TERMS OF REFERENCE (ToR)
FEASIBILITY STUDY FOR THE REHABILITATION/CONSTRUCTION OF TWO DAMS

I. Background to the Consultancy Assignment

COOPI - COOPERAZIONE INTERNAZIONALE has started its operation in Sudan in 2004 supporting people in need living North Darfur who are affected both by natural and human related disasters including drought and conflict. COOPI-Sudan is engaged on supporting people of concern on emergency response, early recovery and resilience building responses in line with the humanitarian-development peace nexus. Under these programmatic interventions WASH, FSL, Nutrition and Protection are the main sectors of intervention. COOPI works with multiple donor partners including DG-ECHO, EU/DEVCO, UNDP, FAO, UNHCR, UNICEF, IOM and others to address the basic needs of its target communities.

Currently, COOPI is implementing a EU financed FSL project entitled "*Mitigate the effect of El Nino for host and IDP Population in North Darfur State*" starting from 1st December 2017. This project aims to strengthen sustainable and alternative livelihoods of local communities, displaced populations and potential migrants in North Darfur State, improving the availability of water and natural resources and increasing income opportunities related to drought-resilient agriculture and sustainable income generating activities.

In order to achieve this purpose COOPI intends to rehabilitate an earth dams in Kerfu (Um Baru locality) and to build a new one in Meski (Kornoi area), in the western part of North Darfur State.

II. Objective of the Assignment

The specific objectives of this assignment are:

- Conducting a technical feasibility study on the rehabilitation of Kerfu dam, Um Baru locality (aiming to increase the water storage capacity);
- Conducting a technical feasibility study on the construction of a new dam in Meski, Kornoi locality (the planned work is an earth embankment with a natural watershed being utilized as a spillway);

Preliminary feasibility study on the works are available in the annex.

IV. Place and Duration of the Assignment

The assignment will be conducted in North Darfur State, localities of Um Baru (Kerfu) and Kornoi (Meski), starting from April 2018 for a period of 2 months.

V. Expected Deliverables

Among others, the following will be the main expected deliverables from the assignment requested by the end of the collaboration:

- For Kerfu dam:
    - Detailed Design, including: Topographical study; Field Investigation and test on the dam site (Geological study on embankment and foundation conditions); Review of the local material available at the dam site; Environmental impact and siltation control; Reservoir capacity investigation; Seepage control analysis; Economic/cost benefit analysis; Drafting of the final technical document (Design and Bill of Quantities) of the rehabilitation works
    - Engineering specification;
    - Work Plan, Bill of Quantities;
    - Drafting of the Tender Dossier

- For Meski dam:
  - Detailed Design, including: Topographic survey of the embankment area and surroundings using a 'Total Station'; Production of a detailed contour plan in electronic format; Building a hydrological catchment model; Running analysis of catchment model; Confirmation of embankment length and elevation; Soil testing and burrow pit identification; Design solution optimisation; Production of detailed technical drawings using computer aided design;
  - Engineering specification;
  - Work Plan, Bill of Quantities;
  - Drafting of the Tender Dossier

VI. Expertise Required

For this consultancy, a master degree in civil or water engineer is required, as well as a good field experience in hydraulic sector, especially in dams, water storage and reservoirs in rural areas of developing countries.

N.B. Interested applicants can send their CV, a financial offer and a detailed work plan of the consultancy to *recruitment.sudan@coopi.org*

Kerfu Dam Rehabilitation Feasibility Report

R.Delaney, March 2017

Overview

The Kerfu embankment dam lies in Um Baru Locality and is about 30 kilometres from Um Baru and about 17km from the Orshi embankment.

According to village elders at Orshi the embankment dam was constructed in 1968 but 11 years after being commissioned it was breached in 1979. Some years after the embankment was breached the local community constructed a small embankment near to 'watershed 2' in an attempt to store some surface water presumably to compensate for the loss of the water storage caused by the embankment breach.

The photograph below shows the breach in the embankment taken from a low point in the *wadi*.

The coordinates of Kerfu embankment are (lat 14.753560°, long 23.761920°).

Catchment

Below is an image showing the location of the Kerfu embankment as well as the catchment area in green. Also provided on the same image are the positions of Orshi embankment dam and Um Baru embankment dam for reference.

The catchment area of Kerfu dam is about 113km^2. This is considerably less than the catchment of Orshi embankment dam which is over 300km^2.

Rainfall data from the World Bank Climate Change Portal is presented below for a position considered to be the centre of the catchment.

AVERAGE MONTHLY RAINFALL FOR SUDAN AT LOCATION (14.85,23.7) FROM 1900-2012													
Mth.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	TOT
Rainfall (mm)	0	0	0	0	3.7	13.9	68.6	131.8	22.4	0	0	0	227

Rainfall data for Kutum is available for catchment modelling although Kutum is about 120km from the centre of the Kerfu catchment area.

