Full Scale Study of Chemically Enhanced Primary Treatment in Riviera de Sao Lourenco, Brazil

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Abstract

Effective, low-cost wastewater treatment that permits removal of pollutants and the deactivation of pathogens is essential to protect public health. An emerging technology that has been proposed to accomplish this goal, is Chemically Enhanced Primary Treatment, or CEPT. CEPT vastly improves the effectiveness of an existing wastewater treatment facility, enabling the plant to not only meet increasing flow demands, but to attain higher removal efficiencies at the same time. Similarly, in the case of a new treatment facility, it can be designed to treat larger amounts of flow, and/or the designed size can be decreased by as much as half, and still meet expected capacity.

The governing principle behind CEPT is the enhancement of the primary settling process through the addition of low dosages of metal salts and extremely small amounts of an anionic polymer. These additions cause the particulate matter in the wastewater to coagulate and flocculate, thus creating larger particles, which in turn settle at a much faster rate.

This thesis looks at the different forms by which CEPT can be implemented in wastewater lagoon systems, namely “pre-pond” and “in-pond” CEPT. While there is discussion of numerous CEPT plants, special attention is paid to the full-scale study and analysis of the CEPT upgrade at Riviera de Sao Lourenco, Brazil. This plant conducted full-scale tests of both “pre-pond” and “in-pond” CEPT. This thesis compares the advantages and disadvantages of “pre-pond” and “in-pond” CEPT, along with the effectiveness of each.

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CHAPTER 1 - INTRODUCTION

This thesis, and the project it is based upon, revolves around the optimization of a wastewater treatment plant at Riviera de Sao Lourenco, Brazil that has been upgraded to use a technology referred to as Chemically Enhanced Primary Treatment, or CEPT. The project and accompanying trip to Riviera was part of the Master of Engineering (M.Eng.) Program in Civil and Environmental Engineering at the Massachusetts Institute of Technology (MIT). The project included four MIT M.Eng. students, Dr. Donald Harleman, Ford Professor Emeritus at MIT, and Susan Murcott, a Lecturer at MIT. The overall project entails four distinct research topics: a bench-scale analysis of CEPT, a full-scale analysis of CEPT, a biosolids management study, and a data management and modeling study. This thesis will focus on the full-scale analysis of CEPT, primarily as it pertains to Riviera.

CEPT is a technology that has been promoted and advanced largely through research conducted at MIT in an effort to develop and improve an innovative and low-cost municipal wastewater treatment technology. The general concept behind the CEPT technology is that it is a method to increase the rate and efficiency of gravitational settling. This is accomplished through the addition of low doses of metal salts, generally iron or aluminum salts, as coagulants. These coagulants have a high positive charge that neutralizes the wastewater particles, which naturally are negatively charged. This results in the formation of large flocs that settle much faster. Additionally, the subsequent addition of an anionic polymer is commonly used to cause the particulate matter and precipitates to form even larger flocs, increasing the settling rate further. As a result of this faster settling rate, the residence time for a primary treatment system is reduced, which translates into the ability to treat a higher volume of wastewater. Alternatively, in the context of a new plant, it can be designed with about half the number of settling tanks and still treat the design flow. Using CEPT technology not only improves the capacity of a wastewater treatment system, but it also dramatically improves removal efficiencies, as shown in Table 1. Pollutant removal improvements are shown for all major liquid wastewater treatment system parameters: Biological and Chemical Oxygen Demand (BOD & COD), Total Suspended Solids (TSS), and Phosphorus.[1]

Table 1: Removal Efficiencies of CEPT compared to Traditional Primary Treatment

% Removals	**CEPT**	**Conventional Primary**
Total Suspended Solids (TSS)	75 - 85 %	60 %
Biochemical Oxygen Demand (BOD_5)	55 – 65 %	30 %
Phosphorus (P)	55 - 85 %	30 %
Nitrogen (N)	30 %	30 %

Riviera, faced with an overloaded wastewater treatment system, upgraded the system to utilize CEPT. While CEPT can be implemented in several forms, the most common is to construct a CEPT clarifier at the front end of the treatment train; assuming that there is not a settling tank already there. In that instance, where a primary settling tank already exists, it can simply be modified to use CEPT. This option is referred to as "pre-pond" CEPT. Riviera upgraded their system by constructing a clarifier at the front end. However, due to circumstances to be described later, during the summer of 2000, the system was run according to the process CEPT known as "in-pond" CEPT, in which the chemical addition is made to the waste stream, and the wastewater is directed into a biological lagoon system instead of a constructed clarifier.

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[1] Murcott, S., Harleman, D. "Chemically Enhanced Primary Treatment." Draft Manuscript. Massachusetts Institute of Technology, 2000.

The following chapters will cover these various implementation alternatives for the utilization of CEPT. Chapter 2 will discuss the governing principles of coagulation and flocculation, which are the ‘enhancing’ part of the CEPT process. Chapter 3 will discuss the methods used to measure and quantify wastewater quality. Chapter 4 will discuss the background and development of CEPT, including several case studies of other CEPT plants. Chapter 5 provides an in-depth look at the treatment plant at Riviera de Sao Lourenco, Brazil, with a particular focus on the January 2000 field study conducted by the MIT M.Eng. group. Finally, Chapter 6 concludes with a comparison of the different implementations of CEPT, both at Riviera and around the world.

CHAPTER 2 - COAGULATION AND FLOCCULATION

2.1 Overview of Chemical Treatment Mechanisms

The Chemically Enhanced Primary Treatment process is one in which chemicals and/or polymers are added to the waste stream to enhance settling. This process includes coagulation, flocculation, and sedimentation, which can be described as the formation of larger particles, or flocs, from the small particles in the wastewater. These larger conglomerates enhance the sedimentation process since larger particles settle much faster. This phenomenon is explained by Stokes Law of Settling, which states that the settling velocity is proportional to the square of the diameter of the particle. More specifically, Stokes Law is written:[2]

$$V_c = g(\rho_s - \rho)\, d^2 / 18\mu$$

Where:

Vc = Terminal Velocity of Particle

g = Acceleration due to gravity

ρ_s = Density of the particle

ρ = Density of fluid

d = Diameter of particle

μ = Dynamic viscosity

Adding to the effect of Stokes Law, is the fact that when these larger particles settle, they also carry with them the smaller particles they collide with on the way to the bottom.[3]

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[2] Metcalf & Eddy, Inc. Wastewater Engineering: Treatment, Disposal, and Reuse. Third Edition. New York: McGraw-Hill Inc., 1991, pp. 222-223.

[3] Morrissey, S.P. "Chemically-Enhanced Wastewater Treatment." Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, 1990. pp. 18-20.

2.2 Coagulation

Coagulation, also referred to as particle destabilization, is defined as the bringing together of small particles into large particles. Coagulation also encompasses the process of precipitation, which refers to the chemical reaction that converts soluble substances into a solid. Precipitation is the mechanism by which phosphorus removal occurs. It is also of primary importance in the first of three destabilization processes, sweep coagulation. Sweep coagulation occurs through the addition of a large amount of metal salt, which causes the wastewater to precipitate a metal hydroxide. The metal precipitate settles very rapidly, taking with it the smaller colloidal size particles present in the wastewater.

The second destabilization process is charge neutralization, in which positively charged coagulants are added to counteract the naturally occurring negative charge in the wastewater. These positive coagulants can include both metal salts like ferric sulfate, as well as a cationic polymer. These cationic coagulants first act by compressing the diffusive layer around the particles, causing the naturally occurring Van der Waals' forces of attraction to be magnified, thus resulting in the particles pulling together and becoming larger. This effect is aided further by the cationic coagulants ability to adsorb to the wastewater particles, further increasing their size and consequently their settling velocity. However, for this process to occur, it is necessary to have rapid mixing when the coagulant is added. This is most easily accomplished by placing the dosing system at the pumping station where there is typically a high degree of turbulence.

The third and final particle destabilization process is interparticle bridging, which occurs primarily when the surface charges of the particles are near zero. During this process, a 'bridge' is formed by a large polymer between the small gap separating two particles that repel each other. Once this begins to happen, a network of these bridges and coagulated particles often referred to as a floc, forms. Figure 1 shows a schematic representation of interparticle bridging that can occur as a result of coagulation of colloids using polymers.[4,5,6]

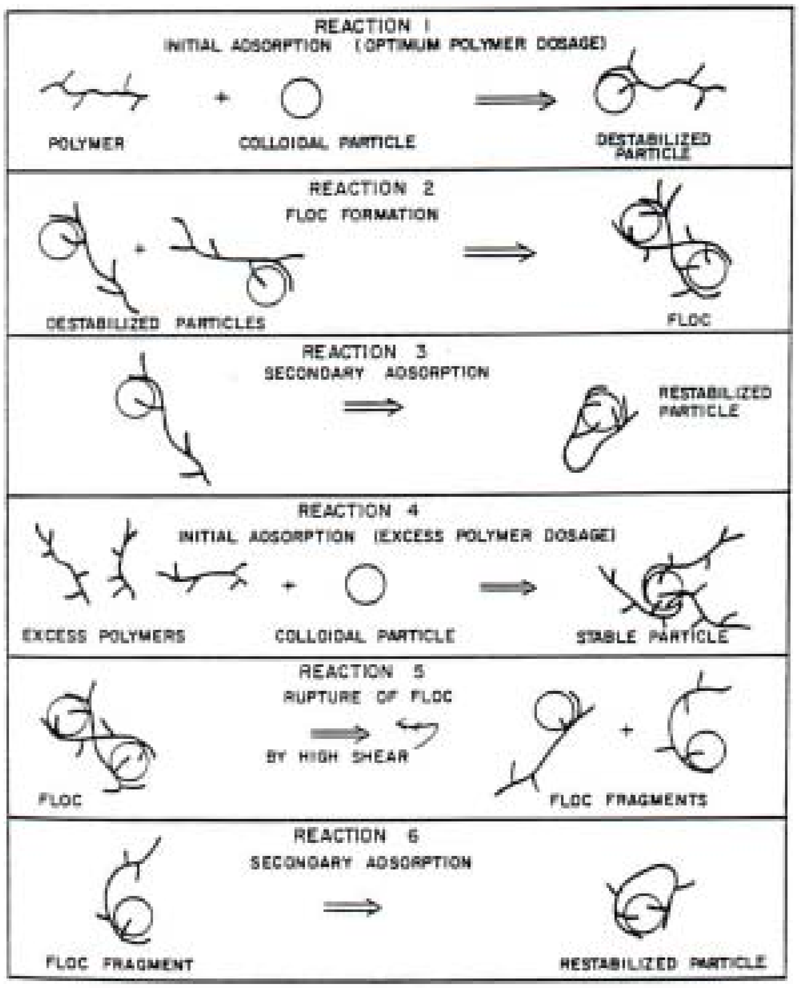

Figure 1: Interparticle Bridging Resulting From Coagulation of Colloids With Polymers[7]

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[4] Ibid. pp. 18-24.

[5] Murcott, S., Harleman, D., 2000.

[6] Gotovac, D.J. "Design and Analysis of Chemical Coagulation Systems to Enhance Performance of Waste Stabilization Lagooons." Department of Civil and Environmental Engineering, Massachusetts Institute of Technology. June 1999. pp. 25-40.

[7] O'Melia, C.R., "Coagulation in Water and Wastewater Treatment." Water Quality Improvement by Physical and Chemical Processes. E.F. Gloyna and W.W. Echenfelder, Jr., eds, 1970, University of Texas Press, Austin and London.

2.3 Flocculation

Flocculation, also referred to as particle transport, is defined as the aggregation of coagulated particles to from large groups of particles, or flocs. While coagulation requires rapid mixing, flocculation occurs under conditions of gentle, slow mixing. This process brings the destabilized particles together, and promotes collisions between them. This results in the formation of even larger size particles, and less of them. The collisions that cause this formation result due to three mechanisms: Brownian motion (perikinetic flocculation), shear force (orthokinetic flocculation), and differential settlement (a special case of orthokinetic flocculation). Brownian motion is due to the thermal energy of the fluid, and is of primary importance for collisions between particles of size less than 1μm. Shear forces are caused by fluid motion, which is induced by mixing. This primarily affects collisions between particles of size greater than 1μm. The third process, differential settlement, is a result of external forces (such as gravity) acting on the particles, causing some to settle faster than others. Because of this, collisions occur vertically as larger particles collide with smaller particles like colloids. It is also important to note that rapid mixing can have a negative effect on all mechanisms of flocculation, causing a break-up of already formed flocs.[8,9]

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[8] Morrissey, S. 1990. pp. 24-27.
[9] Gotovac, D.J. 1999. Pp. 40-41.

CHAPTER 3 - ANALYSIS METHODS

To quantify the level of performance and efficiency of a wastewater treatment plant, there are typically three main methods used. The first of these methods is the quantification of the amount of solids in wastewater sample. Although there are several classifications within the broad definition of solids analysis, the most common method is to measure the Total Suspended Solids (TSS). The other two parameters that are most commonly used to characterize the liquid treatment performance of a wastewater treatment plant, are Chemical Oxygen Demand (COD), and Biological Oxygen Demand (BOD). These two parameters are actually very similar in what they measure, and therefore it is common to attempt to develop a correlation between them.

3.1 Solids

"Solids analyses are important in the control of biological and physical wastewater treatment processes and for assessing compliance with regulatory agency wastewater effluent limitations."[10] According to Standard Methods, there are many different classifications of solids. One sub-category of solids is TSS, which refers to the portion retained on a filter of 2mm (or smaller) nominal pore size after the wastewater sample has been passed through the filter. Fixed Solids refers to the residue of suspended solids after heating to dryness for a specified time at a specified temperature. The weight loss in this ignition process is called the Volatile Solids.[11]

Though solids' testing is important to properly monitor the liquid process train of a wastewater treatment plant, it is seldom measured in Brazil, and has never been done at Riviera prior to the

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[10] APHA, AWWA, WEF. "Standard Methods for Examination of Water and Wastewater," 19th Edition. 1995: pp. 2-53.

[11] Ibid., pp. 2-53 – 2-57.

MIT group's visit. The primary reason that solids testing has not been done previously in Riviera and is rarely done in Brazil is that it is not required by the Brazilian environmental agency.

The general principle behind the TSS test is fairly simple. A well-mixed sample is filtered through a standard glass-fiber filter and the residue retained on the filter is dried to a constant weight at 103 to 105°C. The filter is weighed after drying for one hour, and the increased weight of the residue-covered filter represents the TSS. To carry this one step further, the Fixed and Volatile Solids tests are performed. The principle behind these tests is that the residue from the TSS test is re-ignited, this time at 400°C. The remaining solids after this ignition is the Fixed Solids, while the weight loss in this final process represents the Volatile Solids. This Volatile Solids measurement gives a rough approximation of the amount of organic matter present in the solid portion of the wastewater. Since this is rough, a BOD or COD test is usually performed to obtain a better characterization of the organic matter. The method for COD is described in the next section.[12]

The analytical procedures used at Riviera to perform these tests were based Standard Methods. Since all of the tests are related, the methods used for all three tests are presented together as one, just as they were performed in the lab in Riviera. The procedure that was followed to perform these three tests is as follows:

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[12] Ibid., pp. 2-53 – 2-57.

1) Collect samples; refrigerate if they can not be analyzed immediately.
2) Label and weigh an aluminum dish for each sample to be analyzed.
3) Weigh the aluminum dish with a standard glass-fiber filter paper.
4) Prepare the sample by blending about 100ml for 15 to 20 seconds.
5) Measure either 25 or 50ml of the sample, depending on the anticipated concentration.
6) Assemble the filtering apparatus, placing the filter wrinkle side up.
7) Begin suction and wash the filter with distilled water to pre-wet it.
8) Pour the pre-measured sample onto the filter paper.
9) After the sample has been sucked through the filter, wash the filter 3 times with 10 to 20ml of distilled water.
10) Once dry, discontinue suction and remove the wet filter paper.
11) Replace the filter paper into its original aluminum dish and weigh.
12) Cook the sample for at least one hour at 103 to 105°C.
13) Remove the sample and place in desiccator to equilibrate with room temperature.
14) Weigh dish and dried filter.
15) Place dish and filter in a muffle furnace at 400°C for 15 to 20 minutes. (Note: Standard Methods suggests 550°C, however it was found that the aluminum and filter paper melted at this temperature)
16) Again place the sample in the desiccator and allow it to cool.
17) Weigh dish and filter.

The following formulas can be used to calculate TSS, Volatile Solids and Fixed Solids:

$$\text{TSS (mg/L)} = \frac{(A - B) \times 1000}{\text{Sample Volume (mL)}}$$

$$\text{Volatile Solids (mg/L)} = \frac{(A - C) \times 1000}{\text{Sample Volume (mL)}}$$

$$\text{Fixed Solids (mg/L)} = \frac{(C - B) \times 1000}{\text{Sample Volume (mL)}}$$

Where:

A = Weight of the Filter, Dish, and Dried Residue (103 - 105°C) (mg),

B = Weight of clean Filter and Dish (mg), and

C = Weight of the Filter, Dish, and Residue after ignition (400°C) (mg).

The following formulas can be used to calculate removal rates for the preceding parameters:

$$\text{\% Removal TSS} = \frac{\text{TSS}_{\text{effluent}}}{\text{TSS}_{\text{influent}}} \times 100\%$$

$$\text{\% Removal Volatile Solids} = \frac{(\text{Volatile Solids})_{\text{effluent}}}{(\text{Volatile Solids})_{\text{influent}}} \times 100\%$$

$$\text{\% Removal Fixed Solids} = \frac{(\text{Fixed Solids})_{\text{effluent}}}{(\text{Fixed Solids})_{\text{influent}}} \times 100\%$$

3.2 Chemical Oxygen Demand (COD)

"The chemical oxygen demand (COD) is used as a measure of the oxygen equivalent of the organic matter content of a sample that is susceptible to oxidation by a strong chemical oxidant."[13] While there are several methods used to test for COD, the Hach Dichromatic Method, which has been approved by the U.S. EPA, is by far the most popular. This method involves the utilization of a silver compound catalyst to promote the oxidation of resistant organic compounds present in the wastewater. Additionally, mercuric sulfate is also present in the reagent to reduce the interference caused by the oxidation of chloride ions by dichromate.[14]

While the biological oxygen demand (BOD) is renowned as the most widely used parameter of organic pollution applied to wastewater, the COD test is definitely gaining popularity. Since there is so much history and records related to the BOD test, it is still used for numerous purposes. These range from sizing a wastewater plant, to measuring treatment process efficiencies, to determining compliance with wastewater discharge permits. The BOD test does, however, have several limitations that are causing it to lose popularity. The biggest limitation of the BOD test is that a long period of time (5 days) is required to obtain results. This is a serious limitation because the 5-day period may or may not correspond to the point where the soluble organic matter that is present has been used. This is where the COD test becomes especially appealing since it can be done in 3 hours versus 5 days. It is therefore useful to develop a correlation between COD and BOD, so the BOD test can be performed much less frequently. The COD of wastewater is often higher than the BOD because more compounds can be chemically oxidized than can be biologically oxidized. The correlation is often difficult to

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[13] APHA, pp. 5-13.

[14] http://www.hach.com/Spec/codd.htm

establish, but once it is obtained, COD measurements become an even greater advantage for treatment-plant control and operation.[15]

The procedure for performing the Hach Dichromatic Method for measuring COD is outlined below:

1) Collect samples; refrigerate if they can not be analyzed immediately.
2) Blend wastewater samples.
3) Pipette 2.00 ml of sample into a vial that has already been partially filled with 3.00 ml of the COD reagent.
4) Cap vial, and shake vigorously. Take caution to not touch the glass tube. If the tube is touched, be sure to wipe the glass thoroughly.
5) If samples are not cooked immediately, do not store in sunlight.
6) In additional to wastewater samples, prepare one vial with 2 ml of distilled water (and the 3ml of reagent) to use as a blank.
7) Place the samples in the preheated Hach COD reactor. Cook at 150°C for 2 hours.
8) Let samples cool to room temperature after cooking.
9) Initialize the Hach spectrophotometer by using the blank sample prepared.
10) Follow by placing each sample in the spectrophotometer and record the readings given for each. (More specific instructions are displayed on the spectrophotometer, but are not shown here since they vary for different models.)
11) Properly dispose contents of each vial.

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[15] Metcalf & Eddy, Inc., 1991, pp. 71-83.

The following formula can be used to calculate the removal rate for the COD:

$$\% \text{ Removal COD} = \frac{COD_{effluent}}{COD_{influent}} \times 100\%$$

CHAPTER 4 - BACKGROUND AND CEPT CASE STUDIES

4.1 History and Development of CEPT

While chemical treatment of wastewater is not itself a new practice, CEPT as it is used today has only been around for slightly more than a decade. Chemical addition to the first stage of wastewater treatment has not been widely used since the 1930's, when it fell out of favor because of the large chemical dosages (primarily lime) used, which resulted in an excessive amount of sludge. Modern CEPT now uses metal salts such as ferric chloride at dosages often less than 25 mg/L, often in conjunction with a very small (0.2 – 0.5 mg/L) dosage of anionic polymer. This results in only an incremental increase in sludge production, which enables this process to be much more feasible.

The process of CEPT was actually developed by the plant operators at the Point Loma plant in San Diego, California, and not by a research engineers or scientists. In 1985, the plant, which consisted solely of conventional primary treatment, was suffering severely from overloading due to an increased population. Since the plant was receiving more than twice the original design flow, the plant performance was suffering considerably. Faced with diminished performance, the plant operators turned to the century-old potable water treatment technology of adding trivalent metal salts to increase the solids removal by coagulation and flocculation. A retrofit of this sort was done quickly at a very low cost.

The chemical addition schema included the addition of a low dose of ferric chloride and a miniscule amount of an anionic polymer. These additions caused the plant performance to increase considerably, while only slightly increasing the amount of sludge produced. The original intent of increasing solids removals (to 75%) was accomplished, but they also found a dramatic increase in the removals of BOD (to 55%) and phosphorus (to 85% and greater). Not only did the plant experience remarkable improvements in removal efficiencies, but this was accomplished at over three times the design overflow rate of conventional primary treatment plants.

Since the original testing and implementation of this process was done by the plant operators, it did not receive immediate attention from the wastewater treatment community. This changed, at least to some extent, when the plant fell under severe pressure to construct a two billion-dollar secondary treatment plant to comply with federal regulations. This was challenged by City officials who saw that there would only be an incremental increase in BOD removal if the plant met secondary treatment regulations. Since the plant discharged into the ocean, and scientists were able to show that CEPT treatment was sufficient to protect the marine environment, this court order was challenged. This led to the decision by Congress to grant Point Loma a federal waiver, allowing them to continue the CEPT process. With the money saved, the city of San Diego was able to construct a tertiary treatment plant and reuse 15% of its wastewater. This was the major start to CEPT, and it has gained momentum as a common practice since then.[16]

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[16] Harleman, D.R.F. and Murcott, S. "The Role of Physical-Chemical Wastewater Treatment in the Mega-Cities of the Developing World." *Wat. Env. Tech.*, Vol. 40, No. 4-5, 1999, pp. 75-80.

4.2 Why CEPT Is and Is Not Implemented

CEPT has been, and continues to be implemented primarily because it is a cost-effective method to effectively remove pollutants and deactivate pathogens in wastewater. By accomplishing this goal, the ultimate goal of protecting public health is one step closer. More specifically, CEPT allows a much higher overflow rate in the primary settling tank, which means that it can be constructed more cheaply, or in the case of an existing settling tank, it can be upgraded to handle the increased flow with no additional construction. Not only does CEPT allow a small, efficient settling tank to be used, but the process also achieves much higher removals of TSS, BOD, COD, and phosphorus than conventional primary treatment.

So it is a fair question to ask why, if CEPT is an efficient and cost effective method to treat wastewater, it is not more widely known and implemented? At this point in time, there are several reasons: 1) Original CEPT implementation was done by plant operators and received very little attention; 2) CEPT cannot be studied generically in university laboratories; 3) Most private US design firms are reluctant to try new technologies, fearing they will be sued; 4) There is greater profit in designing plant expansions than plant retrofitting; and 5) The practice in the US utilizes a relatively non-competitive basis to select design-firms. This clearly discourages innovation, especially in comparison to the design/build/operate methodology used in Europe. Many companies in Europe set up research labs to develop the best, most efficient procedures possible. In the US, this practice is almost unheard of. So clearly, given the current structure, methodology, and mindset of American design-firms, it is extremely difficult to introduce a new practice to this industry, no matter how good it may be.[17]

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[17] Harleman, D.R.F. and Murcott, S. pp. 75-80.

4.3 Existing CEPT Plants and New Developments

CEPT is becoming increasingly more common throughout the developing world because it is a simple, low-cost method of effectively treating wastewater. CEPT has begun to gain popularity around the world since the first highly publicized success story in San Diego, CA. Because much of the United States already has existing wastewater treatment systems, the main focus for new implementations of CEPT has been in developing countries, although there are several plants in the US that do use CEPT. This technology has actually made its way to many of the largest cities in the world, as shown below in Table 2:

Table 2: World's Largest Cities (1995) and CEPT Wastewater Projects[18]

City Size Rank	City	Population (millions)	Average Annual Growth Rate: 1990-1995	CEPT Wastewater Projects
2	Sao Paulo, Brazil	16.4	2.01%	full-scale test
3	New York, U.S.A.	16.3	0.34%	full-scale test
4	Mexico City, Mexico	15.6	0.73%	full-scale test
7	Los Angeles	12.4	1.60%	full-scale operation
8	Beijing, China	12.4	2.57%	pilot test
10	Seoul, Republic of Korea	11.6	1.95%	bench-scale test
?	Rio de Janeiro, Brazil	10		full-scale test
19	Cairo, Egypt	9.7	2.24%	full-scale operation
?	Hong Kong	6		full-scale operation
?	Budapest, Hungary	2		full-scale operation

There are however several other CEPT facilities that are not on this list. The remainder of this section will look at three representative CEPT plants. The first is the flagship CEPT facility, Point Loma in San Diego, California. The next two are the only two other CEPT plants in Brazil with full-scale test data available: ETIG, in Rio de Janeiro, and Ipiranga in Sao Paulo.

