Darfur: water supply in a vulnerable environment

Phase Two of Tearfund's Darfur Environment Study

25 October 2007

tearfund

USAID FROM THE AMERICAN PEOPLE

DFID Department for International Development

UNEP

Contents

Tables

Boxes

Figures

Acronyms

BC	Basement Complex
D:RIVE	Darfur: Relief in a vulnerable environment (Tearfund report)
DFID	Department for International Development (of UK Government)
FAO	Food and Agriculture Organisation of the United Nations
GIS	Geographic Information System
GWWD	Groundwater and Wadis Directorate (of Ministry of Irrigation)
HGG	Hunting Geology & Geophysics
HTS	Hunting Technical Services
IDP	Internally displaced person
l/min	litres per minute
lpd	litres per person per day
M&E	Monitoring and evaluation
Mcm	Million cubic metres
m^3/hr	cubic metres per hour
MMP	Sir Murdoch Macdonald & Partners (now Mott Macdonald)
NGO	Non-governmental organisation
NS	Nubian Sandstone
OCHA	United Nations Office for the Coordination of Humanitarian Affairs
OFDA	Office of U.S. Foreign Disasters Assistance
RCO	Resident Coordinators Office
RTF	Radar Technologies France
SRM	Sustainable resource management
T	Transmissivity
TDS	Total Dissolved Solids
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNHCR	United Nations High Commission for Refugees
UNICEF	United Nations Children's Fund
URS	Umm Ruwaba Series
WADS	Water and Development Survey
WES	Water and Environmental Sanitation
WHO	World Health Organisation
ZoC	Zone of Contribution (catchment to a borehole)

The cover photo shows queues of jerry cans waiting to be filled from four tap-stands in Abu Shouk IDP camp in North Darfur. 12-15 boreholes have run dry in the Abu Shouk / Al Salaam camps.

Selected glossary

Dipping / Dippers — Dippers are long tapes with water detectors that send a signal (to a light or buzzer) when they are dipped into water, down a borehole.

Hafir — Traditional rainwater storage reservoir.

Loggers — Groundwater monitoring equipment that stays in a borehole recording changes in groundwater level over time. Data is downloaded periodically to a laptop with appropriate software.

Permeability — A coefficient of proportionality describing the rate at which water can move through a permeable medium.

Porosity — The ratio of the volume of void spaces in a rock or sediment to the total volume of the rock or sediment.

Recharge:

- **Direct recharge** — Water flowing into an aquifer from rain falling directly on the ground surface above the aquifer and infiltrating downwards.
- **Indirect recharge** — Water flowing into an aquifer from flood waters in a wadi.

Storativity — The ratio of the volume of available water in a rock or sediment to the total volume of the rock or sediment (also ‘Storage Coefficient’).

Transmissivity — The rate at which water is transmitted through a unit width of aquifer under a unit hydraulic gradient. It is equivalent to the product of the aquifer permeability and saturated aquifer thickness.

Weathering — The process by which rocks are broken down and decomposed by the action of external agencies such as wind, rain, temperature changes, plants and bacteria.

Wadi — An ephemeral watercourse, normally dry for most of the year.

Summary

S.1 Project background

As a result of the conflict, Darfur has unprecedented concentrations of population, imposing high localised demands on water resources. This is taking place in an area where the rain falls in only four months of the year and the prevailing geology is unfavourable for storage of groundwater. While there are some exceptional areas rich in groundwater such as the wadis or a few sandstone areas, these are of little benefit for populations that are unable to travel to these sources without fear of harassment. This study focuses on the water needs of the IDPs in camps

This assessment was undertaken following the recommendation made in the report "Darfur: relief in a vulnerable environment[1] (D:RIVE)".

D:RIVE calls for a framework of sustainable resource management to be integrated through the Darfur relief response. To ensure water resource security for the camps, both **demands** and **resources** need to be accurately measured in order to be managed. As of May 2007 there was no systematic monitoring of groundwater levels in camps, and little or no analysis of demands. Since the publication of the draft recommendations of this report in May 2007, groundwater monitoring has been introduced in Darfur's humanitarian programme by UNICEF and Oxfam.

Oxfam's household demand survey in Abu Shouk and Al Salaam found water usage levels higher than expected at at least 24 lpd. The survey also found that over 94% of the 200 families questioned said they had more water in Abu Shouk and Al Salaam camps than they used to use in their villages before the crisis, and that a significant portion of this water is being used for livelihoods. These findings were at camps of known water stress - as indicated by the fact that 12 to 15 boreholes have run dry in Abu Shouk.

There is a significant volume of data on groundwater in Darfur collected since the 1970s from projects such as the Jebel Marra, South Darfur, Western Savannah and WADS projects, but these data are not widely accessed within the current Darfur water programme.

Hence uncertainty remains over water resources at many camps - including some of Darfur's largest camps – Otash, Kalma, Abu Shouk and Al Salaam.

The initial objective of the Water Resource Vulnerability Assessment (WRVA) was to assess the risk of water resource vulnerability at four major camps in Darfur: Mornei, Kass, Kalma and Abu Shouk. However due to security constraints Kass was dropped from the programme but Otash and Al Salaam were added (Al Salaam is assessed jointly with Abu Shouk). Camp-specific conclusions and recommendations for the camps reviewed are given in Section 3 to Section 6. General conclusions and recommendations for all camps are given in Section 8.

A second objective was to undertake a desk study to identify other camps potentially vulnerable to groundwater depletion, based on the findings from the field work. This list is given in Section 7. Greater detail on monitoring programmes is provided in Section 9. Further recommendations for water resource management in Darfur are given in Section 10

[1] Darfur: relief in a vulnerable environment. Bromwich B, Abuelgasim Abdalla Adam, Abduljabbar Abdulla Fadul, Chege F, Sweet J, Tanner V, Wright G Tearfund 2007
http://www.tearfund.org/webdocs/website/Campaigning/Policy%20and%20research/Relief%20in%20a%20vulnerable%20envirionment%20final.pdf

Box S.1 Recent remote sensing studies in Darfur[2]

Two remote sensing geological surveys have been undertaken in Darfur recently, which add useful mapping data to the significant body of knowledge developed in Darfur on development projects prior to the crisis as presented in the reports described in the Appendices to this report.

A study was undertaken by RTF in 2006 which reiterated the fact that some of Darfur's wadis and volcanic rocks have significant water resources. The report acknowledged the difficulties of locating sustainable water supplies in areas of Basement Complex rocks away from wadis but was focussed on drawing attention to the resources in the wadis. This study however appears to overestimate the availability of water resources ***for IDPs*** by:

- Concentrating on the locations with more abundant water resources rather than focussing on the locations of demand. The report fails to draw out the difficulties caused by the distance between the people and the resources in the context of the conflict.
- Assuming very high abstraction rates from alluvial aquifers,
- Considering average rather than dry years – in an arid climate like Darfur's, annual rainfall is very variable, and it is in the dry years that water stress becomes critical.

More recently, attention has been drawn to the possible existence of an aquifer beneath the site of an "ancient lake" in the desert region in the far north of Darfur. This lake (known as 'Lake Ptolemy') existed several thousand years ago when Darfur's climate was much wetter than at present. The underlying aquifer is the Nubian Sandstone. The underground resource has not been proven as yet, but even if the resource is good it will have little relevance to the humanitarian programme due to its very remote location in the unpopulated desert area in the far north of North Darfur (it is to the north of the area shown on Figure 1, p6).

The resource may prove to be appropriate for large remote commercial farms, but piping supplies to dispersed villages and camps would not be cost effective, and so this project will have little benefit to traditional livelihoods of displaced or returning populations. Economic benefits to Darfur would depend on the arrangements for ownership and wealth-sharing from the farms in addition to the migrant labour opportunities. The closest large town to the aquifer is El Fasher at a distance of approximately 500km. There are other aquifers closer to El Fasher that have potential for development.

While these studies both bring useful mapping to hydrogeological literature on Darfur, both require interpretation to be governed by conventional hydrogeological analysis – including reviewing existing reports, visiting and test drilling at the sites in question. These studies, suggesting potential abundance of water in a few locations in small areas of Darfur, should not obscure the overall picture of Darfur as being highly constrained by a shortage of water resources.

Greater emphasis on assimilating the knowledge already developed in Darfur, and deploying more hydrogeologists to integrate this knowledge with project implementation, are likely to bring more cost effective benefits to the conflict-affected communities in Darfur than further remote sensing.

S.2 General conclusions and recommendations

S.2.1 Conclusions

Most publications on the groundwater resources of Basement Complex rocks in Africa (e.g. MacDonald, Davies & O Dochartaigh 2002) describe this aquifer as having the potential to provide

[2] Water Exploration in Darfur – Sudan; WATEX Project, 2006 – RTF/USGS, and Boston Universities "Ancient Mega-lake" The location of the potential aquifer is shown at the foot of this site:
http://www.bu.edu/phpbin/news/releases/display.php?id=1298
More details of the project can be found at:
http://www.bu.edu/phpbin/news/releases/display.php?id=1370&template=today

water supplies for villages and rural areas. It is not generally regarded as having the potential for sustainable water supplies to towns with populations of 30,000 or more. In this context, what has been achieved in the large IDP camps in Darfur is quite remarkable. Populations of tens of thousands of people have been supplied with 15 litres or more per head per day of safe drinking water for up to four years in a semi-arid area. What is surprising is that these supplies have been maintained for as long as they have.

To some degree, this may be due to the relatively good rainfall in the past three rainy seasons (except at El Fasher, where 2004 rains were poor). However, it must be expected that another poor rainy season could occur at any time, and NGOs and national authorities need to plan accordingly.

Water resource vulnerability

A significant number of camps are vulnerable or potentially vulnerable to groundwater depletion in a year of below average rainfall. This has not been apparent in Darfur due to years of average or above average rainfall coinciding with the crisis, and the presence of water storage built up over the long term before the crisis. The most vulnerable camps are those with large populations which are sited on Basement Complex rock without sources of recharge other than local rainfall in the area overlying the aquifer. Otash is in this category.

Camps that are *potentially* vulnerable to groundwater depletion are those with a large population sited on Basement Complex geology where adequate annual recharge from a local wadi *has not been proven*. In Kalma (Wadis Kalma and Nyala), and in Abu Shouk and Al Salaam (Wadi Haloof) water in the wadis may or may not adequately recharge the Basement Complex aquifers supplying these camps. Hence monitoring is needed in the camps and at the wadis to determine if sufficient water is able to flow from the wadis into the aquifers beneath the camps. In large camps, some parts of a camp may have reliable recharge while other parts may not.

Water resource management

At present, camp administrators concentrate on managing the water supply points – boreholes and dug wells – and the other elements of the distribution system – pumps, chlorination units, storage tanks and tap stands. There is little consideration of the water resource system as a whole. The study found:

- Little or no monitoring of groundwater,
- Little or no analysis of water use,
- Inadequate data management, both in the field management and in terms of coordination: UNICEF's data base is not well integrated with practical management of water programmes,
- Little awareness of the risks of a season of low rainfall, and therefore:
- Little or no contingency planning for the event of a dry year.

With respect to practice at camp level:

- Data relating to boreholes were often incomplete, or files unavailable. Staff of operating agencies lack access to relevant reports, and are often unaware of reports or maps which could assist their work. Geophysical survey reports (to locate optimum borehole sites) were often not available,
- Reports on geophysical surveys (to locate optimum borehole sites) were often absent,
- Exact locations of boreholes drilled were not recorded, especially for dry or abandoned boreholes,
- It was often impossible to correlate drilling records with water sources in use – e.g. a pumped borehole known by the operating agency as 'Abu Shouk Hand Pump No. 3' could not be correlated with any particular drilling record,

- In almost no cases have the absolute or even relative elevations of well heads been surveyed (GPS-derived elevations are not sufficiently accurate). Therefore it is impossible to infer any groundwater flow directions from water level measurements. This is important where, for instance, recharge to a Basement aquifer is expected to come from a nearby wadi.

Thus there is a very significant issue around information management which requires an appropriate response. Information technology has the capacity to improve this situation if it is properly deployed. Integration with day to day management is essential.

In general a greater level of hydrogeological analysis is needed, involving more data collection, better data management and more capacity for hydrogeological interpretation.

The key risk is of water shortage in a dry year in vulnerable camps. Better analysis of the hydrogeological situation will allow this risk to be defined, and allow contingency plans and mitigation measures to be designed. There is inadequate understanding of the recharge mechanisms for the aquifers being relied on. Monitoring and interpretation of the results will allow better understanding of the risks posed by dry years.

The concentration on supply rather than resource management is associated with reporting procedures, mandates of operating agencies, and possibly a cultural shift that has responded to the need to address 'soft' issues, but has left inadequate attention on more conventional technical issues such as hydrogeology. These issues have been discussed in D:RIVE.[3]

A greater emphasis on technical leadership (water resource management, appropriate M & E, strategic planning, hydrogeological expertise) within the sector is likely to be cost effective by generating savings from more efficient drilling programmes. However, the primary objective of these recommendations is to reduce vulnerability of water supplies in IDP camps.

S.2.2 Recommendations

(Recommended responsibilities are shown in brackets.)

R.1. The following activities must be undertaken at the vulnerable and potentially vulnerable camps. See list in Section 7. This work should be coordinated by UNICEF's field offices.

a. Manual water level measurements (dipping) at production wells in vulnerable and potentially vulnerable camps. These measurements should be made after rainfall events, and intermittently in the dry season.

b. Installation of water level loggers on production wells at vulnerable and potentially vulnerable camps (prioritised in order of population size, with the exception of early installation at Otash).

c. Provision of rain gauges and training in installation and recording of rainfall data.

d. Data collected should be interpreted by an experienced and appropriately qualified hydrogeologist and reported on a 6 monthly basis, one analysis being at the end of the rains. The outcome of this analysis should be shared with the wider humanitarian community including OCHA. These reviews should form the basis of planning expenditure on the following period.

(UNICEF, WES, Implementing agencies, UNEP)

R.2. After prioritising representative boreholes in the most vulnerable camps, groundwater level monitoring should be implemented on all boreholes (motorised boreholes and unused - but not dry - boreholes). Monitoring is not practicable on hand pumps due to the lack of access. Both production and observation wells should be monitored. It is important to monitor production wells in Basement Complex rock because the fracture systems are often unconnected – in

[3] Darfur: relief in a vulnerable environment. Bromwich B, Abuelgasim Abdalla Adam, Abduljabbar Abdulla Fadul, Chege F, Sweet J, Tanner V, Wright G Tearfund 2007
http://www.tearfund.org/darfurenvironment

which case an observation well may not reflect the drawdown at a nearby production well. (This is not the case for "normal" aquifers.) Once borehole performance is established, there will be some instances where monitoring may be reduced. (Coordination by UNICEF, collaboration with implementing agencies, WES, UNEP)

R.3. Contingency plans should be drawn up to respond to a poor wet season. (UNICEF, OCHA)

R.4. All water points should be mapped. OCHA-HIC have been very active in mapping facilities at camps and their work should be assisted as much as possible by agencies in the camps. (Implementing agencies, UNICEF, WES)

R.5. The relative elevations of the wellheads at all borehole (and hand pump[4]) sites should be established by precise levelling (i.e. not via GPS). This will enable monitoring data to be used to determine relative groundwater levels to be determined at each well. This will show hydraulic gradients and hence indicate recharge mechanisms. (Implementing agencies, UNICEF, WES)

R.6. Every water source should have a unique identifier number and have its own paper file in which relevant data can be kept – baseline data, monitoring data and operational notes. (Implementing agencies, UNICEF, WES)

R.7. All information should be assembled in suitable paper files, and on maps, in addition to the UNICEF database. Information copied in this way is much less likely to be lost over time. (Implementing agencies, UNICEF, WES)

R.8. Drilling records and water level monitoring data should be copied to relevant Government bodies. (Implementing agencies, UNICEF, WES)

R.9. Flow meters should be installed, calibrated and periodically checked, on the outflow from all motorised boreholes and all storage tanks, and daily records of output should be kept. (Implementing agencies, UNICEF, WES)

R.10. A single co-ordinator should be appointed to monitor water resources in each camp. Water managers should have reliable and complete information on:

a. groundwater monitoring data, rainfall and wadi flow data,
b. pumping records and flow gauge data,
c. water use from household survey data,
d. relevant background data, maps and reports,
e. interpretation of this data showing status of groundwater vulnerability, and recommended mitigating actions where needed.

(Implementing agencies, WES, UNICEF)

R.11. Inexpensive plastic rain gauges (two per camp) should be installed to give some measurement of the rainfall. The duplication will help to ensure that data are not missed and also to give a check. It is acknowledged that this type of rain gauge does not give data which are acceptable for meteorological purposes. However, in the absence of rain gauges outside the state capitals, such gauges will give reasonably accurate data whereby one rainy season can be compared with another, and potential recharge estimated. (Implementing agencies, UNICEF).

R.12. Water use surveys should be undertaken in wet and dry seasons. (Implementing agencies / UNICEF)

R.13. A coordinated project is needed to ensure that the compilation of all available information on the water supply systems in the camps is complete. (UNICEF, UNEP)

[4] Ground levels at non-monitored sites such as hand pumps may be useful where borehole records provide original water level data, and may help in assessing the vulnerability of such sites to depletion; otherwise, levelling of these sites is a secondary priority.

R.14. A data collection exercise is needed to ensure that important historical hydrological records and reports are scanned and made available to implementing agencies. (Implementing agencies, UNICEF, UNEP)

R.15. An assessment of the effectiveness of the WES/UNICEF database as a management tool should be made, and recommendations made for integrating the database in water management, and monitoring and evaluation of the water programme. The assessment should assess potential for internet access to the database, whereby water managers can enter and read data directly. This has the potential for making the database a "live" document and a useful means of communication. (UNICEF / Implementing agencies / RCO)

R.16. Unless emergencies occur, additional drilling in vulnerable or potentially vulnerable camps should be undertaken only after household water use surveys have been undertaken and the need proven. This recommendation is made in light of Oxfam's survey which identified significantly higher water use than had previously been understood in the camps. (Implementing agencies, UNICEF, WES)

R.17. Provision for groundwater level monitoring should be included in the design of all new boreholes. (Implementing agencies, UNICEF, WES, Donors)

R.18. Existing AU and proposed UN camps should practice sustainable management of water resources as part of a larger do-no-harm approach to environment in Darfur. The inherent vulnerability of Darfur's environment and its central role in Darfur's traditional livelihoods give an urgency to this recommendation that would not exist in more resource-rich environments. (RCO to coordinate, UNEP to advise)

R.19. Observations of surface water flow should be made at vulnerable camps. As with groundwater monitoring, the purpose is to establish the extent to which wadi flow recharges the basement aquifer beneath the camp – therefore both water bodies need to be observed. A staff gauge should be installed (in a concrete pad) in each wadi in or near a camp. Records should be kept of:

a. dates, times and durations of wadi flows,

b. depth (on staff gauge) of maximum flood and at other times,

c. dates and durations of standing water in the wadi.

(Implementing agencies, WES, UNICEF)

R.20. Best practice on water management at camps should be developed, recorded and disseminated on the basis of lessons learnt during the implementation of these recommendations in Darfur. (Implementing agencies, WES, UNICEF, UNEP)

S.3 Camp-specific conclusions and recommendations

Abu Shouk / Al Salaam camps – conclusions

1. The water supply to Abu Shouk and Al Salaam depends substantially on hand pumps, 12-15 of which have run dry or reduced in yield over the past 3 years.
2. Most failed or failing hand pumps are in the raised Qoz areas, whereas most of the 'dependable' hand pumps, and the motorised pumps, are in the lower alluvial areas.
3. The failed and failing hand pumps have been drawing on groundwater storage in areas receiving little or no recharge in the wet season.
4. Dependency on the motorised pumps in the alluvial areas will therefore increase.
5. Lack of data on borehole water levels precludes a conclusion on the sustainability of the water supply as a whole (some areas are already drying). However, consideration of the likely available recharge and the variability of annual rainfall indicates that:
   - the supply may already be unsustainable in an average year, but only a period of groundwater level monitoring can confirm or refute this,

- in a dry year (significantly lower than average rainfall in the wet season) the supply is likely to be unsustainable through the subsequent dry season.

6. Reconstruction of the Wadi Haloof dam would reduce the vulnerability of the camp water supplies.

Abu Shouk/Al Salaam camps – specific recommendation

C.1. A single co-ordinator should be appointed to monitor the water resources at the two camps. (Implementing agency)

C.2. Construction of additional boreholes in the alluvial areas should be considered. (Implementing agency, UNICEF, WES)

C.3. Reconstruction of Wadi Haloof dam should be supported in principle, subject to appropriate hydrological and cost-benefit analyses. (UNICEF)

Kalma camp – conclusions

1. The present water supply in Kalma Camp is understood to be adequate for humanitarian needs, and the camp residents are being supplied, on average, with slightly more than the target of 15 litres/head/day, although this has not been verified by household water use surveys.
2. The water supply depends heavily (over 40%) on four dug wells in the wadi alluvium which are privately owned and rented by the operating agencies. The supply from these wells appears to be sustainable in the long term.
3. In the medium term, it seems unlikely that the current rate of groundwater abstraction from the boreholes in the Basement Complex can be replaced by annual recharge. Therefore the supply is drawing on diminishing storage in the Basement Complex and is inherently unsustainable.
4. To replace boreholes in the Basement Complex which become dry (which is likely) it should be possible to drill new boreholes in the flood plain of Wadi Nyala.

Kalma camp – specific recommendation

C.4. Contingency plans in Kalma camp should include new boreholes close to Wadi Nyala. (Implementing agencies / UNICEF)

C.5. An integrated water management plan is needed for Wadi Nyala, which will take account of the needs of both Nyala city and the nearby camps. (UNEP IWRM programme)

Otash camp – conclusions

1. The water supply in Otash Camp currently appears to be adequate for humanitarian needs, but in view of the absence of obvious sources of recharge, this situation appears unsustainable in the medium term. This camp is particularly vulnerable to the occurrence of a dry year.

Otash camp – specific recommendation

C.6. If water levels in Otash do not recover substantially in the 2007 wet season, contingency plans should be put in place for the possibility of some of the boreholes failing in the next dry season.

Mornei camp – conclusions

1. The groundwater resources at Mornei show no sign of significant depletion in spite of intensive abstraction since the establishment of the camp in 2004.
2. This is due to the relative abundance of groundwater, principally in the wadi alluvium along Wadi Barei and Wadi Azum, and the abundant recharge from floods in the wadis.

3. Problems with the water distribution system require some additional measures, e.g.:
   - rehabilitation or replacement of Well No. 6,
   - drilling additional wells on the north side of Mornei at sites identified by geophysical surveys – to increase capacity and allow reduced pumping hours in existing wells,
   - provision of additional elevated storage tanks, so that tap stands can be fed from storage rather than directly from the pumping mains,
   - replacing some low-yielding hand pumps by tap stands supplied from storage,
   - extension of the distribution mains, particularly in outlying areas of the camp.

Mornei camp – specific recommendations

C.7. Dataloggers should be installed in Well No. 6, where the replaced or rehabilitated borehole should be designed to allow for it, and Well No. 7, at the upstream site, which shows the most drawdown. (The dataloggers sent to WES Mornei are unsuitable because of the diameter of the probes (40 mm) and should be replaced by instruments with smaller probes). (Implementing agencies, WES, UNICEF)

C.8. WES should be supported to reconfigure the distribution system so that all the wells pump to storage, and all tap stands are supplied from storage. To allow this, additional storage capacity should be installed. (Implementing agencies, WES, UNICEF)

S.4 Potentially vulnerable camps

The table below lists 21 camps which have been provisionally identified as being potentially vulnerable to groundwater depletion on the basis of (a) the aquifer type (generally Basement Complex without being directly adjacent to a major wadi close by), and (b) the population (over 15,000). This list is based on limited information and should not be considered definitive. Where agencies have concerns about the sustainability or vulnerability of water supplies in particular camps, they may be added to this list.

Most of the camps are somewhere near a wadi: the further assessment should identify the sources of water to the camp and the aquifer(s) concerned, and evaluate the extent of a hydraulic relationship, if any, between the wadi and the other aquifer(s). Analysis of the sources of recharge by monitoring will allow an evaluation of the actual rather than potential vulnerability to be undertaken.

Table S.1 Large IDP camps potentially vulnerable to groundwater depletion

Camp	No of IDPs (Jan 2007)	Aquifer
North Darfur		
Abu Shouk	54,500	BC
Al Salaam	47,000	BC
Kebkabiya town	42,926	Wadi / BC / VR
Kutum Rural	40,096	Wadi / BC / NS
Tawila town	34,569	Wadi / BC
Kutum Town	26,418	Wadi / BC
Saraf Omra town	24,110	Wadi / BC
Kassab	22,251	Wadi / BC
South Darfur		
Otash	55,000	BC
Kalma	95,000	Wadi / BC
Kass town	89,895	Wadi / BC
East Jebel Marra	33,800	Wadi / BC / VR
Muhajryia - South camp	25,000	Wadi / BC
Dereig	23,156	BC
Beleil	21,440	Wadi / BC
West Darfur		
Golo AU	62,060	Wadi / BC / VR
Umm Dukhun AU	37,361	Wadi / BC
Kereinik AU	25,449	Wadi / BC
Seleah AU	21,344	Wadi / BC
Kulbus AU	16,981	Wadi / BC
Abu Surug	16,062	Wadi / BC

BC = Basement Complex; VR = Volcanic rocks; NS = Nubian Sandstone

S.5 Development of water resource management in Darfur

This is properly the responsibility of an appropriate Government body. As at camp level, management depends on good information:

- good 'Baseline' information,
- good monitoring data.

The relevant Government bodies are well aware of what is needed, but are not well equipped or resourced to undertake the tasks in the current security situation.

However, notwithstanding the severe limitations on fieldwork, there is an opportunity to compile, interpret and process all available groundwater resource data so that, when conditions allow, new initiatives in monitoring will be firmly based on good baseline data.

GWWD in Nyala and El Fasher have good databases but the relief agencies have been slow to contribute data to them. In Geneina, GWWD has no office and UNICEF-WES has assembled a lot of relevant data, yet much is missing.

UNEP are currently proposing to undertake a project to support integrated water resource management in Darfur.

