Public Water Corporation

MIWR – GONU

MWRI - GOSS

Technical Guidelines for the Construction and Management of Slow Sand Filters

A Manual for Field Staff and Practitioners

April 2009

DEVELOPED IN PARTNERSHIP WITH

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Ministry of Irrigation and Water Resources – Government of National Unity

Foreword

Significant progress has been achieved in the provision of water and sanitation services in Sudan has in the last few years. This is attributed to the increased access to many remote villages as a result of the three major peace agreements, the Comprehensive Peace Agreement (CPA) between north and south Sudan, the Darfur Peace Agreement (DPA) and the Eastern Sudan Peace Agreement (ESPA), that were signed in 2005 and 2006 respectively. This access has allowed the Ministries of Irrigation and Water Resource (MIWR) of the Government of National Unity (GoNU), state governments and sector partners (including NGOs and the private sector) to expand water and sanitation services in many areas. This prioritizing of the expansion and sustainability of water and sanitation services in urban and rural areas throughout the county, including to the nomadic population has resulted in a steady annual increase in water and sanitation coverage for the citizens of Sudan.

With this expansion in implementation, the MIWR recognized the need to harmonize the various methodologies utilized by the various actors in the implementation of water and sanitation interventions. It was agreed that this could be best achieved through the development and distribution of Technical Guidelines, outlining best practices for the development of the 14 types of water supply and sanitation facilities in the Sudan. These Technical Guidelines, compiled in a systematic manner will undoubtedly set standards and provide guidance for all water and sanitation sector implementing partners.

The MIWR of the GoNU of the Sudan is grateful to UNICEF, Sudan for financial and technical support in the preparation of the Technical Guidelines.

I believe these Technical Guidelines will go a long way to improving WES sector programmes, allowing for scaling up implementation of activities towards achieving the MDGs for water supply and sanitation in Sudan.

Minister
Ministry of Irrigation and Water Resources
Government of National Unity, Khartoum

Date ………………………………………

Foreword

The historic signing of the Comprehensive Peace Agreement (CPA) in January 2005, culminated in the establishment of an autonomous Government of Southern Sudan (GOSS) and its various ministries, including the Ministry of Water Resources and Irrigation (MWRI). The CPA has enabled the GOSS to focus on the rehabilitation and development of the basic services. The processing of the Southern Sudan Water Policy within the framework of the 2005 Interim Constitution of Southern Sudan (ICSS) and the Interim National Constitution (INC) was led by the MWRI. This Water Policy is expected to guide the sector in the planning and monitoring of water facilities during implementation. The Water Policy addresses issues like Rural Water Supply and Sanitation (RWSS) and Urban Water Supply and Sanitation (UWSS). The Southern Sudan Legislative Assembly (SSLA) of GOSS approved the Water Policy of Southern Sudan in November 2007.

The importance of developing effective water supply and sanitation services is universally recognized as a basis for improving the overall health and productivity of the population, and is particularly important for the welfare of women and children under five. Considering the current low coverage of safe drinking water supply and basic sanitation facilities as a result of the protracted civil war in the country during the last five decades, there are enormous challenges ahead. With the unrecorded number of IDPs and returnees that have resettled in their traditional homelands and the emergence of new settlements/towns in all ten states of SS, the demand for water and sanitation services is immense. There is need for implicit policies, strategies, guidelines and manuals to ensure provision of sustainable supply of quality and accessible water and sanitation services.

The preparation of these WES Technical Guidelines at this stage is very timely, as it enables us to further develop our strategies and prepare action plans for the implementation of the Water Policy. It will also allow us to strengthen existing best practices as well as to test new experiences that will create room for future development.

During the development and finalization of these guidelines for water supply and sanitation facilities, we have consulted WASH sector partners at State level and partner non-government agencies through successive consultative meetings, and appreciate their contribution, which has assisted in finalizing these documents.

The MIWR of the GOSS is thankful to UNICEF, Juba for financial and technical support for the preparation of these Technical Guidelines.

We call upon our WASH sector partners to give us their continuous feedback from the field for the improvement of these Guidelines. We believe that successful implementation and future sustainable service provision will depend on effective coordination and close collaboration among all partners including government, non-government and beneficiary communities.

Mr. Joseph Duer Jakok,
Minister of Water Resources and Irrigation
Government of Southern Sudan, Juba

Date ……………………………………….

Acknowledgements

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The author would also like to thank WES and UNICEF staff of North Darfur, North Kordofan, South Kordofan, Sinnar, Gedaref, Kassala, Red Sea and Blue Nile States; the staff of DRWSS, and UWC in Central Equatoria, Western Bahr el Ghazal, Warap and Upper Nile States; and the staff of UNICEF Zonal Offices responsible for the arrangement of meetings with sector partners and successful field trips to the various facilities.

Many thanks to Emmanuel Parmenas from MWRI, and Mr Mohammed Habib and Mr Jemal Al Amin from PWC, for their contribution in collecting documents and information at the national and state levels, facilitating field trips and contacting relevant persons at state level and to the latter two for their support in translating documents and information from Arabic into English.

The completion of this document would not have been possible without the contributions and comments of staff of SWC, PWC, MIWR, MCRD, MWRI, MOH in GONU, MAF, MARF, MOH MHLE, MWLCT and SSMO in GOSS, UNICEF, National and International NGOs like Oxfam GB, Pact Sudan, SNV, SC-UK, and Medair, and review workshop participants at state and national levels and members of technical working groups.

Acronyms

APO	Assistant Project Officer
BS	British Standard
CPA	Comprehensive Peace Agreement
DG	Director General
DPA	Darfur Peace Agreement
ES (Es)	Effective Size
ESPA	Eastern Sudan Peace Agreement
GONU	Government of National Unity
GOSS	Government of Southern Sudan
IRC	International Reference Center (International Water and Sanitation Center)
MCRD	Ministry of Cooperatives and Rural Development**,** GOSS
MIWR	Ministry of Irrigation and Water Resources, GONU
MPN	Most Probable Number (Faecal coliform counts per 100ml)
MWRI	Ministry of Water Resources and Irrigation, GOSS
NTU	Nephlometric Turbidity Unit
PM	Project Manager
PVC	Polyvinylchloride
PWC	Public Water Corporation
RPO	Resident Project Officer
RWC	Rural Water Corporation
SSMO	Sudanese Standard and Measurement Organization
SWC	State Water Corporation
TCU	True Color Unit
TDS	Total Dissolved Solids
UC	Uniformity Coefficient
UNICEF	United Nations Children's Fund
WATSAN	Water and Sanitation
WES	Water and Environmental Sanitation
WHO	World Health Organization

Document Summary

This summary provides a brief overview of the document and is only meant as a quick reference to the main norms. Reference to the whole document is advised for accurate implementation.

Norms

- It is important to ensure sufficient land is secured for slow sand filters which require relatively large areas of land.
- Another, important factor is the availability of filter media at a reasonable cost.
- Characteristics of raw water for effective treatment:
  a) Turbidity of water less than 20NTU, ideally less than 10NTU.
  b) If turbidity of raw water is more than 20NTU, then pretreatment methods like sedimentation or roughing filtration are required prior to passing the water through slow sand filters. Coagulation, flocculation and chlorination processes **are not advised** as pre-treatment**.**
- Although slow sand filters are 99% effective in removing germs, it is advisable to chlorinate the filtered water before consumption.
- The minimum number (n) of slow sand filtration units required can be determined by: $n = ½ \times (A)^{1/3}$. A is total required area for slow sand filter in m^2.
- Period of operation of slow sand filter: 24 hours per day
- Filtration rates in the filters: 0.1 to 0.2 m/h.
- Filter bed area: 5 to 200 m^2 per filter.
- Height of filter bed:
  a) Initial: 0.8 to 0.9 m
  b) Minimum: 0.5 to 0.6 m
- Specification of sand:
  a) Effective size: 015 to 0.30 mm
  b) Uniformity coefficient: <5, preferably below 3.
- Height of under-drains including gravel layer: 0.3 to 0.5 m
- Height of supernatant water: 1.0m
- No of people to be served:
  a) 500 to 1000 for filtration rate of 0.1m/h, 5-200 m^2 filter area and 50 l/p/d demand
  b) 1000 to 40000 for filtration rate of 0.2 m/h, 5-200 m^2 filter area and 50 l/p/d demand
  c) Economical Number of population to be served with slow sand filters: 30,000 to 40,000

1. Introduction

1.1 The purpose of this document

The Ministry of Irrigation and Water Resources (MIWR), GONU, and the Ministry of Water Resources and Irrigation, (MWRI), GOSS, are responsible for the policy and strategy development, coordination, planning, management, monitoring and evaluation of water supply and sanitation facilities in the country. In order to reduce disparities, improve standards, accelerate implementation and to standardise design and costs, the two ministries agreed to harmonize the methodologies utilised in the implementation of WATSAN interventions Currently, there is no standardised document providing Technical Guidelines for implementation by WES or other water and sanitation agencies and this is detrimental to the longevity of structures and the sustainability of interventions.

In 2006 MIWR and MWRI decided to develop Technical Guidelines for the construction and management of rural water supply and sanitation facilities. These Guidelines are a collection of global and national good practices in water and sanitation that have been collated. The process of the development of the Technical Guidelines is outlined in Annex 2.

These simple Guidelines are primarily intended as a reference for field staff and practitioners in the water and sanitation sector challenged by situations and conditions in the field.

Updating of the Guidelines is recommended biennially; to ensure newer and better practices are incorporated as they are developed/ introduced. Water and sanitation sector implementing partners should contribute in providing feedback to the MIWR and MWRI as necessary during the updating.

1.2 Mobilization of stakeholders

Identifying and mobilizing potential stakeholders is an important step in the realization and sustainability of a rural water supply system. Various stakeholders play various roles at different stages of a project cycle. Roles and responsibilities can be assigned using participatory techniques like participatory rural appraisal. Involvement of the community (including women) in decision making at all stages of the project will promote sustainability. For example in , site selection, distance to water points, community contribution for the construction, operation and maintenance of the water service, selection of the village health committee (for the management of water , sanitation and hygiene promotion activities in their villages) and village mechanics (that could be trained) The community should also be involved in the technical aspects of the water service being provided such as technology choice, choice of preference design, platform and drainage apron.

Local authorities also play a significant role in the facilitation of the implementation of the water supply system. Problems that may arise during the implementation of the water supply system such as for example, land ownership, could be easily solved if the local authorities are brought on board and are involved in the decision making process.

Problems can only be identified by the active involvement of the stakeholders in the decision making process. The long process involved in getting community engagement can be decreased by using a demand-driven

2. Guideline for selection of slow sand filter

Before deciding on a slow sand filter, as the most appropriate choice of water supply scheme for the area, the following parameters must be considered:

1. Assessment of the technical and social feasibility of a new water supply system, with regards to the possible economic and health benefits.
2. Assessment of availability of adequate land, as slow sand filters requires a large area.
3. Assessment of the quality of raw water and the type of the treatment system as the quality of water dictates this.
4. Assessment of whether sufficient water can be provided at all times and at convenient locations.
5. Assessment of demographic data including competence of local technical staff and/or users capable of constructing, operating, maintaining and repairing the water supply scheme.
6. .Availability of reliable equipment locally, if equipment is required.
7. Design consideration of adaptation to local needs and preferences.
8. Design requirement for chemicals, pumping and attendance duration for the pump operator.
9. Participation of the community in the planning, design, construction, monitoring and evaluation process, including management modalities and the involvement of women.
10. Cost of construction materials and availability at local level.
11. Monitoring mechanisms for the performance of the treatment system.
12. Provisions to protect, or deal with possible deterioration of the quality of raw water or breakdown of the treatment system.
13. Hygiene education and the roles of stakeholders.
14. The environmental impact of a slow sand filter.

In most cases a slow sand filter is the least expensive water treatment facility for rural areas. The basic process involves slow filtration of raw water through a bed of fine sand at a rate of 0.1 to $0.3m^3/m^2/h$. The process removes turbidity and greatly reduces the number of micro-organisms (cysts, bacteria, viruses), considerably improving the quality of water

The turbidity of the raw water before it is passed through a slow sand filter is an important factor in the efficiency of the system. The maximum turbidity that can be entertained is 20 Nephlometric Turbidity Unit {NTU} and ideally is should be less than

10 NTU. Bacteriological reduction efficiency depends directly on the reduction of turbidity of the water. The turbidity of influent water will determine the components of the overall treatment process.

When the turbidity of raw water is more than 20 NTU, an additional pretreatment process is required before the raw water is passed through a slow sand filter. Facilities for pretreatment include: grit chambers, sedimentation tanks, pre-roughing filters, etc. Figure 2 shows an example of a large pre-sedimentation basin in Kassala State for pre-treatment of the raw water before it enters a slow sand filter Samples of water taken before and after the pre-sedimentation basin showed a reduction of about 70% in turbidity (from 40 NTU to 12 NTU).Table 1 below provides some basic guidelines in selection of treatment methods of surface water including using slow sand filtration.

Table 1: Recommended water treatment systems for surface water in rural areas[1], based on raw water quality.

No	Average raw water quality	Treatment required
1	Turbidity: 0-5 NTU Faecal coliform MPN*: 0 Guinea worm or schistosomiasis not endemic	-No treatment
2	Turbidity: 0-5 NTU Faecal coliform MPN*: 0 Guinea worm or schistosomiasis endemic	-Slow sand filtration
3	Turbidity: 0-20 NTU Faecal coliform MPN*: 1-500	-Slow sand filtration; -Chlorination, if possible
4	Turbidity:20-30 NTU (30NTU for a few days) Faecal coliform MPN*: 1-500	-Pre-treatment advantageous; -Slow sand filtration; -Chlorination, if possible
5	Turbidity: 20-30 NTU (30NTU for several weeks) Faecal coliform MPN*: 1-500	-Pre-treatment advisable; -Slow sand filtration; -Chlorination, if possible
6	Turbidity: 30-150 NTU Faecal coliform MPN*: 500-5000	-Pre-treatment; -Slow sand filtration; -Chlorination, if possible
7	Turbidity: 30-150 NTU Faecal coliform MPN*: >5000	-Pre-treatment; -Slow sand filtration; -Chlorination is a must/required
8	Turbidity: >150 NTU	-Detailed investigation and possible pilot plant study required

- Faecal coliform counts per 100 ml

[1] Source: Slow Sand Filtration for Community Water Supply, planning, design, construction, operation and maintenance, J.T. Visscher, R. Paramasviam, A. Raman and H.A. Haijinen, IRC, The Hague, Technical Paper No 24

Even where the turbidity of water is very high as shown on Table 2, Table 3 and Figure 1, pre-treatment is very effective in reducing the turbidity..

No	Source of raw water	Turbidity on 30/10/2006
1	Hafir No 1	≈500 NTU
2	Hafir No 2	≈450 NTU
3	Hafir No 3	>500 NTU
4	Earth dam	>500 NTU

Table 2: Turbidity of raw water from hafirs and earth dam at Gedembeliya area, Gedarif State

No	Source of water	Turbidity on 15/11/2006
1	Earth dam	450 NTU
2	Hafir No 3	250 NTU
3	Hafir No 4	100 NTU

Table 3. Turbidity of raw water in Boot area, Blue Nile State

Figure 1. Water in the outlet well of one a hafir in Jebel Moya area, Sinnar State

Figure 2. A pre-sedimentation basin (locally called "lagoon") to treat water from irrigation canals in Kassala State, Sudan before the water is passed through a slow sand filter

Slow sand filters should function on a continuous basis for two major reasons: to build confidence among the users on the availability of quality water; and to use efficiently the bacteria that has been developed in the 'schmutzdecke' (filth cover) of the filter media. The bacteria developed in the "schmutzdecke" requires uninterrupted flow in the filters

Slow sand filters are therefore recommended where the water source is available all the year round. A water source that provides water for only a few months after the rainy season, like some hafirs (Figure 3), should be avoided. If there is no other option of water treatment system, the number of hafirs should be increased to ensure that the supply lasts all year round.

Figure 3. A hafir and its slow sand filter in Kalkalat area, Kassala State. The hafir has dried out due to the lack of rainfall

Availability of filter media at a reasonable cost: This is often a problem and can increase the cost of the system .For example, for Gedaref state, the nearest location where filter media is available is Medani city, and the cost of transporting the filter to Gedaref is costly for the SWC.

Pumping units, for both raw and clear water, should be provided in areas where the flow is not assisted by gravity.

A platform must be provided in the design, for washing the sand for the filter media .

A dumping area, should be identified for accumulated silt in the filter units as well as in the sedimentation basin; otherwise the situation indicated in Figure 4 will follow.

Figure 4. Sludge accumulation in the filter units and sedimentation tank of Tayba slow sand filter, Sinnar State.

