SOS – Management of Sludges
from On-Site Sanitation

Economic Aspects of Low-cost Faecal Sludge Management

Estimation of Collection, Haulage, Treatment and Disposal/Reuse Cost

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Foreword

The Department of Water and Sanitation in Developing Countries (SANDEC) of the Swiss Federal Institute for Environmental Science and Technology (EAWAG), conducts applied research projects on faecal sludge management with local partners in West Africa, Thailand and Argentina. Research focus is based on low-cost faecal sludge treatment technologies, however, implementation and reuse of dewatered faecal sludge, the economic aspects of faecal sludge management in general and treatment options in particular constitute a rather new domain.

This document provides an overview of faecal sludge management costs pertaining to collection, treatment, reuse or disposal of dewatered faecal sludge. It provides a cost estimate tool for faecal sludge management planners and policy makers. The document is based on information obtained from local partners and on numerous internal field reports and documents. It presents a first approach on the subject of faecal sludge treatment, collection and transport costs. The following documents, completed during an internship at SANDEC, form part of a collection of three interrelated reports dealing with the economic aspects of faecal sludge management:

Economic Aspects of Low-cost Faecal Sludge Management – Estimated Collection, Haulage, Treatment and Disposal/Reuse Costs (this document)
Towards Economic Sustainability of Faecal Sludge Management – Selected Money Flow Options
Economic Benefits of Improved Faecal Sludge Management – The Case of Diarrhoea Reduction

Kindly send your valuable comments and suggestions on these documents to:

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Glossary

Annualised capital cost	An amount paid annually to reimburse the borrowed capital and interests at the end of the depreciation period.
Biosolids	The solid fraction of faecal sludge (or sewage sludge) after the solids-liquid separation. If biosolids are hygienically safe, it can be used in agriculture.
Depreciation period	The borrowed capital and interests are reimbursed totally at the end of the depreciation period by paying the annual capital cost every year. After the depreciation period, the installation shows no economic value anymore. Hence, it is assumed that depreciation period corresponds here to the service life of the installation.
Faecal sludge	Sludge removed from different on-site sanitation systems (e.g. septic tanks, bucket latrines, pit latrines, etc.).
Percolate	The liquid seeping through a sludge drying bed or a constructed wetland and collected in an underdrain.
Public toilet sludge	Sludges collected from unsewered public toilets (usually of higher consistency than septage and biochemically less stable).
Septage	Contents of septic tanks (usually comprising settled and floating solids as well as a liquid fraction).
Supernatant	Overflow of settling/thickening tanks and settling ponds.

Abbreviations and Acronyms

AIT	Asian Institute of Technology (Bangkok, Thailand)
BOD	Biological oxygen demand
COD	Chemical oxygen demand
CREPA	Centre Régional pour l'Eau Potable et l'Assainissement à faible coût (Regional Centre for Water Supply and Low-cost Sanitation)
CW	Constructed wetland
DB	Drying beds
EAWAG	Swiss Federal Institute for Environmental Science & Technology
FS	Faecal sludge
FSM	Faecal sludge management
FSTP	Faecal sludge treatment plant
O+M	Operation and maintenance
SANDEC	Department of Water and Sanitation in Developing Countries (at EAWAG)
PE	Population equivalent (in this document: 1 PE = 14 g TS/day per capita)
TS	Total solids
WSP	Waste stabilisation ponds
WWTP	Wastewater treatment plant

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1 INTRODUCTION

Importance of faecal sludge management

In urban areas of Asia, Africa and Latin America, the excreta disposal situation has become dramatic: thousands of tons of sludges from on-site sanitation installations – so-called faecal sludges (FS) – are disposed off daily untreated and indiscriminately into lanes, drainage ditches, onto open urban spaces, into inland waters, estuaries, and the sea. Due to a lack or poor excreta management systems in many cities of developing countries, low-income areas are faced in particular with serious health and environmental problems. These problems can be minimised if appropriate faecal sludge management (FSM) is introduced, not only with regard to FS treatment, but also pertaining to adequate and safe emptying of sanitation facilities, FS transport and its safe disposal or reuse.

Why dealing with economical aspect of FSM?

The economic aspect of FSM should be integrated into the financial planning of every sanitation scheme based on municipal on-site sanitation facilities. Implementation of on-site facilities has often been promoted without solutions and funds for excreta management. Cost data on FSM allows to financially plan construction, operation and maintenance of the FSM infrastructure and organisation.

Cost information on selected FS treatment options enables to adopt economic solutions for the current context. However, the economic aspect is only one criterion with regard to the choice of an appropriate treatment solution.

Since faecal sludge management constitutes an important cost factor, it must be taken into account if sanitation systems are planned. Only when FSM is integrated, on-site sanitation may be compared with sewered systems, which are often perceived as expensive in comparison with on-site sanitation.

Scope, target audience and method

The present document deals with the economic aspects of FSM in general and FS treatment in particular. It allows the planning of FSM costs, where on-site facilities already exist, or are part of a sanitation plan. It provides the costs of several selected FS treatment plants as well as examples on how to assess collection, transport and disposal costs, depending on the local situation. This document does not discuss on-site sanitation systems, as abundant literature is already available on economic sanitation planning.

This report provides practical information on FSM costs for environmental and sanitation engineers and planners. Politicians and decision-makers can use it as a tool to integrate FSM into financial planning. A sound knowledge of the faecal sludge situation and of selected treatment options is required to benefit from this document, as it does not provide technical assistance on the working of treatment options.

The information presented in this report has been compiled from SANDEC's field research documents and information obtained by its partners. In addition, direct contacts with field partners and a general literature review complete the information provided.

Report structure

This report comprises the following five main chapters on the economic aspects of FSM:

Chapter 2: Several **faecal sludge treatment plants** in West Africa, South East Asia and Argentina. A brief description and **overview of construction and O+M costs**. The treatment plants are classified into pilot and full-scale plants.

Chapter 3: Description of the **economy of scale** using a co-composting treatment plant as an example.

Chapter 4: **Comparison of selected FS treatment options**. Three different solids-liquid separation options are designed in the same context and compared from an economic perspective. A comparison of the co-composting plant with separate solid waste and FS treatment is also provided.

Chapter 5: **Guidance tool for planners**: First raw cost estimate of construction and O+M costs of FS treatment.

Chapter 6: **Collection, transport and disposal/reuse costs** are assessed and then summarised with FS treatment costs.

2 COST APPRAISAL OF SELECTED TREATMENT OPTIONS

Economic principles: Capital cost and O+M cost

Economic accounting of an installation includes the annual capital costs on the investment (construction, land acquisition, studies, etc.). The annual capital costs (or annuity or capital recovery factor) are the amount payable annually in order to attain reimbursement of all the capital and interests at the end of the depreciation period. The following equation is used to calculate the annual capital costs (e.g. in WB 1980, Maystre 1985):

$$CC = C_{tot} \frac{(1+i)^n \cdot i}{(1+i)^n - 1}$$ **Equation 1**

with: CC = annual capital cost; C_{tot} = total cost; i = interest rate; n = depreciation period

Annual capital costs do not follow a linear decrease with increasing depreciation period. Capital costs are influenced significantly if the depreciation period is short, however, if the depreciation period is long, the difference is irrelevant (Figure 7, page 26).

In addition to the annualised capital costs, the annual operational and maintenance (O+M) costs also have to be estimated. Costs to cover running costs, such as salaries for workers, electricity, etc. or general repairs, are included in the O+M costs.

The total annual costs of an installation are the sum of annualised capital and O+M costs. A typical difference between a low-cost option (presented in this study) and a high-investment cost option (e.g. activated sludge wastewater treatment plant) is the percentage of O+M costs in relation to the total investment costs. Low-cost options normally have a higher percentage of O+M costs (e.g. 10% of investment costs, cf. following paragraphs), while this figure is lower in high-investment cost options.

Normally, when comparing economic aspects, current prices should be used. However, since this study is based on recent cost information and converted into US$ at corresponding rates[1], this aspect can be neglected.

Economic hypothesis: Annualising capital cost, cost unit, PE

Investment and O+M costs of FS management must be determined on a case-to-case basis, as local conditions are decisive factors. Therefore, existing pilot and full-scale FS treatment schemes are analysed in this chapter with respect to their construction and O+M costs. At this stage, it is not possible to compare directly the different treatment options, as the financial aspects vary significantly and are dependent on several local factors such as:

[1] Cf. http://www.oanda.com/converter/classic for daily currency exchange rates.

Plant size
Economic factors (land price, interest rate, labour cost)
Material cost
Degree of reuse (compost, biogas, irrigation)
Attained treatment and end product quality
Site condition (permeability, groundwater table)
Construction parameters

All the FS treatment plants and their mode of operation are briefly presented hereafter. The economic information is valid only for the corresponding plant and its particular context. A direct comparison is established in Chapter 4 to identify the economic advantages and drawbacks of specific treatment options.

It is important to note that the per capita costs of a plant are dependent on its size. In general, small pilot-scale plants have significantly higher specific capital costs than full-scale plants. However, although investment and O+M costs do not follow a linear increase with plant size, it is possible to extrapolate the capital costs of a small to a larger plant using a mathematical model (Maystre 1985). The so-called 'upscaling' or 'economy of scale' is described in Chapter 3.

Since the analysed FS treatment plants are located in Africa, Asia and South America, the interest rates and depreciation periods vary from one country to another. When comparing project options, the same depreciation period should be adopted. To avoid distortion of cost analysis, the same standard interest rate is applied to all the treatment plants. The following parameters were used:

- 5% interest rate
- 15 years depreciation period

A 5% interest rate corresponds to an average real interest rate (nominal interest rate minus inflation rate) in US$. Similar rates are internationally accepted by health economists and used in WHO guidelines (WHO 2000, Hutton 2002). For example, Varley et al. (1998) used a 3% discount rate to annualise W&S investment. Nevertheless, when using the results of the present report, it is important to remember that the real interest rate can vary from place to place and, hence, also the annual costs.
A depreciation period of 15 years is appropriate for a FSTP in a developing country. After this period, investment costs are supposed to be reimbursed and, hence, the treatment system paid off. In the present study, we assume that the depreciation period is equal to the service life of the installation. A service life of 15 years is low compared to a Western WWTP, but appropriate in the context of a disadvantaged country with less maintenance, lower construction quality and a small-scale expansion potential.
The results of the annualised capital and O+M costs have to be viewed from an economic perspective. They do not provide the real expenditure for FS treatment, but the mean annual costs. The following two hypotheses have to be assumed:

- FSTP is operated at constant design capacity over the entire depreciation period.
- The annual O+M costs are also recurrent and stable.

The FS load to be treated would in fact increase gradually due to the increasing number of emptying services and improved FSM activities. Annual O+M costs usually increase along with age of the installation. Furthermore, theoretical O+M costs unfortunately do not often reflect current conditions, as O+M is frequently neglected in the local context.

Land price is yet another factor influencing annuity of capital costs. Depending on land requirement of the treatment option, it may become a relevant factor.
It is also important to remember that depending on the primary treatment option used, water content and hygienic level of settled/dewatered sludge differ, and, thus, further treatment may be necessary, e.g. a spadable product for disposal or composting or a hygienically safe level for agricultural reuse of sludge.

The economic specification has to be converted into an appropriate scale unit for comparison's sake. Three conceivable possibilities are discussed: First, the *per capita price*, which is difficult to determine as it depends on the number of inhabitants served by the plant. The catchment area cannot be evaluated as easily as the one of a sewer system. Furthermore, sludge production of one person varies according to the sanitation system used (septic tank, pit latrine or public toilet). Second, the *price per volumetric raw sludge load* of the plant. Aside from measurement difficulties, such as truck recording, truck volume, etc., the main problem seems to be the varying types of sludge quality, particularly its solid contents, since the capacity of the treatment plant is far more dependent on the solid contents than on the volumetric load. Third, the *prices per ton total solid (TS) sludge load*. This parameter is probably the most significant scale unit, even if solid content varies considerably from one city and from one septic tank to another. Average sludge quality is, however, generally known, and the volumetric load more or less measurable. Therefore, the economic appraisal in this report is expressed ***per ton TS (contained in arriving sludge to treatment plant) per year***. The cost figures in this study should always be used with caution, as the results are approximate due to varying TS, and the volumetric load measurements may include important uncertainties.
It is possible to convert the chosen unit cost (US$ per t TS) into a theoretical per capita unit if a daily mean TS per capita of 14 g in septage is assumed (Heinss et al. 1998). Hence, plant capacity is expressed in population equivalent (PE). 1 PE corresponds to 14 g TS/day per capita. It provides a theoretical result (assuming that everybody uses a septic tank) and neglects the varying sludge qualities per capita resulting from different sanitation systems. If the public toilet sludge fraction is important, real plant capacity decreases rapidly due to high solids content of fresh public toilet sludge (about 100 g per capita and day). Thus, the per capita cost should be used with caution, and preference given to the more representative per t TS values.

When calculating the overall costs for faecal sludge management, haulage cost should be included as well as dewatered sludge disposal. According to Heinss (1999), haulage cost of FS to an upscaled (20,000 PE) constructed wetland plant of the AIT type amounted to about 30% of the total annual costs (including capital costs, O+M costs, haulage). A remarkably high figure revealing the interest in the use of semi-centralised treatment plants to save transport costs. The economy of scale must, however, also be taken into consideration here. Additional collection and haulage cost examples are given in Paragraph 0.

The overall costs of a sanitation system should also include septic tank construction costs. However, these have not been taken into account as our study only focuses on FSM costs.

Pilot plants

We differentiate between pilot plants and larger full-scale treatment plants on account of their different per capita costs. As aforementioned in Paragraph 0, a small plant often requires higher specific costs than a full-scale plant. We consider small capacity treatment plants (of less than 5,000 PE) as pilot-scale plants. The full-scale plants described in Paragraph 0 comprise larger capacities; i.e., in the order of 100,000 or more (except for the Nam Dinh and Argentina treatment plants with less than 20,000 PE).

2.1.1 Constructed wetlands, AIT, Bangkok

A pilot-scale septage treatment scheme is monitored at the AIT in Bangkok since 1997. It comprises a screen, a balancing and mixing tank followed by three constructed wetlands (CW) planted with cattails. Each CW is 5x5 m in size and treats the septage of about 1,000 inhabitants. Percolate is treated in a series of four attached-growth WSP (AGWSP), each with a 1x4 m surface area and 1 m depth. Final percolate treatment takes place in two polishing ponds of the same dimensions. During field research, plant layout was changed frequently (e.g. addition of a horizontal-flow rock filter, use of a CW bed planted with ornamental flowers for percolate post-treatment). However, we have only assessed the normal layout of three CW beds for WSP and two polishing ponds.

The optimum operating conditions, with maximum removal efficiencies and without cattail wilting symptoms were achieved at a weekly loading frequency of about 8 m^3 septage per drying bed. This corresponds to sludge loads of 140 – 360 kg $TS/m^2 \cdot y$. The mean TS content, based on 150 samples taken between Aug. 1997 and Nov. 2000, amounts to 19 g/l (Koottatep et al. 2001). Based on the assumed ideal sludge loading rate of 250 kg $TS/m^2 \cdot y$ proposed by Koottatep et al. (2001), the overall annual plant capacity is about 19 t TS.

Capital costs (without land costs) of the AIT plant amount to US$ 5,300 per CW unit, including screen and storage tanks. The AGWSP costs amount to US$ 4,000, including percolate pumps, and US$ 1,300 for the polishing pond. The horizontal-flow rock filter, installed for field research prior to the two AGWSP, was not taken into consideration.

The annual O+M costs for FS loading onto the beds, cattail harvesting (once to twice a year) and cleaning of units are estimated at 500 $/unit. However, the dewatered sludge removal costs are not included in this amount. Sludge removal will become necessary after about five or six years of operation. Since the plant was commissioned early 1997, removal was not yet necessary. The following Table 1 summarises the investment and recurrent costs of the pilot plant. Considering land requirement (1.5*net plant area), the total annual costs would increase by US$ 6 per t TS with an assumed land price of US$ 8 per m^2 (Heinss 1999).

Table 1: Costs (without land costs) of FS treatment with constructed wetlands at AIT in Bangkok – 1997 cost basis according to Koottatep et al. (2001) and Surinkul (2002).

	[US$]	Per capita[1)] [US$]	Per t TS FS [US$]
Construction cost CW units (3xUS$ 5,300)	15,900	4.3	837
Construction cost percolate post-treatment	5,300	1.4	279
Annualised capital and O+M cost			
Annual capital cost CW	1,532	0.41	81
Annual capital cost percolate treatment	511	0.14	27
Annual O+M cost[2)] (3xUS$ 500)	1,500	0.40	79
Sum	3,543	0.95	186

[1)] 3,700 PE based on an assumed 14 g TS per day and capita.
[2)] without sludge removal about once every 5 years

Table 2: Construction costs of the three CW units in Bangkok (1997 cost basis, fax from Koottatep to Strauss 1997).

Item	[US$]	[%]
Soil levelling and landscaping	700	6
Concrete material for floor slabs	2,350	19
Wood piling for wetland foundation	400	3
Reinforced concrete for wall slabs	1,450	12
Concrete blocks for percolate underdrainage	550	4
Cement ring (diameter 1m)	75	1
PVC drainage pipes (diameter 20 cm)	700	6
Stainless steel vent pipes (diameter 20 cm)	1,350	11
2.5-inch gravel	260	2
1.5-inch gravel	250	2
Coarse sand	310	3
Fine sand	310	3
Miscellaneous	660	5
Labour	2,950	24
Total	12,315	100

A detailed cost analysis of the three CW units is given in Table 2. Construction costs of the CW beds are calculated without screening and sludge storage tank. Aside from the labour costs, the most expensive materials are reinforced concrete and steel pipes. Depending on construction prerequisites, important savings can be achieved, for example if the stainless steel pipes for ventilation are relinquished or other lining materials used.

Based on the aforementioned data, Heinss (1999) estimated the capital and O+M costs of a full-scale constructed wetland plant (capacity: 10,000 – 30,000 PE). If the expenditure required for the pilot plant character and field research is deducted, the annual costs for a normal plant is estimated at US$ 89 per t TS. This remarkable economy of scale of a factor two is elucidated in Chapter 3. Figure 1 depicts the annual cost distribution of the AIT pilot plant.

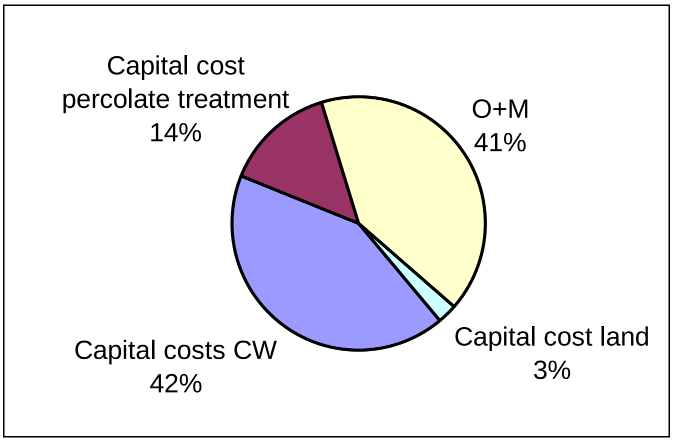


Figure 1 Annual cost distribution of the AIT FS treatment plant (including land cost)

2.1.2 Co-composting plant, Buobai, Kumasi

Operation of the co-composting pilot plant in Kumasi started in February 2002. The plant was built on the site of the Buobai full-scale FSTP (settling ponds), which was not operational yet. After dewatering FS in drying beds, biosolids are co-composted with the organic fraction extracted from the solid waste. The plant is designed to treat about 500 m^3 FS annually (three monthly FS loadings, each containing 15 m^3 FS) composed of a mixture of septage and public toilet sludge at a 2:1 ratio (assumed TS = 25 g/l). Preliminary results reveal about 90% sludge volume reduction during the approx. 15 days drying period. The dried sludge is composted with organic waste at a volumetric ratio of 1:3 (Quarshie 2002).

With about 12.5 t TS treated faecal sludge annually, the theoretical plant size amounts to about 2,500 PE with an assumed daily per capita contribution of 14 g/l. However, if the current sludge mixture is taken into account, the plant serves approximately 1,000 persons. If a daily solid waste production of 0.5 kg per capita is assumed (ρ~500 kg/m^3 and 50% organic content), the co-composting plant size treats approximately the solid waste of 1,000 persons.

The listed construction costs (Table 3) of the plant include the ramp for vacuum trucks, a sludge storage tank (15 m^3), two parallel drying beds (each 5.5 x 5.5 m), a dewatered sludge storage area, a solid waste delivery area, an unloading and handling area, a composting area (for composting, maturation, screening and bagging, compost storage), a closed building, and a percolate storage tank. Land price and percolate polishing are not included, as the latter is used either to moisten the compost heaps or is treated in the stabilisation ponds of the Buobai full-scale treatment plant. The land belongs to the Kumasi Metropolitan Assembly and costs about US$ 0.4 per m^2 (Annoh 2002).

Table 3: Distribution of construction costs of Buobai co-composting pilot plant, Kumasi. (Colan Consult: figures estimated on 11/2001).

Item	[US$][1)]	[%]
General items (insurance, site office, etc.)	5,500	24
Site clearance	50	0.2
Discharge area	750	3
Sludge storage tank	1,250	6
Pipe work and splitting chamber	280	1
Sludge drying beds	2,250[2)]	10
Solid waste handling area	1,300	6
Composting area	4,150	18
Storage area for dewatered sludge	70	0.3
Roofing materials	2,550	11
Percolate storage tank	1,300	6
Daywork[3)]	1,300	6
Contingencies	1,950	9
Total	22,700	100

[1)] Original prices in Cedi (7,400 Cedi = US$ 1, November 2001).
[2)] Original value of US$ 1,100 was modified by the author to US$ 2,250 (more concrete and reinforced steel than quoted).
[3)] Contingencies for materials and contractor's equipment, overhead and profit.

Real FS treatment (discharge area, storage tank, pipework and DB) amounts to about only 20% of the total expenditure. An important cost factor itemised under general expenses is the construction of the site office whose costs amount to US$ 4,300. Use of concrete and reinforcement steel for construction of the composting area has contributed to increasing the total costs. Although the described treatment is a low-cost option, a further reduction in concrete and reinforcement can be achieved by selecting local materials like adobe bricks, a clay layer or a thinner cement lining. Nevertheless, expensive roofing material for the composting area is useful to protect windrows and limit leachate during the rainy season as well as evaporation during the hot season.

Regarding the O+M costs (Table 4), sorting of solid waste is the most time-consuming operation at the co-composting plant. Based on the preliminary results reported by Quarshie (2002), the sorting cost range between US$ 2.8 and 3.8 per m^3 of sorted organic waste depending on the organic content of the initial waste. The rejected material from the initial waste load amounted to 50% and 18% for unsorted household waste, and partially sorted market waste respectively. Sorting market waste with a higher organic content is less labour-intensive than domestic waste.

Table 4: Specification of annual O+M costs of co-composting in Buobai based on man-hour monitoring from Quarshie (2002).

Item	[US$/y]	[%]
Sludge removal[1)]	100	6
Sand refilling[2)]	75	4
Compost turning[1)]	300	17
Waste sorting[1)] (150 m^3 at US$ 3.5)	525	29
Compost screening and bagging[1)]	100	6
Contingencies[2)]	200	11
Salary management[1)]	500	28
Annual O+M cost	1,800	100

[1)] Field experience of Quarshie (2002) and Olufunke (2002), excluding solid waste delivery and transport of remaining solid waste to landfill by the municipality.
[2)] Estimated by the author, details in Appendix 2.4, working time and equipment included.

According to Olufunke (2002), the current O+M costs of the pilot plant would amount to US$ 2,850[2] per year. This higher amount is caused by the cost of the monitoring programme (sampling, transport, weight and volume measurements) and of the salaries of two full-time workers operating the co-composting plant six days a week. Hence, the difference between the estimated in Table 4 in the current O+M cost might be attributed to the research activities conducted at the plant.

The annualised capital and O+M costs from the tables above are contained in Table 5.

The costs could be reduced significantly if biosolids are sold at a reasonable price. Compost production amounts to about 100 m^3/y (50 m^3 dewatered sludge and 150 m^3 organic waste, volume reduction of 50% during the composting period). With an average sales price[3] of about US$ 5 per m^3, it is possible to reduce the annual treatment and production costs from US$ 319 per t TS to around US$ 280 per t TS (reduction of 13%). However, the revenue from biosolids may not be as high if marketing and transport expenditure is required to sell the final product to farmers or households. The sale of biosolids is foreseen. However, preliminary field data is collected at this stage to determine the fertilising characteristics of biosolids and to convince farmers of their fertilising potential. This is essential, since a preliminary survey revealed that farmers are willing to buy biosolids obtained from faecal sludge on condition that they meet the soil amendment and fertilising quality standard.

[2] US$ 1= Cedi 8,400, August 2002.
[3] According to Annoh (2002), a fertiliser bag of compost (50 kg) would cost US$ 1, one ton of compost US$ 5 and a tipper truck (5 m^3) full of compost, including transport, US$ 40.

Table 5: Annual capital and O+M costs of Buobai co-composting plant in Kumasi with solids-liquid separation in drying beds (without percolate treatment ponds).

	[US$]	Per capita[3)] [US$]	Per t TS FS [US$]
Construction cost[1)]	22,700	9	1816
Annualised capital and O+M cost			
Annualised capital cost	2,187	0.9	175
Annual O+M cost[2)]	1,800	0.7	144
Sum	3,987	1.6	319

[1)] Without land cost and percolate polishing ponds.
[2)] Ignoring potential revenue from sale of biosolids.
[3)] Estimated plant size of 2,500 PE based on an assumed per capita TS load of 14 g/day.

As with every treatment plant[4], capital and recurrent costs cannot be covered with the revenue obtained from the sale of compost. However, with an upscaled plant, it would be possible at least to cover partially current O+M costs and create employment.

2.1.3 Sludge drying beds, WRI, Accra

In 1995, three pilot sludge drying beds, each 3x3 m in size, were constructed on the site of the Water Research Institute (WRI) in Accra to test dewaterability of various faecal sludge types. Available cost data on these pilot drying beds is scarce. However, preliminary cost estimates for the three drying beds by SANDEC ranged from US$ 2,000 to 2,800 and were distributed as follows: 50% reinforcement steel, 35% concrete, 10% shuttering and 5% earthwork. Drying beds were constructed without discharge area, as they were loaded directly by the vacuum truck. Post-treatment of percolate or dewatered sludge is not available.

During field research, the equivalent annual volumetric load amounted to about 200 m^3 FS with a TS content of 20 g/l (this corresponds to 4 t TS FS annually) on the total drying bed area of 27 m^2. The assumed loading frequency was 10 days, including loading, drying and removing. Water content of dried sludge can decrease to as low as 30%. However, in order to obtain a hygienically safe product for reuse, dried sludge post-treatment is necessary, e.g. simple storage near the treatment plant. O+M tasks mainly include sludge removal after drying and refilling of the sand layer that is accidentally removed along with sludge.

Table 6 illustrates the capital and O+M cost of the drying beds. O+M costs have been estimated by the author (Appendix 1.6).

[4] Western wastewater treatment or waste incineration plants can never cover their costs with the sale of biogas, heat or electricity. Subsidies, taxes or disposal fees always cover these costs.

Table 6: Capital and O+M costs of the FS pilot drying beds at WRI, Accra (only drying beds, without discharge area, screen and percolate treatment).

	[US$]	Per capita[3)] [US$]	Per t TS FS [US$]
Construction cost[1)]	2,400	3.1	600
Annualised capital and O+M cost			
Annual capital cost	231	0.30	58
Annual O+M cost[2)]	150	0.19	37
Sum	381	0.49	95

1) Including the drying beds only.
2) Estimate by the author, without percolate and sludge post-treatment.
3) Plant size: 780 PE based on an assumed daily load of 14 g TS per capita.

Full-scale plants

2.1.4 Settling/thickening tanks and stabilisation ponds, Accra, Ghana

Table 7: Features of Achimota FSTP.

