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DEVELOPMENT OF COST FUNCTIONS FOR SANITATION SYSTEMS FOR THE CLARA SIMPLIFIED PLANNING TOOL

Master thesis

submitted for the degree of

Diplomingenieur

by

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Abstract

Laut aktuellen Berichten werden mehrere afrikanische Länder die Millennium-Entwicklungsziele der Vereinten Nationen in Bezug auf Trinkwasser und Versorgung mit Sanitären Anlagen bei der Fortsetzung des derzeitigen Trends nicht erreichen. Das vereinfachte Planungsprogramm des CLARA Projekts ist ein objektives und umfassendes Instrument zur Kostenvergleichsberechnung und liefert einen Beitrag zum Erreichen der Millennium-Entwicklungszielvorgaben, indem es Entscheidungsträger und Planer unterstützt und ihre Wissensdefizite bei der Vorgehensweise von Problemen im Bereich Trinkwasserversorgung und Abwasserentsorgung behebt.

Das Schlüsselelement des vereinfachten Planungsprogramms sind die Kostenfunktionen, welche es ermöglichen einen Kostenvergleich von Technologien beliebiger Größe oder Kapazität darzustellen. Für die Herleitung der Kostenfunktion sind folgende fünf Schritte wichtig: 1) Festlegung eines Standarddesigns bezogen aus einer zuverlässigen Quelle. Das Standarddesign sollte reproduzierbar, technisch umsetzbar und für die Zielgruppe auch auf lange Sicht akzeptierbar sein; 2) Bestimmung der Auslegungsgrößen als Grundlage für die Kostenfunktionen und gleichzeitig die Begrenzung des Einsatzbereichs der Kostenfunktion; 3) Ermittlung der Investitions- und Reinvestitionskosten für jede Auslegungsgröße mittels eines Leitungsverzeichnisses. Die Betriebs- und Wartungskosten werden nach dem Aufwand für jede Auslegungsgröße ermittelt; 4) Festlegung der Eingabeparameter, welche die Variablen der Kostenfunktion darstellen. Dabei ist auf Verständlichkeit bei der Anwendung, Repräsentativität und Transparenz zu achten; und 5) Herleitung der Kostenfunktion für Investitions-, Reinvestitions-, Betriebs- und Wartungskosten von den Kosten der einzelnen Anlagengrößen und Berücksichtigung der Eingabeparameter.

Die Erfahrungen aus dieser Arbeit zeigen, dass für eine weitere Entwicklung des vereinfachten Planungsprogramms und der Kostenfunktionen folgende Tätigkeiten empfohlen werden: Vereinheitlichung der Kostenfunktionen, Berücksichtigung der landesspezifischen Einheitspreise und Normen, Vereinfachung der Eingangsparameter, Zusammenführen von mehreren Technologien zu einer einzigen, Möglichkeit der Abweichung von der Kostengrundlage, Überprüfung der Massenbilanz, Hinzufügen von neuen Technologien und in ferner Zukunft die Kostenfunktionen mit ausgeführten Projektskosten ersetzen.

Abstract in English

Most African countries are not on track to meet the UN Millennium Development Goals in water supply and sanitation. The CLARA simplified planning tool is an important instrument within the CLARA project contributing towards the MDGs by supporting decisions makers and planners to remedy deficiencies of knowledge to solve their water supply and sanitation issues by providing an objective and comprehensive economic cost comparison tool.

The key elements of the CLARA simplified planning tool are the technology cost functions that enables comparing technologies of any size or capacity. For the development of a cost function the following five steps are essential: 1) a standard design for the technology has to be defined which is reliable, repeatable, technically feasible and acceptable for the target group on a long term scope; 2) the design sizes as a base for the cost function and simultaneously limit the range of the cost function have to be determined; 3) the investment and reinvestment costs for each design size using bill of quantities and prepare operation and maintenance costs for each design size have to be derived; 4) the input parameters that represent the variables of the cost functions have to be defined (considering comprehensible usability, representativeness and transparency); and 5) derive the cost function for investment, operation and maintenance and reinvestment costs from the costs of each selected design size based on the input parameters have to be derived.

Experience from this work has shown that for subsequent development of the CLARA planning tool and the cost function the following tasks are recommended: mutual standardisation of the cost function, implementation of country-specific unit prices and standards, simplification of the input parameters, combination of technologies, deviation of the cost base, mass balance checks, adding new technologies and finally replace the cost function with real project costs.

List of Abbreviations

BoQ	bill of quantity
BU	billing unit
cf.	confer; compare
CLARA	Capacity-Linked water supply and sanitation improvement for Africa's peri-urban and Rural Areas
EAWAG	Swiss Federal Institute of Aquatic Science and Technology
e.g.	exempli gratia; for example
et al.	et allii/iae; and others
i.e.	id est; that is
MDGs	Millennium Development Goals
NETSSAF	Network for the development of Sustainable Approaches for large scale implementation of Sanitation in Africa, FP6 Coordination Action, project no. 037099, duration: 06/2006 – 11/2008.
No.	number
O&M	operation and maintenance
PE	person equivalent
ROSA	Resource-Oriented Sanitation concepts for peri-urban areas in Africa, FP6 STREP. project no. 037025, duration: 10/2006 – 03/2010.
SANDEC	Department of Water and Sanitation in Developing Countries at the Swiss Federal Institute for Environmental Science and Technology (EAWAG)
q.v.	quod vide; which see
SPT	simplified planning tool
SSWM	Sustainable Sanitation and Water Management
SuSanA	Sustainable Sanitation Alliance
UDDT	Urine-Diversion Dry Toilet
UN	United Nations
WHO	World Health Organisation

1. Introduction

1.1 Background

The UN Millennium Development Goals (MDGs), agreed in 2000, claim to halve the proportion of the population without sustainable access to safe drinking water and basic sanitation (UN, 2000)

The Millennium Development Goals Report 2012 (UN, 2012) states that the world has met the MDG drinking water targets five years ahead of schedule. Unfortunately this statement applies only on a global scale. Firstly, the coverage with improved drinking water for rural areas is still poor compared to cities water access. And secondly two particular regions do not meet the MDG target, namely sub-Saharan Africa and Oceania. In rural sub-Saharan Africa less than half of the population use any form of improved water source. The sanitation situation in rural sub-Saharan Africa is even worse. Among the poorest 20 % of the population 60 % of the households still practice open defecation. Figure 1 illustrates the progress of the African countries towards the MDG targets. Regarding drinking water 23 countries are on track to meet the targets and while in sanitation only 8 countries are on track.

Furthermore Africa will be subjected to the impacts of climate change with likely pressure on the water availability (IPCC, 2007).

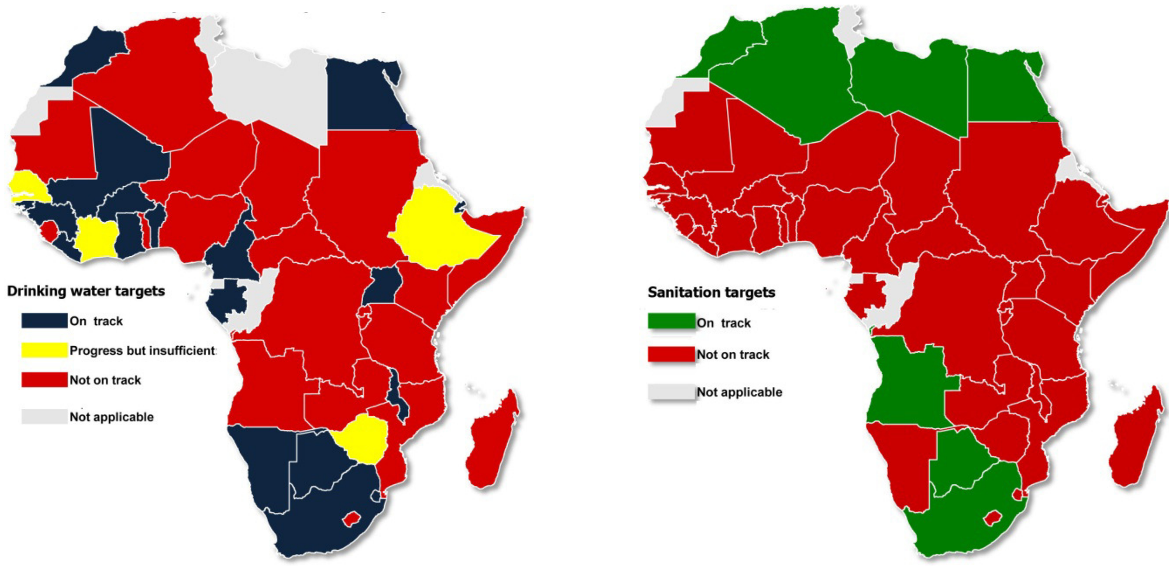

Figure 1 Progress towards the MDG drinking water and sanitation targets (AMCOW and WHO/UNICEF JMP, 2012)

The CLARA project aims to contribute towards the UN MDGs and to adapt water supply and sanitation system to be able to cope with the impacts of climate change by strengthen local capacity in water supply and sanitation sector and promoting resources-oriented concepts that support water, nutrients, organic matter and energy cycles (CLARA, 2011).

1.2 Problem definition

Decision makers and planners in the water and sanitation sector have often deficit of knowledge to adopt adequate approaches to solve their water supply and sanitation issues. Knowledge lacks concerning available technical solutions and regarding methods, approaches and criteria for the planning and implementation process of a system (CLARA, 2012a). The CLARA project was initiated to provide a solution for these problems. The simplified planning tool, developed in course of the CLARA project, acts as a comprehensive instrument for comparing water and sanitation systems.

As this thesis is a part in the planning tool development the problem definition focuses on the comparability of different systems in terms of economic costs. The easiest way to compare various systems would be to obtain their actual cost from prior projects. Due to the lack of real project cost the costs for a comparison have to be derived from several designs. The cost comparison comprises all expenditures during the defined period of consideration that includes investment, operation & maintenance and reinvestment costs.

1.3 Research objectives

As an overall objective this thesis aims to develop cost functions for several sanitation technologies in order to enable a cost comparison of various sanitation systems within the CLARA simplified planning tool. For the achievement of the overall goal following objectives have to be accomplished for each of the selected technologies:

1. Create a standard design and determine on specific design sizes
2. Define the investment, operation & maintenance and reinvestment costs for each design size by utilisation of Bill of Quantities
3. Identify the cost functions for investment, operation & maintenance and reinvestment based on input parameters

1.4 Structure of the thesis

The structure of the thesis is divided into six sections. The introduction is followed by a description of the objectives of the CLARA project and the CLARA simplified planning tool.

Chapter 3 describes the methodology of the thesis and defines the process of setting decisions and assumptions. The main function of this chapter is to explain the general approach of developing the cost functions.

The developed cost functions are described in detail for each technology in Chapter 4.

Chapter 5 discusses results and experiences from the work and gives recommendations for further developments.

Chapter 6 summarises the work and derives conclusions.

2. Objective and Definition

2.1 The CLARA project

The project “Capacity-Linked water supply and sanitation improvement for Africa’s peri-urban and Rural Areas” (CLARA) is an EU funded project to propose integrated resources-oriented water supply and sanitation concepts. The project is collaboration of international partners. The project started in March 2011 with duration of 3 years.

CLARA Background

The CLARA project has been developed based on the results and experiences from the ROSA project and the NETSSAF Coordination Action. The main objective of ROSA was to promote resource-oriented sanitation concepts to establish sustainable sanitation. Such concepts had been implemented and analysed in four pilot cities in Ethiopia, Kenya, Tanzania, and Uganda. The NETSSAF objectives included the coordination and integration of various scientific researches and technological innovations in Africa in order to support collaborations at the large-scale implementation of sustainable sanitation systems in peri-urban and rural areas (ROSA, 2012; NETSSAF, 2012). ROSA and NETSSAF were focused on sanitation issues, whereby CLARA considers also water supply issues with the purpose of promoting resources-oriented concepts. CLARA comprises key partners from both projects.

CLARA consortium

The CLARA consortium consists of partners in Europe and Africa. A key role in the project play Ethiopia, Kenya, Morocco, Burkina Faso and South Africa as case studies will be carried out in these countries. In addition field studies will take place in the Arba Minch region, Ethiopia.

CLARA objectives

Based on the experience of ROSA and NETSSAF projects the following needs and objectives have been identified and defined for the CLARA project (CLARA, 2011).

The **general objectives** of the CLARA project are

- to **strengthen local capacities** to adopt, implement and operate integrated water supply and sanitation for small communities in rural areas and peri-urban areas, and
- to **contribute to the MDGs** and to **climate change adaptation** in the African water sector.

The **specific objectives** are:

- to **assess and adapt existing low cost technologies** for integrated decentralised water supply and sanitation systems for African conditions with the focus on reducing risks in water use and reuse of sanitation products.
- to improve the capability of water supply and sanitation systems to **provide demand oriented water quality** for reuse as well as products from sanitation,
- to develop a **simplified integrated planning tool** for water supply and sanitation systems for small communities and peri-urban areas that

incorporates the key factors for success, i.e. operation and maintenance issues, reuse potential, and can be tailored to available local capacities, and

- to test and evaluate the simplified integrated planning tool in **different geographical African regions** to incorporate different economic, cultural and social boundary conditions.

The overall general objectives of the CLARA project are achieved by the synergy of the specific objectives. One of the CLARA objectives are technical improvements at existing low cost technologies for integrated decentralised water supply and sanitation systems for African conditions. Among other this field studies focuses on the reduction of risks in water use and reuse of sanitation products. Furthermore the capability of water supply and sanitation systems to provide demand oriented water quality should be improved.

The other main objective is the simplified planning tool. This planning tool for water supply and sanitation systems in small communities and peri-urban areas and shall be used in practice by local consultants, planners or municipalities to compare different solutions. As a part of the case studies the simplified planning tool will be tested and evaluated in previously mentioned African regions to incorporate different economic, cultural and social boundary conditions. An adaption of the tool might be necessary after evaluating the case studies.

2.2 The CLARA simplified planning tool

The CLARA simplified planning tool (SPT), being one of the CLARA's main outcomes, determines one important step of the planning process of integrated water supply and sanitation projects. An objective economic cost comparison of system variants under certain framework conditions is the main output of the planning tool. This shall be used by municipalities and/or consultants as a base for their decision making. The planning tool itself cannot be considered as a decision making process; the tool provides an objective evaluation that can be the basis for a decision.

2.2.1 Background

The fundamental principles of the CLARA simplified planning tool are based on a tool used in Austria to compare different variants of water borne sanitation based on their economic costs. The tool is provided by the government of Lower Austria and is mandatory to receive subsidies for the construction of sanitation infrastructure. The main advantages for this tool apply also for the SPT. The result of the tool is transparent due to indisputable input parameters and fixed cost bases. These precautionary measures prevent misuse of the tool by influence the result to favour a socially/politically preferred solution. The tool is also flexible to adapt for different framework conditions and environments. Compliant to technical and legal standards the tool acts as a pre-selection device for feasible technologies and excludes inappropriate solutions (LECHNER, 2011).

2.2.2 Functional groups and technologies

A technology within the SPT is defined as specific infrastructure, method or service within or between the functional groups (CLARA, 2012a). The function groups are used to combine different technologies of similar purpose within one group. Furthermore a system is a combination of technologies to meet a requested task. Technologies implemented in the SPT are categorized based on the functional groups of the Sustainable Sanitation and Water

Management (SSWM) toolbox. The SSWM toolbox is an integrative tool for capacity development on the local level in order to help in getting an overview in terms of water and sanitation and to help identify problems. The toolbox's fundamental approach considers the entire water and nutrient cycle as shown in Figure 2. Furthermore the SSWM toolbox provides extensive information on the technologies (SEECON, 2012).

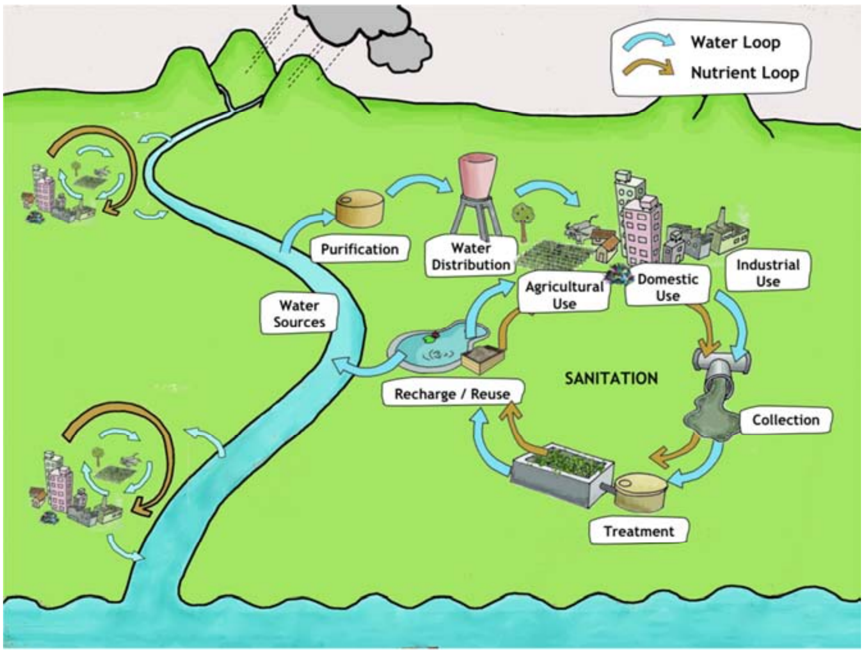

Figure 2 Idealised Water and Nutrient Loop (SEECON, 2012)

The SPT comprises various technologies within the following functional groups as defined in the SSWM toolbox (SEECON, 2012). The technologies implemented in the draft version of the SPT are listed in Table 1. Some modification regarding the SSWM toolbox classifications have been made. This thesis derives cost functions for several technologies in waste collection and waste treatment which are marked with * in Table 1.

Table 1 Functional groups and technologies used in the draft SPT

Water sources	**Waste Collection**
Shallow well	***Water borne system***
Borehole (up to 100 m^3/d)	Septic tanks *
Borehole (more than 100^3/d)	Sewer
Water purification	Pumping station *
Screening	Collection of Sludge with trucks *
Chlorination	Collection of Sludge with manual emptying *
Filtration (Rapid sand filter)	***Dry sanitation system***
Filtration (Slow sand filter)	UDDT chamber *
Sedimentation (plain)	Composting toilet chamber *
Sedimentation + Flocculation	Collection of urine *
Sludge collection tank	Collection of faeces *
Water distribution	Solid waste collection
Water tank surface	**Waste Treatment**
Water tank elevated (concrete, steel, plastic)	Treatment plant- SBR
Pumping station (centrifugal pump)	Lagoon
Water transport main	Anaerobic digester- Borda
Water supply network	HF CWs *
Non-piped water distribution (Emergency)	VF CWs *
Water demand - waste generation	Sludge drying reed bed *
	Urine treatment – Storage *
	Urine treatment - Struvite production *
	Treatment of faeces – Composting *
	Treatment of faeces - LaDePa
	Anaerobic up flow sludge blanket(UASB)
	Rotated Biological Contactor(RBC)
	Recharge – Reuse

* Technologies for which costs functions are derived in this work

2.2.3 Requirements

The CLARA simplified planning tool has to achieve some important requirements. The comparison has to be transparent and objective in relation to the technologies performance. For instance the combination of different technologies has to be possible to give enough flexibility to the planner within the scope of technical feasibility. Mass balances have to be checked by the tool within the alternatives and the technologies itself to avoid in inappropriate output. Finally, as already mentioned, the planning tool has to comply with local legal frameworks and standards.

2.2.4 Main actors

Client

The client could be e.g. a municipality, a ministerial department or a user association, who is confronted with a problem in water supply and sanitation and responsible for a solution. The client starts the CLARA planning process, organises the basics from the target group, pre-selects the systems and makes the final decision. For the technical implementation the client contracts a planner (CLARA, 2012a).

Planner (SPT user)

The proposed SPT user, respectively the planner, is expert with adequate knowledge and experiences in water supply and sanitation equipped with legal permit by the client. The planner is responsible for the development of possible solutions, collecting necessary data, consider local framework condition, and apply the CLARA planning tool according to the information obtained (CLARA, 2012b).

Authority

The authority is the responsible body that assures the compliance of legal requirements in the framework conditions of the planning process (CLARA, 2012a). Furthermore the authority is responsible to specify cost base of the CLARA simplified planning tool in order to ensure a realistic and transparent system comparison within their region or country.

2.2.5 Technology cost functions and input parameters

The key factors of the SPT are the cost function. For adequate assessment of different alternatives each technology has to show comparable costs at any certain design size. These specific costs of a technology are derived from a cost function. Costs for any technology comprise investment costs, cost for operation and maintenance, reinvestment costs and revenues. A crucial element of the cost function is the Bill of Quantities (BoQ) which is a list of positions containing detail information of material, parts and labour required to construct the specific structure. The unit cost for each position included in BoQ results in the cost base of the SPT.

The input parameters represent variables or result in variable of the cost function and are directly related with the size or capacity of the specific technology. In contrast the cost base takes the position as mathematical constant within the cost function.

The development of the cost function for several technologies is the main objective of this thesis. Its methodology is described in Chapter 3.

2.2.6 Cost comparison

For the comparison of system variants the SPT calculates the total costs, derived from the cost functions, over the designated period of consideration which is the project life span selected by the user. In order to make systems comparable it is essential to consider the time value of money of future cash flow in the present. Therefore the SPT determines the net present value (NPV) that is the sum of all the present values of the annual cash flows during the life of the project, minus the initial investments. The period of consideration and the interest rate are general input parameters of the project.

2.2.7 Software implementation

In order to keep the draft version of the planning tool simple and easy to understand and use, the realisation of the tool was done in Microsoft Excel® and Microsoft Visual Basic for Applications®. The latter is used to achieve the functionality. However Microsoft Excel® is not a database software and has therefore some limitation in handling with the amount of data. Therefore it is solely used for the draft version.

The following screenshots are a theoretical example derived from the CLARA simplified planning tool in the draft version 0.4.5 and given for further explanation of the SPT. Figure 3 shows the technology input screen which is accessible for the user. The left upper corner contains a dropdown list for the selection of the technology corresponding to the functional group. The field in the right upper corner gives the technology rank within a combination of technologies. Numbers 1 to 10 are the input parameter fields of the technology, in this example for a vertical flow constructed wetland. The input fields are different for each technology and change automatically after selecting any technology. Figure 4 presents the result sheet for a single technology. The total costs consist of expenses for investment, O&M, reinvestment and revenues over the designated design period are given numerical and graphical. The flow check on the right side of the sheet will be implemented in future for checking correct mass balances within a selected system.

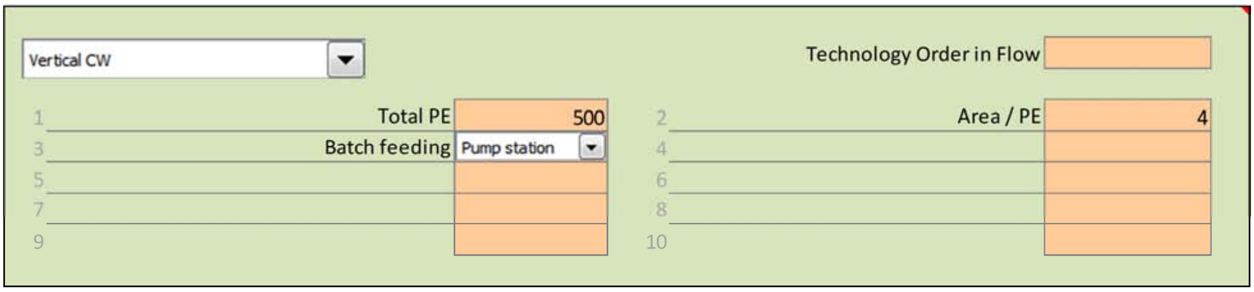

Figure 3 Technology input screen (SPT)

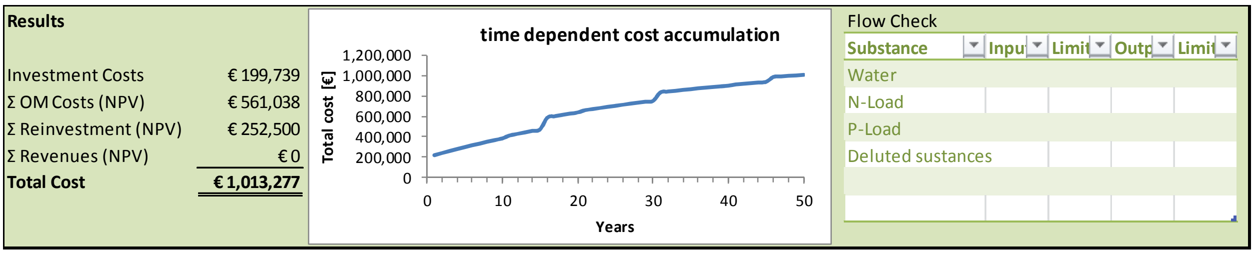

Figure 4 Technology result screen (SPT)

Figure 5 and Figure 6 show the final result screen of the SPT's variant comparison. Figure 5 shows a theoretical example comparing a dry and water borne sanitation system. Figure 6 presents the costs of four system variants over the period of 50 years.

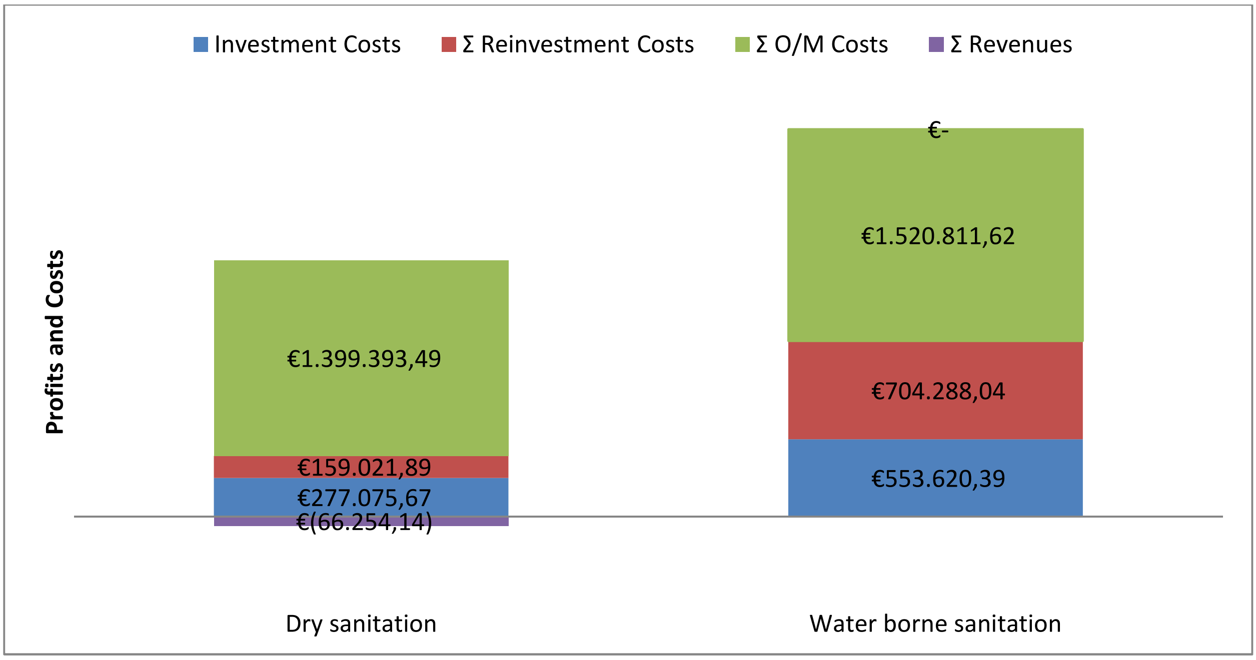

Figure 5 Result sheet of the variant comparison (SPT).

