Sludge Management in Alfenas, Brazil

by

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Submitted to the Department of Civil and Environmental Engineering on May 10, 2002 in Partial Fulfillment of the Requirement for the Degree of Master of Engineering in Environmental Engineering

Abstract

The purpose of this thesis is to propose a sludge management strategy for the city of Alfenas, Brazil. Lacking wastewater treatment facilities, Alfenas, and other cities in the Furnas Reservoir region, are polluting the already drought compromised reservoir, which also serves as their drinking water source. Chemically enhanced primary treatment (CEPT) is recommended as a cost effective and feasible wastewater treatment system (Olive 2002). The CEPT plant, designed for the city of Alfenas, will serve as a model for the Furnas Reservoir region.

A financially feasible strategy for the treatment and beneficial use of the sludge produced by the proposed plant is presented in this thesis. Based on data collected during a field study, conducted in Alfenas in January 2002, and an examination of U.S. and Brazilian regulations on the use of sludge, a sludge treatment system has been designed. Treatment recommendations include disinfection, thickening, and drying the sludge, making it available for use as a fertilizer on local crops. In this study sludge application to coffee crops, the dominant agricultural product in the area, was evaluated as a potential beneficial use strategy. The nutrient value of the sludge was assessed and preliminary land application rates have been calculated. A pilot study at the University of Alfenas coffee farm has been recommended to further study the fertilizer value of the sludge and determine appropriate application rates.

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1. Introduction

The goal of this thesis is to propose a sludge management strategy that is financially and technically feasible for the city of Alfenas, Brazil. This thesis is part of a larger project aimed at providing a wastewater treatment solution for the Furnas Reservoir Region, in the state of Minas Gerais Brazil. The lack of wastewater treatment facilities in the region is exacerbating existing environmental problems. In order to address the region's need for cost effective and technically feasible wastewater treatment a chemically enhanced primary treatment (CEPT) plant is proposed for the city of Alfenas, a 60,000-inhabitant city in the southern portion of the Furnas Reservoir region. This plant is part of a comprehensive regional solution and should serve as a model for other cities surrounding the reservoir. The proposed CEPT plant utilizes the metal salt, ferric chloride, and a locally available organic polymer, Tanfloc, to enhance settling and provide sufficient solids and nutrient removal. The plant design is presented by Olive (2002) and the regional impact of the treatment on the Furnas Reservoir is examined by Fateen (2002).

The most expensive phase of most wastewater treatment systems is sludge treatment and disposal. While the effluent leaves the plant relatively clean the wastewater residuals must be handled carefully in order to prevent the reintroduction of these contaminants into the environment and to minimize health risks to the local community. Without appropriate treatment and disposal the sludge can be more harmful than the raw sewage and the proposed treatment plant will not have the desired effect of improving the human and environmental health in the city and the region. The existing environmental problems and financial limitations made sludge management a particularly vital part of this regional wastewater treatment project. Furthermore, CEPT produces more sludge than conventional primary treatment, increasing the need for effective sludge management. In order for the CEPT plant to be financially feasible the sludge must be treated and disposed of in a manner that is cost effective and consistent with the region's environmental goals. The focus of this thesis is to propose an effective and feasible sludge treatment system and also provide a beneficial use strategy for the city of Alfenas.

1.1 Current Status of the Furnas Reservoir Region

In 1963, the first FURNAS hydroelectric power plant began operation. The construction of this power plant created the Furnas Reservoir, with a surface area of 1,440 km^2. The reservoir has become an important resource for recreation and tourism and also serves as a drinking water source and disposal location for the region's wastewater. Figure 1.1 shows the location of the Furnas Reservoir region.

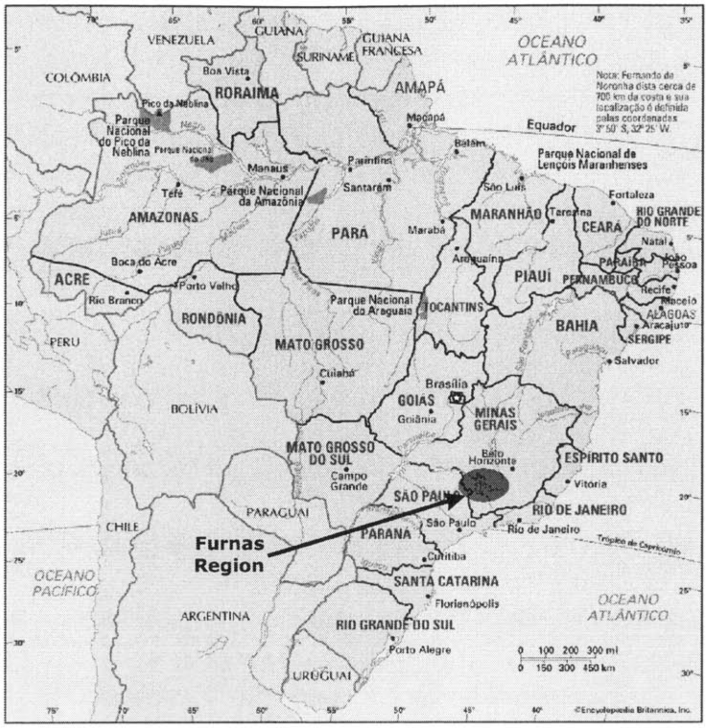

Figure 1.1: Map of Brazil, FURNAS region highlighted

(Geocities)

At present, this FURNAS power plant provides generates 163 kWh of power per month for 23,000 households. The lake provides 99% of the fresh water supply for the region, and collects 98% of the sewage produced (FURNAS website, www.furnas.com.br).

A combination of severe drought conditions and increased power demand have decreased the reservoir to 11% of its originally volume. The disposal of untreated sewage to the reservoir poses human and environmental health risks. The lower water volume increases the concentrations of contaminants and wastewater treatment is vital to improving reservoir water quality.

1.2 Proposed Objectives for the Region's Wastewater Management

The regional wastewater management solution must be cost-effective and technically viable. CEPT is proposed as a first step towards wastewater treatment in the region. This technology will achieve treatment levels comparable to secondary treatment in terms of total suspended solids and phosphorus removal, but with a lower capital cost. Unlike effluent from conventional primary treatment CEPT effluent can also effectively be disinfected. Regional implementation of this technology would be a significant step towards preserving the reservoir as an important water resource.

1.3 The City of Alfenas

The city of Alfenas, located in the southeastern area of the lake, was selected for the design and construction of a CEPT plant that could serve as a model for other cities in the Furnas region. Alfenas is a rapidly growing city with a population of 66,000 inhabitants, located in the state of Minas Gerais, about 500 km inland from Rio de Janeiro (see Figure 1.2).

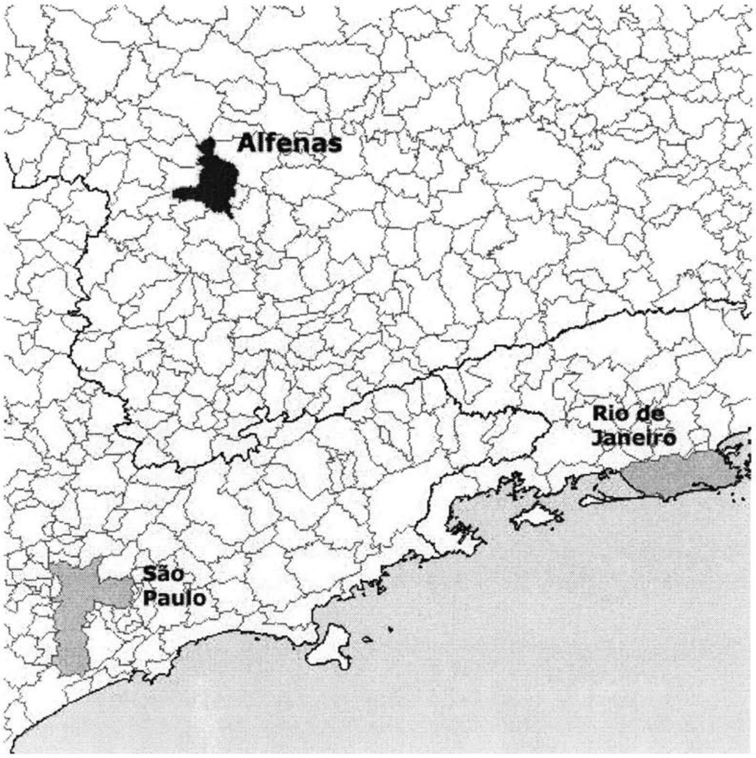

Figure 1.2: Map of Alfenas relative to São Paulo and Rio de Janeiro

(Brazilian Institute of Geography and Statistics)

Wastewater in the city is collected in open channel streams and flows into the Furnas Reservoir. The proposed CEPT plant will treat wastewater collected in the Jardim da Boa Esperança, which collects wastewater from 30% of city's population, approximately 20,000 inhabitants. CEPT plants are also used for municipal wastewater treatment in Rio de Janeiro and São Paulo, two of the largest and most economically prominent cities in Brazil.

1.4 Sludge Management

The purpose of this study is to propose a sludge management strategy that is financially and technically feasible for the city of Alfenas, while providing a level of treatment that allows the sludge to be beneficially used by the community. An important goal of this project was to design a sludge management system that was sustainable and could be maintained for many years without being dependent on the economic status of the region. The treatment technologies proposed were selected with an effort to minimize operational costs. Technically complex equipment was also avoided in order to limit opportunities for equipment failures that could require costly replacement parts and skilled mechanics. Because of the proximity of agricultural land to Alfenas and the importance of agricultural in the region land application of the sludge was selected as an appropriate and beneficial sludge disposal method. By applying the sludge on agricultural land the operation of the treatment plant and the sludge management strategy are not dependent on available landfill or storage space, or incinerator operation.

The sludge treatment techniques recommended in this report were selected based on technical simplicity, minimal operational costs, and compliance with the regulatory requirements for the application of sludge to agricultural land. The U.S. EPA has outlined the planning steps for a sludge land application program (U.S. EPA 1995). These steps are shown in Figure 1.3.

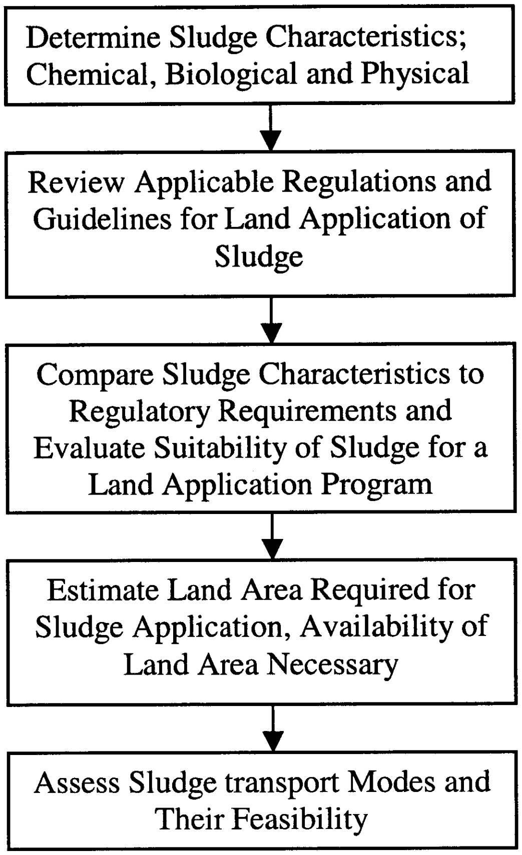

Figure 1.3: Planning Steps for a Sludge Land Application Program

(U.S. EPA 1995)

In developing the following recommendations these basic steps were followed and are addressed in this document. In order to study the local wastewater conditions and test the proposed wastewater and sludge treatment techniques a 3-week field study period was conducted in Alfenas in January 2002. During this period the chemical additives for the wastewater treatment were selected based on availability and treatment efficiency. Sludge samples were also collected for chemical, physical and biological analysis and treatment techniques were evaluated for effectiveness and regulatory compliance. The results of these field tests are discussed in Section 3. Based on these results and the U.S. EPA standards for land applied sludges (also adopted by the Brazilian government) the proposed treatment strategy, presented in Section 4, and land application plan, presented in Section 5, were developed.