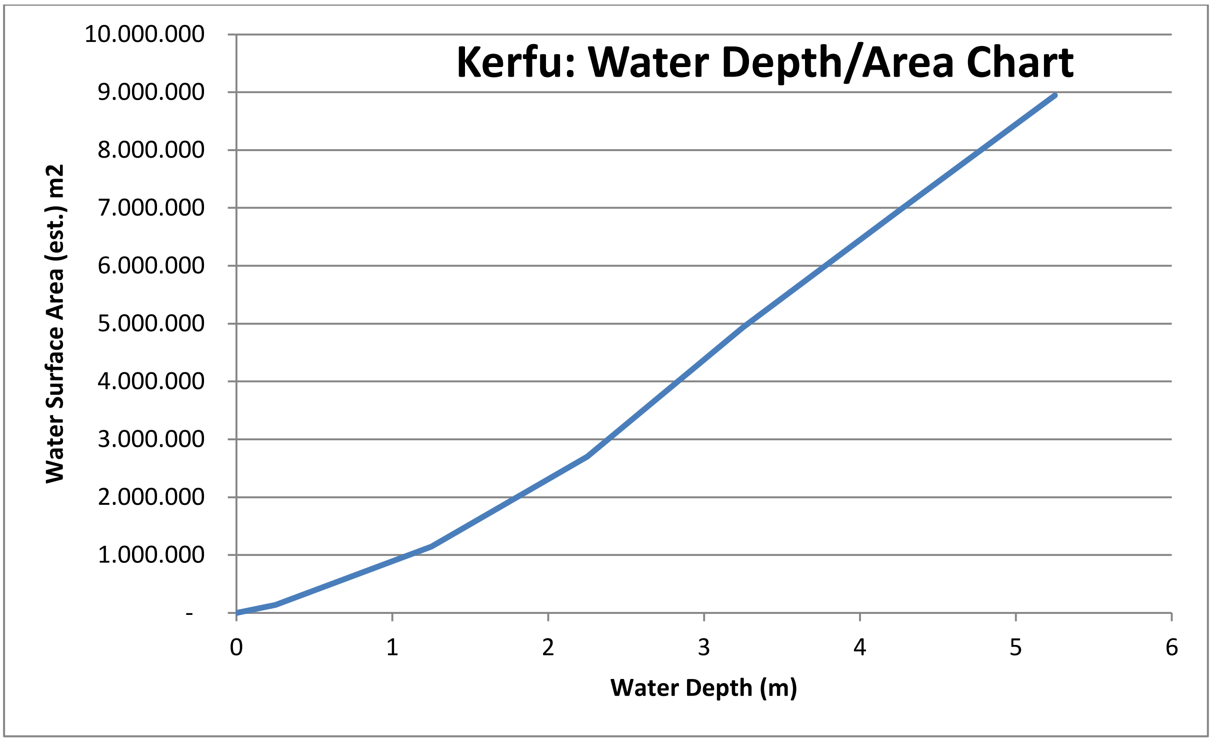
Estimations of the catchment yield estimate are given in the table below.

Parameter	Symbol	Unit	1% yield efficiency	2% yield efficiency	3% yield efficiency
Catchment Area	A	hectares	11,326	11,326	11,326
ditto		km2	113	113	113
Average Annual Rainfall	R	mm	227	227	227
Conversion to megalitres	K	-	0.01	0.01	0.01
Yield	Y	%	0.01	0.02	0.03
Run-off yield (= K x A x R x Y)	V	ML	257	514	771
ditto		m3	257,100	514,200	771,301

Assuming yield efficiency of 3 percent then, on average, 771,000 m^3 of water will run into the reservoir every year.

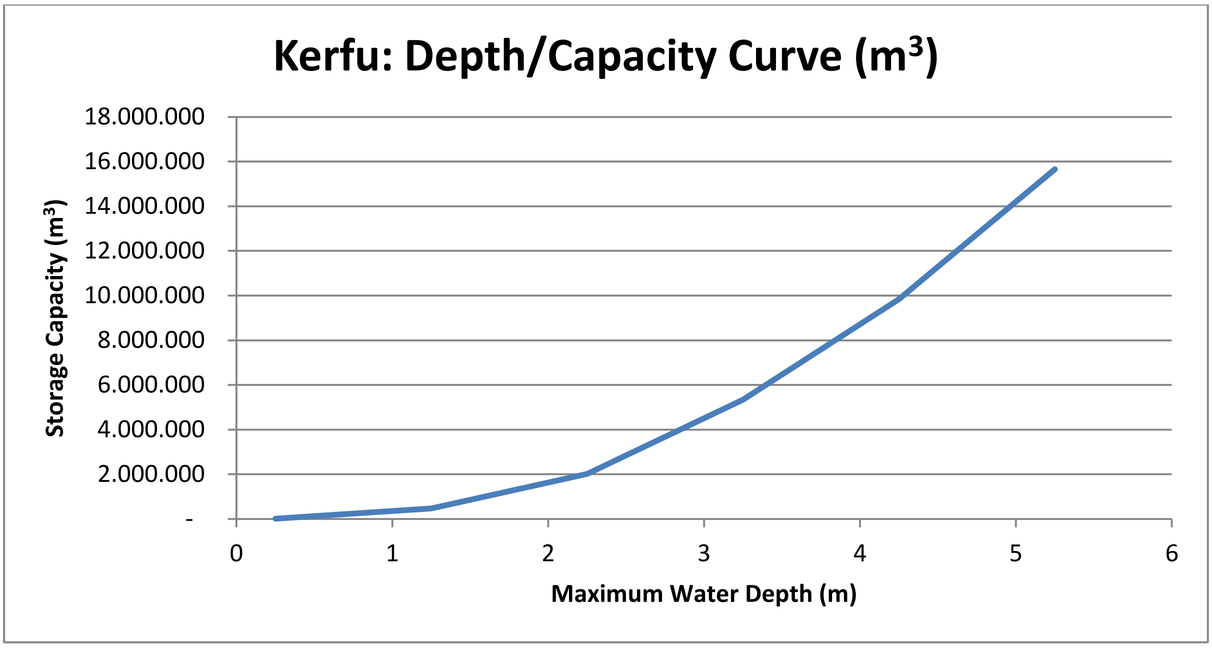
Depth-Area

Below is chart showing the maximum water depth and the water surface area. It shows quite a linear relationship between water depth and surface area. It is however an approximation and undertaking a survey using a Total Station would improve the accuracy of the chart.



Depth-Capacity

Below is a chart showing the relationship between maximum water depth and storage capacity of the reservoir.

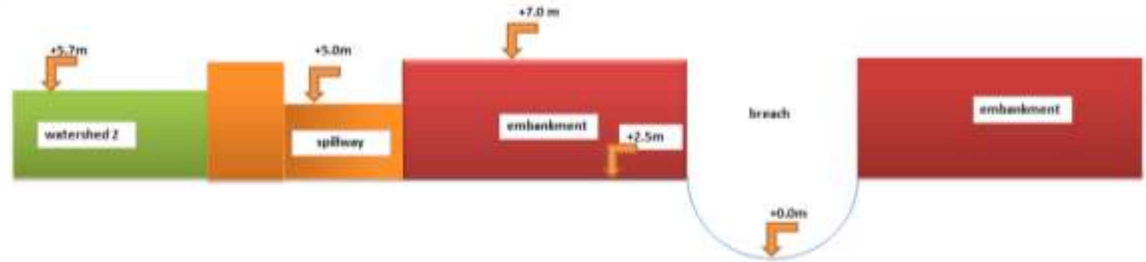


Survey Work

A modest topographic survey was carried as part of this feasibility study. A summary of the survey data is presented below. The elevations are relative to the lowest point in the *wadi* which passes through the breach.

