



Public Water Corporation

MIWR – GONU



MWRI - GOSS

# **Technical Guidelines for the Construction and Management of Drinking Water Treatment Plant**



**A Manual for Field Staff and Practitioners**

**April 2009**

**DEVELOPED IN PARTNERSHIP WITH**



## Table of contents

	Page
Foreword .....	2
Acknowledgements .....	4
Acronyms .....	5
Document Summary.....	
1. Introduction .....	6
2. Natural water and common impurities in water and their effect .....	6
3. Water demand and quantity .....	7
4. Requirements of water for domestic use .....	9
5. Water quality analysis .....	10
Physical .....	10
Chemical .....	11
Microbiological .....	11
6. Common water-borne diseases .....	12
7. Drinking Water Quality Standards .....	12
8. Drinking Water Treatment .....	14
Screening and Aeration .....	17
Sedimentation .....	19
Coagulation/Flocculation .....	20
Clarification .....	21
Filtration .....	21
Rapid gravity filter .....	22
Pressure filters .....	26
Performance of rapid sand filters .....	29
Slow sand filters .....	30
Disinfection .....	30
Water softening .....	31
Miscellaneous treatment methods .....	32
Other miscellaneous units of treatment plants .....	33
Intake .....	33
Pumping unit .....	33
Generating unit .....	34
Clear water storage .....	34
Workshop, Store and chemical shed .....	34
Operation house .....	34
Design example .....	35
9. Construction of treatment plants .....	39
10. Operation and maintenance .....	40
11. Water treatment at household level .....	47
Annex	

**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 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**

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**

<b>CPA</b>	- <b>Comprehensive Peace Agreement</b>
<b>DPA</b>	- <b>Darfur Peace Agreement</b>
<b>ESPA</b>	- <b>Eastern Sudan Peace Agreement</b>
<b>GLUMRB</b>	- <b>Great Lakes Upper Mississippi River Board of State Sanitary Engineers</b>
<b>GONU</b>	- <b>Government of National Unity</b>
<b>GOSS</b>	- <b>Government of Southern Sudan</b>
<b>MCRD</b>	- <b>Ministry of Cooperatives and Rural Development, GOSS</b>
<b>MIWR</b>	- <b>Ministry of Irrigation and Water Resources, GONU</b>
<b>MWRI</b>	- <b>Ministry of Water Resources and Irrigation, GOSS</b>
<b>NTU</b>	- <b>Nephelometric Turbidity Unit</b>
<b>PWC</b>	- <b>Public Water Corporation</b>
<b>SSMO</b>	- <b>Sudanese Standards and Measurement Organization</b>
<b>UNICEF</b>	- <b>United Nation Children's Fund</b>
<b>WATSAN</b>	- <b>Water and Sanitation</b>
<b>WES</b>	- <b>Water and Environmental Sanitation</b>
<b>WHO</b>	- <b>World Health Organization</b>

## 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

- **Possible treatment methods**

**a) Supply of raw water from lake or reservoir:** screening, coagulation & flocculation, sedimentation, rapid sand filtration, chlorination.

**b) Supply of raw water from river:** screening, pre-sedimentation, coagulation & flocculation, sedimentation, rapid sand filtration, chlorination.

**c) Groundwater source with no dissolved gases and undesirable minerals:**  
Chlorination

**d) Groundwater source with dissolved gases and undesirable minerals:**

(i) - aeration, oxidization with chlorine or potassium permanganate, rapid sand filtration and chlorination, or

(ii) -aeration, rapid mixing with soda ash, flocculation, sedimentation, rapid sand filtration and chlorination

The treatment processes of groundwater could include: **re-carbonation or fluoridation** if required.

- **Components of municipal drinking water treatment methods**

**a) Coarse screens:** bars of  $\Phi 25\text{mm}$  and spaced at 75 to 100mm centre to centre, placed on a slope of 1:3-6, maximum head loss through clogged screens is generally below 80cm.

**b) Plain sedimentation basins:** can be rectangular or circular and of horizontal or vertical flow types.

In horizontal flow types, the sedimentation basin is generally rectangular and the length is at least twice the width, whilst the maximum permissible velocity of water is 2.5mm/s.

To avoid scouring or uplift of settled particle, the ratio of length to depth or surface area to cross sectional area should be 10 or  $((L/H = A/a=(B \times L)/(B \times H)) = 10$ .

Detention time not less than 4 hours, overflow rate ( $V_0=Q/A$ ) is in the range of 20 to 33  $\text{m}^3/\text{m}^2 \cdot \text{d}$ . In case of Khartoum, it is between 20 to 40  $\text{m}^3/\text{m}^2 \cdot \text{d}$ .

Maximum weir loading is  $250\text{m}^3/\text{m} \cdot \text{d}$ .

-Circular sedimentation basins with a vertical flow have hopper bottoms and scraper arms for heavy sludge and the detention time is not less than 3 hours..

**c) Flocculator:**

-Depth of tank 3 to 4.5 m.

-Detention time 10 to 40 min, normal 30min.

- Velocity of flow 0.2-0.8m/s, normal 0.4m/s.
- Total area of paddles 10-25% of the cross-sectional area of tank
- Peripheral velocity of blades 0.2 to 0.6m/s, normal 0.2-0.4m/s
- Velocity gradient 10 to 75s
- Outlet flow velocity 0.15 to 0.25 m/s
- Retention time in flash mixers is 30 to 60 seconds

**d) Clarifier:** The principle of the design is the same as a plain sedimentation basin, except that

- Detention time is 2.5 to 3 hours.
- Overflow rate 1.0 to 1.2 m/hr
- Sludge is continuously scrapped by mechanical means

**e) Clariflocculator** (for combined flocculator and clarifier system)

- Mixing and flocculation time not less than 30min
- Minimum detention time 2 to 4 hours for turbidity removal in treatment of surface water and 1 to 2 hours for precipitation in lime-soda ash softening with the calculated detention time based on the entire volume of the flocculator-clarifier.
- Weir loading not exceeding 2.1 l/m.s for turbidity removal units and 4.1 l/m.s for softening units.
- Up flow rates not exceeding 0.68 litres per square meter second ( $l/m^2s$  for turbidity removal and  $1.19 l/m^2s$  for softening units.
- The volume of sludge removed from these units should not exceed 5% of the water treated for turbidity removal or 3% for softening.

**f) Rapid filters:** These can be either gravity filters or pressure filters.

**(i) Rapid gravity filters:** are open tanks where water passes through a filter medium (usually sand), by gravity.

- Filtration rates following flocculation and sedimentation are in the range of 1.4 to 6.8  $l/m^2s$ , with 3.4  $l/m^2s$  being the normal maximum design value.
- The depth of the tank may vary from 2.5 to 3.5m. Each unit may have a surface area of 20 to 50m<sup>2</sup>. They are arranged in series.
- The length to width ratio is maintained between 1.25 to 1.35. In addition to under drainage systems rapid sand filters have troughs made of corrugated iron or reinforced concrete spanning across the length or width of the walls for the distribution of influent water to be filtered during normal operation, and for collection of backwash water during the cleaning operation.
- Rapid filtration is not very efficient in removing all microorganisms, and must be followed by disinfection.
- Filter medium: Course sand is the most commonly used filter medium in rapid filters. Some filters contain a mixture of sand and larger particles of anthracite (effective size about 1mm). An effective size for single medium sand filters is 0.45 to 1.0mm. Uniformity coefficient ranges between 1.3 and 1.7. The specific gravity of the sand should be in the range of 2.55 to 2.65. The depth of the medium in the filter should be in the range of 0.5 to 1.0m.

- The sand is supported on a base material consisting of graded gravel layers. The total depth varies from 45 to 60 cm.
- The filter under-drain system can be made with pipe laterals with orifices, pipe laterals with nozzles, vitrified tile block, plastic dual-lateral block or plastic nozzles.

**(ii) Rapid pressure filters:** water passes under pressure through the filter in a closed container. Operation is similar to the gravity type rapid filter except that the coagulated water is generally applied directly to the filter without mixing, flocculation or conditioning and the filtration rate is much higher: the rate may vary from 6000 to 15,000 litres per hour per m<sup>2</sup> of filter area. This makes this type of filter system unreliable for the removal of bacteria. When used in large treatment works chlorination after filtration is very important and should be well monitored. Pressure filters are most popular in small municipal water plants to process ground water for softening and iron removal and are extensively used for the treatment of industrial water.

**g) Disinfection:** Water coming out of a filter unit, may contain bacteria and other micro-organisms, some of which may be pathogenic. Disinfection kills the microbes, making the water safe to drink and preventing water-borne diseases. Disinfection can be complicated and is best accomplished by skilled personnel, to avoid system breakdown and incorrect dosage. One of the most universal chemical methods used for disinfecting water is chlorination. Chlorine is cheap, reliable and easy to handle, and it may be applied to water in one of the following forms:

- As bleaching powder or hypochlorite
- As chloramodes
- As free chlorine gas
- As chlorine dioxide

#### **h) Removal of minerals and ions:**

**(i) Iron and manganese:** When these occur in water without organic mater, they need to be oxidized to form insoluble complexes, which can be coagulated, sedimented and filtered. Oxidation can be achieved by aeration. Once this is done, Iron and manganese can be removed by softening water by adding lime to the water to reach a pH of 8.2 for iron removal and a pH of 9.6 for manganese removal.

**(ii) Fluoride:** When the fluoride content of water is more than 1.5 parts per million (ppm), it may have a negative effect on human teeth and bones, and must be removed. The following methods are commonly used to remove fluoride:

- Calcium phosphate
- Bone charcoal (bone char)
- Synthetic tri-calcium phosphate
- Ion-exchange
- Lime
- Aluminium compounds (activated alumina)
- Activated carbon

-Most treatment methods use activated alumina or bone char. Water is percolated through insoluble, granular media to remove the fluorides. The media are periodically regenerated by chemical treatment after becoming saturated with fluoride ion.

**(iii) Reverse Osmosis:** In this method, water is forced through a membrane against the natural osmotic pressure by applying operating pressures between 2400 kPa and 10,300kPa (typical range 4,100.to 5,500 kPa). This results in the separation of water and ions. This process is used for desalinization of brackish and sea water. The basic reverse osmosis system consists of pre-treatment units, pumps to provide high operating pressures, post treatment tanks and appurtenances for cleaning and flushing, and a disposal system for rejected brine.

**i) Household treatment methods:** These include: boiling, filtration, disinfection with chlorination or solar disinfection.

**(i) Boiling** is a simple way of killing pathogens. Water must be brought to a rolling boil for at least one minute. If the water is turbid it should be boiled for at least five minutes. Water should be boiled, cooled and stored in the same container. If the water is transferred to another container for cooling, care should be taken to ensure that both the containers are clean and disinfected.

**(ii) Filtration:** There are several types of household filters such as candle filter, stone filter, household sand filter etc.

**(iii) Chlorination:** When disinfecting household drinking water one percent chlorine is added to the water and left for 20 minutes to allow sufficient contact time for the chlorine to work. It is important to use the correct amount of chlorine, as too little will not kill all the germs present and too much may make the water unpalatable, causing it to be rejected by the consumer. As a general rule, three drops of chlorine solution should be added to every litre of water. This can be done using a simple dropper tube or syringe. Sodium hypochlorite or liquid bleach and calcium hypochlorite (the best type high test hypochlorite (HTH) are commercially available.

Sodium hypochlorite can be added directly from the bottle, as it comes in a chlorine concentration of 1%. If calcium hypochlorite or HTH are used, they will need to be diluted to one percent before being added to the water. Check the manufacturer's instruction on the container to determine the quantity of powder required to make a one percent solution. A small amount of residual chlorine in the water will continue to keep it germ-free and help prevent re-contamination

**(iv) Solar disinfection:** This is an effective water treatment method, especially when no chemical disinfectants are available. Ultraviolet rays from the sun are used to inactivate pathogens present in water. This technique involves exposing water in clear plastic bottles to strong sunlight for 6 to 8 hours (or longer if the sun is obscured by cloud). Bottles must be cleaned, filled three quarters and shaken thoroughly 20 times, before being filled to the top. The water can be consumed directly from the bottle or transferred to a clean glass. Solar disinfection is more effective when the water is relatively clear (not turbid).

**(v) Storage of treated water:** Treated household drinking water can be kept clean by using good storage containers, which need to be well designed to ensure protection from contamination. Two important factors that influence contamination of water in storage containers are: the presence of a lid or cover and the way water is drawn from the container. A container without a lid or cover will allow water to become contaminated rapidly, and water must only be drawn from the container with a ladle or scoop.

## **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.

## **2 Natural Water and common impurities in water and their effect**

Natural water can be collected from various sources like rain, surface runoff, river, lake, pond, swamp and ground water. It is not possible to find absolute pure water in nature. Chemically pure water contains two parts of hydrogen and one part of oxygen. Depending largely upon the source, the purity of water and its suitability for different purposes varies.

The primary objective of water treatment and purification is to treat water collected from the best available source to improve the physical quality, making it free from unpleasant taste or odour and ensuring it is free from contaminants harmful to health.

Impurities in water are classified into: a) suspended impurities, b) dissolved impurities, and c) colloidal impurities. Suspended impurities are microscopic and normally remain in suspension, making the water turbid. Dissolved impurities are not visible, but cause bad taste, hardness and alkalinity. Colloidal impurities are electrically charged particles,

usually very small in size that remain in constant motion and do not settle. Table 1 lists the constituents of suspended and dissolved impurities in water and their effect.