2. Agricultural Use of Biosolids

2.1 United States

The benefits of sludge as a fertilizer have been recognized by farmers for as long as agriculture has been practiced. Before the 1940s, when synthetic fertilizer became available and affordable for U.S. farmers, sludge was commonly applied to crops increase yields (Outwater 1995). Commercial fertilizers began replacing sludge and, as a result, sludge was disposed of as a waste product. In the last two decades sludge has been reintroduced as a resource and the amount of sludge applied to U.S crops has been increasing. In 1993 the U.S. EPA promulgated the 40 CFR Part 503 regulations to encourage the beneficial use of sludge and to establish standards for the safe application of biosolids.

Land application of sludge is considered a beneficial alternative to landfilling or incineration because of the negative environmental impacts and high costs of these sludge management practices (McFarland 2001). Processing the sludge for agricultural use is an effective management practice that can also provide a source of revenue. In the U.S. dried biosolids can command between $25 and $40 per ton, depending on the quality (DeLaForest 2001). The high organic and nutrient content of sludge also makes it a valuable resource for farmers as it can increase soil quality and crop yields, while decreasing the need for expensive chemical fertilizers (Outwater 1995). Because the beneficial use has become a cost effective biosolids management practice it is increasing in popularity. Municipal sludge is processed into agricultural fertilizers and soil conditioners in most major U.S. cities, including Philadelphia, Chicago, Baltimore, Denver, Madison, Phoenix, Los Angeles, Boston, and Portland (Outwater 1995). In the U.S. approximately 35% of publicly owned wastewater treatment plants dispose of sludge by land application and 30 states estimated their percentage of beneficially used biosolids to be increasing (Goldstein 2000). The quantity of sludge disposed of by land application is 33%, and approximately 80% is applied to agricultural land (Outwater 1995).

2.2 New England

The New England region of the United States has taken advantage of the benefits of land applying biosolids. In an effort to prevent the pollution of important waterways and conserve landfill space 1/5 of the sludge produced in New England is processed into beneficial fertilizer products (Kruger 2001). The 96,000 dry tons of sludge applied to agricultural land from New England treatment plants contained 3.7 million pounds of nitrogen. If this nitrogen had been purchased in the form of chemical fertilizers it would have costs farmers $1.3 million. By using the sludge as fertilizer 350,000 cubic yards of landfill space was conserved.

Sludge produced at Boston's Deer Island wastewater treatment plant is converted to dried agricultural fertilizer at the Massachusetts Water Resource Athority's Pelletizing Facility at Fore River (www.mwra.state.ma.us). From this location the fertilizer pellets are sent to locations around the country. Between

1992 and 2001, 60,000 tons of biosolids that would have been discharged to the Boston Harbor were processed for agricultural use (www.nefcobiosolids.com).

3. Experimental Results

3.1 Sludge Production

The results presented here were collected in January of 2002 at Unifenas University in Alfenas, Brazil. Raw wastewater samples were collected from the Jardim da Boa Esperança, a wastewater and storm water collection stream, in Alfenas. Sludge was produced from the wastewater samples after no more than eight hours of dark storage. In order to obtain reliable sludge data it was necessary to generate sludge that would be representative of the sludge produced by the proposed CEPT plant. In order to accomplish this goal the chemical addition and mixing regime utilized in the bench scale analyses for chemical selection and plant design (Olive 2002) were also implemented in these experiments. Sludge was produced, for the purpose of these analyses, in the following manner:

1. A volume of well-mixed, raw wastewater was transferred to a 20 liter cylindrical mixing tank.
2. The sample was stirred rapidly for 30 seconds.
3. The coagulant chemical was added at the appropriate dosage.
4. The sample was stirred rapidly for 30 seconds.
5. The flocculent chemical was added at the appropriate dosage.
6. The sample was stirred slowly for 5 minutes.

7. The sample was allowed to settle for approximately 20 minutes.
8. Supernatant was decanted by pouring of excess water, with efforts to leave settled sludge undisturbed.
9. Well-mixed sludge samples were collected for individual analyses.

All stirring was done by hand, using a glass stirring rod two feet in length. The samples were allowed to settle for 20 minutes in order to collect the maximum quantity of sludge for analysis while maintaining time efficiency during the short, 3 week, field study period.

Two types of sludge were produced in order to reflect to the two proposed wastewater treatment options (Olive 2002). Sludge A was produced from the addition of ferric chloride at 30mg/l, as a coagulant, followed by the addition of Tanfloc, a cationic polymer, at 10mg/l, as a flocculant. The sludge B was produced from the addition of Tanfloc at 40mg/l, as a coagulant. Table 3.1 list the chemicals and concentrations added to the wastewater samples to create each of the sludge types. The characteristics of both sludges are discussed in this section.

Table 3.1: Chemical Additives and Dosages for each Sludge Type

Sludge Type	**Coagulant**	**Dosage** (mg/l)	**Flocculant**	**Dose** (mg/l)
Sludge A	Ferric Chloride ($FeCl_3$)	30	Tanfloc	10
Sludge B	Tanfloc	40	none	-

Although the characteristics of the raw wastewater varied slightly with sampling time or day, all of the sludge characteristics measured in this study remained fairly consistent throughout the three-week testing period. For most of the tests presented here more samples of Sludge A than Sludge B were analyzed because the addition of ferric chloride in combination with Tanfloc is the primary treatment recommendation (Olive 2002)

3.2 pH

The pH of sludge can be an important parameter, especially if the sludge is to be eventually utilized as a fertilizer on agricultural land. Because the applied biosolids can influence the pH of the soil, impacting soil chemistry and plant productivity, the pH of the biosolids should not exceed 6.5 (U.S. EPA 1983). The initial pH of the sludge can also influence the downstream treatment process. When utilizing the addition of lime for the purpose of disinfection, as proposed in this report, the pH must be raised above 12.

The pH of the sludge entering the lime addition process affects the dosage of lime required for pH elevation and, as a result impacts operating costs.

The pH of the sludge samples was consistent throughout the testing period and did not vary significantly with chemical additive. Table 3.2 gives the pH values of the sludge samples.

Table 3.2: pH of Sludge Samples

Sludge Type A	**pH**	**Sludge Type B**	**pH**
Sample 1	6.6	Sample 1	6.7
Sample 2	6.9	Sample 2	7.0
Sample 3	6.8	Sample 3	6.6
Sludge A Average	**6.8**	**Sludge B Average**	**6.8**
		Average of All Samples	**6.8**

Both Sludge A and Sludge B were found to have an average pH of 6.8. Untreated primary sludge typically has a pH between 5 and 8 (Metcalf & Eddy 1991). The pH values measured during this test are consistent with raw sludge pH data collected at the Point Loma CEPT plant in San Diego, California. The average pH of raw sludge at the Point Loma plant for the year 2000 was 6.27 (Point Loma Ocean Outfall Annual Monitoring Report 2000).

3.3 Total Solids

Total solids data was collected in order to evaluate the concentration of solid material in the sludge. The percent total solids can also be used in calculations of sludge volume and lime requirements. Total solids content was measured by drying the sample at 105 degrees Celsius for one hour according to Standard Methods for Water and Wastewater Examination, procedure 2540B

(Standard Methods 1991). The results of the total solids testing are given in Table 3.3.

The average percent total solids of Sludge A was 0.36 and the average percent total solids of Sludge B was 0.43. The difference in percent total solids of the two sludge types is 0.7%. This data suggests that there is no significant difference in the total solids content of the two sludges.

Untreated primary sludge ranges from 2% to 8% total solids, with a typical value of 5% (U.S. EPA 1979). The solids content often depends on the influent wastewater composition and can also be affected by the addition of chemicals and the dose. Raw sludge produced at the Point Loma plant averaged 4.5% total solids in 2000 (Point Loma Ocean Outfall Annual Monitoring Report 2000).

Table 3.3: Percent Total Solids

Sludge Type A	**%TS**	**Sludge Type B**	**%TS**
Sample 1	0.36	Sample 1	0.6
Sample 2	0.37	Sample 2	0.42
Sample 3	0.36	Sample 5	0.41
Sample 4	0.39	Sample 6	0.29
Sample 5	0.42	**Sludge B Average**	**0.43**
Sample 6	0.29		
Sample 7	0.29	**Average of All Samples**	**0.38**
Sample 8	0.45		
Sample 9	0.38		
Sample 10	0.29		
Sludge A Average	**0.36**		

There is an order of magnitude difference between the data reported at the Point Loma plant and the percent total solids of the sludge collected in this study. It should be noted that the percent total solids content is influenced by the method of supernatant removal. In wastewater treatment plants settled sludge is pumped from the bottom of the settling tank. For the purpose of this study the excess water was poured out of the top of the mixing tank. This decanting process, while time and resource efficient, did not allow for the effective removal of all the excess water without disturbing the settled sludge. Pumping methods utilized in treatment plants for sludge removal are superior to this decanting process as sludge integrity is better preserved and less effluent water is captured in the sludge flow. The method of sludge collection used in this study resulted in lower percent total solids values.

3.4 Volatile Suspended Solids (VSS)

It is essential to consider the organic fraction of sludge that is to be reused for agricultural proposes. The organic content of the sludge samples was evaluated by measuring the volatile suspended solids concentration. The VSS concentration was measured by baking the total solids samples at 550 degrees Celsius for one hour according to Standard Method procedure (Standard Methods 1991). The volatile suspended solids data is given in Table 3.4 as a percentage of the total solids.

Table 3.4: Volatile Suspended Solids as a Percentage of the Total Solids

Sludge Type A	% VSS	Sludge Type B	% VSS
Sample 1	67	Sample 1	73
Sample 2	65	Sample 2	70
Sample 3	69	Sample 3	57
Sample 4	58	Sample 4	76
Sample 5	72	**Sludge B Average**	**69**
Sludge A Average	**66**	**Average of All Samples**	**67**

The volatile suspended solids content of untreated primary sludge, as a percentage of total solids, ranges from 60% to 80% total solids, with a typical value of 65% (U.S. EPA 1979). Raw sludge produced at the Point Loma plant averaged 75.6% volatile solids in 2000 (Point Loma Ocean Outfall Annual Monitoring Report 2000). The results for volatile solids produced in this study are consistent with untreated primary sludge and slightly lower than sludge produced at the Point Loma plant.

3.5 Volume

In order to estimate the quantity of sludge that will be produced by the proposed CEPT plant the volume of sludge produced from each of the tests was measured by pouring the sample into a 1000ml beaker. The volume of raw wastewater and the volume of sludge produced from it are given in Table 3.5.

Table 3.5: Sludge Volumes as a Percentage of Wastewater Sample Volume

Sludge Type A	**% Sludge Volume**	**Sludge Type B**	**% Sludge Volume**
Sample 1	7	Sample 1	8
Sample 2	7	Sample 2	7
Sample 3	7	Sample 3	10
Sample 4	11	**Sludge B Average**	**8**
Sample 5	10		
Sludge A Average	**8**	**Average of All Samples**	**8**

The proposed CEPT plant will receive wastewater from approximately 20,000 inhabitants of Alfenas. The total volume of wastewater produced by this population, assuming that 180 liters is produced per person per day, is 3.6 million liters per day (Metcalf & Eddy 1991). Using the experimental data presented above, an average of 8% of the influent wastewater flow becoming sludge flow, the plant will produce 290,000 liters of sludge per day. It is important to note, however, that the volume of sludge calculated above would contain on average 0.38% totals solids, as reported in Section 3.3. This volume estimate is compared with calculated estimates in Section 4.2. Based on the data from the Point Loma CEPT plant, the sludge produced at the proposed plant is expected to have approximately 4% total solids (Point Loma Ocean Outfall Annual Monitoring Report 2000). As discussed in Section 3.3, the sludge collection techniques employed in this study do not reflect true plant conditions and the 0.38% total solids figure is not an accurate design value. The expected total solids content is approximately ten times greater than this experimental value. The above calculation of sludge volume predicts that 290,000 liters of sludge will be produced, at approximately 0.4% solids. Increasing the solids concentration to 4% requires a ten-fold decrease in sludge volume to account for the same mass of solids. Therefore the sludge volume of 290,000 l/d, at 0.4% solids predicts a design sludge volume of 29,000l/d at 4% solids.

