Public Water Corporation

MIWR – GONU

MWRI - GOSS

Technical Guidelines for the Construction and Management of Improved Hafirs

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 in the provision of water and sanitation services in Sudan has been achieved 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 MDG goal for water supply and sanitation in Sudan.

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

Date ………………………………………

Ministry of Water Resources and Irrigation – Government of Southern Sudan

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 and manuals. 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

Special thanks go to Mr Mohammed Hassan Mahmud Amar, Mr Eisa Mohammed and Mr Mudawi Ibrahim, for their directions on GONU's sector policy; Engineer Isaac Liabwel, on GOSS's water policy; Mr Sampath Kumar and Dr. Maxwell Stephen Donkor, for their direction on the WASH sector from the UNICEF perspective, and for the provision of relevant documents & information, and facilitating & organizing a number of forums to discuss draft documents.

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
ESPA	Eastern Sudan Peace Agreement
GONU	Government of National Unity
GOSS	Government of Southern Sudan
MCRD	Ministry of Cooperatives and Rural Development of GOSS
MIWR	Ministry of Irrigation and Water Resources of GONU
MWRI	Ministry of Water Resources and Irrigation of GOSS
NTU	Nephlometric Turbidity Unit
NWC	National Water Corporation
PWC	Public Water Corporation
PM	Project Manager
PVC	Polyvinylchloride
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
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

- An ‘improved hafir’ is one with a water treatment system that can provide drinking water primarily for human consumption. A hafir without a water treatment system that is used for purposes other than drinking may not be classified as ‘improved hafir’.

Design considerations

Like any engineering structure, improved hafir needs to be well planned. The following steps are recommended in the planning phase:

- Preliminary survey (reconnaissance study) of the area.
- Feasibility study
- Hafir design: this includes: Comparison of various designs of improved hafirs, and of the various components, to select the best option , protection strategies/measures against potential pollution and contamination, and soil and water conservation measures of the catchment area, cost estimation and cost sharing among all stakeholders, requirements and actions for capacity building, implementation schedule etc
- One of the factors, in the selection of the design of an improved hafir, is the estimation of the design human population.
- The potential livestock population which may use the water from the hafir should be added into the total design population figure.
- In determining the dimensions the size of the hafir: factors such as the surface area that will be exposed to evaporation, effect of sedimentation of silt materials in decreasing the volume of the hafir, and misuse and waste during withdrawal and animal watering, must be considered.
- Since a hafir is mainly a gravity system, a topographical survey covering a wide area is very essential.
- A hydrological and geological survey should identify different parameters like peak flow, possible quantity and quality of raw water, soil analysis to identify the type of soil of the proposed hafir site, and types and locations of other locally available construction materials etc.
- Hafirs should be selected in places where there is clay soil and where there are available construction materials. The depth of the clay soil should be determined during the feasibility study using augering kits at least at three points on each hafir site
- Estimation of the expected quality of raw water could be done by extrapolation using the available data in the area or by measuring the turbidity of water in the nearby hafirs, which are selected randomly or specifically during the feasibility study.

- After estimation of the quality of water, then a decision has to be made on the type of water treatment system that will be appropriate for proper reduction of the turbidity

Design procedures of improved hafirs

Hafirs are simple hydraulic structures that deal with impoundment of water. Although they are simple structures, they must have all and proper components that any hydraulic structure requires. These components are:

- Feeding facilities.
- Drainage facilities.
- Seepage control structures.
- The design and peak flows must be estimated by a hydrological study.

Standardized sizes of hafirs

- Hafirs are rectangular or semi-circular impoundments that store water to be used by both human and livestock population during the dry season.
- Hafir size in Sudan in the past varied by State, from 15,000m^3 to 100,000m^3. In recent years however, attempts have been made to standardize the size for uniformity. The current practice is 30,000m^3 in North Sudan and between 10,000 to 30, 000 m^3 in South Sudan.
- Hafirs should be fenced and protected. Fencing should include the silt retention area in order the community be able to manage the whole available water source and to minimize pollution and hygiene hazards during storage and abstraction.

1. Introduction

1.1 The purpose of this document and frequency of updating

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.

Any issues arising could be identified only through the active involvement of all stakeholders in the decision making process. Although the process of community engagement is time consuming, demand-driven approach will reduce the time for community buy-in.

1.3 Technology options

There are a number of global technology options available for improved rural water supply systems. However, not all can be applied everywhere. In rural North Sudan, hafirs (with or without a combination of filtration systems and hand pumps) are a common choice for the supply of drinking water. Hafirs are selected for the simple reason that there are no other water sources like ground water or surface water sources The Sudan with over 1,500 hafirs nationwide, is one of the few countries using this unique water harvesting systems for arid zone areas.

In Southern Sudan, hafirs provide water to livestock, agriculture, humans and to some extent wildlife. These Technical Guidelines focus on the application of technology in the construction of an improved hafir (hafir with a treatment system) intended to serve as sources of drinking water for the human population.