4.3.1 Point Loma in San Diego, CA

The Point Loma Wastewater Treatment plant is an important plant to review because, as mentioned previously, it is has been a major catalyst in the promotion of CEPT around the world. The motivation for the implementation of CEPT at Point Loma was largely geared towards finding a way to comply with California State's Ocean Protection Plan that passed in 1985. This newly implemented plan required wastewater treatment plants with ocean outfalls increase their suspended solids removal to 75% or better. At that time, and to this present day, Point Loma only has a one-stage treatment plant, which prior to 1985 was conventional primary treatment. In addition to this new imposition placed by the state, the treatment plant was already suffering due to the increase of population, causing the system to be greatly overloaded. Faced with this desperate situation, the plant operators turned to the age-old method commonly used in potable water treatment plants, chemical treatment. The plant was subsequently retrofitted for chemical addition quickly and at a low cost.[19]

The treatment train at Point Loma begins with bar screens, then several pump stations before entering the core of the treatment plant. Upon entering the main portion of the plant, the wastewater traverses through aerated grit tanks, followed by one of 12 rectangular chemically enhanced primary sedimentation tanks. The wastewater is dosed with 25 mg/L ferric chloride prior to entering the grit tanks, and dosed with 0.10 mg/L of anionic polymer following the grit tanks, and prior to the sedimentation tanks. The grit removed in the grit chamber is dewatered with a cyclone separator. The dewatered grit is subsequently hauled off to a landfill in Arizona,

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[18] Murcott, S., Harleman, D., 2000.
[19] Harleman, D.R.F., Murcott, S., 1999, pp. 77.

and the supernatant is reintroduced into the influent wastewater stream at the start of the treatment train.

After the wastewater passes through the grit tanks and enters the clarifiers, it remains in the tanks to settle for an average of 1.5 hours, which is the detention time of the sedimentation tanks. These tanks are equipped with baffles to ensure horizontal flow and a consistent detention time. The tanks operate with an average overflow rate of 2000 gpd/ft^2. The sludge collected in these tanks is treated with a two-stage digester system. Refer to Figure 2 below for a detailed schematic flow diagram of the entire treatment train.

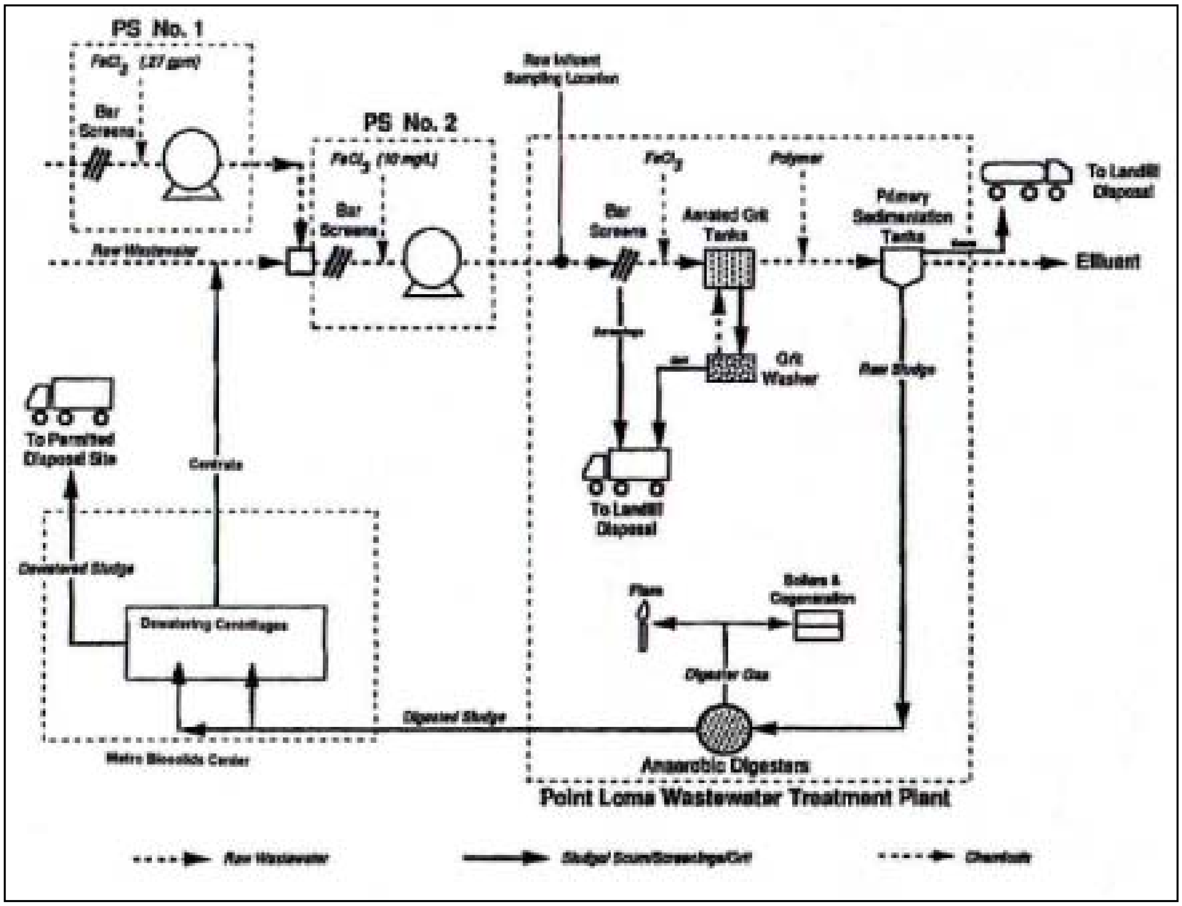

Figure 2: Point Loma Wastewater System Flow Schematic[20]

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[20] Metropolitan Wastewater District. "The City of San Diego: 1998 Annual Reports and Summary, Point Loma Wastewater Treatment Plant, Point Loma Ocean Outfall." 1998, pp. II-5.

The metal salt ($FeCl_3$) dosing system consists of a 10,000-gallon storage tank and a 2-horsepower centrifugal pump. The polymer dosing system consists of a 6,500-gallon storage tank, which feeds a smaller dosing tank. The polymer is then pumped to the flumes of the sedimentation tanks for injection.

The Point Loma Treatment plant currently serves 1.8 million citizens in the San Diego area. The plant treats on average 187 million gallons per day (MGD), and has a peak capacity of 240 MGD. As depicted in Table 3 below, Point Loma achieves very close to what is considered average removal efficiencies for CEPT plants. The removal efficiencies outlined in the table are the average numbers for 1998. Through analysis of the data itself, it can be seen that the data is quite consistent throughout the year. For instance, for TSS the annual average is 86%, while the lowest monthly average in the year, is 76%, and the highest monthly average is 90%.[21,22]

Table 3: Point Loma Removal Efficiencies in 1998[23]

Parameter	Influent Concentration (mg/L)	Effluent Concentration (mg/L)	%Removal
TSS	277	38	86.3%
BOD5	247	106	57.1%
Phosphorus	6.2	0.5	92.0%

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[21] Gotovac, D.J. 1999. pp. 60-62.
[22] Metropolitan Wastewater District, 1998, pp. II-5.
[23] Ibid. pp. II-1 – 10.

4.3.2 ETIG in Rio de Janeiro, Brazil

Estação de Tratamento de Esgotos da Ilha do Governador (ETIG), is located in the state of Rio de Janeiro, Brazil, on Ilha do Governador (Governor's Island) in Guanabara Bay. Currently, Guanabara Bay recieves a large amount of wastewater of domestic and industrial origin. This continuous addition of pollutants to the bay has resulted in the bay becoming highly polluted. The water in the bay contains high levels of coliforms, and low levels of oxygen. The bay has also been plagued with serious eutrophication problems, largely because of the high level of phosphorus allowed to enter the bay. With these serious environmental and health problems surrounding the bay, it was clear that a higher level of wastewater treatment needed to be achieved. Therefore, since April 1997, ETIG wastewater treatment plant has been experimenting with the possibility of upgrading to CEPT.

ETIG was originally constructed in 1980 with conventional primary treatment plus activated sludge treatment. During this time frame, this was a very common and popular way to build a treatment plant. The treatment train at ETIG is shown below in Figure 3. As can be seen, the raw wastewater enters the treatment plant via four pumping stations. The wastewater then travels through the 13m long, by 1.2m high grit chamber, before entering the primary clarifier. The clarifier has a diameter of 24m and a height of 2.55m. Upon exiting the settling tank, the wastewater enters an aeration tank, followed by a secondary clarifier, which is slightly larger than the primary clarifier is, at a diameter of 26m, and a height of 3.23m. The sludge is subsequently treated by a series of two digesters. The final wastewater effluent is deposited into Guanabara Bay. Table 4 below outlines and summarizes the important design parameters.

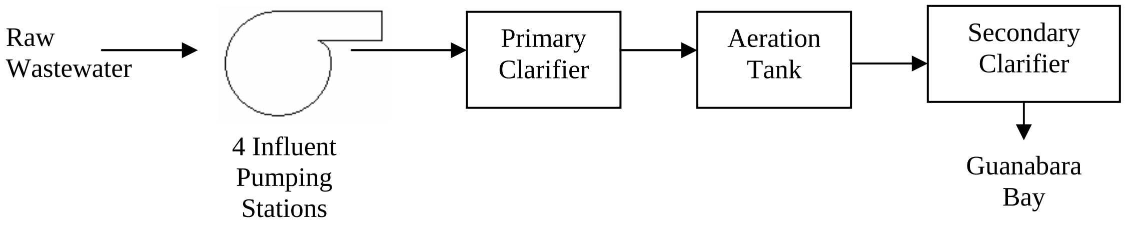

Figure 3: ETIG Wastewater Treatment Plant Schematic Flow Diagram

Table 4: ETIG Wastewater Treatment Plant Design Parameters[24]

Grit Chamber	Length: 13m Height: 1.2m
Primary Clarifier	Diameter: 24 m Height: 2.55 m
Aeration Tank	Length: 48.75 m Width: 9.75 m Height: 5.35 m
Secondary Clarifier	Diameter: 26 m Height: 3.23 m
Primary Digester	Diameter: 20 m Height: 9.6 m
Secondary Digester	Diameter: 9.6 m Height: variable Volume: 4,633 m^3

The original design flow of the ETIG wastewater treatment plant is 230 L/s. From 1994 to 1996, this is in fact close to the actual flow received, which ranged from 220 to 240 L/s. However in 1997, the average flow into the treatment plant jumped to 525 L/s, and occasionally reached a maximum flow of 900 L/s. Thus, the existing treatment was no longer able to handle the load.

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[24] Harleman, D.R.F., and S. Murcott. “Low Cost Nutrient Removal Demonstration Study Report on ETIG Bench Scale Tests Rio de Janeiro, Brasil.” Unpublished Report. MIT April, 1997.

In the years prior to 1997, the average removal rates of the plant were about 37% for TSS and 29% for BOD and COD.

In December of 1998 and January of 1999, a full-scale CEPT test was conducted at ETIG. The primary clarifier flow was divided using a splitter in order to provide a control for the experiments. Hence, one side would use chemical addition, and the other would not. The coagulant used in during the experiments was ferric chloride at three different dosages: 56 mg/L, 35 mg/L, and 59 mg/L. Unfortunately during these test periods, the results of the test were quite sporadic and inconsistent. Once the system ran for a few days, the system did equilibrate to some extent. The only truly consistent results were for COD removal, which was at about 65% removal using only 35mg/L $FeCl_3$. The TSS results ranged from 35-76% removal, and likewise the BOD results varied wildly, ranging from 29-75%. While the results were quite inconsistent, the fact that high removals were achieved for at least some of the runs, shows there is a high likelihood that good performance would be achieved if the system were studied further and optimized.[25]

4.3.3 Ipiranga in Sao Paulo, Brazil

E.T.E. Jesus Neto, also referred to as Ipiranga, is located in Sao Paulo, Brazil, which is the largest city in South America. This plant has been in operation for over 70 years. However, due to the continually growing population in Sao Paulo, the existing infrastructure has been overloaded with flows in excess of the design capacity. Consequently, the Ipiranga wastewater

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[25] Ibid., 1997.

treatment plant was no longer able to comply with the standards set forth by SABESP, the governing environmental agency in Brazil.

The treatment plant at Ipiranga begins by filtering the wastewater first through a bar screen, then filters it further with a sand filter. Both of these steps occur just prior to the pumping stations, which convey the water to a splitter box. At the splitter box, some of the flow is directed to the 254 m^3 primary decanter, some goes to a stabilizing lagoon, another portion goes to an anaerobic reactor, while the remainder by-passes further treatment and is released directly in the Tamanduatei River. The wastewater that does go to the primary decanter will then flow to the aeration tanks after spending on average 2.75 hours in the decanter. The wastewater then goes through the secondary decanter, before finally being deposited into the Tamanduatei River. While Figure 4, below, shows all of these processes, it does not include the biological activated sludge treatment at the plant. This sludge is recycled, and some of it is reintroduced back into the primary decanter.

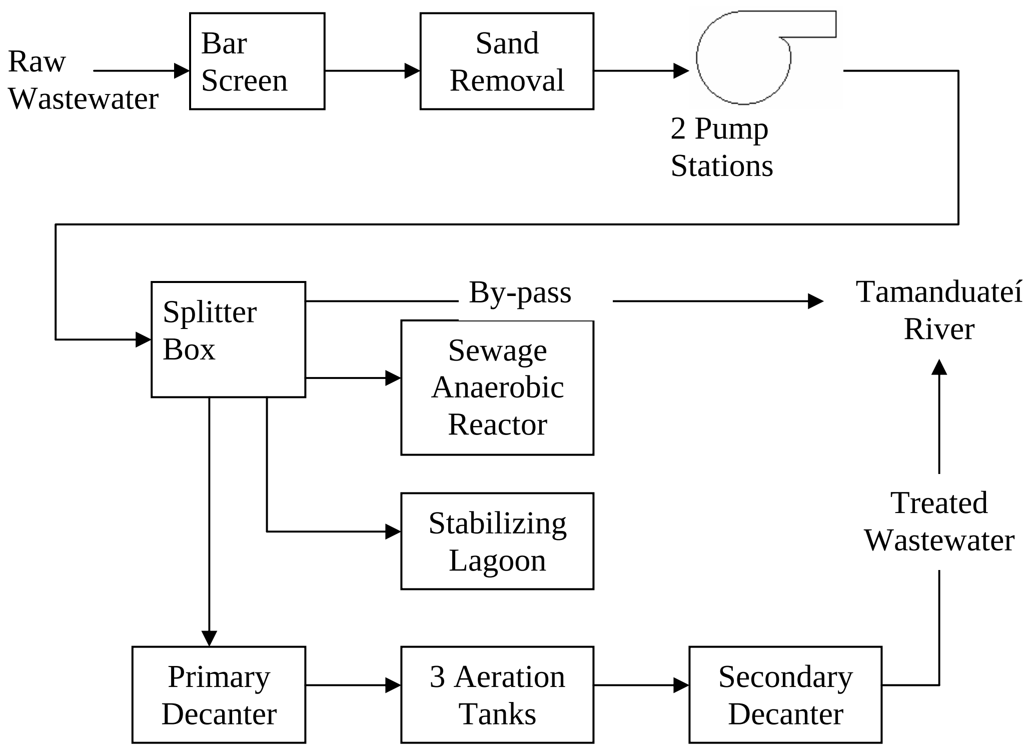

Figure 4: Ipiranga Wastewater Treatment Plant Schematic Flow Diagram

While the previous figure depicts the flow process prior to the CEPT upgrade, the upgrade did not require major changes. The upgrade simply entailed the addition of a dosing system at the pump station. Since the pumps only pump at a constant rate, the dosing rate was determined simply by the number of pumps operating at any given time. Each pump operated at a rate of 25 L/s, which was the average flow rate entering the primary decanter prior to the CEPT upgrade. Since there is another pump present, the flow into the decanter can easily be doubled to 50 L/s.

At Ipiranga, the characteristic influent wastewater has on average a BOD level of 286 mg/L, a COD level of 531 mg/L, and a TSS level of 178 mg/L. Prior to the CEPT upgrade, the primary sedimentation tank would typically yield a BOD removal rate of 30%, a COD removal rate of

20%, and a TSS removal rate of 20%. After the secondary treatment phase, the removal efficiencies improved to 70% of BOD, 65% of COD, and 60% of TSS.

A very comprehensive set of full-scale CEPT tests was conducted in 1996 at the Ipiranga wastewater treatment plant. The tests varied numerous parameters including flow rate, the dosage of the metal salt (ferric chloride), and the type and dosage of polymer used. 'Type' of polymer is either referring to a soluble or emulsion based polymer, both however are anionic polymers. Table 5 shows the averages of the results collected by SAPESB during this series of trials. As can be seen in the table, the removal rates through just the primary decanter went up to as high as 63% for COD, 62% for BOD, and 80% for TSS. The overall performance of the entire treatment plant also increased dramatically, reaching removal rates as high as 93% of COD, 95% of BOD, and 93% of TSS.[26,27,28]

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[26] Fundação Salim Farah Maluf and SABESP. "Segundo Relatório do Teste de Aplicabilidade do "CE.P.T. Tratamento Primário Quimicamente Aprimorado" ao Esgoto da E.T.E. Jesus Neto - SABESP" Unpublished Report. 1996.

[27] Fundação Salim Farah Maluf and SABESP. "Relatório no. 2JN do Teste de Aplicabilidade do "CE.P.T. – Tratamento Primário Quimicamente Aprimorado" ao Esgoto da E.T.E. Jesus Neto - SABESP" Unpublished Report. 1996.

[28] Fundação Salim Farah Maluf and SABESP. "Relatório Final do Teste em Escala Real da Tecnologia C.E.P.T. na E.T.E. Jesus Neto (B. Ipiranga – SP)." Unpublished Report. Nov 1996.

Table 5: Results of Full-Scale CEPT Tests Conducted at the Ipiranga WWTP[29]

Dose of $FeCl_3$ (mg/L)	Dose and Type of Polymer (mg/L)	Flow Rate (L/s)	Treatment Phase	COD Removal Rate (%)	BOD Removal Rate (%)	TSS Removal Rate (%)
No Chemicals	none	25	Primary Secondary	34 88	37 81	52 85
No Chemicals	none	50	Primary Secondary	27 87	28 90	36 78
25	0.5 (E)*	50	Primary Secondary	45 89	44 87	50 86
50	0.5 (E)*	50	Primary Secondary	52 92	52 93	64 91
25	0.25 (S)*	50	Primary Secondary	58 91	60 90	52 92
50	0.25 (S)*	50	Primary Secondary	63 92	62 93	69 89
50	0.5 (S)*	50	Primary Secondary	62 93	58 95	80 93

*(S) – Soluble polymer, (E) – Emulsion based polymer

4.4 Another Implementation of CEPT, "In-Pond" CEPT

As seen in the previous examples, and as can be shown for the majority of CEPT plants around the world, CEPT is typically implemented in one of three main ways. The first, and often easiest is to upgrade an existing primary settling tank. This typically includes the addition of a flow meter, and a metal salt and polymer dosing pump. The second method is typically applied if the treatment system does not have a primary settling tank as part of their treatment train. In this case, the upgrade will generally be the addition of this settling tank, along with the other items mentioned above. The third method for implementing CEPT, which is now becoming more prevalent, is the construction of a new plant that is designed to utilize CEPT. At this point, plants of this type are generally showing the best results.

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[29] Ibid. 1996.

While the starting point for each of the aforementioned methods is different, the end result is essentially the same. However, there is actually one more way in which CEPT can be implemented that is actually quite different from any of the previous methods described. This method, known as “in-pond” CEPT, is differentiated because it does not include a settling tank as the initial treatment phase. Instead, the chemicals are added directly to the wastewater going into, or already in, a wastewater lagoon. Due to the BOD loading that most treatment plants are faced with, this first lagoon is often an anaerobic lagoon.

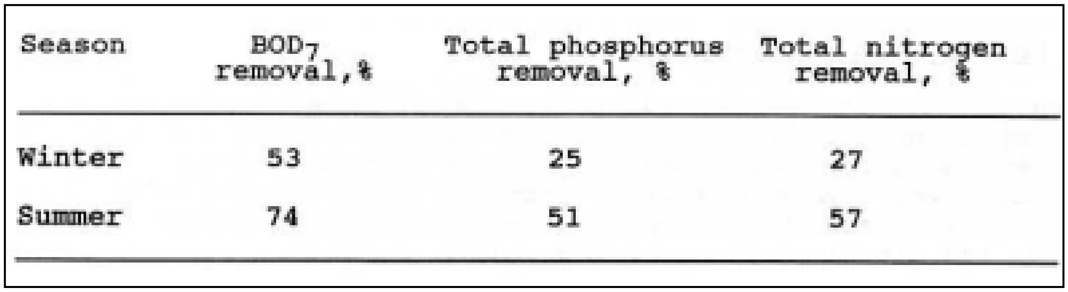
Currently there is very little information and experience with this type of treatment system; However, it is certainly a very worthwhile topic to study further. “In-pond” CEPT, if it proves to be an effective method of treatment, may be the cheapest method available to dramatically upgrade a biological wastewater treatment system. While there is currently additional research on this topic being conducted in Brazil, the only current information on this technology has been developed in Scandinavia, primarily in Norway and Sweden.

4.4.1 “In-Pond” CEPT in Scandinavia

The majority of the more recent research and papers on this topic in Scandinavia, (or at least those in English), have been largely written by one of, or a combination of three scholars: Jorgen Hanaeus from Lulea University of Technology in Sweden, H. Odegaard from the Norwegian Institute of Technology in Norway, and Peter Balmer form the Chalmers University of Technology in Sweden. While the utilization of, and motivation for CEPT technology in Scandinavia has numerous differences to that of Brazil, a review of the results that have been achieved in Sweden, Finland and Norway will likely give some insight into what can be expected in Brazil, and other places around the world.

In this part of the world, wastewater treatment in ponds has been done for hundreds of years. With increasing demands on wastewater effluent quality, numerous stabilization ponds (ponds that receive untreated wastewater) were constructed in Scandinavia. However, since the ponds relied on solar radiation for conversion of organic matter, they functioned poorly in the winter months, while the ponds were covered in ice and snow. To illustrate this, Table 6 below shows the typical removal efficiencies for traditional waste stabilization ponds in both summer and winter months. With this need to improve performance in the winter months, especially with regard to phosphorus removal, chemical precipitation (in-pond CEPT) was introduced at large plants. This method is also commonly referred to as a Fellingsdam in Scandinavia. The phosphorus removal was of particular importance because eutrophication is the primary water quality issue in inland waters in the area.

Table 6: Removal Efficiencies of Waste Stabilization Ponds in a Cold Climate[30]



Season	BOD_7 removal,%	Total phosphorus removal, %	Total nitrogen removal, %
Winter	53	25	27
Summer	74	51	57

In Scandinavian countries, they have been experimenting with and using chemical precipitation since the early 1970's. This research was provoked when numerous plants were forced to close

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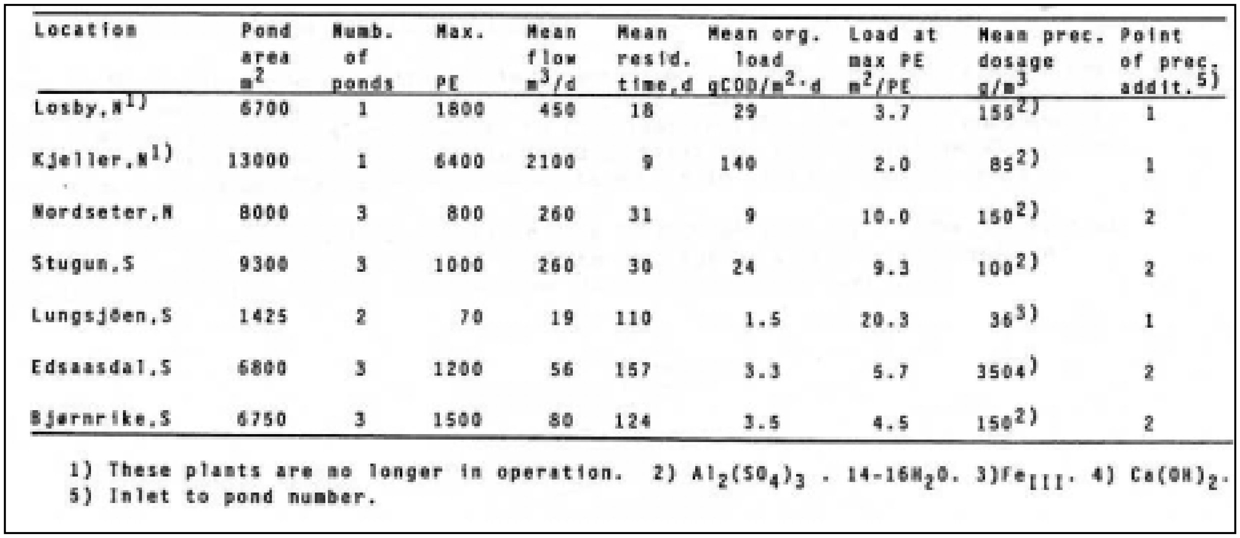
[30] Hanaeus, J. "Wastewater treatment by chemical precipitation in ponds." Division of Sanitary Engineering, Lulea University of Technology. September, 1991. pp. 6.

due to poor performance in the 1960's and 70's. The research for chemical precipitation focused initially on three methods: pre-pond precipitation, in-pond precipitation, and post-pond precipitation. The post-pond precipitation was discarded for a number of reasons. For one, it requires a traditional chemical treatment step, which from experience often requires a considerably qualified operator to control the dosage. They also found that fluctuations in the water quality of the wastewater influent to the post-precipitation step might cause considerable operational problems. While the pre-pond precipitation also has the drawback of needing an operator, it also has one very important advantage. This is that a major part of the sludge is removed in the pre-precipitation step, thus the sludge accumulation in the pond is greatly reduced. Although it should be noted that sludge is still generated in the pre-pond precipitation and has to be removed on a daily basis.

In-pond precipitation also has its drawbacks and advantages. The major drawback being the increased sludge production in the pond, which results in the necessity to desludge the pond at least once a year in a highly-loaded pond. However, for ponds with a varying or average load, the pond may accumulate sludge for many years before needing to be desludged. On the other hand, the major advantages of in-pond precipitation are that there is much less operator attendance required, and that both capital and maintenance costs are considerably lower. For these reasons, in-pond precipitation has become the most popular method treatment method in practice, with nearly one hundred such plants in Sweden alone!