Table 1: Suspended and dissolved impurities in water<sup>1</sup>

Type	Constituents	Effect
1. Suspended impurities	a) Bacteria b) Algae, Protozoa c) Silts	-Some cause disease -Odour, colour, turbidity -Murkiness or turbidity
2. Dissolved impurities	a) Salts i) Calcium and Magnesium Bicarbonate Carbonate Sulphate Chloride ii) Sodium Bicarbonate Carbonate Sulphate Chloride Fluoride b) Metals and compounds i) Iron oxide  ii) Manganese iii) Lead iv) Arsenic v) Barium vi) Cadmium vii) Cyanide viii) Boron ix) Selenium x) Silver xi) Nitrates c) Vegetable dyes d) Gases Oxygen Carbon dioxide Hydrogen sulphide	-Alkalinity -Alkalinity, hardness -Hardness -Hardness, corrosion  -Alkalinity, softening effect -Alkalinity, softening effect -Foaming in boilers -Taste -Dental flurosis or mottled enamel  -Taste, red colour, corrosiveness, hardness -Black or brown colour -Cumulative poisoning -Toxicity, poisoning -Toxic effect on heart, nerves -Toxic, illness -Fatal -Affect central nervous system -Highly toxic to animals, fish -Discolouration of skin, eyes -Blue baby conditions, infant poisoning, colour, acidity  -Corrosiveness to metals -Acidity, corrosiveness -Odour, acidity, corrosiveness

### 3 Water demand and quantity

<sup>1</sup> Water Supply Engineering, B.C. Punmia, Ashok Jain, Arun Jain

Before designing a water works project, it is essential to determine the quantity of water that will be required daily, based on the number of population to be served and the rate of demand per capita per day.

Determination of population growth in the community to be served is important to ensure water supply throughout the design period.. In most circumstances, a design period of 15 to 30 years is selected. Various methods can be used to forecast the population at the end of the design period. These include: arithmetic increase; geometrical increase or uniform percentage increase; incremental increase; etc.

The population growth of a city/ town etc. depends upon a number of factors which include:

- Social customs: Living habits, education level in the community, customs etc
- Social factors: The establishment of educational, recreational, medical and other social facilities.
- Economic factors: Development of new or expansion of industries, discovery and exploitation of minerals, oil, establishment of market outlets etc.
- Development activities: Development of projects or programmes of regional or national importance.
- Tourism: Religious places, tourist facilities etc.
- Communication links: Connection of the city/town with other big cities of national and regional domain.
- Unforeseen factors: Conflicts, earthquakes, floods, epidemics etc

Water requirements of a city/town can be divided into five categories: domestic or residential use, institutional use, public or civic use, industrial use, and water system losses

a) Domestic or residential use: includes water for drinking, cooking, and bathing, washing of clothes, utensils and house and flushing of water closets. The demand varies from place to place and from country to country as seen in Table 2.

Table 2: Domestic use in different countries

Country	Average domestic water demand (l/c/d)
India <sup>2</sup>	135
Germany <sup>3</sup>	204
Sudan (Khartoum) <sup>4</sup>	90 - 120
Sudan (Gedarif, Kassala, Nyala) <sup>5</sup>	60
Sudan (Wad Medani) <sup>6</sup>	125

Demand can also vary within a city depending on the standard of living, type of building/facility etc. For example, in Khartoum, the city is divided into three classes with

<sup>2</sup> Indian Standard IS 1172

<sup>3</sup> Bautabellen, Schneider WIT 40, 6 Auflage, Werner-Verlag, 1984

<sup>4</sup> Source : Khartoum State Water Corporation

<sup>5</sup> PWC: Feasibility study and preliminary design for Wad Medani Water Supply

<sup>6</sup> Ibid

the domestic demand 150-200, 120-150 and 80 -100 l/c/d for first, second and third class areas respectively. For Gedaref, Kassala and Nyala towns, the domestic demand is 110, 75 and 40 l/c/d for the first, second and third class areas respectively, whilst it is 200, 150 and 100 l/c/d for Wad Medani.<sup>7</sup> In rural areas of Sudan, the current demand is set at 20 l/c/d. The development of new water sources aim to meet the demand of 50 l/c/d by 2015.

b) Institutional use: also differs by country., Table 3 shows average water requirement of some selected institutions in Germany and India. This data is not available for Sudan.

Table 3: Water requirement for some selected institutions in Germany and India

Institution	Water requirement (l/c/d)	
	Germany	India
Hospitals	250-600	340-450
Schools	10-50	45-135
Offices	40-60	45
Hotels	200-600	135-180
Restaurants	100-1000	70

c) Public or civic use: includes water for road washing, sanitation, public parks and fire fighting. This varies from 11-14 l/c/d in countries like India and is much higher in developed countries.

d) Industrial use: Water requirement depend on the type of industry, and this should be taken into account during planning. A city with a moderate number of factories will require 20-25% of per capita consumption allowance. In Khartoum this is in the range of 15%.<sup>8</sup>

e) Water system losses from a water distribution system are due to leakage from main and service pipe connections, leakage and overflow from reservoirs, leakage and losses on un-metered household supplies, leakages from public taps etc. This rate varies in the range of 20-50%: well maintained and fully metered distribution systems have the lowest rate, while partly metered domestic connections and partly un-metered municipal taps have the highest rates. In Khartoum, unaccounted-for water has been observed in the range of 35-50% for old network systems and 10% for new networks<sup>9</sup>.

Factors affecting water demand are: type and size of the community, standard of living, climatic condition, pressure in the supply, quality of water, water tariff and metering etc.

The per capita water demand varies from year to year, season to season, day to day and hour to hour. These variations affect the design of every unit of a water supply system, and are addressed with a value of hourly or daily peak factor .

#### **4 Requirements of water for domestic use**

<sup>7</sup> Ibid

<sup>8</sup> Ibid

<sup>9</sup> Ibid

Water for domestic use should be:

- Colourless, sparkling clear, free from solids in suspension and must not deposit sediment on standing;
- Free from odour and taste good;
- Reasonably soft;
- Free from disease producing bacteria or organisms;
- Free from objectionable dissolved gases, such as sulphuretted hydrogen and must contain a sufficient quantity of dissolved oxygen;
- Free from harmful salts;
- Free from objectionable minerals, such as iron, manganese, lead, arsenic and other poisonous metals;
- Free from radio-active substances such as radium, strontium etc;
- Free from phenolic compounds, chlorides, fluoride and iodine;
- Non-corrosive and not lead to scale formation.

## **5 Water quality analysis**

Impurities in water can be determined by water analysis. Water analysis is used to classify, prescribe treatment, control treatment and purification processes and maintain public supplies of water of an appropriate standard of organic quality, clarity and palatability. The analysis of raw water enables the choice of the process for water purification. Analysis at the various stages of treatment allows monitoring the effectiveness of the treatment process, and the analysis of purified water ensures the correct degree of purification, as per required standards, is obtained. Water analysis may be divided into physical, chemical and microbiological analysis.

### **5.1 Physical analysis**

Physical analysis tests include for: colour, taste and odour, temperature and turbidity .

Water gets its colour from organic matters either dissolved or in colloidal suspension. The intensity of colour in water is measured by True Colour Unit (TCU)., This should be 15 TCU for a public water supply.

The presence of mineral salts, tarry substances, industrial wastes, domestic sewage, decomposing organic matter, certain types of microorganisms or chemical compounds such as phenols etc. impart taste and odour to the water. These physical characteristics are difficult to measure quantitatively, because of personal factors related to taste and odour, atmospheric conditions of impurity, temperature and humidity. Odour can be measured by the threshold odour number. This should not be more than 3 for a public water supply.

The palatability of water is dependant on various factors, unique to each system, and every system should determine the best approach for prevention and cure. Aeration is frequently effective in groundwater treatment since the odour causing compounds are often dissolved gases that can be removed from solution. However, aeration is rarely

effective in processing surface waters where the odour-producing substances are generally non-volatile.

The ideal temperature of water from a public water supply is between 10°C to 20°C. Water at a temperature higher than 25°C is considered objectionable.

Turbidity in water is imparted by the colloidal matter present in water. The colloidal matter may be clay and loam or microscopic organisms. In Sudan, the maximum permissible value of turbidity for public water supply is less than 5 NTU.

## **5.2 Chemical analysis**

Chemical analysis is carried out to determine total solids, hardness, chlorides, pH value, nitrogen and its compounds, dissolved gases, metals and other chemical substances like phenols.

To determine the total solids, the amount of suspended, dissolved and colloidal solids is determined separately and then added together. High solid contents indicate either contamination or presence of excessive mineral matters. The recommended amount of total solids is less than 500 mg/l (or ppm).

Hard water contains larger amounts of salts, such as carbonates, bicarbonates, chlorides and sulphates of calcium and magnesium..

The pH value or the hydrogen-ion concentration of water is a measure of the degree of acidity or alkalinity of the water. The measurement of the pH allows classification, and correlation with other characteristics or behaviours such as corrosive activity or other inter-related factors controlling biological function in a body of water. Its knowledge is also helpful in controlling the softening and coagulation processes in water treatment.

Nitrogen can be present in water in four different forms: ammoniac nitrogen (free and saline ammonia), albuminoidal nitrogen, nitrite and nitrate. The occurrence of free ammonia indicates the direct inclusion of organic matter, particularly that from the excrement (urine) of animals and humans. Surface water may get polluted from the discharges of gas industries. Groundwater drawn from strata overlaid with clay may sometimes suffer de-oxygenation and comparatively large quantities of free ammonia can arise from reduction of nitrate. Albuminoidal nitrogen is normally derived from animal and plant life normal to the aquatic environment and its presence gives an indication of organic pollution in a water supply. Trace amounts of nitrite, in raw surface supplies, indicate the presence of pollution while nitrate in pure well waters derived from an extensive catchment is largely the result of biological activity in the surface layers of the soil, enhanced by cultivation and the application of manure.

## **5.3 Microbiological analysis**

Microbiological analysis of water includes bacteriological and biological examination. Bacteriological examination is aimed at determining the fitness of water for use for human consumption, and for use in industries such as food processing and dairy.

Biological examination is aimed at determining the presence of microscopic organisms, other than bacteria, such as algae, moulds or fungi, yeasts, protozoa etc., which can affect the quality of water for drinking and industrial uses.

Drinking water must be free of all pathogenic microorganisms. Testing water for a broad diversity of pathogens (viruses, bacteria, protozoa, and helminthes) is not practically feasible because of the complexity and the long time required for conducting the laboratory analyses for all these types of pathogens. The bacteriological examination of water should have the following purposes:

- To detect and assess the degree of excremental pollution in the supply source.
- To assess the amount of treatment required to render the supply safe for consumption.
- To ascertain the efficiency of the purification treatment at various stages.
- To locate the cause of any sudden deterioration in quality.
- To establish the bacterial purity of final water as it leaves the purification works and to demonstrate the persistence of this high quality in the distribution system and in the premises of the consumer.

Indirect evidence of the presence of pathogenic bacteria in water can be obtained by testing the water for indicator organisms. Faecal bacteria, although harmless in their normal habitat, indicate pollution if found in water and this water must be deemed a potential health hazard. Coliforms and *Escherichia coli* (E-coli) are normally used as indicator organisms, since they are present in larger numbers than other pathogens. They are also identifiable by relatively simple, rapid and economic procedures.

The removal of microorganisms from drinking water is accomplished by physical and/or chemical processes (chemical coagulation and granular media filtration, and disinfection).

## **6 Common water-borne diseases**

Water-borne diseases are caused by pathogenic organisms carried by water contaminated with faeces or sewage. Water-borne diseases are classified into four groups: bacterial, protozoan, viral and helminthic (worm) diseases. These include: typhoid fever, paratyphoid fever, dysenteries (both amoebic and bacillary), gastro-enteritis, infectious hepatitis, schistosomiasis and Asiatic cholera. Guinea worm disease is a serious problem for many communities in parts of Sudan. Drinking water quality standards have been established to ensure that the process of water treatment, conveyance, storage and distribution eliminates the presence of these diseases causing factors from drinking water.