Plant Size		
Two settling/thickening tanks, each:		
Length	[m]	24
Width	[m]	8.3
Maximal depth	[m]	3
Volume	[m3]	300
Five serial ponds, total size:		
Surface	[m2]	4,725
Volume	[m3]	3,500
Depth	[m]	0.6 - 1
Sludge Load		
Daily loading	[m3]	150
Average TS content	[g/l]	20
Annual load[1]	[m3]	45,000
Annual TS load	[t]	900
1 300 days of operation per year		

The Achimota FSTP is equipped with two full-scale batch-operated sedimentation/ thickening tanks, developed in Ghana in 1988. Design and FS flow is given in Table 7. With an average load of 150 m^3/d, the tank will be filled within two days and work subsequently as sludge accumulator, similarly to a septic tank. Based on an assumed daily per capita load of 14 g TS, plant size corresponds to 175,000 PE. The ratio of public toilet sludge (55 g TS/l) and septage (12 g TS/l) ranges from 3:1 to 4:1. Thus, mean TS content is about 20 g/l. The supernatant flows from the tank into the following WSP. An operating cycle lasts from four to eight weeks. Sludge loading is then transferred to a parallel tank. The settled and thickened sludge is removed by front-end loader as late as possible; i.e., when the tank is due for a new operating cycle. The settled sludge in the sedimentation tank of the Achimota FSTP reaches a TS content of up to 150 g/l. Thus, further treatment of the sludge is necessary to enhance the TS content (to render it spadable) and/or to ensure hygienic sludge reuse. Sawdust is for example used in Achimota to remove accumulated sludge in the settling/thickening tank. Dewatered sludge is disposed off on the premises of treatment plant.

At the Teshie FSTP in Accra (commissioned in 1996), a preliminary settling/thickening tank precedes the ponds. The station treats about 100 m^3/d, resulting in an annual sludge load of approx. 750 t TS/y. Thus, the plant corresponds to about 145,000 PE (cf. Table 8).

Table 8: Features of the Teshie FS treatment plant.

Plant Size		
Two settling/thickening tanks, each:		
Surface	[m2]	100
Volume	[m3]	200
Seven ponds, first two parallel, total size:		
Surface	[m2]	5,100
Volume	[m3]	3,950
Sludge Load		
Daily loading	[m3]	100
Average TS content	[g/l]	25
Annual load[1]	[m3]	30,000
Annual TS load	[t]	750
[1] 300 days of operation per year		

Annualised capital and O+M costs of the Teshie treatment plant are listed in Table 9. Unfortunately, the Achimota costs were not available yet.

Both FSTP in Accra, Achimota and Teshie seem to be overloaded if the loading rate of the settling/thickening tank per surface is compared with the proposed ideal loading rate of 1,200 kg TS/ $m^2 \cdot y$ (Heinss et al. 1998). Currently, with a total settling/thickening surface of 400 m^2 and 200 m^2 respectively, the plants treat about 2,250 kg TS/$m^2 \cdot y$ and 3,750 kg TS/ $m^2 \cdot y$ respectively, a considerably higher rate than the proposed loading rate, and most likely at the expense of the effluent quality. By respecting the proposed loading rate, the annual capital and O+M costs per t TS of the settling/thickening tank of the Teshie FSTP would increase (its volume would triple).

Table 9: Capital and O+M costs of Teshie FSTP in Accra, according to Annoh (1996).

	[US$]	Per capita[1)] [US$]	Per t TS FS [US$]
Construction cost[2)]	75,000	0.52	150
Annualised capital and O+M cost			
Annual capital cost	7,262	0.05	10
Annual O+M cost[3)]	7,800	0.05	10
Sum	15,062	0.10	20

[1)] Plant capacity: PE ~ 145,000.
[2)] Excluding land costs.
[3)] Estimate by the author with information from Annoh (2002), see Appendix 1.3. This value does not correspond to the reality, as currently almost nothing is done. However, it represents realistic O+M cost, if the station would be run correctly.

2.1.5 Settling and stabilisation ponds, Kumasi, Ghana

The Buobai FSTP in Kumasi was constructed in 2001 and comprises two primary settling (anaerobic) ponds in series for solids-liquid separation and initial biological load reduction. The supernatant is treated in a facultative pond, followed by three maturation ponds. Settled sludge can be sucked off from primary ponds by vacuum truck using a pipe connected to the ground. In addition, front-loader trucks can access primary ponds via a ramp to remove the thickened sludge. Unfortunately, this plant is not yet operational (institutional problems with the environmental impact study). It is designed to receive a daily load of about 200 m^3 septage and public toilet sludge at an approx. 2.5:1 ratio. Based on an assumed TS content of 25 g/l, 300 loading days and 14 g TS/d per capita load, this corresponds to a plant size of approx. 290,000 PE.

Annual capital and O+M costs are summarised in Table 11, while details of construction and estimated O+M costs are listed in
Table 12 and Table 13, respectively.

Table 10: Features of the full-scale Buobai FSTP in Kumasi.

Plant Size		
Two anaerobic settling ponds, A1 and A2:		
Surface A1 (60x55m)	[m2]	3,300
Depth A1	[m]	6.5
Surface A2 (55x45m)	[m2]	2,475
Depth A2	[m]	5
One facultative pond:		
Surface (130x60m)	[m2]	7,800
Depth	[m]	2.3
Three maturation ponds, each:		
Surface (55x35m)	[m2]	1,925
Depth	[m]	1.5
Sludge Load		
Daily loading	[m3]	200
Average TS content	[g/l]	25
Annual load[1]	[m3]	60,000
Annual TS load	[t]	1,500
[1] 300 days of operation per year		

Table 11: Capital and O+M costs of the built Buobai full-scale plant in Kumasi.

	[US$]	Per capita [US$]	Per t TS FS [US$]
Construction cost[1)]	420,000	1.45	280
Annualised capital and O+M cost			
Annual capital cost (construction)	40,464	0.14	27
Annual capital cost (land)	3,035	0.01	2
Annual O+M costs[2)]	31,575	0.11	21
Sum	75,074	0.26	50

[1)] Global costs, but excluding land costs of US$ 31,500 (approx. US$ 0.4 per m^2).
[2)] Estimate, including dewatered sludge post-treatment (mixture with sawdust and storage) and environmental management plan (see Table 13)

Table 12: Construction cost of the Buobai full-scale plant (after Annoh 2002).

Item	[US$][1)]	[%]
Site clearance	11,000	3
1st anaerobic pond	52,500	13
2nd anaerobic pond	47,000	11
Facultative pond	56,500	13
Three maturation ponds	48,000	11
Ancillary works	16,500	4
Water supply	30,000	7
Road works	47,500	11
Drains and chute	1,500	0.4
Chambers	15,000	4
Two sludge ponds	3,500	1
Contingencies (site office, etc.)	91,000	22
Total	420,000	100

[1)] Prices originally in Cedi (exchange rate: 1 US$ = 3,300 Cedi, November 1999).

Table 13: Details of estimated annual O+M costs of Buobai plant (according to Annoh 2002).

Item	[US$/y]	[%]
Hiring suction truck (12 days)	750	2
Hiring loader (20 days)	4,000	13
Hiring tipper trucks (4 days)	500	2
Hiring excavator (4 days)	1,250	4
Haulage of sawdust	750	2
Environmental management plan[1)]	16,700	53
General repairs	375	1
Material and equipment	250	1
Salaries (7 worker)	7,000	22
Annual O+M cost	31,575	100

[1)] Includes mainly training and awareness seminars; effluent, air and public health monitoring; use of consultants.

Land costs amounted to approximately US$ 31,500 in 1998 for implementation of the entire treatment plant (Annoh 2002). The purchased land is 330 x 240 m in size, and the average land price for FSTP amounted to US$ 0.4 per m^2.

2.1.6 Sedimentation ponds and co-treatment of supernatant with sewage, Alcorta, Argentina

In 1987, a system with two waste stabilisation ponds in series was put into operation in the town of Alcorta, Argentina. In addition to the sewage, septage was dumped directly into the first pond and co-treated with the wastewater. A monitoring programme in 1994 conducted by the Centro de Ingeniería Sanitaria (University of Rosario) indicated a reduced capacity of the primary pond as a consequence of the high content of solids in the septage. Based on these investigations, two sedimentation (settling) ponds (C1&C2) were constructed for a better solids-liquid separation. Design features are given in Table 14. The settling ponds began to work alternately in 1998. One pond is in operation for about six months while the second is put to rest for sludge stabilisation and drying. The supernatant of the settling pond is then co-treated with the sewage in one facultative (L1) and one maturation (L2) pond.

Table 14: Features of the Alcorta sewage and FS treatment plant.

Plant Size		
C1 & C2		
Length	[m]	25
Width	[m]	11
Depth	[m]	1.5
L1		
Length	[m]	83
Width	[m]	57
Depth	[m]	1.2
L2		
Length	[m]	38
Width	[m]	53
Depth	[m]	1.3
Sludge Load		
Average daily loading	[m3]	24
SS concentration	[g/l]	6
Annual load[1]	[m3]	8750
TS load[2]	[t/yr]	100
[1] 365 days*daily average		
[2] estimated TS content of 12 g/L		

Monitoring revealed suitability of sedimentation pond effluents to be discharged in the wastewater stabilisation ponds to allow appropriate removal efficiency of SS, BOD and COD in these WSP designed for sewage treatment. A mean daily flow of 24 m^3 septage was treated during the first monitoring phase. In addition to the supernatant of the septage pond, the stabilisation ponds treated a mean daily flow of 200 m^3 sewage (Ingallinella et al. 2000).

Detailed construction and O+M costs are available for the sedimentation ponds (solids-liquid separation) and the WSP (supernatant post-treatment). Since supernatant and wastewater are co-treated, not the entire capital and O+M costs of the WSP can be attributed to FS treatment. Supernatant makes up approximately 10% of the total flow treated in stabilisation ponds. Hence, we assume to simplify that only 10% of the investment and O+M costs of the WSP are attributable to supernatant treatment. Table 15 summarises annual capital and O+M costs of FS and its supernatant treatment, while cost details are given in Appendix 1.4.

Table 15: Cost summary (without land costs) of the sedimentation ponds in Alcorta, Argentina. (adapted from Ingallinella 2000)

	[US$]	Per capita [1] [US$]	Per t TS FS [US$]
Construction cost (C1+C2)	11,580	0.58/3.2	116
Construction cost (L1+L2)	10,710 [2]	0.54/3.0	107
Annualised capital and O+M cost			
Annual capital cost solids-liquid separation	1,116	0.06/0.3	11
Annual capital cost supernatant polishing	1,032	0.05/0.3	10
Annual O+M cost solids-liquid separation	2,960	0.15/0.8	30
Annual O+M cost supernatant polishing	840	0.04/0.2	8
Sum	5,588	0.30/1.6	59

[1] 20,000 PE if based on an assumed 14 g/l daily per capita. In reality, however, about 1,000 households (~3,600 inhabitants) are served by pits with a typical volume of 4.5 m^3, which are emptied biannually. Therefore, the first value is calculated with 20,000 PE, and the second with 3,600 inhabitants.
[2] Amount represents 10% of the total WSP costs, as FS effluent represents about 10% of total WSP flow.

Total costs of US$ 59 per t TS do not include land price. According to the Centro de Ingeniería Sanitaria (2002), the land price ranges from US$ 6 to 20 per m^2. Based on an assumed land price of US$ 10 per m^2, and a plant size of 1,800 m^2 (1.5*net surface imputable to FS treatment), the total costs would rise from 59 to **US$ 77** per t TS if the land price is included in the calculation. Figure 4 illustrates the composition of the capital, O+M and land costs. The available cost details reveal the structure of settling ponds construction and O+M costs, illustrated in Figure 2 and Figure 3. The O+M costs of sedimentation ponds are more important (38%) than the relatively low annualised construction costs (15%). This typical feature of a low cost option is attributed to the relatively high labour cost of US$ 200 person/month and the use of a plastic membrane lining, which is replaced biannually after each sludge removal operation. The construction costs of stabilisation ponds are similar to those of sedimentation ponds. However, O+M costs of WSP are far lower than for the sedimentation ponds, as less sludge removal work is necessary and no plastic membrane.

This example illustrates the difficulties encountered with calculating a per capita treatment price. Based on an assumed daily per capita TS load of 14 g, the plant treats septage of about 20,000 PE. In actual fact, the plant serves only about 1,000 households with approx. 3,600 inhabitants. This difference is due to the existence of large pits (typical dimensions: 1.2 m diameter, 4.5 m depth). Since the pits are emptied about twice a year, sludge is highly diluted (low TS content of about 12 g/l) and not stabilised yet. Thus, the daily per capita TS production is clearly higher than 14 g.

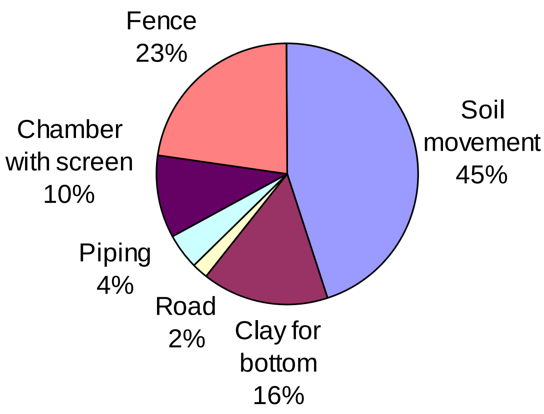


Figure 2: Specification of construction costs of two settling ponds. Total costs amount to US$ 11,580.

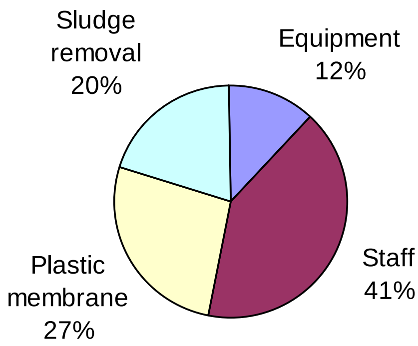


Figure 3: Specification of the annual O+M costs of two settling ponds. Total O+M amounts to US$ 2,960 per year.

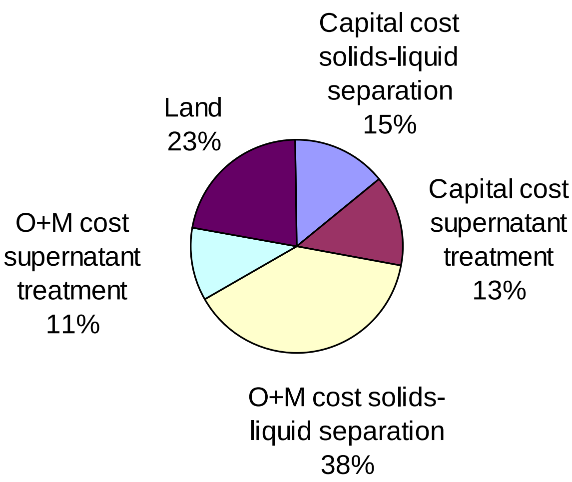


Figure 4: Total cost distribution per t TS FS of Alcorta co-treatment plant. Sewage treatment cost has been deducted.

2.1.7 Settling/thickening tank and stabilisation pond scheme project, Cotonou, Benin

The FSTP, located on the outskirts of Cotonou (Benin), receives a daily FS load of about 265 m^3. However, the load is too important to ensure appropriate treatment. Thus, an extension (rather replacement) project was initiated in 1999 to enhance plant capacity to maximum 600 m^3/d. The study report proposes to replace the current scheme by two new treatment lines; each comprising three settling/thickening tanks and six stabilisation ponds

Table 16: Features of the planned FSTP in Cotonou, Benin.

Plant Size		
Two lines, each with three sedimentation/ thickening tanks and six ponds		
Settling/thickening tank (each, total 6):		
Length	[m]	40
Width	[m]	6
Volume	[m3]	310
Pond (each, total 12 ponds):		
Length	[m]	165
Width	[m]	26
Volume	[m3]	6,000
Sludge Load		
Maximal daily loading	[m3]	600
Annual load [1]	[m3]	180,000
TS load [2]	[t/y]	3,200
[1] 300 days of max. loading per year		
[2] Assuming TS content of 18 g/l		

for supernatant treatment. The project has not been implemented yet, but a detailed investment cost estimate is available (Option Environnement 1999). Estimated costs (subdivided in a primary treatment, supernatant treatment and dewatered sludge post-treatment section) are listed in the following Table 17.

Table 17: Estimate in US$ of the planned FSTP in Cotonou (Option Environnement 1999).

Item	Settling/ thickening tanks	Anaerobic ponds for supernatant	Sludge post treatment area
Excavation/embankment	3,000	86,000	6,000
Waterproofing (Geo-membrane)	0	170,000	22,000
Reinforced concrete	280,000	0	0
Screen	20,000	0	0
Pipes and sliders	11,000	10,000	0
Drainage	7,000	18,000	7,000
Roads	56,000	56,000	56,000
Contingencies (house, site cleaning)	9,000	9,000	9,000
Subtotal for each unity	386,000 (A)	349,000 (B)	100,000 (C)
Total construction without land (A+B+C)			835,000
Land cost			27,000
Unforeseen 10% (of A+B+C+land)			86,200
Subtotal construction, land and unforeseen			948,200
Administration and profits (10%)			94,800
Taxes on imported material			126,000
Total cost in US$			1,169,000

The figures in the table above reveal that the solids-liquid separation in settling/ thickening tanks amounts to only 46% of the construction costs, whereas 54% are required by supernatant and dewatered sludge post-treatment. Concrete is the most important cost factor for this unit, while for the ponds it is the impermeable geo-membrane. Although these two imported items significantly increase the costs (they make up 38% of the total costs), they are necessary for protection against the very high groundwater table caused by the proximity of the sea.

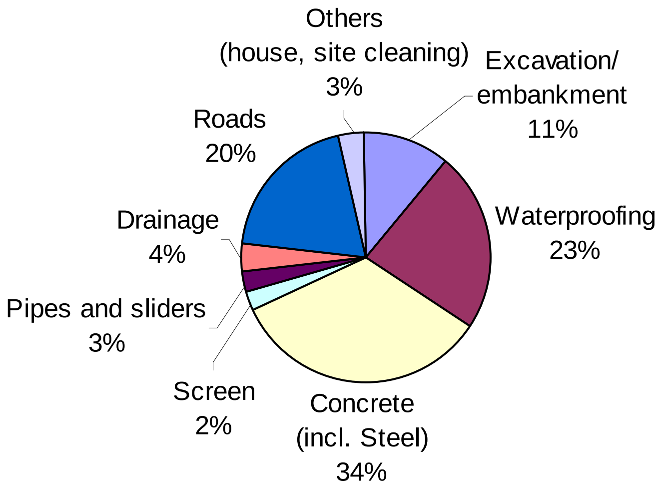


Figure 5: Specification of estimated capital costs without land, unforeseen and administration costs (100% total US$ 835,000; according to Option Environnement 1999).

Table 18: Quotation of the investment costs of the planned FSTP in Cotonou (Option Environnement 1999)

	[US$]	Per capita[2)] [US$]	Per t TS FS [US$]
Construction cost[1)]	1,169,000	1.9	360
Annualised capital and O+M cost			
Annual capital costs	112,624	0.19	35
Annual O+M cost[3)]	45,000	0.08	14
Sum	157,624	0.27	49

1) Including all costs; two lines of settling tanks and stabilisation ponds.
2) An estimated catchment area of 600,000 PE (calculated with 14 g TS/day per capita and an assumed sludge concentration of 18 g TS/l).
3) Estimate by the author based on the Buobai experience, see Appendix 1.6

Note that the maximum daily flow of 600 m^3/d is likely to be reached only in 15 to 20 years. Thus, effective annual capital costs would be higher in relation to the real amount of treated FS.

2.1.8 Comparison of different option in the city of Nam Dinh, Vietnam

A recently conducted FS management planning study (Klingel 2001) compared three feasible FS treatment options in the city of Nam Dinh in North Vietnam. Due to the increased number of septic tanks installed in recent years with the support of the municipality, there is an obvious need for a FSTP. Faecal sludge collected from septic tanks and bucket toilets still remains untreated. The foreseen FSTP would be installed on municipal land directly next to the controlled landfill. The leachate stabilisation ponds from the landfill could thus be used to treat the liquid fraction of FS. The three suggested low-cost FS treatment options producing biosolids safe for agricultural use include:

Constructed wetlands and effluent polishing in landfill ponds.
Drying beds and post-storage of biosolids and effluent polishing in landfill ponds.
Settling/thickening tank followed by secondary sedimentation (anaerobic) pond for supernatant treatment, and drying beds for further dewatering of settled FS, liquid polishing in landfill ponds.

The following estimate in Table 19 is based on an annual capacity of 2,500 m^3 septage. This corresponds to 1,000 septic tanks. Based on an assumed emptying frequency of five years, this capacity would cover about 5,000 septic tanks. Based on the experience with septage in Thailand, an average TS content of 20 g/l is assumed.

Table 19: Treatment options cost – Capital and O+M cost (Klingel 2001).

Comparison of estimated investment costs [in US$]			
Item	Constructed wetland	Drying beds	Settling tank and ponds
CW/drying bed/settling tank	3,500	4,300	5,400
Filling of low lying land	2,500	2,500	2,500
Access road	1,750	1,900	2,100
Septage receiving tank	750	750	0
Vault and pump for percolate	800	800	0
Taxes and general expenses	1,400	1,600	1,600
Detailed design and supervision	7,500	7,500	7,500
Contingencies	5,000	5,000	5,000
Total investment	23,200	24,350	24,100
Comparison of annual O+M costs [in US$/y]			
Electricity for percolate pumping	500	500	0
Sludge removal	300	400	2090
Procurement of rice husks	0	0	730
Maintenance	60	140	0
Post treatment of biosolids	0	200	900
Management costs and taxes	540	770	2,480
Total O+M cost per year	1,400	2,010	6,180

Table 20: Capital and O+M cost estimate of the Nam Dinh (Vietnam) selected treatment options (according to Klingel 2001).

	[US$]	Per capita[2)] [US$]	Per t TS FS [US$]
Construction cost[1)]			
CW	23,200	2.3	464
Drying bed	24,350	2.4	487
Settling/thickening tank	24,100	2.4	482
Annual capital costs			
CW	2,235	0.22	45
Drying bed	2,346	0.23	47
Settling/thickening tank	2,322	0.23	46
Annual O+M costs			
CW	1,400	0.14	28
Drying bed	2,010	0.20	40
Settling/thickening tank	6,180	0.62	124
Sum of annualised capital and O+M			
CW	3,635	0.36	73
Drying bed	4,356	0.43	87
Settling/thickening tank	8,502	0.85	170
Revenues from biosolids sale[3)]	Quantity [t/y]	Net revenue [US$/y]	Revenue per t TS FS [US$]
CW	75	1,000	**20**
Drying bed	100	1,400	28
Settling/thickening tank	300[4)]	4,100	82

1) Excluding land cost and final polishing of the effluent
2) An estimated catchment area of 10,000 PE (calculated with 14 g TS/day per capita and assuming a TS content of 20 g/L)
3) Marketing and transport of biosolids is already deducted from revenues
4) Comprising settled sludge and rice husk in a ratio of 2:1

The selected treatment options have similar investment costs and land requirements; i.e., 250 m^2 net surface for the constructed wetlands and 200 m^2 for drying beds and settling tanks. As regards the O+M costs, the settling/thickening option is four to five times more expensive than the other options, as it requires important sludge removal work. Although O+M costs are higher, settling tanks could be interesting if biosolids are marketed – as a settling tank with ponds produces more sludge (related to its volume) than for instance a constructed wetland or a drying bed, where accumulated sludge is more compact due to its lower water content. If biosolids are marketed, an important revenue can be generated, thereby saving landfill space and supplying Nam Dinh's agriculture with the required soil conditioner. Klingel (2001) assessed the market potential and revenue from the biosolids sale.

Table 20contains all the costs pertaining to investment and sale of biosolids.

It is important to note that the biosolids quality (water content) varies after different primary treatment options. For instance, water content of dewatered sludge from drying beds is estimated at 60% in this climate, while settled sludge still contains 85%. The latter therefore requires further dewatering or drying (e.g. by simple sun drying) or addition of a bulking agent, such as rice husks, to become spadable. However, the study conducted by Klingel (2001) assumed the same sales price irrespective of biosolids quality.

Compared to the other options, the O+M costs of the settling/thickening tank are significantly higher, as more settled sludge has to be removed and handled. The important quantity of dewatered sludge is subsequently reflected in the sale of biosolids (settled sludge and rice husks mixture). However, the water content of this mixture is likely to decrease during storage, thereby reducing the quantity of marketable biosolids.

2.1.9 Settling tank and stabilisation ponds in Bamako, Malil

This document was written at the time when a Peace Corp volunteer was planning to set up a FSTP in collaboration with a local GIE (small local associative structure) in Bamako, the capital of Mali. The GIE was already active in FS collection, but did not dispose of an appropriate dumping site. Therefore, two settling tanks, one anaerobic, two facultative and three maturation ponds were planned to treat FS and reuse the liquid effluent for irrigation and the sale of biosolids (possibly with composting of solid waste) as soil conditioner.
The combination of collection and treatment by one operator deserves special mention. This may allow to cover the treatment costs with FS emptying fees.

Jeuland (2002) designed the treatment scheme (Table 21) according to Heinss et al. (1998) and estimated its cost. It is designed to receive a daily FS load of about 70 m^3, while average TS content is estimated at 22 g/l (7:1 mixture of septage and PT sludge).
Annual O+M costs are estimated at US$ 12,500 for salaries and US$ 500 for contingencies. Collection costs (truck maintenance and gasoline) were deducted. Thus,

Table 22 summarises annual construction and O+M costs for this planned scheme. Details of

Table 21: Features of the planned FSTP in Bamako.

Plant Size		
Two settling tanks, each:		
Surface (36x4m)	[m2]	3,300
Depth	[m]	3
Volume	[m3]	370
One anaerobic pond:		
Surface (27.5x12.2m)	[m2]	335
Depth	[m]	2.5
Two facultative ponds, each:		
Surface (59.5x12.9m)	[m2]	772
Depth	[m]	1.5
Three maturation ponds, each:		
Surface (32.5x12m)	[m2]	390
Depth	[m]	1.5
Sludge Load		
Daily FS loading	[m3]	70
Average TS content	[g/l]	22
Annual load[1]	[m3]	21,000
Approximate TS load	[t/y]	450
[1] 300 days of operation per year		

construction costs are itemised in Table 23.

Table 22: Summary of capital and O+M costs of FSTP in Bamako.

	[US$]	Per capita[1)] [US$]	Per t TS FS [US$]
Construction cost [2)]	77,500	0.86	172
Annualised capital and O+M cost			
Annual capital cost	7,467	0.08	17
Annual O+M cost	13,000	0.14	29
Sum	20,467	0.22	46

1) 90,000 PE with an assumed 14 g TS/d per capita.
2) FS collection and groundwater pumping costs have been deducted. Exchange rate: US$ 1 = 655 FCFA (2002).

Table 23: Estimated cost of the FSTP in Bamako after Jeuland (2002), without land cost, solar pump and boring for water supply.

	Item	Cost [US$]
Tank and ponds	Terrain preparation	1,700
	Excavation	12,400
	Reinforced concrete	14,700
	Pipework	3,000
Buildings	Office and laboratory	6,800
	Toilettes	1,100
	Guard’s house	2,300
Treated FS storage	Roofed storage (composting) area	10,000
	Compost office	6,500
Site installation	Routes	1,000
	Crop zone	500
	Reforestation	2,300
	Fence	8,800
	Study	3,200
	Topographical study	1,000

Equipment	Office and laboratory	1,600
	Tools	600
	Total investment [US$]	77,500

Sensitivity analysis when varying life time and land price

On account of the significant national differences in interest rate, depreciation period and land price, a sensitivity study of these parameters seems appropriate. Therefore, this paragraph illustrated an annual cost comparison by varying only one of these parameters. The sensitivity analysis was conducted at the full-scale Buobai scheme described in Paragraph 2.1.5. Figure 6 reveals that if the land price is increased to about US$ 10, the total annual costs (capital and O+M costs plus annual land cost) would more than double compared to the no land cost alternative. To simplify the calculation, we considered land investment as a type of construction; i.e., the entire capital is paid back after the depreciation period. This is not quite correct, as land has a theoretically eternal service life, which does not correspond to the depreciation period.

As mentioned in Paragraph 0, short depreciation periods increase specific capital costs per t TS exponentially, but these costs are hardly influenced anymore beyond depreciation periods of about 20 years Figure 7. Since a sharp drop occurs approximately between 10 and 15 years, it would be wise to construct a sustainable plant. The service life of a treatment plant in industrial countries is estimated at 30 to 50 years.

