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DOCUMENT 14

RURAL WATER SUPPLY AND SANITATION: TECHNOLOGY OVERVIEW AND COST FUNCTIONS

Comment: this document contains a kind of data-base of rural water supply and sanitation (WSS) technologies that can be used in the EECCA region and beyond. The data-base was prepared to help rural communities and water users associations in EECCA countries identify options for WSS infrastructure development in rural areas that are feasible from the financial (investment and operating costs) point of view and could be sustained by rural communities. It presents the key factors influencing the technology choice, as well as related costs (in EU prices) and experience, and explains briefly how each facility should be properly constructed, operated and maintained

The need for such a data-base was pointed-out by local experts from Armenia, Georgia, Moldova, Kyrgyz republic and Russia at a workshop on rural WSS issues organised in Tbilisi in 2005 by the OECD/EAP Task Force Secretariat in co-operation with the REC Caucasus.

Action Required: for information and dissemination in EECCA countries (water users associations and water utilities operating in rural areas, rural municipalities, etc.).

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List of Acronyms and Abbreviations

BOD	Biological oxygen demand
DEPA	Danish Environmental Protection Agency
DNA	Demand responsive approach
DRA	demand responsive approach
FS	Financing strategy
EECCA	Eastern Europe, Caucasus and Central Asia
EURO	European currency
GRP	Glass reinforced plastic
g/day	gram per day
ha	hectare
HC	house connection
HH	Household
IFI	International financial institution
km	kilometre
l	litre
lcd	litre per person per day
m	metre
mg	milligram
mm	millimetre
m^2	square metre
m^3/day	cubic metre per day
m^3/month	cubic metre per month
M	Mechanical (wastewater treatment)
MB	Mechanical biological (wastewater treatment)
MC	Mechanical and chemical (wastewater treatment)
N	Nitrogen
NH_4-N	Ammonium as nitrogen
NTU	Nephelometric turbidity units
O&M	Operation and maintenance
ø75 mm	Diameter 75 mm pipe
P	Phosphorous
PE	Person equivalent
PE-pipe	Polyethylene pipe
PVC	Polyvinyl chloride
Q	Plant capacity/demand
SP	Standpipe
SS	Suspended solid
UN	United Nations
WH	
WHO	World Health Organisation
WSS	Water supply and sanitation
YT	Yard connection

1 Introduction

This document covers the compilation of a "database" of water supply, sanitation and wastewater collection and treatment technologies for rural areas available or potentially applicable in EECCA countries. However, the technologies described are to a large extent used worldwide and is therefore applicable to be utilised worldwide.

The description is not intended to cover all water and wastewater technologies available, but only to cover some technologies in order to derive cost function to estimate the level of the capital, O&M and total costs required to finance water and wastewater improvements. These cost functions are used to develop a new module on rural water supply and sanitation (WSS) which will be added to, and extend the FEASIBLE model. This model proved to be a useful tool for developing a sound financial strategy (FS) for WSS sector.

The technologies cover only the options which can be classified as "improved water and sanitation" according to UN definition:

- **Water Supply**: "Improved" technologies include: house connection, public standpipe, borehole, protected dug well, protected spring, rainwater collection. "Not improved" technologies are: unprotected well, unprotected spring, vendor-provided water, bottled water (based on concerns about the quantity of supplied water, not concerns over the water quality) and tanker truck-provided water. It is assumed that if the user has access to an "improved source" then such a source should be likely to provide 20 litres per capita per day at a distance of no longer than 1000 metres; and

- **Sanitation:** "Improved" technologies include: connection to a public sewer, connection to septic system, pour-flush latrine, simple pit latrine, ventilated improved pit latrine. The excreta disposal system is considered adequate if it is private or shared (but not public) and if it separates human excreta from human contact in a hygienic manner. "Not improved" are: service or bucket latrines (where excreta are manually removed), public latrines, latrines with an open pit.

In Table 1-1 is shown the categorisation of water supply and sanitation technologies according to official definition.

Table 1-1 Categorisation of Water Supply and Sanitation Technologies according to UN definition

	Water supply	**Sanitation**
"Improved"	• Household connection • Public standpipe • Borehole • Protected dug well • Protected spring • Rainwater collection	• Connection to a public sewer • Connection to septic system • Pour flush latrine • Simple pit latrine • Ventilated Improved Latrine
"Not improved"	• Unprotected well • Unprotected spring • Vendor-provided water • Bottled water • Tanker truck-provided water	• Service (or bucket) latrines (where excreta are manually removed) • Public latrines • Open / uncovered latrines (referring to the hole not to a lack of superstructure)

Source: WHO.

Based upon a long-list of potential water and sanitation technologies a short-list of improved[1] technologies for water supply and sanitation have been selected to derive the cost functions to be included in the FEASIBLE model. This short list is described in Section 2 and covers most of the water and sanitation technologies utilised in rural areas. However, a large number of combinations of technologies are used in different countries and also mixes of technologies are used depending on availability of water resources, topography, customs etc.

The document is aiming at providing on overview of technologies and the related cost formation in order to develop cost functions for estimating total water and sanitation cost for improving the service level at regional and country level.

The basis for the cost information is from official documents and project reports from different countries worldwide to arriving to an "international" cost level for down or up-scaling to local price level.

Enabling local condition to be considered, a number of default value have been selected which the user can modify to actual local condition. The basic elements in the cost estimation methodology are shown in Figure 1-1. The estimated cost for improving water and sanitation is therefore based on service level (input), default values and the cost functions.

The document comprises an overview of technologies followed by more detailed description of the different technologies with cost information. Cost functions used in the model are detailed in Appendix 2 and 3.

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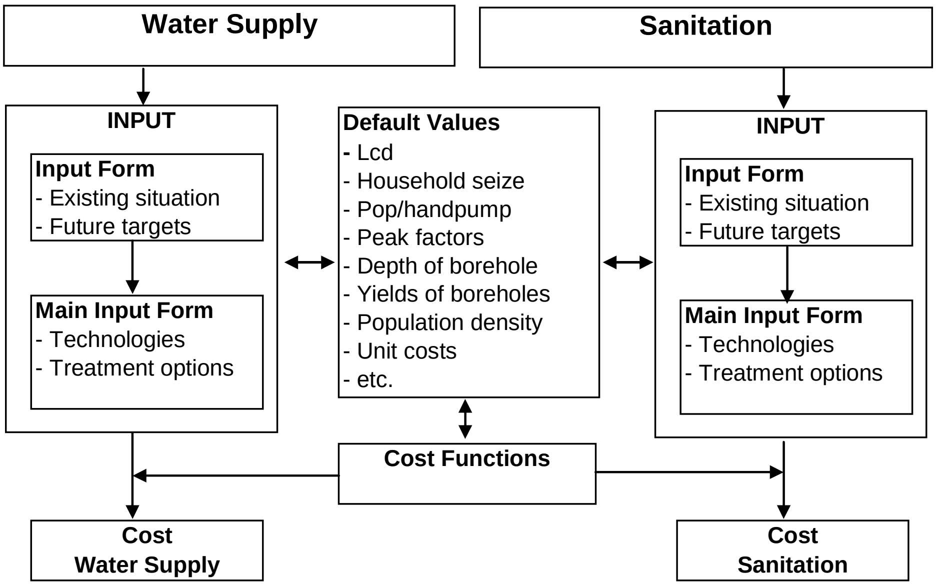
[1] According to the UN definition

By "rural" means in this document town, villages and settlements covering a population say less then 5000 people.

Other glossary of terms used in this report can be found in Appendix 1.

Figure 1-1 Basic Cost Model Structure.



2 Technologies Overview

2.1 Introduction

This chapter gives a brief description of the potential rural water and sanitation technologies for rural areas available or potentially applicable in EECCA countries.

Each settlement, village or town can utilise a wide range of different technologies (mixed level of service) depending on size of the population, structure and development of the town/village/settlement. Moreover, the sanitation options are in some way related to the chosen water supply technologies, e.g. when piped water supply is chosen pit latrines are not often applicable in the piped water supply area.

Which technologies should be adopted is closely linked to the service level chosen and also who is paying for the capital cost of the systems. A demand responsive approach (DRA) is preferable as service level chosen by the consumers based on "willingness to pay" for "full cost recovery" will improve the sustainability of the systems.

Accurate and precise cost estimates for the technologies/solutions under consideration are essential to successfully apply the approach. Recent experience from the Kyrgyz Republic shows that where the unit costs (per person served) are sufficiently underestimated, local rural communities can make serious mistakes selecting the technological options which seemed to be affordable with underestimated unit costs but appeared to be unaffordable with real (much higher) unit costs. This may result in financial problems at investment stage and/or when operating and maintaining the WSS infrastructure.

By service levels means technological options utilised with corresponding level of water consumption and improved access to water and sanitation. By improving service level means to move from a lower technology to a more "advanced" technology often with larger water consumption, but this does not indicate that the water is safe as this depends on the protection and treatment measures provided.

The service level is based on a consideration of the following factors:

- Population size;

- Per capita income of the population of the town;
- Willingness to pay and revenue collection rates; and
- Availability of raw water source.

as well as:

- Available technological options;
- Financing options; and
- Political considerations

From the point of view of the cost model, the service level parameters are proposed to include the technical characteristics of the water supply or the sanitation as described in the following section.

• Technology Options and Related Structures

Different technological options for water and sanitation with related structures to be implemented are presented in Figure 2-1. The figure outlines the range of technology options available within in rural water supply and sanitation. The options considered and described in this document are marked with bold font.

The water supply technologies comprise non-piped supply, small piped supply with the corresponding on-site sanitation options, and piped water supply with off-site sanitation.

Each of the technological options will include some specific structures /facilities which will influence the cost of the option. Some elements of the structures may be possible to vary by users of the model depending on its important of the total cost.

In the following sections are described the technological options for water supply and sanitation.

Figure 2-1 Overview of Technologies Options for Rural Water and Sanitation

Water Supply				Sanitation	Water Supply Structures	Sanitation Structures
Technology	**Variance/source**	**Type of Supply**	**Service Level Options**		**Structures to be Implemented**	**Structures to be Implemented**
Rainwater			One tap	Simple pit latrine Sanplat latrine Improved latrine Ventilated pit latrine Pour-flush latrine	Storage	Pits unlined Pits lined Superstructure with sanplat Superstructure with ventilation
Protected spring		Non-piped supply	Protected spring - one tap		Protected Spring	
Handpump	Hand dug well Hand augered well Borehole		Handpump	-do-	Hand dug well Hand augered well Borehole Handpump	
Handpump with small reservoir	Hand dug well Hand augered well Borehole		Small reservoir	-do-	Hand dug well Hand augered well Borehole Handpump Reservoir Standpost	
Small pipe system, spring with gravity supply		Small Piped Supply	One tap/standpost	-do-	Spring box Pipe Reservoir Standpost	
Small pipe system, spring with pumped supply					Spring box Pump Pipe Reservoir Standpost	
Small piped system, well with handpump	Hand dug well Hand augered well Borehole				Hand dug well Hand augered well Borehole Pump	
Piped supply from protected spring with gravity supply	Protected Spring	Piped system	Multi-tap standpost Yardtap housecon nection	-do- plus	Protected Spring Pipes Reservoir Multi-tap standpost Yardtap Houseconnection	
Surface water, River intake with gravity supply	Stream/river no treatment			On-site septic tank	Stream/river no treatment	Septic tanks Treatment
Piped supply, borehole(s) with pump	Borehole with treatment			Simplified sewerage	Borehole with treatment Pump	Small pipe network
Piped supply, surface water with treatment	Slow sand filter Pre-treatment+slow sand filter Full treatment			Condominal sewerage Sewered interceptor tanks Conventional Sewerage		Pipe network Tank and pipes Pipe network and manholes

3 Technologies - Water Supply

3.1 Introduction

3.1.1 Key Factors Influencing the Choice of Water Supply Options

A long range of improved water supply options exists, from dug wells to piped water system with water treatment.

Water supply technologies are often divided into two main categories of systems:

- Non-piped water supply system (decentralised systems); and
- Piped water supply systems (centralised systems).

Non-piped system means single system for one a few households where the water tap is at the production facility. Non-piped systems such as dug wells, handpumps, and protected spring are easy to maintain and capital cost is often affordable for most rural households if water source is nearby. These technologies are significantly cheaper than the technologies for piped water, and are particularly suitable for low density areas and/or for consumers with a very limited budget for water services.