3.6 Fecal Coliform

If sludge is to be beneficially reused for agricultural purposes, as proposed by this report, it must meet the standards outlined in the EPA 40 CFR part 503 rule: Land Application of Biosolids (U.S. EPA 1993). The Brazilian government has also adopted these standards. Fecal coliforms are used as an indicator organism to assess the health safety of sludge. The presence of fecal coliforms is used as evidence that other pathogenic organisms are also present. In order to meet Class B biosolids standards the sludge must have a fecal coliform count of less than 2,000,000 MPN per gram of dry sludge or be disinfected through one of the approved methods outlined in the legislation. In order to evaluate the treatment steps necessary to make the sludge available for beneficial use, samples were tested for fecal coliform levels. Fecal coliform analysis was done using the most probable number technique, Standard Methods procedure 9221 (Standard Methods 1991). Sample dilutions are incubated in lauryl tryptose broth for 48 hours to test for the presence of total coliform. Positive samples are reinoculated in EC medium and incubated for 24 hours to determine fecal coliform counts. Table 3.6 gives the fecal coliform counts as the most probable number (MPN) per gram of dry sludge.

Table 3.6: Fecal Coliform Counts as most probable number (MPN) per gram of dry sludge

Sludge Type A	MPN (per g dry sludge)	Sludge Type B	MPN (per g dry sludge)
Sample 1	1,000,000	Sample 1	150,000,000
Sample 2	20,000,000	Sample 2	24,000,000
Sample 3	13,000,000	Sample 3	24,000,000
Sample 4	9,000,000	Sample 4	80,000,000
Sample 5	68,000,000	Sample 5	270,000,000
Sludge A Average	**24,000,000**	**Sludge B Average**	**110,000,000**
		Average of All Samples	**67,000,000**

Typical fecal coliform concentrations in unstabilized liquid biosolids are given as 1 x 10^9 MPN per 100ml (McFarland 2001). Converting the average fecal coliform counts for the two types of sludges to these units gives 9.6 x 10^7 MPN per 100ml in Sludge A and 4.4 x 10^8 MPN per 100ml in Sludge B. Therefore, both sludges have fecal coliform concentrations below the typical concentrations. However the fecal coliform concentrations of the two sludges seem to be considerable different, with Sludge B concentrations being much higher than Sludge A concentrations. This may be a result of the characteristics of the chemical additives or the limited number of samples. A larger scale analysis could determine if the fecal coliform counts of the two sludge types are statistically different.

The most probable number counts found in this study indicate that the neither sludge type will meet the quality standards set by the legislation for fecal coliform counts. As a result disinfection methods must be considered if reuse strategies are to be pursued.

3.7 Lime Addition

Lime addition is a commonly used and cost effective disinfection technique (WEF Manual of Practice No. 8). According to the EPA 40 CFR part 503 lime addition is an approved method to significantly reduce pathogens (U.S.EPA 1993). To achieve sufficient disinfection and meet Class B biosolids standards through lime addition the pH of the sludge must be raised to 12 and remain at or above 12 for a least 2 hours. The pH must then remain above 11.5 for at least 24 hours (U.S. EPA 1993).

Commercial grade lime, $Ca(OH)_2$ in dry form, was added to the sludge until a pH of 12 was reached. In this study it was preferable to use locally available products for the purpose of assessing treatment strategies to ensure that the proposed design would be financially and technically feasible. The lime used in these tests was obtained from the drinking water plant at the University of Alfenas. In order to analyze the feasibility of this disinfection technique the quantities of lime necessary to raise the pH of the sample to just above 12 were recorded. This data is given in Table 3.7 as the milligrams of lime added per milligram of solids.

Table 3.7: Quantity of Lime Required to Raise Sample pH to 12

Sludge Type A	Lime (mg/mg of solids)	Sludge Type B	Lime (mg/mg of solids)
Sample 1	0.9	Sample 1	1
Sample 2	0.9	Sample 2	0.8
Sludge A Average	**0.9**	**Sludge B Average**	**0.9**
		Average of All Samples	**0.9**

These samples were monitored for 24 hours and met the time requirements for the desired pH levels. Fecal coliform tests were performed on four of the lime treated sludge samples in order to demonstrate disinfection and ensure the effectiveness of the lime addition. These samples all contained less than 3500 MPN per gram of dry solid. The fecal coliform counts were decreased by a minimum of four orders of magnitude by the addition of lime. This data demonstrates that a lime dosage of 0.9 milligrams (per milligram of dry solids) provides adequate disinfection and reduces the fecal coliform counts in the sludge to well below the 2,000,000 MPN level required by the legislation.

Typical lime dosages for primary sludge are between 0.06 and 0.17 grams of lime per gram of solids (U.S. EPA 1979). However these typical values are for sludges with 2-5% solids, considerable higher solids content than sludge analyzed in this study. The higher quantity of lime required for pH adjustment in this test may reflect the additional volume of water that had to be treated given the high solids dilution (WEF 1995). Sludges with solids content below 2% typically require high lime dosing (WEF 1995). The dosage required in this study may also indicate that the lime used was of low quality. Because lime reacts with iron to form iron hydroxide species, the presence of iron in the Sludge A may also account for some of the lime requirement (McFarland 2001).

Because the sludge studied in these tests had a considerable lower solids content (~0.4) than the sludge that will be produced at the proposed plant (4%) the lime dosage required in these tests (0.9 mg/mg of dry solids) is not an appropriate design value. The actual amount of lime necessary for disinfection will be considerable lower and is expected to be more consistent with typical dosages for primary sludges, between 0.6 and .17 grams of lime per gram of dry solids (U.S. EPA 1979). In order to ensure disinfection and take into account the effect of ferric chloride a design value of 0.2 grams of lime per gram of dry solids will be used.

The addition of lime also impacts the total solids content of the sludge. By mixing lime with the sludge the amount of solids in the sludge, and the final weight of solids to be disposed of, is increased.

3.8 Nutrients

If sludge is to be applied to agricultural land the nutrient content of the sludge must be known. The nutrient concentrations are used to compare the sludge to conventional fertilizers and to calculate sludge application rates. The percentages of nitrogen, phosphorus, and potassium of the total solids in raw and lime-treated sludge samples are given in Table 3.8 through 3.11. Nitrate nitrogen and potassium were measured using Hach methods 8038 and 8049, respectively (Hach 1997). The methods for ammonia nitrogen and phosphorus are described in Appendix A.

Table 3.8: Nitrate Nitrogen Concentrations of Raw and Lime-Treated Sludge and the Typical Concentration Range and Mean as a Percentage of Total Solids
(McFarland 2001)

Sludge Type	Lime to pH = 12	Nitrate N	Typical Range	Mean
Sludge A	NO	0.003	0.0002 - 0.49	0.05
Sludge B	NO	0.011	0.0002 - 0.49	0.05
Sludge A	YES	0.002	0.0002 - 0.49	0.05
Sludge B	YES	0.006	0.0002 - 0.49	0.05

Table 3.9: Ammonia Nitrogen Concentrations of Raw and Lime-Treated Sludge and the Typical Concentration Range and Mean as a Percentage of Total Solids
(McFarland 2001)

Sludge Type	Lime to pH = 12	Ammonia N	Typical Range	Mean
Sludge A	NO	0.443	0.0005 - 6.76	0.65
Sludge B	NO	0.400	0.0005 - 6.76	0.65
Sludge A	YES	0.445	0.0005 - 6.76	0.65
Sludge B	YES	0.224	0.0005 - 6.76	0.65

Table 3.10: Phosphorus Concentrations of Raw and Lime-Treated Sludge and the Typical Concentration Range and Mean as a Percentage of Total Solids
(McFarland 2001)

Sludge Type	Lime to pH = 12	P	Typical Range	Mean
Sludge A	NO	0.433	<0.1 - 14.3	2.3
Sludge B	NO	0.407	<0.1 - 14.3	2.3
Sludge A	YES	0.160	<0.1 - 14.3	2.3
Sludge B	YES	ND	<0.1 - 14.3	2.3

ND - No Data

Table 3.11: Potassium Concentrations of Raw and Lime-Treated Sludge and the Typical Concentration Range and Mean as a Percentage of Total Solids
(McFarland 2001)

Sludge Type	Lime to pH = 12	K	Typical Range	Mean
Sludge A	NO	0.600	0.02 - 2.64	0.4
Sludge B	NO	0.300	0.02 - 2.64	0.4
Sludge A	YES	0.117	0.02 - 2.64	0.4
Sludge B	YES	0.063	0.02 - 2.64	0.4

Comparing the typical values to the experimental results indicates that the nutrient levels of the sludge samples were within the typical ranges and fell below the mean value for all nutrients examined. Application rate calculations of the sludge to crops and an assessment of the feasibility of agricultural sludge usage, are discussed in Section 5.

4. Recommended Sludge Treatment

Based on the experimental results presented in Section 3 and the U.S. EPA standards for land applied sludges (also adopted by the Brazilian government) the proposed treatment strategy was developed. The proposed sludge treatment system is shown in Figure 4.1.

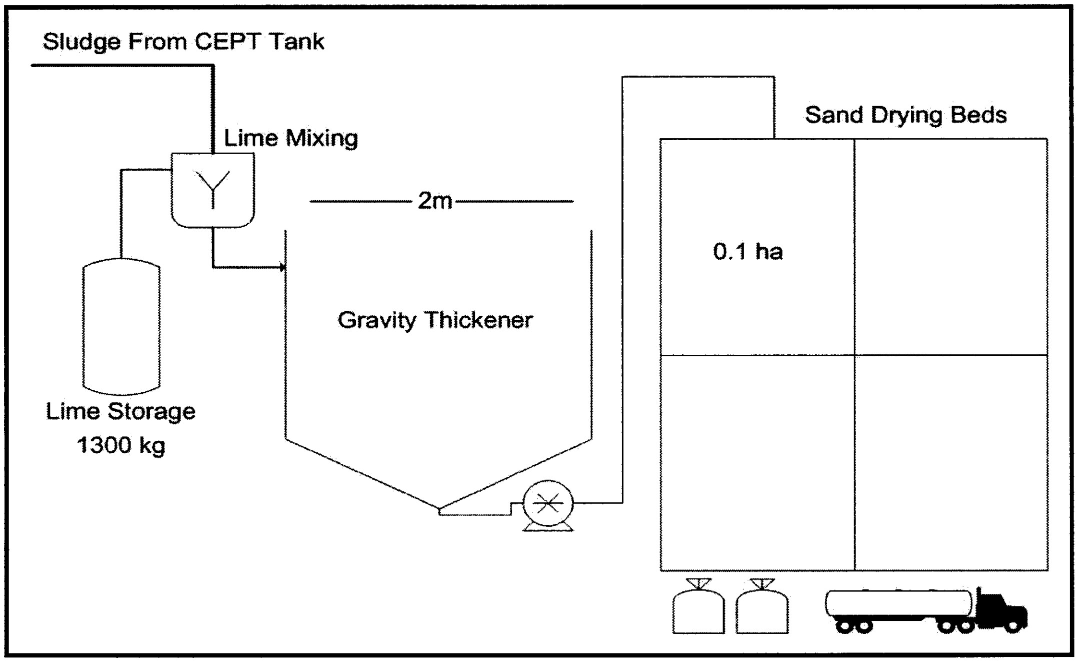

Figure 4.1: Proposed Sludge Treatment System

The sludge collected from the CEPT is pumped into a lime mixing tank where lime is added to a pH of 12 for the purpose of disinfection. After exiting the lime mixing tank sludge enters the gravity thickener, where the solids content of the sludge is increased. The liquid is removed from the top of the gravity thickener and returned to the head of the plant. The thickened sludge is pumped out to sand drying beds where the sludge is dried for a period of 1 to 2 weeks. From these drying beds the sludge can be removed and transported off site to agricultural locations.

4.1 Sludge Production

Calculations of sludge production are vital to wastewater treatment plant design as sludge treatment and handling can account for a large portion of the construction and maintenance costs of the plant. The volume of sludge produced depends on the influent wastewater quality and the type of wastewater treatment process used (WEF Manual of Practice 1998). CEPT plants typically create more sludge than primary treatment plants. This is due, in part, to the enhanced settling of particles, and the chemicals that are added during the CEPT process, that eventually become part of the sludge.

Several methods have been employed to calculate the volume of sludge flow and dry weight of sludge that will be produced by the proposed CEPT plant. The analysis of these methods and the estimates they provide ensures that the sludge management facilities will be appropriately sized.