2. Guidelines for selection of improved hafirs

Hafirs are considered improved, if and only if they are associated with appropriate water treatment systems. In terms of definition of improved hafir, the current practice differs from place to place and from state to state. The types of the water treatment systems that are currently utilised with hafirs are either infiltration galleries or slow sand filtration systems. For instance, some hafirs in North Kordofan are attached to series of wells (Figure 1). The first well serves as a valve control and first filter chamber. Layers of gravel have been packed in this well. The water is then conveyed by gravity to the second well. The water in the second well is filtered again through gravel pack and then to a third well where twin hand pumps are installed.

Figure 1. Hafir attached to series of wells, North Kordofan State.

The required quality of water (as per Sudanese/WHO guidelines for drinking water) cannot be guaranteed from these wells due to the type of treatment method used and the very high turbidity of the raw water from the hafir.

Figure 2. Slow sand filtration system under construction for the hafir at Dar Hashay, Kassala State

Figure 2 shows a hafir in Kassala State, attached to slow sand filtration systems During the treatment process, water from the hafir is conveyed to a raw water well of diameter 150cm. The water is pumped out of the raw water well with a surface pump and collected in a rectangular sedimentation tank (locally called ‘heading tank’) of width 400cm, length 1000cm and depth 150cm. Then the water flows by gravity to the next single rectangular tank which is 750cm long, 300cm wide and 300cm deep. Sand as filter media is filled in this tank to serve as “slow sand filter”. From the filter unit water flows to a two-chamber “clear water” well, where three hand pumps are installed. Every component of such a type of slow sand filtration system lacks a means for complete drainage of each unit. There is no mechanism for backfilling of water of the filter media. Sand washing facilities (for scrapped sand from the top layer of filter media) are not provided. The filtration system, under high turbidity condition of the raw water may not produce good quality of water. This was an observation in October 2006 in one of the hafirs in Kassala State, when the turbidity was more than 500 NTU. Slow sand filtration systems require raw water that has a maximum of 20 NTU and ideally less than 10 NTU[1]. A hafir with raw water **of turbidity more than 500 NTU** requires a chemically assisted conventional treatment system (that uses coagulation and flocculation process) and **not a slow sand filtration system**.

However, hafirs can serve as a pre-treatment component before slow sand filtration systems, for raw water from irrigation canals with a relatively low turbidity, like the case again in Kassala State (Figure 3), when they significantly assist in reduction of turbidity. The turbidity check (at the entrance and exit of the hafir), conducted in October 2006 showed a 70% reduction in turbidity (from 40 to about 12 NTU).

Figure 3. Hafir in Kassala State utilized as a pre-treatment component before slow sand filtration

2.1 Design considerations

To ensure optimum utilization and sustainability, the following steps must be considered in the planning of an improved hafir. The following activities constitute the planning phase:

[1] Source: WHO

- Preliminary survey (reconnaissance study) of the area: Appropriateness of the site of the improved hafir including estimation of the area for topographical survey, estimation of the design population, socio-economic survey in upstream and downstream locations of the area, rough environmental impact assessment (including the health threats such as the spread of malaria and prevalence of guinea worm and recommended solutions), impact of the hafir on water rights at the development and upstream/downstream areas etc, consultation with local authorities and beneficiary communities and justifications to conduct the feasibility study.
- Feasibility study: Site selection, topographical survey of the area, hydrological and hydrogeological studies community participation including roles and responsibilities of all stakeholders, needs assessment for capacity building etc.
- Since a hafir is mainly a gravity system, a topographical survey covering a wide area is very essential. The area should include areas for all design facilities with accurate elevations and distances. An appropriate (suitable) size of area, from the experience of Public Water Corporation/State Water Corporation (PWC/SWC) and depending on the nature of the site, is about 2 square kilometer.
- A hydrological and geological survey should identify different parameters like peak flow, possible quantity and quality of raw water, soil analysis to identify the type of soil of the proposed hafir site, and types and locations of other locally available construction materials etc.
- Design: This includes, identification and selection of the most suitable option of improved hafir, design of different components of improved hafir, protection strategies/measures against potential pollution and contamination, soil and water conservation measures of the catchment area, cost estimation and cost sharing among all stakeholders, requirements and actions for capacity building, implementation schedule etc
- An important factor to consider in selecting the right kind of improved hafir is the estimation of the design human population. The population of any community at the end of the design period of a hafir can be estimated based on the annual population growth rate[1] of a community to be served. Various formulas are available, but the following may be used for this purpose:

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

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

The potential livestock population, which may use the water from the hafir, should also be added into the total design population figure.

[1] The figures for present population and the annual growth rate can be obtained from national or state authorities who are dealing with population census.

- In determining the dimensions of the size of the hafir: , factors like surface area of a hafir that will be exposed for evaporation, effect of sedimentation of silt materials in decreasing the volume of a hafir, and misuse and wastage during withdrawal and watering, must be considered. From experience, 40-50% of water is lost due to evaporation, 8-10% due to sedimentation and a little less than 5% due to misuse and spillage from existing hafirs[1]. The remaining volume will be in the range of 35 to 47 percent. In some areas infiltration into the soil could contribute to the reduction of the overall volume of water in the hafirs.