Piped systems are more advanced systems with distribution pipes conveying water from water sources or production units to points of water use. For piped water supply this document operates with three possible service level options: Household Connection (HC), Yard Taps (YT) and Standpipes (SP), see Table 3-1. The first two options are private connections and the SP is often called improved community supply.

Table 3-1 Water Supply Service Level Terminology

Piped Water Supply			Non-piped Water Supply	
House Connections	Yard Taps	Standpipes	Handpumps	Springs
Private Connections		Improved Community Supply		

The selection of water supply technologies is influenced by a large number of factors. The key factors are:

- Availability of water source (quantity and quality wise) close to the community/end users;
- Topography;
- Population density in town/village/settlement;
- Service level adopted (water demand, connection type etc.) depending on the willingness to pay and affordability; and
- Institutional factors, in particular the issue of responsibilities.

Availability of water resources
The applicable technical water supply options are closely related to the availability of protected/safe water sources within or in the vicinity of the service area to be supplied. In most rural areas the water supply technology options are mostly based on abstraction of groundwater in various ways, where each have each their advantages and disadvantages. The main reason is that treatment of the water can be avoided or treatment is relatively simple, and often mainly consists of iron removal only.

Springs are inexpensive to develop and operate, but may have a seasonally fluctuating yield and have a risk of pollution, as the soil layers covering the spring are thin.

Hand dug and hand augered wells are exploiting fairly shallow aquifers in the upper soil layers, whereas boreholes can exploit hard rock aquifers at greater depth. The risk of pollution of the aquifer will decrease with depth, but the cost of developing the aquifer will increase.

Water from spring wells and boreholes may often be bacteriological polluted due to improper protection of the source. In most cases this is can be avoided through proper construction, maintenance of the intake and appropriate localization of sources in relation to possible sources of pollution, in particular on-site sanitation must also be considered.

Water supply based on surface water is proposed to be used only where other options are precluded as treatment is required and the costs and complications of operating a surface water treatment plant can be considerable.

Rainwater collection, in the following called rainwater harvesting, comprises methods for taking water for water supply early in the hydrologic cycle (as rainfall or just after) and storing it under the users' control instead of letting it run off, evaporate or store naturally as groundwater or in surface water bodies.

Rainwater harvesting in this report comprises roof catchments only. Roof rainwater harvesting can be problematic in colder climate or places with server air pollution.

Topography
The location of water resource and the topography often strongly influence the choice and lay-out of the system, especially if gravity and pumping system are chosen or a combination. Gravity systems are often less expensive considering life cycle cost.

Population density in town/village/settlement
The population density will in most cases determine the technological water supply options available often with piped water supply in the core area of the town, and more simple technologies in the fringe areas, and is closely related to the chosen sanitation options.

Service level adopted
The service level adopted by the users or the authorities is crucial not only for the total capital cost but also for the annual operation and maintenance cost. A service level which is not based upon the affordability will in the long-term not be sustainable. Furthermore, a high level of water service is often loosely linked to off-side sanitation options.

Institutional factors
Water supply is often considered as a public issue as the water quality for human consumption should comply with a certain quality standard. In some cases water supply options are implemented without considering peoples willingness and ability to pay for the services provided. Therefore, responsiveness approach should be considered providing water quality which does not compose a serious health risk for the consumers.

3.1.2 Water Demand

The demand for water may be expressed in an average lcd, in m^3/hour and in m^3/day. Water demand estimate -present and future - is critical for the design of the water systems especially for piped systems. The demand (water consumption) depends on the technology adopted and the distance to "water taps". Another factor is the design guidelines which depends on the consumption pattern, engineering standards, safety etc.

3.1.3 Water Supply Options

The following water supply options have been identified, described and assessed:

- Rainwater Collection;
- Protected Dug wells;
- Protected springs with tap;
- Boreholes with handpumps;
- Protected springs with gravity system and reservoir;
- Borehole with submersible pumps with piped system and without and with treatment and reservoir;

- Surface water with intake with gravity piped system without and with treatment and reservoir; and
- Surface water with intake with pumping system without and with treatment and reservoir.

The exact cost of each technology depends on a number of site specific circumstances, such as for instance the distance between the raw water source and the town, population density, depth to ground water, demand for water (lcd) etc. Generally, the first three technologies (non piped systems) are cheaper than the piped systems. Surface water sources requiring full treatment, if not taken from "protected" stream and a pumped supply, is often the most expensive solution.

3.2 Technologies

The water supply technologies listed in Section 3.1.3 are presented below as follows: a short description, experience of the technology, operation and maintenance, expected lifetime, cost and conclusion.

3.2.1 Roof Rainwater Collection/Harvesting

Description
Rooftop harvesting gather rainwater caught on the roof of a house, school, etc. using gutters and down pipes (made of local wood, galvanized iron or PVC) and lead it to one or more storage containers/tanks ranging from simple pots to large storage tanks. If properly designed, a foul flush device or detachable down pipe is fitted for exclusion of the first 20 litres of runoff during a rainstorm, which is mostly contaminated with dust, leaves, insects and bird droppings. Sometimes runoff water is led through a small filter consisting of gravel, sand and charcoal before entering the storage tank. Water may be abstracted from the tank by a tap, handpump or a bucket and rope system.

The absolute maximum water that you can get off a roof, on average is:

Water volume (m^3/month) = 1/1000 x average monthly rainfall (in mm per month) x coefficient of runoff x roof area (m^2). A coefficient of runoff of 0.8 can be used to obtain a rough estimate.

Experience
There will be situations (depending on rainfall in the area and the roof area) where rainwater tanks will not supply water at a sufficient level of security normally expected in houses connected to other supplies. Under these circumstances, compromises may be needed. These could include a reduced standard of water supply or availability of our supplies.

In case there is no foul flush device, the user or caretaker has to divert away the first 20 litres or so of every rainstorm. Fully automatic foul flush devices are often not very reliable. Water is taken from the storage tank by tapping, pumping, or using a bucket. For reasons of hygiene, the first two methods are preferred. Just before the start of the rainy season, the complete system has to be checked for holes and broken parts and repaired if necessary. During the rainy season the system is checked regularly, and cleaned when dirty and after every dry period of more than a month. Filters should be cleaned every few months, filter sand should be washed at least every six months, and the outside of metal tanks may be painted about once a year. Leaks have to be repaired throughout the year, especially leaking tanks and taps, as they present health risks. Chlorination of the water may be necessary.

Tanks may provide a breeding place for mosquitoes if not proper sealed, which may increase the risk of diseases like malaria. Leaking taps at the reservoir and problems with handpumps.

Tiled or metal roofs give the cleanest water. Tar-based roof coating materials are not recommended if rainwater is to be collected as the phenol and other organic compounds they contain will impair the taste of the water. The acceptance of rooftop water harvesting as a suitable system may depend on the users' views on the water's taste.

Expected lifetime
The average expected life time of good material and proper construction is 15 years.

Operation and Maintenance
All operation and maintenance activities can normally be executed by the users of the system. Major repairs, such as a broken roof or tank, can usually be executed by a local craftsman using locally available tools and materials.

Recurrent costs for materials and spare parts are very low. In most cases these costs are even considered negligible, but corrosion of metal roofs, gutters, etc. may take place.

The water may be insufficient to fulfil the drinking-water needs at certain times in the year, making it necessary to develop other sources or go back to traditional sources during these periods. The investment needed for the construction of a tank and suitable roofing is often beyond the financial capacity of households or communities.

Cost
The major cost of a rainwater harvesting system is the storage tank and the volume required is depending on the rainfall and demand needed. Ferro-cement tanks in Africa can cost from 30-50 Euro per m^3 volume. The cost is for a household of 6 people:

Cost Components	**Capital Cost in EUR**	**Annual O&M Cost in EUR/year**	**Replacement Cost in EUR/year**
Total Cost	**300**	**6**	**20**
Cost per Capita	**50**	**1**	**3.3**

Conclusion
Rainwater harvesting is a relative cheap technology but is very much depending on the availability of rain, and may be seen as a supplement to other supplies.

3.2.2 Protected Dug Wells

Description
A protected dug well are wells that are dug by hand or by machinery, and consist of the following main parts as:

- Concrete apron;
- Headwall of stone, bricks or concrete (the part of the well lining above ground) at a convenient height for collecting water; and
- A lining that prevents the well from collapsing.

One of the most important issues about the protection of the well is to prevent surface water to run towards the well and to prevent storage and spilling of pollutants in the vicinity of the well, or to have animal entering into the "protection zone" of the well.

The well lining between the ground level and the water level is made of reinforced concrete rings, masonry with bricks or concrete blocks, etc., and prevents the well from collapsing. The well lining beneath the water level also facilitates the entry of groundwater into the well, and is usually perforated with small holes, or has a different composition (e.g. permeable concrete) from the lining above the groundwater level.

Caisson sinking is a method of deepening the well safely through unstable soils. It can also be used in stable soil conditions, and is the more effective for having been started before problems of instability developed. In addition to providing an efficient, permanent, cost-effective lining material, it stabilises the well shaft, protecting the workers and the well itself during excavation.

The spill from the use of the well should be conveyed towards a soak-away filled with large stones where the water can infiltrate back into the ground down hill the well.

Achieving these benefits, however, depends on provision of the necessary tools and equipment, quality of the caisson moulds themselves, and on the training of the diggers.

The diameter of the well is normally not less than 1 meter.

Experience
Utilising of dug well is one of the most used ways of abstraction groundwater depending on depth to the water table and the quality of the water.

Dug well are mostly shallow with a depth ranging from a few metres to 10 to 15 meters (in desert areas wells down to 50 or more are made). Also the yield of the well varies with the type of aquifers and the depth of the water table.

Because of their larger diameter, dug wells can be used where a community is unable to afford a pump. With suitable design, windlass, bucket pumps, or a variety of other low technology pumps can be used in place of a commercial hand pump.

No latrines or other sources of contamination should be constructed within 30 m of the well, unless hydrogeological studies demonstrate that it is safe to do so.

Operation and Maintenance
Dug wells encourage entrepreneurial construction at a local level, owing to very low capital investment requirements. Because they are easily replicated, they place the project control back

Maintenance activities may include:

- Checking the well daily and removing any debris in the well (well covers is recommendable to avoid pollution and accidents);
- Cleaning the concrete apron;
- Checking the fence and drainage, and repairing or cleaning as needed; and
- Repairing where necessary, and disinfecting the well if required;

Maintenance can normally be carried out by the users of the system, or by a caretaker or watchman; larger repairs may require skilled labour, which can usually be provided by local craftsmen.

Expected lifetime
The expected life-time of a modern dug well is at least 25 years considering the handpump. For the well alone 50 years life time can be expected.

Cost
A 15 meter deep dug well fitted with handpump is estimated to cost 3850 Euro.

A well with a good yield of 5 m^3/day can serve about 100 people a day with 50 lcd, or say 10-20 houses.

Cost Components	Capital Cost in EUR	Annual O&M Cost in EUR/year	Replacement Cost in EUR/year
Total Cost	**3850**	**77**	**154**
Cost per Capita	**39**	**0.8**	**1.54**

Note: Well serving 100 people, 50 lcd

Conclusion
A modern dug well is a well established technology and a sustainable technology when protection zone and good material and workmanship are used. The fluctuation of the ground water level is crucial for the depth of the well and also for the capacity.

3.2.3 Boreholes with Handpumps

Description
A handpump provides a basic service level, but has the advantage over a protected spring, that within certain limits it can be established where it is convenient for the users. The technology is fairly inexpensive and simple to maintain. The main drawbacks are that it needs regular maintenance and that there can be a risk of pollution if it is not properly constructed or maintained.

This technology typically comprises the structure as follows;

- A borehole - mechanical drilled or hand augered (or a well with handpump as described in Section 3.2.2);
- A handpump and a platform; and
- Related site works.

The technology has two variants, where the difference lies in the structure for water abstraction:

1 Handpump on a hand augered well; and
2 Handpump on a borehole.

The variants are not fully interchangeable; the choice of technology is made on the basis of technical and economical considerations.

A) Hand Augered Well

Hand augered wells are often constructed to depths up to approx. 20 m depending on the tools applied for drilling. The completed well is equipped with a screen in the water bearing soil layers and with plain casing on the rest of the depth. The screen is surrounded by a gravel pack, and the casing with backfilled soil or clay.