4.1.1 Method 1: Mass Balance

Step 1: Calculate the mass of solids entering the plant

The influent TSS concentration ranged from 96 to 320mg/l, with a mean of 200mg/l (Olive 2002). The maximum value of 320mg/l will be used in these calculations to ensure that the sludge handling facilities are appropriately sized for maximum loading conditions. The proposed plant will receive wastewater from 20,000 inhabitants of Alfenas. The volume of influent wastewater is calculated based on a daily usage of 180 liters per person (Metcalf & Eddy 1991). The expected daily influent is calculated to be 3.6 million liters per day (Olive 2002).

$$S_{in} = TSS \times Q_{in}$$

Where: S_{in} = Influent solids mass (mg/d)

TSS = Influent total suspended solids concentration (mg/l)

Q_{in} = Influent wastewater volume (l/d)

Using this equation the mass of solids entering the plant is found to be 1,150 kilograms per day.

Step 2: Calculate the mass of solids exiting the plant

The calculation of the mass of solids exiting the plant is based on the 75% removal efficiency of both of the proposed CEPT treatment options (Olive 2002).

$$S_{out} = .25(TSS) \times (Q_{in} - Q_{sludge})$$

Where: S_{out} = Exiting solids mass (mg/d)

TSS = Influent total suspended solids concentration (mg/l)

Q_{in} = Influent wastewater volume (l/d)

Q_{sludge} = Sludge volume (l/d)

Step 3: Calculate the mass of Sludge

The mass of sludge is based on the assumption that the sludge will have 4% total solids. Because the proposed plant will utilize technology similar to that in place at the Point Loma plant the sludge produced is expected to have similar solids content. Sludge produced at the Point Loma CEPT plant has an average of 4.5% total solids.

$$S_{sludge} = TS \times Q_{sludge} = (S_{in} - S_{out})$$

Where: S_{sludge} = Dry mass of sludge (mg/d)

S_{in} = Influent solids mass (mg/d)

S_{out} = Exiting solids mass (mg/d)

TS = Total solids concentration (mg/l)

Q_{sludge} = Sludge volume (l/d)

Step 4: Solve for the volume and mass of sludge

By combing the above equations the volume and mass of sludge can be calculated.

$$S_{out} = S_{in} - S_{sludge}$$

Where: S_{sludge} = Dry mass of sludge (mg/d

S_{in} = Influent solids mass (mg/d)

S_{out} = Exiting solids mass (mg/d)

Using this mass balance the mass of sludge produced is calculated as 863 kilograms per day. The corresponding sludge volume is calculated to be 22,000 liters per day. This calculation predicts that the sludge flow will be approximately 0.6% of the daily influent flow. However, this method neglects the additional sludge resulting from chemical addition.

4.1.2 Method 2: Murcott Equation

Murcott developed this equation for calculating CEPT sludge production (1992). This method accounts for TSS removal and for additional sludge produced from chemical addition.

$$S_p = Q \times [TSS_{rem} + F(P_{rem}) + K(C_c)] \times 10^{-3}$$

Where: S_p = Dry mass of sludge (kg/d)

Q = Influent flow rate (m^3/d)

TSS_{rem} = Concentration of total suspended solids removed (mg/l)

F = Stoichiometric factor; 1.42 for mono and trivalent metals, 2.48 for divalent metals

P_{rem} = Concentration of phosphorus removed (mg/l)

K = constant (.66 for $FeCl_3$)

C_c = Concentration of metal salt added (mg/l)

This equation calculates the sludge production based on the total suspended solids removal, as in the mass balance method, but also calculates sludge mass produced by metal salt precipitation ($Fe(OH)_3$) and phosphorus removal. Assuming that Tanfloc does not react chemically in the wastewater and no chemical precipitates are formed, the addition of Tanfloc does not increase the amount of sludge produced.

The total suspended solids removed by the ferric chloride and Tanfloc treatment is 240 milligrams per liter and 7 milligrams per liter of phosphorus are removed. Using this data in the Murcott equation gives a predicted sludge mass of 970 kilograms per day. If the sludge is assumed to be 4% solids the volume of sludge can be estimated as 24,000 liters per day. These calculations are consistent with method 1. Using this type of calculation to determine sludge production from primary treatment without chemical addition gives a sludge mass of 860 kilograms per day and a sludge volume of 22,000 liters per day. Therefore, CEPT produces approximately 10% more sludge than conventional primary treatment. According to these calculations 7% of the sludge produced by the proposed plant will be due to ferric chloride precipitation and 4% will be due to phosphorus removal.

4.1.3 Method 3: Typical production rates

The ASCE manual "Design of Municipal Wastewater Treatment Plants" reports that sludge production rates at municipal plants typically fall between 0.2 and 0.3 kg/m^3 and recommends 0.25 kg/m^3 as an approximation (1998). This method predicts the mass of sludge produced to be 900 kg/d, with a sludge volume of 23,000 l/d (assuming 4% solids).

This is the least accurate of the sludge production estimations, however it is in agreement with the values produced by the more reliable methods.

4.1.4 Design Sludge Volume

The sludge mass and volumes obtained from each of the calculation methods is summarized in Table 4.1.

Table 4.1: Sludge Mass and Volume for each Calculation Method

Calculation Method	Sludge Mass (kg/day)	Sludge Volume (L/d)
Method 1	863	22,000
Method 2	970	24,000
Method 3	900	23,000

The sludge volume and mass used to design the sludge treatment facilities is selected based on the three estimations presented above. These three approximations were relatively in agreement, with the highest estimate of sludge mass of 970 kg/d being only 12% greater than the lowest estimate of 863 kg/d. In order to size the plant and the necessary equipment appropriately, and to accommodate for seasonal peak loadings, the highest estimate of sludge production, 970 kg/d, will be used as the design value. Assuming that the sludge will be 4% solids the design sludge volume is 24,000 l/d. The sludge flow is approximately 0.7% of the influent wastewater flow.

4.2 Lime Stabilization

Lime addition is recommended for the purpose of sludge disinfection. In order for sludge to be utilized on agricultural land, as proposed in this report, it must be effectively disinfected. The U.S. EPA has developed the *Standards for the Use and Disposal of Sewage Sludge* regulations to ensure that sludge applied to land is not a threat to human or environmental health (U.S. EPA 1993). The Brazilian government has also adopted these standards. In order to meet Class B biosolids standards the sludge must have a fecal coliform count of less than 2,000,000 MPN per gram of dry sludge or be disinfected through one of the approved methods outlined in the legislation. As discussed in Section 3.6 the sludge samples did not meet the fecal coliform standards and one of the disinfection methods must be employed. Complying with Class B biosolids requirements using lime disinfection requires that the pH of the sludge be raised to 12 for a minimum of 2 hours and remain above 11.5 for 22 hours (U.S. EPA 1993). Other methods could be employed for the reduction of pathogens that would also comply with regulatory standards for agricultural use of biosolids. The advantages of lime treatment, and the motives for recommending it here, are its low capital cost and simplicity of operation (McFarland 2001, WEF 1995). Lime is one of the least expensive and the most widely used alkaline additives available for wastewater treatment (WEF 1995). In addition, lime treatment is feasible because of its availability in Brazil. It is currently used at the University of Alfenas drinking water plant.

In order to comply with the regulatory requirements outlined above it is recommended that the sludge be treated with calcium hydroxide, or hydrated lime ($Ca(OH)_2$). There are several types of lime that could be used effectively in this process, including quicklime, which is often selected for its heat generating benefits (WEF 1995). Hydrated lime has been chosen for this plant because it holds several advantages over quicklime. Although hydrated lime costs approximately 30% more than quicklime, it requires significantly less operating equipment. Because quicklime must be converted to hydrated lime, a process called slaking, before it can be added to sludge, additional equipment is required.

The use of hydrated lime is economically feasible for small facilities where usage does not exceed 3.5 million grams per day (WEF 1995). The calculations below for lime requirements at the proposed plant indicate that lime usage will be below this limit, confirming the appropriateness of using hydrated lime.

4.2.1 Lime Quantity

In order to calculate the quantity of lime necessary to raise the pH of the sludge above 12 bench scale tests were conducted during the field study period, January 2002. The results of these tests, discussed in Section 3.5, indicate that 0.9 gram of lime must be added per gram of dry solids in the sludge. However this quantity of lime was required for samples with 0.4% solids, considerable more dilute sludge than will be limed treated at the proposed plant. The actual amount of lime necessary for disinfection will be considerable lower and is expected to be more consistent with typical dosages for primary sludges, between 0.6 and 0.17 grams of lime per gram of dry solids (U.S. EPA 1979). In order to ensure disinfection and take into account the effect of ferric chloride a design value of 0.2 grams of lime per gram of dry solids will be used. Based on the mass of sludge produced by the plant, calculated in Section 4.1 as 970 kg/d, approximately 190 kg/d of lime are necessary to stabilize the sludge. Lime, in the form of a 10% liquid solution, will be added to the sludge in a lime mixing tank. The volume of liquid solution required is approximately 1,900 liters per day.

4.2.2 Level of Disinfection

The lime treated samples used for lime quantity analysis were also tested for fecal coliforms to verify appropriate disinfection. The results of these tests presented Section 3.6, show a decrease in fecal coliform counts by four orders of magnitude when compared to samples without lime treatment. The treated samples all contained less than 3500 MPN per gram of dry solid. Monitoring the pH of these samples indicated that they stay at or above the necessary levels to comply with the 40 CFR 503. The tests confirm that disinfection can be attained through the addition of hydrated lime.

It is important to note that if a fecal coliform monitoring program was instituted it may be possible to utilize less lime while still producing Class B biosolids. Sludge can meet the Class B standards if the fecal coliform count is below 2 million MPN/g solid and adding lime decreases the count to well below this level. This suggests that decreasing the fecal coliform count below 2 million MPN/g solid would require less lime than the amount used in this study. However in order to comply with the regulations, if the pH is not raised to 12, the fecal coliform concentrations in the sludge must be monitored to confirm adequate disinfection. While cost savings could be accrued by reducing the amount of lime required, regular fecal coliform testing will require financial resources and a reliable testing location or trained staff. This may be infeasible and challenging to maintain, and monitoring does not eliminate the need for the lime addition system. However, further investigation could determine if the lime cost savings is more significant than the cost of fecal coliform monitoring. This report recommends lime addition to a pH of 12 in order to comply with Class B standards.

4.2.3 Equipment Requirements

The lime mixing tank should allow for a contact time of two hours to ensure that the sludge remains at a pH above 12 for this time period. Therefore the size of the lime mixing tank depends on how often the sludge is pumped from the CEPT tank. Assuming the sludge is pumped into the lime mixing tank only once a day, the tank must hold both the 24,000 liters of sludge and the 1,900 liters of lime solution. The lime mixing tank should therefore have an effective volume of 26,000 liters. This tank must also be equipped with a device for mixing, either mechanical mixing or aeration can be used. Further equipment requirements for this procedure include:

- A storage facility for dry lime with a capacity equal to at least a one-week supply of lime, or approximately 1,300 kg (WEF 1995).

- A tank for lime solution preparation, with a volume equal to a one-day lime solution demand or 1,900 liters.

- A chemical addition system to convey the dry lime from the storage facility to the solution mixing tank and appropriately dose the lime.

- A pump to inject the lime solution into the lime mixing tank.

- A pH meter to ensure adequate disinfection.

The hydrated lime will react with bicarbonate alkalinity in the water and atmospheric carbon dioxide producing calcium carbonate that can clog pipelines (WEF 1995). As a result, the facilities listed above should be located in close proximity to one another to decrease the distance the lime slurry has to be transported.

4.2.4 Mass Balance and Solids Content

The addition of lime increases the solids content of the sludge. Because lime is being added at a ratio of 0.2 grams of lime per gram of solids, the total solids content of the sludge is expected to increase. However, the water added to the sludge with the lime also has a dilution effect and increases the volume of sludge flow. A mass balance can be used to determine the volume of sludge and the concentration of solids exiting the lime-mixing tank.

$$(Q_{in})(C_{sin}) + (Q_{lime})(C_{lime}) = (Q_{out})(C_{sout})$$

Where: Q_{in} = Volume of sludge entering the lime mixing tank (l/d)

C_{sin} = Total solids concentration of sludge entering the lime mixing tank (g/l)

Q_{lime} = Volume of lime solution entering the lime mixing tank (l/d)

C_{lime} = Concentration of the lime solution entering the lime mixing tank (g/l)

Q_{out} = Volume of sludge exiting the lime mixing tank (l/d)

C_{sout}= Total solids concentration of the sludge exiting the lime mixing tank (g/l), equal to Q_{in} + Q_{lime}

The above mass balance calculates the total solids of the lime tank effluent to be 4.5%. The volume of sludge exiting the lime mixing tank is the sum of the volume of sludge entering the tank and the volume of lime added, equal to 26,000 liters. The total mass of sludge exiting the lime mixing tank, at 4.5% solids, is therefore 1170 kg/d.

