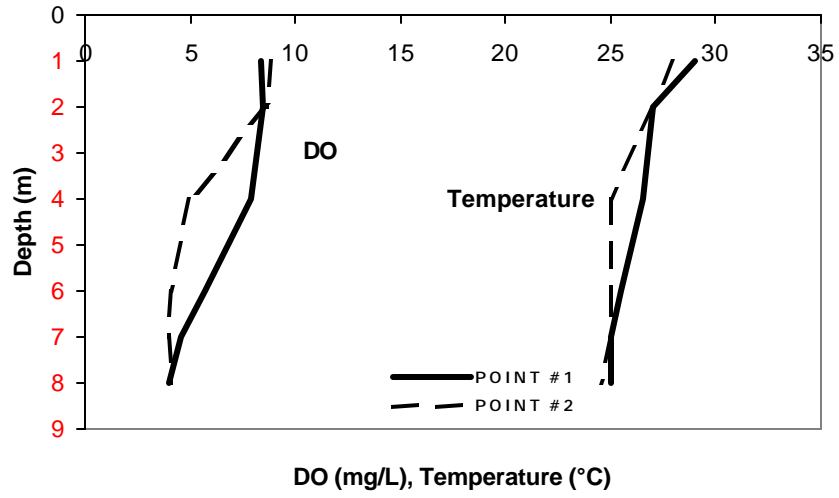
Figure A-8: pH Profiles versus Depth
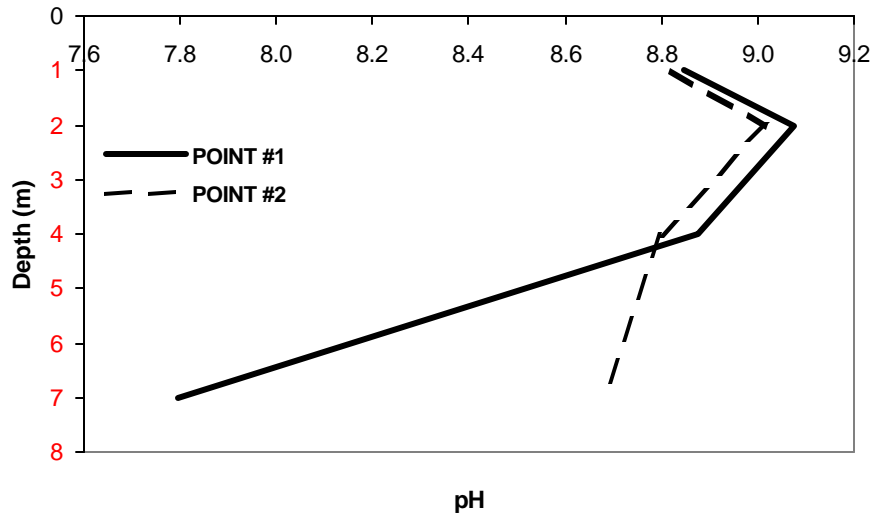
Figure A-9: Concentration Profiles for % Saturation of DO Concentrations
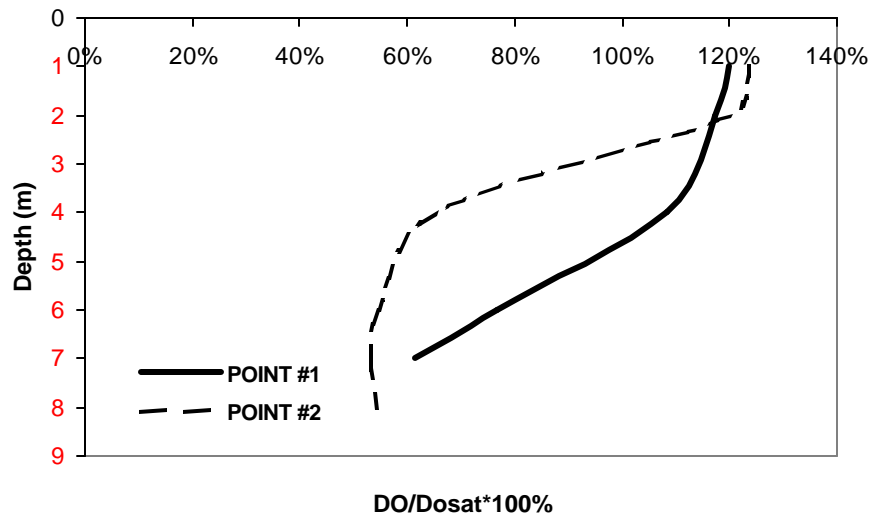
Appendix B – Field Measurements