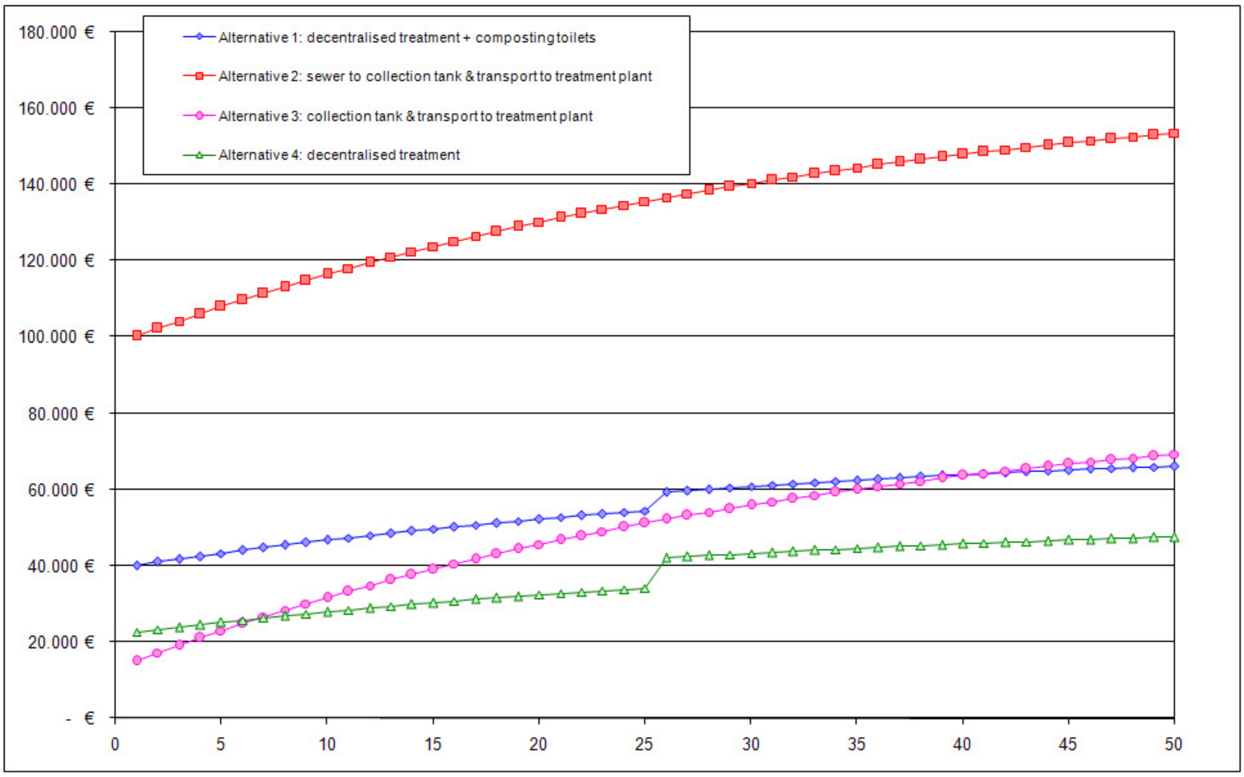

Figure 6 Total costs of four system variants over 50 years (STP).

3. Methodology

3.1 Literature research

Nowadays plenty of information on sanitation in developing countries is available in the internet provided by various governmental and non-governmental organisations. Most of this literature is in English and can be obtained free of charge. A web-based literature research was the main source of gathering information for this thesis. Due to the fact that the SPT is based on the SSWM toolbox this portal was the initial point of the survey. Following portals and websites provide useful information:

- Sustainable Sanitation and Water Management (SSWM) toolbox
  http://www.sswm.info
- Sustainable Sanitation Alliance
  http://www.susana.org
- Eawag
  http://www.eawag.ch
- WHO's Institutional Repository for Information Sharing
  http://apps.who.int/iris/
- UNHABITAT Water and Sanitation
  http://www.unhabitat.org/categories.asp?catid=270
- World Bank – Water
  http://water.worldbank.org
- Well
  http://www.lboro.ac.uk/well/

3.2 Selection of the technologies

The selection of the technologies implemented in the SPT was made due to the supposed occurrence of the technologies in the partner countries and the practical feasibility. Hence only technologies with a certain operational experience were considered. The decisions were made by the project team in the course of regular meetings and confirmed in the CLARA consortium meeting in Arba Minch, Ethiopia, in September 2012.

3.3 Selection of the technology design

The standard designs used in this thesis are primarily based on prior projects of EcoSan Club Consulting KG and case studies obtained from previously mentioned organisations and portals. The selection of the standard design was discussed and defined in the project team. The main requirements for the selection were the universal applicability of the design and if it is already applied and considered reliable.

3.4 Cost function development approach

Creating a cost function is similar for any technology. The basic steps are presented in Figure 7 and further discussed in the subsequent chapter (q.v. 3.5). An example of a cost function is shown in Figure 8 presenting the total investment costs based on the size of a plant. The development of the cost functions requires following tasks:

1. Create a standard design incl. dimensioning and design drawing and determine design sizes.
2. Provide a bill of quantity for each design size and calculate with the specific unit price of each position in order to get the individual investment costs.
3. Determine O&M costs for each design size
4. Determine reinvestment costs at defined life span for each design size.
5. Determine revenues if existing.
6. Define input parameters for the cost function.
7. Create investment, O&M and reinvestment cost function based on the input parameters.

In some cases the method was different: The cost function development by various BoQ is replaced by a single position, e.g. a transport vehicle, and the total costs are derived by alteration of the unit number. This approach is described in detail in the respective chapters (q.v. 0-4.6 and 4.12).

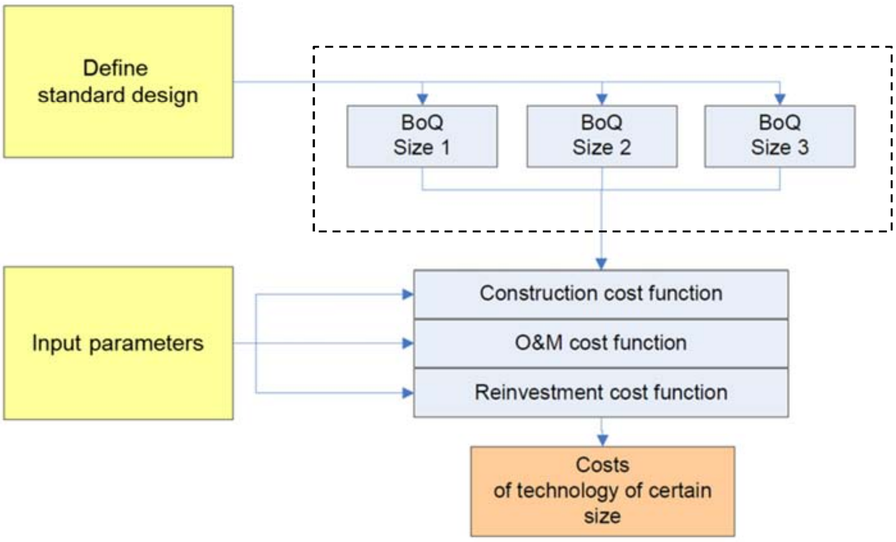

Figure 7 Cost function development

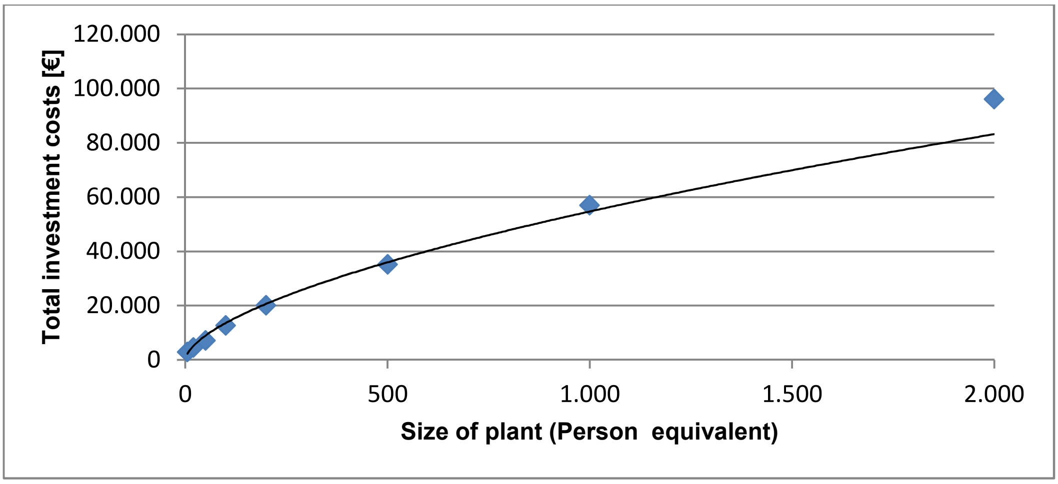

Figure 8 Example for a cost function

3.5 Explanation of the cost functions development

3.5.1 Short descriptions

The short description gives a brief overview of the technology. A detailed description and further information is available on the Sustainable Sanitation and Water Management Toolbox (SEECON, 2012).

3.5.2 Input parameters

The input parameters represent the variables of the cost functions. They are essential to alter the cost function to display the result for any size of the technology. The parameter's characteristics comprehend usability, representativity and transparency. Usability is important for the planer. The input parameter should be easy to understand and easy to use. The elicitation of the required data has to be simple and affordable and its applicability in various technologies has to be ensured. Thus data surveys get less expensive. The parameters have to be representative in respect of comparability between technologies and an accurate final outcome. Finally the input parameters have to be transparent in order to avoid potential manipulation and distortion of the result.

A frequently used input parameter is the person equivalent (PE) which serves as a reference level for the waste water load. Within the CLARA simplified planning tool the PE is set at a load of 80 litres per person per day. In dry sanitation technologies the term PE is used to describe the amount of urine or faeces produces by one person respectively.

3.5.3 Dimensioning

The cost functions are based on designs for different sizes. In the thesis the term design sizes is used for this. The process starts by scaling the standard design for a specific size or capacity. Once known the scale of this design the range of the design sizes can be set and the design sizes determined. The dimensioning for the design sizes is done in exactly the same way as for the standard design. The next step is to create a drawing for each design size and prepare bills of quantities (BoQs) based on the drawings.

The dimensioning process can differ from technology to technology. For the collection and transport technologies the dimensioning was done contrarily and described in detail in the respective chapters (cf. 0, 0 and 4.6).

3.5.4 Design assumptions

The design assumptions include all necessary data to reproduce the selected design. This section describes whether components or works are considered by the cost function or excluded. Following expenditures are not considered by any cost function:

- Land purchase
- Set-up and removal of construction site equipment
- Site office
- Any transport
- Supervision of an engineer or an experienced construction foreman
- Documentation

3.5.5 Investment cost function

Investment costs are unique incurred expenses required for the construction of a facility (LAWA, 2005). The investment costs in this thesis are divided into cost categories to determine the cost allocation between the categories. Depended on the technology, but in the majority of the cases, the cost categories compose of earthworks, construction and equipment.

The investment cost function serves to determine the costs for a specific technology size. As mentioned above the cost function is based on the investment costs of the specified design sizes and derived by the particular BoQs. Due to the lack of real project cost the approach of using BoQs and specific unit costs to obtain investment costs is necessary. A BoQ contains all positions of material, parts and labour necessary for the construction of the technology. The numbering system of the positions is done according to the Austrian standard specification for tenders due to the fact that unit prices can be obtained more easily and shared between the technologies. Some positions do not exist in the standard specification therefore they do not have a numbering. The BoQs with inserted unit prices result in the investment costs of a technology of a specific size. In further consequence the cost function can be derived from the costs of each design size BoQ. Within the spread-sheet the definition of all cost functions is done by a trend function add-in.

For further assessment the cost categories proportion of the investment cost is given for each design size to see if any cost category is insignificant and can be neglected as a part of a future revision.

Please note:

The unit costs used in this thesis are derived from projects implemented by EcoSan Club Consulting KG, manufacturer's price sheets or estimations. This applies to O&M costs and revenues as well. Thus the generated cost functions cannot be used for a practical application. These cost function are used in the first draft of the SPT which is primarily for testing purpose. In near future the actual unit costs delivered by the partner countries will be implemented in the cost function.

3.5.6 Operation and maintenance cost function

O&M costs are periodic or intermittent running expenses during operation phase required for operation, service, maintenance and monitoring. The O&M costs consider reinvestment of system components with an operation life up to 5 years unless noted otherwise (LAWA, 2005).

Principally used categories of O&M cost:

- Labour costs (operation staff, service and maintenance staff,…)
- Energy costs (fuel, electricity,…)
- Material costs (Spare parts,…)

As for the investment cost function the O&M cost function is derived from the O&M costs of selected design sizes. All O&M unit costs used in this thesis are based on estimations and will be reviewed as soon as partner countries provided real costs.

3.5.7 Revenues function

The revenues are incomes generated from the marketing of finished products such as compost or struvite. The revenues are a direct function of the plant's capacity. The market prices for the products in this thesis are estimations and will be reviewed as soon as partner countries provided real costs.

3.5.8 Reinvestment cost function

Reinvestment costs include replacement expenses for system components whereby their operation life span is shorter than the operational time of the facility (LAWA, 2005). As for the investment cost function the reinvestment cost function is derived from the BoQs of selected design sizes.

3.6 Presentation of data

The data presented within Chapter 4 of this thesis characterise only the results of dimensioning and deriving the cost functions. Every step of the calculations can be found as Annex 1 and all design drawing as Annex 2 on the enclosed compact disk. Chapter 8 provides a comprehensive list of all appendices.

4. Results

4.1 Sewage pumping station

4.1.1 Short technology description

A pumping station is an additional component of a sewer system that enables sewage to overcome head differentials. The need for a sewage pumping station arises due to the topography when required sewer grades cause deep excavation. Pumping stations raise the sewer to avoid high excavation costs. Furthermore a pump might be necessary to overcome obstacles, at the inlet or discharge of a treatment plant.

4.1.2 Input parameters

Input parameters for the SPT user are:

- flow of the pump (l/s)
- height difference (m)
- number of required pumping stations

The required power is calculated by flow and height and gives basis for the cost function. In addition the number of pumping stations is an input by the user. Although the power is assumed to be equal for each pumping station.

The design is valid for a flow range from 0.05 l/s to 80 l/s and a height of 5 m to 30 m which equals a theoretical power of 5 to 8000 W.

4.1.3 Dimensioning

The basis for the selection of the design sizes is the required electrical power (P) of the pump which is calculated by following equation:

$$P = \frac{\rho \times g \times h \times Q}{\eta}$$

ρ density of sewage, is assumed to be 1 kg/dm³.

g gravitational acceleration, is 9.81 m/s²

η pump efficiency, is assumed to be 50 %

Q given flow [l/s]

h given height to overcome [m]

Following design sizes for flow and pumping height are defined and used to determine the electrical power requirement that is the base for the cost function:

Height [m]	Flow [l/s]											
5	0,05	0,1	0,25	0,5	1	2,5	4	5	10	25	50	80
10	0,05	0,1	0,25	0,5	1	2,5	4	5	10	25	50	-
20	0,05	0,1	0,25	0,5	1	2,5	4	5	10	15	-	-
30	0,05	0,1	0,25	0,5	1	2,5	4	5	10	-	-	-

4.1.4 Design assumptions

The pump station consists of the concrete structure and two electrical powered submerged pumps whereby one pump is always on standby. The well should be easily accessible and provide proper ventilation. The pumps should be able to be removed easily by lifting equipment.

A pump is started as soon as the sewage exceeds the maximum water level and it pumps until the minimum water level is reached. Float switches are used to operate the pumps.

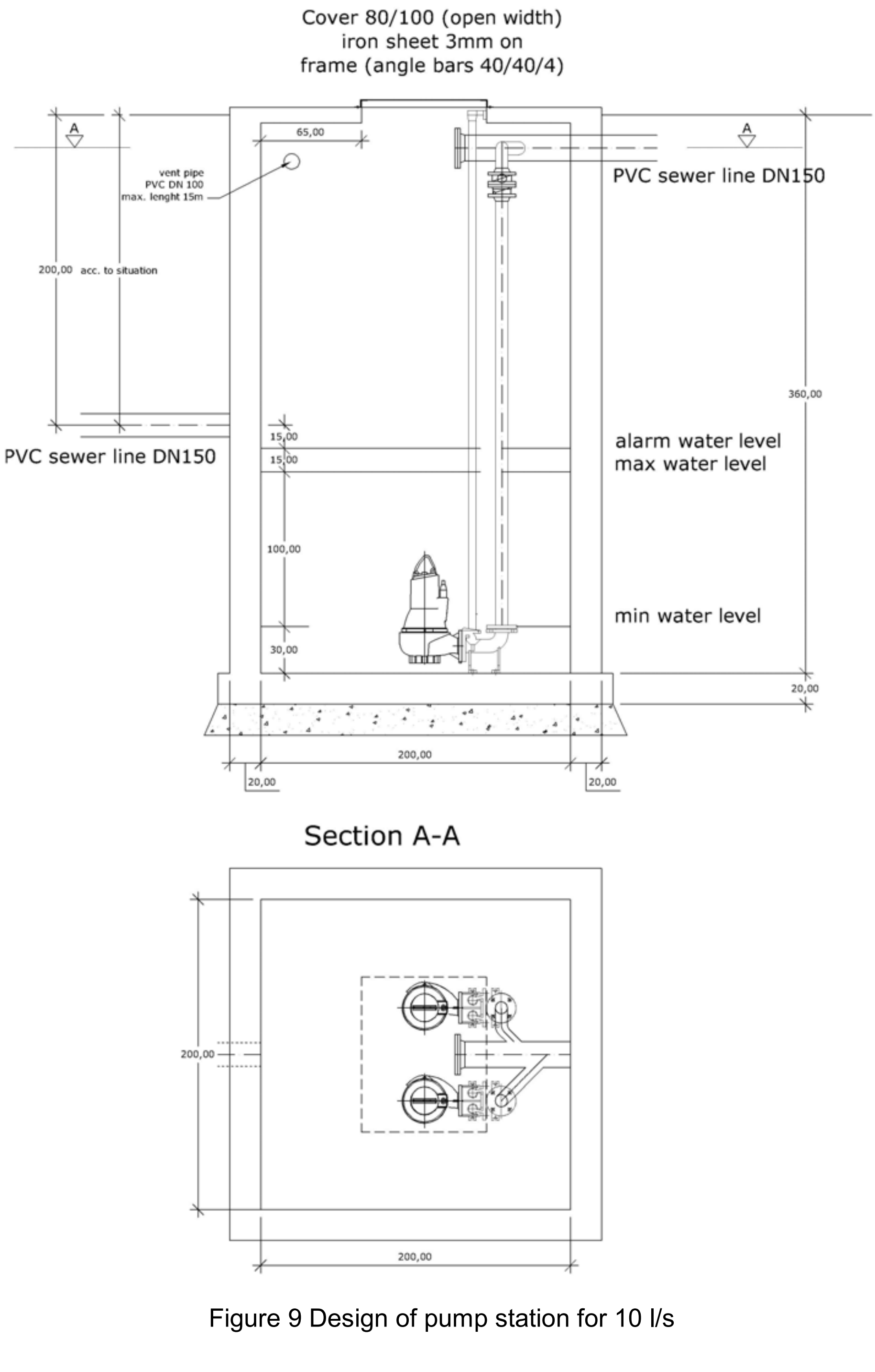

Figure 9 Design of pump station for 10 l/s

4.1.5 Cost functions

The cost functions for investment, operation and maintenance and reinvestment are based on the electrical power of the pump. The cost functions are derived from cost calculated for different design sizes.

4.1.5.1 Investment cost function

The investment cost function is calculated by the total price of 42 designs of different height and flow. The total cost of a particular pumping station compromise of costs for earthworks, construction and equipment specified in a bill of quantity.

Earthworks costs

Earthworks costs include positions shown in Table 2. These positions consider preparation, excavation and backfilling works. The pit excavation is performed as an excavation with inward-slope and followed by backfilling after finishing the construction. The bedding beneath the floor slab is done with gravel. The building's upper edge is flush with the surface. According to the particular site the level of the inlet pipe might be deeper than given in the design assumption. Additional excavation works is not considered in the investment costs.

Table 2 Positions of earthworks costs (Sewage pumping station)

Item no.	Position	Unit
020201A	Clearing area	m^2
030201A	Remove topsoil	m^3
030206A	Replace Topsoil	m^3
030211B	Re-Cultivate topsoil	m^2
030331A	Pit excavation with inward-sloping	m^3
030701B	Backfilling of trenches	m^3
030703C	Bedding with gravel	m^3

Construction costs

Construction costs consist of concrete works shown in Table 3. The quality of the concrete is supposed to be C20/25. All reinforcement works have to be included in the unit price for concrete and performed according to static requirements.

Table 3 Positions of construction costs (Sewage pumping station)

Item no.	Position	Unit
110302A	Slab C20/25 up to 30cm	m^3
110401A	Wall 12-20cm C20/25	m^3
110605A	Concrete slab ceilings C20/25 up to 20cm	m^3

Equipment costs

Equipment costs cover the pump assembly, all required accessories, piping and manhole cover as presented in Table 4.

Table 4 Positions of equipment costs (Sewage pumping station)

Item no.	Position	Unit
n/a	Manhole cover of different size; iron sheet 3mm on frame (angle bars 40/40/4)	pcs
n/a	Submerged lifting pump; producer: Grundfos; type: SEG, SEV or SE1	pcs
n/a	Baseplate for pump	pcs
n/a	Guidance rail and lifting chain for pump	pcs
n/a	Control system for pump	pcs
n/a	Control cabinet for pump	pcs
n/a	Cabling for pump	pcs
n/a	Pressure test and start-up of pump	pcs
n/a	Check valve of different size	pcs
n/a	Gate valve of different size	pcs
n/a	Steel pipe of different size	m
n/a	Steel fitting of different size	pcs

Investment cost function

The costs for each design size results in following investment cost function:

$$\textit{Investment costs} = -0.0003 \times P^2 + 6.3 \times P + 9333$$

In Table 5 the investment costs are described in costs per Watt. The costs are shown for selected design sizes while Figure 10 shows the total investment costs for all design sizes and the resulting cost function.

Table 5 Investment costs per Watt for selected design sizes (Sewage pumping station)

P	**100**	**200**	**500**	**1,000**	**2,000**	**5,000**	**10,000**	**W**
Costs per W	113.04	65.15	31.44	18.12	10.44	5.04	2.90	€/W

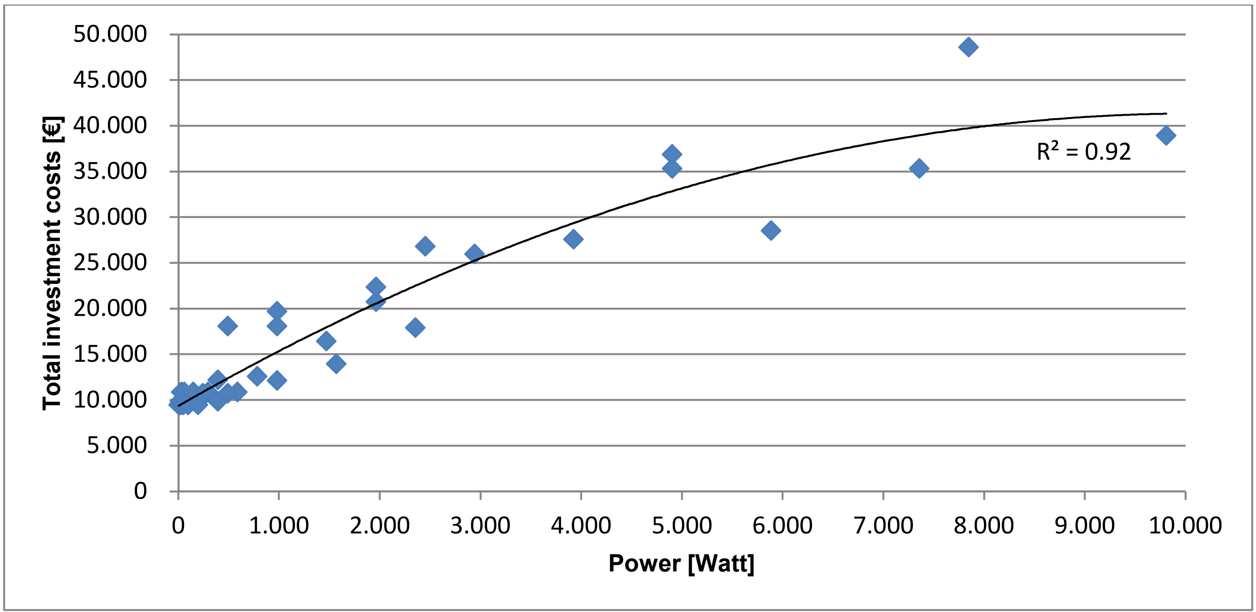

Figure 10 Investment cost function for sewage pump station

Cost category allocation

Table 6 describes the cost allocation between the categories based on selected design sizes. The most significant cost factors by far are the pump equipment construction and the earthworks whereby construction is accounting for more than 50 % of the investment costs with increasing proportion at increasing tank size.

Table 6 Cost allocation between the categories (Sewage pumping station)

P [Watt]	100	200	500	1,000	2,000	5,000	10,000
Earthworks	9%	9%	9%	9%	8%	8%	8%
Construction	18%	19%	20%	22%	24%	25%	27%
Equipment	73%	72%	71%	69%	68%	67%	65%

4.1.5.2 Operation and maintenance costs function

The O&M cost function includes assumed costs for energy based on a daily pump runtime of 8 to 12 hours and electricity costs of 0.10 € per kWh.

Inspections are performed on monthly basis (AMT DER OBERÖSTERREICHISCHEN LANDESREGIERUNG, 2010). Visual inspections include checking of blockage in ventilation opening, inlet and outlet pipes and water tightness of the construction (WMP, 2011).

Cleaning and removing sediments from the station is performed twice a year. Maintenance works will ensure proper and continuous functionality of pumps and accessories and are executed quarterly (ERTL and PLIHAL, 2011; WMP, 2011). In addition annual spare part costs are assumed to be 2% of the equipment investment costs.