4.3 Thickening

A gravity thickener is recommended, following the lime addition process, to improve the sludge treatment process efficiency and reduce sludge drying costs. Thickening decreases the volume of sludge to be transported to the drying beds and minimizes the sludge drying time, resulting in financial benefits. A gravity thickener operates similar to a settling tank. Sludge accumulates in the bottom of the tank, by gravity, and the water is removed from the top and pumped back to the head of the treatment plant (WEF 1998). The removal of liquid from the sludge stream increases the solids content of the sludge and reduces the volume. The increased solids percentage of thickened sludge allows for faster drying, resulting in reduced acreage requirement for the drying beds, as well as land acquisition and equipment cost savings.

There are a variety of techniques used to thicken sludges, including gravity, flotation, centrifugal, gravity belt, and rotary drum thickeners (WEF 1998). Gravity thickening has been selected for its low capital cost and technical simplicity.

4.3.1 Size

Typically gravity thickeners are designed as circular tanks with a depth of 3 to 4m (WEF 1998). The bottom of the tank is cone shaped with a slope of 2:12 to 3:12 (WEF 1998). A gravity thickener depth of 3m and a floor slope of 2:12 should be adequate for this relatively small treatment plant.

The necessary surface area of the gravity thickeners is often calculated using a method based on bench scale testing and the solids flux theory. An array of settling column tests is conducted to determine the settling velocity of the sludge particles at various solids concentrations (McFarland 2001). The settling velocities are then used to compute the surface area of the thickener. This method is not completely valid because it assumes that the settling velocity of the sludge solids is only a function of the concentration (WEF 1998). Conducting the bench scale tests as required by this method is time consuming and was infeasible for this study. However, gravity thickeners can also be sized based on the extensive existing data on gravity thickener performance (WEF 1998). The

Process Design Manual for Sludge Treatment and Disposal published by the U.S. EPA gives typical gravity thickener data for various types of sludges (1979). For primary sludge receiving high lime dosing the typical feed solids concentration entering the thickener is 7.5% and the typical concentration of solids exiting the thickener is 12% (U.S. EPA 1979). The typical unit solids loading, or the quantity of sludge that can be applied to the thickener per unit area per time, is given as 120 kg/$m^{3/}$d (U.S. EPA 1979). The concentration of solids exiting the lime mixing tank and entering the gravity thickener was calculated, in Section 4.2.4, to be 4.5%. Although this concentration is lower than the typical value of 7.5% given in the EPA guidance document, it is assumed that the unit solids loading rate of 120 kg/ $m^{3/}$d is a valid design value. This value can used to calculate the area of the thickener using the following equation (WEF 1998):

$$A = (S \div U_s) / h$$

Where: A = Surface area of the gravity thickener (m^2)

S = Expected daily solids loading (kg/d)

U_s = Unit solids loading (kg/ m3/d)

h = Height of the gravity thickener (m)

The expected solids loading rate, 1160 kg/d, is the sum of the mass of solids entering the lime mixing tank, approximately 970 kg/d, and the mass of lime required, approximately 190 kg/d. Using the equation above the surface area of the gravity thickener is calculated to be 3.3 m^2, giving a tank diameter of 2 m. The overflow rate, based on a sludge volume of 26 m^3/d, as calculated in Section 4.1.4, is 8 $m^3/m^2/d$. Maximum overflow rates for primary sludge are typically 15.5 to 31.0 $m^3/m^2/d$.

4.3.2 Equipment Requirements

If possible the lime treated sludge exiting the lime mixing take will be fed by gravity into the gravity thickener, eliminating the need for a pump. The thickener must contain a rake mechanism for sludge collection and a skimming mechanism and baffle to remove scum and other floating material (WEF 1998). A pump is necessary to transfer solids from the gravity thickener to the sand drying beds and a second pump is required to transfer the overflow liquid back to the head of the plant.

4.3.3 Operational Procedures

The retention time of the thickened sludge can be up to 2 to 4 days, however 1 to 2 days is ideal. The sludge depth within the tank should be kept between 1 and 2m to minimize dilution. If possible the sludge should be removed continuously to ensure consistent and effective thickening. Removal on an intermittent bases should be frequent, once every few hours, rather than once or twice per day (WEF 1998).

4.3.4 *Mass Balance and Solids Content*

As previously calculated, the sludge entering the gravity thickener will be approximately 4.5% solids and the daily flow rate will be 26,000 liters. As described above for primary sludges, treated with high dosages of lime, the typical solids concentration, of sludge exiting the gravity thickener, is 12%. This value is an appropriate assumption because the sludge entering the gravity thickener is expected to have enhanced settling ability due to its chemical content. The sludge contains lime and, for the primary treatment option, ferric chloride. These chemicals are the most commonly used inorganic conditioning agents, chemicals added to sludge to aid in water removal during thickening and dewatering processes (WEF 1998). The addition of lime introduces calcium carbonate to the sludge, which is dense and porous and creates pathways for rapid water removal (WEF 1998). Ferric chloride aids in thickening in the same manner it enhances settling, through coagulation. The presence of these chemicals in the sludge suggests that it will thicken to at least the 12% solids concentration recommended in the EPA manual.

The volume of sludge exiting the gravity thickener can be calculated assuming a thickened solids content of 12%, and that all the solids entering the thickener exit in the sludge. Using 1160 kg/d as the total solids mass entering and exiting the gravity thickener, the volume of sludge exiting the thickener is approximately 10,000 liters, at 12% solids.

4.4 Sand Drying Beds

Dry sludge is considerable less expensive and more convenient to handle and transport than liquid sludge. Sand drying beds provide a cost effective method for dewatering sludge and is recommended as the final sludge treatment step. The beds allow for dewatering through two processes, evaporation and drainage. Conventional sand drying beds are rectangular and contain layers of sand and gravel which overlay an under drain system for leachate collection.

A variety of mechanical systems are available for sludge dewatering. However the high capital and operating costs of these systems make them inappropriate for this design (WEF 1998). Furthermore mechanical techniques are often employed when space constraints exist and land is not available for the construction of drying beds. The city of Alfenas has an abundance of open land along the periphery of the city and in the area proposed for the treatment plant. The availability of land and favorable climatic conditions indicate that sand drying beds are appropriate and feasible.

4.4.1 Bed Design

The floor of the beds can be constructed of concrete with a slight slope towards the center of the bed to a culvert drain and a slight slope towards one end of the bed for fluid collection. A gravel layer, between 20 and 46 cm deep, should be placed below the sand (WEF 1998). The sand layer should be between 20 and 46cm deep and the sand should be of good quality, free from clay and foreign matter (WEF 1998). Bricks can be layed on top of the sand with some space left between bricks for drainage. The sidewalls and dividers between the beds can also be constructed of concrete and should rise 0.5 to 0.9 meters above the top of the sand (WEF 1998). A diagram of a sand drying bed is shown in Figure 4.2.

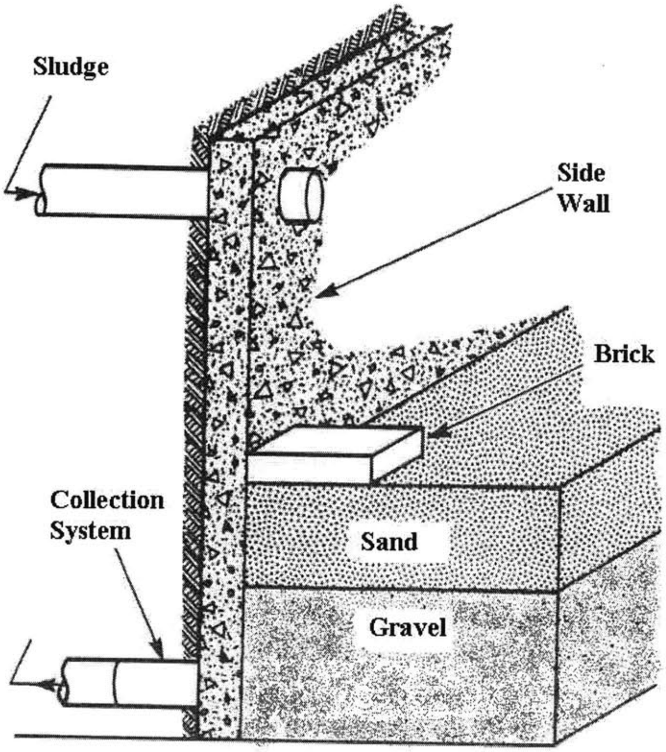

Figure 4.2: Side View of a Sand Drying Bed
(McFarland 2001)

4.4.2 Size

The area of drying beds required is based on the length of time the sludge will require to dry. According to plant operators at a municipal wastewater treatment plant in Serenia, Brazil, where sand drying beds are used, sludge drying requires approximately one week in dry weather conditions and 2 weeks in wet weather conditions. Assuming a 2 week drying period, the drying beds must be capable of containing a 2 week volume of sludge. The volume of sludge entering the drying beds is 10,000 liters per day, requiring a drying bed volume of

140 m^3. Sludge is typically applied to drying beds at a thickness of 20 to 23 cm (McFarland 2001). Using a design depth of 20cm, the sludge drying bed area required is 700m^2. A safety factor of 1.5 or higher is typically used in the design of sand drying beds, increasing the area requirement to 1050 m^2, or approximately 0.1 hectares.

5. Sludge Disposal Recommendations – Agricultural Use

Disposing of the sludge in an efficient and inexpensive manner will increase the feasibility and effectiveness of the proposed CEPT plant. The disposal technique recommended for the city of Alfenas is agricultural land application. This recommendation is based on analyses of local land usage, recommended wastewater and sludge treatment strategies, sludge characteristics, and financial considerations.

Because of the limited time available for the field study, approximately 3 weeks, the extensive sample collection and analysis that would be required to accurately design a land application system was not conducted. While some sludge nutrient testing was completed, a much larger sample size and a more in depth analysis would provide the data necessary to confidently recommend a land application strategy. The experimental results collected during the field study are used here to obtain a preliminary estimate of the appropriate sludge application rate. A number of locally grown crops may be appropriate for sludge application, however in this study application rates are calculated for coffee, as it is an important and abundant crop in Alfenas and the Furnas Reservoir region. It is recommended that the application rate estimate calculated here be used as the starting point for the land application pilot study outlined below. Before sludge application to agricultural land begins the effect of the sludge on soil and crops should be carefully evaluated. Because the sludge will most likely not contain the precise nutrient ratio required for optimum plant growth and production, maximum benefit may result from the combined application of sludge and supplemental chemical fertilizers. The calculations presented below provide evidence of the value of the sludge as a fertilizer. However, by conducting a pilot study at the University of Alfenas coffee farm optimal application rates and supplemental fertilizer requirements can be determined and the sludge characteristics can be more thoroughly investigated.

5.1 Advantages of Utilizing Sludge as a Fertilizer

Land application is a cost effective sludge disposal method that holds significant advantages for the community and local agricultural production. Sludge can be an effective fertilizer because of its rich nutrient content. Sludge from municipal wastewater treatment plants contains the plant macronutrients nitrogen and phosphorus, as well as the micronutrients boron, manganese, copper, molybdenum, and zinc (U.S. EPA 1995). While the nutrient content of sludge will not match plant needs as well as a carefully formulated commercial fertilizer, most agronomic crops respond favorably to sludge nutrients (U.S. EPA 1995). The nutrients in sludge are released and made plant available at a rate better suited to crop growth and harvesting. The rate of nitrogen release from biosolids is more similar to nitrogen uptake of corn plants than the nitrogen release from commercial fertilizers, which typically create excess nitrogen conditions at the beginning of the growing season and depleted nitrogen conditions near the end (WEF 1998). This excessive nitrogen is a potential pollutant that can be transported to ground or surface water. The comparison of nitrogen release from biosolids and commercial fertilizers to the nitrogen requirements of corn is shown in Figure 5.1.