3. Design procedures of slow sand filters

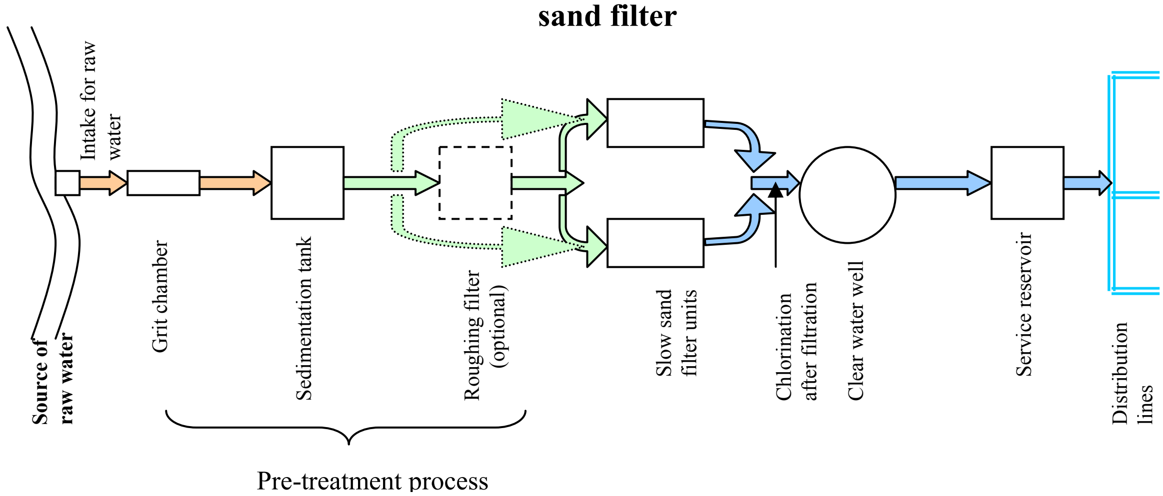
3.1 Capacity of a slow sand filter

Slow sand filtration is more cost effective than rapid sand filtration for populations in the range of 30,000 to 40,000, but not for larger populations as this would require larger areas to accommodate a number of filtration units. If additional pre-treatment facilities like sedimentation tanks are required, as is almost always the case, this would entail even more space requirement.

3.2 Quality of influent water for slow sand filter

The turbidity of incoming water or influent to slow sand filters should not exceed 20 NTU and ideally should be below 10 NTU. Water with a turbidity of more than 20 NTU, should be pretreated with treatment facilities like grit chambers, settling tank, roughing pre-filters or with a combination of various pre-filtration systems as indicated in Figure 5.

Figure 5: Schematic sequence of water treatment facilities when using slow sand filter



3.2.1 Pretreatment facilities

Grit chambers, sedimentation tanks, roughing filters (with horizontal or vertical up/down flow) etc. can be used for pre-treatment.

3.2.1.1 Grit chambers: These facilities are coarse sedimentation tanks in which the water flows at a maximum speed of 0.75m/s. The retention time in these tanks needs to be just a few minutes. Coarse particles/grit are removed in the grit chambers, before the water enters the settling tank and roughing pre-filter.

3.2.1.2 Sedimentation tank: Finer suspended particles can be reduced further by allowing the raw water from the grit chamber to flow slowly through a sedimentation tank (Figure 5). The sedimentation tank should be designed for a specific retention time and in most cases for a minimum of 2 hours. The arrangement and design of inlet (A), outlet (D), baffle structures (B), settling and sludge zones (E), as indicated on Figure 6, are very important in order for the sedimentation tank to function properly. The settling of suspended solids and removal is realized by positioning a large diameter drain valve at the lowest point of the floor of the sedimentation tank (F) and with the floor adequately tilted towards the drain valve. Table 4 provides design criteria for rectangular sedimentation tanks.

Table 4: Design criteria for rectangular sedimentation tanks[2]

Parameter	Calculation	Range of values
Detention time	V/Q	4-12 h
Surface loading	Q/A	2-10 m/d
Depth of basin	H	1.5-2.5 m
Outlet weir overflow rate	Q/R	3-10 m^3/m/h

[2] Source: Slow Sand Filtration for Community Water Supply, planning, design, construction, operation and maintenance, J.T. Visscher, R. Paramasviam, A. Raman and H.A. Haijinen, IRC, The Hague, Technical Paper No 24

Length/width ratio	L/W	4:1 to 6:1
Length/depth ratio Large basins Small basins	L/H	 25:1 to 35:1 5:1 to 20:1

H = depth (m), L = length (m), W = width (m), R = total length of overflow of the outlet weir (m), V = volume of the basin: L x W x H (m^3), Q = raw water feed flow (m^3/h), A = surface are of the basin: L x W (m^2)

The inlet structure of the sedimentation tank includes an inlet pipe and a perforated vertical baffle. The baffle wall is located a little way forward from the inlet pipe to distribute the water evenly across the tank. Water must flow evenly into the tank to avoid turbulence and areas of stagnation. There may be also a weir across the width of the tank before the baffle. Rapid transit of water across the tank must be avoided as this will reduce the retention time. A low retention time will prevent the suspended solids from settling in the sedimentation tank.

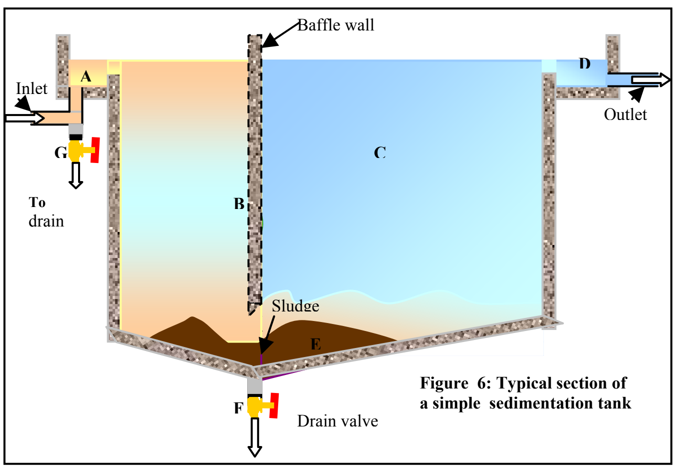


Figure 6: Typical section of a simple sedimentation tank

The outlet of the sedimentation tank includes a weir and an outlet pipe. The weir collects clarified water from the top layer of the tank after the settling zone and the outlet pipe conveys the water to the next treatment component, either a roughing pre-filter or slow sand filter, depending on the reduction in turbidity of the effluent water from the sedimentation tank.

An effective sedimentation tank should remove 70-90% of turbidity from the raw water.

3.2.1.3 Roughing pre-filter: (Figures 7 & 8) In addition to reducing suspended matters, a roughing pre-filter also contributes to the removal of microorganisms from the water during the treatment process. In a typical roughing pre-filter, water passes through packs of gravel of different sizes where suspended particles are trapped. Flow through gravel may be horizontal, vertical up-flow or vertical down-flow. The up-flow configuration is the most efficient and facilitates hydraulic cleaning.

Aspects of design to be considered:

1.The turbidity of water leaving the roughing pre-filter should be less than 10NTU after 70-90 percent reduction in turbidity.

2.The flow rate through the pre-filter should be in the range of 0.5-1.5 meter per hour.

3.The filter media should have several sections, usually three, each filled with different sizes of gravel. For three-section gravel pre-filter, the sizes of gravel would be 15-25mm, 8-15mm and 4-8mm. The largest size of gravel is used at the raw water inlet side and the smallest towards the outlet.

4.The dimensions of a horizontal flow roughing filter can be estimated using the parameters indicated in Table 5.

Table 5: Preliminary design guidelines for horizontal flow-roughing filters

Parameter	Average suspended solid concentration in raw water	
	High (150mg/l)	Medium (100-150mg/l)
Horizontal flow (m/h)	0.5 – 0.75	0.75 – 1.50
Depth (m)	1.0 – 1.50	1.00 – 1.50
Width (m)	1.0 – 1.50	1.00 – 5.00
Length of filter media (m):		
First compartment (15-25mm)	3.0 – 5.0	3.0 – 4.0
Second compartment (8-15mm)	2.0 – 4.0	2.0 – 3.0
Third compartment (4-8mm)	1.0 – 3.0	1.0 – 2.0

Source: Wegelin (1986)

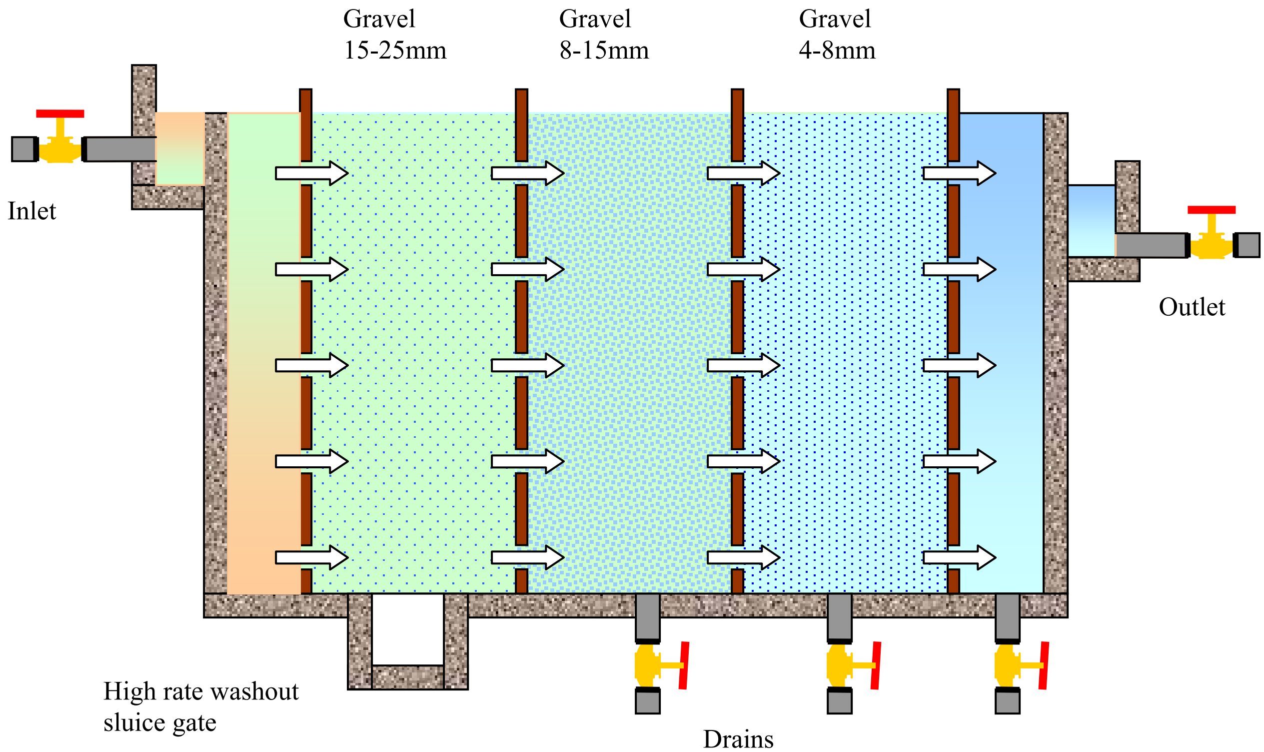


Figure 7 - Section of horizontal roughing gravel pre-filter

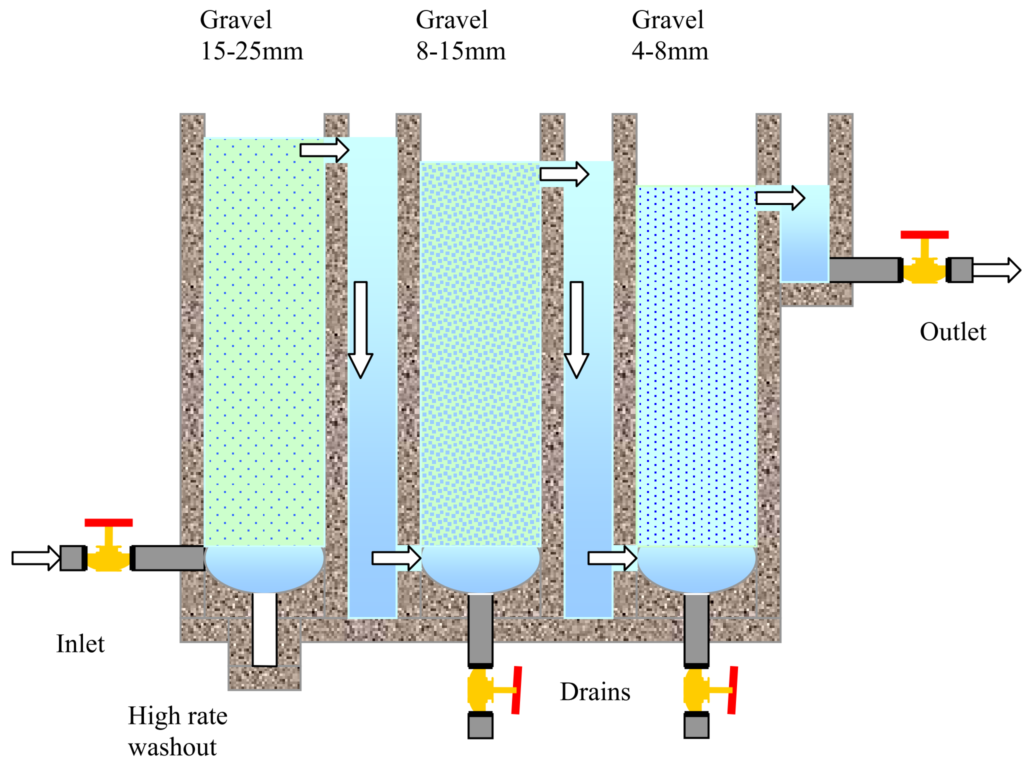


Figure 8 - Section of up-flow roughing gravel pre-filter

3.3 Filter box

Most filter boxes (Figure 9) are built with vertical or near vertical walls (in which case the horizontal dimensions will be those of the filter-bed surface) of a depth sufficient to accommodate the constituent parts (filter bottom, gravel support, filter medium, supernatant water depth and freeboard). The internal depth of the box would therefore be the sum of the depth of each part, ranging between 2.6m and 2.9m (table 6)as illustrated in the example below.

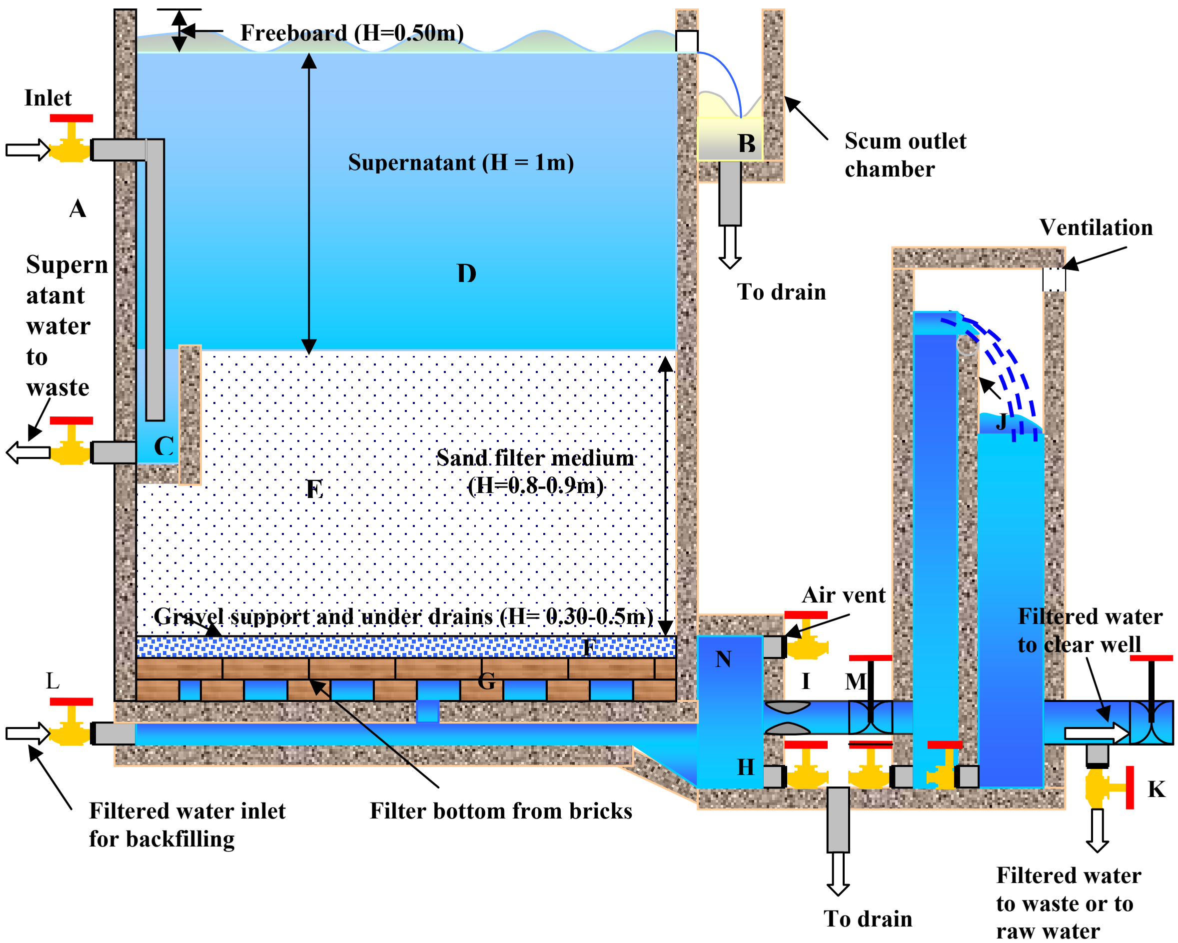


Figure 9 - Section of a typical rectangular slow sand filtration unit adapted from WHO

3.4 Design criteria for slow sand filters

The general design criteria in Table 6 can be used for designing slow sand filtration units

Table 6: General design criteria for slow sand filters in rural water supply[3]

Design criteria	Recommended level
Design period	10-15 years
Period of operation	24 h/d
Filtration rates in the filters	0.1-0.2 m/h
Filter bed area	5-200 m2 per filter, minimum of 2 units
Height of filter bed: Initial Minimum	 0.8 -0.9 m 0.5-0.6 m
Specification of sand: Effective size Uniformity coefficient	 0.15-0.30 mm <5, preferably below 3
Height of under-drains including gravel layer	0.3-0.5 m
Height of supernatant water	1 m

In order to ensure that the a slow sand filter functions correctly and an adequate water supply is maintained, the flow rate in the filter should be maintained within the range of 0.1 to 0.3 cubic meter of water per hour per square meter area of filter media. The smaller the flow rate the greater the surface area of the slow sand filter and vice versa.