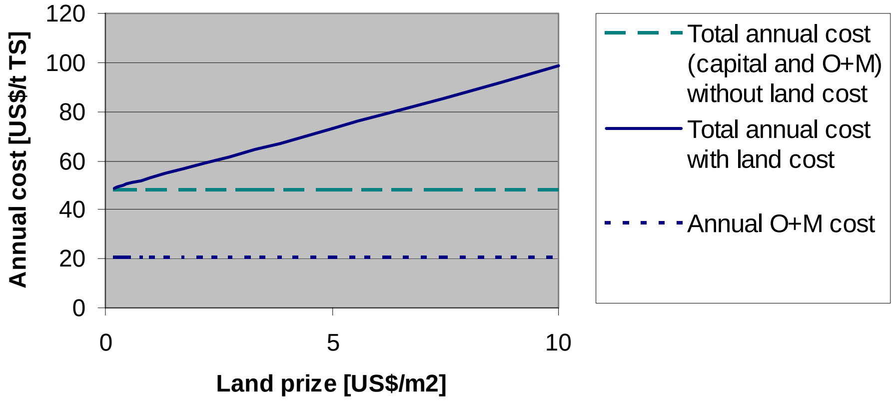


Figure 6: Importance of land prize in relation to total costs (capital, O+M and land) based on the Buobai full-scale treatment plant (cf. Paragraph 2.1.5).

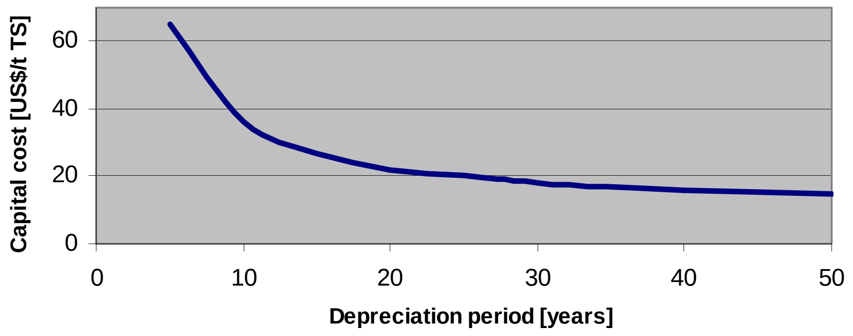


Figure 7: Importance of depreciation period in relation to capital costs based on the Buobai full-scale settling pond treatment scheme.

Based on an assumed depreciation period of 15 years, different interest rates also have a significant influence on the treatment scheme costs. For example, annualised capital costs of the Buobai treatment plant at an assumed interest rate of 5% amount to US$ 27 per t TS. These capital costs would decrease to US$ 19 per t TS with a 0% interest rate, whereas annuity would rise to US$ 37 per t TS with an interest rate of 10% (cf. Figure 8).

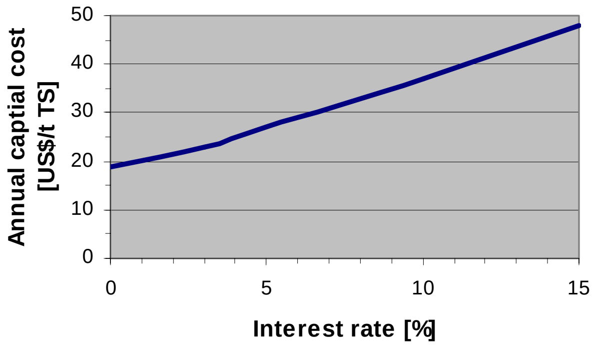


Figure 8: Variation of annual capital costs (without land) based on the example of the Buobai full-scale FSTP as a function of interest rate.

For comparison's sake, the interest rate in Kumasi was about 12% at the time of completing this report (Annoh 2002). However, since the inflation rate is very high in Ghana[5], the real interest rate in US$ is much lower. In Argentina, the nominal interest rate in 2001, before the economic crises, amounted to 6% with a very low inflation rate (the real interest rate is the nominal interest rate minus inflation).

Considering that a variation in interest rate has a significant influence on treatment costs, different interest rates in time and space complicate a possible cross-country study. Incidentally, with a short depreciation period (e.g. five years), the significance of interest rate variation in comparison with annual capital costs is less important, as annuity is high anyway.

Land requirement

[5] E.g. 15% from September 2001 to September 2002.

As aforementioned, land requirement can be an important decision factor when selecting a treatment option. If plant size increases, either land requirement becomes too expensive because of land price or ownership, or there is a lack of available space within a reasonable distance to where FS is produced. Low-cost options generally require more land than capital and energy intensive schemes (e.g. activated sludge).
Land requirements per t TS (or per capita) can be estimated using monitoring results of pilot and full-scale plant research. Land requirement has to be calculated for each plant, as it is dependent on climatic conditions and required water content of dewatered sludge, thus complicating an extrapolation and generalisation. Drying beds are the best example to illustrate this aspect: A long drying period normally indicates a high TS content, but also a greater land requirement. A hot and dry climate certainly also enhances the drying process.
All the examined settling/thickening tanks require a much smaller area per t TS FS than the other treatment options, as the solids separation process has a relatively short hydraulic retention time. However, organic and solid loads in the percolate (effluent of CW and drying beds) are significantly lower than in the supernatant (effluent of sedimentation/thickening tanks and settling ponds). Thus, regarding only organic pollution, post-treatment of percolate from drying beds and CW is assumed to require less space than from settling/thickening tanks owing to the lower effluent load (Heinss et al. 1998). Apart from a supernatant with a higher load than the percolate, sludge quality also differs, as the water content of thickened sludge is higher (about 85% to 90%) than that of dewatered sludge issued from drying beds or constructed wetlands. Thus, this sludge requires further treatment (e.g. addition of sawdust) to render it spadable. Unfortunately, land requirement for percolate treatment originating from drying beds has not been calculated, but estimated to be in the same order of magnitude as for the effluent from CW.

Table 24: Net land requirement for selected FS treatment options (solids-liquid separation and effluent treatment in ponds), without further biosolids post-treatment.

Type of solids-liquid separation	Reference	**Annual loading rate solids-liquid separation [kg TS FS/m^2·y]**	Land requirement solids-liquid separation [m^2/t TS FS·y]	Land requirement liquid treatment [m^2/t TS FS·y]
Settling/ thickening tanks	Achimota, Accra	2,250[1)]	0.4	5
	Teshie, Accra	3,750[1)]	0.3	7
	Sibeau, Cotonou	2,200[2)]	0.5	16
	Bamako	1,500	0.6	7
Drying beds	WRI, Accra	150[3)]	7	-
	Buobai, Kumasi (co-composting)	200	5	-
Settling ponds	Buobai, Kumasi	240[4)]	4	9
	Alcorta, Argentina	180	5	7[5)]

Constructed wetlands	AIT, Bangkok	250	4	1.3[6)]	4[7)]

[1)] Full-scale plants that could be overloaded, thus low treatment efficiency.
[2)] Planned full-scale unit, not yet constructed.
[3)] Pilot-scale plants, ideal loading rates determined during research.
[4)] Constructed plant, but not yet operational, therefore estimated values.
[5)] Co-treatment of sewage and supernatant from FS treatment. Effluent from septage pond corresponds to about 10% of total load. Thus, 10% of pond surface was used to calculate land requirement for theoretical supernatant post-treatment only.
[6)] Attached-growth stabilisation and polishing ponds.
[7)] Percolate post-treatment in a constructed wetland planted with ornamental flowers.

However, supernatant treatment is significantly more important than solids-liquid separation as regards land requirement for settling/thickening tanks, and similar for the other options. Waste stabilisation ponds and constructed wetlands are likely to be low-cost, simple and efficient options to treat supernatants or percolate from solids-liquid separation processes. The reason for the high land requirement of the Cotonou scheme is the high ammonia (NH_3) concentration, which is toxic for algae growth in aerobic ponds.

It is possible to convert the results from Table 24 expressed per t TS of annual incoming FS into per capita land requirement. The main problem, however, is that per capita TS production is dependent on the sanitation system used (pit latrine, septic tank or public toilet). If we assume that every user disposes of a septic tank (corresponding to 14 g TS per capita and day), the net land requirement for solids-liquid separation followed by WSP (for effluent treatment) ranges from 0.03 to 0.08 m^2 per capita. Land for access road, sludge storage and treatment, discharge area, site office etc., has to be added to obtain a real land requirement. Based on an assumed additional land requirement of 50%, the required land would range from **0.05 to 0.12 m^2 per capita.**
If public toilets or pit latrines are used, the per capita land requirement increases further due to a higher TS load per capita (e.g. from 14 g TS to 100 g TS for septage and public toilet respectively).

Evaluation

The results from the cost analysis of selected faecal sludge treatment plants are summarised in Table 25. Although the economic analysis of the particular FS treatment plants in Thailand, West Africa and Argentina provided only limited cost data, the following conclusions can be drawn:

Availability of comparable data is scarce. The cost information often does not refer to the same plant layout (with or without polishing pond, etc.). Some data used relate only to theoretical design values from planned FSTP and may therefore deviate from reality. Hence, cost differences may not be due to the chosen treatment option, but rather due to different local conditions and specific plant features. Therefore, Chapter 4 will provide more directly comparable results, depending on treatment options.

This report provides approximate results or orders of magnitude of the corresponding treatment schemes. Although the results are given in absolute values, they should be regarded as indicator values accompanied by an uncertainty interval where the real value is situated. An example of such an uncertainty interval is given in Paragraph 0.

- Annual capital and O+M costs per t TS content of incoming faecal sludge are likely to be an appropriate unit. Cost per capita is, however, difficult to estimate due to the important variations in sludge loads depending on the sanitation systems used. Nevertheless, TS content also varies, but more empirical values are available and sludge loads (m^3 FS/day/month/year) usually known for a particular plant.
- Nevertheless, analysis reveals that the specific capital costs per t TS of a pilot plant are, without exception, significantly higher than those of a full-size plant. Chapter 3 provides a brief introduction into the principles of economy of scale. All the options for Nam Dinh (average plant size) are somewhere in between.

In general, concrete and reinforced steel constitutes the most important expenditure. Therefore, other construction options, such as a geo-membrane or adobe bricks, could offer an interesting alternative to concrete.

Table 25: Summary of annualised capital and annual O+M costs of all the treatment plants examined. Costs are calculated without land acquisition or revenue from biosolids sale.

	FSTP	Capital cost [US$/t TS]	O+M cost [US$/t TS]	Remarks
Pilot plants	Constructed wetlands, Bangkok	108	79	Complete treatment, including WSP
	Drying beds, Accra	58	38*	Percolate treatment not included; drying beds only
Full-scale plants	Settling/thickening tank, Accra (Teshie)	10	10*	Complete treatment, including WSP
	Settling ponds, Kumasi (Buobai)	27	21	Complete treatment; land cost estimated of US$ 2 per t TS; biosolids post treatment included; plant constructed, but not operational yet,
	Settling pond and co-treatment with sewage, Alcorta	21	38	All included, but sewage treatment fraction is deducted
	Settling/thickening tank, Cotonou	35	14*	Complete treatment, including WSP; planned scheme, not constructed yet

	Settling/thickening tank, Bamako	17	29	Complete treatment, including WSP; planned scheme, not constructed yet
Between pilot and full-scale	Nam Dinh CW DB Settling/ thickening tank	 45 47 46	 28 40 124	 Without effluent polishing; projected schemes

* Estimated by the author on the basis of local information (details in Appendix 1.6)

No cost position for plant monitoring is included in O+M cost (except Buobai settling pond plant). However, it is very important to analyse at least a minimal number of parameters of some samples to survey treatment process. Refer to Klingel et al. (2002) for type and frequency of analyses.

According to cost estimates, the annual capital and O+M cost fraction is normally of the same order of magnitude. The specific O+M costs per t TS are likely to reduce, the larger the plant capacity. The Nam Dinh settling/thickening tank option is an exception, as it requires extremely high O+M costs per t TS for sludge removal and handling (in addition to rice husk).

The treatment of the liquid fraction after solids-liquid separation by waste stabilisation ponds constitutes an important cost factor. Cost saving is likely to be achieved by co-treating the FS liquid in an existing ponds system, e.g. co-treating with wastewater (Alcorta, Argentina) or with the leachate from a landfill (Nam Dinh, Vietnam). However, capacity and suitability of an existing pond system have to be recalculated on the basis of the estimated new load.

The co-composting costs should not be compared with those of other treatment plants, as the services provided are too different. A significant fraction of the co-composting costs is attributed to the solid waste treatment process used (composting area, waste sorting, etc.). Cost comparisons can be made if a separate solid waste composting scheme is added to an ordinary FS treatment plant. Paragraph 0 therefore illustrates solid waste composting costs.

The sale of biosolids could reduce the FS treatment costs. However, in the examined FS treatment locations, biosolids commercialisation has only recently been planned. The co-composting scheme in Kumasi will hopefully provide technical, institutional and economical progress. Hygienically safe biosolids should be guaranteed through storage or composting.

From an economic viewpoint, land cost can become an important factor when land is expensive (e.g. more than US$ 5-10 per m^2, cf. Paragraph 0). The most favourable condition is probably the availability of already enough land if the municipality is planning a FSTP. For private entrepreneurs, land acquisition can constitute a main FSTP investment obstacle. However, land requirement is not a decisive factor when selecting a solids-liquid separation option, as effluent (issued from solids-liquid separation) post-treatment by WSP is anyhow land intensive. Only settling/thickening tanks are very land efficient and, thus, far less land intensive than drying beds, constructed wetlands or settling ponds. However, land requirement for supernatant treatment is probably superior due to its higher pollutant load compared to the percolate issued from drying beds or constructed wetlands.

3 ECONOMY OF SCALE

Principles of the economy of scale

The cost data in Chapter 2 reveals that small pilot scale plants are more cost intensive per capita or per t TS delivered than full-scale plants. This is mainly attributed to the fact that treatment plant capacity and price do not follow a linear increase. In a settling/thickening tank, the most important cost factor is the concrete required for wall and floor construction. The volume of a tank determines its capacity, but the costs will rise with increasing surface area lined by concrete.
In practice, the concept of a larger treatment plant does not consist in enhancing the three dimensions in equal proportion, such as in the aforementioned example, where capacity does not follow a linear increase to the surface. Therefore, the two parameters should be determined as follows:

$S = a \cdot V^{\alpha}$ **Equation 2**

surface = S, volume = V and a coefficient of proportionality = a, parameter of economy of scale = α

If price P and capacity C of the plant substitute S and V respectively, we obtain the following equation:

$P = a \cdot C^{\alpha}$ **Equation 3**

The parameters a and α can be determined on the basis of statistics or theoretical construction considerations. The theoretical value of α in the surface-volume example is 2/3 (see Maystre 1985, p. 143). More important, the parameter α is less than 1. Thus, plant cost rises less than proportionally when capacity is increased. Therefore, the average specific ASC costs of a treatment plant, in US$ per capita or per t TS decrease, is expressed as:

$ASC = P / C = a \cdot C^{\alpha - 1} \quad with\, \alpha < 1$ **Equation 4**

This relation is called *principles of the economy of scale*. It can even be used for an entire installation such as a FSTP, including screen, solids-liquid separation, sludge and effluent post-treatment. An economy of scale can be applied not only for each unit (tank or pond, etc.), but also for other items such as discharge area or screen. If capacity is doubled for example, it is not absolutely necessary to double the number of discharge areas or screens. Figure 9 illustrates application of the economy of scale to entire installations originating from statistics of Swiss wastewater treatment plants. Specific costs of each plant are illustrated as a function of their respective capacity. To obtain a simplified generalisation, all deviations were neglected. The only differentiation made were plants with or without chemical phosphate removal (with and black marks, respectively).

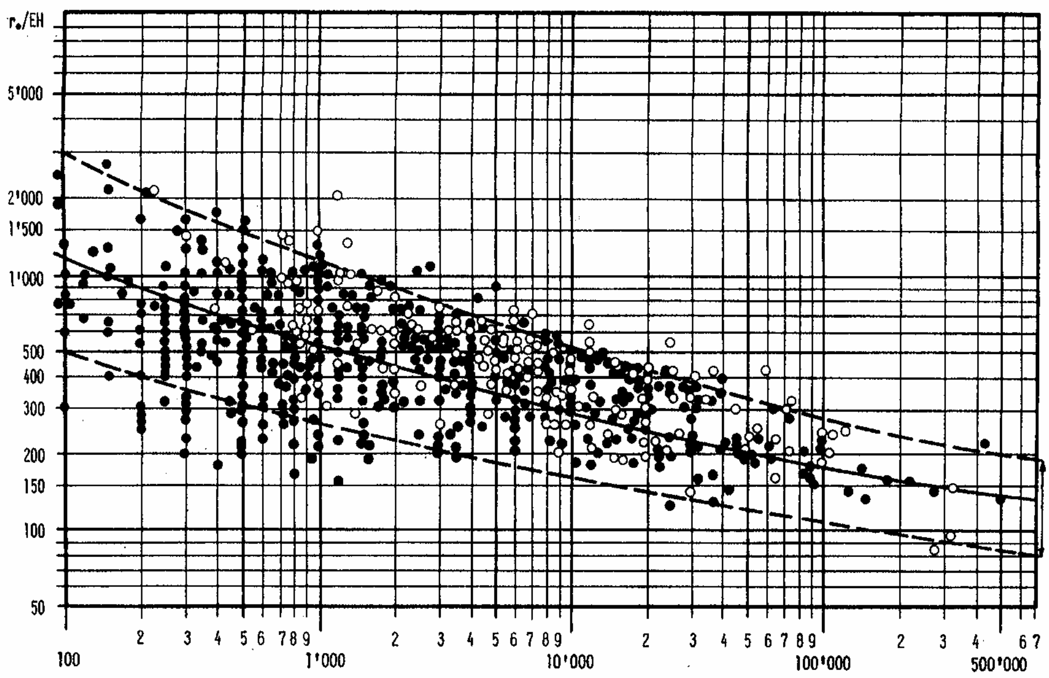


Figure 9: Illustration of the economy of scale of WWTP in Switzerland. X-coordinate represents the plant capacity in PE and the y-coordinate the average specific cost in Swiss Fr./PE.(after Maystre 1985).

Figure 9 clearly shows an economy of scale for this type of installation. However, special mention should be made that the parameters in Figure X are only valid for the Swiss wastewater treatment plants constructed in the examined period. It would be unwise to apply them to other time periods or countries, and inadmissible to apply them directly to other types of installation (Maystre 1985).

However, the economy of scale is no longer implicitly valid beyond a certain plant size. It is indeed likely that a large plant is more cost intensive because of a change in adopted construction technique (for instances if high resistance materials, special reinforcement or security installations are necessary). In this case, the curve of the ASC as a function of plant size comprises a so-called *zone of diseconomy*. However, as regards the low cost and very simple treatment options of FS management, we will probably not be confronted with such a *zone of diseconomy* of scale.

When dealing with a multiple chain installation with parallel treatment lines, the entire installation is regarded as the sum of several identical lines. The following reasons justify a multiple chain installation: to avoid falling into the *zone of diseconomy*, to obtain a high operational security, to allow a step-by-step construction, and to guarantee operation during maintenance. However, there are no economies of scale if plant capacity is doubled by a second identical treatment line (or chain). In this case, ASC would just remain about the same as for one treatment line. Or to avoid *diseconomy* of scale; it is possible to choose the number of identical treatment lines so that the ASC of the multiple installation amounts to about the minimal attainable value of the average specific cost of one treatment line.

Centralisation or decentralisation?

According to the principles of the economy of scale, centralisation would be the solution for FS management; i.e., construction of large FS treatment plants. However, this would be an error, as the system of haulage, which does not follow the economy of scale, has to be included. Haulage costs increase as a function of distance from collection point to plant site. Thus, the larger the plant size, the higher the haulage cost. An additional side effect of long haulage distances is the illegal and uncontrolled disposal of FS to save fuel, treatment or dumping fees and time. If these two relations (treatment plant and haulage costs) are added, they amount to the global annualised costs (Figure 10). More information on collection and haulage costs is given in Paragraph 0.

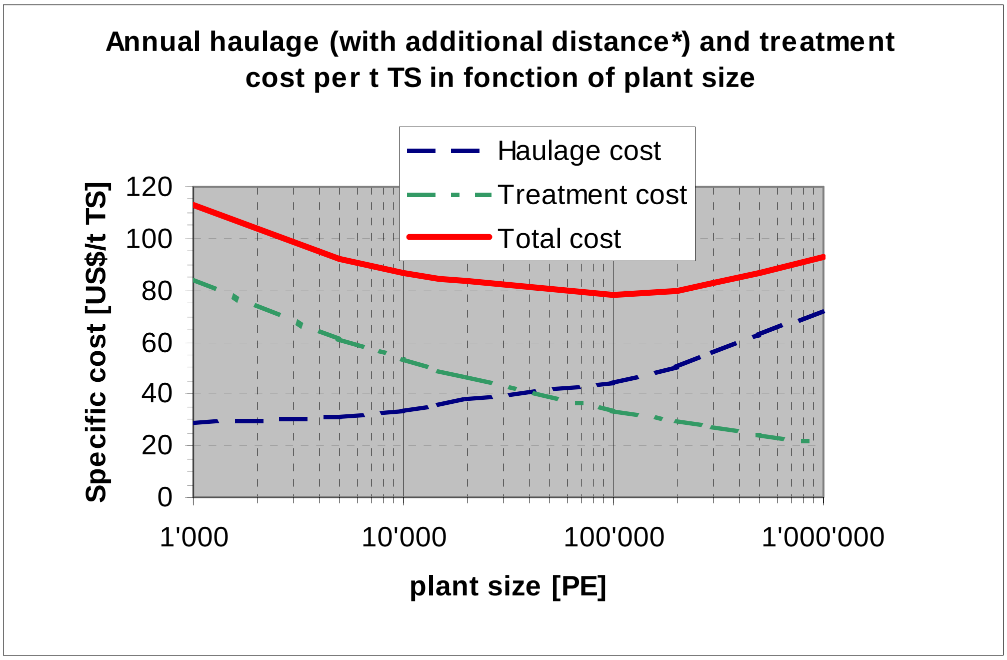


Figure 10: Optimal plant size with regard to annualised haulage and capital costs of the treatment plant. (*Details of the calculation base are given in Paragraph 5.1.3)

Figure 10 above permits to draw following conclusion:

An optimal plant size exists where the sum of specific annual capital and haulage costs is minimal. The curve in this minimal area runs flat. For instance, if total annual costs per t TS range from US$ 80 to US$ 85, the corresponding plant capacity amounts from approx. 20,000 to 200,000 PE.

However, even if a plant capacity of 1,000,000 PE has an acceptable haulage cost (depending mostly on assumed distance to FS collection), there is a trend towards decentralisation options. There are two main reasons for this trend: on the one hand, it is difficult to find large areas for plant construction within the city and, on the other, the danger of uncontrolled dumping increases with haulage distance. However, it is also difficult to build small treatment plants within the city due to opposition from nearby residents.

Case study: Up scaling of the co-composting pilot plant

3.1.1 Calculation of the parameter α from the principle of the economy of scale

The co-composting plant in Kumasi is a typical small-scale pilot plant. Its capital costs per t TS are assumed to be high compared to a full-scale plant of the same type. As mentioned in the previous paragraph, a larger treatment plant is generally more economical due to several cost saving factors (material and labour). A simple way to achieve a financial upscale of a pilot plant to a full-size plant is to apply the principles of the economy of scale based on the pilot plant cost, and assuming an appropriate value for the parameter α. A more time-intensive, but also more credible alternative is to increase the size of the same plant and then calculate its new costs. This also allows estimating the parameter α with a system of equations such as:

$$P_0 = a \cdot C_0^{\alpha}$$
$$P_1 = a \cdot C_1^{\alpha}$$

Equation 5

P_0, P_1 and C_0, C_1 for the pilot and full-scale plant costs and corresponding pilot and full-scale plant capacity respectively.

Therefore, we chose to increase (upscale) 10 times and again 5 times the initial size of the Buobai co-composting capacity. This corresponds to a plant size of 25,000 and 125,000 PE respectively, with a pilot scale plant size amounting to 2,500 PE.

3.1.2 Design features and costs of up scaled plant (25,000 PE)

The initial capacity of the Buobai co-composting pilot plant amounted to about 2,500 PE (cf. Paragraph 2.1.2). This plant is upscaled about ten times to an approximate capacity of 25,000 PE. The raw calculation base and diagram of the new plant are given hereafter, and its design data in Appendix 2.1.

Calculation base:

Annual load: 5,000 m^3 FS ($\rightarrow$ 125 t TS per year).
Average TS content in FS mixture: 25 g/l.
FS mixture: 2:1 septage and public toilet sludge.
Loading cycle: after loading, 10-15 days drying period.
FS loading rate: 200 kg $TS/m^2 \cdot y$.
5 drying beds, every bed is loaded for 2 to 3 days (corresponding to about 40 m^3 FS per bed and load); the volume is reduced about 10 times during drying.
Composting method: with the organic fraction of sorted solid waste at a 3:1 ratio (waste:dewatered sludge), 1 month composting (about 50% volume reduction), maturation for 1 to 2 months.
Upscaling without percolate post-treatment in ponds.

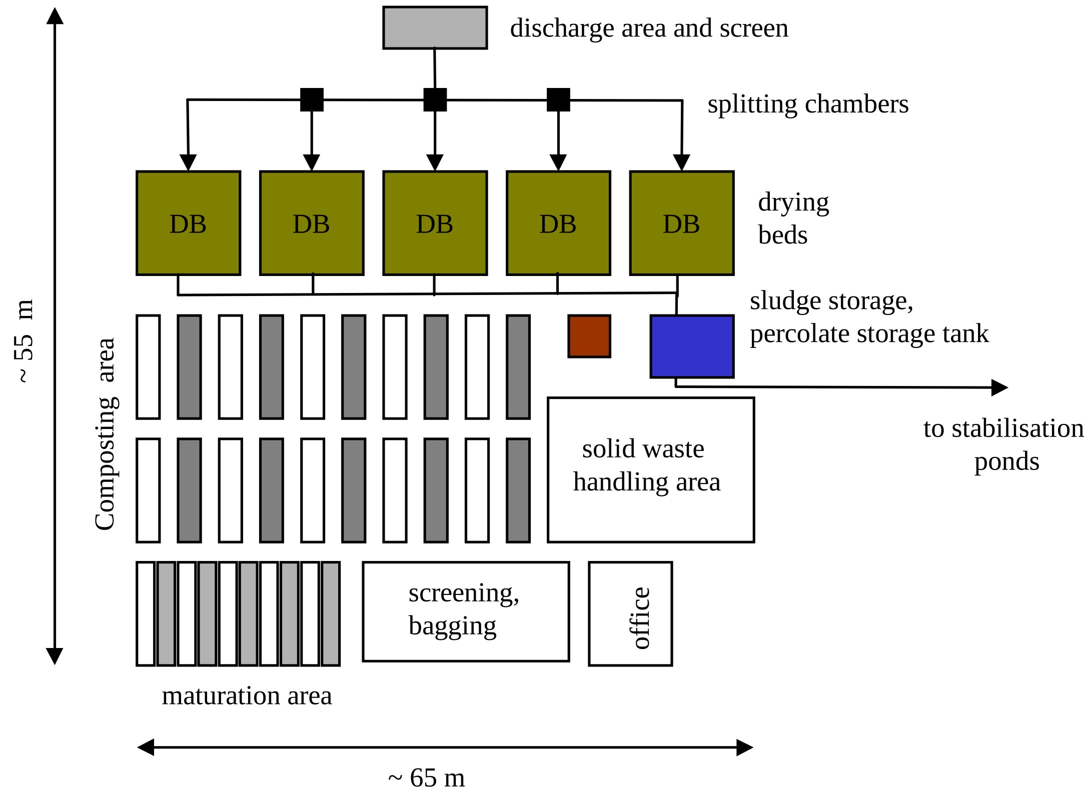


Figure 11: Diagram of upscaled co-composting plant (25,000 PE), not to scale.

Based on the raw design criteria and on the pilot plant estimate, the costs were estimated for the aforementioned full-scale plant. With the help of both cost estimates (pilot and full-scale plant), the parameters a and α of Equation 5 can be calculated for each treatment unit and for the overall system. The results obtained are given in the following Table 26, while the details of the estimate are contained in Appendix 2.3.

Table 26 reveals that the construction costs of drying bed and composting area rise almost proportionally with the capacity (therefore α is close to 1), as a double capacity is needed for a double net surface. Cost economies of upscaled drying beds are thus not so important as for instance for a percolate storage tank. They are even less important if plant capacity is further increased, as cost economies (due to reduced wall requirement) are no longer applicable if ideal bed size is reached (e.g. maximum 20x20m). Several small beds instead of large beds should be constructed to simplify homogenous sludge distribution. Nevertheless, the global parameter α for total construction cost is much lower than α of the most cost intensive items (drying beds, composting area and roofing). It is of the same order of magnitude as α in the surface-volume example (Paragraph 0). However, as aforementioned, this is not due to a surface-volume (cost-capacity) relation, but to the fact that the associated items of the treatment plant do not have to be upscaled. For instance, site office remains the same, no further sludge discharge area has to be constructed (therefore very low α values) and the sludge storage tank could even be omitted.