B.1 January 17, 2002 Field Measurements

Table B-1: Sampling Point Coordinates for January 17, 2002

CODE	Sample #	Depth (m)	Elevation	Latitude, S	Longitude, W	Sampling Time
1-0117	1	7	756	21°23.213'	46°00.937'	3:00 PM
2-0117	2	7	767	21°22.819'	46°00.532'	3:15 PM
3-0117	3	8	767	21°21.730'	46°00.184'	3:30 PM
4-0117	4	9	767	21°20.786'	45°59.940'	4:00 PM
P3-0117	Stream	Pedra Branca	781	21°21.531'	45°57.472'	9:30 AM
P4-0117	Stream	JBE	768	21°23.924'	45°58.900'	10:30 AM

Table B-2: Nutrient and pH Measurements for January 17, 2002

CODE	Sample #	Sample Location	Rep #	Ammonia N (mg/L Nitrogen)	Orthophosphate (mg/L Phosphate)	Orthophosphate (mg/L Phosphorus)	Nitrate (mg/L Nitrate)	pH
1-0117-1	1	Reservoir	1	<0.1	0.02	0.007	ND	7.47
1-0117-2	1	Reservoir	2	--	0.02	0.007	--	--
2-0117-1	2	Reservoir	1	<0.1	0.02	0.007	ND	8.16
2-0117-2	2	Reservoir	2	--	0.02	0.007	--	--
3-0117-1	3	Reservoir	1	<0.1	0.03	0.010	ND	7.64
3-0117-2	3	Reservoir	2	--	0.02	0.007	--	--
4-0117-1	4	Reservoir	1	<0.1	0.02	0.007	ND	7.7
4-0117-2	4	Reservoir	2	--	0.03	0.010	--	--
P3-0117-1	Stream	Pedra Branca	1	1.2	0.16	0.053	0.001	--
P3-0117-2	Stream	Pedra Branca	2	1.4	0.22	0.073	--	--
P4-0117-1	Stream	JBE	1	2.45	0.2	0.067	0.001	7.68
P4-0117-2	Stream	JBE	2	2.5	0.18	0.060	--	--

Table B-3: Total and Fecal Coliforms and COD for January 17, 2002

CODE	Sample #	Sample Location	Repetition #	MPN Total Coliform/100ml	MPN Fecal Coliform/100ml	COD (mg/L)
1-0117-1	1	Reservoir	1	--	--	23.3
1-0117-2	1	Reservoir	2	--	--	--
2-0117-1	2	Reservoir	1	--	--	15.5
2-0117-2	2	Reservoir	2	--	--	--
3-0117-1	3	Reservoir	1	--	--	25.8
3-0117-2	3	Reservoir	2	--	--	--
4-0117-1	4	Reservoir	1	790	170	21.6
4-0117-2	4	Reservoir	2	--	--	--
P3-0117-1	Waste stream	Pedra Branca	1	920000	17000	12.2
P3-0117-2	Waste stream	Pedra Branca	2	--	--	--
P4-0117-1	Waste stream	JBE	1	35000000	2200000	37.8
P4-0117-2	Waste stream	JBE	2	--	--	--