3.5 Determination of size and number of slow sand filters

The weakest part of a filter, from the point of effluent quality, is the edge of the filter-bed, where the raw water may leak and bypass the sand if care is not taken in design and operation. In order to minimize this weakness, filters should not be too small. Even though the minimum recommended size is 5 m^2, a workable size is usually 100 m^2, with a maximum of 200m^2 preferred in rural areas, so they can be cleaned in a day.

The system should posses a minimum of two filters to ensure that one is functional whilst the other is being cleaned. A minimum of four filters is recommended for a public water supply for increased amount of treated water. The following formula can be used to obtain a rough estimation, of the appropriate number of filters for a system:

$n = ½(A)^{(1/3)}$ …………[4], or

$n = ¼ (Q)^{(1/2)}$ …………[5]

where,

n – Number of rectangular filter units and minimum n has never been less than 2

A – Total required area for slow sand filters in m^2

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[3] Source: Slow Sand Filtration for Community Water Supply, planning, design, construction, operation and maintenance, J.T. Visscher, R. Paramasviam, A. Raman and H.A. Haijinen, IRC, The Hague, Technical Paper No 24

[4] Ibid

[5] Source: www.catas1.org/eng/water/ssf_4

Q - Average daily water demand and it is expressed in m^3/h

3.6 Depth of supernatant water reservoir

The supernatant water reservoir consists essentially of an upward extension of the walls of the filter box from the sand-bed surface. The reservoir formed to serves two purposes:

a) A waiting period of some hours is created, which allows oxidation, sedimentation and agglomeration of particles occur, and

b) It provides a head of water sufficient to overcome the resistance of the filter-bed, thereby inducing downward flow through the filter.

The second purpose (b) determines the vertical dimension of the reservoir. The resistance varies from a minimum to a maximum. The minimum head occurs when the bed is newly cleaned and the maximum head occurs at the end of the filter run. In practical terms the depth of supernatant water should be kept constant, equal to or greater than the maximum head. This can be achieved by imposing an artificial resistance on the effluent pipe with the aid of a regulating valve. This constant depth reduces the dangers of disturbing the 'schmutzdecke' (filth cover) as it forms, enables floating impurities to be removed from the supernatant reservoir through the scum outlets, and prevents the deep penetration of sunlight, which might encourage the growth of rooted aquatic plants in the filter surface.

The depth of water in the supernatant reservoir can be determined by the maximum resistance anticipated. In practice, a head of between 1.0 m and 1.5 m is usually selected and an additional freeboard of 50cm is provided above the water level.

3.7 Filter bed and filtration sand size of slow sand filter

In Sudan, the medium through which the water is passed is normally sand, which is available in most places.. Other countries use alternative materials like crushed coral and burnt rice husk. The composite sand for slow sand filter is expressed with its effective size (Es or D_{10}) and uniformity coefficient (UC). Effective size of the composite sand is defined as the sieve opening in mm that permits passage of 10% by weight of the sand. The uniformity coefficient of sand is defined by the ratio between the sieve size that permits passage of 60% of sand (by weight) and effective size D_{10} of the composite sand i.e. $UC = D_{60} / D_{10}$.

The effective sand size for continually operated slow sand filters is in the range of 0.15 to 0.30mm[6]. Effective size and the uniformity coefficient can be determined by sieve analysis (Annex 3) and as indicated below:[7].

[6] Source: WHO

[7]Source: Slow Sand Filtration for Community Water Supply, planning, design, construction, operation and maintenance, J.T. Visscher, R. Paramasviam, A. Raman and H.A. Haijinen, IRC, The Hague, Technical Paper No 24

- A mixture of four or five samples is taken as a representative sample of the sand in a staked area. The sample is washed thoroughly to remove impurities and allowed to dry.
- Some 500g of dried sand is then sieved for 15 minutes, using a mechanical sieving shaker through a series of standard sieves with the coarsest sieve at the top and the finest at the bottom.
- The sand retained in the coarsest sieve is weighed. Sand retained in each of the subsequent sieves is added to the previous one, and the total amount of sand retained weighed.

Both fine and coarse materials have been found to work satisfactorily in practice and the final selection depends on what is available locally. It is possible to combine two or more types of available sand to reach the effective ideal diameter. Mixing must be carried out very thoroughly, preferably in a concrete mixer. It must be remembered that finer sand will result in better quality water output, but will increase the head loss of the filters, thus increasing the rate of cleaning required (of the filter beds).

As the amount of sand required for the filter units is huge, it is usual to employ un-graded material excavated from natural deposits. Some degree of uniformity, however, is desirable in order to ensure that pore sizes are reasonably regular and that there is sufficient porosity. In this regard, sand with a coefficient of uniformity of less than 5, preferably less than 3 and greater than 1.5 is preferred. There is little advantage, in terms of porosity and permeability, in sand with a coefficient below 1.5[8].

The grains of sand used for slow sand filters should preferably be perfectly round. The sand should be free from any clay, soil or organic matter, and, must be washed before use, if necessary. If the raw water is expected to have high levels of carbon dioxide, then the sand must contain less than 2% of calcium and magnesium, calculated as carbonates. This is to prevent the formation of voids in the filter media if the calcium and magnesium are removed by solution (Huisman and Wood, 1974).

The thickness of the filter bed can be more effectively determined by experiment than by other means keeping in mind three important considerations:

1) Immediately below the filter-skin lies the zone in which purifying bacteria abound. The thickness of this zone is usually between 0.3m and 0.4m, the latter if the sand grains are relatively coarse and the filtration rate is reasonably high.

2) Below the depth mentioned above, chemical reactions take place in what may be described as the mineral oxidation zone, within which the organic materials liberated by the bacterial life-cycle in the upper sand layer are chemically degraded. The thickness of this zone may be between 0.4 and 0.5m; the latter

[8] Source: www.catas1.org and www.oasisdesign.net/water/treatment/slowsandfilter

when the raw water has a high organic content. Under no circumstances should the total bed thickness of 1 and 2 be less than 0.7m.

3) Continuous sedimentation and straining of particles will gradually increase the resistance in the filter skin, and after one to three months the resistance becomes too high for the filter to produce sufficient safe water. Filtration capacity can be restored by cleaning the filter, which is done by draining off the supernatant water and removing the top 1-2 cm of the sand bed, including the filter skin. This material is not immediately replaced, and on re-starting the filter, the whole filtration process takes place at the same depth below the new surface, i.e. 1-2cm lower in the same bed. Only after the filter has been operating in this way for some years will the bed surface be brought back to its former level by addition of new material. Provision must therefore be made in the original thickness to allow for successive cleanings during this period. In a filter having an average run of two months between cleanings, some 9-10cm will be removed each year, and an allowance of an additional 0.5m of thickness will allow for five years of operation before re-sanding becomes necessary.

Taking the above three factors into consideration, a filter-bed of thickness 1.2-1.4m should be provided at the initial stage. This thickness can reduce if the raw water is reasonably clear. When an effluent of particular high quality is desired, a layer of 0.1m thick activated carbon is sometimes incorporated into the filter-bed near the bottom of the filter-bed, in order to adsorb any last traces of taste and odor-producing substances that have passed through the filtration process (catas1.org).

Effect of sand size on bacteriological quality[9]: Results from some studies have shown that there is scope for the relaxation of typical values that have been used as benchmarks of slow sand filter design. One such study (Muhammad et al, 1996) done on coarser sand with a constant uniformity coefficient of 2 found that the treatment efficiency (for removal of bacteria, turbidity and color) of slow sand filters was not very sensitive to sand sizes up to 0.45mm, although a slight increase in treatment efficiency was observed with decreasing sand size as indicated on Table 7. It is clear that finer sand produces better quality water, filters with sand sizes larger than 0.2mm (up to 0.45mm) produce satisfactory quality water with the added advantage of a longer filter run.

Impact of effective size (D_{10}) on filter performance at filtration rate of 0.1 m/h				
D_{10} (mm)	Average % removal			
	Feacal coliforms	Total coliforms	Turbidity	Color
0.20	99.60	99.70	96.50	95.10
0.35	99.30	99.30	96.50	95.10
0.45	99.00	98.60	96.20	92.00

Table 7 – Effect of effective size (D_{10}) on filter performance[10]

[9] Source: www.biosandfilter.org/biosandfilter/index.php/item/289
[10] Source: www.biosandfilter.org

Effect of sand size on removal of Cryptosporidium oocysts[11]: Research done by Logan et.al (2001) on intermittent sand filter columns of 0.60m sand revealed that fine-grained sand columns (D_{10} 0.16mm) effectively removed oocysts under the variety of conditions examined, with low concentrations of oocysts infrequently detected in the effluent. Coarse-grained media columns (D_{10} 0.90mm) yielded larger numbers of oocysts, which were commonly observed in the effluent regardless of operating conditions. Factorial design analysis indicated that grain size was the variable that most affected the oocyst effluent concentrations in these intermittent filters.

Effect of sand depth on bacteriological quality: Bellamy et al, (1985) and Muhammad et al, (1996) found that bacteriological treatment was not highly sensitive to sand bed depth, suggesting that a continually operated slow sand filter bed could be reduced even further to 0.4m. However bacteriological treatment efficiency does become more sensitive to depth with larger sand sizes because the total surface area within the filter is reduced in a sand bed with larger grains, as well as higher flow rates potentially increasing breakthrough.

Effect of sand depth on removal of Cryptosporidium oocysts: Research done by Logan et al, (2001) on intermittent sand filter columns of 60cm sand revealed that while grain size was the variable that most affected the oocyst effluent concentrations, the depth of sand was also important in removal, and became more important for coarser sands (D_{10} 0.90mm). Filters with fine-grained sand that were run under a variety of hydraulic loadings (4cm to 20cm) still had no oocysts deeper than the top 10-15cm of sand. In comparison, in coarser-grained sand, oocysts were found at depths ranging from 20cm (4cm hydraulic loading) to 60cm (10 and 20cm hydraulic loading). Sand bed depth therefore becomes very important with coarser sands, and becomes critical when coupled with hydraulic loads of 10cm or 20cm.

Effect of sand depth on turbidity and color removal: Although bacteriological quality of water does not improve drastically after 0.4m of sand bed, turbidity and color removal efficiencies were found to definitely improve as bed depth increased beyond 0.4m. This shows that adsorption occurs throughout the filter column in purifying water. Consequently, a decrease in sand bed depth causes a reduction in total surface area of the sand grains and ultimately total adsorption capacity is reduced (Muhammad et al, 1996).

Effect of sand depth on removal of nitrogenous organic compounds: While most bacteriological purification occurs mainly in the top 0.4m of a filter, this does not mean that there is no biological activity below 0.4m. While not sensitive to sand size and filtration rates, biochemical oxidation of nitrogenous organic compounds was found to be dependent on sufficient sand bed depth. These compounds were not completely oxidized within the top 0.4m (Muhammad et al, 1996).

[11] Cryptosporidium oocysts : A water-borne protozoan parasite that contaminates drinking water supplies, causing intestinal infections in human beings and domestic animals

3.8 Under-drains of slow sand filters

The under-drain system plays an important part in the efficient operation of a filter. It serves the dual purpose of supporting the filter medium and of providing unobstructed passage way for the treated water to leave the underside of the filter.

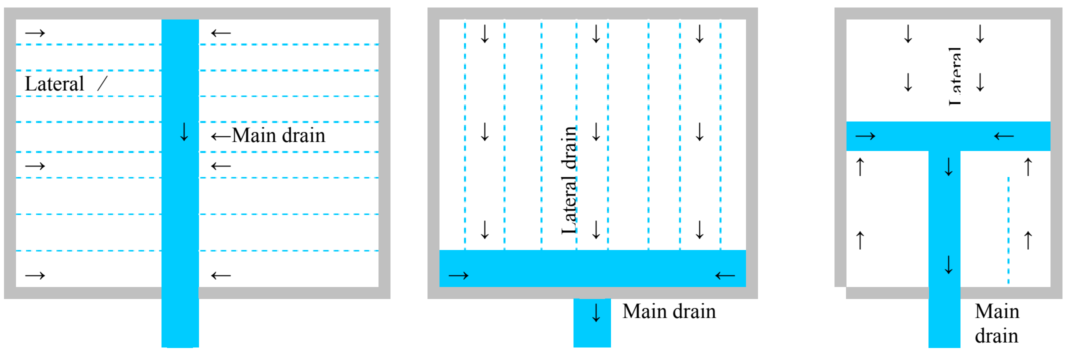


Figure 10: Common arrangements for the main drain of a slow sand filter

Once the filter bed has been laid, the under drainage system cannot usually be inspected, cleaned, or repaired in any way without a major disturbance to the bed as a whole, and it is therefore important that it should be so designed and constructed that it cannot become choked by the entry of granular material from above.

The simplest form of under-drain consists of a system of main and lateral drains (Figure 10). In the simple piped system, the lateral drains consist of porous or perforated unglazed drainage tiles; glazed pipes laid with open joints, or perforated PVC pipes, covered with layers of gravel of successively diminishing grain size to prevent the intrusion of filtering medium. In small filters the main drain may also be constructed of pipes, but in larger filters it is more commonly made of concrete, frequently buried into the floor of the filter box. Figure 11 shows a number of arrangements for the construction of the filter bottom. The under drain systems that use perforated pipes should, however, be designed carefully using the criteria outlined in Table 8.

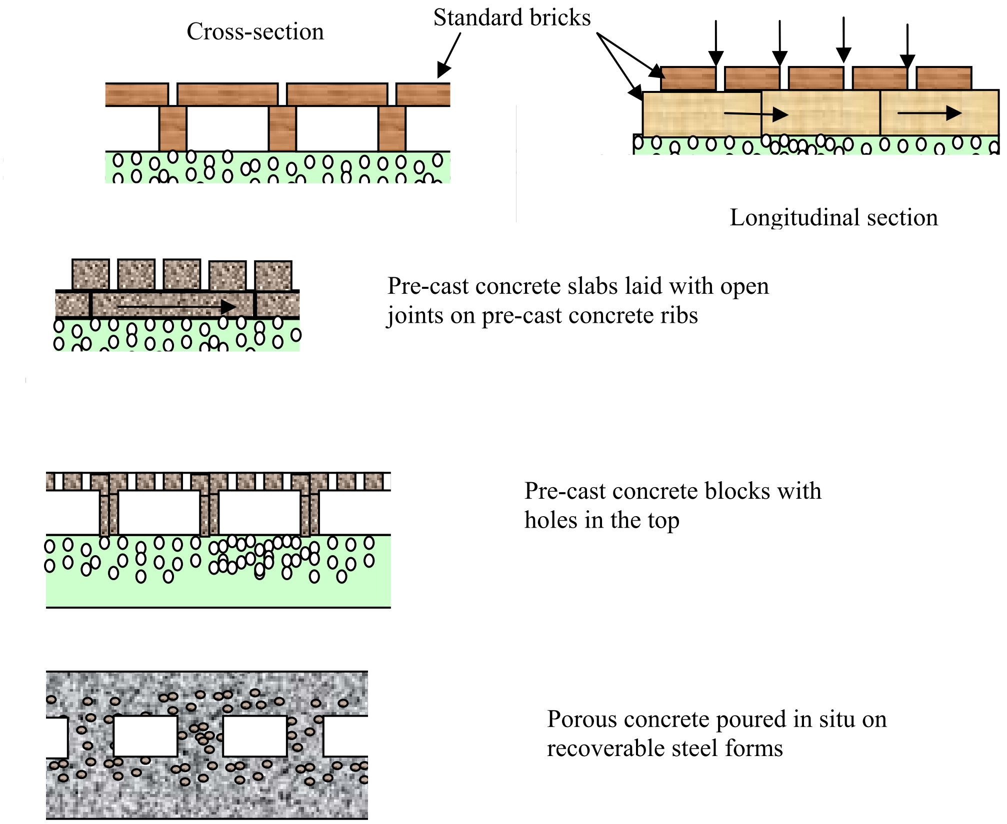


Figure 11. Various types of filter bottom (WHO)

Table 8: Criteria for dimensioning of under-drain system using perforated pipes[12]

Dimensioning criteria	Values
Maximum velocity in manifold	0.5 m/s
Maximum velocity in laterals	0.5 m/s
Spacing of laterals	1 – 2 m
Size of holes in laterals	2 – 4 mm
Spacing of holes in laterals	0.1 – 0.3 m

Between the under-drain system proper and the filter-bed itself, there should be some layers of gravel (Figure 11) to prevent the filtering medium from entering and choking the drainage waterways and to ensure a uniform abstraction of the filtered

[12] Source: Slow Sand Filtration for Community Water Supply, planning, design, construction, operation and maintenance, J.T. Visscher, R. Paramasviam, A. Raman and H.A. Haijinen, IRC, The Hague, Technical Paper No 24

water when a limited number of drains are provided. This supporting gravel system is built up of various layers, ranging from fine at the top to coarse at the bottom, each layer composed of carefully graded grains (i.e., the D_{10} and D_{90} passing diameters) should differ by a factor of not more than $\sqrt{2} = 1.41$ (catas1.org).

