Consultancy Service to Identify, Study and Design Potential Water Harvesting Interventions Rehabilitation of Azagarfa earth Dam, in El Fasher Locality – North Darfur State

Rehabilitation Azagarfa Earth Dam for Water Spreading

in North Darfur

Technical Design Report

By

D.E.E. DAMS ENINEERING ENTERPRISES

الهندسية دامس

Mob. ,00249122606797 ,00249912319503 e-mail :

dams.dee2020@gmail.com ,hashimna59@gmail.com

Arkaweet-48Africa Street-Building258Khartoum,SUDAN

Khartoum, **November 2021**

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1. Introduction

The key objective design and study of the Azagarfa Dam in North Darfur is to provide water supply for people living in the respective areas and their animals.

The scope of work of this consultancy as stipulated in the agreement has four specific stages:

Stage 1: Identify potential locations for water harvesting structures. To identify with support from PA, relevant state government ministries and departments, and from local communities of the most suitable locations within the mentioned area of low cost, suitable and environmentally friendly water harvesting structures. To fulfill the aforementioned requirement, the followings are needed.

- Undertake a rapid socio-economic and environmental assessment of the wider area surrounding the proposed locations.
- Examine existing water harvesting structures
- Consider the most beneficial interventions according to available financial resources

Stage 2: Carry out a topographical survey and hydrological investigations. The survey should include: conducting leveling to assess the topography of the terrsin, plotting of contour maps ans use the relevant surveying instruments and modeling of mapping (Aecview, GIS). The hydrological investigation is to assess hydrological parameters to estimate design flow, check high water marks levels, etc…

Stage 3: Design on the base of the above analysis, the most appropriate water harvesting structures and two Dams for suitable locations

Stage 4: Conduct monitoring and supervision of implementation of water harvesting structures during the implementation period. The consultant shall be available for periodic sites visits throughout the construction of the water harvesting structures with a view monitoring and ensuring quality – control of the construction work.

This report is handling the design of Azagarfa Dam as well as the preparation of the Bill of Quantities for the works to be carried for the construction.

2. Dam Location

An inception report was prepared and submitted to PA. That report describes the consultant methodology, meetings with relevant bodies, the sites visits conducted and the report concluded with the identification of the three water harvesting interventions. The locations are as shown in table 1 below.

Table 1:Location of Azagarfa Dam (marked in blue)

Name	Type	Coordinates		Sub-Catchment
		Eastern	Northern	
Azagarfa	Dam	324001	1535805	Tabouse

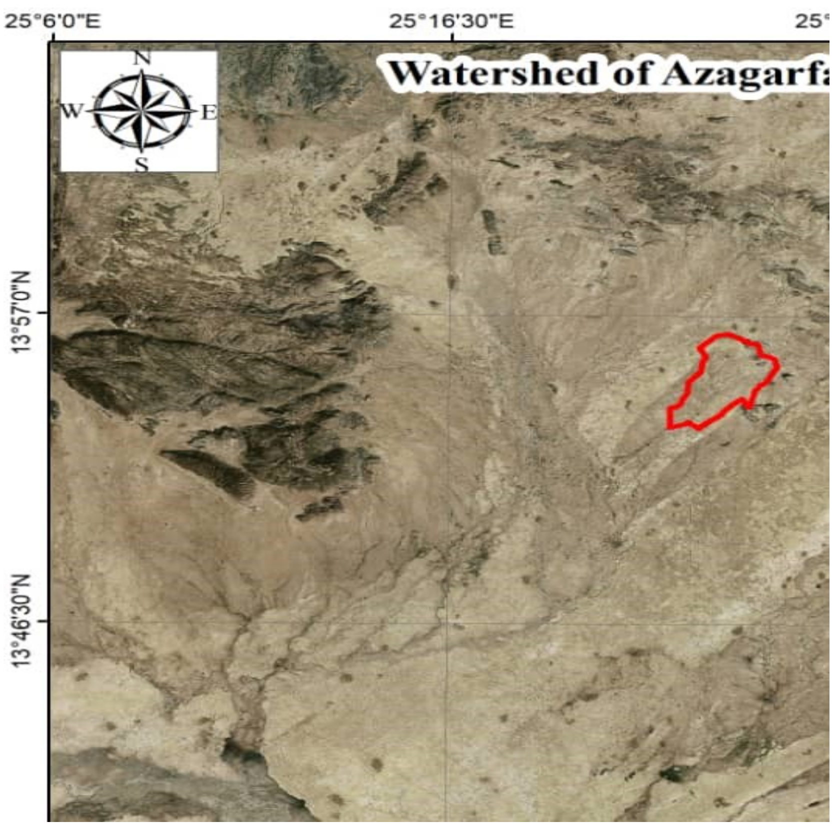

Figure 1: Location of Azagarfa Dam (Watershed)

3. Topography & Soil Characteristics

3.1 Topography

The terrain of the project area is generally gentle with so many hills in the area. The slope is almost from west to east in Azagarfa, Dam observed very high water mark at existing Dam site. The project area is within the attitudes 819 m above sea level.