Table 7 describes the annual O&M costs per PE for a single septic tank while Figure 11 shows the total O&M cost function per year. All labour is based on an assumed hourly rate of 10€. The following O&M cost function results in the annual O&M costs:

$$\textit{O\&M costs per year} = -0.00004 \times P^2 + 0.77 \times P + 1060$$

Table 7 Annual O&M costs per Watt for selected design sizes (Sewage pumping station)

P	100	200	500	1,000	2,000	5,000	10,000	W
Costs per W	113.04	65.15	31.44	18.12	10.44	5.04	2.90	€/W/yr

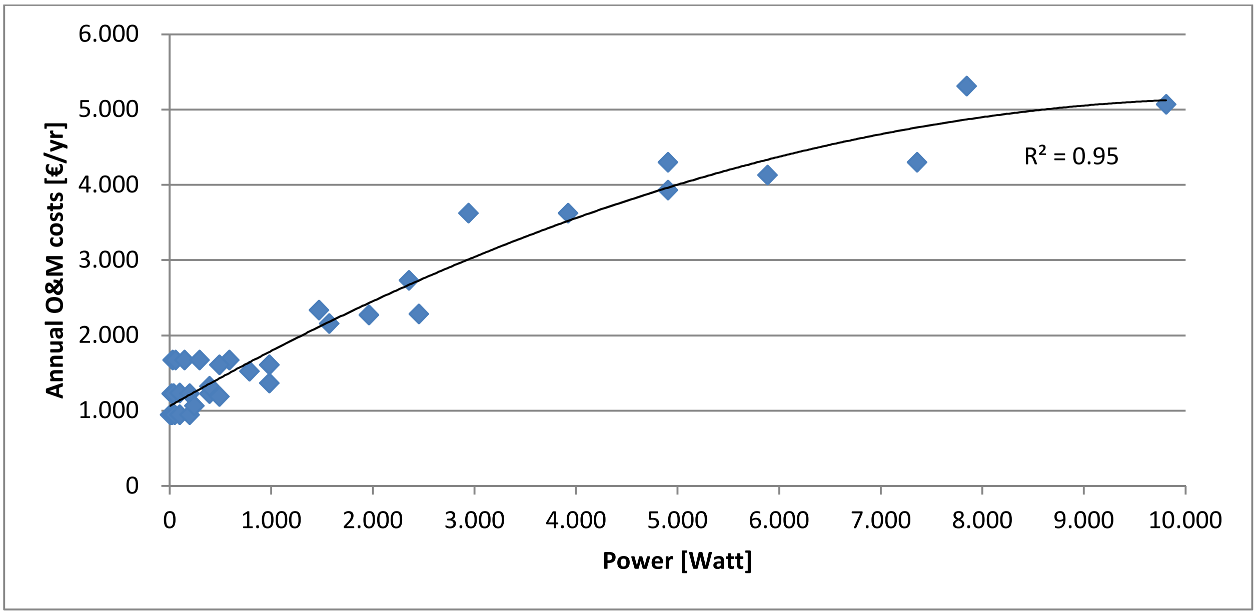

Figure 11 Annual O&M cost function for sewage pump station

4.1.5.3 Reinvestment cost function

The reinvestment cost compromises replacement of the total equipment after 10 years. The structure will last for 30 years (LAWA, 2005). The costs for reinvestment are derived from the investment BoQ for each design size.

4.2 UDDT chamber

4.2.1 Short technology description

The urine diversion dehydration toilet (UDDT) is a simple, low-cost, on-site sanitation facility that collects and stores urine and faeces separately. The advantages of this technology are pathogen destruction, reduction of faeces volume and minimising the creation of smell (LECHNER, 2007).

4.2.2 Input parameters

Input parameters for the SPT user are:

- total person equivalent (PE) to be served
- minimum number of toilet locations
- urine emptying interval, that is selectable weekly, fortnightly or monthly

There is no limitation in range.

4.2.3 Dimensioning

The determining factor for the cost function is the number of toilets per location on one hand and storage volume on the other hand. For calculation the required toilets following parameters are assumed:

- Maximum number of PE per toilet: 15
- Maximum number of toilets per block: 4

The number of toilets is calculated by dividing the PE with the maximum PE per toilet. Furthermore the minimum number of blocks results by dividing the required toilets by the maximum number of toilets per block. Hence the number of required toilet blocks can be determined which either the entered minimum number of toilet location or the minimum number of blocks as calculated before. Dividing the required number toilets by the actual number of block results in the aver number of toilets per block that is relevant for the cost function. The selected design size for determine the cost function are a single toilet block and a four toilet block.

The required volume to storage urine in the toilet blocks is the product of PE and the storage duration. Following parameter is assumed to calculate the volume:

- Urine volume per PE per year: 500 l/yr (LECHNER, 2007)

Table 8 gives the accumulating urine volume for each toilet block during the emptying interval depending on the number of toilets per block. The number in brackets shows the size of the selected storage tank in litres (based on commercially available tank sizes).

Table 8 Urine volume (in litre) at the emptying interval

	1 toilet	2 toilets	3 toilets	4 toilets	
7 days emptying	144 (150)	288 (460)	432 (460)	575(920)	L
14 days emptying	288 (460)	575 (920)	863 (920)	1151 (1350)	L
30 days emptying	616 (920)	1233 (1350)	1849 (2500)	2466 (2500)	L

4.2.4 Design assumptions

The UDDT is designed with a single vault and interchangeable containers. Whereby the costs of the containers and their collection are considered transport technology (q.v. Chapter 4.6). The separating squatting pan splits faeces and urine. The vault holds the container for faeces and a pipeline connected to all toilets in a block collects the urine and conveys it to the storage container. Vaults are accessible by a corridor in the rear and closed by metal lid. The floor of vault and corridor are covered with a perforated concrete plate to avoid muddy conditions. The ventilation pipe for the vault is PVC pipe and a savonius fan on the top which is a wind-powered evacuation fan. The superstructure above floor level is not included in the cost function due to the fact that superstructure is not considered in a cost function of a water-borne system as well e.g. flush toilet in a dwelling house. Figure 12 shows the design of the UDDT. Further drawings are in Appendix 2.

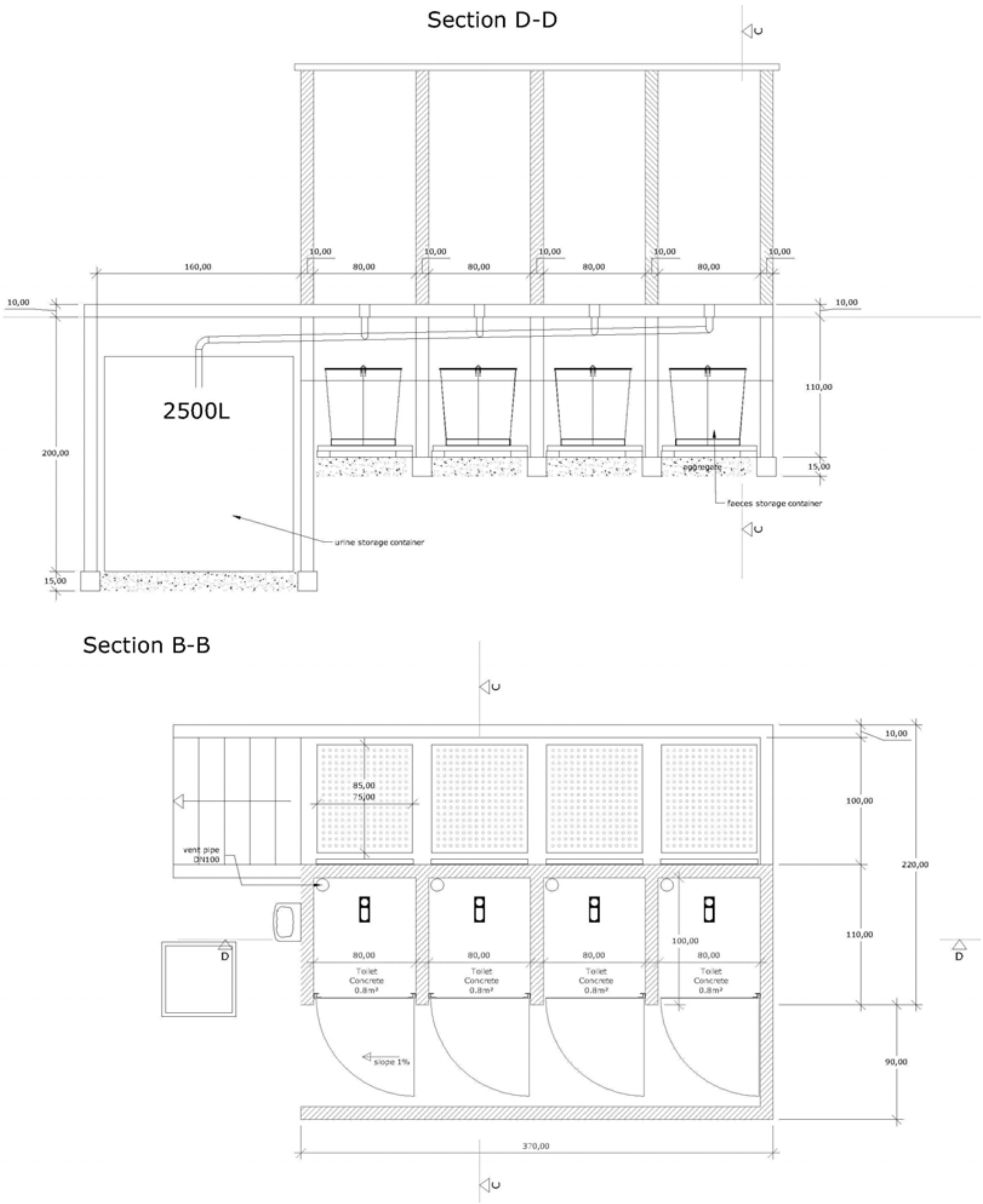

Figure 12 Design UDDT with four toilets

4.2.5 Cost functions

4.2.5.1 Investment cost function

The cost functions for investment, operation and maintenance and reinvestment consist of two separate cost functions for the structure and the storage tank. While he cost functions for the structure is based on the average number of toilets per block, the function for the storage tank is dependent on storage time. Both cost function will be added up to get the total costs.

Earthworks costs

Earthworks costs include positions shown in Table 9. These positions consider preparation, excavation and backfilling works. The pit excavation is performed as an excavation with inward-slope and followed by backfilling after finishing the construction. The bedding beneath the floor slab is done with gravel.

Table 9 Positions of earthworks costs (UDDT)

Item no.	Position	Unit
020201A	Clearing area	m^2
030201A	Remove topsoil	m^3
030206A	Replace Topsoil	m^3
030211B	Re-Cultivate topsoil	m^2
030331A	Pit excavation with inward-sloping	m^3
030701B	Backfilling of trenches	m^3
030703C	Bedding with gravel	m^3

Construction costs

Construction costs consist of concrete works shown in Table 10. The quality of the concrete for the foundation is supposed to be C12/15 for all other structures it is C20/25. All reinforcement works have to be included in the unit price for concrete and performed according to static requirements.

Table 10 Positions of construction costs (UDDT)

Item no.	Position	Unit
110301A	Foundation C12/15	m^3
110401A	Wall 12-20cm C20/25	m^3
110605A	Concrete slab ceilings C20/25 up to 20cm	m^3

Equipment costs

Equipment costs cover urine piping, concrete plate for the floor, ventilation, opening lids and the separating squatting pan as presented in Table 11.

Table 11 Positions of equipment costs (UDDT)

Item no.	Position	Unit
n/a	UPVC sewer pipes DN/OD 50	pcs
n/a	Surcharge UPVC fittings	BU
n/a	Brick	pcs
n/a	Perforated concrete plate 90x165cm (min. thickness 3cm with at least 10 holes)	pcs
n/a	Cover for chamber opening	pcs
n/a	PVC ventilation pipe DN150	m
n/a	Savonius fan	pcs
n/a	Separating squatting pan	pcs

Storage tank costs

The urine is stored in plastic containers. In this case the tank is the product "Kentainers" of AquaSanTec (AQUASANTEC, 2012). The selected tank capacities are shown in Table 12.

Table 12 Positions of storage tank (UDDT)

Item no.	Position	Capacity [m³]
n/a	Kentank, type: ccv 150	0.15
n/a	Kentank, type: cv 460	0.46
n/a	Kentank, type: cv 920	0.92
n/a	Kentank, type: ccv 1350	1.35
n/a	Kentank, type: ccv 2500	2.50

Structure investment cost function

The structure investment costs for a single toilet block of any design size result from following cost function based on the average number of toilets per block:

Structure investment costs per block = 1,002 x average number of toilets per block + 950

The SPT multiplies this result by the number of blocks to obtain the total investment cost of this technology. In Table 13 the structure investment costs for the design sizes are described in costs per toilets. The cost function is shown in Figure 13.

Table 13 Structure investment costs per toilet (UDDT)

No. of toilets	**1**	**2**	**3**	**4**	**-**
Costs per toilet	1,953	1,478	1,319	1,240	€/toilet

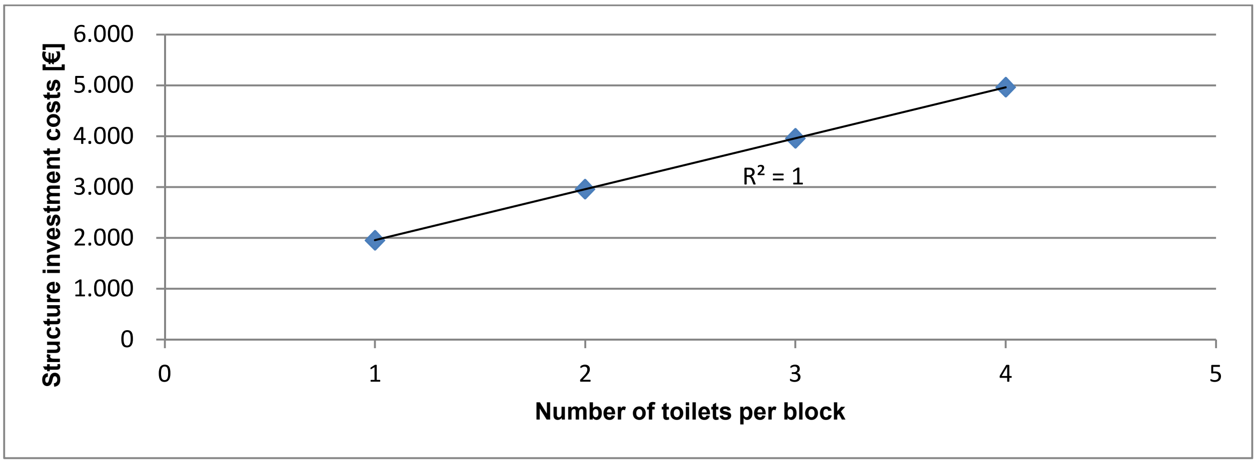

Figure 13 Structure investment cost function for a UDDT block

Storage tank investment cost

The storage investment costs of a single block of any design size are given for each available emptying period. Following cost functions calculate the investment cost based on the average number of toilets per block:

Storage tank investment costs (7 days) per block =
26 x average number of toilets per block + 8

Storage tank investment costs (14 days) per block =
26 x average number of toilets per block + 44

Storage tank investment costs (30 days) per block =
31 x average number of toilets per block + 83

The SPT multiplies the result by the number of blocks to obtain the total investment costs for this technology. Table 14 specifies the storage tank investment costs for the designated design sizes and each available urine tank emptying interval. The cost functions for the various intervals are described in Figure 14 by showing the total storage tank investment costs.

Table 14 Storage tank investment cost per toilet for the defined emptying intervals (UDDT)

No. of toilets	**1**	**4**	**-**
Costs per toilet (7 days emptying)	35	29	€/toilet
Costs per toilet (14 days emptying)	70	37	€/toilet
Costs per toilet (30 days emptying)	114	52	€/toilet

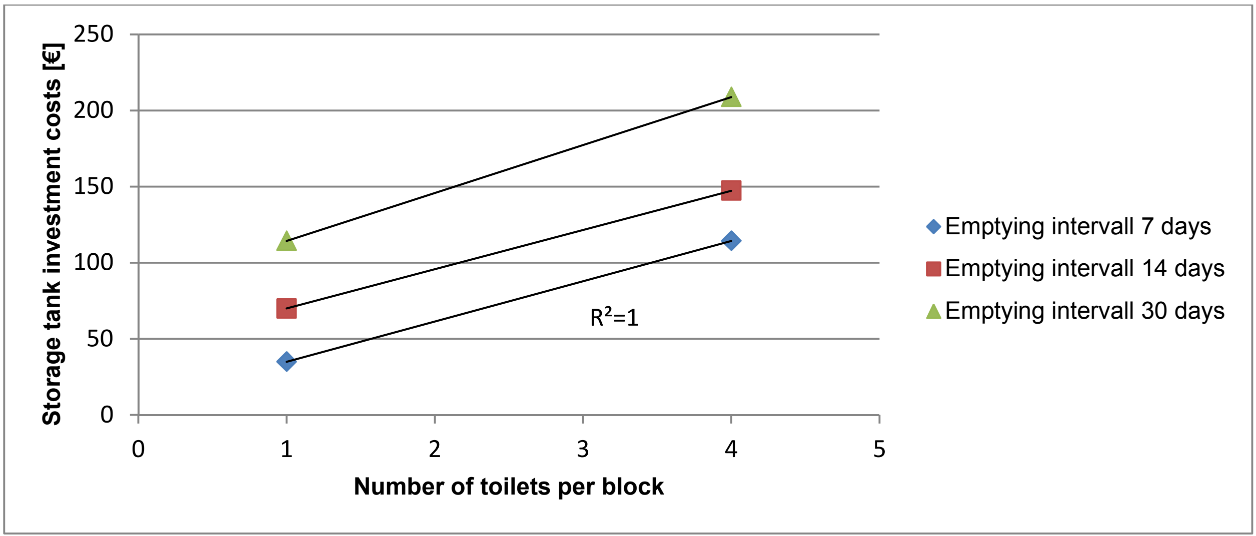

Figure 14 Storage tank investment cost function for a UDDT block

Total investment cost function

The SPT adds up the structure cost function and the selected storage tank cost function automatically to calculation the total investment costs.

Cost category allocation

Table 15 describes the cost allocation between the categories based on the design sizes. The most significant cost factor is construction. The storage tank accounts just for 2% to 6% of the structure investment costs

Table 15 Cost allocation between the categories (UDDT)

No. of toilets	**1**	**4**
Earthworks	12%	10%
Construction	56%	49%
Equipment	32%	41%

4.2.5.2 Operation and maintenance costs function

The annual O&M costs are summarised in one cost function. RIECK et al. (2012) suggest weekly delivery of bulk material and monthly inspections for the urine pipe for blockages. Minor repair works to ensure proper operation are assumed to be included in the monthly inspection works.

The monthly inspection takes 30 minutes for a single toilet block and 1.5 hours for a four toilet block. Supplying bulking material takes 1 hour for a single toilet block and 2 hours for a four toilet block. The annual O&M costs are based on an assumed hourly rate for labour of 10€. Costs for emptying and conveyance of urine and faeces are included in the transport technologies (q.v. 0 and 4.6). Table 16 describes the annual O&M costs per number of average toilets per block while Figure 15 shows the total O&M cost function per year. The total annual O&M cost result by multiplying the O&M cost per block per year by the number of blocks which is done automatically in the SPT. The following equation of the O&M cost function results in the annual O&M costs:

O&M costs per block per year = 220 x average number of toilets per block + 380

Table 16 Annual O&M costs per toilet (UDDT)

No. of toilets	**1**	**2**	**3**	**4**	**-**
Costs per toilet per year	600	410	347	315	€/toilet/yr

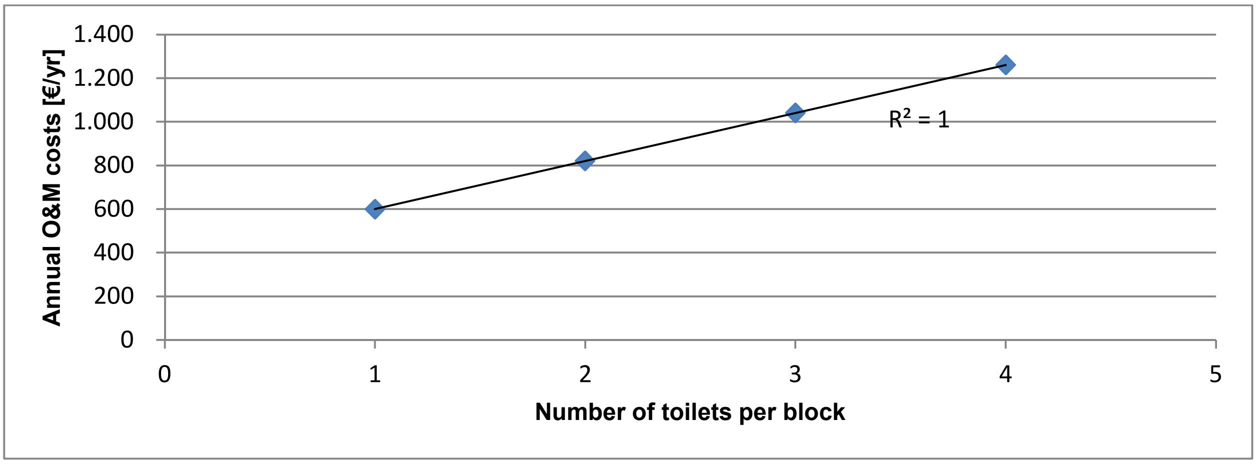

Figure 15 Annual O&M cost function for a UDDT block

4.2.5.3 Reinvestment cost function

A total reinvestment after 30 years is assumed for all technology components.

4.3 Compost chamber toilet

4.3.1 Short technology description

The compost chamber toilet collects and stores faeces and urine together with cleansing material in a processing chamber. Addition of bulking material provides proper environmental conditions for thermophilic composting (LECHNER, 2007).

4.3.2 Input parameters

Input parameters for the SPT user are:

- total person equivalent (PE) to be served
- minimum number of toilet locations

There is no limitation in range.

4.3.3 Dimensioning

The determining factor for the cost function is the number of toilets per location similar to UDDT (cf. 0). For calculation the required toilets following parameters are assumed:

- Maximum number of PE per toilet: 15
- Maximum number of toilets per block: 6

The number of toilets is calculated by dividing the PE with the maximum PE per toilet. Furthermore the minimum number of blocks results by dividing the required toilets by the maximum number of toilets per block. Hence the number of required toilet blocks can be determined which either is the entered minimum number of toilet location or the minimum number of blocks as calculated before. Dividing the required number toilets by the actual number of block results in the average number of toilets per block that is relevant for the cost function. The selected design size for determine the cost function are a single toilet block and a six toilet block.

4.3.4 Design assumptions

The composting chamber toilet consists of a processing chamber with a single opening in the toilet floor. The chamber is designed with a wired and welded mesh where excreta and additives are kept for degradation. The chamber is accessible by a metal door and a revision opening. Emptying of the chamber is manageable by the corridor. Whereby the costs for emptying and collecting the compost are considered in the transport technology (cf. 4.6). The ventilation for the chamber consists of a black-painted PVC pipe and a savonius fan on the top which is a wind-powered evacuation fan. The emergency drain is designed in case of inaccurate operation. The superstructure above floor level is not included in the cost function due to the fact that superstructure is not considered in a cost function of a water-borne system as well e.g. flush toilet in a dwelling house. Figure 12 shows the design of the UDDT and detailed drawings are in Appendix 2.

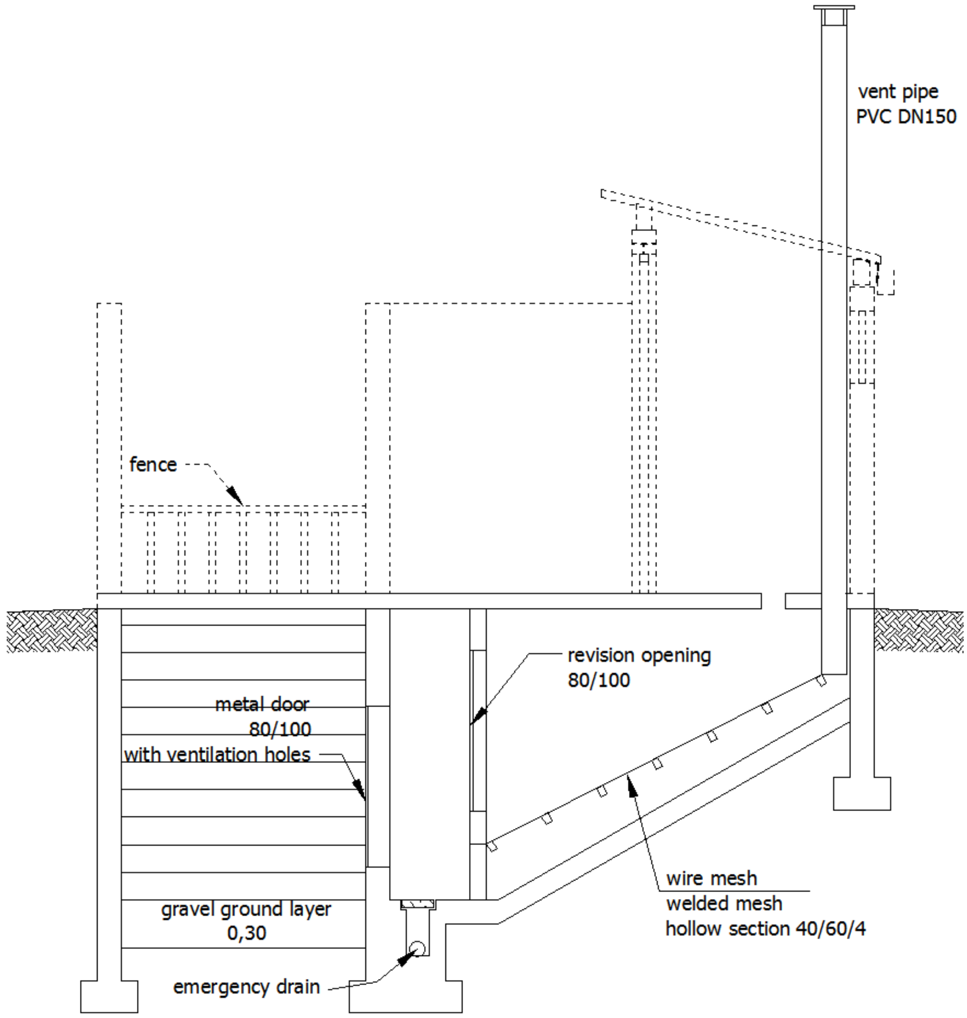

Figure 16 Design of Composting chamber toilet

4.3.5 Cost functions

4.3.5.1 Investment cost function

The investment cost function is calculated by the total prices out of three designs of different size: a single compost chamber toilet, a three and a six toilet block. The total cost of a particular compost toilet block compromise of costs for earthworks, construction, piping and equipment specified in a bill of quantity.

Earthworks costs

Earthworks costs include positions listed in Table 17. These positions consider preparation, excavation and backfilling works. The pit excavation is performed as an excavation with inward-slope and followed by backfilling after finishing the construction. The bedding beneath the floor slab is done with gravel.

Table 17 Positions of earthworks costs (Compost chamber toilet)

Item no.	Position	Unit
020201A	Clearing area	m^2
030201A	Remove topsoil	m^3
030206A	Replace Topsoil	m^3
030211B	Re-Cultivate topsoil	m^2
030331A	Pit excavation with inward-sloping	m^3
030701B	Backfilling of trenches	m^3
030703C	Bedding with gravel	m^3

Construction costs

Construction costs consist of concrete works shown in Table 18. The quality of the concrete for the foundation is supposed to be C12/15 for all other structures it is C20/25. All reinforcement works have to be included in the unit price for concrete and performed according to static requirements.