The grains of the bottom layer of gravel should have an effective diameter of at least twice the size of the openings into the drainage system (e.g. the spacing between bricks or between open jointed pipes). Each successive layer should be graded so that its smaller (D_{10}) particle diameters are not more than four times smaller than those of the layer immediately below.

If the joints in the under-drainage system are 8mm or less in width, a top layer of gravel with D_{10} value of 1mm and D_{90} value of 1.4mm followed by 4 and 5.6mm and followed by a third layer of 16 and 23mm will suffice.

Where grading of gravel within a layer to the recommended ratio of $1: \sqrt{2}$ is too difficult or expensive, then the requirement may be relaxed to a factor of 1:2, but in this case the layers should have their D_{10} values restricted to three times that of the layer above. In the example given above, four layers would then be required with grading of 0.7-1.4mm, 2-4mm, 6-12mm and 18-36mm. Some engineers even prefer the D_{10} ratio between layers to be restricted to a factor of 2, which in the above example would call for six layers with grading of 0.6-1.2mm, 1.2-2.4mm, 2.4-4.8mm, 4.8-10mm, 10-20mm and 20-40mm.[13]

Gravel for slow sand filters should conform to similar specifications to those applied to the filtering medium itself. The stones should be hard, preferably rounded, with a specific gravity of at least 2.5, and should be free from sand, clay, loam, dirt, and organic impurities of all kinds. If necessary the gravel should be washed to ensure its cleanliness. Not more than 5% by weight should be lost after immersion for 24 hours in warm concentrated hydrochloric acid. The thickness of each layer should be at least three times the diameter of the largest stones in its grading, but for practical purposes the minimum thickness of the layers is usually increased to 5-7cm for the finer gravel and to 8-12cm for the coarser gravel.

A number of such layers amount to an appreciable depth of gravel, which has little effect on the quality of the effluent but involves expense in the construction of the filter box as well as in the provision of the gravel itself. To reduce this expense to the minimum, the openings into the under-drainage system are kept as small as possible, often by use of porous concrete or similar material having fine openings. A floor of such material made of porous concrete using 5-10mm aggregate would require only one layer of 1.2-2.4mm gravel to support filter sand with an effective size of 0.3mm or more. Because of the high permeability of gravel, the resistance to downward flow is negligible.

[13] Source: Catas1.org

The gravel layers must be carefully placed, since subsequent movement may disturb the filter sand above and either lead to choking of the under-drainage system or produce cavities through which the water may pass with insufficient treatment.

3.9 Effluent quality:

The performance of slow sand filters, in terms of removal/reduction of colour, turbidity, faecal coliforms etc, depends on several factors as described under point 3.10. The overall performance in most cases is as indicated in Table 9.

Table 9: Performance of slow sand filters[14]

Parameter of water quality	Purification effect of slow sand filtration
Colour	30-100% reduction
Turbidity	Turbidity is generally reduced to less than 1 NTU
Faecal coliforms	Between 95-100% and often 99-100% reduction in the level of faecal coliforms
Cercariae	Virtual removal of cercariae of schistosoma, cysts and ova
Viruses	Virtually complete removal
Organic matter	60-75% reduction in COD
Iron and manganese	Largely removed
Heavy metals	30-95% reduction

3.10 Factors influencing slow sand filtration efficiency.

The removal of microbes and organisms in a slow sand filter is a biological process. The efficiency of the filter is therefore affected by time, oxygen, temperature and the need for beneficial microbes in the water to grow.

Time: The time available for the reactions to take place in the filter bed is determined by the sand depth and the flow rate. The minimum sand depth should not be less than 0.7m and the flow rate should be in the range of between 0.1 and 0.3m per hour.

Oxygen: The activity of the bacteria in the filter bed uses up Oxygen. If the amount of oxygen in the incoming water is low or it has a high organic content, the microbial reactions will be less effective and the bacterial quality of the effluent water will decrease.

Temperature: In Sudan, temperature is not an issue, but in colder weather in other, countries filters may need to be sheltered.

Maturation: The microorganisms which remove bacteria from the water take time to establish themselves in the filter. Slow sand filtration, operates less efficiently when it is first commissioned and every time the filter is cleaned, hence it is recommended

[14] Source: Slow Sand Filtration for Community Water Supply, planning, design, construction, operation and maintenance, J.T. Visscher, R. Paramasviam, A. Raman and H.A. Haijinen, IRC, The Hague, Technical Paper No 24

that cleaning is not too frequent. In addition the turbidity of the raw water should be reduced as much as possible before the water is passed through a slow sand filter.

3.11 Chlorination

Chlorination of the filtered water is important to neutralize any pathogenic organism that has escaped the filtration process and to keep the water potable.. Chlorination can be done with calcium hypochlorite or gas/liquid chlorine.

Calcium Hypochlorite

Calcium hypochlorite $Ca(OCl)_2$ for drinking water disinfection is most commonly encountered as: chlorinated lime or bleaching powder; high test hypochlorite (HTH); or calcium hypochlorite in tablet form.

Chlorinated lime or bleaching powder is a white powder which is a mixture of calcium hydroxide, calcium chloride and calcium hypochlorite, containing 20 to 35 percent available chlorine.

HTH is also a white powder and contains a greater concentration of chlorine than ordinary bleaching powder (65 to 70 percent). It is also more stable.

Often it is necessary to dissolve calcium hypochlorite in water, and the clear solution that is produced, used as the disinfectant.

The concentration of chlorine in a solution (once prepared), should not exceed 5 percent. If it does, then considerable chlorine may be lost in the sediment. Preparation of a chlorine solution of a given strength can be calculated following the formulae below:

Calculation of powder weight needed to make up a chlorine solution in a tank

Weight of powder required, W = 1000 x (VxC) / S (in grams)

Where: V = Volume of tank in liters
C = Concentration of solution required in percent (percentage by weight available chlorine)
S = Strength of powder in percent weight chlorine.

Example: A solution of concentration 0.5% (5 gm available chlorine per 1 liter water) is to be prepared, using a tank of 80 liters volume and a powder with strength of 20% weight chlorine.

Weight of powder required W = 1000 x (80 x 0.5) / 20 = 2000 grams

A volume v, of this solution of concentration 0.5% (500 mg/l) can be diluted into a new volume V_1 to give new solution of concentration C_1:

$$C_1 = (v \times C) / V_1$$

Example: 2 ml of the 0.5% solution is added to 1 liter of water. The concentration of the new solution will be:

$$C_1 = (2 \text{ ml} \times 0.5) / 1000 \text{ ml} = 0.001\% = 10 \text{ mg/l}$$

Calcium hypochlorite solution dosing is usually accomplished in three steps: solution preparation, flow control and application.

As calcium hypochlorite preparations contain some inert material, it is important that the prepared solution is allowed to rest before the clear solution is decanted and used.

Flow control mechanisms may be constructed from readily available materials like drip-feed chlorinators, constant- head aspirator (Mariotte Jar), gravity solution feeder, venture systems and dosing pumps.

Application of hypochlorite solutions should be at the point of turbulence to ensure adequate mixing. Solutions should only be added after slow sand filtration, Chlorinated water should ideally, flow into a contact tank, like a clear water reservoir, and remain there to ensure a contact time of at least one hour, before the water enters the distribution network.

Chlorine gas or liquid in cylinders

Liquid chlorine is available in standard cylinders containing approximately 45 kg or 70 kg at about 5 atmospheres pressure (the actual pressure varies with temperature). These sizes are sufficient for small water treatment plants with capacities of up to 20 l/s (approximately 1800 m^3/d). Liquid chlorine is stable and a cylinder Liquid chlorine which occupies about 80% of the cylinder at 65^0C is stable and not likely to lose any strength when stored in a cool place.

Gas or liquid chlorine is suitable only for water supplies in larger communities, and generally not recommended for supplies of under ten cubic meters per day. Bleaching powder or HTH materials are more commonly used for water disinfection in smaller communities and in rural areas.

Vacuum-type gas chlorinators for dosing with gas chlorine are suitable where the daily chlorine demand does not vary much and where the water flow is steady.

Chlorinators used for dosing chlorine should be sized to match the hourly flow to be dosed and this is calculated by:

Chlorine flow (g/h) = water flow (m3/h) x chlorine dose (mg/l)

Safety

Appropriate precautions should be taken when handling concentrated chlorine solutions, as chlorine is a hazardous substance. In solution it is highly corrosive and can cause burns and damage eyes. Ideally, gloves and protective eye glasses should be worn. In the event of contact with the skin, and especially the eyes, it is important to rinse immediately with water. Hands must always be washed after handling chlorine.

All containers in which chlorine is stored should be labelled clearly, identifying the contents, and with a hazard warning in a form/language that will be readily understood locally. Chlorine should be stored in places which are secure against unauthorized access.

4. Construction methods for slow sand filter

The quality and characteristics of building materials used for slow sand filters vary from place to place and from time to time depending on climatic conditions, quality of raw materials etc. The most common construction materials are concrete, masonry, ferrocement etc. Reinforced concrete is widely used for the floors of intake structure, grit chambers, sedimentation tanks, roughing pre-filters and slow sand filters. The walls, can be made of concrete (mass or reinforced), stone or brick masonry, depending on readily available local material and skills.

To ensure a long lasting and good filter plant, a good design together with adequate skilled supervision is important for construction. The quality of materials used for construction and the skills of the labourers is also an important factor. Often, insufficient attention is paid to these factors. For example, concrete if not properly compacted and cured will be low in quality and less durable,

Concrete, stone or brick masonry works, reinforcement bars, pipes and fittings etc. must conform to British Standards as indicated below.

Cement:	Portland cement to BS 12
Reinforcement:	Bars, Plain Reference R to BS 4449, Deformed Reference T to BS 4449, Fabric to BS 4443
Sand, coarse:	Clean, free from lime, clay and any organic substance, less than 5mm
Coarse aggregate:	Clean, free from lime, clay and any organic substance, passing 20mm sieve.
Bricks:	Red bricks 1st class.
Stone:	Clean, free from lime, clay and organic substance
uPVC:	Pipes for cold potable water to BS 3505 and joints and fittings to BS EN 1452-1 to 5-2000

GI: Pipes to BS 21 (ISO R7)

Filter boxes should be water tight to prevent loss of treated water or entry of groundwater. It is also recommended that the floor of the filter box is above the highest groundwater table.

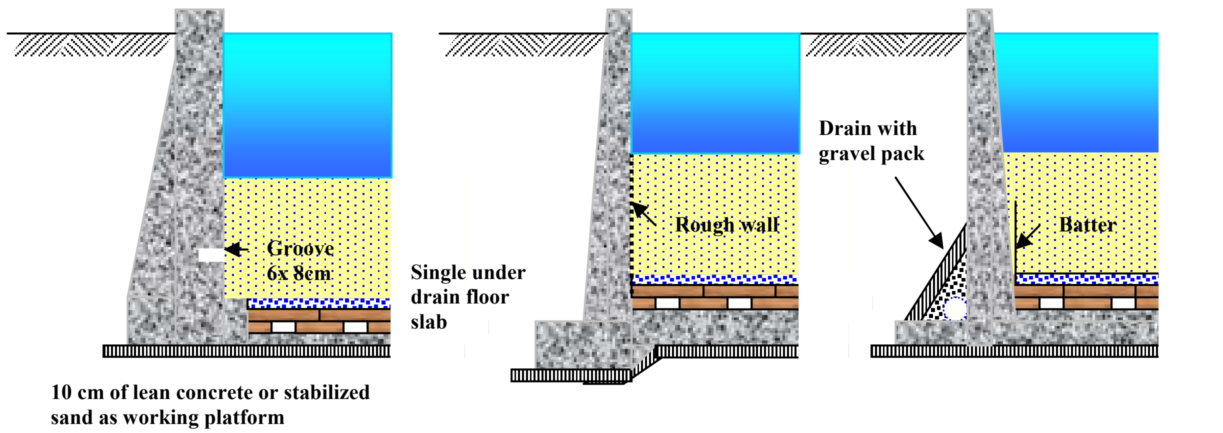


Figure 12: Method of preventing the short circuiting of the filter bed along the vertical wall (WHO)

Short circuiting or the downward percolation of water along the inner wall face, by passing the filter-bed, endangers the purity of the effluent, and structural precautions must be taken against it. The problem occurs with vertical walls and it is necessary to incorporate devices such as built-in grooves or artificial roughening of the internal surface (Fig 12). The most effective way to combat prevent this is to slope the walls with a slight outward batter, in addition to grooving or roughening the surfaces..

5. Design example of slow sand filter

The following procedure illustrates the steps required to design a slow sand filter. This can be either a pumping or a gravity system. Two communities with design population figures of 5000 and 10000 were arbitrarily selected although these have to be worked out as shown under item 5.2. These steps are only examples: every system will have its own site specific situations.

5.1 Selection of design period: The design period (the time period the plant should be expected to produce potable water) should not be too short (less than 10 years) or too long (more than 15 years). For this example, the design period was set for 15 years.

5.2 Estimation of design population: The population of the community at the end of the design period can be estimated by extrapolating the annual growth rate of the community. The current population figure and the annual growth rate can be obtained from national or state authorities, dealing with the census. Various formulae can be applied. For this example population figures of 5,000 and 10,000 for two communities respectively were on=obtained using the following formula:

$P_d = P_p (1 + 0.01a)^y$,

Where:
P_d = design population
P_p = present population
a = annual growth rate of the population
y = design period in years.

- **Calculation of design daily water demand:** Factors influencing the daily water demand of any community include: quality and availability, cost, cultural practice, climate etc. In developing countries the daily need varies from 20 to 150 litres per person per day. The per capita daily water demand should be in line with the government development strategy. In Sudan, the current daily water demand is set at 20 liter per capita per day (l/c/d). The Government of Sudan aims to reach to 50 l/c/d by 2015. As achieving 50 l/c/d requires huge amount of budget allocation, it is advisable to maintain the minimum per capita of 20 l/c/d for some time to come in the future. Allowing an additional 20% for losses and wastages, the daily water demand works out at 24 litres per person per day. The water demands for the design populations are calculated as below:
  For 5000 design population: 5000 x 24 = 120000 l/d = 120m^3/d = 5 m^3/h
  For 10000 design population: 10000 x 24 = 240,000 l/d = 240 m^3/d = 10 m^3/h

5.4 Estimation of maximum hourly water demand: Recorded data on the daily pattern of water use in the community, would simplify the determination of the peak factor between average daily water demand and maximum hourly water consumption. In most cases, the expected daily pattern of water use is not known and following the Indian Standard, peak factors of 3 and 2.5 would be applicable for design populations of 5000 and 10,000 respectively. The peak factor could be as high as 5 for some small communities. The design hourly water demand is required for the design of the clear water tank and distribution system.

For 5000 design population, maximum hourly water demand = 5 x 3 = 15 m^3/h
For 10000 design population, maximum hourly water demand = 10 x 2.5 = 25 m^3/h

The water use pattern for both design populations has been shown in Figure 13

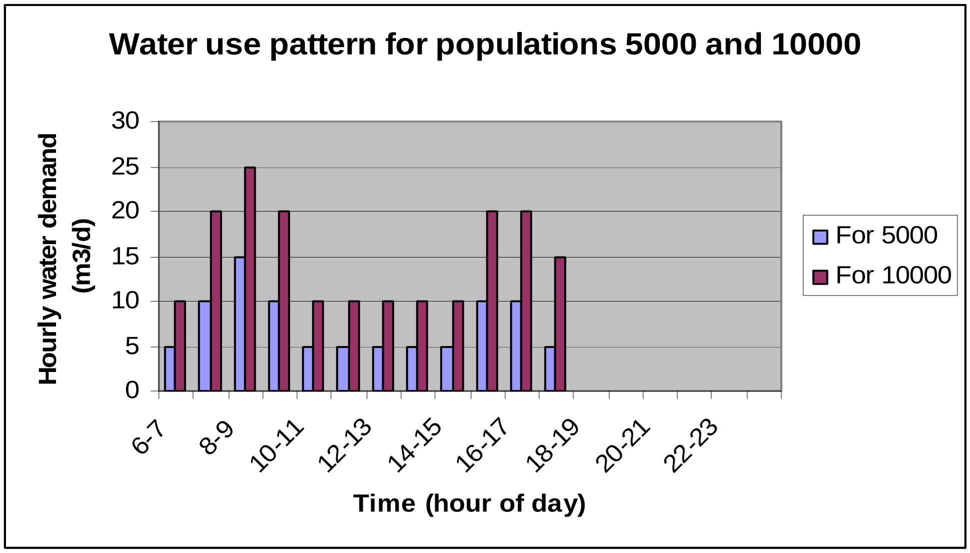


Figure 13 Water use pattern of a sample community with 5000 and 10000 design population

5.5 Selection of raw water source:. Source of raw water in Sudan for slow sand filters can be a nearby stream, a perennial river, an irrigation canal, a hafir or a dam. It is important to ensure that the source is enough to supply the design water demand. Other demands (if any) on the raw water source upstream and down stream should also be taken into account.