Sanitary seals between the casing and the surrounding, intact soil are placed above the gravel pack and again just below ground level in order to prevent contamination of the aquifer with surface water.

Around and above the well is cast a platform of reinforced concrete, and the handpump is fixed in this platform. The platform slopes away from the handpump pedestal and leads water spill to the drain.

B) Borehole

The depth of a borehole is normally between 30 m and 130 m, most frequently in the range of 60 to 100 m. The completed well typically has plain casing on the upper section through loose or low yielding upper soil layers, and is left with filter/screen in the water bearing aquifers.

Borehole drilled with mechanized rigs can be a suitable alternative in areas with thick sedimentary aquifers.

On a borehole a sanitary seal between the casing and the surrounding, intact soil is placed just below ground level in order to prevent contamination of the aquifer with surface water.

Around and above the well is cast a platform of reinforced concrete, and the handpump is fixed in this platform. The platform slopes away from the handpump pedestal and leads water spill to the drain.

Handpumps

There are a large number of handpumps available worldwide. The most common types are

- The low lift pumps (restricted to water tables less than 7 metres below ground),
- Direct action pumps (suitable for lifts up to about 25 metres); and
- Deep well reciprocating pumps (suitable down to 45 metres or more).

The pumps are adapted to shallow, normal or high lift through the use of different handles etc., but is otherwise quite similar.

Handpumps are using galvanized iron rising pipes, stainless steel or PVC/PE pipes. The pump cylinders can be stainless steel, steel, PVC and GRP material. The hand pumps can deliver 0.5 to 2 m^3/hour or 5 to 30 l/minutes depending on the required lift and the type of handpumps.

Related Site Works

The handpump area is fenced to keep out animals. Up to a distance of 3 m from the well the ground must slope away from the well in all directions, and this requirement may necessitate filling up of the area around the well to a suitable level.

The handpump installation shall have an adequate drainage system to lead water spill away from the pump platform and its immediate surroundings, so that stagnant water can be avoided and the area can be kept clean. The drain may lead the water to a natural water course, to a soak pit or to a garden.

Experience

Handpumps are relatively cheap options to provide rural areas with improved water. However, the construction of the borehole and the selection and maintenance of the handpumps are crucial for the recurrent and replacement cost. Also the availability of spare parts is very important especially for the rising pipe and pump cylinders.

O&M

The O&M of handpump options mainly depends on the institutional set-up. For village based or community based handpump supplying a number of households are often lacking the required responsibility to maintain the facilities. On the other hand, in household-managed systems, the responsibility for O&M of privately owned on-plot facilities rests with the owner or plot-holder and therefore an incentive to good maintenance.

Expected lifetime

The expected lifetime of the entire system components are 15-30 years, but lifetime of the main components may be:

- Borehole: 30 years;
- Hand pump: 15 years;
- Platform: 20 years; and
- Related site works: 20 years.

Cost for mechanical drilled borehole

In the table below is shown the estimated capital and recurrent cost of the mentioned handpump technological options.

.Cost Components	Capital Cost in EUR	Annual O&M Cost in EUR/year	Replacement Cost in EUR/year
Total Cost	**14875**	**279**	**744**
Cost per Capita	**149**	**3**	**7**

Note: Serving 100 people (depth, 40 m and demand, 10 m3/day)

Conclusion

Handpumps are a relative affordable and well tested decentralised water supply options for improving rural water supply. Consumer's responsiveness and involvement is crucial for community based handpumps to ensure ownership and responsibility for operation and maintenance.

3.2.4 Protected Springs

Description

A spring is a place on the earth's surface where groundwater surfaces naturally. A spring is normally used in connection with a gravity pipe system. The spring can provide a high service level depending on the yield of the spring and is an often a cheap construction.

Springs often occur as either concentrated springs (along hillside) and seepage springs (water seeps from the soil over a large area). A protected spring is often constructed as a spring box (water is collected in a chamber) and as a spring without a chamber (normally a head wall is constructed to trap the water). By protected spring means here a spring which is protected at the spring and also measures are undertaking to protect the water in the catchment of the spring from being polluted.

A spring box can be useful if sedimentation is required and storage of water where the peak rate of demand exceeds the rate of flow of the spring, and it makes it easier to protect the spring, but also more expensive.

Experience

Springs with or without piped gravity (or pump piped system) is a sustainable system if yield and water quality (protection infiltration zone) are sufficient to cover the demand. The main drawbacks are the risk of pollution and a possibility of seasonally fluctuating yield. Clogging of pipes, leaking water outside the construction etc. are other frequent problems.

Water from spring should be permitted to flow all the time to prevent relocation of outlet.

Operation and Maintenance

O&M of a spring consist normally of protecting the spring from pollution, cleaning/flushing of spring box, testing water quality. Recurrent cost is usually very low, and consist mainly of personnel costs, and also costs for water quality testing.

Expected lifetime

The lifetime of a spring can vary depending on the nature of the spring and quality of the construction. Life time of 40-50 years can be expected. However, fluctuation in minimum flow can reduce the useful lifetime.

Cost

In the table below is shown the estimated capital and recurrent cost of a protected simple spring.

Cost Components	Capital Cost in EUR	Annual O&M Cost in EUR/year	Replacement Cost in EUR/year
Total Cost	**5317**	**106**	**133**
Cost per Capita	**53**	**1**	**1,3**

Note: Serving 100 people

Conclusion
Protected springs with a stable minimum flow is a perfect source of a good and reliable cheap water supply.

3.2.5 Piped System with Protected Spring with Gravity Supply

Description
A water supply system utilising a protected spring often consists of a gravity pipe line (transmission pipe), a distribution system, reservoir (s) and connection to customers as standpipes, yard taps and house connections. Treatment is often not required, and if required treatment is often located a sufficient high point or at the spring to maintain the advantages of the gravity system.

Experience
Piped system with protected spring with gravity supply is a relative by cheap system if transmission pipe is not too long. With large geometric height between source and supply area break pressure tanks (chambers) must be introduced to avoid burst depending on the pressure class of pipe and not to have an excessive pressure at customers. Reservoirs are often concrete reservoirs.

Gravity system supplying a number of villages/towns designs of the system need proper design but also development of organisational and institutional arrangements.

Operation and Maintenance
Recurrent costs for materials and spare parts are low, and operating costs are also low if the system is properly designed and construction is of good quality.

One disadvantage often experienced is the maintenance of the spring if locate far away from the supply area.

Expected lifetime
The expected lifetime of the entire system components are 30-50 years, but lifetime of the main components may be:

- Spring 25-30 years;
- Transmission main 40-50 years depending on the terrain etc.;
- Distribution pipes 40-50 years depending on pipe material etc.; and
- Reservoir 30 to 50 years.

Cost
In the table below is shown the estimated capital and recurrent cost of the mentioned technological options.

Cost Components	Capital Cost in EUR	Annual O&M Cost in EUR/year	Replacement Cost in EUR/year
Total Cost	**1,304,242**	**26,805**	**32,606**
Cost per Capita	**261**	**5**	**7**

Note: Based on 5000 people, average lcd 108, 1000 m transmission, 20 km distribution pipes, reservoir, 20% SP, 40% yard taps, 40% HC - no treatment. 100 inh/km2 in core area and 40 in fringe area.

Conclusion
Protected spring with gravity supply is a relative cheap and sustainable system the recurrent cost is low.

3.2.6 Piped System with Boreholes with Submersible Pumps.

Description
A water supply system utilising a groundwater as the water source often consists of a number of boreholes with varied depth with well heads, transmission main (transmission pipe), treatment plant if required, reservoir (s), a distribution network, and connection to customers as standpipes, yard taps and house connections. Without treatment the groundwater is pumped either directly into the distribution pipes or to a reservoir. If treatment is required a clean water pumping unit is required to deliver the water under sufficient pressure to customers.

Experience
Groundwater is normally a reliable source and can be found near the supply area. Groundwater often contains iron exceeding the maximum limit and is therefore required to be reduced. Treatment in rural areas can cause maintenance problems and is also costly to build and operate. Groundwater abstraction needs reliable power supply or a sufficient reservoir volume.

Water quality is often better than surface water from streams and rivers.

Treatment can consist of various methods, such as pressure filters (steel cylinder) and gravity filters. Pressure filters required trained technical personnel and is 100% depending on power supply.

Operation and Maintenance
Operation and maintenance is relatively high and power consumption will normally amount the largest part of the operating cost. The energy consumed is

depending on the total lift of the water (depend on the groundwater level and the topography).

Expected lifetime

The expected lifetime of the entire system components are 30-50 years, but lifetime of the main components may be:

- Borehole 30 years;
- Submersible pumps 10-15 years;
- Reservoirs 30 to 50 years;
- Pipe network 40-50 years depending of quality and constriction;
- Distribution pipes 40-50 years depending on pipe material etc.;
- Treatment plant 35 to 40 years; and
- Standpipe, yard tap and house connection 20 years.

Cost

In the table below is shown the estimated capital and recurrent cost of the mentioned technological options.

Cost Components	Capital Cost in EUR	Annual O&M Cost in EUR/year	Replacement Cost in EUR/year
Total Cost	**1,309,885**	**45,763**	**32,747**
Cost per Capita	**262**	**9**	**7**

Note: Based on 5000 people, average lcd 108, 500 m transmission, 20 km distribution pipes, reservoir, 20% SP, 40% yard taps, 40% HC - no treatment.

Conclusion

Piped groundwater supply system is a reliable system with a stable water quality but investments and operation cost is also higher then gravity schemes.

3.2.7 Piped System with Surface Water and Gravity Supply

Description

Piped water system with surface water as the source and gravity supply is cheap system, but the main problem is the quality of the raw water. The main challenge here is to abstract surface water with a good quality. This again depends on the type of source and the way of abstraction at the intake. Clean mountainous streams are preferable, or infiltration galleries should be investigated.

Treatment of surface water can vary depending on the quality of the water. Often slow sand filter (SSF) are used in rural areas as conventional surface treatment (pre-treatment, coagulation/flocculation, sedimentation, filtration and disinfection) is expensive for smaller villages/towns, and is not recommendable, if a rural settlement does not have the willingness and capability to manage, operate this comparatively complex technology.

In this model slow sand filter a conventional treatment can be chosen. Sometime a pre-treatment (roughing filter) are used before the slow sand filters, which often depends on the turbidity (higher than 25-30 NTU pre-treatment is required).

Experience

Piped water supply system utilising surface water as the source with gravity supply is a good system if the water quality do not require conventional treatment. For smaller towns conventional treatment will not be sustainable.

Slow sand filters operate with a continuous flow with the velocity in the range of 0.1 to 0.3 m/hour.

Operation and Maintenance

Operation and maintenance is relatively low if only slow sand filters are used. SSF needs dedicated operation and maintenance, but the recurrent cost is mainly the caretaker's fee.

Expected lifetime

The expected lifetime of the entire system components are 30-50 years, but lifetime of the main components may be:

- Intake50 years;
- Reservoirs 30 to 50 years;
- Pipe network 40-50 years depending on quality and constriction;
- Distribution pipes 40-50 years depending on pipe material etc.;
- Treatment plant 35 to 40 years; and
- Standpipe, yard tap and house connection 20 years.

Cost

In the table below is shown the estimated capital and recurrent cost of the mentioned technological options.

Cost Components	Capital Cost in EUR	Annual O&M Cost in EUR/year	Replacement Cost in EUR/year
Total Cost	**1,579,551**	**42,420**	**39,489**
Cost per Capita	**316**	**8**	**9**

Note: Based on 5000 people, average lcd 108, 1000 m transmission, 20 km distribution pipes, reservoir, 20% SP, 40% yard taps, 40% HC; slow sand filter treatment.

Conclusion

Gravity supply of water from surface water source is a reliable system if proper design and treatment of the water takes place. Conventional treatment for smaller villages/towns would be very costly and therefore is not recommendable.

3.2.8 Piped System with Surface Water and Pumped Supply

Description

Piped system with surface water and pumped supply to network is more or less the same as described above for the gravity except that water is pumped instead of flowing by gravity.

Experience and Operation and Maintenance

Pumped system increases the investment cost and also the O&M increases.

Expected lifetime

Same as for the gravity system.

Cost

In the table below is shown the estimated capital and recurrent cost of the mentioned technological options.