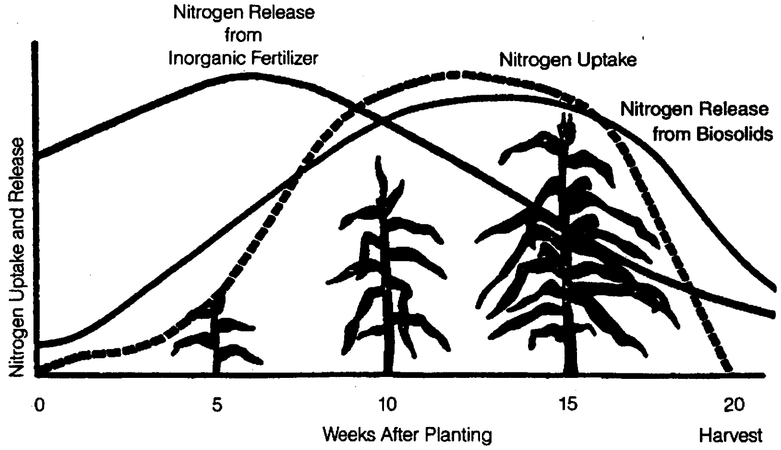

Figure 5.1: Nitrogen Release from Sludge and Commercial Fertilizers and Nitrogen Uptake by Corn Plants

(WEF 1998)

The physical properties of the soil can also be improved through the application of sludge. Fine clays can be made loser and the porosity can be increased, creating space for root growth and water flow. The addition of sludge to sandy soil can increase its water holding capacity and provide chemical sites for nutrient exchange and absorption (U.S. EPA 1995).

Other advantages of sludge application to agricultural land are financial benefits to the community. The municipality may reduce the operational costs of the wastewater treatment plant as agricultural usage is often less expensive than other sludge disposal techniques (U.S. EPA 1995). Agricultural land application eliminates the need for land acquisition which results in further costs savings.

This disposal technique also saves valuable landfill space and is an effective method of nutrient recycling. Since the sludge is often provided to the farmers free of charge, farmers can also experience significant financial benefit from the application of sludge to their crops (Matthews 1996).

In addition to being economically favorable, the application of biosolids to agricultural land is relatively low-risk. This practice is considered safe and acceptable, and is encouraged by the U.S. EPA. Nitrogen contamination of groundwater and surface water is the most likely type of contamination resulting from biosolids application (WEF 1998). However, soil microbes release the nitrate-nitrogen in sludge slowly as the crop grows and takes up nitrogen, whereas the nitrogen in commercial fertilizers is released more quickly and is less soluble. As a result nitrogen in commercial fertilizers is more available for movement into the groundwater and presents a greater risk of contamination (WEF 1998). Furthermore, excessive nitrogen loading is avoided by calculating sludge application rates based on the nitrogen needs of the specific crop receiving the biosolids (WEF 1998).

The risk to human health by sludge-born pathogens is negligible when the applied sludge has been treated by lime stabilization, the disinfections technique recommended by this report. Concentrations of disease causing organisms are decreased to levels that do not present a health risk. Furthermore, there has never been a documented case of disease caused by the application of biosolids, when applied according to the EPA regulations (WEF 1998).

5.2 Disadvantages of Utilizing Sludge as a Fertilizer

Sludge can contain chemicals and metals that may be harmful to the plants it is applied to and the eventual end consumers, animals or humans (U.S. EPA 1995). In order to avoid potential negative health effects to humans, livestock, and the environment, regulations have been developed to ensure safe application techniques and rates. The U.S. EPA's 40 CFR part 503 regulations set limits on the quantity of sludge that can be applied per unit area on an annual and cumulative basis (U.S. EPA 1995). The land application of municipal sludge can be carried out safely and effectively by following the management practices outlined by the legislation. Calculations of appropriate sludge application rates, based on the U.S. EPA standards are presented in Section 5.6.

5.3 Availability of Coffee Crops

Brazil is the world's largest coffee producer and the second largest consumer (Romero 1999). The coffee industry in Brazil produces over 20 million bags per year and employs 3% of the population. The map in Figure 5.2 indicates the large areas of Brazil where coffee is cultivated.

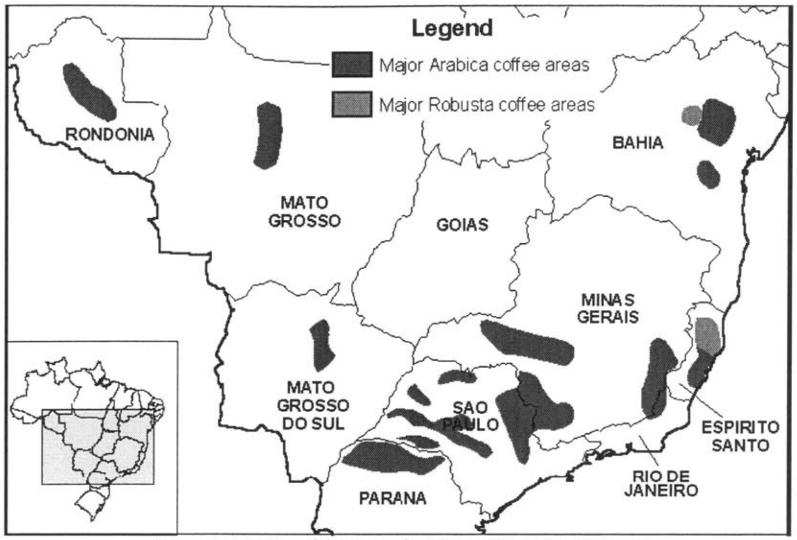

Figure 5.2: Coffee Cultivation in Brazil

(U.S Department of Agriculture,
www.usda.gov/agency/oce/waob/jawf/profiles/html/brz/brzcoff.html)

The abundance and importance of coffee in Brazil, as well as the specific characteristics of the crop, make it an appropriate crop for the application of biosolids.

Sludge transportation costs can be considerable and the feasibility of land application as a disposal technique is highly dependent upon cost considerations. Coffee farms have been recommended as potential sludge application sites because of their presence in and around Alfenas and the Furnas Reservoir region. Because of the abundance of coffee plantations in Brazil the techniques recommended here may be applicable in other regions.

5.3.1 Alfenas

Coffee is the primary agricultural crop in and around the city of Alfenas, with 14,100 hectares devoted to coffee cultivation (personal conversation with Renata Santos de Mandonca 2002). The city is home to 360 coffee producers and the annual production of coffee from Alfenas is approximately 330,000 bags or 20 million kilograms(personal conversation with Renata Santos de Mandonca 2002). Approximately the 3% of the coffee crop is consumed locally and 97% is sold commercially.

Small Brazilian cities, such as Alfenas, generally do not have suburbs and as a result the agricultural land directly abuts the city limits. As a result sludge produced at the proposed CEPT plant would most likely only travel a short distance to the final disposal site, minimizing transport costs. The proximity of coffee farms to the city and the proposed treatment plant, as well as the abundance of the crop in the area, indicate that sludge application would be both feasible and sustainable for Alfenas.

5.3.2 Minas Gerais and the Furnas Reservoir Region

The state of Minas Gerais produces 40% of Brazil's coffee, and, as shown in Figure 5.2, most of this coffee is grown in the southeastern region of the state. This region contains the Furnas Reservoir and the surrounding area. The abundance of coffee throughout the Furnas region indicates that the land application techniques recommended in this report may be feasible for implementation in others cities developing wastewater treatment strategies.

5.4 Coffee Fertilization with Class B Biosolids

Coffee crops provide a more feasible and sustainable application site, as compared to other food crops. Because the coffee plant's cherries, which contain one to three beans, are not in direct contact with the applied biosolids, regulatory compliance is more easily attained and site restrictions and management practices are less stringent.

The sludge treatment techniques outlined in this document meet the Class B biosolids standards of the U.S. EPA's 40 CFR part 503 rule. According to these regulations when Class B biosolids are applied to food crops with harvested parts that touch the biosolids and soil mixture (such as melons, cucumbers, squash, etc.) the crops should not be harvested for 14 months after application (U.S. EPA 1995). Food crops with harvested parts below the soil surface (such as potatoes, carrots, radishes) should not be harvested for 20 months after the application of Class B biosolids (U.S. EPA 1995). However food crops, feed crops, and fiber crops (that do not touch the soil or applied sludge) can be harvested as early as 30 days following the Class B biosolids application (U.S. EPA 1995).

The cherries, containing the coffee beans, are produced above the land surface and therefore have limited contact with the soil or applied biosolids. As a result coffee plants are subject to the least stringent harvesting requirements following sludge application. Figure 5.3 gives the yearly schedule for coffee blooming and harvesting in Brazil.

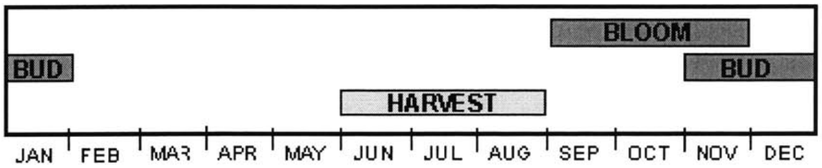

Figure 5.3: Coffee Blooming and Harvesting Schedule in Brazil

(From the U.S Department of Agriculture, www.usda.gov/agency/oce/waob/jawf/profiles/html/brz/brzcoff.html)

Depending on the harvesting schedule, it may be possible to apply sludge on a regular bases. If sludge application to coffee crops is not possible during the 3-month harvest period, it may be possible to apply to sludge to other local crops. The region also produces fruit, rice, beans, and potato crops that have not been analyzed for sludge application potential in this study. The pilot study, recommended in Section 5.11, may provide an opportunity to examine sludge application on other locally available crops. For 9 months of the year coffee is not harvested and sludge can be applied without harvesting time constraints. As a result sludge application on coffee crops is both a feasible and sustainable disposal technique for the city of Alfenas and the surrounding region.

5.5 Site Selection

5.5.1 Site Selection Process

Before the proposed plant is operational specific coffee farms and possibly specific fields will have to be selected for sludge application. The physical and hydrological characteristics of the application sites must be evaluated to ensure that sludge application will be effective and will not impose environmental or human health risks. Economic feasibility and social acceptance issues must also be considered during the site selection process (U.S. EPA 1995). The U.S. recommends a five-step method for evaluating potential application sites (U.S. EPA 1995):

1. Initial site screening
2. Field site survey
3. Field investigations and testing
4. Economic feasibility
5. Final site selection

The details of each of these steps are described in the U.S. EPA's Process Design Manual for the Land Application of Municipal Sludge (1995). This procedure is recommended for the identification of coffee farms in and around the city of Alfenas for the application of sludge produced at the proposed CEPT plant. Conducting this type of assessment allows for maximum benefit to the community as the site chosen will be one that is environmentally, financially, and socially appropriate.

In the United States site selection requirements for the land application of biosolids are set by each state and state permits must be obtained before the application program can begin. It may be necessary to obtain permits for the application of biosolids at a specific sight from the appropriate agency in Brazil.

5.5.2 Site Characteristics of Coffee Farms in Alfenas

As suggested by the five-step site selection procedure there are important physical site characteristic that must be investigated and considered when planning a land application program. The physical characteristics of concern, as identified by the U.S. EPA are (U.S. EPA 1995):

- Topography
- Soil permeability, infiltration, and drainage patterns
- Depth to groundwater
- Proximity to surface water

During the field investigation period in January 2002 several coffee farms were visited and visual observations of physical characteristics were made. However, specific soil investigations were not conducted at the potential applications sites. General information about the soil and topography in the area of Alfenas was available and can be used, in combination with visual observations, to evaluate the appropriateness of the application of biosolids on coffee farms in Alfenas.

5.5.2.1 Topography

Topography affects the surface water and groundwater flow, which can impact the rate of erosion and runoff at the site. Runoff is of concern when considering biosolids application because rapid overland flow can transport applied biosolids offsite into areas of increased risk, for examples surface water bodies (U.S. EPA 1995). The steepness and length of the slope, as well as the overall shape of the landsurface determine the rate of runoff (U.S. EPA 1995). The U.S. EPA does not recommend the application of biosolids on sites with slopes greater than 15% (U.S. EPA 1995). It was noted, during the field study period, that many of the coffee farms around the city of Alfenas are on hillsides and other uneven or sloped terrain. While no slope measurements were taken, the slope and resulting runoff at some potential sites may be of concern.