5.6 Choice of treatment system: The water quality of the raw water source (one at low flow and one at high flow) should be determined in order to select the most suitable type of the treatment system. Water from hafirs and dams, should be analyzed for physical, chemical and bacteriological content, and the guide in Table 1 (on page 10) used to select the right type of the treatment system.

For this example, a water source with the following water quality has been selected:

- Turbidity 5 – 100 NTU
- Faecal coliforms +100 – 2000/100ml
- Most of other water quality parameters are within acceptable limits for human consumption.

Raw water with the above parameters can not be treated by slow sand filter alone, as the turbidity is above 20 NTU. and reaches up to 100 NTU. Raw water with a turbidity level greater than 50NTU over periods of several weeks, or over 100 NTU for longer than few days, causes rapid clogging of the slow sand filters. This would require frequent cleaning of the filters, which is not recommended as explained earlier, because of the reduction in production of treated water and the increased work load. There is need to pre-treat the raw water to reduce the initial turbidity, and this can be done by any of the methods below:

- River bed filtration,
- Horizontal flow roughing filtration,
- Vertical flow roughing filtration, and
- Plain sedimentation

To attain the required removal of 70-90% turbidity and 80-99% faecal coliform it may be necessary to use a combination of plain sedimentation with roughing filters. The following types of pre-treatment may be applied:

- Only plain sedimentation if 90% efficiency is attained. The efficiency of plain sedimentation is in the range of 70-90%. The raw water after the plain sedimentation will have ((100 – (100 x 90%)) = 10NTU
- A combination of plain sedimentation and roughing filtration. When the efficiency of plain sedimentation is 70% and that of the roughing filtration 70-90%. The raw water that is being treated by plain sedimentation and roughing filtration will have ((100 – (100 x 70%) – (70 to 90%)) = 3 to 9 NTU.

Slow sand filtration following this pre-treatment will be quite efficient, as the raw water has a turbidity of less than or equal to 10NTU.

Important design guideline parameters have been shown in Table 5 for designing horizontal flow-roughing filters.

The following parameters have been selected for this design example:

Average suspended solid in raw water: Medium
Horizontal flow: 1.0m/h
Depth: 1.0m
Width: 2.0m
Length: First compartment 3.0m, Second compartment 2.5m and Third compartment 2.0m

5.7 Location of treatment plant: Factors which influence the location of the treatment plant are:

- Location of the water intake;
- Availability of a suitable area;
- Topography;
- Soil properties;
- Ground water level; risk of flooding;
- Location of water intake and length of distribution system;
- Protected from biological and industrial pollution.

For this design example, schematic layouts of treatment plants have been indicated in Figures 15 and 16. An ideal location is near the intake, which allows the caretaker to look after the treatment plant and the water intake without having to travel long distances.

5.8 Selection of mode of operation: Continuous operation for 24 hours per day is most appropriate for slow sand filters, using either a) Gravity system or b) Pumping system.

In the gravity system, raw water is taken from a higher elevation and fed by gravity to the filters. In the pumping system, raw water is pumped and fed to the raw water balancing chambers and later by gravity to the filters. Depending on the location, additional pumping units might be necessary. For this example, a pumping unit is required only from the source to the raw water balancing chamber.

In both situations, the raw water may need to be passed through a grit chamber for removal of coarse material. The grit chamber is located before the sedimentation tank in the gravity system and before the suction well of the raw water pump in the pumping system. Assuming that the retention time in the grit chambers is about 10 minutes, the sizes of the grit chambers will be:

For the gravity system

For 5,000 population: 5 m^3/h x 10/60 h = 0.83 m^3, and (take dimensions of length 1m, depth 1m and width 0.85 m.
For 10,000 population: 10 m^3/h x 10/60 h = 1.67 m^3 (take dimensions of length 1.70m, depth 1m and width 1m)

For the pumping system

For 5,000 population: 15 m^3/h x 10/60 h = 2.5 m^3, and (take dimensions of length 3m, depth 1m and width 0.90 m.

For 10,000 population: 30 m^3/h x 10/60 h = 5.0 m^3 (take dimensions of length 4.0m, depth 1m and width 1.25m)

5.9 Dimensioning of plain sedimentation tank: Table 4 shows the design criteria recommended for dimensioning rectangular sedimentation tanks.

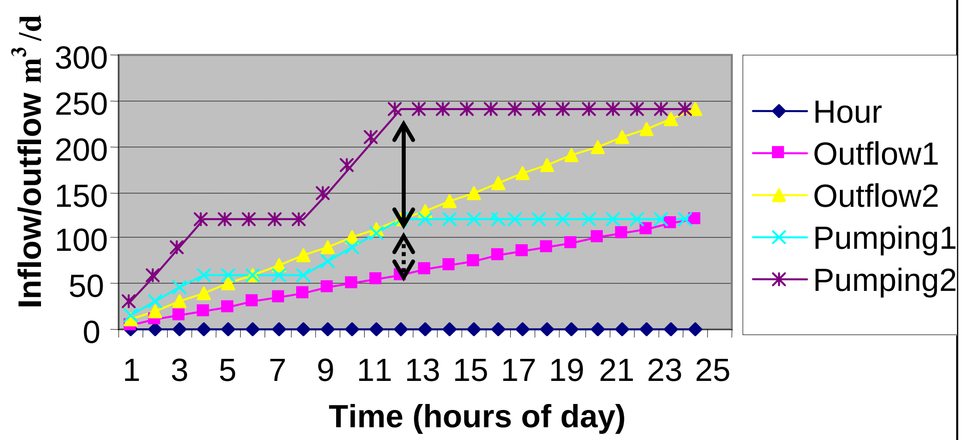
a) For the gravity system
For a detention time of 8 hours, the volume will be 5 x 8 = 40m^3 for 5000 population and 10 x 8 = 80 m^3 for 10,000 population. For plain sedimentation of depth 2m, the dimensions will be 2 x 10 m^2 and 3 x 13.5 m^2 for population of 5000 and 10,000 respectively. The dimensions are within the range of values.

b) For the pumping system
In order to make the filters work for 24 hours, an additional component of a balancing chamber or tank is required for the pumping type of filtration system. As continuous pumping is not possible, and the operator is assumed to works for 8 hours per day, the capacity of the raw water pump needs to be calculated to pump the required daily demand during 8 hours of operation. In this regard, for the slow sand filter to work 24 hours, the capacities of raw water pumps will be 120/8 = 15m^3/h and 240/8 = 30m^3/h for 5000 and 10,000 population respectively.

The balancing tank should be at a higher elevation to feed the plain sedimentation tank by gravity. The variations in the quantities of water in the balancing tanks are shown in Figure 14, assuming that the raw water pump is operational from 06:00 to 10:00 and from 14:00 to 18:00 daily. The highest differences between the inflows and outflows are 60m^3

and $120m^3$. These mean that the balancing tanks need to have a capacity of $60m^3$ and 120 m^3 for 5000 and 10000 population respectively. Simple balancing tanks of $30m^2$ and $60m^2$ with a 2.5 m depth need to be constructed for 5000 and 10,000 population respectively

Figure 14: Inflow and outflow to and from balancing tanks in a day



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5.10 Selection of size of filters: The design criteria for slow sand filters are indicated in Table 6.

At a rate of filtration of 0.1m/h, a continuously operated filter will produce 2.4 m^3 of water per m^2 of filter bed surface area per day. Thus the total surface area required can be determined by dividing the design daily water demand by 2.4 (or the average daily water demand expressed in m^3/h divided by 0.1m/h). The total surface area should be provided in several units rather than a single unit. The number of units required can be obtained using the following equations

a) n([15]) = $0.50 (A)^{1/3}$, or
b) n([16]) = $0.25 (Q)^{1/2}$

where:
n = total number of rectangular units
A = total surface area (m^2)
Q = average daily water demand expressed in m^3/h

Equation (a) gives a higher number of units than Equation (b), for similar infiltration rates until Q is about 6400 m^3/h, following which Equation (b) gives a higher figure. The number of units required, however, depends on the following factors:

[15] Source: Slow Sand Filtration for Community Water Supply, IRC, 24 Technical Paper Series
[16] Source: Catas1.org/eng/water/ssf -4

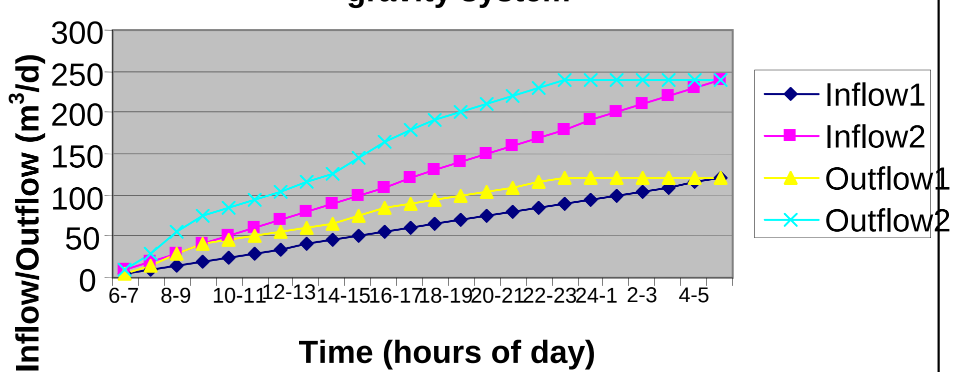
- At least two filters are required alternately to ensure safe and continuous operation (to allow alternate cleaning of each bed).
- The maximum size of the filter bed is generally 200 m^2 in rural areas to ensure that cleaning can be carried out within a day.
- As a rule, the minimum size of a filter bed is 5 m^2, although some experiments show that filters of less than 1m^2 are equally efficient provided raw water doesn't flow without being filtered.
- Construction and operation costs as they differ from country to country and from system to system.

For these examples, total filter areas will be 50 m^2 and 100 m^2 for 5000 and 10000 populations respectively. The number of units in each case using equation (a) will be 1.8 and 2.3 for these design populations. Taking the above factors into consideration, the choice of 2 and 3 units for 5000 and 10000 populations respectively is probably the most economical. The dimensions of the filter unit would be 4 x 6.25 m^2 .for 5000 and 5 x 6.75 for 10000 populations.

5.11 Dimensioning of the clear water tank:

Gravity flow: The dimensions of clear water tanks should be determined with the data of the daily water use pattern of the community (as shown in Figure 15) and the daily water production by the filters. It can be concluded from this figure that the maximum differences between the inflows and outflows to/from clear water tanks are 30m^3 and 60m^3 for 5000 and 10000 populations respectively. Therefore, the capacities of clear water tanks should not be less than 30 m^3 and 60 m^3 for 5000 and 10000 populations respectively.

Figure 15: Inflow and outflow to and from clear water tank - gravity system



Pumping system
Water from clear water tank is pumped to service (storage) reservoirs and from there to the consumers by gravity. Suitable dimensions for clear water tanks for these types

of systems can be determined the same way as those of raw water balancing tanks. Therefore the volumes of the balancing tanks will be 30 m^3 and 60 m^3 for 5000 and 10000 populations respectively.

The dimensions of service (storage) reservoirs for these types of systems can be calculated using the operation time of the pumping units as 8 hours and water use pattern indicated in Figure 13. Accordingly the required volumes of the service (storage) reservoirs will be 30 m^3 and 60 m^3 for 5000 and 10000 populations respectively. If data on the expected pattern of water consumptions are not available, the volume of the storage tank for gravity supply may be assumed to be 40% of the daily water production of the treatment plant.

Provision of additional storage to cater for minor interruptions is recommended. Assuming that there is a 2 hour interruption in the system, the volumes of the service reservoirs will be 30 + 10 = 40m^3 and 60 + 20 = 80 m^3 for 5000 and 10000 populations respectively. Assuming a variation in water level in the reservoirs is 2m, and then the net areas will be 20m^2 and 40m^2.

5.12 Hydraulic design: The hydraulic design of the water supply system depends on the head loss in the treatment units, piping arrangements and the topography of the area. For this design example, two possible hydraulic profiles have been shown in Figures 18 and 19 for gravity and pumping systems. The heads of both raw and clear water pumps depend on specific site conditions and definite figures are not given. These should be specified by the designer of the plant.

Table 10: Summary of design data for slow sand filters

Gravity system	**Pumping system**
1) Grit chambers Retention time: 10 minutes **Population** 5000 10000 Depth: 1m 1m Width: 0.85m 1m Length: 1m 1.7m **2) Plain sedimentation tank** Population: 5000 10000 Depth: 2m 2m Width: 2m 3m Length: 10m 13.5m **3) Roughing filter (optional)** Horizontal flow: 1.0m/h Depth: 1m Width: 2m Length 1st compartment (15-25mm): 3m 2nd compartment (8-15mm): 2.5m 3rd compartment (4-8mm): 2m **4) Slow sand filters** Population: 5000 10000 Period of operation: 24h 24h Filtration rate: 0.1m/h 0.1m/h Total area of filter: $50m^2$ $100m^2$ No of units: 2 3 Area of each unit: $4x6.25m^2$ $5x6.75m^2$ Freeboard: 0.5m 0.5m Depth of filter media: 0.9m 0.9m Effective size of sand: .15-0.30mm 0.15-0.30mm Uniformity coefficient: <3 <3 Height of under drain: 0.5m 0.5m	**1) Grit chambers** Retention time: 10minutes **Population** 5000 10000 Depth: 1.00m 1.00m Width: 0.90m 1.25m Length: 3.00m 4.00m **2) Raw water pump** Pumping hour (operational time): 8h Population: 5000 10000 Pump capacity (discharge): $15m^3/h$ 30m3/h Pump head: as per each specific site condition **3) Balancing tank** Population: 5000 10000 Volume: $60m^3$ 120m3 Depth: 2.5m 2.5m Area: $30m^2$ $60m^2$ **4) Plain sedimentation tank** Population: 5000 10000 Depth: 2m 2m Width: 2m 3m Length: 10m 13.5m **5) Roughing filter (optional)** Horizontal flow: 1.0m/h Depth: 1m Width: 2m Length 1st compartment (15-25mm): 3m 2nd compartment (8-15mm): 2.5m 3rd compartment (4-8mm): 2m **6) Slow sand filters**

Height of supernatant water: 1m 1m

5) Clear water tank

Population:	5000	10000
Volume :	$30m^3$	$60m^3$
Freeboard:	0.5m	0.5m
Depth of water:	2m	2m
Area:	$15m^2$	$30m^2$

Population:	5000	10000
Period of operation:	24h	24h
Filtration rate:	0.1m/h	0.1m/h
Total area of filter:	$50m^2$	$100m^2$
No of units:	2	3
Area of each unit:	$4x6.25m^2$	$5x6.75m^2$
Freeboard:	0.5m	0.5m
Depth of filter media:	0.9m	0.9m
Effective size of sand:	0.15-0.30mm	
Uniformity coefficient:	<3	
Height of under drain:	0.5m	0.5m
Height of supernatant water:	1m	1m

7) Clear water tank

Population:	5000	10000
Volume :	$40m^3$	$80m^3$
Freeboard:	0.5m	0.5m
Depth of water:	2m	2m
Area:	$20m^2$	$40m^2$

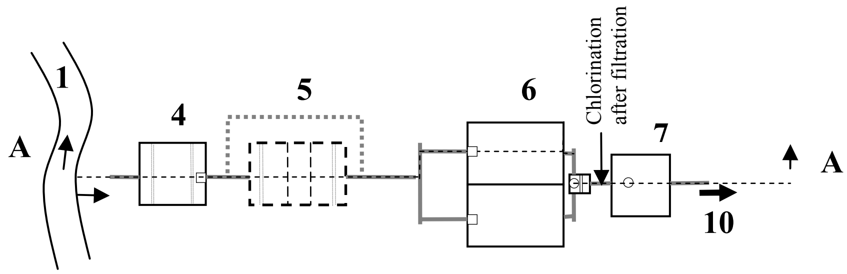
8) Clear water pump

Pumping hour (operational time): 8h

Population:	5000	10000
Pump capacity (discharge):	$15m^3/h$	30m3/h
Pump head:	as per each specific site condition	