Cost Components	Capital Cost in EUR	Annual O&M Cost in EUR/year	Replacement Cost in EUR/year
Total Cost	**2,103,752**	**85,049**	**52,594**
Cost per Capita	**421**	**17**	**11**

Note: Note: Based on 5000 people, average lcd 108, intake with pumps, 1000 m transmission, 20 km distribution pipes, reservoir, 20% SP, 40% yard taps, 40% HC; conventional treatment.

Conclusion

Water supply with surface water pumped to customers can be the only technology to be applied but the options is not recommendable for smaller towns /villages. One or more of the other options should be investigated.

3.2.9 Water Treatment

The technologies chosen for the water treatment are:

- Slow sand filters (SSF);
- Rapid filter for ground water; and
- Conventional treatment for surface water.

Slow Sand Filters

Description

A slow sand filter (SSF) is comprised of a bed of graded sand which is supported by a layer of gravel. This filter media is confined in a box with openings at both ends allowing water to flow in and out, while operating on a top-down, gravity basis. The filtration process is a form of natural, biological water treatment used to remove solids, precipitates, turbidity (muddiness) and in some cases bacterial particles that produce bad taste and odour. The SSF works by a combination of biological action, adsorption and straining. The SSF consists of a structure that consists of:

- Inlet structure and filter box;
- Filter consisting of a support bed and a bed of fine sand;
- Drainage system; and
- Outlet structures.

For a high amount of suspended solids (SS) a sedimentation tank or horizontal roughing filters (**HRF**)[2] can be used in front of the SSF removing the larger particles. The SSF is often designed to have a very low filter velocity of 0.1 to 0.3 m/hour (m^3/m^2/hour).Often the filter bed consists of 1 meter of fine sand with about 1 meter of water on top to drive the water trough the filter. The top layer of the filter sand is often called the "schutzdecke" in which the bacteria and microscopic plants multiply to form a straining mat improving the quality of the water. This top layer needs to be removed when the headloss to a certain level, and therefore a number of filters are preferable. Disinfection shall take place after the filters.

Experience
SSF are being used worldwide for water treatment of surface water. For water with turbidity more than10 to 20 NTU for the influent water to the SSF a roughing filter is recommendable. SSF has the disadvantage of requiring an extensive land area to provide significant quantities of treated water as the as the filter velocity is very low compared to rapid filters.

Operation and Maintenance
SSF is simple to operate and maintain and the main activity is to control the filtration process and remove/reinstall new sand layer.

Expected lifetime
The expected life time of the entire construction is 30 years.

Cost
In the table below is shown the estimated capital and recurrent cost of the mentioned technological options.

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[2] In a horizontal roughing filter (HRF), the filtration rate ranges between 0.3 to 1.5 m/hr. Length of filter is dependent on raw water turbidity. Filter cleaning is also carried out with hydraulic filter flush which helps in periodical removal of accumulated solids from filter media. Hydraulic filter cleaning plays key role in long term and efficient roughing filter operation. Turbidity reduction can be achieved to the extent of 70-90 percent and even in some cases up to 98 per cent, depending upon raw water characteristics. HRF is simple in construction, using locally available material and skills for operation. Neither mechanical parts nor chemicals are necessary for HRF.

Cost Components	Capital Cost in EUR	Annual O&M Cost in EUR/year	Replacement Cost in EUR/year
Total Cost	**125,713**	**2,514**	**4,190**
Cost per Capita	**35**	**0,5**	**0,8**

Conclusion

SSF filters are relative cheap low technology treatment compared to conventional surface treatment.

Rapid Filters for Ground Water Treatment

The technologies chosen for the water treatment of groundwater are:

- Gravity rapid filters; and
- Pressure filters.

Description

Gravity Filters

Gravity filters are the most often used treatment method to treat groundwater for iron, manganese and ammonium as the most common ones. Manganese generates more or less the same problems as iron, but both have no serious health effect in normal concentration in water resources. Ammonium can cause bacterial growth in pipe network and increase corrosion.

Iron[3] in water supplies causes various aesthetic and operational problems including bad taste, discoloration, staining, and deposition in distribution system leading to after growth and incidence of high turbidity.

Gravity filter can consist of:

- Inlet with often gravity aeration over a number of steps;
- Reaction chamber before lead to;
- Sand filters (pre-filter and after filters depending on the iron content - normally more than 2 - 3 mg/l of iron require double filtration - ammonium require more oxygen than iron (3.7 mgO_2 per mg/l ammonium compared to 0.14 mg O_2 per mg/l iron(II)); and
- Back wash facilities.

Filter velocities are often around 4-7 m/hour.

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[3] In anaerobic groundwater (groundwater is normally with very little content of oxygen, iron is commonly present in soluble iron (II) form. Soluble iron (II) is first oxidized to insoluble iron (III) by aeration or chemical oxidation and the flocs formed are subsequently removed in a rapid sand filter.

Pressure Filters

Pressure filters are consisting of steel tanks where the filtration is taken place. Water is pumped into the tanks and aerated by a compressor and after filtration lead to clean water reservoir. The entire filtration process takes place in the steel tanks. The tanks are having filter material as the gravity filters, but the filter velocities are often 10-15 m/hour.

Experience

Gravity filters are relative low technologies and are used worldwide. The requirement for aeration and the filters composition depends on the content of the iron, manganese and ammonia. Filter material is often sieved sand.

Pressure filters require more technological experience as the filtering is not visible, and require compressed air (if not aerated before lead to filters).

Operation and Maintenance

Operation and maintenance of gravity filters is relatively easy, as the only work to be done is the routine backwashing of the filters, which can be done automatically.

Pressure filters require experienced trained technician.

Expected lifetime

The expected life time of the entire con is 45 years for gravity and 35 years for pressure filters.

Cost

In the table below is shown the estimated capital and recurrent cost of the mentioned technological options.

Cost Components	Capital Cost in EUR	Annual O&M Cost in EUR/year	Replacement Cost in EUR/year
Total Cost	**1,295,049**	**90,653**	**28,779**
Cost per Capita	**259**	**18**	**5,8**

Conclusion

Rapid gravity filters are recommendable treatment method for treating groundwater for rural towns and villages except for the smaller ones, as it require trained technicians. Pressure filters should only be used when similar technologies are available in nearby larger towns or industries and people can afford to pay for services.

Conventional Water Treatment for Surface Water

Description

Water treatment of surface water differs from treatment of groundwater for a number of reasons. Surface water is not "natural protected" as groundwater by a higher temperature, more organic matters, nutritive salt (nitrogen and phosphor connections), and algae - quality do also vary depending on the water source and seasonal variation. Treating surface water may be more complicated than groundwater and more advanced treatment may be required where pollution of water resources has taken place.

The conventional treatment utilised in the cost estimate consist of

- Pre-treatment with chemicals - (Chlorine, Aluminium Sulphate (Alum) etc. which kill germs and improve the treatment process.). Chemical are added in a mixer to react with dissolved and suspended compounds (coagulation) and followed by flocculation (polymer may be added to enhance flocculation);
- Sedimentation in a basin where the flocs settle;
- Filtration of settled water on filter beds consisting of sand/gravel/anthracite to remove any remaining impurities in the water;
- Disinfection/chlorination in clean water reservoir to keep bacteria from developing in the water network.

Experience
Conventional surface water treatment is used world wide, but it is normally more complicated to construct and maintain, and also qualified operators are required as fluctuating water quality require more water sampling and chemical adjustments.

Operation and Maintenance
Operation and maintenance of conventional surface water treatment require professional trained personal in water treatment. Operation is more complicated than simple groundwater treatment (low iron, manganese and ammonium content) and may be in most cases more costly to operate and maintain.

Expected lifetime
The expected life time of an entire plant may be 45 years.

Cost
In the table below is shown the estimated capital and recurrent cost of the mentioned technological options.

Cost Components	**Capital Cost in EUR**	**Annual O&M Cost in EUR/year**	**Replacement Cost in EUR/year**
Total Cost	**546,716**	**43,737**	**12,149**
Cost per Capita	**109**	**8,7**	**2,4**

Conclusion

Conventional surface water treatment should be avoided for smaller rural villages and towns as the treatment is complicated, costly and require professional trained operators.

4 Technologies - Sanitation

4.1 Introduction

4.1.1 Key Factors Influencing the Choice of Sanitation Options

A long range of improved sanitation options exists, from actual simple pit latrine to waterborne sewerage systems with advanced wastewater treatment plants.

Sanitation is normally divided into two categories of systems:

- On-site systems; and
- Off-site systems.

On-site systems mean that the main structures and operations are on the plot (or in the very close vicinity) of the household. For rural areas, on-site systems are from a technical, financial and institutional point of view preferable, if at all possible. For on-site systems the HHs themselves are responsible for O&M. Off-site systems are more complicated and require more organised management and operation & maintenance, and are more costly. However, on-site sanitation has its limitations. Soil and water table conditions can make on-site solutions difficult or impossible; and population densities can be so high that it might be difficult or an environmental hazard to operate on-site sanitation solutions if water abstraction takes place close to or downstream of the infiltration of wastewater.

When selecting the most suitable sanitation option for a certain area, one would consider the cheapest, health-wise and socio-culturally acceptable, financially affordable, technically and institutionally feasible solution. The actual selection of technology is influenced by a large number of factors, some of them touched upon above. The key factors include:

- Corresponding water and sanitation service levels;
- Soil conditions;
- Population densities;
- Sullage problem complex;
- Institutional factors, in particular the issue of responsibilities; and
- Socio-economic factors; in particular the affordability to pay for services.

Corresponding Water and Sanitation Service Levels

The applicable sanitation service level options are closely related to the provided water supply service levels, as reflected in Table 4-1. For instance, if a household has taps for water supply inside the house ,relative large amounts of water will normally be consumed, thereby creating a demand for a sanitation option which can cope with this high water demand (if sufficient water resources are available), i.e. typically one form of waterborne sewerage.

Table 4-1 Corresponding Water and Sanitation Service Levels

Water Supply Service Level	Service Level Options for Sanitation
Multi-tap, in house water supply (typically called House Connections)	• Waterborne off-site sanitation options • Waterborne on-site sanitation options
On-plot water supply (typically called Yard Taps and also in the form of single-tap, in house water supply)	• Waterborne off-site sanitation options • Waterborne on-site sanitation options • Non-waterborne on-site sanitation options
Water for sanitation purposes	• Waterborne off-site sanitation options • Non-waterborne on-site sanitation options

Soil and Ground Conditions

The applicability of on-site sanitation solutions requires adequate soak-away properties of the soil. In EECCA a high number of different soil types exist in rural areas where sanitation is required. However, some sanitation options - seepage solutions - need proper soil type to allow infiltration.

Population Densities

On-site sanitation solutions physically require space, and hence a relatively low population density is required. Also, the protection of groundwater sources - in particular if there are wells and boreholes nearby - demands a certain minimum distance between on-site sanitation facilities and water supply sources. A third issue is the costs. Off-site solutions are relatively costly for the rural population. One of the most cited studies of cost comparison between conventional waterborne sewerage, other types of waterborne sewerage and on-site solutions[4] concludes that first at population densities of more than 160 pers/ha, simplified (centralised) sewerage systems became comparable or cheaper than on-site solutions in Northern Brazil.

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[4] 'The Design of Shallow Sewer Systems', Sinnatamby 1986, UNCHS, Habitat

The population density in EECCA countries may vary considerable depending on the developments in the specific area and may vary from about 20 to more than 300 person/ha in the central core area.

Sullage Problem Complex[5]
Sullage is domestic wastewater other than that which comes from the toilet. It results from food preparation, personal washing, and washing of cooking and eating utensils and clothes. It is also called *greywater* (to distinguish it from *blackwater* which contains human excreta).

A family served only by a remote standpipe or handpump may discard less than 10 litres of sullage per person each day, whereas members of a household with numerous plumbing fixtures may discard 200 litres each or more per day.

The nature of the sullage is markedly influenced by factors such as diet, methods of washing clothes and utensils, habits of personal hygiene, and the existence of bathrooms and other facilities.

There are several reasons for keeping sullage separate from the blackwater, containing excreta. First, there may be a system for on-site disposal of excrete that cannot accept large volumes of water. Alternatively, the sullage may be transported away from the site by a small-diameter pipe that could not handle faeces. A third reason might be to reduce the hydraulic loading on a septic tank by diverting the sullage away from it.