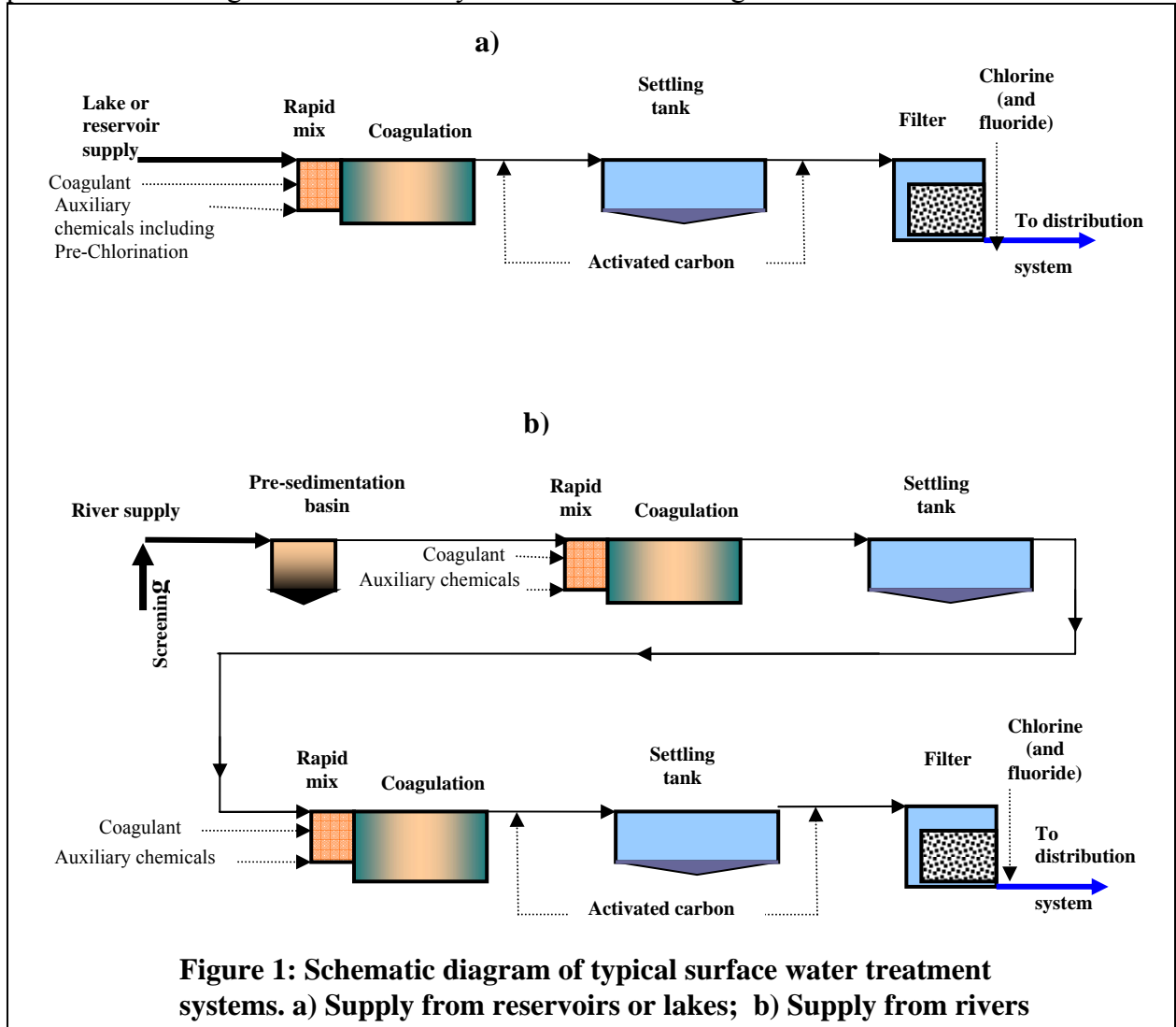
## **7 Drinking Water Quality Standards**

The development of standards for water quality is of paramount importance for every nation. The World Health Organisation, the leading agency in this regard, is a referral point for many countries in the world and has prepared guideline values for drinking water standards. Some countries also have their own additional guidelines The SSMO,

2008 parameters for Sudan as compared to WHO guidelines of 2006 can be seen in Annex No 1.

## 8 Drinking Water Treatment

Common water sources for municipal water supplies are deep wells, shallow wells, rivers, natural lakes, and reservoirs. Depending on the quality of the raw water, the extent of pollution and the regulations for safeguarding of public health, drinking water is treated by various methods before it reaches the consumer. Some typical schematic patterns of drinking water treatment systems are shown in Figures 1 and 3.



**Figure 1: Schematic diagram of typical surface water treatment systems. a) Supply from reservoirs or lakes; b) Supply from rivers**

Pollution and eutrophication are major concerns in surface water supplies. Water quality depends on agricultural practices in the watershed areas, location of municipal and industrial outfall sewers, river development such as dams, season of the year, and climatic conditions. Periods of high rainfall flush silt and organic matter from cultivated fields and forest land, while drought flows may result in higher concentrations of wastewater pollutants from sewer discharges.

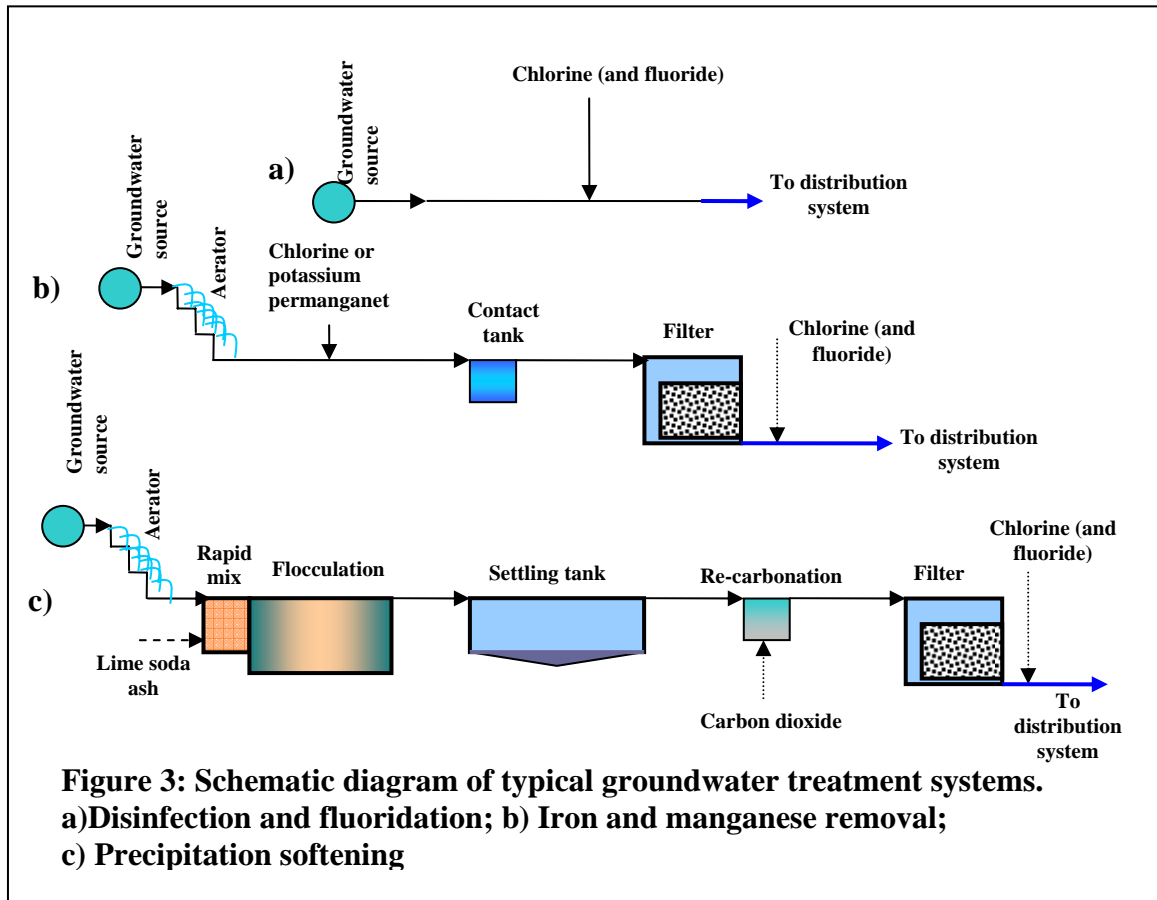
The primary process in surface water treatment is chemical clarification by coagulation, flocculation, sedimentation, and filtration. Lake and reservoir water has a more uniform year round quality and requires a lesser degree of treatment than river water. Natural purification results in the reduction of turbidity and coliform bacteria, and the elimination of day-to-day variations. On the other hand, algal growth cause increased turbidity and may produce difficult-to-remove tastes and odours. The choice of chemicals to coagulate the water for removal of turbidity depends on the character of the water and economic conditions. The most popular coagulant is alum (aluminium sulphate). As a flocculation aid, the common auxiliary chemical is a synthetic polymer. Activated carbon is applied to remove taste and odour-producing compounds. Chlorine and fluoride are post treatment chemicals. Pre-chlorination may be used for disinfection of the raw water only if it does not result in formation of trihalo-methanes.



**Figure 2: River intake of a treatment plant in Khartoum**

River supplies normally require the most extensive treatment facilities with greater operational flexibility to handle the day-to-day variations in raw water quality. The preliminary step is often pre-sedimentation to reduce silt and settle-able organic matter prior to chemical treatment. Many river water treatment plants have two stages of chemical coagulation and sedimentation. The units may be operated in series or by split treatment, with softening in one stage and coagulation in the other. As many as a dozen

different chemicals may be used under varying operating conditions to provide satisfactory finished water.



Well supplies normally yield cool, uncontaminated water of uniform quality that is easily processed for municipal use. Processing may be required to remove dissolved gases and undesirable minerals. The simplest treatment is disinfection and fluoridation. Deep well supplies may be chlorinated to provide residual protection against potential contamination in the water distribution system. In the case of shallow wells not under the direct influence of surface water, chlorination serves to disinfect the groundwater and provide residual protection. Fluoride is added to reduce the incidence of dental caries. Dissolved iron and manganese in well water oxidize when they come in contact with air, forming tiny rust particles that discolour the water. These can be removed by oxidizing the iron and manganese with chlorine or potassium permanganate, and removing the precipitates by filtration.

Excessive hardness is commonly removed by precipitation softening. Lime and, if necessary, soda ash are mixed with well water, and settle-able precipitate is removed. Carbon dioxide is applied to stabilize the water prior to final filtration. Aeration is a common first step in the treatment of most ground waters to strip out dissolved gases and add oxygen.

The two primary sources of waste from water treatment processes are sludge from the settling tank, resulting from chemical coagulation or softening reactions, and wash water from backwashing filters. These discharges are highly variable in composition, containing concentrated materials removed from the raw water and chemicals added in the treatment process. The wastes are produced continuously, but are discharged intermittently. Because of the unique characteristics of each plant's waste, no specific process can be applied for the disposal of plant wastes. A variety of methods can be applied, for example, piping to the municipal sewer for processing or to the nearby watercourse downstream of the intake (if the environmental protection law allows this) as seen in Figure 4 or discharged to lagoons provided a sufficient land area is available.



**Figure 4: Sludge from flocculator-clarifiers of a treatment plant that is being discharged to the near-by water course.**

## **8.1 Screening and Aeration**

Water from surface sources may contain suspended matter including floating debris such as sticks, branches, leaves etc. or fine particles such as sand, silt etc, which cause turbidity. Screens, which serve as a protection for succeeding parts of water treatment can be of two types: a) coarse screens, and b) fine screens.

Coarse screens mostly in the form of bar grills are intended to intercept only larger floating materials. The bars are generally of diameter 25 mm and are spaced at 75 to 100 mm centre to centre. They are generally kept inclined on a slope of 1 horizontal to 3 to 6 of vertical, to facilitate cleaning with a rake. The head loss through unobstructed screens depends upon the nature of their construction (shape of the screen element, open area, blocked area etc), as well as the approach velocity head. The empirical relationship and

coefficients suggested by Kirshmer could be used to calculate the head loss through racks and screens as

$$h = \beta(w/b)^{4/3} h_v \sin\theta \dots\dots\dots^{10}$$

Where:

h = head loss

$h_v$  = approach velocity head

b = minimum width of clear opening between pairs of bars

$\theta$  = angle of rack with horizontal

$\beta$  = a shape factor (2.42 for sharp-edged rectangular bars, 1.83 for rectangular bars with semi-circular upstream face and 1.79 for circular rods)

The maximum head loss through clogged racks and screens is generally below 80cm. Fine screens are used at surface water intakes, sometimes alone, sometimes following a bar screen. In order that fine screens do not get clogged, a continuous cleaning device is setup involving the arrangement of fine screens as endless bands or drums of material perforated with holes of about 6mm diameter.

Aeration is important for gas transfer and is done to accomplish the following:

- It removes tastes and odours caused by the gases as a result of organic decomposition.
- It increases the dissolved oxygen content of the water.
- It removes hydrogen sulphide, and odours associated with this gas.
- It decreases the carbon dioxide content of water, thereby reducing its corrosiveness and raising the pH.
- It converts iron and manganese from soluble states to insoluble precipitates that can be removed.
- The agitation of water during aeration, may destroy some bacteria..

Aeration is accomplished by various types of aerators, including free fall (or gravity) aerators, spray aerators, and air diffuser basins. Aeration has the following limitations:

- It is not an efficient method of removal of tastes and odours caused by: relatively non-volatile substances such as algal oils, chemicals left by industrial wastes and some organism e.g. Odour removal was only 50% when *Symura* was the causative organism.
- The addition of more oxygen in water (to removing iron and manganese), may make it more corrosive.
- Iron and manganese can be precipitated by aeration only when organic matter is not present.
- Air-borne contamination of water is possible.
- Additional lime may be required to neutralize  $CO_2$  that would be removed by aeration.
- Aeration is economical only in warmer months.

---

<sup>10</sup> Water Supply Engineering, B.C. Punmia, Ashok Jain, Arun Jain

## 8.2 Sedimentation

Sedimentation is the process of removal of suspended particles by gravitational settling. Sedimentation Tanks are designed to reduce the velocity of the flow of water to allow suspended solids to settle by gravity. Sedimentation tanks can be of either fill and draw type or continuous flow type, depending on the type of operation,. The continuous flow type can be horizontal or vertical. In the horizontal flow type, the tank is generally rectangular in with the length at least twice the width. The water flows horizontally, with a maximum permissible velocity of 0.3 m/s. Vertical flow type tanks are generally deep, circular or rectangular basins with hopper bottoms. In order to prevent the scouring or uplifting of a particle that has settled in the sludge zone, the relation of length (L) to depth (H) in the rectangular basin, or of the surface area (A = B x L) to cross-sectional area (a = B x H) must be:

$$L/H = A/a = 10 \dots \dots \dots^{11}$$

The common criteria for sizing settling basins are detention time, overflow rate, weir loading and for rectangular tanks, horizontal velocity. Detention time, expressed in hours, is calculated by dividing the basin volume by the daily average flow. i.e.

$$t = (V \times 24) / Q$$

Where:

- t = detention time (hr)
- V = basin volume (m<sup>3</sup>)
- Q = average daily flow (m<sup>3</sup>/d)
- 24 = number of hours per day

The overflow rate (surface loading) is equal to the average daily flow divided by total surface area of the settling basin. i.e.

$$V_0 = Q / A$$

Where:

- V<sub>0</sub> = overflow rate (surface loading) in m<sup>3</sup>/m<sup>2</sup>/d
- Q = average daily flow (m<sup>3</sup>/d)
- A = total surface of basin in m<sup>2</sup>

Most settling basins in water treatment plants are essentially up-flow clarifiers where the water rises vertically for discharge through effluent channels.

