Public Water Corporation

MIWR – GONU

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Technical Guidelines
for the Construction and Management of
Improved Small Dams

A Manual for Field Staff and Practitioners

April 2009

DEVELOPED IN PARTNERSHIP WITH

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Ministry of Irrigation and Water Resources – Government of National Unity

Foreword

Significant progress has been achieved in the provision of water and sanitation services in Sudan 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

AEP	Annual Exceedance Probability
APO	Assistant Project Officer
ARI	Average Recurrence Interval
BS	British Standard
CPA	Comprehensive Peace Agreement
DG	Director General
DPA	Darfur Peace Agreement
ESPA	Eastern Sudan Peace Agreement
GONU	Government of National Unity
GOSS	Government of Southern Sudan
MCRD	Ministry of Cooperatives and Rural Development, GOSS
MIWR	Ministry of Irrigation and Water Resources, GONU
MRF	Modified Rational Formula
MWRI	Ministry of Water Resources and Irrigation, GOSS
NTU	Nephlometric Turbidity Unit
NWC	National Water Corporation
PM	Project Manager
PVC	Polyvinylchloride
PWC	Public Water Corporation
RPO	Resident Project Officer
RWC	Rural Water Corporation
SCS	Soil Conservation Service
SSMO	Sudanese Standard and Measurement Organization
SWC	State Water Corporation
TCU	True Color Unit
TDS	Total Dissolved Solids
UNICEF	United Nations Children's Fund
WATSAN	Water and Sanitation
WES	Water and Environmental Sanitation
WHO	World Health Organization

Definitions

Appurtenant works: Structures or materials built and maintained in connection with dams. These can be spillways, low-level outlet works and conduits.

Auxiliary spillway: A secondary spillway designed to operate only during large floods.

Conduit: An enclosed channel used to convey flows through or under a dam.

Crest: The highest point or level top of a dam

Dam: In principle a dam is a structure that retains certain types of flows, such as water, debris, sediment, etc.

Earth Dam: Made by compacting excavated earth obtained from borough area.

Energy Dissipater: A structure constructed in a waterway which reduces the energy of fast-flowing water

Erosion: The wearing away of soil, rock or other material by the flow of water

Evaporation: Loss of water to the air as heat changes it from liquid form to vapor

Freeboard: The vertical distance between the design high water level and the top of the dam. This height is added to a dam as a safety factor to prevent waves or run-off caused by storms from overtopping the embankment.

Gravity Dam: A dam constructed of concrete and / or masonry an or laid-up stone that relies upon its weight for stability

Low-Level Outlet: An opening at low level used to drain or lower the water

Overtopping: Water flowing over the crest of a dam due to inadequate spillways.

Percolation: Movement of water downward through the pores of the soil

Piping: Is contact erosion along the bottom of embankment (in the dam-foundation interface).

Probable Maximum Flood (PMF): The flood that can be expected from the severest combination of critical meteorological and hydrologic conditions possible for the particular region and it is the flow resulting from the probable maximum precipitation.

Probable Maximum Precipitation (PMP): The maximum amount of precipitation that can be expected over a drainage basin.

Rip-Rap: Blanket foundation or wall made of large stones thrown together irregularly or loosely.

Seepage: Water leaking from the ground or a dam embankment.

Service Spillway: The principal or first used spillway during flood flows.

Silt: Sediment made up of fine particles carried or laid down by moving water.

Spillway: A channel built to control the level of water in a dam reservoir; flood water is drained from a dam through spillways.

Toe of Dam: The junction of the downstream or upstream face of a dam and the natural ground surface also referred to as downstream toe or upstream toe.

Torrent: A rapid high discharge whose volume and velocity exceed soil capacity for retention in the watershed.

Unit hydrograph: A situation in which a storm of, say, 1-hour duration produces rainfall at a constant rate, uniformly over the drainage basin above a recording stream gauging station

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

Guideline for selection of improved small dams

- The first step is to carry out a feasibility study at every location proposed.
- The feasibility study should include factors, such as the type and purpose of the dam, the socio-economical significance/importance, technical data etc.
- The basic hydrological data required for the design and construction of small dams includes the amount and intensity of rainfall of the drainage basin, and the associated runoff expected at the site of the dam.

Rainfall analysis

- The knowledge of rainfall data is essential, the rainfall analysis being fundamental to the rainfall-runoff process in the catchments of small dams.

Rainfall – runoff analysis

- Runoff is generated by rainstorms and its occurrence and quantity are dependent on the characteristics of the rainfall event i.e. intensity, duration and distribution.

Site investigation The construction of a dam involves much work, skilled labor and allocation of significant resources. It is therefore important to ensure proper investigation of the dam site to allow informed decision-making. Preliminary investigations include aerial and ground reconnaissance, which consider sharp breaks in topography, surface soil, rock outcrops, drainage pattern, surface water, ground water, erosion, land use, and existing structures

Classification of dams

- In Northern Sudan and the Red Sea State, dams are primarily classified by their storage capacity.
- In Southern Sudan, dams are categorized by a combination of height and storage capacity.

Make-up of a Dam A dam is generally made from earth, masonry, concrete or reinforced concrete.

Earth dams:

- The critical components of an earth dam are the dam body, its outlet and spillway. A spillway can be located outside of the dam body or designed as part of the dam body.
- In Sudan, chute spillways are preferred for small earth dams.

Masonry dams

- Masonry dams have components similar to those of earth dams, the only difference being that the spillway is not necessarily constructed outside of the dam body. The spillway could be part of the dam body itself.
- Spillways for masonry gravity dams can be chute, ogee, or free fall type..
- Masonry dams are gravity dams and depend solely on their weight for stability.

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 3.

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

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

1.2 Mobilization of stakeholders

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

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

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

1.3 Improved Small Dams

The term 'Improved' in these Technical Guidelines for small dams, refers to constructions designed to hold raw water from a run-off and have a water treatment system attached to ensure water is safe for human consumption. A small dam without a water treatment system, constructed for purposes other than the provision of drinking water, should not be considered as 'Improved". As water treatment methods have been discussed in other technical guidelines (available for reference), this document will deal mainly with the construction of the dam.

2. Guidelines for selection of improved small dams

A feasibility study should be conducted to select a suitable site or the dam. The feasibility study to be conducted at every location should result in the justification of the dam as the best option of water supply facility in the area. Factors to be considered include: the type and purpose of the dam, the socio-economical significance/importance, like meteorological, hydrological and geological data that support the justification, its impact on the environment including the potential of vector breeding (like mosquitoes, snails, guinea worms etc) and mitigation methods for these. The effect on down stream users and the environment must also be taken into consideration.

2.1 Hydrology for small dam study

Basic hydrological data required for the design and construction of small dams includes the amount and intensity of rainfall of the drainage basin, and the associated runoff expected at the site of the dam. Methods of analysis and estimation of these data have been described in the following paragraphs.

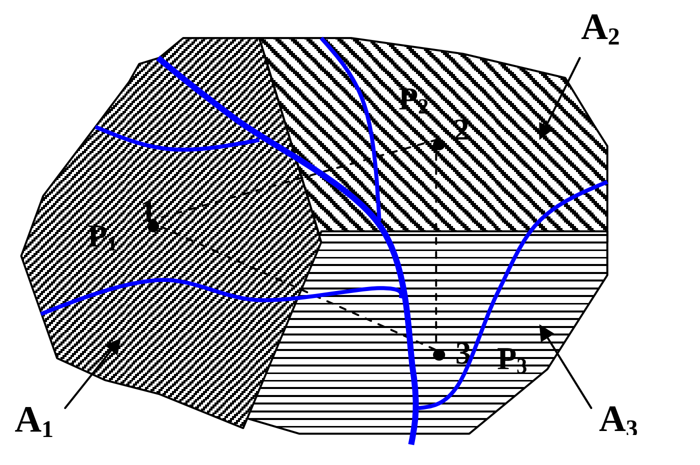
2.1.1 Rainfall analysis:

The knowledge of rainfall data is essential, the rainfall analysis being fundamental to the rainfall-runoff process in the catchments of small dams. The accuracy of the rainfall data is extremely significant to all rainfall-runoff analysis.

Precipitation in arid and semi-arid zones results largely from convective cloud mechanisms producing storms typically of short duration, relatively high intensity and limited areal extent. Water harvesting planning and management in arid and semi-arid zones present difficulties which are due less to the limited amount of rainfall than to the inherent degree of variability associated with it. In arid and semi-arid climates, like in most parts of Sudan, the ratio of maximum to minimum annual amounts is much greater and the annual rainfall distribution becomes increasingly skewed with increasingly aridity.[1] An analysis of only 5 or 6 years of observations is inadequate as these 5 or 6 years may belong to a particularly dry or wet period and hence may not be representative for the long term rainfall pattern.

Rainfall measured at a rain gauge is called point rainfall. Although rain gauges measure the amount of rain that has fallen at a specific point, this may not be representative of the amount of rain that has fallen over the entire area, which is what the hydrologists require A better estimate of rainfall may be achieved by installing a dense gauge network (more rain gauges), but such a network is very expensive.

For the application of point rainfall data to a rainfall-runoff calculation, a basin average rainfall must first be determined. Several methods are available and routinely used to calculate basin average rainfall from an assumption of areal (i.e. spatial) distribution using point rainfall from a gauge network. Two common methods in use are the Thiessen Polygon and the Isohyetal Method.