Recommendations:

W.1. Greater collaboration with Government offices in water management processes should be promoted at field level, in order to benefit from the technical skills and local experience of their hydrogeological staff. (Implementing agencies, with coordination from UNICEF & WES,) W.2. Data management using UNICEF's borehole database needs to be developed further and more integrated in programme design and management. Appropriate communication protocols should be established between the GWWD database in Khartoum and the field based WES/UNICEF database. Implementing agencies and other stakeholders need to be included in standardising data transfer procedures. This will require coordination and appropriate capacity building. (WES, UNICEF, Implementing agencies, UNEP)

W.3. A project should be undertaken with the assistance of a dedicated water resource specialist and information management specialist to bring databases up to date and ensure their integration with all relevant stakeholders (Implementing agencies, WES, UNICEF, UNEP)

W.4. A strategic plan for water resource management should be developed for Darfur. This plan should include scenarios for return, partial return or long term displacement, in the humanitarian and recovery contexts. The uncertainty of the political situation makes this range of contingencies expedient. This will provide a framework for investment in water resource infrastructure, water supply and agricultural development in Darfur. (UNEP, GONU)

W.5. A contact group on water resource management within the humanitarian community should be established. This group should be established within the larger framework of setting up Integrated Water Resource Management in Darfur as per the UNEP/UNICEF proposals. The humanitarian water resource group should be set up in order to achieve the advantages of keeping the attainment of demand targets, and promotion of sustainable resource management, separate from an institutional perspective. A collaborative effort on both objectives will be required. (UNEP, UNICEF, FAO, RCO, OCHA, UNHCR, Implementing agencies)

W.6. Community, government, private and NGO capacity in water resource management and engineering (sand dams, rainwater harvesting, hafirs, terracing, dams etc) needs to be assessed, mapped and built up. This will need appropriate knowledge management and networks to ensure that capacity exists to design, build and manage appropriate water resource infrastructure. Additional capacity building will then need to be designed. The identification of projects under different return scenarios should be addressed under the strategic plan for water resource management. (UNEP, RCO, UNICEF)

W.7. While these activities need to be done for the short term effort which focuses on the humanitarian context and builds the capacity for potential return, concurrent effort must be made to develop capable institutions for Integrated Water Resource Management for the longer term. There will be limitations to what can be achieved during the crisis, but the process should begin. It should be part of the consultative process of developing a strategic plan for water resources. (UNEP/UNICEF project to work with appropriate stakeholders)

W.8. The development of best practice in water resource management in camps in the humanitarian context should be seen as an opportunity to develop capacity within the Darfurian water resource management community. Water resource management is increasingly important in the context of growing population and climate change, so these skills are vital for Darfur's recovery and sustainable development. (Implementing agencies, UNICEF, WES, UNEP),

1 Introduction

1.1 Project background

As a result of the conflict, Darfur has unprecedented concentrations of population, imposing high localised demands on water resources. This is taking place in an area where the rain falls in only four months of the year and the prevailing geology is unfavourable for storage of groundwater. While there are some exceptional areas rich in groundwater such as the wadis or a few sandstone areas, these are of little benefit for populations that are unable to travel to these sources without fear of harassment. This study focuses on the water needs of the IDPs in camps where the demand on the resources is new, and because of the constraints that IDPs face in travelling even short distances to collect water from where it may be more abundant.

This assessment was undertaken following the recommendation made in the report Darfur: relief in a vulnerable environment[5] (D:RIVE).

The geology of Darfur is dominated by the widespread occurrence of African Basement Complex rocks. These rocks are not usually considered to have the potential to sustain water supplies to urban populations of 30,000 or more people in a semi-arid area. In this context, what has been achieved in large IDP camps in Darfur is quite remarkable - camps of tens of thousands of people have been supplied with water for approaching four years. What is surprising is that these supplies have been maintained for so long. This may be due to the relatively good rainfall in the past two rainy seasons (although the 2004 rains were poor at El Fasher and about average elsewhere). But another poor rainy season could occur at any time, and UN, NGOs and national authorities need to plan accordingly.

D:RIVE calls for a framework of sustainable resource management to be integrated through the Darfur relief response. To ensure water resource security for the camps, both **demands** and **resources** need to be accurately measured in order to be managed. As of May 2007 there was no systematic monitoring of groundwater levels in camps, and little or no analysis of demands. Since the publication of the draft recommendations in May 2007 groundwater monitoring has been introduced in Darfur's humanitarian programme by UNICEF and Oxfam.

Oxfam's demand survey in Abu Shouk and Al Salaam found water usage levels higher than expected at at least 24 lpd. The survey also found that over 94% of the 200 families questioned said they had more water in Abu Shouk and Al Salaam camp than they used to use in their villages before the crisis, and that a significant portion of this water is being used for livelihoods. These findings were at camps of known water stress - as indicated by the fact that 12 to 15 boreholes have run dry in Abu Shouk / Al Salaam.

There is a significant volume of data on groundwater in Darfur collected since the 1970s from projects such as the Jebel Marra, South Darfur, Western Savannah and WADS but these data are not widely accessed within the current Darfur water programme.

Hence uncertainty remains over water resources at many camps - including some of Darfur's largest camps – Otash, Kalma, Abu Shouk and Al Salaam.

The initial objective of the Water Resource Vulnerability Assessment (WRVA) was to assess the risk of water resource vulnerability at four major camps in Darfur: Mornei, Kass, Kalma and Abu Shouk. However due to security constraints Kass was dropped from the programme but Otash and Al Salaam were added (Al Salaam is assessed jointly with Abu Shouk). Camp-specific conclusions and recommendations for the camps reviewed are given in Section 3 to Section 6. General conclusions and recommendations for all camps are given in Section 8.

A second objective was to undertake a desk study to identify other camps potentially vulnerable to groundwater depletion, based on the findings from the field work. This list is given in Section 7. Greater detail on monitoring programmes is provided in Section 9. Further recommendations for water resource management in Darfur are given in Section 10.

[5] Darfur: relief in a vulnerable environment. Bromwich B, Abuelgasim Abdalla Adam, Abduljabbar Abdulla Fadul, Chege F, Sweet J, Tanner V, Wright G Tearfund 2007 http://www.tearfund.org/darfurenvironment

Box 1 Recent remote sensing studies in Darfur

Two remote sensing geological surveys have been undertaken in Darfur recently, which add useful mapping data to the significant body of knowledge developed in Darfur on development projects prior to the crisis as presented in the reports described in the Appendices to this report.

A study was undertaken by RTF in 2006 which reiterated the fact that some of Darfur's wadis and volcanic rocks have significant water resources. The report acknowledged the difficulties of locating sustainable water supplies in areas of Basement Complex rocks away from wadis but was focussed on drawing attention to the resources in the wadis. This study however appears to overestimate the availability of water resources ***for IDPs*** by:

- Concentrating on the locations with more abundant water resources rather than focussing on the locations of demand. The report fails to draw out the difficulties caused by the distance between the people and the resources in the context of the conflict.
- Assuming very high abstraction rates from alluvial aquifers,
- Considering average rather than dry years – in an arid climate like Darfur's, annual rainfall is very variable, and it is in the dry years that water stress becomes critical.

More recently, attention has been drawn to the possible existence of an aquifer beneath the site of an "ancient lake" in the desert region in the far north of Darfur. This lake (known as 'Lake Ptolemy') existed several thousand years ago when Darfur's climate was much wetter than at present. The underlying aquifer is the Nubian Sandstone. The underground resource has not been proven as yet, but even if the resource is good it will have little relevance to the humanitarian programme due to its very remote location in the unpopulated desert area in the far north of North Darfur (it is to the north of the area shown on Figure 1, p6).

The resource may prove to be appropriate for large remote commercial farms, but piping supplies to dispersed villages and camps would not be cost effective, and so this project will have little benefit to traditional livelihoods of displaced or returning populations. Economic benefits to Darfur would depend on the arrangements for ownership and wealth-sharing from the farms in addition to the migrant labour opportunities. The closest large town to the aquifer is El Fasher at a distance of approximately 500km. There are other aquifers closer to El Fasher that have potential for development.

While these studies both bring useful mapping to hydrogeological literature on Darfur, both require interpretation to be governed by conventional hydrogeological analysis – including reviewing existing reports, visiting and test drilling at the sites in question. These studies, suggesting potential abundance of water in a few locations in small areas of Darfur, should not obscure the overall picture of Darfur as being highly constrained by a shortage of water resources.

Greater emphasis on assimilating the knowledge already developed in Darfur, and deploying more hydrogeologists to integrate this knowledge with project implementation, are likely to bring more cost effective benefits to the conflict-affected communities in Darfur than further remote sensing.

The study focussed on water quantity rather than quality but it was observed that groundwater quality is chemically and microbiologically acceptable for drinking in most of the camps. Water quality problems encountered in some places are (a) chemically: nitrate and fluoride, and occasionally iron and manganese; (b) bacteriologically: some contamination and sanitary pollution occurs at aquifer level and sometimes at household level due to poor hygiene.

[6] Water Exploration in Darfur – Sudan; WATEX Project, 2006 – RTF/USGS, and Boston Universities "Ancient Mega-lake" The location of the potential aquifer is shown at the foot of this site:
http://www.bu.edu/phpbin/news/releases/display.php?id=1298
More details of the project can be found at:
http://www.bu.edu/phpbin/news/releases/display.php?id=1370&template=today

The main water well siting techniques used are geophysical methods using electromagnetic profiling (EM- APEX –MAX- MIN I) and vertical resistivity sounding (VES) and profiling. Local and expatriate staff have considerable experience in the successful use of these techniques.

1.2 Assessment methodology

The assessment made use of records of water provision in camps including drilling and pumping records, field observations at camps, discussions with stakeholders in Darfur and Khartoum, and previous hydrogeological reports in Sudan and the UK.

Essentially, two approaches were used in the groundwater assessments:

1. Physical evidence - groundwater levels, groundwater monitoring, or evidence of boreholes drying up - to demonstrate the extent, if any, of groundwater depletion.
2. A ‘Water Budget’ approach, assessing the likely recharge to the local aquifer, the current withdrawals of water from the aquifer, and the likely balance, or lack of it, between the two.

Clearly the first approach is preferable, but depends on the availability of suitable data. At Mornei, the data demonstrate clearly that no groundwater depletion has occurred or is likely to occur. At the camps near Nyala (Kalma and Otash) there are insufficient data to allow any firm conclusions to be reached, and a water budget approach was adopted. However, the water budget approach is hindered by the lack of data because the recharge mechanisms cannot be precisely defined or quantified (where is the recharge coming from? Does water seep through from the nearby wadi?).

At El Fasher (Abu Shouk/Al Salaam) there are some water level data, and significant evidence of reduced yields in a number of boreholes, so the assessment combines both approaches Field visits took place from 23 February to 14 March 2007. The team comprised: Geoff Wright, Hamid Omer Ali, Ahmed Hussein Maneise (Hydrogeologists) and Brendan Bromwich (Water and Environment Engineer).

At the state level in Darfur, the key water sector includes the Ministry of Urban Planning and Public Utilities, the Ministry of Agriculture and Irrigation and Ministry of Health. However the focal institutions dealing with water supply and sanitation are the State Water Corporation and Water and Environmental Sanitation (WES) Programme. In the humanitarian community, coordination is provided by UNICEF.

A summary of the arrangements for the water sector in Darfur is given in Appendix B.

1.3 Acknowledgements

This component of the study was undertaken with financial support from DFID OFDA and UNEP, building on earlier work that had had additional funding from UNHCR. The work was carried out with assistance from UNICEF, WES, GWWD, NWC, Concern, Oxfam, CARE, Spanish Red Cross, Nyala Water Corporation and the broader water and sanitation community in Darfur. We would also like to acknowledge the assistance of the Humanitarian Affairs Commission and the people of Abu Shouk, Al Salaam, Kalma, Otash and Mornei camps.

2 Hydrogeological context

2.1 Hydrogeology

Darfur has four basic types of aquifer:

- Deep sedimentary basin aquifers:
  - Nubian Sandstone (mainly in North & South Darfur)
  - Umm Ruwaba Series (South Darfur)
  - Paleozoic Sandstone (West Darfur only)
- Wadi Alluvial aquifers (sand and gravel):
  - Deep (>10 metres, up to about 40 metres)
  - Shallow (<10 metres)
- Volcanic rocks (such as basalt and tuff, variably fractured), mainly around Jebel Marra;
- Basement Complex (hard crystalline metamorphic rocks such as granite and schist, variably fractured and weathered)

The properties of these aquifers are summarised in Box 2.

Box 2 Summary of aquifer types in Darfur

Sandstone aquifers (deep sedimentary aquifers) combine high levels of storage with high borehole yields. However the water is typically at greater depth than in the other aquifers. Deeper boreholes are therefore often used in sandstone aquifers. Geneina and Gereida are both on sandstone aquifers.

Wadi sand (alluvial) aquifers vary in saturated depth between the wet and dry season, but provide important storage of water if the wadi area is large and the sand is sufficiently deep. Water may be stored in the wadi sands upstream of camps and may recharge Basement Complex aquifers if there is a route for the groundwater to flow (a hydraulic connection).

Volcanic rocks make reasonable aquifers and are situated in areas of high rainfall in Jebel Marra.

Basement Complex aquifers have low typical borehole yields, and low storage. The low storage is a function of the solid nature of the rocks compared with sands and sandstones. Consequently the Basement Complex rocks, which form the main aquifer underlying many IDP camps, have the highest vulnerability to groundwater depletion. This is the most prevalent type of geology in Darfur, underlying many if not most camps.

A comparison of the properties of the main aquifers in Darfur is given in Table 2.1. Detail of extent of the sedimentary, alluvial and Basement Complex aquifers is given in Table 2.2. (The volcanic rocks are not included). A map showing the distribution of the main aquifers in Darfur is shown in Figure 1.

Table 2.1 Comparison of aquifer properties in Darfur

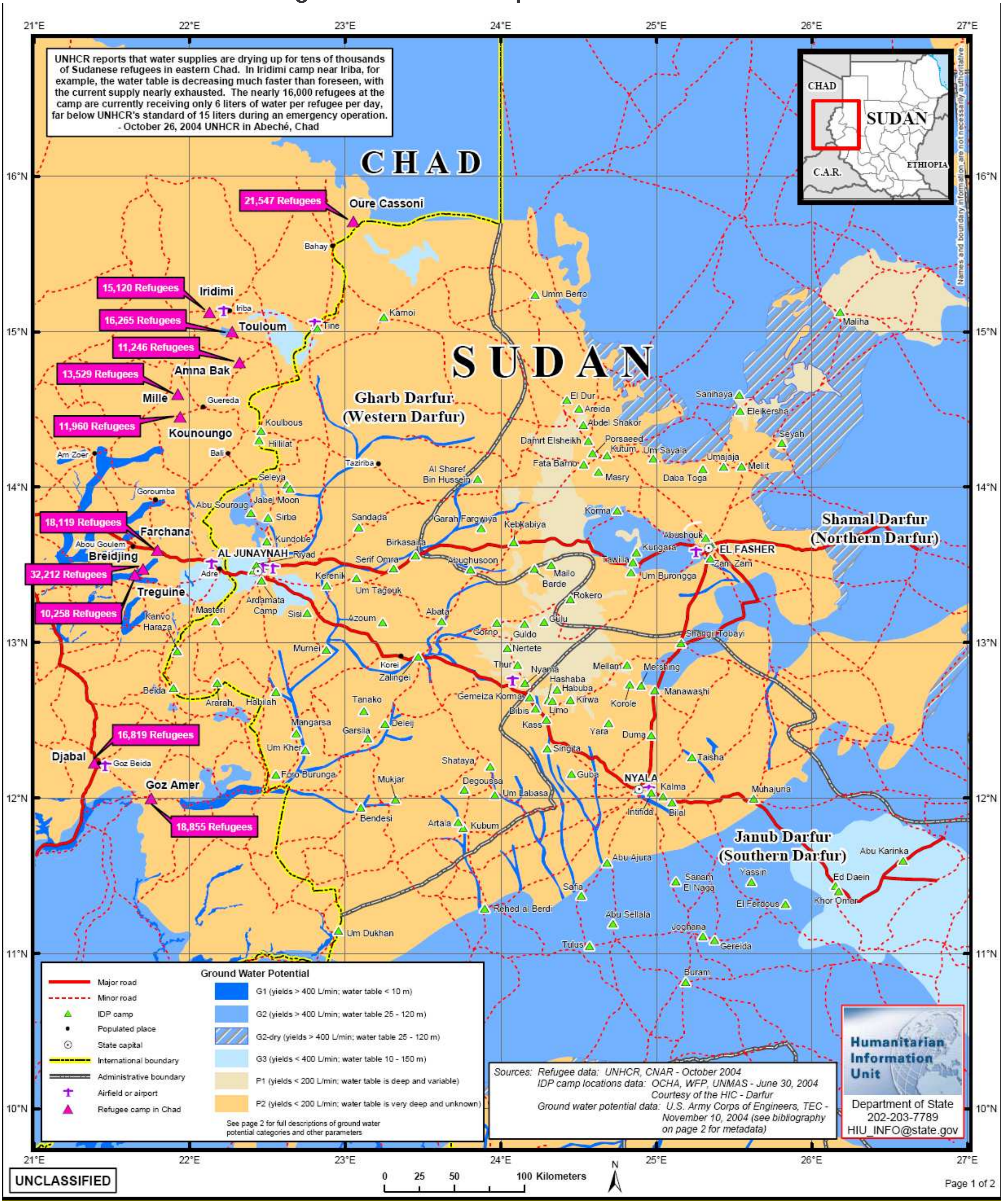
Aquifer type	Sandstone / sedimentary	Volcanic rocks	Wadi Sands	Basement Complex
Groundwater potential	Moderate - High	Moderate	Moderate – high	Low
Typical borehole yield	1 – 10	0.5 – 5	1 – 20	0.1 - 1
Typical depth to water	30 -110	very variable	2 -10	15 - 55
Typical depth of borehole	200 – 350	?50	5 – 40	30 - 75
Relative Aquifer storage capacity	Very High	Moderate	Moderate – High	Very low
Relative vulnerability to depletion	Very low	High	Low – Moderate	High
Designation on Figure 1				

Table 2.2 Distribution of the major groundwater basins in Darfur[7]

Basins	Area x 1000 Km^2	Storage Km^3	Annual Recharge Mcm	Annual Abstraction Mcm	Average well depth m	Average water level m	TDS ppm
Nubian Basins							
Umm Keddada	53	300	47	17	280-350	30-80	80-1500
Shagera	1.5	0.02	4	1	200-300	30-50	400-700
Sag El Na'am	2.7	11	26	16	200-250	60-90	200-700
Subtotal	57.2	311.02	77	34			
Umm Ruwaba Basins							
Baggara	120	1700	30	28	100-400	30-110	500-800
Alluvial deposits							
Wadi Nyala		0.03	20	15	20-50	5-10	200-600
Wadi Kutum		0.06	60	12	20-40	5-10	200-800
Wadi Azum		2.75	460	45	10-30	2-13	200-600
Subtotal		2.84	540	72			
Basement Complex							
(All Regions of Sudan)		2.5	1800	120	30-75	15-55	500-3000

[7] Hamid Omer Ali, 2002

Figure 1 Groundwater potential in Darfur[8]



---

8 Sudan (Darfur) – Chad Border Region – Ground Water Potential. Humanitarian Information Unit, Department of State, HIU_Info@State.gov www.reliefweb.int/rw/rwb.nsf/db900SID/JHEN-66VP58?OpenDocument

Legend to groundwater potential map, Figure 1

The region can be divided into two groundwater potential categories: Good (G) and Poor (P) and further sub-divided into units; G1, G2, G3, P1, and P2. The most productive units are G1, G2 and G3. Units P1 and P2 should not be considered as sources of groundwater.

UNIT G1: Quaternary-aged, unconsolidated alluvial deposits of gravels, sands, silts and clay from wadis and rivers of local to sub-regional extent. Groundwater quality is fresh, as much of it is classified as recently infiltrated surface water from wadi discharge. The depth to the water table is shallow (<10m). Aquifer thickness is expected to be less than 40m, with saturated thicknesses of less than 10m. Transmissivities are high and yields are greater than 400 l/min.

UNIT G2: Coarse-grained sandstones, conglomerates, mudstones, and limestones of the Mesozoic-aged Nubian Sandstone and Gedaref Formations. Groundwater is generally fresh (total dissolved solids (TDS) < 800 mg/l) and the water table ranges from 25m to 120m below ground surface. Aquifer thickness ranges from 160m to greater than 300m. Transmissivities range from 100 to 3,000 m^2/day. Yields are often greater than 400 l/min. The overburden for this unit includes the unconsolidated materials of the Umm Ruwaba Formation (Unit G3). Areas with hatching are dry aquifers.

UNIT G3: Tertiary-aged unconsolidated and discontinuous layers of sand, silt, and clay of the Umm Ruwaba Formation. Overburden materials include consolidated sands and clays. Groundwater is found in the saturated sand and conglomerate beds. Thickness rarely exceeds 100m. Depths to the water table vary between 10m to greater than 150m below ground surface. Groundwater quality varies widely, from 100 to more than 5,000 mg/l TDS. Transmissivities are generally low but yields can be greater than 400 l/min.

UNIT P1: Tertiary-aged undifferentiated volcanics (basalt and trachytes accompanied by tuffs and pumic layers). Overburden materials include consolidated sands and clays. Groundwater occurs in fractures and faults. Groundwater quality is generally fresh, but thermal saline water may occur. Depth to water and aquifer thicknesses are highly variable. Yields are relatively unknown but are expected to be low (<200 l/min).

UNIT P2: Precambrian-aged bedrock *(Basement Complex)* aquifers composed of schists, gneisses, granites, and rhyolites. The unit is overlain by sedimentary (sandstones and conglomerates) or igneous rocks that have been folded and intruded by volcanic rocks. Groundwater occurs only in fractures and fault zones. Local perched perennial or ephemeral aquifers may occur, as well as thin saturated layers at depth. Groundwater quality is highly variable but expected to be poor (saline). Depth to water and aquifer thicknesses are unknown. Yields are also relatively unknown but are expected to be low (<200 l/min). This unit should not be considered a source of groundwater.

2.1.1 Deep sedimentary basin aquifers

These aquifers are widespread in North and South Darfur but are often away from large centres of population, and occur to a lesser extent in West Darfur. They are characterised by a moderate to high permeability, a deep water table and very large total storage capacity. Hence they are relatively invulnerable to drought and, once a supply has been commissioned, it should be reliable for many years. Where large IDP populations are dependent on supplies from these aquifers, it will be important to have sufficient surface storage capacity and standby borehole capacity to cover breakdowns. These aquifers do not occur at any of the IDP camps considered in detail in this report. El Geneina and Gereida are both on deep sedimentary basin aquifers.

2.1.2 Wadi alluvial aquifers

These are characterised by high to very high permeability, a shallow water table and high specific storage capacity (i.e. storage per unit volume of aquifer). Provided the aquifer is deep enough and the upstream catchment area large enough, the supply should be able to survive at least one dry season. However, many wadi alluvial aquifers in Darfur are relatively shallow and hold groundwater for only a portion of the dry season.

2.1.3 Volcanic rocks

These rocks occur in a relatively small, but important, area around the main Jabel Marra massif. Groundwater occurs in fractures in the harder rocks, and may also occur in the pore space of the less well-cemented volcanic ash deposits. The area of occurrence is of relatively high relief, which means that water table gradients are high and groundwater will tend to flow rather rapidly along the fracture zones. Groundwater often issues as springs. Owing to the occurrence of mobile minerals in the volcanic rocks, there are often problems with the chemical quality of the groundwater in these aquifers.

Volcanic aquifers do not occur at any of the IDP camps considered in detail in this report.

2.1.4 Basement Complex aquifers

Rocks of the Basement Complex are very widespread in central Darfur, in all three states. Consequently, they underlie many (probably most) of the IDP camps with water supply problems. Until about 20 years ago, the Basement Complex in Sudan was hardly considered as an aquifer. All groundwater investigation and research concentrated on the deep sedimentary aquifers and, to a lesser extent, on the wadi alluvial aquifers.

Two things happened to change this:

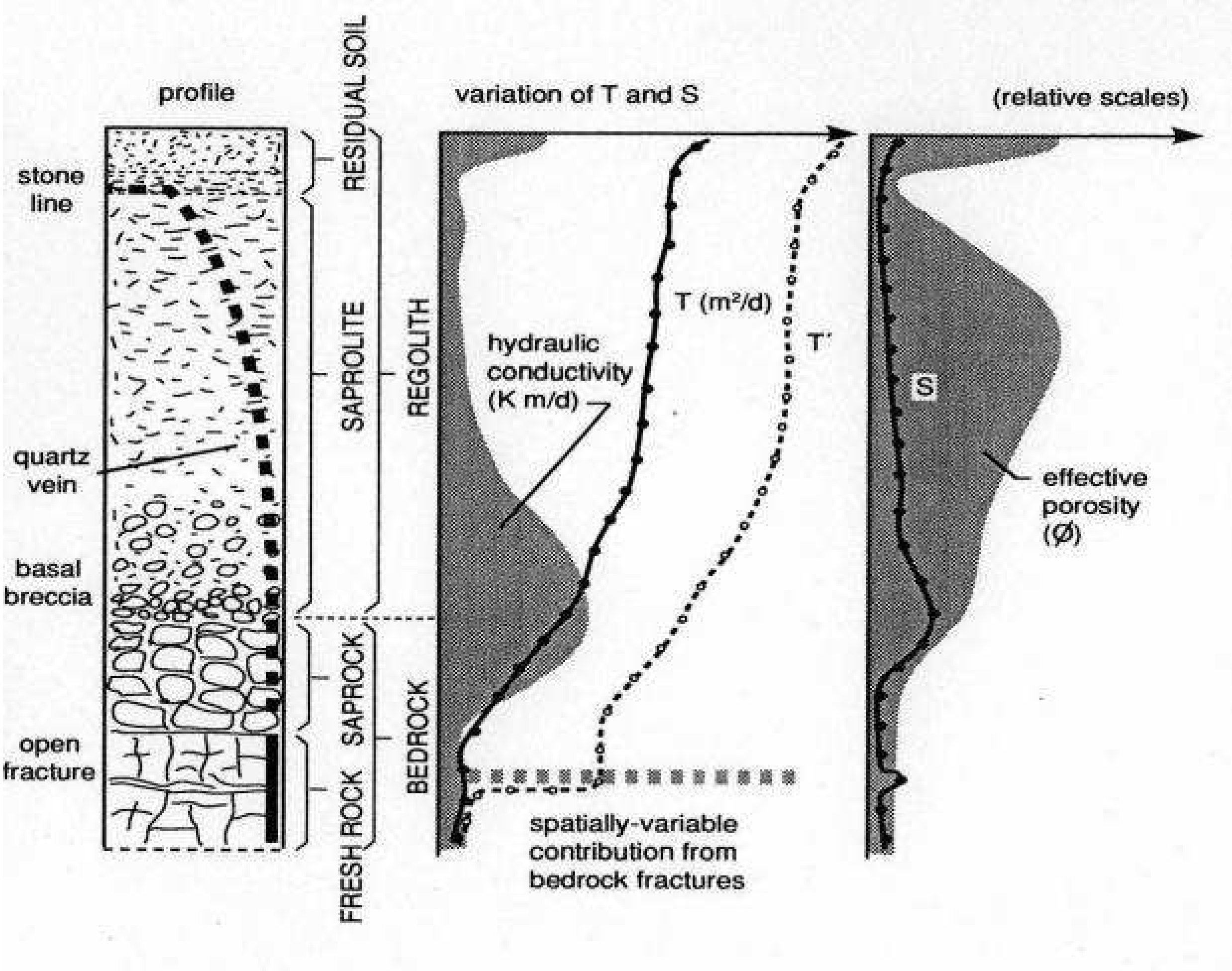
- Use of geophysical surveys to optimise drilling sites in Basement Complex
- The advent of ‘Down-the-hole-hammer’ (DTH) drilling rigs, making it possible to drill boreholes quickly in hard rocks.