9) Storage (service) reservoir

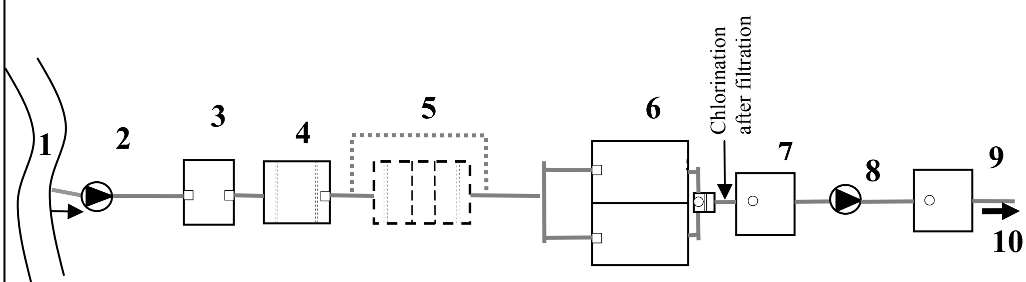
Population:	5000	10000
Volume :	$40m^3$	$80m^3$
Freeboard:	0.5m	0.5m
Depth of water:	2m	2m
Area:	$20m^2$	$40m^2$



Gravity system

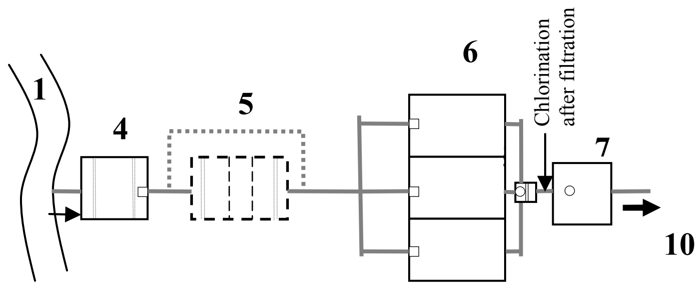
Legend

1	Raw water source	6	Slow Sand Filtration units
2	Raw water pump	7	Clear water tank
3	Raw water balancing tank	8	Clear water pump
4	Sedimentation tank	9	Storage or service reservoir
5	Roughing filter (optional)	10	To distribution system



Pumping system

Figure 16: Schematic layout of the water treatment plant for gravity and pumping systems, design population 5000



Gravity System

Legend

1 **Raw water source**

2 **Raw water pump**

3 **Raw water balancing tank**

4 **Sedimentation tank**

5 **Roughing filter (optional)**

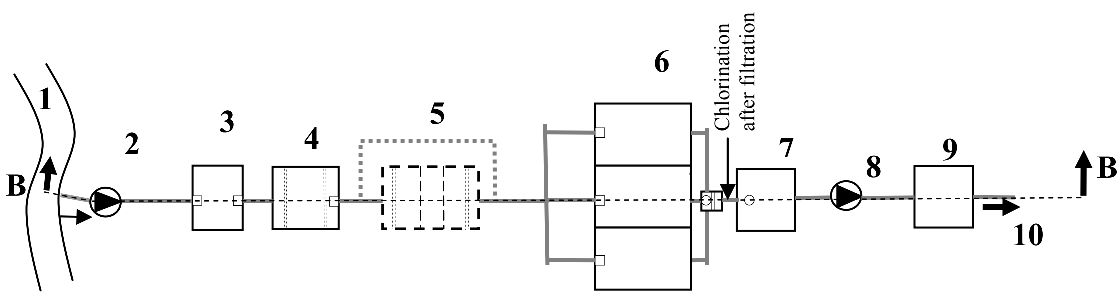
6 **Slow Sand Filtration units**

7 **Clear water tank**

8 **Clear water pump**

9 **Storage or service reservoir**

10 **To distribution system**



Pumping System

Figure 17: Schematic layout of treatment plant for gravity and pumping systems, design population 10,000

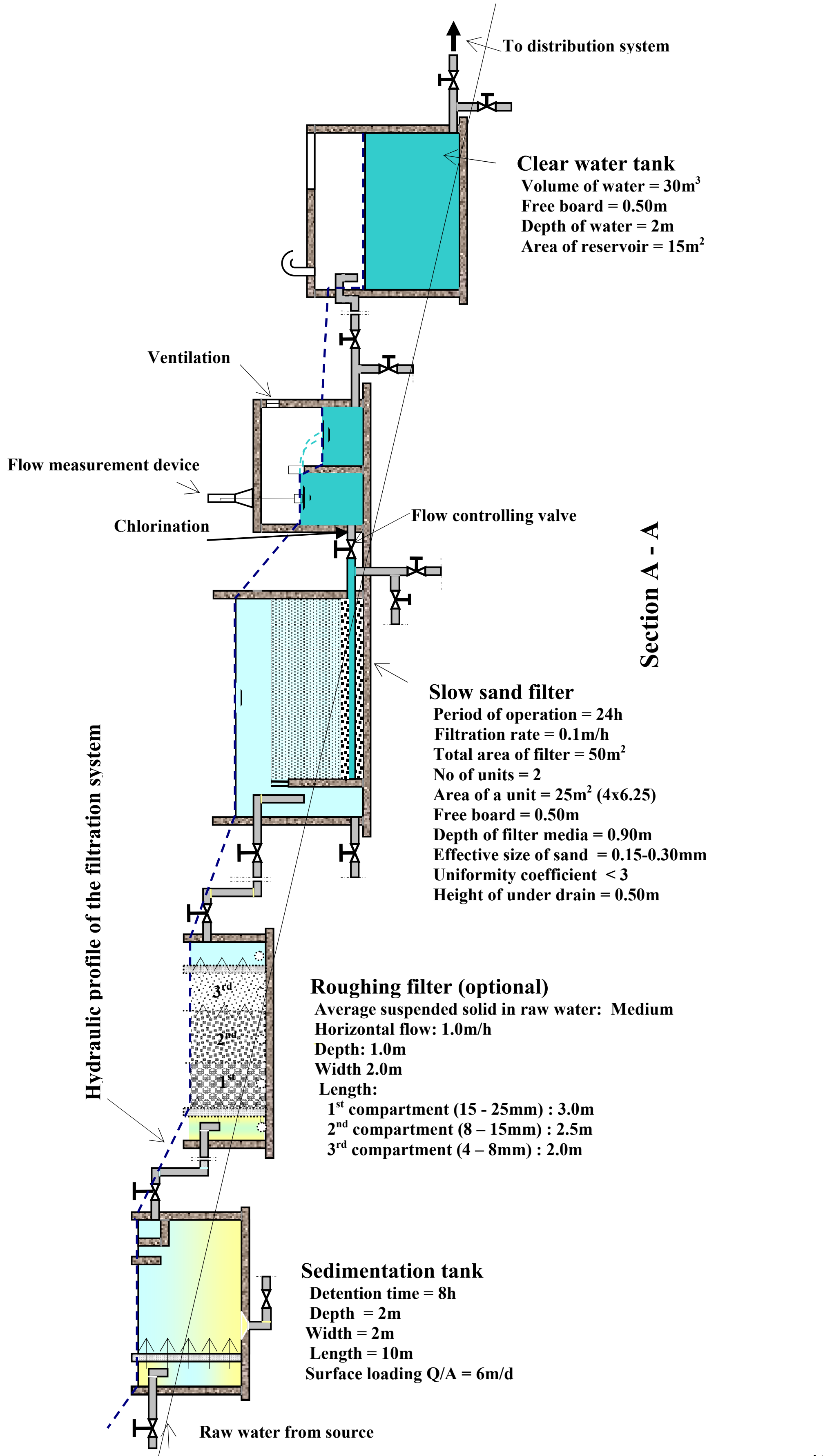


Figure 18: Section of a gravity slow sand filter for a population of 5000

Drawing not to scale

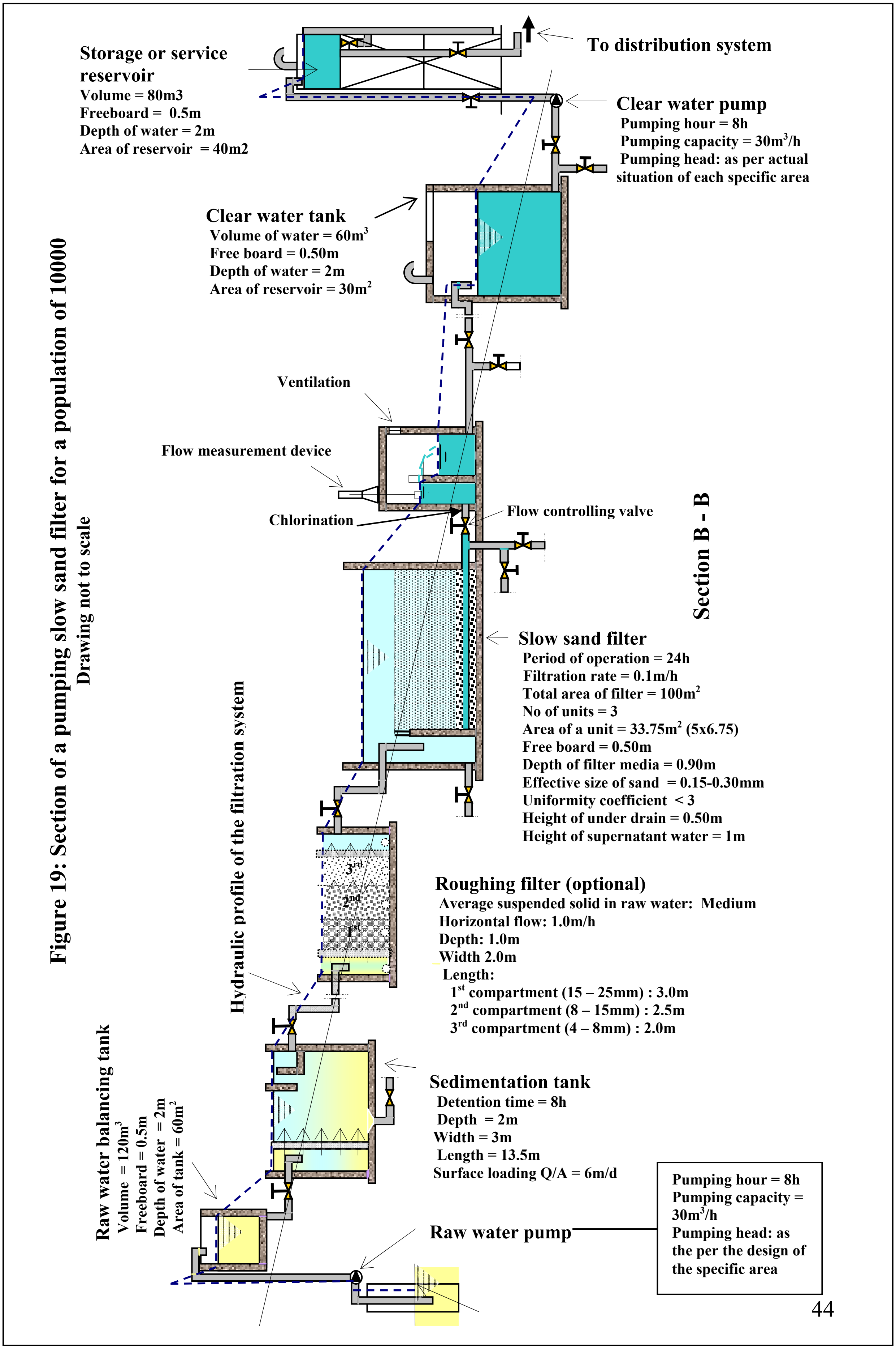


Figure 19: Section of a pumping slow sand filter for a population of 10000
Drawing not to scale

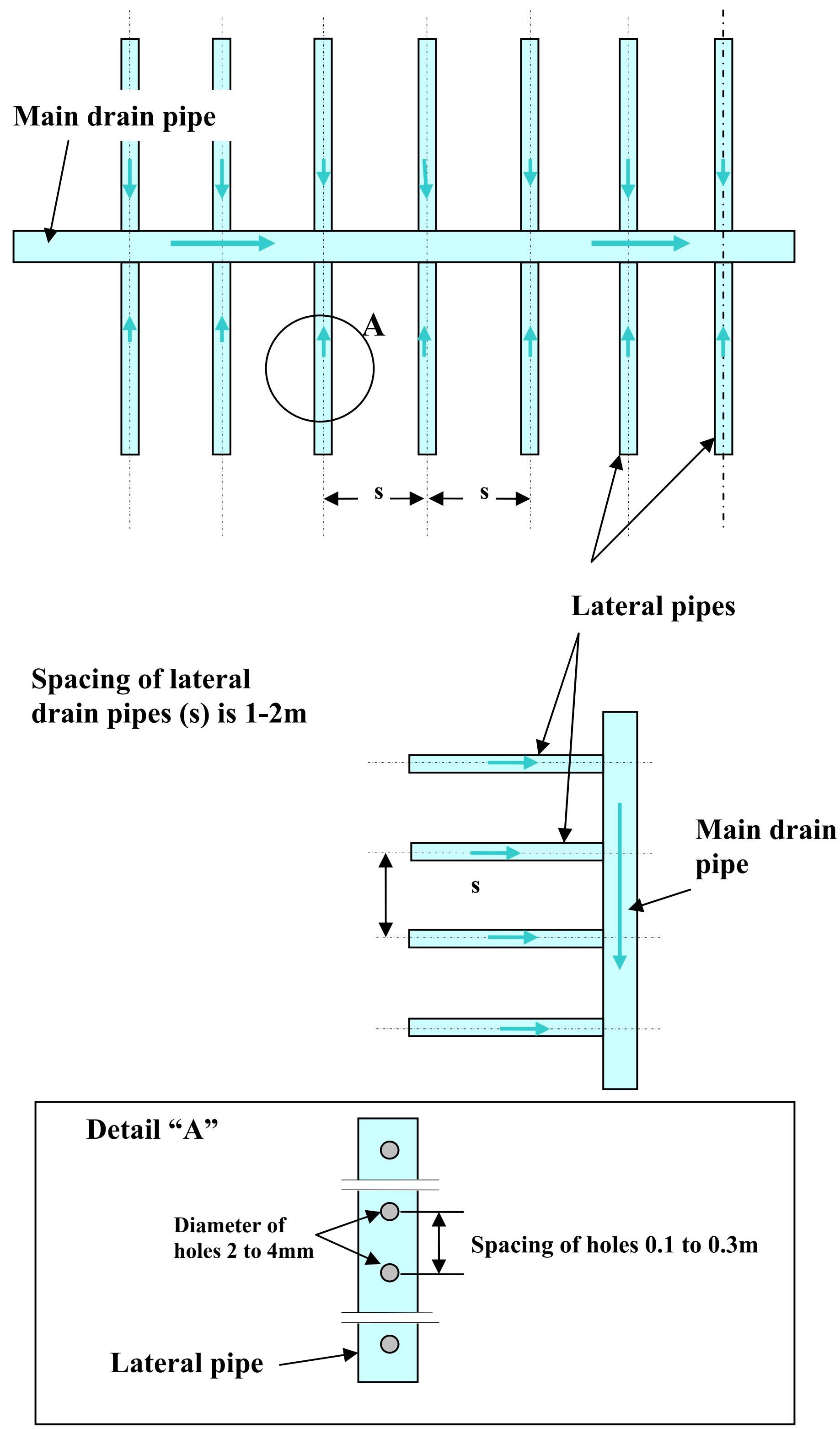


Figure 20: Spacing of under drain pipes and holes

6. Management, operation and maintenance procedures, and capacity building

6.1 Management of slow sand filters

In most states in North Sudan, the community is responsible for the management of slow sand filters. Unfortunately, it has been observed that communities lack the skills to manage the systems properly, with technical management of the systems left to pump operators who have not had any proper training. It is recommended that where a slow sand filter is established, training is provided for personnel who will support the technical management of the systems. State Water Authorities should strengthen the community management capacity with training and technical backup. Slow sand filters in Southern Sudan are managed by the State Urban Corporation, which has trained personnel..

6.2 Operation and maintenance procedures

Intake: The intake should be checked regularly for clogging by coarse materials or debris (wood, fabric or plastic). Supervision should be on daily basis during the flooding seasons. In addition the raw water should be checked for physical, chemical and bacteriological properties, daily during the flooding season and weekly/monthly at other times.

Sedimentation tank: Regular maintenance of the sedimentation tank is limited to the removal of accumulated sludge at the floor of the tank. This can be done by opening the drain valve provided at the lowest point of the tank. If the turbidity reduction of the sedimentation tank is less than 50 per cent, the tank should be drained and cleaned. The drain valve should be kept greased and functional and the floor of the tank should be cleaned regularly.