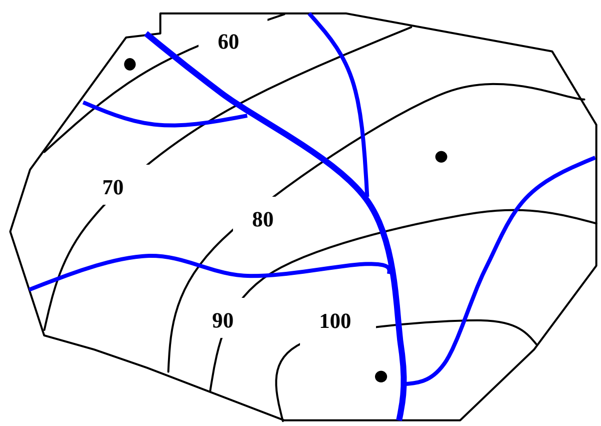


Thiessen Polygon Method

The Thiessen method weighs each gauge in direct proportion to the area it represents of the total basin without consideration of topography or other catchments physical characteristics. The area represented by each gauge (A_1, A_2, A_3,…A_n) is assumed to be that which is closer to it than to any other gauge. The area of influence of each gauge is obtained by constructing polygons determined by drawing perpendicular bisectors to lines connecting the gauges. The bisectors are the boundaries of the effective area for each gauge. The enclosed area is measured and converted to percent of total basin area. The polygon weighted rainfall is the product of gauge rainfall (P_1, P_2, P_3,…P_n) and the

[1] Natural Resources Management and Environment Department, FAO

associated polygon area in percent. The sum of these products is the basin average rainfall (P_{av}). The Thiessen method is usually the best choice for prairie states during thunderstorms, since elevation differences (topographic) are insignificant and gauge density is inadequate to use other methods to define the areal pattern of the thunderstorm cells. When analyzing several storm events having different gauges reporting for each event, the Thiessen method becomes more time-consuming than other methods.



Isohyetal Method

Isohyetal method provides for consideration of topographic effects and other subjective information on the meteorological patterns in the region. A rainfall-depth contour map is determined by tabulating gauge rainfall on a map of the region and constructing lines of equal rainfall. Average depths are obtained by measuring the areas between adjacent isohyets (zones). Each increment of area in percent of total basin area is multiplied by the estimated rainfall depth for that area. This product for each zone is summed to obtain the basin average rainfall. The Isohyetal method allows the use of judgment and experience in drawing the contour map. The accuracy is largely dependent on the skill of the person performing the analysis and the number of gauges. If simple linear interpolation between stations is used for drawing the contours, the results will be essentially the same as those obtained by the Thiessen method.

$P_{av} = (A_1P_1 + A_2P_2 + \ldots + A_nP_n) / (A_1 + A_2 + .. + A_n) = \Sigma (A \times P) / \Sigma A$ Thiessen method
$P_{av} = \Sigma ((A \times (P_1 + P_2) / 2)) / \Sigma A$ … Isohyetal method[2]

The advantages of both the Thiessen and Isohyetal methods can be combined where the area closest to the gauge is defined by the polygons but the rainfall over that area is defined by the contours from the Isohyetal method. This combination also eliminates the disadvantage of having to draw different polygon patterns when analyzing several different storm events with a variety of reporting gauges. Regardless of the technique

[2] Water Supply Engineering, B.C.Punmia, Ashok Jain, Arun Jain, 2001

selected for analysis of basin average rainfall, a regional map of areal distribution for the total storm event is also produced.

Having already determined basin average rainfall, one or more recording gauges in or near the watershed of interest must be located and used as a pattern to estimate the temporal (i.e. time) distribution of the basin average rainfall.

For a water harvesting planner, the most difficult task is to select the appropriate design rainfall which is usually assigned to a certain probability of occurrence or exceedance. The design rainfall, from which design runoff is computed, is determined by means of a statistical probability analysis. Multi-year data is required to calculate the probability of exceedance or occurrence (P%).

$P(\%) = ((m - 0.375) / (N + 0.25)) \times 100$…..[3]

Where:

P = Probability in % of the observation of the rank m
m = The rank of the observation (order of observation from highest to lowest)
N = Total number of observations used.

The return period T (in years) or Average Recurrence Interval (ARI) can easily be derived once the exceedance probability P (%) or Annual Exceedance Probability (AEP) is known from the equation

$T = 100 / P$ (years)[4]

2.1.2 Rainfall – runoff analysis

Runoff is generated by rainstorms and its occurrence and quantity are dependent on the characteristics of the rainfall event i.e. intensity, duration and distribution. Apart from the rainfall characteristics, there are site (or catchment) specific factors which have a direct bearing on the occurrence and volume of runoff. These are: porosity of the soil, vegetation of the catchment (kind and growth stage), and slope and catchment size.

Apart from the above-mentioned site-specific factors which strongly influence the rainfall-runoff process, consideration should also be given to the fact that the physical conditions of a catchment area are not homogeneous. Even at the micro level there are a variety of different slopes, soil types, vegetation covers etc. Each catchment has therefore its own runoff response and will respond differently to different rainstorm events.

The design of water harvesting schemes requires the knowledge of the quantity of runoff to be produced by rainstorms in a given catchment area. It is commonly assumed that the quantity (volume) of runoff is a proportion (percentage) of the rainfall depth.

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[3] Natural Resources Management and Environment Department, FAO

[4] Ibid

Runoff (mm) = K x Rainfall depth (mm)[5]

In rural catchments where no or only small parts of the area are impervious, the coefficient K, which describes the percentage of runoff resulting from a rainstorm, is however not a constant factor. Instead its value is highly variable and depends on catchment-specific factors and on the rainstorm characteristics.

The use of runoff coefficients which have been derived for watersheds in other geographical locations should be avoided for the design of a water harvesting scheme. Also runoff coefficients for large watersheds should not be applied to small catchment areas. An analysis of the rainfall-runoff relationship and subsequently an assessment of relevant run-off coefficient should best be based on actual, simultaneous measurements of both rainfall and runoff in the project area.

In actual practice, the hydrological engineer is usually faced with the problem of providing a flood hydrograph for design purposes at location where no stream flow data has been accumulated. These flood hydrographs are developed using hypothetical rainfall amounts for the drainage basin, appropriate infiltrations loss rates, and a synthetic unit hydrograph. Synthetic unit hydrographs are developed from parameters representing the salient characteristics of the rainfall-runoff phenomena found by reconstructing observed flood events on similar drainage basins. Reconstruction of observed events generally provides two significant items of information. The first item is an indication of infiltration rates expected with certain types of soils, and the second item is a unit hydrograph for each of the basin analyzed. Associated with each unit hydrograph are two characteristics used to determine synthetic unit hydrographs for ungauged drainage basins. These characteristics are the lag in time between the rainfall and the rise in runoff (unit hydrograph lag time) and the time versus discharge rate of change relationship (temporal distribution of unit runoff)[6]

The relationship between unit hydrograph lag time and measurable basin parameters is given as:

$L_g = C\,(LL_{ca} / S^{0.5})^N$ ………..[7]

Where:

L_g = unit hydrograph lag time, in hours,
C = constant, which is $26K_n$,
N = constant which is 0.33
L = the length of the longest watercourse from the point of concentration to the boundary of the drainage basin, in miles. The point of concentration is the location on the watercourse where a hydrograph is desired.
L_{ca} = the length along the longest watercourse from the point of concentration to

[5] Ibid
[6] Design of small dams, US Bureau of Reclamation.
[7] Ibid

a point opposite to a centroid of the drainage basin, in miles, and

S = the overall slope of the longest watercourse (along L), in feet per mile.

K_n = average Manning's n value representing the hydraulic characteristics of the drainage network. It is primarily a function of the magnitude of discharge and normally decreases with increasing discharge.

The lag time of a drainage basin is only half the information required for developing a synthetic unit hydrograph. The other half is the means by which the runoff from the unit rainfall is temporally distributed (the time versus the discharge rate of change relationship). This distribution is accomplished by using a dimensionless form of an observed unit hydrograph for a similar drainage basin.

According to SCS dimensionless unit hydrograph, the total volume under the hydrograph is:

$Q = ((q_p \times T_p) / 2) + ((q_p \times T_r) / 2) = (q_p / 2) \times (T_p + T_r)$, then............[8]

$q_p = 2Q / (T_p + T_r) = (654.33 \times 2 \times A \times Q) / (T_p + T_r) = (484 \times A \times Q) / T_p$
$= (484 \times A \times Q) / ((D/2) + L)$

$L = 0.6 \times T_c$

$T_c + D = 1.7 \times T_p$, and $(D/2) + (0.6 \times T_c) = T_p$, then

$D = 0.133 \times T_c$ or $D = (0.133 \times L) / 0.6$,

Where:

Q = total volume in inches per hour
q_p = peak rate or runoff in inch per square mile
T_p = time to peak in hour and is expressed as $T_p = (D/2) + L$
T_r = recession limb time, which is 1.67 times the time to peak T_p
T_c = time of concentration in hours
A = Drainage area in square miles
D = Duration of unit excess rainfall
L = drainage basin lag time

According to the Modified Rational Formula (MRF)[9] method, the peak runoff rate (Q_p) is given as:

$Q_p = 0.28 \times C_s \times C \times I \times A$

Where:

Q_p = peak runoff rate in m^3/s

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[8] USA, National Weather Services, National Operational Hydrologic Remote Sensing Center
[9] International Institute for Geo-Information Science and Earth Observation (ITC)

C_s = storage coefficient that accounts for a recession time larger than the time the hydrograph takes to rise
C = runoff coefficient
I = Rainfall intensity in mm/hr
A = drainage area in km^2

The formula of MRF assumes the following:

- Consideration of the entire drainage area as a single unit,
- Estimation of flow at the most downstream point only, and
- The assumption that rainfall is uniformly distributed over the drainage area.

In this regard the time of concentration by using Kirpich/Ramser formula is:

$$Tc = 0.0195 \times L^{0.77} \times S^{-0.385}$$

Where:

Tc = time of concentration in minutes
L = length of main river in meters
S = distance weighted channel slope in (m/m)

In order to use SCS Dimensionless Unit Hydrograph the time to peak and the peak discharge are estimated and this method assumes that:

- The duration of excess rainfall is less or equal to 0.133 x the time of concentration, and that
- The rainfall duration is not too long (D<0.2 time to peak).