Table 18 Positions of construction costs (Compost chamber toilet)

Item no.	Position	Unit
110301A	Foundation C12/15	m^3
110302A	Slab C20/25 up to 30cm	m^3
110401A	Wall 12-20cm C20/25	m^3
110601A	Staircase/Platform C20/25 up to 15cm	m^3
110605A	Concrete slab ceilings C20/25 up to 20cm	m^3

Equipment costs

Equipment costs include revision opening cover, compost chamber equipment, ventilation and squatting pan as presented in Table 19.

Table 19 Positions of equipment costs (Compost chamber toilet)

Item no.	Position	Unit
n/a	Revision opening 100x80cm	pcs
n/a	Metal door with ventilation holes 100x80cm	pcs
n/a	Wired mesh	pcs
n/a	Profile steel 60x40mm	pcs
n/a	PVC ventilation pipe DN150	pcs
n/a	Savonius fan	pcs
n/a	Squatting pan	pcs

Investment cost function

The investment costs are based on the average number of toilets per block are calculated by following function:

Investment costs = 6627 x ln(average number of toilets per block) + 5943

The SPT multiplies this result by the number of blocks to obtain the total investment cost this technology. In Table 13 the structure investment costs for the design sizes are described in costs per toilets. The cost function for a single block of toilets is presented in Figure 17.

Table 20 Investment costs per toilet (Compost chamber toilet)

No. of toilets	**1**	**3**	**6**	**-**
Costs per toilet	5,368	4,304	2,818	€/toilet

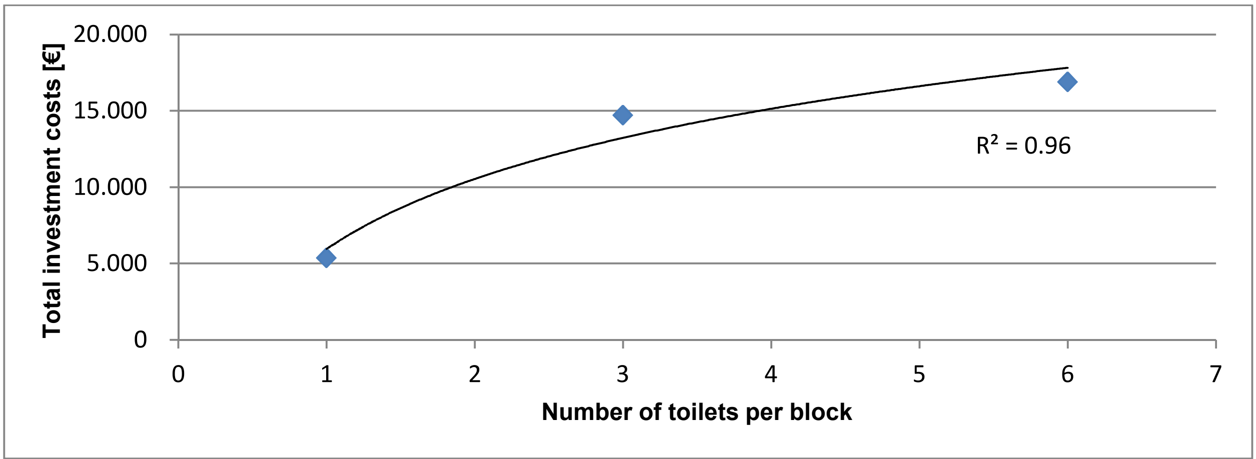

Figure 17 Investment cost function for a compost chamber toilet block

Cost category allocation

Table 21 describes the cost allocation between the categories based on the design sizes. The most significant cost factor for composting chamber toilet is the construction.

Table 21 Cost allocation between the categories (Compost chamber toilet)

No. of toilets	1	3	6
Earthworks	11%	7%	8%
Construction	77%	80%	70%
Equipment	12%	13%	22%

4.3.5.2 Operation and maintenance costs function

RIECK et al. (2012) suggest weekly delivery of bulk material and monthly inspections. Minor repair works to ensure proper operation are assumed to be included in the monthly inspection.

The monthly inspection takes 30 minutes for a single toilet block and 2 hours for a six toilet block. Supplying bulking material takes 1 hour for a single toilet block and 2.5 hours for a six toilet block. The annual O&M costs are based on an assumed hourly rate for labour of 10€. Costs for emptying and conveyance of the compost are included in the transport technologies (cf. 4.6). Table 22 describes the annual O&M costs per number of average toilets per block while Figure 15 shows the total O&M cost function per year. The total annual O&M costs result by multiplying the O&M cost per block per year by the number of blocks which is done automatically in the SPT. The following equation of the O&M cost function results in the annual O&M costs:

O&M costs per block per year = 198 x average number of toilets per block + 402

Table 22 Annual O&M costs per toilet (Compost chamber toilet)

No. of toilets	1	2	3	4	5	6	-
Costs per toilet per year	600	399	332	299	278	265	€/toilet/yr

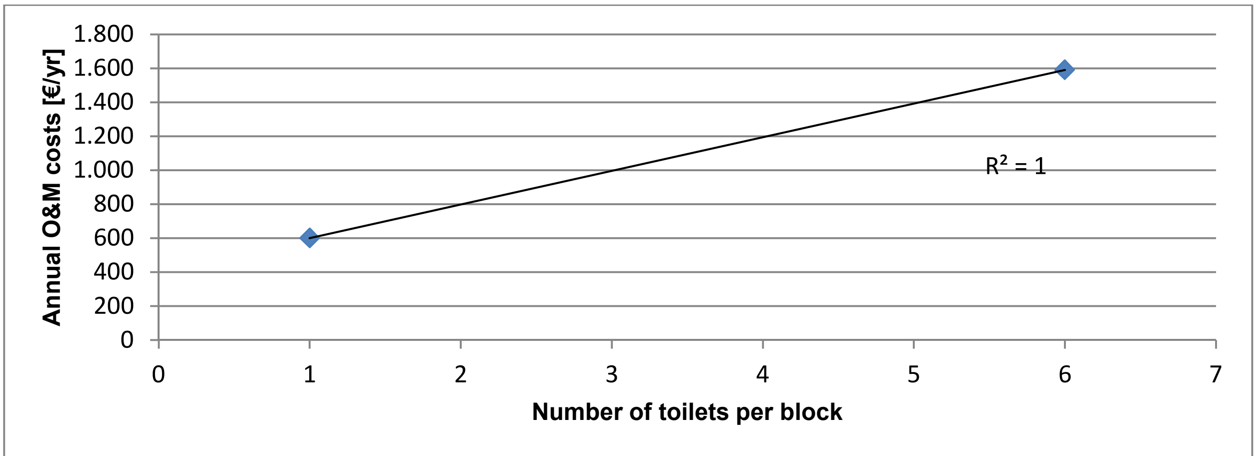

Figure 18 Annual O&M cost function for a compost chamber toilet block

4.3.5.3 Reinvestment cost function

A total reinvestment after 30 years is assumed for all technology components.

4.4 Collection of sludge

4.4.1 Short technology description

This technology covers the collection of sludge at any pick-up point and the transportation and the discharge at the disposal site by motorised vehicle.

In principle the technology consists of a motor vehicle equipped with a vacuum pump and a tank. Desludging of e.g. septic tanks is achieved by the pump creating a vacuum in the tank and hose. Emptying of the vacuum tanker is done by pressurised discharge or by tipping the truck (BRIKKE and BREDERO, 2003).

Two options are available for the collection and transportation of sludge in the SPT:

Vacuum truck

Commonly used vacuum truck consists of a 4-6 m³ tank and a pump assembly installed on a truck. In general the collection of sludge by vacuum trucks is the fast, suitable for large areas, efficient in terms of capacity but limited by the size of the road and the accessibility of the site to empty (BRIKKE and BREDERO, 2003; O'RIORDAN, 2009).

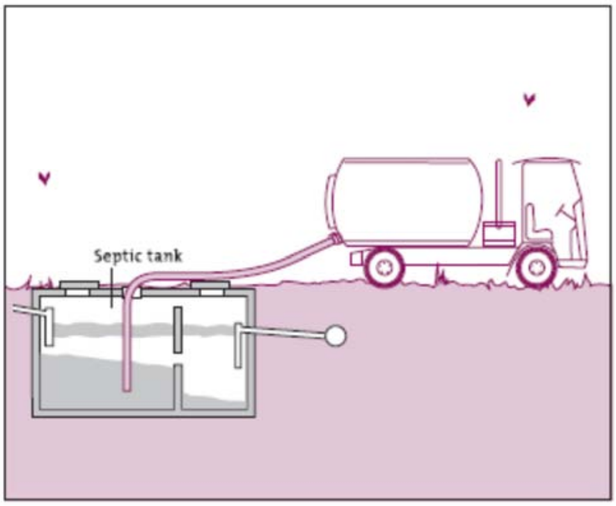

Figure 19 Vacuum truck (BRIKKE and BREDERO, 2003)

Vacutug

The Vacutug was designed to provide a simple and inexpensive method for emptying pit-latrines in areas where access by conventional vacuum trucks is impossible. It has a tank of 500 litres capacity and a pump assembly on wheels. The small gasoline engine is used to operate the pump and transport the waste at a maximum speed of 5 km/h. The vacuum pump has a 1700 litres a minute air flow and can be reversed for discharging. A 3 inch diameter PVC hose is attached to the pump (UN-HABITAT, 2012).

Figure 20 Vacutug (UN-HABITAT, 2012)

4.4.2 Input parameters

The cost function is based on the number of required transport units. This number is calculated from following input parameters:

- type of transport (either vacuum truck or vacutug)
- number of pick-up points for sludge
- average distance between the pick-up points and the disposal site
- total volume of sludge to be transported per interval
- interval of emptying

No limitation in range is given by the design.

4.4.3 Design assumptions and dimensioning

The dimensioning is done by calculating the number of required transport vehicles for the special application. Hence the maximum number of locations that can be served is compared with the given locations. Following assumptions and parameter are set for the vacuum truck and the vacutug:

Table 23 Parameters for dimensioning the vacuum truck and vacutug for sludge transport

	Vacuum truck	**Vacutug**	**Unit**	**Reference**
Working hours per day:	10		hours	
Working days per year:	295		days	
Average speed:	20	5	km/h	UN-HABITAT, 2012
Maximum load:	5	0.5	m³	BRIKKE and BREDERO, 2003 UN-HABITAT, 2012
Time spent at costumer:	45	30	min	
Time for discharge at disposal site:	45	30	min	

These points describe the procedure to determine the maximum number of locations that can be served by a single vehicle:

- Amount of sludge that occurs per location per interval: Total volume of sludge to transport divided by the number of pick-up points.
- Amount of sludge collected per trip per location is either maximum load of the vehicle or the amount of sludge per location, as calculated before, if this value is smaller.
- Number of trips per location: Amount of sludge that occurs per location per interval divided by the amount of sludge collected per trip per location.
- Number of location served per trip is the load of the tanker divided by the amount of sludge collected per trip per location. This value is limited by a 10 hours working day.
- Time per trip compromised the time spent at costumer for emptying, the time for hauling to the disposal facility and the time for discharging.
- Trips per day: Hours per working day divided by the time per trip.
- Number of location served per day: Product of the number of trips per location and the number of locations served per trip divided by the number of trips per day.
- Maximum number of locations served by a single vehicle is the number of location served per day multiplied by the number of working days per collection interval.

4.4.4 Cost functions

All cost functions for the sludge transport are based on the number of required vehicles. The number of vehicles is calculated by maximum number of locations that are served by a single vehicle divided by the given number of pick-up points.

4.4.4.1 Investment cost function

The investment cost function considers the capital costs for a selected vehicle.

Investment costs = Number of required vehicles x vehicle investment costs

4.4.4.2 Operation and maintenance costs function

Annual O&M costs include expenses for gasoline, maintenance and labour. Following assumptions are set:

Vacuum truck

- Annual gasoline costs for a vehicle is 5 % of the investment costs.
- Maintenance cost for a vehicle is 15 % of the investment costs.
- One driver and one unskilled labourer are required to operate a vehicle.

Vacutug

- Gasoline consumption is 3 litres per day (UN-HABITAT, 2000).
- Maintenance cost for a vehicle is 15 % of the investment costs (UN-HABITAT, 2000).
- One skilled and one unskilled labourer are required to operate a vehicle.

O&M costs per year = Number of required vehicles x vehicle O&M costs

4.4.4.3 Reinvestment cost function

The reinvestment cost function consider a total replacement of the special vehicles after 10 years (LAWA, 2005)

4.5 Collection of urine

4.5.1 Short technology description

This technology covers the collection of urine at any pick-up point and the transportation and the discharge at the disposal site by motorised vehicle. In principle the technology consists of a motor vehicle equipped with a vacuum pump and a tank as described in the technology Collection of sludge (cf. 0). Both mentioned vehicle options are appropriate for the urine transportation as well.

4.5.2 Input parameters

The cost function is based on the number of required transport units. This number is calculated from following input parameters:

- type of transport (either vacuum truck or vacutug)
- person equivalent (PE) served
- number of pick-up points for urine
- average distance between the pick-up points and the disposal site
- interval of emptying

No limitation in range is given by the design.

4.5.3 Design assumptions and dimensioning

The dimensioning is done by calculating the number of required transport vehicles for the special application. Hence the maximum number of locations that can be served is compared with the given locations. Following assumptions and parameter are set for the vacuum truck and the vacutug:

Table 24 Parameters for dimensioning the vacuum truck and vacutug for urine transport

	Vacuum truck	**Vacutug**	**Unit**	**Reference**
Working hours per day:	10		hours	
Working days per year:	295		days	
Average speed:	20	5	km/h	UN-HABITAT, 2012
Maximum load:	5	0.5	m³	BRIKKE and BREDERO, 2003 UN-HABITAT, 2012
Time spent at costumer:	45	30	min	
Time for discharge at disposal site:	45	30	min	

These points describe the procedure to determine the maximum number of locations that can be served by a single vehicle:

- Total urine volume per interval: Served PE multiplied by the urine volume per PE per year that is 50 l/PE/yr (LECHNER, 2007) and related to the selected emptying interval.
- Amount of urine that occurs per location per interval: Total volume of urine per interval divided by the number of pick-up points.
- Amount of urine collected per trip per location is either maximum load of the vehicle or the amount of urine per location, as calculated before, if this value is smaller.

- Number of trips per location: Amount of urine that occurs per location per interval divided by the amount of urine collected per trip per location.
- Number of location served per trip is the load of the tanker divided by the amount of urine collected per trip per location. This value is limited by a 10 hours working day.
- Time per trip compromised the time spent at costumer for emptying, the time for hauling to the disposal facility and the time for discharging.
- Trips per day: Hours per working day divided by the time per trip.
- Number of location served per day: Product of the number of trips per location and the number of locations served per trip divided by the number of trips per day.
- Maximum number of locations served by a single vehicle is the number of location served per day multiplied by the number of working days per collection interval.

4.5.4 Cost functions

All cost functions for the sludge transport are based on the number of required vehicles. The number of vehicles is calculated by maximum number of locations that are served by a single vehicle divided by the given number of pick-up points.

4.5.4.1 Investment cost function

The investment cost function considers the capital costs for a selected vehicle.

Investment costs = Number of required vehicles x vehicle investment costs

4.5.4.2 Operation and maintenance costs function

Annual O&M costs include expenses for gasoline, maintenance and labour. Following assumptions are set:

Vacuum truck

- Annual gasoline costs for a vehicle is 5 % of the investment costs.
- Maintenance cost for a vehicle is 15 % of the investment costs.
- One driver and one unskilled labourer are required to operate a vehicle.

Vacutug

- Gasoline consumption is 3 litres per day (UN-HABITAT, 2000).
- Maintenance cost for a vehicle is 15 % of the investment costs (UN-HABITAT, 2000).
- One skilled and one unskilled labourer are required to operate a vehicle.

O&M costs per year = Number of required vehicles x vehicle O&M costs

4.5.4.3 Reinvestment cost function

The reinvestment cost function considers a total replacement of all special vehicles after 10 years (LAWA, 2005).

4.6 Collection of faeces

4.6.1 Short technology description

The technology describes the collection of dried faeces from designated pick-up points and their transportation and disposal at the treatment site. The system for the collection of faeces consists of the collection container in the dry toilet and a collection service provider who collects the excreta on a regular level and transports them to a treatment site in the containers by a vehicle. The treatment equipment at the treatment site is not part of the transport system.

For transporting three systems are available: donkey chart, small truck and big truck

While the advantages of trucks are the capacity and the speed, the donkey cart is beneficial in areas where roads are narrow and in rural area where trucks might not operate at full capacity.

4.6.2 Input parameters

The cost function is based on the number of required transport units. This number is calculated from following input parameters:

- type of transport (either donkey cart, small truck or big truck)
- person equivalent (PE) served
- number of pick-up points for solids
- average distance between the pick-up points and the disposal site
- faeces source (UDDT or compost camber toilet)

No limitation in range is given by the design.

4.6.3 Design assumptions and dimensioning

The dimensioning is done by calculation the number of required transport vehicles. Hence the maximum number of locations that can be served is compared with the locations given. Following tables give the parameter for the determination of faeces volume and the transport capacities:

Table 25 Parameters for the faeces volume determination

Faeces per person per year:	50	l/PE/yr	LECHNER, 2007
Addition of bulk material:	100% of faeces volume	-	
Density of faeces:	1.3	kg	
Shrinking of faeces in UDDT:	20%	-	
Shrinking of faeces in compost chamber:	75%	-	
Capacity of faeces container:	50	l	
UDDT emptying interval:	12	days	Derived from faeces formation and container capacity
Compost chamber emptying interval:	6	month	LECHNER, 2007

Table 26 Parameters for the dimensioning of faeces transport

	Donkey cart	Small truck	Big truck	Unit
Container for faeces collection:	50			l
Time spent at costumer:	10			min
Time for offload at treatment area:	60			min
Working hours per day:	10			hours
Working days per year:	295			days
Average speed:	3	20	20	km/h
Maximum load:	300	1200	10,000	kg
Rate of loading utilisation:	90%	90%	90%	-

These points describe the procedure to determine the maximum number of locations that can be served by a single vehicle:

- Total faeces volume per interval: Served PE multiplied by the faeces volume per PE per year multiplied by the shrinking percentage and related to the selected emptying interval.
- Amount of faeces that occur per location per interval: Total volume of faeces per interval divided by the number of pick-up points.
- Amount of containers collected per interval per location: Amount of faeces per location per interval divided by the container volume and the faeces density
- Amount of containers collected per trip per location: Is either the maximum load of the vehicle or the amount of containers collected per interval per location
- Number of trips per location: Amount of containers that occur per interval per location divided by the amount of containers collected per trip per location.
- Number of location served per trip is the load of the vehicle divided by the amount of urine collected per trip per location. This value is limited by a 10 hours working day.
- Time per trip compromised the time spent at costumer for loading, the time for hauling to the disposal facility and the time for offloading.
- Trips per day: Hours per working day divided by the time per trip.
- Number of location served per day: Product of the number of trips per location and the number of locations served per trip divided by the number of trips per day.
- Maximum number of locations served by a single vehicle is the number of location served per day multiplied by the number of working days per collection interval.

4.6.4 Cost functions

All cost functions are based on the required quantity of transport vehicles. For the calculation of the required vehicles a relationship will be established between the number of actually served locations and the maximum locations that could be served.

4.6.4.1 Investment cost function

The investment cost function considers the capital costs for a selected vehicle and the required containers.

Investment costs = Number of required vehicles x vehicle investment costs

4.6.4.2 Operation and maintenance costs function

Annual O&M costs include expenses for gasoline or food, maintenance and labour. Following assumptions are set:

Donkey cart

- Food and water for the donkey is 7 % of the investment costs. Derived from GRAMBAUER (2011).
- Maintenance and spare part costs for a vehicle are 7 % of the investment costs. Derived from GRAMBAUER (2011).
- Two unskilled labourers are required to operate a vehicle.

Small truck

- Gasoline consumption is 15 litres per 100 km.
- Maintenance & spare part cost for a vehicle is 7 % of the investment costs.
- One driver and one unskilled labourer are required to operate the small truck.

Big truck

- Gasoline consumption is 25 litres per 100 km.
- Maintenance & spare part cost for a vehicle is 7 % of the investment costs.
- One driver and two unskilled labourers are required to operate the small truck.

O&M costs per year = Number of required vehicles x vehicle O&M costs

4.6.4.3 Reinvestment cost function

The reinvestment cost function considers a total replacement of all special vehicles after 10 years (LAWA, 2005).

4.7 Septic tank

4.7.1 Short technology description

Septic tanks are watertight chambers und usually used for primary treatment of sanitary wastewater form individual households. The treatment process works by settling of solid phase and anaerobic digestion of settled solids while scum (oil and fat) will float on the top. The settled sludge has to be removed regularly. The treated wastewater leaves the septic tank after the designated retention time at the outlet pipe (OECD, 2005; TILLEY et al., 2008). Within the SPT the septic tank will be used as pre-treatment for constructed wetlands.

4.7.2 Input parameters

Input parameters for the SPT user are:

- total person equivalent (PE) to be served
- number of required septic tanks, whereby the size of the individual septic tanks is assumed to equal

The design range of the cost function is limited from 5 to 2000 PE for a single septic tank.

4.7.3 Dimensioning

The determining factor for the design of the septic tank is the capacity. The dimensioning of the septic tank is done according to FRANCEYS et al. (1992).

The total capacity (C) of the tank compromises the liquid retention volume (and the volume for sludge and scum storage. The design is done by following equations:

C = A+ B [litres]

A liquid retention volume [litres]; This is the minimum capacity required for a liquid retention of 24 hours.

B volume for sludge and scum storage [litres]

A = PE x q [litres]

PE number of people served by the tank

q sewage flow per person per day [litres/PE/day]; The sewage flow is assumed to be 80 litres per person per day.

B = PE x N x F x S [litres]

N number of years between sludge emptying [years]; The tank is assumed to be emptied every three years.

F relation of sludge digestion rate to outside temperature and the desludging interval (see Table 27); At an assumed temperature of more than 10°C throughout the year and at the given desludge interval of three years the factor is supposed to be 1.

S rate of sludge and scum accumulation per person per year [litre/PE/year]; The system is designed for sewage including greywater. Therefore the accumulation of sludge and scum is 40 litres per person per year.

Table 27 Value of sizing factor “F” in determining volume for sludge and scum storage (FRANCEYS et al., 1992)

Number of years between desludging	Value of *F*		
	Ambient temperature		
	>20°C throughout year	>10°C throughout year	<10°C during winter
1	1.3	1.5	2.5
2	1.0	1.15	1.5
3	1.0	1.0	1.27
4	1.0	1.0	1.15
5	1.0	1.0	1.06
6 or more	1.0	1.0	1.0

For calculating the cost function the specific PE is assigned for each designed capacity. Therefore PE is the base for all cost functions and the main input parameter.

Following design sizes are defined:

PE	**5**	**20**	**50**	**100**	**200**	**500**	**1000**	**2000**

4.7.4 Design assumptions

The septic tank is divided into two compartments. The first compartment might have reduced efficiency due to the inlet disturbances. Hence the second compartment settlement process is considered to be less affected (FRANCEYS et al., 1992). T-shaped pipes will reduce turbulences at the inlet and diminish discharge of scum and solid at the outlet (TILLEY et al., 2008).

Figure 21 shows the design of the septic tank for 100 PE. For further design drawings see Appendix 2.

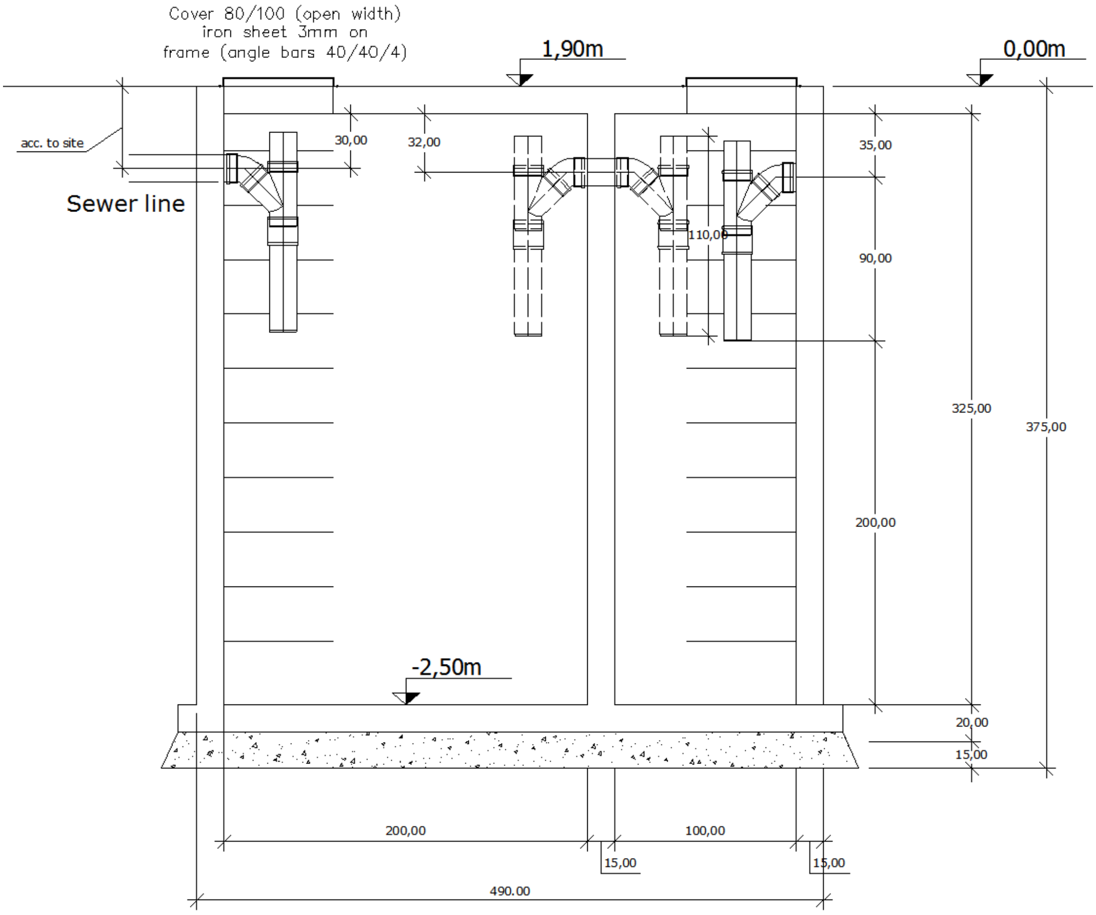

Figure 21 Design Septic tank for PE=100

4.7.5 Cost functions

The cost functions for investment, operation and maintenance and reinvestment are based on the PE and valid for a single septic tank. The cost functions are derived from cost calculated for different design sizes. To gain the total costs for all septic tanks, the SPT multiplies the number of tanks and the costs of an average sized tank.

4.7.5.1 Investment cost function

The investment cost function is calculated by the total price out of eight designs of different size. The total cost of a particular septic tank compromise of costs for earthworks, construction, piping and equipment specified in a bill of quantity.

Earthworks costs

Earthworks costs include positions shown in Table 28. These positions consider preparation, excavation and backfilling works. The pit excavation is performed as an excavation with inward-slope and followed by backfilling after finishing the construction. The bedding beneath the floor slab is done with gravel. The tank’s upper edge is flush with the surface. According to the particular site either deeper excavation or a pumping station might be necessary. Both are not considered in the investment costs.