Characteristics of the Basement Complex aquifer:

- The rock itself has zero intrinsic permeability
- Weathering has taken place, mainly near within 30 metres of the ground surface
- Fractures and fracture zones are common but variably spaced
- Deep weathering occurs along fracture zones
- Water occurs only in fracture zones and in the weathered rock
- Well yields are low – generally <1 litre/sec (<3.6 m^3/hr); the initial yield measured after drilling (or estimated in a short pumping test) is often not sustainable in the longer term (This is characteristic of fractured low-permeability aquifers around the world)
- Aquifer properties are different in different directions, due to preferential directions of fractures (Anisotropy)
- There is a significant incidence of dry boreholes
- Pumping from boreholes creates elongated ‘cones’ of depression – due to the fracture orientation
- There is a substantial reduction in permeability and specific storage capacity (storativity) with depth

Several of these characteristics are illustrated in Figure 2.

Figure 2 Variation of permeability and porosity with depth in Basement Complex aquifers[9]



Notes: T = Transmissivity; T' = Transmissivity including bedrock fractures
S = Storage coefficient; Hydraulic conductivity = permeability

The diagram illustrates a hypothetical borehole down through the weathered Basement Complex, reaching fresh, hard fractured rock at (typically) about 30 metres depth. The permeability (hydraulic conductivity) of the rock increases gradually with depth, as the clay content reduces and then abruptly decreases in the fresh rock, where only occasional fractures allow water to move. Porosity in the weathered rock is higher just below the surface, because clayey material has a high porosity but a low permeability. As the clay percentage falls with depth, the porosity declines, and becomes very low in the fresh rock. The storage coefficient, however, roughly parallels the permeability, increasing slightly with depth but falling quite abruptly when bedrock is reached.

In Darfur, the water table in most camp boreholes is now **below** the zone of higher permeability and storage capacity, so that the available storage capacity is low. Most boreholes have struck water in the fairly fresh, fractured rock, where both permeability and storage are low. As the water table falls further, the available yield and storage get lower and lower.

Recharge to the Basement Complex aquifer

Recharge can occur in three ways:

1) Direct recharge - from the surface through superficial deposits

When rain falls on a fairly flat ground surface, in a hot dry place like Darfur, it can:

- Evaporate (estimates of open water evaporation rates at Nyala (HTS/MMP 1974) range from 4.2 mm/day in August to 10.7 mm in March), or

[9] P J Chilton & S S D Foster, 1995, Hydrogeological characterisation and water-supply potential of basement aquifers in tropical Africa: Hydrogeology Journal, 3 (1), 36-49.

- Run off the ground surface into a wadi, or
- Infiltrate into the ground.

If the rainfall is light, it will soak into the upper few centimetres of soil, and then quickly evaporate. If rainfall is heavy, it will quickly saturate the upper layers of soil, and then the excess rainfall will run off into local wadis, where it will soak into the alluvial sand deposits. It has been observed near Nyala (HTS/MMP 1974) that it requires about 6 mm of rainfall to generate any runoff into local wadis.

Any given soil has a maximum rate (infiltration coefficient) at which it can absorb rainfall – if the rainfall intensity is higher, the excess will run off. Sandy soils have a much higher capacity to absorb rainfall than silty or clayey soils. If the soil can absorb the rain, then as long as the rain continues, the rain will infiltrate deeper and deeper into the soil, and may eventually reach a depth where it is effectively beyond the reach of evaporation. After this, the infiltrating water has a chance to continue downwards to reach the water table, at which point it becomes recharge to the aquifer.

To maximise infiltration, and hence recharge to the Basement Complex aquifer, the ideal scenario is for moderate but persistent rainfall on several successive days. This process is more likely to result in recharge in sandy deposits (Qoz) than in the clayey soils which normally result from weathering of Basement Complex.

Hence in order to maximise direct recharge to the Basement Complex, what matters is not just the annual amount of rainfall, but the number of rainy days and the intensity of the rainfall events. Global warming scenarios are predicting more intensive storms, which does not favour recharge of the Basement Complex.

In general, direct recharge to the Basement is not expected to occur in normal years except on Qoz soils, where a maximum of perhaps 20 mm per year is possible.

2) Recharge from wadis

Rain water which runs off into wadis leads to rapid saturation of the wadi sands, which can then allow water to infiltrate deeply into the Basement Complex rocks underlying the wadis. Since wadis often flow along courses which pick out weaknesses (i.e. fractures) in the rock, they are often favourable routes for deep infiltration. This is why boreholes close to wadis are often the most favourable places to optimise well yields.

Work in South Darfur (HTS/MMP 1974) indicated that most wadis are fully recharged by the end of July in an average year. However there is evidence of a reduction in rainfall since that time.

3) Recharge through fractures

Even beneath the interfluves between wadis, fracture zones are expected to provide preferential paths for infiltration of rainwater. However, in general, interfluves are less likely to be underlain by fracture zones. As noted above, recharge is not expected unless the surface soils are sandy (Qoz).

Zones of contribution (ZoCs) to boreholes

The ZoC to a borehole (sometimes referred to as its ‘catchment’) is the area of ground which supplies water to that borehole.

In the natural state, groundwater flows from areas of higher water table towards areas of lower water table. A pumping borehole creates a ‘cone of depression’ in the water table which interferes with the natural flow system, and ‘captures’ all the flow within a certain width of aquifer. The width of aquifer captured in this way depends mainly on the pumping rate and the aquifer transmissivity – the higher the pumping rate, and the higher the transmissivity, the wider the zone. Poor aquifers, such as the Basement Complex, tend to have narrow capture zones, and hence long, narrow ZoCs. But where numerous boreholes are pumping within a small area, as at the IDP camps, the various ZoCs may overlap and create one larger ZoC which may encompass all or most of the camp plus an area on the up-gradient side of the camp. In addition, the ZoC can be considered to include the surface catchment area of any wadis which also feed into the groundwater system.

In order to estimate the ZoC at a site, the following information is needed:

1. The exact location and elevation of every dug well and borehole need to be mapped, including (as far as possible) dry or unsuccessful boreholes.
2. The catchment area of any wadis likely to supply recharge to the aquifer.
3. Relative water level data (hence elevations of all well-heads are needed).
4. Estimates of the aquifer properties – transmissivity, storativity, and porosity.
5. Monitoring data:
    - water output from all sources
    - water levels in all boreholes, dug wells & springs
    - wadi flow data – dates & durations of flow, flood depths, high water marks, ponding
    - rainfall

Little of this information is currently available for the sites visited, It is clear that improved information management is crucial to the management of the water resources.

2.2 Climate

The climate of Darfur ranges from arid in the far north, to semi-arid in the south. It is characterised by high temperatures, high evaporation (typically 4–12 mm/day) and regular seasonal, but highly variable, rainfall.

2.2.1 Rainfall

Rainfall has been monitored at El Fasher since 1917, and at Nyala and El Geneina since 1946. At present, the rain gauges at the airports in the three state capitals are the only ‘official’ rain gauges in Darfur which are recognised by the Sudan Meteorological Service. In the past, a number of other rain gauges were operated and some data are available in various reports, such as that by HTS/MMP for South Darfur (1974). Today, some rain gauges are operated by the Agricultural Planning Unit (El Fasher). There may be others.

Data from the three airport gauges are illustrated in the graphs below. These graphs illustrate some important points:

1. Annual rainfall in Darfur is very variable from year to year.
2. There is a rather weak correlation between the annual rainfalls at the three state capitals. This shows that rainfall is often rather localised.
3. From the 1960s to the mid-1980s annual average rainfall decreased by around 30%. Since then it appears to have partially recovered, but is still significantly lower than in the 1950s, especially at El Fasher.

More detailed records show that there are rather few days in any year on which significant rain falls, i.e. ‘rain days’. Rainfall is largely confined to the months from June to September, although small amounts may fall in May or October, especially on the west side of Jebel Marra, as represented by El Geneina.

The longer term prospects are unclear, but climatic change modelling indicates that rainfall is likely to become even more variable with shorter rainy seasons in the future. This will lead to an increase in frequency of failed harvests.

Figures 3 to Figure 5 show rainfall records for the three state capitals.

Figure 3 El Fasher Rainfall 1917 to 2006

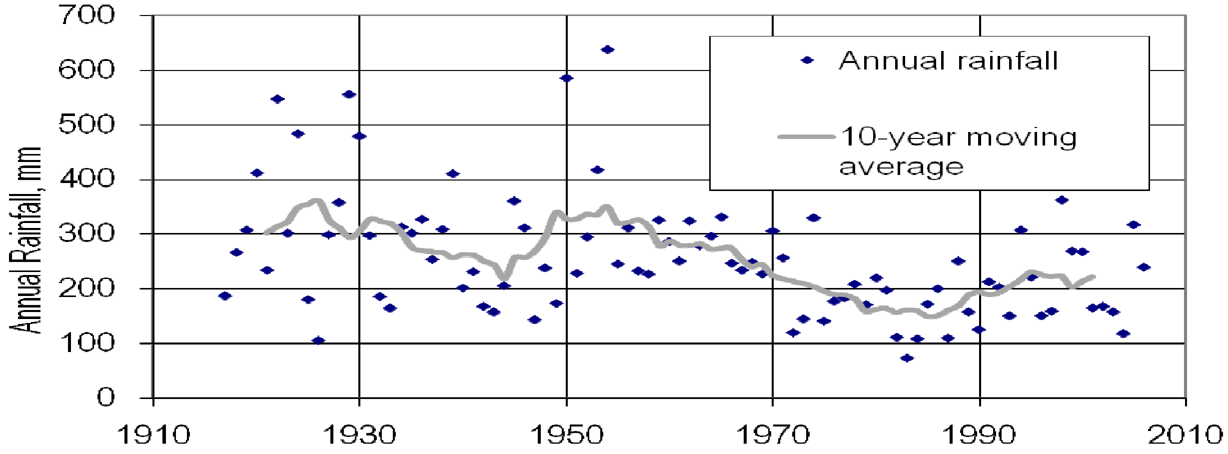


Figure 4 Nyala Rainfall 1946 to 2006

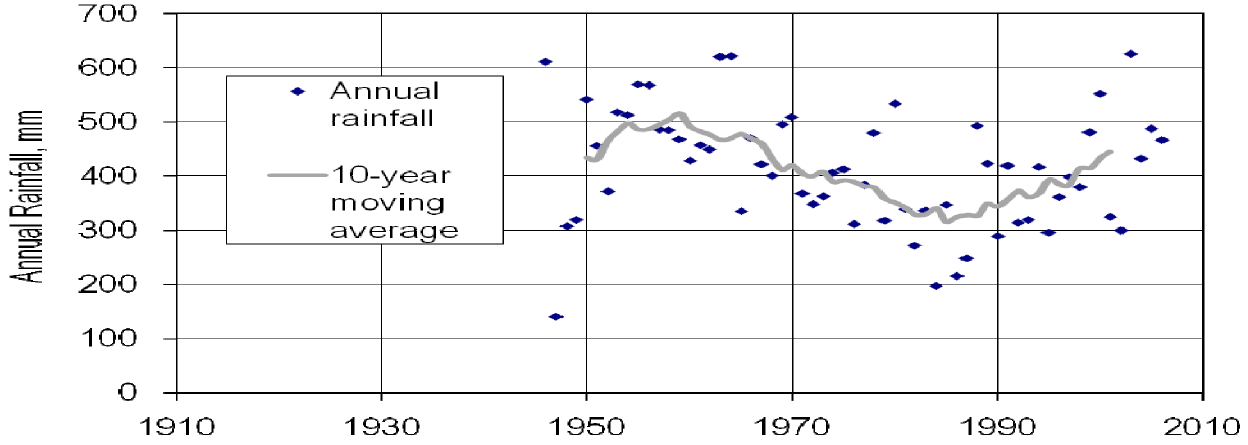
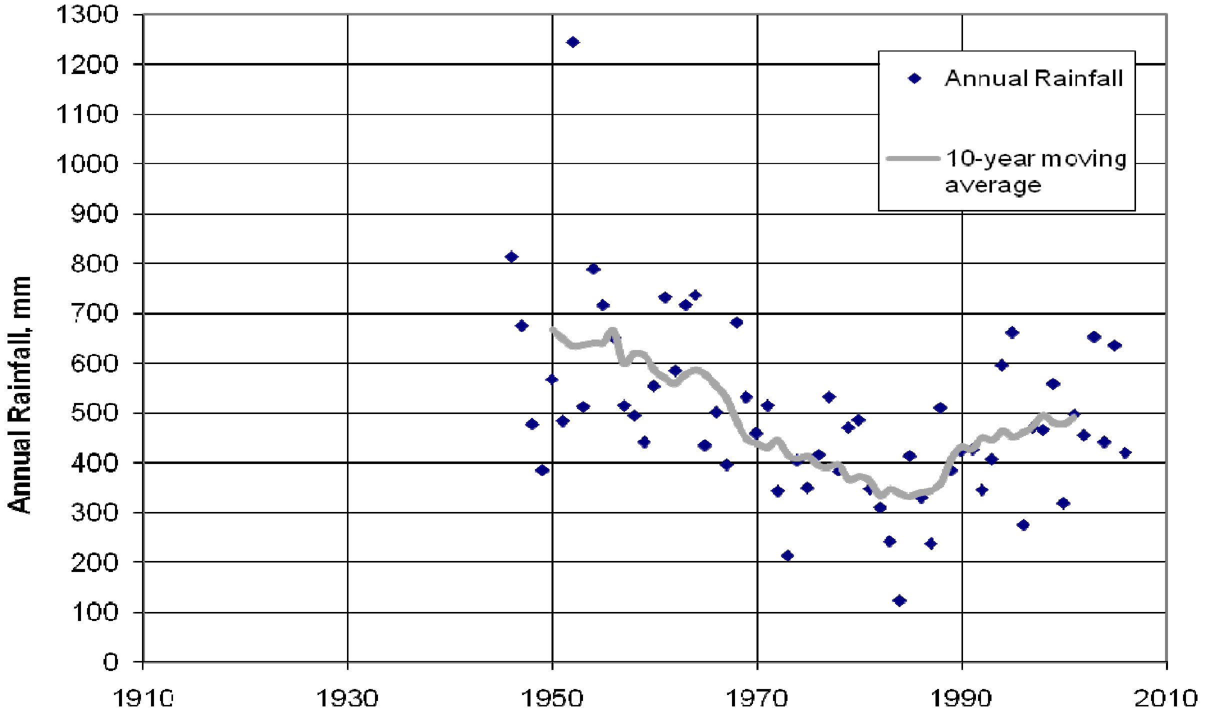


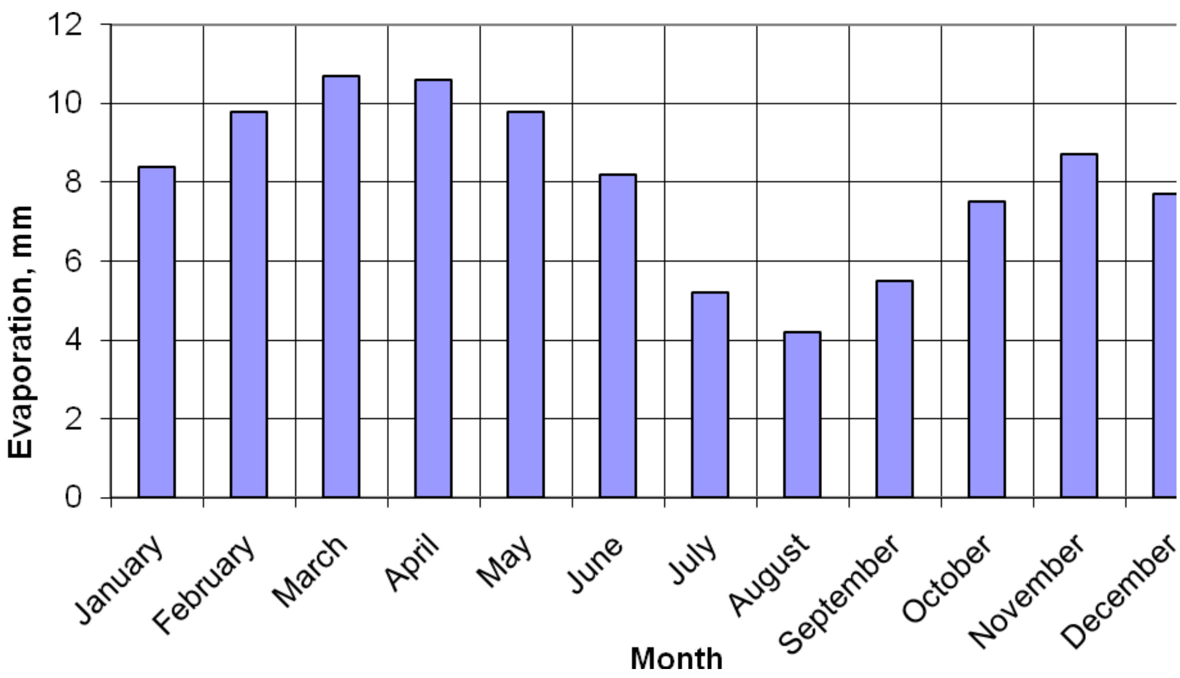
Figure 5 El Geneina Rainfall 1946 to 2006



2.2.2 Evaporation

The variation in evaporation for Nyala throughout the year is illustrated by the graph in Figure 6. Evaporation decreases in the rainy season because of increased cloud cover, and decreases in the winter months as temperatures fall, so there are peaks in the early and late dry season. (Discussion above with respect to aquifer recharge)

Figure 6 Estimated daily average open water evaporation for Nyala[10]



[10] HTS/MMP 1974

3 Abu Shouk & Al Salaam water assessment

Figure 7 Oxfam Haloof Borehole, between Abu Shouk and Al Salaam camps

3.1 Camp context

The influx of IDPs to Abu Shouk began in April 2004 with the transfer of people from Meshtel camp, which was considered unsuitable. Planned capacity was 54,000. By January 2005 the population had increased to 89,000.

After unsuccessful efforts to identify alternative sites with adequate water supplies, the site of Al Salaam, about 1 km east of Abu Shouk, was approved, and in June 2005 23,500 people were relocated to Al Salaam. Further influxes to Al Salaam occurred since then.

In August 2005 the failure of the Haloof Dam caused severe flooding in the southeastern part of Abu Shouk, affecting 1700 households.

Abu Shouk was closed to new arrivals in November 2005. The current population of Abu Shouk is estimated at about 54,500, while Al Salaam has a population of about 47,000.

Several agencies are involved with humanitarian aid in the camps: Co-ordination is by the Spanish Red Cross, OCHA and HAC. Water and Sanitation are by Oxfam GB and UNICEF/WES.

3.2 Field visit

The camps were visited on Sunday 10th March 2007, and again on Tuesday 12th March 2007, facilitated by Oxfam, UNICEF and WES.

3.3 Hydrogeological & hydrological context

Abu Shouk and the neighbouring Al Salaam IDP camps lie to the north of El Fasher. The two camps are separated by the Wadi Haloof. For the purpose of a water resource assessment, it is appropriate to consider the two camps as one site. Abu Shouk covers an area of about 4 km^2, while Al Salaam covers an area of about 2.3 km^2. Taking the two camps together, with the open ground in between, the overall 'footprint' is about 8 km^2.

Topographically, the land occupied by Abu Shouk and Al Salaam is characterised by four slightly raised (Qoz) areas and three lower areas; from west to east they are:

- Abu Shouk west (Columns A to H on the Abu Shouk map): a slightly raised area of Qoz.
- Western depression, where a number of hand pumps are clustered.
- Abu Shouk east (columns I to W on the Abu Shouk map), a slightly raised area of Qoz.
- Wadi Haloof
- Al Salaam camp
- Eastern depression
- A more substantial ridge rising to the east of Al Salaam.

At both sites, the weathered Basement Complex is overlain by a relatively thin covering of superficial deposits. In the raised areas the superficial deposits are generally sand (Qoz), while in the lower areas they are usually a few metres of clay above a few metres of sand. At Abu Shouk the superficial deposits are generally about 12 metres thick, while at Al Salaam they are usually 6-8 metres, but occasionally deeper.

It is notable from satellite imagery before the breaching of the Haloof Dam that the flood plain of Wadi Haloof downstream of the dam shows little sign of the sandy deposits which are now seen in the channel, suggesting that the operation of the dam successfully delayed flood flow in the wadi and that the sands now evident have been deposited by floods in 2005 and 2006.

The Haloof Borehole is reported to be pumped at about 14 m^3/h (336 m^3/d) for a drawdown of about 9m, giving a specific capacity of 37 $m^3/d/m$ and a transmissivity of perhaps 45 m^2/d. This is a high value for a borehole in Basement Complex.

3.4 Water supply

Abu Shouk's water supply comes from 5 boreholes fitted with submersible pumps, and about 45 hand pumps (about 21 of which have now run dry or are out of use for other reasons). Total supply is estimated at 550 m^3/day.

In Al Salaam camp, there are 4 boreholes with submersible pumps and 17 hand pumps, and total supply is estimated at 450 m^3/day. It is generally understood that the best-yielding wells are those along the wadi between the camps.

The available borehole data, from both drilling reports and database printouts, are tabulated in the Appendices.

Summary, Abu Shouk camp borehole data:

Total boreholes drilled:	48: 45 successful, 3 unsuccessful
Water-bearing formation:	Basement Complex
Static water level range:	31-50 m; Average static water level 36 m
Total Motorized Pumps setting depth range:	51-57 m
Total hand pumps setting depth range:	51-57 m
Total boreholes chemically and bacteriologically fit:	45
Boreholes depth range:	37-48 m
Boreholes yield range:	0.75 m^3/h - 1.5 m^3/h for hand pumps
Boreholes yield range:	3.5 m^3/h-4.5 m^3/h for motorized pumps.
Borehole casing used:	PVC

Summary, Al Salaam camp borehole data:

Total boreholes drilled:	18: 17 successful, 1 unsuccessful
Water-bearing formation:	Basement Complex
Static water level range:	28.5-29.5 m, average 28.5 m
Depth to water struck range:	30-42 m
Motorized pumps setting depth range:	51-57 m
Hand pumps setting depth range:	51-54 m
Boreholes chemically and bacteriologically fit:	18
Total boreholes depth range:	49-63 m
Boreholes yield range:	1.3-3.0 m^3/h for hand pumps
Boreholes yield range;	9.5 m^3/h for motorized pumps
Borehole casing used:	PVC

Table 3.1 Summary of hand pumps setting depth in Al Salaam & Abu Shouk Camps

BH. Location/Name	BH Depth (m)	SWL (m)	Water Column (m)	Pump Setting Depth (m)
Al Salaam Camp School (C)	57	34	21	54
Al Salaam Camp East	57	34	21	54
Abu Shouk Camp Market	63	39	24	54
Al Salaam Camp School (12)	54	33	21	51
Al Salaam Camp School Wasat	54	33	21	51
Abu Shouk Camp block 4	60	49	21	57
Abu Shouk Camp block 1	60	49	21	57

Hand pumps

About 45 hand pumps have been in use in Abu Shouk. Of these, about 24 are still in use, some of which are relatively new pumps to replace others which have been abandoned. At least three are said to have low yields.

Of the 21 which have gone out of use, about 12-15 appear to have gone dry, while the rest are out of operation for other reasons. Most of the abandoned pumps are in the raised areas, where they would be expected to receive little or no recharge. Hence the remaining, working, hand pumps are mostly clustered in the wadi/depression areas where annual flooding provides recharge.

The reported yields of boreholes fitted with hand pumps are generally in 0.75-2 m^3/hr (18-48 m^3/d). The ‘yields’ noted on drilling reports were often higher than those in database printouts. This may reflect a common feature of fractured aquifers –yields estimated on completion of drilling often decline later.

3.5 Groundwater levels and monitoring

During the field visit of 10/3/07, it was possible to measure water levels in only three boreholes:

ICRC BH: SWL 38.96 m below top of casing; 38.48 m below ground level

This borehole was out of service and awaiting replacement of the pump.

On 12/3/07, the water level was 38.95 m (using a different dipper) – essentially unchanged from 10/3/07. This unchanged water level (albeit over only two days) suggests that the ICRC borehole is unaffected by pumping in any other boreholes.

HP 6: SWL 37.37 m below top of casing; 36.91 m below ground level

The pump was removed from this borehole about 5 months previously because of its poor yield.

Oxfam T11 BH: SWL 31.96 m below top of casing; 31.64 m below ground level.

This borehole is pumped for only 3 hours per day, and had not been pumped for several hours before measuring.

In all the other boreholes seen, there was no access for a water level dipper, although since each has only a 2" diameter rising main, it should be possible to modify the wellhead to allow access.

Most of the boreholes have no flow meter attached, so monitoring of outputs is based on pump capacity and the time taken to fill a tank of known volume.

Oxfam Haloof borehole

On 12/3/07 the water level in the Oxfam Haloof borehole was measured but was recovering from pumping. Levels of 34.51 m below top of casing (about 40 minutes after pumping stopped) and 33.72 m (at about 60 minutes) were measured. By comparison with data logging from August-September 2006, these levels suggest a static level of about 32 m blow ground, roughly 3 metres below the likely static level in September 2006.