Table B-4: DO and Temperature Measurements in the Reservoir

Depth (m)	Sample 1 7 meters deep DO (mg/L)	Temperature (°C)	Sample 2 7 meters deep DO (mg/L)	Temperature (°C)	Sample 3 8 meters deep DO (mg/L)	Temperature (°C)	Sample 4 9 meters deep DO (mg/L)	Temperature (°C)
0.5	7.4	29	7.8	28	7.6	26.5	7.8	29
2	7	26	7.8	25.5	6.8	25.9	7	26.2
4	6.1	25.5	5	25	6.4	25	5.6	25.5
5	4.6	25.2	4.8	25	6	25	4.8	25
6	4.6	25.1	4.8	25	5.2	25	4.6	25
7	4.4	25	4.4	25	5	25	4	25
8	--	--	--	--	4.8	25	2	25
9	--	--	--	--	--	--	0.8	24.8

B.2 January 18, 2002 Field Measurements

Table B-5: Sampling Point Coordinates for January 18, 2002

CODE	Sample #	Depth (m)	Elevation	Latitude, S	Longitude, W	Sampling Time
1-0117	1	8	764	21°22.912'	46°00.937'	9:00 AM
2-0117	2	9	765	21°21.816'	46°00.532'	9:15 AM
3-0117	3	10	768	21°21.506'	46°00.184'	9:30 AM
4-0117	4	11	764	21°18.593'	45°59.940'	9:45 AM
P3-0117	Stream	Pedra Branca	781	21°21.531'	45°57.472'	2:00 PM
P4-0117	Stream	JBE	768	21°23.924'	45°58.900'	3:45 PM

Table B-6: Nutrient and pH Measurements for January 18, 2002

CODE	Sample #	Sampling Location	Repetition #	Ammonia N (mg/L Nitrogen)	Orthophosphate (mg/L Phosphate)	Ortho-phosphate (mg/L Phosphorus)	Nitrate (mg/L Nitrate)	pH
1-0118-1	1	Reservoir	1	<0.1	0.27	0.090	ND	7.39
1-0118-2	1	Reservoir	2	--	0.10	0.033	--	--
2-0118-1	2	Reservoir	1	<0.1	0.03	0.010	ND	7.57
2-0118-2	2	Reservoir	2	--	0.02	0.007	--	--
3-0118-1	3	Reservoir	1	<0.1	0.02	0.007	ND	7.51
3-0118-2	3	Reservoir	2	--	0.03	0.010	--	--
4-0118-1	4	Reservoir	1	<0.1	0.04	0.013	ND	7.79
4-0118-2	4	Reservoir	2	--	0.02	0.007	--	--
P3-0118-1	Stream	Pedra Branca	1	1.2	0.08	0.027	0.001	7.54
P3-0118-2	Stream	Pedra Branca	2	1.4	0.04	0.013	0.001	--
P4-0118-1	Stream	JBE	1	2.45	0.17	0.057	0.002	7.54
P4-0118-2	Stream	JBE	2	2.5	0.50	0.167	0.002	--

Table B-7: Total and Fecal Coliforms and COD for January 18, 2002

CODE	Sample #	Repetition #	MPN Total Coliform/100 ml	MPN Fecal Coliform/100 ml	COD (mg/L)
1-0118-1	1	1	--	--	23.10
1-0118-2	1	2	--	--	--
2-0118-1	2	1	--	--	7.80
2-0118-2	2	2	--	--	--
3-0118-1	3	1	--	--	22.70
3-0118-2	3	2	--	--	--
4-0118-1	4	1	2000	1200	23.70
4-0118-2	4	2	--	--	--
P3-0118-1	Pedra Branca	1	1.10E+06	2.20E+05	54.40
P3-0118-2	Pedra Branca	2	--	--	--
P4-0118-1	JBE	1	2.40E+08	1.60E+08	148.40
P4-0118-2	JBE	2	--	--	--