To help understand the effectiveness of this process, the aforementioned scholars reviewed and studied numerous plants in Scandinavia. As can be seen, in Table 7 below, many of the plants at the time of the study were using very high chemical dosages, some as high 350 mg/L. This table also illustrates the size of the ponds, the flow rates and loading experienced. Table 8, also below, shows the average removal efficiencies that these plants were achieving. With the exception of one plant, which showed unusually poor results, the average removal of COD for the plants was 72%. The phosphorus removals were also quite high, with an average of 83%, which is quite an improvement over the removals that were achieved without chemical precipitation. Actually, another plant in Ruuki, Finland not included in the table, achieved phosphorus removal rates as high as 98%. The last item that the table shows is Suspended Solids removal rates, which on average were about 85%.

Table 7: Operating Conditions of Various Chemical Precipitation Ponds in Scandinavia[31]



Location	Pond area m^2	Numb. of ponds	Max. PE	Mean flow m^3/d	Mean resid. time, d	Mean org. load $gCOD/m^2 \cdot d$	Load at max PE m^2/PE	Mean prec. dosage g/m^3	Point of prec. addit. 5)
Losby, N 1)	6700	1	1800	450	18	29	3.7	155 2)	1
Kjeller, N 1)	13000	1	6400	2100	9	140	2.0	85 2)	1
Nordseter, N	8000	3	800	260	31	9	10.0	150 2)	2
Stugun, S	9300	3	1000	260	30	24	9.3	100 2)	2
Lungsjöen, S	1425	2	70	19	110	1.5	20.3	36 3)	1
Edsaasdal, S	6800	3	1200	56	157	3.3	5.7	350 4)	2
Bjørnrike, S	6750	3	1500	80	124	3.5	4.5	150 2)	2

1) These plants are no longer in operation. 2) $Al_2(SO_4)_3 \cdot 14\text{-}16H_2O$. 3) Fe_{III}. 4) $Ca(OH)_2$.
5) Inlet to pond number.

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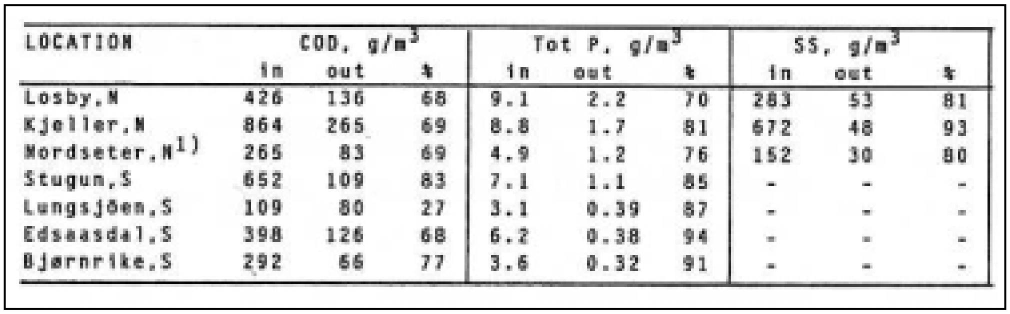
[31] Odegaard, H., Balmer, P., Hanaeus, J. "Chemical Precipitation in Highly Loaded Stabilization Ponds in Cold Climates: Scandinavian Experiences." Wat. Sci. Tech. Vol. 19, No. 12, pp. 74, 1987.

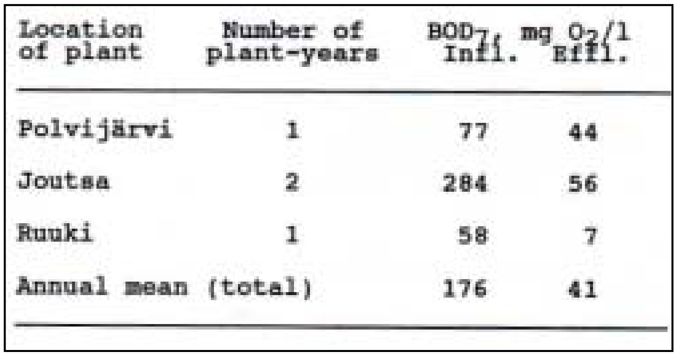
Table 8: Operating Conditions of Various Chemical Precipitation Ponds in Scandinavia[32]



LOCATION	COD, g/m³			Tot P, g/m³			SS, g/m³		
	in	out	%	in	out	%	in	out	%
Losby,N	426	136	68	9.1	2.2	70	283	53	81
Kjeller,N	864	265	69	8.8	1.7	81	672	48	93
Nordseter,N1)	265	83	69	4.9	1.2	76	152	30	80
Stugun,S	652	109	83	7.1	1.1	85	-	-	-
Lungsjöen,S	109	80	27	3.1	0.39	87	-	-	-
Edsaasdal,S	398	126	68	6.2	0.38	94	-	-	-
Bjørnrike,S	292	66	77	3.6	0.32	91	-	-	-

Since the only plant above that showed poor performance was using an iron salt, it is important to look at other plants that are also using iron salts. In Table 9 below, the BOD levels for three Finnish plants using iron salts are shown. While the removal rates are not shown, they compute to 43% at Polvijarvi, 80% at Joutsa, and 88% at Ruuki. Therefore, the average BOD removal rate was 77%. This was accomplished with a dosing rate of only 10-15 mg Fe/L.[33,34,35]

Table 9: Values of BOD_7 in Three Finnish Plants Using Iron Salts for In-Pond Precipitation[36]



Location of plant	Number of plant-years	BOD_7, mg O_2/l Infl.	Effl.
Polvijärvi	1	77	44
Joutsa	2	284	56
Ruuki	1	58	7
Annual mean (total)		176	41

Through the results found in Scandinavia, it has been shown that in-pond CEPT actually achieves very similar results to that of the pre-pond CEPT, which is currently being promoted

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[32] Ibid. pp. 74.
[33] Ibid. pp. 71-77.
[34] Balmer, P., Bjarne, V. "Domestic Wasteater Treatment With Oxidation Ponds in Combination with Chemical Precipitation." Prog. Wat. Tech., Vol 10, Nrs 5/6, 1978, pp 867-880.
[35] Hanaeus, J., 1991, pp. 1-29.
[36] Ibid. pp. 20.

around the world. One additional note that should be made with regard to pre-pond CEPT, is that one of the claims made by these scholars may not being entirely true today. This is that pre-pond CEPT is much more expensive to maintain in part due to the necessity of having a highly trained operator. However, with current automated dosing systems, this cost and effort can be reduced. Also, one major point of recent study with regard to pre-pond CEPT, is the optimization of chemical dosages to reduce the amount of sludge production, which could certainly be transferable to in-pond CEPT. Doing this would reduce the frequency that the ponds need to be desludged, and would therefore translate to additional cost savings.

CHAPTER 5 - FULL SCALE STUDY AT RIVIERA

5.1 Introduction to Riviera de Sao Lourenco, Brazil

Riviera de Sao Lourenco is a small resort community located on the coast of Brazil about two hours to the northeast of Sao Paulo, the largest city in South America, and about 6 hours to the south of Rio de Janeiro (See Figure 5). The resort area was designed, built, and is now maintained by Sobloco Construction Company. The community began very small, but in recent years, the population has begun to increase rapidly. During the majority of the year, the population is about 40,000 persons. However, during the summer months, which are from December through early March, the average population soars to about 80,000. In coming years, this peak population is projected to increase to 100,000 persons, and possibly even higher.

Figure 5: Map of Brazil Showing the Approximate Location of Riviera de Sao Lourenco

As a result of this huge influx to Riviera, the wastewater treatment system as it was originally designed is unable to handle the extra loading that occurs. The flow and loading more than double during this 3 month period, and since the wastewater treatment plant was not designed to handle this magnitude of loading, the treatment plant is unable to meet environmental regulations.

This situation is perfectly suited to be solved through the implementation of CEPT technology. As was discussed previously, one of the primary reasons to use CEPT is to upgrade an overburdened wastewater system. This is because, through the addition of chemicals and polymer, coagulation and flocculation is increased. Since this is increased, the floc size is also increased, and therefore the settling rate is increased. Since the particulate matter is settled faster, a larger amount of flow can be treated in a relatively small settling tank (compared to a conventional primary treatment settling tank). By constructing the settling tank, a large amount of the solids and organic matter will be removed before the wastewater even reaches the biological portion of the treatment plant. The lower loading on the biological portion of treatment will also improve the efficiency of this part of the plant, and of the system as a whole.

5.2 Characteristics of the Riveira WWTF

The treatment facility at Riviera was a typical biological wastewater treatment facility, as is commonly used for small communities. The original treatment plant was comprised of a pumping station, one anaerobic lagoon, and three facultative lagoons. Among other things, the upgrade to use CEPT involved the construction of two large settling tanks. The most important design parameters of the system are summarized below in Table 10:

Table 10: Summary of Riviera Wastewater Treatment Plant Design Parameters

Pumping Station - 3 Constant Flow Pumps	Pump 1: 89 m^3/hr Pump 2: 526 m3/hr Pump 3: 665 m3/hr
Distance From Pumping Station to Feed Channel	2841 m
Feed Channel	Length: 33 m Width: 1.5 m
Flocculation Chambers (2)	Length: 23 m
CEPT Clarifiers (2)	Length: 30 m Width: 6 m Depth: 3.7 m
Anaerobic Lagoon	Depth: 3.2 m Surface Area: 6,600 m^2 Volume: 21,120 m^3
Facultative Lagoons (3)	Depth: 1.5 m Surface Area: 45,000 m^2 Volume: 67,500 m^3

5.2.1 Plant Dimensions, Layout, and Specifications

Figure 6 below shows the schematic layout of the wastewater treatment process in Riviera. The wastewater is collected through a sewer collection system, which encompasses Riviera, and ends up at the final pumping station. While at the final pumping station, the wastewater is dosed with a metal salt (i.e. ferric sulfate).

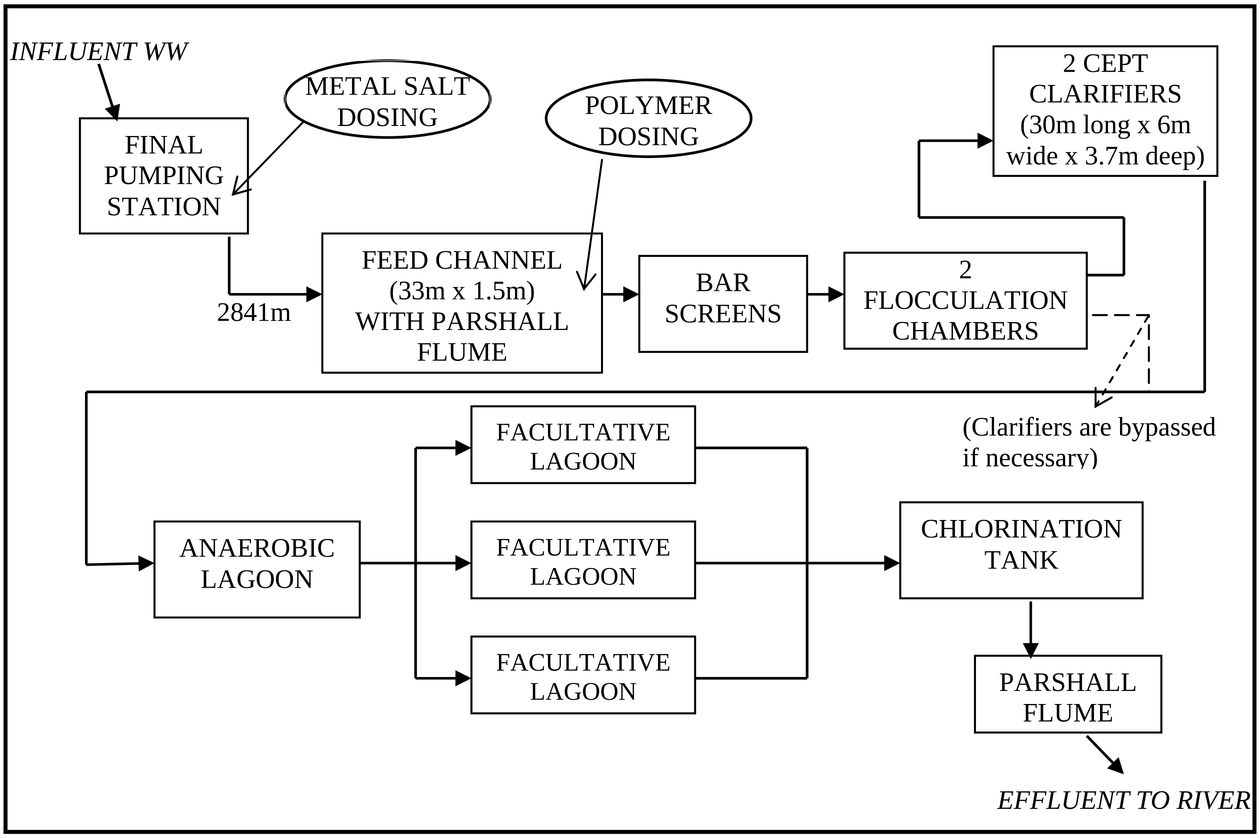

Figure 6: Schematic Layout of Wastewater Treatment Process at Riviera

The wastewater exits the final pumping station via a combination of two 150 mm ducts, and 2 300 mm ducts. Which of the four pipes that are used is determined by which of the three pumps is operating at a given time. The raw wastewater now dosed with the metal salt travels 2841m to the feed channel (See Figure 7). The feed channel is 33m long and 1.5m wide and is fed by three pipes carrying the wastewater. Towards the end of the feed channel is a Parshall flume. At the Parshall flume there is an ultrasonic flow meter. This flow meter is calibrated with the polymer dosing system, located in the same place, to adjust to the proper dose of polymer.

Figure 7: Feed Channel, Parshall Flume, Flow Meter, and Polymer Dosing

On exiting the Parshall flume, the wastewater drops about a meter and passes through the bar screen (See Figure 8). After passing through the bar screens, which are cleaned manually on a regular basis, the wastewater enters two parallel flocculation chambers (See Figure 9). These chambers, formerly the grit boxes under the original non-CEPT design, are each 23m long. Through the whole length of the grit boxes there are air hoses on one side of each chamber about 20 cm apart, with the ends submersed in the wastewater. By placing these air hoses on one side and injecting air as the water passes through, a helicoilodal motion is generated in the chamber. This motion aids in the floc formation.

Figure 8: Bar Screen

Figure 9: Flocculation Chambers (23m long)

In the original system, and when the CEPT clarifiers are offline, the wastewater then passes into the anaerobic lagoon. It does this by traveling down a small channel next to the lagoon where it is fed into several pipes, which direct the wastewater beneath the surface of the lagoon.

When the CEPT clarifiers are online, then the wastewater, instead of entering the lagoon directly, travels down a channel that is a continuation of the aerated floc chambers, and into the CEPT clarifier. The two parallel clarifier tanks are 30m long by 6m wide by 3.7m deep. The water enters the clarifiers through three gates at the top of the tanks (See Figure 10). On entering the tank, the wastewater is diffused by a large plastic baffle just within the tank.

Figure 10: Entrance to the CEPT Clarifier Tanks

Once in the tank, the wastewater that has been flocculating begins to clear as the floc settles. In the tank, sludge-scrapers run the length of the clarifier with the purpose of pulling this settled floc to the sludge weir at the end of the tank (See Figure 11). Once this sludge is gathered, it is intermittently pumped out of the weir and into a storage tank, where it is dosed with a lime slurry to stabilize it. This means that there is also a lime pump to accomplish this task. The sludge pump is operated by the plant personnel, and turned on occasionally and run until it visually appears that more wastewater than sludge is being pumped, at which point it is turned off.

Figure 11: CEPT Tank and the Sludge Scrapers

In addition to this process of sludge removal from the clarifier, there is also a scum scraper at the surface of the tank. This is essentially just a pipe with a slit in it, as seen in Figure 12. This is in place to remove any floating floc or other floating materials that may have passed through the bar screen. Once the scum has entered the pipe, it is also pumped by a third pump into the liming tank.

Figure 12: Scum Scraper Located at the Surface of the Clarifier Tank

While the ultimate CEPT design is to have both clarifiers operational at the peak season, January - March, for the year 2000 only one tank was online. The other tank was being used as the temporary storage for the sludge. However, the ultimate design is for each tank to be able to handle the peak flow from 40,000 people, which is estimated to be 8,400 m^3/day. So, with one tank running during the peak season, the peak Overflow Rate (OFR) can be calculated as follows:

$$\text{OFR (m/day)} \quad = \quad (Q / A_{surface}) \quad = \quad (8{,}400\ m^3/\text{day}) / ((30m) \times (6m)),$$

Where,

Q is the max flow rate in peak season, and

$A_{surface}$ is the surface area of the tank.

This results in a peak overflow rate of 46.7 m/day. However, this is not entirely accurate because the three pumps do not pump at a constant flow all day long. In fact, the flow can be as high as 754 m^3/hour, which is equivalent to 18,096 m^3/day, though this flow rate is never sustained for a whole day. With this flow rate, the overflow rate in the clarifier can surge up to about 100 m/day.

The residence time (detention time) can also be computed for the CEPT clarifier. The residence time, t*, is computed as follows:

$$t^* \text{ (days)} \quad = \quad (\text{Vol} / Q) \quad = \quad ((3.7\text{m}) \times (6\text{m}) \times (30\text{m})) / (8{,}400 \text{ m}^3/\text{day})$$

Where,

Vol is the volume of the clarifier.

Hence, the detention time in the clarifier is 0.0793 days, or 1.9 hours.

The wastewater overflows out of the CEPT clarifier tanks and into a channel that connects back into the original system, which then feeds into the anaerobic lagoon. The wastewater now enters this lagoon in the same manner that it did before the clarifiers were in use.

The 3.2-meter deep anaerobic lagoon, as seen in Figure 13, has a surface area of 6,600 m^2 and a volume of 21,120 m^3. Like the clarifier, the residence time for the anaerobic lagoon can be computed using the same formula. Assuming the same flow of 8,400 m^3/day, the residence time in the lagoon is about 2.5 days.

Figure 13: Anaerobic Lagoon

On exiting the anaerobic lagoon, the wastewater enters a splitter box where the flow is directed to one of the three facultative lagoons (See Figure 14). It is, however, not always split three ways. In the non-peak season, often one of the facultative lagoons is pulled offline, and the system is operated with only two facultative lagoons.

Figure 14: Two of the Facultative Lagoons

The total area of the three facultative lagoons is 45,000 m^2, and the total volume for the 1.5-meter deep lagoons is 67,500 m^3. Using the same method and flow rate as for the anaerobic lagoon, the residence time in the facultative lagoons can also be computed. This calculation yields a residence time of 8.0 days.

When the flow exits each of the facultative lagoons, it is combined into one channel before entering the chlorination tank (See Figure 15). The flow enters the chlorination tank, and travels through the system via perforations in the walls below the surface. The chlorine addition itself, which is below the surface, seeps through the bottom of the tank.

Figure 15: Chlorination Tank

The flow then exits the chlorination tank and passes through another Parshall flume to enable the effluent flow to be measured. From here, the treated wastewater exits the treatment plant. It goes through one last pumping station before entering the Itapanhau River, about 500 meters downstream of the drinking water collection point.

5.2.2 Pumps and Flow Characteristics

All flow is collected from the city and ends up at the final pumping station before going to the rest of the treatment plant. The pumps and pumping scheme at this station determine the flows and flow patterns that the rest of the treatment plant will see. This primarily effects the CEPT clarifier and the residence time and overflow rate for the wastewater passing through the clarifier. This is because it will see a widely varying inflow rate throughout the day.

There are three pumps at the final pumping station. All of the pumps operate at only one rate, as set by the manufacturer. Therefore flow is controlled to meet the demand by turning pumps on and off. Pump # 3, the smallest pump runs continuously, 24-hours a day, at a flow rate of 89 m^3/hour. Often this is the only pump operating at a given time. However, at this low pumping rate, during times of heavier use the volume of wastewater at the station waiting to be pumped builds up. When the volume reaches a certain level, one of the other two pumps will turn on. Pump # 1 operates at a flow rate of 526 m^3/hour, and Pump #2 operates at 665 m^3/hour. When wastewater builds up, and another pump is needed, Pump # 1 or Pump # 2 will turn on. The two pumps alternate each time one of them is needed. The additional pump will operate until the volume at station reaches an acceptable level. This typically takes about 15 minutes to lower the wastewater level back down to a base level. During heavy flow periods, it is typically necessary to run one of the additional pumps about once an hour for a 15-minute period.

At peak flows, all three pumps can be run at the same time. This results in an absolute max pumping rate of 1280 m^3/hour. This has never yet occurred, and even with the expected increase in population, it is unlikely that this will be necessary in the future.

5.2.3 Chemicals and Dosing

In 1999-2000, the CEPT upgrade was designed and operated using ferric sulfate and an anionic polymer. The ferric sulfate, during the time of the fieldwork that was conducted by the MIT M.Eng. team, was being dosed at 50 mg/L. The ferric sulfate ($Fe_2(SO_4)_3$) has a solids content of 42.4%. The polymer was dosed at 0.5 mg/L. The particular polymer that is being used is Nalco 4684, which is an anionic polymer of high molecular weight and high charge.

Although this is the dosage and specific chemicals used when CEPT originally went online, a number of alternatives were considered and tested during the January fieldwork period by M.Eng. student Irene Yu. These alternatives are tested through a bench-scale, or jar-scale tests in the laboratory. One metal salt alternative that is being heavily tested is ferric chloride. This chemical has proven to be very effective in numerous other plants in Brazil, and shows promise for Riviera as well. Likewise, numerous other polymers, primarily anionic, are being tested as well. The goal is to obtain the highest removals with the least amount of chemical addition at the lowest cost.

The locations of the dosing systems have been mentioned previously. However, to reiterate, the metal salt, in this case ferric sulfate, is dosed at the final pumping station. This allows additional time for mixing and coagulation before reaching the clarifier. The polymer is dosed at the Parshall flume just prior to the flocculation chambers and the clarifier. This allows some time for flocculation prior to entering the clarifier.

5.2.4 Metal Salt Dosing System

The metal salt, ferric sulfate, is stored in a large fiberglass chemical storage tank next to the final pumping station (See Figure 16). This tower is 5 meters high and 2.6 meters in diameter, and is often full, or near full at a capacity of 25 m^3. Because of this there is an additional 5 meters of hydraulic head that is undesirable for the dosing system, and would actually cause it not to function properly. Therefore, it is necessary to bleed this addition head out of the system. To do this, a large plastic pressure relief tank was used at ground level next to the rest of the dosing system. The pressure relief tank is filled with the metal salt and is open to the atmosphere. Inside the pressure relief tank atop the chemical is a floater. This floater, along with a ball valve at the base of the chemical storage tank, controls the flow of chemical into the pressure relief tank, thus bleeding the unwanted head.

Figure 16: Chemical Storage Tank

Once in the pressure relief tank, the main dosing system takes over (See Figure 17). As can be seen in the figure, all of the tubes are plastic. This is because the metal salts used are highly corrosive and any metal pipes would corrode. The concept behind the dosing system is that there are three chemical dosing pumps that correspond to each of the three wastewater pumps. Since the flow rate of each wastewater pump is constant, each dosing pump just needs to pump an amount of chemical that is proportional to the flow. The specific amount is determined by the specific concentration that is desired. Therefore, once each of the dosing pumps is calibrated to be proportional to one of the wastewater pumps, it just needs to be operating at the same time as its corresponding wastewater pump. To accomplish this, there is a sensor on each wastewater pump that communicates to the corresponding dosing pump when it turns on and off. Another detail that is important to mention relates to some of the additional tubes seen in Figure 17. These tubes carry potable water used to dilute the chemical. Besides providing the water to obtain the proper dosing concentration, this is another step taken to preserve the equipment and materials by reducing the corrosivity in the chemical being added.

Figure 17: Metal Salt Dosing System

From the dosing system shown above, the chemical is pumped over to one of the pump wells. It travels half-way down the pump well in a small metal tube, and it is opened at the bottom allowing metal salt to drop the rest of the way into the pump well (See Figure 18).

Figure 18: Metal Salt Injection into the Pump Well

5.2.5 Polymer Dosing System

A slightly different approach to dosing had to be taken with the polymer dosing system. This is because, unlike the metal salt dosing system, there is not a constant flow rate to which the pumps can be calibrated. Therefore, the first step in this dosing system is to determine how much flow there is at any given time. To accomplish this, first a two-foot Parshall flume was constructed at the point where it was desired to dose the polymer. Above the Parshall flume, a Nivosonar ultrasonic sensor was installed (See Figure 19). This uses the "fish finder" technology. Essentially, it bounces a signal down to the water, and times how long it takes to return the signal. The time to bounce the signal to the bottom (i.e. no water) is known, so it can compute the difference in time for a measurement at any given water level to that of a zero water level.

This time difference corresponds to a height of water, and since the measurement is done in a Parshall flume, the height of water directly corresponds to a flow rate. Thus, the flow rate can be determined continuously over time.

Figure 19: Parshall Flume, Ultrasonic Sensor, and Polymer Dosing

The ultrasonic sensor then communicates the flow rate to the dosing pump so it can inject the correct amount of polymer. It communicates this by sending a signal ranging from 4 to 20 mA, which represents flow rates from 0 to 1,200 m^3/hour. The dosing pump receives this signal and converts it to strokes per minutes (SPM). The same range of 4 to 20 mA represents an SPM range of 0 to 100. In order to correlate the SPM to a specific pumping flow rate, the stroke length has to be adjusted within its operating range of 20 to 100% of its full length.

Since the polymer is extremely thick, it has to be diluted in order to flow through the pipes. This dilution happens at the polymer pump shown in Figure 20. The pump pumps the diluted polymer a short distance to the Parshall flume. At the Parshall flume, the polymer is sprayed into incoming wastewater, as shown above in Figure 19.