If these conditions are met, the following formulas can be used:

$$q_{peak} = 2.8\ ((RO \times A) / t_{peak})$$

Where:

q_{peak} = peak runoff rate in m3/s
RO = Storm runoff or excess rainfall volume in cm
A = watershed area in km2
t_{peak} = time to peak in hr which is equal to (D/2) + t_{lag}
D = duration of excess rainfall in hr
t_{lag} = the lag time of the watershed in hr which is equal to 0.6 x t_c, and

$$t_{lag} = 2.587 \times L^{0.8}(((1000/CN) - 9)^{0.7}) / 1900 \times H^{0.5})$$

t_c = time of concentration in hr
L = hydraulic watershed length in meters which is equal to 110 x $A^{0.6}$
CN = hydraulic area-weighted curve number
H = average watershed land slop in %
A = watershed area in ha

The following procedure outlines the steps to determine the peak runoff rate using SCS dimensionless unit hydrograph:[10]

- Determine the area weighted curve number. The SCS method uses curve numbers. These numbers are related to the different land cover types, soil properties and antecedent moisture conditions. Within the catchment more than one land cover type and soil type exist. In order to find a representative curve number, an overall catchment curve number has to be determined using areas of the different land cover and soil types as weighing factor.
- Determine the lag time: For the calculation of the lag time, a number of watershed parameters have to be determined, and these are hydraulic watershed length, average watershed slope and overall curve number.
- Determine the unit duration of excess rainfall
- Determine the peak runoff for 1 cm (or 1 inch) of excess rainfall. When calculating the peak runoff of any unit hydrograph, the amount of excess rainfall equals a unit depth, i.e. 1mm or 1cm. To determine the peak runoff for 1 cm of excess rainfall, first the time to peak should be determined. Based on the unit hydrograph, the peak flow rate for other storms with a different rainfall excess amount can be calculated.

As the evaporation rate is high and rainfall is erratic and limited in arid and semi-arid areas, it is always good to plan and consider a multi-year storage capacity (to last at least a minimum of 2 years) for every small dam that is constructed for drinking water supply purposes.

2.2 Site investigation

The construction of a dam involves much work, skilled labor and allocation of significant resources. It is therefore important to ensure proper investigation of the dam site to allow informed decision-making. The first step in site investigation is to conduct a preliminary investigation that includes aerial and ground reconnaissance.

The preliminary surveys in site selection should focus on selecting a tributary with minimum sediment. Small dams and reservoirs are used to harvest and store rainwater, to help areas depressed by increasing aridity. Water storage is affected by:

- Evaporation losses.
- Seepage beneath the structure; through the structure; at the bottom of the reservoir; and through the banks of the reservoir.
- Sedimentation.

The aerial reconnaissance would provide an Engineer with an idea of the topography, providing information on the probable hydrological characteristics of the catchment area. A geologist would assist the Engineer in the selection of the dam site, and a construction Engineer would study access and possible sources of local construction materials.

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[10] USA, National Weather Services, National Operational Hydrologic Remote Sensing Center

The features to be investigated during ground reconnaissance include old and potential land slides, geological faults and major joints parallel with the valley where the dam is likely to be constructed. This will provide information on which type of dam may be most appropriate, and highlight important any problems which may be encountered, before extensive drilling or exploratory works are performed.

Detailed geotechnical investigation (subsurface explorations using drill holes, test pits and auger holes) along the centreline of the dam, at the proposed service spillway locations and other critical locations should be conducted before a final decision is made. The minimum depth of explorations should not be less than 3 meters with one or more borings extending to a depth equal to the proposed height of the dam

If excavation is proposed in the reservoir area, the possibility of previous foundation layers should be investigated by explorations or a review of the geology of the area.

Siltation in the reservoir reduces the overall storage capacity. Provisions on how to deal with it should be included in the design and as well as in the management, operation and maintenance plan.

Summary of general rules for choosing the site of a reservoir are:

- The reservoir site must have adequate capacity for storage, so as to maximise upstream retention e.g. drainage slopes have to be mild (not exceeding 25 percent), so as to allow impoundment of water over a reasonable distance.
- A deep reservoir is preferable to a shallow one because of lower land costs per unit of capacity, less evaporation loss, and less likelihood of weed growth.
- Tributary areas that are extremely productive of sediment should be avoided if possible.
- The reservoir banks and adjacent hill-slopes should be stable, i.e. they should be less prone to dam burst by torrential phenomenon such as landslides.

A check list for site investigation[11]

- Topography - Flat, gentle undulating, rolling, sharp hills, mountains, difference between highest and lowest areas.
- Sharp breaks in topography – Ridges, canyons, depressions.
- Surface soil – Loose, hard, moist or dry, boulders and gravel (scattered or in zones), topsoil and organic matter.
- Rock outcrops – Surface, highway and railroad cuts, hillsides, weathered and unweathered.
- Drainage pattern – Dendritic, lattice, parallel, water gaps, waterfalls, direction of primary drainage.
- Surface water – Stream, seasonal or perennial, fluctuations, floods, lakes, marshes, disappearing rivers.
- Ground water – Wells, seeps, springs, artesian wells.

[11] www.dur.ac.uk/~des0www4/cal/dams/site/scheck.htm

- Erosion – Severe or moderate, U or V shaped cross section, steep or gentle sloping heads of gullies.
- Land use – cultivated or barren, type of crop or vegetation, good or poor quality.
- Existing structures, recollection of old residents.

Water supply from dams should be considered as safe only if the raw water has passed through a series of treatment processes (simple or complex) and the final water produced conforms to Sudanese/WHO drinking water standards. The type of treatment system to be used must be identified during the designing of the improved small dams. The treatment system is primarily dependent on the quality of raw water and is entirely area specific. Water from a dam can be treated either by a slow sand filtration system like it is done in Port Sudan, or using a conventional water treatment system using coagulation and flocculation processes, or the water could be infiltrated into the ground to recharge down-stream boreholes as done in Gedaref Town. There is no typical design of a treatment system common to all dams.

3. Classification of dams

Dams are classified in various countries according to their heights or storage capacity (whichever is the larger). In New York State, USA, dams are classified by their size, i.e. small and large dams. Small dams have a height less than 12m (40 feet) and storage capacity at normal water surface of less than 1,233,526 m^3 (1000 acre feet). Large dams have a height equal to or more than 12m and storage capacity equal to or greater than 1,233,526 m^3. In Northern Sudan and the Red Sea State, SWC classifies dams primarily according to their storage capacity. Dams with a storage capacity of less than 3,000,000 m^3 are categorized as small size dams, between 3,000,000 and 5,000,000 m^3 as medium dams and from 5,000,000 m^3 and above as large dams. In Southern Sudan[12], dams are categorized by a combination of height and storage capacity. Dams up to 15m height and storage capacity of less than 3,000,000 m^3 are categorized as small dams, those of capacity between 3,000,000 m^3 and 5,000,000 m^3, with a height of 15 to 25m as medium and those with storage capacity over 5,000,000 m^3 and height over 25m as large dams. Potential sites for dam construction in Southern Sudan are located in the valleys of Eastern Equatoria, Jonglei and Western Bahir el Ghazal.

These Technical Guidelines discuss small dams. Other categories of dams require specialist construction techniques and experienced engineers to design them. **Each dam is by nature site specific and should be designed and constructed according to the specific site conditions (geophysical, hydrological, hydrogeological data, availability of construction materials, intended service of the dam, environmental impact etc)**.

In hot climates like in Sudan the evaporation from the reservoir is very high and under such circumstances the height of any dam should not be less than 3m in order to provide a year round water supply to small communities.

[12] Information from the Ministry of Water Resources and Irrigation , Government of Southern Sudan.

4. Make-up of dams

Dams are generally made from earth, masonry, concrete or reinforced concrete. These Technical Guideline discuss small dams made from earth fill or masonry. It is very important to consider the effect of a sudden failure of the dam on people and property downstream. Even a low dam may impound large quantities of water, which can cause considerable damage if released suddenly. The make-up of a dam, should consider the safety of life and property downstream of the dam site. The environmental impact of the dam to the area should also be considered

5. Components of small dams and their configuration

The major components of small dams are the dam body, spill way and conduit with inlet structure (this is optional and is only considered when abstraction of water by pumping is avoided). The configuration of dam components differs according to the make of dams.

5.1 Earth dams

The critical components of an earth dam are the dam body, its outlet and spillway. Overtopping i.e. overflow over the top of the dam, must not be allowed, to prevent erosion of the downstream side of the embankment and weaken the dam stability (Figure 1).Spillway can be located outside of the dam body or designed as part of the dam body. In the latter design, the spillway must be designed as a chute channel with a horizontal crest on the dam axis and the channel on the dam body with energy breakers at the end sections of the channel.

Figure 1. Overtopping of flood water over the body of an earth dam that was caused by a combined effect of high silt accumulation in the storage area and occurrence of high flood. The embankment has been damaged at the left side of the spillway and the dam is not holding the water any more.

An outlet with a conduit pipe is another component of an earth dam. This is an enclosed channel to convey flows through or under a dam body. Constructing the conduit through the dam body is difficult as there is likely to be seepage along the outside of the pipe. This could be prevented by providing anti-seepage collars at the beginning and end sections of the pipeline. The length of the seepage line should be increased to more than 125% by using collars. Collars should be avoided in the interior section of earth dams.

The spillway is a structure that discharges the flood water when the water level exceeds its normal operational level in the reservoir. Whethere the spillway is constructed outside of the dam body or is part of the dam body, it should be directed towards the nearby natural courses (Figure 2) with a guiding channel and side walls.

Figure 2. Spillway for the earth dam, constructed outside of the dam body and directed to the nearby natural drainage way

In case the spillway is designed and constructed within the dam body, it is recommended that a protection against seepage is incorporated under the spill way as well as at the contact surface between the earthen embankment and the masonry structure of the spill way. This is to prevent loss of water under the spillway (Figure 3).

Figure 3. Seepage problem under the free falling spillway of an earth dam

Chute spillways are preferred for small earth dams in Sudan. Chute spillways ordinarily consist of an entrance channel, a control structure (like the broad crest), a discharge channel, a terminal structure (stilling basin), and an outlet channel. The simplest form of a chute spillway has a straight centreline and uniform width. The discharge from a chute spillway is conveyed from the reservoir to the downstream river level through an open channel, which is placed either along the dam abutment or through the saddle. The broad crest control is placed normal to the axis of an open channel. Often, either the axis of the entrance channel or that of the discharge channel must be curved to fit the alignment to the topography. If possible the curvature is confined to the entrance channel because of the low approach velocities. When the discharge channel is curved, its floor is sometimes super-elevated to guide the high velocity flow around the bend, thus avoiding a piling up of flow toward the outside of the chute.