Table 26: Size and price comparison of pilot (2,500 PE) and full-scale plant (25,000 PE) (without percolate post-treatment).

Item	Size pilot scale	Size full scale	Price pilot scale [US$]	Price full scale [US$]	Parameter α
General (site office, insurance, etc.)	-	-	5,500	8,700	0.20
Site clearance	900 m^2	3,500 m^2	50	200	0.59
Sludge discharge area	one ramp	one ramp	750	750	0
Sludge storage tank	15 m^3	-	1,250	-	-
Splitting chamber and pipework	1 8.5 m	3 200 m	280	2,100	0.87
Sludge drying beds	60,5 m^2	605 m^2	2,250[1)]	19,000	0.90
Solid waste handling area	~75 m^2	~300 m^2	1,300	5,600	0.65
Composting area	~200 m^2	~1,500 m^2	4,200	28,300	0.83
Dried sludge storage area	2 m^2	16 m^2	70	350	0.69
Roofing materials	235 m^2	1,500	2,550	16,800	0.82
Percolate storage tank	~15 m^3	~80 m^3	1,300	3,900	0.47
Daywork			1,300	6,000	0.67
Contingencies			1,900	8,500	0.66
TOTAL			22,700	100,000	0.64

[1)] Corrected by the author from initial quotation of 1,100 to 2,250 US$

Annual construction costs per t TS (without percolate post-treatment) as calculated in Chapter 2 **dropped from US$ 175 to US$ 77** if upscaling plant size by a factor ten. This remarkable specific capital cost reduction corroborates with the example according to Maystre (1985) illustrated in Figure 9 and renders a larger treatment plant really interesting in comparison to small plants.

3.1.3 Design features and costs of up scaled plant (125,000 PE)

The main question now is whether further upscaling to a larger plant size is possible by using the principles of the economy of scale and the parameter α estimated above. Would plant specific construction costs per t TS further decrease in this way?

Diseconomy of scale is theoretically possible if the technology adopted is changed, for instance if expensive machines for compost turning or a complicated sludge distribution device are used.
To obtain a partial answer to these questions, we proceeded to apply the exact same upscaling process, but this time the pilot plant capacity was increased 50 times (→ 125,000 PE). Calculation bases and diagram are given bellow and in Figure 12.

Calculation base:

Annual load: 25,000 m^3 FS (→ 625 t TS FS per year).
Average TS content in FS mixture: 25 g/l.
FS mixture: 2:1 septage and public toilet sludge.
Loading cycle: after loading, 10 days of drying period.
FS loading rate: 200 kg $TS/m^2 \cdot y$.
Loading cycle: after loading 10 days of drying period.
9 drying beds, every bed is loaded with about 80 m^3 at an interval of 10 days; every day, one bed is thus loaded with all incoming sludge (no loading on Sunday), no sludge storage tank is needed; the volume is reduced about 10 times during drying.

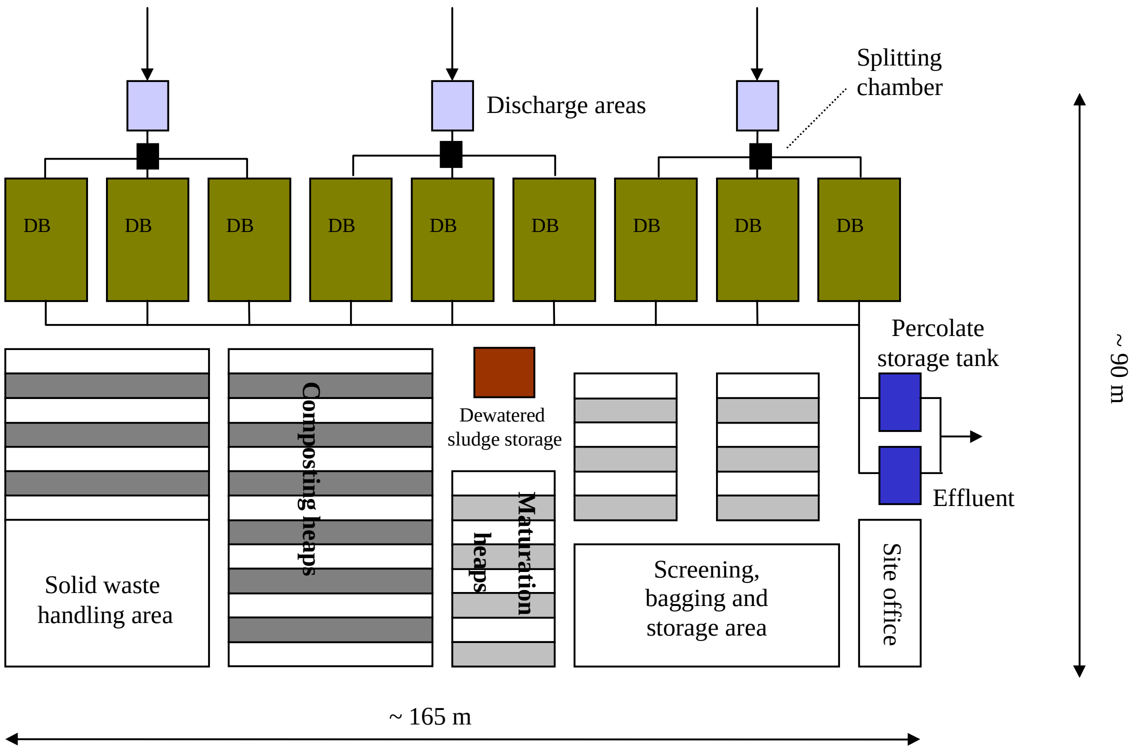


Figure 12: Diagram of upscaled plant (125,000 PE), not to scale.
3 drying beds are connected to one discharge area with enough space for two trucks.
Composting method: with the organic fraction of sorted solid waste at a 3:1 ratio (waste:dewatered sludge), 1 month composting (about 50% volume reduction), maturation during 1 to 2 months.
Upscaling without percolate post-treatment in ponds.

A detailed cost estimate for this full-size co-composting plant (50 times larger capacity than the pilot plant) is given in Appendix 2.3. The parameter α can be calculated based on this new cost information. It is possible to calculate α if the pilot plant or the already upscaled plant (10 times larger capacity than the pilot plant) is used as initial plant for the values C_0 and P_0 from Equation 5. Figure 13 illustrates the different upscaling parameter α. The results are listed in the following Table 27.

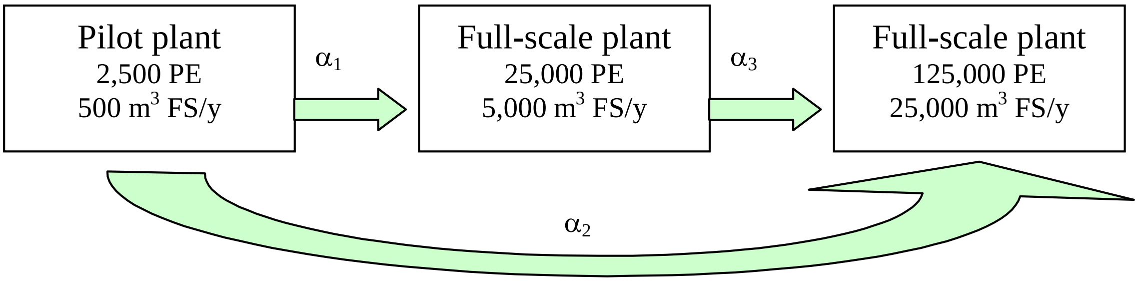


Figure 13: Two different ways of upscaling, hence two different parameters α. Parameter α_2 is a kind of average value of α_1 and α_3.

Parameter α_1 is lower than α_2 and reveals a decrease in the economy of scale regarding further upscaling (50 times the pilot plant) compared with the first pilot plant upscaling (10 times the pilot plant). The per capita or per t TS economy of scale decreases for every item (parameter α increase) if plant capacity is enlarged, except for the pipework and treated FS storage area. The size of the latter two items does not rise much if the capacity is increased. The upscaling parameter α does not appear to be constant, however, it will tend to range between 0.8 and 1. If this value amounts to 1, then we will have reached the zone where no further economy of scale is possible, and where the potential zone of diseconomy of scale starts.

In other words, specific capital cost economies are highest when upscaling a pilot plant. Cost economies are less important if a full-scale plant is upscaled even further; the latter corresponds to the operation using parameter α_3.

Of course, this upscale example cannot be extrapolated nor can it be applied to every FSTP. We rather intended to show the problem areas and to reveal the order of magnitude of the economy of scale. However, when using a parameter α of about 0.8 (or slightly higher for a conservative estimate), it is possible to obtain a raw, but extremely rapid, capital cost estimate (total plant cost or cost per t TS of incoming FS) of any plant capacity.

Table 27: Upscaling parameter α and construction cost comparison.

Item	Prize pilot scale (2,500 PE) [US$]	Prize full scale (25,000 PE) [US$]	α_1	Prize full-scale (125,000 PE) [US$]	α_2	α_3
General (site office, insurance, etc.)	5,500	8,700	0.20	24,100	0.38	0.64
Site clearance	50	200	0.59	900	0.72	0.90
Sludge discharge area and screen	750	750	0.00	4,500	0.46	1.11
Sludge storage tank	1,250	0	0.59	0	-	-
Splitting chamber and pipework	280	2,100	0.87	5,400	0.75	0.58
Sludge drying beds	2,250[1)]	19,000	0.90	86,000	0.93	0.94
Solid waste handling area	1,300	5,600	0.65	19,000	0.70	0.76
Composting area	4,200	28,300	0.83	112,600	0.84	0.86
Dried sludge storage area	70	350	0.69	700	0.58	0.42
Roofing materials	2,550	17,000	0.82	66,000	0.83	0.85
Percolate storage tank	1,300	3,900	0.47	9,800	0.51	0.57
Daywork	1,300	6,000	0.67	17,500	0.67	0.67
Contingencies	1,900	9,000	0.64	33,500	0.72	0.84
TOTAL	22,700	100,000	0.67	380,000	0.72	0.83

[1)] Corrected by the author from initial estimate of US$ 1,100 to 2,250

3.1.4 Summary of annual capital and O+M costs of upscaled schemes

Operation and maintenance costs of the co-composting pilot plant were already estimated in Paragraph 2.1.2. To evaluate these costs for the upscaled treatment plants, the following factors were taken into consideration:

Waste sorting and compost turning are the most labour intensive and thus costly items. These costs are assumed to increase proportionally with treated FS, as manual handling remains (no machines are used for the full-scale plant). However, the sludge and compost quantities to be handled call for mechanical equipment like tipper and loader trucks or heap turning machines. The O+M cost summary of the constructed Buobai full-scale settling pond plant (Table 13 page 15), reveals that the hiring costs for such vehicles seem to be higher than manual work, thus the O+M costs increase at the expense of employment.
The composting cost per m^3 is likely to increase with plant size due to longer transport distances from composting area to maturation and bagging area and, thus, more time intensive. However, this factor is neglected to simplify the task.
Contingencies (cleaning, repairs, etc.) are likely to increase also proportionally to plant size.
Particular efforts (e.g. marketing or transport) to sell the compost are not considered.
The salary for the plant manager does not rise proportionally. It is assumed that one manager is employed for both the upscaled plants, while a part-time manager (50%) is likely to be sufficient for the pilot plant.

Based on these considerations, annual O+M costs amount to about US$ 105 per t TS (details are given in Appendix 2.4 and 2.5) for the largest plant capacity. Table 28 summarises rounded off results of the upscaling procedure with respect to capital and O+M costs.

Table 28: Annual capital and O+M cost results of the co-composting up scaling procedure.

	Pilot plant 500 m^3 FS per year (12.5 t TS/y)		Full-scale 5,000 m^3 FS per year (125 t TS/y)		Full-scale 25,000 m^3 FS per year (625 t TS/y)	
	[US$/y]	[US$/t TS]	[US$/y]	[US$/t TS]	[US$/y]	[US$/t TS]
Capital cost	2,200	175	10,000	80	37,000	60
O+M cost	1,800	145	14,000	110	66,000	105
Total	4,000	320	24,000	190	103,000	165

As regards this important economy of scale, a logical consequence would be to adopt large treatment plants. However, in addition to the haulage cost aspect (Paragraph 0 and 0) further considerations favour smaller co-composting plants:

The upscaled plant, treating 25,000 m^3 FS per year, would produce 5,000 m^3 of compost. It will be very difficult to sell this quantity within a reasonably perimeter. Transport costs are likely to be high probably due to long distances to buyers.
Trucks are required if large quantities of solid waste have to be delivered, and transport expensive, while e.g. small entrepreneur (carts with animal or human traction) can supply also decentralised plants.

Construction costs of a large-scale plant are high and could be out of reach for disadvantaged countries. It is often easier to invest several small amounts than one a large sum.
In developing countries, planning of a FSTP is usually based on a short to middle term perspective (e.g. 5-15 years), as local conditions vary rapidly and capital is scarce. Smaller capacity expansion steps are thus preferable.

The specific cost per t TS of the co-composting plant comprises FS and solid waste treatment. The cost structure of the composting area, comprising roof and waste sorting area, amounts to about 35% (pilot plant) and up to 50% (full-size plant) of the total investment costs. Hence, if the costs imputable to solid waste treatment are deducted from the total costs, the specific capital costs per t TS of the aforementioned upscaled FS treatment plant (solids-liquid separation with DB) are of the same order of magnitude as the ones of a comparable plant such as the one in Cotonou or the settling pond in Kumasi. A direct comparison is given in Paragraph 0, page 50.

As regards the integrated cost-benefit aspect, several environmental benefits of FS and solid waste management (landfill economy, recycling of organic matter), as well as public health and socio-economic issues (raising awareness through workers and compost sale, creation of employment) would significantly reduce the treatment costs. Steiner (2002) tried to approach briefly these challenging issues.

4 DIRECT COMPARISON OF SELECTED TREATMENT OPTIONS

Comparison of three different standard size treatment options

4.1.1 Introduction

This section aims at comparing selected FS treatment options to illustrate possible cost differences between the solids-liquid separation technologies used. Therefore, three different treatment options of the same standard size and similar effluent and biosolids quality were designed. A detailed cost estimate was then conducted in the same context and under the same conditions for each option. Since detailed cost information on the co-composting treatment plant in Kumasi (Paragraph 2.1.2, page 8) is available, raw estimates were made for Kumasi or Accra in Ghana. The following three alternative treatment options were selected:

"Tank" Option: Settling/thickening tank followed by waste stabilisation ponds
"Pond" Option: Settling pond followed by waste stabilisation ponds
"CW" Option: Constructed wetlands followed by waste stabilisation ponds

As aforementioned, the supernatant and percolate of the alternative options are to be treated in WSP (its configuration is dependent on primary treatment). In addition to appropriate treatment, the dewatered sludge from the settling/thickening tank and settling pond is mixed with sawdust and stored further to attain a hygienic level for reuse. Biosolids from constructed wetlands are to reveal the same hygienic level as the biosolids from the other two options after storage.

The three selected treatment options are expressed as a function of their solids-liquid separation, e.g. "Tank" option comprises the entire FSTP, including primary and liquid treatment and all the associated items like screens, pipes, site office, and dehydrated sludge storage.

Furthermore, capital and O+M costs of these three treatment options are compared with the Buobai full-scale settling pond plant (Paragraph 2.1.5, page 14) and the upscaled drying beds issued from the co-composting plant (Paragraph 0, page 34) in Kumasi. This serves to examine the order of magnitude of the results and to install a fourth treatment option (drying beds) in the Ghanaian context. The results are given in Paragraph 0, page 50.

To compare the co-composting treatment plant of FS and organic waste with other treatment options, we designed a separate solid waste composting plant and added it to the FSTP. This may also serve to compare the co-composting option with independent FS treatment and separate solid waste composting. The results are given in Paragraph 0, page 54.

Since this section does not aim at providing a design manual, kindly consult specialised literature on FS treatment design (Heinss et al. 1998 and Koottatep et al. 1999).

4.1.2 Design of standard-size settling/thickening tank, constructed wetland, settling ponds and associated waste stabilisation ponds

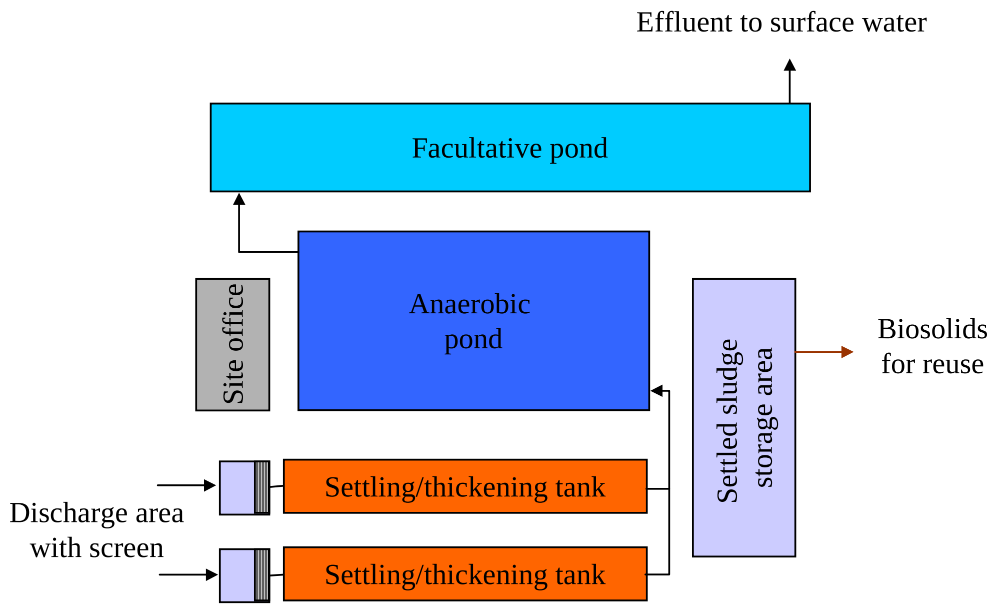
For detailed comparison, the following parameters were assumed to design the three alternative options:

20,000 m^3 FS load per year
25 g/l TS content (public toilet sludge: septage = 1 : 4)
500 t TS load in incoming FS $\rightarrow$ 100,000 PE (with 1 PE = 14 g TS/day per capita)
4,000 mg BOD/l in incoming FS
BOD removal efficiency of primary treatment:
 – 50% for settling/thickening tank
 – 70% for settling pond
 – 85% for constructed wetland
Waste stabilisation pond design criteria for solids- liquid treatment effluent:
– Anaerobic pond: 0.25 kg BOD/m^3·day, 70% BOD removal efficiency
– Facultative pond: 0.035 kg BOD/m^3·day, 80% BOD removal efficiency
– No maturation ponds needed, as effluent is not used in agriculture
No pumping required, topography allows gravity flow
No rocky soil, easy to excavate
Concrete is used for settling/thickening tank and CW construction (0.2 m thickness, 40 kg steel per m^3). The embankment of all settling and waste stabilisation ponds are lined with a 0.2-m thick concrete layer and a width of 1-1.5 m, the rest is covered with an 0.2-m thick clay layer
The slope of settling, anaerobic and facultative pond embankments is 1:3
The sludge storage area comprises a concrete layer and an aluminium roof

An estimated final BOD load of 50-120 mg/l for the liquid effluent after polishing treatment (theoretical values, rather optimistic) and hygienically safe biosolids should be obtained from FS treatment. Diagram and raw design of the selected treatment options are given below, while design details are illustrated in Appendix 3.1.

<u>Design of settling/thickening tank and supernatant treatment (“Tank” option)</u>

Figure 14 contains a diagram of a potential FS treatment plant comprising two parallel settling/thickening tanks for solids-liquid separation, an anaerobic and two facultative ponds in series for supernatant polishing. The loading period of a tank is about one month, the second tank is then loaded, while the first rests for FS settling and thickening. Prior to new loading, thickened sludge is removed and mixed with sawdust. This spadable dewatered sludge is stored in heaps or windrows for at least one month on a roofed area for further safe reuse.



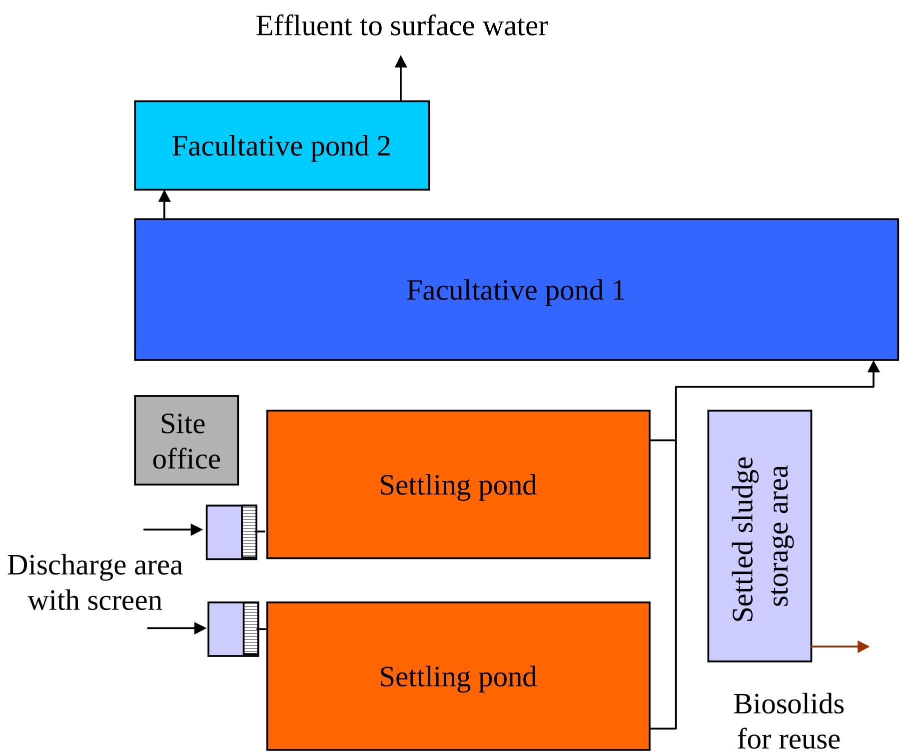
	Number of units	Dimensions	[m]
Settling/thickening tank	2	Length (bottom/top)	32/42
		Width	5
		Depth (incl. 0.2 m freeboard)	3
Anaerobic pond	1	Length (bottom/top)	24/44
		Width (bottom/top)	5/25
		Depth (incl. 0.5 m freeboard)	2.5
Facultative ponds	1	Length (bottom/top)	65/75
		Width (bottom/top)	10/20
		Depth (incl. 0.2 m freeboard)	1.5

Figure 14: Diagram and main dimensions of the “Tank” option (not to scale).

<u>Design of settling ponds and associated supernatant treatment (“Pond” option)</u>

This second treatment option is similar to the settling/thickening tank option, as the same principle is used for solids-liquid separation; i.e., sedimentation of solids. Compared to the tank, the settling pond has a higher hydraulic retention time (a few days) and a greater volume for settled sludge storage. Therefore, settled sludge removal frequency is lower (we choose one year). Incoming vacuum trucks load both settling ponds, however, during emptying procedure, the other pond is able to receive all incoming FS. Regarding construction, the settling pond follows the same structure as an ordinary WSP (clay lining with a concrete edge) in contrast to fully concrete-lined settling/thickening tanks.
The supernatant from the settling ponds is treated in two facultative ponds in series, while the settled sludge is mixed with sawdust and stored on a roofed area for further hygienic reuse. Instead of two facultative ponds, it is possible to install an anaerobic pond followed by a facultative pond. The design of the latter option would be slightly smaller and, hence, probably slightly cheaper. Although, the chosen design comprises

two facultative ponds, Figure 15 contains a diagram with the main dimensions of the FS treatment plant.



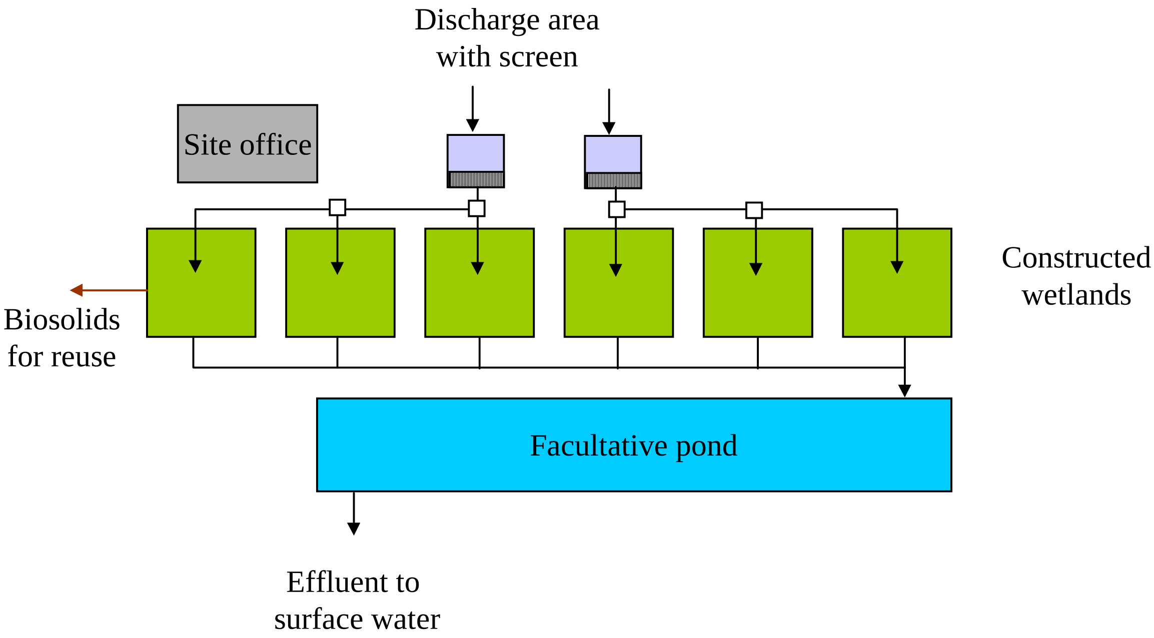
	Number of units	Dimensions	[m]
Settling ponds	2	Length (bottom/top) Width (bottom/top) Depth (incl. 0.2 m freeboard)	40/60 10/30 2.5
Facultative pond 1	1	Length (bottom/top) Width (bottom/top) Depth (incl. 0.2 m freeboard)	95/105 15/25 1.5
Facultative pond 2	1	Length (bottom/top) Width (bottom/top) Depth (incl. 0.2 m freeboard)	35/45 5/15 1.5

Figure 15: Diagram with the main dimensions of the “Pond” option (not to scale).

Design of constructed wetlands and percolate treatment (“CW” option)

The structure of constructed wetlands is similar to the one of the drying beds except that the bed is planted with wetland plants, e.g. cattails or reeds. The main advantage of CW is the very low frequency of sludge removal (about every 4 to 5 years at the AIT plant with 1.0 m freeboard). An important consequence is that the removed and dehydrated sludge does not require further treatment or addition of sawdust as binding material. However, the designed treatment option comprises six beds of constructed wetlands, are loaded once a week with an entire daily sludge load (Kottatep 1999) (no loading on

Sundays). The percolate is treated in a facultative pond. The design base of the CW based on the AIT field research amount to an annual load of 250 kg TS/m^2. Since incoming faecal sludge does not have to be stored, but can be spread onto one bed, a sludge storage tank is not planned. A device to distribute FS evenly to protect plants and filter bed may be necessary.



	Number of units	Dimensions	[m]
Constructed wetlands	6	Length	19
		Width	18
		Depth (incl. 1.0 m freeboard)	1.6
Facultative ponds	1	Length (bottom/top)	65/75
		Width (bottom/top)	10/20
		Depth (incl. 0.2 m freeboard)	1.5

Figure 16: Diagram and main dimensions of the “CW” option (not to scale).

4.1.3 Estimate and comparison of capital and O+M costs

Investment cost estimate

On the basis of preliminary design and cost information from the Buobai co-composting plant in Kumasi, estimates of all three options were made (Appendix 3.2-3.4). These costs can be compared directly, as all the plants have the same capacity, and effluent and biosolids quality are basically the same for all options. The results are given in Table 29; land costs were not taken into consideration.

Table 29: Comparison of estimated investment cost of three treatment options in US$.