Roughing pre-filter: The turbidity of water leaving the roughing pre-filter should be less than 10NTU. If turbidity is above this value the filter may need cleaning or the flow rate needs to be decreased. The flow rate can be controlled with a V-notch and a weir at the inlet. For horizontal flow roughing pre-filter, flow rates should be in the range of 0.4 to 1.0 meter per hour. A log of flow rates should be maintained.
The roughing pre-filter should be cleaned regularly. In order to allow hydraulic cleaning of the filters, the gravel pre-filters should have sloping floors and a channel leading to rapid opening wash-out gates. Steps to be followed for cleaning: a) Close the outlet valve and allow the filter to fill with water. b) Open the wash-out gates, causing the filter to drain rapidly which will carry much of the sediment with the wash-out water, and, c) Close the wash out gates and allow the gravel pre-filters to fill again

Slow sand filter units (Figure 20): Continuous operation of the filter is feasible where raw water can be fed into the filters by gravity , but in many cases the raw water has to be pumped in. If continuous pumping cannot be guaranteed because of an intermittent power supply or lack of trained staff, continuous operation at constant rate may be ensured by constructing a raw water balancing tank. Water is pumped into this tank at certain intervals, before being continuously fed into the filters by gravity flow. The tank may need to be covered to prevent algal growth, particularly when it holds pre-treated water.

The raw water that is being fed by gravity enters into the supernatant water reservoir in such a way that the sand bed (E) below is not disturbed by turbulence. A drainage trough (C) or a plinth at the level of the sand is constructed under the inlet to absorb the vertical force of the incoming water at the start of filling operation, before a sufficient layer of water has accumulated to protect the filter surface.

Scum outlet: If scum is expected in the filters, it is excluded from the supernatant water through the scum trough (B) built at different sides of the filter so that regardless of the wind direction, floating matter will be removed by simply increasing the rate of inflow very slightly and allowing the supernatant water to spill over the lip of the trough.

Supernatant water drain: Clogging of the filter bed will cause the supernatant water (D) to rise and this requires the filter bed to be cleaned. For cleaning, it is necessary to remove the supernatant water so that the bed surface is exposed. Supernatant water can be emptied by opening the high drain valve of the drainage trough. The supernatant water may be discharged to waste if water is plentiful or returned to the raw water reservoir for treatment through other filters. As successive cleanings reduce the height of the filter bed, the sill of the drainage trough must be adjusted to the new surface after each cleaning.

Bed drainage: After the supernatant water is drained, it is necessary, before cleaning, to lower the level within the bed by a further 10cm or more so that the schmutzdecke and the top layer is relatively dry and easy to handle. Re-sanding, replacement of active charcoal layer, or repairs to the under-drainage system need complete drainage of the bed using the drainage valve (H).

Diversion of filtered water: During the ripening period of a new or recently cleaned filter, it is necessary to divert the effluent to waste or return it to the raw water reservoir, until the bacterial action of the bed has become established and the effluent quality is satisfactory. Valve K serves this purpose.

Backfilling: After the cleaning of a filter-bed (as well as during its initial filling) filtered water is introduced from the bottom to drive out air bubbles from the filter medium as the water level inside the sand rises. The filtered water is obtained from the clear well or from the outlet side of another filter and is admitted through valve L.

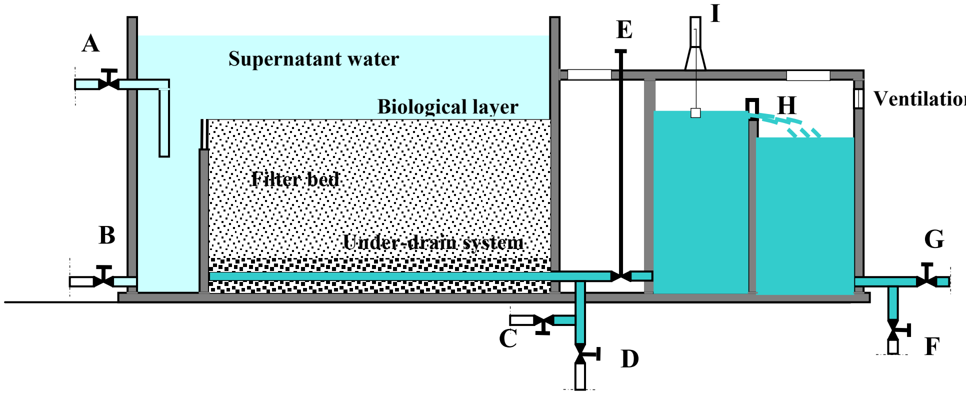
Flow control (Figure 20): Maintenance of a constant flow through the bed is important for filter efficiency. Flow control can be practiced at the inlet or outlet. When the flow is controlled at the outlet, an outlet valve must be adjusted frequently, often daily, or output will fall. This ensures the maximum retention of water even at the beginning of a filter run. This method maximizes treatment efficiency but increases operator involvement. Inlet flow control can be accomplished by a gate valve plus V-notch weir. As the resistance of the filter bed increases, the water level rises. When it reaches the overflow pipe the bed should be cleaned. Inlet flow control requires less operator involvement but decreases filter efficiency slightly.

Slow sand filters are very easy to maintain. If the bed becomes clogged the top layer of sand is removed. To do this, the water in the bed is drained to 30.to 40cm below the top of the bed and the top layer (1-2cm) scrapped off. Once this is done, filtered water (from clear water well or other filter unit) is allowed in by opening valve L from the under-drains to cover the sand layer E. During this process valves H and M should be closed. As this filtered water flows through the bed, raw water may be re-introduced. In case air is trapped in chamber N, it has to be released by opening the air vent valve I. After all air is released, valve I should be closed.

It takes 1-2 days to get the bed re-functional. It is recommended that re-filter the first lot of water that exited the filter after cleaning. The sand which was removed should be washed immediately to prevent it putrefying and then stored for re-use.

When the depth of sand in the slow sand filter bed has reached the minimum level of 0.7m, after years of service, the bed must be re-sanded. An additional 0.3m of sand should be removed before fresh sand is added. Once the new sand is installed, the old sand can be placed above that to promote the growth of bacteria.

Basic components of an outlet controlled slow sand filter



A – Raw water inlet valve
a – Valve for raw water inlet and regulation of filtration rate

B, b – Valve for drainage of supernatant water layer

C, c – Valve for backfilling the filter bed with clean water

D, d – Valve for drainage of filter bed and outlet chamber

E – Valve for regulation of the filtration rate

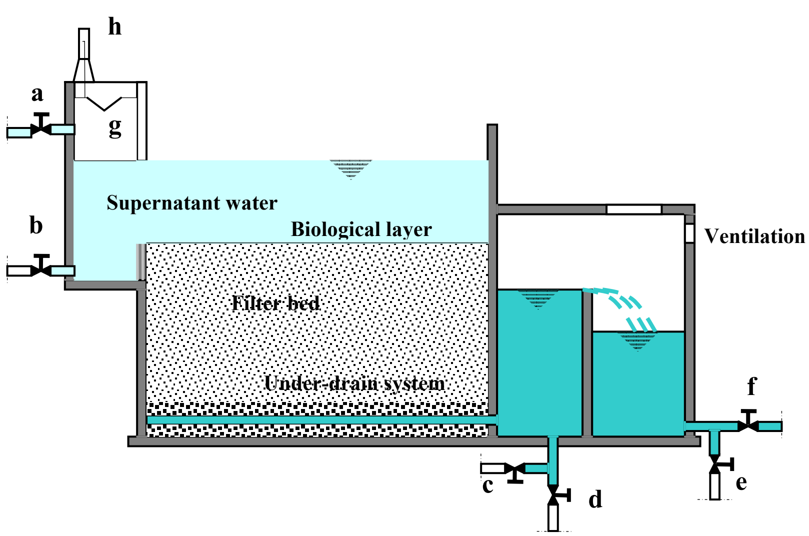
F, e – Valve for delivery of treated water to waste

G, f – Valve for delivery of treated water to the clear water reservoir

g– Inlet weir

H – Outlet weir

I, h – Calibrated flow indicator



Basic components of an inlet controlled slow sand filter

Figure 20: Basic components of inlet and outlet controlled slow sand filters

The sustainability of this type of facility depends on placement of proper management system, operation & maintenance procedures, and regular revision and amendment of the water tariff.

The following operation/maintenance tasks are recommended for slow sand filters.

Checklist for Operation

For proper operation of slow sand filters, various activities are required at various times. One or more persons might be responsible for the activities. People that take part in the activities could be pump operator, trained technician, daily labor etc depending on the type and agreed upon management and operation modalities of the treatment system. Therefore, the person(s) responsible for each level of activities should perform and document that:

On daily basis

1. Check the raw water intake (some intakes may need checking less frequently)
2. Check and adjust the rate of filtration
3. Check water level in the filter
4. Check water level in the clear water well
5. Sample and check water quality
6. Check pumping system, if pump is used
7. Check for residual chlorine, if chlorination is applied
7. Enter observations in the logbook of the plant

On weekly basis:

1. Check and grease any pumps and moving parts
2. Check the stock of fuel; order more if necessary
3. Check the distribution network and taps; repair if necessary
4. Clean the site of the plant

On monthly basis:

1. Scrape the filter beds if necessary
2. Wash the scrapings; store the retained sand

On yearly basis:

1. Clean the clear water well
2. Disinfect the clear water well
3. Check that the filter and clear water well are watertight

Every two years:

1. Re-sand the filter unit

6.3 Capacity building

The availability of trained technical personnel within the community is important for the O&M of the system. Hence, training of such technical people and provision of continuous support is very critical for sustainability.. Various modules of training plans should be developed based on need. Some of these are listed below:

- At community level, the provision of turbidity measurement kits and strengthening the reporting capacity on the situation of the water supply system.

- At states/locality level enhancing construction supervision activities, monitoring and technical backup as well as on water quality monitoring including the provision of mobile water quality testing kits.

- At federal level a refresher workshop on slow sand filter design, construction and operation and management for all stakeholders.

6. Recommendations

The management, operation and maintenance of slow sand filters require skilled personnel. Skilled, trained people who understand how slow sand filters function should be assigned at states/localities as well as at each location of a slow sand filter..

The choice of durable materials and proper supervision is necessary for construction to avoid early malfunctioning of the slow sand filter (Figure 21).

Figure 21. Damaged and leaking supply and connection pipes of sedimentation tank, and filter units at Kerima Al Bahir slow sand filter.

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Slow sand filters have no mechanisms to indicate when the filters need cleaning. This should be considered in the design

The application of slow sand filter for raw water from hafirs needs to be looked at critically, since the turbidity of water from this source is too high for a slow sand filter to be effective as a stand alone treatment system. Raw water from hafirs should be treated differently depending on its quality

Similarly, slow sand filters that have been constructed along the irrigation canals or big rivers need to consider the inclusion of pre-sedimentation basins to reduce the turbidity significantly (example - Kassala State).

Annexes

1. Sudanese/WHO drinking water standards
2. The process of development of these technical guidelines
3. Sample sieve analysis made by University of Khartoum, Department of Civil Engineering
4. List of contacted people
5. Technical Working Group Members
6. Some selected bibliography and references

Annex 1: Drinking Water Standards

No	Dissolved substances in water	Sudanese maximum permissible (mg/l) by SSMO, 2008	WHO guideline value (mg/l), 2006
1	Antimony	**0.013**	0.02
2	Arsenic	**0.007**	0.01 (P)
3	Barium	**0.5**	0.7
4	Boron	**0.33**	0.5 (T)
5	Cadmium	0.002	0.003
6	Chromium (total)	**0.033**	0.05 (P)
7	Copper	**1.5**	2
8	Cyanide	**0.05**	0.07
9	Fluoride	1.5	1.5
10	Lead	**0.007**	0.01
11	Manganese	0.27	0.4 (C)
12	Mercury (for inorganic Mercury)	**0.004**	0.006
13	Molybdenum	**0.05**	0.07
14	Nickel	**0.05**	0.07 (P)
15	Nitrate as NO3	50	50 Short term exposure
16	Nitrite as NO2	**2**	3 Short term exposure
17	Selenium	**0.007**	0.01
18	Uranium	0.01	0.015 (P,T)

Microbiological contents			
No	Organisms	Sudanese guideline value by SSMO	WHO guideline value
1	All water intended for drinking a) E-coli or thermotolerant coliform bacteria b) Pathogenic intestinal protozoa	Must not be detectable in any 100ml sample	Must not be detectable in 100ml sample
2	Treated water entering the distribution system a) E-coli or thermotolerant coliform bacteria b) Total coliform bacteria c) Pathogenic intestinal protozoa	Must not be detectable in any 100ml sample	Must not be detectable in 100ml sample
3	Treated water in the distribution system a) E-coli or thermotolerant coliform bacteria b) Total coliform bacteria c) Pathogenic intestinal protozoa	Must not be detectable in any 100ml sample Must not be detectable in any 100ml sample. In the case of large supplies where sufficient samples are examined, must not be detectable in 95% of samples examined through out any consecutive 12 months period. Must not be detectable in any 100ml sample.	Must not be detectable in 100ml sample

Maximum permissible limit for other parameters which affect the acceptability of water			
	Parameter	Levels likely to give rise to consumer complaints by SSMO, 2008	
1	Physical parameters		
	Colour	15 TCU	
	Taste & odour	Acceptable	
	Temperature	Acceptable	
	Turbidity	5 NTU	
	pH	6.5 – 8.5	
2	Inorganic constituents		
	Aluminum	0.13 mg/l	
	Ammonia	1.5 mg/l	
	Chloride	250 mg/l	
	Hydrogen sulfide	0.05 mg/l	
	Iron (total)	0.3 mg/l	
	Manganese	0.27 mg/l	0.4 mg/l
	Sodium	250 mg/l	
	Sulfate	250 mg/l	
	Total dissolved solids (TDS)	1000 mg/l	
	Zinc	3 mg/l	
3	Organic constituents		
	2-Chlorophenol	5 µg/l	
	2,4-Dichlorophenol	2 µg/l	

Parameter	Permissible level in µg/l by SSMO, 2008	WHO guideline value in mg/l, 2006
Carbontetrachloride	2.7	0.004
Dichloromethane	14	0.02
1,2-Dichloroethane	20	0.03
1,2-Dichloroethene	33	0.05
Trichloroethene	13	0.02 (P)
Tetrachloroethene	27	0.04
Benzene	7	0.01
Toluene	470	0.7(C)
Xylenes	330	0.5 (C)
Ethylbenzene	200	0.3 (C)
Styrene	13	0.02 (C)
1,2-Dichlorobenzene	700	1 (C)
1,4-Dichlorobenzene	200	0.3 (C)
Di(2-ehylhexyl) phthalate	5.4	0.008
Acrylamide	0.3	0.0005
Epichlorohydrin	0.3	0.004 (P)
Edetic acid (EDTA)	400	0.6 Applies to the free acid
Nitrilotriacetic acid (NTA)	130	0.2
Hexachlorobutadiene	0.4	0.0006
Dioxane	33	0.05
Pentachlorophenol	7	0.009 (P)

Parameter	Maximum Permissible level in µg/l	WHO guideline value in mg/l, 2006
Pesticides		
Alachlor	15	0.02
Aldrin/Dieldrin	0.02	0.00003 For combined Aldrin and Dieldrin
Aldicarb	7.5	0.01 Applies to Aldicarb Sulfonide and Aldicard Sulfone
Atrazine	1.5	0.002
Carbofuran	4.5	0.007
Chlordane	0.15	0.0002
Chlorotoluron	20	0.03
1,2-Dibromo-3-Chloropane	0.7	0.001
DDT	0.7	0.001
2,4-Dichlorophenoxy acitic acid	20	0.03
1,2-Dichloropropane (1,2 DCP)	26	0.04 (C)
1,3-Dichloropropene	13	0.02
Isoproturon	6	0.009
Lindane	1.3	0.002
MCPA	1.3	0.002
Methoxychlor	13.5	0.02
Metholachlor	7	0.01
Molinate	4	0.006
Pendimethalin	13.5	0.02
Pentachlorophenol	7	0.009 (P)
Permethrin	200	0.3
Simazine	1.3	0.002
Trifluralin	13.5	0.02
2,4-DB	60	0.09
Dichlorprop	66	0.1
Fenoprop	6	0.009
Mecoprop	7	0.01
2,4,5-T	6	0.009
Cyanazine	0.4	0.0006
1,2 Dibromoethane	0.27	0.0004 (P)
Dimethoate	4	0.006
Edin	0.4	0.0006
Terbuthylazine	5	0.007
Chlorpyrifos	20	0.03
Pyriproxyfer	200	0.3
Disinfectants and disinfectants' byproducts		
Chlorine	3	5
Monochloroacetate	13	0.02

Bromate	6.6	0.01 (A,T)
Chlorate	470	0.7 (D)
2,4,6-Trichlorophenol	135	0.2 (C)
Bromoform	70	0.1
Dibromochloromethane	70	0.1
Bromodichloromethane	66	0.06
Chloroform	200	0.3
Dichloroacetate	33	0.05 (T,D)
Trichloroacetate	133	0.2
Dichloroacetonitrile	13	0.02 (P)
Dibromacetonitrile	50	0.07
Cyanogen Chlorides (CN)	50	0.07
Chlorote	470	0.7 (D)
Disinfectants byproducts		
Gross alpha activity	0.07	
Gross beta activity	0.7	

P= Provisional guideline value as there is evidence of a hazard, but the available information on health effects is limited.
T= Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection etc.
C= Concentration of the substance at or below the health-based guideline value may affect the appearance taste or odor of the water, leading to consumer complaints.
A= Provisional guideline value because calculated guideline value is below the achievable quantification level.
D= Provisional value because disinfection is likely to result in the guideline value being exceeded.
TCU = True Colour Unit
NTU = Nephlometric Turbidity Unit

Annex 2: The Development of these Technical Guidelines

The Technical Guidelines development process was completed in two stages: preparation and finalization.