Upstream flow of the crest is generally at sub-critical velocity and a critical velocity over the crest. Flows in the discharge channel are maintained at supercritical stage, either at constant or accelerating rates, until the terminal structure is reached. For good hydraulic performance, abrupt vertical changes or sharp convex or concave vertical curves in the chute profile should be avoided. Similarly, the convergence or divergence in plan should be gradual to avoid cross waves, wave run-up on the walls, excessive turbulence, or uneven distribution of flow at the terminal structure.

5.2 Masonry Dams

Masonry dams have components similar to earth dams, with the difference that the spillway is not necessarily constructed outside of the dam body; it can be part of the dam body itself (Figure 4)

Figure 4. Two spillways for a masonry dam in Red Sea State. (One of them is part of the dam body whilst the other is outside the dam body)

Spillways for masonry gravity dams can be chute, ogee, or free fall type.. When and where possible ogee type spillways are most suitable for masonry and concrete dams.

The ogee spillway has a control weir that is ogee-shaped (S-shaped) in profile. The upper curve of the ogee spillway ordinarily conforms closely to the profile of the lower nappe of a ventilated sheet falling from a sharp-crested weir. Flow over a crest adheres to the face of the profile by preventing access of air to the underside of the sheet. For discharges at designed head, the flow glides over the crest with no interference from the boundary surface and attains near-maximum discharge efficiency. For geometrical shape of ogee spillway refer to “Figure 9.22, page 368 of Design of Small Dams, US Bureau of Reclamation”.

6. Design consideration and specifications of the components

The design of concrete and masonry dams is complex and should only be attempted by an engineer with experience in the design of dams, who should consider all local factors.

Spillway design discharges should be estimated based on PMF based on a probable maximum storm. A 100-year flood should be the design discharge of spillways of small dams. This 100-year flood has a probability of 1/100 of being equalled or exceeded in any year. The peak discharge-frequency curve has to be prepared in order to determine the sizes of a spillway. In Sudan, a discharge of $200m^3/s$ might be taken as design flood discharge for spillways for small dams.

Data is not easily available on discharges of small streams. In the absence of hydrologic data, oneway to get a design flood is to look for clear water marks.

The design discharge for underneath gates is dictated by downstream needs, flood control regulation, storage considerations etc. The hydraulics of outlet works usually involves either open-channel (free) flow or full conduit (pressure) flow. Analysis of open-channel flow in outlet works is based on the principle of steady non-uniform flow conforming to the law of conservation of energy. Full-pipe flow in closed conduits is based on pressure flow, which involves a study of hydraulic losses to determine the total head needed to produce the required discharge.

Hydraulic-jump basin baffles or impact-block dissipaters, stilling wells, or other stilling devices are normally used to dissipate the energy of flow at the downstream end of the outlet works. Many of these devices are designed on the basis of the law of conservation of momentum.

The seepage line should remain well within the downstream face of the dam, so that no sloughing of the face occurs.

Seepage through a flood control dam will not do much harm, but a conservation dam must be as water tight as possible

6.1 Earth dams

The following points are essential for the design of a small earth dam:
- under all conditions, the dam must have a secure foundation to support the dam weight
- The dam body should have an impermeable core of puddle clay to prevent water from seeping through it.

- The sides of the dam embankment (Figure 5) should slope at an angle that will provide a stable structure depending on the type of fill materials (Table 1). The upstream slope of earth dams should be no steeper than 1 vertical on 3 horizontal. The downstream slope of earth dams without seepage control measures should be no steeper than 1 vertical on 3 horizontal. If seepage control measures are provided, the downstream slope should be no steeper than 1 vertical on 2 horizontal.
- The upstream side should be covered with stone pitching (rip-rap) and filter with recommended depth of 20 to 30 cm.

Table 1: Side slopes of earth dams according to fill materials used (a 3:1 slope means 3m horizontal distance for every 1m in height)[13]

Fill material	Side slopes (horizontal to vertical)	
	Upstream	Downstream
Clay, clayey sand, sandy clay, silty sand	3:1 – 3.5:1	2.5:1 – 3:1
Silty clay, clayey gravel, silty gravel	3:1 – 3.5:1	2.5:1 – 3:1
Silts or clayey silt	3.5:1 – 4:1	3:1 – 3.5:1

- The top or crest of the embankment must be at least 3m wide. In Sudan the practice is 4m (Figure 5). This is recommended as it allows provision for the use of machinery during maintenance or extension. The crest of the dam should be at least 1m above the maximum anticipated water level under extreme flood conditions (or the freeboard height should be minimum of 1m)
- Foundations of earth dams can be classified as: foundations of rock; foundations of coarse-grained material (sand and gravel); or foundations of fine-grained material (silt and clay).
- Rock foundations are generally considered to be more competent and do not usually present any problem for small dams. Rock foundations should be carefully investigated for permeability. If erosive leakage, excessive uplift pressure, or high water losses can occur through joints, fissures, permeable strata, or along fault planes, one must consider grouting the foundation. The advice of an experienced designer should be sought when in doubt.
- Sand and gravel foundations are pervious materials that may range from fine sand to openwork gravel. Generally, sand and gravel foundations have sufficient strength to adequately support loads induced by the embankment and reservoir, but this must be verified by adequate exploration, testing, and analysis. Two basic problems related to pervious foundation are; the amount of under-seepage; and the forces exerted by seepage.
- The amount of under-seepage can be estimated using Darcy's formula:

$$Q = k \times I \times A$$

Where:

[13] Source: Technical Note No RWS 1.D.5, Designing of Small Dams, Water for the World

Q = discharge volume per unit time
k = coefficient of permeability for the foundation; i.e. discharge through a unit area at unit hydraulic gradient
A = gross area of foundation through which flow takes place

- Various measures to prevent seepage and percolation can be used. These include cutoff trenches, partial cutoff trenches, sheet piling cutoffs, cement bound and jet-grouted curtain cutoffs, slurry trench cutoffs, grouting, upstream blankets, downstream embankment zones, toe drains and drainage trenches, and pressure relief wells.
- Whenever economically possible, seepage through a pervious foundation should be cut off by a trench extending to bedrock or other impervious stratum. This is the most positive means of controlling the amount of seepage and ensuring that no difficulty will be encountered by piping through the foundation or by uplift pressures at the downstream toe. Various methods of seepage and percolation control can be used, depending on the requirements for preventing uneconomical loss of water and the nature of the foundations in regard to stability from seepage forces. Cutoff trenches or cutoff walls can be used depending on the type of dam.
- For earthen small dams, cutoff trenches, which are backfilled with impervious materials, may be appropriate. The impervious materials must be compacted in the same manner as the impervious zone of the embankment of the dam body. The cutoff trench should be located at or upstream from the centreline of the crest of the dam but not beyond a point where the cover of the impervious embankment above the trench cannot provide resistance to percolation at least equal to that offered by the trench itself.
- The portion of the dam, downstream of the impervious core, should be properly drained by providing a suitable horizontal filter drain, toe drain, or chimney drain.,.
- Silt and clay foundations treatment methods are based on the soil type, the location of the water table, and the density of the soil. Two conditions need to be checked; saturated foundations and relatively dry foundations.
- The stability of the embankment of a small dam can be analyzed using the Swedish, or slip-circle method by calculating the safety factor against sliding for an assumed circle, i.e.

Safety factor = ((c' x L + tan φ'(N – U)) / T ……[14]

Where:

N = summation of normal forces along the arc
U = summation of uplift forces caused by pore water pressure along the Arc
T = algebraic summation of tangential forces along the arc
L = length of arc of slip circle
c' = effective cohesion intercept, and
φ' = effective angle of internal friction

[14] Design of small dams, US Bureau of Reclamation.

- The dam should have an overflow channel (spillway) to divert excess water under flood conditions. Always consider an auxiliary spillway to backup the first spillway located a little above the first one. Water must not be allowed to flow over the top of the dam.
- The means of abstraction of water from the reservoir should be discussed during the designing.. If building conduit pipes through the dam does not guarantee the seepage along the outside of the pipes, the method of abstracting of water by pumping just upstream of the dam is recommended.
- Where river water is used downstream, there should be an outlet for water to flow from the reservoir to the river bed downstream of the dam.
- A Spillway can be designed as a chute channel with a horizontal broad-crest on the dam axis and the channel on the dam body with energy breakers at the end of sections of the channel.

From equation of continuity

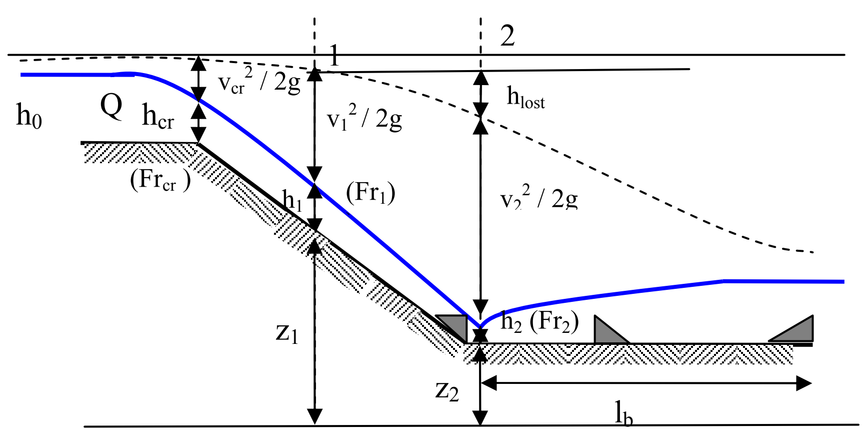
$Q = v_1 \times b \times h_1 = v_2 \times b \times h_2$, with Froude's number $Fr_1 = v_1 / (g \times h_1)^{1/2}$

This means,

$h_2/h_1 = ½ \times ((8Fr_1^2 + 1)^{1/2} - 1)$

and from energy equation,

$h_{lost} = h_1 - h_2 + ((v_1)^2 - (v_2)^2) / 2g + z_1 - z_2$



Critical depth and critical velocity for rectangular channel are expressed as

$h_{cr} = ((Q^2 / (g \times b^2))^{1/3}$
$v_{cr} = (g \times h_{cr})^{1/2}$

Three types of flows could be expected

a) Sub-critical flow when; $h > h_{cr}$, $v < v_{cr}$ and $Fr < 1$

b) Super-critical flow when $h < h_{cr}$, $v > v_{cr}$ and $Fr > 1$, and
c) Critical flow $h = h_{cr}$, $v = v_{cr}$ and $Fr = 1$

Where,
Q = Discharge (flow) quantity in m^3/s
b = width of channel in m
h_1, h_2 = depth of water at locations 1 and 2
v_1,v_2 = velocity of flow at locations 1 and 2
Fr = Froude's number
g = Gravitational acceleration in m/s^2

The value of Q should be estimated for every specific drainage area using the procedure described in Section 2.1.2. In the absence of hydrological and meteorological data, the spillway size can be calculated by obtaining local information and an estimate. Find out how high the stream rises at the wettest time of the year and estimate the width of a similar stream running 60 cm deep. Allow for extra width according to whether the previous year was dry, wet or average and then double the amount to allow for heavy storm. This is the minimum size of the spillway. If in doubt, widen the spillway. A wider spillway is better than allowing overtopping of an earth dam.