Item	"Tank" Option	"Pond" Option	"CW" Option
General items	12,000	12,000	12,000
Site clearance	400	800	400
Discharge area	2,000	2,000	2,000
Pipework and splitting chamber (only for CW)	1,800	1,800	6,500
Tank/settling pond/CW	21,900	21,800	82,000
Anaerobic pond	10,200	-	-
Facultative pond 1	14,800	20,700	14,800
Facultative pond 2	-	7,100	-
Sludge storage area	8,600	7,200	-
Roofing material	8,600	7,100	-
Road work	10,000	10,000	10,000
Daywork[1)]	4,200	4,200	5,600
Contingencies (10%)	9,000	9,000	12,800
TOTAL [US$]	103,500	103,500	146,000

[1)] Contingencies for materials and contractor's equipment, overhead and profit.

The capital costs of both settling options (tanks and ponds) happened to be the same, whereas the capital costs of constructed wetlands are higher. The high construction costs of CW are attributed to the important concrete lining requirement of each bed and to the gravel/sand layer.
If the land price were added to the capital costs, the settling tank would be the cheapest technology, as it is the most land efficient. Constructed wetlands are also land efficient, as the percolate's better quality requires smaller ponds for effluent treatment and the sludge does not have to be stored. The overall costs of the three treatment options as a function of land price are graphically illustrated in Paragraph 4.1.4.

O+M cost estimation

The main advantage of constructed wetlands is their low operation and maintenance costs. The CW technology is indeed the cheapest option to operate, while the settling technologies are both of the same order of magnitude regarding O+M costs. High costs for settled sludge removal, addition of sawdust and handling of biosolids make these two options considerably more expensive to operate than CW.

Table 30: Estimate of operation and maintenance costs of selected treatment options in US$ per year.

Item	"Tank" option	"Pond" option	"CW" option
Sludge loading control, screen and chute cleaning	500	500	1,000
Sludge removal from solids-liquid separation and from anaerobic pond for the "Tank" option	5,250	4,200	1,200
Bed refilling after sludge removal	-	-	1,000
Facultative pond sludge removal (approx. every 5 years)	300	700	300
Procurement of sawdust	1,000	800	-
Dewatered sludge handling	3,500	2,800	-
Plant harvest (annually to biannually)	-	-	200
General repairs and equipment	750	750	1,500
Contingencies (10%)	1,000	1,000	500
TOTAL [US$/y]	12,250	10,750	5,700

Summary of total costs based on annualised capital and annual O+M costs

Annualised capital and annual O+M costs of each treatment plant can be expressed in US$ per t TS comprised in incoming faecal sludge as applied in Chapters 2 and 3. The depreciation period and interest rate assumed are 15 years and 5%, respectively. The results are contained in Table 31.

Table 31: Cost comparison of different treatment options including all cost (solids-liquid separation, liquid treatment and associated items), but excluding land cost.

		"Tank" option	"Pond" option	"CW" option
Capital cost	[US$/t TS]	20	20	28
O+M costs	[US$/t TS]	24	21	11
Total costs	[US$/t TS]	44	41	39

With the same estimate bases and identical plant capacity, these figures are assumed to be comparable. According to the results obtained, the constructed wetland treatment option is the cheapest, whereas the settling tank option is the most expensive. Given the numerous assumptions and restricted data information, the differences in total costs cannot be regarded as significant. However, there is at least one obvious variation in capital and O+M costs. The significant difference between CW and the two settling options is the more capital-intensive CW, but its much cheaper O+M costs. The settling options require fewer investments, but higher O+M costs, mainly attributed to its frequent dewatered sludge removal and post-treatment requirement.

4.1.4 Influence of land price in the comparison

The influence of land price on capital costs has already been discussed with regard to one treatment plant in Paragraphs 0 and 0. In addition, Figure 17 illustrates the total annualised cost trend of the three treatment options designed (in the Ghanaian context[6]) as a function of land price It is clear that the land price alters the cheapest treatment option. For example, if the land price increases to about US$ 4 per m^2, then the settling/thickening tank technology becomes cheaper than the settling pond option. Land efficient options like the settling/thickening tank or the constructed wetland are the favoured options if the land price is high. While a settling pond technology is cheaper than the tank option if space is available and prices low.

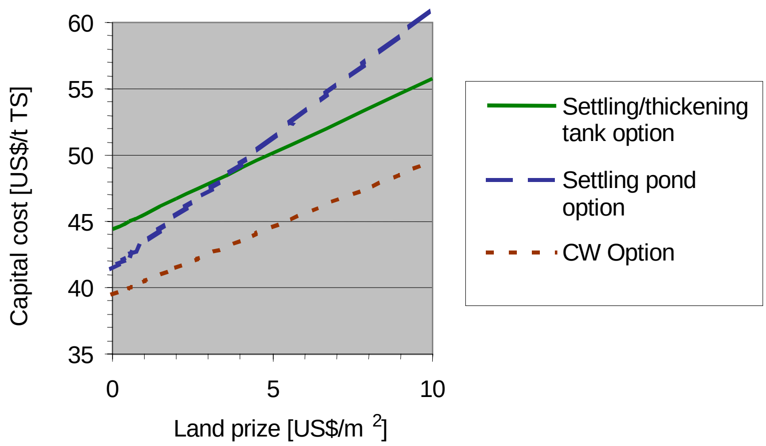


Figure 17: Capital costs of the three standard-size FSTP treating 20,000 m^3 FS per year as a function of land price.

Comparison with existing treatment options in Kumasi

4.1.5 Comparison with full-scale settling ponds

The purpose of this paragraph is to compare the order of magnitude of the cost estimates for the three selected treatment options with the costs of the existing Buobai full-scale FS treatment plant (Paragraph 2.1.2). This allows to estimate the accuracy of the rather theoretical results in the previous section. The Buobai full-scale plant is constructed, but not yet operational. It is designed to treat about 200 m^3 FS per day, corresponding to 1,500 t TS annually to be treated in settling ponds and associated WSP, including maturation ponds. However, this capacity is three times higher than our annual standard size capacity of 500 t TS FS. Therefore, we applied the upscaling formula (Equation 3) with a parameter α=0.8 to downscale plant capacity and prices to the standard plant size. Furthermore, the maturation ponds were deducted from the plant costs (Table 12, page 15), as the three selected treatment options were designed without them. Hence, the construction costs of Buobai full-scale plant are estimated at US$ 154,000 for an

[6] According to Annoh (2002), the land price of Buobai FSTP amounted to about US$ 0.4 per m^2.

annual capacity of 500 t TS, corresponding to an annualised **capital cost** of **US$ 30 per t TS**.

The specific **O+M costs** per t TS are likely to be the same as the ones described in Paragraph 2.1.5 (page 14), irrespective of plant size; i.e., **US$ 21 per t TS**. Thus, the sum of annualised capital and annual O+M costs amount to US$ 51 per t TS. This amount is higher (about 14-23%) than for the three selected treatment options. The difference seems to be attributed to higher construction costs. The available cost information on the Buobai plant only reveals that the road, site clearance and contingencies are more important than the estimate of the designed plant in the previous Paragraph 0. The comparison allows to assume a credible order of magnitude of the costs of the three designed treatment plants. However, as it is often the case, estimates may be slightly lower than the real costs.

4.1.6 Comparison with drying beds of the co-composting plant

A fourth treatment option (drying beds) was used in the co-composting plant in Kumasi and adapted to the three designed alternative treatment options. Even if the Buobai co-composting scheme is constructed in the same context, it is not possible to compare it directly with the results of this chapter, as it is not based on the same parameters. The solid waste composting process is not included in the normal FS treatment option but in the co-composting scheme. Therefore, the capital and O+M cost fraction, attributed to the solid waste treatment, was deducted from the co-composting plant, and the costs of a facultative pond for percolate treatment from the drying beds were added.

The upscaled co-composting plant with an annual capacity of 625 t TS FS (cf. 3.1.3) is used to adapt the plant to the same standard conditions as the three designed treatment plants. Estimates show that approximately 55% of the capital costs are attributed to the treatment of solid waste, while only 45% correspond to the actual FS treatment. Corresponding investment costs (US$ 170,000, 625 t TS per year) of the FS treatment only are downscaled to a capacity of 500 t TS FS per year using the Equation 3 and a parameter α of 0.8, resulting in investment costs of about US$ 143,000. The costs of a facultative pond are added to this amount (US$ 15,000, the same as designed for the “CW” option in Paragraph 4.1.2, page 42) in order to have a drying bed treatment plant with effluent polishing. Hence, the annualised **capital costs** of the co-composting plant, without composting of sludge and solid waste, amount to about **US$ 30 per t TS** (US$ 158,000 investment costs). This treatment scheme can no longer be called co-composting plant, but simply FS treatment plant with drying beds and associated liquid treatment in one facultative pond.

The O+M costs are assumed to be proportional to plant size. Thus, upscaling is not necessary and the O+M cost estimate of the Buobai co-composting plant can be used directly except for the costs incurred by the solid waste composting process. The specific annual **O+M costs** amount to **US$ 24 per t TS** (US$ 12,000 O+M costs annually, for details see Appendix 4.1).

Summary and discussion of treatment option comparison

Paragraphs 0 and 0 provide capital and O+M cost information on four different primary treatment technologies (settling tank, settling pond, DB, CW). All the costs are assumed to be directly comparable, as all the plants are of the same size (20,000 m^3 FS per year) and include liquid post-treatment in ponds and biosolids production of a hygienic quality. A summary of the specific costs per t TS is given in Table 32. Apart from the expenditure, one is tempted to include the revenue from the potential biosolids sale, thus resulting in a specific cost decrease per t TS. The same sales price and a 50% volume reduction during storage (no storage for CW) are assumed irrespective of the treatment option chosen.

Table 32: Comparison of capital and O+M costs of different FS treatment options in Ghana, expressed in **US$ per t TS FS**. All the costs were converted for a plant capacity of 500 t TS FS per year. Capital costs do not include land costs.

	"Tank" option [1)]	"Pond" option [1)]	"CW" option [1)]	Settling ponds, Buobai [2)]	Drying beds, Buobai [3)]
Annualised capital costs	20	20	28	30	30
O+M costs	24	21	11	21	24
Total costs	44	41	39	51	54
Biosolids production [m^3] [4)]	1,750	1,400	600	1,400	1,000
Cost minus biosolids sale at US$ 2/m^3	37	35	37	45	50
Cost minus biosolids sale at US$ 5/m^3	27	27	33	37	44

1) Designed treatment schemes in Paragraph 0, page 42.
2) Existing full-scale treatment plant in Kumasi, O+M cost estimate with information from Annoh (2002).
3) Deducted from the co-composting pilot plant in Kumasi, O+M cost estimate with information from Quarshie (2002) and Olufunke (2002).
4) According to sludge accumulation rates (cf. Appendix 3.1) in anaerobic tanks/ponds/beds with a 50% volume reduction during storage/composting.

All the cost information provided refers to the corresponding treatment schemes described in Paragraphs 2.1.5, 0 and 0. Modifications in plant construction lead to different investment costs, for instance if a clay layer is used instead of concrete or if annual loading rates are altered, etc.

The specific cost information is expressed in absolute values. In reality, however, due to uncertainties, special attention should be paid to the fact that the real costs are likely to be situated within a range of values (especially the costs of designed but not yet constructed plants). Therefore, Figure 18 illustrates the intervals of all costs if 20% and 50% uncertainties are added (10% and 25% up and 10% and 25% down, respectively) to the absolute values. A 20% uncertainty would be quite good, but a 50% uncertainty may be closer to reality for the estimates.

Based on the results of Table 32, several conclusions can be drawn:

The results of the three designed FSTP cost estimate are of the same order of magnitude as the ones of the two already built plants. Nevertheless, the capital cost of the Buobai settling pond scheme is higher than that of the designed option. The existing drying bed technology is more expensive than the designed CW[7]. However, since these two options are very similar, they should have about the same capital costs. Hence, it is likely that the estimates of the three designed FSTP are somewhat lower than the real costs.
Assuming a capital cost uncertainty of 50% (Figure 18), all five treatment schemes overlap each other. Therefore, it is difficult to determine the cheapest option. We can tentatively conclude that settling options tend to result in lower investment costs due to simple plant assembly and lower concrete requirement. While drying beds and CW have higher investment costs.
The O+M costs are all rather similar, except for the constructed wetlands costs, which are significantly lower (about the half) than the other technologies. This factor is clearly visible with the 50% uncertainty figure and confirms its importance. As aforementioned, this is possible since far less dehydrated sludge removal is required and hygienically safe sludge quality is already attained, thereby making sludge storage superfluous.
Owing to low O+M costs, constructed wetlands are generally the most economic technology. If framework conditions change, for instance with a depreciation period decrease or an interest rate increase, the low O+M costs may be rapidly offset by high capital costs.
If potential gain resulting from biosolids sale is deducted from the total costs, then the cheapest option changes again depending on attained sales price per m^3. This can be attributed to different sludge accumulation rates and addition of sawdust depending on solids-liquid separation. Constructed wetlands are the least favourable option if a high biosolids sales price is achieved. However, even at a sales price of US$ 5 per m^3 for the end product, the revenue only covers 25% (drying beds) to 44% (settling/thickening tank) of the corresponding annual O+M costs. However, further investigations are necessary, and most of all further commercialisation of biosolids, since the current potential market for large quantities of dried faecal sludge remains low in Ghana.

[7] Since the sludge loading rate of the drying bed is lower, more surface is required, however, the bed depth is lower than that of constructed wetlands. Percolate quality is likely to be similar.

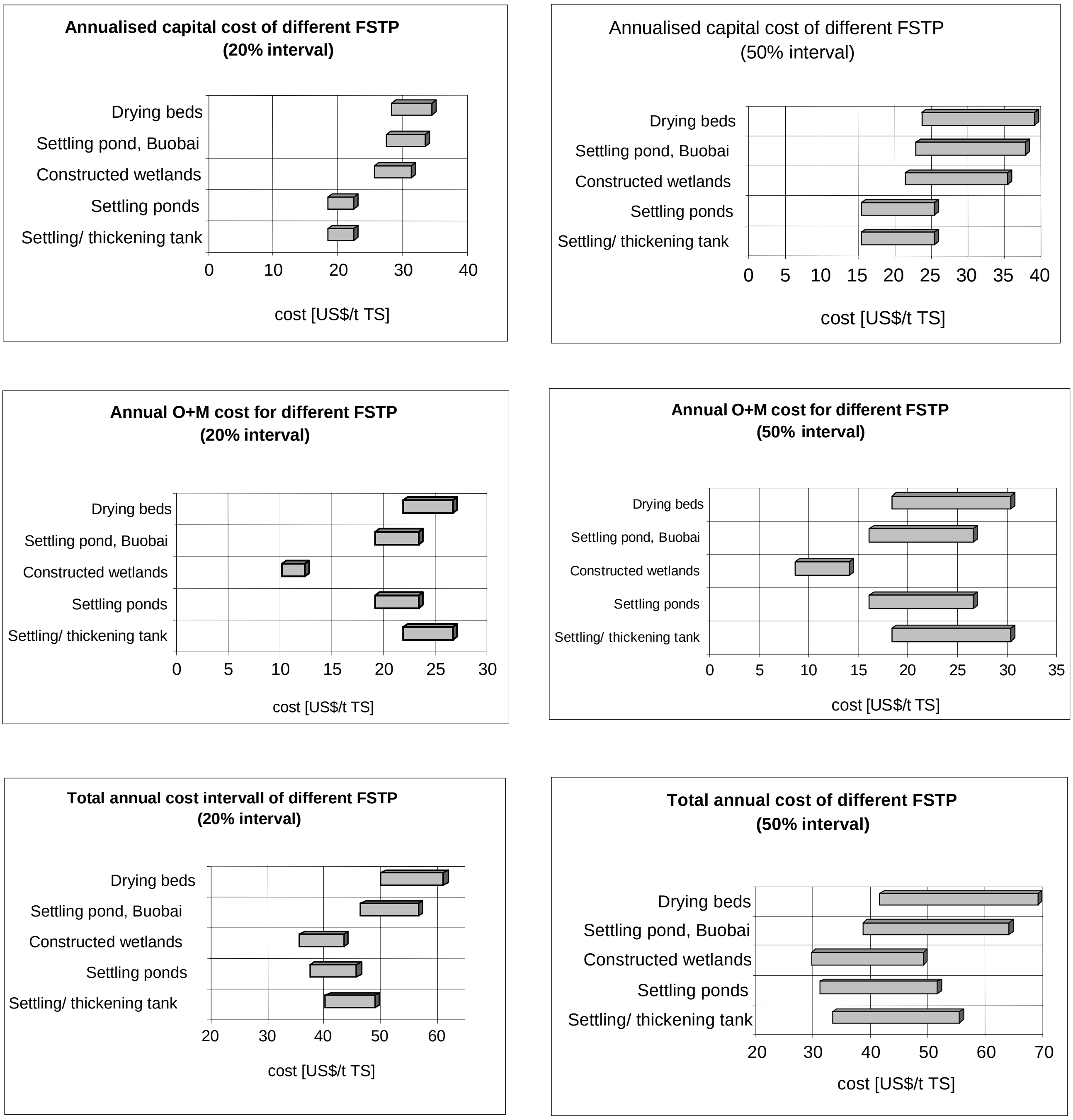


Figure 18: Capital, O+M and total cost comparison of five FSTP with two different intervals of uncertainty (20% and 50%, respectively). The costs of Buobai drying beds and the settling pond option originate from real treatment schemes in Kumasi. The costs of the other three options (CW, settling ponds, settling/thickening tank) are estimated on the basis of fictitious design plans. The plant capacity of all the options amounts to annually 20,000 m^3 FS; liquid post-treatment in facultative ponds is included, whereas land purchase and plant monitoring are not considered.

Comparison co-composting vs. separate FS treatment

The co-composting scheme in Kumasi treats the organic fraction of solid domestic/market waste and dewatered sludge at a 3:1 ratio. To compare this treatment plant with an ordinary FS treatment option evaluated earlier on, a separate composting plant is designed and its costs added to the ones of the FS treatment. Therefore, a fictitious composting plant is designed to treat about 6,000 m^3 of organic solid waste[8]. This amount corresponds to the quantity of organic waste treated in the co-composting plant whose annual capacity totals 20,000 m^3 raw FS (see 0 and 4.1.6). The composting scheme comprises a site office and a concrete-lined and roofed composting area. Its design, capital costs and O+M estimates are given in Appendix 4.2 and 4.3, and the results in Table 33.

Table 33: Cost estimate of a composting scheme.

	Costs of composting [US$]	Costs per m^3 final compost [US$] [1)]	Costs per t TS FS [US$] [2)]
Construction cost	260,000	-	-
Annualised capital cost	25,000	8	50
Annual O+M costs	37,000	12	74
Total costs	62,000	20	124

[1)] If a volume reduction of 50% of the initial composted organic waste is assumed, 3,000 m^3 of compost are produced annually.
[2)] 6,000 m^3 of organic waste treated annually correspond to an annual 500 t TS of FS treated by the co- composting plant.

If these solid waste composting costs are added to the ones of FS treatment shown in Table 32 (page 51), it is possible to compare the upscaled co-composting plant with the separate FS treatment and solid waste composting. The capital and O+M costs of the selected options in Table 34 reveal that – as expected – the co-composting option is of the same order of magnitude as the other options treating FS and solid waste separately. However, the co-composting plant treats the FS in drying beds, which appear to be a rather expensive option for FS solids-liquid separation (see Table 32). Therefore, the co-composting scheme is also compared with the separate FS treatment in drying beds and separate waste composting. We used the results in Table 32 and Paragraph 3.1.4 (page 39) for the drying beds and the upscaled co-composting plant, respectively. The latter was downscaled from an annual capacity of 625 t TS to 500 t TS (downscaling parameter α = 0.8) and received a facultative pond (US$ 15,000) for liquid polishing. The results and different capital and O+M cost structures are illustrated in Figure 19.

[8] The raw FS loaded onto the drying beds of the co-composting plant leads to a faecal sludge volume reduction of 90%. This dehydrated FS (2,000 m^3 annually) is later co-composted at a 3:1 ratio of organic waste and dewatered FS. Hence, 6,000 m^3 of organic solid waste are treated annually.

Table 34: Co-composting vs. separate FS and solid waste treatment. All the treatment schemes were adjusted to the same treatment capacity (500 t TS annually) and include FS treatment, effluent polishing and solid waste composting, without land costs.

	"Tank" option	"Pond" option	"CW" option	Settling ponds, Buobai	Co-composting
Annualised capital cost	20 + 50	20 + 50	28 + 50	30 + 50	64
O+M costs	24 + 74	21 + 74	11 + 74	21 + 74	108
Total costs	168	165	163	175	172

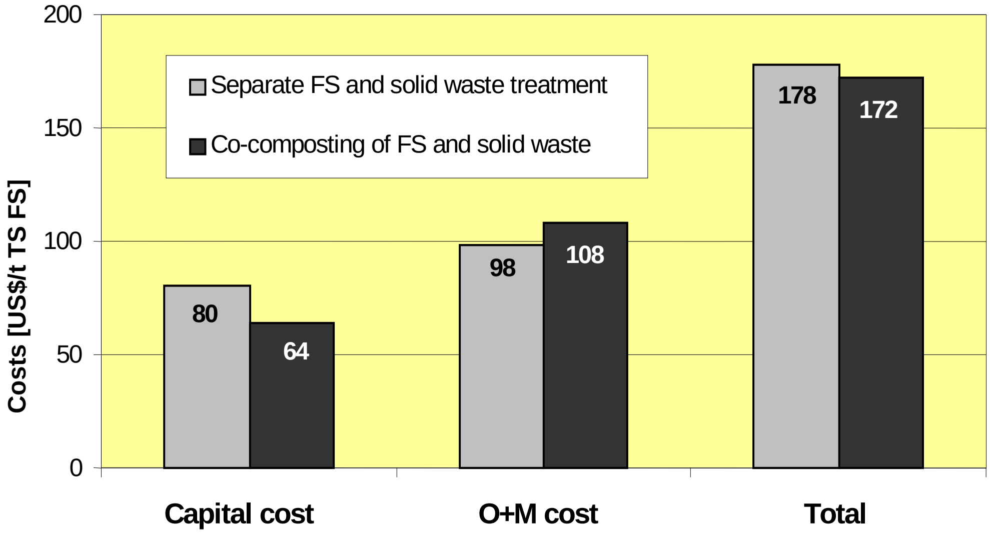


Figure 19: Co-composting vs. separate FS and solid waste treatment.

The total specific co-composting plant and separate FS and waste treatment costs per t TS, as shown above, are practically the same. There is no significant difference in total costs, as the lower capital costs of the co-composting plant resulting from the combination of solid waste and dewatered sludge treatment, are offset by the higher O+M costs. Slightly higher O+M costs can be attributed to the cost-intensive turning and screening. This is due to the fact that dewatered FS and solid waste are co-composted, 25% more dewatered FS material has to be turned and screened than if FS is treated separately (assuming that no turning and screening is required for separate post-treatment of dewatered FS).

Cross-country comparison

The capital and O+M costs in Table 32 can be compared with FS treatment plants in other countries with similar treatment capacities and liquid polishing. However, cost differences may be due to different local conditions (salaries, material costs, etc.).

Thailand:
Heinss (1999) estimated for example that the annualised capital and O+M costs amount to **US$ 42** and **US$ 47,** respectively per t TS for a constructed wetland (AIT-type) in Thailand with an annual capacity of about 100 t TS FS. These costs are considerably higher than the estimated costs for the same type of treatment plant in Ghana. The main difference – which is decisive for O+M costs – is the monthly salary calculation base of a skilled worker (US$ 350 in Thailand, compared to about US$ 100 in Ghana). Another important reason for the higher investment costs is the five times lower plant capacity compared to the standard size used in Ghana. An increase in plant capacity may reduce capital costs due to the economy of scale.

Argentina:
Co-treatment of sewage with the supernatant of FS settling ponds in Alcorta (Paragraph 2.1.6), with an annual capacity of about 100 t TS FS, shows **capital and O+M costs**[9] of **US$ 18** and **US$ 30**, respectively. Thus, construction costs are similar to the designed settling pond scheme in Ghana (US$ 17), whereas O+M costs are a third higher due to higher labour costs (US$ 200 for an unskilled worker) and annual replacement of the pond's geo-membrane.

Benin:
The annual **capital costs** of the planned settling/thickening tanks (Paragraph 2.1.7) with associated pond system for liquid treatment in Cotonou amount to **US$ 29**. If similar price levels and basic conditions are assumed in both Benin and Ghana, the higher capital costs are attributed to the use of several small settling/thickening tanks and an extensive post-treatment of its effluent (six ponds for each treatment line). A large pond system is required to allow natural ammonia (NH_3) stripping – a process requiring extensive retention periods.

Mali:
Jeuland (2002) designed a settling/thickening tank with associated liquid post-treatment in ponds (Paragraph 2.1.9). With a similar plant capacity as the standard size schemes, he estimates the annual **capital costs to amount to US$ 12 per t TS** (construction costs of US$ 75,000 without land, trucks or solar pump). This low capital cost might be due to extremely low salaries in Mali.

As aforementioned, a cross-country comparison is delicate. A comparison is possible with similar framework conditions, however, differences may occur and are mainly attributed to the salary level. It would be interesting to compare, as in Ghana, the different TS treatment options in countries like Thailand or Argentina. However, this would go beyond the scope of the present document.

[9] Costs attributed only to FS treatment, as the sewage treatment costs were deducted.

Conclusion

This chapter aimed at developing cost comparisons of different FS treatment options to establish a type of economic ranking of capital and O+M costs of FS treatment as regards the solids-liquid treatment technology. It is not possible to favour a treatment option, which would be the most economical under all the prevailing conditions. Cost differences are too insignificant and too many local unknown factors influence the total specific costs of a treatment plant (e.g. land requirement and its price, service life of the plant, interest rate, and potential biosolids sales price). Final treatment always has to be selected as a function of current conditions. Nevertheless, if biosolids sale are neglected and the interest rate and depreciation period are assumed at 5% and 15 years, constructed wetlands prove to have the highest capital costs. However, if O+M costs are included, CW turns out to be the most economical choice! Investment costs of drying beds are of the same order of magnitude as CW, however, due to regular sludge removal, O+M costs are higher than those of CW. Furthermore, the O+M costs of all options were found to be similar, except for CW, which are significantly lower. Settling/thickening tanks and CW options are the most land efficient (including WSP), whereas the settling pond option requires significantly more land (almost double in the present example).

The economic comparison of the co-composting plant and FS treatment plants associated with a separate composting scheme did not reveal any significant difference in total specific costs. The capital economy of the co-composting plant is offset by the higher O+M costs attributed to higher amounts of compost to be turned (organic waste + dewatered FS). Nevertheless, from an integrated sanitation viewpoint and in order to save investment costs, FS treatment and solid waste composting (with or without dewatered FS) should be associated with the same plant site and within an appropriate perimeter to FS and waste production if sufficient land is available.

5 PRELIMINARY COST APPRAISAL FOR PLANNERS AND DECISION-MAKERS

Cost estimate of faecal sludge treatment plants

5.1.1 Construction cost

Decision-makers and engineers prefer to use simple construction cost information (without annualising capital costs) to establish a rough estimate of the investment costs necessary for a planned installation. Therefore, as described in the former chapter, cost accounting of annualised costs with a fixed depreciation period and interest rate is not appropriate for fast construction cost planning. A rapid estimate of the construction costs required for a FSTP of a certain capacity can be based on the available experience and cost information (cf. Paragraph 2), as well as on the fictitious plants in Ghana (cf. Paragraph 0) as listed below. For simple use, investment (in US$) was divided by the annual plant capacity (in t TS). These costs include solids-liquid separation, but not land costs.

Since the economy of scale follows an obvious trend, it is important to integrate the plant size into the cost information. Therefore, a preliminary capital cost estimate consists in multiplying the assumed plant capacity with the corresponding specific capital costs of Figure 20 and Table 35.