The consultant carried out engineering topographical survey 2.0x1.0 km^2 surrounding of the Dam area. This involves topographic surveying and leveling (longitudinal, cross sections, site survey and layout plan). The topographical survey had been carried out using Total Station technology, profiles with Engineering Level global positioning with GPS with competent surveyors that have a reliable experience.

Figure 2: Topography Survey using Total Station

The survey works also involve establishing of Temporary Bench Marks (TBM).and numbered in sequence.

Table 2:Coordinates of benchmarks UTM

BM.NAME	EASTING	NORTHING
BM1	324001.066	1535805.547

Drawings showing designated number of TBMs, its co-ordinates and elevations have been produced as shown in table below as well as they included in the working drawings attached with this report.

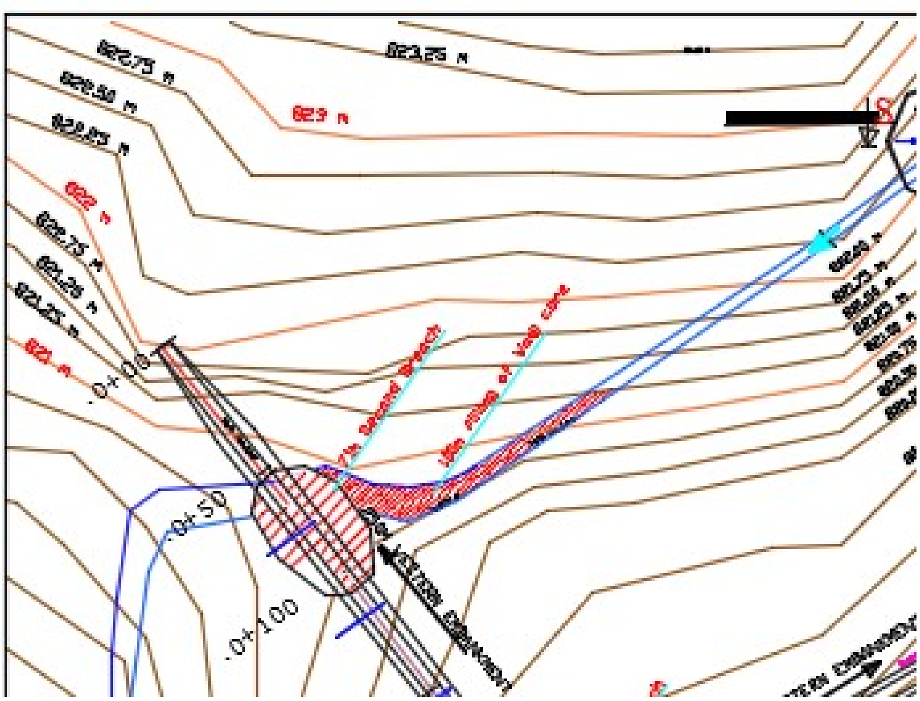

Figure 3:Contour Map of the dam reservoir

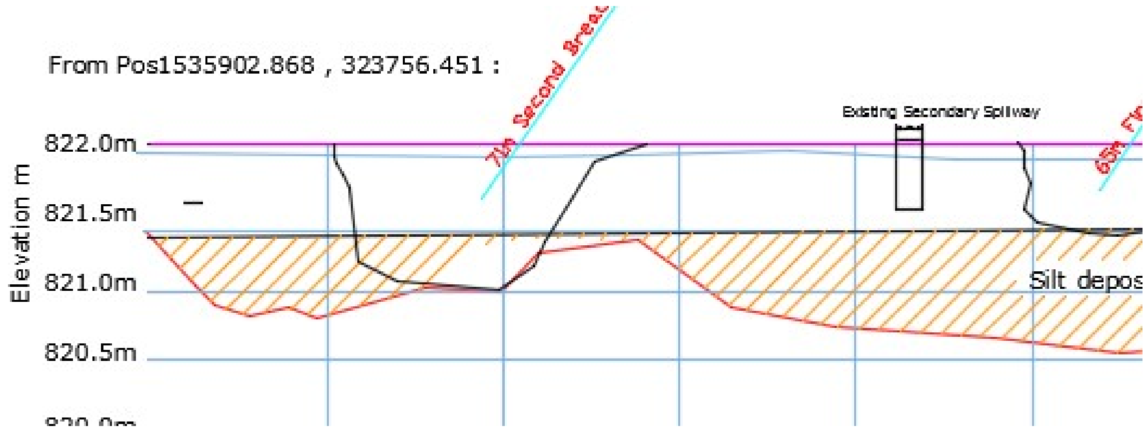

Figure 4:Cross Section in the upstream vicinity of the Dam Axis

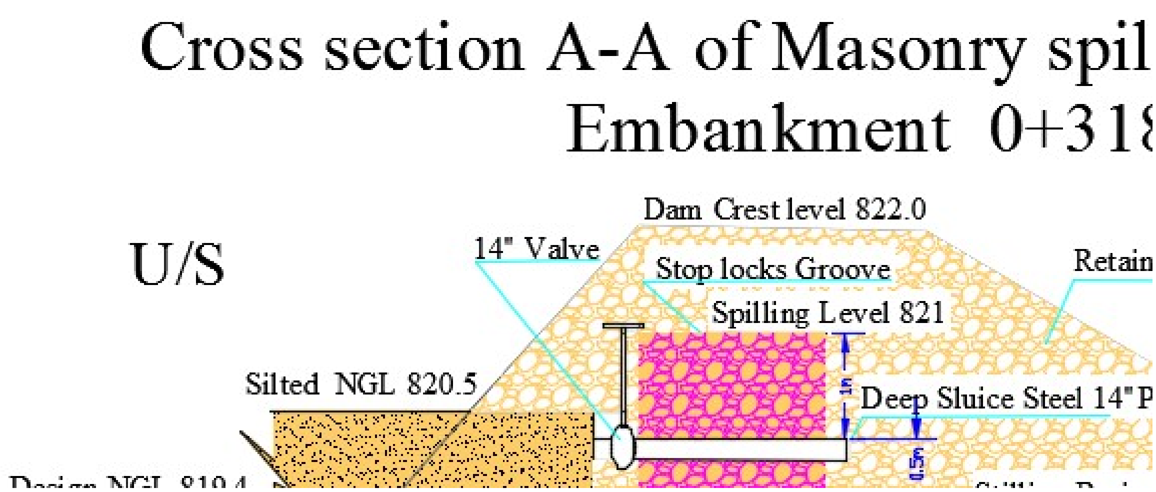

Figure 5:cross section of existing main spillway

3.2 Soil Characteristics & Recommended Dam Height

For the existing dam location and within its axis the soil found is silty sand silty clay soil. It is very suitable for the earth-fill dam foundation. The consultant decided not to take further samples. Fig. 4 shows the geological profile within the dam axis. The dam height is about 3.0 m