Figure 20: Polymer Pump and Dosing System

5.3 Events and Conditions During the January 2000 Field Study

From the time that the group arrived in Brazil, the wastewater treatment facility was plagued with numerous problems. This is important to discuss here in order to understand the condition of the system at the various times that the samples were taken. Therefore, this section will address the events that took place at the treatment plant and the times in which they occurred. A summary of the most important events that had an effect on the operation of the wastewater treatment system are outlined below in Table 11:

Table 11: Summary of Riviera Wastewater Treatment Plant Major Events

DATE	EVENT
Friday, January 7th, 2000 (4:30 PM)	"In-Pond" CEPT begins with the addition of 50 mg/L Ferric Chloride and 0.5 mg/L anionic polymer.
Tuesday, January 11th, 2000 (5:30 PM)	"Pre-Pond" CEPT begins when sludge scrapers are repaired. Operates until 6:00 PM, then reverts back to "In-Pond" CEPT.
Wednesday, January 12th, 2000 (10:30 AM)	Pre-Pond CEPT began again. This time it ran until mid-afternoon when the sludge scraper broke again. System Switched back to "In-Pond" CEPT.
Friday, January 14th, 2000 (evening)	Major electrical storm damaged the polymer dosing system. Hence no polymer was added until January 19th.
Wednesday, January 19th, 2000 (mid-day)	The polymer pump and sludge scrapers were repaired, and "Pre-Pond CEPT began once again.

The CEPT system was originally scheduled to go online on January 1st, 2000. However, when the MIT M.Eng. team arrived in Brazil on Wednesday, January 5th, the pre-pond CEPT was not yet online due to mechanical problems with the sludge scrapers in the CEPT clarifiers.

By Friday, January 7th, because of the continued mechanical problems in the CEPT clarifier, this portion of the system remained offline. The decision was made by Dr. Ricardo Tsukamoto to commence with chemical addition directly into the anaerobic lagoon, which is often referred to as “in-pond” CEPT. Thus, at about 4:30pm, the addition of ferric sulfate and anionic polymer began. Ricardo Tsukamoto made this decision influenced by the fact that at this time of year, there is extremely large loading on the treatment system. Such loading prevented the plant from producing results that were in compliance with environmental regulations. Given this, Ricardo hoped that running in-pond CEPT until the full system was ready would improve the efficiency of the lagoon system. The primary effect of this decision was expected to be an improved performance of the anaerobic lagoon, which would then result in a lower loading on the facultative lagoons, allowing them to be more effective, and improve the efficiency of the overall process.

Although in-pond CEPT officially began Friday afternoon, its full effectiveness would increase over several days. This is because the residence time in the anaerobic lagoon is about two and a half days, and the residence times through each of the facultative lagoons is about eight days. Therefore, the full effect of the in-pond CEPT would not be seen for about ten days, but since most of the change in performance was expected to take place is the anaerobic lagoon, the chemical addition would essentially be in effect within two days of starting the chemical treatment. Thus, the samples taken on the morning of Sunday, January 9th, would likely be the first set of samples where the effect of the chemicals in the anaerobic lagoon would be noticed, since it was 41 hours after the chemical addition began.

In-pond CEPT ran from Friday, January 7th, to Tuesday, January 11th, when the sludge scrapers were finally repaired. On Tuesday, January 11th, at about 5:30pm, the pre-pond CEPT system was started. When they put the system online by diverting the wastewater flow from the anaerobic lagoon to the clarifier, the clarifier tank was already about half full with potable water used to test the sludge scrapers. Thus, the initial effluent from the tank would be a plug of fresh water, so samples would be meaningless initially. The system did not however run long. In order to ensure that staff members could watch the system on a 24-hour basis, the system was pulled off line at about 6pm, and in-pond CEPT was continued. They planned to put the system back on line the following morning.

The pre-pond CEPT system was in fact put back online at about 10:30am on Wednesday, January 12th. The tank filled the rest of the way with the wastewater, and as previously noted, the initial effluent was a plug of fresh water. The system ran for the afternoon only. Sometime in the mid-afternoon the operations technicians noticed some problems with the sludge scraper. It turned out that it did break, so the system was pulled offline again, returning to in-pond CEPT once again.

The CEPT clarifier remained offline while repairs were being made to the sludge scraper. However, before this was completed, there was an additional snag. On Friday, January 14th, there was a major electrical storm in the evening. During the storm, some part of the polymer dosing system was either hit, or just effected by the lightning. Consequently, when the system turned back on, the dosing system malfunctioned. They believe that there was no water being added to dilute the polymer as is usually done. Therefore, straight polymer was pumped through the dosing system for more than a day. When the problem was discovered, the entire system was completely clogged and not functional. The polymer dosing system was then shut off until it could be repaired. Therefore, it can be assumed that no polymer was added to the system starting Friday afternoon. However, the ferric sulfate dosing was continued as normal.

The polymer pump remained incapacitated for several days, so the remainder of the samples that were taken at the lagoons were without the benefit of the polymer. However, after several days of repairs, on Wednesday January 19th, the last day the group was at Riviera, the system repairs were completed. Not only did the rebuilding of the polymer dosing system get completed by mid-day, but the sludge scrapers were also supposedly working. Therefore, with everything working all at the same time, the pre-pond CEPT system was again put back online. Similar to last time, the clarifier was partially filled with potable water before the system was put online, and the wastewater diverted into the tank. Consequently, the initial plug of water was again expected to be essentially just the potable water, and would not be a representative sample of the CEPT system. Therefore, once again, no samples were taken at this time.

From the information supplied by Ricardo, the system ran for several days before the sludge scraper broke yet again.

5.4 Methods and Procedures for Sampling

5.4.1 Sampling Locations

There were a total of nine sampling points designated throughout the treatment facility, though many of them were not used on a daily basis. See Figure 21 for a schematic layout of all nine sampling points. The first sampling point (I-1, i.e. first influent point) was at the final pumping station, which is about 3 kilometers from the lagoons, and is where the MIT M.Eng. group worked in the adjacent Riviera laboratory. This sample was taken immediately prior to the addition of the ferric sulfate at the pump station. This sampling point represents the raw sample with no influence from the CEPT process.

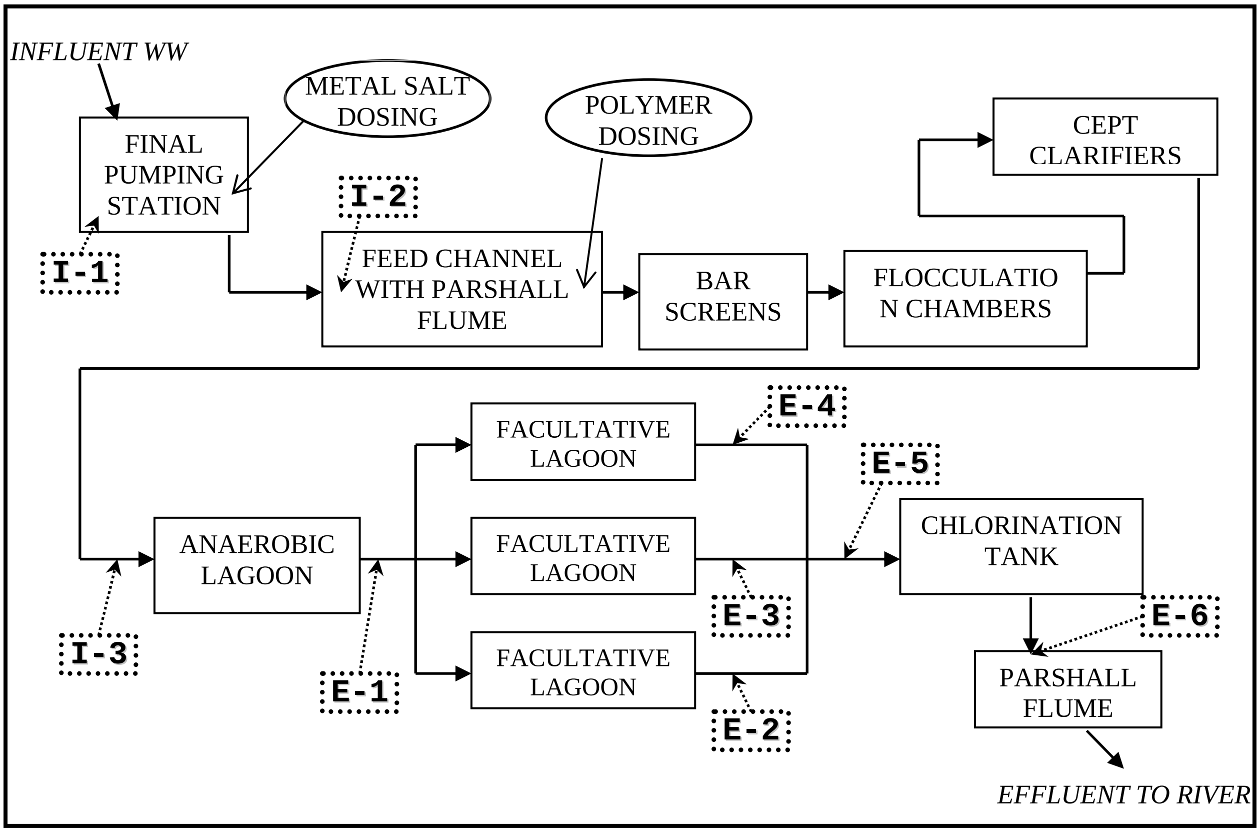

Figure 21: Schematic Layout Depicting the Nine Sampling Points

The second sampling point was never actually used during the time the MIT M.Eng. group was at Riviera. This point (I-2, i.e. second influent point) was at the Parshall flume at the inlet to the lagoons (See Figure 22). This point would be useful for two purposes. The first would be when in-pond CEPT is used, the sample would represent the wastewater before the polymer addition. Additionally, during pre-pond CEPT, it would be a representative sample of the influent to the clarifier tank.

Figure 22: Sampling Point I-2, Influent Parshall Flume

The third sampling point (I-3, i.e. third and final influent sampling point) was at the immediate influent to the anaerobic lagoon. The sample at this location was consistently taken at the center inlet structure to the lagoon, which is the same spot that the lagoon technicians typically used as a sampling point (See Figure 23). This sample represents the influent to the lagoon portion of the in-pond CEPT, and would also be the effluent to the pre-pond CEPT clarifier when that is online.

Figure 23: Sampling Point I-3, Inlet to the Anaerobic Lagoon

The fourth sampling point (E-1, i.e. first effluent point) was directly across from I-3 at the effluent to the anaerobic lagoon. That sample was also collected at the center outlet structure; Again this was the same point used by the lagoon personnel for regular sampling (See Figure 24). This point represents not only the effluent from the anaerobic lagoon, but also the influent to all of the facultative lagoons.

Figure 24: Sampling Point E-1, Outlet to the Anaerobic Lagoon

The next three sampling points were at the effluent end of each of the three facultative lagoons (E-2, E-3, & E-4, i.e. second, third, and fourth effluent point). Again, to be consistent with sampling done regularly at the lagoons, each of these sampling points was set at the center outlet structure (See Figure 25). These points are of primary interest only if the performance differential of each of the three facultative lagoons is desired.

Figure 25: Sampling Point E-3, Outlet to the Facultative Lagoon (Representative of Sampling Points E-2 and E-4 as well)

To obtain a composite effluent from the three facultative lagoons, the eighth sampling point (E-5, i.e. fifth effluent point) was used. This point was immediately prior to the cholorination tanks, and contained the combined effluent of all three facultative lagoons (See Figure 26). This point represented essentially all of the treatment that the wastewater was going to receive through the facility, with the exception of the chlorine addition.

Figure 26: Sampling Point E-5, Composite Effluent from the Facultative Lagoons

The final sampling point (E-6, i.e. sixth effluent point) was located immediately following the chlorination tank at the Parshall flume (See Figure 27). This sample represented the final treated water that would reenter the Itapanhau River.

Figure 27: Sampling Point E-6, Final Effluent – From Chlorination Tank

While all of these points for sampling were designated and have or will be used, they were not all used for everyday sampling. With the exception of the first set of samples, all of the sample sets were collected at the following points: I-1, I-3, E-1, E-5, and E-6. I-2 was not typically used since it should be essentially the same as I-3 when the in-pond CEPT was running. E-2, E-3, and E-4 were used on the first day only. This first day however did not include samples taken at E-5 and E-6. After the first day it was decided that since the focus was on the performance of the anaerobic lagoon that a composite sample of the three facultative lagoons was all that would be necessary. Therefore, E-5 was used in place of E-2, E-3, and E-4 after the first day of sampling. Though not critical, it was also decided that the final effluent after chlorination should be measured. It is not critical because there should be little or no removal of TSS or COD in the chlorination tank.

5.4.2 Sample Collection

The sampling method was simple - glass or plastic bottles were used to collect and store the samples. Often these bottles were simply mayonnaise or water bottles. They were cleaned thoroughly before use. Additionally, the bottles were rinsed with the sample water immediately prior to collection of the sample. The sample was collected by hand with the aid of a rubber glove. When the sample was collected, the bottle was fully submersed in the water with the opening facing upstream. The bottle was swirled in a circular motion to ensure a representative and mixed sample. Once full the bottle was removed from the water and the top inch or so of water was poured back out. This enabled the same bottle to be used effectively to mix the sample prior to lab work by shaking vigorously.

5.4.3 Frequency of Sampling

The samples were collected typically once or twice every day that the MIT M.Eng. group was in Riviera. The number of samples that could be taken was limited by the fact that the samples and analysis was done for the most part by one person, and by the lab was 3 km away from the wastewater lagoons. Sampling time varied a great deal as well. Samples were taken during the day any time between 9am and about 6:30pm. Since the residence time in the anaerobic lagoon is nearly two days, the efficiency of this or the other lagoons does not vary dynamically through the day. Thus, this variation is actually not of great importance.

5.4.4 Visual Observations

Each time that a set of samples was collected, a log of visual observations was also recorded at each sampling point. The observations that were taken were done with the purpose of qualitatively observing how the CEPT system changed over time.

There were a number of parameters that were measured or observed each day and at each sampling point. There were general observations made about the weather, temperature, wind and parameters of this nature. The first full set of observations were made around the I-2 and I-3 sampling points. The observations here generally revolved around the influent wastewater, flocculation chambers, and part of the anaerobic lagoon. Parameters that were noted included the number of pipes carrying influent flow (i.e. number of pumps operating at the time), the color of the water, and the operation, or lack thereof, of the polymer dosing system. In the flocculation chambers and often at the I-3 sampling point, temporary samples were taken to observe the floc formation and size. The relative smell potency of the sampling point was also recorded here, and at the other points as well. A scale of 1 to 5 was used to quantify the results, a 1 being no noticeable smell, and a 5 being an extremely strong odor. The last observations at this point were made concerning the anaerobic lagoon, and were taken in a bit more detail at the opposite end of the lagoon at sampling point E-1. These observations were mainly regarding the color of the lagoon water, the amount and presence of both bubbling and foam formation in the lagoon. Observations were also made about the presence, and amount of scum and algae floating on the surface and the lagoon. The observations at this point again included smell. Similar observations were also made at sampling point E-5. This point however encompassed all of the observations made with regard to the facultative lagoons. This point also included the observations about the chlorination tanks. The last sampling point in which observations were made was at sampling point E-6, at the Parshall flume. Since the flume had a calibrated flow meter, the effluent flow rate of the wastewater was easily read and therefore recorded with each sample set taken.

5.5 Test Results

5.5.1 Visual Observations Analysis

Making visual observations is a critically important factor in the attempt to fully understand a system. Through the course of the January 2000 field study, the wastewater system was closely observed to see how it changed with the implementation of "in-pond" CEPT. While a complete and detailed observation log can be found in Appendix A, this section will highlight the most important trends.

From the day that the chemical addition began, the system began to make changes very rapidly. One of the first noticeable items was the tremendous decrease in odors. On a measurement scale of 1 to 5 for odor, 5 being the worst, the plant at the location of strongest smell went from being a 5, down to about 2.5 to 3 within a day or two. Another point that became evident early was the formation of visible floc near the inlet of the anaerobic lagoon. Referring to the Floc Size Measuring Scale shown in Appendix B, the floc sizes at this location generally ranged between 'b' size and 'C' size. The flocs were often larger during low flow periods when there was less turbulence in the flocculation chambers. Along with a high flow rate, the absence of polymer also had a large effect on decreasing the size of the floc present.

As the system evolved over the first few days of CEPT operation, a few additional important observations were made. The next of these to become evident was the increase in bubbling and gassing of the lagoons. This was often strongest in the anaerobic lagoon, but was certainly prevalent in the facultative lagoons as well. This was likely the cause, or at least partial cause of another very interesting phenomena. A few days after the chemical addition began, small pieces of floating sludge began to appear near the entrance of the facultative lagoons (See Figure 28). Within a few days of their initial presence, the 'sludge bombs' could be seen throughout the entire lagoon, in all of the facultative lagoons. This is most likely a result of the gassing dislodging sludge that had settled at the bottom, allowing it to float to the surface. However, it is possible that additional bio-chemical reactions aided in this phenomenon.

Figure 28: Floating 'Sludge Bombs' in the Facultative Lagoons

Another interesting observation that was made was that the wastewater in the anaerobic lagoon and at the bottom of the facultative lagoons turned black. This was a slow process, which began within a day or two of the initialization of the chemical addition. It was clearly a direct result of the ferric sulfate addition. This is because the color change migrated through the lagoons at the same rate that the flow would be expected to move, based upon theoretical residence times of the lagoons. It turned out that after review by a seasoned chemist, that the discoloration was a result of a chemical reaction that was occurring because of the presence of the additional iron and sulfate, as well as the change in pH resulting because of this addtion. It is likely that the reaction was in part due to the anaerobic conditions present. This can be said for two reasons: 1) The black water not present in the top of the facultative lagoons where the system is aerobic, and 2) The black water was not simulated in the jar tests, where the sample was always kept aerated by the mixers.

One final observation that is interesting to note was the formation and presence of foam in the lagoons (See Figure 29). This generally formed in the anaerobic lagoon, and then flowed out into the facultative lagoons. This often occurred after a heavy rain, so rain likely has some impact. It is likely that the foam formation too was aided by the excess bubbling in the lagoons.

Figure 29: Formation of Foam at the Exit of the Anaerobic Lagoon

5.5.2 Riviera Plant Efficiencies Prior to CEPT

Being a privately owned and operated plant, the data collected and maintained at Riviera is actually quite good, especially by Brazilian standards. In terms of the wastewater treatment plant, the staff measures a number of parameters on a regular basis. The flow in and out of the treatment system is measured every day. Samples are also taken and tested for BOD and COD on different days and at different locations. On Tuesdays and Thursdays, they sample the raw influent (I-2), the effluent from the anaerobic lagoon (E-1), the effluent from each of the facultative lagoons (E-2, E-3, & E-4), and the final effluent (E-6). On Mondays and Saturdays, they sample only at the influent (I-2) and effluent (E-6) to the plant as a whole.

The records go back two years, starting from late December in 1997 (See Appendix C for complete set of data). For this two-year period, the overall influent raw wastewater had an average BOD level of 183 mg/L, and a COD level of 415 mg/L. The average for the final effluent for BOD was 44 mg/L and 156 mg/L for COD. Thus, for this 2-year period the system had an average removal efficiency for BOD of 72.3%, and 56.7% for COD. While this is good, the average effluent flow rate over this period was only 3,225 m^3/day.

While this data is useful, looking at the entire data set is not always appropriate. Since the January 2000 field study was conducted in the peak summer season, it is useful to isolate the summer months over the past couple of years for comparison. Additionally, since the primary effect that is desired to be measured and analyzed is the change in performance in the anaerobic pond due to in-pond CEPT, the removal efficiency of just this pond should be isolated. Therefore, Figure 30 below, shows the removal efficiencies of BOD and COD in the anaerobic lagoon over the past two summers, before CEPT was initiated. As can be seen from the figure, the removal efficiencies during summer months are not only quite low, but they are also quite variable.

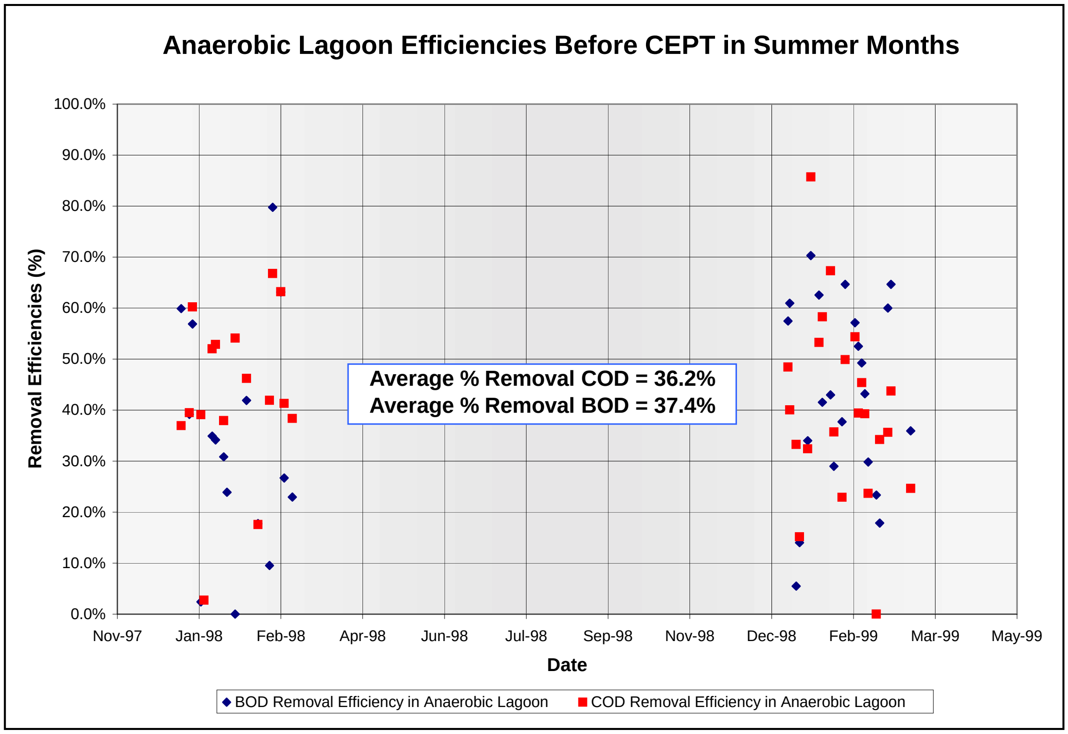

Figure 30: Efficiencies in the Anaerobic Lagoon in Summer Months Prior to CEPT Upgrade

Since there was a full-scale test done with pre-pond CEPT during Carnival 2000, it is also of interest to look at the original system prior to the upgrade during Carnival 1999. During both of these periods, extensive measurements were taken at the normal locations. During Carnival 1999, measurements were taken every two hours, starting at 8:00 AM and continuing until 8:00 PM, on the dates 2/13/99 – 2/16/99 (See Appendix D for raw data). During Carnival 1999, the wastewater influent to the anaerobic lagoon had an average value for BOD of 176 mg/L, and average COD of 584 mg/L. The final effluent wastewater had an average value for BOD of 36 mg/L, and an average COD of 252 mg/L. This corresponds to average removal efficiencies through the whole system, of 79% and 57% for BOD and COD, respectively. It is also important to note that the average flow during this period was 6,969 m^3/day.

5.5.3 In-Pond CEPT Test Results

Measurements and analysis of the in-pond CEPT system was performed from January 7, 2000 to January 18, 2000. During this time, the two parameters that were measured were TSS and COD. From this sampling period, there are unfortunately four sample sets that clearly contain an error in the test results. These data points are denoted below in Table 12. This figure contains the summary data from all of the analysis during this period. The figure shows only the removal of TSS and COD for both the entire treatment system, and the removal efficiency of the anaerobic lagoon alone.

Table 12: TSS and COD Removals During "In-Pond" CEPT at Riviera

Date	**Time**	**% Removal of TSS from I-1 to E-6 (Total System)**	**% Removal of TSS from I-3 to E-1 (Anaerobic Lagoon)**	**% Removal of COD from I-1 to E-6 (Total System)**	**% Removal of COD from I-3 to E-1 (Anaerobic Lagoon)**	**Comments**
01/07/00	4:00 PM	54.7%	-212.5%	-----	-----	Bad Data
01/08/00	5:00 PM	72.4%	92.2%	-----	-----	Bad Data
01/09/00	9:00 AM	80.4%	79.0%	59.8%	45.5%	Good Data
01/10/00	12:00 PM	77.6%	98.8%	60.5%	30.2%	Bad Data
01/10/00	6:00 PM	64.3%	75.6%	66.9%	46.8%	Good Data
01/11/00	10:30 AM	54.4%	-117.9%	40.5%	17.0%	Bad Data
01/11/00	4:45 PM	85.2%	83.3%	75.8%	56.0%	Good Data
01/12/00	10:00 AM	81.1%	82.3%	74.9%	58.6%	Good Data
01/12/00	6:30 PM	74.1%	77.9%	76.2%	47.1%	Good Data
01/16/00	1:00 PM	79.8%	76.1%	73.9%	65.1%	No Polymer
01/17/00	2:00 PM	87.9%	81.0%	63.4%	66.1%	No Polymer
01/17/00	6:00 PM	79.4%	73.9%	47.7%	47.7%	No Polymer
01/18/00	10:30 AM	83.3%	65.8%	68.7%	33.5%	No Polymer
Average: All Data:		75.0%	42.7%	64.4%	46.7%	
Average: "Good Data":		**77.0%**	**79.6%**	**70.7%**	**50.8%**	
Average: Good & No Polymer Data:		**79.5%**	**77.2%**	**67.5%**	**51.8%**	

While there are three averages presented in the figure, the set that is most appropriate is the one that includes all of the good data points, regardless of whether polymer was added. From this set, the parameters of greatest interest are the removals of TSS and COD that take place in the anaerobic lagoon. This is the most important parameter to look at in this instance because this is where the major change in the system will occur due to the upgrade to "in-pond" CEPT. Figure 31 below depicts the performance of the lagoon during this period. It is interesting to note that the removal efficiencies begin to drop in the last couple of days shown. This is very possibly a direct result of the lack of polymer addition to the system. It has in fact been shown through bench-scale analysis that the addition of polymer does improve the removal rates. At another plant in Brazil, ETIG, it was found that the addition of 50 mg/L increase the COD removal efficiency over 20%.[37]

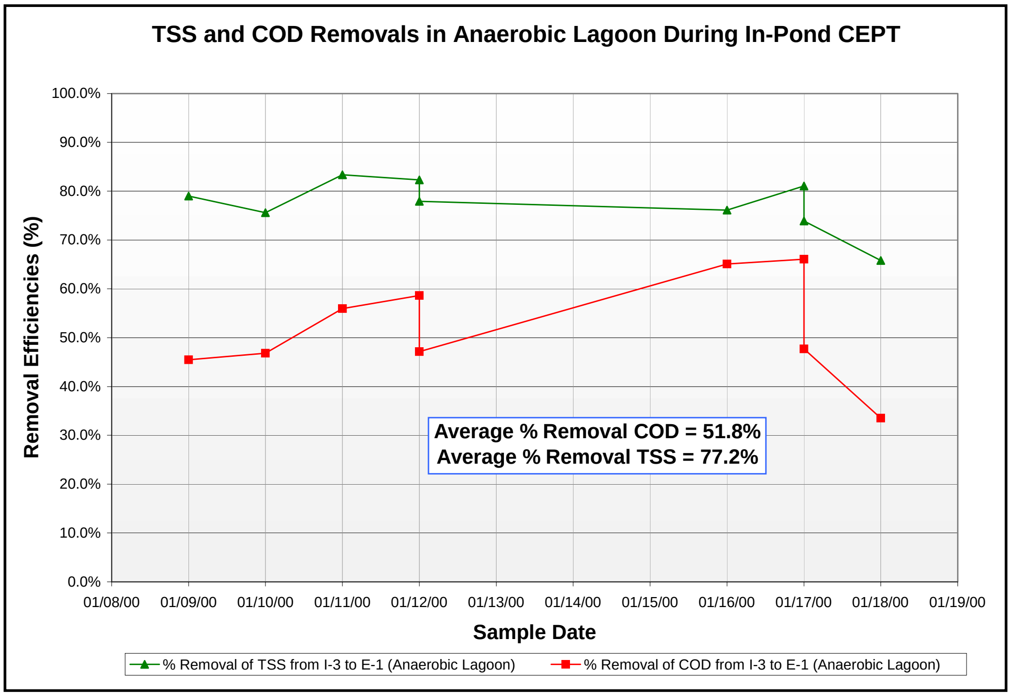

Figure 31: Graphical Representation of COD and TSS Removals in the Anaerobic Lagoon During "In-Pond" CEPT

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[37] Yu, I.W., "Bench-Scale Study of Chemically Enhanced Primary Treatment in Brazil." Department of Civil and Environmental Engineering, Massachusetts Institute of Technology. May 2000, pp. 54.