This is the highest yielding borehole in Abu Shouk or Al Salaam, currently producing about 180 m^3/day. A water level transducer and datalogger was installed for a few weeks in August-September 2006. Installing the transducer was difficult owing to the very narrow annulus available outside the rising main, which also contains the electrical cable. Although not recognised at the time of installation, the transducer was not installed at the intended depth (just above the pump) and therefore the record of water level fluctuation is incomplete – in each pumping period, the water level fell below the transducer, so the actual pumping water levels were not recorded. However, the record does show that recharge to the aquifer took place at least three times – in mid-August, late August, and mid-September. The water level rises were, respectively, about 0.5 m, 1 m, and 3.5 m. It is seen that in each case, the water level rises quickly, followed by a fairly rapid fall. This indicates that the borehole is near the centre of the 'recharge mound' (alongside a wadi) and that the recharged water then moves away laterally into the aquifer.

The Haloof borehole is in a good position to benefit from the recharge provided by the wadi, and therefore is probably sustainable, at least in normal years. It is impossible to predict (using available data) how vulnerable it may be to a poor rainy season.

3.6 Aquifer properties

No information was available on aquifer properties at this site.

3.7 Available groundwater resources

The daily supply to Abu Shouk, 550 m^3, amounts to 200,000 m^3 in a full year. The daily supply to Al Salaam, 450 m^3, amounts to 164,000 m^3 in a full year. The total supply of about 1000 m^3/day, or 0.365 Mcm/yr, would be equivalent to 45 mm/yr of recharge over the footprint of the camps.

In a normal year, no direct recharge would be expected to penetrate the weathered Basement Complex. It must be assumed that recharge will take place only below the wadis and in the depressions, where sufficient water can accumulate. However, the catchment area to the two depressions is very small, so the bulk of the annual recharge must be derived from the flow in the Wadi Haloof.

The catchment of Wadi Haloof is roughly triangular, extending to the northeast for about 26 km. The catchment area does not carry runoff from the Jebel Marra massif, but from a rather flat area of weathered Basement, surrounded by slightly higher areas of Qoz sand. Its runoff-generating area (excluding Qoz) is in the region of 320 km^2. The average annual runoff is not known, but may be of the order of 50 mm, amounting to 1.6 Mcm. This would probably occur on a few days (5 – 10) per year. Most of this runoff would flow through the wadi at Abu Shouk / Al Salaam and on downstream, so only a minor part would recharge the aquifer at Abu Shouk / Al Salaam.

The capacity of the alluvium (between Abu Shouk and Al Salaam) to absorb the flow will depend partly on its geometry. The width is approximately 1500 m; if we take a length of about 2 km along the wadi, the area is 3 km^2. If this is flooded to a depth of 0.5 m, and 20% of this infiltrates to become recharge, that would give 0.3 Mcm of recharge, or almost enough to supply the camps for a year. However, this may be in error by a wide margin. In practice, the available recharge in an average year may be substantially in excess of a year's abstraction. Equally, it may be less, and in a dry year may be substantially less. Monitoring plus hydrogeological analysis should allow determining this.

Haloof Dam

The Haloof Dam lies about 2 km north of Abu Shouk, on the Wadi Haloof. It was built in 1976, with earth embankments and a central concrete spillway, and is said to have held about 500,000 m^3 of water. It combined flood protection, water supply and recharge enhancement functions.

The dam was breached on 12/8/05, probably due to scouring at the foot of the spillway. (The rain gauge at El Fasher Airport recorded exceptionally heavy rainfall (132 mm) on 3rd August 2005.) The flood resulting from the dam's collapse caused substantial damage in Abu Shouk camp. There are plans to repair the dam but no budget has yet been allocated.

Repair of the dam would almost certainly benefit Abu Shouk and Al Salaam camp water supplies by enhancing recharge to the aquifer – mainly by allowing flood flows to infiltrate more slowly. By providing an alternative source of water in (and shortly after) the rainy season, it would also take some of the pressure of the camp water supplies. More hydrological data and a cost estimate are needed to develop the cost-benefit ratio. However, given the defence provided to the camp by the structure before its collapse it is reasonable to assume that the repair will bring significant flood control benefit in addition to the benefits of aquifer recharge.

3.8 Groundwater quality

Groundwater quality from the camp boreholes is generally satisfactory, as shown by the analyses tabulated below.

Table 3.2 Abu Shouk Camp borehole water quality data

Physical properties range			
Colour	FTU	Odour	N
Turbidity	0.41-1.74 ptco.	Taste	N
pH	7.3-7.4	EC	740-780 µS/cm
Aesthetic Properties range (ppm) :			
Total dissolved solids (TDS)	448-480	SO_4	9-18
Total hardness as $CaCO_3$	150-200	Ca	54-75
Total alkalinity as $CaCO_3$	100-260	Mg	0.0-17.6
Na_2CO_3	0.0	Na	2.0-49
Cl	3.0-70.0	Fe	---

Inorganic constituents of health significance (range in ppm)			
F	0.0-1.0	S.S	-
NO3	13.6-17.6	AL	-
NO2	0.0-0.0	CN	-
NH3	0.0	MN	-

Table 3.3 Al Salaam Camp boreholes water quality data

Physical properties range			
Colour	FTU	Odour	N
Turbidity	N. ptco.	Taste	N
pH	7.3-7.9	EC	495-770 µS/cm
Aesthetic Properties range (ppm) :			
Total dissolved solids (TDS)	346-375	SO_4	14-22
Total hardness as $CaCO_3$	90-170	Ca	26.4-62
Total alkalinity as $CaCO_3$	185-230	Mg	2.2-16.3
Na_2CO_3	0.0-149	Na	15.8-65.8
Cl	2.0-53	Fe	---
Inorganic constituents of health significance (range in ppm)			
F	0.0-1.0	S.S	-

NO_3	5-26	Al	-
NO_2	0.0-0.009-0.066	CN	-
NH_3	0.0	Mn	-

3.9 Conclusions

1. The water supply to Abu Shouk and Al Salaam depends substantially on hand pumps, 12-15 of which have run dry or reduced in yield over the past 3 years.
2. Most failed or failing hand pumps are in the raised Qoz areas, whereas most of the 'dependable' hand pumps, and the motorised pumps, are in the lower alluvial areas.
3. The failed and failing hand pumps have been drawing on groundwater storage in areas receiving little or no recharge in the wet season.
4. Dependency on the motorised pumps in the alluvial areas will therefore increase.
5. Lack of data on borehole water levels precludes a conclusion on the sustainability of the water supply as a whole (some areas are already drying). However, consideration of the likely available recharge and the variability of annual rainfall indicates that:
   - the supply may already be unsustainable in an average year, but only a period of groundwater level monitoring can confirm or refute this,
   - in a dry year (significantly lower than average rainfall in the wet season) the supply is likely to be unsustainable through the subsequent dry season.
6. Reconstruction of the Wadi Haloof dam would reduce the vulnerability of the camp water supplies.

3.10 Specific recommendations

C.1. A single co-ordinator should be appointed to monitor the water resources at the two camps. (Implementing agency)

C.2. Construction of additional boreholes in the alluvial areas should be considered. (Implementing agency, UNICEF, WES)

C.3. Reconstruction of Wadi Haloof dam should be supported in principle, subject to appropriate hydrological and cost-benefit analyses. (UNICEF)

3.11 References

HGG/MMP Darfur Water Resource Survey 1970.

4 Kalma water assessment

Figure 8 CARE hand dug well at Kalma

4.1 Camp context

Kalma camp is located about 20 km east of Nyala city, capital of South Darfur state, and is the second biggest IDP camp in Darfur. It was established in April 2004 comprising 89,754 IDPs, later increasing to 95,000 IDPs of different tribes, the majority of them of Fur and Zaghawa tribes.

UNICEF–WES in collaboration with OXFAM, CARE and SPRC are providing and facilitating water supply services to the vulnerable, conflict-affected population of Kalma Camp.

4.2 Field visit

The field visit was undertaken on Wednesday 7th March 2007, facilitated by UNICEF, WES, Oxfam, and Care International.

4.3 Hydrogeological & hydrological context

Kalma camp lies some 20 km east-southeast of Nyala. The camp extends over a triangular area of some 10 km^2, and is about 7 km from east to west and 1.5 km from north to south. The camp occupies an elongated site bounded between the Nyala-Ed Daein railway line to the south, and the Wadi Kalma on the north side.

Hydrologically, the camp sits on a low interfluve between Wadi Kalma (to the north) and the much larger Wadi Nyala (to the south). Visually, the site appears virtually flat. The soil cover of the camp surface is of Aeolian deposits and alluvial to fluvial deposits closer to the wadi course.

The rock underlying the site is entirely of the Basement Complex, and hence is a poor aquifer.

The natural direction of groundwater flow through the Basement Complex is not known. The bed of the Wadi Kalma is probably at a slightly higher elevation than that of Wadi Nyala, so it might be expected that the natural direction of groundwater flow through the Basement Complex would be approximately southeastwards towards Wadi Nyala. However, the alluvium in Wadi Nyala retains groundwater all year round, whereas the groundwater in Wadi Kalma probably percolates into the underlying Basement soon after the end of the rains, and hence may have a deeper water table in the dry season. If this is so, the natural groundwater flow may be northeastwards from Wadi Nyala. In any case, the rate of such natural groundwater flow would be very small, limited by the low permeability and the low gradient.

In the current situation, with fairly intensive pumping of groundwater from the Basement Complex aquifer, groundwater is likely to flow from both wadis towards the centre of the camp, but again such flow will be limited by the low permeability of the Basement.

4.4 Water supply

The water supply for Kalma Camp comes from a number of boreholes, dug wells and hand pumps. There appear to be some 12 motorised boreholes, 21 hand pumps, and 4 dug wells – these dug wells are privately owned and leased to the operating agencies for camp use.

4.5 Groundwater levels and monitoring

During the field visit, water levels were taken in 4 dug wells and 3 boreholes, i.e. wherever it was practicable. The results are listed in Table 4.1.

Table 4.1 Measured water levels in Kalma dug wells and boreholes

Well	Static water level, m	Dynamic water level, m	Depth of well, m	Height of reference point above ground, m
CARE Dug well 1		6.26	10.6	0.86
CARE Dug well 5		5.81	11.5	0.55
CARE Dug well	3.90		9.64	0.50
WES Dug well		4.48	9.2	0.62
CARE BH		29.85		
Oxfam BH 2		27.87		
Oxfam BH 3		13.11		

4.6 Aquifer properties

The only data from which aquifer properties may be inferred are some step test results from two Oxfam boreholes at Kalma, carried out by REFCO (Rehaid El Furssan for Investment and Development Company) in December 2004:

Table 4.2 Pumping tests on Kalma boreholes

	BH (2)	BH (3)
Latitude	12:00:33.32	
Longitude	25:01:00.29	
Date of test	14/12/04	13/12/04
Total depth, m	37	32
Casing depth, m	37	32
Static water level, m	6.1	5.7
Pump setting depth,m	34	28
Step 1, pumping rate, m^3/h	6.48 (20 minutes)	5.04 (10 minutes)
Maximum drawdown, m	14.39	1.62
Specific capacity, $m^3/d/m$	10.81	74.7
Step 2, pumping rate, m^3/h	7.065 (30 minutes)	11.606 (20 minutes)
Maximum drawdown, m	20.2	12
Specific capacity, $m^3/d/m$	8.39	23.2
Step 3, pumping rate, m^3/h	7.77 (120 minutes)	12.96 (135 minutes)
Maximum drawdown, m	27.36	16.91

Specific capacity, $m^3/d/m$	6.82	18.39
Estimated transmissivity, m^2/d	5.3	27.1

4.7 Available groundwater resources

While the dug wells supplying Kalma Camp draw water from the wadi alluvium, the boreholes and hand pumps draw their water from the Basement Complex. Recharge to the aquifers is limited to the rainy season, generally between June and September, and can be derived from three sources:

- Direct recharge from the infiltration of rain falling directly on the Basement Complex, in and around the camp. Since the Basement Complex has a generally low permeability, it is assumed that the zone of contribution (ZoC) to the wells does not extend far beyond the extent of the wells. Hence a maximum ZoC of about 10 km^2 can be envisaged. If annual recharge over this area amounts to 20 mm, this would result in recharge of 200,000 m^3. No data are available to confirm this inference, but it is unlikely to be higher.
- Indirect recharge of flood waters in Wadi Nyala - firstly into the wadi alluvium, and then (hypothetically) laterally, via fractures/fissures, into the Basement Complex. Previous reports on the water resources of Wadi Nyala have derived average values for the annual flood flow at Nyala. HTS/MMP (1974) suggested that annual average flow was about 90 Mm^3.
- Indirect recharge of flood waters in Wadi Kalma - firstly into the wadi alluvium, and then (hypothetically) laterally, via fractures/fissures, into the Basement Complex. The wadi has a catchment area of very approximately 120 km^2, which could give rise to average annual runoff at Kalma of perhaps 5 million m^3.

Among the professional and technical staff consulted, opinions differ as to the likely magnitude of substantial lateral groundwater flow from Wadi Nyala into the aquifer beneath Kalma Camp. A rough calculation illustrates the problems of making such estimates:

$Q = T \times I \times W$ where Q = rate of groundwater flow, T = aquifer transmissivity, I = hydraulic gradient, and W = width of aquifer flow sector.

If $T = 5\ m^2/d$, $I = 0.005$, and $W = 7$ km, then $Q = 175\ m^3/d$, or 63,875 m^3/year.

If this is compared with the annual groundwater abstraction from boreholes (excluding the dug wells) of about 373,000 m^3/year, it can be seen that only a minor proportion of the annual abstraction can be recharged from this source. The quantity of water recharging from Wadi Kalma is unlikely to be any larger.

The inference is that the annual recharge to the aquifer from the wadis is unlikely to replace what is currently being abstracted by boreholes.

It is inferred that the recharge to the four dug wells to the south of the camp is drawn from Wadi Nyala. The output of these four wells is approximately 760 m^3/d, or 277,000 m^3 in a full year.

The further inference can be made that in a dry year, when rainfall is well below average, the quantity of annual recharge may be insufficient to sustain the camp supply, and that the deficiency will not be made up by inflow from either Wadi Nyala or Wadi Kalma.

4.8 Groundwater quality

A number of chemical analyses of water samples were supplied by WES and Care International. They are listed in Appendix C.

The analyses indicate that there are no major problems of chemical water quality across the camp area, except in Sector 1, where several wells were found to contain unacceptable levels of nitrate, as well as some other parameters. It is not clear why boreholes in this sector are affected while boreholes in other sectors are not.

4.9 Wadi Nyala and Nyala City Water Supply

A summary of the situation in Nyala was kindly supplied by Mr Fadhl Mahmood Nasser, Manager of the Nyala Water Corporation:

The city of Nyala has experienced enormous growth in the past 20-30 years, and now has a population of approximately 1.5 million (no exact figure is known).

The city water corporation currently supplies an average of about 15,000 m^3/day. There are plans to increase this to 25,000 m^3/day by the end of 2007, by commissioning a number of new boreholes - some have already been drilled and others are in progress. The new boreholes are located at Kundua, some 2 km downstream of the main wells.

Further into the future, a scheme has been designed and approved to bring an additional 40,000 m^3/day from Gereida, 70 km south of Nyala in the Baggara Basin (Nubian Sandstone) aquifer.

At present, there are some 10,000 household connections in Nyala, and 106 km of pipeline (4" to 14" diameter). Storage capacity of 3,250 m^3 is available.

The city water supply comes from about 22 boreholes in Wadi Nyala, each producing 20-25 m^3/hour. Most are operated for 24 hours per day. The boreholes range in depth from 15 to 30 metres and are mostly 203 mm (8") in diameter.

The main problems with the city supply are:

- *The rapid rate of growth of the city. Currently only 35% of the people have a piped supply – by end 2007 this may be 50-55%.*
- *The limited pipe network, which will not cover the whole city – the length of the pipe network needs to be doubled.*
- *There is also a shortage of storage capacity, which currently amounts to only 22% of daily output.*

Discussions are in progress about the possibility of constructing a subsurface dam downstream of Kundua to reduce groundwater outflow downstream.

4.10 Conclusions

1. The present water supply in Kalma Camp is understood to be adequate for humanitarian needs, and the camp residents are being supplied, on average, with slightly more than the target of 15 litres/head/day, although this has not been verified by household water use surveys.
2. The water supply depends heavily (over 40%) on four dug wells in the wadi alluvium which are privately owned and rented by the operating agencies. The supply from these wells appears to be sustainable in the long term.
3. In the medium term, it seems unlikely that the current rate of groundwater abstraction from the boreholes in the Basement Complex can be replaced by annual recharge. Therefore the supply is drawing on diminishing storage in the Basement Complex and is inherently unsustainable.
4. To replace boreholes in the Basement Complex which become dry (which is likely) it should be possible to drill new boreholes in the flood plain of Wadi Nyala.

4.11 Specific recommendation

C.4. Contingency plans in Kalma camp should include new boreholes close to Wadi Nyala. (Implementing agencies / UNICEF)

C.5. An integrated water management plan is needed for Wadi Nyala, which will take account of the needs of both Nyala city and the nearby camps. (UNEP IWRM programme)

4.12 References

HTS/MMP South Darfur Land Use Planning Survey 1974

WADS 1985

5 Otash water assessment

Figure 9 Oxfam borehole No. 3 at Otash

5.1 Camp context

Because of prevailing conflicts in most of South Darfur State, a gradual influx of conflict-affected people moved towards Nyala town to settle at Otash camp in 2004. It is located about 6 km north of Nyala at 12:05:37.57 N and 24 54 20.79 E, and covers an area of about 2.4 km².

The total population of about 14,600 IDPs at the establishment of the camp (2004) increased to 55,000 population by 2007.

The main agencies working in the field of humanitarian drinking water assistance are WES – UNICEF and CARE .

5.2 Field visit

The field visit was undertaken in the afternoon of Wednesday 7th March 2007, facilitated by UNICEF, WES, Oxfam, and Care International.

5.3 Hydrogeological & hydrological context

Otash IDP Camp lies some 5 km NNE of Nyala centre at coordinates (to the nearest water point) of 1205 37.57 N and 24 54 20.79 E. The camp occupies a compact site with an area of about 2.4 km^2, the camp being about 1.8 km from east to west and 1.5 km from north to south.

The camp site is a flat surface of hard rocks with thin soil cover; sometimes the rocks are exposed at surface, outcropping as small low hills representing higher land, from which very localized surface streams flow in small khors parallel to each other, their gentle slopes from NW to SE.

The camp is underlain by weathered Basement Complex rocks, with a thin covering of wind-blown sands comprising granite gneiss fragments. The Basement Complex is a poor aquifer. The natural direction of groundwater flow through the Basement would be approximately southeastwards.

5.4 Water supply

According to information supplied, 16 boreholes in Otash are used for supply – 8 hand pumps and 8 submersible pumps. It is assumed, but cannot be assured, that these 16 correspond to the 16 successful boreholes reported in Tables 5.2A and 5.2B.

Drilling records were supplied for 23 boreholes drilled in Otash, of which 16 were deemed successful, i.e. a ratio of about 2 in 3. (Details in Appendix C).

The borehole details supplied lack much information which would be useful. Some features which appear:

- Most of the boreholes (15 out of 23) were drilled since the 2005 wet season, and four were drilled since the last (2006) wet season, hence most of the wells are relatively recent.
- The latest holes to be drilled (November 2006) were much deeper than the earlier holes, but the pump setting depths indicate that most of the water found was still at a depth of 30-40 metres, in fractured (rather than weathered) Basement Complex. This suggests (a) that water is becoming harder to find, and (b) that water is now being drawn from depths where the unit storage capacity of the aquifer is very low.

5.5 Groundwater levels and monitoring

Some routine groundwater monitoring is said to have been undertaken in the past, but no data were available. During the field visit, water levels were taken in 2 boreholes; no measurement was possible in the other boreholes visited. The results are listed in Table 5.1.

Table 5.1 Measured water levels in Otash boreholes

Borehole	Static water level, m	Dynamic water level, m	
WES BH 6	12.38		
WES BH 4		29.9	

Since the pump setting is usually about 34 m below ground, a dynamic water level of 29.9 m indicates that pumping water levels may be approaching pump depths by the end of the 2007 dry season. It will then be important to measure how far the water levels can recover in the wet season. If water levels do not recover substantially, contingency plans should be put in place for the possibility of some of the boreholes failing in the next dry season.

5.6 Aquifer properties

The only data from which aquifer properties may be inferred are the drilling data supplied by WES and Care International, and some more detailed pumping test data from two boreholes. Specific capacities, and hence approximate transmissivities (T), can be estimated from the figures for 'yield', static water level and dynamic water level. The estimated T values range from 3 to 27 m^2/d. Note that these represent values in successful boreholes drilled at optimum drill sites; average values in the Basement Complex will be significantly lower.

5.7 Available groundwater resources

The water supply for Otash Camp comes from a number of boreholes, dug wells and handpumps. All these wells draw their water from the Basement Complex. Recharge to the aquifer, if any, is limited to the rainy season, generally between June and September. This recharge could only arise from direct recharge from the infiltration of rain falling directly on the Basement Complex, in and around the camp. Since the Basement Complex has a generally low permeability, it is assumed that the zone of contribution (ZoC) to the wells does not extend far beyond the extent of the wells. Hence a maximum ZoC of about 2 km^2 can be envisaged.

The average quantity of water abstracted for Otash Camp is approximately 600 m^3/day, or 219,000 m^3/year. Assuming a Zone of Contribution of 2 km^2, this requires an annual recharge of over 100 mm/year. This is extremely unlikely at Otash, hence the camp water supply appears to be unsustainable and is drawing on storage.

It is extremely difficult to estimate the storage capacity (storativity) of the Basement Complex. *(Storativity is defined as the quantity of water, expressed as a fraction or percentage of unit rock volume, which can be abstracted by a water well.)* Fresh Basement rocks will have a storativity of almost zero. Fractured (but unweathered) Basement may have a storativity of perhaps 0.5 - 1%, while weathered Basement may have a storativity of perhaps 5%. Taking an area of 2 km^2 and an aquifer thickness of 20 metres, and assume that the proportions of fresh, fractured and weathered Basement are about 80%, 10% and 10% respectively, then the total storage capacity could be of the order of 240,000 m^3, or roughly one year's supply.

These figures are speculative, but simply serve to emphasise that, under any reasonable assumptions, the Otash Camp water supply appears to be unsustainable in the medium term – say, over the next 1 to 3 years.

5.8 Groundwater quality

A number of chemical analyses of water samples were supplied by WES and Care International. They are listed in Table 3.

The analyses indicate that there are no major problems of chemical water quality across the camp area.

5.9 Conclusions

1. The present water supply in Otash Camp appears to be adequate for humanitarian needs, but in view of the absence of obvious sources of recharge, this situation appears unsustainable in the medium term. This camp is particularly vulnerable to the occurrence of a dry year.

5.10 Specific recommendation

C.6. If water levels in Otash do not recover substantially in the 2007 wet season, contingency plans should be put in place for the possibility of some of the boreholes failing in the next dry season.

5.11 References

HTS/MMP South Darfur Land Use Planning Survey 1974

WADS 1985

6 Mornei water assessment

Figure 10 Water visible at surface of Wadi Azum near Mornei, 28/2/07

6.1 Camp context

Community displacement to Mornei started in September 2003, up to early January 2004. The people were displaced from a large number of villages in three administrative units: Geneina, Zalingei and Wadi Salih. The number of IDPs ranged from 20,000 to 25,000, receiving their food from the resident populations of Mornei town, Mornei Zakat Office and Gemaria.

The number of IDPs later increased, but many of them subsequently moved to Khartoum and other secure towns in Sudan. The water supply system at that time was started by four water points operated by Oxfam.

In January 2004, MSF began their water intervention in Mornei Camp through supporting the water supply system in May-June 2004, in addition to their curative health and nutrition programmes, targeting the children.

WFP began IDP registration in April 2004, and found that the numbers of IDPs ranged from 65,000 to 70,000, but without food distribution.

Concern's office was established in July 2004, mandated on sanitation and nutrition.

UNICEF/WES was established in March 2004, mandated on sanitation, hygiene promotion, soap distribution, education as IDP school intervention and school health education. In 2005 Oxfam took over some water points from MSF and added to the operational system.

The current population of Mornei is estimated as follows:

By WFP and Concern: 74,000 IDPs

By HAC Mornei: 80,000 IDPs, plus 7,563 residents

The main water supply issues are:

1. Head loss in the water supply pipelines.
2. Location of some tap stands on the delivery pipe from the boreholes, thereby reducing the head available to deliver water to the further water storage tanks: additional tanks are needed.
3. The distribution of tap stands within sectors (access distances).

6.2 Field visit

On Wednesday 28th March 2007 all the supply boreholes were visited, as were several of the hand pumps (India Mark II), storage tanks and tap stands around the camp. All these facilities have been mapped by OCHA/HIC (Map). Chlorine dosing equipment was also inspected, as was a large dug well (near Hand Pump 10) which is sometimes used for emergency cover.

6.3 Hydrogeological & hydrological context

The town of Mornei, with its associated IDP camp, lies beside the confluence of Wadi Azum with Wadi Barei. The area is underlain by rocks of the Basement Complex, predominantly muscovite schists intruded by quartzitic dykes. The schists, being highly weathered, are not exposed around the town but the dykes are seen at the core of a series of low ridges.

The available aquifers therefore comprise the weathered Basement Complex and the wadi alluvium. The geophysical evidence for the thickness of the wadi alluvium is ambiguous given the difficulties of defining the transition from wadis sand to weathered basement. A geophysical section in the 1987 report (Mastour) shows a maximum depth of 35 metres in a narrow trough-like feature which might be fault-controlled. In general, the depth to Basement is around 15 metres.

The aquifer exploited is a combination of the wadi alluvium and highly weathered Basement Complex. It is possible that in some places the two aquifers may be confused, because the chip samples from DTH (down-the-hole hammer) drilling may look similar.

The aquifers at Mornei receive both direct and indirect recharge. During the dry season the wadi aquifer will also receive additional subsurface flow in the wadi alluvium from upstream. The rate of this subsurface flow depends upon the aquifer's width and thickness (i.e. its cross-sectional area), its permeability, and the water table gradient. For example, if the saturated thickness is 12 m, the width 500 m, the permeability 50 m/d and the gradient 0.001 (1 metre per kilometre), then the rate of flow will be 300 m^3/day. This is not enough in itself to supply more than one borehole, but it makes a useful contribution to the resource. Of most significance in Mornei is the large local storage.