Table 28 Positions of earthworks costs (Septic tank)

Item no.	Position	Unit
020201A	Clearing area	m²
030201A	Remove topsoil	m³
030206A	Replace Topsoil	m³
030211B	Re-Cultivate topsoil	m²
030331A	Pit excavation with inward-sloping	m³
030701B	Backfilling of trenches	m³
030703C	Bedding with gravel	m³

Construction costs

Construction costs consist of concrete works shown in Table 29. The quality of the concrete is supposed to be C20/25. All reinforcement works have to be included in the unit price for concrete and performed according to static requirements.

Table 29 Positions of construction costs (Septic tank)

Item no.	Position	Unit
110302A	Slab C20/25 up to 30cm	m³
110401A	Wall 12-20cm C20/25	m³
110605A	Concrete slab ceilings C20/25 up to 20cm	m³

Piping costs

Table 30 shows positions of piping costs which consider inflow and outflow pipes as well as in-tank pipes and fittings.

Table 30 Positions of piping costs (Septic tank)

Item no.	Position	Unit
201001A	UPVC sewer pipes DN/OD 110	m
201001C	UPVC sewer pipes DN/OD 160	m
201004A	Surcharge UPVC fittings	BU

Equipment costs

Equipment costs cover access ladder and manhole cover as presented in Table 31.

Table 31 Positions of equipment costs (Septic tank)

Item no.	Position	Unit
232101A	Aluminium ladder	m
n/a	Manhole cover 100x80cm; iron sheet 3mm on frame (angle bars 40/40/4)	pcs

Investment cost function

The costs for any design size results in following investment cost function:

$$\textit{Investment costs} = 839 \times PE^{0.6}$$

In Table 32 the investment costs for the design sizes are described in costs per PE for a single septic tank while the total investment cost function for a single septic tank is shown in Figure 22.

Table 32 Investment costs per PE for design sizes (Septic tank)

PE	**5**	**20**	**50**	**100**	**200**	**500**	**1000**	**2000**	**-**
Costs per PE	583.30	238.43	146.84	129.83	101.58	70.98	57.22	48.16	€/PE

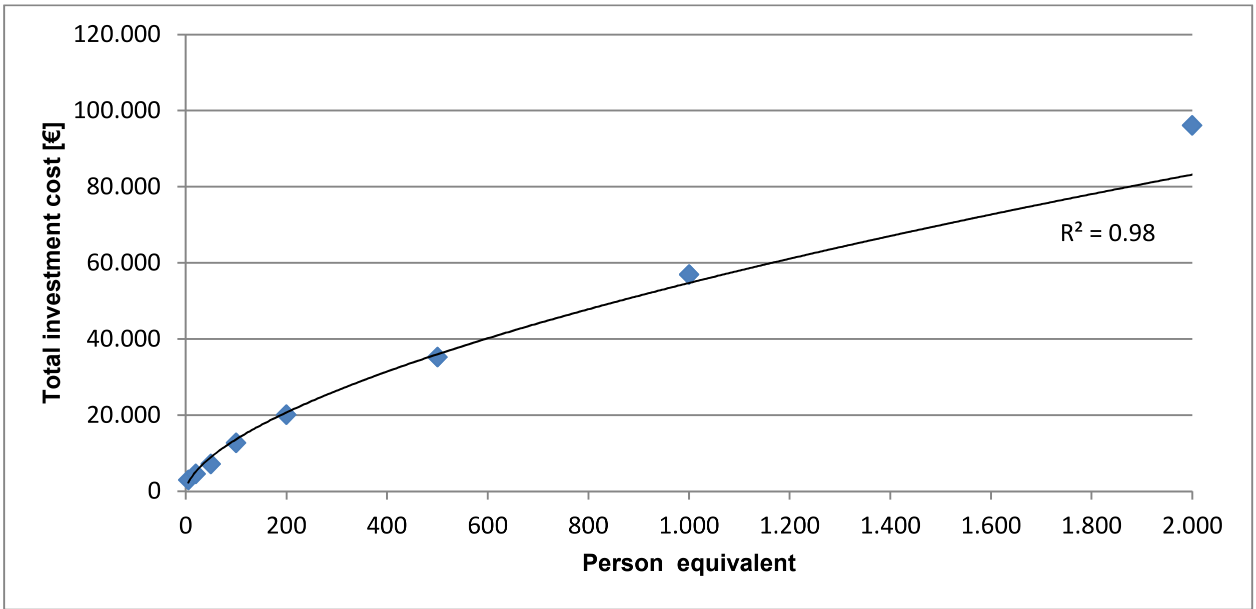

Figure 22 Investment cost function for septic tank

Cost category allocation

Table 33 describes the cost allocation between the categories based on the design sizes. The most significant cost factors are construction and earthworks whereby construction is accounting for more than 50 % of the investment costs with increasing proportion at increasing tank size.

Table 33 Cost allocation between the categories (Septic tank)

PE	5	20	50	100	200	500	1000	2000
Earthworks	35%	28%	24%	21%	18%	17%	16%	16%
Construction	51%	64%	71%	75%	74%	79%	81%	83%
Piping	3%	2%	1%	1%	6%	3%	2%	1%
Equipment	11%	7%	4%	3%	2%	1%	1%	0%

4.7.5.2 Operation and maintenance costs function

Inspections of the septic tank includes periodic checks to ensure proper operation of the septic tank such as controlling the level of scum and sludge every six month to determine if solids have to be removed and checking the ventilation opening, inlet and outlet pipes for blockage,. To avoid problems such as leakage the general condition of the tank should be examined on a regular basis (FRANCEYS et al., 1992; WMP, 2011).

The O&M cost function includes inspection works as mentioned before. It is assumed that the inspections are performed twice a month and time for inspection is from 30 minutes for a small tank to 1 hour for the largest design.

Emptying of the septic tank is not considered in the cost function of the septic tank. These costs are included in the technology of sludge transport (cf. 0.).

Table 34 describes the annual O&M costs per PE for a single septic tank while Figure 23 shows the total O&M cost function per year. The annual O&M costs for the designed septic tanks are based on an assumed hourly rate for labour of 10€. The following equation of the O&M cost function results in the annual O&M costs:

$$\textit{O\&M costs per year} = 101 \times PE^{0.11}$$

Table 34 Annual O&M costs per PE (Septic tank)

PE	5	20	50	100	200	500	1,000	2,000
Costs per PE	24.00	7.20	3.12	1.68	0.90	0.38	0.22	0.12

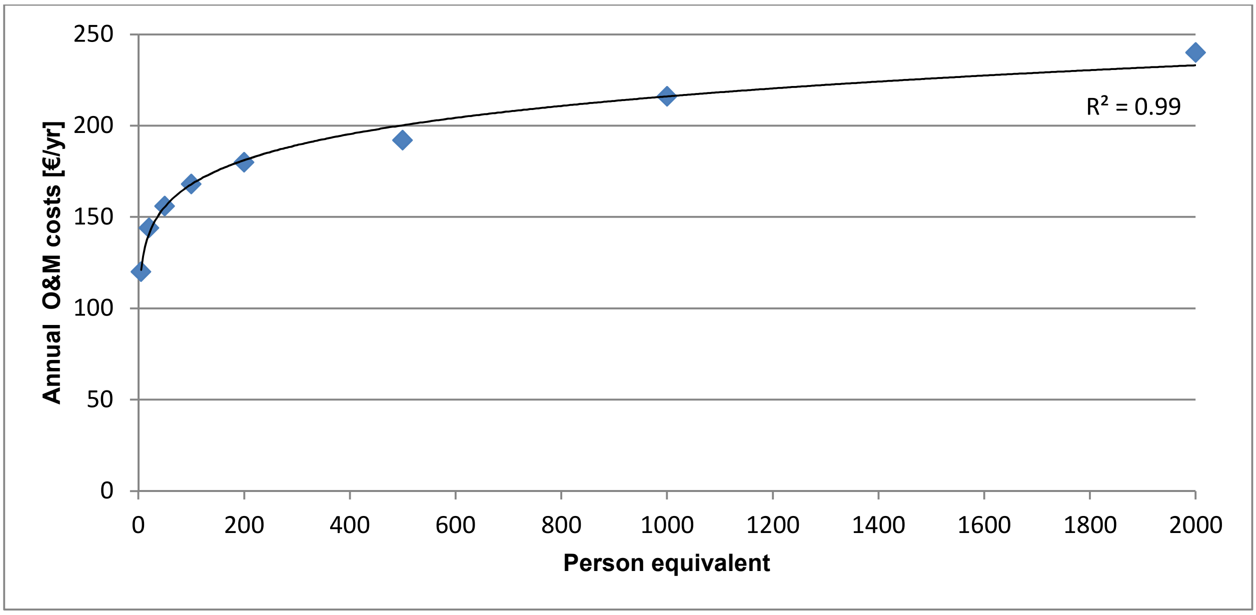

Figure 23 Annual O&M cost function for septic tank

4.7.5.3 Reinvestment cost function

The reinvestment cost function assumes replacement of pipework and manhole every 15 years. The structure will last for 50 years (OECD, 2005). The costs for reinvestment are derived from the investment costs for each design size.

4.8 Horizontal flow constructed wetland

4.8.1 Short technology description

The subsurface horizontal flow constructed wetland (HFCW) is a planted sand and gravel filter bed for secondary or tertiary treatment. The water flows horizontally through the channel and is treated by a combination of biological and physical processes. In order to operate the filter bed proper mechanical treatment of solids will be necessary in advance.

4.8.2 Input parameters

Following input parameters are necessary for the constructed wetland cost function:

- total person equivalent (PE)
- required area per person equivalent (m²/PE)

The required area is depending upon the local standards and the application. Both input parameters multiplied result in the required bed area. The given area is basis for the cost function.

The design is limited from 8 to 4,000 m² total bed area.

4.8.3 Dimensioning and design assumptions

The horizontal flow constructed wetland consists of a channel-formed excavation covered with an impermeable EPDM geomembrane which is protected by a geotextile above and beneath the geomembrane. The wastewater enters the constructed wetland by the inlet pipe and is discharged into the filter bed by a drainage pipe. After passing the filter bed the treated water is collected by drainage pipes and heads to the outlet structure. The outlet structure controls the water level of the filter bed and discharges the treated water. The filter bed includes various sand and gravel layers and a gravel zone in the distribution and collection area. Figure 24 shows a schematic design of a horizontal subsurface flow constructed wetland. Detail design drawings are available in Appendix 2.

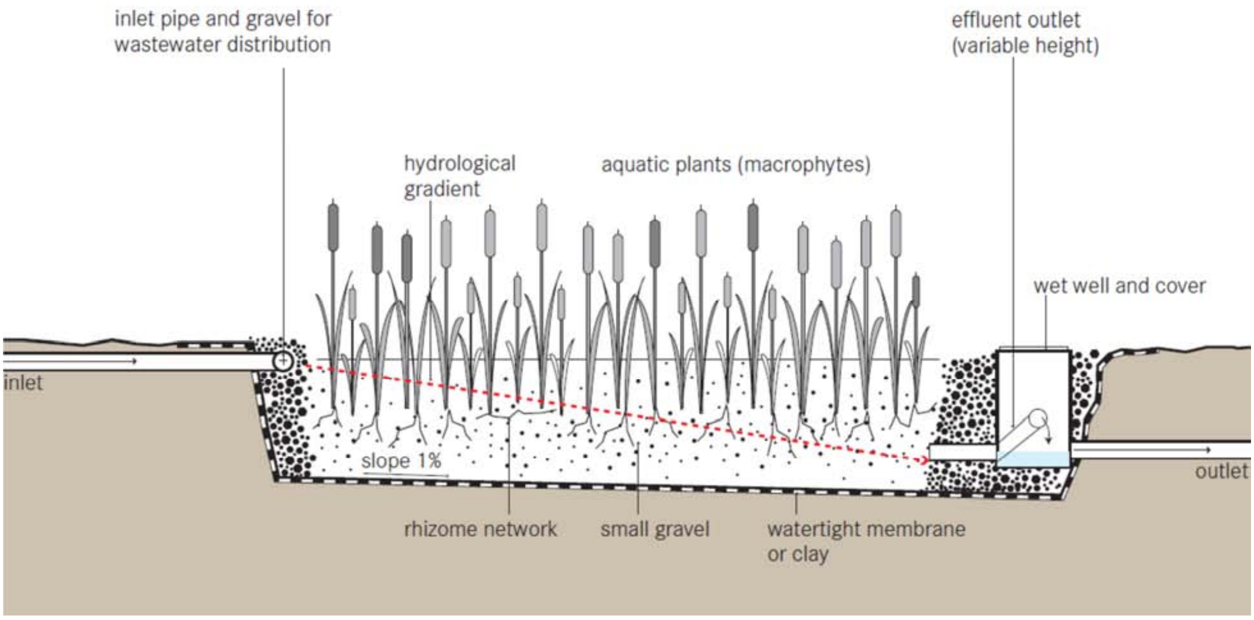

Figure 24 Schematic design of a subsurface horizontal flow constructed wetland (TILLEY et al., 2008)

The dimensioning is based on these assumptions:

- Bed length/wide ratio: 2:1
- Maximum size for one bed: 400 m²
- Systems with from three single beds require a pumping station to ensure equal distribution

Following design sizes are used as basis for the cost function:

Area	**8**	**20**	**80**	**400**	**800**	**1,200**	**2,000**	**4,000**	**m²**

4.8.4 Cost functions

4.8.4.1 Investment cost function

The investment cost function is calculated by the total price out of eight designs of different sizes. The total costs of a particular constructed wetland compromise of costs for earthworks, construction, piping, equipment specified in a bill of quantity. Costs for distribution and collections piping is included if the system has more than two beds and cost for a pumping station is included if the system has more than three beds.

Earthworks costs

Earthworks costs include positions specified in Table 35. These positions consider preparation, excavation, backfilling works and embankment preparation.

Table 35 Positions of earthworks costs (HFCW)

Item no.	Position	Unit
020201A	Clearing area	m²
030201A	Remove topsoil	m³
030331A	Pit excavation with inward-sloping	m³
030701B	Backfilling of trenches	m³
030710A	Dam embankment	m³

Construction costs

Construction costs consist of concrete works for small structures as described in Table 36. The quality of the concrete is supposed to be C20/25. All reinforcement works have to be included in the unit price for concrete and performed according to static requirements. Furthermore establishing of the filter body consisting of sand, gravel, geomembrane and geotextile according to the design is included in construction costs.

Table 36 Positions of construction costs (HFCW)

Item no.	Position	Unit
030703C	Bedding with gravel	m³
030703D	Bedding with sand	m³
030901A	Filter and drainage geotextile	m²
n/a	EPDM layer	m²
110801A	In situ manholes, small concrete structures C20/25	m³

Piping costs

Table 37 shows positions of piping costs which consider inflow and outflow pipes and drainage pipes within the bed area.

Table 37 Positions of piping costs (HFCW)

Item no.	Position	Unit
201001A	UPVC sewer pipes DN/OD 110	m
201004A	Surcharge UPVC fittings	BU
205101A	Drain pipes PE, rigid DN 80	m

Equipment costs

Equipment costs include manhole cover and planting of the reed bed with locally common reed as presented in Table 38.

Table 38 Positions of equipment costs (HFCW)

Item no.	Position	Unit
n/a	Manhole cover 80x80cm; iron sheet 3mm on frame (angle bars 40/40/4)	pcs
n/a	Planting with common reed (density 1 plant per 2m²)	pcs

Distribution and collection pipe costs

Table 39 describes positions of distribution and collection pipes between beds. These costs come into consideration in case of more than one bed.

Table 39 Positions of distribution and collection pipe costs (HFCW)

Item no.	Position	Unit
201001A	UPVC sewer pipes DN/OD 110	m
201001B	UPVC sewer pipes DN/OD 125	m
030310A	Trench excavation	m³
030701B	Backfilling of trenches	m³
030703C	Bedding of pipelines with gravel	m³
030703D	Bedding of pipelines with sand	m³

Pumping station costs

Cost considerations for pumping stations are described in detail in chapter 4.1. Pumping stations are included in systems with more than two beds with is equivalent of a total bed area more than 800 m². The costs consider a pumping station for each bed of a flow up to 2.5 l/s and a height up to 10m (Grundfos SEG.40.09.2.1.502).

Investment cost function

The investment cost function for horizontal flow constructed wetlands is divided into two separate functions. The distribution and collection pipes and the pumping station create a cost factor at a certain bed size. Due to these varying cost influences the SPT uses two single cost functions valid for either up to 800 m² total bed area or greater than 800m². The costs for any design size results in following investment cost functions:

Investment costs for total bed area ≤ 800 m² = 51 x Area + 1275

Investment costs for total bed area > 800 m² = 72 x Area - 6272

In Table 40 the investment costs for the design sizes are described in costs per m². It shows the considerably the increase of cost for bed sizes larger than 800 m² due to the fact of mandatory pumping stations for systems with more than 800 m² bed area. The two investment cost functions are shown in Figure 25.

Table 40 Investment costs per m² for the design sizes (HFCW)

Area	**8**	**20**	**80**	**400**	**800**	**1,200**	**2,000**	**4,000**	**m²**
Costs per m²	202.68	121.78	71.71	51.78	52.88	66.89	68.37	70.26	€/m²

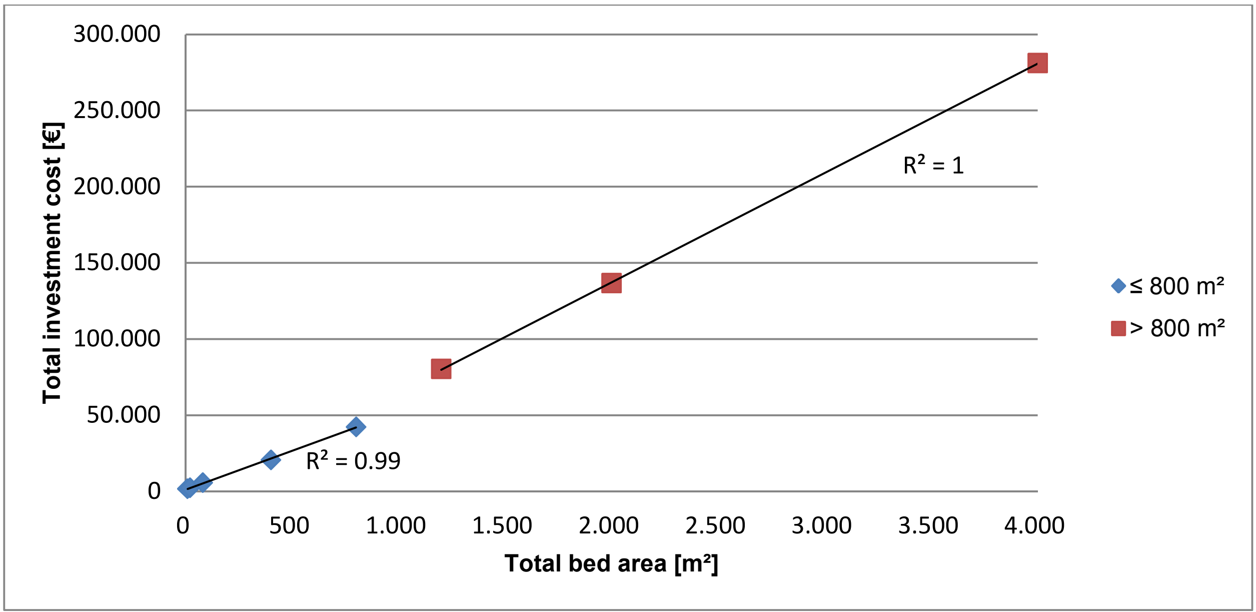

Figure 25 Investment cost function for horizontal flow constructed wetland

Cost category allocation

Table 41 describes the cost allocation between the categories based on the design sizes. The most significant cost factor is the wetland construction accounting for more than 50 % of the investment costs.

Table 41 Cost allocation between the categories (HFWC)

Area [m²]	**8**	**20**	**80**	**400**	**800**	**1,200**	**2,000**	**4,000**
Earthworks	5%	6%	7%	7%	8%	7%	8%	12%
Construction works	81%	82%	84%	86%	84%	66%	65%	62%
Pipe works in bed	6%	5%	3%	1%	1%	1%	1%	1%
Equipment	8%	7%	6%	6%	6%	5%	5%	5%
Distr. + Coll. piping	0%	0%	0%	0%	1%	1%	2%	2%
Pumping station	0%	0%	0%	0%	0%	20%	19%	18%

4.8.4.2 Operation and maintenance costs function

O&M cost function includes maintenance works given below. In addition the O&M cost for the pumping station is included if present. These costs are assumed to be 17% of the investment costs as derived from the pump station cost function (cf. 4.1.5).

Inlet and outlet structures should be checked for blockage every month which takes 30 minutes per bed. Depending on the local climate it is necessary to cut the reed vegetation roughly every 10 months. The manual harvest yield is around 50 m² per person per day (GAUSS, 2008).

Furthermore the vegetation should be checked for diseases, insects and weed especially until the vegetation is fully established (WMP, 2011).

The cost function is again divided into two parts. The first cost function is valid for total bed area not larger than 800 m², the second cost function for total bed area larger than 800 m² which includes a pumping station. Table 42 shows the annual O&M costs per m² for the selected design sizes. The O&M cost function based on the total annual costs is described in Figure 26. The annual O&M costs are based on an assumed hourly rate for labour of 10€. The following equation of the O&M cost function results in the annual O&M costs:

O&M costs per year for total bed area ≤ 800 m² = 4 x Area + 54

O&M costs per year for total bed area > 800 m² = 6 x Area + 394

Table 42 Annual O&M costs per m² for each design size (HFCW)

Area [m²]	**8**	**20**	**80**	**400**	**800**	**1,200**	**2,000**	**4,000**
Costs per m²	11.50	7.00	4.75	4.15	4.15	6.45	6.37	6.24

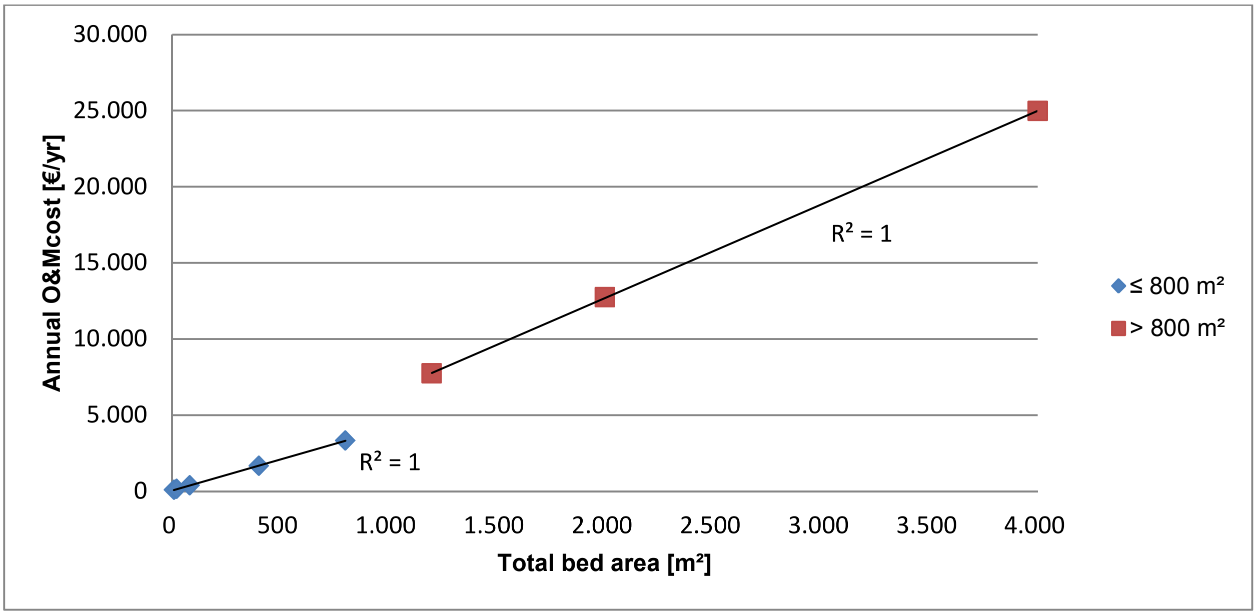

Figure 26 Annual O&M cost functions for horizontal flow constructed wetland

4.8.4.3 Reinvestment cost function

Any pump station will be replaced after 10 years. The filter bed including filter material, geomembrane, geotextile, plants, inlet and drain piping will be replaced after 15 years. The distribution and collection pipes between the beds will last for 30 year (LAWA, 2005; WMP, 2011). All costs are derived from the investment costs for each design.

4.9 Vertical flow constructed wetland

4.9.1 Short technology description

The vertical flow constructed wetland (VFCW) is a filter bed with aquatic plants. The wastewater is fed intermittently by a mechanic system onto the wetland surface. The water runs vertically through the filter matrix and is treated by biological and chemical processes. In order to operate the filter bed proper mechanical treatment of solids is necessary in advance (TILLEY et al., 2008).

4.9.2 Input parameters

Following input parameters are necessary for the constructed wetland cost function:

- total person equivalent (PE)
- required area per person equivalent (m²/PE)
- type of batch feeding equipment (pumping station or siphon)

The required area is depending upon the local standards and the application. Both input parameters multiplied result in the required bed area. The given area is basis for the cost function. Additionally the batch feeding equipment, either pumping station or siphon, is a significant parameter on all cost functions.

The design is limited from 8 to 4,000 m² total bed area.

4.9.3 Dimensioning and design assumptions

The vertical flow constructed wetland consists of a shallow excavation covered with an impermeable EPDM geomembrane which is protected by a geotextile above and beneath the geomembrane. The filter bed is made of various sand and gravel layers of different grain size and shown in detail drawings (q.v. Appendix 2). The wastewater is distributed by a pipe network and applied evenly on the surface of the VFCW. After passing the filter layers the treated water is collected by drainage pipes and head to the effluent collection tank. The treated water is discharged by an outlet pipe. Figure 27 shows a schematic drawing of a VFCW.

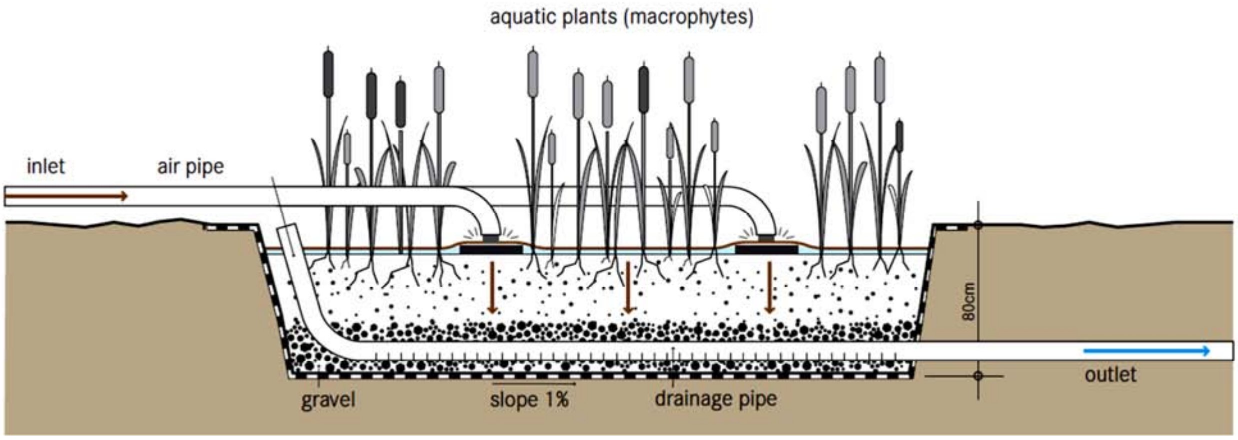

Figure 27 Schematic drawing of a vertical flow constructed wetland (TILLEY et al., 2008)

Two options are available for batch feeding: The siphon is a simple batch feeding unit that is applicable if for a total bed size up to 400 m² and only if the geodetic height is sufficient. The pump station is mandatory in all other cases.