Weir loading is computed by dividing the average daily quantity of flow by the total effluent weir length expressed in m<sup>3</sup>/m/d. Sedimentation basins, either circular or rectangular, are designed for slow uniform water movement with a minimum of short circuiting.

---

<sup>11</sup> Ibid

For sedimentation basins, following chemical flocculation, the *Great Lakes Upper Mississippi River Board of State Sanitary Engineers* (GLUMRB) recommend a detention time of not less than 4hr. The maximum recommended horizontal velocity through the sedimentation basin is 2.5mm/s and the maximum weir loading is 250 m<sup>3</sup>/m.d. The overflow rate is generally in the range of 20 to 33 m<sup>3</sup>/m<sup>2</sup>.d. In Khartoum it is 20 to 40 m<sup>3</sup>/m<sup>2</sup>.d.<sup>12</sup>

Pre-sedimentation basins may be installed for muddy river water, to allow heavy solids to settle prior to chemical flocculation and sedimentation. Generally, circular sedimentation tanks with hopper bottoms and scraper arms are used for heavy sludge. The recommended GLUMRB standard is a detention time of not less than 3 hr.

### 8.3 Coagulation/Flocculation

Flocculation is the controlled motion or agitation of water which will assist in the formation of settle-able floc formation. Finer particles must be chemically coagulated to produce larger floc that is removable in subsequent settling and filtration processes. Coagulation and flocculation are sensitive to factors such as type and nature of turbidity-producing substances, concentration of turbidity, type of coagulant and its dose, the rate of change of velocity per unit distance normal to a section, the pH of the water etc.

Commonly used metal coagulants in water treatment are (1) based on aluminium such as aluminium sulphate, sodium aluminates, potash alum, and ammonia alum, and (2) based on iron such as ferric sulphate, chlorinated ferrous sulphate, and ferric chloride. Aluminium sulphate is the most widely used coagulant. Synthetic polymers are used as coagulant aids to improve settling and toughness of floc.

Jar tests are widely used to determine optimum chemical dosages for treatment. This laboratory test attempts to simulate the full scale coagulation-flocculation process and can be conducted for a wide range of conditions. The interpretation of test results involves visual and chemical testing of the clarified water.

Flocculation can be achieved by various methods which include: Gravitational or hydraulic methods (such as horizontal flow baffled flocculator, vertical flow baffled flocculator, jet flocculator etc), mechanical methods (such as paddle flocculators), and pneumatic methods.

The following design criteria are commonly adopted in a flocculator<sup>13</sup>:

- Depth of tank 3 to 4.5 m
- Detention time 10 to 40 min; normal 30min
- Velocity of flow 0.2 to 0.8 m/s; normal 0.4 m/s
- Total area of paddles 10 to 25% of the cross-sectional area of the tank

---

<sup>12</sup> Khartoum Water Corporation

<sup>13</sup> Water Supply Engineering, B.C. Punmia, Ashok Jain, Arun Jain

- Peripheral velocity of blades            0.2 to 0.6 m/s; normal 0.3 to 0.4 m/s
- Velocity gradient                            10 to 75 s<sup>-1</sup>
- Outlet flow velocity                        0.15 to 0.25 m/s
- The retention time in flash mixers      30 to 60 seconds.

## 8.4 Clarification

After flocculation, water enters the settling tank, commonly known as a clarifier. Water is retained for a sufficient period of time to allow the floc to settle at the bottom of the clarifier. The principles of design of a clarifier are the same as for plain sedimentation basins, except that the detention time in this case is lower – usually 2.5 to 3 hours with an overflow rate of 1 to 1.2 m/hr. Sludge is continuously scrapped by mechanical means. In modern practice, the flocculator and clarifier are provided in one single unit called a clariflocculator, in which the flocculating chamber is based in the centre and the clarifier compartment is formed by the peripheral space. Clariflocculators, also referred as up-flow tanks combine the processes of mixing, flocculation, and sedimentation in a single compartment tank. The GLUMRB standards for clariflocculators are:

- Mixing and flocculation time of not less than 30 minutes based on the total volume of mixing and flocculation zones.
- Minimum detention time of 2 to 4 hours for turbidity removal in treatment of surface waters and 1 to 2 hours for precipitation in lime-soda ash softening of ground water with the calculated detention time based on the entire volume of the flocculator-clarifier.
- Weir loading not exceeding 2.1 litres per meter second for turbidity removal units and 4.1 litres per meter second for softening units
- Up flow rates not exceeding 0.68 litres per square meter second (l/m<sup>2</sup>s) for turbidity removal units and 1.19 l/m<sup>2</sup>s for softening units.
- The volume of sludge removed from these units should not exceed 5% of the water treated for turbidity removal or 3% for softening.

## 8.5 Filtration

Filtration is a process of removing of non-settleable floc remaining after chemical coagulation and sedimentation through a granular media. Filtration rates following flocculation and sedimentation are in the range of 1.4 to 6.8 l/m<sup>2</sup>s. For the practical implementation, the value of 3.4 l/m<sup>2</sup>s is used as the maximum design value.

These guidelines discuss rapid gravity filters and pressure filters. Slow sand filtration, which is another important type of filter, is dealt with in a separate set of guidelines.

### 8.5.1 Rapid gravity filters

Rapid gravity filters are open tanks where water passes through a filter medium, usually sand, by gravity. The tanks can be covered with a shed (Figure 5). Filters with a shed have the advantage that algae growth and dust accumulation in the filters is prevented.

Water is supplied to the top of a bed of sand, which is supported on a bed of graded sand gravel with a drain system underneath .



**Figure 5: Gravity filters with shed (under construction) and without shed in Khartoum**

The tank is generally rectangular, constructed of either masonry or concrete, and coated with water proof material. The depth of the tank may vary between 2.5 to 3.5m. Each unit may have a surface area of 20 to 50m<sup>2</sup>. The tanks are arranged in series. The length to width ratio is normally maintained between 1.25 to 1.35. In addition to under drainage systems, rapid sand filters have troughs made of corrugated iron or reinforced concrete spanning across the length or width of the walls for the distribution of influent water to be filtered during normal operation, and for collection of backwash water during the cleaning operation. During the normal filtration operation, the troughs remain submerged.



**Figure 6: New municipal water treatment plant under construction in Juba city, Southern Sudan**

A rapid filter does not efficiently remove fine suspended solids. It is therefore essential that coagulation and flocculation should be performed prior to rapid filtration. A well operated rapid filter will reduce turbidity to less than 1NTU and often less than 0.1 NTU. Rapid filtration is not very efficient in removing all micro organisms, and should be followed by terminal disinfection.

In order to force the water through the sand, a depth of about 1.5 to 2 meters<sup>14</sup> (0.9 to 1.2m)<sup>15</sup> of water must be maintained above the sand. The filtration rate in rapid gravity filters varies widely and many installations are designed in the range of 4 to 12 meters per hour.

### 8.5.1.1 Filter medium

Filter media could be single, dual or multimedia. Coarse sand is the most commonly used filter medium in rapid filters. Some filters contain a mixture of sand and larger particles of anthracite (effective size about 1mm). After backwashing, the larger, lighter anthracite particles settle on top of the sand. Water is therefore filtered consecutively through coarse anthracite and then less coarse sand. This enables longer filter runs between cleaning.

Effective size for single medium sand filters is 0.45 to 1.0mm (0.45 to 0.55mm<sup>16</sup> or 0.45 to 0.70 mm<sup>17</sup> or 0.5 to 1.0mm<sup>18</sup>). Uniformity coefficient is not less than 1.3 or more than 1.7. The specific gravity of sand is in the range 2.55 to 2.65. Additionally the sand filter medium should satisfy the following criteria:

- The sand should be of hard and resistant quartz or quartzite and free of clay, fine particles, soft grains and dirt.
- Ignition loss should not exceed 0.7 percent.
- Soluble fraction in hydrochloric acid should not exceed 5% by weight.
- Wearing loss should not exceed 3%.

A coal-sand dual medium filter uses relatively coarser anthracite at the top of the medium with an effective size between 0.9 to 1.1mm and a specific gravity of 1.4 to 1.6 over a finer sand layer of effective size 0.45 to 1.0mm. The uniformity coefficient of anthracite should be less than 1.7. The upper layer of coarse anthracite has voids about 20% larger than the sand, and thus a coarse-to-fine grading of media is provided in the direction of flow. After backwashing, the bed stratifies with the heavier sand on the bottom and the lighter, coarser coal medium on the top. Larger floc particles are absorbed and trapped in the surface of the coal layer, while fine material is held in the sand filter; therefore, the bed filters in greater depth, preventing premature plugging.

The depth of the medium in the filter should be in the range of 0.5 to 1.0m. The filter sand media is supported on base material consisting of graded layers of gravel which should be free from clay, dirt, vegetable and organic matter, and should be hard, durable and round. The total depth of the base material varies from 45 to 60 cm and is layered as below<sup>19</sup>:

---

<sup>14</sup> Fact sheet No 2.14, WHO

<sup>15</sup> Water and Wastewater Technology, Mark J. Hammer and Mark J. Hammer Jr

<sup>16</sup> Ibid

<sup>17</sup> Water Supply Engineering, B.C. Punmia, Ashok Jain, Arun Jain

<sup>18</sup> Fact sheet No 2.14, WHO

<sup>19</sup> Water Supply Engineering, B.C. Punmia, Ashok Jain, Arun Jain

Layer	Depth	Grade size
Top most	15cm	2 to 6mm
Intermediate	15cm	6 to 12mm
Intermediate	15cm	12 to 20mm
Bottom most	15cm	20 to 50mm

### 8.5.1.2 Filter under drains

The function of an under drain is to support the filter media, collect the filtered water, and distribute backwash water and air scouring. The various types of under drainage systems are indicated below:

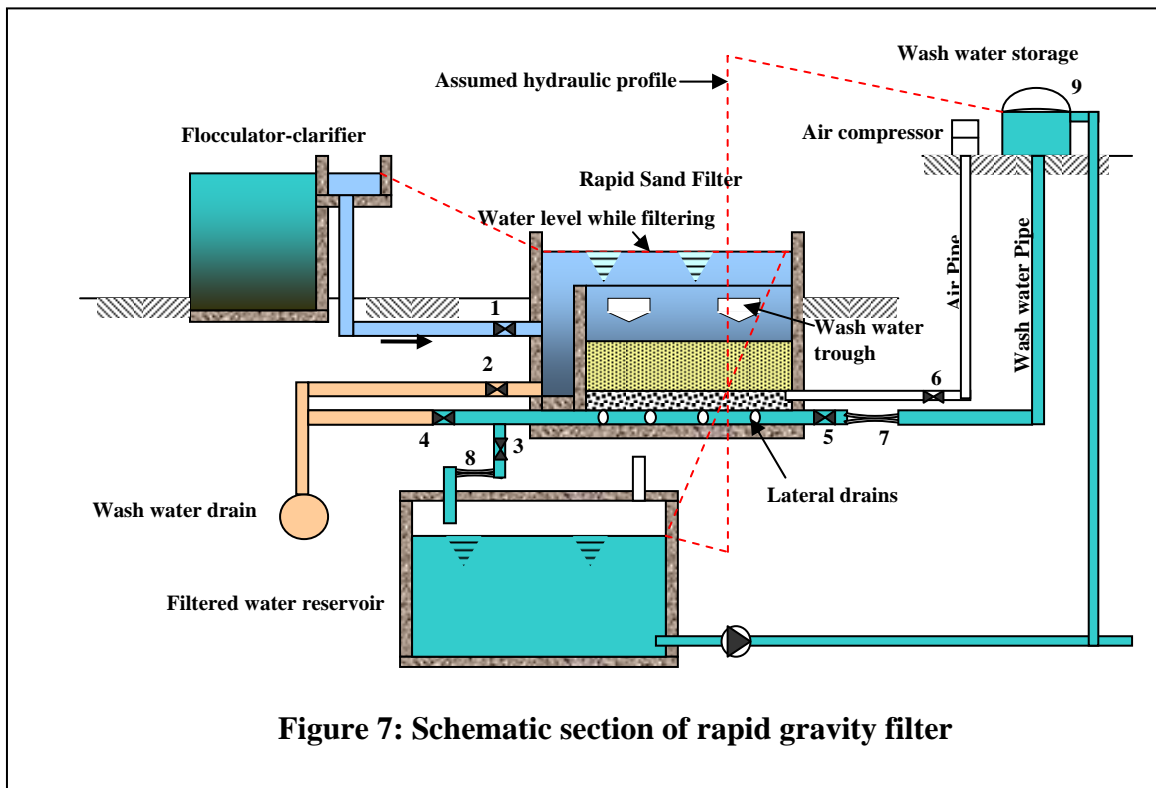
Under drain system	Characteristics
Pipe laterals with orifices	Deep gravel layer, medium head loss, no air scour
Pipe laterals with nozzles	Shallow gravel layer, high head loss, air scour
Vitrified tile block	Shallow gravel layer, medium head loss, no air scour
Plastic dual-lateral block	Shallow gravel layer, low head loss, air scour or concurrent air-and-water scour
Plastic nozzles	Shallow or no gravel layer, high head loss, air scour or concurrent air-and-water scour

Some under drain systems allow separate air scouring before water backwash some do not allow air scouring, whilst some allow concurrent air-and water-scouring.