Where the energy of flow in a spillway must be dissipated before the discharge is returned to the downstream river channel, the hydraulic jump stilling basin is an effective device for reducing the exit velocity to a tranquil state. The jump that will occur in such a stilling basin has distinctive characteristics and assumes a definite form, depending on the relation between the energy of flow that must be dissipated and the depth of the flow. The jump form and the flow characteristics can be related to the kinetic flow factor ($v^2/2g$) of the discharge entering the basin, to the critical depth or to the Froude number parameter ($(v / (gd)^{1/2})$). As the dimensions of stilling basin, chute blocks, baffle piers and dentated end sill depend on the Froude numbers, designers must check the flow characteristics with different values of Froude numbers.

Rectangular stilling basins with vertical sidewalls are preferred to trapezoidal stilling basins, to ensure good hydraulic performance,

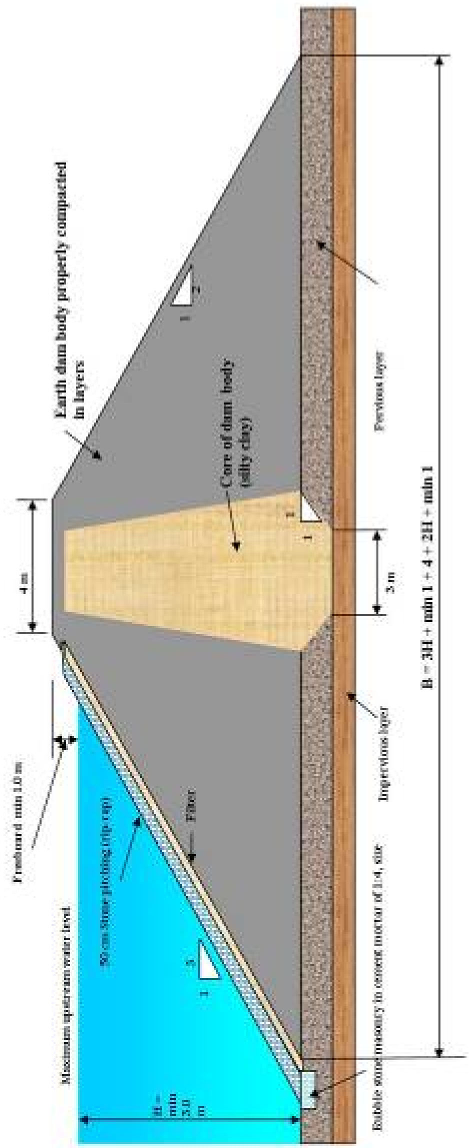
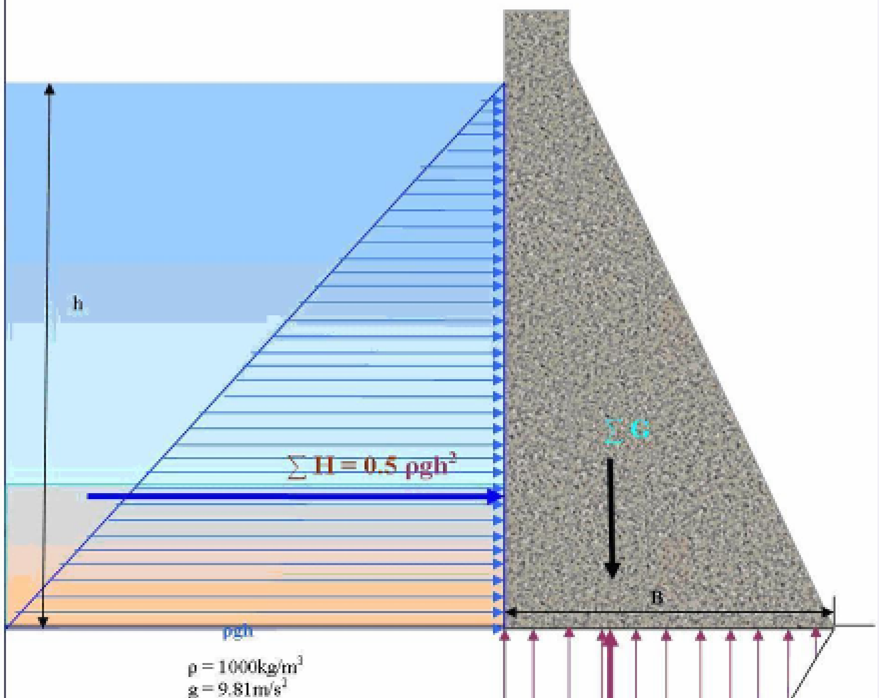


Figure 5. Cross-section of a typical earth dam (Adapted from Gedarif SWC)

6.2 Masonry Dams

Masonry dams are gravity dams that depend solely on their weight for stability. The forces that influence the stability of small gravity dams are: external water pressure, internal water pressure (or uplift), silt pressure, earth quake and weight of the dam (Figure 6).



ρ = 1000kg/m³
g = 9.81m/s²

Loads to be considered in stability analysis are those due to:
External water pressure, internal water pressure (pore pressure or uplift) in the dam and foundation, silt pressure, earthquake and weight of the structure

Therefore, Coefficient of stability (or safety factor) of the dam (Cs) will be:

$$Cs = f(\sum G - \sum U) / \sum H \geq 2.0$$

Where, f is coefficient of friction between the dam and the soil on which the dam is constructed, $\sum G$ sum of all forces contributing to the weight of the dam, $\sum U$ sum of all uplift forces, $\sum H$ sum of all horizontal forces that are acting on the body of the dam. It is assumed that the silt pressure is insignificant for small dams. It is also assumed that the value of shear or cohesion between the dam and the soil is equal to zero.
The resultant force from an overturning analysis should be in the middle third of the base. The designer should consider seismic loading where it may be found important under Sudan condition for the safety of the dam.

Figure 6 Stability analysis of small gravity dam

During stability analysis for the sum of the horizontal forces, the effect of the silt pressure is considered insignificant. However if local conditions require this factor to be taken into account, the designer should include the silt pressure in the stability analysis. Seismic factors need to be considered as well wherever when significant.

Where there is a need to access the crest of the dam with machinery, the width of the crest should accommodate the dimensions of the machinery. The minimum width in this case should not be less than 3 m.

A small gravity dam can have an ogee spillway as part of the dam body.

As the gravity dam depends on its weight for its stability, the reduction of the weight of the dam by introducing a step shaped approach at the downstream face of the dam (Figure 7) should not compromise its stability.

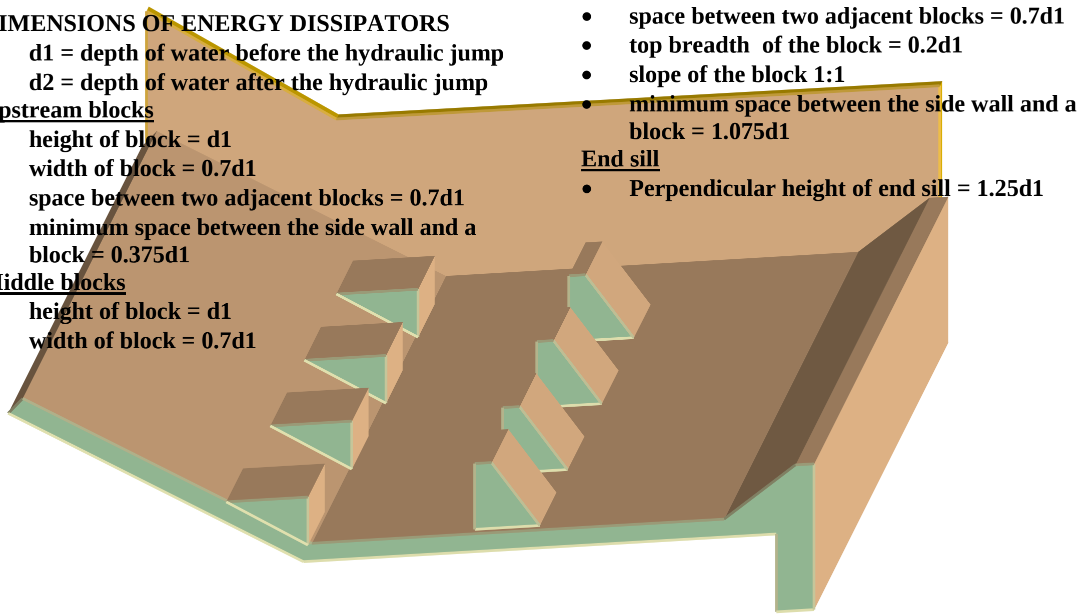
Figure 7. A masonry dam at Arbaat in Red Sea State, Sudan.

In permeable foundations, for masonry rock filled dams, cutoff walls are appropriate for controlling seepage. The cutoff wall should be constructed into the foundation near the upstream toe of the dam. If an inspection on an existing rock filled dam indicates possible excessive seepage at, or just downstream of the toe of a dam, which could lead to failure by piping, the dam could be rehabilitated through the installation of a cutoff wall. A concrete cutoff wall is the most popular for this purpose.