Location	Elevation m (above datum)
Highest point of 'watershed 2'	5.7
Top of earth embankment	7.0
Crest of spillway	5.0
Ground level near embankment	2.5
Lowest point of the *wadi* at the breach	0.0

The information presented in the above table is now presented below as a schematic.



In addition the width of the breach was measured at 45m.

The interesting aspect of the survey work is that it appears that the elevation of 'watershed 2' is only 700mm higher than the spillway crest. This means that once the water depth at the spillway crest is greater than 700mm water will start to bypass the embankment by flowing over 'watershed 2'. In affect the embankment has two spillways, the concrete which starts to discharge when the water is 2.0m below the top of the embankment and a natural spillway ('watershed 2') which functions when the water level is 1.3m below the top of embankment.

The spillway crest was found to be 2m below the top of the embankment. The spillway width was measured and found to be 16.85m. Assuming that 1m is kept as a freeboard this means that the discharge rate through the spillway crest can be a maximum of $26m^3/s$.

Breach of the Embankment

A possible scenario for dam failure is that the spillway discharge capacity is too small which caused the water level to rise above the top of dam. Thus the embankment was overtopped which in turn lead to the breach. Certainly the spillway discharge does appear to be too small but this could be confirmed by creating a model of the catchment and running some rainfall events to analyse how the spillway performs under different extreme rainfall events.

However there is good reason to question this over-topping theory. Firstly it isn't thought plausible that the amount of the runoff from a catchment the size of Kerfu could, even in an extremely wet year, fill the reservoir to the top of the embankment. From the survey work undertaken there is about 4.5m height difference between the ground and the top of the embankment. At such a water depth the storage capacity in the reservoir is estimated at 12,000,000m^3. Since the annual run-off yield is estimated to be less than 1,000,000m^3 the chance than in any one year the water level could have reached the top of the embankment is extremely remote.

Secondly 'watershed 2' acts a natural spillway so together with the concrete spillway the discharge capacity would be very high once the water level is close to the top of the embankment. This is not to say that the embankment wasn't over-topped but it appears very unlikely based on estimates. Therefore it is very unlikely that the embankment was over-topped and another reason for failure is more plausible.

During the inspection of the embankment in 2017 burrows were observed in the downstream batter slope of the embankment. These burrows are very big and thought to be possibly the work of anteaters. If any seepage from the upstream batter slope found its way into the burrow it would quickly lead to 'piping' which would create a breach in the embankment.

The photograph below (taken in 2017) is of an animal burrow in the actual embankment at Kerfu.

While it is not known if these burrows are present at the time of the embankment being breached they certainly need to be removed and the void repaired during any rehabilitation. Also the community must be informed of the dangers of allowing animals to establish burrows in the embankment.

On inspection of Kerfu it's clear the standard of construction and level of supervision was very high. The embankment, constructed almost 50 years ago, is still in a good condition as evidenced by the photograph (below) taken in 2017. Also of note is that there is no evidence of over-topping on the remaining section of the embankment – the gravel on the top is still in place.

It is very difficult to know for certain what caused the embankment to fail in 1979 but the finger points towards poor maintenance such as letting animals making burrows in the embankment.

Rehabilitation Activities

Based on the above information it would appear that the maximum water depth is about 2.5m. Since the annual evaporation is in the region of 2m per year, it's likely that during the years the reservoir was functioning there was very little, if any, water remaining in it by the time the following year's rains started. Ideally therefore the rehabilitation of Kerfu dam should consider increasing the maximum water depth or 'top water level'. This would improve the chances of the reservoir holding water all year round and increase the amount of land coming into flood recession irrigation. However the water level is also determined by the amount of the water flows into the reservoir and for Kerfu this is far less than say at Orshi as the Kerfu catchment is only a third in size compared to the Orshi catchment.

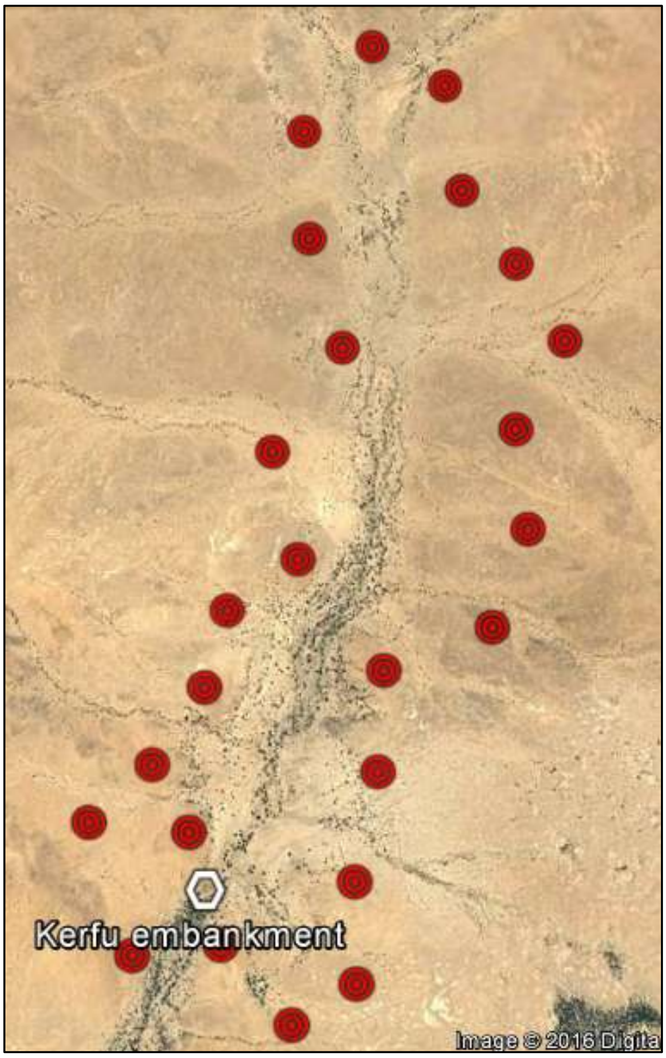
In Darfur there is a high degree of variability of rainfall compared to places with higher mean annual rainfall. What this means in practise is that it can be expected the annual rainfall and hence catchment yield will vary about the mean much more than other wetter areas of the world. By increasing the storage capacity of Kerfu reservoir this will help to store more water in the wetter than average years losing less water via the discharge over the spillway. On drier than average years however this could mean the reservoir failing to fill to the 'top water level' meaning very little, if any, water being left in the reservoir before the rains start again.