The following also need to be considered.

- Hafirs should be selected in places where there is clay soil and where there are available construction materials. The depth of the clay soil should be determined during the feasibility study using augering kits at least at three points on each hafir site

- Estimation of turbidity of the water in a hafir to be constructed can be extrapolated using the available data in the area or by measuring the turbidity of water in the nearby hafirs, which are selected randomly or specifically during the feasibility study. A quick assessment conducted in October and November 2006 in different states, showed the levels of turbidity to be in the range of 250 and 500 NTU (table 1)

State	**Number of hafirs and dams assessed**	**Average turbidity (NTU)**
Gedarif	3 hafirs	500
	2 dams	500
Kassala	1 hafir	> 500
Sinnar	2 hafirs	500
Blue Nile	5 hafirs	250
	1 dam	450

Table 1. Average value of turbidity in hafirs and dams in different states of Sudan in October and November 2006

Hafirs in Blue Nile State recorded the lowest, probably as a result of the introduction of pre-sedimentation basin (or silt retention pool) before the hafirs and relatively better vegetation coverage of the area.

- Once water quality has been estimated, a decision on the type of water treatment system that will be appropriate for proper reduction of the turbidity can be made. Possible treatment methods include: infiltration gallery, slow sand filtration system or conventional water treatment method.

[1] Engineer Mohammed Elhassan Eltayeb (expertise comment and opinion on previously prepared draft document, August 2007)

- Once an appropriate treatment method has been selected, Technical Guidelines available on slow sand filtration systems or conventional water treatment plants can be referred to in order to determine the type and capacity of the facilities.

3. Design procedures of improved hafirs

Although hafirs are simple hydraulic structures that deal with impoundment of water, **they must have the necessary components** for efficient service provision. These are:

- Feeding facilities: These are structures that ease the flow of water to the hafir with a minimum sediment load by controlling the velocity ($v \leq 1m/s$) of flow. This can be achieved through construction (provision) of weirs, drops and diversion structures.
- Drainage facilities: These are structures to drain excess water away from and before overtopping the body of a hafir. The provision of spilling structures (spillways) minimizes partial or total damage during high floods or during uncontrolled flow of water.
- Seepage control structures: These are provisions like lining of hafirs that minimize or avoid seepage through the body or floor of hafirs. Plastic or concrete lining could be applied as a mitigation measure provided the cost of lining is not significant and affordable.

The design and peak flows must be estimated by a hydrological study. The schematic flow diagrams of improved hafirs have been indicated in Figure 4 and Figure 5 for raw water sources from rain water harvesting and irrigation canals/streams respectively.