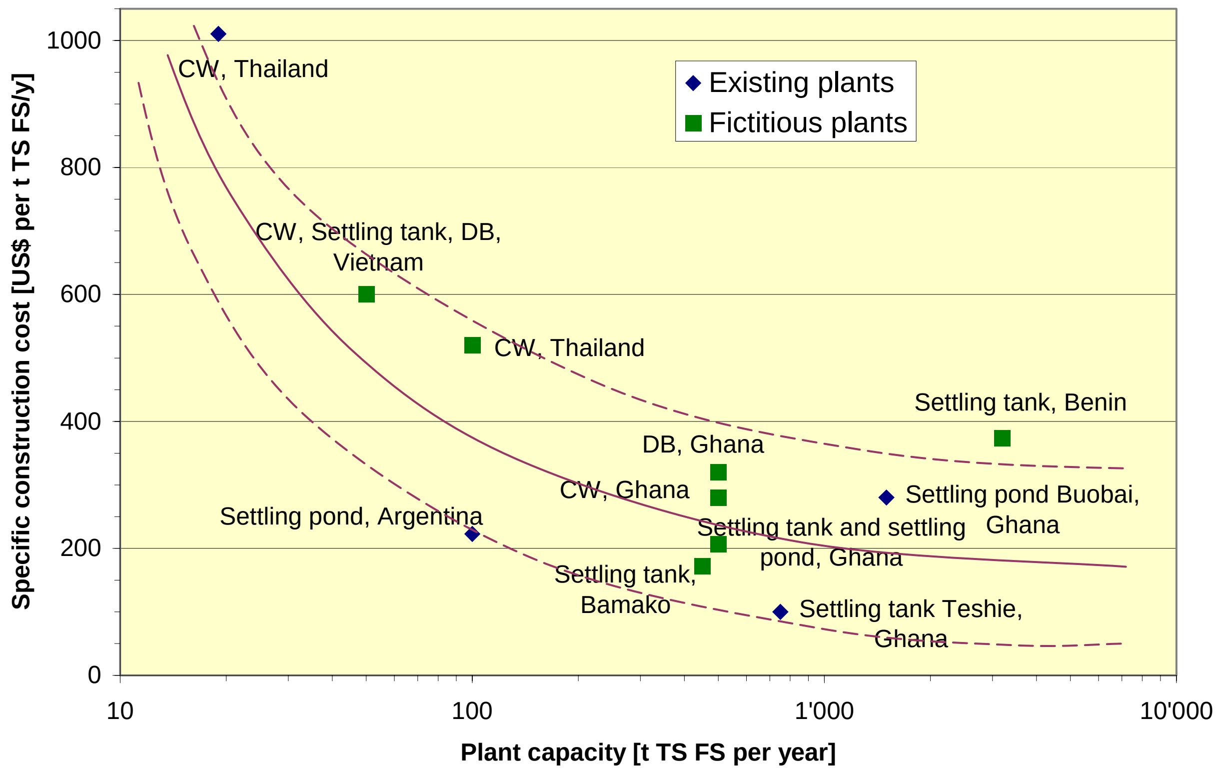


Figure 20: FSTP construction costs for different treatment options and countries, including liquid effluent post-treatment, but excluding land costs.

Table 35: FSTP investment cost estimate based on selected FSTP (excluding land costs, but including liquid post-treatment).

Plant	Country	Plant capacity [t TS/y]	Construction cost [US$/t TS·y]	Source and remarks
CW, AIT, Bangkok	Thailand	12.5	1,000	Kottatep et al. (2001); existing pilot plant.
Settling pond, Alcorta	Argentina	100	220	Ingallinella et al. (2000); existing full-scale plant, supernatant is co-treated with sewage, but only costs imputable to FS treatment are considered.
Settling tank, Teshie, Kumasi	Ghana	750	100	Annoh (2002); existing full-scale plant.
Settling pond, Buobai, Kumasi	Ghana	1,500	280	Annoh (2002); existing full-scale plant.
Settling tank, settling pond, Kumasi	Ghana	500	210	Designed full-scale plant in Paragraph 0.
CW, Kumasi	Ghana	500	280	Designed full-scale plant in Paragraph 0.
Drying bed, Kumasi	Ghana	500	320	Derived from the Buobai upscaled co-composting plant, where composting costs are deducted.
CW	Thailand	100	520	Upscaled AIT type according to Heinss (1999).
Settling tank, Cotonou	Benin	3,200	375	Option Environnement (1999); planned plant with extensive liquid pond post-treatment.
CW, DB, settling tank, Nam Dinh	Vietnam	50	600	Planned plants according to Klingel (2001); post-treatment of liquid was added according to Heinss (1999), assuming the same costs as in Thailand.

5.1.2 The need to appraise operation and maintenance cost

Decision-makers or planers are often not interested in appraising the recurrent costs. However, these operation and maintenance costs should be definitely integrated into a short and long-term financial plan for FS treatment operators (municipality/city). As seen by the Ghanaian CW example (Paragraph 4.1.3), higher investment costs may create lower O+M costs and, thus, lower total annual costs.

Figure 21 contains the specific O+M costs per t TS based on the experience described in Paragraph 2 and on the fictitious plants in Ghana as a function of plant size. Specific recurrent costs tend to decrease with plant capacity. Note that O+M costs are greatly dependent on local wages, as operation of the selected low-cost treatment alternatives mainly requires manual labour. Since the O+M costs of the Nam Dinh settling/thickening tank option seemed unrealistic, they were not included in the diagram.

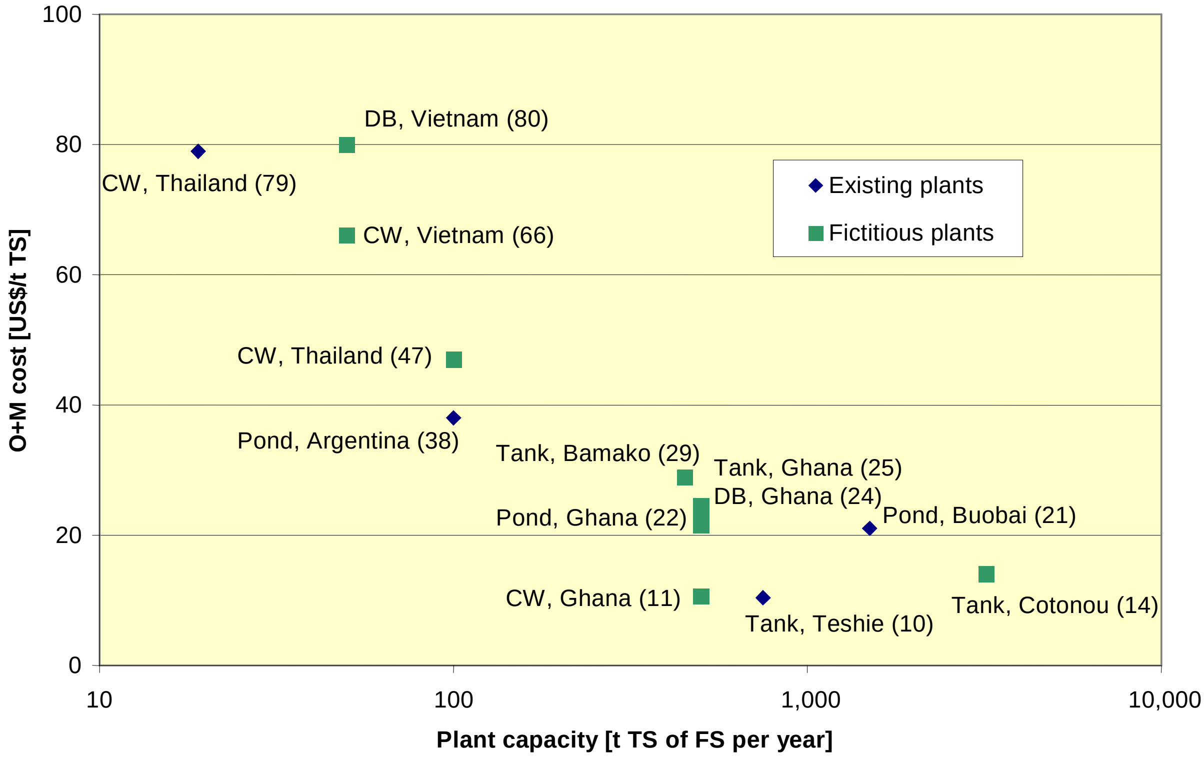


Figure 21: Overview of specific O+M costs, expressed in US$/t TS (annual O+M cost divided by annual plant capacity in t TS FS)

Cost estimate of co-composting of dewatered FS and organic waste

The costs of the Buobai co-composting treatment plant in Kumasi, where dehydrated FS is composted with the organic fraction of sorted solid waste, were described in Paragraph 2.1.2 and upscaled in Paragraph 0. It would not make any sense to include this cost information in Figure 20 and 22, as the input and output of a simple FSTP and co-composting scheme are not the same. To roughly estimate the investment costs of a co-composting scheme such as the one in Kumasi with drying bed solids-liquid separation, the cost information of three different plant sizes are presented in Table 36. Solid waste is supposed to be co-composted with dewatered sludge at a 3:1 ratio.

Annual O+M costs per t TS range from about US$ 105 to 145, depending on plant capacity (see Table 28, page 40). As previously estimated, about 30% of the O+M costs can be attributed to FS treatment, and the remaining costs to the co-composting process (see Paragraph 0 for details).

Table 36: Investment costs of a co-composting plant using drying beds for FS dewatering.

Plant capacity [t TS/y]	Construction cost [US$]			Total construction cost [US$/t TS·y]
	Solids-liquid separation	Co-composting	Liquid polishing	
12.5	10,300	12,600	1,000	1,910
125	48,000	59,000	5,000	895
625	170,000	210,000	18,000	**635**

Cost estimate of solid waste composting

A single composting plant was designed and its costs estimated in Paragraph 0. The results are given per t TS of FS to compare the co-composting process with an ordinary composting plant combined with a FSTP. Capital and O+M costs are contained in Table 37. Transport costs of solid waste to the treatment plant and of the inorganic fraction to a landfill are not taken into consideration.

Table 37: Investment and O+M costs of a solid waste composting scheme. Annual plant capacity amounts to 6,000 m^3 initial organic waste, and to 3,000 m^3 final compost produced.

	Cost [US$]	Cost per t TS [US$] [1)]	Cost per m^3 of final compost produced [US$]
Construction cost [2)]	260,000	520	87
Annual O+M cost	37,000	74	12

[1)] 6,000 m^3 of organic waste treated annually correspond to 500 t TS of FS per year in a co-composting plant like the one in Kumasi.
[2)] Initial construction cost, not annualised.

5 INTEGRATED COST CONSIDERATIONS

Introduction

The previous chapters only illustrated cost examples of FS treatment plants. However, several additional cost factors have to be taken into account to assess the overall costs of FS management. Treatment is just one cost factor in the following cost positions of the FS management process:

Collection
Haulage
Treatment
Dewatered sludge disposal or agricultural reuse

To gain an economic view of the overall cost structures, it would be interesting to estimate all these different costs. Awareness of the major costs involved allows to determine the potential of cost optimisation. Note that if the overall FSM costs are considered, not all costs are imputable to the same stakeholder.

Haulage costs

Haulage costs, i.e. transport from on-site sanitation systems to the treatment plant by a vacuum truck, are based on the sum of the capital costs for the vacuum truck and on the kilometre-dependent costs per ton TS (gasoline, O+M truck, salaries). Collection expenditure (salaries for workers) is integrated into the haulage costs.

5.1.1 Truck cost

To calculate the capital costs per ton of transported TS of raw FS, we assume an average truck volume of 8 m^3 (CREPA-Ivory Coast 2002, CREPA-Benin 2002, CREPA-Senegal 2002), with 3 trips a day and 20 days a month. The following cost information also has to be assumed:

Truck price (second hand): US$ 20,000

Truck service life (= depreciation period): 10 years

Interest rate: 5%
TS content of FS: 25 g/l (Ghana)
Annually collected volume of FS: 6,000 m^3

Annual capital costs therefore amount to US$ 2,590. Based on an assumed annual transported load of 150 t TS of FS, the vacuum truck costs amount to about **US$ 17 per t TS**. If the assumed initial truck price or service life is changed, this value varies considerably. With a service life of only 5 years for example, the annual capital costs of the truck would almost double to US$ 31 per t TS.

If the truck is not operated at full capacity (less than assumed), the capital costs per t TS also increase significantly, depending on the annual load. Furthermore, we assume that the truck always runs at the mentioned capacity of 150 t TS per year.

5.1.2 Kilometre-dependent truck cost

If km-dependent truck costs per t TS of FS are estimated, the average distance from the septic tank to the disposal site (treatment plant) is of key importance. This is confirmed by the current practice of uncontrolled dumping of FS by the driver of the emptying truck even though a FS treatment plant is available. Distance, dumping fees and congested roads are the main reasons for this behaviour. Haulage costs per km and t TS of collected FS can be calculated with the following formula established by Heinss (1999):

$$C_{collection}\left[{}^{US\$}\!/_{t\ TS.km}\right] = \frac{truck\ cost\ per\ km + \dfrac{man\ hour\ cost}{average\ speed}}{\text{truck capacity}\cdot\left[m^3\right]\cdot TS\ content\left[t/m^3\ FS\right]}$$ **Equation 6**

The following data are included in the formula:

Truck costs per km (fuel, O+M): US$ 0.5
Truck capacity: 8 m^3
Average speed: 10 km/h
Man hour costs (driver +worker): US$ 2
Mean TS content in FS: 0.025 t/m^3

The haulage costs therefore amount to about **US$ 3.5 per ton TS and kilometre**. A relatively low average speed was assumed to include real collection time (i.e. pumping of septic tank). This amount is only valid for the previous assumption, but can rise quickly if truck volume is smaller, roads more congested and salaries higher. Further costs for the collection company, such as authorisation fees, office and administration expenditures or fines are not included. According to an extract of the account statement of a private emptying company in Ivory Coast (CREPA-CI 2002), these costs amount to 20%, whereas most of the costs are attributed to bribes.

The effective haulage costs per t TS depend on the distance to the dumping site. This distance is dependent on the catchment area of the treatment plant: the larger the plant capacity, the bigger the catchment area and, hence, also the haulage distance. Assuming an almost circular collection area served with a FSTP in the centre, the average distance

$$\text{Distance} = \sqrt{\frac{(radius\ served\ area)^2}{2}}$$ **Equation 7**

from a septic tank to the plant amounts to:

With the use of the above equation and a given population density (density = population/$r^2 * \pi$), the average distance to the treatment plant can also be expressed as

$$\text{Distance} = \sqrt{\frac{served\ \ population}{2 \cdot \pi \cdot population\ density}} \qquad \textbf{Equation 8}$$

Figure 22 illustrates the mean distances as a function of plant capacity (corresponding to the served population) calculated with the previous equation.

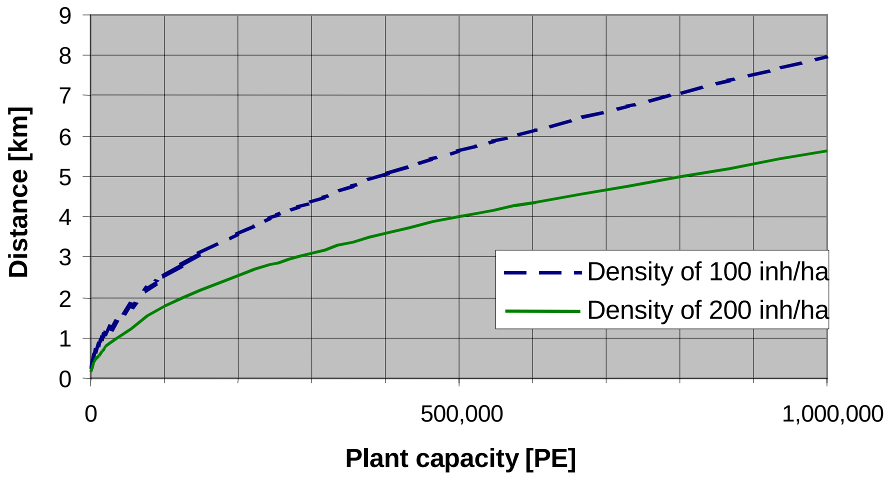


Figure 22: Haulage distance (bi-directional) as a function of served population with two different population densities. A circular area served with the FSTP in its centre is assumed.

This distance (bi-directional) has to be multiplied by US$ 3.5 per km per t TS to obtain the haulage costs per t TS. The calculated distance is a theoretical value, as the population density will not be homogeneous and the treatment plant will not be in the centre. The latter results in a relatively short distance to the treatment plant. The larger the treatment plant, the greater the likelihood that it is located a few kilometres outside the settlement. With a small plant size of 1,000 PE, the theoretical value of the bi-directional distance amounts to 200 m. This value is not very realistic under real life conditions. To take into account these assumptions, we gradually added a distance of 3 km (for plant capacity of 1,000 PE) to 10 km (for plant capacity of 1,000,000 PE) to the theoretical haulage distance. By multiplying the haulage distance with the specific km-dependant costs, the haulage costs are obtained as a function of plant size (Figure 23).

It is important to note that the served population corresponds only theoretically to the actually served population if a daily TS load of 14 g per capita is assumed. This empirical value corresponds to septage (sludge from a septic tank), as the use of public toilet sludge is not considered in the calculation. Public toilet sludge would reduce haulage costs per t TS, as it is highly concentrated.

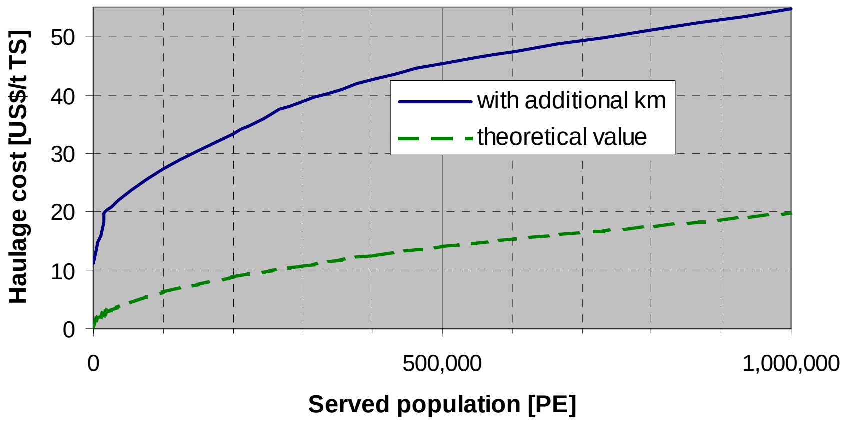


Figure 23: Haulage costs as a function of served population (plant size). Theoretical values (a circular area with the FSTP in the centre is assumed) and chosen additional distance of 3 to 10 km, depending on plant size. (Population density amounting to 200 inhabitants/ha).

5.1.3 Haulage cost influencing plant size

The previous paragraphs described the capital truck and haulage costs depending on planned capacity. It is interesting to add truck capital and haulage costs to the annual capital costs as a function of plant size (served population). Haulage costs increase the larger the plant capacity (longer distances), whereas the annual treatment plant costs per t TS decrease if plant size increases as a result of the economy of scale.

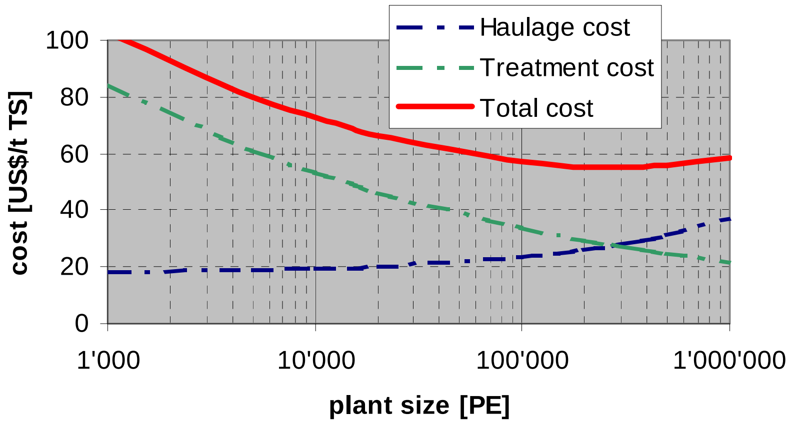


Figure 24: Haulage and annualised capital costs (treatment) exemplified by the Buobai treatment plant (settling ponds and WSP). (Population density amounting to 200 inhabitants/ha).

To illustrate the behaviour of the overall costs (haulage and treatment) as a function of plant capacity, the Buobai full-scale treatment plant (settling ponds and WSP, Paragraph 2.1.5) was scaled up and down to various plant sizes based on the principles of the economy of scale with 0.8 as its parameter α (Paragraph 0 and Appendix 5.2). If theoretical haulage distances (FSTP in the centre) and a truck capital cost of US$ 17 per t TS are used in addition to the Buobai treatment plant costs, the corresponding results obtained are given in Figure 24.

If, as in Figure 23, an additional haulage distance is used, to account for the too theoretical approach, the resulting higher haulage costs are illustrated in Figure 10 (page 33). If an additional distance is used, the ideal plant size decreases from an economic point of view.

Special mention should be made that results presented in this chapter are valid only for assumed context. This section aimed at providing approaches to assess haulage costs and to illustrate their influence and behaviour on the overall FSM costs. Haulage costs can be easily adapted to other conditions if for example an Excel sheet and local parameters are used for the calculation.

Dewatered sludge disposal

Biosolids issued from faecal sludge treatment plants have to be disposed of appropriately or safely reused in agriculture. Landfill disposal costs are dependent on the size of the landfill (economy of scale) and engineering aspects (e.g. liner, drainage, leachate treatment). A landfill without engineered liner or leachate system might be sufficient for dewatered FS disposal. According to Cointreau-Levine (1997), capital and O+M landfill costs (without clay lining or leachate collection) in low-income areas range between US$ 6 and US$ 10 per ton capacity (a large landfill of 1,000 t/day and a small landfill of 250 t/day, respectively) for a 10-year landfill life.
If a mean landfill (US$ 8 per ton) and an average TS content of 25% of the dewatered FS are assumed, the approximate landfill costs for sludge disposal amount to US$ 32 per t TS of FS. We assumed that the TS present in raw sludge corresponds to the disposed of TS. However, depending on the FS treatment option adopted, a percentage of incoming TS is lost via the liquid effluent and degradation. This factor is neglected and we assumed that the loss of TS is offset by the addition of sawdust in order to render settled/dewatered sludge spadable.

In addition to the actual landfill costs, important costs are also incurred by the transport of the dewatered FS from the treatment plant to the landfill. Depending on the distance to the landfill and means of transport, these costs may be assessed similarly to the transport costs of raw FS in Paragraph 0. Assuming a truck is used at full capacity with 8 t dewatered FS (investment costs of US$ 20,000, annual capacity of 6,000 t at 25% TS), its annual capital costs would amount to about US$ 2 per t of transported TS. Km-dependent transport costs per t TS amount to about US$ 0.3 per km (at a speed of 30 km/h and 25% TS content). By assuming a distance of 10 km from the treatment plant to the landfill, the transport costs will rise to US$ 3 per t TS. Hence, annual truck and transport costs to the landfill amount to about US$ 5 per t TS.

Experience on the aforementioned dewatered sludge disposal is still scarce, as the sludge is generally still disposed of near the treatment plant (and not on a landfill).

Compilation of all costs: with and without biosolids reuse

Cost accounting allows to itemise the overall FSM costs. It elucidates the cost distribution and, hence, the potentials of cost optimisation. Table 38 contains a compilation of summarised FSM costs in the Ghanaian context. These values are only valid for the particular local context and are a result of the described assumptions. Absolute costs will differ from one place to another, even within the same country or city.

Table 38: Compilation of the overall FSM costs based on the Buobai full-scale treatment plant example (settling pond and WSP, with an annual capacity of 1,500 t TS of FS). Capital costs have been annualised with 15 years depreciation period (10 years for trucks) and 5% interest rate.

Item (annual cost)	Cost per t TS FS [US$]	Reference/assumption
FS collection:		
Truck capital cost	17	§ 5.1.1
Truck cost haulage of FS	11	§ 5.1.2, FSTP in the centre of the catchment area
FS treatment:		
Land cost	2	§ 2.1.5, settling, facultative and maturation ponds
Capital cost	27	
O+M cost	16	
Biosolids disposal:		
Landfill cost	32	§ 0, TS loss neglected, as it is assumed to be offset by the addition of sawdust; 5 km distance to landfill
Transport to landfill	5	
Sum	110	

Compared with real FS treatment, the high collection and biosolids disposal costs are remarkable. The emptying fees paid by the household to the emptying company cover only the collection costs, whereas FS treatment and disposal costs are borne by the community. The latter costs are only theoretical, as disposal of dewatered FS sludge is not practice yet. The only benefit derived from biosolids disposal is a reduced dewatered sludge post-treatment (no storage or further drying). By placing the values from Table 38 (without biosolids disposal) into a pie chart, the proportionate share of every cost is itemised individually (Figure 25). Therefore, collection, treatment and disposal costs per t TS amount to 25%, 42% and 33%, respectively. Hence, high collection and disposal costs in relation to the real FS treatment underlines the importance to integrate these expenditures into economic considerations of FSM..

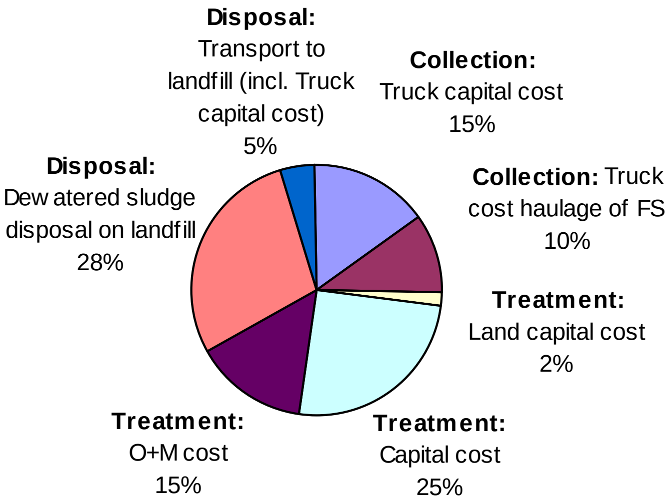


Figure 25: Distribution of annual FSM costs per t TS based on the Buobai treatment plant in Kumasi (settling ponds and WSP, with an annual capacity of 1,500 t TS).

Note that the estimated costs are only valid for the assumed context. If truck capacities or haulage distances are modified, the overall cost composition may change significantly.

However, the disposal costs amount to approximately one third of the overall costs. This amount could be reduced easily by reusing the biosolids. If biosolids could be sold instead of disposed of, so much the better. However, reuse of biosolids as soil amendment and organic manure is also connected with expenses: additional O+M effort due to biosolids handling and storage, commercialisation, bagging, marketing, and transport.

To assess the potential revenue from the sale of biosolids, the following is assumed and only valid for the Buobai treatment plant with settling ponds:

Annual biosolids production of 4,500 m^3 (sludge accumulation rate of 0.1 m^3/m^3, 50% addition of sawdust to dewatered FS, 50% volume reduction during storage → 0.1*60,000*1.5*0.5=4,500).
Sales price of biosolids: US$ 5 per m^3 → **US$ 15 per t TS revenue** (4,500*5/1,500).
Transport distance to buyer: 5 km (10 km return) → **US$ 5 per t TS transport costs.**
Additional effort for dewatered sludge handling is included in the O+M amount of **US$ 21 per t TS** (O+M cost amounts to US$ 16 per t TS if there is dewatered FS disposal of)
No additional construction costs due to biosolids handling (neglected).

Table 39 contains a compilation of the FSM costs with integrated biosolids commercialisation and reuse.

Table 39: Overall FSM costs based on the Buobai full-scale plant (settling pond and WSP, with an annual capacity of 1,500 t TS of FS), including the sale of biosolids. Capital costs have been annualised with 15 years depreciation period and 5% interest rate.

Item (annual cost)	Cost per t TS FS [US$]	Reference/assumption
FS collection:		
Truck capital cost	17	§ 5.1.1
Truck cost haulage of FS	11	§ 5.1.2, without additional km
FS treatment:		
Land cost	2	§ 2.1.5, settling, facultative and maturation ponds
Capital cost	27	
O+M cost	21	
Biosolids sale:		
Transport to buyer	5	§ 5.1.2, mean distance to buyer 5 km
Sum	83	
Revenue biosolids sale:	-15	Sales price of US$ 5 per m^3 biosolids
Net total cost	68	

The overall cost comparison of dewatered faecal sludge disposal and reuse after storage in Table 38 and 39 illustrate the economic benefits from FS reuse, provided it is hygienically safe. However, as aforementioned, dewatered faecal sludge is actually not always disposed of correctly on a landfill, but often just remains on the treatment site or is dumped in the immediate neighbourhood without any further costs. Even with an official waste dumping site, it is often not a real landfill with assumed costs. However, the costs saved today by inappropriate disposal will entail more costs in future for remediation of the impacts caused by uncontrolled waste and faecal sludge disposal.