The following points need to be observed in designing under drainage systems with a perforated pipe system:

- Ratio of length to diameter of lateral should not exceed 60. The spacing of laterals closely approximates the spacing of orifices and shall be from 150 to 300mm.
- Diameter of perforations in the lateral should be between 5 and 12mm.
- The spacing of perforations varies from 80mm (for 5mm perforation) to 200mm (for 12mm perforations).
- The ratio of the total area of perforations in the under drainage system to total cross-sectional area of laterals should not exceed 0.5 (for 12mm perforations) and should decrease to 0.25 (for 5mm perforations).
- The ratio of the total area of perforations in the under drainage system to the entire filter area may be as low as 0.002 to 0.003.

- Area of manifold should preferably be 1.5 to 2 times the total area of laterals, to minimize frictional losses and for best distribution



**Figure 7: Schematic section of rapid gravity filter**

Back washing: The filter medium is washed when the loss of head through it has reached the maximum permissible. Rapid filters are washed by sending air and water upwards through the bed by reverse flow through the collector system in the sequence indicated below:.

- Close influent valve 1. Allow the filter to operate till the water level reaches the edge of the troughs. Some water treatment operators permit the water level to fall to about 15cm from the top of the sand.
- Close effluent valve 3
- Open air valve 6, so that air blows back through the collector system at a rate of 1 to 1.5 m<sup>3</sup> free air per minute per m<sup>2</sup> of bed area at a pressure of 0.5 bar for about 2 to 3 minutes. This will break up the surface scum and loosen the dirt. Where air distribution system and water collector systems are separate, both air and water are circulated simultaneously.
- Close air valve 6, and open the wash water valve 5 gradually to prevent dislodgement of finer gravel. Open waste water valve 2 to carry the wash water to drain. Continue washing until the wash water appears fairly clear.
- Close wash water valve 5. Close waste water valve 2 after the water in the filter has drained down to the edge of the wash water trough. Allow a short period to

- permit material in the water to settle on the sand and form a very thin, sticky layer.
- Open influent valve 1 slightly. Open the valve 4 for few minutes.
  - Close valve 4 and open effluent valve 3. Open influent valve 1 fully, to put the filter back in service.

Water used for back washing should be filtered water and the total wash water used should normally not exceed 2% of the treated water. The wash water applied is of such rates that expansion of stationary bed is in the order of 25 to 50% of its depth. The pressure at which wash water is applied is about 5m head of water as measured in under drains. The rate of application of wash water may be 600 litres per m<sup>2</sup> of the filter surface, equivalent to a rise in the filter box of 60 cm/min for a period of 10 minutes.

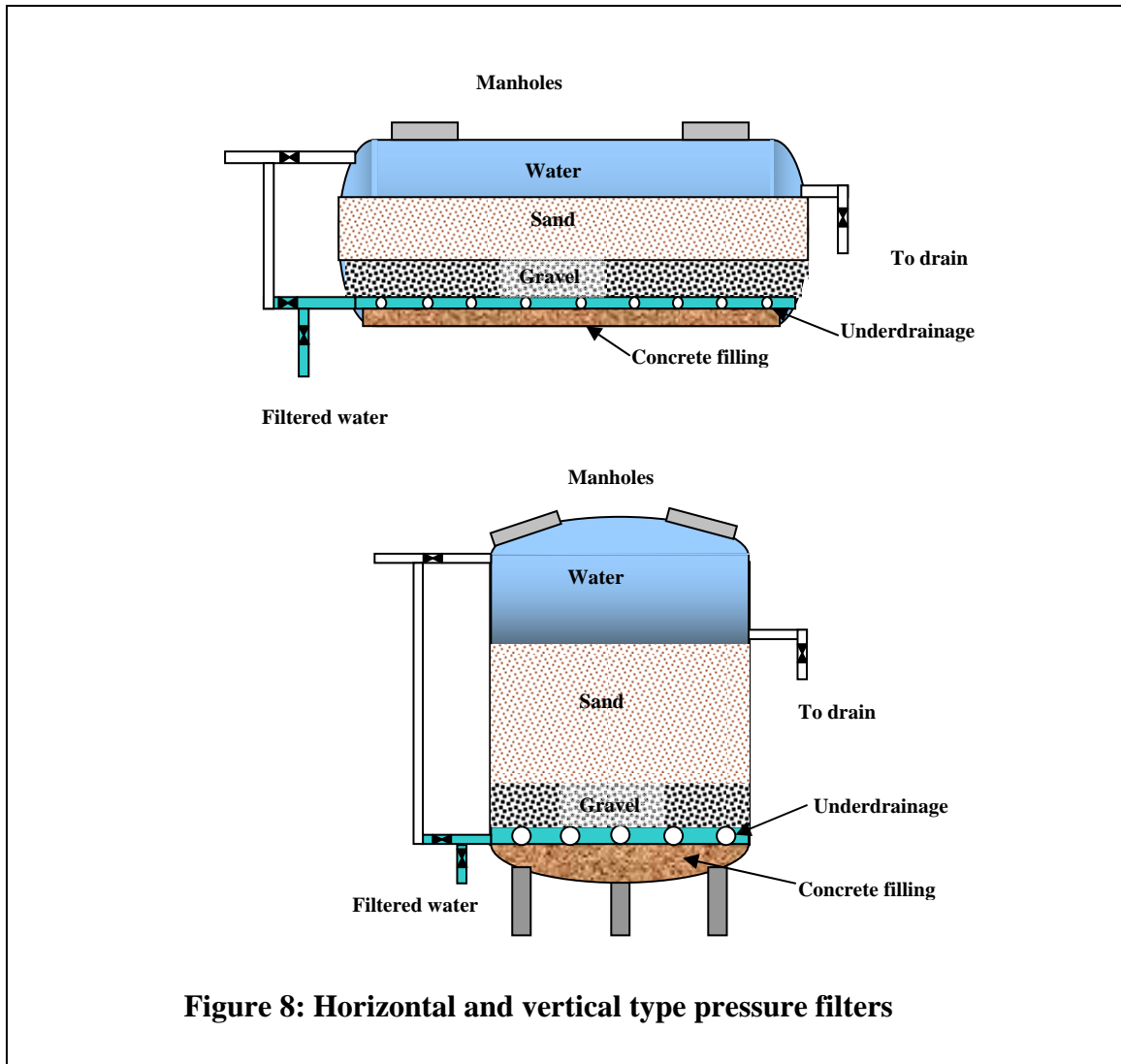
Through repeated operations of back washing, the finer sand tends to stratify at the top. It is difficult to clean the finer sand by the conventional back washing system. Surface washing is used to clean this upper layer and also to prevent the formation of mud balls, dead or clogged area. In the surface wash system, clean filtered water is applied from above by jets of water through nozzles of special design, at a rate of 200 to 400 litres per minute per m<sup>2</sup> of area, under pressure of 0.7 to 1 kg/cm<sup>2</sup>.

When a cleaned bed is put into operation, the loss of head through it will be small, usually of the order of 15 to 30cm. This increases as the water is filtered through it, by the impurities is arrested by the filter media, and the thickness of the suspended matter on the top of sand bed increases. This reaches a point when the frictional resistance exceeds the static head above the sand bed and the head becomes negative. Water is sucked through the filter media rather than being filtered through it. The formation of the negative head, allows the release of dissolved gases and air which fill the pores of the filter and the under drainage system. The filter becomes air bound; the head losses rise sharply, and the filter output capacity drops rapidly.

In rapid gravity sand filters, the permissible head loss may be between 2.5 and 3.5 m, and the permissible negative head may be 0.8 to 1.2m. When these limits are reached the filter must be back washed. Under normal conditions, the frequency between filter washes is one to four days.

### **8.5.2 Pressure filters**

The pressure filter is a type of rapid sand filter which is in a closed container and through which the water passes under pressure. The pressure may vary from 3 to 7 kg/cm<sup>2</sup> and may be developed by pumping. It may be either horizontal or vertical type (Figures 8&9).



**Figure 8: Horizontal and vertical type pressure filters**

The diameter of vertical pressure filter varies from 2 to 2.5m and length varies from 2.5 to 8m. The filter is operated similar to a gravity type rapid filter except that the coagulated water is usually applied directly to the filter without mixing, flocculation or conditioning.

The uniformity coefficient and effective size of filter sand is practically the same as that provided for rapid gravity filters, while the thickness of sand bed may vary from 50 to 60 cm. Gravel layers also follow the same practice as in gravity sand filters. The underdrainage system may consist of pipe grids or false bottom. Washing of filter media is accomplished by reversing the flow by manipulating the pipes in the piping. Automatic pressure filters are also available in which backwashing is done automatically after a fixed interval of time or the head loss has reached a given value.



**Figure 9: Vertical pressure filter at Malakal, Upper Nile State and horizontal pressure filter at Ousli, Northern State, Sudan**

Pressure filters are particularly advantageous for installations where water is received under pressure, as no pumping after filtration is required. Because the filter container is air tight, this filter may be placed on a pressure line. The only loss of head is that required to force the water through the filter. The filtration rate is much higher than the rapid gravity filter; the rate may vary from 6000 to 15,000 litres per hour per m<sup>2</sup> of filter area. Due to this they are considered to be unreliable in the removal of bacteria. Their use for large treatment works should be carefully observed and the chlorination process after the filtration should be monitored regularly. Pressure filters are most popular in small municipal water plants the process ground water for softening and iron removal. Their most extensive application has been treating water for industrial purposes.

### **8.5.3 Performance of rapid sand filters**

**Turbidity:** The filter can reduce the turbidity to less than 1 NTU, if the influent water turbidity does not exceed 35 to 40 NTU,

**Colour:** Rapid sand filters are very efficient in the removal of undesirable colour., the intensity of colour can be brought down below 3 on the cobalt scale. Colourless water can be obtained if poly electrolytes are added immediately before rapid filtration.

**Iron and manganese:** The removal of oxidized or oxidizing iron is more efficient than the removal of manganese.

**Taste and odour:** Unless special treatment such as activated carbon or pre-chlorination is provided, rapid filters will not ordinarily remove tastes and odours.

**Bacterial efficiency:** Rapid filters are not too efficient in the removal of bacterial load and filtration must be followed by adequate chlorination.

**Filter runs:** The filter runs should not be less than 24 hours with a head loss not exceeding 2m.

**Wash water consumption:** For an efficient filter, the wash water consumption should not exceed 2% of the quantity of filtered water in between washing.

### **8.5.4 Slow sand filters**

These type of filters are discussed in separate guidelines.

### **8.6 Disinfection**

When water comes out of filter units, it may contain bacteria and other micro-organisms, some of which may be pathogenic. Disinfection kills the microbes, making the water safe to drink and preventing water-borne diseases. Disinfection can be complicated and is best accomplished by skilled personnel, to avoid system breakdown and incorrect dosage.

One of the most universal chemical methods used for disinfection of water is the chlorination of water, which destroy micro organisms that can cause diseases in humans. The disinfecting action of chlorine results from a chemical reaction between HOCl and the microbial cell structure, inactivating the life processes of the cell

Chlorine is cheap, reliable and easy to hand, and it may be applied to water in one of the following forms:

- As bleaching powder or hypochlorite
- As chloramodes
- As free chlorine gas
- As chlorine dioxide

#### **Calcium Hypochlorite**

Calcium hypochlorite  $\text{Ca}(\text{OCl})_2$  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,  $W = 1000 \times (V \times C) / S$  (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  $W = 1000 \times (80 \times 0.5) / 20 = 2000$  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 solution is prepared and allowed to rest settle 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, venturi 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<sup>3</sup>/d). In large plants like in Khartoum gas containers weigh 1000 kg (gross), i.e. a net weight of 800 to 850 kg. Liquid chlorine which occupies about 80% of the cylinder at 65°C 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 less than 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 (m<sup>3</sup>/h) x chlorine dose (mg/l)

Free chlorine is generally applied in gaseous or in liquid form. When chlorine gas is subjected to a pressure of 7 kg/cm<sup>2</sup>, it is converted to liquid. Hence chlorine is stored and supplied in liquid form in metal containers under pressure of 10.5 kg/cm<sup>2</sup>. As chlorine gas is a respiratory irritant, chlorine cylinders should be stored in a cool, well ventilated room.

The chlorine dose depends upon factors such as: organic matter in the water to be treated, pH value of water, amount of carbon dioxide in the water, temperature and time of contact.

Chlorination can be by plain sedimentation, pre-chlorination, or post chlorination. During pre-chlorination, chlorine is applied to water before it is filtered. Some times pre-chlorination is done before the raw water enters the sedimentation tanks. This helps in reducing the amount of coagulants required because of the oxidization of organic matter. In alkaline water, chlorination may precede aeration. The dose of chlorine should be so adjusted such that water has a chlorine residual of 0.1 to 0.5 ppm when it enters the filter plant. Pre-chlorination has the following advantages:

- It reduces the quantity of coagulants required
- It reduces the bacterial load on filters
- It helps in maintaining longer filter runs
- It controls the algae and planktons in basins and filters
- It prevents putrefaction of sludge in settling basins
- It eliminates tastes and odour

For satisfactory disinfection, pre-chlorination is done to maintain 0.3 to 0.4 mg/l free available chlorine throughout the treatment. At normal pH values, the free available residual chlorine in the plant effluent should be 0.2 to 0.3 mg/l. At higher pH values ( 8 to

9), the free available residual, required for complete bacterial kill, with 10 minutes contact time, is 0.4 mg/l. This dosage can be reduced to 0.2 to 0.3 mg/l if the contact time is increased to 30 minutes. For inactivation of *E. histolytica* cysts, higher doses of 0.5 mg/l may be required. If the raw water is infected with nematodes, water should be pre-chlorinated for 6 hours to maintain a free available residual of 0.4 to 0.5 mg/l, to render the nematodes immobile, so that they can be removed by settling processes.