If water is abstracted from the reservoir of the dam by pumping, there is no need to design a conduit pipe as an inlet for abstraction. Locate an appropriate place for a moveable pump at the upstream of the dam. The capacity of the pump to be installed should be determined based on the daily demand by the community and the pumping rate required to supply this demand.

But if a conduit pipe is included in the design as a rigid inlet, , care should be taken to protect the inlet from silt deposits. Silt deposits could totally block the conduit making it nn-functional. Other movable types of inlet, for example a flexible polyethylene pipe with a raft float intake is recommended to avoid the effect of silt deposits.

Figures 8 and 9 show the method of arrangement of energy dissipating blocks in the stilling basin. Refer to "Design of small dams, US Bureau of reclamation Figures 9.19 and 9.39 to 9.42" for dimensions.



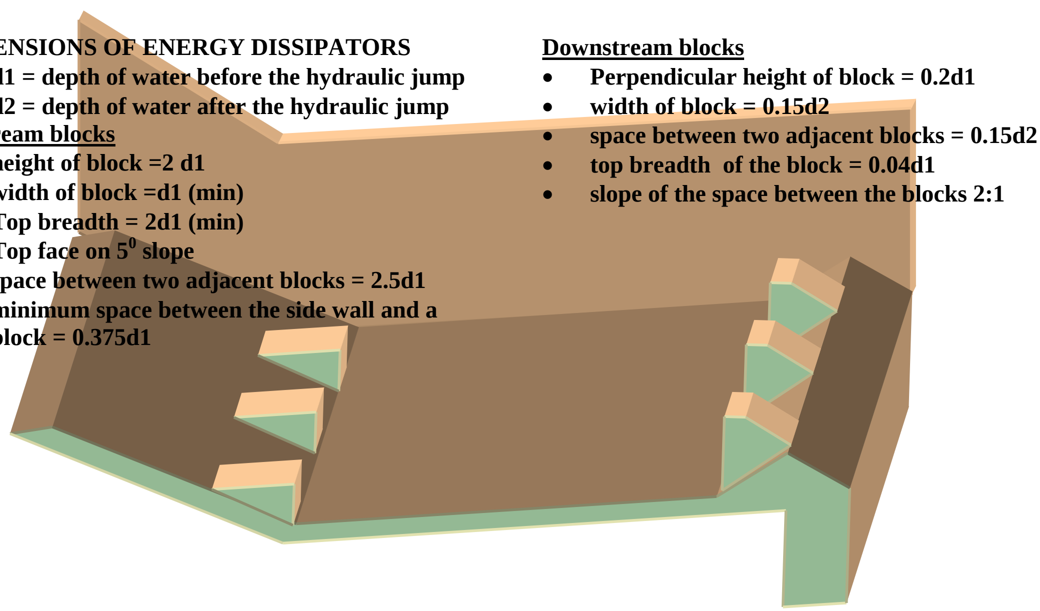


Figure 8: Methods of arrangement of energy dissipating blocks

DIMENSIONS OF ENERGY DISSIPATORS

- **d1 = depth of water before the hydraulic jump**
- **d2 = depth of water after the hydraulic jump**

Upstream blocks

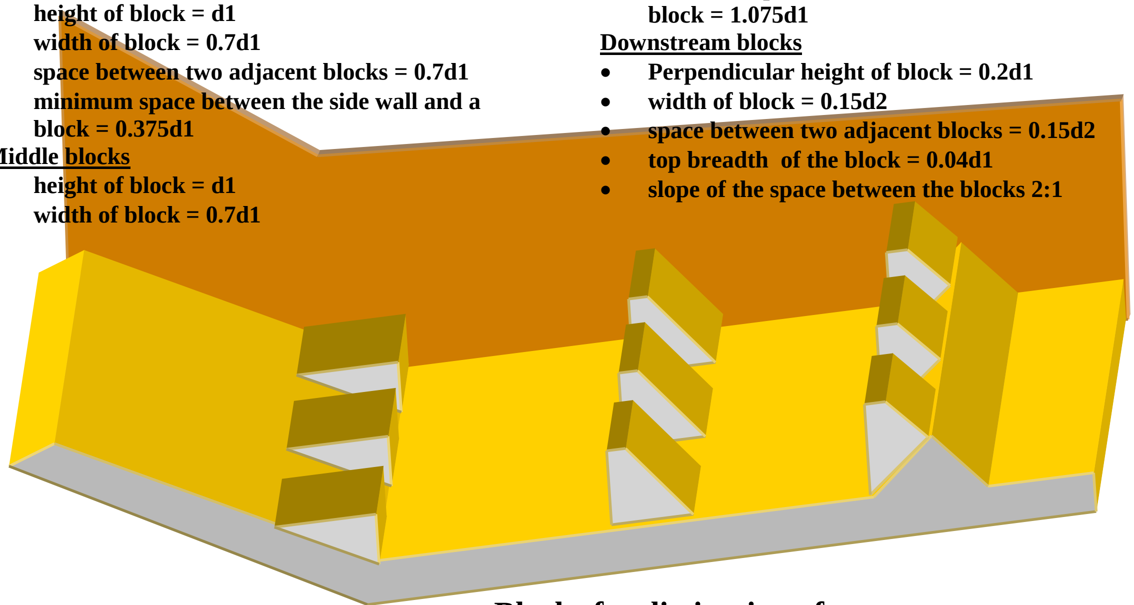
- **height of block = d1**
- **width of block = 0.7d1**
- **space between two adjacent blocks = 0.7d1**
- **minimum space between the side wall and a block = 0.375d1**

Middle blocks

- **height of block = d1**
- **width of block = 0.7d1**
- **space between two adjacent blocks = 0.7d1**
- **top breadth of the block = 0.2d1**
- **slope of the block 1:1**
- **minimum space between the side wall and a block = 1.075d1**

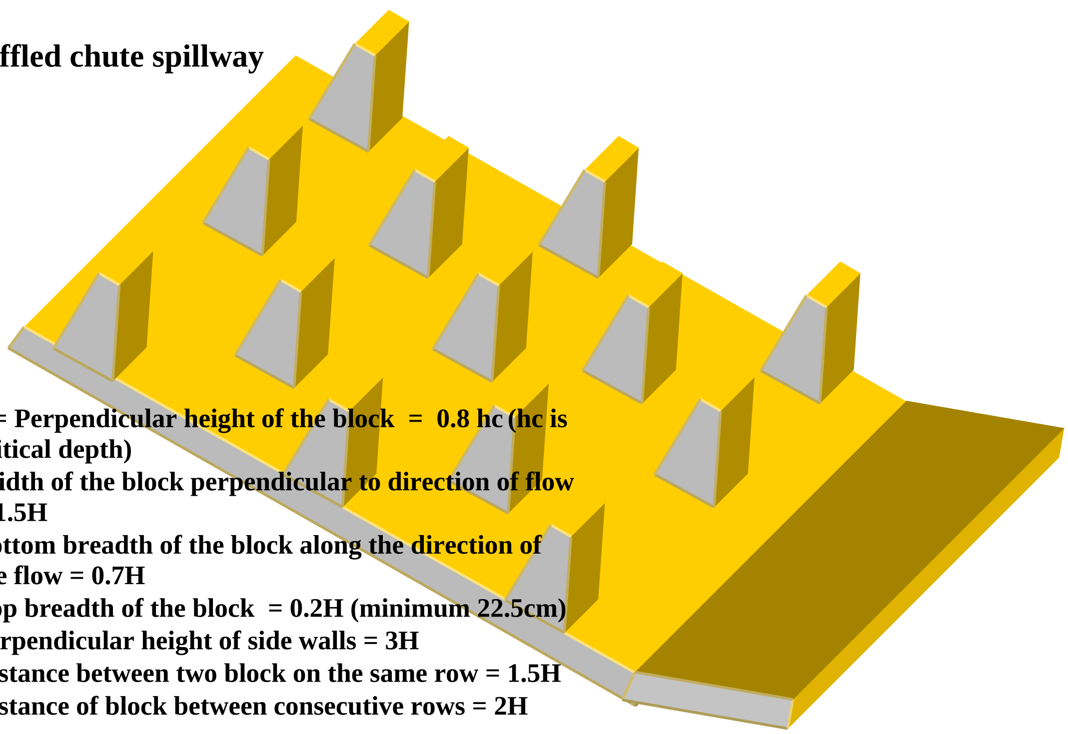
Downstream blocks

- **Perpendicular height of block = 0.2d1**
- **width of block = 0.15d2**
- **space between two adjacent blocks = 0.15d2**
- **top breadth of the block = 0.04d1**
- **slope of the space between the blocks 2:1**



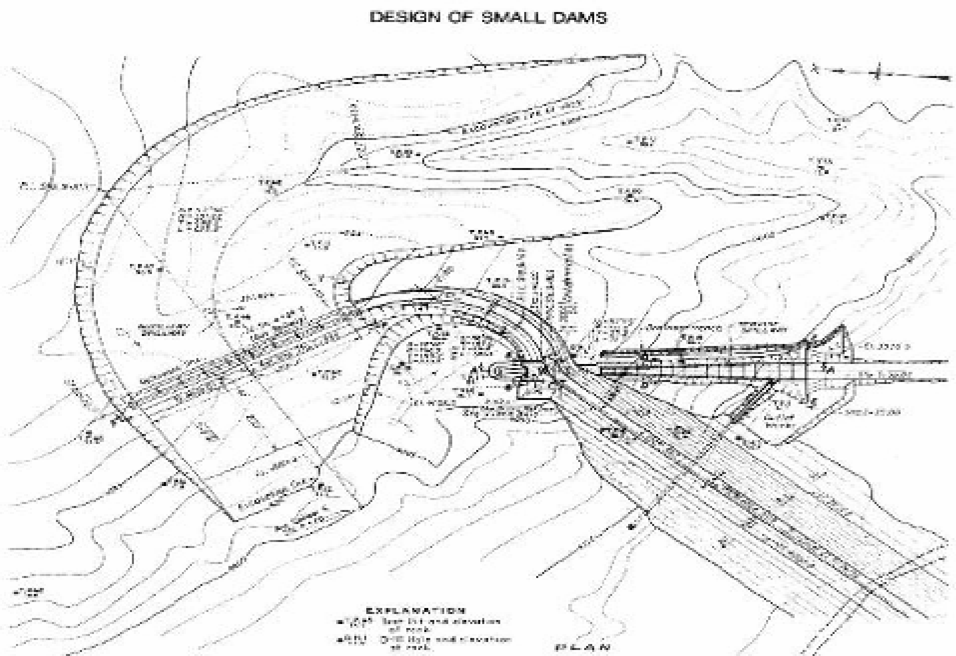
Blocks for dissipation of energy

Baffled chute spillway



- **H= Perpendicular height of the block = 0.8 hc (hc is critical depth)**
- **Width of the block perpendicular to direction of flow = 1.5H**
- **Bottom breadth of the block along the direction of the flow = 0.7H**
- **Top breadth of the block = 0.2H (minimum 22.5cm)**
- **Perpendicular height of side walls = 3H**
- **Distance between two block on the same row = 1.5H**
- **Distance of block between consecutive rows = 2H**