The dimensioning is based on these assumptions:

- Bed length/wide ratio: 4:3
- Maximum size for one bed: 400 m² (ÖNORM B 2505, 2009)
- Batch feeding equipment is included, whereby siphon is only available up to 400 m² bed area

Following design sizes are used as basis for the cost function:

Area	**8**	**20**	**80**	**400**	**800**	**1,200**	**2,000**	**4,000**	**m²**

4.9.4 Cost functions

4.9.4.1 Investment cost function

The investment cost function is calculated by the total price out of eight designs of different sizes. The total cost of a particular constructed wetland compromise of costs for earthworks, construction, piping, equipment and the selected batch feeding equipment specified in a bill of quantity. Costs for distribution and collections piping is included if the system has more than two beds.

Earthworks costs

Earthworks costs include positions specified in Table 43. These positions consider preparation, excavation, backfilling works and embankment preparation.

Table 43 Positions of earthworks costs (VFCW)

Item no.	Position	Unit
020201A	Clearing area	m²
030201A	Remove topsoil	m³
030331A	Pit excavation with inward-sloping	m³
030701B	Backfilling of trenches	m³
030710A	Dam embankment	m³

Construction costs

Construction costs consist of concrete works for small structures as described in Table 36. The quality of the concrete is supposed to be C20/25. All reinforcement works have to be included in the unit price for concrete and performed according to static requirements. Furthermore establishing of the filter body consisting of sand, gravel, EPDM geomembrane and geotextile according to the design is included in construction costs.

Table 44 Positions of construction costs (VFCW)

Item no.	Position	Unit
030703C	Bedding with gravel	m^3
030703D	Bedding with sand	m^3
030901A	Filter and drainage geotextile	m^2
n/a	EPDM layer	m^2
110801A	In situ manholes, small concrete structures C20/25	m^3

Piping costs

Table 45 shows positions of piping costs which consider inflow and outflow pipes and the distribution and collection network within the bed area.

Table 45 Positions of piping costs (VFCW)

Item no.	Position	Unit
201001A	UPVC sewer pipes DN/OD 110	m
201001C	UPVC sewer pipes DN/OD 160	m
201001I	UPVC sewer pipes DN/OD 50	m
201004A	Surcharge UPVC fittings	BU
205101A	Drain pipes PE, rigid DN 80	m
205101B	Drain pipes PE, rigid DN100	m
205110A	Surcharge Drain pipe fittings	BU

Equipment costs

Equipment costs include manhole cover and planting of the reed bed with locally common reed as presented in Table 46.

Table 46 Positions of equipment costs (HFCW)

Item no.	Position	Unit
n/a	Manhole cover 80x80cm; iron sheet 3mm on frame (angle bars 40/40/4)	pcs
n/a	Planting with common reed (density 1 plant per $2m^2$)	pcs

Distribution and collection pipe costs

Table 47 describes positions of distribution and collection pipes between beds. These cost come into consideration in case of more than one bed.

Table 47 Positions of distribution and collection pipe costs (VFCW)

Item no.	Position	Unit
201001A	UPVC sewer pipes DN/OD 110	m
201001B	UPVC sewer pipes DN/OD 125	m
030310A	Trench excavation	m³
030701B	Backfilling of trenches	m³
030703C	Bedding of pipelines with gravel	m³
030703D	Bedding of pipelines with sand	m³

Pumping station costs

Cost considerations for pumping stations are described in detail in chapter 4.1. A pumping station is optional up to 400 m² bed area and included in systems with more than two beds which is equivalent of a total bed area of more than 400 m². The costs consider a pumping station for each bed of a flow up to 2.5 l/s and a height up to 10m (Grundfos SEG.40.09.2.1.502).

Siphon costs

The siphon is a simple batch feeding equipment and total construction costs are compiled by positions specified in Table 48.

Table 48 Positions of siphon (VFCW)

Item no.	Position	Unit
020201A	Clearing area	m²
030201A	Remove topsoil	m³
030211B	Re-Cultivate topsoil	m²
030331A	Pit excavation with inward-sloping	m³
030703C	Bedding with gravel	m³
110302A	Slab C20/25 up to 30cm	m³
110401A	Wall 12-20cm C20/25	m³
110605A	Concrete slab ceilings C20/25 up to 20cm	m³
n/a	Siphon equipment	BU

n/a	Manhole cover of different size; iron sheet 3mm on frame (angle bars 40/40/4)	pcs

Investment cost function

As there are two options for the batch feed equipment the SPT uses two separate cost functions to determine the costs for the VFCW:

Investment costs for VFCW with pumping station = 97 x Area + 8813

Investment costs for VFCW with siphon = 84 x Area + 1857

In Table 49 the investment cost per m² are listed for each design size and for both of the batch feeding options. Figure 28 describes the total investment costs for both options.

Table 49 Investment costs per m² for each design size and both options (VFCW)

Area	**8**	**20**	**80**	**400**	**800**	**1,200**	**2,000**	**4,000**	**m²**
Costs per m² w. pump station	1,656.04	723.90	246.87	114.13	100.50	99.59	100.28	99.66	€/m²
Costs per m² w. siphon	276.59	173.90	112.97	88.47	-	-	-	-	€/m²

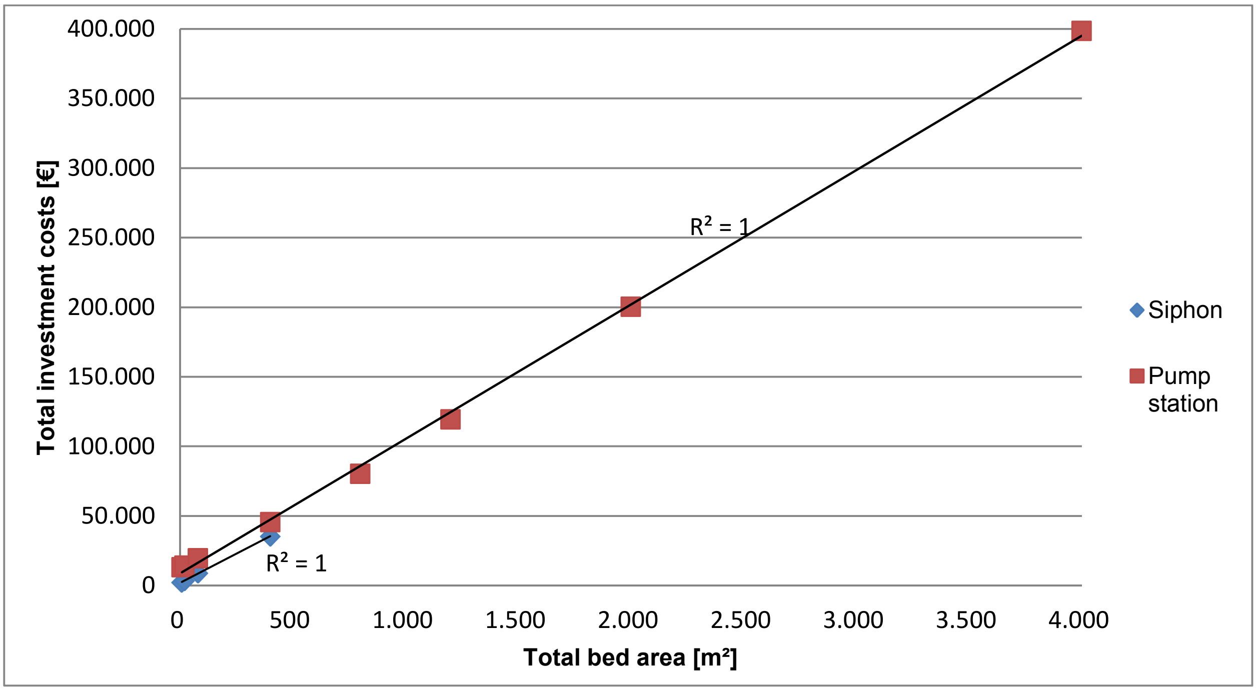

Figure 28 Investment cost functions for vertical flow constructed wetland

Cost category allocation

Table 50 describes the cost allocation between the categories for a bed system with a pump station based on the design sizes while Table 51 lists the cost allocation between the categories for a bed system with siphon feeding. The most significant cost factor is the wetland construction accounting for more than 50 % of the investment costs apart from small scale wetlands with pump stations where the pump station makes the majority of costs.

Table 50 Cost allocation between the categories with pumping station feeding (VFWC)

Area [m²]	**8**	**20**	**80**	**400**	**800**	**1,200**	**2,000**	**4,000**
Earthworks	0%	1%	3%	5%	6%	6%	6%	6%
Construction works	11%	17%	35%	62%	71%	71%	71%	72%
Pipe works in bed	2%	2%	3%	5%	5%	5%	5%	5%
Equipment	1%	1%	2%	3%	3%	3%	3%	3%
Distr. + Coll. piping	0%	0%	0%	0%	1%	1%	2%	2%
Pumping station	86%	79%	57%	25%	14%	14%	13%	12%

Table 51 Cost allocation between the categories with siphon feeding (VFWC)

Area [m²]	**8**	**20**	**80**	**400**
Earthworks	3%	4%	5%	7%
Construction works	66%	70%	76%	80%
Pipe works in bed	10%	10%	8%	6%
Equipment	6%	5%	4%	4%
Siphon	15%	11%	7%	3%

4.9.4.2 Operation and maintenance costs function

O&M cost function includes following maintenance works and utilises following assumptions: Inlet and outlet structures should be checked for blockage every month which takes 30 minutes per bed. Depending on the local climate it is necessary to cut the reed vegetation roughly every 10 months. The manual harvest yield is around 50 m² per person per day (GAUSS, 2008). Furthermore the vegetation should be checked for diseases, insects and weed especially until the vegetation is fully established (WMP, 2011).

In addition the O&M cost for the pumping station is included if present. These costs are assumed to be 17% of the investment costs as derived from the pump station cost function (cf. 4.1.5). For the siphon a monthly inspection of 30 minutes is considered.

Two separate O&M cost functions are each batch feeding option are selectable by the SPT. Table 52 specifies the annual O&M costs per m² for the selected design sizes and for both feeding options. Both O&M cost functions based on the total annual costs are described in Figure 29. The annual O&M costs are based on an assumed hourly rate for labour of 10€. The following equations of the O&M cost function results in the annual O&M costs:

O&M costs per year for VFCW with pumping station = 0.0003 x Area² + 3 x Area +1842

O&M costs per year for VFCW with siphon = 2.4 x Area +120

Table 52 Annual O&M costs per m² for each design size and both options (VFCW)

Area [m²]	8	20	80	400	800	1,200	2,000	4,000
Costs per m² w. pump station	251.67	102.11	27.33	7.39	4.97	4.85	4.77	251.67
Costs per m² w. siphon	17.40	8.40	3.90	2.70	-	-	-	-

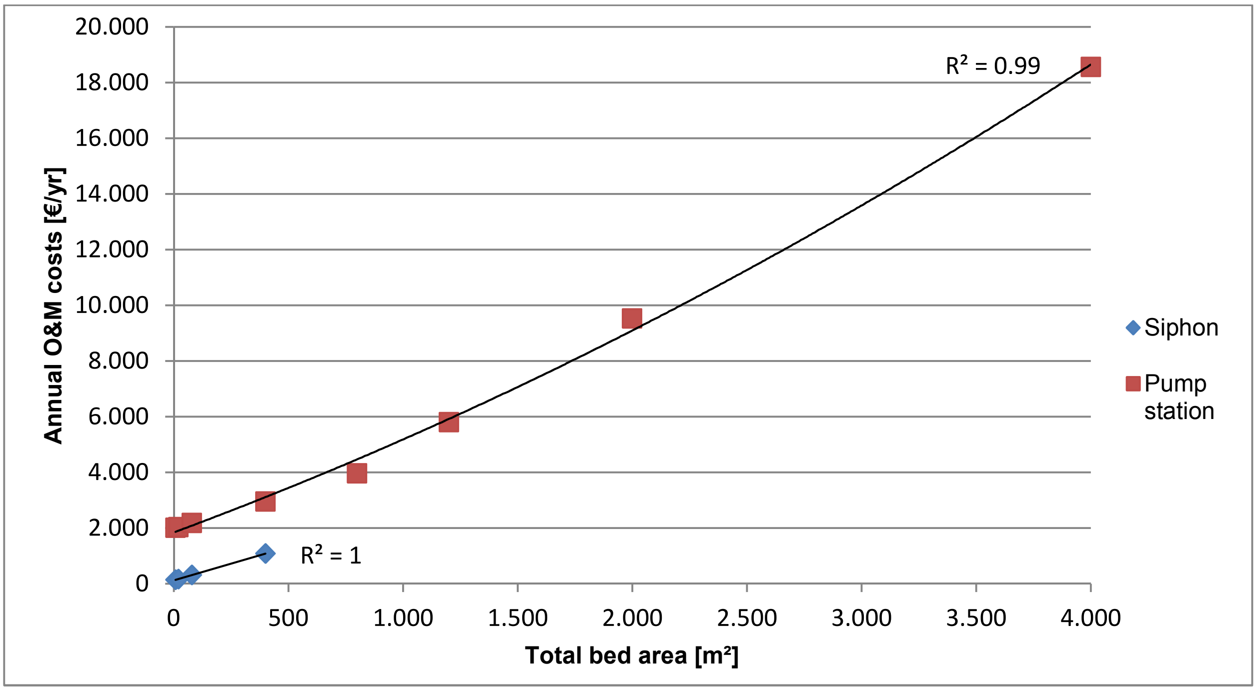

Figure 29 Annual O&M cost functions vertical flow constructed wetland

4.9.4.3 Reinvestment cost function

Any pump station or siphon equipment will be replaced after 10 years. The filter bed including filter material, geomembrane, geotextile, plants, inlet and drain piping will be replaced after 15 years. The distribution and collection pipes between the beds will last for 30 year (LAWA, 2005; WMP, 2011). All costs are derived from the investment cost for each design size.

4.10 Sludge drying reed bed

4.10.1 Short technology description

The sludge drying reed bed is a planted sealed shallow pond used for dewatering, stabilisation and hygienisation of sludge. Fresh sludge is applied directly on the surface of the bed and liquid fraction is separated from solids by percolation, evaporation and transpiration. Dried sludge will be removed after a certain time.

4.10.2 Input parameters

Following input parameters are required for the cost function of the sludge drying reed bed:

- sludge volume per year (m^3/yr)
- water content of the sludge (%)

Those parameters result in the solid load per year. The recommended area loading rate per year gives the required bed area for the entered sludge amount.

The design is limited from 5 to 50,000 m^2 total bed area.

4.10.3 Dimensioning and design assumptions

The sludge drying reed bed consists of a shallow excavation covered with an impermeable EPDM geomembrane. The geomembrane is protected by a sand layer above and beneath. A filter layer consisting of sand and gravel layer is used to drain the percolate towards the control manhole. The control manhole serves as outlet structure for discharging the percolate into the outlet pipeline and as emergency overflow in case of heavy rainfall. The outlet pipeline is controlled by a gate valve. The design considers an inlet pipe with a flexible hose to distribute the incoming sludge within the bed. The inlet is controlled by a gate valve. Figure 30 shows the schematic design of the sludge drying reed bed.

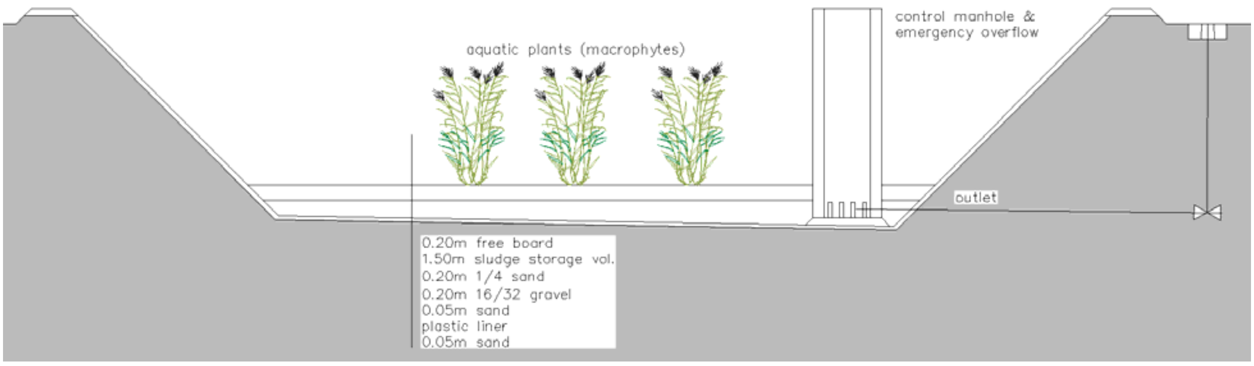

Figure 30 Schematic design Sludge drying reed bed

The design considers single beds of nine different sizes:

Single bed area	**5**	**10**	**20**	**50**	**100**	**250**	**500**	**1,000**	**2,500**	**m²**

The dimensioning of the different beds is based on assumptions listed in Table 53 and the detailed design drawings (q.v. Appendix 2).

Table 53 Design parameters sludge drying bed

Bed length/wide ratio:	approx. 3:2		
Maximum size for one bed	2500	m²	
Recommended areal loading rate per year	250	kg TS / m² / yr	KLINGEL et al., 2002
Average sludge accumulation per year	20	cm / yr	KLINGEL et al., 2002
Storage time of sludge	5	yrs	
Height of protection sand layer	5	cm	
Height of gravel layer	20	cm	
Height of filter sand layer	20	cm	

A sludge drying reed bed system uses several single beds to ensure a rest phase between the loadings. According to NIELSEN (2005) the rest phase is about 40 days. At an assumed loading period of 5 days 10 basins have to be built to meet the given rest phase. These assumptions are basis for the selection of the bed configuration. Table 54 specifies the design sizes and bed configurations that have been selected for the calculation of the cost function.

Table 54 Selected design sizes and bed configuration (Sludge drying reed bed)

Design size [m²]	**Bed configuration**
5	1 x 5 m²
10	2 x 5 m²
50	5 x 10 m²
100	10 x 10 m²
250	10 x 25 m²
500	10 x 50 m²
1,000	10 x 100 m²
2,500	10 x 250 m²
5,000	10 x 500 m²
10,000	10 x 1,000 m²
25,000	10 x 2,500 m²
50,000	20 x 2,500 m²

4.10.4 Cost functions

4.10.4.1 Investment cost function

The investment cost function is calculated by the total price out of nine designs of different size and the combination of these designs. The total cost of a particular sludge drying reed bed system compromise of costs for earthworks, construction, piping, equipment specified in a bill of quantity.

Earthworks costs

Earthworks costs include positions shown in Table 55. These positions consider preparation, and excavation works.

Table 55 Positions of earthworks costs (Sludge drying reed bed)

Item no.	Position	Unit
020201A	Clearing area	m²
030201A	Remove topsoil	m³
030331A	Pit excavation with inward-sloping	m³

Construction costs

Construction costs consist of concrete works for small structures as described in Table 56. The quality of the concrete is supposed to be C20/25. All reinforcement works have to be included in the unit price for concrete and performed according to static requirements. Furthermore establishing of the filter body consisting of sand, gravel and geomembrane according to the design is included in construction costs.

Table 56 Positions of construction costs (Sludge drying reed bed)

Item no.	Position	Unit
030703C	Bedding with gravel	m³
030703D	Bedding with sand	m³
n/a	EPDM layer	m²
110801A	In situ manholes, small concrete structures C20/25	m³

Piping costs

Table 57 lists positions of piping costs which consider inflow and outflow pipes and gate valves within the bed area.

Table 57 Positions of piping costs (Sludge drying reed bed)

Item no.	Position	Unit
201001C	UPVC sewer pipes DN/OD 160	m
214006D	Gate valve for PVC DN 150 PN 16	pcs
217004B	Telescopic extension spindle DN 150 1,8m	pcs
217101C	Street cover caps for gate valves	pcs

Equipment costs

Equipment costs include manhole cover and planting of the reed bed with locally common reed as presented in Table 58.

Table 58 Positions of equipment costs (Sludge drying reed bed)

Item no.	Position	Unit
n/a	Manhole cover 80x80cm; iron sheet 3mm on frame (angle bars 40/40/4)	pcs
n/a	Planting with common reed (density 1 plant per 2m²)	pcs

Investment cost function

The investment cost function for sludge drying reed bed is divided into two separate functions valid for either up to 50 m² total bed area or greater than 50m². The costs for any design size results in following investment cost functions:

$$\textit{Investment costs for total bed area} \leq 50\ m^2 = 522 \times Area^{0.72}$$

$$\textit{Investment costs for total bed area} > 50\ m^2 = 31 \times Area + 10523$$

In Table 59 the investment costs for the design sizes are described in costs per m² total bed area. The two investment cost functions are shown in Figure 31 and Figure 32.

Table 59 Investment costs per m² for the design sizes (Sludge drying reed bed)

Area	**5**	**10**	**50**	**100**	**250**	**500**	**1,000**	**2,500**	**5,000**	**10,000**	**25,000**	**50,000**	**m²**
Costs per m²	309	309	171	171	88	60	46	37	34	32	31	31	€/m²

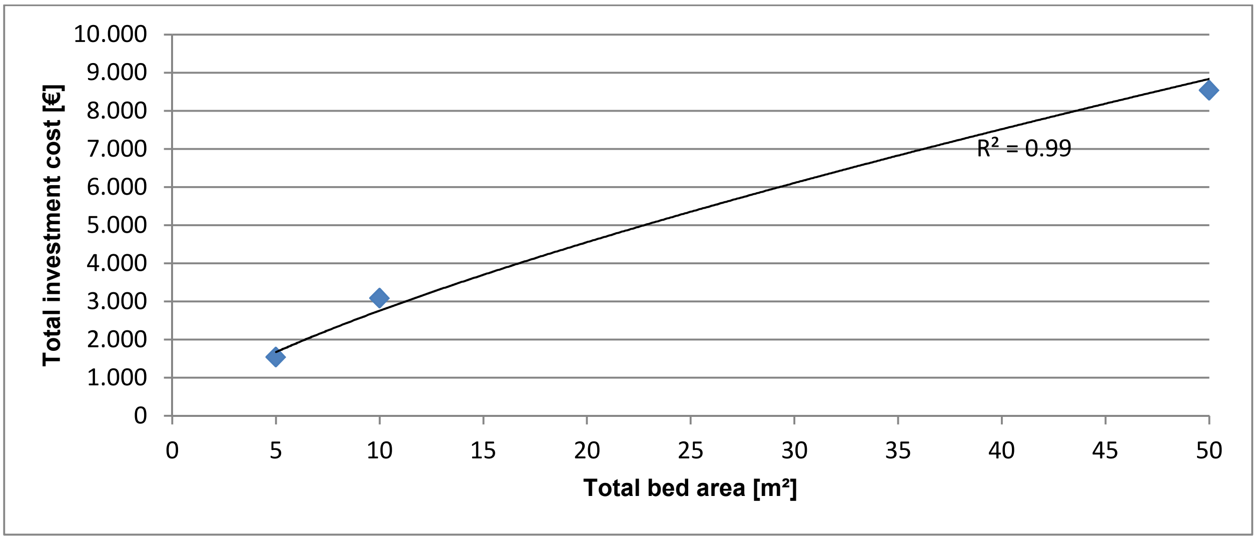

Figure 31 Investment cost function for sludge drying reed bed up to 50 m²

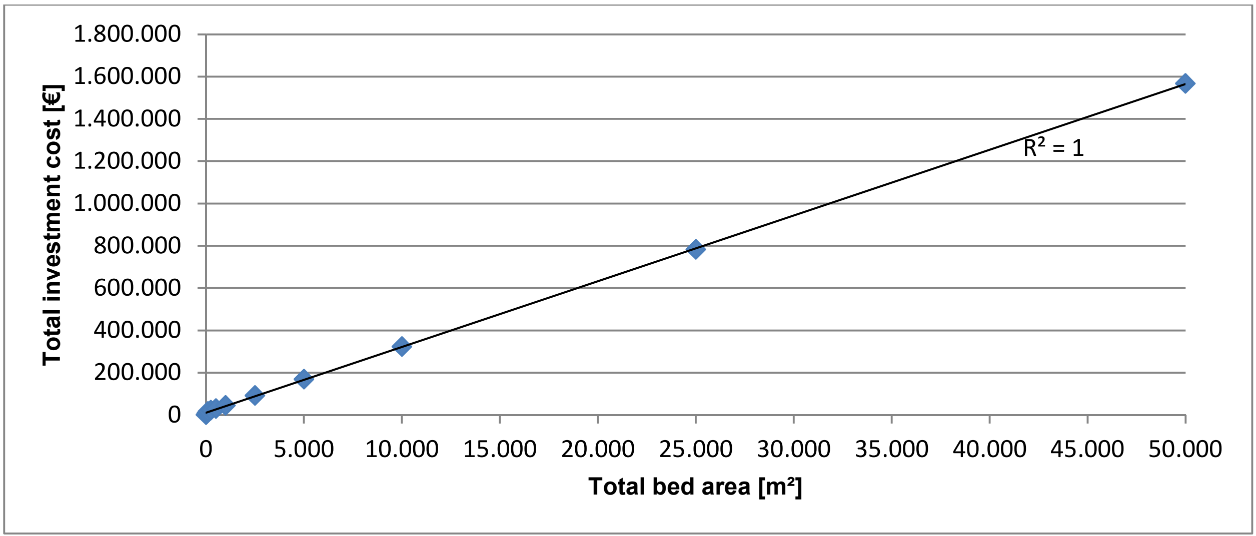

Figure 32 Investment cost function for sludge drying reed bed larger than 50 m²

Cost category allocation

Table 60 describes the cost allocation between the categories based on the design sizes. The most significant cost factor for smaller bed sizes are the piping and construction costs. For greater bed sizes the major cost factor is just the cost for construction.

Table 60 Cost allocation between the categories (Sludge drying reed bed)

Area [m²]	**5**	**10**	**50**	**100**	**250**	**500**	**1,000**	**2,500**	**5,000**	**10,000**	**25,000**	**50,000**
Earthworks	3%	3%	4%	4%	5%	5%	5%	5%	4%	4%	3%	3%
Construction works	37%	37%	42%	42%	53%	64%	75%	85%	91%	93%	96%	96%
Pipe works in bed	60%	60%	54%	54%	42%	31%	20%	10%	5%	3%	1%	1%

4.10.4.2 Operation and maintenance costs function

The O&M works are derived from GAUSS (2008). These works include an inspection, maintenance and potential repair works such as checking for blockage in pipelines, sludge for bad odour and for plant diseases and insects until the vegetation is fully established. The expenditure of time for this works differs in size of beds. In addition O&M works include the harvest of the reed vegetation that has to be cut roughly every 10 month depending on the local climate. The manual harvest yield is around 50 m² per person per day. Stabilised sludge has to be removed every 5 years. Costs for removal is part of the annual O&M cost proportionally and assumed to be 10 €/m³.