As is shown is the previous figure, the average removal of COD during the in-pond CEPT test period was 51.8%, and 77.2% for TSS. As shown in the previous section, the removal of COD during summer months prior to the upgrade to CEPT was on average 36.2%. Thus, the COD removal efficiency jumped over 15% in this short period. While TSS was not measured prior to the January field study, it can be compared to a couple of benchmark numbers. The first is a typical primary treatment facility, which generally achieves about 60% removal of TSS. This system is clearly doing considerably better than a traditional primary treatment facility, in fact, more than 17% better. The second benchmark that is appropriate to use is an optimized pre-pond CEPT clarifier, which on average achieves about 85% removal of TSS. While, this system is not as high as that, it is close. It is also important to consider that while these results do seem quite good, the system did only run for about two weeks. Therefore, to truly see the performance of in-pond CEPT at Riviera, a longer study really should be considered.

Besides the performance of just the anaerobic lagoons, it is also interesting to look at the effect that in-pond CEPT has on the treatment system as a whole. As shown above in Table 12, the removal efficiencies of the whole system were generally only slightly better than the anaerobic lagoon by itself, and in some instances slightly less. As can be seen in the complete data set located in Appendix E, the TSS and COD level actually worsened from the exit of the anaerobic lagoon to the exit of the facultative lagoons. This is most likely in part due to a couple factors. The first, and likely most important, is the presence of the floating ‘sludge bombs’ mentioned previously. These would certainly have an adverse effect on the performance of the facultative lagoons given that they were able to exit the lagoon in high quantity. The other factor that would detract from the performance of the facultative lagoons is the presence of algae in the ponds.

This is actually a common problem in lagoon systems, regardless of whether CEPT is used, and seems to have played a role at Riviera as well. The presence of algae in the effluent will raise both the COD measurement and the TSS measurement. Again, this is likely given the ability of the algae to flow out of the lagoons.

5.5.4 Pre-Pond CEPT Test Results

While the pre-pond CEPT system never ran for more than a few hours at a time during the January 2000 field study, it was running off and on in the months following. Luckily, they did get the system to run during the most heavily loaded time of the year, Carnival 2000. As is usually done during this time of the year, comprehensive data collection and analysis was performed. They conducted a five-day series of 24-hour composite sampling collection from 3/3/2000 to 3/7/2000, the peak of Carnival. The complete data set from Carnival 2000 can be found in Appendix F.

During this period, one additional measurement was taken compared to the years prior in order to give an indication of the CEPT clarifier. During this time, the average influent BOD level was 230 mg/L, while the average influent COD was 471 mg/L, and the average influent TSS level was 197 mg/L. Effluent from the CEPT clarifier, the averages dropped to 121 mg/L for BOD, 235 mg/L for COD, and 65 mg/L of TSS. This corresponds to an average removal efficiency of 47% for BOD, 50% for COD, and 67% for TSS. Unfortunately, TSS was not measured at the final effluent, although BOD and COD were still measured. The final effluent measurement for BOD was 34 mg/L, and 140 mg/L for COD. This corresponds to an overall removal efficiency of 85% for BOD, and 70% for COD. Additionally, it should be noted that during this measurement period, the average flow rate was 7,481 m^3/day.

Therefore, in comparison to Carnival 1999, the system did show a slight increment of higher performance. The BOD efficiency increased by 6%, while the COD efficiency increased by 13%. While the increment of average change is not astonishing, it is important to note that the efficiencies obtained with pre-pond CEPT were considerable more consistent than those prior to CEPT. Additionally, the CEPT clarifier is actually performing below average compared to typical results from pre-pond CEPT systems. This is despite the fact that the metal salt was changed from ferric sulfate to ferric chloride, which has proven to have the best results for CEPT plants in Brazil.

5.5.5 Comparative Analysis of Treatment Alternatives

To provide a useful comparison, it is appropriate to look first at the change in performance through the anaerobic lagoon, then the whole system. Because both the in-pond and pre-pond CEPT tests were conducted during the summer months in Brazil, it is appropriate to use previous years' summer data as a baseline for comparison. First, as mentioned previously, the removal efficiency in the anaerobic pond alone for these summer periods without CEPT was 37.4% for BOD, and 36.2% for COD. During the in-pond CEPT test, the efficiency of the anaerobic lagoon was 51.8% for COD, and 77.2% for TSS. Looking at the same point, effluent to the anaerobic lagoon for the pre-pond CEPT trial, it is important to first note that the wastewater has completed two treatment processes at this point following this treatment train. Given that, the removal efficiency for pre-pond CEPT through the anaerobic lagoon was 59% for BOD, and 60% for

COD. Looking at the common analysis method, COD, the efficiency at the effluent end of the anaerobic lagoon went from 36.2% without CEPT, up over 15% using in-pond CEPT, and up about 24% using pre-pond CEPT.

For this same summer periods prior to the CEPT upgrade, the overall removal efficiencies were 71.8% for BOD, and 50.5% for COD for the entire treatment system prior to the CEPT upgrade. For the in-pond CEPT test, the total system removal efficiencies were 67.5% for COD, and 79.5% for TSS. Similarly, for the pre-pond CEPT test, the final removal efficiencies were 85% for BOD, and 70% for COD. Again, the common analysis tool used that links the three methods is COD. Thus, it can be seen that prior to the CEPT upgrade, the system removed on average 50.5% COD, and this increased 17% using in-pond CEPT, and 19.5% using pre-pond CEPT. This analysis is summarized below in Table 13:

Table 13: Comparison of Different CEPT Implementations at Riviera

	Efficiency Through the Anaerobic Lagoon (I-2 to E-1)			**Efficiency Through the Entire Treatment System (I-2 to E-6)**		
	% BOD Removal	**% COD Removal**	**% TSS Removal**	**% BOD Removal**	**% COD Removal**	**% TSS Removal**
Prior to CEPT	37.4%	36.2%	----	71.8%	50.5%	----
In-Pond CEPT	----	51.8%	77.2%	----	67.5%	79.5%
Pre-Pond CEPT	59.0%	60.0%	----	85.0%	70.0%	----

5.6 The Future at Riviera

5.6.1 Possibilities for Improvements in Testing Methods

There are several items that could be improved at Riviera to obtain better and more consistent analytic results in the lab. Most of these items are due to errors and difficulties experienced by the M.Eng. group during the January 2000 field study. The first item was largely resolved during the field study, but caused problems throughout most of January 2000. This is the method used to test for Fixed and Volatile Solids. While Standard Methods specifies a cooking temperature of 550°C, it was found that this temperature actually melted the aluminum tins used at that time. If ceramic crucibles were used to do the firing, they were heavy enough that all precision was lost. Many of these problems are apparent in the data analysis presented in Appendix E. The best solution was to fire the sample in the aluminum dishes at 400°C, instead of 550°C.

Another issue that posed problems was the humidity in the lab. Many of the testing methods require a sample to be cooked for the purpose of removing all moisture; However, this effect is diminished due to the high moisture content in the air in the laboratory. This problem can be resolved or at least lessened by installing an air conditioner in the main lab facility.

The final issue that is crucial to achieve meaningful data is composite sampling. For the most part, the samples that are taken at Riviera were grab samples taken a few times a week. However, since the wastewater quality can fluctuate dramatically throughout any given day, grab samples are often not a very good representation of the system. Adding automatic composite samplers would allow plant technicians to test only one sample a day that represented a combined wastewater sample from the whole day at each location. Doing this would provide more meaningful results.

5.6.2 Possibilities for Improving the Overall Plant Efficiency

There are also a few things that could likely improve the overall performance of the system over what was achieved during the January 2000 field study. The first issue concerns the performance of the facultative lagoons during the in-pond CEPT test. As mentioned previously, due to the presence of the floating ‘sludge bombs’ and algae, the final wastewater quality actually worsened on numerous occasions. There are a few possible ways to resolve this problem. One would be to simply take the facultative lagoons offline and run the system without them. This however, is not an ideal situation. Another possibility is to obtain better filters at the effluent end of the facultative ponds, and to keep them well maintained. This would greatly reduce the amount of large sludge and algae particles that flow out of the lagoons. Yet another alternative is to clean the facultative lagoons to remove the sludge and algae. However, the cheapest and most likely alternative is to allow the system to run, and hope that the system stabilizes and that the ‘sludge bombs’ cease to form.

Another way to possibly improve the system is to optimize the chemicals and dosages used. This was in fact done, by changing the metal salt from ferric sulfate to ferric chloride. This was done because ferric chloride not only showed the best results in the bench-scale tests that were done in Riviera, but it has also proved to be the most effective chemical for CEPT throughout Brazil.[38]

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[38] Yu, I.W., 2000.

CHAPTER 6 - CONCLUSIONS

Chemically Enhanced Primary Treatment has proven to be a cost-effective and efficient method of treating wastewater, not only in Riviera de Sao Lourenco, Brazil, but also throughout the world. There are essentially two ways in which CEPT technology is being implemented in the world today. The first is referred to as “pre-pond” CEPT, which entails utilizing a modified primary settling tank that has been built or retrofitted to use metal salts to enhance settling. This is currently the most widely used method of CEPT. In Riviera, the full-scale test using this implementation resulted in an efficiency of the CEPT clarifier of 47% removal of BOD, 50% removal of COD, and 67% removal of TSS. Likewise, in other pre-pond CEPT plants, removal efficiencies for BOD have ranged from about 57% in San Diego, which has no secondary treatment, to 62% for the CEPT portion of the plant in Ipiranga. COD removal efficiencies have been found consistently at 65% in ETIG, and 63% in Ipiranga, again after only the CEPT stage of the treatment process. The third parameter, TSS, was about 86% at Point Loma, and as high as 80% in Ipiranga.

The second implementation of CEPT is referred to as “in-pond” CEPT, which entails adding chemicals into the waste stream that flows directly into a stabilization pond. This technique is almost exclusively used in Scandinavian countries. It is only by circumstance that this technique was used for a short period in Riviera. Regardless of the reason, in-pond CEPT at Riviera actually generated quite good results. In terms of COD removals, the anaerobic lagoon alone removed about 52%, and about 67% was removed through the whole process. For TSS, the anaerobic lagoon removed about 77%, and the whole system removed just slightly more TSS at just about 80%. In Scandinavia where they have spent years optimizing the performance of their chemical precipitation ponds, they get considerably better results on average. The average removal of COD is about 72%, and the average removal of (T)SS achieved is about 83%. This is a good indication of how far this technology can go. Actually, in part because of the success at Riviera, it is currently being studied further in Brazil by former M.Eng. student Christian Cabral, at a new treatment plant in San Juan Buena Vista, Brazil.

Both CEPT implementations have their advantages and disadvantages. In comparing the two methods, the major advantage of pre-pond CEPT is that it greatly reduces the sludge accumulation in the pond, and furthermore increases the performance of the pond by decreasing the influent loading. Of course, the sludge still does have to be removed, often on a daily basis, from the pre-pond CEPT clarifier. On the other hand, the major advantage of in-pond CEPT is more cost and maintenance based. Since there is not a clarifier tank required, the capital cost is considerably lower. Additionally, the operational costs and maintenance cost are quite a bit lower, largely because a highly qualified technician is not required to closely monitor the system on a frequent basis. However, regardless of the specific implementation of CEPT, it is clear that this is a very effective treatment method, and it is slowly changing the way wastewater treatment is done around the world.

APPENDIX A - VISUAL OBSERVATIONS LOG

January 7, 2000 – Friday:

While formal observations were not taken this day, there were a few notable observations. First were the extremely strong odors that were concentrated primarily at the inlet and Parshall flume. However the odor at the anaerobic lagoon was also quite strong. The color of the anaerobic lagoon did not seem out of the ordinary. It was a dark greenish-blue color, similar to what would be expected in any lake of similar depth.
Samples collected about 4pm.
Samples taken at the final pumping station (I-1), the effluent end of the anaerobic lagoon (E-1), and the effluent end of each of the three facultative lagoons (E-2, E-3, & E-4).
Chemical addition started at 4:30pm.

January 8, 2000 – Saturday:

At 5pm the next set of samples were taken.
The sampling points were changed slightly from those used Jan 7th.
The sampling points that were decided upon and corresponding visual observations for this day are as follows:

Influent to the system taken at the final pumping station (I-1):
No visual observations were taken at this location.

Influent to the anaerobic lagoon, after chemical and coagulant addition (I-3):
Flow from all three inlet pipes (i.e. two of the three pumps in operation). Larger flow causing many flocs to break. Floc size ~ d. Flocs form well in flocculation channel, but breakup at the drop off to about b size, which is what it was at the sampling point. Smell much less than yesterday – On a scale from 1 to 5 (1 being a negligible smell to 5 being extremely strong), today would rank a 3.5 versus yesterday which was at a 5.

Effluent to anaerobic lagoon / influent to facultative lagoons (E-1):

Compared to yesterday, the anaerobic lagoon appears much darker, blackish in color. Smell ~ 2. Very little floc visible to the eye, perhaps b size. Foam formation on lagoon surface, 1mm to 3mm in diameter.

<u>Composite effluent to Facultative lagoons (observations taken at center lagoon) (E-5):</u>
Facultative lagoons contain some large green foaming patties. Greenish-brown color in lagoon and at the sampling point. Smell ~ 1.5-2.

<u>Effluent to the chlorination tanks (E-6):</u>
Flow at 80 L/s at the calibrated Parshall flume. Color is green with light brown. Odor is negligible ~ 1.

<u>January 9, 2000 – Sunday:</u>

First thing in the morning was a trip to the lagoons at 9am.
At this point the chemical addition has been running for about 41 hours.
The following visual observations were made at the lagoons during this morning's sampling:

<u>General:</u>
Sunny day. No Wind.

<u>I-3:</u>
Medium flow. WW is black in color. Visual samples indicate poor flocculation, size ~ b. Some scum on the two easternmost corners of the anaerobic lagoon. H_2S smell is medium strong today (3.5)

<u>E-1:</u>
Small amounts of bubbling on anaerobic lagoon. Smell ~ 3. There was foam in the weir after the anaerobic lagoon.

E-5:

Same as yesterday. Some sum / green algae floating in corner. More bubbling than yesterday.

E-6:

Flow = 45 L/s.

January 10, 2000 – Monday:

The next trip to the lagoons was taken at about 12 noon. The visual observations for this sample set are as follows:

General:

Sunny day. Light Wind.

I-3:

In the flocculation chambers there was foam of a diameter ranging from 2-5cm floating on the surface. After drop off at end of floc chambers, floc size ~ c. In the chamber itself, floc size ~ c. Floc clearly not breaking up upon exiting the flocculation channels today. Odor ~ 3.5.

E-1:

Small (0.5-5cm diameter) white foam at surface of the anaerobic lagoon. Water color very black. Lesser amount of algae and algae blooms today as compared to yesterday and previous days. Almost no bubbling today.

E-5:

Less scum than yesterday. Much less, almost no bubbling in facultative lagoon today. A few black sludge blobs have surfaced and are floating on top on the lagoon: diameter ~ 5-40cm. Blobs isolated to the region near the influent end only. Effluent entering the chlorination tanks is much darker than ever before (muddy green color). Possible short-circuit through facultative lagoons. All but first chamber in chlorine tanks are the same green color.

E-6:
Flow = 50 L/s.

The next set of samples was collected later that day at 6pm. The corresponding visual observations are as follows.

General:
Sunny day. No Wind.

I-3:
Only the smallest of the three inlet pipes flowing at this instance ~ low flow. Some larger floc forming in floc chamber ~ D size. Slightly less black, somewhat brownish. Very small floc only in channel at sampling point ~ b size. Thick algae layer in corner of anaerobic lagoon.

E-1:
Still small white foam on the very black lagoon. Small amount of bubbling, but much more than earlier in the day. Smell ~ 2.5 (higher than at noon).

E-5:
Only a few of the large black floating blobs remain. Green algae blooms in lesser numbers. Small amount of bubbling over entire facultative lagoon. Continuing to dump darker water into the chlorination tanks. Foam has begun to form in the first two chlorine tanks. It appears all chlorine tanks are slightly more brownish than earlier in the day.

E-6:
Flow = 70 L/s.

January 11, 2000 – Tuesday:

The first set of samples for the day were taken at 10:30am. The visual observations for this sampling session are as follows:

General:

Sunny, minimal clouds, slight clouds, and about 90°F.

I-3:

Smallest pump only running at time of sampling. At sampling point – C size floc. Smell as it has been ~ 3.5. So algae and bubbling in lagoon, but no change from last night.

E-1:

Small foam formations over entire anaerobic lagoon (approx. 1cm diameter). Almost no smell today ~ 1.5 (likely due in part to wind direction). Small amount of bubbling over entire arnaerobic lagoon.

E-5:

Smell ~ 2. Still floating algae on facultative lagoons. Increasing number of small black floating blobs. The sludge bombs are still only near the influent end of lagoon, but starting to advance further through the lagoon. [Note: Time since chemical addition start = 90 hours.] Chlorine tanks are same color as last night.

E-6:

Flow = 40 L/s.

Just prior to the flow being diverted into the clarifiers, another set of samples to test the efficiency of the in-pond CEPT were taken. These samples were taken at about 4:45pm; The visual observations at that time are as follows:

General:

Overcast, still warm ~ mid 80s, almost no wind.

I-3:

Flow currently from all 3 inlet pipes (2pumps). Floc channel closest to the anaerobic lagoon was closed this morning, in part to allow the collection of sludge in the floc chamber. At sampling point, floc size ~ B. In the one operating floc chamber, floc size ~ C. Much more bubbling in anaerobic lagoon this afternoon than earlier in the day.

E-1:

Smell still light ~ 2. Small foam bubbles floating on the surface of the anaerobic lagoon. All algae on lagoon are in one corner of the anaerobic lagoon near the clarifiers. Lots of bubbling over whole lagoon. Of interesting note, the foam once again is forming and dissipating in a rather unusual manner. The foam gradually forms over more and more of this end of the lagoon; then with no apparent reason, the foam begins to dissipate moving along as a wave move across the water. Sometime it also starts from a point and dissipates concentrically from that point. The formation and disappearance do not seem to be related to the wind.

E-5:

Facultative lagoon odor ~ 1.5. Less algae clumps, only a few in the corners and edges of the facultative lagoons. Still black sludge bombs, but less concentrated by the inlet area as compared to earlier in the day.

E-6:

Flow = 70 L/s.

January 12, 2000 – Wednesday:

At 10am, a set of samples for pre-pond CEPT was collected, and expected to be the last samples for in-pond CEPT. The visual observations for this sample set were as follows:

General:

Sunny and Hot (~100°F), very low wind, some clouds in the sky.

I-3:

Both floc chambers are open and running. Beginning to switch to pre-pond CEPT. Odor ~3. Lots of bubbling in anaerobic lagoon. Still black water. Floc size at sampling point ~ b. Same amount of algae at this side of lagoon.

E-1:

Large amount of bubbling over entire anaerobic lagoon. Still many white foam bubbles on surface of lagoon. No visible algae formations on this side of the lagoon. Odor ~2.

E-5:

Same small black floaters today. They do however seem more mixed throughout the lagoon and are broken into smaller pieces with a diameter ranging from ~ 0.5 – 2cm. Black blobs are well mixed with the green floating algae. Smell ~ 2.5. Darker water still entering chlorine tanks. Slightly less dark in color today though. However the same color scheme (first two tanks darker than the rest) remains in the chlorine tank system.

E-6:

Flow = 40 L/s.

At about 6:30pm, I went to the lagoons to collect another set of samples. The corresponding visual observations are below:

General:

Raining since mid afternoon, temperature in the high 60s.

I-3:

Smell ~ 2. Fairly high flow at time samples were taken. In floc chamber and at sampling point, floc size ~ c. Less algae in anaerobic lagoon. Water still very black. Also had additional flow being pumped out of the non-functioning clarifier into the influent to the anaerobic lagoon.

E-1:

Lots of foam in effluent from the anaerobic lagoon. Per Christian, at about 4pm today, there were huge sheets of foam flowing into the facultative lagoons. Smell ~ 3.5.

E-5:

Facultative lagoons appeared to have a lesser amount of black sludge bombs this evening. Almost no algae present on surface of facultative lagoons. (Both likely due to the rain). Some foam in lagoon, but only near inlets.

E-6:

Flow = 135 L/s.

January 16, 2000 – Sunday:

At approximately 1pm I returned to the lagoons to take a set of samples. It is important to note that the polymer dosing system was still not working at this time, and that it had not been working at this point for approximately 40 – 45 hours. Therefore, much of the effluent to the anaerobic lagoon was likely without full benefit of the anionic polymer. As usual, visual observations were taken in conjunction with the samples. These observations were as follows:

General:

Hot and humid day, many white and some dark clouds in sky.

I-3:

All 3 pipes flowing at this time (i.e. 2 of the 3 pumps are operating). Both flocculation cambers are open and running. CEPT still not operational. Polymer dosing system is still broken, hence no polymer addition. Black water in infleunt. Smell ~ 3. Some algae blooms in the anaerobic lagoon; about normal amount. At sample point there is only very small flocs forming ~ A – b.

E-1:

The anaerobic lagoon is very black today. Very small amount of gassing (bubbling) today. Less algae formations on this end of lagoon. Water appears to have a filmy layer on the surface. Very little foam on the lagoon surface. Smell ~ 2.

E-5:

Facultative lagoons have some green algae formations at surface. Still a few small sludge bombs (0.5cm – 10cm in diameter) on surface near the inlet. At the inlet channel to the facultative lagoons, there is a very large amount of foaming (looks like a bubble bath). Smell ~ 2. Still darker water entering the chlorine tanks.

After a walk around all three facultative lagoons, the black sludge bombs are now clearly dispersed throughout the entire lagoon. Additionally the sludge bombs are clogging the filters at the effluent ends of the facultative lagoons. It is likely that some of the sludge is either flowing into the effluent in clumps, or by sitting on the filters and subjected to constant running water, being forced back into solution and leaving in the effluent. This is a likely explanation for the negative performance results of the anaerobic lagoons that have been observed in the laboratory test results.

E-6:

Flow = 90 L/s.

January 17, 2000 – Monday:

After lunch at about 2pm I returned to the lagoons to take the next set of samples and observations. Following are the observations taken at this time:

General:

Sunny, hot, and humid with some clouds in the sky. Note that it rained very hard yesterday evening and last night for a number of hours.

I-3:

Polymer dosing still not working. Practically no visible floc without the polymer, possibly about A – b size if any at all. Lots of bubbling in the anaerobic lagoon today. Very little floating algae on this side of lagoon today. Still quite black water. Smell ~ 3.

E-1:

All of the algae have apparently floated to this end of the lagoon. The algae look very white in color today. There are lots of small foam formations on this side of the lagoon. Color has not changed (still same black). Smell ~ 2.

E-5:

Facultative lagoons appeared very murky today. There is a lot of the black floating sludge bombs all over the facultative lagoons. Effluent from facultative lagoons still looks very dark today. Some more of the chlorine tanks look a bit darker in color today. Still foam coming into the facultative lagoons. No visible bubbling on facultative lagoons.

E-6:

Flow = 110 L/s.

I returned to the lagoons at about 6pm. Again, samples and the following visual observations were taken:

General:

Sunny and hot, some clouds.

I-3:

Still no polymer addition. Massive amount of bubbling in the anaerobic lagoon. Floc size at sampling point ~ B. Still dark water, though the influent seems slightly more transparent today. Same algae situation as earlier today. Smell ~ 2.

E-1:

Lots of foam bubbling in anaerobic lagoon. Same floating stuff and whitish algae as observed earlier. Still a lot of bubbling, but it is less on this side of the lagoon. Still blackish water. Smell ~ 2.5.

E-5:

Still black floaters throughout facultative lagoons. Today the color of the facultative lagoons is a milky green. Smell ~ 2.

E-6:

Flow = 100 L/s.

January 18, 2000 – Tuesday:

I arrived at the lagoons at about 10:30am and collected the regular samples and the following visual observations:

General:

Sunny and Hot thus far today. Some dark clouds in the sky, and a slight breeze. Weather reports indicate that it will rain later in the day.