6 CONCLUSION AND OUTLOOK

Main findings

Typical FS treatment costs: Faecal sludge treatment costs depend mainly on treatment capacity, geographic location and treatment quality (effluent and dewatered sludge quality). Nevertheless, typical investment costs for a full-scale FS treatment plant (including WSP for liquid effluent polishing) in West Africa should amount to about US$ 100 to 400 per ton TS/year[10] (see Figure 20, page 58). Operation and maintenance costs for a full-scale treatment plant in West Africa were estimated to range from about US$ 10 to 30 per t TS (see Figure 21, page 60). Cost information for Thailand, Vietnam and Argentina showed higher specific O+M costs. This fact could be attributed mainly to higher wages, but also to smaller plant sizes of the selected FSTP in these countries.

As investment and O+M costs have to be considered to allow a FS treatment cost estimate and to compare different treatment options, the investment costs have been annualised with a depreciation period of 15 years and an interest rate of 5%. Thus, the sum of annualised capital and O+M costs of a full-scale treatment plant typically amounts from US$ 40 to 60 per t TS for the Ghanaian context and for the treatment plant in Argentina. Capital and O+M costs of installations in Thailand and Vietnam amount to about US$ 80 to 100 per t TS, according to Heinss (1999) and Klingel (2001)[11], respectively (see Paragraphs 2.1.1 and 2.1.8). However, the treatment capacities of the reported plants in Thailand and Vietnam are smaller than in Ghana.

It is interesting to note that (theoretical[12]) O+M costs per t TS are of the same order of magnitude as annualised capital costs per t TS. Hence, it is extremely important to include O+M costs in the financial planning of faecal sludge treatment, as construction of a treatment installation is not worthwhile if operation and maintenance are not included.

It is important to note that O+M costs presented in this report do not include expenditures relative to a monitoring plan for the treatment plant. However, this additional cost must be integrated in financial planning in order to control and guarantee the treatment yield. Besides the number of analysis, additional specific cost per t TS will depend heavily on the plant size.

Cheapest option: Different FS primary treatment options (solids-liquid separation) have been compared in the Ghanaian context and under the same conditions (same capacity, including liquid effluent polishing, same treatment quality, etc.). Nevertheless, it was not possible to identify the cheapest treatment option, as cost differences were not significant enough. However, differences were found in the cost structure of capital and O+M costs. Settling/thickening tanks and settling ponds as primary treatment are less capital intensive than constructed wetlands, but more expensive with regard to O+M

[10] Investments costs [US$] divided by annual capacity [t TS/year], TS relates to incoming FS.
[11] Without settling/thickening tank option, as its cost estimate seems to be overestimated.
[12] In reality, O+M is often not done, hence there are less dispenses than needed for correct operation.

costs. This difference is due to the regular dewatered sludge removal frequency (some weeks to a year) for settling tanks and ponds. In contrast, the sludge accumulated in constructed wetlands (AIT-type) is only removed about every five years! Drying beds are assumed to show similar capital costs as CW, but higher O+M costs due to regular sludge removal after every bed loading.

Hence, constructed wetlands may be an interesting option to maintain O+M efforts low and to reuse biosolids directly in agriculture, whereas land efficient settling/thickening tanks are favoured if land prices are high. However, different options should be compared for each FS treatment project, as final costs are dependent on local circumstances. The economic aspects are not the only criteria, as the cheapest technology is not necessarily the most appropriate.

Economy of scale: FS treatment costs are dependent on the treatment plant capacity. As shown, the specific capital costs per t TS of a pilot plant were halved if plant capacity was enlarged ten times (see Paragraph 3.1.3). Specific O+M costs per t TS are also assumed to decrease if plant size is enlarged, but to a lesser extent compared with the capital costs. However, larger treatment plants require longer haulage distances from the FS production to the treatment site. Indiscriminate disposal of untreated FS is the consequence of long haulage distances.

Regarding treatment and haulage costs as a function of plant size, the ideal treatment plant capacity is situated between 20,000 and 200,000 PE to minimise the treatment and haulage costs (see Figure 10, page 33).

Integration of FS collection and disposal costs: Economic faecal sludge management costs not only include FS treatment, but also collection, haulage, disposal or reuse of dewatered sludge. Figure 26 illustrates the importance of collection and disposal costs in relation to the treatment costs.

Figure 26: Comparison of faecal sludge management cost structure, with or without biosolids reuse.

Figure 27 illustrates the cost difference between biosolids reuse and disposal. Overall costs amount to US$ 110 per t TS, if dewatered sludge is disposed of on landfills, while they amount to US$ 83 per t TS if dewatered sludge is stored and reused in agriculture. The revenue from biosolids sale is not yet included. Hence, reuse of biosolids is not only an environmentally friendly concept, but also more economical than its disposal, even if biosolids are not sold.

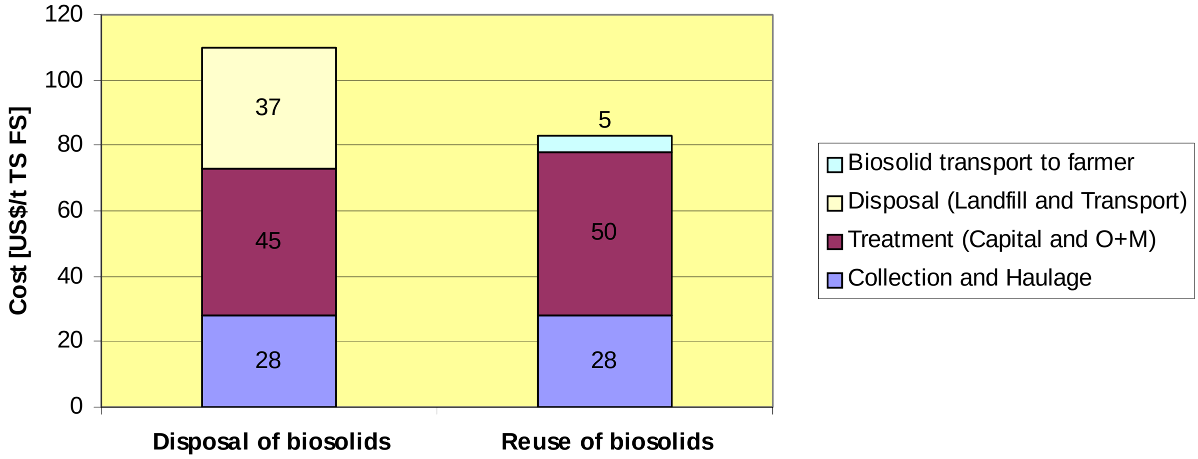


Figure 27: Integrated faecal sludge management cost comparison between the landfilling and the reuse of biosolids. Costs are expressed in US$ per t TS in raw FS.

Outlook

Cost information on faecal sludge management in general and FS treatment in particular is scarce. Therefore, additional cost data should be collected to provide a reliable economic base for decision guidance in FSM.

Faecal sludge management not only entails costs, but also benefits, e.g. public health improvement and reduction of groundwater and surface water pollution. It would be a challenging task to express these benefits in monetary terms in order to convince local authorities and policy-makers of the beneficial aspects of faecal sludge management.

It could be possible to render faecal sludge treatment economically more attractive if additional direct benefits were generated. E.g. the sale of biosolids on a large scale (for industrial farming), the use of biosolids (and possibly liquid effluent) for crop production and the sale of bricks produced with the liquid effluent both within the treatment plant.

References

Annoh, C. (2002). Personal communication.
Annoh, C. (1996). Personal communication to Mr Martin Strauss (SANDEC).
Cointreau-Levine, S. (1997). *Project Preparation: Solid waste Management, Section IV.* In Urban Waste Management; Guidelines, Tools and Practices in Sub-Saharan Africa. World Bank, Washington.
Centre of Sanitation Engineering, Rosario (2002). Personal communication.
Colan Consult (2001). Quotation from the Buobai co-composting Pilot Plant, 11/2001. Kumasi.
CREPA-CI (2002). Etat des lieux de la gestion des boues de vidange dans la ville de Bouaké. CREPA-Ivory Coast, Abidjan.
CREPA-Senegal (2002). Etat des lieux de la gestion des boues de vidange dans les zones urbaines au Senegal. CREPA-Senegal, Dakar.
CREPA-Benin (2002). *Gestion des boues de vidange au Benin: Etat des lieux.* Final report CREPA-Benin, Cotonou.
Heinss, U., Larmie, S.A. and Strauss, M. (1998). Solids Separation and Pond Systems for the Treatment of Faecal Sludges in the Tropics – Lessons Learnt and Recommendations for Preliminary Design. SANDEC report No. 5/98, Duebendorf.
Heinss, U. (1999). *Economic aspects of constructed wetlands.* Intern unpublished paper. SANDEC, Duebendorf.
Hutton, G. (2002). Personal communication. Swiss Tropical Institute, Basle.
Ingallinella, A.M., Fernandez, R. and Sanguinetti, G. (2000): Field research reports. Unpublished.
Jeuland, M., (2002). Personal communication.
Klingel, F., Montangero, A. and Strauss, M. (2002). *Guide on Faecal Sludge Management Planning.* EAWAG/SANDEC, drafted. Duebendorf.
Klingel, F. (2001). *Nam Dinh Urban Development Project – Septage Management Study.* Nam Dinh, Vietnam. EAWAG/SANDEC and Colenco (Vietnam).
Koottatep, T., Thi Kim Oanh, N. and Polprasert, C. (1999). *Preliminary Guidelines for Design and Operation of Constructed Wetlands Treating Septage.* Paper presented at the international seminar on constructed wetlands, March 1999 in Bangkok. AIT centre, Bangkok.
Koottatep, T., Polprasert, C., Thi Kim Oanh, N., Montangero, A. and Strauss, M. (2001). *Sludges from On-site Sanitation Systems – Low-cost Treatment Alternatives.* Paper presented at the IWA conference on water & sanitation management for developing countries. Kuala Lumpur, Oct. 29-31.
Maystre, L. Y. (1985). Initiation aux calculs économiques pour les ingénieurs. PPUR, Lausanne, Switzerland.
Olufunke, C. (2002). Personal communication.
Option Environnement (1999). *Projet de traitement des matières de vidange.* Etude technique – rapport d'étape de la phase 1. Cotonou, Benin.
Quarshie, S. (2002). Co-composting, Buobai – Brief report on operations so far. Intern field report.
Steiner, M. (2002). Economic Benefits of Improved Faecal Sludge Management – The Case of Diarrhoea Reduction. 1st draft. EAWAG/SANDEC, Duebendorf.
Surinkul, N. (2002). Personal communication.

Varley, R. and Tarvid, J. (1998). A reassessement of the Cost Effectiveness of Water and Sanitation Interventions in Programmes for Controlling Childhood Diarrhoea. Bulletin of the World Health Organisation 76(6): 617-631

WB (1980). Appropriate Technology for Water and Sanitation – A planner's Guide. World Bank, Washington.

WHO (2000). Considerations in Evaluating the Cost-effectiveness of Environmental Health Interventions. World Health Organisation, Geneva.

Table of appendices

A 1 DETAILS OF SELECTED FS TREATMENT PLANTS

A 1.1 Constructed wetlands, AIT, Bangkok

Plant size and sludge load						
Surface per unit (5x5 m) [m2]		25				
Total surface [m2]		75				
Total volumetric load [m3/y]		1000	20 m3 per week, one week loading cycle			
TS average [g/l]		19	Koottatep et al. (2001)			
optimal sludge load [kg/y.m2]		250	Koottatep et al. (2001)			
sludge load [m3/y]		1'000	about 3700 PE			
TS load [t/y]		19	calculated with 250 kg TS/y			
Construction cost						
		[US $]				
Three CW units (3x5,300$)		15'900	screen, pipework included			
AGWSP incl. percolate pumps		4'000	4 units, each 1x4x1 m			
Polishing pond		1'300	2 units, each 1x4x1 m			
Total		**21'200**				
Land (US$ 8 per m2)		1'250	(75+16+30)m2*1.3			
Operation and Maintenance cost						
		[US $]				
Salary (harvest and cleaning, each CW)		500	without sludge removal about every 5 years			
Total		**1500**				
Annual cost						
life time of the plant	[years]	15				
interest rate	[%]	5				
	[US$/y]	[US$/t TS]				
CW units	1532	81	Koottatep et al. (2001)			
AGWSP	385	20	Narong quotation received august 2002			
Polishing pond	125	7	Narong quotation received august 2002			
O+M	1500	79	Koottatep et al. (2001)			
Total witout land cost	3542	**186**				
Land (150 m2 à 8$)	116	6	Estimated by the author, land prize Heinss (1999)			
Total with land cost	3658	**193**				

A 1.2 Co-composting plant, Buobai, Kumasi (solids-liquid separation with the help of drying beds)

Technical Design								
Faecal sludge load			[m3/d]	1.5				
Sludge volume			[m3/y]	500				
Ratio septage : PTFS				2 : 1				
TS content			[kg TS/m3]	25				
Total treated FS			[t TS/y]	12.5	PE=2500			
depreciation period			[years]	15				
interest rate			[%]	5				
Construction and O+M cost, revenue biosolids sale								
				[US$]	[US$/year]	[US$/t TS]		
Construction (without polishing)				22'700	2'187	175		
O+M				-	1'800	144		
Total					3'987	**319**		
Revenue biosolids sale		$5	per [m3]		500	40		
Details O+M cost								
Sludge removal				100	Olufunke (2002)			
Replenishment of sand				75	by the author			
Compost turning				300	Olufunke (2002)			
Waste sorting				525	Quarshie (2002), 2.8-3.8 $/m3 organic waste			
Compost screening and bagging				100	Olufunke (2002)			
Contingencies				200	by the author			
Management				500	Olufunke (2002)			
annual O+M			**[$]**	**1'800**				
Details construction cost (without percolate polishing)								
				[US$]	[%]			
General items				5'500	24.2			
Site clearance				50	0.2			
Discharge bay				750	3.3			
Sludge storage tank				1'250	5.5			
Pipework & splitting chambers				280	1.2			
Sludge drying beds				2'250	9.9			
Solid waste handling area				1'300	5.7			
Composting area				4'150	18.3			
Sludge storage area				70	0.3			
Roofing materials				2'550	11.2			
Percolate storage tank				1'300	5.7			
Daywork				1'300	5.7			
Contigences				1'950	8.6			
Total				**22'700**	100			

A 1.3 Settling ponds and WSP, Buobai, Kumasi (full-scale)

Sludge load						
Daily FS load			[m3/d]	200		
Annual load			[m3]	60'000		
TS content			[g/L]	25		
TS load			[t TS/yr]	1'500		
Depreciation period			[years]	15		
Interest rate			[%]	5		
Construction, O+M and land cost						
Construction costs			[US$]	420'000	Annoh (2002)	
Annualised capital costs			[US$/y]	**40'464**		
Land (330x240)			[m2]	79'200	Annoh (2002)	
Land prize			[US$/m2]	0.4		
Land cost			[US$]	31'680	Annoh (2002)	
Annualised capital cost land			[US$/y]	**3'052**		
Desluding			[US$/y]	750	Annoh (2002)	
Composting (hiring of different trucks, sawdust)			[US$/y]	6'500	idem	
Environmental management plan			[US$/y]	16'700	idem	
Repairs and general equipement			[US$/y]	600	idem	
Salaries (7 workers)			[US$/y]	7'000	idem	
Total O+M cost			[US$/y]	**31'550**		
Annual cost						
Capital cost land			[US$/t TS]	2		
Capital cost construction			[US$/t TS]	27		
O+M			[US$/t TS]	21		
TOTAL			[US$/t TS]	**50**		
Details of construction cost						
			[US$]	[%]		
Site clearance			11'000	3		
1st anaerobic pond			47'000	11		
2nd anaerobic pond			52'500	13		
Facultative pond			56'500	13		
Three maturation ponds			48'000	11		
Ancillary works			16'500	4		
Water supply			30'000	7		
Road works			47'500	11		
Drains and chute			1'500	0.4		
Chambers			15'000	4		
Two sludge ponds			3'500	1		
Contingencies			91'000	22		
Total			**420'000**	100		
Details of O+M cost						
			[US$]	[%]		
Hiring suction truck (12 days)			750	2		
Hiring pay loader (20 days)			4'000	13		
Hiring tipper trucks (4 days)			500	2		
Hiring excavator (4 days)			1'250	4		
Haulage of sawdust			750	2		
Environmental management plan			16'700	53		
General repairs			375	1		
Material and equipement			250	1		
Salaries (7 worker)			7'000	22		
Annual O+M cost			**31'575**	100		
Economy of scale:plant for 500 t TS per year						
Economy of scale formula application:						
P0	C0	P1	C1	a	alpha	
370'000	1500	153'640	500	1064.948771	0.8	
Construction costs			[US$]	154'000	without maturation ponds	
Capital costs (annualised)			[US$/y]	14'837	and without land	
Capital cost per t TS			**[US$/t TS]**	**30**		

A 1.4 Septage treatment in settling ponds (septage ponds) and subsequent treatment with sewage in WSP in Alcorta, Argentina

Design, septage and sewage load (C1+C2: septage ponds; L1+L2: WSP)						
		C1, C2 (each)		L1		L2
Large [m]		25		83		38
Width [m]		11		57		53
Depth [m]		1.3		1.2		1.3
Results of operation stage January - July 1999:						
septage flow [m3/d]		24		sewage flow in L1, L2 [m3/c		200
SS content [g/L]		6		BOD tot sewage[mg/L]		198
TS content [g/L]*		12		BOD tot supernatant [mg/L]		150
TS load [t/y]		100		COD tot sewage [mg/L]		531
* estimated at the base of mesured SS content				COD tot supernatant [mg/L]		654
Construction costs						
Septage ponds (C1+C2)		[US$]		**WSP (L1+L2)**		[US$]
Embankment		4'000		Embankment		40'000
Excavation		1'200		Excavation		13'800
Soil-clay for bottom		1'800		Soil-clay for bottom		20'700
Road		240		Road		4'800
Pipe (200mm)		500		Piping (150 and 200mm)		8'600
Chamber pipe (1.2m)		800		Chambers		7'700
Screen		200		Fence		11'500
Outlet weir		200		**Total**		**107'100**
Fence		2'640				
Total		**11'580**		Land cost (1,800m2 à 10$)		18000
Operation and maintenance cost						
Septage ponds (C1+C2)		[US$]		**WSP (L1+L2)**		[US$]
Equipment		360		Equipment		1'200
Staff (0.5 labourer)		1'200		Staff (3 labourer)		7'200
Plastic membrane (2)		800		**Total**		**8'400**
Sludge removal (twice)		600				
Total		**2960**				
Annual cost (only cost imutable to FS treatment, about 10% of WSP)						
		[US$/yr]	[US$/t TS]			
Capital cost solids-liquid separation		1116	11			
Capital cost supernatant treatment		1032	10			
O+M cost solids-liquid separation		2960	30			
O+M cost supernatant treatment		840	8			
Total without land cost		5947	**59**			
Land (1.5*net surface: 1,800 m2)		1734	17			
Total with land cost		7682	**77**			
Remarks:						
costs relating only to FS, it is assumed that 10 % of L1+L2 are imputable to FS, 90 % to sewage						
land estimation: 1.5*net area = 1.5*(2*25*11[C1+C2]+0.1*83*57[10% of L1]+0.1*38*53[10% of L2])						
land prize about 6-20 US$/m2; CIS, Rosario (2002)						
interest rate 6% (2001), 36% (2002)! CIS, Rosario (2002)						
reference: Ingallinella et al. (2000)						

A 1.5 Cost overview of planned settling/thickening tanks and WSP in Bamako (after Jeuland 2002)

Original values in [FCFA], US$ 1 = 655 FCFA (July 2002)

							Fonctionnement	***Historique***	***An 1***	***An 2***	***An 3***
Bassins			[FCFA]		[US$]		Employés du GIE	540000	990000	2970000	4410000
Préparation terrain	4124.06 m2	270	1113669		1700.25802		Technicien	0	180000	720000	720000
Fouilles	4633.2 m3	1750	8108100		12378.7786		Gardien	0	270000	270000	270000
Béton armé	64.06	150000	9609000		14670.229		Main d'œuvre simple	0	0	0	1080000
Canalisations			2000000		3053.43511		Homologue du volontaire	540000	540000	540000	540000
Bâtiments + annexes							Planification et consultants (ingénieur + architec	3000000	4324480	3000000	3000000
Toilettes	2	370000	740000		1129.77099		Formations (compostage, tech.)	0	0	660000	0
Maison gardien			1485000		2267.17557		***Total***	**4080000**	**6304480**	**8160000**	**10020000**
Sludge storage											
Hangar			6500000		9923.66412		***DEPENSES***	***Historique***	***Année 1***	***Année 2***	***Année 3***
Magasin de compost			4291813		6552.38626		Imprévus	0			
Aménagement du terrain					0		Frais administratifs	0			
Routes			648500		990.076336		Marketing / promotion				
Zones de cultures			325000		496.183206		Questionnaires	0	5000	5000	5000
Reboisement	1 200	1250	1500000		2290.07634		Transparents	0	7000	0	0
Clôture	1 050 m	5500	5775000		8816.79389		Radiodiffusion	0	15000	15000	15000
Frais d'étude			2092043		3193.95878		(30% compost)				
Etude de topographie			700000		1068.70229		***Total***	**0**	**27000**	**20000**	**20000**
TOTAL			**44888125**		**68531.4885**						

A 1.6 Operation and maintenance estimates

O+M cost Drying beds, WRI, Accra

	unit	unit price [US$]	quantity	cost [US$]
Sludge removal and further storage (removal 1 $ and transport 0.5 $)	[m3]	1.5	20	30
Replenishment of sand (for times per year and bed a layer of 10 cm), sand included in prize	[m3] of replaced sand	3	10	30
dewatered sludge handling	[m3] of final organic waste	2.0	20	40
Contingences	sum			50
Total				**150**

O+M cost Settling/thickening tanks and WSP, Teshie, Accra

	unit	unit price [US$]	quantity	cost [US$]
Sludge removal by front loader (10 cycles each tank, have a day truck hiring per empting operation)	[days]	200	10	2000
Pond sludge removal (approx. every 5 years)	[sum]			600
Labour	[worker]	4	1'000	4000
General repairs and equipement	[sum]			500
Contingences (10%)	[sum]			700
Total				**7'800**

O+M cost Settling/thickening tanks and WSP, Cotonou

	unit	unit price [US$]	quantity	cost [US$]
Sludge removal by front loader (10 cycles each tank, half a day truck hiring per empting operation)	[days]	200	30	6000
Pond sludge removal (approx. every 5 years)	[sum]			2000
Providing of rice husk	[sum]			10000
Truck for dewatered sludge handling	[days]	200	10	2000
Labour	[worker]	16	1'000	16000
General repairs and equipement	[sum]			5000
Contingences (10%)	[sum]			4'000
Total				**45'000**

A 2 DETAILS OF THE UP-SCALING PROCESS OF THE CO-COMPOSTING TREATMENT PLANT, KUMASI

A 2.1 Design features of the up-scaled co-composting FSTP treating 5,000 m^3 FS per year (corresponding to 125 t TS)

Item	Design
General	Same site office as pilot plant, including insurances and material testing.
Site clearance	About 3,500 m^2 (drying beds 600, composting area 1,500, waste sorting area 200 multiplied by a 1.5 factor).
Sludge discharge area and screen	3 to 4 trucks daily, thus one ramp of the same size and cost as the pilot plant is designed.
Sludge storage tank	Not foreseen, as sludge is loaded regularly onto the drying beds.
Splitting chamber and pipework	3 splitting chambers to distribute FS in each bed. About 200 m of inter-unit and percolate disposal connections.
Sludge drying beds	5 beds, each 11x11 m (0.8 m deep), 10-cm sand layer, 30 cm layer of aggregate, loading rate about 200 kg TS/m^2·y.
Dried sludge storage area	4x4 m area is foreseen and sufficient for about two dewatered sludge loads.
Solid waste handling area (waste dumping, sorting, storage of inorganic waste)	About 250 m^3 of solid waste (50% organic content) has to be sorted monthly, about 12 m^3 of organic waste are required per drying bed load. A 300 m^2 (15x20 m) area should be large enough.
Composting area	Composting of about 160 to 180 m^3 per month (10 to 12 bed loads of 4 m^3 dried FS and 12 m^3 waste): 10 heaps, each 2.5x9 m (height of pyramid 1.5 m), total 20 heap areas to allow compost turning. Maturation of about 80 to 90 m^3 of compost (50% volume reduction during composting): 10 heaps, each 2x10 m (height of pyramid 1-1.5 m, depending on maturation period). Screening and bagging area: 10x20 m. Total composting area about 1,500 m^2.
Percolate storage tank	Tank 6x9 m (1.5 m depth), enough to retain percolate of about 5 days, if it can be used to water the heaps.
Percolate post-treatment	This process step has not been designed for lack of information (pilot plant treats percolate in the adjacent full-scale FSTP for which no cost data are available).

A 2.2 Design features of the up-scaled co-composting FSTP treating 25,000 m³ FS per year (corresponding to 625 t TS)

Item	Design
General	Site office is double the size of the pilot plant; including insurance and material testing.
Site clearance	About 15,000 m^2 (drying beds 3,000; composting area 6,000; waste sorting area 1,000; multiplied by a 1.5 factor).
Sludge discharge area	Approximately 20 trucks daily, 6 ramps (only two are used daily to load a bed directly) + 3 screens.
Sludge storage tank screen	No sludge storage tank is foreseen; all the daily sludge is loaded onto the same bed.
Splitting chamber and pipework	3 splitting chambers to distribute FS in each bed. About 350 m of inter-unit and percolate disposal connections.
Sludge drying beds	9 beds, each 17x20 m (0.8 m deep), 10 cm sand layer, 30 cm layer of aggregate, loading rate about 200 kg $TS/m^2 \cdot y$.
Dried sludge storage area	6x6 m area is foreseen and sufficient for about two dewatered sludge loads (sludge stock for two days).
Solid waste handling area	24-m^3 organic waste has to be sorted daily (corresponding to about 50 m^3 solid waste), approximately 850 m^3 sorted every month, therefore a 1,000 m^2 (40x25 m) area should be large enough.
Composting area	Composting of about 850 m^3 per month (27 bed loads of 8 m^3 dried FS and 24 m^3 organic waste): 10 heaps, each 3x40 m (height of pyramid 1.5 m), total 20 heap areas to allow compost turning. Maturation of about 600 m^3 of compost (1.5 month maturation; 50% volume reduction during composting): 20 heaps, each 2x20 m (height of pyramid 1-1.5m depending on maturation period). Screening and bagging area: 20x50 m. Total composting area about 6,000 m^2.
Percolate storage tank	Two tanks, each 10x8 m (1.5 m deep), enough to retain percolate of about 3 days.
Percolate post-treatment	This process step has not been designed for lack of information (pilot plant treats percolate in the adjacent full-scale FSTP for which no cost data are available).