Sullage is discharged or disposed of in a number of ways. Often it is simply tipped on to the ground in the yard or outside the property where it evaporates or percolates into the soil. It may be used to irrigate a vegetable, fruit trees or flower garden. It may find its way by natural or designed routes into open or subsurface storm drains. Soak pits or drainage fields may be built to disperse the sullage. In some cases the greywater from a number of properties is collected, screened and treated in ponds before it is discharged or reused.

Institutional Factors
Sanitation is mainly considered a private issue, meaning that on-site installations are constructed, operated and owned by private HHs. In case of sludge-emptying, private owners rely on public or private operators. For off-site sanitation, institutional responsibilities are split between individuals (inside the plot) and organisations (outside the plot). When implementing rural sanitation programmes all stakeholders have to agree on the borderline between private and public responsibilities.

To ensure that all stakeholders contribute towards proper implementation and O&M of technical sanitation installations, and thereby cooperate towards an acceptable level of hygiene and health, inputs from one responsible authority is usually considered to be a requirement. An authority's responsibilities are usu-

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[5] A Guide to the Development of on-site Sanitation, WHO, 1992

ally to define aims and the households and local authorities' responsibilities, and to educate, inspect and control.

Socio-economic and socio-cultural factors
Two issues are of importance:

- People's acceptability of sanitation solutions; and
- People's ability and willingness to cover at least the O&M costs of the sanitation solution.

There will have to be different service levels of sanitation. The affordability of the various HHs will differ, so unless there is a full cross-subsidisation, the very poor HHs cannot afford the most hygienic and technically correct option. HHs receiving water carried by hand cannot be served by the more advanced water-borne sanitation solutions; solutions that other HHs might opt for. So, the conclusion is that there most likely will be a range of sanitation technologies applied in a given village.

The service level of village water supply is anticipated to increase depending on the economic development in the rural areas or depending on state/IFI financed projects. One problem could be that villagers which are now happy with their on-plot sanitation facilities will resist changes: it may be difficult to convince the ones with inferior solutions or with solutions that are unsuitable on certain soils, to improve or change sanitation facilities. Reluctance to change could lead to worsening health and house-damages if more water is supplied.

4.1.2 Sanitation Options

The following sanitation options have been identified, described and assessed:

- Simple dry pit latrine;
- Improved latrine;
- Pour flush latrine with holding tank;
- Small communal sewerage with septic tank, reed bed, biological sand filter and stabilisation ponds;
- Sewered interceptors;
- Simplified sewerage; and
- Conventional waterborne sewerage.

The above technological options covered by this document are outlined in Section 2.1. The options are detailed one by one in the subsequent section.

Below is illustrated the interrelation between water supply and sanitation service levels.

Water Supply Service Level	Service Level Options for Sanitation
House Connections	Waterborne Sewerage (only large towns) Septic Tanks
Yard Taps	Septic Tanks Improved or Simple Pit Latrines
Standpipes	Improved or Simple Pit Latrines
Handpumps / Protected Springs / Traditional Sources	Improved or Simple Pit Latrines

4.2 Technologies

The sanitation technologies listed in Section 4.1.2 are described below as follows: a short description, experience, operation and maintenance, expected lifetime, cost and conclusion.

4.2.1 Simple Dry Pit Latrine

Description

This is the simplest version of pit latrines not intended for emptying; a hole (the pit) dug in the ground and covered by a slab with a hole for defecation and urination. Only the water required for cleansing after defecation should and is allowed to be discharged into any kind of pit latrine. It is not intended for sullage. This latrine is without lined or sealed pit has a pit volume to last for 10 years before it is filled and has a concrete top slab with a prefabricated squatting pan. Based on typical design criteria[6] a pit for a household of 6 people, with an anticipated 10 years' life time, should have a volume of at least 2.9 m^3.

Experience

Simple pit latrines are commonly used in rural areas in developing countries, as a cheap, reliable and hygienically and health-wise acceptable means of sanitation. They have not proved to be hygienically suitable in more densely populated areas approaching town like physical features, where for instance sullage becomes important also to address. An improved ventilated pit latrine is in many countries preferred, especially where odours at the latrines and fly and mosquito breeding in the pits have proved to be a general problem.

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[6] Environmental Health Engineering in the Tropics, Sandy Caircross and Richard Feachem, 1993

O&M
None, but when the pit is full it has to be covered with a concrete slab, a new pit has to be dug and the original slab with the squatting pan has to be shifted to the new pit.

Expected lifetime
If a ceramic/concrete, and not a plastic, squatting pan is used, its life-span is expected to be long (15 years).

Costs
In the table below is shown the estimated capital and recurrent cost of the mentioned technological options.

Cost Components	Capital Cost in EUR	Annual O&M Cost in EUR/year	Replacement Cost in EUR/year
Total Cost	**400**	**8**	**40**
Cost per Capita	**67**	**1.3**	**6.7**

Note: Serving 6 people.

Conclusion
The simple pit latrines cannot from a health point of view be considered an appropriate future sanitation option. However, the simple pit latrine could still be an interim solution for areas with appropriate soil texture.

4.2.2 Improved Latrine

Description
The most sophisticated form of the pit latrine, VIP (ventilated improved pit) latrine is ventilated in order to avoid odours at ground level and to avoid insects to spread from it. A ventilation stack with a mosquito screen covering the top end is applied. The floor of an improved latrine should always be of concrete with a squatting pan or of a prefabricated floor squatting plate. Pan or plate should be made of an easy to clean material, have footrests to facilitate for the users to position themselves over the drop hole, and have a rather small drop hole that makes it impossible for small children to fall through.

Pits should preferably not read groundwater level, and should be located not closer then 30-50 meter from groundwater source intakes.

Experience
The improved latrine provide a more durable latrine, but to a higher price.

Operation and Maintenance
Little maintenance is required, but regular cleaning, check of cracks in slab, walls and emptying the pit or moving the superstructure to a new position.

Expected lifetime
A 15 year lifetime or more can be expected with proper construction.

Cost
In the table below is shown the estimated capital and recurrent cost of the mentioned technological options.

Cost Components	Capital Cost in EUR	Annual O&M Cost in EUR/year	Replacement Cost in EUR/year
Total Cost	**800**	**16**	**53**
Cost per Capita	**133**	**2.7**	**8.9**

Note: Serving 6 people

Conclusion
The ventilation system makes this option more expensive than the simple pit latrines. It is only an appropriate solution when odours and insects from the latrine cause problems.

4.2.3 Pour Flush Latrine Toilet

Description
The pour flush latrine consist of latrine superstructure, a pan with a water seal in the defecation hole, on top of the pit or with one or two lined leaching pits (used here in the cost function) connected to the latrine via a diversion chamber. Other option is a holding tank followed by a soakage facility. Botch the leaching pits and holding tanks shall be emptied.

All leaching pits should be designed to cater for 10 persons, despite a present average household size of about 6 persons pit with 2-3 m^3 water volume should be sufficient. However, the tank dimensions have to be large enough to accommodate workers during construction. Proposed water depth is 1.5 m, and the horizontal inner cross sectional dimensions for each tank is proposed at 0.8 m x 1.25 m. The system is not intended for sullage.

The amount of water needed is mainly depending on the pan design and the distance to the pit, but about 2–5 litres per flush is required.

Experience
Used in rural or peri-urban areas where sufficient water is available and the soil is permeable. Holding tanks are often used where it is difficult to dispose of wastewater by direct soakage.

O&M

Pan and U-trap should be inspected monthly for blockages. The system requires that the pits are emptied for sludge regularly, say every 2nd year depending on seize. The system requires well organised emptying services.

Expected lifetime

10-15 years depending on the quality of construction.

Cost

In the table below is shown the estimated capital and recurrent cost of the mentioned technological options.

Cost Components	Capital Cost in EUR	Annual O&M Cost in EUR/year	Replacement Cost in EUR/year
Total Cost	**1100**	**28**	**73**
Cost per Capita	**183**	**4.6**	**12**

Note: Serving 6 people

Conclusion

The pour-flush toilet with leaching pits is from a health / technical point of view an ideal option for semi-permeable soil.

4.2.4 On Site Septic Tank

Description

Septic tanks are usually used for treatment of sanitary wastewater from individual households. In principle, septic tanks provide primary treatment with settling of solid phase and cold anaerobic digestion of settled solids. Effluent overflows to the recipient via drain trenches/soak-away trenches. Sludge must be removed regularly, e.g. once or twice a year, and transported for final treatment in a wastewater treatment plant or otherwise stabilised. Septic tank can serve several households if designed accordingly.

Experience

Septic tanks and soak-away trenches are used world wide in rural areas.

There are normally three main types of tanks for on-site sewage holding and pre-treatment with 2 to 3 compartments:

- Concrete tanks;
- Fibreglass tanks; and
- Polyethylene/plastic tanks.

Tanks (wet volume) should be designed for a retention time of 3-6 days.

The greater the liquid’s surface area, the more sewage the tank can accommodate. As solids collect in the tank, the water depth decreases, which reduces the time sewage flow is retained in the tank. Less solids will settle in the tank, resulting in increased solids in the tank effluent that may have a negative impact on the final treatment process.

Operation and Maintenance

The operation of the septic tank includes emptying the tank, transport and final treatment/disposal of the sludge. The model offers the following options:

- No collection and disposal of the sludge;
- Collection, transport and disposal at a wastewater treatment plan; and
- Collection, transport and disposal at a municipal landfill.

It is assumed that the amount of sludge collected in the tank is 0.5 m^3 per year per person (PE).

Expected lifetime

The lifetime of the septic tank is assumed to be 30 years and say 10-15 years for drainage fields.

Cost

In the table below is shown the estimated capital and recurrent cost of the mentioned technological options.

Cost Components	Capital Cost in EUR	Annual O&M Cost in EUR/year	Replacement Cost in EUR/year
Total Cost	**4552**	**148**	**228**
Cost per Capita	**759**	**25**	**38**

Note: Serving 6 people

Conclusion

Septic tank is an ideal option for on-site sanitation rural and semi-urban area.

4.2.5 Sewered Interceptor/Settled Sewerage

Nomenclature

The nomenclature and terminology within unconventional sewerage and the literature on it is somewhat confusing. Terms like small bore sewerage and shallow sewerage are not fully clear. A recent study[7] suggests the following strict nomenclature, in order to avoid confusions:

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[7] 'Low Cost Sewerage', Duncan Mara, 1996

- *Settled sewerage:* Household wastewater passes a tank (interceptor or septic tank). The wastewater fluid (the settled wastewater) is discharged into shallow, small bore gravity sewers; and

- *Simplified sewerage:* HHs wastewater is discharged into sewers without settling first. The simplified sewerage is essentially a conventional sewerage system without any of its conservative design requirements. Sewers are most often laid at shallow depth and in small dimensions.

Description
Settled sewerage is an off-site sanitation option. In the settled sewerage, the sewers can be laid following the topography as long as the gravity flow is secured and backflow in the sewers do not enter into inceptor tanks connected to the system. The settled sewerage as mentioned requires an interceptor tank. This means that the system is in particular applicable as upgrading of septic tank systems, as the effluent pipe from the septic tank can be connected directly to the sewers. Minimum sewer pipe dimension is typically ø75mm - ø100mm. The settled sewerage system caters for the sullage problem, as far as the sullage is discharged into the system. The collected wastewater has to be treated in a wastewater treatment plant. The cost of settled sewerage is between a third and a half of conventional sewerage. Originally developed in South Australia to overcome problems with failing septic tanks, it has been used quite widely worldwide to upgrade septic tank systems.

O&M
The system requires an organisation responsible for administration and O&M of the system, comprising the sewers and the wastewater treatment plants. Due to the incorporation of inceptor tanks, these tanks have to be emptied frequently, a service which has to be vested with the operating organisation, not the individual HHs, to minimise the risk of clogging of the sewers as a result of HHs not emptying the inceptors.

To reduce cost, the wastewater from a group of houses can be connected to one interceptor tank. Just like in a septic tank, the accumulation of sludge has to be removed regularly from an interceptor tank.

Experience
Most experience with the settled sewerage system is in Australia, USA, Columbia, Nigeria and Zambia[8]. The experience is, however, not very well documented. It is still the 1985 design manuals[9] which most frequently are referred to for details about the system.