I-3:

The polymer pump is still in the process of being repaired, therefore there continues to be no polymer added to the system. Still a huge amount of gassing (bubbling) in the anaerobic pond. Continues to be very black influent. There is a filmy scum layer on the edges of the anaerobic lagoon. Smell ~ 2.5.

E-1:

All of the algae blooms in the anaerobic lagoon have blown to the effluent end of the pond today. Still very black water. Scum layer on surface of anaerobic lagoon. Some bubbling in lagoon. Small amount of foaming on pond. Smell ~ 2.

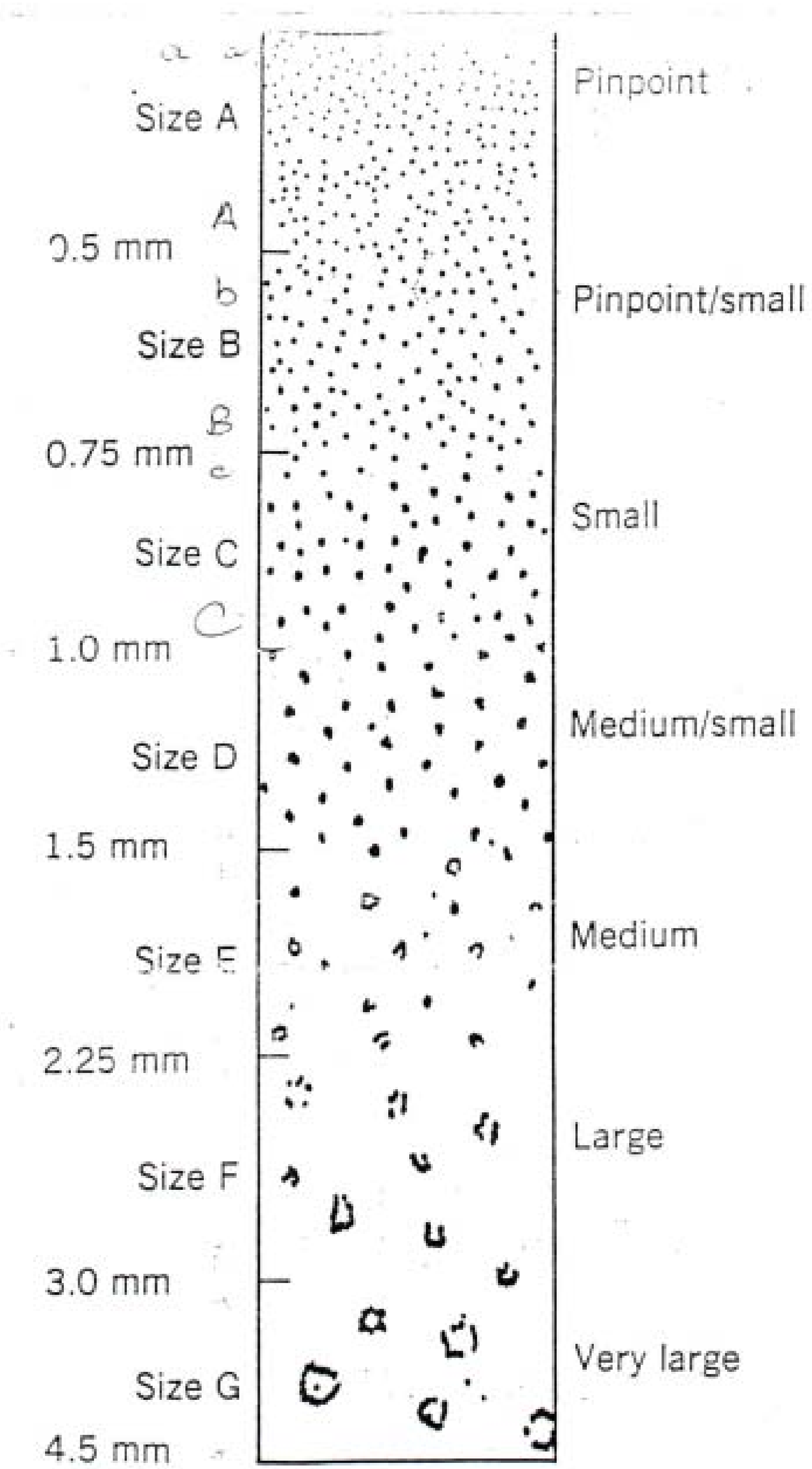
E-5:

Black plumes excreting into the facultative lagoons from every inlet point, versus just the one single inlet point where this typically occurs. Black sludge bombs remain all over lagoons. Less algae on surface of facultative lagoons at this of lagoon today; Likely that they have blown to opposite end of lagoons. Additionally it should be noted that it appears that the grass near the lagoons was cut today. As a result there is a large amount of grass in the Effluent (E-5) sample that may effect the test results.

E-6:

Flow = 45 L/s.

APPENDIX B – FLOC SIZE MEASURING SCALE


a a
Size A
A
0.5 mm
b
Size B
B
0.75 mm
c
Size C
C
1.0 mm
Size D
1.5 mm
Size E
2.25 mm
Size F
3.0 mm
Size G
4.5 mm
Pinpoint
Pinpoint/small
Small
Medium/small
Medium
Large
Very large

APPENDIX C – RIVIERA DATA PRIOR TO CEPT (2 YRS)

Date	Raw Inluent (I-2)		Anaerobic Lagoon Effluent (E-1)		Facultative Lagoon 1 Effluent (E-2)		Facultative Lagoon 2 Effluent (E-3)		Facultative Lagoon 3 Effluent (E-4)		Final Effluent (E-6)		% Removals		Flow Rate (m^3/day)	
m/d/yr	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**Entrance**	**Exit**
12/24/97	358	1450	75	210	45	150	52	160			39	170	89.1%	88.3%	3607	1596
12/25/97	217	460	87	290	55	210	52	210			43	210	80.2%	54.3%	4845	3348
12/26/97															4760	5362
12/27/97	148	278									39	210	73.6%	24.5%	4984	7038
12/28/97															5450	7236
12/29/97	130	278									42	198	67.7%	28.8%	5358	8965
12/30/97	235	476	143	288	60	208	60	108			37	198	84.3%	58.4%	5907	6930
12/31/97															6774	8748
1/1/98	392	862	169	343	59	235	77	225			54	235	86.2%	72.7%	7189	6912
1/2/98															6741	9108
1/3/98	181	389									75	243	58.6%	37.5%	6625	8658
1/4/98															5513	7074
1/5/98	215	486									58	282	73.0%	42.0%	4344	5238
1/6/98	209	614	204	374	84	269	79	259			71	278	66.0%	54.7%	4471	5400
1/7/98															6241	6966
1/8/98	147	365	159	355	59	269	75	269			76	269	48.3%	26.3%	5226	1037
1/9/98															5433	1177
1/10/98	140	346									57	259	59.3%	25.1%	4920	8640
1/11/98															4472	6264
1/12/98	252	548									58	259	77.0%	52.7%	3968	4482
1/13/98	252	548	164	263	74	217	81	227			67	236	73.4%	56.9%	3802	3240
1/14/98															3975	4428
1/15/98	246	628	162	296	78	222	68	222			69	231	72.0%	63.2%	4659	5292
1/16/98															5107	6858
1/17/98	157	351									90	231	42.7%	34.2%	5284	6264
1/18/98															5266	6534
1/19/98	164	330									77	229	53.0%	30.6%	4125	4793
1/20/98	253	522	175	324	85	225	84	225			97	252	61.7%	51.7%	4146	4590
1/21/98															4645	4158
1/22/98	180	137	137	282	85	243	71	233			76	233	57.8%	-70.1%	5252	4374
1/23/98															5173	4806
1/24/98	162	408									82	243	49.4%	40.4%	5093	5508

Date	Raw Inluent (I-2)		Anaerobic Lagoon Effluent (E-1)		Facultative Lagoon 1 Effluent (E-2)		Facultative Lagoon 2 Effluent (E-3)		Facultative Lagoon 3 Effluent (E-4)		Final Effluent (E-6)		% Removals		Flow Rate (m^3/day)	
m/d/yr	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**Entrance**	**Exit**
1/25/98															4670	7992
1/26/98	184	525									92	262	50.0%	50.1%	5060	5220
1/27/98	233	691	233	317	55	230	65	209			65	250	72.1%	63.8%	5010	4320
1/28/98															5750	3672
1/29/98															5178	4050
1/30/98															5953	3564
1/31/98															6981	4212
2/1/98															0	4248
2/2/98															0	3186
2/3/98	210	487	122	262	85	262	90	262			73	253	65.2%	48.0%	0	1998
2/4/98															2086	1782
2/5/98															1923	1890
2/6/98															1463	3240
2/7/98	150	388									54	249	64.0%	35.8%	5470	2448
2/8/98															2368	2700
2/9/98	32	92									71	220	-121.9%	-139.1%	2933	6804
2/10/98	107	256	88	211	88	293	92	256			55	202	48.6%	21.1%	3945	1948
2/11/98															6645	1253
2/12/98	51	99	104	117	52	144	65	180			60	162	-17.6%	-63.6%	7819	15444
2/13/98															6613	13500
2/14/98	28	99									53	126	-89.3%	-27.3%	4538	7452
2/15/98															3432	2916
2/16/98	137	217									51	109	62.8%	49.8%	5561	5400
2/17/98	105	186	95	108	62	196	72	206			42	176	60.0%	5.4%	4194	3456
2/18/98															4194	2214
2/19/98	168	403	34	134	34	106	33	106			27	115	83.9%	71.5%	3396	2106
2/20/98															2345	2430
2/21/98	243	499									25	134	89.7%	73.1%	4476	3996
2/22/98															4897	5454
2/23/98	307	571									30	133	90.2%	76.7%	5229	5886
2/24/98	339	647	125	238	47	133	42	143			37	133	89.1%	79.4%	4995	6372

Date	Raw Inluent (I-2)		Anaerobic Lagoon Effluent (E-1)		Facultative Lagoon 1 Effluent (E-2)		Facultative Lagoon 2 Effluent (E-3)		Facultative Lagoon 3 Effluent (E-4)		Final Effluent (E-6)		% Removals		Flow Rate (m^3/day)	
m/d/yr	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**Entrance**	**Exit**
2/25/98															2681	5859
2/26/98	176	438	129	257	37	153	44	152			33	171	81.3%	61.0%	3994	5009
2/27/98															3482	4752
2/28/98	148	318									53	168	64.2%	47.2%	3859	3726
3/1/98															2175	2322
3/2/98	150	300									41	131	72.7%	56.3%	1482	1836
3/3/98	183	425	141	262	66	262	54	212			66	203	63.9%	52.2%	1076	1944
3/4/98															1469	1728
3/5/98	172	370	249	62	62	249	69	286			44	139	74.4%	62.4%	1076	1944
3/6/98															1962	1890
3/7/98	131	277									49	157	62.6%	43.3%	1549	1674
3/8/98															1493	1404
3/9/98	184	270									44	144	76.1%	46.7%	1258	1350
3/10/98	254	560	104	250	58	200	51	180			50	80	80.3%	85.7%	1011	3780
3/11/98															3848	8262
3/12/98	81	198	75	188	38	149	41	149			60	149	25.9%	24.7%	3505	5076
3/13/98															3254	3672
3/14/98	129	218									50	159	61.2%	27.1%	3156	5184
3/15/98															3340	3780
3/16/98	63	198									44	149	30.2%	24.7%	2346	1836
3/17/98	117	255	63	157	38	167	51	186			53	167	54.7%	34.5%	1780	1350
3/18/98															1390	1290
3/19/98	152	333	77	157	59	216	60	176			48	176	68.4%	47.1%	1841	1512
3/20/98															1567	1944
3/21/98	126	294									65	265	48.4%	9.9%	3076	3996
3/22/98															2535	2862
3/23/98															1381	2052
3/24/98	154	369	67	185	38	165	37	175			43	194	72.1%	47.4%	1946	3672
3/25/98															1381	3348
3/26/98	90	248	55	162	34	200	38	190			52	190	42.2%	23.4%	2114	4212
3/27/98															1303	2214
3/28/98	94	248									34	181	63.8%	27.0%	3066	7614

Date	Raw Inluent (I-2)		Anaerobic Lagoon Effluent (E-1)		Facultative Lagoon 1 Effluent (E-2)		Facultative Lagoon 2 Effluent (E-3)		Facultative Lagoon 3 Effluent (E-4)		Final Effluent (E-6)		% Removals		Flow Rate (m^3/day)	
m/d/yr	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**Entrance**	**Exit**
3/29/98															2476	2862
3/30/98	91	243									49	178	46.2%	26.7%	1391	2380
3/31/98	141	333	61	166	39	166	43	185			51	203	63.8%	39.0%	818	1890
4/1/98															2260	2016
4/2/98	108	238	77	211	54	202	54	202			64	202	40.7%	15.1%	1469	3618
4/3/98															1822	1944
4/4/98															2302	1494
4/5/98															1607	1613
4/6/98	227	380									45	150	80.2%	60.5%	1809	1905
4/7/98	140	397	37	139	19	139	26	129			25	119	82.1%	70.0%	2178	1429
4/8/98															1265	432
4/9/98															2485	0
4/10/98	204	529	74	196	34	167	37	147			30	157	85.3%	70.3%	3373	3078
4/11/98															3360	4698
4/12/98															2325	4428
4/13/98	236	525									30	126	87.3%	76.0%	1111	2182
4/14/98	215	525	89	224	32	156	33	165			34	146	84.2%	72.2%	798	486
4/15/98															1093	972
4/16/98	144	408	63	204	24	165	23	156			39	165	72.9%	59.6%	1180	3564
4/17/98															1568	2354
4/18/98	200	544									49	175	75.5%	67.8%	2880	2106
4/19/98															3023	2862
4/20/98	212	461									34	163	84.0%	64.6%	3350	3672
4/21/98	190	518	80	259	26	182	27	182			43	182	77.4%	64.9%	2085	3618
4/22/98															1155	1944
4/23/98	182	400	86	276	38	238	35	219			39	181	78.6%	54.8%	1149	1620
4/24/98															1087	2214
4/25/98	143	362									58	190	59.4%	47.5%	932	1944
4/26/98															893	1782
4/27/98	105	321									46	179	56.2%	44.2%	804	1350
4/28/98															1284	1861
4/29/98															2152	997

Date	Raw Inluent (I-2)		Anaerobic Lagoon Effluent (E-1)		Facultative Lagoon 1 Effluent (E-2)		Facultative Lagoon 2 Effluent (E-3)		Facultative Lagoon 3 Effluent (E-4)		Final Effluent (E-6)		% Removals		Flow Rate (m^3/day)	
m/d/yr	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**Entrance**	**Exit**
4/30/98															1448	1350
5/1/98	294	562	82	225	42	187	46	168			48	178	83.7%	68.3%	2125	1872
5/2/98															2495	3078
5/3/98															2870	3726
5/4/98															2413	6318
5/5/98	64	94	72	197	35	140	26	131			37	149	42.2%	-58.5%	2460	7128
5/6/98															1413	3942
5/7/98	182	268	72	232	36	161	42	152			35	152	80.8%	43.3%	1218	2648
5/8/98															1895	1999
5/9/98	170	250									42	143	75.3%	42.8%	1268	1350
5/10/98															1864	1134
5/11/98	189	278									44	169	76.7%	39.2%	1493	1728
5/12/98	139	353	70	176	38	167	33	137			38	147	72.7%	58.4%	1079	1350
5/13/98															1229	1296
5/14/98	182	365	68	173	26	173	33	115			28	144	84.6%	60.5%	1182	1728
5/15/98															1379	1512
5/16/98	112	249									42	163	62.5%	34.5%	1286	1526
5/17/98															2100	1296
5/18/98	152	364									33	144	78.3%	60.4%	1882	2808
5/19/98	172	438	72	181	32	152	42	176			41	162	76.2%	63.0%	1535	2376
5/20/98															1575	1134
5/21/98															1090	225
5/22/98															1965	213
5/23/98															2325	339
5/24/98															1601	1664
5/25/98	145	324									28	133	80.7%	59.0%	1849	1332
5/26/98	162	340	68	160			22	113			25	122	84.6%	64.1%	1136	1194
5/27/98															990	475
5/28/98	152	321	55	151			28	123			29	123	80.9%	61.7%	1142	1401
5/29/98															1470	2354
5/30/98	108	245									26	113	75.9%	53.9%	1177	1876
5/31/98															2100	1643

Date	Raw Inluent (I-2)		Anaerobic Lagoon Effluent (E-1)		Facultative Lagoon 1 Effluent (E-2)		Facultative Lagoon 2 Effluent (E-3)		Facultative Lagoon 3 Effluent (E-4)		Final Effluent (E-6)		% Removals		Flow Rate (m^3/day)	
m/d/yr	BOD	COD	BOD	COD	BOD	COD	BOD	COD	BOD	COD	BOD	COD	BOD	COD	Entrance	Exit
6/1/98	85	185									28	120	67.1%	35.1%	1217	1571
6/2/98	80	179	44	109			22	59			20	50	75.0%	72.1%	1484	1331
6/3/98															1546	1238
6/4/98	151	337	74	198			47	179			40	169	73.5%	49.9%	1703	1419
6/5/98															1633	1398
6/6/98	86	198									33	139	61.6%	29.8%	1653	1327
6/7/98															1576	1416
6/8/98	119	253									27	107	77.3%	57.7%	1385	1256
6/9/98	238	544	71	185			52	136			34	136	85.7%	75.0%	1546	1190
6/10/98															1857	1014
6/11/98	242	557	82	240			55	173			44	182	81.8%	67.3%	2867	1537
6/12/98															3173	2872
6/13/98	163	347									42	182	74.2%	47.6%	3189	2781
6/14/98															2497	2290
6/15/98															1645	1370
6/16/98	208	438	89	267			47	171			40	168	80.8%	61.6%	1586	1007
6/17/98															1629	1034
6/18/98	177	457	74	248			73	243	8	76	37	200	79.1%	56.2%	1698	553
6/19/98															1748	1287
6/20/98	165	396									35	198	78.8%	50.0%	1647	865
6/21/98															1507	660
6/22/98	157	412									30	143	80.9%	65.3%	1427	1212
6/23/98															1407	691
6/24/98	174	449	93	243					20	37	13	56	92.5%	87.5%	2022	1257
6/25/98															1737	1620
6/26/98															1754	1296
6/27/98	165	333									28	139	83.0%	58.3%	1881	1296
6/28/98															1704	1296
6/29/98	157	314									22	120	86.0%	61.8%	1605	1098
6/30/98	179	476	95	238					38	137	30	137	83.2%	71.2%	1450	1066
7/1/98															1630	1296
7/2/98	304	824	104	330					48	156	42	174	86.2%	78.9%	1670	1296

Date	Raw Inluent (I-2)		Anaerobic Lagoon Effluent (E-1)		Facultative Lagoon 1 Effluent (E-2)		Facultative Lagoon 2 Effluent (E-3)		Facultative Lagoon 3 Effluent (E-4)		Final Effluent (E-6)		% Removals		Flow Rate (m^3/day)	
m/d/yr	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**Entrance**	**Exit**
7/3/98															1858	1512
7/4/98	176	440									45	183	74.4%	58.4%	2042	1296
7/5/98															1896	1566
7/6/98															1737	1458
7/7/98	208	504	89	225					28	81	25	117	88.0%	76.8%	1775	1296
7/8/98															2077	1350
7/9/98	229	551	117	339					22	89	23	116	90.0%	78.9%	2673	2430
7/10/98															3631	2538
7/14/98															1995	1512
7/15/98															2128	1674
7/16/98	219	445									55	182	74.9%	59.1%	2305	1782
7/17/98															2330	1836
7/18/98	219	540									39	150	82.2%	72.2%	2711	1944
7/19/98															2376	2562
7/20/98															2216	1998
7/21/98	269	680	118	240					71	170	59	170	78.1%	75.0%	2377	2077
7/22/98															2335	2177
7/23/98	170	395	115	267					66	178	46	178	72.9%	54.9%	2380	2221
7/24/98															2606	2355
7/25/98															2965	2580
7/26/98															2570	2625
7/27/98	230	568									59	225	74.3%	60.4%	1982	2023
7/28/98	242	764	122	284					68	147	55	186	77.3%	75.7%	2024	1955
7/29/98															2190	2225
7/30/98	225	408	128	204					56	146	55	194	75.6%	52.5%	2240	2119
7/31/98															2381	2167
8/1/98															2554	3959
8/2/98															1966	3118
8/3/98	245	467									55	204	77.6%	56.3%	1402	2641
8/4/98															1547	2818
8/5/98	223	538	117	298					60	173	52	182	76.7%	66.2%	3132	3027
8/6/98	186	447	100	282					44	146	49	156	73.7%	65.1%	2737	2779

Date	**Raw Inluent (I-2)**		**Anaerobic Lagoon Effluent (E-1)**		**Facultative Lagoon 1 Effluent (E-2)**		**Facultative Lagoon 2 Effluent (E-3)**		**Facultative Lagoon 3 Effluent (E-4)**		**Final Effluent (E-6)**		**% Removals**		**Flow Rate (m^3/day)**	
m/d/yr	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**Entrance**	**Exit**
8/7/98															2483	2441
8/8/98															1677	1697
8/9/98															1522	1577
8/10/98	209	373									40	205	80.9%	45.0%	1922	1829
8/11/98	326	522	188	270					77	224	75	224	77.0%	57.1%	2344	2318
8/12/98															2300	2275
8/13/98	230	487	170	300									100.0%	100.0%	1709	3316
8/14/98															4451	5242
8/15/98	200	505									76	225	62.0%	55.4%	2226	2239
8/16/98															2461	2535
8/17/98	195	468									54	180	72.3%	61.5%	1768	2023
8/18/98															1621	1548
8/19/98	163	460	89	290					57	170	54	180	66.9%	60.9%	1648	1627
8/20/98	180	540	122	320					58	230	65	260	63.9%	51.9%	1502	1526
8/21/98															1721	1779
8/22/98	384	893									41	208	89.3%	76.7%	2033	2253
8/23/98															1211	1953
8/24/98	181	392									35	176	80.7%	55.1%	1465	1476
8/25/98															1511	1379
8/26/98															1518	1429
8/27/98															1606	1489
8/28/98															1722	1577
8/29/98	227	661									47	155	79.3%	76.6%	2117	1915
8/30/98															1878	1882
8/31/98	153	389									52	165	66.0%	57.6%	1587	1532
9/1/98	158	538	88	259					34	192	32	240	79.7%	55.4%	1575	1387
9/2/98															1616	1418
9/3/98															1793	1456
9/4/98															2314	1821
9/5/98	235	576			56	134							100.0%	100.0%	4070	2975
9/6/98															4845	4325
9/7/98															3529	3158

Date	Raw Inluent (I-2)		Anaerobic Lagoon Effluent (E-1)		Facultative Lagoon 1 Effluent (E-2)		Facultative Lagoon 2 Effluent (E-3)		Facultative Lagoon 3 Effluent (E-4)		Final Effluent (E-6)		% Removals		Flow Rate (m^3/day)	
m/d/yr	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**Entrance**	**Exit**
9/8/98															2480	2887
9/9/98	204	495	128	266					52	171	48	171	76.5%	65.5%	2238	2714
9/10/98															1949	1803
9/11/98	154	428	127	272					54	175	50	204	67.5%	52.3%	1911	515
9/12/98															2134	167
9/13/98															2029	
9/14/98															1728	
9/15/98															1725	
9/16/98															1726	
9/17/98															1797	
9/18/98					34	148			55	203					947	1242
9/19/98	243	554			31	138			52	185	52	194	78.6%	65.0%	2269	1598
9/20/98															2180	3078
9/21/98	172	366			24	112			44	145	42	137	75.6%	62.6%	1834	2304
9/22/98	51	147	98	211	34	108			41	156	47	156	7.8%	-6.1%	1568	6156
9/23/98															593	2268
9/24/98	144	378	72	216	31	126			21	135	28	180	80.6%	52.4%	836	1134
9/25/98															2264	1856
9/26/98															2379	1950
9/27/98															2345	2560
9/28/98															1632	1684
9/29/98	399	846	175	396	41	135			30	162	30	144	92.5%	83.0%	2345	2560
9/30/98															1887	5947
10/1/98		350		198		131				131	36	140		60.0%	1576	5900
10/2/98															1574	3568
10/3/98		328									38	138		57.9%	2053	3957
10/4/98															1355	3598
10/5/98		291									45	163		44.0%	1723	2870
10/6/98	319	676	150	338	56	186			33	180	26	124	91.8%	81.7%	2678	5570
10/7/98															3714	5712
10/8/98		168	63	189	45	116			27	116	39	137		18.5%	3424	6065
10/9/98															3335	4613

Date	**Raw Inluent (I-2)**		**Anaerobic Lagoon Effluent (E-1)**		**Facultative Lagoon 1 Effluent (E-2)**		**Facultative Lagoon 2 Effluent (E-3)**		**Facultative Lagoon 3 Effluent (E-4)**		**Final Effluent (E-6)**		**% Removals**		**Flow Rate (m^3/day)**	
m/d/yr	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**Entrance**	**Exit**
10/10/98	205	458									29	146	85.9%	68.1%	4294	4707
10/11/98															4915	8908
10/12/98															4045	5025
10/13/98	164	428	95	245	71	163			42	163	39	163	76.2%	61.9%	2476	3894
10/14/98															2511	3552
10/15/98	182	478	103	218	63	114			38	104	46	146	74.7%	69.5%	2459	2606
10/16/98															2752	3124
10/17/98	168	395									53	166	68.5%	58.0%	3569	4815
10/18/98															3067	7844
10/19/98		312									34	166		46.8%	1877	3199
10/20/98		428	80	214	45	143			35	163	44	153		64.3%	1779	2480
10/21/98															1599	2278
10/22/98	180	627	65	223	55	223			36	202	30	142	83.3%	77.4%	1820	2122
10/23/98															1975	1882
10/24/98	177	405									27	132	84.7%	67.4%	4536	8816
10/25/98															288	5188
10/26/98		263									32	152		42.2%	2348	4099
10/27/98															1633	3219
10/28/98															1538	2281
10/29/98		504	47	171	48	121			31	141	31	141		72.0%	1507	2015
10/30/98															1788	2130
10/31/98	180	383									24	91	86.7%	76.2%	3245	2944
11/1/98															3960	4198
11/2/98															3023	4095
11/3/98	228	580	89	260	38	100			33	120	28	120	87.7%	79.3%	1850	2292
11/4/98															1735	1772
11/5/98	254	620	86	230	23	90			37	130	28	110	89.0%	82.3%	1509	1782
11/6/98															1534	1706
11/7/98	157	397									32	139	79.6%	65.0%	1998	2047
11/8/98															1960	2418
11/9/98	163	311									38	126	76.7%	59.5%	1393	1847
11/10/98	158	349	66	233	28	87			36	97	34	126	78.5%	63.9%	1377	1912