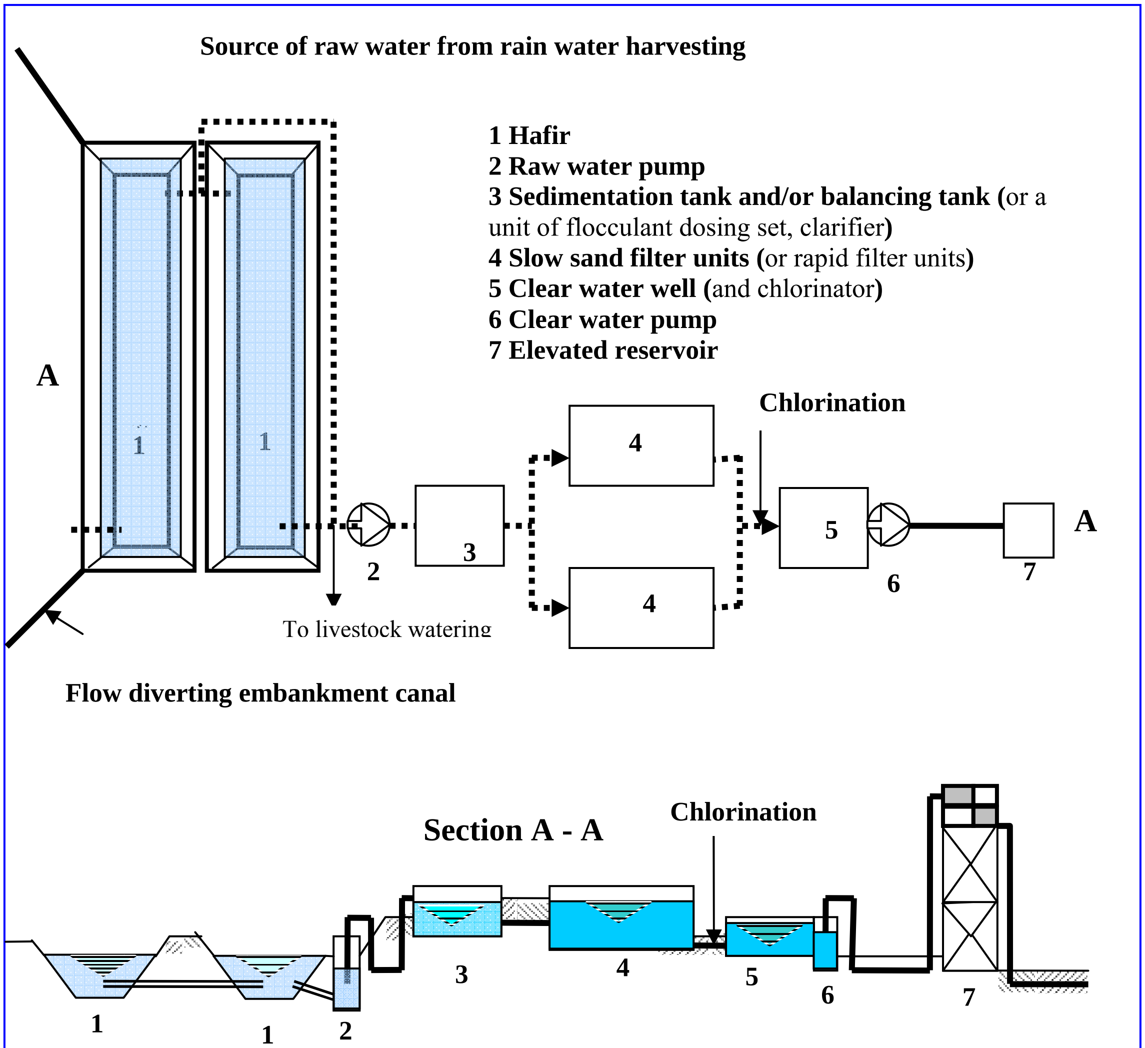

Figure 4. Schematic flow diagram of improved hafir for raw water source from rain water harvesting

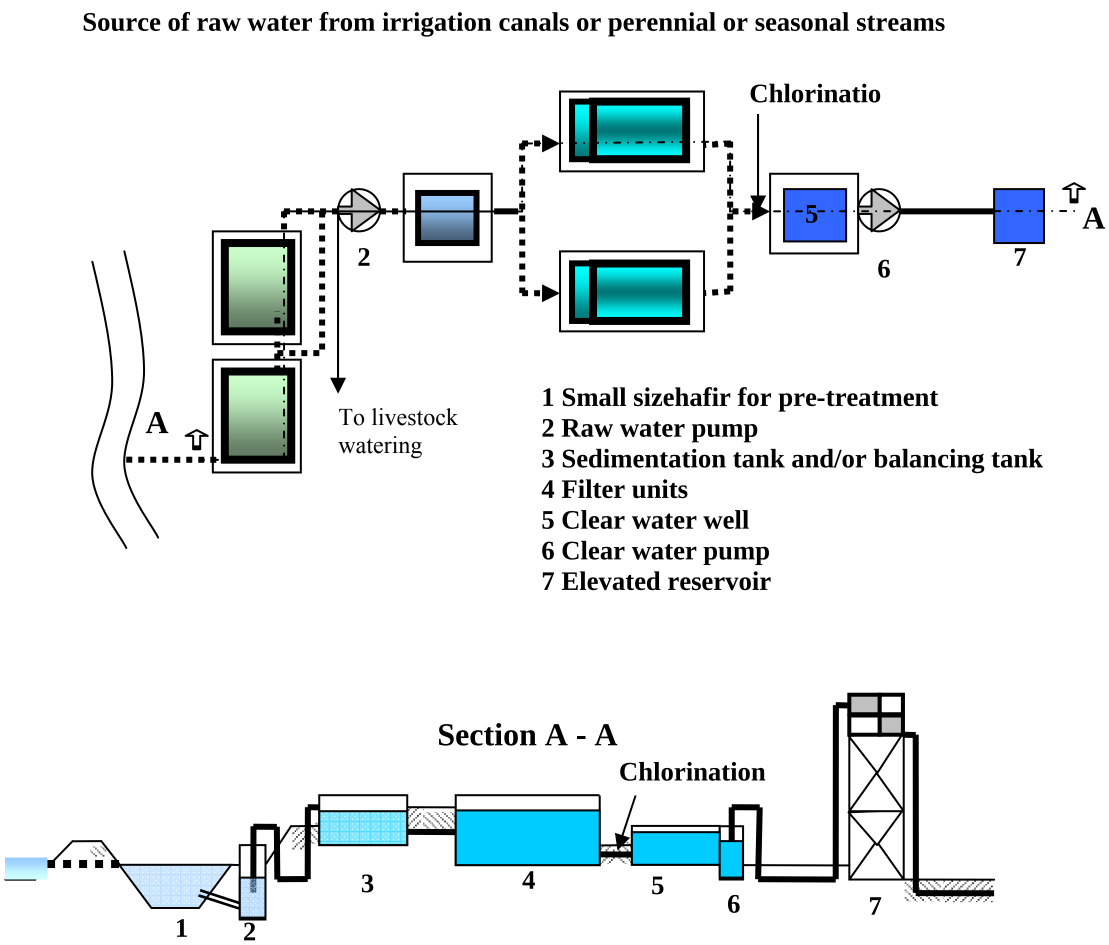

Figure 5. Schematic flow diagram of improved hafir for raw water source from irrigation canals, perennial or seasonal streams