6.4 Water supply

Mornei (Camp & Town) is served by seven boreholes with submersible pumps. The boreholes were drilled in two batches – some in June 1987, and some in May 2005. The wells are at two sites in and near the Wadi Barei – upstream (wells 1,2,3,4 & 7) and downstream (wells 5 & 6). Details are listed in Table M.1.

Well No. 6 is currently out of use due to damage by flood waters in the 2006 rainy season. It appears that the force of the wadi flow has bent the casing (both the outer steel casing and inner PVC casing) and that the inner casing has parted and allowed wadi sand, and gravel pack, into the well. WES are proposing to rehabilitate this well and have already constructed a low brick wall (about 1.2 m high) around the well as flood protection. Since repairing the well may be difficult, and the depth is small, a more satisfactory outcome, with less trouble, could probably be achieved by abandoning the well and drilling another alongside.

Water storage

Most of the current water storage is in the form of 45 m^3 cylindrical tanks with conical roofs, situated at ground level. There are also a few 'square' tanks elevated on steel towers.

We visited the site of **three storage tanks** on a low hill: one 45 m^3 cylindrical tank at ground level, one 22.5 m^3 'square' tank on a low tower, and one 50m^3 'square' tank on a high tower. The largest tank has obvious structural problems – bending in the supporting girders, and bulges in the tank walls. Replacement of this tank seems desirable in the context of increasing the overall storage capacity.

WES currently stores water in 8 tanks of 45 m^3, 2 of 70 m^3, 1 of 50 m^3, and 1 of 22.5 m^3, making a total storage capacity in the 12 tanks of 572.5 m^3, equivalent to only 30% of daily usage.

GPS locations and elevations were provided by WES for all the pumping boreholes and hand pumps. However, the elevations given by GPS units are insufficiently accurate for the calculation of groundwater gradients, so all wellheads should be levelled in to a suitable local datum.

Many of the tap stands are supplied directly from pumped boreholes rather than from storage. On the other hand, some storage tanks, having been filled overnight, are empty by early afternoon. WES wants to install additional storage and supply as many tap stands as possible from storage. This would also facilitate water treatment and metering to monitor production.

Hand pumps (visited)

Hand Pump No. 7 became contaminated in the 2006 rainy season. The pump was close to a latrine (about 7 m away). WES took remedial action in August 2006: the latrine was closed and filled in, the pump removed and the borehole sterilised with chlorine. The pump remained unused for six months. In February 2006 the pump was re-installed and the water tested for bacteria. On receiving a clear report, the pump was again opened for use. The incident emphasises the relatively high vulnerability to pollution of boreholes in the weathered Basement Complex, and the need to be vigilant about the presence of latrines in the vicinity of any water sources.

Hand Pump No. 4 has a very low yield – perhaps 1 litre/minute or less at the time of our visit. A queue of users was waiting for water, in contrast to other hand pumps and tap stands where no users were waiting. Local people were complaining about the lack of water in the well. There are evident inequalities in the people's access to water, which need to be attended to. This pump is apparently completely dry from April to June, and the people have to travel much further to an alternative source.

Hand Pump No. 10, beside the wadi but in Basement Complex, is unused due to its very low yield.

Hand Pump No. 6 has a good yield and hence was not in use when we visited, the users having already satisfied their needs.

Each hand pump is in the care of a local caretaker and a local committee. All those seen were clean and tidy and protected by a *zariba* (thorn fence).

6.5 Groundwater levels and monitoring

During the field visit, dynamic water levels (i.e. during pumping) were measured in six of the supply wells: numbers 1, 2, 3, 5, 6, and 7. Well No. 4 has a larger diameter rising main and there is insufficient space to insert a measuring probe. The measurements are in Table 6.1:

Table 6.1 Water levels measured in Mornei wells

Well No.	Measured DWL, m bgl 28/2/06	Original SWL, m.	Measured SWL, 2/3/07 (before pumping), m	Remarks
1	6.22	3.9 (11/5/87)	2.80	
2	3.63	2.9 (7/5/87)	2.59	
3	3.05	3 (3/5/87)	2.63	
5	1.75	1 (14/6/05)		In the wadi bed; relation to actual ground level very approximate
6	0.5 (approx)	1 (13/6/05)		
7	8.29	5 (11/6/05)	4.44	

From the data in the table, it is clear that (a) drawdowns in the wells are small, due to the high transmissivity of the aquifer, and (b) static water levels have not declined significantly since the wells were drilled.

The only groundwater level monitoring data available are from April-May 2006, when a datalogger was installed in BH 7 (then unused) for a period of 24 days. The results are shown in Figure M.1. The data show an overall water level decline of about 60 mm (= 2.5 mm/day) over 24 days, which is almost negligible. Such a fall could be expected in a wadi aquifer even without any pumping, due to the slow downstream flow of the groundwater in the aquifer. Such a small rate of decline, even near the end of the dry season, confirms that the aquifer showed no significant sign of stress at this time. However, if there should be an abnormally poor rainy season the situation may be different, so a groundwater monitoring programme is still essential.

At the end of February 2007, over halfway through the dry season, water was still accessible about 0.5 m below the wadi bed, and many people were drawing water from shallow temporary wells ('masheesh') in the wadi. Further downstream, below the confluence with Wadi Azum, some surface water could still be seen in the wadi bed.

6.6 Aquifer properties

The properties of an aquifer, principally permeability (k), transmissivity (T) and storativity (S), are normally calculated or estimated from pumping tests undertaken for that purpose. However, some more approximate estimates can be made from lesser amounts of data. In this case, it is possible to estimate the aquifer permeability and transmissivity from the available data for pumping rates and dynamic water levels, and also from the short period of water level monitoring.

From the data below, it appears that the aquifer has a Permeability (k) in the range of 10 to 140 m/d, and a Transmissivity (T) in the range of 100 to 1500 m^2/day, values typical of such aquifers.

The water level monitoring from Well No. 7 in May 2006 (when it was not being pumped) showed a drawdown of about 0.45 m, due to pumping in Well No. 4 at 648 m^3/d. The distance between the two wells is approximately 100 metres. From these data, the approximate value for T was 400 m^2/day.

Table 6.2 Transmissivity estimates, Mornei

Well No.	SWL, m, approx	SWL, m 2/3/07	DWL, m,	Draw-down, m, approx	Pumping rate, m^3/d	Specific Capacity, m^3/d/m	Estimated T m^2/d (Logan method)	Saturated aquifer thickness m	Est. k m/d
1	3.9	2.8	6.22	3.42	336	98.25	120	12	10
2	2.9	2.59	3.63	1.04	528	508	619	13	48
3	3	2.63	3.05	0.42	528	1257	1534	11	139
4					648			20	
5	0.5		1.75	1.25	336	269	328	6	55
6			not pumping					6	
7	5	4.44	8.29	3.85	336	87.3	106	3	35

6.7 Available groundwater resources

The available groundwater resources can be estimated in two ways: the available annual recharge, and the available water in storage (which is important if recharge is abnormally low). For estimating purposes, I assume the area of the aquifer to be approximately 3 km long by 0.75 km wide, i.e. 2.25 km^2. (However, a larger area is available if needed.)
The available annual recharge comprises:

a) Direct recharge from rainfall over the aquifer: if annual rainfall = 500 mm, and infiltration is 10%, the recharge is 112,500 m^3

b) Recharge from the wadi floods: unknown but very large. Water depth in the wadi can reach 2 metres.

c) Subsurface flow in the wadi alluvium: 109,500 m^3. In a natural situation, this would be balanced by downstream outflows.

If the aquifer as a whole is dewatered each year by 3 metres, and the storativity is 15% (up to 20% is quite possible), that represents a quantity of just over 1 million m^3, compared to the estimated annual abstraction of about 700,000 m^3. At present, this is replaced every year, to which the flood recharge probably makes the highest contribution.

6.8 Groundwater quality

No water quality analyses were available, but no significant water quality problems are believed to occur.

6.9 Conclusions

1. The groundwater resources at Mornei show no sign of significant depletion in spite of intensive abstraction since the establishment of the camp in 2004.
2. This is due to the relative abundance of groundwater, principally in the wadi alluvium along Wadi Barei and Wadi Azum, and the abundant recharge from floods in the wadis.
3. Problems with the water distribution system require some additional measures, e.g.:
   - rehabilitation or replacement of Well No. 6;
   - drilling additional wells on the north side of Mornei at sites identified by geophysical surveys – to increase capacity and allow reduced pumping hours in existing wells;
   - provision of additional elevated storage tanks, so that tap stands can be fed from storage rather than directly from the pumping mains.
   - replacing some low-yielding hand pumps by tap stands supplied from storage;
   - extension of the distribution mains, particularly in outlying areas of the camp.

6.10 Specific recommendations

C.7. Dataloggers should be installed in Well No. 6, where the replaced or rehabilitated borehole should be designed to allow for it, and Well No. 7, at the upstream site, which shows the most drawdown. (The dataloggers sent to WES Mornei are unsuitable because of the diameter of the probes (40 mm) and should be replaced by instruments with smaller probes). (Implementing agencies, WES, UNICEF)

C.8. WES should be supported to reconfigure the distribution system so that all the wells pump to storage, and all tap stands are supplied from storage. To allow this, additional storage capacity should be installed. (Implementing agencies, WES, UNICEF)

6.11 References

Mastour 1987. Summary Report on Mornei Town Water Resources (in Arabic).

Hunting Technical Services, 1977. Jebel Marra report.

7 Identification of potentially vulnerable camps

The term 'Groundwater vulnerability' is used in a number of different ways. In the context of the IDP camps in Darfur, two kinds of vulnerability are of concern: vulnerability of camp water sources to depletion of the groundwater resource; and vulnerability of the camp groundwater supplies to significant contamination. For this project, the issue of concern is vulnerability to depletion.

Vulnerability to groundwater depletion

Factors to consider:

- **Aquifer storage:**

Aquifer storage capacity depends on two things – the saturated thickness of the aquifer, and the Storage Coefficient or Storativity, which is the percentage of a given volume of aquifer (e.g. 1 cubic metre) which can be occupied by accessible water. Wadi alluvial aquifers can have a storativity of 10 – 20%, while for the Nubian or Umm Ruwaba Series it is probably below 10%, and for the Basement Complex perhaps 1-2%. The thicker the aquifer, the greater is the storage capacity for a given area of aquifer, and hence the less vulnerable to depletion. The least vulnerable aquifers are therefore the deep sedimentary basin aquifers of the Nubian and Umm Ruwaba Series, followed by the deeper alluvial aquifers.

  - Nubian/Umm Ruwaba — Very Low Vulnerability to depletion
  - Deep Wadi Alluvium (>15 m) — Low Vulnerability to depletion
  - Medium-thick Wadi Alluvium (8-15 m) — Moderate Vulnerability to depletion
  - Thin Wadi Alluvium (<8 m) — Very High Vulnerability to depletion
  - Basement Complex — Very High Vulnerability to depletion
  - Volcanics — Moderate Vulnerability to Depletion

- **Recharge:**

The greater the available groundwater recharge, the lower the vulnerability. In this context, the variability of recharge from year to year is important. Recharge in a wet year is likely to be two or three times as large as recharge in a dry year. The large Nubian/Umm Ruwaba basins are largely exempt from this issue. Wadi alluvial aquifers will receive some recharge even in a dry year, but with Basement aquifers, much depends on the location of the boreholes with respect to a wadi – Basement close to a wadi will receive recharge via the wadi bed or banks, but Basement away from a wadi will receive much less recharge.

- **Zone of Contribution (catchment area):**

Any borehole or wellfield (group of boreholes) draws its water from a certain area of aquifer, which is termed its 'Zone of Contribution' or ZoC (often called a catchment, but this can also refer to a surface water catchment or watershed). The ZoC is not fixed but can vary according to the pumping rate, time of year, etc., but a maximum likely ZoC can be delineated in most situations.

Note that the ZoC is not limited to the 'cone of drawdown' or radius of influence' of a borehole. In practice, the ZoC will include a significant area up-gradient of the borehole(s) which is outside the drawdown cone, while on its downstream side a small part of the drawdown cone is often outside the ZoC.

The larger the ZoC, the more water is available to the borehole, which affects the amount of recharge which is available. Boreholes in highly permeable aquifers, such as the Nubian Series or wadi alluvium, can develop wide ZoCs, whereas boreholes in poorly permeable aquifers like the Basement Complex typically develop only small ZoCs.

- **Total pumpage (related to dependent population)**

Obviously, the higher the total pumpage from the aquifer, the greater the risk of depletion.

In considering a process for the assessment of vulnerability to depletion, the above four factors should ideally be integrated. However, for the sake of simplicity, the three aquifer-related factors can be grouped together for the first (prioritisation) stage, which aims to identify those camps where depletion MAY be a concern, so that they can be evaluated in some more detail.

At the second stage (evaluation) the camps with a significant risk of depletion can be subjected to a 'semi-detailed' assessment, with a view to establishing which camps (if any) have serious vulnerability concerns and should be studied in more detail. In this second stage, approximate ZoCs should be delineated and approximate recharge estimates developed. Stage 2 would be similar to what has been undertaken at the four priority sites for the Tearfund project, so would probably require about 3-5 days work per site.

Stage 3 would probably involve detailed monitoring.

The table below lists 17 camps, in addition to the four identified as potentially vulnerable above, which have been provisionally identified as being at significant risk of groundwater depletion on the basis of (a) the aquifer type (generally Basement Complex without a major wadi close by), and (b) the population (threshold arbitrarily set at 15,000).

This list is based on limited information and should not be considered definitive. Where agencies have concerns about the sustainability or vulnerability of water supplies in particular camps, they may be added to this list. The same measures should also be undertaken at Mornei due to its size and importance, although it does not face the same level of vulnerability as the camps listed below.

Note that most of the camps are somewhere near a wadi: the further assessment should identify the sources of water to the camp and the aquifer(s) concerned, and evaluate the extent of a hydraulic relationship, if any, between the wadi and the other aquifer(s).

Table 7.1 Large IDP camps potentially vulnerable to groundwater depletion

Camp	No of IDPs (Jan 2007)	Aquifer
North Darfur		
Abu Shouk	54,500	BC
Al Salaam	47,000	BC
Kebkabiya town	42,926	Wadi / BC / VR
Kutum Rural	40,096	Wadi / BC / NS
Tawila town	34,569	Wadi / BC
Kutum Town	26,418	Wadi / BC
Saraf Omra town	24,110	Wadi / BC
Kassab	22,251	Wadi / BC
South Darfur		
Otash	55,000	BC
Kalma	95,000	Wadi / BC
Kass town	89,895	Wadi / BC
East Jebel Marra	33,800	Wadi / BC / VR
Muhajryia - South camp	25,000	Wadi / BC
Dereig	23,156	BC
Beleil	21,440	Wadi / BC
West Darfur		
Golo AU	62,060	Wadi / BC / VR
Umm Dukhun AU	37,361	Wadi / BC
Kereinik AU	25,449	Wadi / BC
Seleah AU	21,344	Wadi / BC
Kulbus AU	16,981	Wadi / BC
Abu Surug	16,062	Wadi / BC

8 General conclusions and recommendations

8.1 Conclusions

Most publications on the groundwater resources of Basement Complex rocks in Africa (e.g. MacDonald, Davies & O Dochartaigh 2002) describe this aquifer as having the potential to provide water supplies for villages and rural areas. It is not generally regarded as having the potential for sustainable water supplies to towns with populations of 30,000 or more. In this context, what has been achieved in the large IDP camps in Darfur is quite remarkable. Populations of tens of thousands of people have been supplied with 15 litres or more per head per day of safe drinking water for up to four years in a semi-arid area. What is surprising is that these supplies have been maintained for as long as they have.

To some degree, this may be due to the relatively good rainfall in the past three rainy seasons (except at El Fasher, where 2004 rains were poor). However, it must be expected that another poor rainy season could occur at any time and NGOs and national authorities need to plan accordingly.

Water resource vulnerability

A significant number of camps are vulnerable or potentially vulnerable to groundwater depletion in a year of below average rainfall. This has not been apparent in Darfur due to years of average or above average rainfall coinciding with the crisis, and the presence of water storage built up over the long term before the crisis. The most vulnerable camps are those with large populations which are sited on Basement Complex rock without sources of recharge other than local rainfall in the area overlying the aquifer. Otash is in this category.

Camps that are *potentially* vulnerable to groundwater depletion are those with a large population sited on Basement Complex geology where adequate annual recharge from a local wadi *has not been proven*. In Kalma (Wadis Kalma and Nyala), and in Abu Shouk and Al Salaam (Wadi Haloof) water in the wadis may or may not adequately recharge the Basement Complex aquifers supplying these camps. Hence monitoring is needed in the camps and at the wadis to determine if sufficient water is able to flow from the wadis into the aquifers beneath the camps. In large camps, some parts of a camp may have reliable recharge while other parts may not.

Water resource management

At present, camp administrators concentrate on managing the water supply points – boreholes and dug wells – and the other elements of the distribution system – pumps, chlorination units, storage tanks and tap stands. There is little consideration of the water resource system as a whole. The study found:

- Little or no monitoring of groundwater
- Little or no analysis of water use
- Inadequate data management, both in the field management and in terms of coordination: UNICEF's data base is not well integrated with practical management of water programmes
- Little awareness of the risks of a season of low rainfall, and therefore:
- Little or no contingency planning for the event of a dry year.

With respect to practice at camp level:

- Data relating to boreholes were often incomplete, or files unavailable. Staff of operating agencies lack access to relevant reports, and are often unaware of reports or maps which could assist their work. Geophysical survey reports (to locate optimum borehole sites) were often not available.
- Reports on geophysical surveys (to locate optimum borehole sites) were often absent
- Exact locations of boreholes drilled were not recorded, especially for dry or abandoned boreholes

- It was often impossible to correlate drilling records with water sources in use – i.e. a pumped borehole known by the operating agency as 'Abu Shouk Hand Pump No. 3' could not be correlated with any particular drilling record.
- In almost no cases have the absolute or even relative elevations of well heads been surveyed (GPS-derived elevations are not sufficiently accurate). Therefore it is impossible to infer any groundwater flow directions from water level measurements. This is important where, for instance, recharge to a Basement aquifer is expected to come from a nearby wadi.

Thus there is a very significant issue around information management which requires an appropriate response. Information technology has the capacity to improve this situation if it is properly deployed. Integration with day to day management is essential.

In general a greater level of hydrogeological analysis is needed, involving more data collection, better data management and more capacity for hydrogeological interpretation.

The key risk is of water shortage in a dry year in vulnerable camps. Better analysis of the hydrogeological situation will allow this risk to be defined, and allow contingency plans and mitigation measures to be designed. There was inadequate understanding of the recharge mechanisms for aquifers being relied on. Monitoring and interpretation of the results will allow better understanding of the risks posed by dry years.

The concentration on supply rather than resource management is associated with reporting procedures, mandates of operating agencies, and possibly a cultural shift that has responded to the need to address 'soft' issues, but has left inadequate attention on more conventional technical issues such as hydrogeology. These issues have been discussed in D:RIVE.[11]

A greater emphasis on technical leadership (water resource management, appropriate M & E, strategic planning, hydrogeological expertise) within the sector is likely to be cost effective by savings from more efficient drilling programmes. However, the primary objective of these recommendations is to reduce vulnerability of water supplies in IDP camps.

At present, the concentration is on managing the water sources – the boreholes and dug wells – and the other elements of the distribution system – pumps, chlorination units, storage tanks and tap stands. Little or no consideration is given to the water resource system as a whole. If the water resource were a surface water reservoir, this would not be so. Someone would be monitoring the level of the lake, the flows of tributary streams into the lake, and so on. But underground water is out of sight and therefore out of mind. It may help to keep in mind the analogy with a surface reservoir.

Because the underground reservoir is out of sight, the managers need the best possible 'picture' of its shape and characteristics, as derived from the available evidence:

- Evidence from the surface – rock outcrops, wadis, etc.
- Evidence from any relevant geophysical surveys, with copies of any reports.
- Evidence from boreholes and dug wells - copies of borehole logs,
- Measurements of water levels, by dipping or by automatic recorders.
- Measurement of rainfall. Every camp should have a simple plastic rain gauge.
- Measurements and surveys of water pumping and water use.
- Records of surface water flow.

Camp managers and the wider relief community need to be informed of the status of water resource vulnerability (water security) at camps.

[11] Darfur: relief in a vulnerable environment. Bromwich B, Abuelgasim Abdalla Adam, Abduljabbar Abdulla Fadul, Chege F, Sweet J, Tanner V, Wright G Tearfund 2007
http://www.tearfund.org/webdocs/website/Campaigning/Policy%20and%20research/Relief%20in%20a%20vulnerable%20envirionment%20final.pdf

The need practicalities of monitoring are described in greater detail in Section 8.

8.2 Recommendations

(Recommended responsibilities are shown in brackets.)

R.1. The following activities must be undertaken at the vulnerable and potentially vulnerable camps. See list in Section 7. This work should be coordinated by UNICEF's field offices.

a. **Manual water level measurements (dipping) at production wells in vulnerable and potentially vulnerable camps. These measurements should be made after rainfall events, and intermittently in the dry season.**

b. **Installation of water level loggers on production wells at vulnerable and potentially vulnerable camps (prioritised in order of population size, with the exception of early installation at Otash).**

c. **Provision of rain gauges and training in installation and recording of rainfall data.**

d. **Data collected should be interpreted by an experienced and appropriately qualified hydrogeologist and reported on a 6 monthly basis, one analysis being at the end of the rains. The outcome of this analysis should be shared with the wider humanitarian community including OCHA. These reviews should form the basis of planning expenditure on the following period.**

(UNICEF, WES, Implementing agencies, UNEP)

R.2. After prioritising representative boreholes in the most vulnerable camps, groundwater level monitoring should be implemented on all boreholes (motorised boreholes and unused - but not dry - boreholes). Monitoring is not practicable on hand pumps due to the lack of access. Both production and observation wells should be monitored. It is important to monitor production wells in Basement Complex rock because the fracture systems are often unconnected - in which case an observation well would not reflect the drawdown at a nearby production well. (This is not the case for "normal" aquifers.) Once borehole performance is established, there will be some instances where monitoring may be reduced. (Coordination by UNICEF, collaboration with implementing agencies, WES, UNEP)

R.3. Contingency plans should be drawn up to respond to a poor wet season. (UNICEF, OCHA)

R.4. All water points should be mapped. OCHA-HIC have been very active in mapping facilities at camps and their work should be assisted as much as possible by agencies in the camps. (Implementing agencies, UNICEF, WES)

R.5. The relative elevations of the wellheads at all borehole (and hand pump[12]) sites should be established by precise levelling (i.e. not via GPS). This will enable monitoring data to be use to determine relative groundwater levels to be determined at each well. This will show hydraulic gradients and hence indicate recharge mechanisms. (Implementing agencies, UNICEF, WES)

R.6. Every water source should have a unique Identifier number and have its own paper file in which relevant data can be kept – baseline data, monitoring data and operational notes. (Implementing agencies, UNICEF, WES)

R.7. All information should be assembled in suitable paper files, and on maps, in addition to the UNICEF database. Information copied in this way is much less likely to be lost over time (Implementing agencies, UNICEF, WES)

R.8. Drilling records and water level monitoring data should be copied to relevant Government bodies. (Implementing agencies, UNICEF, WES)

[12] Ground levels at non-monitored sites such as hand pumps may be useful where borehole records provide original water level data, and may help in assessing the vulnerability of such sites to depletion; otherwise, levelling of these sites is a secondary priority.

R.9. Flow meters should be installed, calibrated and periodically checked, on the outflow from all motorised boreholes and all storage tanks, and daily records of output should be kept. (Implementing agencies, UNICEF, WES)

R.10. A single co-ordinator should be appointed to monitor water resources in each camp. Water managers should have reliable and complete information on:

a. groundwater monitoring data, rainfall and wadi flow data.

b. pumping records and flow gauge data.

c. water use from household survey data

d. relevant background data, maps and reports

e. interpretation of this data showing status of groundwater vulnerability, and recommended mitigating actions where needed.

(Implementing agencies, WES, UNICEF)

R.11. Inexpensive plastic rain gauges (two per camp) should be installed to give some measurement of the rainfall. The duplication will help to ensure that data are not missed and also to give a check. It is acknowledged that this type of rain gauge does not give data which are acceptable for meteorological purposes. However, in the absence of rain gauges outside the state capitals, such gauges will give reasonably accurate data whereby one rainy season can be compared with another, and potential recharge estimated. (Implementing agencies, UNICEF).

R.12. Water use surveys should be undertaken in wet and dry seasons. (Implementing agencies / UNICEF)

R.13. A coordinated project is needed to ensure that the compilation of all available information on the water supply systems in the camps is complete. (UNICEF, UNEP)

R.14. A data collection exercise is needed ensure that important historical hydrological records and reports are scanned and made available to implementing agencies. (Implementing agencies, UNICEF, UNEP)

R.15. An assessment of the effectiveness of the WES/UNICEF database as a management tool should be made, and recommendations made for integrating the database in water management, and monitoring and evaluation of the water programme. The assessment should assess potential for internet access to the database, whereby water managers can enter and read data directly. This has the potential for making the database a "live" document and a useful means of communication. (UNICEF / Implementing agencies / RCO)

R.16. Unless emergencies occur, additional drilling in vulnerable or potentially vulnerable camps should be undertaken only after household water use surveys have been undertaken and the need proven. This recommendation is made in light of Oxfam's survey which identified significantly higher water use than had previously been understood in the camps. (Implementing agencies, UNICEF, WES)

R.17. Provision for groundwater level monitoring should be included in the design of all new boreholes. (Implementing agencies, UNICEF, WES, Donors)

R.18. Existing AU and proposed UN camps should practice sustainable management of water resources as part of a larger do-no-harm approach to environment in Darfur. The inherent vulnerability of Darfur's environment and its central role in Darfur's traditional livelihoods give an urgency to this recommendation that would not exist in more resource-rich environments. (RCO to coordinate, UNEP to advise.)

R.19. Observations of surface water flow should be made at vulnerable camps. As with groundwater monitoring, the purpose is to establish the extent to which wadi flow recharges the basement aquifer beneath the camp – therefore both water bodies need to be observed. A staff gauge should be installed (in a concrete pad) in each wadi in or near a camp. Records should be kept of:

a. dates, times and durations of wadi flows

b. depth (on staff gauge) of maximum flood and at other times.

c. dates and durations of standing water in the wadi

(Implementing agencies, WES, UNICEF)

R.20. Best practice on water management at camps should be developed, recorded and disseminated on the basis of lessons learnt during the implementation of these recommendations in Darfur. (Implementing agencies, WES, UNICEF, UNEP)

9 Groundwater monitoring – practicalities

9.1 Review

At the time of the assessment, it appeared that virtually no groundwater monitoring is being undertaken in Darfur by anybody, Government or NGO, except for one observation well being monitored in Wadi Nyala by the Nyala Urban Water Corporation, and possibly some wells in the Shagera Basin supplying El Fasher.