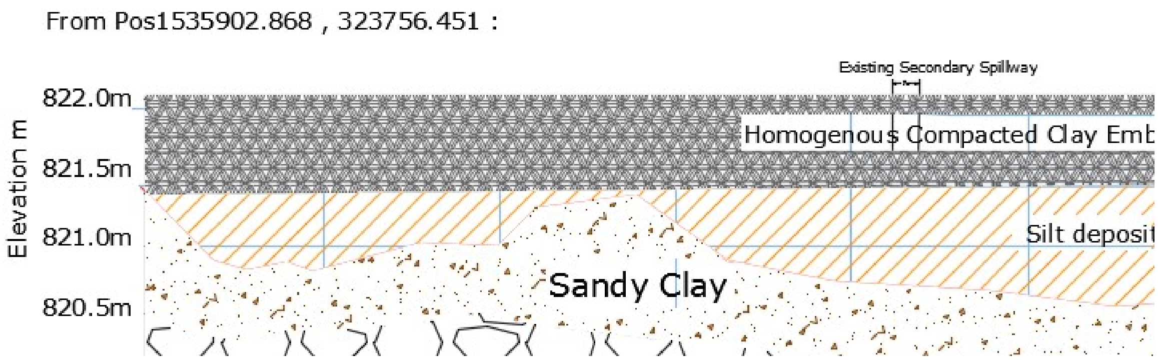

Figure 6:Dam Axis Geological Profile

4. Water Availability & the Water Demands

4.1 Water Availability

4.1.1 Rainfall

The project area (North Darfur) rainfall has recorded almost since 1981. Table (4) shows the historical annual rainfall of the town.

Table 3 North Darfur Historical Annual Rainfall

Year	*Annual Rainfall (mm)*	*Year*	*Annual Rainfall (mm)*
1981	*197.2*	*1996*	*149.8*
1982	*110.4*	*1997*	*159.7*
1983	*72.7*	*1998*	*380*
1984	*107.5*	*1999*	*269.5*
1985	*171.6*	*2000*	*268*
1986	*200.1*	*2001*	*165.2*
1987	*214*	*2002*	*166.7*
1988	*246.3*	*2003*	*154.3*
1989	*157.7*	*2004*	*98.8*
1990	*125.2*	*2005*	*317.2*
1991	*212.6*	*2006*	*222.2*
1992	*202.9*	*2007*	*281.9*

1993	*150.1*	*2008*	*159.1*
1994	*306.8*	*2009*	*130.7*
1995	*221.1*	*2010*	*240.3*

Annual rainfall in project area is particular characterized by consecutive years below the average, this was continued till 1985 and then started to be interrupted by wet years till 1997 but still oscillated below the average. Then the pattern is changed to reverse, i.e.; a number of consecutive years of rainfall above the mean interrupted by few years of rainfall below the mean.

The highest recorded rainfall in single year was 380 mm occurred in 1998.