Should 'watershed 2' be found to provide the high discharge capacity, which is likely especially if the trees were cut down, then it may be concluded the existing spillway isn't required. This in turn could provide an opportunity to convert the exiting concrete spillway into a 'fuse plug' spillway. Basically this would entail placing an earth embankment between the spillway walls but the top of this embankment would be set at a slightly lower elevation than the main embankment. The concept is that should the water rise to an extremely high during an extreme rainfall event the 'fuse plug' embankment would fail first as this embankment section would be over-topped before the main embankment. The effect of this would be a sudden reduction of the water level in the reservoir which should (in theory) prevent the main embankment from being over-topped. The main advantage would be that rebuilding the embankment for the 'fuse plug' spillway would be a relatively simple task that could be done by community alone without external support.

Should the project be approved the next step would be to carry the detailed design work. This stage should include, but not limited to, the following activities;

- Topographic survey of embankment area and surrounding area using a 'total station'.
- Production of a detailed contour plan in electronic format.
- Building a hydrological catchment model.
- Running and analysis of catchment model runs.
- Confirmation of embankment length and elevation.
- Soil testing and burrow pit identification.
- Design solution optimisation.
- Production of detailed technical drawings using computer aided design.
- Preparation of contract documents including bill of quantities, specification and tender documents.

The experience gained from the rehabilitation of Orshi embankment dam highlights the importance of providing plenty of land for irrigation. Small, deep reservoirs may provide water all year round for animals but do little for irrigating large areas of land. For this reason it is recommended that an extended topographical survey is carried not only taking into account the embankment area but also upstream. This will allow the relationship between the water depth and land area to be understood accurately. Below is an image showing the proposed area to be surveyed, with red circles showing the places where temporary benchmarks could be positioned.



Much depends on the detailed contour survey so it recommend that as much preparation is as done as possible prior to the commencement of the actual survey work. In additional to actual procurement of the survey instruments and tools the following should be well-ahead of the field work;

1. Clearing of vegetation to allow line-of-sight between station and prism. Since this can be time-consuming and big job, often done by the community, it needs to be well planned in advance.
2. Positioning of benchmarks around the area to be surveyed. This task will take a few days in total. If the personnel could be found to undertake the task ahead of time so much the better. The object is to have benchmarks places around the survey area and there is a clear line-of-sight between adjacent benchmarks. Enough vegetation should be cleared around the wadis so that survey readings can be made from the benchmarks to all parts of the wadi. The trees don't have to be cut down but rather cut-back.

Conclusions & Recommendations

It's unlikely that the breach was caused by 'over-topping', rather poor maintenance may have played a critical part in the events that cumulated in the abandonment of the dam.

Due to relatively small catchment area (compared to that of Orshi & Meski) the yield of the catchment is likely to be, on average, less than 1,000,000m^3 every year. This would seem to equate to a typical maximum water depth of only 1.5m which means for most years the reservoir will be very nearly dry before the following rains begin.

It appears technically possible to repair the breach and at the same time increase the maximum water depth.

It is recommended that the detailed design stage goes ahead including a full topographic survey to produce a detailed contour map.

No settlement was observed at the Kerfu embankment unlike Um Baru & Orshi. Looking at satellite imagery no settlements can be seen close the water. It's not clear therefore about the issue of ownership and where would be beneficiaries are living. It could be simply that people have moved away, to say Orshi, since the embankment was breached.

The issue of maintenance is a concern especially since nobody lives next to the embankment. It could be that people will settle once the dam is functioning but these issues need to be clarified with local leaders to avoid any rehabilitation project becoming a 'white elephant'.

In summary therefore while the rehabilitation of the dam is technically feasible what is lacking so far is clear evidence by the local community that they want the Kerfu dam rehabilitated, will benefit from it and will maintain it. Should these concerns be addressed then it recommended that Kerfu dam is rehabilitated.

Meski Ebeid Embankment Dam Feasibility Report

R. Delaney (March 2017)

Background

Meski Ebeid (lat 14.868550°, long 23.628890°) is within the Kornoi Locality but is actually is only about 20km from Um Baru therefore it is accessible from the COOPI base at Um Baru.

In 2016 employees of COOPI were approached by people from Meski Ebeid to whether COOPI would be interested in helping to construct a dam at their village, presumably because they had become aware of COOPI's involvement with Um Baru and Orshi dams which are not that far away.

The site was studied by the Surface Water Department based in El Fasher which resulted in an outline design with Bill of Quantities.

COOPI investigated the site in early 2017, discussed the project which stakeholders, carried out a topographic survey and took a soil sample.