9.2 Monitoring at camps

For Darfur, the main objective is to monitor groundwater levels in IDP camps, to monitor the impact on water levels in the contribution zones to the water sources. The priority is to measure water levels in boreholes, but where relevant, dug wells and/or springs should be included. If springs are involved, the main priority would be to measure the outflow, using, e.g. a v-notch weir.

A programme of groundwater monitoring should be implemented at camps wherever practicable. This programme should include:

- Manual measurement ('dipping') of the water level in as many motorised boreholes as possible, once a week in the dry season, and every day in the wet season.
- Weekly measurement of EC levels in water from each borehole and hand pump

Equipment: the best options are (1) 'dippers' (electric tapes) for one-off measurements, and (2) transducers + data loggers for continuous recording.

Electrical conductivity (EC) is an easily measured indicator of the water salinity and its variations – marked changes in EC usually indicate very rapid throughput of water, which suggest high vulnerability to pollution, while a steady rise in EC over time may indicate falling water levels and the drawing in of deeper water of higher salinity. EC does not indicate specific chemical problems, such as excessive Fluoride or Nitrate, both of which are common problems in some parts of Darfur.

Monitoring may involve a number of people doing different jobs: installing the equipment; taking the measurements or samples; transmitting and storing the data; examining and interpreting the data; maintaining and repairing the equipment; taking action on the basis of the results. Each person must understand his/her role in the programme and take responsibility for it. All roles need accuracy, reliability and attention to detail.

(1) At camps, the responsible agency should be one of the agencies working in the camp. Alternatively, another (state) agency could undertake the task, but in the short-to-medium term, this seems impractical.

(2) Regional monitoring is properly the responsibility of a state agency – in this case, GWWD. At present, GWWD is undertaking no groundwater level monitoring, but is doing some groundwater quality sampling and analysis.

(3) Training of personnel in understanding their responsibilities and procedures, and the importance of monitoring, is a significant issue.

(4) It is important that information acquired through monitoring should move both ways – from the field site to the 'manager' and BACK AGAIN – in this way the field people are helped to appreciate the importance of what they are doing.

Water levels should be monitored in as many boreholes as practicable, but in at least one borehole (or other water source) at each camp. Attention should focus on camps where there is particular stress on the aquifer – this will mostly be in Basement Complex areas with large IDP populations.

In general, it is useful to begin monitoring at a relatively high frequency until the system is understood, after which it may be possible to reduce the frequency. During the dry season, weekly dipping will normally be sufficient, but daily dipping in the rainy season (or every day for a week after significant rain) will help to reveal the magnitude of recharge occurring.

As far as possible, the borehole design should take account of monitoring needs:

- Providing access through the wellhead for dippers and/or recorders
- Avoiding obstructions – keeping the cable tight to the rising main, avoiding unnecessary flanges, etc.
- Where possible, a dip tube (a small diameter tube leading down to a point just above the pump) should be installed.

Consideration should be given to the use of flexible rising mains: these (a) have a smaller diameter for the equivalent capacity, (b) have a continuous lug for the attachment of the cable, thus keeping it tidy, (c) have no sharp edges to catch dipper probes or tapes, (d) are light to transport and handle, and easy to install.

With existing boreholes, access may be difficult, but not usually impossible. In most cases seen in the field, the inner borehole casing in boreholes drilled in Basement Complex has a nominal diameter of 4.5 inches (113 mm). The nominal diameter of the rising main is normally 1.5 inches (38 mm) or 2 inches (51 mm). Where a 1.5" pipe is involved, access should be reasonably easy (with care) for a dipper probe. With a 2" pipe, it is more difficult and may sometimes be impossible.

Since the diameter of a datalogger probe is normally larger than for a dipper probe (22 mm compared with 15 mm), access for a datalogger is even more difficult, but should be possible with care. The best approach is probably to attach the probe to the rising main with tape.

At many boreholes, access is prevented by a steel plate on the well head or by the clamps holding the rising main. However, it should usually be possible to drill a hole through the plate to allow access, or to lift the clamp. However, operators should always be careful to ensure that the well is protected – i.e. that stones, etc., cannot be dropped into the well.

9.3 Automatic recording of water levels

Where automatic recorders are being ordered, two aspects need careful consideration:

- The frequency of readings must be related to the desired intervals between downloading the data. In the Abu Shouk trial, readings at 2 minute intervals resulted in filling up the memory in about one month. It is more economical of memory to set the logger to event-based readings, where the logger records a reading each time the water level changes by a set amount, e.g. 20 mm. Thus when the water level changes quickly (as when pumping begins) it reads very frequently, but when the water level stabilises, it reads much less frequently. This configuration provides the data that the monitoring agency needs.
- The range of water levels appropriate to the logger – this must be specified when ordering. The equipment tried in the Haloof Borehole has a range of only 5 metres, which is too small in a borehole whose sustainability is in question - which will have large drawdown (the difference between water levels when pumping and not pumping). A range of 30 m is likely to be needed. Clearly, a higher range implies a reduction in resolution (the ability to detect small changes in water level), but this is unlikely to be important in the kind of monitoring foreseen.

Table 9.1 Comparison of manual and automatic monitoring

Manual		Automatic	
Advantages	Drawbacks	Advantages	Drawbacks
Simplicity	Depends on regular reading		
Low purchase cost	No intermediate data – likely to miss peaks	Readings as frequent as required	High purchase cost
		Very fine detail	Needs skilled personnel to download
	Remote sites involve much travel	Little staff time/travelling	Equipment breakdown causes missed readings for long period
Data immediately available	Data must be entered into computer	Data loaded directly to computer	No immediate data to view
		Reduces operator errors	Sensor must be calibrated

Box 3 Guidance on using 'Dippers' (electric water level indicators)

Dippers are simple but very useful instruments for measuring water levels in wells. However, they are not foolproof and every hydrogeologist has encountered the same basic problems in using them. Therefore every person using a dipper should first receive some guidance and training. Dipping should be done in the early morning, before pumping starts.

There are particular problems using them in pumped boreholes, even when not pumping:

- The space in the borehole between the rising main and the borehole wall or casing is usually small.
- Boreholes are rarely exactly vertical and very rarely straight, hence while there may be, say, a nominal 2" clearance between the rising main and casing, this will inevitably narrow down to less than an inch in places.
- In an uncased borehole there may be small pieces of rock which slip into the hole.
- In a cased borehole there may be flanges or pieces of welding material projecting into the hole.
- There may be flanges and/or centralisers on the rising main.
- For a submersible pump, there will be a cable along the outside of the rising main, with fastening loops to hold it in place.
- Lower the probe very gently down the bore, by hand, feeling the weight all the time. Do not just lower it directly from the reel.
- If you feel (and/or hear) the probe hit an obstruction, lift it and try to ease it around the obstruction by moving it sideways.
- Never continue to pay out the tape unless you can feel the full weight.
- After passing an obstruction, make sure you can bring it back up again and pass it again before continuing to lower the probe.
- After reaching the water level, repeatedly lift and lower the probe until you have the water level exactly (within 5 or 10 mm should be possible).
- When raising the probe to the surface, bring it up very gently. If you meet an obstruction, don't pull hard, move it sideways and wriggle the tape until it comes past. Sometimes it can help if you push the rising main sideways.
- Going up or down: be very careful not to allow the tape to rub hard against any sharp edges of casing or concrete – if possible, protect it using a rag or something to cover any sharp edges, or use your hand to guide it away from the edge.
- Wipe the tape and probe to remove any excess water, and make sure the probe is clean so that the battery is not discharged.
- When the dipper is out of use, remove the batteries to prevent them going flat.

The above warnings are also relevant to the installation of loggers, and even more so because a logger normally has a larger diameter than a dipper probe. Borehole design may need to be modified to accommodate monitoring equipment.

10 Managing groundwater resources at the wider level

This is properly the responsibility of an appropriate Government body. As at camp level, management depends on good information:

- Good 'Baseline' information
- Good monitoring data

At present, the relevant Government bodies are well aware of what is desirable, but are not well equipped or resourced to undertake the tasks. The current security situation also severely constrains what can be done.

However, notwithstanding the severe limitations on fieldwork, there is an opportunity to compile, interpret and process all available groundwater resource data so that, when conditions allow, new initiatives in monitoring will be firmly based on good baseline data.

GWWD in Nyala and El Fasher have good databases but the operating agencies have been slow to contribute data to them. In Geneina, GWWD has no office and UNICEF-WES has assembled a lot of relevant data, yet much is missing.

UNEP are currently proposing to undertake a project to support integrated water resource management in Darfur.

Hydrogeologists

Since Darfur is facing unprecedented concentrations of demand for groundwater, and even without the crisis, the great majority of the population depends on groundwater for drinking water, livestock watering and irrigation, especially in the dry season, it is essential that:

- the available technical expertise of hydrogeologists, both Sudanese and expatriate, is better deployed.
- water resource work is strengthened by (a) more hydrogeologists, and (b) more training of people in other disciplines whose work involves groundwater.

Recommendations:

W.1. Greater collaboration with Government offices in water management processes should be promoted at field level, in order to benefit from the technical skills and local experience of their hydrogeological staff. (Implementing agencies, with coordination from UNICEF & WES,)

W.2. Data management using UNICEF's borehole database needs to be developed further and more integrated in programme design and management. Appropriate communication protocols should be established between the GWWD database in Khartoum and the field based WES/UNICEF database. Implementing agencies and other stakeholders need to be included in standardising data transfer procedures. This will require coordination and appropriate capacity building. (WES, UNICEF, Implementing agencies, UNEP)

W.3. A project should be undertaken with the assistance of a dedicated water resource specialist and information management specialist to bring databases up to date and ensure their integration with all relevant stakeholders (Implementing agencies, WES, UNICEF, UNEP)

W.4. A strategic plan for water resource management should be developed for Darfur. This plan should include scenarios for return, partial return or long term displacement, in the humanitarian and recovery contexts. The uncertainty of the political situation makes this range of contingencies expedient. This will provide a framework for investment in water resource infrastructure, water supply and agricultural development in Darfur. (UNEP, GONU)

W.5. A contact group on water resource management within the humanitarian community should be established. This group should be established within the larger framework of setting up Integrated Water Resource Management in Darfur as per the UNEP/UNICEF proposals. The humanitarian water resource group should be set up in order to achieve the advantages of keeping the attainment of demand targets, and promotion of sustainable resource management separate from an institutional perspective. A collaborative effort on both objectives will be required. (UNEP, UNICEF, FAO, RCO, OCHA, UNHCR, Implementing agencies)

W.6. Community, government, private and NGO capacity in water resource management and engineering (sand dams, rainwater harvesting, hafirs, terracing, dams etc) needs to be assessed, mapped and built up. This will need appropriate knowledge management and networks to ensure that capacity exists to design, build and manage appropriate water resource infrastructure. Additional capacity building will then need to be designed. The identification of projects under different return scenarios should be addressed under the strategic plan for water resource management. (UNEP, RCO, UNICEF)

W.7. While these activities need to be done for the short term effort which focuses on the humanitarian context and builds the capacity for potential return, concurrent effort must be made to develop capable institutions for Integrated Water Resource Management for the longer term. There will be limitations to what can be achieved during the crisis, but the process should begin. It should be part of the consultative process of developing a strategic plan for water resources. (UNEP/UNICEF project to work with appropriate stakeholders)

W.8. The development of best practice in water resource management in camps in the humanitarian context should be seen as an opportunity to develop capacity within the Darfurian water resource management community. Water resource management is increasingly important in the context of growing population and climate change, so these skills are vital for Darfur’s recovery and sustainable development. (Implementing agencies, UNICEF, WES, UNEP),

Appendix A: Bibliography

A.1 Reports in Groundwater & Wadis Department (GWWD) Library

Ref #	Author(s)	Title	Year
130/1	Mohamed El-Shafi Abdel Sh	Hydrogeological and environmental isotopes studies at Buram, Darfur	1984
130/2	BRGM	Rural water supply project in western Sudan	1984
130/3	BRGM	Rural water supply project in western Sudan	1984
130/4	Darfur workshop	Rehabilitation and devlopment strategy for Darfur region	1985
130/5	Hassan Abdalla El Mangouri	Umm Kadada district (Northern Darfur Province)	1985
130/6	Hunting Geology & Geophysics	Water supply & development project in Darfur province	1969
130/7	Hunting Geology & Geophysics	Water supply & development project in Darfur province Report 4	1970
130/8	Hunting Technical Services	Southern Darfur land use planning survey Annex 2 water resources and engineering Wadi Bulbul	1974
130/9	Hunting Technical Services	Savanna development project Annex 2 Part 1 Hydrogeology	1976
130/10	Hunting Technical Services	An indicative land use for the western savanna project	1984
130/11	Howard Humphrey & Partners	Nyala water supply	1981
130/12	Howard Humphrey & Partners	El Fasher water supply, final report Vol. 1, Draft final report vol. 1	1983
130/13	Howard Humphrey & Partners	El Fasher water supply, final report Vol. 2, Draft final report vol. 2	1983
130/14	Hunting Geology & Geophysics	Water supply & development project in Darfur province	1970
130/15	Jansen, A G W	Identification of water supply project in Nyala and Geneina, Win Vander lender	1985
130/16	NWC	Geneina water resources, WAPS-2 Technical Bulletin	1984
130/17	PRC Engineering Consultants	Western Sudan water supply project	1980
130/18	PRC Engineering Consultants	Western Sudan water supply project	1980
130/19	PRC Engineering Consultants	Western Sudan water supply project (Draft)	1980
130/20	Tesco-Viziterv, Budapest	Agricultural development in the Jebel Marra area; Irrigation operation plan - Technical report Annex 5	1974
130/21	Tesco-Viziterv, Budapest	Agricultural development in the Jebel Marra area; Overall development plan - Technical report 5	1974
130/22	TNO	Report on a first hydrogeological supervisory mission to the Nyal groundwater assessment project	1983
130/23	Western Savanna Development Corporation	The Western Savanna Project, Annual Report	1985
130/24	WADS	Geophysical Survey in Qoz Dango, Report No. wn-01-86	1986
130/25	Hunting Geology & Geophysics	Water supply & development project in Darfur province (No. 1)	1968
130/26	TNO	Kas, groundwater resources study	1986
130/27	TNO-NWC	A Summary of the results of the investigations in 1983-85	1986
130/28	TNO-NWC-DGV WADS2	Geneina water resources study, final report	1985
130/29	TNO-NWC-DGV WADS2	Nyala water resources study, final report	1984
130/30	WADS	Rainfall in South Darfur	1986
130/31	NWC, WADS Geohydrological Data Bank	Water Wells in Darfur until 1988	1988
130/32	NCDRWR	(in Arabic)	1988
130/33	NCDRWR	88-89 (in Arabic)	1988
130/34	TNO-NCRWD	Hemmeiza groundwater resources study - Bileil	1987
130/35	TNO-NCRWD	Groundwater resources study - Bileil	1987
130/36	TNO-NCRWD	Hydrogeology of the Baggara Basin, south Darfur, technical report No. wn-o1-88	1988
130/37	WADS	Groundwater Study, Buldanga area	1988
130/38	BRGM	Rural water supply project in western Sudan agreement	1987
130/39	BRGM	Rural water supply project in western Sudan, final report	1987
130/40	BRGM	Rural water supply project in western Sudan - Appendices	1987
130/41	BRGM	Rural water supply project in western Sudan - village files	1987
130/42	BRGM	Rural water supply project in western Sudan, Hydrogeophysical survey, Appendix 2, village files	1987
130/43	Al Nammari	Summary view of the water sector development requirements in Darfur region and suggested	1986

		proposals	
130/44	WADS	Groundwater Resources Study preliminary report	1987
130/45	Brinkman	Hydrological and hydrogeological irrigation in Darfur area	
130/46	WADS	Aspect of a Master Plan for groundwater development in South Darfur, Appendix M	
130/47	WADS	Hydrogeological Studies South Darfur Appendix N	1989
130/48	WADS	Technical Committee Nyala-Geneina Appendix O	1989
130/49	WADS	Hydrogeology and Development of the Water Resources of South Darfur Appendix J	1989
130/50	WADS	Village Water Suply Programme South Darfur Appendix F	1989
130/51	WADS	Siting for Hand Dug Wells Appendix K	1989
130/52	WADS	Construction and Maintenance of Hand-Dug Wells Appendix L	1989
130/53	WADS	Manuals for Extension Workers Appendix H	1989
130/54	WADS	Extension for Village Water Supply Appendix G	1989
130/55	Hunting Technical Services	Agricultural Development in the Jebel Marra Area Annex II Volume I Hydrogeology	1977
130/56	Western Savanna Development Corporation	Study on Water Supply Improvement in South Darfur, A, B	1990
130/57	Hunting Technical Services	Study on Water Supply Improvement in South Darfur, Vol 1, Vol 2	1990
130/58	WADS	Progress Report - WADS Nyala	
130/59	WADS	The Hydrogeology of the Baggara Basin South Darfur	1988
130/60	IWACO	Mission Report Logistic Advisor	1991
130/61	IWACO	Training Course Well Construction Technology	1989
130/62	Siddig Adam Omer & Ali Abdelrahman	Diesel Pump Field Tests in Northern Darfur	1989
130/63	NRWC	Wells Programme South Darfur Sudan, Interim Report	1990
130/64	Mr A Hordijk, Mr Salih	Wells Programme South Darfur Sudan, Review Mission Report	1990
130/65		(in Arabic)	1991
130/66	IWACO	Wells Progress Report January-March	1991
130/67	NRWDC	Protocol for the Transfer of the Wells Programmes - South Darfur	
130/68	El Tohami M S	Hydrology of the Baggara Basin S W Sudan	1977
130/69	IWACO	Wells Programme South Darfur Phase (1990 - 91) Plan of Operations	1990
130/70	Planning Unit of Project proportions	(in Arabic)	1990
130/71	IWACO	Wells, procurement list for the period 1990-94 draft	1989
130/72	Mr A Hordijk	Wells Programme South Darfur Sudan, Review Mission Report	1989
130/73	IWACO	Wells Programme South Darfur Sudan, Review Mission Report management advisor	1991
130/74	IWACO	Wells Programme South Darfur Sudan, Financial Status of the Project	1990
130/75	IWACO	Wells Programme South Darfur Sudan, 6th Progress Report April-June	1991
130/76	IWACO	Wells Programme South Darfur Sudan, 3rd Progress Report July-September	1990
130/77	Kaskous H.M.	Wells Programme South Darfur Sudan, Quarterly Reports June-Feb-March	1990
130/78	Wells	Wells Programme South Darfur Sudan, Proposal for extension of Phase 1 January-July 1992	1991
130/79	Salih M Kheir	Transfer wells programme mission report	1991
130/80	Frans A M van Putten	Village Hand-Dug Wells Programme South Darfur - Sudan, Quarterly report Jan-March	1990
130/81	IWACO	Wells Programme South Darfur. Production Planning and Information Systems Workshop	1991
130/82	Nogud E MS MA Omenmyin, Mr A Hordijk	Village Hand-Dug Wells Programme South Darfur - Sudan, Project Document (draft)	1989
130/83	Iskander W	Sustainable rural water supply and sanitation seminar 17-22/11/1991 Water sanitation and hygiene education	1991
130/84	Abdalla El Amin Hag Abbas	Sustainable rural water supply and sanitation seminar 17-22/11/1991 Nyala South Darfur	1991
130/85	Hassan Mohamed Kaskous	Sustainable rural water supply and sanitation seminar 17-22/11/1991 Hand-Dug Wells techniques suitability and sustainability in South Darfur	1991

130/86	WADS-2	Geneina Water Resources Study, Interim Report	1985
130/87	Abdel Rahman M Esmail E A	Water Resources Development in Northern Darfur Province	1991
130/88	Mohamed Khiar Salih, Ali Abd AlHafeiz	(in Arabic)	1984
130/89	Mastour H, Salih M K, Mohamed W A	Site investigation for Five Villages in the Northwest Darfur Region	1985
130/90	Mohamed Khair Salih, Ali Mohamed Ali Fatoh	(in Arabic)	1985
130/91	IWACO	Wells Programme in South Darfur Phase 1990-1991 Interim Report	1992
130/92	Salih Mohamed Kheir	Series of Progress Reports Well Project (Nyala) extension Phase 1	1992
130/93	AWACO	Manufacturing of Windless	1992
130/94	IWACO	Experience in water use and management	1992
130/95	Strojexport	Geophysical Investigation of Groundwater Structures Darfur Province Preliminary	1982
130/96	IWACO	Workshop and Store Management	1992
130/97	IWACO	A Course for Community Health Workers and Sanitation Overseers (Manual for Trainers)	1992
130/98		(in Arabic)	1987
130/99		(in Arabic) 1982-83	1987
130/100	(in Arabic)	(in Arabic)	
130/101	U Thorweoje, P.J Brinkma, M H-C Sonntag	Hydrological and Hydrogeological Investigation in the Darfur Area	1990
130/102	Mr Dan Bekker IWACO (Weels)	Final Report	1992
130/103	UNDP	Tender documents for borehole drilling works for water supply system of Zalingei Town South Darfur	1993
130/104	IWACO	Mission Report Data Management Advisor	1991
130/105	IWACO	Wells Programme South Darfur	1991
130/106	IWACO	Mission Report Project Director	1991
130/107	Abd El Razig	Year Plan - Nyala	1989
130/108	Abd Alla Mohamed Khier	Quarterly Report	1988
130/109		(in Arabic)	
130/110		Hydrogeological Verdict Nyala Southwest RC	
130/111	Ir A O N Jansen, Aquanet	Village Hand-Dug Wells Programme South Darfur	1992
130/112	Abdin Mohamed A Salih, Mohamed El Hassan El Tayeb	Wadi Nyala water resources - an approach towards a nomination	1993
130/113	WRM	Appendix 3 Final Report Technical Committee Nyals	1994
130/114	M E Ibrahim	Mission Report Nyala 2-5 December	1991
130/115	WRM	Wadi Nyala water resources	
130/116	Babiker Daffalla Balla	(in Arabic)	
130/117	WRM	Report on working visit to T C Nyala 1-6 TH	1991
130/118	El Wasiela A M Bakhiet	Summary of the application of the environmental isotope hydrology in Geneina area West of Sudan	
130/119	Ir W van der Linden	Geohydrologist TNO-DGV	1986
130/120	Howard Humphreys & Partners	Geneina Water Supply Final Reports Appendix B	1983
130/121	WADS	Agreement for supply of services	
130/122	Hamdan Mastor Ibrahim	(in Arabic) 1995-96	
130/123	PPU, Howard	Nyala Water Supply	1983
130/124	Wilson Iskander	Development Potentialities of Water Resources in Darfur Region evaluation	
130/125	Howard Humphreys & Partners	Geneina Water Supply	1983
130/126	TNO, Drs J M J van	Application of Geophysics for shallow wadi aquifer studies: an Evaluation Hunting	1984
130/127	Hunting Technical Services (David Ball)	Hydrogeological Studies of Jebel Marra Area	1977
130/128	Hamdan Mastor Ibrahim	(in Arabic)	1994
130/129	WADS	(in Arabic) 1992	1992
130/130	IWACO	Mission Report Management Advisor October	1992
130/131	Tijani Abdel Karim	Training Report Course Logistics	1992
130/132	Mr Elfad Nugud, Mr ad Hardijk, Ms M A Oomen-Myin	Short Review of Dutch-assisted Activities in the Water Sector	
130/133	Livestock Route Project	geophysical Investigation, Final Report (Delebaya)	
130/134		(in Arabic)	1996
130/135	(in Arabic)	(in Arabic)	1996
130/136	(in Arabic)	(in Arabic)	1996
130/137		(in Arabic)	1996
130/138			

130/139			
130/140	Hamdan Mastor Ibrahim	General administration for Non-Nile Water Resources - Darfur - Nyala	1995
130/141		(in Arabic) 1988/89	1989
130/142		Kluis Exemplaar	1990
130/143			
130/144	Wim Van Der Linder	Mission Report	1987
130/145	S Blomendaal	Mission Report	1989
130/146	WADS - Nyala	An Overview with Recommendations for Development and Further Investigations	1988
130/147	Bob Blankwaardt	Inception Report Part I	1987
130/148	Bob Blankwaardt	Inception Report Part II	1987
130/149	WADS - Nyala	Progress Report 1st Quarter	1988
130/150	WADS - Nyala	Progress Report 4th Quarter	1988
130/151	WADS - Nyala	Hydrogeology and Development of the Water Resources of South Darfur	1988
130/152	WADS - Nyala	Unit Cost Price of Water Supply System in South Darfur Province	1988
130/153	WADS - Nyala	Progress Report	1988
130/154		Water Well Construction Progress Report 2nd Quarter	1988
130/155		2nd Progress Report April-June 1990	1990
130/156			
130/157		Memorandum of Agreement on the Working Relationships between the NCDRWR Provincial Office Nyala - the Ministry of Health Nyala - the Wells Programme South Darfur	1989
130/158			
130/159			
130/160		Training Course Aspects of Extension	1989
130/161		Training Plan Phase I	
130/162	WADS - Nyala	Water Well Construction Technical Documentation for Operation and Maintenance	1989
130/163		Training Course in EM surveys with Apex Max Min Equipment for Groundwater Exploration in Areas with Shallow Basement	
130/164	WADS - Nyala	Progress Report WADS Nyala 1st Quarter	1989
130/165	Abdalla Mohamed Kheir	Quarterly Report	1988
130/166	WADS - Nyala	Water Well Construction: Final Report	1989
130/167	Frank Jaspeir	Report on Bottlenecks in Well Construction	1988
130/168	Mr Henk Van Der Least	Handing Over Report: Job on Technical Management Technical Manager	1989
130/169	W Senden	Quarterly report: October, November	1987
130/170	W Senden, Mohamed Kheir Saleh (WADS)	Quarterly report: January, February, March 1988	1987
130/171	Drs R G M De Bruin (TNO-DGV)	Electromagnetic Surveys with the EM-34-3 Equipment	1988
130/172	TNO - L H Sprey, Economist	Mission Report	1986
130/173	Volunteers in Technical Assistance	Darfur Regional Finance and Planning Project Life of Project Workplan	1989
130/174	WADS-Nyala: Abdallah Awad Al Kareem	Training Course Metal Workshop Technology Mission Report	1988
130/175	WADS-Nyala:	Hydrogeology and Water Resources of South Darfur	1988
130/176		(in Arabic)	1991
130/177	Marieke Boot, Awad Elkarim Mansour, Mustafa Alkahim Yousif, Mohamed Nasir Medani	End of Mission report for the WADS Project, Nyala, Sudan. Volume 1: Monitoring and Evaluation Course	1988
130/178	TNO WADS	Seismic Refraction Test Measurements	1987
130/179			
130/180	TNO-DGV WADS	Water Demand Study for South Darfur Province, Preliminary Draft	1988
130/181	A Hordijk, M A Oomen-Myin (Matrix)	Memorandum for the Formulation Mission of the Village Water Supply Programme in South Darfur, 2nd Draft	1989
130/182	IWACO - WADS	Draft Protocol on the Working Arrangements between VHDW and the NCDRWR/Nyala for Phase I of VHDW	
130/183	IWACO - WADS		1988
130/184	BRGM	Rural Water Supply Project in Darfur Region: Agreement	1983
130/185	TNO-DGV WADS	Report of TA to the Village Project Section of the Village Water Supply Programme in South Darfur Province	1989
130/186A	IWACO Wells Programme South Darfur	Phase I 1990-91: 7th Progress Report July-September 1991	1991

130/186B	IWACO Wells Programme South Darfur	Phase I 1990-91: 4th Progress Report October-December 1990	1991
130/187	IWACO Wells Programme South Darfur	Support in Mobilizing the Community: Mission Report of the Extension Expert	
130/188		(in Arabic)	1988
130/189		(in Arabic)	1994
130/190	WAPS-2: Geneina Water Resources	A Summary of the results of the investigations in 1984-85	1986
130/191	TNO-DGV for NCRWD WADS	Unit Cost Price of Water Supply System in South Darfur Province	1988
130/192	A I Silake, DG Ministry of Housing, Water & Public Utilities, Darfur Region, El Fasher	Coordinating Meeting on Water Activities in Darfur Region; one-day working session, 19/3/86	1986
130/193			
130/194			
130/195			
130/196	GWWD Darfur Section, Nyala	Garsila, Dilej and Umm Khair Geophysical Surveys for Norwegian Church Aid	2005
130/197	GWWD Darfur Section, Nyala	Dumma, Minwashi and Mershing IDP Camps, Geophysical Survey; for World Vision International (WVS)	2005
130/198			
130/199	GWWD Darfur Section, Nyala	Bileil Camp Geophysical Survey for International Rescue Committee (IRC)	2004
130/200	Jebel Marra Project	Appendices: B Summary of Borehole Information; C Analyses of Aquifer Tests; D Test Well Completion Reports; E Report on the Water Supply Problems of Golo, Daya and Turra Villages; F Computer Model STRIPAC; G Bibliography	1977?