Table B-8: DO and Temperature Measurements in the Reservoir for January 18, 2002

	Sample 1		Sample 2		Sample 3		Sample 4	
	8 meters deep		9 meters deep		10 meters deep		11 meters deep	
Depth (m)	DO (mg/L)	Temperature (°C)	DO (mg/L)	Temperature (°C)	DO (mg/L)	Temperature (°C)	DO (mg/L)	Temperature (°C)
0.5	6.4	25	5.4	25	5.8	25	5.7	25
2	5	25	5.2	25	5.7	25	5.7	25
4	4.8	25	5	25	5.3	25	5.7	25
6	4.2	24.8	4.8	25	5.2	25	5.2	25
8	4	24.6	4.8	25	5	25	4.8	25
9	--	--	4.8	25	4	25	4.2	25
10	--	--	--	--	--	--	4	25
11	--	--	--	--	--	--	3.9	25

B.3   January 21, 2002 Field Measurements

Table B-9: Sampling Point Coordinates for January 21, 2002

CODE	Sample #	Depth (m)	Elevation	Latitude, S	Longitude, W	Sampling Time
1-0121	1	8	767	21°23.051'	46°00.163'	2:00 PM
2-0121	2	9	765	21°21.716'	46°00.651'	2:15 PM
3-0121	3	10	768	21°19.506'	45°59.508'	2:30 PM
4-0121	4	11	770	21°18.115'	45°58.946'	2:45 PM
5-0121	5	farm	775	21°22.687'	46°00.103'	3:00 PM
6-0121	6	farm	767	21°23.589'	46°00.892'	3:15 PM
7-0121	7	farm	764	21°23.729'	46°01.133'	3:30 PM
WB1	at 8 m	11	765	21°21.716'	46°00.651'	3:45 PM
WB2	at 7 m	10	768	21°19.506'	45°59.508'	4:00 PM
WB3	at 7 m	12	770	21°18.115'	45°58.946'	4:15 PM
P3-0117	Pedra Branca	Waste stream	781	21°21.531'	45°57.472'	9:30 AM
P4-0117	JBE	Waste stream	768	21°23.924'	45°58.900'	10:00 AM

Table B-10: Total and Fecal Coliforms and COD for January 21, 2002

CODE	Sample #	MPN Total Coliform/100 ml	MPN Fecal Coliform/100 ml	COD (mg/L)
1-0121-1	1	--	--	36.50
2-0121-1	2	--	--	21.90
3-0121-1	3	--	--	125.30
4-0121-1	4	1800	93	101.10
5-0121-1	5	3500	700	39.50
6-0121-1	6	--	--	88.10
7-0121-1	7	16000	460	33.40
WB1-0121-1	8/11 m	--	--	78.30
WB2-0121-1	7/10 m	--	--	78.40
WB3-0121-1	7/12 m	700	45	30.90
P3-0121-1	Pedra Branca	700000	2000	11.80
P4-0121-1	JBE	7900000	450000	36.50

Table B-11: Nutrient Concentrations and pH Measurements for January 21, 2002

CODE	Sample #	Repetition #	Ammonia N (mg/L Nitrogen)	Orthophosphate (mg/L Phosphate)	Orthophosphate (mg/L Phosphorus)	Nitrate (mg/L Nitrate)	pH
1-0121-1	1	1	<0.1	0.08	0.027	ND	9.19
1-0121-2	1	2	--	0.05	0.017	--	--
2-0121-1	2	1	<0.1	0.06	0.020	ND	9.29
2-0121-2	2	2	--	0.05	0.017	--	--
3-0121-1	3	1	<0.1	0.04	0.013	ND	9.31
3-0121-2	3	2	--	0.05	0.017	--	--
4-0121-1	4	1	<0.1	0.08	0.027	ND	9.23
4-0121-2	4	2	--	0.06	0.020	--	--
5-0121-1	5	1	<0.1	0.04	0.013	ND	9.3
5-0121-2	5	2	--	0.03	0.010	--	--
6-0121-1	6	1	<0.1	0.04	0.013	ND	9.23
6-0121-2	6	2		0.04	0.013	--	--
7-0121-1	7	1	<0.1	0.06	0.020	ND	8.83
7-0121-2	7	2	--	0.04	0.013	--	--
WB1-0121-1	8/11 m	1	<0.1	0.04	0.013	ND	8.96
WB1-0121-2	8/11 m	2	--	--	--	--	--
WB2-0121-1	7/10 m	1	<0.1	0.02	0.007	ND	9.11
WB2-0121-2	7/10 m	2	--	0.04	0.013	--	--
WB3-0121-1	7/12 m	1	<0.1	0.04	0.013	ND	9.17
WB3-0121-2	7/12 m	2	--	0.03	0.010	--	--
P3-0121-1	Pedra Banca	1	2.2	0.24	0.080	ND	6.96
P3-0121-2	Pedra Banca	2	2.5	0.22	0.073	--	--
P4-0121-1	JBE	1	2.5	0.46	0.153	ND	7.05
P4-0121-2	JBE	2	2.5	0.42	0.140	--	--