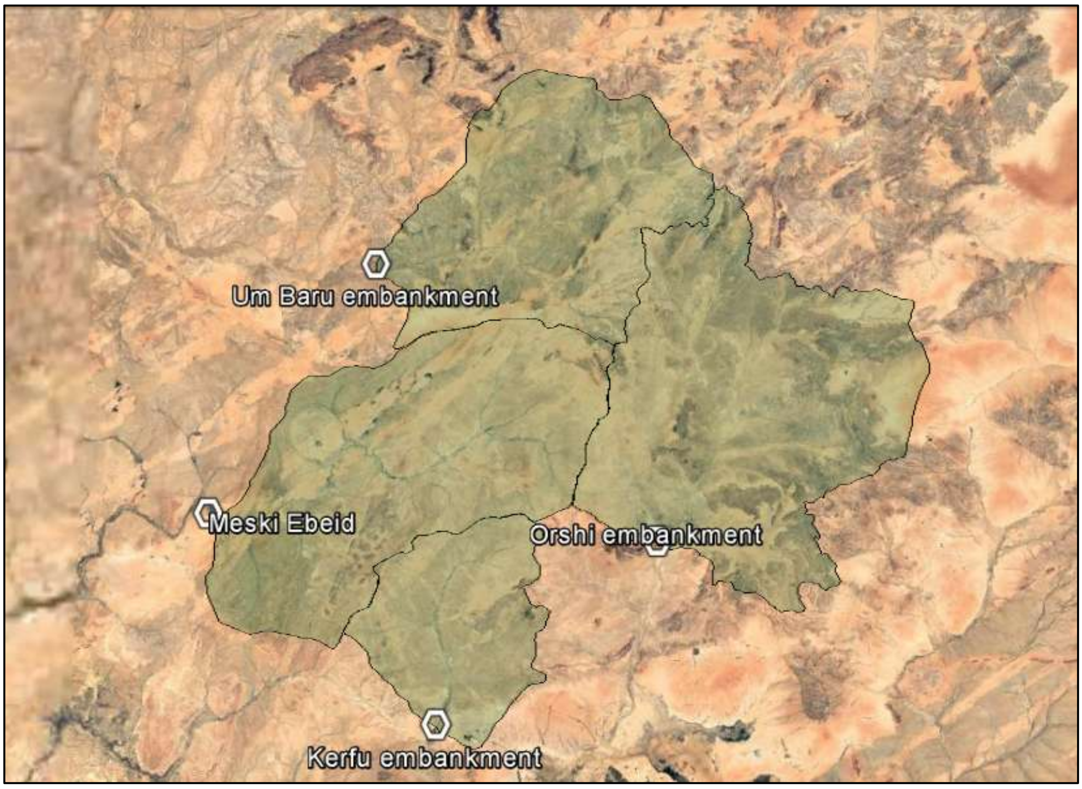
Water is scarce at Meski Ebeid and presently people have no irrigation options outside of the rainy season. The community have recently tried to construct a small dam wall (see photo below taken in 2016) but it failed to hold water due to technical reasons and when inspect in 2017 is had been badly damaged during the rainy season.

Catchment

The catchment area for a dam at Meshi Ebeid is approximately 295km^2 although this figure may be adjusted somewhat during the detailed design stage. The catchment area of a Meshi Ebeid dam therefore is a little under that of Orshi dam which has a catchment area of 334km^2.

The image below shows the catchment area in green as well as the locations Meski Ebeid and the embankment dams that COOPI has or will be involved in, namely Um Baru, Orshi and Kerfu.

Also of note are the shared watersheds of the four catchments areas of Meski Ebeid, Um Baru, Orshi and Kerfu. This is shown on the image below with catchment areas of all the four listed sites. This could prove very interesting for supplementary developmental projects involving say soil conservation and land husbandry since improvements in how the land is used within the catchment area will reduce the amount of silt entering the water storage reservoirs.



The area of each catchment together with the combined total is given in the table below.

Catchment	**Catchment Area (km^2)**
Um Baru	235
Orshi	334
Kerfu	113
Meski Ebeid	295
Total Combined Area	977

Extreme event rainfall data already obtained for the Orshi dam rehabilitation can be utilised for catchment modelling and spillway design.

World Back Climate Change Portal was used to estimate mean annual rainfall and the findings are presented in the table below.

(AVERAGE MONTHLY RAINFALL FOR SUDAN AT LOCATION (14.93, 23.79) FROM 1900-2012)													
Mth	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	TOT.
Rain (mm)	0	0	0	0	0	10.23	63.84	121.98	18.71	0	0	0	215

The mean annual rainfall is therefore expected to be close to 215mm per year. However this figure is based on historic rainfall data and with climate change the mean annual rainfall is likely to become less than 215mm per year.

Catchment Yield

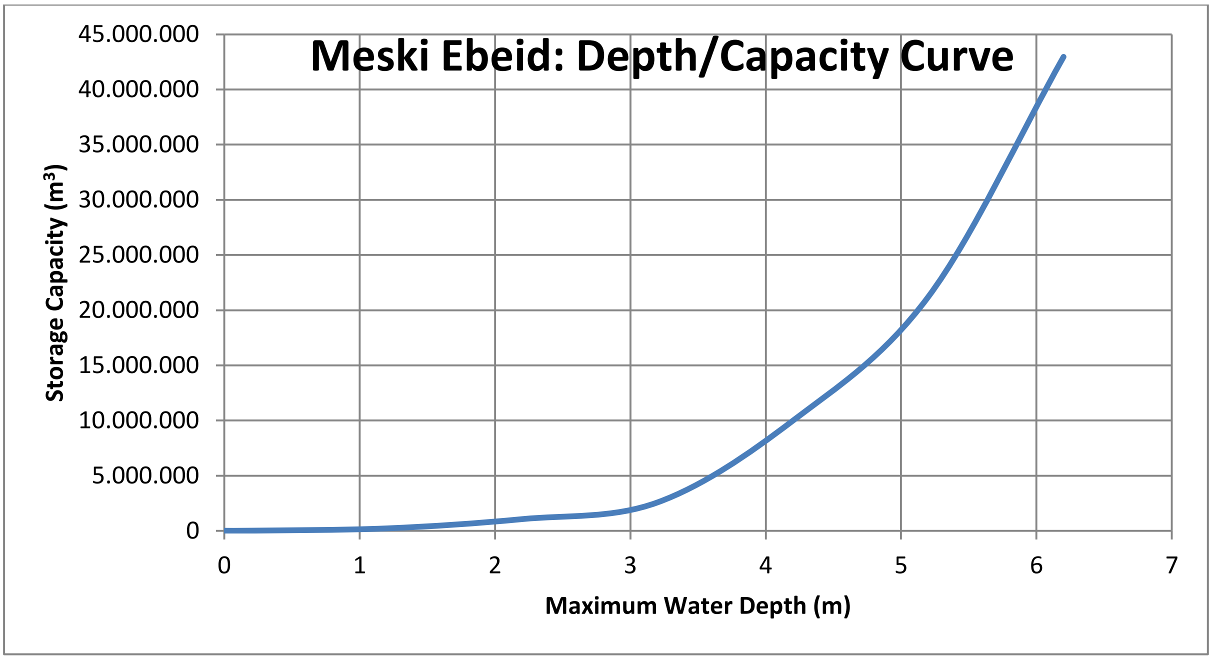
The amount of water actually entering any reservoir is dependent on the 'yield efficiency'. The table below gives some estimates of the catchment yield for three different yield efficiencies since it's not known what the yield efficiency with any degree of certainty.