A.2 Bibliography of the groundwater resources of the Sudan Compiled by Hamid Omer Ali

(**Located at different sources: e.g. University of Khartoum, Federal Ministry of Agriculture, UNESCO Chair for Water, Khartoum Department of Land Use and Soil Conservation, National Water Corporation (NWC), etc.)**

Abdel Rahman MA, Abdel Latif OM (1997) Ground Water Pollution and Sanitation in Western Sudan. In: Engineering Geology and the Environment, ed Marinos Koukis, pp.2107-2112, Rotterdam, Balkema.

Abdel Salam YEH________________, (1975) Bibliography of the Hydrogeology of the Sudan. University of Khartoum , Department of Geology.

______________, Salama RB (1976) Ground Water Resources in the Sudan. Geological Society of Africa, 3rd. Conference on African Geology Abstracts – University of Khartoum, Sudan.

Abdel Salam YEH (1983) Aspects of the Hydrogeology of the Sudan Republic Report No.1 Project 184, I GCP (UNESCO), Australian Meeting Melbourne pp 104-106.

______________ (1985) Groundwater Resources in the Republic of the Sudan, Vth. World Congress on Water Resources Brussels, Belgium, IWRA Abstract, No. 227 X12.

Abdel Shafie M Sh (1980) Hydrogeological and Environmental Isotope Studies at Buram, Darfur, Unpublished MSc Thesis, Azhar University, Egypt.

Abdou GM, Abdel Salam YEH, Salih MK (2003) Understanding surface and groundwater interaction for proper water resource management in Sudan. Water harvesting and the future of development in Sudan. Conference UNESCO Chair in Water Resources, Omdurman Islamic University.

Abdou GM (2003) Status of groundwater quality and pollution risk in Sudan. IHP UNESCO Chair for Water Resources, Khartoum

Abdullah MA (2005) Groundwater resources management optimum pumping from Wadi Nyala aquifer. Partial fulfillment for MSc. UNESCO Chair for Water Resources, Omdurman Islamic University, 62 pp.

Ahmed MU (1988) Ground Water Resources the key for combating drought in Africa. Desertification Control Bulletin, pp 1-6

Albul SP, Dafallah OEO (1973) Scheme of Hydrogeological Regionalization of the territory of Darfur Province, Sudan in Connection with Water Supply of Population Centres (In Russian), Vyssh. Uchebu Zawed 13 Ves Geol. Razred, Moscow 5,104-110pp.

Ali HO ______ (2002) Issues, Problems and Policy Principles Related to Ground Water Resources in SUDAN, In: Water Resources Development and Management eds A. Rashed, Sing and Sherif, Swets and Zeilinger Lisse, ISBN 90 5809 3662. Holland,Elsevier

Ali HO (1985) Gravity and Seismic refraction measurements for deep groundwater search in Southern Darfur region, Sudan. Surface and boreholes geophysical methods in groundwater, National Water well Association, USA.

Ali HO (1986) Gravity and Seismic refraction for deep groundwater in southern Darfur region, Sudan. J. Uni. Kuwait (Sci.) Vol. 13, p. 245-158

Ali HO (1988) Separation of residual from Bouguer gravity data measured over a deep sedimentary basin, Western Sudan. J. Uni. Kuwait (Sci.) Vol, PP. 347-357.

Ali HO (2003) The Role of water resources in development, Darfur State. Workshop on Development is a Key for Peace in Darfur State (in Arabic) eds Dr Adam Z Mohammed et al, University of Khartoum.

Ali HO (2005) Water Harvesting for Rural Development in Drought Stricken Areas, South Darfur State. International conference on Role of Water in Development, Roorkee University, India.

Ambroggi RP (1966) Water Under the Sahara. Sci. Am, Vol.214, pp.21-29.

Andrew G (1944) Rural Water Supplies. In: Soil Conservation Report, Appendix 9, Sudan Government.

_______ (1946) Rural Water Supplies, In: Soil Conservation Report, App.IX, Sudan Government.

Andrew G (1948) Geology of the Sudan, In: Agriculture in the Sudan, - Editor, Tothill, J.D., London, Oxford University Pres.. pp84-128

Andrew G (1972) New Light on the Geology of the Sudan, Geog. J., Vol.138/70-72pp.

Andrew G (1972) Review of the Geology of the Sudan Republic by A.J. Whiteman, Mining Mag Vol.3, pp.772-773.

Ayed MA (1976) Geophysical Prospecting and Ground Water Exploration in the Sudan, 3rd. Conference on African Geology Abstract Geological Society of Africa, Khartoum, Sudan.
Bakheit AK (1981) Hydro-chemical Facies of Ground Water in the Western Provinces of the Sudan, Unpublished M.Sc,.Thesis, University of Wisconsin, Madison, U.S.A.
Bland C (1981) Planning for Rural Water Supply in case of Sudan, Unpublished MPhil. Thesis, University of Edinburgh, UK
BRGM (1984) Rural Water Supply Project in Western Sudan, Water Resources and Requirement Study. Final Report ands Annexes.
_____ (1987) Rural Water Supply Project in Western Sudan, Final Report and Annexes. Paris, France
_____ (1987) Rural Water Supply Project Western Sudan, Village Files.
BRGM (1987) Rural Water Supply Project Western Sudan, Hydrogeophysical Survey, Appendix 2.
Brouwer GK (1982) A Geohydrological Data Bank in the Sudan. First Progress Report.
Burdon DJ (1977) Flow of Fossil Ground Water, Q J Eng Geol Vol 10, No 2, p.97-124.
Clark (1982) Proposal for Draft National Water Resources and Ancillary Legislation. Unpublished report NWC, Khartoum.
Dafallah OE (1973) The Characteristics of Ground Water Formation in the Arid Zones with Special Reference to Wadi El Ku, Darfur Province, Sudan (Russian Language), unpublished PhD Thesis, University of Friendship, Moscow, USSR.
Debenham F (1954) The Water Resources of Africa, Sudan Notes and Records, Vol.35, Pt.2, 69.
Dray M, Gofiantini RL, Zuppi GM (1983) Istotopic Composition of Groundwater in the Southern Sahara. Paleoclimates and Paleo Waters Inter. At, Energ. Agency, Vienna, pp 187-199.
Edmunds WM, Gayel (1994) Estimating the Spatial Variability of Ground Water Recharge in the Sahel Using Chloride, J. of Hydrology, 156 – 47-59.
________ (1996) Geochemical framework for Water Quality Studies in Sub-Saharan Africa. Journal of African Earth Sciences 22.
El Amin EM (1973) Hydrogeological Principles in Ground Water Exploration in Western Sudan, unpublished PhD. Thesis, Moscow University (in Russian).
El Kabir ME (1989) Application of Environmental Isotopes in Water in Sudan, (Unpublished Report) NWA, Groundwater and Wadis Directorate, Sudan.
__________1992) Rural Water Resources in the Sudan, Unpublished Report, N.W.A,, Sudan.
El Mansouri HA (1985) Umm Keddada District. Unpublished Report, RWC/Ground Water and Wadis. Sudan.
El Tayeb El Sadig (1993) Isotopes and Chemistry in Ground Water of Western Sudan and Eastern Chad, In: Geoscientific Research in North-east Africa, (Editor) Thor Weihe and Schandelmeir, pp.665-669, Balkema, Rotterdam,pp.665-669
El Tohami M Sh (1977) The Hydrogeology of the Baggara Basin South Western Sudan Unpublished PhD Thesis, University of London.
Fadul Suliman AH (2005) A Geophysical Assessment of Ground Water Reservoir Characteristics of Shagera Basin, North Darfur State, Partial Fulfillment for MSc Thesis, UNESCO Chair in Water Resources, Omdurman Islamic University.40pp.
FAO (1968) Land and Water Resources of Jebel Marra, FAO/SF 48 Sup. 17, Rome.
FAO (1974) Savannah Development – The Sudan – Comprehensive Technical Report – ASG. DP/SUD/71/525. Rome, pp.91-
Gabert G, et al (1961) Some Results of Groundwater Investigations in the Republic of Sudan, Publ. IASH, Ground Water in Arid Zones, 57 ,pp.201-213.
Gillan JA (1918) Jebel Marra and Deriba Lakes. Sudan Notes and Records, No.1, pp.263-267.
Grishler CE (1976) Present and future trends in Water Resources Development in the Arab States, UNESCO, Rostas.
Grabham GW (1910) Notes on Some Recent Contributions to the Study of Desert Water Supplies, Cairo Sci. J., Vol.4 No.46, pp.166-174.
___________ (1919) Climate Change, Sudan Notes and Records, No.2, p.154.
___________ (1934) Water Supplies in the Anglo-Egyptian Sudan, Geol. Surv. Dept. Sudan, Bull.2, pp.1-42.
Grabham GW (1936) Water Supplies in the Anglo-Egyptian Sudan. Water, Vol.38, pp.9-17.
Groning M, et al (1993) Isotopic Evidence for Extremely Low Ground Water Recharge in the Sahel Zone of Sudan. In: Geoscientific Research in North East Africa. Eds Thorweihe and Schandelmeier, pp.671-676, Balkema, Rotterdam.
Hammerton D (1966) Hot Springs and fumaroles at Jebel Marra, Sudan, Nature, Vol.109, pp.1290.
Heinl M, Hollunder R (1984) Some Aspects of a New Ground Water Model for the Nubian Aquifer System, Berliner Geowiss Abh. Reihe A, 50, pp.221-231.
_______, Thorweihe U (1993) Ground Water Balance of the Sedimentary Aquifer in Darfur. In: Geoscientific Research in North East Africa, Editor Thorweihe and Schandelmeier, Balkema, Rotterdam, pp.687-692.
Holt HL (1954) Rural Water Supply and Land Use Development in the Semi-Arid Regions of the Sudan. Soil Conservation Report, Khartoum, Sudan Government.
Hordijik (1990) Well Program in South Darfur. Unpublished Report to NWC.
______ (1991) Well Program Nyala South Darfur. Unpublished Report to NWC, Khartoum and Nyala Water Corporation.
Howard Humphreys and Partners(1981) Nyala Water Supply. Preliminary Report to NWC.
____________________________(1983)El Fasher Water Supply. Final Report to NWC, Sudan.
Hunting Technical Services Ltd (1958) Jebel Marra Investigations. Report on Phase I Studies, Report to Ministry of Irrigation, Sudan.
Hunting Geology & Geophysics Ltd (1969) Water Survey and Development Project in Darfur Province, Report No.2 to NWC, Sudan.
Hunting Geology & Geophysics Ltd (1968) Water Survey and Development Project in Darfur Province No. I, Preliminary Appraisal Annexures to NWC, Sudan.
Hunting Geology & Geophysics Ltd (1970) Water Survey and Development in Darfur Province. Report No.4. A Regional Hydrogeological Survey, Report to RWDC Sudan.
Hunting Technical Services Ltd (1974) Southern Darfur Land Use Planning Survey. Annex 2, Water Resources and Engineering Report to NRWC
__________________________(1976) Sag El Na'am Evaluation and Pre-Investment Study. Report to Ministry of Agriculture, Sudan.
Hunting Technical Services Ltd (1976) Savannah Development Project Phase II Annex 2, Part I, Hydrogeology.Report to UNDP/FAO
___________________________(1977) Agricultural Development in the Jebel Marra Area. Annex 2, Vol.I, Hydrogeology and Engineering Report to UNDP/FAO.
Iskander W (1963) Geology and Hydrogeology of Sheet No. 54-C, Unpublished Report, Sudan Geological Survey.
_________ (1967) An Appraisal of Ground Water Resources of Zalingei Area, Darfur Province, unpublished MSc Thesis, Univ. of Arizona.
_________ (1970) A New Plan for Ground Water Investigation Programmes in the Sudan. Seminar on Community Water Supply, University of Khartoum. Faculty.of Engineering, Sudan.
_________ (1973) Ground Water in the Sudan (in Arabic), Arab League Edn. Cult. Monograph No. 2.
Iskander W (1986) Ground Water in the Sudan. In: National Resources/Water Series No. 18, United Nations ST/TCD/5 Ground Water in North and West Africa, pp.338-370.
Iskander W, Salih MK, Fadul (1995) Development and Utilization of the Nubian Sandstone Aquifer in the Sudan. Unpublished Report, NWA, Sudan.
Iskander W (1967) Agricultural Development of Sag El Na'am, Darfur Province.Ground Water Dept. Rural Water Corporation, Sudan, Unpublished Report.

IWACO (1991) Well Program South Darfur Unpublished Report to NRWC Sudan.
______ (1992) Prog. South Darfur Phase 90-91, Unpublished Report to NRWC.
Jansen AGW (1984) Identification of Water Supply Projects in Nyala and Geneina, Report to NRWC, Sudan.
Karkanis BG (1965) Hydrochemical Facies of Ground Water in the Western Province of Sudan, Unpublished MSc Thesis, University of Arizona, U.S.A.
__________ (1966) Ground Water Geology in Darfur Province. Unpublished Report No 246, Sudan Geological Survey.
Kaskous H (1992) The Hydrogeology of Sag El Na'am Basin, Unpublished MSc Thesis, University of Khartoum.
Kheiralla MK (1984) Summary of Ground Water Geology of the Sudan. Unpublished RWDC Report).
Kleinsorge H, Zscheked H (1958) Geologic and Hydrologic Research in Arid and Semi-Arid Zone of Western Sudan, Part I. Amt. Jur. Berdenforschung, Hannover, Germany.
Lambert H (1968) Land and Water Resources of the Jebel Marra Area, UNDP/FAO.Mansour,A.O (1963) Source of Water Supply as Related to Geology in Kordofan Province. Proc. Ninth Annual Conference on Surveying and Development in Sudan, Phil Soc, Sudan. pp.99-103.
Ministry of Foreign Affairs (1983) Report and Recommendations on Domestic water activities undertaken by the Netherlands 1975-1980, Sudan.
Ministry of Health (1982) Sudanese National Standard for Drinking Water, Khartoum, Sudan
Moon PA (1954) The Static Water Level in the Sedimentary Formations of North Western Sudan. Sudan Geolog. Survey Open File Report.
Mukhtar AR (1975) The Hydrogeology of the Shagera Basin with Special Reference to the Water Supply of El Fasher Town, Unpublished MSc Thesis, University of Khartoum.
Mukhtar AR (1992) Exploitation of Ground Water in Food Security Projects in Sudan, RWDC Unpublished Report.
Mukhtar AR (2003) Water Resources in Sudan. Unpublished report EDS
__________(2004) Ground Water Resources in Sudan, International Conference and Exhibition on Ground Water, UNICEF Ethiopia, pp.1-12.
Muller M (1976) Water Under the Sand. New Sci., Vol. 71 No.1020, pp.702-703.
Mustafa MI (1982) The Development of Rural Water Supply System in Particular Reference to the Sudan, Unpublished MSc Thesis, Strathcyde, UK
Nash HG (1979) Review of the Hydogeology and Ground Water Studies in the Sudan, Inst. Of Geol. Sci. Report No. WD/OS/79/23, 100pp, London. UK
National Council of Research, Sudan (1982) Water Resources in Sudan, ed by Salih, AM, Khartoum, 223pp.
NCRWD(1988) Annual Reports, Sudan.
_______(1988) Water Programs, Sudan.
_______(1988) The Committees Reports of Visiting Regions, Sudan.
_______, TNO & Kheir M (1986) Annual Report of WADS Activities in Khartoum, Nyala and Kassala, Sudan.
NCRWD, (1985) Different Well Reports, Sudan.
NWC WAPS 2 (1984) Geneina Water Resources, Technical Bulletin, Sudan.
NWC/TNO (1985) Geneina Water Resources Study, Sudan.
NWC WADS, Data Bank (1988) Water Wells in Darfur Until 1988.
NWC (1996) Baseline Survey of Water Resources of Sudan.
____ (2003) Water Supply Strategy Papers 2003-2007, Sudan.
Omer EO (1973) Hydrogeological Properties of the Ground Water Body in Wadi El Ku, Darfur Province, Sudan. Unpublished PhD Thesis, Patrice Lumumba University, Moscow, USSR (In Russian Language).
PRC Engineering Consultants (1980) Western Sudan Water Supply Project, Phase II, Main Report to NRWC, Vol.III App. GE, Vol.IV K-M.
Regwa (1970, 1971) Sudan Anti-thirst Project, Vol. A and B. Report to R.W.C.
Rodier J (1963) Bibliography of African Hydrology, UNESCO.
Saeed EM (1982) Ground Water Resources of the Sudan. In: Water Resources in Sudan. Edited by Salih AM, National Council for Research Sudan, pp.51-84.
Salama RB (1971) Hydrogeology of Wadi Nyala at Nyala Town, unpublished MSc Thesis, University of London.
Salama RB (1977) Ground Water Resources of Sudan. In: Biswas Editor, Water Development and Management Proc. United Nations Conf. Argentina Par 4, Pergamon Press.
Salama RB (1977) Ground Water Resources of the Sudan. Abstract Aqua No.1-2 GB, pp.88.
Salama RB (1997) Rift Basin of the Sudan, In: (Selley RC, Hsu KJ, Editors, African Basins, Sedimentary Basins of the World, 3, Elsevier Science, 105-149, Amsterdam.
Salih ABDEEN Mohmed (1980) Artificial Ground Water Recharge, a technique for water resource mangement.3rdConf. Afro-Asian Regions, New Delhi, pp.211-221.
Salih MK, Kheir OM (1994) Ground Water Assessment and Estimation in Sudan. Proc. Int. Conf. Efficient Utilization and Management of Water Resources in Africa, Sudan, Khartoum, Vol.2, pp.620-639.
Sandford KS (1935) Sources of Water in the NW Sudan, Geog. Journ. Vol.85, pp.412-431.
Satakopan V (1965) Water Balance in the Sudan. Sud. Met. Service, Memoir, No.5.
Schull TJ (1988) Rift Basins Interior of the Sudan, Am. Ass. Petr. Geol. Bull, 72, 1128-1142.
Senden WJMK (1989) Hydrogeological Map of the Sudan. Explanatory Notes. WADS Netherlands, TNO National Corporation for Development
Sir El Khatim, Evert Holleman (1988) The Progress Report: A Geohydrological Data Bank in Sudan, Report to NRWDC
SNWP (2000) Sudan National Water Policy. Ministry of Irrigation & Water Resources, Khartoum, Sudan.
South Darfur Western Savannah Development Corporation (1990) Study on the Water Supply of South Darfur (Unpublished Report).
Strojexport (1982) Geophysical Investigation of Ground Water Structure, Darfur Province. Prague, Czech.
Suckow A et al, (1993) Ground Water Recharge in the Umm Keddada Basin, N.W. Sudan. Derived from Environmental Isotopes of Soil Moisture in Samples Collected from Deep Dug Wells. In: Geoscientific Research in North East Africa. Thorweihe and Schandelmeier, editors, Balkema, Rotterdam, pp.677-685.
Swenker JMP (1983 1984) A Geohydrological Data Bank in the Sudan, 3rd & 4th Progress reports
Texas Instrument Company (1962) Geophysical Report on Western Sudan, Sudan Geological Survey Open File Report.
Throrweihe U et al (1990) Investigations in the Darfur Area, Western Sudan. Berliner Geowiss. Abh, A 1201 Berlin, pp.279-326.
Tudor Engineering Company (1959) Report on Potable Water Supply in the Republic of the Sudan. Report to International Co-operation Administration, Washington.
TNO (1984) Nyala Water Resources Study. Final Report, WAPS 2, Water Resources Assessment Program in Sudan, Report to NRWDC.
TNO (1985) Water Resources Assessment Program in the Sudan, Phase 3, Report to NRWDC.
TNO/NWC (1986) Water Resources Assessment Program in the Sudan, WAPS 2, Final Report to RWDC.

TNO/NWC (1986) A Summary of the Results of WAPS 2 Investigations at Wadi Nyala. Report to NWC.
TNO(1987) Water Resources Assessment and Development Project in the Sudan. Report to RWDC.
_____ (1987) Kas Ground Water Resource. Study Report to RWDC.
TNO/RWDC (1987) Hydrogeology of the Baggara Basin Southern Darfur.
TNO/RWDC (1987) Gemmeiza Ground Water resources, Study Report to RWDC
TNO Brinkman (1990) Western Sudan Hydrological and Hydrogeological Investigations in Darfur Area.
TNO (1987) Water Resource Assessment and Development Project in the Sudan, Report to NRWDC.
UNDP (1987) Report of Mission to the Democratic Republic of the Sudan.
UNDP and World Bank (1988) Water Supply and Sanitation Sector Review Sudan. Brief on the country progress.
UN (1988) Transitional Project Major Aquifers in North East Africa (Nubian Aquifer).
UNDP/FAO (1986) Land and Water Resources Survey in Jebel Marra Area. Final Report FAO 48/SUD-H (27), pp. 21 – Rome.
UN (1987) Report of Mission to the Democratic Republic of the Sudan.
UNDP/FAO (1974) Agricultural Development in the Jebel Marra Area, Sudan, Final Report SF/SUD/67/530, Rome.
UNDP (1993) Tender Document for Borehole Drilling – Zalingei Town.
UNESCO CHAIR (2000) Ground Water Resources Assessment Visit, Report by Eng. Al Mowtaz AH
UNICEF (1986) Water Supply Sanitation and Hygiene Education Annual Report, Sennar WES, Sudan.
UNICEF NCDRW (1990) Recommendation and Report on National Conference on Rural Drinking Water, Khartoum.
UNICEF (1990) Water and Sanitation Sector during 1990 in Sudan.
Vail JR (1978) Outline of the Geology and Mineral Resources of the Democratic Republic of Sudan and Adjacent Area. Overseas Geol. and Mineral Resources No.49, Inst. Geol. Sci. London.
WADS (1988) Ground Water Study Buldanga Area, Report to RWDC.
______ (1986) Nyala Baggara Basin, Report to RWDC.
______ (1988) Hydrogeology and Water Resources of South Darfur, RWDC Khartoum and TNO Institute of Applied Geosciences, Delft, Netherlands.
Waite HA (1955) Program of Ground Water Investigations for the Anglo-Egyptian Sudan, U.S.A. Geological Survey, Washington D.C.
WAPS 2 (1985) Geneina Water Resource Study Report to NWC.
WES (1999) Baseline Survey of Water Uses, Report of NWC
Whiteman AJ (1971) The Geology of the Sudan, Clarendon Press, Oxford, 290pp.
Widitallah AL (1963) Ground Water Resources of the Sudan. Proc. 9th. Ann. Conf. on Surveying for Development, Phil. Soc. Sudan, pp.88-92.
Widitallah AL (1972) Ground Water Resources of the Sudan. In: Sudan Path to Self-Sufficiency, pp.382-385, Editor, Imam FB, 2nd Erkowit Conference, 1967.