S. Cairncross and R. Feacham summarise the results of international experience[10]:

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[8] 'Low Cost Urban Sanitation', Duncan Mara, 1996
[9] 'The Design of Shallow Sewer Systems, UNCHS, Habitat, 1985, and 'The Design of Small Bore Sewer Systems', Richard Otis and Duncan Mara, TAG Technical Note No. 14, 1985.
[10] 'Environmental Health Engineering in the Tropics', 1993.

- *When intercepting tanks do not exist and cost of septic tanks has to be included, the typical construction costs of settled sewerage and conventional sewerage are about the same;*

- *Settled sewerage depends on regular and efficient emptying of the septic tanks; and*

- *Desludging can not be done at the last minute when the interceptor tanks begins to overflow, or on the owner's request. It must be done at fixed intervals to avoid that solid materials block the sewers.*

When selecting settled sewerage as a waterborne sewerage option, due consideration should be given to local suitability cost etc. when assessing alternatives.

The cost of the settled sewerage is less than for the conventional waterborne sewerage, because of shallow excavations (which then require that the pipes trace are not prone for vehicle loads) and because of smaller dimensions of the sewers.

USA experience shows a cost saving compared to conventional waterborne sewerage of 20-50%.

Expected Lifetime
Depending on the design and quality of construction - say 30 to 40 years.

Cost
In the table below is shown the estimated capital and recurrent cost of the mentioned technological options.

Cost Components	Capital Cost in EUR	Annual O&M Cost in EUR/year	Replacement Cost in EUR/year
Total Cost	**3,461,675**	**64,666**	**86,542**
Cost per Capita	**692**	**13**	**17**

Note: Based on 5000 people, average lcd 108, one tank per household, 20 km pipes, 20% SP, 40% yard taps, 40% HC; mechanical and biological treatment.

Conclusion
The system requires septic tanks/inceptor tanks, and if these are not already in existence, the cost of construction of these tanks decreases the feasibility of this option. This means that the system would be most ideal for areas where septic tanks already exist, in high income areas with in-house water supply and high water consumption. The system requires an effective operations organisation, not the least in ensuring emptying of septic tanks/inceptor tanks.

4.2.6 Simplified Sewerage

Description
Simplified sewerage - also known as condominial sewerage - is an off-site sanitation option. In the simplified sewerage the sewers are laid in small diameters at shallow depths, typically inside housing blocks, thereby minimising the total length of sewers. Manholes are often constructed as simplified manholes (e.g. smaller than for conventional waterborne sewerage). Hydraulically the simplified design operates with lower minimum design velocities, which means either smaller dimensions or less slope requirements. The result is that more efforts (higher O&M costs) are needed to maintain the sewers clean and non-clogged. The simplified sewerage is most appropriate in high density lower/middle income areas, where on-site solutions are not possible due to space or soils. The system requires large flows, also initially, typical design practices require 90% initial connection rate.

The simplified sewerage system caters for the sullage problem, as far as sullage is discharged into the system. The wastewater has to be treated in a wastewater treatment plant. The same problems as mentioned for the settled sewerage option also apply for the simplified sanitation option.

The cost of construction of simplified sewerage can be 30 to 50 % less than conventional sewerage depending on local conditions.

Experience
It was developed in the early 1980s in Brazil and is mostly used in Brazil and Latin America, in Asia, and in some pilot schemes in southern Africa. Some experience The simplified sewerage are cheaper than conventional sewerage and has been constructed for many years, but in some cases legal and institutional problems need to be solved with some technical issues such as clocking, increasing depth in very flat areas. In colder climate the shallow depth of the pipes will not be recommendable due to long cold winter period.

O&M
The system requires an organisation to be responsible for administration and O&M of the system, comprising sewers and wastewater treatment plants. Special emphasis shall be paid to cleaning of sewers due to the "non-self cleansing" operation conditions of the simplified sewerage system.

Expected Lifetime
Depending on the design and quality of construction - say 20 years.

Costs
In the table below is shown the estimated capital and recurrent cost of the mentioned technological options.

Cost Components	Capital Cost in EUR	Annual O&M Cost in EUR/year	Replacement Cost in EUR/year
Total Cost	**3,349,392**	**37,134**	**167,470**
Cost per Capita	**670**	**7**	**33**

Note: Based on 5000 people, average lcd 108, 20 km pipes, 20% SP, 40% yard taps, 40% HC; mechanical and biological treatment.

Conclusion
The simplified sewerage system might not be an appropriate sanitation solution in many EECCA countries in winter time due to the shallow depth of the pipes. The technical applicability in EECCA of the system is not found documented for EECCA countries. Wastewater pumping and treatment will be required which will require an efficient operating organisation.

4.2.7 Conventional Waterborne Sewerage

Description
Conventional waterborne sewerage is an off-site sanitation option. HHs are connected to the conventional waterborne sewerage system through gravity property drains. Sewers (gravity or a combination of gravity and pumped) convey the wastewater to a wastewater treatment plant. The conventional waterborne sewerage is most appropriate in high density areas where the predominant water supply service level is house connections.

The conventional waterborne sewerage system caters for the sullage problem, as far as sullage is connected to the system. The wastewater has to be treated in a wastewater treatment plant.

Experience
Conventional sewerage either combined or single system is expensive because the sewerage pipes are laid deep beneath the ground. Pumping is generally required at various stages of the sewer pipe network, especially if the landscape is fairly flat. The larger the population served by the sewerage system, and the longer the planning horizon is to cope with future population increases, the larger the diameter of the final pipes becomes. The costs of the pipes, inspection manholes, pumps and pumping stations and their construction/installation are therefore high.

O&M
The system requires an organisation to be responsible for administration and O&M of the system, comprising sewers and wastewater treatment plants.

Expected lifetime
Depending on the design and quality of construction and O&M - say 50 years.

Cost
In the table below is shown the estimated capital and recurrent cost of the mentioned technological options.

Cost Components	Capital Cost in EUR	Annual O&M Cost in EUR/year	Replacement Cost in EUR/year
Total Cost	**3,844,040**	**48,235**	**76,881**
Cost per Capita	**769**	**10**	**15**

Note: Based on 5000 people, average lcd 108, 20 km pipes, 20% SP, 40% yard taps, 40% HC; mechanical and biological treatment

Conclusion
The conventional waterborne sewerage system will only be an appropriate sanitation solution if willingness and ability to pay are high enough in the rural area.

4.2.8 Wastewater Treatment

Small Treatment Plants
The model gives four options for treatment of wastewater:

- Conventional mechanical and biological/chemical treatment;
- Reed bed treatment;
- Biological sand filters; and
- Stabilisation ponds.

Conventional Treatment Plant
This component includes the wastewater treatment plant and the outfall pipeline, if applicable.

Expenditure functions for wastewater treatment were developed as part of a project for DEPA[11]. Data was collected for 24 newly constructed treatment plants, systematised and compared with the costing model. Overall, the ratio between model price and actual price was 0.96. The model underestimated the expenditure (ratio 0.89) for plants below 10,000 PE, while the ratio for larger plants was close to 1.0[12] .

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[11] DEPA: Calculation system for investment costs for wastewater treatment (in Danish), COWI and Lønholt&Jans I-S, 1990.

[12] For the two plants larger than 100,000 p.e. the model overestimated the cost with 24%, however, the low number of plants did not permit any generalisation or correction.

The operational expenditure of wastewater treatment presented is based on the experience of the consultant with advanced treatment plants, during the last 10 years.

The following combinations of wastewater treatment plants are considered:

Mechanical (M) Category 1

Mechanical-Biological/Chemical (MB/C) Category 2

The investment expenditure of wastewater treatment plants is divided into categories 1 to 2 as shown above.

The influent water quality assumed is illustrated in the table below

Table 4-2 Influent quality in mg/L (yearly average)

BOD	N	NH_4 - N	P	SS
250	50	30	8	300

Source: Consultant's estimates.

The categories are assumed to provide the effluent quality illustrated.

Table 4-3 Effluent quality by type of treatment (in mg/L - yearly average)

Treatment	Expenditure category	Effluent quality in mg/L				
		BOD	N	NH_4 - N	P	SS
M	1	175	45	35	7	25
MC	2	100	40	35	2	25
MB	2	25	35	30	6	25

Source: Consultant's estimates.
Note: The assessment of effluent quality is based on frequent 24-hour sampling proportional to flow (say, at least 12 samples taken at regular intervals over one year).

Organic pollution is the primary parameter for establishing the expenditure functions for the capital expenditure of new wastewater treatment plants.

The following assumptions have been made:

- The pollution parameter used in the expenditure functions is PE. The number of PE is defined at the total load of BOD per day (including industry) divided by 60 g/day.
- The function assumes a wastewater flow of 200 l/PE/day.
- $BOD_{inlet}/N_{inlet} = 4.5$
- Peak $flow_{rain}$/Peak $flow_{dry\ weather}$ is equal to 2

- The design temperature of inlet water is 7 ^{o}C[13]
- "Medium quality" design. Very fancy and very cheap solutions have not been assumed.

Reed Bed Filter

Description´
Normally 2 reed bed filters are used vertical and horizontal filters. Reed bed plants consist of a primary sedimentation tank (septic tank) followed a shallow soil filter planted with reed. Sanitary wastewater flows through the plant and undergoes treatment by means of settling, biological decomposition, filtration and adsorption to humus and clay.

Reed bed filters are often designed to use 4-7 m^2 per person connected. If phosphorus and nitrogen is to be removed it needs 10-15 m^2 per person.

The treated wastewater flows to the recipient. Septic sludge must be removed frequently and transported for final treatment at a wastewater treatment plant or otherwise stabilised.

Experience
Most reed bed treatment plants the wastewater is running on the surface instead of peculation through the roots. The advantages are relatively cheap operating cost and good reduction in organic matter and bacteria. The disadvantages are running-in period is 5-8 years, high capital cost, and low ammonia removal. Using this option for communities bigger than 2000 PE should be avoided.

Operation and Maintenance
Operation and maintenance is low, and consist of cutting down and disposal of reeds, cleaning feeding pipes etc.

Expected lifetime
Vary depending on the construction and maintenance and is not documented - say 20 years

Cost
In the table below is shown the estimated capital and recurrent cost of the mentioned technological options.

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[13] We acknowledge the fact that inlet temperatures in many towns in the CIS are substantially higher, maybe 12 ^{o}C, which reduces the capital costs significantly. However, we believe that inlet temperatures will fall to European levels as energy prices go up and energy efficiency concerns lead to less waste of hot water.

Cost Components	Capital Cost in EUR	Annual O&M Cost in EUR/year	Replacement Cost in EUR/year
Total Cost	**6,009,587**	**42,750**	**300,479**
Cost per Capita	**1,202**	**8,6**	**60**

Note:

Conclusion

Reed bed filter are sustainable treatment options for household, group of households or smaller villages. However, the capital costs are relatively high, though O&M cost is low.

Biological Sand Filter

Description

Biological sand filters consist of a primary sedimentation tank (septic tank) followed a ventilated sand filter. Sanitary wastewater flows through the plant and undergoes treatment by means of settling, biological decomposition and filtration. The loading is often 3-7 m^2/PE.

The treated wastewater flows to the recipient. Septic sludge must be removed frequently and transported for final treatment at a wastewater treatment plant or otherwise stabilised.

Experience

The advantages with biological sand filters are relatively cheap operating cost, are functioning immediately, removed nearly all organic matters and reduce ammonia, but treatment effect can be reduced with insufficient oxygen.

The main problem is the availability of sand for the filters.

Operation and Maintenance

Maintenance is low and consists of cheeking possible clogging in the system.

Expected lifetime

Vary depending on the construction and maintenance and is not documented - say 20 years

Cost

In the table below is shown the estimated capital and recurrent cost of the mentioned technological options.

Cost Components	Capital Cost in EUR	Annual O&M Cost in EUR/year	Replacement Cost in EUR/year
Total Cost	**4,650,547**	**67,500**	**232,527**
Cost per Capita	**930**	**12,5**	**46,5**

Conclusion
Biological sand filters are treatment options for household, group of households or smaller villages. However, the capital costs are relatively high, although O&M cost is low. Availability of sand is required.

Stabilisation Pond

Description
A simple pond system consists of a screen, grit, a grease chamber and stabilisation ponds. Stabilisation ponds are shallow earthen basins with a long detention time. Micro organisms provide biological treatment. The solids and dead micro organisms settle on the bottom, and the treated wastewater overflows to the recipient. Settled sludge is removed regularly e.g. once a year and utilised as fertilizer or disposed of to a landfill after dewatering.