Parameter	**Symbol**	**Unit**	**1% Yield Efficiency**	**2% Yield Efficiency**	**3% Yield Efficiency**
Catchment Area	A	hectares	29,457	29,457	29,457
ditto		km^2	295	295	295
Average Annual Rainfall	R	mm	215	215	215
Conversion to megalitres	K	-	0.01	0.01	0.01
Yield	Y	%	0.01	0.02	0.03
Run-off yield (= K x A x R x Y)	V	ML	633	1,267	1,900
Run-off yield		m^3	633,326	1,266,651	1,899,977

Assuming a 3% yield efficiency then around $1{,}900{,}000m^3$ of water can be expected to flow into the reservoir on an average year.

Depth/Capacity Curve

Below is an estimated relationship between maximum water depth and water storage capacity for a reservoir at Meski Ebeid.

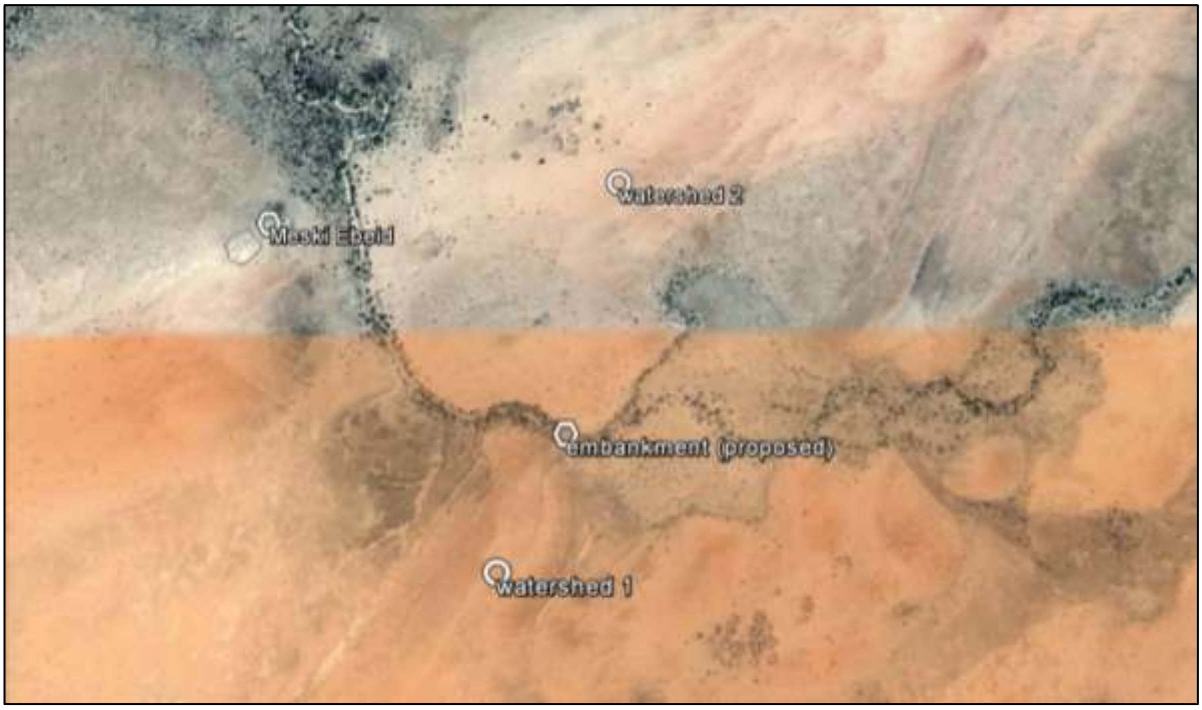


The above curve is based using the digital elevation data extracted from Google Earth. A topographical survey done on the ground using say a Total Station would provide a more accurate relationship between depth and storage capacity.

Design Options

The image below shows the location on the main Meski Ebeid village and the proposed location of the embankment (lat 14.862966°, long 23.636911°). Also shown on the same image are the locations of two natural watersheds. Water flows from right to left during the rainy season.

The proposed design solution involves the construction of an earth embankment dam at the point shown to such at an elevation that either ‘watershed 1’ or ‘watershed 2’ acts as a natural spillway.



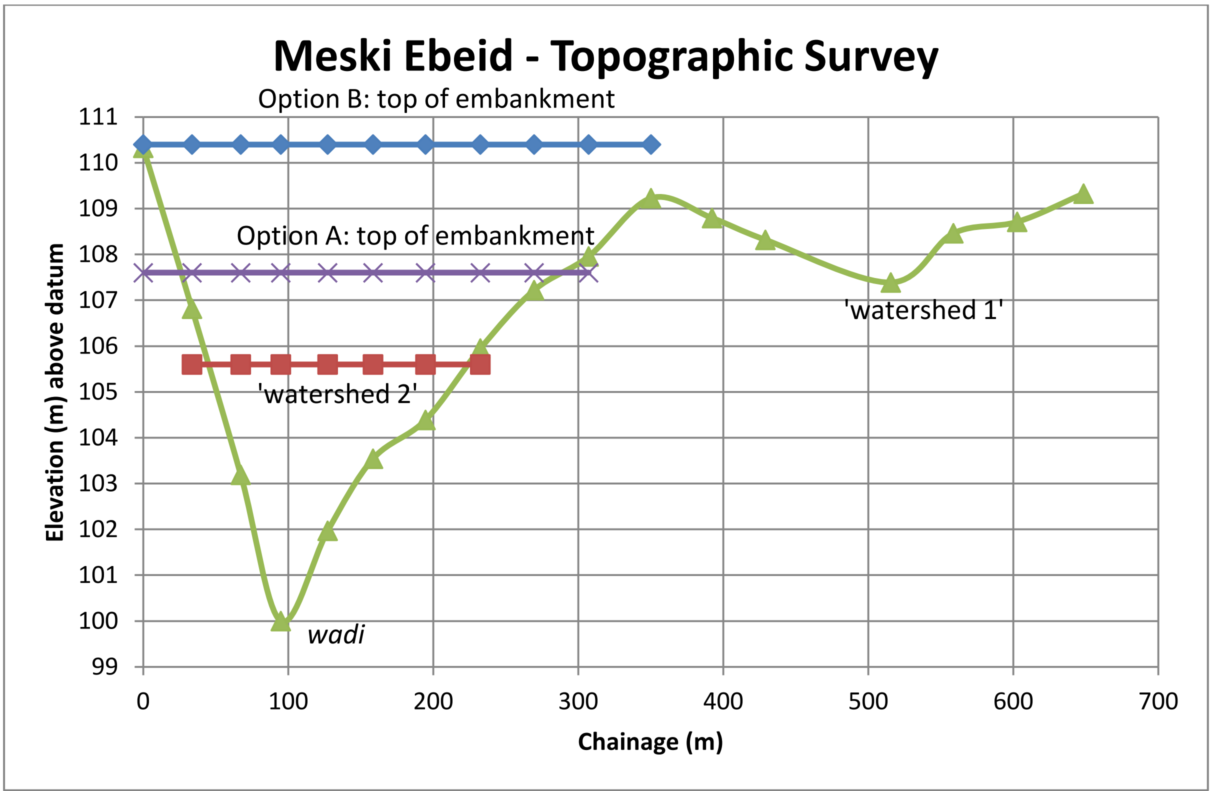
A brief topographical survey was undertaken on-site and it was found that ‘watershed 2’ is at a lower elevation than that of ‘watershed 1’. This provides two possible design solutions’;