The standard form of chlorination is post chlorination, which is the application of chlorine to water after leaves the rapid filters and before it enters the distribution system. The dose of the chlorine should be so adjusted so that the residual chlorine is about 0.1 to 0.2 mg/l before distribution. This is useful for protection against contamination from cross-connections.

### **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.

### **8.7 Water softening**

Water is said to be hard when it contains relatively large amounts of bicarbonates, sulphates and chlorides of calcium and magnesium dissolved in it. Hard water causes the following problems:

- It causes more consumption of soap making uneconomical for washing processes and in the textile industries.
- It leads to the modification of some of the colours, and thus affects the working of the dyeing system
- It causes serious difficulties in the manufacturing process, such as paper making, canning, ice manufacture, rayon industry etc
- It causes chocking and clogging of house plumbing due to precipitation of salts causing hardness
- It causes formations of scales on the boilers and other hot water heating system
- It makes food tasteless, tough or rubbery

When the contents of total hardness as mg/l (or ppm) of carbonate is in the range of less than 50, between 50 and 150, between 150 and 300, and more than 300, the water is classified to be soft, moderately hard, hard and very hard water respectively.

Hardness of water is classified into two categories, temporary hardness and permanent hardness. Temporary hardness is caused when bicarbonates of calcium or magnesium are present in the water, while permanent hardness is caused when there are sulphates and chlorides of calcium or magnesium in the water. Temporary hardness can be removed either by boiling or by adding lime. In bulk water supply, addition of lime is the practical method. Permanent hardness can be removed by lime-soda ( $\text{Ca(OH)}_2 - \text{Na}_2\text{CO}_3$ ) process, zeolite process or demineralization (de-ionization) process. The economical is the lime-soda process; however it should be assisted with re-carbonation process.

## **8.8 Miscellaneous treatment methods**

### **8.8.1 Iron and Manganese Removal**

When Iron and Manganese occur in water without organic matter, they need to be oxidized to form insoluble complexes, which can be coagulated, sedimented and filtered. Oxidation can be achieved by aeration. Once this is done, Iron and manganese can be removed by softening water by adding lime to the water to reach a pH of 8.2 for iron removal and a pH of 9.6 for manganese removal.

### **8.8.2 Defluoridation**

When the fluoride content of water is more than 1.5 parts per million (ppm), it must be removed. The process of reduction of fluoride concentration in water is known as defluoridation. The following methods are commonly used to remove fluoride:

- Calcium phosphate
- Bone charcoal (bone char)
- Synthetic tri-calcium phosphate
- Ion-exchange
- Lime
- Aluminium compounds (activated alumina)
- Activated carbon

Most treatment methods use activated alumina or bone char. Water is percolated through insoluble, granular media to remove the fluorides. The media is periodically regenerated by chemical treatment once it becomes saturated with fluoride ion. Regeneration of bone char consists of backwashing the bed with a 1% solution of caustic soda, followed by rinsing. Reactivation of alumina also involves backwashing with a caustic solution.

### **8.8.3 Reverse Osmosis Method**

Water is forced through a membrane against the natural osmotic pressure by applying operating pressures between 2400 kPa and 10,300kPa (typical range 4,100.to 5,500 kPa). This results in the separation of water and ions. This process is used for desalinization of brackish and sea water. The basic reverse osmosis system consists of pre-treatment units, pumps to provide high operating pressures, post treatment tanks and appurtenances for cleaning and flushing, and a disposal system for rejected brine.

## **8.9 Other miscellaneous units of treatment plants**

### **8.9.1 Intake**

An intake structure is required to withdraw water from a river, lake or reservoir. Typical intakes are towers (for lakes and reservoirs), submerged ports (for small rivers and lakes) and shoreline structures (for rivers). The intake of a reservoir is often built as an integral part of the dam. The primary function of an intake is to supply the highest quality water from the source and to protect piping and pumps from damage or clogging as a result of wave action, flooding or floating and submerged debris. Intake structures are equipped with coarse and fine screens to exclude undesired objects.

### **8.9.2 Pumping units**

Depending on the location of the source and the treatment plant, and where the flow of treated water to the distribution system cannot be achieved by gravity, various types of pumping units may be required within the treatment plant itself. The design of the pumping unit depends on the requirement. In general pumping units can be categorized into low lift and high lift pumping units.



**Figure 9: Low lift and high lift pumping units**

### **8.9.3 Generating unit**

Treatment plants require power for normal operation of electromechanical units, associated controlling devices, lighting of operation rooms, offices and accessories, and compounds etc. The power supply needs to come either from the national grid or from an internal generating unit. Treatment plants that get power from the national grid need to have a standby generator in case of power cuts from the grid. The capacity of the generating unit including the pumping units should be designed by experienced electromechanical engineers.

### **8.9.4 Clear water storage**

To accommodate the variations in the hourly demand of clean water, treatment plants need good storage facilities for the treated water. The capacity of these storage facilities must consider the deficit during the peak hours of water consumption. Design examples in section 8.9.7 provide the procedure for designing water storage facilities.

### 8.9.5 Workshop, Store and chemical shed

Various types of electromechanical units like raw water pumping units, treated water pumping units, chemical dosing units, generating unit, chlorination and coagulation chemical etc. are housed within a treatment plant. These specific units and materials need to be stored or kept safely and maintained/repared regularly to sustain the proper operation of the plant. This requires a well-functioning workshop and store/shed. Medium to large size treatment plants must have these facilities adjoined to the main plant.

### 8.9.6 Operation house

Medium to large size treatment plants have various units, some of which require prompt intervention. Filters need to be backwashed immediately when they are clogged; pumping units need to be switched on/off as necessary; the quality of raw water or treated water needs to be tested continuously in the laboratory so that the required amount of coagulant or disinfectant can be administered correctly. These interventions require the qualified and skilled personnel who are housed in the operation house and are able to centrally monitor and operate the plant. The operation house is the heart of the treatment plant and it is important that it is well equipped with all the necessary equipment in good working order.

### 8.9.7 Design example of municipal drinking water treatment system

Specific design criteria<sup>20</sup>

<b>Pipes from intake to distribution shaft</b>
Velocity of water in pipes between 0.6 m/s (sedimentation velocity) and 3 m/s (scouring velocity), preferably taken 1.0 m/s
<b>Distribution shaft</b>
Water head on the crests of the distribution shaft weirs from 0.1 to 0.2 m.
<b>Flash mixer</b>
Retention time from 30 to 60 seconds preferable taken 30 seconds
<b>Clariflocculators</b>
Surface loading from 1.0 to 1.3 m <sup>3</sup> /m <sup>2</sup> /hr, preferably taken 1.0m <sup>3</sup> /m <sup>2</sup> /hr,
Retention time from 2 to 4 hr, preferably taken 3 hr
Additional time to be added to retention time for flocculator from 30 to 45 min, preferably taken 36 min (20% of retention time),
For best hydraulic characteristics of the clariflocculator, the basin diameter be from 7 to 15 times depth of water.
Rate of flow over weir of basin should be less than 6.6m <sup>3</sup> /meter linear/hr,

<sup>20</sup> Source: Ministry of Irrigation and Water Resources, Public Water Corporation, Feasibility Study of Wad Medeni Water Supply, Final Report

Velocity of water in pipes from 0.6 to 0.9 m/s, preferably taken 0.7 m/s.
<b>Filters</b>
Least number of filters = $0.044\sqrt{\text{(capacity of plant) ... (m}^3\text{/d)}}$
Add at least two filters for wash and stand-by for repair
Rate of filtration from 120 to 150 m <sup>3</sup> /m <sup>2</sup> /d
Best recommended area for the filter for optimum operation conditions = 50 to 70 m <sup>2</sup>
Ration of breadth to length from 1:1 to 1:1.35
Velocity of clarified water in pipes from 0.6 to 0.7 m/s, preferably taken 0.6 m/s
Rate of flow of wash water 42 m <sup>3</sup> /m <sup>2</sup> /hr
Velocity of flow of wash water from 1.5 to 2.5 m/s
Air velocity through filter bed 60 m/hr
Air velocity in pipes from 10 to 15 m/s preferably taken 10 m/s
Velocity of filtered water in pipes 1.5 m/s
<b>Sludge collecting tanks</b>
Volume of sludge collecting tanks = sludge volume from clariflocculators (50,000 m <sup>3</sup> / one million m <sup>3</sup> of treated water) + (filter back wash sludge 6 to 8% of filtered water), collected in one shaft
<b>Ground Storage tanks</b>
Capacity of ground storage tanks = 4/3 (equalization storage tanks capacity + fire demands). Capacity is preferably be 25 to 30% of total daily capacity of plant.
<b>Disinfection</b>
Contact time not less than 30 min
Residual chlorine is preferably be:
Not more than 0.7 ppm at inlet of network.
Not less than 0.2 ppm at ends of network

### **Municipal Drinking Water Treatment design procedure**

a) Plant capacity

Daily requirements = 1,400 l/s (given or calculated based on the development plan of a particular area)

Adding 10% for wash water

Design capacity = 1,540 l/s = 5,544 m<sup>3</sup>/hr = 133, 056 m<sup>3</sup>/day

b) Raw water pipes

To prevent sedimentation and erosion, the velocity of water should be between 0.6 and 1.5 m/s

$$Q = 1.54 \text{ m}^3\text{/s}$$

Chosen 3 pipes + 1 for emergency

$$Q/\text{pipe} = 1.54 / 3 = 0.51 \text{ m}^3/\text{s}$$

For average velocity of 1.0 m/s; area = 0.51 m<sup>2</sup>; taken 4 pipes of Ø = 800mm and actual velocity = 1.02 m/s

c) Roughing settlers

$$\text{Design } Q = 133,056 \text{ m}^3/\text{day}$$

$$\text{Hydraulic surface loading (S)} = 36 \text{ m}^3/\text{m}^2/\text{day}$$

$$\text{Surface area} = Q / S = 133,056 / 36 = 3,696 \text{ m}^2$$

$$\text{No of units} = 2$$

$$\text{Tank diameter} = 48\text{m}$$

$$\text{Retention time} = 2 \text{ hours}$$

$$\text{Water depth} = S \times t = 36 \times (2 / 24) = 3 \text{ m}$$

$$2 \text{ tanks } \varnothing 48\text{m, side water depth} = 3 \text{ m}$$

d) Design of distribution shaft

$$\text{Design } Q = 1.54 \text{ m}^3/\text{s}$$

$$\text{No of shafts} = 1$$

$$Q_{\text{weir}} = 0.67 \times C_d \times L_{\text{weir}} \times \sqrt{(2g)} \times H^{1.5}$$

Where:

$$C_d = \text{Coefficient depends upon weir type} = 0.62$$

$$L_{\text{weir}} = \pi D \text{ (m)} = \text{weir length (m)}$$

$$H = \text{water head on the weir crest assumed} = 0.18 \text{ m}$$

$$D = \text{diameter of weir}$$

$$1.54 = 0.67 \times 0.62 \times \pi \times D \times \sqrt{(2 \times 9.81)} \times 0.18^{1.5}$$

$$D = 4.0 \text{ m}$$

e) Flash mixers

$$\text{Retention time } T = 30 \text{ to } 60 \text{ seconds, taken } 30 \text{ seconds}$$

$$\text{No of units} = 4$$

$$Q / \text{unit} = 1.54 / 4 = 0.39 \text{ m}^3/\text{s}$$

$$\text{Volume of each unit} = 0.39 \times 30 = 11.7 \text{ m}^3$$

$$d = 0.6 \text{ m}$$

$$L = 3d = 1.8 \text{ m}$$

$$\text{Water depth} = \text{Volume} / (L \times L) = 11.7 / (1.8 \times 1.8) = 3.6 \text{ m}$$

$$4 \text{ units} = 1.8 \times 1.8 \times 3.6$$

f) Clariflocculators

$$\text{Surface loading} = 1.3 \text{ m}^3/\text{m}^2/\text{hr}$$

Retention time = 2 – 4 hr taken 4 hr, additional 20% must be added to detention time for flocculator which is 48 min (standard 30 to 50 minutes)

$$\text{Total capacity} = 1.2 \times 4 \times 5,544 = 26, 611 \text{ m}^3$$

$$\text{No of units} = 4$$

Surface area for clarifier =  $5,544 / (1.3 \times 4) = 1,066 \text{ m}^2$   
 Total area for clariflocculators =  $1,066 \times 1.2 = 1,279 \text{ m}^2$   
 Tank diameter =  $40.35 = 40 \text{ m}$   
 Actual loading =  $(5544 \times 1.2) / (4 \times \pi \times 20 \times 20) = 1.32 \text{ m}^3/\text{m}^2/\text{hr}$   
 Capacity per unit =  $26,611 / 4 = 6,652 \text{ m}^3$   
 Area per unit =  $\pi (20)^2 = 1,257 \text{ m}^2$   
 Water depth =  $6,652 / 1,275 = 5.2 \text{ m}$

Check:

Diameter / depth =  $40 / 5.2 = 7.6$  ....**ok** as for optimum hydraulic properties dia / depth = 7 to 15