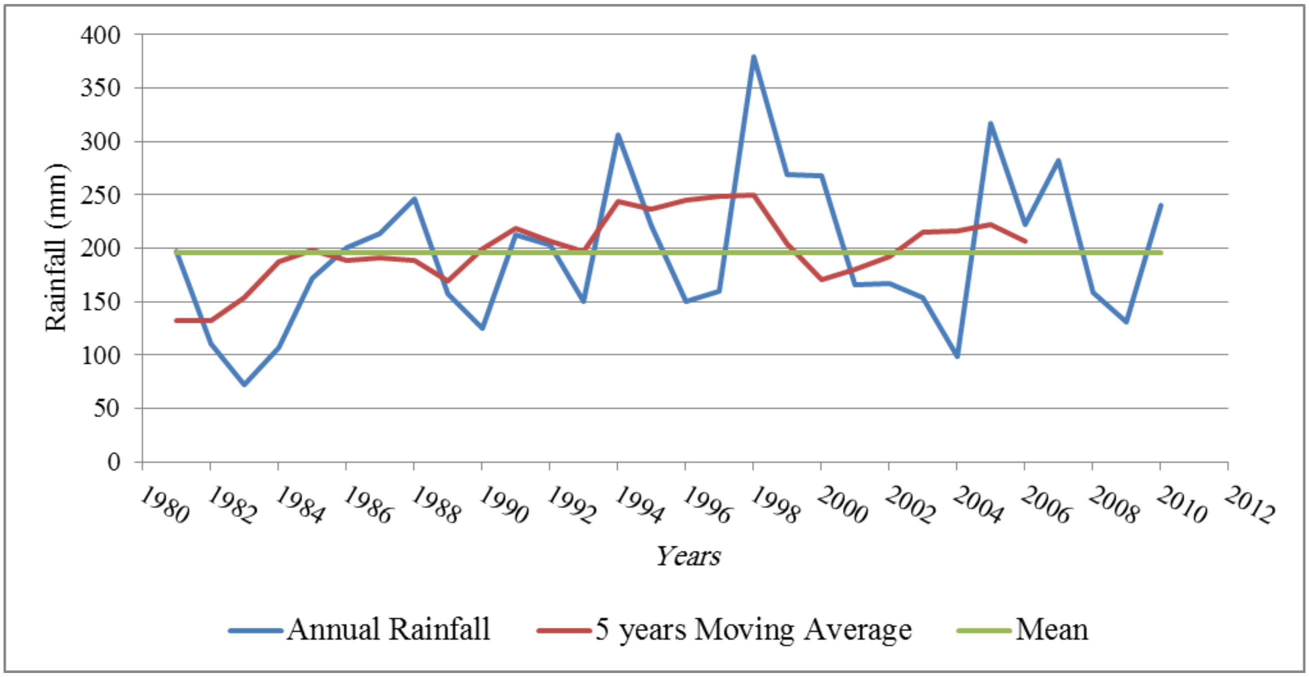

Figure 7: North Darfur Annual Rainfall Oscillation

4.1.2 Rainfall Intensity

Rainfall intensity is an important factor in the development of the floods and influence strongly the highest peak discharges. Highest Maximum Daily Annual Rainfall for 30 years is shown in the table below.

Table 4: North Darfur Annual Highest Event Rainfall

No.	year	Max Rainfall (mm)	No.	Year	Max Rainfall (mm)
1	1981	39.2	17	1997	41.7
2	1982	29.8	18	1998	44
3	1983	18.4	19	1999	51.8
4	1984	40	20	2000	30
5	1985	40	21	2001	43.6
6	1986	28.2	22	2002	20.7
7	1987	77	23	2003	42.2
8	1988	51	24	2004	14
9	1989	35.4	25	2005	132.4
10	1990	29	26	2006	39.1
11	1991	75.3	27	2007	59.1
12	1992	29.4	28	2008	15.6
13	1993	30.7	29	2009	25.1
14	1994	32.1	30	2010	46.3
15	1995	31	31	2011	40
16	1996	27.9	32	2012	53.2

The highest rainfall of North Darfur was subjected to return period analysis to obtain the highest rainfall against design return period.

4.1.3 Maximum Rainfall Return Period Analysis

Intensity data of rainfall for the area is estimated by analyzing statistically maximum daily rainfall observed at North Darfur. These data are subjected to return period or recurrence interval analysis to obtain flood for different recurrence intervals.

Steps for Return period analysis:

- Arrange the floods data in descending order.
- Give each flood value a rank starting from the highest and then go down to the lowest.

- Calculate the return period in years using equation:

  T = n+ 1 /m.

  Where:

  T = recurrence interval in years.

  n = number of observations.

  m = rank of flood data.

  Then plot flood data against corresponding Ts.