Option A) ‘watershed 2’ is used as the main spillway.

Option B) Constructing another embankment at ‘watershed 2’ so that ‘watershed 1’ acts as the only spillway.

Option B will provide the highest water depth and provide the greatest area of land that is irrigated by flood recession.

Below shows the results of the topographic survey displayed as a chart. If ‘watershed 1’ were to be used as the main spillway it would give a maximum water depth of about 7m. This would involve the construction of the embankment dam at the *wadi* to a height of 10.5m and an embankment at ‘watershed 2’ of a height of 5m.



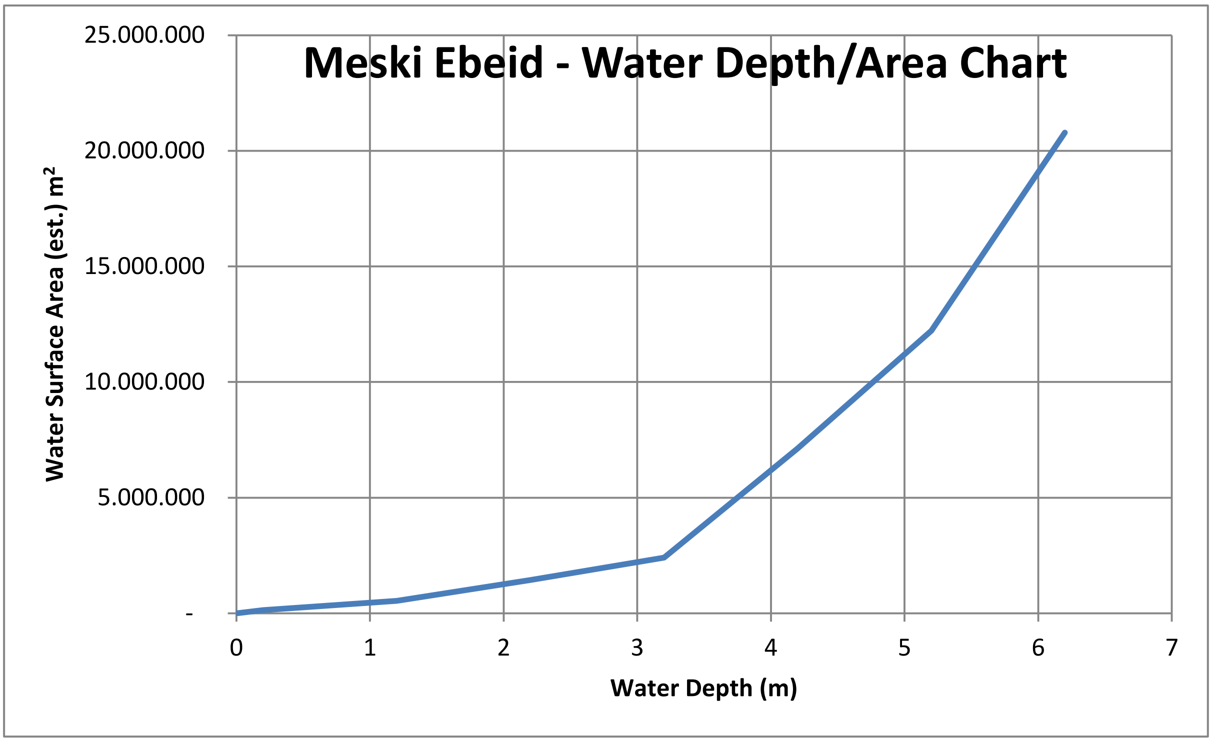
The difficulty with design Option B is that it the storage capacity may be in far excess of the mean annual runoff. This would that for most years the reservoir will not fill to the top water level. Option B uses ‘watershed 1’ as the spillway which means the maximum water depth is slightly over 7m. At such a depth the storage capacity is over 50,000,000m^3 while the expected mean inflow is just less than 2,000,000m^3. Based on these estimates therefore it is extremely unlikely that the reservoir will fill and water discharged over ‘watershed 1’ acting as a spillway. It could however the estimates are wrong and the ‘yield efficiency’ for the catchment as much greater than 3%. However based on the estimates to date in would appear that Option A would be the most cost-effective solution.

Option A has a lower water depth than Option B but the material for embankment construction is less than for Option B so will be the cheaper of the two options. Also since the maximum water level is less for Option A than Option B the number of houses having to move will be less since the water level will not rise as far.

Other designs options are technically feasible, such as masonry dam wall with spillway or a concrete dam wall with spillway, but these are not being proposed at this stage due to technically challenging nature of these interventions. Earth embankments are technically suitable as they have been done many times previously in Darfur and using natural watersheds as spillways can provide a very high discharge capacity.