Overflow rate = Q per unit /  $L_{\text{weir}}$ , taking two sides weir of average diameter 38m,

Q per unit =  $5544 / 4 = 1386 \text{ m}^3/\text{s}$

Q per meter =  $1386 / (2 \times \pi \times 38) = 5.8 \text{ m}^3/\text{m}/\text{hr} < 6.6 \text{ m}^3/\text{m}/\text{hr}$

.....**ok**

g) Flocculators

Q =  $1.54 \text{ m}^3/\text{s}$

No of tanks = 4 tank

Q per unit =  $1.54 / 4 = 0.39 \text{ l/s}$

Total area of clariflocculator =  $1279 \text{ m}^2$

Area of flocculator =  $1279 \times 0.20 = 255 \text{ m}^2$ , then

Diameter = 18 m

h) Alum Sulphate ( $\text{Al}_2\text{SO}_4$ ) tanks

Concentration of  $\text{Al}_2\text{SO}_4 = 25$  to 30 ppm

Taken = 30 ppm

Required amount of  $\text{Al}_2\text{SO}_4 = (133056 \times 30) / 1000 = 3992 \text{ kg/day}$

No of tanks = 2 tanks

Capacity of each tank (6% concentration) =  $(3992 \times 100) / (1000 \times 6 \times 2) = 33 \text{ m}^3$

Taken 2 tanks  $3 \times 3 \times 3.7 \text{ m}$

i) Filters

Q =  $133056 \text{ m}^3/\text{day}$

Minimum No of filters (N) =  $0.044 \times \sqrt{Q} = 0.044 \times \sqrt{133056} = 16$

Minimum No of filters = 16 + 1 for washing + 1 for repair = 18 filters

Dimension of filters =  $8 \times 6 \text{ m}$

Rate of filtration =  $133056 / (18 \times 8 \times 6) = 174 \text{ m}^3/\text{m}^2/\text{day}$ , considered **too high**

Preferable rate of filtration =  $120 \text{ m}^3/\text{m}^2/\text{day}$

Total areas of filter =  $133056 / 120 = 1109 \text{ m}^2$

No of filters =  $1109 / (8 \times 6) = 23.1 = 24$

Total No of filters = 24 + 2 for washing + 2 for repair = 28 filters

j) Sludge collecting tanks

A) Volume of settled sludge from clarifier at 5% concentration =  
 $50,000 \text{ m}^3 / \text{million m}^3 \text{ treated water} = (50000/1000000) \times 133056 =$   
 $= 6653 \text{ m}^3 / \text{day}$

B) Filter backwash sludge = Area of filters rate of backwash water  
(Backwash water rate) =  $42 \text{ m}^3 / \text{m}^2 / \text{hr}$

Assuming filter washing occurs once per day,  
 $= 48 \text{ m}^2 \text{ (filter area)} \times 42 \text{ (m}^3 / \text{m}^2 / \text{hr)} \times 28 \text{ (No of filters)} \times 6/60 \text{ (wash time)}$   
 $\times 1.10 \text{ (safety factor)} = 6210 \text{ m}^3 / \text{day}$

Total sludge volume =  $6653 + 6210 = 12863 \text{ m}^3 / \text{day}$

Ratio of sludge volume to treated water =  $12863 : 133056 = 9.7\%$

Assuming storage capacity equivalent to period of one working shift (8 hours),

Tanks' volume =  $12863 / 3 = 4288 \text{ m}^3$

Taking 4 tanks of 4.0m depth, area of each tank =  $4288 / (4 \times 4) = 268 \text{ m}^2$

Taken 30 x 10 m, and 4 tanks each of 30 x 10 x 4m

k) Ground Storage Reservoirs

A) According to the daily consumption and storage chart, recommended equalizing storage =  $25000 \text{ m}^3$

B) Fire demand =  $50 \text{ l/s}$  for 10 hours =  $1800 \text{ m}^3$

C) 1/3 of A+B should be added for repairs (emergency), therefore, design capacity =  $(25000 + 1800) \times (4/3) = 35733 = 26\%$  of total capacity

No of tanks = 4 tanks

Depth of water = 5 m

Area of each tank =  $35733 / (4 \times 5) = 1787 \text{ m}^2$

Taken, L = 60m, and B = 30m

4 tanks 60 x 30 x 5 m

## 9. Construction of treatment plants

Medium to large size treatment plants are largely made of reinforced concrete. These structures need to be water tight and must be constructed by reputable and experienced companies. Some parts of the piping system like bends may be manufactured on site from steel pipes. Strict supervision by the client is essential during the construction so that quality control is maintained and any defects are detected and dealt with timely.

Rapid gravity sand filter units in Sudan must be closed and roofed to protect from the sun, wind and dust

Construction and installation of compact treatment plants with pressure filters must follow the installation guidelines provided by the manufacturer.

It is important that the client maintain copies of detailed drawings during construction and 'as-built' after construction for future reference.



**Figure 10: Piping system under construction in a gravity sand filter unit at the New Soba Water Treatment plant in Khartoum**

## **10. Operation and maintenance of treatment plants**

The primary focus of the operation and maintenance of every treatment plant is to produce quality potable water that complies with WHO/Sudanese Drinking Water Guidelines. Recommendations for drinking water supply system operators to ensure that every component of the treatment system operates properly and satisfactorily:

### **10.1 Treatment plants with rapid gravity filters**

The quality of the raw water supply, chemical processes used in the treatment and physical facilities of flocculation, sedimentation, and filtration can be automatically controlled (fully or partially) from a central control, equipped with a low cost computer control system, depending on the size of the plant. The control system allows dial-in capabilities whereby operating personnel can dial in to the system remotely to determine plant operation and modify control strategies. Online turbidity meters are used to automatically adjust chemical dosage and signal calls to backwash. Local vendors or equipment manufacturers provide service contracts for inspection and replacement of defective components.

The maintenance of complete laboratory reports is important for public relations and in assessing system vulnerability. Laboratory tests on physical, chemical and bacteriological contents of raw and treated water must be part of the protocol of the operation of treatment plants, the frequency of the tests depending on the need (to satisfy the requirements of the quality of both raw and treated water). Operational procedures should be established based on local conditions.

The efficient management of treatment plants is founded on detailed records of physical facilities, operation and maintenance. Record keeping encompasses water quality and quantity data and plant operations. Daily tests include coliform analyses and usually one or more chemical parameters. Periodic analyses are performed for inorganic and organic chemicals.

Dosage and quantities of chemicals applied in the treatment are recorded. Quantity and flow data include the amount of influent water, finished water, filter rates, water loss by backwashing of filters, and sludge wastage. When ground water is the source, well data including: hours of operation, pumping rate, static and pumping water levels, discharge pressure, power consumption, and maintenance must be recorded.

Daily check by plant operator

a) Raw water source: Ground Water

- Daily operational hours of submersible pump(s)
- Pumping rate
- Static and dynamic water levels
- Discharge pressure
- Power consumption
- Physical observation of the plant
- Residual chlorine

b) Raw water source: Surface Water

- Turbidity during flooding periods
- Chemical analysis of raw water
- Bacteriological analysis of water during flooding periods
- Residual chlorine
- Daily production
- Physical observation of the plant

## 10.2. Compact treatment plants with pressure filters

The operating procedure is similar to other conventional treatment systems. However, this type of treatment system may require more manual operation than conventional bigger treatment plants. Operation and maintenance guidelines provided by the manufacturers must be followed by the operators.

## 11. Water treatment at household level

As water from may be polluted while it is being transported or stored, it is always good to treat it at household level and store it in a safe storage facility before it is consumed. Contaminated water can be purified in the home by using the following methods:

- Boiling
- Filtration,
- Chlorination
- Solar disinfection

**Boiling:** Although this is the simplest way of killing pathogens, it has several disadvantages:

- It uses a lot of fuel. About 1kg of wood is needed to boil 1 liter of water. The cost of fuel may be prohibitive in many areas.
- It can leave an unpleasant taste in the water.
- There is a chance of re-contamination once the water has cooled.

Water must be brought to a rolling boil for at least one minute. If the water is turbid it should be boiled for at least five minutes. Water should be boiled, cooled and stored in the same container. If the water is transferred to another container for cooling, care should be taken to ensure that both the containers are clean and disinfected.

**Filtration:** There are several types of household filters such as candle filters, stone filters, household sand filters etc. In a candle filter the contaminated water is filtered slowly through a porous ceramic material. Most pathogens are left in the outer layer of the filter material and must be washed away once every month by gently scrubbing the filter under clean, running water. Viruses such as hepatitis A are not removed by candle filters. Candle filters have to be made commercially and their quality carefully controlled. They are often expensive. Some candle filters contain silver which helps to kill pathogens.

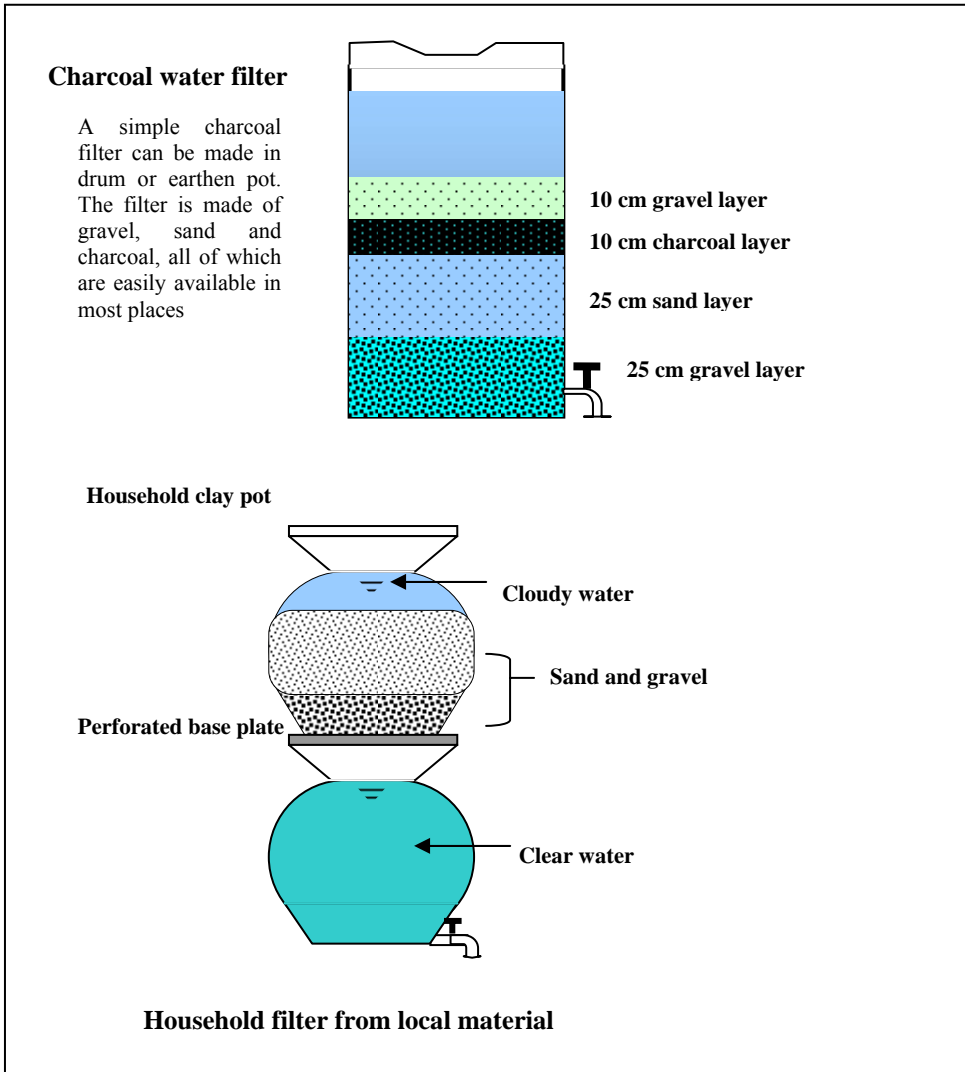
Clay or porous stone filters often remove turbidity only and not pathogens. These types of filter are difficult to clean as they are heavy to lift, but usually quite cheap if the type of stone or skill of manufacturing can be found locally.

Household sand filter: This type of filter will remove solids and silt, and some pathogens, including guinea worm larvae. It does not, however, remove all pathogens.