Date	Raw Inluent (I-2)		Anaerobic Lagoon Effluent (E-1)		Facultative Lagoon 1 Effluent (E-2)		Facultative Lagoon 2 Effluent (E-3)		Facultative Lagoon 3 Effluent (E-4)		Final Effluent (E-6)		% Removals		Flow Rate (m^3/day)	
m/d/yr	BOD	COD	BOD	COD	BOD	COD	BOD	COD	BOD	COD	BOD	COD	BOD	COD	Entrance	Exit
11/11/98															1734	3403
11/12/98	171	442	68	221	25	77			35	96	30	115	82.5%	74.0%	1538	1848
11/13/98															1530	1716
11/14/98		362									40	181		50.0%	1992	1956
11/15/98															2403	2001
11/16/98	203	304									40	121	80.3%	60.2%	1766	1762
11/17/98															1483	1091
11/18/98															1481	1623
11/19/98	234	620	65	198	42	125			38	112	39	140	83.3%	77.4%	2048	2256
11/20/98															1750	1204
11/21/98		460									56	190		58.7%	1894	1553
11/22/98															1724	1543
11/23/98		337									34	169		49.9%	1381	984
11/24/98	177	436	64	198					32	109	30	139	83.1%	68.1%	1565	965
11/25/98															1693	403
11/26/98															2070	0
11/27/98															2310	0
11/28/98															2424	756
11/29/98	176	412	60	216							48	206	72.7%	50.0%	2259	756
11/30/98															1783	432
12/1/98	176	470	75	206	44	127	55	157	60	186	42	172	76.1%	63.4%	1733	648
12/2/98															1708	432
12/3/98	191	408	71	204					46	146	41	136	78.5%	66.7%	1893	648
12/4/98															2254	1080
12/5/98															3224	1134
12/6/98															2566	0
12/7/98															1925	758
12/8/98	168	422	72	211					34	135	25	154	85.1%	63.5%	1844	1458
12/9/98															2780	1782
12/10/98	264	1523	80	248					59	143	44	171	83.3%	88.8%	2381	2592
12/11/98															2730	4113
12/12/98		324									48	171		47.2%	2868	3568

Date	Raw Inluent (I-2)		Anaerobic Lagoon Effluent (E-1)		Facultative Lagoon 1 Effluent (E-2)		Facultative Lagoon 2 Effluent (E-3)		Facultative Lagoon 3 Effluent (E-4)		Final Effluent (E-6)		% Removals		Flow Rate (m^3/day)	
m/d/yr	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**Entrance**	**Exit**
12/13/98															2669	2448
12/14/98		321									33	151		53.0%	2109	1296
12/15/98															2125	1188
12/16/98															2139	432
12/17/98	191	508	71	218			25	127	28	163	24	163	87.4%	67.9%	1854	0
12/18/98															1946	432
12/19/98		345									32	136		60.6%	2493	1620
12/20/98															2479	2376
12/21/98		357									35	152		57.4%	2241	2178
12/22/98	250	567	65	202	43	304	31	202	42	213	35	213	86.0%	62.4%	2360	2214
12/23/98															3295	4406
12/24/98															3295	5189
12/25/98	246	620	82	260	50	140	51	130	53	210	32	170	87.0%	72.6%	3329	3626
12/26/98															4375	4210
12/27/98															5327	7130
12/28/98	197	405									46	152	76.6%	62.5%	5398	6223
12/29/98	226	660	105	270	58	130	67	180	64	190	38	160	83.2%	75.8%	5896	7566
12/30/98															5981	7232
12/31/98	261	640	111	330	49	140	35	130	48	200	42	170	83.9%	73.4%	8453	11965
1/1/99	343	794	134	476	49	208	32	169	38	208	42	198	87.8%	75.1%	9313	11910
1/2/99															8888	12628
1/3/99															7683	10090
1/4/99	228	529									42	304	81.6%	42.5%	6153	9533
1/5/99	219	583	207	389	48	146	62	185	44	185	51	204	76.7%	65.0%	6297	10050
1/6/99															5944	13210
1/7/99	150	389	129	330	47	175	47	175	47	194	45	194	70.0%	50.1%	10407	15875
1/8/99															6426	14160
1/9/99															8712	10675
1/10/99	150	192									82	202	45.3%	-5.2%	9920	15315
1/11/99															11139	15835
1/12/99	150	324	99	219	45	162	48	171	46	171	49	181	67.3%	44.1%	6093	11870
1/13/99															4550	6296

Date	Raw Inluent (I-2)		Anaerobic Lagoon Effluent (E-1)		Facultative Lagoon 1 Effluent (E-2)		Facultative Lagoon 2 Effluent (E-3)		Facultative Lagoon 3 Effluent (E-4)		Final Effluent (E-6)		% Removals		Flow Rate (m^3/day)	
m/d/yr	BOD	COD	BOD	COD	BOD	COD	BOD	COD	BOD	COD	BOD	COD	BOD	COD	Entrance	Exit
1/14/99	330	1322	98	189	52	113	53	132	55	142	58	142	82.4%	89.3%	8117	11103
1/15/99															6495	10841
1/16/99															8538	6767
1/17/99															6270	8622
1/18/99	199	734									78	194	60.8%	73.6%	5196	12390
1/19/99	291	627	109	293	46	152	45	213	41	181	51	202	82.5%	67.8%	5044	11942
1/20/99															5514	10149
1/21/99	224	729	131	304	47	172	58	182	54	213	62	213	72.3%	70.8%	5329	5586
1/22/99															6044	7143
1/23/99	252	647									41	162	83.7%	75.0%	7197	9212
1/24/99															7340	10306
1/25/99	243	580									53	210	78.2%	63.8%	6352	10807
1/26/99	300	1031	171	337	82	208	57	188	69	228	44	248	85.3%	75.9%	5167	8308
1/27/99															4588	6475
1/28/99	214	549	152	353	78	284	84	265	57	225	53	196	75.2%	64.3%	4479	4280
1/29/99															4555	5995
1/30/99	230	490									56	196	75.7%	60.0%	5613	6792
1/31/99															3960	3740
2/1/99	184	486									43	214	76.6%	56.0%	4576	7673
2/2/99	175	428	109	330	43	204	62	262	48	233	52	262	70.3%	38.8%	2718	3060
2/3/99															2581	2392
2/4/99	232	495	82	248	31	149	35	149	31	152	36	181	84.5%	63.4%	2420	2648
2/5/99															2790	2712
2/6/99	304	647									49	181	83.9%	72.0%	3290	2977
2/7/99															2969	2711
2/8/99	164	434									42	170	74.4%	60.8%	2090	2214
2/9/99															2231	2251
2/10/99	175	434	75	198	52	217	44	208	48	227	42	208	76.0%	52.1%	2419	2943
2/11/99															3225	4517
2/12/99	179	345	85	209	36	109	40	145	34	154	38	173	78.8%	49.9%	3180	3158
2/13/99															3517	5172
2/14/99	197	445	100	243	44	111	43	121	37	132	34	152	82.7%	65.8%	7976	8885

Date	Raw Inluent (I-2)		Anaerobic Lagoon Effluent (E-1)		Facultative Lagoon 1 Effluent (E-2)		Facultative Lagoon 2 Effluent (E-3)		Facultative Lagoon 3 Effluent (E-4)		Final Effluent (E-6)		% Removals		Flow Rate (m^3/day)	
m/d/yr	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**Entrance**	**Exit**
2/15/99															8856	12500
2/16/99	206	466	117	283	44	132	47	132	32	142	28	162	86.4%	65.2%	7534	8338
2/17/99															5569	5562
2/18/99	171	380	120	290	38	130	33	120	35	130	34	150	80.1%	60.5%	3714	4126
2/19/99															4007	4429
2/20/99	150	240									51	160	66.0%	33.3%	4489	7698
2/21/99															3092	4396
2/22/99	222	417									44	188	80.2%	54.9%	2200	2401
2/23/99	150	277	115	277	42	139	51	149	47	139	47	158	68.7%	43.0%	2032	2058
2/24/99															2134	2130
2/25/99	168	377	138	248	55	129	62	158	60	149	59	168	64.9%	55.4%	2215	2109
2/26/99															5090	8003
2/27/99															3052	3372
2/28/99															2584	2530
3/1/99	150	194									42	155	72.0%	20.1%	1955	2601
3/2/99	150	216	60	139	42	106	35	111	43	103	33	108	78.0%	50.0%	1895	1856
3/3/99															1874	2148
3/4/99	150	240	53	135	34	81	29	85	35	93	39	133	74.0%	44.6%	2007	1106
3/5/99															2096	2370
3/6/99	150	249									34	125	77.3%	49.8%	2634	2765
3/7/99															2392	2569
3/8/99		268										134		50.0%	1622	1672
3/9/99		448		129		76		104		90		67		85.0%	1997	1987
3/10/99															1819	1054
3/11/99		464		178		88		95		92		108		76.7%	3651	2700
3/12/99															3498	5103
3/13/99															2754	3680
3/14/99															2485	2360
3/15/99	100	220									28	62	72.0%	71.8%	1968	1858
3/16/99	103	219	66	165	35	101	23	82			33	109	68.0%	50.2%	1906	1211
3/17/99															1878	1546
3/18/99	121	320	59	110	29	80	22	78			29	77	76.0%	75.9%	1843	2183

Date	Raw Inluent (I-2)		Anaerobic Lagoon Effluent (E-1)		Facultative Lagoon 1 Effluent (E-2)		Facultative Lagoon 2 Effluent (E-3)		Facultative Lagoon 3 Effluent (E-4)		Final Effluent (E-6)		% Removals		Flow Rate (m^3/day)	
m/d/yr	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**Entrance**	**Exit**
3/19/99															2032	1128
3/20/99	122	280									28	98	77.0%	65.0%	2848	2820
3/21/99															2732	2502
3/22/99															1983	1930
3/23/99	136	308	64	155	37	76	31	65			32	76	76.5%	75.3%	2617	3113
3/24/99															1862	1393
3/25/99	103	384	57	131	33	87	37	90			32	115	68.9%	70.1%	1955	3600
3/26/99															2055	1899
3/27/99	106	248									21	115	80.2%	53.6%	2538	2281
3/28/99															2522	2660
3/29/99	133	248									27	84	79.7%	66.1%	2215	3074
3/30/99	191	776	57	129			33	81	37	84	49	95	74.3%	87.8%	2073	2335
3/31/99															2567	2306
4/1/99	159	372									23	105	85.5%	71.8%	4130	3687
4/2/99															5532	5092
4/3/99															5830	5410
4/4/99															3817	4177
4/5/99		224										117		47.8%	2071	2238
4/6/99	139	328	107	178			50	153	44	128	31	105	77.7%	68.0%	1756	1622
4/7/99															2014	1884
4/8/99	220	376	135	177			51	102	45	92	50	102	77.3%	72.9%	3555	5227
4/9/99															8278	1857
4/10/99															3445	1514
4/11/99															2224	3307
4/12/99	143	488									34	14	76.2%	97.1%	1784	1716
4/13/99															2169	600
4/14/99															3090	6245
4/15/99	73	132	55	82			27	56	30	62	32	65	56.2%	50.8%	2588	2768
4/16/99															2431	2802
4/17/99	95	172										79	100.0%	54.1%	2315	3246
4/18/99															1922	1949
4/19/99	92	212									46	98	50.0%	53.8%	1767	1670

Date	Raw Inluent (I-2)		Anaerobic Lagoon Effluent (E-1)		Facultative Lagoon 1 Effluent (E-2)		Facultative Lagoon 2 Effluent (E-3)		Facultative Lagoon 3 Effluent (E-4)		Final Effluent (E-6)		% Removals		Flow Rate (m^3/day)	
m/d/yr	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**Entrance**	**Exit**
4/20/99															1747	1712
4/21/99															1937	1949
4/22/99															1857	2108
4/23/99	120	500	57	131			32	89	41	170	17	94	85.8%	81.2%	1823	1364
4/24/99															1982	1893
4/25/99															1818	1164
4/26/99	215	296									75	105	65.1%	64.5%	1455	1559
4/27/99	139	296	63	133	62	145			63	123	19	115	86.3%	61.1%	1500	1432
4/28/99															1392	2154
4/29/99															1506	1567
4/30/99		128		97		40				23		64		50.0%	1663	1712
5/1/99															2327	2209
5/2/99															2219	2277
5/3/99	246	336									42	107	82.9%	68.2%	1284	636
5/4/99															1604	451
5/5/99															1774	2740
5/6/99	240	330	117	194	32	116			35	186	28	94	88.3%	71.5%	1786	2635
5/7/99															1281	741
5/8/99															1247	2072
5/9/99															1267	1614
5/10/99	92	128									21	57	77.2%	55.5%	1308	1464
5/11/99	248	352	72	101	33	80			35	101	32	81	87.1%	77.0%	1423	1580
5/12/99															2012	2555
5/13/99	358	812	121	197	59	165			62	171	68	236	81.0%	70.9%	1845	3198
5/14/99															1777	2143
5/15/99															1935	2082
5/16/99															1871	2111
5/17/99	238	350									37	101	84.5%	71.1%	1454	1708
5/18/99															1432	1710
5/19/99															1513	1810
5/20/99	179	312	72	138	53	97			57	91	44	101	75.4%	67.6%	1619	996
5/21/99															1763	2393

Date	Raw Inluent (I-2)		Anaerobic Lagoon Effluent (E-1)		Facultative Lagoon 1 Effluent (E-2)		Facultative Lagoon 2 Effluent (E-3)		Facultative Lagoon 3 Effluent (E-4)		Final Effluent (E-6)		% Removals		Flow Rate (m^3/day)	
m/d/yr	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**Entrance**	**Exit**
5/22/99	185	292									33	95	82.2%	67.5%	1874	1833
5/23/99															1688	1785
5/24/99	234	396									44	132	81.2%	66.7%	1397	1524
5/25/99	181	316	82	136	59	80			47	92	37	100	79.6%	68.4%	1469	823
5/26/99															1561	859
5/27/99	157	374	83	180			60	82	53	127	47	142	70.1%	62.0%	1665	2225
5/28/99															1772	1950
5/29/99	182	400									24	120	86.8%	70.0%	1956	1953
5/30/99															1740	1737
5/31/99	158	283									53	152	66.5%	46.3%	1709	1805
6/1/99	194	465	80	202			75	172	72	192	50	162	74.2%	65.2%	1553	1644
6/2/99															1910	1662
6/3/99	204	425	83	213			57	71	70	121	47	121	77.0%	71.5%	2983	2822
6/4/99															3667	7263
6/5/99	250	420									41	130	83.6%	69.0%	3917	5400
6/6/99															5069	1284
6/7/99	31	99									38	119	-22.6%	-20.2%	2640	7472
6/8/99	75	176	91	196			56	98	42	137	42	147	44.0%	16.5%	2118	2833
6/9/99															1910	2314
6/10/99	146	274	97	194			49	88	48	127	44	127	69.9%	53.6%	1852	2054
6/11/99															1825	2040
6/12/99	216	352									57	157	73.6%	55.4%	1608	1831
6/13/99															1479	1914
6/14/99	236	412									56	147	76.3%	64.3%	1797	2248
6/15/99	152	350	95	185			52	97	45	116	39	126	74.3%	64.0%	1646	1846
6/16/99															1639	1772
6/17/99	174	422	83	192			34	125	42	154	30	144	82.8%	65.9%	1657	1816
6/18/99															2586	1820
6/19/99	198	480									30	140	84.8%	70.8%	1720	1986
6/20/99															3077	5600
6/21/99	84	189									49	151	41.7%	20.1%	1700	2034
6/22/99	133	384	82	202			70	121	35	142	38	142	71.4%	63.0%	1603	1824

Date	Raw Inluent (I-2)		Anaerobic Lagoon Effluent (E-1)		Facultative Lagoon 1 Effluent (E-2)		Facultative Lagoon 2 Effluent (E-3)		Facultative Lagoon 3 Effluent (E-4)		Final Effluent (E-6)		% Removals		Flow Rate (m^3/day)	
m/d/yr	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**Entrance**	**Exit**
6/23/99															1625	1755
6/24/99	156	304	89	202			51	111	56	142	40	152	74.4%	50.0%	1572	1765
6/25/99															1669	1850
6/26/99															1888	2118
6/27/99															1722	1991
6/28/99	176	360									24	110	86.4%	69.4%	1560	1598
6/29/99	158	377	71	198	34	69			36	109	42	119	73.4%	68.4%	1659	1385
6/30/99															1631	1632
7/1/99	179	456	76	179	36	79			37	119	51	119	71.5%	73.9%	1816	1877
7/2/99															1913	2042
7/3/99	253	714									39	89	84.6%	87.5%	2506	2610
7/4/99															3923	7389
7/5/99		233										78		66.5%	4661	1089
7/6/99	61	117	92	174	57	68			49	117	44	107	27.9%	8.5%	3129	3912
7/7/99															2948	3068
7/8/99															3658	5445
7/9/99															3571	3542
7/10/99	145	253									29	117	80.0%	53.8%	3720	3732
7/11/99															3215	3411
7/12/99	139	307									54	173	61.2%	43.6%	2144	2441
7/13/99	200	384	113	202	42	86			39	106	38	125	81.0%	67.4%	2637	2822
7/14/99															2506	2691
7/15/99	184	399	111	219	42	95			38	105	40	133	78.3%	66.7%	2660	2685
7/16/99															3059	3550
7/17/99															3460	3856
7/18/99															3369	6055
7/19/99	169	339									56	132	66.9%	61.1%	2533	2872
7/20/99	192	425	118	240	64	92			48	111	45	157	76.6%	63.1%	2529	2762
7/21/99															2590	2616
7/22/99	203	425	129	253	66	132	78	162			65	142	68.0%	66.6%	2684	2763
7/23/99															2870	2705
7/24/99	203	400									27	120	86.7%	70.0%	3288	2918

Date	Raw Inluent (I-2)		Anaerobic Lagoon Effluent (E-1)		Facultative Lagoon 1 Effluent (E-2)		Facultative Lagoon 2 Effluent (E-3)		Facultative Lagoon 3 Effluent (E-4)		Final Effluent (E-6)		% Removals		Flow Rate (m^3/day)	
m/d/yr	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**Entrance**	**Exit**
7/25/99															2746	2594
7/26/99	245	540									45	150	81.6%	72.2%	2125	2193
7/27/99	196	456	126	278	51	79			51	119	42	139	78.6%	69.5%	2330	2712
7/28/99															2690	3202
7/29/99	172	377	136	298	81	169			64	119	44	179	74.4%	52.5%	2496	1492
7/30/99															2656	2409
7/31/99	201	372									17	78	91.5%	79.0%	2595	4278
8/1/99															1870	2066
8/2/99	256	435									128	178	50.0%	59.1%	1581	1740
8/3/99	209	428	175	262	70	117	58	87			73	156	65.1%	63.6%	1375	1336
8/4/99															887	562
8/5/99	303	816			64	126	61	126	49	156	55	156	81.8%	80.9%	963	969
8/6/99															1816	3169
8/7/99	214	505									36	117	83.2%	76.8%	2112	2930
8/8/99															1953	3220
8/9/99	243	461									54	134	77.8%	70.9%	1755	3830
8/10/99	305	768			66	115	78	124	84	153	61	115	80.0%	85.0%	1718	3766
8/11/99															1674	1802
8/12/99	211	514			57	133	56	105	54	123	57	152	73.0%	70.4%	1847	2222
8/13/99															1940	1743
8/14/99	203	415									50	132	75.4%	68.2%	2706	3500
8/15/99															3267	3988
8/16/99	104	280									46	140	55.8%	50.0%	2127	2957
8/17/99	201	360			60	120	53	120	53	130	41	160	79.6%	55.6%	1828	2000
8/18/99															1666	1674
8/19/99	142	336			40	118	50	128	46	148	43	148	69.7%	56.0%	1620	1424
8/20/99															1776	1520
8/21/99	141	258									44	159	68.8%	38.4%	2075	1808
8/22/99															1474	1419
8/23/99	162	333									42	157	74.1%	52.9%		696
8/24/99																492
8/25/99																

Date	Raw Inluent (I-2)		Anaerobic Lagoon Effluent (E-1)		Facultative Lagoon 1 Effluent (E-2)		Facultative Lagoon 2 Effluent (E-3)		Facultative Lagoon 3 Effluent (E-4)		Final Effluent (E-6)		% Removals		Flow Rate (m^3/day)	
m/d/yr	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**Entrance**	**Exit**
8/26/99																382
8/27/99																944
8/28/99																439
8/29/99																453
8/30/99																406
8/31/99	173	384	77	221	44	96	57	106	51	134	30	106	82.7%	72.4%		697
9/1/99																934
9/2/99																541
9/3/99	185	365	91	269	52	96	55	96	66	144	52	106	71.9%	71.0%		2512
9/4/99	145	307									56	192	61.4%	37.5%		4924
9/5/99																5009
9/6/99	310	476									42	143	86.5%	70.0%		4887
9/7/99																3614
9/8/99	185	320	123	283	63	113	53	113	68	160	40	132	78.4%	58.8%		5236
9/9/99																8550
9/10/99	169	378	149	312	64	113	66	113	88	189	56	151	66.9%	60.1%		7004
9/11/99																4214
9/12/99																2373
9/13/99	109	222									54	157	50.5%	29.3%		1519
9/14/99	176	366	238	145	73	137	66	119	75	183	66	156	62.5%	57.4%		2771
9/15/99																5749
9/16/99	145	294	119	255	64	137	58	137	186	89	53	147	63.4%	50.0%		8638
9/17/99																1496
9/18/99	124	255									41	177	66.9%	30.6%		1418
9/19/99																1567
9/20/99	123	253									42	146	65.9%	42.3%		1018
9/21/99	167	330	111	224	53	117	52	117	65	185	58	165	65.3%	50.0%		1132
9/22/99																1497
9/23/99	213	346	106	240	52	125	53	125	52	125	52	154	75.6%	55.5%		3354
9/24/99																1254
9/25/99	144	326									35	154	75.7%	52.8%		1175
9/26/99																925

Date	Raw Inluent (I-2)		Anaerobic Lagoon Effluent (E-1)		Facultative Lagoon 1 Effluent (E-2)		Facultative Lagoon 2 Effluent (E-3)		Facultative Lagoon 3 Effluent (E-4)		Final Effluent (E-6)		% Removals		Flow Rate (m^3/day)	
m/d/yr	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**Entrance**	**Exit**
9/27/99	149	343									34	171	77.2%	50.1%		1013
9/28/99	156	396	67	227	36	113	48	132	58	169	43	151	72.4%	61.9%		919
9/29/99																4027
9/30/99	145	396	70	227	37	113	46	123	46	151	41	151	71.7%	61.9%		2283
10/1/99																604
10/2/99	125	318									38	149	69.6%	53.1%		6550
10/3/99																8136
10/4/99																6730
10/5/99																1872
10/6/99																3057
10/7/99																1014
10/8/99	165	384	78	201	35	128	46	156	42	146	39	147	76.4%	61.7%		1130
10/9/99																7419
10/10/99																9038
10/11/99	214	357									35	143	83.6%	59.9%		8085
10/12/99	136	336	123	287	48	166	42	148	52	188	58	138	57.4%	58.9%		5847
10/13/99																3140
10/14/99	207	431	154	274	32	117	35	117	45	176	56	157	72.9%	63.6%		3024
10/15/99																3252
10/16/99																3606
10/17/99																5552
10/18/99	115	235									35	127	69.6%	46.0%		4107
10/19/99	258	990	127	204	22	68	28	97	25	87	32	87	87.6%	91.2%		3830
10/20/99																3882
10/21/99	141	438	103	247	40	114	22	114	38	133	58	200	58.9%	54.3%		1182
10/22/99																1174
10/23/99	173	408									32	146	81.5%	64.2%		1167
10/24/99																1156
10/25/99	105	215									34	94	67.6%	56.3%		1164
10/26/99	175	474	95	237			44	110			56	144	68.0%	69.6%		1180
10/27/99																1112
10/28/99	194	550	87	229			48	110			58	146	70.1%	73.5%		1142

Date	Raw Inluent (I-2)		Anaerobic Lagoon Effluent (E-1)		Facultative Lagoon 1 Effluent (E-2)		Facultative Lagoon 2 Effluent (E-3)		Facultative Lagoon 3 Effluent (E-4)		Final Effluent (E-6)		% Removals		Flow Rate (m^3/day)	
m/d/yr	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**BOD**	**COD**	**Entrance**	**Exit**
10/29/99																1190
10/30/99																9310
10/31/99																5243
11/1/99	229	467									40	126	82.5%	73.0%		4503
11/2/99	232	576	111	307	32	96	86	144	12	154	38	144	83.6%	75.0%		5227
11/3/99																2415
11/4/99	193	442	123	288	44	96	25	115	36	144	42	134	78.2%	69.7%		4580
11/5/99																2755
11/6/99	176	403									50	154	71.6%	61.8%		2030
11/7/99																1849
11/8/99	178	381									58	171	67.4%	55.1%		1839
11/9/99	255	654	71	383	22	102	44	149	46	140	41	177	83.9%	72.9%		3624
11/10/99																3593
11/11/99	186	388	111	249	52	102	70	120	63	139	60	157	67.7%	59.5%		2201
11/12/99																2997
11/13/99																5120
11/14/99																6633
11/15/99																1198
11/16/99	145	300	76	174	69	102	92	120	36	139	45	157	69.0%	47.7%		10688
11/17/99																11570
11/18/99	147	397	101	248	81	109	44	119			31	149	78.9%	62.5%		2420
11/19/99																1518
11/20/99	168	490									23	137	86.3%	72.0%		1064
11/21/99																1453
11/22/99	215	428									37	136	82.8%	68.2%		1760
11/23/99																1962
11/24/99																2700
11/25/99	156	359	93	227	42	113	40	94			45	132	71.2%	63.2%		1883
11/26/99																2329
11/27/99																2340
11/28/99																2488
11/29/99	220	366									60	174	72.7%	52.5%		1999