Table B-12: DO and Temperature Measurements at Point 2 in the Reservoir for January 21, 2002

Depth (m)	Sample 2	
	11 meters deep	
Depth (m)	DO (mg/L)	Temperature (°C)
0.5	8	28
2	7.4	25.5
4	4.2	25
6	4.2	25
8	4	25
10	4	25

B.4   January 24, 2002 Field Measurements

Table B-13: Sampling Point Coordinates for January 24, 2002

CODE	Elevation	Latitude, S	Longitude, W
P1-0124	757	21°22.715'	46°00.409'
P2-0124	751	21°22.021'	46°00.320'

Table B-14: DO, Temperature and pH Measurements for January 24, 2002

Depth (m)	Point 1			Point 2		
	DO (mg/L)	Temperature (°C)	Average pH	DO (mg/L)	Temperature (°C)	Average pH
1	8.4	29	8.84	8.8	28	8.82
2	8.5	27	9.08	8.7	27	9.02
4	7.9	26.5	8.88	4.9	25	8.80
6	5.7	25.5	--	4.1	25	--
7	4.6	25	7.79	4	25	8.68
8	4	25	--	4.1	24.5	--

Appendix C – Dissolved Oxygen Saturation Concentrations

C.1 January 17, 2002

Table C-1: Dissolved Oxygen at Saturation, Sample Points 1 & 2, January 17, 2002

Depth (m)	Sample Point 1 7 meters deep				Sample Point 2 7 meters deep			
	DO (mg/L)	DO$_{sat}$ (mg/L)	Temperature (°C)	DO/DO$_{sat}$	DO (mg/L)	DO$_{sat}$ (mg/L)	Temperature (°C)	DO/DO$_{sat}$
0.5	7.4	7.0	29.0	105.5%	7.8	7.1	28.0	109.4%
2	7.0	7.4	26.0	95.1%	7.8	7.4	25.5	105.1%
4	6.1	7.4	25.5	82.2%	5.0	7.5	25.0	66.8%
5	4.6	7.5	25.2	61.7%	4.8	7.5	25.0	64.1%
6	4.6	7.5	25.1	61.5%	4.8	7.5	25.0	64.1%
7	4.4	7.5	25.0	58.8%	4.4	7.5	25.0	58.8%
8	--	--	--	--	--	--	--	--
9	--	--	--	--	--	--	--	--

Table C-2: Dissolved Oxygen at Saturation, Sample Points 3 & 4, January 17, 2002

Depth (m)	Sample Point 3 8 meters deep				Sample Point 4 9 meters deep			
	DO (mg/L)	DO$_{sat}$ (mg/L)	Temperature (°C)	DO/DO$_{sat}$	DO (mg/L)	DO$_{sat}$ (mg/L)	Temperature (°C)	DO/DO$_{sat}$
0.5	7.6	7.3	26.5	104.1%	7.8	7.0	29.0	111.2%
2	6.8	7.4	25.9	92.2%	7.0	7.3	26.2	95.4%
4	6.4	7.5	25.0	85.5%	5.6	7.4	25.5	75.4%
5	6.0	7.5	25.0	80.1%	4.8	7.5	25.0	64.1%
6	5.2	7.5	25.0	69.5%	4.6	7.5	25.0	61.4%
7	5.0	7.5	25.0	66.8%	4.0	7.5	25.0	53.4%
8	4.8	7.5	25.0	64.1%	2.0	7.5	25.0	26.7%
9	--	--	--	--	0.8	7.5	24.8	10.6%