Table 5: Analysis of Return Period Method

Rank	*Max Rainfall (mm)*	*T (Recurrence period (n+1)/m)*	*log T*
1	132.4	33.0000	1.5185
2	77	16.5000	1.2175
3	75.3	11.0000	1.0414
4	59.1	8.2500	0.9165
5	53.2	6.6000	0.8195
6	51.8	5.5000	0.7404
7	51	4.7143	0.6734
8	46.3	4.1250	0.6154
9	44	3.6667	0.5643
10	43.6	3.3000	0.5185
11	42.2	3.0000	0.4771
12	41.7	2.7500	0.4393
13	40	2.5385	0.4046
14	40	2.3571	0.3724
15	40	2.2000	0.3424
16	39.2	2.0625	0.3144
17	39.1	1.9412	0.2881
18	35.4	1.8333	0.2632
19	32.1	1.7368	0.2398
20	31	1.6500	0.2175
21	30.7	1.5714	0.1963
22	30	1.5000	0.1761
23	29.8	1.4348	0.1568
24	29.4	1.3750	0.1383
25	29	1.3200	0.1206
26	28.2	1.2692	0.1035
27	27.9	1.2222	0.0872
28	25.1	1.1786	0.0714
29	20.7	1.1379	0.0561

30	*18.4*	*1.1000*	*0.0414*
31	*15.6*	*1.0645*	*0.0272*
32	*14*	*1.0313*	*0.0134*

Figure (8) and table (7) depict the results of the analysis represented on graph and the displayed equation.

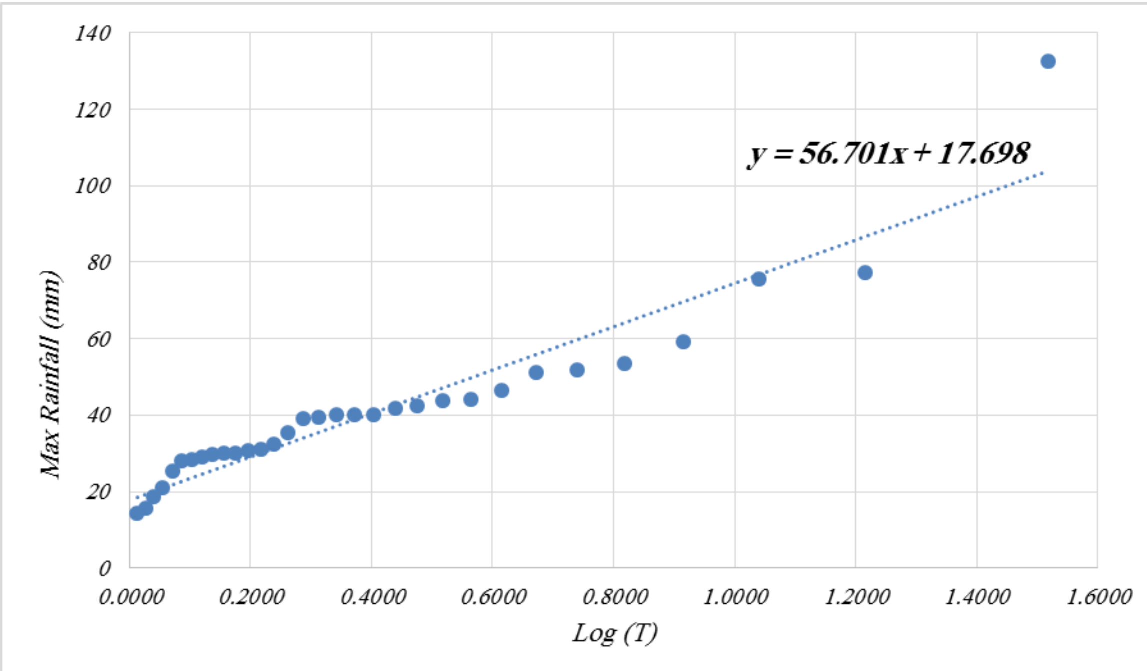

Figure 8: Maximum Rainfall Return Period Analysis

Y = 56.701 x + 17.698

Where:

Y = Design Rainfall for given Return Period.

X = log T (return period in years).

This equation is used to calculate the Design Rainfall expected for different Return Periods as shown in table below:

Table 6: Design Rainfalls for Different Return Periods

Return period(years)	10	20	50	70	100
Design Rainfall(mm)	74	91	114	122	131

The Design return period is determined according to the importance of the dam and the financial investment in the construction. 50 years return period is recommended and the design rainfall of 114 mm will be considered in computation of peak discharge of Azagarfa wadi.

4.1.4 Peak Flow Estimation

The relationship between rainfall and runoff is far from direct measurements. The Table below summarizes the main factors that influence the magnitude of flood peaks within a rural catchment. If at a particular site of interest, detailed flow observations are available, together with the appropriate rainfall records; these can be considered directly to help the assessment of extreme floods. However, this data is not normally available, and so recourse has to be made to other statistical methods to estimate flood flows. The basis of these is catchment and climatic characteristics.

Table 7: Factors Influencing the Magnitude of Flood Flows from a Rural Catchment

Factor	Comment
Rainfall	The magnitude and flood flows are influenced not just by the amount, but also by the duration and intensity of recent rainfall.
Catchment area	The magnitude of flood flows is influenced by the catchment shape and orientation as well as area.
Slope and drainage network	The mean catchment slope and density of the drainage network influence the amount and rate of runoff.
Soil and geology	Runoff is strongly dependent on the ability of the surface and subsurface soil to accept rainfall, which is in turn essentially, related to the underlying soil, rock type and groundwater conditions.
Type and extent of	Vegetation influences catchment runoff through interception of

vegetation	rainfall and the effect of transpiration on soil moisture, which in turn affects the ability of the soil to absorb additional rainfall. The overall effect on flood peaks is dependent on vegetation type and age, the style of land management and the average drainage ability of the catchment.