3.1 Standardized sizes of hafirs

Hafirs are rectangular or semi-circular impoundments that store water to be used by both human and livestock population during the dry season. Hafir size in Sudan in the past varied by State, from 15,000m^3 to 100,000m^3. In recent years however, attempts have been made to standardize the size for uniformity. The current practice is 30,000m^3 in North Sudan and 10,000 to 30, 000 m^3 in Southern Sudan.

It has been recognized however that 30,000m^3 of water is not enough to last for the whole year, and once the hafir is empty; the treatment system remains idle until the following rainy season starts (Figure 6). It has been recommended that at least two hafirs are constructed in each location.

Demand with other environmental and developmental aspects should be the governing factor for the determination of the capacity (size) of any hafir.

Experience has shown that over-sizing a hafir (instead of constructing an additional hafir in another location) can attract people from other areas, lead to overuse and increased over-grazing by livestock from other areas and is likely to trigger conflicts.

Under-sizing a hafir, on the other hand, would result in empting the hafir in a short period of time, which will create mistrust between the users and implementing agency as the facility does not provide service for the whole year.

It is, therefore important to consider the above factors critically before deciding on the size of a hafir.

Figure 6. Dry hafir with its slow sand filtration system

3.2 Source of incoming water into impounding reservoirs of hafirs

Hafirs are fed mainly from seasonal water sources i.e streams and 'khors' (valleys), 'Jebel' (mountain) catchments, self catchments and depression, and irrigation canals and perennial courses. Rain water harvesting sometimes will not bring adequate quantity of water to hafirs. This is because of the erratic and uneven nature of rainfall in most places, particularly in eastern, northern and western parts of Sudan

In areas where improved hafirs contain rain harvested water, there should be at least two standard size hafirs of 30,000m^3 in one location. The reasoning behind this is:

- The proposed treatment systems will function for longer period with two hafirs than with one hafir.
- One hafir can serve while the other is under repair.
- It is also possible to pump water from one hafir to the other during dry seasons and when necessary.
- The raw water will have more detention time in two hafirs which could contribute to the reduction of turbidity. This was demonstrated in Boot village, Blue Nile State. Raw water from the earth dam passes through four hafirs that are connected in series. An assessment in November 2006 measured the turbidity in the dam itself at 450

NTU, whilst the turbidity in the third and fourth hafirs was 250 and 100 NTU respectively, relating to 78% reduction.

3.3 Design specification of components of improved hafirs[1].

The components of improved hafirs shown in Figures 4 and 5 are:

a) Hafir
b) Raw water pump
c) Slow sand filtration systems (that include sedimentation tank and minimum 2 filtration units), or chemically assisted water treatment systems (that include flocculation & coagulation systems, rapid sand filters and chlorinator etc)
d) Clear water well,
e) Clear water pump,
f) pump/generator house
g) Elevated steel reservoir and
h) distribution points
i) Animal trough (raw water is diverted to the trough before it is treated)

Dimensions of the current typical standard design for 30,000 m^3 capacity hafirs are:

- Top width 70m
- Top length 130m
- Depth 4m
- Bottom width 54m
- Bottom length 114m and
- Slopes: 2:1 for the length and one of the width and 4:1 for the remaining width. By maintaining the bottom dimensions of the hafir

These dimensions are appropriate where the thickness of the clay soil is more than 6m like in Sinnar and Blue Nile States but they may not be acceptable in most parts of Kassala and Red Sea States as the thickness of the clay soil is less than 6m. In this case, designers should determine the dimensions of hafirs as indicated in Figure 7. Wherever possible, it is always better to increase the depth of hafir than to increase the surface area. The lesser the surface area is, the lesser the evaporation rate.

The slope of the embankments around hafirs and the embankments of the drainage area should be the same as small earth dams. For clay soil this will be 3:1.

The proposed two hafirs in each location should be connected by 12" pipe (steel or uPVC of proven thickness and minimum working pressure of 6 bars). There should be inlet and outlet wells at each end of the pipe. There should be an outlet well for abstraction of raw water from the hafir. A bypass pipe should be provided before the treatment facility to convey water to animal troughs.