C.2 January 18, 2002

Table C-3: Dissolved Oxygen at Saturation, Sample Points 1 & 2, January 18, 2002

| Depth (m) | Sample Point 1 | | | | Sample Point 2 | | | |
| | 8 meters deep | | | | 9 meters deep | | | |
	DO (mg/L)	DO_{sat} (mg/L)	Temperature (°C)	DO/DO_{sat}	DO (mg/L)	DO_{sat} (mg/L)	Temperature (°C)	DO/DO_{sat}
0.5	6.4	7.5	25.0	85.5%	5.4	7.5	25.0	72.1%
2	5.0	7.5	25.0	66.8%	5.2	7.5	25.0	69.5%
4	4.8	7.5	25.0	64.1%	5.0	7.5	25.0	66.8%
6	4.2	7.5	24.8	55.9%	4.8	7.5	25.0	64.1%
8	4.0	7.5	24.6	53.1%	4.8	7.5	25.0	64.1%
9	--	--	--	--	4.8	7.5	25.0	64.1%
10	--	--	--	--	--	--	--	--
11	--	--	--	--	--	--	--	--

Table C-4: Dissolved Oxygen at Saturation, Sample Points 3 & 4, January 18, 2002

| Depth (m) | Sample 3 | | | | Sample 4 | | | |
| | 10 meters deep | | | | 11 meters deep | | | |
	DO (mg/L)	DO_{sat} (mg/L)	Temperature (°C)	DO/DO_{sat}	DO (mg/L)	DO_{sat} (mg/L)	Temperature (°C)	DO/DO_{sat}
0.5	5.8	7.5	25.0	77.5%	5.7	7.5	25.0	76.1%
2	5.7	7.5	25.0	76.1%	5.7	7.5	25.0	76.1%
4	5.3	7.5	25.0	70.8%	5.7	7.5	25.0	76.1%
6	5.2	7.5	25.0	69.5%	5.2	7.5	25.0	69.5%
8	5.0	7.5	25.0	66.8%	4.8	7.5	25.0	64.1%
9	4.0	7.5	25.0	53.4%	4.2	7.5	25.0	56.1%
10	--	--	--	--	4.0	7.5	25.0	53.4%
11	--	--	--	--	3.9	7.5	25.0	52.1%

C.3 January 21, 2002

Table C-5: Dissolved Oxygen at Saturation, Sample Point 2, January 21, 2002

Depth (m)	DO (mg/L)	DO_sat (mg/L)	Temperature (°C)	DO/DO_sat
	Sample 2			
	8 meters deep			
0.5	8	7.1	28	112.3%
2	7.4	7.4	25.5	99.7%
4	4.2	7.5	25	56.1%
6	4.2	7.5	25	56.1%
8	4	7.5	25	53.4%
10	4	7.5	25	53.4%

C.4 January 24, 2002

Table C-6: Dissolved Oxygen at Saturation, Sample Points 1& 2, January 24, 2002

Depth (m)	DO (mg/L)	DO_sat (mg/L)	Temperature (°C)	DO/DO_sat	DO (mg/L)	DO_sat (mg/L)	Temperature (°C)	DO/DO_sat
	Sample 1				**Sample 2**			
1	8.4	7.0	29.0	119.7%	8.8	7.1	28.0	123.5%
2	8.5	7.2	27.0	117.4%	8.7	7.2	27.0	120.1%
4	7.9	7.3	26.5	108.2%	4.9	7.5	25.0	65.4%
6	5.7	7.4	25.5	76.8%	4.1	7.5	25.0	54.8%
7	4.6	7.5	25.0	61.4%	4.0	7.5	25.0	53.4%
8	4.0	7.5	25.0	53.4%	4.1	7.6	24.5	54.3%