A 2.3 Detailed quotations of all co-composting treatment plants

Plant size (annual capacity)			Pilot plant (12.5 t TS)		Full-scale plant (125 t TS)		Full-scale plant (625 t TS)	
	Unit price	Unit	Quantity	Amount	Quantity	Amount	Quantity	Amount
General items								
Site office		sum	1	4325	1	4325	2	8650
Insurances		sum		540		2500		10'000
Material testing, first aid box		sum		304		350		500
Water for works		sum		336		1500		5000
				5505		**8675**		**24150**
Site clearance								
General clearance of site	6	100 m2	9	54	35	210	150	900
				54		**210**		**900**
Discharge bay (Tipping platform and stopping block)								
Provision of concrete	60	m3	8.27	496		one		six
Placing of concrete	5	m3	8.27	41		discharge		discharge
Mild steel reinforcement bars	0.7	kg	286.2	200		bay		bays
Formwork	2	m2	7.8	16				
				753		**753**		**4518**
Sludge storage tank								
Excavate tank (1.5m)	1.8	m3	22.5	41				
Provision of concrete	60	m3	8.4	504				
Placing of concrete incl. built in ends of pipes	5.7	m3	8.4	48				
Mild steel reinforcement bars	0.7	kg	782	547				
Formwork	2	m2	46	92				
Wooden stock	1	no.	7	7				
				1239		**0**		**0**
Pipework and splitting chamber								
Fixtures for sludge storage tank		sum	1	110	2	220	0	0
Inter-unit and leachate disposal connections (300mm PVC)	13	m	8.5	111	130	1690	400	5200
Splitting chamber	60	no.	1	60	3	180	3	180
				281		**2090**		**5380**

Plant size (annual capacity)			Pilot plant (12.5 t TS)		Full-scale plant (125 t TS)		Full-scale plant (625 t TS)	
	Unit price	Unit	Quantity	Amount	Quantity	Amount	Quantity	Amount
Sludge drying beds								
Excavate foundation (0.2m)	0.85	m3	12	10	121	103	612	520
Provision of concrete	60	m3	20	1200	165	9900	745	44700
Mild steel reinforcement bars	0.7	kg	800	560	6600	4620	29800	20860
Placing of concrete incl. drains	5.7	m3	21	120	165	941	745	4247
Formwork	2	m2	29	58	175	350	533	1066
Wooden stock	7	no.	2	14	5	35	9	63
100 mm thick coarse sand	4	m3	6	24	60	240	305	1220
100 mm thick coarse aggregate	15	m3	6	90	60	900	305	4575
200 mm thick coarse aggregate	15	m3	12	180	120	1800	610	9150
				2256		**18888**		**86401**
Solide waste handling area								
Excavate foundation (0.25m)	0.85	m3	15	13	65	55	765	650
Provision of concrete	60	m3	13.36	802	60	3600	200	12000
Placing of concrete incl. built in ends of pipes	5	m3	13.36	67	60	300	200	1000
Mild steel reinforcement bars	0.7	kg	526.5	369	2350	1645	7880	5516
Formwork	2	m2	7	14	15	30	26	52
				1264		**5630**		**19218**
Composting area								
Excavate foundation and drains (0.25 m deep)	0.85	m3	49.5	42	375	319	1500	1275
Provision of concrete	60	m3	43.85	2631	300	18000	1200	72000
Placing of concrete incl. built in ends of pipes	5	m3	43	215	300	1500	1200	6000
Mild steel reinforcement bars	0.7	kg	1800	1260	12000	8400	47500	33250
Formwork	2	m2	13	26	44	88	70	140
				4174		**28307**		**112665**
Dried sludge storage area								
Excavate foundation (0.25 m deep)	0.85	m3	0.6	1	4	3	9	8
Provision of concrete	60	m3	0.5	30	3	180	7	420
Placing of concrete	5	m3	0.5	3	3	15	7	35
Mild steel reinforcement bars	0.7	kg	49	34	200	140	300	210
Formwork	2	m2	1.5	3	4	8	6	12
				70		**346**		**685**

Plant size (annual capacity)			Pilot plant (12.5 t TS)		Full-scale plant (125 t TS)		Full-scale plant (625 t TS)	
	Unit price	Unit	Quantity	Amount	Quantity	Amount	Quantity	Amount
Roofing materials								
Aluminium	6.65	m2	235	1563	1500	9975	6000	39900
Sawn hardwood	1.2	m	834	1001	5300	6360	20000	24000
Joinery	1.3	m	64	83	400	520	1600	2080
				2564		**16855**		**65980**
Percolate storage tank								
Excavate tank (1.5 deep)	1.8	m3	15	27	80	144	240	432
Provision of concrete	60	m3	5.6	336	22	1320	58	3480
Placing of concrete (base and walls, 0.25 m thick)	5.5	m3	5.7	31	22	121	58	319
Mild steel reinforcement bars	0.7	kg	521	365	2010	1407	5220	3654
Formwork	2	m2	30.7	61	100	200	400	800
Cut-off drain to divert storm water		sum	1	216	2	432	4	864
Drain from percolate tank to facultative pond		sum		277		277		277
				1313		**3901**		**9826**
Daywork								
Labour	235	manhour		369		1500		5000
Materials				370		1500		6000
Contractor's equipment				185		600		1500
40% of sub-total for constractor's overhead, profit, etc.				370		2400		5000
				1294		**6000**		**17500**
Contingences								
10% of construction cost (without daywork) for contingences				**1947**		**8566**		**32972**
TOTAL				**22714**		**100221**		**380195**

A 2.4 O+M estimates for the co-composting plants

Operation and Maintenance cost			Pilot plant (500 m3 FS)		Full-scale (5,000 m3 FS)		Full-scale (25,000 m3 FS)	
	unit	unit price [US$]	quantity	cost [US$]	quantity	cost [US$]	quantity	cost [US$]
Sludge removal and transport to composting area (removal [3h/m3] 1 $ and transport 1 $)	[m3]	2	50	100	500	1000	2500	5000
Replenishment of sand (for times per year and bed a layer of 10 cm), sand included in prize	[m3] of replaced sand	3.0	25	75	250	750	1'250	3'750
Waste sorting (~10 h/m3) and transport to composting area	[m3] of final organic waste	3.5	150	525	1'500	5'250	7'500	26'250
Compost turning (every third days) including watering, heaping, removal to maturation heaps (5 h/m3)	[m3] of initial composted material	1.5	200	300	2'000	3'000	10'000	15'000
Compost screening and bagging (3 h/m3)	[m3] of final compost	1	100	100	1'000	1'000	5'000	5'000
Cleaning screen and storage tank, contigencies (desinfectant, masks, etc.), general repairs	sum			200		2'000		10'000
Salary plant manager	[US$]	1'000	0.5	500	1	1'000	1	1'000
Total				**1'800**		**14'000**		**66'000**

A 2.5 Summary of capital and O+M cost for different plant sizes

Construction and O+M cost, without percolate polishing						
12.5 t TS/year				[US$]	[US$/year]	[US$/t TS]
Construction				22'700	2'187	175
O+M				-	1'800	144
Total					3'987	**319**
125 t TS/year				[US$]	[US$/year]	[US$/t TS]
Construction				100'221	9'656	77
O+M				-	14'000	112
Total					23'656	**189**
625 t TS/year				[US$]	[US$/year]	[US$/t TS]
Construction				380'195	36'629	59
O+M				-	66'000	106
Total					102'629	**164**
Economy of scale: plant for 500 t TS/year						
Economic of scale formula application:						
Po	Co	P1	C1	a	alpha	
380000	625	317874	500	2203.33	0.8	
				[US$]	[US$/year]	[US$/t TS]
Construction (without polishing)				317'874		
Construction facultative pond				15'000		
Construction (with polishing)				333'000	32'082	64
O+M				-	54'000	108
Total					86'082	**172**

A 3 COMPARISON OF THREE STANDARD-SIZE FSTP

A 3.1 Design layout

Solids/liquid separation				
	unit	**settling/ thickening tank**	**settling ponds (anaerobic pond)**	**Constructed wetlands**
BOD influent	[mg/l]	4'000	4'000	4'000
BOD removal efficiency	[%]	50	70	85
Number treatment units	[nb of unit]	2 (parallel)	2 (parallel)	6
FS loading per unit	[m3/year]	10'000	10'000	3300
Approximately daily FS loading	[m3/day]	60	60	-
Loading cycles	-	6 cycles, 1 month loading, 1 month consolidation	continous, yearly sludge emptying	1 loading/week for each unit; sludge empting every 2-5 years
Sludge accumulation rate	[m3/m3]	0.1	0.1	0.03
Accumulated sludge per loading cycle and per unit	[m3]	167	1'000	2
Chosen sludge depth	[m]	1	1	1
Surface bottom per unit (5x32m)	[m2]	160	-	-
Access ramp slope (3m:10m)	[%]	30	-	-
Chosen width	[m]	5	30 top / 10 bottom	19
Chosen length	[m]	42 top / 32 bottom	60 top / 40 bottom	18
TS loading rate	[kg TS/m2.yr]	1200	180	250
Volume per unit (with freebord)	[m3]	555	2'025	545
Volumetric BOD load per unit	[kg/day]	-	120	-
Chosen permissible BOD volumetric load	[kg/m3.day]	-	0.25	-
Volume for BOD elimination	[m3]	-	480	-
Tank depth (scum 0.8, clear zone 0.5, separation zone 0.5, storage zone 1.0, freebord 0.2)	[m]	3	-	-
Ponds depth (2.0 sludge storage, 0.8 BOD removal and scum, 0.2 freebord)	[m]	-	3	-
Wetland depth (freebord for sludge 1.0, sand 0.1 and gravel 0.2, drainage 0.3)	[m]	-	-	1.6
Net surface per unit	[m2]	210	1375	2'000
Anaerobic pond				
BOD influent (tank effluent)	[mg/l]	2000	-	-
BOD removal efficieny	[%]	70	-	-
Number of anaerobic ponds	[nb]	1	-	-
Volumetric BOD load	[kg/day]	120	-	-
Chosen permissible BOD volumetric load	[kg/m3.day]	0.25	-	-
Volume for BOD elimination	[m3]	480	-	-
Sludge accumulation rate	[m3/m3]	0.025	-	-
Accumulated sludge per year (yearly emptying)	[m3]	500	-	-
Length (bottom/middle/top)	[m]	24/34/44	-	-
Width (bottom/middle/top)	[m]	5/15/25	-	-
depth (1.0 sludge storage, 1.0 BOD removal, 0.5 freebord)	[m]	2.5	-	-

Facultative pond				
		settling/ thickening tank	**settling ponds (anaerobic pond)**	**Constructed wetlands**
First facultative pond				
BOD influent (anaerobic pond effluent)	[mg/l]	600	1200	600
BOD removal efficieny	[%]	80	80	80
BOD load (20,000 m3 per year)	[kg/day]	36	72	36
Chosen permissible BOD loading rate	[kg/m2.day]	0.035	0.035	0.035
Needed surface area	[m2]	1029	2057	1029
Chosen depth	[m]	1.5	1.5	1.5
Chosen length (bottom/middle/top)	[m]	65/70/75	95/100/105	65/70/75
Chosen width (bottom/middle/top)	[m]	10/15/20	15/20/25	10/15/20
BOD effluent	[mg/l]	120	240	120
Retention time	[days]	22	43	22
Second facultative pond				
BOD load	[kg/day]	-	14.4	-
Needed surface area	[m2]	-	411	-
Chosen length	[m]	-	35/40/45	-
Chosen width	[m]	-	5/10/15	-
BOD effluent	[mg/l]		50	
Land requirement				
Primary treatment	[m2]	420	2750	2000
Anaerobic ponds	[m2]	1100	0	0
Facultative ponds	[m2]	1500	3300	1500
Sludge stockage area	[m2]	900	750	0
Total net land (treatment and sludge storage)	[m2]	3920	6800	3500
Specific land requirement (without sludge storage)	[m2/t TS]	6	12	7
Land requirement solids-liquid separation		0.8	5.5	4.0
Land requirement effluent polishing	[m2/t TS]	5.2	6.6	3.0
Land requirement biosolid treatment	[m2/t TS]	1.8	1.5	0
Dewatered sludge composting/stockage area				
Accumulated sludge	[m3/year]	2500	2'000	600
Quantity of sawdust	[m3/year]	1000	800	-
Monthly sludge and sawdust volume (10 composting cycles)	[m3]	350	280	-
Net area needed (windrows of 3 width and 1.5 higth, one month stockage)	[m2]	450	375	-
Effective area needed for windrows (2*net area)	[m2]	900	750	-

A 3.2 Quotations settling/thickening tank and WSP

Quotation settling/thickening tank + anaerobic pond + facultative pond	Unit	Unit price [US$]	Quantity	Amount [US$]
General items				
Site office	sum		1	7'000
Insurances	sum			2'500
Material testing, first aid box	sum			500
Water for works	sum			2'000
				12'000
Site clearance				
General clearance of site (2* net area)	100 m2	6	66	396
				396
2 discharge bay (Tipping platform and stopping block)				
Provision of concrete (2*(5m*8m) à 0.2 m & chutes)	m3	60	20	1'200
Placing of concrete	m3	5	20	100
Mild steel reinforcement bars	kg	0.7	700	490
Formwork (border and screen chute)	m2	2	24	48
Screen (steel bars)	sum	50	2	100
				1'938
Pipework				
Clutches for discharge bay and settling tanks	sum	50	4	200
Inter-unit and leachate disposal connections (300mm PVC)	m	13	120	1'560
				1'760
2 Settling/thickening tank (42x5m)				
Excavate foundation (3.5 m deep) 2*(32*5.5*3.5+10*5.5*3.5/2)	m3	3	1'400	4'200
Provision of concrete 2*((32*5+10*5+(2*32+5)*3)*0.2m)	m3	60	170	10'200
Placing of concrete	m3	6	170	1'020
Mild steel reinforcement bars	kg	0.7	6'800	4'760
Formwork	m2	2	850	1'700
				21'880
Anaerobic pond A1 (15x34m)				
Excavate foundation (3 m deep) (15.5*34.5*3)	m3	3	1'600	4'800
Provision of concrete (only upper border (1.5m) is concreted, 0.2 m	m3	60	40	2'400
Placing of concrete (border plus ramp)	m3	5	40	200
Mild steel reinforcement bars	kg	0.7	1'600	1'120
Formwork	m2	2	200	400
Clay for bottom (0.2 m layer)	m3	10	130	1'300
				10'220
Facultative pond F1 (15x70m)				
Excavate foundation (70.5*15.5*2)	m3	3	2'200	6'600
Provision of concrete ((70+15)*2*1.5*0.2+10(ramp))	m3	60	56	3'360
Placing of concrete (border is concreted)	m3	5	56	280
Mild steel reinforcement bars	kg	0.7	2'240	1'568
Formwork	m2	2	300	600
Clay for bottom (0.2 m layer)	m3	10	240	2'400
				14'808
Dewatered sludge stockage area				
Excavate foundation (0.25 m deep, 900m2)	m3	0.85	225	191
Provision of concrete (0.1 m thick layer)	m3	60	90	5'400
Placing of concrete	m3	5	90	450
Mild steel reinforcement bars	kg	0.7	3'600	2'520
Formwork	m2	2	33	66
				8'627
Roofing materials				
Aluminium material	m2	6.65	900	5'985
Sawn hardwood	m	1.2	2'000	2'400
Joinery	m	1.3	200	260
				8'645
Road work				
Paving stone and road work	sum			**10'000**
Daywork				
Labour	manhour	235		1'000
Materials				1'500
Contractor's equipment				500
40% of sub-total for constractor's overhead, profit, etc.				1'200
				4'200
Contingences				
10% of construction cost (without daywork) for contingences				**9'027**
TOTAL				**103'502**

A 3.3 Quotation settling ponds and WSP

Quotation settling ponds + 2 facultative ponds	Unit price [US$]	Unit	Quantity	Amount [US$]
General items				
Site office	sum		1	7'000
Insurances	sum			2'500
Material testing, first aid box	sum			500
Water for works	sum			2'000
				12'000
Site clearance				
General clearance of site (2* net area)	100 m2	6	126	756
				756
2 Discharge bays (Tipping platform and stopping block)				
Provision of concrete (2*(5m*8m) à 0.2 m & chutes)	m3	60	20	1'200
Placing of concrete	m3	5	20	100
Mild steel reinforcement bars	kg	0.7	700	490
Formwork (border and screen chute)	m2	2	24	48
Screen (steel bars)	sum	50	2	100
				1'938
Pipework				
Clutches for discharge bay and settling ponds	sum	50	4	200
Inter-unit and leachate disposal connections (300mm PVC)	m	13	120	1'560
				1'760
2 Settling ponds (55x25m)				
Excavate foundation (3.0 m deep) 2*(50.5*20.5*3)	m3	3	4'230	12'690
Provision of concrete (2*((55+25)*2*1.5*0.2m)+ramp(12))	m3	60	60	3'600
Placing of concrete	m3	6	60	360
Mild steel reinforcement bars	kg	0.7	2'400	1'680
Formwork	m2	2	120	240
Clay for bottom (0.2 m layer)	m3	10	320	3'200
				21'770
Facultative pond F1 (20x100m)				
Excavate foundation (2 m deep) (20.5*100.5*1.5)	m3	3	3'100	9'300
Provision of concrete (only border 1.5m, 2*(100+20)*1.5*0.2)	m3	60	72	4'320
Placing of concrete (border plus ramp)	m3	5	72	360
Mild steel reinforcement bars	kg	0.7	2'880	2'016
Formwork	m2	2	360	720
Clay for bottom (0.2 m layer)	m3	10	400	4'000
				20'716
Facultative pond F2 (10x40m)				
Excavate foundation (10.5*40.5*2)	m3	3	850	2'550
Provision of concrete ((10+40)*2*1.5*0.2+5(ramp))	m3	60	35	2'100
Placing of concrete	m3	5	35	175
Mild steel reinforcement bars	kg	0.7	1'400	980
Formwork	m2	2	150	300
Clay for bottom (0.2 m layer)	m3	10	100	1'000
				7'105
Dewatered sludge stockage area				
Excavate foundation (0.25 m deep, 750m2)	m3	0.85	188	160
Provision of concrete (0.1 m thick layer)	m3	60	75	4'500
Placing of concrete	m3	5	75	375
Mild steel reinforcement bars	kg	0.7	3'000	2'100
Formwork	m2	2	22	44
				7'179
Roofing materials				
Aluminium material	m2	6.65	750	4'988
Sawn hardwood	m	1.2	1'600	1'920
Joinery	m	1.3	160	208
				7'116
Road work				
Paving stone and road work	sum			**10'000**
Daywork				
Labour	manhour	235		1'000
Materials				1'500
Contractor's equipment				500
40% of sub-total for constractor's overhead, profit, etc.				1'200
				4'200
Contingences				
10% of construction cost (without daywork) for contingences				**9'034**
TOTAL				**103'573**

A 3.4 Quotation constructed wetlands and WSP

Quotation constructed wetlands + facultative pond	Unit	Unit price [US$]	Quantity	Amount [US$]
General items				
Site office	sum		1	7'000
Insurances	sum			2'500
Material testing, first aid box	sum			500
Water for works	sum			2'000
				12'000
Site clearance				
General clearance of site (2* net area)	100 m2	6	70	420
				420
2 Discharge bays (Tipping platform and stopping block)				
Provision of concrete (2*(5m*8m) à 0.2 m & chutes)	m3	60	20	1'200
Placing of concrete	m3	5	20	100
Mild steel reinforcement bars	kg	0.7	700	490
Formwork (border and screen chute)	m2	2	24	48
Screen (steel bars)	sum	50	2	100
				1'938
Pipework and splitting chamber				
Clutches for discharge bay and CW	sum	50	8	400
Inter-unit and leachate disposal connections (300mm PVC)	m	13	450	5'850
Splitting chamber	no.	60	4	240
				6'490
6 Constructed wetlands (18x19m)				
Excavate foundation (2 m deep) 6*(18.5*19.5*2)	m3	3	4'330	12'990
Provision of concrete 6*(18*19+2*(18+19)*1.6)	m3	60	550	33'000
Placing of concrete	m3	6	550	3'300
Mild steel reinforcement bars	kg	0.7	22'000	15'400
Formwork	m2	2	460	920
Sand layer (10 cm)	m3	4	200	800
Gravel layer (20+30 cm)	m3	15	1'000	15'000
Cattail	sum			600
				82'010
Facultative pond F1 (15x70m)				
Excavate foundation (70.5*15.5*2)	m3	3	2'200	6'600
Provision of concrete ((70+15)*2*1.5*0.2+10(ramp))	m3	60	56	3'360
Placing of concrete (border is concreted)	m3	5	56	280
Mild steel reinforcement bars	kg	0.7	2'240	1'568
Formwork	m2	2	300	600
Clay for bottom (0.2 m layer)	m3	10	240	2'400
				14'808
Road work				
Paving stone and road work	sum			10'000
				10'000
Daywork				
Labour	manhour	235		1'000
Materials				2'000
Contractor's equipment				1'000
40% of sub-total for constractor's overhead, profit, etc.				1'600
				5'600
Contingences				
10% of construction cost (without daywork) for contingences				**12'767**
TOTAL				**146'033**

A 3.5 O+M estimation of the three FSTP

O+M cost settling/thickening tank + A1 + F1

	unit	unit price [US$]	quantity	cost [US$]
Sludge loading survey and chute cleaning	sum			500
Sludge removal and further storage (2500 m3 sludge and 1000 m3 sawdust; 1.5 $/m3 truck hiring and labour)	[m3]	1.5	3500	5'200
Pond sludge removal (approx. every 5 years)	sum			300
Procurement of sawdust	[m3]	1	1'000	1000
Dewatered sludge handling	[m3]	1.0	3'500	3500
General repairs and equipment	sum			750
Contingences (10%)	sum			1'000
Total				**12'250**

O+M cost settling ponds + F1 + F2

	unit	unit price [US$]	quantity	cost [US$]
Sludge loading survey and chute cleaning	sum			500
Sludge removal and further storage (2000 m3 sludge and 800 m3 sawdust; 1.5 $/m3 truck hiring and labour)	[m3]	1.5	2800	4200
Pond sludge removal (approx. every 5 years)	sum			700
Procurement of sawdust	[m3]	1	800	800
Dewatered sludge handling	[m3]	1.0	2'800	2800
General repairs and equipment	sum			750
Contingences (10%)	sum			1'000
Total				**10'750**

O+M cost constructed wetlands + F1

	unit	unit price [US$]	quantity	cost [US$]
Sludge loading survey and chamber and chute cleaning	sum			1000
Sludge removal (supposed to occur every 2 years)	[m3]	2	600	1200
Bed replenishment after sludge removal	[m3]	5	200	1000
Pond sludge removal (approx. every 5 years)	sum			300
Cattail harvest (once to twice per year)	sum			200
General repairs and equipement	sum			1500
Contingences (10%)	sum			500
Total				**5'700**

A 3.6 Summary of capital and O+M cost per t TS

Capital and O+M cost of selcted treatment options in Ghana				
		settling/ thickening tank	**settling pond**	**CW**
TS load	[t TS/yr]	500	500	500
Depreciation period	[years]	15	15	15
Interest rate	[%]	5	5	5
Construction costs	[US$]	103'500	103'500	146'000
Annualised capital cost	[US$/yr]	**9'971**	**9'971**	**14'066**
Land requirement	[m2]	5'880	10200	5250
Assumed land prize	[$/m2]	0.5	0.5	0.5
Land cost	[US$]	2'940	5'100	2'625
Capital cost land	[US$/yr]	**283**	**491**	**253**
O+M cost	[US$/yr]	**12'250**	**10'750**	**5'700**
Annual cost per t TS				
Captial cost	[US$/t TS]	19.9	19.9	28.0
O+M cost	[US$/t TS]	24.5	21.5	11.4
Total (without land)	**[US$/t TS]**	**44**	**41**	**39**
Land (0.5 US$/m2)	[US$/t TS]	0.6	1.0	0.5
Total with land (0.5 $/m2)	**[US$/t TS]**	**45**	**42**	**40**

A 4 CO-COMPOSTING VS. SEPARATE FS AND SOLID WASTE TREATMENT

A 4.1 O+M cost of drying beds (issued from the co-composting plant)

5.1.3 Operation and Maintenance cost, only FS treatment			Full-scale plant (20,000 m^3 FS/year)	
Item	unit	unit price [US$]	quantity	cost [US$]
Sludge removal and transport to composting area (removal [3h/m3] 1 $ and transport 1 $)	[m3]	2	2000	4000
Replenishment of sand (for times per year and bed a layer of 10 cm), sand included in prize	[m3] of replaced sand	3.0	1'000	3000
Waste sorting (~10 h/m3) and transport to composting area	[m3] of final organic waste	3.5	0	0
Compost turning (every third days) including watering, heaping, removal to maturation heaps (5 h/m3)	[m3] of initial composted material	1.5	0	0
Biosolids screening and bagging (3 h/m3)	[m3] of final compost	1	1'000	1000
Cleaning screen and storage tank, contigencies (desinfectant, masks, etc.), general repairs	sum			3'500
Salary plant manager	[US$]	1'000	0.5	500
Total				12'000

A 4.2 Quotation of a full-scale composting plant, treating 6,000 m^3 of organic waste per year (corresponding to 500 t TS of FS in relation to the co-composting plant)

	Unit price [US$]	Unit	Quantity	Amount [US$]
General items				
Site office		sum	2	5'000
Insurances		sum		5'000
Material testing, first aid box		sum		500
Water for works		sum		3'000
				13'500
Site clearance				
General clearance of site	6	100 m2	75	450
				450
Solide waste handling area				
Excavate foundation (0.25m)	0.85	m3	765	650
Provision of concrete	60	m3	200	12'000
Placing of concrete incl. built in ends of pipes	5	m3	200	1'000
Mild steel reinforcement bars	0.7	kg	7880	5'516
Formwork	2	m2	26	52
				19'218
Composting area				
Excavate foundation and drains (0.25 m deep)	0.85	m3	1500	1'275
Provision of concrete	60	m3	1200	72'000
Placing of concrete incl. built in ends of pipes	5	m3	1200	6'000
Mild steel reinforcement bars	0.7	kg	47500	33'250
Formwork	2	m2	70	140
				112'665
Roofing materials				
Aluminium	6.65	m2	6000	39'900
Sawn hardwood	1.2	m	20000	24'000
Joinery	1.3	m	1600	2'080
				65'980
Percolate storage tank				
Excavate tank (1.5 deep)	1.8	m3	240	432
Provision of concrete	60	m3	58	3'480
Placing of concrete (base and walls, 0.25 m thick)	5.5	m3	58	319
Mild steel reinforcement bars	0.7	kg	5220	3'654
Formwork	2	m2	400	800
Drain		sum		277
				8'962
Daywork				
Labour	235	manhour		5'000
Materials				6'000
Contractor's equipment				1'500
40% of sub-total for constractor's overhead, profit, etc.				5'000
				17'500
Contingences				
10% of construction cost (without daywork) for contingences				**22'078**
TOTAL				**260'353**

A 4.3 O+M cost of the designed composting plant (annual capacity of 6,000 m^3 organic waste)

Operation and Maintenance cost

	unit	unit price [US$]	quantity	cost [US$]
Waste sorting (~10 h/m3) and transport to composting area	[m3] of final organic waste	3.5	6'000	21'000
Compost turning (every third days) including watering, heaping, removal to maturation heaps (5 h/m3)	[m3] of initial composted material	1.5	6'000	9'000
Compost screening and bagging (3 h/m3)	[m3] of final compost	1	3'000	3'000
Contigencies (desinfectant, masks, repairs, etc.)	sum			4'000
Total				**37'000**

A 4.4 Capital and O+M cost comparison of co-composting and separate FS and solid waste treatment

Capital and O+M cost comparison of co-composting and separate FS and solid waste treatment					
	Unit	**Composting**	**FS treatment with drying beds**	**Sum of separate FS and waste treatment**	**Co-composting**
Annual load	[t TS FS] / [m3 organic waste]	- / 6,000	500 / -	500 / 6,000	500 / 6,000
Construction cost *	[US$]	260'000	158'000	418'000	333'000
Annualised capital cost	[US$/yr]	**25'049**	**15'222**	**40'271**	**32'082**
O+M cost	[US$/yr]	**37'000**	**12'000**	**49'000**	**54'000**
Annual cost per t TS					
Capital cost	[US$/t TS]	50	30	80	64
O+M cost	[US$/t TS]	74	24	98	108
Total (without land)	**[US$/t TS]**	**124**	**54**	**178**	**172**

* FS treatment with drying beds cost corresponds to 45% from co-composting plant + US$ 15,000 for facultative pond (0.45*318,000 + 15,000)

Cost of co-composting plant: 318,000 (downscaled to a capacity of 500 t TS) + 15,000 (facultative pond)

A 5 HAULAGE COST AND IDEAL PLANT SIZE CALCULATION SUMMARY

A 5.1 Km-dependant and truck capital cost

Basic data:		200 inh./ha
Population density	[inh./km2]	20000
Served population	[inh.]	100'000
Average distance, go and back	[km]	1.78
Additional distance	[km]	0.00
Truck km cost		0.5
Truck capacity	[m3]	8
Average speed	[km/h]	10
Salary (driver + worker)	[$/h]	2
Average TS content	[g/L]	25
Haulage cost	[$/t TS]	**6.2**
Truck volume	[m3]	8
Price of one truck	[$]	20'000
Yearly collected volume	[m3]	6000
TS content	[g/L]	25
Life time	[years]	10
Interest rate	[%]	5
Cap cost per truck	[$/yr]	2590
TS transported per truck	[t]	150
Annual cap cost per t TS	[$]	**17.3**

A 5.2 Up and downscale from the Buobai settling pond FSTP with corresponding specific haulage costs (an additional distance were added to theoretic distance) to estimate ideal plant size

Plant capacity [PE]	addi dist. (go and back) [km]	Haulage cost [US$/t TS]	Truck cost [US$/t TS]	Total haulage cost [US$/t TS]	Plant capacity [t TS/y]	Captial cost treatment [US$]	Captial cost [US$/t TS]	Total cost [US$/t TS]
1'000	3	11.1	17	28	5	4381	84	113
5'000	3.5	13.6	17	31	25	15876	61	92
10'000	4	16.0	17	33	50	27641	53	87
15'000	4.5	18.2	17	35	75	38232	49	85
20'000	5	20.3	17	38	100	48126	46	84
100'000	6	27.2	17	45	500	174402	34	78
200'000	7	33.3	17	51	1000	303652	29	80
300'000	8	38.8	17	56	1500	420000	27	83
500'000	9	45.5	17	63	2500	632016	24	87
1'000'000	10	54.7	17	72	5000	1100404	21	93