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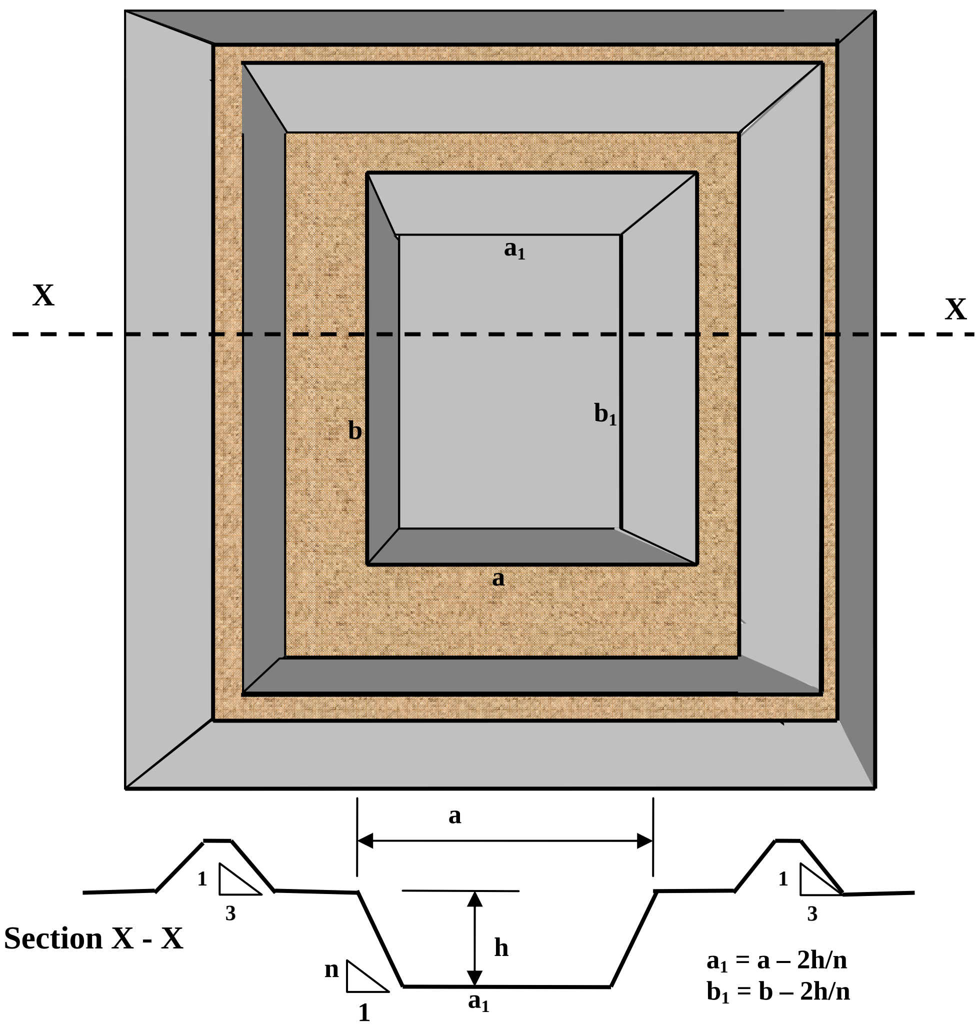
[1] This technical guideline covers only the hafir component. Slow sand filtration systems have been discussed on the respective technical guideline of "SLOW SAND FILTRATION SYSTEMS".

The hafir should have a retention pool or basin at the upstream location. This will serve at least two purposes: a) The retention basin will trap sediment particles before it reaches the proper hafir, contributing to the reduction of turbidity. b) The retention basin will also hold water in addition to the amount of water in the proper hafir. This enables an increase in the overall volume of water in each particular area.



Equation for determination of dimensions of a hafir for a given volume

$$V = (A + A_1) \times (½) \times (h) = ((a \times b) + (a_1 \times b_1)) \times (½) \times (h)$$
$$= (abh) - (a+b) \times (h^2/n) + (2h^3/n^2)$$

Where, V is volume of a hafir, A is area of hafir at the top, A_1 is area of hafir at the bottom, h is depth of a hafir, a is top width of a hafir, a_1 is width of a hafir at depth of h, b is top length of a hafir, b_1 is a length at depth h, n is vertical height of the slope of the sides of a hafir for horizontal distance of 1 unit.

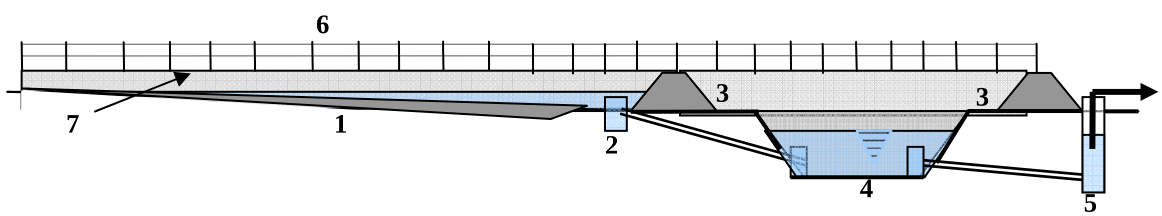
Depth of a hafir is very important as it is determined as per to the thickness of clay soil

Figure 7. Equation for calculation of any one dimension of a hafir

4 Construction and supervision of improved hafirs

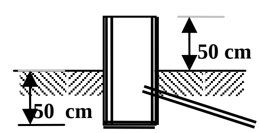
Hafirs are constructed in Sudan using earth moving equipment. Before any construction starts, the layout of the hafir should be marked on the ground. The excavated soil should be used for the construction of the embankments of the hafir, which should be well compacted using appropriate compaction equipment. The sides of hafirs should have a slope of 2:1 (2 units horizontal for every 1 unit of vertical depth). The embankments of the hafirs should be constructed with a side slope of 3:1 and top width of minimum 3 m preferably 4m. Less than 3m width will make the use of equipment difficult during maintenance. On the upstream side of a hafir (for rain water harvesting), embankments should be connected on both sides (Figure 4) to flow diverting embankments.