Intensity data of rainfall for the area is lacking. Several methods, each with its own assumptions and constraints, may be used to estimate watershed runoff. Rational Method is used in the preliminary analysis for estimating runoff from the catchment area crossed by the project. The application of the method depends on the availability and type of rainfall data, flow records, and the catchment size.

Since there are no gauging stations located within the wadi. One has to rely on the hydrologic and hydraulic approaches to obtain annual rainfall and discharge of the wadi. The annual runoff is required to be able to calculate storage volume (capacity) of the proposed dam. The peak discharge is needed for the design of spillway. SCS Curve Number and Rational methods are used to estimate these values.

As stated in the afore-mentioned sections a hydrology study was conducted and represented in volume 2. The main findings for Azagarfa Dam are summarized in table 3 and Figure 5. The rational method was used to calculate the peak flow for 114 a return period of 50 years, while the total annual volume of flow was calculated based on 5 years return period.

Table 8:Watershed Characteristics and Calculated Hydrology Parameters

Name	Catchment Area (Km^2)	Slope	Length (m)	Time of Concentration (min)	Rainfall Intensity – mm- (50 years return period)	Annual Volume ‘1000 m3	Peak (m3/sec)
Azagarfa Dam	16.32	0.0108	7500	1.79	63.69	2,653	49.13

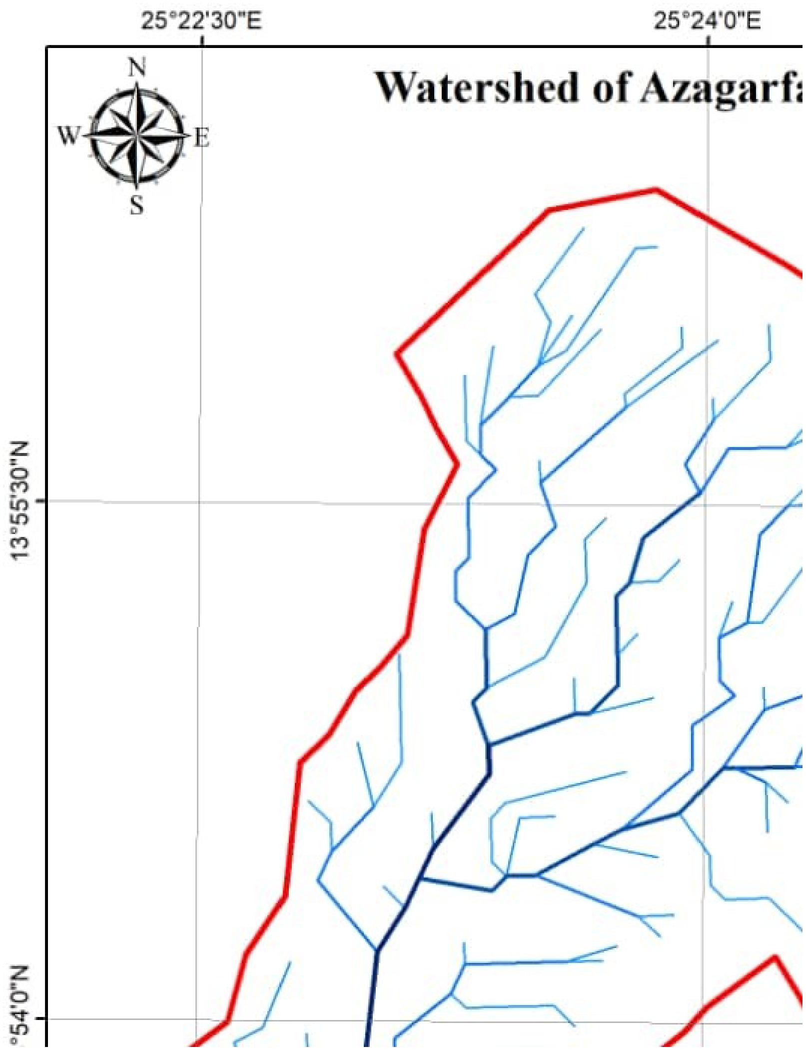

Figure 9 :Azagarfa Dam Watershed

4.2 Water Demand

4.2.1 Dam Design Criteria

The dam reservoir has been silted up to a meter high in some places but because the purpose of the dam is to spread water, not storage. There is no need to rise the dam embankment, but the crest of the dam must be at one level. This is one of the causes of the collapse caused by the overtopping of the embankment made breaches, the other reason of the dam failure was the poorness of the dam embankment materials and compaction

The design criteria for the re Dam is based on the following parameters:

- The number of hectares being irrigated by the Dam,
- Soil conditions that permit water retaining for the longest period possible,
- The available water (based on the hydrology study),
- The dry period length to avail water, and
- Easy access to the Dam.