A.3 Reports at the Newtech Library, Khartoum

Author(s)	Project	Report	Year
HTS	Jebel Marra	Jebel Marra Investigations: Report on Phase I Studies	1958
Tesco-Viziterv, Budapest	Jebel Marra	Agricultural Development in the Jebel Marra Area: Irrigation Operation Plan	1974
HTS	Agricultural Development in the Jebel Marra Area	Working Paper #1	Dec-76
HTS	Agricultural Development in the Jebel Marra Area	Working Paper #2	Mar-77
HTS	Agricultural Development in the Jebel Marra Area	Working Paper #3	Jun-77
HTS	Agricultural Development in the Jebel Marra Area	Irrigation Development in the Pilot Development Areas	Aug-77
HTS	Agricultural Development in the Jebel Marra Area	Working Paper #4	Sep-77
HTS	Agricultural Development in the Jebel Marra Area	Regional Development Plan: Main Report (Draft)	Dec-77
HTS	Agricultural Development in the Jebel Marra Area	Regional Development Plan: Annex 1: Land Resources: Part One, Soils	Dec-77
HTS	Agricultural Development in the Jebel Marra Area	Regional Development Plan: Annex 1: Land Resources: Part Two, Vegetation	Dec-77
HTS	Agricultural Development in the Jebel Marra Area	Annex II: Volume 1: Hydrogeology	Dec-77
HTS	Agricultural Development in the Jebel Marra Area	Annex II: Volume 2: Hydrology and Engineering	Dec-77
HTS	Agricultural Development in the Jebel Marra Area	Annex III: Livestock and Range Resources	Dec-77
HTS	Agricultural Development in the Jebel Marra Area	Annex IV: Agriculture	Dec-77
HTS	Agricultural Development in the Jebel Marra Area	Annex V: Social Organisation and Structure	Dec-77
HTS	Agricultural Development in the Jebel Marra Area	Annex VI: Infrastructure of the Region: Part One: Infrastructure	Dec-77
HTS	Agricultural Development in the Jebel Marra Area	Annex VI: Infrastructure of the Region: Part Two: Development Administration	Dec-77
HTS	Agricultural Development in the Jebel Marra Area	Annex VII: Economics and Evaluation of Specific Projects	Dec-77
HTS	Agricultural Development in the Jebel Marra Area	Annex VIII:Forestry	Dec-77
HTS	Agricultural Development in the Jebel Marra Area	Run-off Data	Dec-77
HGG/MMP	Darfur Water Survey & Development Project in Darfur Province	Report #3: Surface Water Studies Season 1969/70	Sep-70
HTS	Sag El Na'am	Sag El Na'am Project Evaluation and Pre-Investment Study	Aug-76
HTS/MMP	South Darfur Land Use Planning Survey		1974
HTS	Savanna Development Project, Phase II	Livestock Marketing	
HTS	Savanna Development Project, Phase II	Agronomic Investigations - Umm Rakuba	1975
HTS	Savanna Development Project, Phase II	Livestock and Range Investigations - Ghazala Gawazat	1975
HTS	Savanna Development Project, Phase II	Development Plan - Volume I Eastern District Council	

HTS	Savanna Development Project, Phase II	Development Plan - Volume II Agricultural Research in the Western Savanna	
HTS	Savanna Development Project, Phase II	Annex 1: Soils and Vegetation	
HTS	Savanna Development Project, Phase II	Annex 2: Part I, Hydrogeology	
HTS	Savanna Development Project, Phase II	Annex 2: Part II, Hydrology and Engineering	
HTS	Savanna Development Project, Phase II	Annex 3: Livestock and Range Resources	Mar-76
HTS	Savanna Development Project, Phase II	Annex 4: Agriculture	
HTS	Savanna Development Project, Phase II	Annex 5: Social Organisation and Development Administration	
HTS	Savanna Development Project, Phase II	Annex 6: Economics and Project Evaluation	
HTS	Savanna Development Project, Phase II	Interim Report on Southern Kordofan	
HTS	Savanna Development Project, Phase II	Final Report	
World Bank		Sudan: Appraisal of the Savannah Development Project, Report No. 1445-SU	06-May-77

Appendix B: The Water Sector in Darfur

At the state level in Darfur, the key water sector includes the Ministry of Urban Planning and Public Utilities, the Ministry of Agriculture and Irrigation and Ministry of Health. However the focal institutions dealing with water supply and sanitation are the State Water Corporation and Water and Environmental Sanitation (WES) Programme.

State Water Corporation

In all the three states of Darfur the state water corporation is under the auspices of the Ministry of Urban Planning and Public Utilities and of similar generic structure. Under the SWC are a number of departments including the rural water and urban water departments. The rural department is responsible for managing Wateryards Maintenance and Sale Centres, mainly at the locality levels. The Urban Department is responsible for operation, maintenance, management and development of water supply services and facilities in the urban centres such El Fasher, El Geneina, Ed Daein (South Darfur). As a result of restructuring (in 2006), the Nyala Locality Water corporation has been established with a board of directors chaired by the state Minister of Finance and Economic Planning of South Darfur State. It is responsible for water supplies in Nyala town and rural areas in the locality.

The staff of the State Water Corporations comprises engineers, water technicians, chemists and other support staff accommodated in different departments at the head quarters and the localities. The following figures outline the generic structure of the SWC at the state and locality levels.

Responsibilities and functions of SWC include the following:

- Planning, design and execution of water projects in the state.
- Manufacturing water equipment in the state.
- Investment in water industry in accordance with the regulations.
- Encouraging the private sectors to invest in water industry and water projects.
- Formulation and implementation of water polices and acts.
- Operation, maintenance and management of water supply sources.
- Protection of water resources in state.
- Up keeping of technical data and information on water supply sources.

WES project

The WES project is a UNICEF- and NWC- supported project, established under the auspices of SWC at the state level with effective coordination and supervision by the NWC and UNICEF. WES is responsible for delivery of rural water supply and sanitation services , especially simple water technologies such as slim boreholes fitted with hand pumps, improved hand dug wells and water yards, in additional to latrine construction , health awareness and community mobilization as integral parts of implementation and sustainability of rural water and sanitation programs. WES (in Darfur states) also coordinates the works of the NGOs involved in WATSAN activities, especially in the IDPs' camps. WES main department s are Drilling, installation of wells and health (as shown in the following structure). WES also works closely with the GWWD and the state water Corporation and facilitate monitoring and conduction of geophysical investigation for properly location and drilling of boreholes.

Appendix C Data collected during this Project

C.1 Abu Shouk

C.1.1 Abu Shouk boreholes

BH. Location	Superficial deposits, m	Wthd. Rocks, m	Fractured/ Decayed rocks, m	Hard rock @ (m)	D.W.S m	Yield, m³/h	Drilling Date
Abshk1	0-14	14-24 (12)	24-32 (8)	32-42	36	1.8	9/7/04
Abshk 2	0-12	12-26 (13)	26-32 (6)	32-45	33	2.2	10/7/04
Abshk 3	0-12	12-24 (12)	24-45 (21)	45-51	42	-	11/7/04
Abshk 4	0-9	9-24 (15)	24-36(12)	36-48	33	2.2	12/7/04
Abshk 5	0-11	11-26 (15)	26-37(11)	37-42	36	1.2	22/7/04
Abshk 6	0-9	9-24 (15)	24-46 (8)	36-45	36	1.2	22/7/04
Abshk 7 Elmdaris	0-11	11-26 (15)	26-34(8)	34-48	39	1.2	24/7/04
Abshk 8	0-11.5	11.5-28 (13.5)	28-42(14)	42-57	51	1.2	31/7/04
	0-9	9-24 (15)	24-34(10)	34-51	45	1.2	01/8/04
Abshk 10	0-12	12-27 (15)	27-40(13)	40-45	39	1.2	01/8/04
Abshk 11	0-12	12-27 (15)	27-38(11)	38-48	36	2.0	02/8/04
Abshk 12: N:13-39-977 E:25-21-312	0-12	12-39 (27)	39-54(15)	54-66	42	6.8	13-15/11/06
Abshk 13: N: 13-39-861 E: 25-21-410	0-12	12-36 (14)	36-67(31)	67-69	37	-	15-16/11/06

Table C.1.2 Hand pump location co-ordinates at Abu Shouk Camp

Hand Pump No.	Longitude	Latitude	Altitude (by GPS)
1	025–20-639	13-40-960	--
3	025–20-838	13-40-224	755
4	025–20-832	13-40-207	758
5	025–20-914	13-40-138	751
6	025–20-955	13-39-159	751
7	025–20-923	13-39-174	751
8	025–20-595	13-39-931	748
9	025–20-609	13-39-952	745
10	025–20-595	13-39-931	748
11	025–20-568	13-39-916	750
12	025–20-605	13-39-838	--
13	025–20-596	13-39-804	749
14	025–20-572	13-39-799	748
15	025–20-547	13-39-620	--
16	025–20-535	13-39-610	746
17	025–20-499	13-39-540	744
18	025–20-514	13-39-355	745
19	025–20-634	13-39-614	
20	025–20-542	13-39-344	749
21	025–20-904	13-40-343	--
22	025–20-628	13-39-582	745
23	025–20-625	13-39-531	746
24	025–20-730	13-39-520	745
25	025–20-990	13-39-669	745
26	025–21-018	13-39-795	745
27	025–21-022	13-39-759	745
28	025–21-027	13-39-791	747
29	025–21-038	13-39-912	747
30	025–21-039	13-39-912	--
31	025–21-041	13-39-963	750
32	025–21-040	13-39-987	750
33	025–21-221	13-40-097	748
34	025–21-258	13-40-230	751
35	025–21-264	13-40-243	--
IRC12	025–20-657	13-39-667	746

C.1.3 Al Salaam camp –Borehole lithological Information

BH Location	Superficial deposits, m	Wthd. Rocks, m	Fractured/ Decayed Rocks, m	Hard Rock, m	Depth water struck, m	Yield, m³/h	Drilling Date
Al Salaam 3 BH: N:13-40-588 E: 25-22-501	0-18	18-63	--	--	30	-	31/07/05
Al Salaam 3 HP: N:13-40-623 E: 25-22-453	0-15	15-57	--	--	42	-	30/07/05
El Salaam 3 HP: N:13-40-537 E: 25-22-416	0-15	15-57	--	--	39	-	29/07/05
Al Salaam 1 HP: N:13-40-472 E: 25-22-419	0-12	12-57	--	--	39	-	28/07/05
Al Salaam 2 BH: N:13-40-929 E: 25-22-809	0-9	9-54	--	--	33	-	27/07/05
Al Salaam 1 BH: N:13-40-835 E: 25-21-923	0-6	6-48	48-57	--	33	-	25/07/05
Al Salaam 26 HP: N:13-40-075 E: 25-21-938	0-11.6	11.6-41.6	41.6-52	52-53	SWL (m) 29.5	1.3	14/06/05
Al Salaam 27 HP: N:13-40-080 E: 25-21-872	0-8	8-42	42-60	60-61	28.5	2.6	15/06/05
Al Salaam 28 HP: N:13-39-093 E: 25-21-811	0-6	7-42	42-53	53-55	29	3.0	15/06/05
Al Salaam 30 HP: N:13-39-040 E: 25-21-444	0-6	6-37.5	37.5-48	48-48.5	28.5	3.0	18/06/05
Al Salaam 31 BH: N:13-40-166 E: 25-21-519	0-6.5	6.5-27	27-48	48-48.5	29	1.3	19/06/05
Al Salaam 32 HP: N:13-40-138 E: 25-21-493	0-7.6	7.6-38.1	38.1-48.8	48.8-50.3	28	9.5	20/06/05
Al Salaam 31 BH: N:13-40-166 E: 25-21-570	0-6.1	6.1-18.3	18.3-54.9	54.9-56.4	28.5	1.8	21/06/05

C.2 Kalma Camp

Table C2 Groundwater Quality Analyses for Kalma IDP Camp

Sector	BH/HP	Lat	Long	Date	pH	EC	TDS	TH	T Alk	Cl	SO4	Ca	Fe	Mn	F	NO3	NO2	NH3	
1	BH	12:00:567	25:00:996	28/06/2005	7.5	690	480	165	300	0.26	4.53		0	0.22	0.47	55.64	0.033	0.04	UNFIT
	HP	12:00:247	25:01:178	28/06/2005	7.5	730	510	155	310	0	5.65		0.21	0.07	1.15	56.62	0.066	0	UNFIT
	HP	11:59:832	25:01:742	28/06/2005	7.4	800	560	175	300	1.55	7.4		0.08	0.16	0.55	55.48	0.066	0.02	UNFIT
	HP	11:59:978	25:01:788	28/06/2005	7.7	580	400	125	225	0	3.63		0.05	0.15	0.79	50.86	0.066	0	UNFIT
	HP	12:00:062	25:01:671	28/06/2005	7.5	620	430	185	250	0.04	3.72		0.02	0.16	0.26	240.8	0.066	0	UNFIT
	ST	11:59:894	25:01:642	28/06/2005	7.7	770	540	145	315	0.05	5.8		0	0.31	0.81	116.5	0.033	0	UNFIT
	HP	12:00:495	25:00:564	28/06/2005	7.6	790	550	155	325	0	3.69		0.11	0.27	0.32	58.88	0.033	0	UNFIT
2	BH	12:00:390	25:00:606	31/08/2005	7.4	1000	700	180	250	0.44	5.63		0	0.13	0.85	1.14	0.1	0.1	
	HP	12:00:297	25:00:810	31/08/2005	7.4	950	660	135	250	0.98	3.44		0.35	0.17	1	0.97	0.03	0.13	
	BH	12:00:211	25:00:824	31/08/2005	7.3	1020	710	170	175	0.57	5.82		0	0.05	0.75	0.44	0.03	0.35	
	BH	12:00:386	25:00:426	31/08/2005	7.3	1030	730	130	150	1.71	13.11		0	0.11	0.67	0.75	0.1	0.16	
	HP	12:00:387	25:00:538	31/08/2005	7.4	800	530	113	200	4.13	7.66		0.23	0.1	0.68	2.2	0.06	0.15	
	BH	12:00:265	25:00:856	31/08/2005	7.2	970	670	170	200	0.69	5.39		0	0.23	0.91	0.66	0	0.1	
3	BH	12:00:920	25:00:540	03/08/2005	7.8	580	390	150	250	2.85	5.7		0	0.38	0.39	0.66	0.02	0	
	HP	12:00:702	25:00:706	03/08/2005	7.4	770	530	200	175	32.58	19.84		0.59	1.06	0.57	122.6	2.2	0.4	UNFIT
	HP	12:00:655	25:00:689	03/08/2005	7.6	530	360	170	200	5.09	5.03		0	0.41	0.52	0.62	0.2	0.16	
	HP	12:00:679	25:00:501	03/08/2005	7.5	1050	730	120	350	8.51	10.78		0.35	0.41	1	1.45	0.04	0.2	
	BH	12:00:622	25:00:513	03/08/2005	7.8	920	650	100	370	7.13	0.3		0.16	0.24	0.77	0.62	0.02	0.15	
4	HP	12:00:594	25:00:213	14/08/2005	7.5	1010	690	85	375	5.4	7.4		0	0.68	1.7	2.98	0.033	0.16	
	ST	12:00:766	24:59:733	14/08/2005	7.4	600	410	175	235	3.6	14.04		0	0.25	0.4	7.35	0.033	0.2	
	HP	12:00:473	25:00:448	14/08/2005	7.6	1050	740	80	500	4.6	5.8		1.7	1.4	0.5	0.99	0.099	0.18	
	ST	12:00:469	25:00:446	14/08/2005	7.6	870	610	155	350	10.9	6.9		0.3	0.07	0.6	1.12	0.033	0.35	
	ST	12:00:414	25:00:360	14/08/2005	7.6	670	470	185	260	4.5	7.2		0.11	0.3	0.4	1.54	0.033	0.39	
	HP	12:00:741	24:59:602	14/08/2005	7.3	1470	960	260	425	30	57.3		0.05	0.4	0.9	21.12	0.099	0.62	
	HP	12:00:931	24:59:337	14/08/2005	7.2	1560	1110	220	450	26.3	39.4		0.4	0.24	0.7	55.4	1.22	0.48	
	HP	12:00:963	24:59:252	14/08/2005	7.3	1440	920	262	500	28.6	12.5		0	0.9	0.4	28.4	0.2	0.17	
	Tank CARE)	12:00:933	24:59:179	14/08/2005	7.5	1060	730	277	400	27	43.8		0	0.4	0.6	53.19	0.066	0.366	
5	BH	12:00:803	25:00:229	07/08/2005	7.5	790	560	140	350	8.49	8.24		0.43	0.19	0.75	7.3	0.066	0.122	
	HP	12:00:824	25:00:273	07/08/2005	7.5	740	500	140	280	11.1	7.88		0.5	0.27	0.63	21	0.066	0.0854	
	HP	12:00:637	25:00:264	07/08/2005	8.1	1020	700	85	470	6.72	9.76		0.34	0.32	1.23	2	0.22	0.0732	
	BH	12:00:654	25:00:253	07/08/2005	7.5	960	660	65	350	5.06	7.7		0.03	0.21	1.6	2	0.066	0.0122	
7	HP	12:01:038	24:59:582	21/08/2005	7.5	1520	1080	130	700	26.4	14.7		0.9	n/a	0.3	28.3	0.03	0.2	
	HP	12:00:952	24:59:796	21/08/2005	7.7	1470	1040	85	700	28.4	19.6		0.1	n/a	1.5	21.6	0.01	0.1	
	HP	12:01:248	24:59:802	21/08/2005	7.8	1450	900	56	550	17.5	2.5		0	n/a	0.8	19.4	0.03	0.1	
	HP	12:01:254	24:59:053	21/08/2005	7.9	1310	930	80	680	8.9	5.4		0.1	n/a	1.1	1.1	0.01	0.1	
8	BH	12:01:657	24:59:708	23/08/2005	7.7	720	1060	52	520	7.9	5		0.26	1.6	0.55	0.03	0.01	0.05	
	BH	12:01:529	24:59:167	23/08/2005	7.3	540	760	155	380	5.3	3		0.01	0.3	0.69	0.03	0.01	0.19	
	BH	12:01:333	24:59:819	23/08/2005	7.6	650	940	165	470	5.9	3		0.23	0.3	0.43	3.03	0.02	0.23	

C.3 Otash

C.3.1 Borehole details, Otash

Borehole No.	Otash 1	Otash 2	Otash 3	Otash 4
Date completed	18/11/06	19/11/06	20/11/06	22/11/06
Total depth, m	81	66	66	78
Latitude	12:06:14.83	12:06:23.25	12:06:24.29	12:06:18.34
Longitude	24:54:34.62	24:54:55.56	24:54:50.83	24:55:06.62
Status	Successful	Successful	Successful	Unsuccessful
SWL, m	12	13	22.4	
DWL, m	33.3	25	29	
Drawdown, m	21.3	12	6.6	
Yield, m^3/d	54.5	87.3	87.3	
Specific capacity, $m^3/d/m$	2.56	7.27	13.22	
Estimated T m^2/d	3	9	16	
Pump setting, m	33	30	30	
Inner casing diameter, mm	114	114	114	
Screen setting, m	27-30; 72-78	24-30; 54-60	30-33; 54-60	
EC, microSiemens/cm	430	690	510	
pH	8.1	8.3	8.3	

C.3.2 Borehole details, Otash

Borehole No.	Otash (1)	Otash (2)	Otash Camp (1)	Otash Camp (2)	Otash Camp (3)	Otash Camp (4)	Otash Camp (5)
Date completed	23/12/05	26/12/05	3/5/06	4/5/06	10/5/06	15/5/06	18/5/06
Total depth, m	32	46	40	46	39.5	40	40
Latitude			24:55:23.58		24:54:39.2	24:55:23.7	
Longitude			12:05:47.4		12:05:47.4	12:06:32	
Status	successful (HP)	DRY	successful	DRY	successful (SP)	successful (SP)	successful
SWL, m			5.72		10	10	5.72
DWL, m					13	14.6	
Drawdown, m					3	4.6	
Yield, m^3/d			72		67.2	60	
Specific capacity, $m^3/d/m$					22.4	13.1	
Estimated T m^2/d					27	16	
Pump setting, m	34				34	34	
Inner casing diameter, mm	114		114		114	114	114
Screen setting, m							
EC, microSiemens/cm							
pH							

C.3.3 Otash Camp Boreholes

Date completed	for Agency	BH No.	Latitude	Longitude	Total Depth, m	Water strike, m	SWL, m	Yield, m3/d	Pump
19/02/2005	WES	Outash (1)	12:05:26.8	24:53:43.4	42	30		163.6	?SP
17/02/2005	WES	Outash (2)	12:05:19.7	24:53:15.6	45	33		43.6	?HP
17/02/2005	WES	Outash (3)	12:05:45.4	24:54:55.8	51			unsuccessful	
03/03/2005	WES	Outash (4)	12:06:30.3	24:54:47.3	48	27		163.6	?SP
28/02/2005	WES	Outash			48	21		163.6	?SP
08/06/2005	WES	Otash (1)			42	30	22	54.5	?HP
09/06/2005	WES	Otash (2)			36	21	18	98.2	?HP
23/12/2005	CARE	Otash (1)			32			(hand pump)	HP
26/12/2005	CARE	Otash (2)			46			dry	
15/01/2006	WES	Outash (1)			33	28	15	87.3	?HP
16/01/2006	WES	Outash (2)			36	27	18	163.6	?SP
17/01/2006	WES	Outash (3)			42			unsuccessful	
18/01/2006	WES	Outash (4)			30			unsuccessful	
19/01/2006	WES	Outash (5)			42			unsuccessful	
03/05/2006	CARE	Otash Camp (1)	12:05:47.40	24:55:23.58	40		13	72	SP
04/05/2006	CARE	Otash Camp (2)			40			dry	
10/05/2006	CARE	Otash Camp (3)	12:05:47.40	24:54:39.20	39.5		10	67.2	SP
15/05/2006	CARE	Otash Camp (4)	12:06:32.00	24:55:23.70	40		10	60	?HP
18/05/2006	CARE	Otash Camp (5)			40				?HP
18/11/2006	WES	Otash 1	12:06:14.83	24:54:34.62	81		12	54.5	?HP
19/11/2006	WES	Otash 2	12:06:23.25	24:54:55.56	66		13	87.3	?SP
20/11/2006	WES	Otash 3	12:06:24.29	24:54:50.83	66		11	87.3	?SP
22/11/2006	WES	Otash 4	12:06:18.34	24:55:06.62	78			unsuccessful	
Field	WES	WES #1	12:05:37.57	24:54:26.79				229	SP
	WES	WES #2	12:05:21.70	24:53:45.03				216	SP
	WES	WES #3	12:06:30.25	24:54:47.46				163	SP
	WES	WES #4	12:05:30.27	24:53:59.52				210	SP
	WES	WES #5	12:06:10.42	24:54:42.15					SP
	WES	WES #6	12:06:13.25	24:54:24.75			12.38		SP
	CARE	CARE#1	12:06:32.26	24:54:40.09					SP
	CARE	CARE#2	12:06:27.49	24:54:39.05				168	SP
	WES	HP1							
	WES	HP2							
	WES	HP3							
	WES	HP4							
	WES	HP5							
	CARE	HP1							
	CARE	HP2							
	CARE	HP3							

C.4 Mornei

C.4.1 Mornei new borehole logs

All data in metres below ground; BC = Basement Complex

BH 1

0 - 9	Clay	
9 - 13.5	Clay sand	
13.5 - 18	Clay	
18 - 21	Coarse Gravel	screened 17-23
21 - 23	Weathered BC	

BH 2

0 – 3	Clay	
3 – 4.5	Clayey sand	
4.5 – 6	Weathered BC	
6 – 13.5	Highly weathered	
13.5 – 19.5	Highly weathered	
19.5 – 24	Highly weathered	
24 – 30	Highly weathered	screened 24-30
30 – 31	Fresh BC	

BH3

Dry, TD 15m

BH4

0 – 1.5	Clay	
1.5-10.5	Coarse gravelly	screened 6-12
10.5 – 12	Highly weathered BC	
12 – 16.5	Weathered BC	
16.5 – 18	Weathered BC	

BH5

0 – 1	Clay	
1 – 6	Weathered BC	
6 – 15	Weathered BC, dark grey	
15 – 24	Weathered BC, grey	
24 – 27	Weathered BC, grey	
27 – 33	Highly weathered BC, green	
33 – 36	Highly weathered BC, grey	screened 32-38
36 – 38	Highly weathered BC, white	
38 – 39	Weathered BC, grey	

BH6

0 – 3	Fine Sand	
3 – 12	Coarse gravelly Sand	screened 9-15
12 – 18	Gravelly Sand	

C4.2 Mornei Boreholes

BH #	Motor Pump ID	Hand pump ID	Lat	Long	Date Drilled	Total Depth m	Depth to BC m	Status	Q m3/h	Hrs per day	Out-put m3/d	Orig SWL m	SWL m 2/3/07	DWL m 28/1/07	Elev m	Aquifer	BH dia mm	
MP-1	4		12:57:19.3	22:53:07.4	22/04/1987	35	35	Success	27	15	405	6			708	Wadi		
MP-2					27/04/1987	13.6	12	Failure				6				Wadi		
MP-3	3		12:57:23.6	22:53:13.1	03/05/1987	14.3	14	Success	22	17	374	3	4.52	3.05	710	Wadi		
MP-4					04/05/1987	19.7	18	Failure				3.2				Wadi		
MP-5	2		12:57:27.0	22:53:15.1	07/05/1987	16.9	16	Success	22	17	374	2.9	4.61	3.63	724	Wadi		
MP-6	1		12:57:30.5	22:53:18.0	11/05/1987	16.8	16	Success	14	17	238	3.9	4	6.22	719	Wadi		
1	7		12:57:21.9	22:53:09.9	11/06/2005	23	21	Success	17	17	289	5	6.19	8.29	718	Wadi	177.8	casing 0-17; screen 17-23
2		10	12: 56:46.3	22:53:10.4	12/06/2005	31	4.5	*Success*				16			719	Wadi	177.8	casing 0-24; screen 24-30; sump 30-31; now disused
3					12/06/2005	51		Failure								Wadi	127	DRY
4	6		12:57:46.9	22:53:12.8	13/06/2005	18	10.5	Success				1		1.75	714	Wadi	177.8	casing 0-6; screen 6-12; sump 12-18
5		5	12:56:52.7	22:52:56.3	13/06/2005	39	1	*Success*				21			725	Wadi	127	casing 0-32; screen 32-38; sump 38-39
6	5		12:57:50.7	22:53:13.5	14/06/2005	18	?18	*Success*	14	18	252	1		0.5	722	Wadi	177.8	casing 0-9; screen 9-15; sump 15-18
									116		1932							
		1	12:56:49.5	22:52:17.8				*Success*							742	Wthd BC		
		2	12:56:58.0	22:52:32.4				*Success*							731	Wthd BC		
		3	12:56:54.4	22:52:40.7				*Success*							736	Wthd BC		
		4	12:56:41.9	22:52:40.3				*Success*	0.06 ?						736	Wthd BC		Very low yield
		6	12:57:52.5	22:52:44.2				*Success*							726	Wthd BC		Good yield reported
		7	12:57:21.9	22:53:09.9				*Success*							718	Wthd BC		Polluted by latrine Aug 2006; reopened Feb 2007
		8	12:57:26.6	22:52:34.4				*Success*							740	Wthd BC		
		9	12:57:41.1	22:53:10.4				*Success*							719	Wthd BC		