The procedure for making a household sand filter:

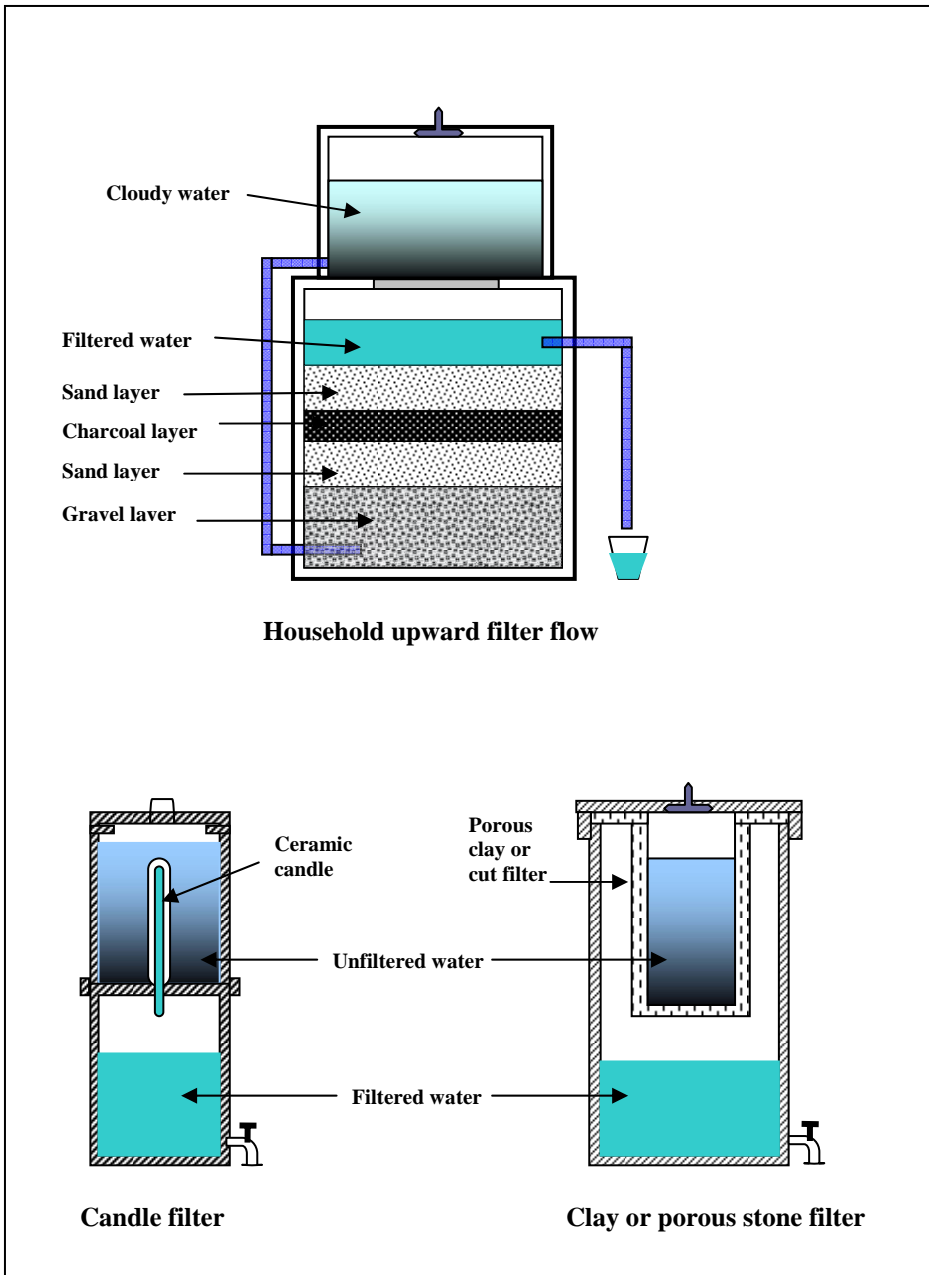
- Line two containers made of fired clay or plastic on top of one another.
- Make some holes in the base of the upper container either when manufacturing the pot or later with a drill, to allow the water to pass through to the lower container.
- Make a hole at the bottom of the lower container and fit it with a tap, using a short length of galvanized iron or plastic pipe and cement if necessary. (The tap prevents contamination of stored water from hands and dirty objects like cups being inserted into the treated water).
- Allow five days for the cement to become fully hardened before using the filter.
- Place washed, clean gravel in the upper container to a depth of 5-7 cm
- Add well washed, clean, river sand on top of the gravel to a depth of 75cm. Leave a 5-10cm space above the sand where the water can stand.

- Once the first lot of water has gone through to the bottom pot, add more water slowly for the next round of filtration. Add water several times a day to the top container, so that there is always plenty of filtered water in the lower container.





**Water filter using bone-char being promoted in Jonglei State, Southern Sudan**



**Disinfection:** When disinfecting household drinking water one percent chlorine is added to the water and left for 20 minutes to allow sufficient contact time for the chlorine to work. It is important to use the correct amount of chlorine, as too little will not kill all the germs present and too much may make the water unpalatable, causing it to be rejected by the consumer. As a general rule, three drops of chlorine solution should be added to every litre of water. This can be done using a simple dropper tube or syringe. Sodium hypochlorite or liquid bleach and calcium hypochlorite (the best type High Test Hypochlorite (HTH) are commercially available.

Sodium hypochlorite can be added directly from the bottle, as it comes in a chlorine concentration of 1%. If calcium hypochlorite or HTH are used, they will need to be

diluted to one percent. Check the manufacturer's instruction on the container to determine the quantity of powder required to make a one percent solution. A small amount of residual chlorine in the water will continue to keep it germ-free and help prevent re-contamination

Preparation of 1 liter of 1% chlorine stock solution:

Add the quantity of one of the chemical sources indicated below, to water, mix and make up to 1 liter in a glass, plastic or wooden container. This stock solution should be fresh, i.e. made every day, and protected from heat and light.

Chemical source	Percentage available chlorine	Quantity required	Approximate measures
Bleaching powder	35	30 g	2 heaped tablespoons
Stabilized/tropical bleach	25	40 g	3 heaped tablespoons
High-test-hypochlorite (HTH)	70	14 g	1 table spoon solution
Liquid household disinfectant	10	100 ml	7 tablespoons
Liquid laundry bleach	5	200 ml	1 teacup or 6-oz milk tin or 14 tablespoons
Liquid laundry bleach	7	145 ml	10 tablespoons
Javelle water or antiseptic solution e.g. Milton	1	1 litre	No need to adjust as it is a 1% solution

A 1% solution contains 10 g of chlorine per litre which is equal to 10,000 mg/l or 10,000ppm (parts per million).

Container size	1 gallon or 4.5 litre	20 litres	45 gallon drum or 200 litres
Volume of 1% solution required	8 drops	Half teaspoon	1 table spoon + 1 teaspoon

Guide based on the approximate volume of 1 teaspoon = 5 ml and 1 tablespoon = 15 ml

**Solar disinfection:** This is an effective water treatment method, especially when no chemical disinfectants are available. Ultraviolet rays from the sun are used to inactivate pathogens present in water. This technique involves exposing water in clear plastic bottles to strong sunlight for 6 to 8 hours (or longer if the sun is obscured by cloud). Bottles must be cleaned, filled three quarters and shaken thoroughly 20 times,

before being filled to the top. The water can be consumed directly from the bottle or transferred to a clean glass. Solar disinfection is more effective when the water is relatively clear (not turbid).

**Storage of treated water:** Treated household drinking water can be kept clean by using good storage containers, which need to be well designed to ensure protection from contamination. Two important factors that influence contamination of water in storage containers are: the presence of a lid or cover and the way water is drawn from the container. A container without a lid or cover will allow water to become contaminated rapidly, and water must only be drawn from the container with a ladle or scoop. The ladle should not be used for any other purpose and should be kept in the water storage container. Another good way of preventing water in the storage container from getting contaminated is to pour the water from the container into a cup or to make water containers with narrow necks. In some countries, water storage containers are made with taps so that water can be drawn from the tap. Users should be made aware of the many ways that pathogens can get into the water when water is taken out of the container, and to avoid these.

## **Annex**

1. Drinking Water Standards
2. The development of these technical guidelines
3. People contacted
4. Technical working group members
5. Some 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	<b>0.013</b>	0.02
2	Arsenic	<b>0.007</b>	0.01 (P)
3	Barium	<b>0.5</b>	0.7
4	Boron	<b>0.33</b>	0.5 (T)
5	Cadmium	0.002	0.003
6	Chromium (total)	<b>0.033</b>	0.05 (P)
7	Copper	<b>1.5</b>	2
8	Cyanide	<b>0.05</b>	0.07
9	Fluoride	1.5	1.5
10	Lead	<b>0.007</b>	0.01
11	Manganese	0.27	0.4 (C)
12	Mercury (for inorganic Mercury)	<b>0.004</b>	0.006
13	Molybdenum	<b>0.05</b>	0.07
14	Nickel	<b>0.05</b>	0.07 (P)
15	Nitrate as NO <sub>3</sub>	50	50 Short term exposure
16	Nitrite as NO <sub>2</sub>	<b>2</b>	3 Short term exposure
17	Selenium	<b>0.007</b>	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 throughout 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 Taste & odour Temperature Turbidity pH	15 TCU Acceptable Acceptable 5 NTU 6.5 – 8.5	
2	Inorganic constituents Aluminum Ammonia Chloride Hydrogen sulfide Iron (total) Manganese Sodium Sulfate Total dissolved solids (TDS) Zinc	0.13 mg/l 1.5 mg/l 250 mg/l 0.05 mg/l 0.3 mg/l 0.27 mg/l 250 mg/l 250 mg/l 1000 mg/l 3 mg/l	0.4 mg/l
3	Organic constituents 2-Chlorophenol 2,4-Dichlorophenol	5 µg/l 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-ethylhexyl) 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
<b>Pesticides</b>		
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 Aldicarb Sulfone
Atrazine	1.5	0.002
Carbofuran	4.5	0.007
Chlordane	0.15	0.0002
Chlorotoluron	20	0.03
1,2-Dibromo-3-Chloropropane	0.7	0.001
DDT	0.7	0.001
2,4-Dichlorophenoxy acetic 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
<b>Disinfectants and disinfectants' byproducts</b>		
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
Chlorate	470	0.7 (D)
<b>Disinfectants byproducts</b>		
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 = Nephelometric 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 three 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:**

#### People Contacted

1. Mr Omer ElKhadir, Director of New Soba Water Works Project
2. Mr Gaser Elfarouk, Resident Mech. Engineer, New Soba Water Works Project
3. Mr Khalid M Khier, Resident Civil Engineer, New Soba Water Works Project
4. Mr Khidir Eltom, Director, Mogran Water Treatment Plant
5. Mrs Samia Maki, Lab. Director Mogran Water Treatment Plant
6. Mr Ahmed Gasim Elseed, Director, Khartoum North Water Treatment Plant
7. Mr Ahmed Hassan, Technical Director, Khartoum North Water Treatment Plant
8. Mr Mohammed Abdel Rahman, Eng. Tech. Office, Khartoum Water Corporation
9. Mr Burhan Ahmed Almustafa, Projects/Networks Department, KWC
10. Dr A. Khadam, University of Khartoum
11. Mr Mohammed Asab Alrasul, Civil Eng., Supply Director, PWC

#### 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. Andrew 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 9. 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:

Mr. Nyasigin Deng, MWRI-GOSS  
Ms. Maryam Said, UNICEF- Consultant  
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  
Mr. Menguistu T. Mariam, PACT  
Mr. Manhiem Bol, MWRI-GOSS  
Mr. Eshetu Abate, UNICEF- Consultant  
Ms. Rose Tawil, UNICEF  
Mr. Mike Wood, EUROPIAN CONSULT  
Mr. Sahr Kemoh, UNICEF  
Mr. John Pangech, MCRD  
Mr. Joseph Brok, MAF  
Mr. Gaitano Victor, MAF  
Dr. Lasu Joja, MOH-GOSS  
Mr. Kees Van Bommel, MEDAIR  
Mr. Lawrence Muludyang, MHLPU  
Ms. Anatonía Wani, MARF  
Mr. Acuth Makuae, MCRD-GOSS  
Mr. Martin Andrew, RWD/CES  
Mr. Feliciano Logira, RWD/CES  
Mr. Philip Ayliel, MHLPU  
Mr. James Adam, MWRI

## **Annex 5: Selected bibliography and references**

1. Water Supply Engineering, B.C. Punmia, Ashok Jain, Arun Jain
2. WHO guideline value for drinking water
3. WHO Water, Sanitation and Hygiene – Fact sheet No 2.13
4. WHO Water, Sanitation and Hygiene – Fact sheet No 2.14
5. WHO Water, Sanitation and Hygiene – Fact sheet No 2.18
6. WHO Water, Sanitation and Hygiene – Fact sheet No 2.23
7. WHO Water, Sanitation and Hygiene – Fact sheet No 2.32
8. Ministry of Irrigation and Water Resources, Public Water Corporation, Feasibility Study of Wad Medeni Water Supply, Final Report
9. Water and Wastewater Technology, Mark J. Hammer and Mark J. Hammer Jr
10. Bautabellen, Schneider WIT 40, 6 Auflage, Werner-Verlag, 1984
11. Feasibility study and preliminary design for Wad Medani Water Supply, PWC

## Contact Addresses for Feedback by WASH Sector Partners

### **Mr Mohammed Hassan Mahmud Amar**

Director General  
Public Water Corporation  
Ministry of Irrigation and Water Resources  
El Sahafa South-Land Port West  
P.O. Box 381, Khartoum  
Tel: +249 (0)83 417 699  
Fax: +249 (0)83 416 799  
Email: [nwcarm@sudanmail.net](mailto:nwcarm@sudanmail.net)

### **Eng. Isaac Liabwel**

Under Secretary  
Ministry of Water Resources and Irrigation (MWRI)  
Government of Southern Sudan (GOSS)  
Hai el Cinema, Juba  
Phone: Office: +249 811 823557  
Cellular: +249 912 328686  
E-mail: [Isaac.liabwel@gmail.com](mailto:Isaac.liabwel@gmail.com)

### **Mr Sampath Kumar**

Chief, WASH Section  
Water and Environmental Sanitation (WASH) Section  
UNICEF Sudan Country Office  
House 74, Street 47, Khartoum 2  
P.O.Box 1358 – Khartoum - Sudan  
Tel.: +249 1 83471835/37 ext 350  
Fax: +249 1 834 73461  
Mobile: +249 912390648  
Email: [skumar@unicef.org](mailto:skumar@unicef.org)

### **Dr Stephen Maxwell Donkor**

Chief, WASH Section  
Water and Environmental Sanitation (WASH) Section  
UNICEF SCO, Juba  
Southern Sudan  
Tel. : +249 126 537693  
Email: [smdonkor@unicef.org](mailto:smdonkor@unicef.org)