4.2.2 Composition of Dam Water Demand

Data estimates are mainly based on discussions with local people. Also discussions with the local authority in many cases either confirm the figures obtained or modified based on their experience. Table 9 below gives the number feddan will be saturated or irrigated be the dam

Table 9: locations and areas of irrigated land

Dam Name Azagarfa	**Upstream dam**	**Downstream dam area**	**Fill of low land by back effect of the dam**	**Total Fadden**
Irrigated areas	15.6	16.4	12	44
Water Demand m^3	62400	65600	48000	176000

5. Azagarfa Dam Design Capacity

5.1 Hydraulic Analysis

5.2 eepage & Evaporation Losses

From the Rapid assessment socioeconomic and environment report, it is assumed that:

- **Evaporation losses** - Allow for7 mm/day for 120 days.
- **Seepage losses** - Allow for 3mm/day for 120 days (this may be left out if clay blanket is provided on water pan bed and sides)

Table 10:Evaporation and Seepage Losses

Dam Area(m^2)	**Evaporation Loss (m^3)**	**Seepage Loss (m^3)**	**Total Loss (m^3)**
141450 (Average Area)	118818	50,922	169,740

5.3 Dam Reservoir Capacity

The Dam capacity was selected to be (176,000 + 169,740) which is equal to 345,740m^3. Fig 9 shows the reservoir capacity which is 308,000 m3 (81 % of the required capacity)

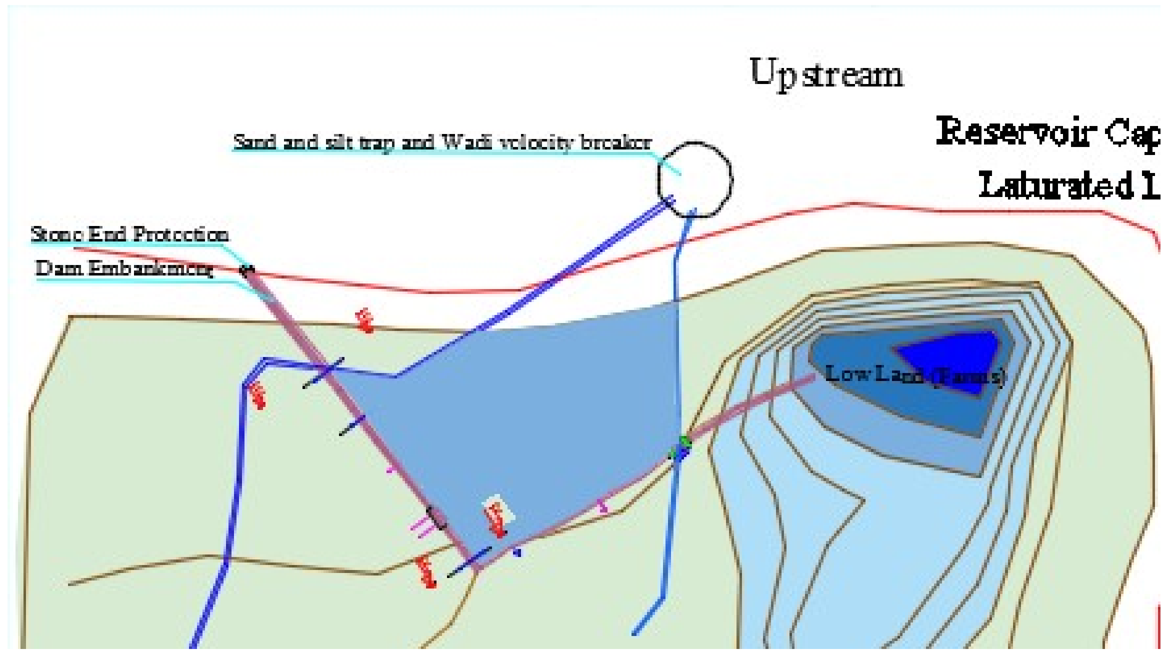

Figure 10:Reservoir Design Capacity and irrigated land

6. Dam Design Structural Considerations

6.1 General Considerations

The design flood for 50 years return period has been adopted for reservoir routing and sizing of spillways in Dam project. The design flood is found to be 49.13 m^3/s.

The dam axis is relatively long 435 m. The soil all through the dam axis is sandy clay and subjected to very high rate of seepage, therefore earth-fill dam will be the more appropriate selection. Other considerations include:

1. The dam should have appropriate spillway to ensure safety and integrity.
2. Seepage underneath the dam and through the dam body is not allowed.
3. The dam should be facilitated with appropriate free board to safeguard the dam abutment.

6.2 Fondation

In accordance with dam site strata conditions, it is recommended for the embankment foundation to remove the 1m top soil and the placed clay on compacted clay bed, and for the core foundation to remove completely weathered granite and sand to the depth of 0.5-1m below the excavated foundation. This measure is aimed at reducing seepage below the dam body.

A drainage layer of suitable filter material is provided to relieve seepage pressure and any seepage problems in the downstream areas on the embankment which lies on the pervious foundation.

6.3 Embranchement Design

The embankments are usually constructed with compacted homogenous clay material.