During the rainy season raw water coming into the hafir contains large amount of suspended solids. In order to ensure that these are retained in the silt retention basin (pool) at the upstream face of a hafir, the bottom layer of the silt retention basin (pool) should be slightly deepened from the level of the ground. In addition the wall of the inlet well should be raised by 50 cm from the ground (Figure 8). This will prolong the life of the hafir from being filled with silt.



Key

1 Silt retention basin (pool)
2 Raw water inlet well
3 Embankment of a hafir
4 Hafir
5 Raw water abstraction well (or intake for the treatment system)
6 Fence
7 Flow diversion embankment



DETAIL OF 2

Figure 8. Longitudinal section and arrangement of components of a hafir

Raw water from the inlet well to the hafir is conveyed through 12” pipes (steel or concrete). There must be a flow control valve to maintain the level of water in the hafir so that excess water collected during high flood is diverted before it damages the embankment around the hafir.

Raw water from the hafir to the abstraction well can be conveyed through a 6” pipe with a minimum working pressure of 6 bars. All wells, inlet and outlet, are circular in shape and can be constructed either from brick or stone masonry in cement mortar or from concrete rings. The preferred internal diameter of these wells is 150 cm, but should not be less than 100cm, to allow maintenance crew easy access for maintenance/ cleaning.

Where raw water is abstracted directly from the hafir using a surface pump, the construction of inlet and outlet wells for abstraction are not necessary, but the risk of pollution of water by the pump should not be ignored.

Hafirs should be fenced and protected; the most common is with angle irons posts and barbed wire mesh. This type of fencing is not accepted by all, as the openings allow access to small livestock, and prefabricated mesh wire is preferred. The choice depends on cost analysis and the comparative advantage of the two types of fencing.

Fencing should include the silt retention area in order to enable the community to manage the entire area of the water source and to minimize pollution and hygiene hazards from livestock during storage and abstraction. Fencing will prevent direct access of livestock to the improved hafir and its corresponding silt retention area.

5 Management, operation, maintenance and capacity building for improved hafirs

5.1 Management

The management of hafirs, in North Sudan, varies from state to state. In North Kordofan, the management aspect is the responsibility of each community whilst in Blue Nile State it is the responsibility of SWC. Each has its advantage and disadvantage as discussed below:

	Management by communities	Management by SWC
Advantages:	-Decisions are made at local level -Community mobilization is possible and fast -Mobilization of additional resources is possible	-There is a technical capacity to design, construct, monitor, plan etc -Maintenance of the facilities could not be a problem as long as budget is allocated
Disadvantages:	-Lack of technical capacity for monitoring, planning etc -Lack of financial capacity for maintenance and dependent on SWC	-Decisions may not be made by SWC, like changing the water tariff -Mobilization of communities is relatively slow

The maintenance and sustainability of an improved hafir, requires the involvement of skilled personnel. It is recommended that a joint community/SWC management system is applied for a transitional period, during which management remains the responsibility of the community, whilst SWC takes charge of monitoring and the technical aspect of maintenance. To ensure a strong and capable community management system, capacity needs of the community members should be identified and strengthened during the transitional period.

The size and make up of the management committee (ensuring gender balance) will depend on location and the revenue generating capacity of the facility. The minimum number on a committee should not however, be less than 5.

A community based management system that is enforced by viable tariff and strong legislations is recommended. A substantial part of the revenue should be allocated to maintain and improve the facilities.

Extensive training of communities and local authorities together with awareness campaigns on the danger of guinea worm is necessary to ensure that hafir water is only used for by humans when it is treated.

The management of hafirs in Southern Sudan is the responsibility of State Directorate of Rural Water Supply and Sanitation or Urban Water Corporation depending on the location of the hafirs.

5.2 Operation and maintenance

Operation and maintenance of improved hafirs requires the availability of skilled personnel at the location of the hafir. The operation and maintenance of the improved hafir will depend on the type of the water treatment system of each facility. Technical Guidelines are available for “SLOW SAND FILTER”, where slow sand filters are in place as component of improved hafir.

Technical Guidelines are also available for “IMPROVED SMALL DAMS”. which provide guidance for the maintenance of the embankments of hafirs.

It is important that every inlet and outlet well should be cleared from silt and debris before the rainy season. When necessary, depending on the volume of material deposited in, the silt retention basin should be cleared and removed outside of the drainage area.