Figure 9: Energy dissipating blocks



Typical configuration of spillway for a small dam. Adapted from design of small dam, Bureau of Reclamation, USA

7. Construction methods for small dams

7.1 Earth dams

7.1.1 Embankment

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- If the dam is located on a perennial stream, flow of water must be diverted away from the dam construction site. Two methods in use are: a) Installation of large diameter steel pipe in the stream, b) Construction of a diversion ditch
- The installation of the pipes requires the placement of the opening of the pipe beyond the furthest extension upstream of the dam embankment. Enough pipes should be laid so that the entire length extends past the furthest downstream extension of the embankment. Before laying the pipes, anti-seepage collars should be welded to the pipes at a distance not more than 7m one to the other.

- Regardless of how the water is diverted, the dam should be built during the dry season so that less water will need to be diverted.
- Mark out the dam site with stakes and rope. Mark the proposed water lines using a levelling instrument (e.g hand level). Tie a string across the valley to mark the high point of the dam. The line should be levelled before proceeding with the next steps..
- All trees, dead leaves, branches, logs, roots and other debris that will be covered by water should be cleared. Special care must be taken to clear out all roots and debris at the site of the dam so that percolation and possible embankment leakage and failure do not occur.
- An important step in the construction of the dam is to determine the width of the embankment. Find the width of the embankment at its widest point. The widest point is also the lowest point of the reservoir. Dam width is equal to the height of the dam times the upstream slope added to the height of the dam times the downstream slope added to the top width. An earth dam with a height of 6 m, upstream slope of 3:1, downstream of slope 2:1 and crest width 4 m will have a total width of 34 m.
- The width of the dam should be checked continually to ensure the slopes/width ratio as indicated in Table 2.

Fill height above ground (m)	Embankment width (m)
Base	34.0
0.5	31.5
1.0	29.0
1.5	26.5
2.0	24.0
2.5	21.5
3.0	19.0
3.5	16.5
4.0	14.0
4.5	11.5
5.0	9.0
5.5	6.5
6.0	4.0

Table 2. Widths of Dam Embankments at different fill heights for embankment slopes of 3:1 and 2:1 for upstream and downstream faces respectively with impermeable core

- Before beginning the building of the embankment with soil, mark its width with rope and pegs to ensure accuracy. Dig out the pegged area until solid ground is reached. Make the bottom rough and irregular to strengthen the bond to the ground.. Use clayey silt for the core of the dam and a clay soil containing some silt and sand for the dam body.
- The embankment may crack if only clay is used and water may percolate through if too much sand is used, If the quality of any of the material is questionable it should be used only on the downstream side of the embankment. If there is any doubt about the suitability of the embankment material, a soil expert or geologist should be consulted or soil samples sent to a soil laboratory for analysis.
- To ensure the strength of the dam, the fill material should be spread in continuous horizontal layers across the entire length of the dam for both impermeable core and other dam body. Each layer should be 20 to 30 cm thick and compacted carefully and thoroughly with an appropriate compacting machine to the specified relative density

before the next layer is added. The compaction ratio should be checked on enough samples, and should not be less than 90%.

- Dry soil should be moistened to the correct level of moisture, depending the type of the soil, as the water tightness and strength of the dam depends on compaction.
- If the embankment is being constructed during the wet season, precautions should be taken to ensure that water does not stay on the surface of the fill material. To ensure the drainage, build up the centre line of the dam and keep it a little higher than the sides so that rain runs off both the upstream and downstream sides. No part of the dam should be more than 90 cm above any other part.
- When building the embankment, make sure that the soil is well compacted around the drain pipe (if provided) and the soil is well bonded to the pipe to prevent any flow of water along the pipe. The anti-seepage collars are installed specifically to prevent the wearing away of soil from around the pipe.
- Continue to build the dam up layer by layer until the desired height and dimensions are reached.
- On the upstream side, to prevent erosion by the wave action of the water in the reservoir, pave the upstream slope with stone pitching (rip-rap) up to the crest level. Also use a toe wall or cutoff.
- Protect the downstream slope.
- Protect the surface of the road way using gravel (or any other material) to avoid cracks and gullies.
- Once the embankment is completed, install a cut-off valve at the downstream side of the drainage pipe (if this pipe is provided).

7.1.2 Spillway

- A Spillway is one of the most important parts of the dam structure, which channels water away from the dam during times of high water and protects the dam from overtopping. For extra safety, two spillways are recommended, one to be placed higher than the other.
- Depending on the design, the location of the spillways could be outside of the dam body or part of the dam body. Accordingly mark the locations of the dimensions of the spillway.
- If the spillway is part of the dam body, extra precaution is required to ensure that there is proper and adequate bondage maintained between the wall of the spillway and soil embankment in order to prevent leakage in between.
- Construct the spillway according to the specification given in the design. Spillways in Sudan are constructed from stone masonry (the body) and reinforced concrete (the crest). The masonry and reinforced concrete works should be constructed according to the given design specifications and or according to the guidance of the Engineer who is supervising the work.
- Spillways need to have energy dissipaters. These should be constructed as per the dimensions and types identified in the given design. The position, the shape, the number and make of these energy dissipaters should be clearly indicated in the design

7.2 Masonry Dams

The preparation work for the construction of masonry dam is similar to that of construction of an earth dam. This includes: diversion of flow, marking out of dam site and removing of roots, debris and other unnecessary materials from the dam site and the reservoir area) The construction of the dam body, however, varies. The following procedures are recommended.

- Mark the width of the dam at the lowest point of the dam height according to the dimensions identified in the given design.
- Before starting construction of the foundation, remove all top soil layers that contains organic matter and the sedimentary pervious layer. Excavate the foundation to the rock formation following the dimensions given in the design. If there is thick sedimentation formation under the dam foundation, and cut-off walls are provided), mark the widths of the cut-off walls.
- Once this is done, the excavation of the foundation of the dam and the cut-off walls to the depth given in the design can begin.
- Construction of the cut-off walls should be completed depending on the make and the design.
- The base of the dam should be thoroughly keyed into the rock formations along the foundations and abutments.
- The Upstream portion is made of stone masonry or dry rubble, and the downstream portion is made of loose rock fill.
- Igneous rocks, small enough to be lifted and placed by hand, should be used for the masonry work. The length of each stone should not exceed three times its height, while its breadth at the stone base should not be less than 15cm. Stones with a round surface should be avoided.. All stones should be moistened before use. Percentage of water absorption should not be more than 5 percent.
- Impervious membrane (concrete, reinforced concrete or asphaltic concrete) can be used on the upstream face.
- Mortar for the masonry work should be composed of Portland cement, sand and water in the following mixing ratio, depending on the location of use. The minimum amount of water necessary should be used to permit placing and packing.

  Cement : Sand

  1 : 4 Upstream face of wall

  1 : 6 Downstream face of wall

  1 : 8 Middle of the dam
- Unless otherwise specified, concrete class K140 should be used for all plain concrete works and concrete class K 300 for all reinforced concrete.
- The spillway, if designed as part of the dam body, should be constructed from the recommendd class of concrete as it is given in the plans and drawings
- An engineering geologist should monitor the construction work, examining all excavations to ensure that the expectations of the preceding investigations have been realized. Early diagnosis of potential problems will allow early redemption..
- Monitoring at the post-commissioning stage involves regular readings of installed instrumentation (if any), to check performance against design criteria. This should serve as an 'early warning' system which will initiate a contingency programme, thus minimizing the delays which would result from the development of an adverse situation.

8. Management, operation and maintenance of small dams and capacity building

8.1 Management

In some states like Kassala, Red Sea and Blue Nile, management, operation and maintenance is the responsibility of the SWC whilst in Gedaref responsibility belongs to both SWC and communities. The management, operation and maintenance of dams, require expertise, skills and budgets; and follow-up should not be left entirely to the community. Delays in maintenance occurring as a result of lack of community know-how or lack of resources for the SWC, ent resources, the safety of the dams can be compromised. This has been demonstrated in some states, where some earth dams filled with silt have developed leakages under the spillways. This has prevented accumulation of enough water in the space in the reservoir. Each state needs to review its current status and adapt a suitable and viable management system. A joint management system including communities, local authorities and SWC is recommended.

8.2 Operation and maintenance

A small dam is considered improved when the water abstracted from the dam is treated appropriately to obtain the required quality. Abstracted water is conveyed to the treatment facilities either by gravity or pumping. If abstraction is by gravity, regular cleaning of the inlet is required: this may be more frequent during the flooding season and when necessary during the dry season. If water is abstracted by pumping, the manufacturer's guidelines on operation and maintenance should be followed.

Proper dam maintenance is very important to ensure sustainability of the investment, availability of community water supply and protection of people and property near and downstream of the dam.

Earth dams' failures can be hydraulic, seepage or structural. . Hydraulic failures include overtopping, erosion of upstream face, erosion of downstream face by gully formation and erosion of downstream toe. Seepage failure is due to piping through foundations, piping through the dam body and sloughing of the downstream toe. Structural failure is due to foundation slide and slides in embankments. Factors like poor watershed management can affect the quality of water. Reservoirs can become breeding places for disease-carrying insects such as snails and mosquitoes which are potential health hazards. These problems are amplified if proper maintenance is not carried out.