Stabilisation ponds are suitable for hot climates only.

Experience
The number of basins most commonly used is 3. Daily surface load is often 10-15 m2/PE.

Operation and Maintenance
Operation and maintenance is low, and consist of cutting the dikes, cleaning screens, cleaning feeding pipes etc.

Expected lifetime
Vary depending on the construction and maintenance - say 25 years

Cost
In the table below is shown the estimated capital and recurrent cost of the mentioned technological options.

Cost Components	Capital Cost in EUR	Annual O&M Cost in EUR/year	Replacement Cost in EUR/year
Total Cost	**1,358,073**	**569,250**	**54,323**
Cost per Capita	**272**	**114**	**11**

Conclusion

Stabilisation ponds are suitable treatment options for household, group of households or smaller villages. The capital cost is relatively high, though O&M cost is low. However the stabilisation ponds are bets suited for warm climatic areas.

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Appendix 1 Glossary of Terms

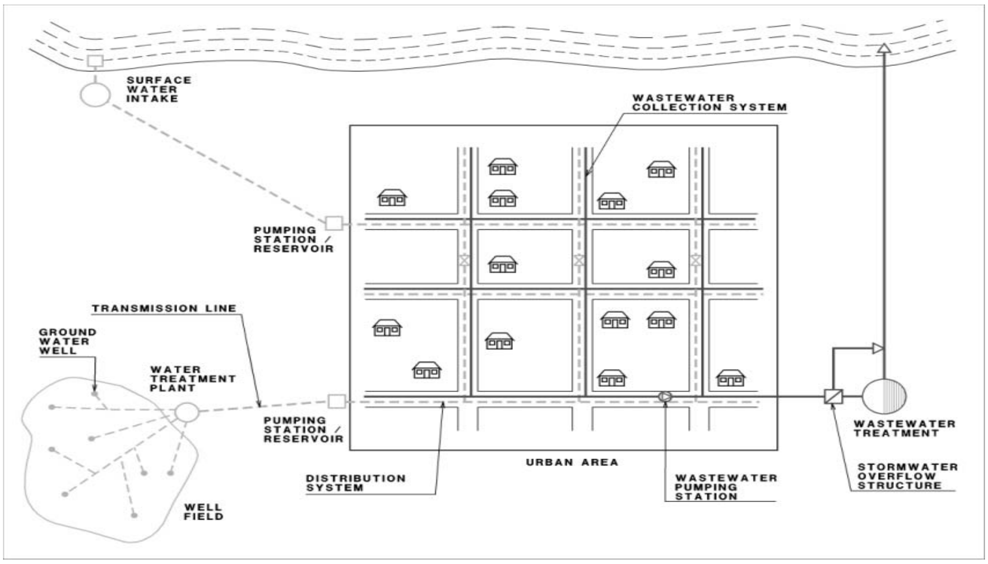
Affordability	The issue of how much a household can pay for municipal services, without substantially reducing consumption of other vital goods and services (food, lighting and heating, etc). Often measured as % of average household income. It is a political decision to set the maximum affordable level of payment for services.
Investment	The act of obtaining a capital asset consisting of goods (and services) that are not intended for immediate consumption, but rather help to generate a stream of goods or services during some period in the future. In our definition, such goods and services will normally have a life span of at least one year, and they add new capital stock or replace worn out parts of the existing capital stock.
Demand responsive approach	Development approach which is based on the demand from users instead of "supply driven approach" whish is driven by government, donors etc.
EECCA	The EECCA is an abbreviation for Eastern Europe, Caucasus and Central Asia and it includes the following 12 countries: Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Republic of Moldova, Russian Federation, Tajikistan, Turkmenistan, Ukraine and Uzbekistan.
Peak flow	Demand or capacity required at peak of demand/flow
Polyethylene	Material to produce e.g. pipes used for both water supply and wastewater pressure mains, drainage etc. with normally low maintenance, low installation cost.
Proportion of the population with access to improved sanitation	Refers to the percentage of the population with access to facilities that hygienically separate human excreta from human, animal and insect contact. Facilities such as sewers or septic tanks, poor-flush latrines and simple pit or ventilated improved pit latrines are assumed to be adequate, provided that they are not public -(UN, WHO).
Reasonable access to water	Reasonable access was broadly defined as the availability of at least 20 litres per person per day from a source located within 1 kilometre of the user’s dwelling.

Appendix 2: Documentation of Expenditure Functions - Water Supply

6 Water Supply

The documentation of the cost functions for rural water supply is structured according to the technologies overview components as listed below: starting at the raw water intake moving through the distribution network, via sewage collectors to the wastewater treatment plant as illustrated in the figure below.

Figure 2 Schematic illustration of the basis for expenditure functions



Source: Consultant's layout

There are two types of expenditure function:

- Investment expenditure functions (capital cost); and
- O&M expenditure functions.

The cost is international price level, 2005. By international level means an average price level experienced or estimated to be representative for an international cost level.

The investment expenditure function is actually a replacement value functions which is used to estimate three types of expenditure need: 1) the annual reinvestment expenditure, 2) the renovation need and 3) the investment expenditure in case of service extensions requiring new infrastructure.

These expenditure functions are described in sections 6.1.

6.1 Investment Expenditure Functions

Water supply investment cost functions are divided into each technology and for piped system for each functional facility, such as intake, transmission main, treatment etc.

6.1.1 Roof Rainwater Collection/Harvesting

The cost of rooftop rainwater harvesting from a 60 m^2 roof, with 15 meter of gutters, plumbing, 2 m^3 storage tank is estimated to 325 EURO, excluding roof material. O&M cost is 2% of capital cost.

This price is used per household covered with rainwater harvesting independent on the amount of rain and seize of the household.

6.1.2 Dug Well with Pump/Tap

The capital cost function for a dug well with a pump is depending on the depth, and has the functions as:

Cost = (135*Depth+1850)/Q - €/m^3/day;

O&M = 2% of capital cost; where:

- Depth is the total depth of well in meter; and
- Q is the demand in m^3/day.

6.1.3 Borehole with Handpumps

The capital cost function for a borehole with a handpump is depending on the depth, and has the functions as:

Cost = (215*Depth+3408)/Q - €/m^3/day;

O&M = 2% of capital cost; where:

- Depth is the total depth of well in meter; and
- Q is the demand in m^3/day.

6.1.4 Protected Spring

Two spring type are considered, the simple spring and the spring box.

Simple Spring (without box/storage)
The unit capital cost for a simple protected spring is 1200 €.

O&M = 2% of capital cost

Spring Box
The capital cost function for a spring box:

Capital cost = 2250*Q^ $^{-0.52}$ - €/m^3/day;

O&M = 2% of capital cost; where:

Q is the demand in m^3/day.

6.1.5 Surface Water Intake

Two surface intakes are considered: one intake structure for gravity pipes and one intake including pumping station.

Intake for gravity
The capital cost function for intake:

Capital cost = 513*Q^ $^{-0.344}$ - €/m^3/day;

O&M = 2% of capital cost; where:

Q is the demand in m^3/day

Intake with pumping station
The capital cost function for intake:

Capital cost = 1443*Q^ $^{-0.323}$ - €/m^3/day; and

O&M = 3% plus energy cost; where:

Q is the demand in m^3/day

6.1.6 Transmission Main

The cost function for transmission main is the same as for distribution pipes. An average cost per meter is used comprising pipe, excavation, laying and backfilling plus 15% for fittings etc. The cost is an average price for steel, PVC and PE pipe.

Cost = 0.0009*dia.^2+0.2884*dia., €/m of pipe; dia.= diameter of pipe in mm.

The length of transmission is either default value or user inserted value. The mean diameter of transmission is calculated depending on the default value of geometric head and hydraulic head or user inserted values.

The mean diameter is calculated according to Hazan Williams formula:

H_t (headloss) = $10.9*(Q/C)^{1.85}*L/D^{4.87}$; $Q=m^3$/second, L= length of pipe in m, D= diameter of pipe in m; C (fiction coefficient) =dimensionless

O&M = 1% of capital cost.

6.1.7 Boreholes

The cost function for a borehole with a submersible pump is depending on the depth and the flow, and has the functions as:

Cost = $Depth*(200/S+85) +6047+260*Q^{0.45}$, (€/$m^3$/day), where

D = depth of borehole,
S = success rate of drilling (0.75 for 75% success rate)
Q = flow in m^3/day.

O&M = 4% of capital cost plus energy cost.

6.1.8 Treatment

The cost functions operate with four type of treatment:

Surface water:

The following technologies are used in the model:

- Slow sand filter for spring water/clean stream water; and
- Conventional treatment (pre-treatment, coagulation/flocculation, sedimentation, filtration and disinfection).

Capital cost functions:

Slow sand filter: Capital cost = $9900*Q\wedge^{-0.634}$ - €/m^3/day; and

Conventional treatment: Capital cost = $18200*Q\wedge^{-0.51}$ - €/m^3/day.

O&M costs:

Slow sand filter: 2% per year of capital cost.

Conventional treatment plant: 8 % per year of capital cost.

Groundwater:

- Pressure filter (in closed filter); and
- Open gravity filters.

Capital cost functions:

Pressure filter: Single filtration; Capital cost = 2582*Q^ $^{-0.421}$ - €/m^3/day

Pressure filter: Double filtration; Capital cost = 3754*Q^ $^{-0.417}$ - €/m^3/day

Gravity Filtration: Single filtration; Capital cost = 15000*Q^ $^{-0.583}$ - €/m^3/day

Gravity Filtration: Double filtration; Capital cost = 14083*Q^ $^{-0.523}$ - €/m^3/day

O&M costs:

Pressure filter: Single filtration: 6% per year of capital cost.

Pressure filter: Double filtration: 7% per year of capital cost.

Gravity Filtration: Single filtration: 5% per year of capital cost.

Gravity Filtration: Double filtration: 6% per year of capital cost.

Q = demand per day in m^3/day.

6.1.9 Pumping Station

The capital cost function for clean water pumping station:

Capital cost = 2400*Q^ $^{-0.6}$ - €/m^3/day; Q = demand per day in m^3/day.

O&M = 3% of capital cost plus energy cost

6.1.10 Reservoirs

The capital cost function for clean water reservoir covers two types:

- Concrete ground reservoir (partly under ground with soil cover); and
- Elevated steel tank 10 m above ground.

Ground reservoir: Capital cost = 370*V $^{-0.138}$ - €/m^3/day; and

Elevated steel reservoir: Capital cost = 7726*V $^{-0.522}$ - €/m^3/day, where

V is total volume of reservoir in m^3.

V is the total volume of reservoir and is depending on the peak demand. User can change default of % of peak demand.

O&M for ground reservoir: 0.5% of capital cost.

O&M for elevated steel reservoir: 2% of capital cost.

6.1.11 Distribution Pipes

The cost function for distribution pipes is the same as for transmission pipes. An average cost per meter is used comprising pipe, excavation, laying and backfilling plus 15% for fittings etc. The cost is an average price for steel, PVC and PE pipe.

Cost = 0.0009*dia.^2+0.2884*dia., €/m; where, Dia= diameter of pipe in mm.

The length of length of the distribution is either an estimated length or a user inserted value. The estimated length by the model is based on supply area with with a plot seize of 900 m^2:

Length of distribution pipe: $L = 144*A^{1.15}$ (m), A in hectares

The mean diameter of transmission is calculated depending on the default value of geometric head and hydraulic head or user inserted values.

The mean diameter is calculated according to Hazan Williams formula:

H_t (headloss) = $10.9*(Q/C)^{1.85}*L/D^{4.87}$; Q=$m^3$/second, L= length of pipe in m, D= diameter of pipe in m; C (fiction coefficient) =dimensionless

O&M = 2% of capital cost.

6.1.12 Standpipe, Yard Taps and House Connections

The unit cost for stand-post, yard tap and house connection is as follows: Cost Item Share of Technologies

Standpipe: Cost = 605 €/each;

O&M = 2% of capital cost.

House connection: Cost = 280 €/each;

O&M = 2% of capital cost.

Yard connection: Cost = 315 €/each

O&M = 2% of capital cost.