The cost function is again divided into two parts. The first cost function is valid for total bed area up to 100 m², the second cost function for total bed area larger than 100 m². Table 61 shows the annual O&M costs per m² for the selected design sizes. The O&M cost function based on the total annual costs is described in Figure 33 for a total bed area up to 100 m² and in Figure 34 for a total bed area greater than 100 m². The annual O&M costs are based on an assumed hourly rate for labour of 10€. The following equation of the O&M cost function results in the annual O&M costs:

O&M costs per year for total bed area ≤ 100 m² = $8 \times Area^{0.96}$

O&M costs per year for total bed area > 100 m² = $4.5 \times Area + 664$

Table 61 Annual O&M costs per m² bed area for each design size (Sludge drying reed bed)

Area [m²]	**5**	**10**	**50**	**100**	**250**	**500**	**1,000**	**2,500**	**5,000**	**10,000**	**25,000**	**50,000**
Costs per m²	7.40	7.40	6.65	6.65	5.96	5.60	5.15	4.88	4.76	4.67	4.58	4.58

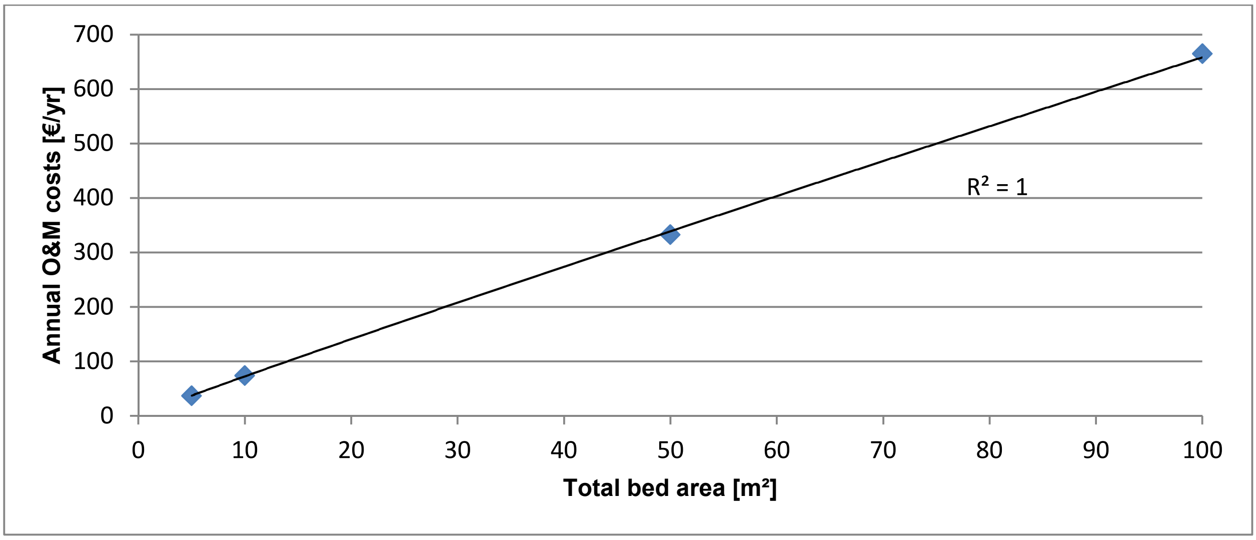

Figure 33 Annual O&M cost function for Sludge drying reed bed up to 100 m² total bed area

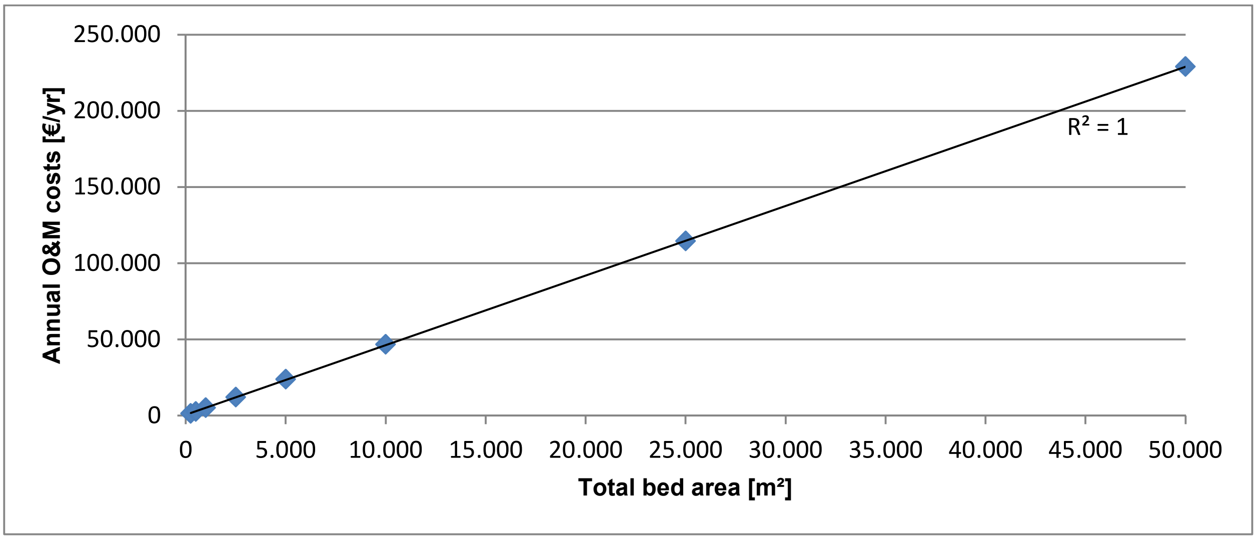

Figure 34 Annual O&M cost function for Sludge drying reed bed larger than 100 m² total bed area

4.10.4.3 Reinvestment cost function

The filter bed including filter material, geomembrane, geotextile, plants, inlet and outlet piping will be replaced after 15 years (LAWA, 2005).

4.11 Treatment of urine – Urine storage

4.11.1 Short technology description

The technology urine storage is applied on one hand in short term as buffer storage for further processing or on the other hand as a long time storage for hygienisation treatment.

4.11.2 Input parameters

Basis for the cost function are the number of served individuals and the storage time. The storage time can be either three days or six month depending on further usage.

The limitation for a 6-month storage system is set to 2,000 PE which equals a storage volume of 500 m³. The 3-days storage has no limitations in range.

4.11.3 Dimensioning and design assumptions

The design is based on following assumptions:

- *Urine volume:* The parameter for the calculation of the storage volume is 500 l of urine per person per year (LECHNER, 2007).
- *6-month storage:* For safe reuse of urine in agriculture WHO (2006) recommends a storage time of six month to ensure health risks.
- *3-day storage:* The 3-day storage is used as buffer storage for further processing such as struvite production.

The design considers plastic containers of the product “Kentainers” for storage (AQUASANTEC, 2012). The tanks have a lid to prevent odour and nitrogen loss via ammonia gas (VON MÜNCH and WINKER, 2011). The tanks are situated on the ground surface.

Figure 35 Design Storage tank (AQUASANTEC, 2012)

The design includes just the storage tank. An office building and a specially prepared storage site is not considered in the design. Also filling and emptying operations are not considered in the cost function.

4.11.4 Cost functions

The cost functions for investment, operation and maintenance and reinvestment are based on the number of served PE. The cost functions are derived from cost calculated for different design sizes.

4.11.4.1 Investment cost function

Storage tank costs

The investment cost function is calculated by the total price of the urine storage tanks listed in Table 62.

Table 62 Position of investment costs (Urine storage)

Item no.	Position	Capacity [m³]
n/a	Kentank, type: ccv 15	0.15
n/a	Kentank, type: cv 46	0.46
n/a	Kentank, type: cv 92	0.92
n/a	Kentank, type: ccv 135	1.35
n/a	Kentank, type: ccv 250	2.50
n/a	Kentank, type: ccv 500	5.00
n/a	Kentank, type: ccv 1000	10.00
n/a	Kentank, type: ccv 2400	24.00

Investment cost function

The SPT used two investment cost function to calculate the actual investment costs. The first cost function is used for storage capacity up to 24 m³ which is the largest storage tank available. The second cost function is used for a storage capacity of 24 m³ or greater. This function is based on the price for the largest tank.

Investment costs for storage capacity < 24 m³ = 2.6 x Capacity² + 58.1 x Capacity + 12

Investment costs for storage capacity ≥ 24 m³ = 120.8 x Capacity

Table 63 shows the investment cost for the design sizes described in costs per m³ storage capacity. The investment cost function up to a storage capacity of 24 m³ is shown in Figure 36. The costs per storage capacity increase from 10 m³ due to the fact of higher wholesale price for larger storage tanks.

Table 63 Investment costs per m³ for the design sizes (Urine storage)

Storage capacity	**0.15**	**0.46**	**0.92**	**1.35**	**2.5**	**5**	**10**	**24**	**m³**
Costs per m³	100	98	92	80	64	67	88	121	€/m³

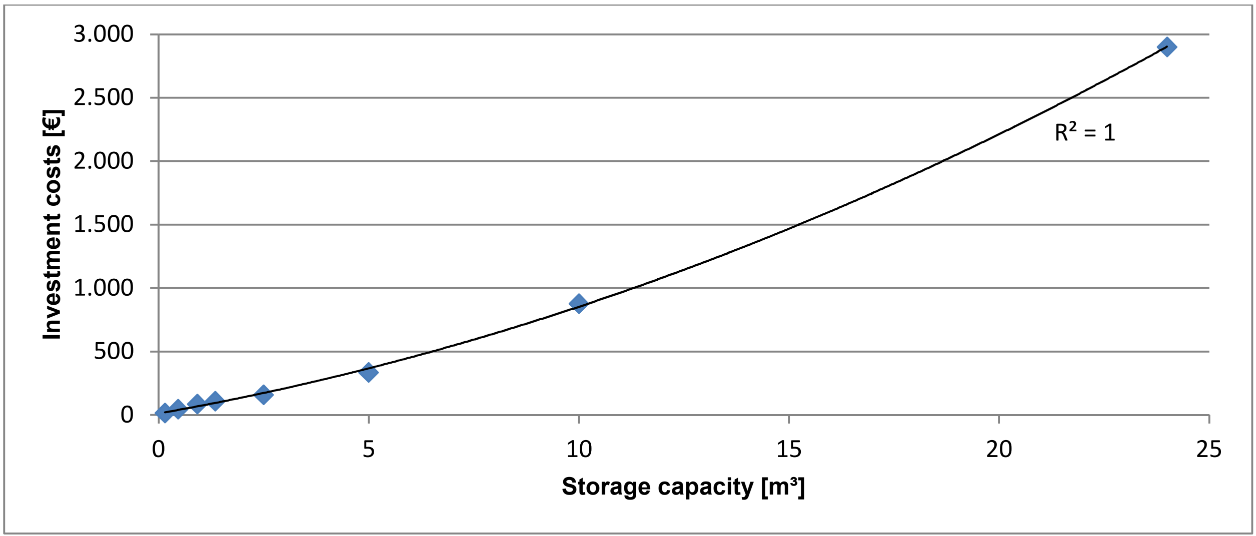

Figure 36 Investment cost function for urine storage up to 24 m³ storage capacity

4.11.4.2 Operation and maintenance costs function

The O&M cost function includes cleaning of the tank suggested by VON MÜNCH and WINKLER (2011). The cleaning works include inspections of the general condition of the tank. The cost function is again divided into two parts. The first cost function is valid for storage capacity up to 24 m³, the second cost function for capacity larger than 24 m³. Table 64 shows the annual O&M costs per m³ storage capacity for the selected design sizes. The O&M cost function based on the total annual costs is described in Figure 37 for a total storage capacity up to 24 m³. The annual O&M costs are based on an assumed hourly rate for labour of 10€. The following equation of the O&M cost function results in the annual O&M costs

$$\textit{O\&M costs per year for storage capacity} < 24\ m^3 = -0.06 \times Cap.^2 + 5.4 \times Capacity + 24$$

$$\textit{O\&M costs per year for storage capacity} \geq 24\ m^3 = 5 \times Capacity$$

Table 64 Annual O&M costs per m³ storage capacity for each design size (Urine storage)

Storage capacity	**0.15**	**0.46**	**0.92**	**1.35**	**2.5**	**5**	**10**	**24**	**m³**
Costs per m³	133	54	33	26	16	10	7	5	€/m³

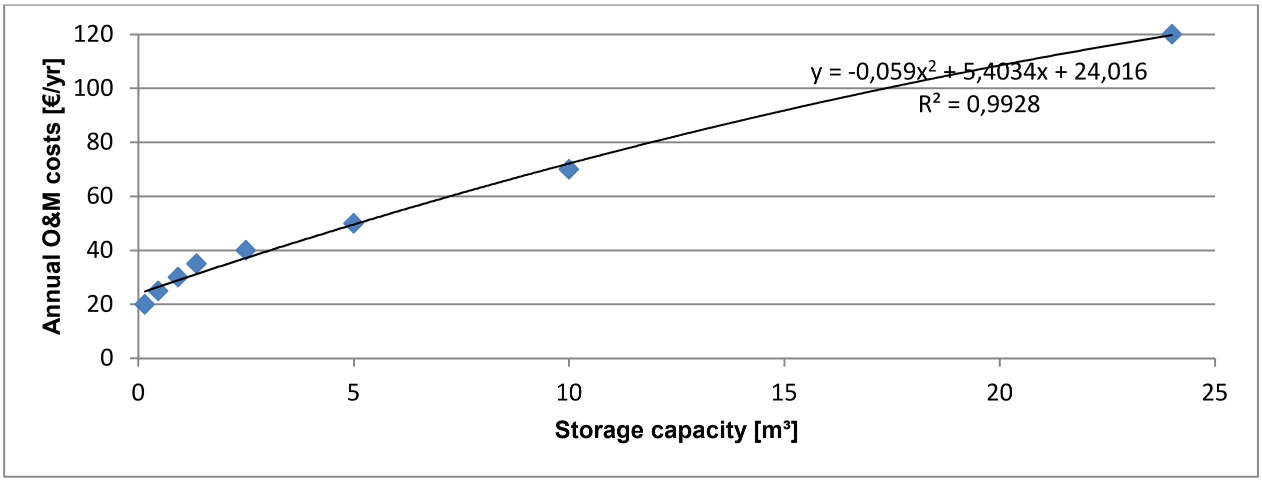

Figure 37 Annual O&M cost function for urine storage up to 24m³ storage capacity

4.11.4.3 Reinvestment cost function

The cost function assumes a total reinvestment after 20 years.

4.12 Treatment of urine – Struvite production

4.12.1 Short technology description

Struvite production is a precipitation process to create a fertiliser in a safe and hygienic condition. The white, odourless powder called struvite or magnesium ammonium phosphate hexahydrate results from a basic precipitation reaction of urine and magnesium salts or magnesium solutions in a struvite reactor. The struvite is filtered out and gives a valuable fertilizer product (ZANDEE and ETTER, 2011; ETTER et al., 2011).

4.12.2 Input parameters

The cost function is based on the number of required struvite reactors. This number is calculated from the amount of urine produced by a number of person equivalent (PE). For calculation the O&M costs type of precipitation agent is necessary to determine the agent input and struvite yield.

The design range of the cost function is not limited.

4.12.3 Dimensioning and design assumptions

The design is based on the research done in the STUN project by EAWAG (2012). The system compromised the reactor vessel, a stirring mechanism, the reactor stand, an access platform, the outlet valve and a filter bag. The reactor vessel is a barrel with a tapered bottom made of galvanised sheet metal. The manual stirring mechanism in the vessel is necessary to mix the urine and the magnesium. The vessel is installed on the top of the stand and accessible by a platform. At the bottom of the reactor an outlet valve controls the flow of the magnesium urine mix into the filter bag. The filter bag which is installed at the outlet valve is made of strong nylon cloth (ZANDEE and ETTER, 2011). Figure 38 shows a schematic drawing of the design used by the STUN project.

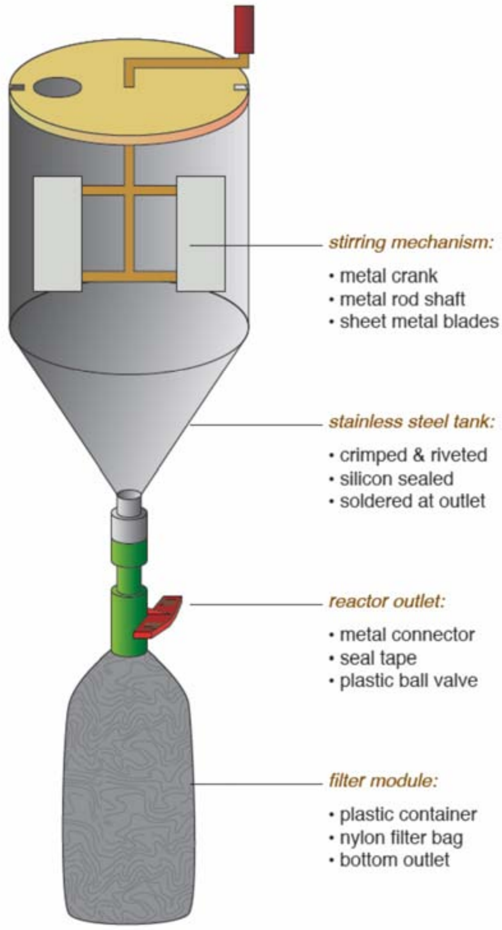

Figure 38 Design of the struvite precipitation reactor (MEYER et al., 2011)

The dimensioning is done by calculation the number of required struvite reactors. Hence the maximum urine processing capacity of one reactor is compared with the actual urine formation.

Following parameters are assumed for the dimensioning of the struvite reactor:

Table 65 Parameters for dimensioning of the struvite reactor

Urine volume per PE per year	500	l/PE/yr	LECHNER, 2007
Reactor batch size	200	l	MEYER et al., 2011
Reactor batch duration	1	h	MEYER et al., 2011
Daily operation hours	8	h	
Working days per year	295	days	

These parameters result in a daily urine processing capacity of 1.6 m³ and an annual capacity of 472 m³. The amount of the annual urine formation will be divided by the annual capacity of the reactor in order to get the number of required reactors.

For the calculation of the O&M costs the input of the magnesium source is necessary. Furthermore the struvite yield is required to determine the revenue of the struvite sales. The struvite yield is depended on the precipitation agent. Table 66 gives the parameters for the required precipitation agent input, the struvite yield and an estimated agent price for each selectable magnesium source. These parameters are based on a calculation by EAWAG (2010).

Table 66 Precipitation agent parameters

Precipitation agent		Agent input in kg per l urine	Struvite yield in kg per l urine	Estimated agent price in € per kg
Magnesium Sulfate	$MgSO_4$ $7H_2O$	1.67	1.51	0.40
Magnesium Oxide	MgO	0.59	1.43	0.20
Bittern	$MgCl_2$ $6H_20$	2.35	1.57	0.20

An effluent storage and treatment is not considered in this design.

4.12.4 Cost functions

The cost functions for investment, operation and maintenance and reinvestment are based on the PE and for the required number of struvite precipitation reactors. The cost functions are derived from cost calculated for different design sizes.

4.12.4.1 Investment cost function

Table 67 lists the position considered in the total costs for a single struvite precipitation reactor and assembled according to design.

Table 67 Positions of the struvite precipitation reactor (Struvite production)

Item no.	Position	Unit
n/a	Sheet metal reactor vessel	pcs
n/a	Stirring mechanism	pcs
n/a	Reactor stand	pcs
n/a	Access platform	pcs
n/a	PP-R outflow assembly	pcs
n/a	Filter bags	pcs
n/a	Pump	pcs
n/a	Superstructure	pcs

Investment cost function

The investment cost function is calculation based on eight different design scenarios shown in Table 68. In addition this table shows the costs per PE for the reactors. Figure 39 shows the investment cost function for struvite production graphically while the equation is following:

Investment costs = 0.8 x PE + 607

Table 68 Investment costs per PE for the design scenarios (Struvite production)

PE	**100**	**500**	**1,000**	**2,000**	**5,000**	**10,000**	**20,000**	**50,000**	**-**
Costs per PE	7.62	1.52	1.52	1.14	0.91	0.84	0.84	0.81	€/PE

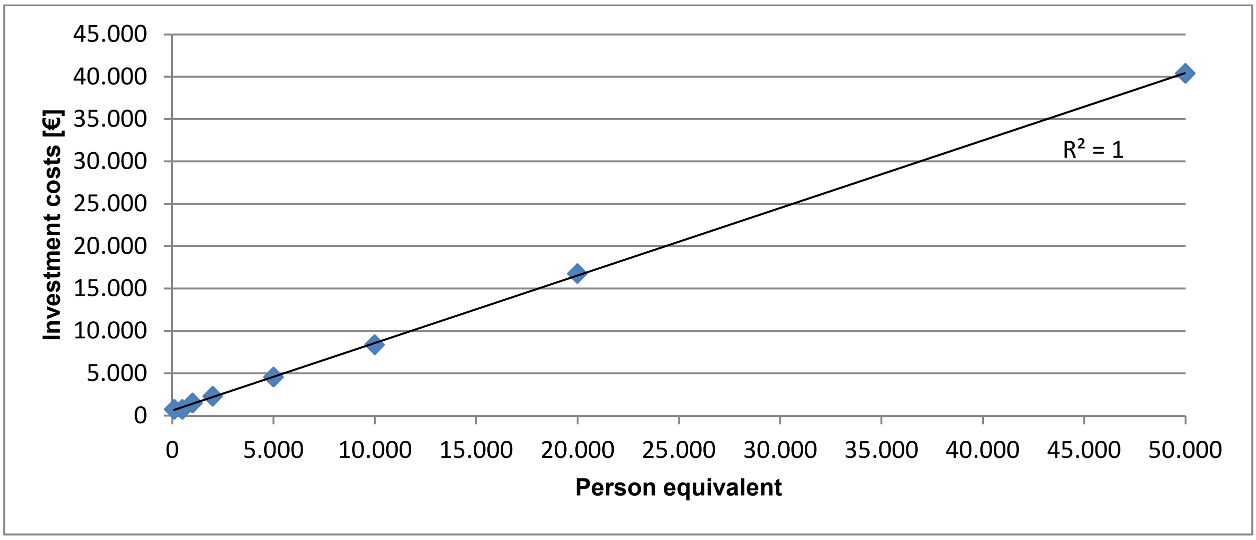

Figure 39 Investment cost function for struvite production

4.12.4.2 Operation and maintenance costs function

The O&M costs of the struvite production consider a labour cost, the precipitation costs and cost for the filter replacement. Any maintenance and repair work are assumed to be included in the labour cost. Due to the fact that no data on operational stuff is available, following stuff requirements are estimated for specific reactor units:

No of reactors	**1**	**4**	**16**	**32**	**64**
No. of craftsman	1	1	2	3	4
No. of unskilled labourer	0	1	2	4	10

The monthly wage of a craftsman is supposed to be 300 € and 100 € for an unskilled labourer. The precipitation agents are calculated according to the parameters given in Table 66. Replacement of the filter takes place every two month. Based on these parameters following three cost functions for each precipitation agent result in the annual O&M costs:

*O&M costs per year for magnesium sulfite = 0.74 * PE + 3529*

*O&M costs per year for magnesium oxide = 0.47 * PE + 3529*

*O&M costs per year for bittern = 0.64 * PE +3529*

The cost functions are demonstrated in Figure 40 and the annual O&M cost per PE for the design scenarios are listed Table 69.

Table 69 Annual O&M costs per PE (Struvite production)

PE	**1,000**	**4,000**	**15,000**	**30,000**	**60,000**	**-**
Magnesium Sulfite	4.17	1.63	1.00	0.88	0.80	€/PE
Magnesium Oxide	3.90	1.36	0.72	0.60	0.52	€/PE
Bittern	4.07	1.53	0.90	0.78	0.70	€/PE

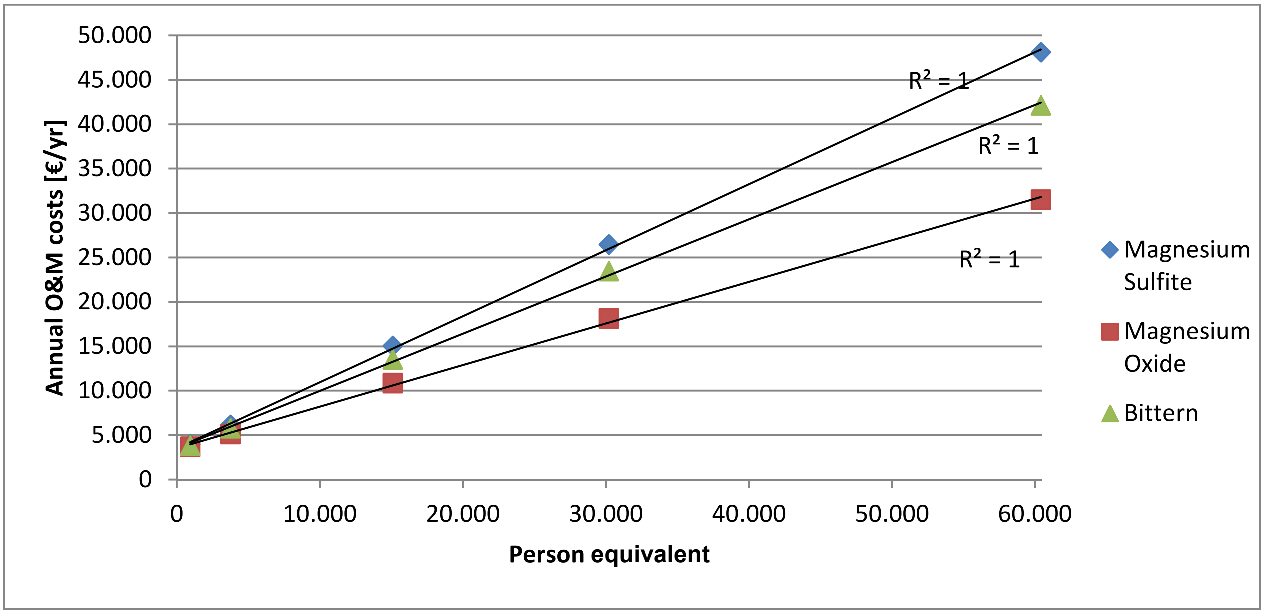

Figure 40 Annual O&M cost function for each precipitation agent

Revenues

The revenue is given by the struvite yield of the agent and the struvite market price which is assumed to be 0.40 € per kg in the revenue cost function. The revenue cost function is specified for each precipitation agent:

*Revenue per year for magnesium sulfite = 0.3 * PE*

*Revenue per year for magnesium oxide = 0.29 * PE*

*Revenue per year for bittern = 0.31 * PE*

4.12.4.3 Reinvestment cost function

The reinvestment cost function assumes a total reinvestment after 10 years.

4.13 Composting

4.13.1 Short technology description

The composting plant is design to process municipal organic waste and faeces of dry toilets in order to produce marketable compost.

4.13.2 Input parameters

Input parameters for the SPT are:

- total person equivalent (PE) generating solid waste
- total person equivalent (PE) using dry toilets

The design range of the cost function is limited for a composting plant from 1 to 1,000 m³ of compostable waste per day.