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Figure 10: Erosion effect of embankment.
Irrigation canal in Kassala State: a good example for the need of regular maintenance of embankment of earth dams

All dams should be inspected periodically, prior to the season and after every heavy rain, to determine if there is a need for repairs. Check the dam for any seepage or cracks. If there is seepage through or under the dam, consult an engineer immediately for advice on correcting the problem promptly to prevent the condition from getting worse.

Maintenance work, begins after completion of the construction, and includes removal of trees, bushes and grasses from the reservoir. Debris including floating trees can create problem at the dam. Organic material that does not decay can create an undesirable odour in water. Before filling the dam with water, soil cracking that caused by desiccation must be closed up. The dam will be threatened by sliding if such actions were not taken.

Burrowing animals on the embankments of the dam were found to cause great damage to a dam in Boot, Blue Nile State. An agricultural expert should be consulted if burrowing activities are a problem.

Erosion caused by rain or wave action in the reservoir must be controlled. Where it is possible and appropriate, plant grass (not trees) as a protective measure against erosion on the downstream face and construct rip-rap on the upstream face of earth dams.

Water should never be allowed to flow over the top of an earth dam. Spillways are installed to prevent overtopping and their maintenance is very important. Check the conditions of the spillways before and after every flood season. After heavy rains, make sure that nothing is blocking the channels. Any large debris should be removed from the spillways to prevent water from backing up during heavy rains.

Mosquitoes and snails generally breed in shallow water. To prevent this, steepen the edges of the reservoir by about 1m. Deep pond edges discourage breeding and the growth of vegetation..

Dams may lose their storage capacity due to siltation. Soil and water conservation activities of the catchment area, like planting trees, terracing, check dams, prevention of overgrazing, etc, should be part of the O&M activity in order to minimize the rate of siltation and deposition of sediment material in the reservoir.

Seasonal streams exert traction force on bed particles and this force detaches and transports materials from the streambeds, inducing a torrential flow characterized by sediment discharge produced by surface sheet and gully erosions in the watershed. This results in progressive streambeds and stream banks degradation, which are likely to destabilize adjacent land. This calls for watershed management (torrent control) intervention, to reduce water flow during the season and to care for stream beds and banks through the introduction of hydraulic, biological and socio-economic measures.

- Hydraulic measures include the construction of primary/check dams that are mere vertical and transverse structures such as dry stone or masonry walls, constructed across steep areas to control streambed erosion and to stabilize bank slopes.
- Biological measures include maintaining vegetation through plantation of permanent plants on the watershed, to lower the traction force of torrential drainage, so that the flow does not scour the soil.
- Socio-economic measures entail establishing contour farming on hillsides (terracing across slopes) that would yield partial control of surface direct runoff, reducing the quantity of suspended sediment that contributes to the turbid and dense flow, and thereby weakening its traction force.

8.3 Capacity building

There is a dire need for capacity building at different levels for the management, operation and maintenance of small dams.

At community level: The site of the reservoir dam needs to be fenced so that access is restricted. This will increase the revenue generation capacity of communities and reduce pollution and transmission of waterborne diseases in the reservoir.

As most dams are located off main roads and very far from SWC offices, it is important that community members are trained to detect problems and able to report, defects, damages, malfunctioning, leakages etc. promptly to the SWC..

Hygiene and sanitation promotion activities need to be introduced or strengthened as part of the water supply interventions. Indigenous traditional knowledge on water filtration must be researched and encouraged.

At state/locality level: Training on monitoring of dams should be provided to staff members of SWC as well as to members of the management committee of the water supply facilities so that they can report and take appropriate action on time. This will improve the planning capacity of SWC on an annual basis, allowing for timely allocation of resources as SWC is responsible for technical back-up.

9. Recommendations

Guidelines for the construction of small dams must be followed carefully to ensure the construction of a solid structure that is likely to last for many years. Whenever possible, an expert should be consulted before and during the construction process. Poor construction can cause dam leakage and breakage, resulting in physical, service, investment and economic loss.

Seepage of dams must be checked by qualified experts and their recommendations considered in consequent actions relating to the dam.

The boundaries of reservoirs and dams must be protected to ensure that they are free from settlement and other human activities

As malaria is a problem in Sudan, aquatic growth and shoreline vegetation should not be permitted in the reservoirs of dams. It is important to deepen all edges of the reservoir by about 60 to 100cm to prevent the growth of vegetation and weeds and the breeding of mosquitoes and snails

Relevant authorities from each state should take full responsibility for the safety of the dams in their area. The SWC should be supported with the necessary operation and maintenance budget on a regular basis. Routine and regular maintenance is very important. The damage that may be caused by natural disasters or otherwise, due to delays or neglect of maintenance activities can be disastrous to life, property and the environment.

Local authorities and communities must be involved in the daily management, operation and maintenance of small dams. The involvement of expert staff is important, and they should be provided with adequate training in management, operation and maintenance of small dams.

The volume of the dam reservoir decreases with an increase in the deposit of sediments, directly affecting the proper operation of dam components e.g. the outlet structures. An estimation of the expected sediment deposit, allows for proper planning for its removal. Although time consuming and expensive, it is worth treating the drainage basin with various soil conservation methods e.g. planting, to reduce the rate of sedimentation in the dam reservoir. If this is not practical, auxiliary structures like detention basins, lateral spillways etc. should be constructed upstream of the dam reservoir. This should be indicated in the feasibility as well as detail design phase.

The water in the reservoir can be protected by simple watershed management and sanitation practices. These include: restricting entry to both the reservoir and watershed area for livestock and other domestic animals. In areas where small dams are successful, community members and SWC have indicated that fencing of the reservoir and ensuring prompt repairs has increased the community’s management capacity of the system

Annexes

1. Sudanese/WHO drinking water standards
2. Typical check list of improved dams for annual routine maintenance
3. The process of development these technical guidelines
4. List of contacted people
5. Technical working group members
6. Some selected bibliography and references

Annex 1: Drinking Water Standards

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

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

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

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

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

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

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

Annex 2: Typical check list of improved dams for annual routine maintenance

An initial routine maintenance checklist should be prepared for every dam by the constructor and approved by the owner. Every dam is peculiar in its own location. The following checklist is a guide and not exhaustive, and only refers to the dam – not the water treatment system.

A) Earthen Small Dam

Upstream Face:

Riprap	--------------------------------
Erosion	--------------------------------
Vegetative growth	--------------------------------
Settlement	--------------------------------
Debris	--------------------------------
Upstream apron (if any)	--------------------------------

Downstream Face:

Erosion	-------------------------------
Vegetative growth	-------------------------------
Downstream apron (if any)	-------------------------------

Crest:

Roadway	-------------------------------
Settlement	-------------------------------

Seepage and Drainage

Location	-------------------------------
Toe drain	-------------------------------
Measurement	-------------------------------
Measurement method	-------------------------------
Amount	-------------------------------
Change in flow	-------------------------------

B) Masonry Small Dam

Upstream Face

Settlement	-------------------------------
Debris	-------------------------------
Upstream apron (if any)	-------------------------------

Downstream Face:

Settlement	-------------------------------
Vegetative growth	-------------------------------
Downstream apron (if any)	-------------------------------
Foundation at downstream toe of dam	-------------------------------

Crest	
Top road	-----------------------------------
Parapet wall	-----------------------------------
Settlement	-----------------------------------
Seepage around dam	
Location	-----------------------------------
Measurement	-----------------------------------
Measurement method	-----------------------------------
Amount	-----------------------------------

C) Spillway

Approach Channel	-----------------------------------
Control Structures	
Crest	-----------------------------------
Walls	-----------------------------------
Apron	-----------------------------------
Chute	
Walls	-----------------------------------
Floor	-----------------------------------
Blocks (if any)	-----------------------------------
Stilling Basin	
Walls	-----------------------------------
Floor	-----------------------------------
Blocks	-----------------------------------
Outlet Channel	
Riprap	-----------------------------------
Erosion	-----------------------------------

D) Outlet Structures

Inlet Structures	
Oiling or greasing of sluice gates	----------------------------------
Seepage	----------------------------------
Outlet Conduit	----------------------------------
Chute (if any)	----------------------------------
Stilling basin (if any)	----------------------------------
Outlet Channel (if any)	----------------------------------

Annex 3: The Development of these Technical Guidelines

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

A. The Preparation Stage

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

Collection of Information:

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

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

Analysis of collected information:

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

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

B. The Finalization Stage

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

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

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

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

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

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

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

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

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

Annex 4. List of contacted people

Gedarif State

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

Kassala State

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

Red Sea State

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

Sinnar State

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

Blue Nile State

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

People Contacted in Southern Sudan, July 2008

1. Juma Chisto, Operator of Kator Emergency Water Supply, Juba
2. Habib Dolas, Member of Watsan committee, Hai Jebel
3. Andew Wan Stephen, Member of Watsan committee, Hai Jebel
4. Francis Yokwe, Member of Watsan committee, Hai Jebel
5. William Ali Jakob, Member of Watsan committee, Hai Jebel
6. William Nadow Simon, Member of Watsan committee, Hai Jebel
7. Ali Sama, Director General, Rural Water Department, Central Equatoria State (CES)
8. Engineer Samuel Toban Longa, Deputy Area Manager, UWC, CES
9. Sabil Sabrino, Director General UWC, WBeG
10. James Morter, Technician, UWC, Wau
11. Carmen Garrigos, RPO, Unicef Wau
12. Sevit Veterino, Director General, RWC, WBeG
13. Stephen Alek, Director General, Ministry of Physical Infrastructure (MPI), Warap
14. John Marie, Director of Finance, MPI, Warap State
15. Angelo Okol, Deputy Director of O&M, Warap State
16. Santino Ohak Yomon, Director, RWSS, Upper Nile State
17. Abdulkadir Musse, RPO, Unicef Malakal
18. Dok Jok Dok, Governor, Upper Nile State
19. Yoanes Agawis, Acting Minister, MPI, Upper Nile State
20. Bruce Pagedud, Watsan Manager, Solidarites, Malakal
21. Garang William Woul, SRCS, Malakal
22. Peter Onak, WVI, Malakal
23. Gailda Kwenda, ACF, Malakal
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