After every rainy season, an inspection of the components of the improved hafir is a good practice. This information should be recorded, and recommendations for the next maintenance schedule included in the report.

5.3 Capacity building

Capacity building at community, ‘mahalia’/county and state levels is very important for the successful management, operation and maintenance of improved hafirs. Since improved hafirs have been introduced very recently, an understanding of the facility should be in place at all levels. Raw water with turbidity of more than 500 NTU (refer Figure 9) can not be treated solely with a slow sand filtration system. A complete package of training on the operation and maintenance of slow sand filtration systems should be given to persons who are assigned to operate the system, PWC/SWC could organize and facilitate this.

Figure 9: Very turbid water in the abstraction well of a hafir

At community level: The site of every hafir, which includes the silt retention basin (pool), needs to be fenced so that free access is halted. This will have double effect. 1) It will increase the revenue generation capacity of communities as free and uncontrolled access to the hafir will be hindered, and 2) It will reduce pollution of the water in the hafir as well as in the silt retention basin. Therefore communities need to be provided with complete fenced hafirs so that they can manage their water supply system in a better situation than without a fence.

Most hafirs are located off the main road and often a distance from a SWC office. It is therefore important that every community has people trained on understanding the malfunction of a hafir (defects, damages, malfunctioning, leakages etc.), and can prepare a report on the situation.

Hygiene and sanitation promotion activities need to be introduced or strengthened as part of the water supply activities. In addition, indigenous traditional knowledge on water filtration such as the use of 'zirs', must be researched and encouraged. Education and research institutions could assist in this regard

Figure 10. Samples of water taken from Abu Jeyli slow sand filtration system and Sinnar town water supply. From left to right: 1. supernatant water, 2. filtered water from Abu Jeyli, 3. Tap water from Sinnar town water supply. 4. Water sample taken after filtration of water from Sinnar town water supply system and re-filtered using traditional pot container ("Zir")

At state and mahalia/county levels: SWC staff and members of the water supply facility management committee should be trained in the proper monitoring of hafir efficiency so that they can take timely and appropriate action as required.

6 Recommendations

The establishment of an improved hafir requires the knowledge of the turbidity level of the raw water in the hafir. Furthermore, the type of the treatment system required. The current practice of utilizing only slow sand filters in highly turbid water does not produce the required quality of drinking water (as per Sudanese/WHO guidelines).

Recently, a compacted type of chemical treatment system has been introduced for the water with high turbidity level. The downside of this is that it requires a constant supply of chemicals, which may not be available or affordable by the community. Furthermore, this system requires highly skilled persons for operation as compared to a slow sand filtration system.

When selecting a site for a hafir, care must be taken to ensure that the site is a reasonable distance from settlements, to reduce the chance of pollution of the hafir.

Fencing around the entire area of hafir, including the silt retention basin, is recommended to facilitate the management of the facility.

The embankment of the hafir should be well constructed and compacted to minimize erosion and to avoid fill up of the hafir as a result of erosion.

In case the layer of impermeable soil is thin, the hafir will be shallow. In this case, the construction of an over-ground storage facility is recommended.. Two meters of embankment height would allow for the storage of more water. Additional costs for this construction would include pumps, valves and operational costs[1]. A mathematical analysis done based on this recommendation showed that there will be about 31% reduction in the total surface area of two hafirs and a retaining of 81% of the total volume of twin hafirs. This data needs to be tested further in various states in collaboration with universities, for confirmation.

The old practice of lining hafirs against seepage was discontinued mainly because of the cost and often unavailability of lining materials. This practice may be re-applied if cheap lining material can be manufactured locally[2].

For hafirs to compete as a source for potable water among other types of potable water sources, the cost of water per cubic meter should be determined. The cost includes studies, design, construction, operation, maintenance and rectification costs for the anticipated life time of any hafir[3].

A regular maintenance schedule and budget allocation for the maintenance is very important. A delay in maintenance of the hafir will lead to greater costs. Improved hafirs, if properly studied, designed, constructed and managed, can be a competent water supply system both in terms of sustainability and cost.[4]

Capacity building of all persons involved in the management, operation and maintenance of improved hafirs should be planned and implemented.

[1] Engineer Mohammed Elhassan Eltayeb (expertise comment and opinion on previously prepared draft document, August 2007)
[2] Ibid
[3] Ibid.
[4] Ibid

Annexes

1. Sudanese/WHO drinking water standards
2. The process of development and finalization of the Technical Guidelines
3. List of contacted people
4. Technical working group members
5. 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: the preparation and the 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 has 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 feedback to receive comments 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. 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

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 4. 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
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Ms. Jennifer Keji, SSMO
Ms. Rose Lidonde, SNV
Mr. Elicad Nyabeeya, UNICEF
Mr. Isaac Liabwel, MWRI
Mr. Moris Monson, SC UK
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Mr. Philip Ayliel, MHLPU
Mr. James Adam, MWRI

Annex 5. Selected bibliography and references

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Contact Addresses for Feedback by WASH Sector Partners

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