Date	Raw Inluent (I-2)		Anaerobic Lagoon Effluent (E-1)		Facultative Lagoon 1 Effluent (E-2)		Facultative Lagoon 2 Effluent (E-3)		Facultative Lagoon 3 Effluent (E-4)		Final Effluent (E-6)		% Removals		Flow Rate (m^3/day)	
m/d/yr	BOD	COD	BOD	COD	BOD	COD	BOD	COD	BOD	COD	BOD	COD	BOD	COD	Entrance	Exit
11/30/99	157	508									41	163	73.9%	67.9%		1512
12/1/99																1509
12/2/99																2096
12/3/99																2096
12/4/99																3000
12/5/99																3428
12/6/99																4942
12/7/99																7113
12/8/99																4942
12/9/99																16548
12/10/99																8214
12/11/99																16548

APPENDIX D - RIVIERA DATA DURING CARNIVAL 1999

02/13/99	**Raw Wastewater**								**Effluent WWTP**							
Time	**COD**	**BOD**	**TSS**	**pH**	**T air**	**T ww**	**PO4**	**OG**	**COD**	**BOD**	**TSS**	**pH**	**T air**	**T ww**	**PO4**	**D.O.**
08:00	184	54	152	7.5	30ºC	23ºC	2.12		109	31	-----	6.8	30ºC	30	1.47	0
10:00	220	66	172	7.5	31ºC	26ºC			115	33	-----	6.9	31ºC	31		0
12:00	562	149	151	7.6	27ºC	26ºC			119	34	-----	6.9	27ºC	27		0.2
14:00	494	152	242	7.6	32ºC	30ºC	2.58	82	164	47	-----	7.0	32ºC	32	0.47	1.4
16:00	504	190	195	7.5	31ºC	27ºC			188	53	-----	6.8	31ºC	31		0.8
18:00	632	180	302	7.5	30ºC	29ºC			242	69	-----	6.8	30ºC	30		0.2
20:00	596	161	246	7.5	25.5ºC	29ºC	3.0		136	39	-----	7.0	25.5ºC	26	1.23	0

02/14/99	**Raw Wastewater Inflow WWTP**								**Effluent WWTP**							
Time	**COD**	**BOD**	**TSS**	**pH**	**T air**	**T ww**	**PO4**	**OG**	**COD**	**BOD**	**TSS**	**pH**	**T air**	**T ww**	**PO4**	**D.O.**
08:00	340	102	252	7.3	25ºC	25ºC	2.15		452	51	-----	6.8	25ºC	25ºC	0.9	0
10:00	925	279	303	7.6	27ºC	28ºC			382	44	-----	6.9	27ºC	27ºC		0.3
12:00	728	219	283	7.6	29ºC	28ºC			290	33	-----	6.8	29ºC	29ºC		0.8
14:00	754	227	298	7.6	31ºC	29ºC	2.52	115	261	30	-----	6.9	31ºC	27ºC	0.9	0.3
16:00	602	181	190	7.5	33ºC	28ºC			275	31	-----	7.1	33ºC	28ºC		1.7
18:00	956	289	215	7.6	30ºC	27ºC			311	36	-----	7.0	30ºC	27ºC		0.8
20:00	483	145	309	7.6	28ºC	28ºC	2.36		214	24	-----	7.0	28ºC	28ºC	1.22	1.0

02/15/99	**Raw Wastewater**								**Effluent WWTP**							
Time	**COD**	**BOD**	**TSS**	**pH**	**T air**	**T ww**	**PO4**	**OG**	**COD**	**BOD**	**TSS**	**pH**	**T air**	**T ww**	**PO4**	**D.O.**
08:00	304	92	134	7.6	23ºC	27ºC	2.43		184	21	-----	6.9	23ºC	27ºC	0.8	0
10:00	368	111	200	7.5	26ºC	28ºC			259	30	-----	6.9	26ºC	27ºC		0.4
12:00	791	238	311	7.6	27ºC	27ºC			293	33	-----	7.0	27ºC	26ºC		1.0
14:00	639	192	232	7.5	28ºC	28ºC	2.48	145	284	32	-----	7.0	28ºC	31ºC	1.52	0.4
16:00	850	256	212	7.6	27ºC	28ºC			466	53	-----	7.0	27ºC	29ºC		0.6
18:00	630	190	258	7.6	27ºC	28ºC			275	31	-----	6.9	27ºC	27ºC		0.6
20:00	757	228	222	7.6	27ºC	27ºC	2.28		263	30	-----	6.9	27ºC	27ºC	1.35	0.3

02/16/99	**Raw Wastewater**								**Effluent WWTP**							
Time	**COD**	**BOD**	**TSS**	**pH**	**T air**	**T ww**	**PO4**	**OG**	**COD**	**BOD**	**TSS**	**pH**	**T air**	**T ww**	**PO4**	**D.O.**
08:00	**284**	**86**	**209**	**7.6**	**23°C**	**27°C**	**2.52**		**192**	**22**	**-----**	**6.8**	**23°C**	**27°C**	**1.22**	**0**
10:00	**346**	**104**	**182**	**7.5**	**27°C**	**26°C**			**244**	**28**	**-----**	**6.9**	**27°C**	**27°C**		**0**
12:00	**698**	**221**	**307**	**7.6**	**31°C**	**26°C**			**286**	**33**	**-----**	**6.8**	**31°C**	**29°C**		**0**
14:00	**623**	**188**	**255**	**7.6**	**31°C**	**28°C**	**2.32**	**86**	**295**	**34**	**-----**	**6.8**	**31°C**	**28°C**	**1.42**	**0.2**
16:00	**742**	**223**	**188**	**7.6**	**31°C**	**27°C**			**303**	**35**	**-----**	**6.9**	**31°C**	**28°C**		**0.4**
18:00	**694**	**209**	**195**	**7.5**	**31°C**	**27°C**			**241**	**28**	**-----**	**6.9**	**31°C**	**28°C**		**0.8**
20:00	**642**	**193**	**242**	**7.6**	**28°C**	**27°C**	**2.14**		**258**	**29**	**-----**	**6.9**	**28°C**	**27°C**	**1.22**	**0**

Remarks:
TSS was measured photometrically acc. Hach's method. It was measured for all Inlet samples since those were plain sewage (and the method is specific for sewage). In contrast, it was *not* used for Effluent samples since those contained mainly phytoplankton, which may not give a good correlation w/TSS in that method.

2) In 1999, phoshate analysis was done on the "ortophoshate" or "reactive phosphate" fraction of total phosphorus. In 2000 (another table), phosphate figures mean TOTAL phosphate.

APPENDIX E - RIVIERA IN-POND CEPT DATA

Date sample was taken: 01/07/00

Time sample was taken: 4:00 PM

Collection Point	Sample Number	Total Suspended Solids (TSS) (mg/L)	% Removal of TSS based on infuent at I-1	Volatile Solids (mg/L)	% Removal of Volatile Solids based on infuent at I-1	Fixed Solids (mg/L)	% Removal of Fixed Solids based on infuent at I-1	Chemical Oxygen Demand (COD) (mg/L)	% Removal of COD based on infuent at I-1
I-1	0R	128	-----	14.0	-----	-1.2	-----	-----	-----
E-1	1	16	87.5%	2.4	82.9%	-0.8	33.3%	-----	-----
E-2	2	50	60.9%	2.0	85.7%	3.0	350.0%	-----	-----
E-3	3	46	64.1%	156.0	-1014.3%	-151.4	-12516.7%	-----	-----
E-4	4	58	54.7%	17.6	-25.7%	-11.8	-883.3%	-----	-----

% Removal TSS from influent to effluent of the Anaerobic Lagoon (I-3 to E-1):	-212.5%
% Removal COD from influent to effluent of the Anaerobic Lagoon (I-3 to E-1):	-----

Date sample was taken: 01/08/00

Time sample was taken: 5:00 PM

Collection Point	Sample Number	Total Suspended Solids (TSS) (mg/L)	% Removal of TSS based on infuent at I-1	Volatile Solids (mg/L)	% Removal of Volatile Solids based on infuent at I-1	Fixed Solids (mg/L)	% Removal of Fixed Solids based on infuent at I-1	Chemical Oxygen Demand (COD) (mg/L)	% Removal of COD based on infuent at I-1
I-1	5R	152	-----	19.2	-----	-4.0	-----	-----	-----
I-3	6	232	-52.6%	16.4	14.6%	6.8	270.0%	-----	-----
E-1	7	18	88.2%	0.4	97.9%	1.4	135.0%	173	-----
E-5	8	22	85.5%	4.0	79.2%	-1.8	55.0%	168	-----
E-6	9	42	72.4%	2.0	89.6%	2.2	155.0%	190	-----

% Removal TSS from influent to effluent of the Anaerobic Lagoon (I-3 to E-1):	92.2%
% Removal COD from influent to effluent of the Anaerobic Lagoon (I-3 to E-1):	-----

Date sample was taken: 01/09/00

Time sample was taken: 9:00 AM

Collection Point	Sample Number	Total Suspended Solids (TSS) (mg/L)	% Removal of TSS based on infuent at I-1	Volatile Solids (mg/L)	% Removal of Volatile Solids based on infuent at I-1	Fixed Solids (mg/L)	% Removal of Fixed Solids based on infuent at I-1	Chemical Oxygen Demand (COD) (mg/L)	% Removal of COD based on infuent at I-1
I-1	10R	204	-----	----	-----	-----	-----	560	-----
I-3	11	162	20.6%	----	-----	-----	-----	398	28.9%
E-1	12	34	83.3%	----	-----	-----	-----	217	61.3%
E-5	13	62	69.6%	----	-----	-----	-----	206	63.2%
E-6	14	40	80.4%	----	-----	-----	-----	225	59.8%

% Removal TSS from influent to effluent of the Anaerobic Lagoon (I-3 to E-1):	79.0%
% Removal COD from influent to effluent of the Anaerobic Lagoon (I-3 to E-1):	45.5%

Date sample was taken: 01/10/00

Time sample was taken: 12:00 PM

Collection Point	Sample Number	Total Suspended Solids (TSS) (mg/L)	% Removal of TSS based on infuent at I-1	Volatile Solids (mg/L)	% Removal of Volatile Solids based on infuent at I-1	Fixed Solids (mg/L)	% Removal of Fixed Solids based on infuent at I-1	Chemical Oxygen Demand (COD) (mg/L)	% Removal of COD based on infuent at I-1
I-1	15R	232	-----	22.8	-----	0.4	-----	739	-----
I-3	16	160	31.0%	14.2	37.7%	1.8	-350.0%	381	48.4%
E-1	17	2	99.1%	5.2	77.2%	-5.0	1350.0%	266	64.0%
E-5	18	78	66.4%	8.6	62.3%	-0.8	300.0%	181	75.5%
E-6	19	52	77.6%	5.6	75.4%	-0.4	200.0%	292	60.5%

% Removal TSS from influent to effluent of the Anaerobic Lagoon (I-3 to E-1):	98.8%
% Removal COD from influent to effluent of the Anaerobic Lagoon (I-3 to E-1):	30.2%

Date sample was taken: 01/10/00

Time sample was taken: 6:00 PM

Collection Point	Sample Number	Total Suspended Solids (TSS) (mg/L)	% Removal of TSS based on infuent at I-1	Volatile Solids (mg/L)	% Removal of Volatile Solids based on infuent at I-1	Fixed Solids (mg/L)	% Removal of Fixed Solids based on infuent at I-1	Chemical Oxygen Demand (COD) (mg/L)	% Removal of COD based on infuent at I-1
I-1	20R	196	-----	19.2	-----	0.4	-----	668	-----
I-3	21	172	12.2%	15.2	20.8%	2.0	-400.0%	515	22.9%
E-1	22	42	78.6%	5.4	71.9%	-1.2	400.0%	274	59.0%
E-5	23	48	75.5%	6.4	66.7%	-1.6	500.0%	204	69.5%
E-6	24	70	64.3%	8.6	55.2%	-1.6	500.0%	221	66.9%

% Removal TSS from influent to effluent of the Anaerobic Lagoon (I-3 to E-1):	75.6%
% Removal COD from influent to effluent of the Anaerobic Lagoon (I-3 to E-1):	46.8%

Date sample was taken: 01/11/00

Time sample was taken: 10:30 AM

Collection Point	Sample Number	Total Suspended Solids (TSS) (mg/L)	% Removal of TSS based on infuent at I-1	Volatile Solids (mg/L)	% Removal of Volatile Solids based on infuent at I-1	Fixed Solids (mg/L)	% Removal of Fixed Solids based on infuent at I-1	Chemical Oxygen Demand (COD) (mg/L)	% Removal of COD based on infuent at I-1
I-1	25R	136	-----	14.4	-----	-0.8	-----	496	-----
I-3	26	56	58.8%	13.2	8.3%	-7.6	-850.0%	401	19.2%
E-1	27	122	10.3%	4.2	70.8%	8.0	1100.0%	333	32.9%
E-5	28	82	39.7%	9.2	36.1%	-1.0	-25.0%	269	45.8%
E-6	29	62	54.4%	7.0	51.4%	-0.8	0.0%	295	40.5%

% Removal TSS from influent to effluent of the Anaerobic Lagoon (I-3 to E-1):	-117.9%
% Removal COD from influent to effluent of the Anaerobic Lagoon (I-3 to E-1):	17.0%

Date sample was taken: 01/11/00

Time sample was taken: 4:45 PM

Collection Point	Sample Number	Total Suspended Solids (TSS) (mg/L)	% Removal of TSS based on infuent at I-1	Volatile Solids (mg/L)	% Removal of Volatile Solids based on infuent at I-1	Fixed Solids (mg/L)	% Removal of Fixed Solids based on infuent at I-1	Chemical Oxygen Demand (COD) (mg/L)	% Removal of COD based on infuent at I-1
I-1	30R	216	-----	24.0	-----	-2.4	-----	865	-----
I-3	31	192	11.1%	20.4	15.0%	-1.2	50.0%	570	34.1%
E-1	32	32	85.2%	5.2	78.3%	-2.0	16.7%	251	71.0%
E-5	33	68	68.5%	8.8	63.3%	-2.0	16.7%	272	68.6%
E-6	34	32	85.2%	5.2	78.3%	-2.0	16.7%	209	75.8%

% Removal TSS from influent to effluent of the Anaerobic Lagoon (I-3 to E-1):	83.3%
% Removal COD from influent to effluent of the Anaerobic Lagoon (I-3 to E-1):	56.0%

Date sample was taken: 01/12/00

Time sample was taken: 10:00 AM

Collection Point	Sample Number	Total Suspended Solids (TSS) * (mg/L)	% Removal of TSS based on infuent at I-1	Volatile Solids (mg/L)	% Removal of Volatile Solids based on infuent at I-1	Fixed Solids (mg/L)	% Removal of Fixed Solids based on infuent at I-1	Chemical Oxygen Demand (COD)* (mg/L)	% Removal of COD based on infuent at I-1
I-1	35R	296	-----	12.8	-----	-4.4	-----	852	-----
I-3	36	192	35.1%	19.6	-53.1%	-0.4	90.9%	602	29.3%
E-1	37	34	88.5%	5.4	57.8%	-2.0	54.5%	249	70.8%
E-5	38	66	77.7%	7.2	43.7%	-0.6	86.4%	194	77.2%
E-6	39	56	81.1%	7.0	45.3%	-1.4	68.2%	214	74.9%

% Removal TSS from influent to effluent of the Anaerobic Lagoon (I-3 to E-1):	82.3%
% Removal COD from influent to effluent of the Anaerobic Lagoon (I-3 to E-1):	58.6%

* Note: Values for I-1 were taken from Irene's raw sample data, which was the same sample.
The original measurement for TSS was 504 mg/L, and the measurement for COD was 84 mg/L.
Both are clearly unreasonable given the rest of the data.

Date sample was taken: 01/12/00

Time sample was taken: 6:30 PM

Collection Point	Sample Number	Total Suspended Solids (TSS) (mg/L)	% Removal of TSS based on infuent at I-1	Volatile Solids (mg/L)	% Removal of Volatile Solids based on infuent at I-1	Fixed Solids (mg/L)	% Removal of Fixed Solids based on infuent at I-1	Chemical Oxygen Demand (COD) (mg/L)	% Removal of COD based on infuent at I-1
I-1	40R	224	-----	23.6	-----	-1.2	-----	853	-----
I-3	41	136	39.3%	14.4	39.0%	-0.8	33.3%	437	48.8%
E-1	42	30	86.6%	35.6	-50.8%	-32.6	-2616.7%	231	72.9%
E-5	43	88	60.7%	9.4	60.2%	-0.6	50.0%	178	79.1%
E-6	44	58	74.1%	-24.0	201.7%	29.8	2583.3%	203	76.2%

% Removal TSS from influent to effluent of the Anaerobic Lagoon (I-3 to E-1):	77.9%
% Removal COD from influent to effluent of the Anaerobic Lagoon (I-3 to E-1):	47.1%

Date sample was taken: 01/16/00

Time sample was taken: 1:00 PM

Collection Point	Sample Number	Total Suspended Solids (TSS) (mg/L)	% Removal of TSS based on infuent at I-1	Volatile Solids (mg/L)	% Removal of Volatile Solids based on infuent at I-1	Fixed Solids (mg/L)	% Removal of Fixed Solids based on infuent at I-1	Chemical Oxygen Demand (COD) (mg/L)	% Removal of COD based on infuent at I-1
I-1	45R	168	-----	18.4	-----	-1.6	-----	583	-----
I-3	46	176	-4.8%	17.2	6.5%	0.4	125.0%	524	10.1%
E-1	47	42	75.0%	5.0	72.8%	-0.8	50.0%	183	68.6%
E-5	48	56	66.7%	6.4	65.2%	-0.8	50.0%	141	75.8%
E-6	49	34	79.8%	4.8	73.9%	-1.4	12.5%	152	73.9%

% Removal TSS from influent to effluent of the Anaerobic Lagoon (I-3 to E-1):	76.1%
% Removal COD from influent to effluent of the Anaerobic Lagoon (I-3 to E-1):	65.1%

Date sample was taken: 01/17/00

Time sample was taken: 2:00 PM

Collection Point	Sample Number	Total Suspended Solids (TSS) (mg/L)	% Removal of TSS based on infuent at I-1	Volatile Solids (mg/L)	% Removal of Volatile Solids based on infuent at I-1	Fixed Solids (mg/L)	% Removal of Fixed Solids based on infuent at I-1	Chemical Oxygen Demand (COD) (mg/L)	% Removal of COD based on infuent at I-1
I-1	50R	116	-----	15.2	-----	-3.6	-----	489	-----
I-3	51	116	0.0%	16.0	-5.3%	-4.4	-22.2%	507	-3.7%
E-1	52	22	81.0%	5.2	65.8%	-3.0	16.7%	172	64.8%
E-5	53	20	82.8%	4.8	68.4%	-2.8	22.2%	251	48.7%
E-6	54	14	87.9%	4.8	68.4%	-3.4	5.6%	179	63.4%

% Removal TSS from influent to effluent of the Anaerobic Lagoon (I-3 to E-1):	81.0%
% Removal COD from influent to effluent of the Anaerobic Lagoon (I-3 to E-1):	66.1%

Date sample was taken: 01/17/00

Time sample was taken: 6:00 PM

Collection Point	Sample Number	Total Suspended Solids (TSS) (mg/L)	% Removal of TSS based on infuent at I-1	Volatile Solids (mg/L)	% Removal of Volatile Solids based on infuent at I-1	Fixed Solids (mg/L)	% Removal of Fixed Solids based on infuent at I-1	Chemical Oxygen Demand (COD) (mg/L)	% Removal of COD based on infuent at I-1
I-1	55R	68	-----	13.2	-----	-6.4	-----	386	-----
I-3	56	92	-35.3%	12.4	6.1%	-3.2	50.0%	411	-6.5%
E-1	57	24	64.7%	5.0	62.1%	-2.6	59.4%	215	44.3%
E-5	58	26	61.8%	4.8	63.6%	-2.2	65.6%	218	43.5%
E-6	59	14	79.4%	4.6	65.2%	-3.2	50.0%	202	47.7%

% Removal TSS from influent to effluent of the Anaerobic Lagoon (I-3 to E-1):	73.9%
% Removal COD from influent to effluent of the Anaerobic Lagoon (I-3 to E-1):	47.7%

Date sample was taken: 01/18/00

Time sample was taken: 10:30 AM

Collection Point	Sample Number	Total Suspended Solids (TSS) (mg/L)	% Removal of TSS based on infuent at I-1	Volatile Solids (mg/L)	% Removal of Volatile Solids based on infuent at I-1	Fixed Solids (mg/L)	% Removal of Fixed Solids based on infuent at I-1	Chemical Oxygen Demand (COD) (mg/L)	% Removal of COD based on infuent at I-1
I-1	60R	132	-----	16.8	-----	-3.6	-----	585	-----
I-3	61	76	42.4%	11.6	31.0%	-4.0	-11.1%	358	38.8%
E-1	62	26	80.3%	5.0	70.2%	-2.4	33.3%	238	59.3%
E-5	63	56	57.6%	7.8	53.6%	-2.2	38.9%	199	66.0%
E-6	64	22	83.3%	4.6	72.6%	-2.4	33.3%	183	68.7%

% Removal TSS from influent to effluent of the Anaerobic Lagoon (I-3 to E-1):	65.8%
% Removal COD from influent to effluent of the Anaerobic Lagoon (I-3 to E-1):	33.5%

APPENDIX F - RIVIERA PRE-POND COMPOSITE CEPT DATA DURING CARNIVAL 2000

Raw Wastewater

Day	COD	BOD	pH	Total Susp. Solids	Fixed Solids	Volatile Solids	Total Phosphate
03/03/2000	495	227	6,7	184	16	168	5,2
04/03/2000	456	256	6,5	125	36	89	4,6
05/03/2000	476	212	6,6	284	104	180	4,8
06/03/2000	470	221	6,4	268	96	172	4,6
07/03/2000	456	234	6,5	125	35	90	4,2

Effluent CEPT

Day	COD	BOD	pH	Total Susp. Solids	Fixed Solids	Volatile Solids	Total Phosphate
03/03/2000	248	124	6,8	60	16	44	0,8
04/03/2000	258	136	6,7	60	36	24	0,6
05/03/2000	218	126	6,8	88	23	65	0,8
06/03/2000	235	112	6,6	60	24	36	0,6
07/03/2000	215	109	6,7	56	12	34	0,6

Date	*Effluent Anaerobic Lagoon*			*Effluent Facultat. 3 Lagoons*			*Effluent WWTP (after chlorination)*		
Day	**COD**	**BOD**	**pH**	**COD**	**BOD**	**pH**	**COD**	**BOD**	**pH**
03/03/2000	168	83	6,9	133	34	7,7	133	31	7,1
04/03/2000	188	96	7,0	129	40	7,3	139	32	7,1
05/03/2000	179	83	7,2	119	38	7,4	129	32	7,3
06/03/2000	196	105	6,9	137	49	7,2	157	37	7,0
07/03/2000	204	110	7,0	132	41	7,3	143	38	7,1

REFERENCES

APHA, AWWA, WEF. "Standard Methods for Examination of Water and Wastewater," 19th Edition. 1995.

Balmer, P., Bjarne, V. "Domestic Wasteater Treatment With Oxidation Ponds in Combination with Chemical Precipitation." Prog. Wat. Tech., Vol 10, Nrs 5/6, 1978.

Fundação Salim Farah Maluf and SABESP. "Segundo Relatório do Teste de Aplicabilidade do "CE.P.T. Tratamento Primário Quimicamente Aprimorado" ao Esgoto da E.T.E. Jesus Neto - SABESP" Unpublished Report. 1996.

Fundação Salim Farah Maluf and SABESP. "Relatório no. 2JN do Teste de Aplicabilidade do "CE.P.T. – Tratamento Primário Quimicamente Aprimorado" ao Esgoto da E.T.E. Jesus Neto - SABESP" Unpublished Report. 1996.

Fundação Salim Farah Maluf and SABESP. "Relatório Final do Teste em Escala Real da Tecnologia C.E.P.T. na E.T.E. Jesus Neto (B. Ipiranga – SP)." Unpublished Report. Nov 1996.

Gotovac, D.J. "Design and Analysis of Chemical Coagulation Systems to Enhance Performance of Waste Stabilization Lagooons." Department of Civil and Environmental Engineering, Massachusetts Institute of Technology. June 1999.

http://www.hach.com/Spec/codd.htm

Hanaeus, J. "Wastewater treatment by chemical precipitation in ponds." Division of Sanitary Engineering, Lulea University of Technology. September, 1991.

Harleman, D.R.F., and S. Murcott. "Low Cost Nutrient Removal Demonstration Study Report on ETIG Bench Scale Tests Rio de Janeiro, Brasil." Unpublished Report. MIT April, 1997.

Harleman, D.R.F. and Murcott, S. "The Role of Physical-Chemical Wastewater Treatment in the Mega-Cities of the Developing World." *Wat. Env. Tech.*, Vol. 40, No. 4-5, 1999.

Metcalf & Eddy, Inc. Wastewater Engineering: Treatment, Disposal, and Reuse. Third Edition. New York: McGraw-Hill Inc., 1991.

Metropolitan Wastewater District. "The City of San Diego: 1998 Annual Reports and Summary, Point Loma Wastewater Treatment Plant, Point Loma Ocean Outfall." 1998.

Morrissey, S.P. "Chemically-Enhanced Wastewater Treatment." Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, 1990.

Murcott, S., Harleman, D. "Chemically Enhanced Primary Treatment." Draft Manuscript. Massachusetts Institute of Technology, 2000.

Odegaard, H., Balmer, P., Hanaeus, J. "Chemical Precipitation in Highly Loaded Stabilization Ponds in Cold Climates: Scandinavian Experiences." Wat. Sci. Tech. Vol. 19, No. 12, 1987.

O'Melia, C.R., "Coagulation in Water and Wastewater Treatment." Water Quality Improvement by Physical and Chemical Processes. E.F. Gloyna and W.W. Echenfelder, Jr., eds, 1970, University of Texas Press, Austin and London.

Tsukamoto, Ricardo. Personal interview. January, 2000.

Yu, I.W., "Bench-Scale Study of Chemically Enhanced Primary Treatment in Brazil." Department of Civil and Environmental Engineering, Massachusetts Institute of Technology. May 2000.