5.5.2.2 Soil Permeability and Infiltration

The permeability of the soil and the rate of infiltration through the soil column influences how well and how quickly the sludge will be incorporated into the soil and become available for absorption through plant roots. These parameters also affect the time necessary for rainwater and applied sludge to reach the water table. The U.S. EPA states that with proper design and operation, sludge can be successfully applied to virtually any soil (U.S. EPA 1995). Sites with moderate soil permeability, between 0.24 and 2.4 cm/hr, are preferable to areas with very slow or very rapid permeability (U.S. EPA 1995).

The soil studies in localities around Alfenas have reported the soils to have predominantly sand-clay texture (Silva 1997). The soil is further described as mud to very clayey, with granular texture and having good drainage (Silva 1997). While soil studies at specific potential application sites have not been conducted, these observations of local soil characteristics suggest that land application of biosolids is feasible and appropriate.

5.5.2.3 Depth to Groundwater

The important groundwater parameters that should be considered during the site selection process are the depth to the water table, the existing groundwater quality and the type of usage (U.S. EPA 1995). The U.S. EPA recommends that depth to the groundwater, at an agricultural biosolids application site, be no less than 1 meter if the aquifer is used for drinking water and no less than 0.5 meters if it is an excluded aquifer (U.S. EPA 1995). Generally sites with deeper water tables are preferable to those located above shallow aquifers (U.S. EPA 1995). It is recommended that the water table depth at potential application sites in Alfenas be identified during the site screening process for this proposed project.

5.5.2.4 Proximity to Surface Water

The U.S. EPA recommends examining surface water bodies that may receive runoff from the proposed site, in order to minimize the potential environmental and human health risks of contaminating these water bodies with the wastewater residuals that have been applied at the site (U.S. EPA 1995). It is recommended that surface water bodies in the vicinity of the agricultural sites receiving biosolids from the proposed CEPT plant be identified and an evaluation of the risk of contamination be conducted.

5.6 Nutrient Comparison – CEPT Sludge v. Coffee Plant Requirements

In order to evaluate the effectiveness of sludge from the proposed CEPT plant as a fertilizer for local coffee crops the nutrient content of the sludge must be compared with the nutrient requirements of coffee plants. It is also important to evaluate the content and application schedule of commercial fertilizers currently being used on coffee farms.

5.6.1 Nutrient Requirements of Coffee Plants

The recommended method for determining the fertilizer needs of coffee plants requires the measurement of nutrient concentrations in the soil and plant leaves. The procedure, as outlined by the Brazil Department of Agriculture, suggests that fertilizer application should begin after the coffee trees are three years old (Thomaziella 1999). During the three-year maturation period, the trees grow and adjust to existing soil conditions. The nitrogen concentration of the leaves and the phosphorus and potassium concentrations in the soil are then determined in order to assess the fertilizer requirements. Application rates of nitrogen, phosphorus, and potassium are recommended based on this testing and the expected crop yield. Table 5.1 gives the fertilizer requirements of coffee trees based on these criteria.

Table 5.1: Coffee Crop Fertilizer Requirements, in kg/ha, based on Leaf and Soil Testing and the Expected Yield
(Thomaziella 1999)

Expected Yield (kg/Ha)	N in leaves (g/kg)			P in Soil (mg/dm^3)				K in Soil (mg/dm^3)			
	<25	**26-30**	**>30**	**0.5**	**6-12**	**13-30**	**>30**	**0-0.7**	**0.8-1.5**	**1.6-3.0**	**>3.0**
<600	150	100	50	40	20	20	0	150	100	50	20
600-1200	180	120	70	50	30	20	0	180	120	70	30
1200-1800	210	**140**	90	60	40	**20**	0	240	140	**90**	40
1800-2400	240	160	110	70	50	30	0	240	160	110	50
2400-3600	300	200	140	80	60	40	20	300	200	140	80
3600-4800	360	250	170	90	70	50	30	360	250	170	100
>4800	450	300	200	100	80	60	40	450	300	200	120

As discussed in Section 5.3.1 Alfenas produces 20 million kilograms of coffee per year on 14,100 hectares. Given these figures the expected yield can then be estimated as 1400 kg per hectare. In general the coffee farms selected for biosolids application would be composed of mature trees already receiving fertilizer. The fertilizer requirements have, therefore, already been determined and fertilizer is applied at an appropriate rate. The amount of nitrogen, phosphorus, and potassium fertilizer utilized at a particular farm could provide the nutrient requirement information needed to calculate sludge application rates.

In order to estimate typical coffee crop fertilizer needs, for the purpose of this study, a median value for nitrogen leaf concentrations and soil phosphorus and potassium concentrations is chosen from Table 5.1. The nitrogen leaf concentration can be estimated as 26 to 30g/kg, indicating a nitrogen fertilizer requirement of 140kg/ha, for the calculated crop yield of 1400kg/ha. The soil phosphorus concentration of 13-30 is selected because it is a large range of concentrations and is the most conservative estimate that still permits for phosphorus application. Utilizing this estimate gives a phosphorus requirement of 20kg/ha. The soil potassium concentration is also conservatively estimated to be 1.6-3.0 mg/dm^3, giving a potassium requirement of 90kg/ha. These approximations of the nutrient requirements of coffee trees will be compared to the nutrient concentrations of sludge samples in order to calculate sludge application rates.

5.6.2 CEPT Sludge

The results of nutrient analysis conducted on sludge samples produced during the field study period are presented in Section 3.8. Nutrient concentrations were measured in both untreated and lime treated samples. The proposed sludge treatment method includes lime treatment of the sludge. As a result, it is appropriate to use the data collected for lime treated samples. Because of the limited sample number and the relative similarity between the two sludge types, the Sludge A and Sludge B concentrations have been averaged. These average nutrient concentrations shown in Table 5.2, serve as approximations that can be utilized to calculate sludge application rates.

Table 5.2: Average Nutrient Concentrations of Lime-Treated Sludge Samples
(as % of total solids)

Nitrate N	Ammonia N	Phosphorus	Potassium
0.004	0.335	0.160	0.090

5.7 Approximation of Biosolids Application Rate

The amount of biosolids applied to a specific site and the rate of application can be determined based on the nutrient requirements for the crop selected or on the limiting metals concentrations (U.S. EPA 1995). Either the nitrogen requirements or the phosphorus requirements of the crop can be used to obtain biosolids loading rates. The legislative limits for annual cadmium addition can also be used to determine appropriate application quantities. The method selected for these calculations is generally chosen based on the sludge composition and on specific site characteristics and concerns, such as existing soil condition.

5.7.1 Calculations Based on Nitrogen Requirements

Because nitrate does not absorb onto soil particles, nitrate contamination of groundwater is a concern whenever nitrogen is applied to soils (U.S. EPA 1995). Calculations of biosolids application rates are often based on the nitrogen requirements of the selected crop to ensure that excessive nitrogen loading does not occur. The organic nitrogen in biosolids, unlike ammonia nitrogen, NH_4^+, and nitrate nitrogen, NO_3^-, is not immediately available for plant uptake (U.S. EPA 1995). Because it is released slowly, for several years after application, residual organic nitrogen from previous years must be considered in calculating biosolids application quantities. The following equation is used to estimate the sludge application rate, in metric tones per hectare, for the first year (U.S. EPA 1993).

$$S = Np / \{[(NO_3) + K_v(NH_4) + F_{(\text{year } 0\text{-}1)}(N_o)]*10\}$$

Where: N_p = Plant available nitrogen (kg/ha)

S = Sludge application rate (mt/ha)

NO_3 = Percent nitrate nitrogen in the sludge

K_v = Volatilization factor

NH_4 = Percent ammonia nitrogen in the sludge

$F_{(\text{year } 0\text{-}1)}$ = Mineralization factor for organic nitrogen in the sludge in the first Year

N_0 = Percent organic nitrogen in the sludge

The plant available nitrogen provided by the applied sludge must not exceed the crop nitrogen requirement, estimated above as 140kg/ha. The volatilization factor for dewatered sludge is 1. The percentage of the organic nitrogen applied that is mineralized in a given year is represented as the mineralization factor and is dependent on the type of sludge treatment and the years since the application. In the first year following application 40% of the organic nitrogen in unstabilized primary sludge is made plant available (U.S. EPA 1995). The percentages of nitrate nitrogen and ammonia nitrogen in the sludge samples are listed in Table 5.2, however the organic nitrogen content of the samples was not measured. Typical percentages of organic nitrogen in municipal sludge are between <0.1 and 17.6, with a mean of approximately 3 (WPCF 1989). Using these assumptions, the sludge application rate for the first year can be estimated as 9 metric tons per hectare.

For the years following the first year, sludge application rates must take into account residual organic nitrogen from previous years application that becomes plant available during the current year. The organic nitrogen that is mineralized in subsequent years can be calculated using the following equation (U.S. EPA 1993).

$$N_m = (K_m)(N_o)(S)$$

Where: N_m = Quantity of N_0 mineralized in the year under consideration (kg/ha)

Km = Mineralization factor for the year under consideration (kg/mt/%N0)

N_o = Percent organic nitrogen in the sludge

S = Sludge application rate (mt/ha)

The sludge application rate for the second year can then be calculated by combining the two above equations, so that the plant nitrogen needs are met by the plant available nitrogen added in the second year and the residual nitrogen from year one which is mineralized.

$$N_p = N_p \text{ (from second year)} + N_m \text{ (from first year)}$$

As mentioned above, the Np, plant available nitrogen, must equal the plant nitrogen needs of 140 kg/ha. This equation can be rewritten in order to solve for the application rate for year two.

$$S = N_p/[(NO_3 + (K_v)(NH_4) + (F_{(\text{year } 0\text{-}1)})(N_o))(10) + (K_m)(N_o)]$$

Where: K_m = Mineralization factor for the second year (kg/mt/%N0)

N_o = Percent organic nitrogen in the sludge

S = Sludge application rate in year 2(mt/ha)

N_p = Plant available nitrogen (kg/ha)

NO_3 = Percent nitrate nitrogen in the sludge

K_v = Volatilization factor

NH_4 = Percent ammonia nitrogen in the sludge

$F_{(\text{year } 0\text{-}1)}$ = Mineralization factor for organic nitrogen in the sludge in the first Year

Using U.S EPA recommended values of K_m for unstabilized primary sludge, the sludge application rate for year two and subsequent years can be calculated (1993). The application rates for the first 5 years of sludge application are given in Table 5.3.

Table 5.3: Sludge Application Rates for the First Five Years of Application

Application Year	**Sludge Application Rate** (mt/ha)
1	7.4
2	6.9
3	6.6
4	6.5
5	6.4

5.7.2 Calculations Based on Phosphorus Requirement

Another method for calculating sludge application rates utilizes the crop phosphorus requirement. This alternate sludge application rate based on plant phosphorus needs can be calculated, using the following equation (U.S. EPA 1993):

$$S_p = (C_p/P_p) * (1{,}000 \text{ kg/mt})$$

Where: S_p = Sludge application rate (mt/kg)

C_p = Crop phosphorus requirements (kg/ha)

P_p = Phosphorus concentration of the sludge (mg/kg)

Most sludges contain relatively equal concentrations of nitrogen and phosphorus, however crop nitrogen needs are often much greater than phosphorus needs. As a result application rates based on phosphorus requirements can eliminate the potential for the over application of phosphorus. This may be particularly important for CEPT sludge because of the increased phosphorus removal from the waste stream, as compared to primary treatment. However, the nitrogen concentration of the sludge analyzed here was roughly twice the phosphorus concentration; as a result sludge application rates based on phosphorus concentrations will be significantly greater than the rates calculated for nitrogen requirements. Only approximately half of the phosphorus contained in the sludge can be considered available for plant uptake (U.S. EPA 1993). Using the experimental values for sludge phosphorus concentrations, the sludge application rate can be calculated as 25 mt/ha. Because this rate is much greater than the nitrogen based rate, there is potential for the over application of nitrogen.