The chart below shows the approximate relationship between the maximum water depth and area of land that will be flooded.

Assuming that 1,900,000m^3 of water enters the reservoir every year, on average, then this would equate to a water depth of around 2.5m. Given that evaporation is around 2,000mm every year usually there will little water left in the reservoir before the rains start again. In addition for the years when there is less runoff than normal the reservoir may dry up before the next rainy season. For wetter than normal years the amount of irrigated land will be greater than normal which could be exploited by the community by increased land put to agriculture use.



Detailed Design Work

A soil sample was taken from a pit close to the location of the proposed embankment. The sample was found to have a high clay percentage and this kind of clay would make a good core material of any earth embankment. However the pit (dug for a previous dam survey) from which the sample was taken is too close to the proposed embankment so would not make a suitable burrow pit. It does show however there is a good chance of finding suitable a burrow pit within a reasonable distance to the proposed embankment.

The present water situation at Meski Ebeid is a concern for the construction of an embankment dam. The only water available is from a handpump located at the Meski Ebeid village. However COOPI team who are familiar with the water source say, based on their experience, the yield is very small and there is no possibility of increasing the output by installing an electric submersible pump. Water will have to be transported in from Um Baru and stored on-site during the construction period.

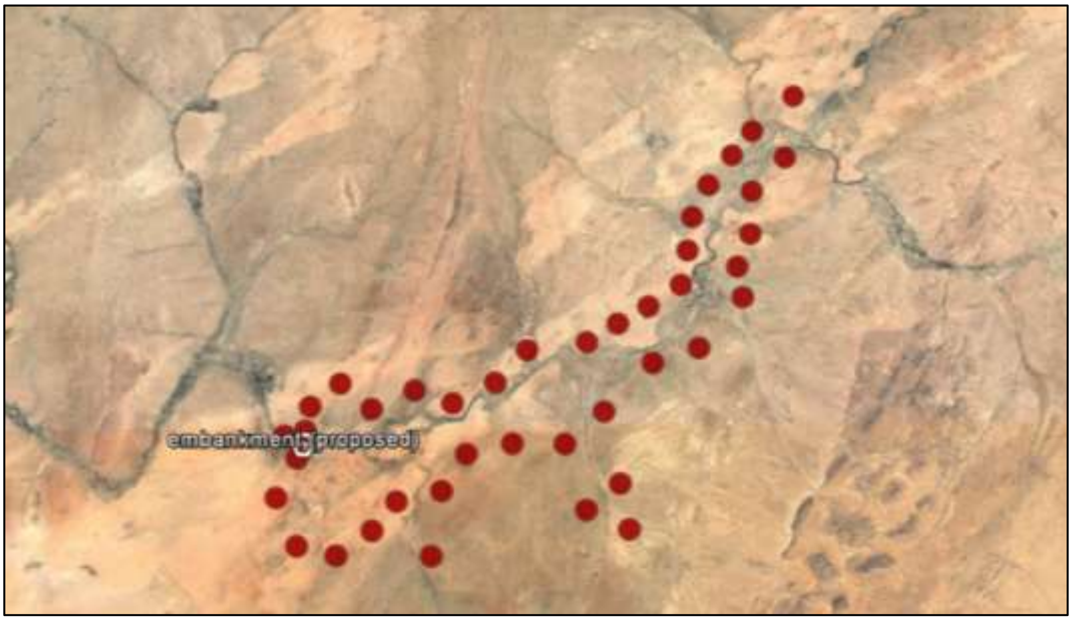
On one side of the *wadi* rock can be seen at the surface along the path that the line of the embankment will follow. From a design point of view this is challenging since it's a not simple operation to dig a trench in rock along the line of the embankment for the 'core trench'. A solution could be construct a low and wide **key wall** (using stone) on the rock and a typical core trench on the section where bedrock is below the surface. This requires a detailed design and very importantly good site supervision. An option may be to bring in a specialist contractor just for the key wall prior to main 'earth moving' contractor. This may also have the advantage of the people can see things happening on-the-ground sooner rather than later.

Should this project be approved the next stage would be to carry out detailed design work. This stage would involve, but not limited to, the following;

- Topographic survey of embankment area and surrounding area using a 'Total Station'.
- Production of a detailed contour plan in electronic format.
- Building a hydrological catchment model.
- Running and analysis of catchment model runs.
- Confirmation of embankment length and elevation.
- Soil testing and burrow pit identification.
- Design solution optimisation.
- Production of detailed technical drawings using computer aided design.
- Preparation of contract documents including bill of quantities, specification and tender documents.

An expansive topographic survey is required using a 'Total Station' not only to produce an accurate contour plan of the embankment and spillways areas but also the area will potentially become the reservoir. The image below indicates the area that should be surveyed with circles being points for temporary benchmarks. The distance from the proposed embankment to the furthest point is about 10km.

In order to prepare for the survey work vegetation needs to be cut back to allow for line-of-sight vision between the station and the prism so reading can be made between temporary benchmarks and to the *wadi*. This work should ideally be done before the surveyor arrives on-site in order to safe time.


embankment (proposed)

Conclusions & Recommendations

A new earth embankment dam at Meski Ebeid appears to be technically feasible and if it were to go ahead it would be a huge benefit to the people of the surrounding area if terms of improving water security.

The proposed dam design is an earth embankment with a natural watershed being utilised as a spillway. The detailed design stage will determine the most suitable design solution.

Construction of a dam would mean it is likely that some people will have to move their houses to higher ground to avoid high water levels. Such a scenario was discussed with the villager elders of Meski Ebeid and it doesn’t present a significant issue. The nature of the houses and small distances people will have to move mean the inconvenience of moving will be far outweighed by the benefits of the dam. The community state that they will not expect compensation for moving the homes to higher ground.

The project could be managed from the COOPI base at Um Baru.

The recommended next stage would be to undertake a detailed design of the project which would be best done over the winter of 2017-2018, say from Oct 2017 to Feb 2018.

It is recommended the actual construction work starts the following year around October 2018 at the latest. The work would have to be completed before the rains of 2019 begin or the embankment will be destroyed.