4.13.3 Dimensioning

The total compostable waste compromises of the solid organic waste generated and the solid matter from dry toilets.

Total solid waste per day = Total solid waste per day + Solid matter from dry toilets

Solid organic waste

The calculation of the total solid waste generation per day is done by following equation:

Total solid organic waste per day = Total solid waste x Organic waste content

The organic waste content is based on the waste characteristics shown in Table 70. The organic waste content is depended on the size of the municipality. The actual organic content is calculated based on a linear function derived from following assumptions:

1,000 PE = 85 % organic waste content

100,000 PE = 40 % organic waste content

Total solid waste per day = PE generating solid waste x Waste generation per PE per day

The waste generation per capita per day is based on the waste characteristics shown in Table 70. Also the waste generation is depended on the size of the municipality. The waste generation per PE content is calculated based on a linear function derived from following assumptions:

1,000 PE = 0.6 kg / PE / day

100,000 PE = 0.8 kg / PE / day

Table 70 Waste characteristics

Waste generation per PE per day	0.6 – 0.8	kg / PE / day	EAWAG, 2008
Organic waste content	40 – 85	% of total sold waste	EAWAG, 2008
Bulk density of raw composting material	350	kg/m³	DULAC, 2001

Solid matter from dry toilets

The calculation of solid matter from dry toilets is done by following equation:

> *Total solid matter from dry toilets = PE using dry toilets x Faeces per PE per year / 365 + bulking material*

The volume of faeces generated per PE per year is 50 l (LECHNER, 2007) and the bulking material is assumed to be 100 % of the faeces volume.

Following design sizes are defined for creating the cost function:

Compostable waste capacity	**1**	**5**	**25**	**100**	**500**	**1,000**	**m³ / day**

4.13.4 Design assumptions

The composting plant uses a windrow system and includes areas for active composting, curing, storage and required facilities dependent on the plant size. In addition a runoff pond is considered to collection rainfall. The plant is based on a design recommendation by the British Columbia Ministry of Agriculture & Food (BCMAF, 1996). Some adaptions according to ROTHENBERGER et al. (2006) and DULAC (2001) are considered.

The area for the windrows is capable to process compostable material for six weeks. The area includes space for turning the windrows which is the size required for windrows. Curing piles allows maturating the compost for further four weeks. Due to shrinkage the curing volume is the half of the active composting volume. Compost will be stored up to nine weeks before leaving the plant. Facilities depend on the capacity of the composting plant. Following facilities are included:

- Weigh bridge
- Control room as office and laboratory
- Shed for processing machinery with space for storing and bagging
- Vehicle shed

Depending on the capacity of the plant any processing machinery and equipment is considered in the design. For the collection of rainfall a pond is considered. This pond is capable to capture a 500 mm rainfall on the total plant area. All assumed parameters are summarized in Table 71.

The design does not include any transport from or to the composting plant.

Table 71 Design parameters composting plant

Size of windrows			
Active composting phase	6	weeks	BCMAF, 1996
Windrow width	2 – 6	m	
Windrow height	0.9 – 3.6	m	
Windrow turning area	100	% of windrow area	
Size of curing piles			
Shrinkage after active composting	50	%	BCMAF, 1996
Time required for curing	4	weeks	BCMAF, 1996
Curing pile height	0.7 – 4	m	
Curing pile width	5.5 – 6	m	
Size of storage area			
Pile height	1.5 – 3.5	m	
Storage time	9	weeks	BCMAF, 1996
Size of facilities			
Additional area for facilities	20 – 50	% of total area for windrows and piles	
Size of runoff collection pond			
Six month rain in the worst 25 years	500	mm	BCMAF, 1996
Runoff from hard surface	100	%	BCMAF, 1996
Runoff from windrow and piles	50	%	BCMAF, 1996
Pond depth	3	m	

4.13.5 Cost functions

The cost functions for investment, operation and maintenance and reinvestment are based on the capacity of the plant and valid for a single centralized composting plant. The cost functions are derived from cost calculated for different design sizes.

4.13.5.1 Investment cost function

The investment cost function is calculated by the total price out of six designs of different size. The total cost of a particular septic tank compromise of costs for the surface construction, pond construction and facilities specified in a bill of quantity.

Surface construction

The asphalt surface is considered for all windrow, curing, storage and facility areas. This cost category considers positions for the construction of the asphalt surface as listed in Table 72.

Table 72 Positions of surface construction (Composting)

Item no.	Position	Unit
020201A	Clearing area	m^2
180311B	Subplane	m^2
180318C	Subbase 15cm	m^2
180501B	Bituminous binder course BT16	m^2
180611B	Rolled asphalt	m^2

Pond construction

Table 73 shows the position for the construction of the rainwater collection pond, including excavation and concrete works.

Table 73 Positions of pond construction (Composting)

Item no.	Position	Unit
030331A	Pit excavation with inward-sloping	m^2
030703C	Bedding with gravel	m^3
110301A	Foundation C12/15	m^3
110302A	Slab C20/25 up to 30cm	m^3
110401A	Wall 12-20cm C20/25	m^3

Facilities

This cost category summarises various position presented in Table 74. The geotextile is used for covering windrows and piles. The composting plant area is fenced to ensure safe operation. Following machinery and objects are included in the cost function depending on the size of the composting plant: a weigh bridge to weight incoming and leaving matter, a control room and laboratory for proper operation, processing machinery and equipment such a rotary screens, tractors and wending machines and housing.

Table 74 Positions of facilities (Composting)

Item no.	Position	Unit
030901A	Filter and drainage geotextile	m²
n/a	Fencing	BU
n/a	Weigh bridge	BU
n/a	Control room as office and laboratory	BU
n/a	Shed for processing machinery with space for storing and bagging	BU
n/a	Processing machinery (such as rotary screens with conveyor belts)	BU
n/a	Processing equipment	BU
n/a	Vehicle shed	BU

Investment cost function

The costs for any design size results in following investment cost function:

$$\textit{Investment costs} = 18528 \times \textit{Capacity}^{0.7}$$

Table 75 describes the investment costs for the design sizes in costs per m³ processed compostable waste per day for the composting plant while the total investment cost function for a composting plant is shown in Figure 41.

Table 75 Investment cost per m³ waste for each design size (Composting)

Compostable waste capacity	**1**	**5**	**25**	**100**	**500**	**1,000**	**m³ / day**
Costs per m³ / day	18,391	12,678	6,864	4,147	3,467	2,392	€ / m³ / day

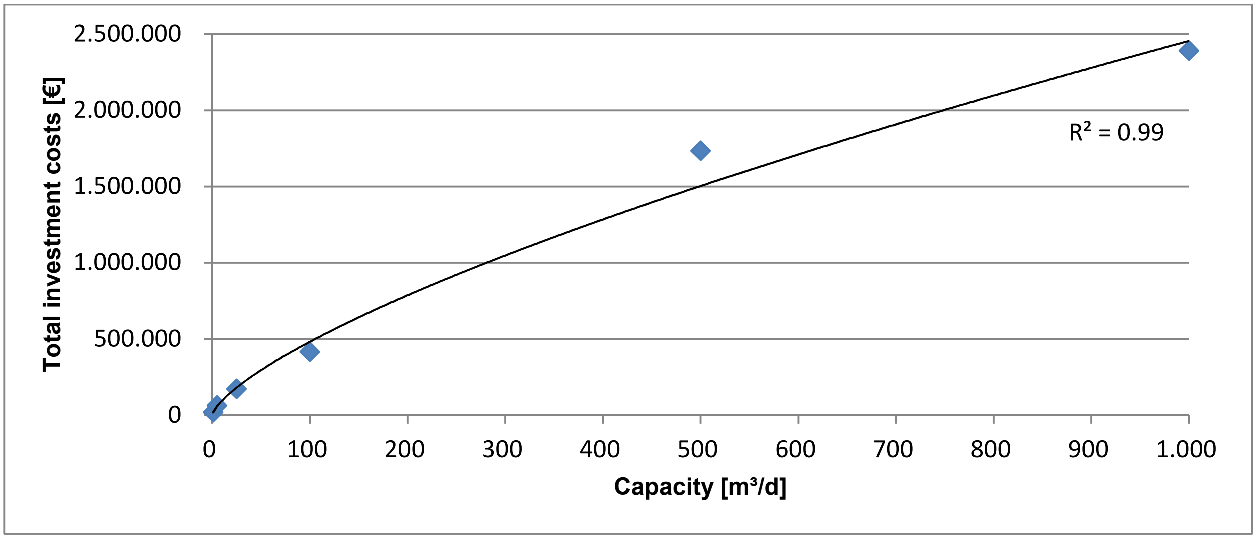

Figure 41 Investment cost function for composting

Cost category allocation

Table 76 describes the cost allocation between the categories based on the design sizes. The cost proportion for the surface construction increases with increasing plant capacity while the others proportion decline.

Table 76 Cost allocation between the categories (Composting)

Compostable waste capacity [m³/day]	**1**	**5**	**25**	**100**	**500**	**1,000**
Surface construction	27%	27%	28%	35%	43%	42%
Pond construction	38%	29%	25%	28%	30%	29%
Facilities	35%	45%	47%	37%	27%	29%

4.13.5.2 Operation and maintenance costs function

The O&M cost function considers of costs for labour, electricity, fuel and repair works. The labour cost is calculated by the assumed staff requirements and their salaries shown in Table 77. These numbers are derived from 3 t/d composting plant (ROTHENBERGER et al., 2006). For all other cost factors apply following assumptions:

- Annual electricity costs: 5 % of the machinery costs
- Annual fuel costs: 5 % of the machinery costs
- Annual repair costs: 10 % of total investment costs

Table 77 Staff requirements and salary

Capacity	**1**	**5**	**25**	**100**	**500**	**1,000**	**Monthly salary**
Manager / Engineer		1	1	2	4	5	1,000 €
Composting workers	2	6	20	20	40	60	300 €
Driver			1	2	6	8	500 €
Lab staff		1	1	2	4	6	600 €
Marketing staff		1	1	2	4	6	600 €

Table 78 describes the annual O&M costs per plant capacity while Figure 42 shows the total O&M cost function per year. The following equation of the O&M cost function results in the annual O&M costs:

O&M costs per year = 16235 x Capacity$^{0.51}$

Table 78 Annual O&M costs per m³ waste for each design size (Composting)

Compostable waste capacity	**1**	**5**	**25**	**100**	**500**	**1,000**	**m³/day**
Costs per m³ / day	15,752	7,801	3,322	1,667	784	550	€/m³/day/yr

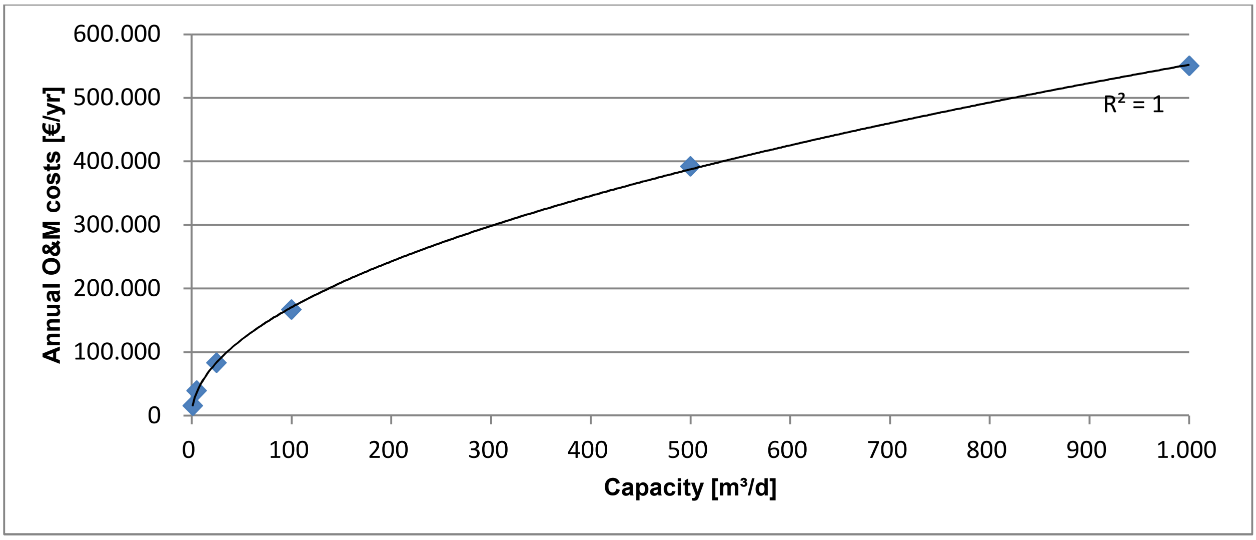

Figure 42 Annual O&M cost function for composting

Revenues

The revenue follows from selling compost. The market price for 1 m³ compost is assumed to be 10 €. The following equation of the revenue cost function results in the annual revenues:

Revenues per year = 1825 x Capacity

4.13.5.3 Reinvestment cost function

The STP assumes a life span of 50 years for the composting plant due. All reinvestment efforts are covered by the O&M repair costs.

5. Discussion

5.1 Cost function development

5.1.1 Standard designs

One of the major challenges during the development of the cost functions was to define the standard design. A huge number of literature describing various designs of water supply and sanitation infrastructure exists in the internet and are open for everyone. Although certain publications cannot be taken seriously still a plenty of literature is available from reliable sources (q.v. 3.1). The majority of this literature is precisely and comprehensible documented. As already mentioned the basis for the technology design was the SSWM toolbox that provided useful examples of designs and links to further information. However the variety of designs from this source delivers different parameters on the design of a technology. A typical example is the retention time of waste water in a septic tank. While the ‘Compendium of Sanitation Systems and Technologies’ argues a retention time of 48 hours (TILLEY et al., 2008), the WHO ‘Guide to the development of on-site sanitation’ sets the retention at 24 hours (FRANCEYS et al., 1992). The decision was made on the design that provided more information and was easier to reproduce.

SSWM provides a lot of designs tested in case studies and prototypes. Some of them might not have been tested on a long term scope or for any scale. For instance certain publications use jerry cans for the emptying of UDDTs where the person responsible has to deal with odorous urine (RIECK et al., 2012; TILLEY et al., 2008; MÜLLEGGER, 2011). This raises the question of whether it is acceptable to assume such unpleasant tasks to be performed for an SPT planning period of e.g. 50 years, unthinkable for the Western world.

For that reason several designs were utilised as a base that had already been tried and tested in life practice. In most case the designs were prior projects of EcoSan Club implemented in African countries such as South Sudan and Uganda.

Nevertheless this thesis uses designs from pilot projects since there are less alternatives in some circumstances e.g. struvite production (q.v. 4.12). This design of the struvite production was tested only on a small scale (ETTER et al., 2011). There is not sufficient knowledge for the application on large scale. TILLEY et al. (2009) investigated the social and economic feasibility of struvite production at the community level in Nepal and concluded that the true value of struvite only becomes obvious until it is produced and sold. This illustrates one problem of this technology. Another one is the treatment of the effluent which requires further infrastructure at a large scale. The design used in this thesis assumes revenues at an estimated struvite selling price similar to synthetic fertilizer and does not include an effluent treatment. As there are no recommendations and experience in literature the cost function of the struvite production has no limitation in range.

5.1.2 Operation & maintenance assumptions

As for the standard designs the data for O&M effort in literature was often inconsistent or not available for any design size. Hence the data of various publications was combined or deduced to describe the O&M effort close to reality for a specific design size (cf. 4.1 Sewage pumping station; 0-4.6 Collections; 0 HFCW; 0 VFCW). This O&M effort has been adopted to fit the selected design sizes.

5.1.3 Operational life span

The reinvestment cost function is dependent on the operational life span of the structure or engaged equipment. The data for the life span assumed in the cost functions refers to the German guideline of cost comparison method which provides data on various water supply and sanitation infrastructure (LAWA, 2005). However this guideline is appropriate for large-scale infrastructure and does not provide information on low-cost solutions. The assumptions for the life span of the technologies UDDT, Compost chamber toilet, urine storage tank and struvite reactor was derived mostly from the LAWA guideline respectively.

5.2 Further development of the CLARA simplified planning tool

Due to the continuous development of the CLARA simplified planning tool consistently new ideas for improvements arose during writing this thesis. The following chapters describe recommendations to be implemented.

5.2.1 Standardisation of the cost functions

Due to the fact that a number of people were working on the development of the cost functions the approach of developing was different depending on the responsible person. The major issue is caused by the item positions within the BoQs. At time initial equal items positions use different naming or separate items positions are combine in one position. For instance this thesis assumes concrete works including reinforcement whereas in the water treatment BoQs the concrete works and reinforcements are listed separately. A mutual standardisation of the cost functions would especially ease the input of the particular unit prices.

5.2.2 Country-specific unit prices

As the BoQs, developed within this thesis, uses estimated unit prices one of the first tasks for the further development of the tool will be to implement the actual unit costs in order to obtain the correct cost functions. The list, containing all used position in the BoQs, has to be provided to the project partners. As soon as the partners supply the country-specific unit prices of the BoQ positions they have to be implemented into the cost function sheets for each country to get correct cost function.

5.2.3 Adaptions to country-specific standards and frameworks

The technology designs used in the draft version of the SPT are universal and might not meet local standards or frameworks in the partner countries. One of the next steps is the customisation of CLARA planning tool for each country. On one hand the country-specific unit prices as mention before and on the other hand the adaption of the technologies to meet the local standards and frameworks. The adaption of the technologies is crucial for the tool in order to avoid technologies that are legally permitted. Therefore the project partner should supported and supervise the adaptation process.

5.2.4 Simplification of input parameters

The major improvement of the usability will be the simplification of the input parameter. The experience of developing recent cost functions show that input parameters should be reduced if their significance on the result is not given. Fewer input parameters might increase the risk of an inaccurate result although susceptibility for input errors will be decreased. During the discussions it was agreed that a maximum of four input parameters should be used. In order to identify the negligible input parameter a sensitivity analysis should be performed for certain parameters.

5.2.5 Combination of technologies

A pre-definition of combinations of suitable technologies within a functional group will reduce the risk of incorrect input (e.g. as a constructed wetland requires a mechanical pre-treatment such as a septic tank both technologies can be combined to one system. The input of the person equivalent has to be done only once. Hence input is faster and the susceptibility for input errors diminished.

5.2.6 Deviation of the cost base

Fundamentally the user is not permitted to change the cost base within the SPT to prevent misuse. Although there might be some cases when the final result is not shown correctly by the SPT and a deviation of the cost base is necessary. For instance, if the user, due to his extensive experience, is convinced that a cost base is not in line with the reality, he has to be able to alter the cost base. However the user has to justify his decision to ensure transparency.

5.2.7 Mass balance checks

Mass balances have to be checked by the tool within the alternatives and the technologies itself to monitor the mass flows of water and nutrients and avoid in improper output. All mass inputs and outputs are taken into account and the tool admits only systems which consider the entire flow of water and nutrients. Furthermore the mass balances check serves to prevent systems that do not meet effluent standards by comparing the mass balance output with the standards. The mass balance check was planned in the draft version of the SPT but deferred due to complexity. Since the mass balance check is an important instrument it should be implanted in the final version of the SPT.

5.2.8 Replace cost functions with real project costs

A long term target of the CLARA simplified planning tool should be to replace the BoQs as a cost base by real construction and O&M costs. If certain projects of different sizes are implemented the authorities should have gained enough data to use their construction and operational costs as a basis for a more accurate cost function.

5.2.9 Additional technologies

Another important task is to include further technologies which are recently developed or required by the users. Additional technologies also provide the planner with more options.

6. Summary and Conclusion

The technology cost functions are the key elements of the CLARA simplified planning tool enabling the economic cost comparison of different technologies. A comparison of systems of any size or capacity is possible by the means of the cost functions. From the results of this work it can be summarised that following steps are required for deriving of the cost function:

1) The first step starts by defining a standard design for the technology. The selection of the standard design represents a major challenge due to the variety of the available designs. The most crucial requirements of the standard design are a reliable source with simple repeatability. Additionally the design has to be technically feasible and accepted by the target group in present and remote future considering the fact that the CLARA planning tool is designed on a long term scope. For this reason it is favourably to use technologies widely tried and tested. Although in some cases it cannot be avoided to use prototypes or systems tested in case studies as there is no similar established system available in this particular field of application e.g. struvite production.
2) After selecting the standard design for a technology the determination of the design sizes is required. The design sizes are the foundation for the cost functions since the cost function is derived from the total costs of various design sizes. In order to obtain the effort for any design a dimensioning and a design drawing is essential for all design sizes initially. Additionally the design sizes define the limits of the cost function's range i.e. designs smaller or larger than the design size's range are not covered by the cost function.
3) Due to the lack of real project cost the individual investment costs for each of the design sizes are obtained by the Bill of Quantities (BoQ) which is a list of positions containing detail information of material, parts and labour required to construct the specific structure. The single positions and their number of units are ascertained using the design drawings for each design size. For easier classification the positions are allocated in different cost categories within the BoQ such as earthworks, construction or equipment. The BoQs with inserted unit prices result in the investment costs of a technology of a specific size.
4) The operation and maintenance (O&M) costs consisting of expenses for labour, energy and material required for the operation, service, maintenance and monitoring of a facility. Similar to the approach for determining the investment costs the O&M costs will be ascertained for each design size. A major challenge is to specify the O&M effort for the selected design and for any design size. Frequently O&M data is not available for a design or just for a specific design size. Hence the O&M effort was deduced from various available data and adopted for one specific design size and further more adopted for each single design size.
5) The reinvestment costs occur in case a system component has a shorter operation life span than the systems period of consideration. Reinvestment costs are derived from the investment BoQs for each design size.
6) The revenues are incomes generated from the marketing of finished products and are a direct function of the plant's capacity. Especially for technologies that are not established yet, e.g. struvite production, the market prices and acceptance for the products can just be estimated until they are widely implemented.
7) The input parameters represent variables or result in variable of the cost function and are directly related to the size or capacity of the specific technology whereas the cost base takes the position as mathematical constant within the cost function. The cost function produces a specific result by altering the input parameters. Hence defining input parameters is an essential task and has to be in scope of specific characteristics such as comprehensible usability, representativity and transparency. The input parameter should be easy to understand and easy to use. Required data have to be obtainable in a simple way and applicably in various technologies. The parameters have to be representative in respect of comparability between technologies and an accurate final outcome. At last the input

parameters have to be transparent in order to avoid potential manipulation and distortion of the result.

8) The final step is to derive the cost function for investment, operation and maintenance costs from the costs of each selected design size based on the input parameters. For those technologies that do not use BoQs and design sizes, e.g. collection and transport, the investment cost are directly linked with the number of required units. As for the revenue the function is directly linked with the capacity of the facility.

As an additional result of working on the development of the cost functions can be concluded that various tasks are necessary for the development of the final CLARA simplified planning tool:

- Mutual standardisation of the technologies' cost functions to simplify further editing
- Implementation of country-specific unit prices provided by the partners to obtain realistic country specific cost functions and costs
- Adaptation of the technologies to meet country-specific standards and frameworks
- Simplification of the input parameters to improve the usability and robustness against for input errors of the planning tool without deteriorate the results
- Combination of technologies in functional groups in order to simplify the use of the simplified planning tool
- Enabling the planner to deviate the cost base in order to adjust the cost function based on widely gained experience over time
- Implementation of the mass balance checks to ensure a closed system in terms of water and nutrient flow and to avoid improper systems that do not meet standards
- Replace the cost function with real project cost in remote future for a more accurate result
- Implementation of additional technologies to be up to date and to provide more planning options

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7.1 List of figures

7.2 List of tables

8. Appendices

Following appendices can be found on the enclosed compact disk:

Appendix 1 “Cost function spread sheets”

1-01_sewage-pump-station.xlsx
1-02_UDDT.xlsx
1-03_composting-chamber-toilet.xlsx
1-04_collection-sludge.xlsx
1-05_collection-urine.xlsx
1-06_collection-faeces.xls
1-07_septic-tank.xlsx
1-08_HFCW.xlsx
1-09_VFCW.xlsx
1-10_sludge-drying.xlsx
1-11_urine-storage.xls
1-12_stuvite.xlsx
1-13_composting.xlsx

Appendix 2 “Design drawings”

1-01_drawing_sewage-pump-station.dwg
1-02_drawing_UDDT.dwg
1-03_drawing_composting-toilets.dwg
1-07_drawing_septic-tank.dwg
1-08_drawing_HFCW.dwg
1-09_drawing_VFCW.dwg
1-10_drawing_sludge-drying.dwg
1-12_drawing_stuvite.dwg

9. Curriculum Vitae

Personal information	
First name / Surname	**Martin Brettl**
Address	Laudongasse 35/27 A-1080 Vienna Austria
Telephone	+43 699 11667070
E-mail	martin.brettl@gmx.at
Nationality	Austrian
Date of birth	23.02.1982
Gender	Male
Work experience	
Dates	March 2007 – today
Occupation or position held	Project advisor (work only part time)
Main activities and responsibilities	Assistant for project manager, Temporary replacement in Kiev office, various
Name and address of employer	Cofely Austria, 1110 Vienna, Leberstrasse 120 www.cofely.at
Type of business or sector	Building service engineering
Dates	January 2006 – February 2007
Occupation or position held	Project manager; Team leader of technical department
Main activities and responsibilities	Responsible for complete project process for projects in Ukraine Responsible for design process for projects in Russia
Name and address of employer	Cofely Russia, Moscow www.cofely.ru
Type of business or sector	Building service engineering
Dates	June 2002 – December 2005
Occupation or position held	Technical designer
Main activities and responsibilities	Design of projects (heating, ventilation, cooling, fire fighting, water supply) in CEE
Name and address of employer	Cofely Austria, 1110 Vienna, Leberstrasse 120 www.cofely.at
Type of business or sector	Building service engineering
Education and training	
Dates	October 2010 – today
Principal subjects/occupational skills covered	International Joint Master Program in Natural Resources Management and Ecological Engineering
Name and type of organisation providing education and training	BOKU, University of Natural Resources and Life Sciences, Vienna, Austria
Dates	July 2011 – November 2011
Principal subjects/occupational skills covered	International Joint Master Program in Natural Resources Management and Ecological Engineering

Name and type of organisation providing education and training	Lincoln University, Lincoln, New Zealand
Dates	March 2007 - September 2010
Title of qualification awarded	Bachelor of technical science
Principal subjects/occupational skills covered	Bachelor Program in Environment and Bio-Resources Management
Name and type of organisation providing education and training	BOKU, University of Natural Resources and Life Sciences, Vienna, Austria
Dates	September 1995 – June 2001
Principal subjects/occupational skills covered	Building service engineering and energy planning
Title of qualification awarded	Engineer
Name and type of organisation providing education and training	Technical high school, Pinkafeld, Austria
Dates	September 1990 – June 1995
Name and type of organisation providing education and training	Grammar School, Neusiedl am See, Austria
Dates	September 1986 – June 1990
Name and type of organisation providing education and training	Primary School, Halbturn, Austria

Personal skills and competences

Mother tongue: **German**

Other languages

	Understanding	Speaking	Writing
English	Proficient user	Independent user	Independent user
Russian	Basic user	Basic user	Basic user

Social skills and competences	Team spirit; Good ability to adapt to multicultural environments, gained though my experience abroad
Organisational skills and competences	I developed a sense of organisation and have practical experience in project and team management.
Computer skills and competences	Competent with Microsoft Office and Autodesk AutoCAD