5.8 Metals - U.S. EPA Maximum Loading Restraints

When sludge is to be land applied the potential for the contamination of soil and groundwater with heavy metals is a major concern. The EPA has addressed this potential hazard, in the 40 CFR Part 503 rule, by establishing maximum metals concentration limits in sludge and cumulative metals loading rate for agricultural sites (Crites et al. 2000). The first type of standards limits the concentrations of pollutants in the sludge and the second set of standards limit the rate at which sludge can be applied to land (McFarland 2001). These regulations can also limit the number of years that sludge can be applied to the same agricultural location (U.S. EPA 1995). The specific metals concentration limits are outlined in the legislation and are also summarized in a numbered of texts (McFarland 2001, Crites et al. 2000).

Metals analyses were not conducted on the sludge samples produced during the field study period. However, in order to comply with the Brazilian regulations and ensure that metals contamination will not occur, metals testing of sludge samples produced at the proposed plant will have to be conducted before land application can proceed. If metals concentrations of the sludge are of concern, the sludge application rate can be calculated based metal limitations set by the legislation (U.S. EPA 1995).

5.9 Final Recommendation for Disposal

The recommendations presented here are preliminary estimates of the appropriate sludge application rates. The proposed pilot test is a comprehensive study that will provide more extensive and accurate data for determining the value of sludge as a fertilizer and effective application rates. The application rates calculated here can be used as the initial rates for beginning the pilot study.

The calculations of land application rates reveal that the nitrogen based rate is considerably more conservative than the phosphorus based rate. In order to minimize unnecessary nutrient application, and prevent nitrogen, metals, or pathogen contamination of the soil, groundwater, or nearby surface water bodies it is recommended that the lower nitrogen based application rates be used as the design values. The quantity of sludge required to meet the nitrogen needs of coffee crops in the first year of application was calculated as 9 mt/ha. Based on the calculations of sludge production presented in Section 4.1 the proposed plant will produce approximately 3.5×10^5 kilograms of sludge per year, or 350 metric tons per year. Using the recommended sludge application rate of 9 mt/ha, the sludge from the proposed plant could be used to fertilize approximately 40 hectares of coffee crops in the first year of application.

The nitrogen based calculations show that the sludge application rate decreases over the subsequent five years due to the presence of residual nitrogen and the calculations indicate that an appropriate long-term sludge application rate would be approximately 6 mt/ha (See Table 5.3). As a result, after the first year the sludge from the proposed plant could be used to fertilize approximately 60 hectares of coffee crops. Sludge applied at the recommended rates to these approximated land areas is meant to meet the nitrogen requirements of coffee trees. However, the sludge may not meet the phosphorus, potassium, or other micronutrient needs of the crop and it may be necessary to apply supplemental fertilizer in order to ensure the expected production and crop yields.

5.10 Feasibility, Transportation, and Cost

The major advantage of drying the sludge in the sand drying beds at the treatment plant site is the ease with which sludge can then be transported and land applied. Removing the sludge from the site by truck is considered an appropriate mode of transporting dry sludge by the EPA (U.S. EPA 1995). Because the sludge is does not require specialized equipment for handling and transport, the feasibility and cost effectiveness of land applying the sludge is improved. An evaluation of sludge transportation modes by the U.S. EPA finds that truck transport is the most reliable and least complex and requires low capital investment and operator skill (U.S. EPA 1995).

5.11 Pilot Study at the University of Alfenas Coffee Farm

5.11.1 The University of Alfenas Coffee Farm

The University of Alfenas (Unifenas) has several farms that are used for educational and experimental purposes. The largest farm, Sociedade Agricola Vitoria, is over 1800 hectares and has both agricultural crops and animals. Coffee trees are grown on 120 hectares of the university owned farm, and animals are kept on 35 hectares, with the largest area of the farm, 900 hectares being devoted to orange trees. (Personal Conversation with Renata Santos de Mendanca January 2002)

5.11.2 Experimental Setup

The purpose of the pilot study would be to evaluate the effectiveness of CEPT sludge as a fertilizer on local coffee trees. The feasibility of the land application of sludge could be evaluated by comparing the effects of sludge from the proposed plant and commercial fertilizers on the tree characteristics and soil conditions. The area of the Sociedade Agricola Vitoria planted with coffee trees is very large,120 hectares and is larger than the potential land area that could be fertilized by sludge from the proposed plant. An experimental study of CEPT sludge as a fertilizer for local coffee trees would require only a portion of the universities coffee farm. As calculated above if all the sludge produced at the proposed plant were to be used in the experiment, approximately 40 hectares of coffee trees could be fertilized. Assuming that the coffee farm would be available, it is recommended that 80 hectares be devoted to this study. This 80 hectares can be divided in half so that 40 hectares receives sludge fertilization and 40 hectares receives commercial fertilizer, serving as a control.

The sludge from the proposed plant may not meet the phosphorus, potassium, or other micronutrient needs of the crop and it may be necessary to apply chemical fertilizer in combination with the sludge to obtain the expected production and crop yields. Furthermore, because the sludge production is relatively small compared to the available coffee acreage, it is unlikely that a farm will depend solely on sludge for fertilizer. Farmers may choose to apply sludge in combination with commercial fertilizers and the field study should also address this possibility. Varying combinations of sludge and chemical fertilizer can be experimented with and an ideal mixture and application schedule can be developed.

5.11.3 Proposed Tests

5.11.3.1 Metals Uptake

In order to comply with regulations sludge must be tested to determine theconcentration of the following metals: arsenic, cadmium, copper, lead, mercury, molybdenum, nickel, selenium, zinc (McFarland 2001). As discussed in Section 5.8. concentration limits and maximum loading rates exist for these metals and monitoring is required. Before the pilot study begins the concentrations of these metals in the sludge should be determined and a metals analysis should be conducted periodically during the study. Because the wastewater stream, Jardim da Boa Esperança, being treated by the proposed plant does not include any industrial outputs, it is not anticipated that metals concentrations will be of concern. However metals testing must still be carried out as naturally occurring metals may be present.

Metals uptake by plants is also a concern when land applying biosolids. While evidence suggests that metals accumulation in plants is minimal, especially in the fruits of trees (like the coffe cherry), the pilot study should conduct some analysis of the metal content of the coffee cherries and leaves (U.S. EPA 1993).

5.11.3.2 Soil Quality and Crop Productivity

The quality of the soil determines the plant productivity and should be monitored closely to determine if optimum crop yields can be obtained using sludge as a fertilizer. To assess the effectiveness of sludge fertilization both the soil parameters and the crop productivity must be monitored closely and compared. Monitoring the nutrient content of the soil is particularly important, as sludge nutrients may not be as available for plant uptake as nutrients contained in commercial fertilizers. The nutrient content of the coffee plant leaves can also be tested to quantify the availability of the nutrients in the two fertilizer types. Sludge application may also require the addition of supplemental fertilizers and the quantities necessary should also be recorded during the pilot study. Soil pH should be monitored to ensure that it remains above 6.5 to minimize metals uptake. The recommended sludge treatment system raises the pH of the sludge above 12. The addition of this sludge will raise the pH of the soil and, as a result, low soil pH is not expected to be a concern. Productivity can be assessed by counting or weighing the cherry or coffee bean production of the trees.

5.12 Community Acceptance

The addition of sludge to food crops is a controversial issue because the general public, the end users of the crops, and environmentalists often have concerns about human and environmental health. This recommended pilot study should provide evidence that sludge application to coffee crops is not only a financially feasible sludge disposal solution, but is safe, effective and beneficial to local farmers, and the community as whole. Confidence in the safety of the sludge application program can be increased by presenting data and information about the sludge characteristics and the pilot study results to the local community.

6. Conclusion

This report outlines a sustainable, financially feasible, and effective sludge management strategy for the city of Alfenas, Brazil. The goal of the proposed sludge treatment system is to convert the waste products produced by the CEPT plant into a valuable resource for the local community, in a financially and ecologically sustainable manner. By utilizing inexpensive and locally available technologies the sludge can be treated to compliance with U.S. EPA and Brazilian standards for land applied sludges, ensuring the health of the community and environment. The recommended treatment system includes lime addition for disinfection, thickening by gravity settling, and takes advantage of the warm climate by dewatering the sludge in sand drying beds. Land application is an ideal sludge disposal method for Alfenas because the city is surrounded by an abundance of agricultural land and, as a result, the nutrient rich sludge can be easily and cheaply transported to the crops. Furthermore, the city minimizes costs by eliminating the need for landfill space for the sludge and farmers can cut costs by supplementing chemical fertilizers with sludge. These financial benefits are particularly important for Brazilian communities and increase the feasibility of the project for a developing country.

Coffee production is a primary source of income for Alfenas and the Furnas Reservoir region and coffee crops are well suited for sludge application due to the plant characteristics and favorable harvesting schedule. A pilot study at the University of Alfenas experimental farm, testing sludge and chemical fertilizer application would provide valuable data on the effectiveness of sludge as a fertilizer and appropriate application rates to coffee and other crops. The treatment and disposal strategies recommended in this report are a vital part of a regional approach to the preservation of the Furnas Reservoir as a valuable resource through wastewater treatment, and provide a model solution for other cities in the region.

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Appendix A – Nutrient Testing Techniques

Ammonia Nitrogen Procedure

Courtesy of Professor Eduardo Luiz Tanure, University of Alfenas, Brazil

1. Use 500ml of sample
2. Pour into 500ml beaker
3. Add 25ml of buffer solution
4. Add 6N sodium hydroxide to a pH of 9.5
5. Pour all of the sample into a flask
6. Add 50ml of boric acid at a concentration of 20g/l to an flask that will collect the distillate
7. Distill the sample until 200-220ml have been condensed. Adjust the volume to 250ml with distilled water
8. Remove 100ml and add 1.5ml of 6N sodium hydroxide and 2ml of Messler reagent.
9. Measure using program 2400 on the Hach spectrophotometer. Adjust to 425 nm and calibrate with a blank.

Total Phosphorus Procedure

Courtesy of Professor Eduardo Luiz Tanure, University of Alfenas, Brazil

Solutions:

1. Phenolphaline indicator solution
2. Suluric solution, 30%: slowly add 300ml of concentrated H_2SO_4 to 600ml of distilled water, complete the volume to 1000ml.
3. Potassium persulfate solution (prepare within an hour of use): 5g $K_2S_2O_8$ in distilled water and complete the volume to 100ml.
4. Sodium hydroxide solution, 1N: 40g NaOH in distilled water and complete the volume to 1000ml.
5. Combined mixture: dissolve .13g of $KsbOC_4H_4O_6 * ½ H_2O$ in 700ml of distilled water, add 5.6 g of $(NH_4)_6Mo_7O_{24} * 4H_2O$ and dissolve, add 70ml of concentrated H_2SO_4, cool and dilute to 1000ml in a volumetric flask.
6. Combined Reagent (1-week stability): add .5g of ascorbic acid to 100ml of the combined mixture. If the solution is muddy, let it sit for a few minutes and store in a refrigerator.
7. Phosphorus stock solution: dissolve 219.5 mg of KH2PO4 in distilled water and complete the volume to 1000ml in a volumetric flask. 1ml = 50ug PO_4^{-3} as P.

8. Phosphorus standard solution: dilute 50ml of the phosphorus stock solution in 1000ml of distilled water in a flask. 1ml = 2.5ug PO_4^{-3} as P.

Procedure:

1. Collect 100ml of sample in a 250ml flask
2. Add 1 drop of phenophaline solution (if the sample becomes colored, discolor it with 30% sulfuric acid, adding 1ml at a time)
3. Add 15ml of potassium persulfate (5g per 100ml – prepare before use)
4. Boil for 30 minutes, maintaining the a volume of 25-50ml with distilled water.
5. Cool and add 1 drop of phenophaline and add sodium hydroxide until the sample turns pink.
6. Transfer the mixture to a 100ml flask and complete the volume with distilled water.
7. Pipette 50ml of sample to a 125ml test tube.
8. Add 10ml of the combined reagent, shake well and let it sit for at least 10 minutes, but not more than 30 minutes.
9. Read transmittance at 880nm.
10. Prepare a 100ml blank with steps 1 through 9.

Construction of the standard curve:

Prepare standard solutions of varying phosphorus concentrations, amking dilutions of the standard solutions in volumetric flasks according to the table:

Concentration of PO4 as P (mg/l)	**ml of Standard Solution**
0	0
0.005	20
0.1	40
0.2	80
0.35	140
0.5	200

Complete the volume of each solution to 1000ml with distilled water. Treat 100ml of each of the standard solutions according to steps 1 through 5.