A. The Preparation Stage
The preparation stage began in April 2006 with the agreement to select eight WASH facilities. At the request of the GONU, 3 additional water supply facilities were added, making the total eleven. The preparation stage that included information collection and analysis was completed in December 2006.

Collection of Information:
Technical and managerial information related to the development of the 14 Technical Guidelines was collected from the following sources:

- PWC/WES, SWCs and GWWD
- UNICEF, WHO, World bank and NGOs
- National institutions like SSMO
- International institutions like IRC and WEDC
- Donors like DFID.
- Different countries' standards like BS, IS, DIN, etc.
- Field trips to 14 states in the northern and southern states of Sudan to visit the different existing facilities and to have live discussion with the sector professionals and community members.

Analysis of collected information:
The Steering Committee, which comprised senior staff from PWC, WES and UNICEF together with the consultant analyzed the collected information, which led to the development of the outlines of the documents in a zero draft. The draft documents were shared with the Steering Committee at Khartoum level. The committee met to discuss the drafts, and provided comments, which were incorporated, resulting in the first draft. .

The first draft was widely circulated to PWC, UNICEF, various SWCs, INGOs and GOSS for information and feedback. All relevant feedback from the sector actors were incorporated into the documents and the second draft prepared and presented to the first national review workshop in December 2006. The relevant recommendations and comments of the national review workshop were incorporated into the documents resulting in a third draft. The first National Review Workshop recommended that this draft of the Technical Guidelines be shared with a wider range of stakeholders, including specific technical working groups.

B. The Finalization Stage
The finalization of the 14 Technical Guidelines involved wider consultation with WASH sector partners through technical working group discussions, 3 regional review workshops, wider consultation and revision by GoSS and a national review workshop at the final stage.

Technical Working Group Discussions:
Professionals from various ministries participated in these technical working group discussions. MIWR, MOH, University of Khartoum, Sudan Academy of Science, private sector, NGOs, PWC/WES, UNICEF and Khartoum Water Corporation were also represented in these groups. This technical consultation process started in July 2007 and continued up to December 2007 resulting in the fourth draft of Technical Guidelines.

Regional Review Workshops:
Three Regional Review Workshops were conducted in Nyala, Wad Medani and Juba in November-December 2007 for GoSS and state level inputs into the documents. The Juba workshop recommended that the need for wider consultation within Southern Sudan to review the documents and to incorporate Southern Sudan specific contexts into the documents such as information relating to the location and different hydrogeological situations. These 3 workshops, resulted in the fifth draft.

Wider Consultation by GoSS:
Based on the recommendation of the Juba Review Workshop, a wider consultation process was started in July 2008 and completed in October 2008. The process included state level consultation with sector actors, technical working group discussions and a final consultation workshop in Juba. The process was concluded by the finalization and the approval of the final draft documents which were reviewed at a final National Workshop.

Final National Workshop:
The final National Workshop was conducted in April 2009 in Khartoum under the guidance and the presence of H.E. Eng. Kamal Ali Mohamed, Minister of Irrigation and Water Resources of GONU, Eng. Isaac Liabwel, Undersecretary, Ministry of Water Resources and Irrigation of GoSS, Eng. Mohammed Hassan Mahmud Amar, DG of PWC and Eng. Adam Ibrahim, Minister of Physical Planning and Public Utilities of South Darfur State.

The workshop was attended by ninety two participants representing MIWR, MWRI, MOH, PWC, WES, GWWD, Engineering Council, SWCs, SMoH, University of Khartoum, UNICEF, WHO, IOM, ICRC, NGOs, USAID and private sector.

The National Workshop reviewed the 14 WASH Technical Guidelines and approved them as the national WASH Technical Guidelines.

The workshop recommendations included:

- Publication and wide distribution of the Guidelines;
- Translation of the Guidelines into Arabic and other major Sudanese languages;
- Organization of training and advocacy courses/workshops related to the Guidelines;
- Adoption of supportive policies, strategies, laws and regulations to ensure best utilization of the Guidelines;

- Development of a system for further feedback from implementing partners for inclusion in future updates of the Guidelines. MIWR/PWC, MWRI and SWCs were selected as focal points for that purpose.

Annex 3: Sample sieve analysis, for Slow Sand Filtration Media, (University of Khartoum, Department of Civil Engineering)

Selection of slow sand filter media from soil test

The enclosed grain size distribution curve was produced from the result of sieve analysis shown in the attached table. Soil sample was divided into three categories; fine particles that have a grain size of less than 0.2mm, medium particles with grain size between 0.2 and 0.4 mm and coarse particles with grain size more than 0.4 mm. The percentage of each category - by - weight is tabulated below.

Fine particles (%)	Medium particles (%)	Coarse particles (%)
5.5	24.5	70.0

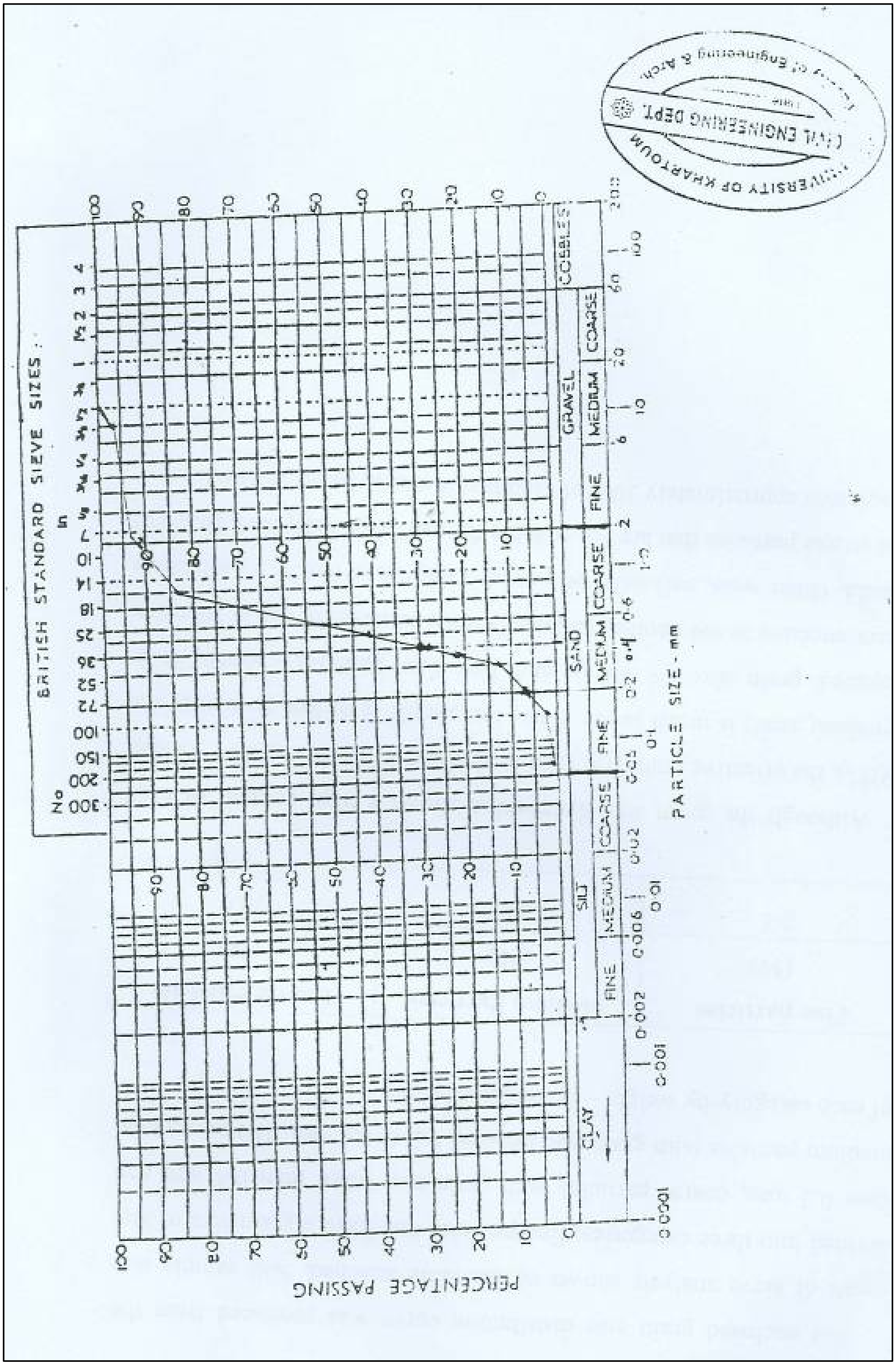
Although the grain size distribution shows a high content of sand (91%) the effective grain size used in slow sand filtration is 0.2 to 0.4 mm (medium sand) is much lower. Since the sample is of low portion of required grain size (<30%), and low fine particles content, it is recommended to use a different soil that is more suitable for use as filtration media. Otherwise, the soil must be sieved, using sieve No 36 to eliminate the coarse particles that are not suitable for use in the filter bed. This will provide approximately 30% of sand that could be useable for slow sand filtration.

Grading of aggregate

Description of sample: Soil sample from central Sudan
Operated by:
Date:

US Sieve No	Retained		% pass	Remarks
	Wt	%		
½ (12.5)	0	0	100	
3/8 (9.5)	34.8	3.5	96.5	
4 (4.75)	52.1	5.3	94.7	
8 (2.36)	81.1	8.3	91.7	
16 (1.18)	151.0	15.3	84.7	
30 (0.6)	575.5	58.4	41.6	
50 (0.3)	863.5	87.6	12.4	
100 (0.15)	969.5	98.4	1.6	
200 (0.07)	949.0	99.3	0.7	

Dry oven: 985.5 g


BRITISH STANDARD SIEVE SIZES
PERCENTAGE PASSING
PARTICLE SIZE - mm
CLAY
SILT
SAND
GRAVEL
COBBLES
FINE
MEDIUM
COARSE
UNIVERSITY OF KHARTOUM
CIVIL ENGINEERING DEPT.

Annex 4. List of contacted people

Gedarif State

1. Mohammed Hussein Mohammed	DG of Gedarif SWC
2. Mutasim Kamal	Gedarif WES Manager
3. Saad Abbas	Managing Director of Faw Water Supply
4. Radi Abualkher	Rural Water Supply Director
5. Ms Mazahib Aldaw	Civil Engineer, SWC
6. Mohammed Alhassen Omer Ali	Director of Ground Water & Wadis Research Corporation
7. Omar Mohammed Salih	Civil Engineer, Rural Water Corporation
8. Mohammed Hassen Ahmed Ali	Director of Al Hawata Water Supply System

Kassala State

1. Ali Abulkassim	RPO, UNICEF
2. Abud Rahman Eldood	APO, UNICEF
3. Abu Zaid Mohammed Ali	DG, SWC
4. Mustafa Mohammed Dein	Director of RWC
5. Isam Khagali	Civil Engineer, Project Department, SWC
6. Ms Amal Osman	Chemist in laboratory of SWC
7. Yasir Abu Elnur	Kassala WES Manager

Red Sea State

1. Mohammed Hassen Mussa	Acting DG, SWC, Manager of Water Projects
2. Mubarak Fatah El Rahman	WES Area Manager
3. Nazaar Omer Adem	Civil Engineer, Water Supply Projects Department, SWC

Sinnar State

1. Mohammed Hamed Alnil	DG of SWC
2. Hamad Adam Khatir	WES Coordinator, Central Region
3. Kamal Alsadik Adam	Surface water Director, SWC
4. Alsari Kamal Edin	Director of Water Projects, SWC
5. Ali Hassan	WES PM
6. Ms Enas	Survey Engineer, Surface water, SWC

Blue Nile State

1. Ahmed Hassabala	WES Project Manager
2. Ibrahim Ali Fadl Elmola	Acting DG of SWC
3. Abdurahman Mohammed Ahmed	Civil Engineer, Projects' Department, SWC

Khartoum

1. Dr. A. Khadam, University of Khartoum
2. Mr. Ibrahim Adam, NWC
3. Dr. V. Haraprasad, UNICEF

People Contacted in Southern Sudan, July 2008

1. Juma Chisto, Operator of Kator Emergency Water Supply, Juba
2. Habib Dolas, Member of Watsan committee, Hai Jebel
3. Andew Wan Stephen, Member of Watsan committee, Hai Jebel
4. Francis Yokwe, Member of Watsan committee, Hai Jebel
5. William Ali Jakob, Member of Watsan committee, Hai Jebel
6. William Nadow Simon, Member of Watsan committee, Hai Jebel
7. Ali Sama, Director General, Rural Water Department, Central Equatoria State (CES)
8. Engineer Samuel Toban Longa, Deputy Area Manager, UWC, CES
9. Sabil Sabrino, Director General UWC, WBeG
10. James Morter, Technician, UWC, Wau
11. Carmen Garrigos, RPO, Unicef Wau
12. Sevit Veterino, Director General, RWC, WBeG
13. Stephen Alek, Director General, Ministry of Physical Infrastructure (MPI), Warap
14. John Marie, Director of Finance, MPI, Warap State
15. Angelo Okol, Deputy Director of O&M, Warap State
16. Santino Ohak Yomon, Director, RWSS, Upper Nile State
17. Abdulkadir Musse, RPO, Unicef Malakal
18. Dok Jok Dok, Governor, Upper Nile State
19. Yoanes Agawis, Acting Minister, MPI, Upper Nile State
20. Bruce Pagedud, Watsan Manager, Solidarites, Malakal
21. Garang William Woul, SRCS, Malakal
22. Peter Onak, WVI, Malakal
23. Gailda Kwenda, ACF, Malakal
24. Amardine Atsain, ACF, Malakal
25. Peter Mumo Gathwu, Care, Malakal
26. Engineer John Kangatini, MPI, Upper Nile State
27. Wilson Ajwek Ayik, MoH, Upper Nile State
28. James Deng Akurkuac, Department of RWSS, Upper Nile State
29. Oman Clement Anei, SIM
30. Abuk N. Manyok, Unicef, Malakal
31. Jakob A. Mathiong, Unicef, Malakal
32. Emmanuel Badang, UNMIS/RRR
33. Emmanuel Parmenas, DG of O&M, MCRD GOSS
34. Cosmos Andruga, APO, Unicef Juba

Annex 5. Technical Working Group Members

A) At Khartoum level

1) For Slow Sand Filters

Dr Mohammed Adam Khadam, University of Khartoum
Dr V. Haraprasad, UNICEF
Mr. Ibrahim Adam, PWC
Mr Eshetu Abate, UNICEF - Consultant

2) For Borehole Hand pumps, Hand dug well Hand pumps, Hand dug well Water yards, Mini Water yards and Water yards

Mr. Mohamed Hassan Ibrahim, GWW
Mr. Mohy Al Deen Mohamed Kabeer, GWW
Mr. Abd el Raziq Mukhtar, Private Consultant
Mr. Mohamed Salih Mahmoud, PWC
Mr. Mohamed Ahmed Bukab, PWC
Mr. Mudawi Ibrahim, PWC/WES
Mr. Yasir Ismail, PWC/WES
Mr Eshetu Abate, UNICEF - Consultant

3) For Improved Small Dams

Dr. Mohamed Osman Akoud, University of Khartoum
Professor Saif el Deen Hamad, MIWR
Mr. Mohamed Salih Mohamed Abdulla, PWC
Mr Eshetu Abate, UNICEF - Consultant

4) For Improved Haffirs

Mr. Mohamed Hassan Al Tayeb, Private Consultant
Mr. Hisham Al Amir Yousif, PWC
Mr. Hamad Abdulla Zayed, PWC
Mr Eshetu Abate, UNICEF - Consultant

5) For Drinking Water Treatment Plants, Drinking Water Distribution Networks and Protected Springs & Roof Water Harvesting

Dr Mohamed Adam Khadam, University of Khartoum
Mr. Burhan Ahmed Al Mustafa, Khartoum State Water Corporation (KSWC)
Mr Eshetu Abate, UNICEF - Consultant

6) For Household Latrines, School Latrines and Rural Health Institution Latrines

Mr. Sampath Kumar, UNICEF
Mr. Fouad Yassa, UNICEF
Dr. Isam Mohamed Abd Al Magid, Sudan Academy of Science
Mr. Badr Al Deen Ahmed Ali, MOH
Ms Awatif Khalil, UNICEF
Mr Eshetu Abate, UNICEF - Consultant

B) At Juba level:

For all facilities:

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Dr. Bimal Chapagain, UNICEF- Consultant
Mr. Marto Makur, SSMO
Ms. Jennifer Keji, SSMO
Ms. Rose Lidonde, SNV
Mr. Elicad Nyabeeya, UNICEF
Mr. Isaac Liabwel, MWRI
Mr. Moris Monson, SC UK
Mr. Peter Mahal, MWRI
Mr. Alier Oka, MWRI
Mr. Emmanuel Ladu, MWRI
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Mr. Gaitano Victor, MAF
Dr. Lasu Joja, MOH-GOSS
Mr. Kees Van Bemmel, MEDAIR
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Mr. Philip Ayliel, MHLPU
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Annex 6. Selected biblography and references

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