6.2 Cost Element Shares

The weight factors for correction of investment expenditure and operation and maintenance cost to reflect the local price level are given in Table 1and Table 2. These weight factors are equal to the structure of the total investment expenditure. For each type of water infrastructure, the table shows how the total investment is distributed on various expenditure elements. The shares for each type sum to 100% (each row).

Cost of land is not included in the cost functions.

Table 4 Weight factors for price correction of investment expenditure (% of investment expenditure)

Water Supply Capital Cost Component	Land	Power	Fuel	Labour (Blue collar workers)	Professionals (White collar workers)	Consumables	Equipment	Buildings and construction materials	Other costs
Rainwater Harvesting	0	0	0	15	0	0	30	55	0
Dug well	0	0	1	17	2	0	20	60	0
Protected spring	0	0	1	25	4	0	15	55	0
Borehole with handpump	0	0	1	30	9	0	10	50	0
Protected spring box	0	0	1	25	5	0	14	55	0
Intake surface water, gravity	0	0	1	30	5	0	5	59	0
Intake surface water with pumps	0	0	0	25	8	0	17	50	0
Transmission main	0	0	0	20	5	0	45	30	0
Borehole with submersible pump	0	0	2	18	5	0	45	30	0
Reservoir, concrete	0	0	2	40	8	0	10	40	0
Elevated steel reservoir	0	0	2	25	8	0	10	55	0
Treatment plant, pressure filter	0	0	1	15	10	0	25	49	0
Treatment plant, gravity filter	0	0	1	20	6	0	20	53	0
Treatment plant, slow sand filter	0	0	0	40	2	25	20	13	0
Tretament plant, conventional surface	0	30	0	18	2	15	20	15	0
Pumping station	0	0	1	24	10	0	25	40	0
Distribution network	0	0	0	20	5	0	45	30	0
House connection	0	0	0	20	2	0	38	40	0
Yard connection	0	0	0	20	2	0	38	40	0
Stand post	0	0	0	25	2	0	28	45	

Source: Consultant's estimates.

Table 5 Weight factors for price correction of operation expenditure (in international price level)

Water Supply O&M Cost Component	Land	Power	Fuel	Labour (Blue collar workers)	Professionals (White collar workers)	Consumables	Equipment	Buildings and construction materials	Other costs
Rainwater Harvesting	0	0	0	30	0	0	50	20	0
Dug well	0	0	0	35	0	0	30	35	0
Protected spring	0	0	0	40	0	0	10	50	0
Borehole with handpump	0	0	0	30	0	0	50	20	0
Protected spring box	0	0	0	30	0	0	10	60	0
Intake surface water, gravity	0	0	0	40	0	0	10	50	0
Intake surface water with pumps	0	60	0	15	1	0	14	10	0
Transmission main	0	0	0	30	0	0	60	10	0
Borehole with submersible pump	0	40	0	20	10	0	20	10	0
Reservoir, concrete	0	0	1	60	1	0	15	23	0
Elevated steel reservoir	0	0	1	43	1	0	15	40	
Treatment plant, pressure filter	0	40	0	20	2	0	28	10	0
Treatment plant, gravity filter	0	25	0	33	2	0	20	20	0
Treatment plant, slow sand filter	0	0	1	25	5	0	15	54	0
Tretament plant, conventional surface	0	0	2	23	10	0	25	40	0
Pumping station	0	60	0	17	2	1	10	10	0
Distribution network	0	0	0	30	0	0	60	10	0
House connection	0	0	0	20	0	0	40	40	0
Yard connection	0	0	0	20	0	0	40	40	0
Stand post	0	0	0	30	0	0	20	50	0

Source: Consultant's estimates.

Blue collar are workers, and white collar are other employees.

Appendix 3: Documentation of Expenditure Functions - Wastewater

7 Wastewater

The wastewater infrastructure comprises the following elements:

- Simple pit latrine
- Improved latrine
- Pour flush latrine
- Septic tanks;
- Sewered interceptor tanks with or without treatment;
- Simplified sewerage with or without treatment;
- Small treatment plants;
- Conventional sewerage collection;
- Pumping stations; and
- Conventional wastewater treatment plants.

Below are described the investment and O&M expenditure functions of each type of infrastructure.

The investment expenditure function is actually a replacement value functions which is used to estimate three types of expenditure need the annual re-investment expenditure, the renovation need and the investment expenditure in case of service extensions requiring new infrastructure.

The cost is international price level, 2005. By international level means an average price level experienced or estimated to representative for an international cost level.

The investment expenditure function is actually a replacement value functions which is used to estimate three types of expenditure need: 1) the annual re-investment expenditure, 2) the renovation need and 3) the investment expenditure in case of service extensions requiring new infrastructure.

These expenditure functions are described in sections 1.1 to 1.5.

7.1 Simple Pit Latrines

The capital cost function for a simple unlined pit latrine:

Cost = 400 €/each unit;

O&M = 2 % of capital cost.

7.2 Improved Larine

The capital cost function for an improved latrine:

Cost = 800 €/each unit;

O&M = 2 % of capital cost/year

7.3 Pour Flush Latrine

The capital cost function for a pour flush latrine:

Cost = 1100 €/each unit;

O&M = 2.5 % of capital cost/year

7.4 Septic Tank

The capital cost function used for septic tank for a single household is:

Cost = -98 * log (PE) + 835[14] - €/PE

O&M = 8* PE + 100, €/year; where PE is here number of people[15]

7.5 Small Treatment Plants

There are three options as to small treatment plant technology:

- Reed bed treatment;
- Biological sand filters; or
- Stabilisation ponds.

7.5.1 Reed Bed Treatment Plants

Reed bed plants consist of a primary sedimentation tank (septic tank) followed a shallow soil filter planted with reed.

Expenditure functions, less than 2,000 p.e.
The replacement value function is:

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[14] Connection to existing sewer pipes is assumed, i.e. excl. connection to house installations and discharge facilities.

[15] PE is the number of person equivalent calculated based on a total demand assuming e.g. a person is consuming 200 litres per day. In this rural context the one PE is assumed to be one person regardless the amount of water consumed as the BOD content is assumed to be the same.

Cost = 1521 * log(PE) + 6892, €/PE

O&M = 13.5 * PE + 6,750 - €/year

7.5.2 Biological Sand Filters

Expenditure functions, less than 2,000 PE
The replacement value function is shown below:

Cost = -777 * log(PE) + 3,872 - €/PE.

O&M = 13.5 * PE + 6,750 - €/year

7.5.3 Stabilisation Ponds

Expenditure functions, less than 2,000 PE.
The replacement value function is shown below assuming that the average temperature in ponds is 18°C[16].

Cost =-283 * log(PE.) + 1232 - €/PE

O&M = 13.5 * PE + 6,750 - €/year

7.5.4 Conventional Wastewater Collection

This component includes the works in relation to a single pipe wastewater collection system from the property lines to the wastewater treatment plant, i.e.

- Network collection system
- Service connections
- Main/trunk/interceptor sewers

The function for estimation of the total pipe length (L) is:

If population < 50,000 then L= Pop * (-0.00005833 * Pop + 4.92); where Pop is the population serviced.

Cost of pipe per meter: 0.004235*Dia^1.6811+152.8 - €/m, Diameter in mm.

Total capital cost = Unit price * length of pipe network.

O&M = 2 % of capital cost/year

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[16] Stabilisation ponds are best suitable for hot climates.

7.5.5 Sewered Interceptor Tanks and Collection Pipes

One interceptor tank is used per household, and a unit cost per connection. For each of the house connection a default length of pipe to tank and to outfall from interceptor tank is used (can be changed by the user).

Capital cost of interceptor tank = 2000 $/each; and

Pipe cost = 0.0009*dia.^2+0.2884*dia., €/m, diameter in mm.

O&M for tanks are as for septic tanks.

O&M pipes= 1 % of capital cost/year ((default value, can be changed by user).

7.5.6 Simplified Sewerage

The simplified sewerage consists of small diameter collection network. The prices for pipes are the same as for interceptor pipes, and length of network is the same as defined under conventional wastewater collection network.

O&M = 1 % of capital cost/year (default value, can be changed by user).

7.5.7 Pumping Stations

Pumping stations for wastewater collection is only anticipated for conventional wastewater collection. The capital cost function for pumping station is:

Capital cost = 2*(16570*KW installed^0.559) - €/pump station; KW= total KW installed.

Power installed is calculated according to default values/user defined values for lift and efficiency of pump.

O&M = 3% of capital cost plus energy cost (default value, can be changed by user).

7.5.8 Wastewater Treatment

The expenditure functions are shown in Table 6.

New connections are estimated as the number of people assuming one P.E per person, while the effect of industries has to be assessed as part of the pre-model analysis.

Table 6 Investment expenditure functions for wastewater treatment plants, in €/PE in 1990 prices.

	Load in PE			
Technology	<400	400-2,000	2,000-100,000	>100,000
M	188.1	=10^(-0.2745*log(PE)+3.8605)/7.44	=10^(-0.2073*log(PE)+3.6385)/7.44	53.8
MB/ MBC	403.2	=10^(-0.4735*log(PE)+4.7093)/7.44	=10^(-0.2632*log(PE)+4.0149)/7.44	67.2

Source: Consultant's estimates.
Note: The new module on rural WSS in the Feasible model, the figures have been corrected to reflect the 2005 price level.

Operational Expenditure
The operational expenditure for wastewater treatment is estimated using a percentage of the investment expenditure. This covers all operational expenditure except electricity, which will be specified separately.

*Electricity consumptio*n (values are for efficiency of 40%):

Mechanical treatment:	15 kWh/year/PE
Mechanical/biological/chemical:	25 kWh/year/PE

*Other operational expenditur*e: 3% of the total investment expenditure for wastewater treatment default value can be changed by user).

7.6 Cost Element Shares

The weight factors for correction of investment expenditure and operation and maintenance cost to reflect the local price level are given in Table 7 and Table 8.

These weight factors are equal to the structure of the total investment expenditure and O&M costs at the international price level. E.g. for each type of wastewater infrastructure, the Table 7 shows how the total investment is distributed on various expenditure elements. The shares for each type sum to 100% (in each row).

Cost of land is not included in the cost functions.

Table 7 Weight factors for price correction of investment expenditure (cost item in % of total investment expenditure)

Sanitation Capital Cost Component	Land	Power	Fuel	Labour (Blue collar workers)	Professionals (White collar workers)	Consumables	Equipment	Buildings and construction materials	Other costs
Simple pit latrine	0	0	0	30	0	0	0	70	0
Improved latrine	0	0	0	20	0	0	0	80	0
Pour flush latrine	0	0	0	15	0	0	10	75	0
On site septic tank	0	0	1	20	0	0	10	69	0
Sewerage interceptor	0	0	1	20	3	0	30	46	0
Simplified sewerage	0	0	1	30	2	0	25	42	0
Convetional sewerage	0	0	1	20	10	0	30	39	0
Pumping station	0	0	1	25	10	0	30	34	0
Sandfiter	0	0	1	20	5	0	30	44	0
Reed bed filter	0	0	1	20	5	0	25	49	0
Stabilisation pond	0	0	1	20	5	0	20	54	0
M treatment	0	0	1	15	10	0	30	44	0
M&B teatment	0	0	1	15	10	0	30	44	0

Source: Consultant's estimates.

Table 8 Weight factors for price correction of O&M (cost item in % of total O&M cost)

Sanitation O&M Cost Component	Land	Power	Fuel	Labour (Blue collar workers)	Professionals (White collar workers)	Consumables	Equipment	Buildings and construction materials	Other costs
Simple pit latrine	0	0	0	40	0	0	0	60	0
Improved latrine	0	0	0	20	0	0	0	80	0
Pour flush latrine	0	0	0	30	0	0	10	60	0
On site septic tank	0	0	0	30	0	0	10	60	0
Sewerage interceptor	0	0	0	30	2	0	25	43	0
Simplified sewerage	0	0	0	38	2	0	20	40	0
Convetional sewerage	0	0	0	25	2	0	30	43	0
Pumping station	0	50	0	20	2	0	15	13	0
Sandfiter	0	0	0	30	0	20	10	40	0
Reed bed filter	0	0	0	30	0	0	30	40	0
Stabilisation pond	0	0	0	40	0	0	20	40	0
M treatment	0	10	0	30	5	0	25	30	0
M&B teatment	0	25	0	30	5	5	15	20	0

Source: Consultant's estimates.

Blue collar are workers, and white collar are other employees.