. The upstream impervious zone has the following merits:

- Afford stability against rapid drawdown
- Acts as drain to control seepage and lower the phreatic surface.
- Allow using steep slopes of embankment that leads to consequent reduction in its volume.
- A wide variety of material could be used.

6.4 Free Board

Spillway freeboard is the distance between the spillway crest and the top (crest) of the settled embankment which is designed as 3.0 m. Net freeboard is the distance between the maximum design high water (peak flood level) and the top (crest) of the settled embankment will be 0.75 m. Net freeboard should be sufficient to prevent waves from overtopping the embankment.
Wave height for moderate size reservoir areas can be determined from (Design manual December 2008).

:h = $0.014(Df)^{½}$

Where:

h = height of wave, m (0.48 m)

Df = fetch or exposure, m. (400 m)

A value of 0.15 m is usually added to the freeboard to account for the damage zone.
Generally, freeboard should not exceed 1 m for water depths up to 1 m (in our case the freeboard is 0. 7 m this plus 0.5 wave wall).

6.5 Seepage Control

Seepage control measures are provided to control piping, erosion, sloughing and excessive loss of water through the dam and foundations. 35 cm of shell and similar one of coarse materials are used as downstream filter.

6.6 Structure of Dam Crest

Dam body shall be homogenous compacted clay earth dam. The width of the embankment is 4 m as recommended in <Design Guide for Rolled Earth Rock-Fill Dams in Small Size Water Resources and Hydroelectric Engineering>. The dam crest level is 822m ground level is 820.4 at spillway,

Dam Slopes

Upstream side slope is 1:3 and downstream side slope is 1:2. Upstream side slopes are all protected in sequence from top to bottom by dry pitching in 30 cm thickness, underlying gravel sand filter 15 cm thickness beneath which is clay.

6.7 Dam Body Design

A homogeneous clay been adopted in Azagarfa dam project. The dam axis and the reservoir area considered more impervious. The most critical consideration is:

- Dam foundation
- Dam Abutment

With respect to the dam foundation, Nevertheless the dam is Existing and most of it founded on a bed rock, specially the breached areas. Fig. 11 shows the dam cross section.

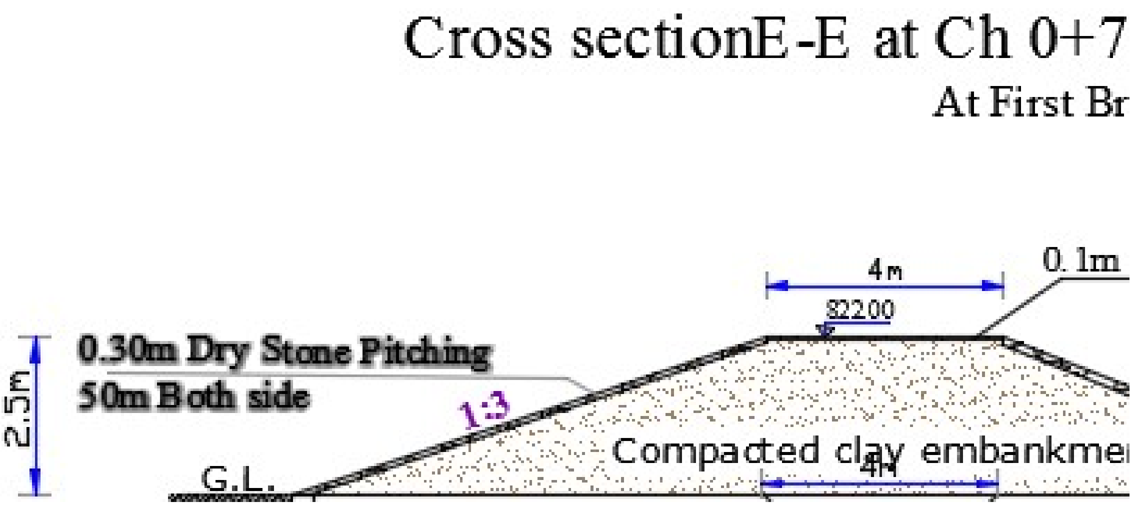

Figure 11:Azagarfa Dam embankment X-Section

With respect to the abutment, all weathered rocks and loose soil shall be carted and removed. A retaing wall is going to be construted in order to seal any cracks and ensure good bond between the dam and the sandy abutment.

Stilling basin and the dam downstream apron and protection are badly needed because of the sandy nature of the stream channel bed.

6.8 Free Board

The free board is taken as 4.0 m.

6.9 Structure of Dam Crest

Dam body was constructed of clay. The bottom width of the dam is 16.5 while the crest is 4m , The dam crest level is 822 m, while spillage will take place at level 821.

6.10 Spillway Design

The required spillway length at the adopted design flow is determined using the hydraulic equation applicable for straight crested type spillway crest.

$$Q = 1.8 H^{3/2} L$$

Where:

Q = Design flow (m^3/sec).

H = Flow height above the crest of spillway (m).

L = Spillway length (m).

At adopted design flow;

$Q = 49.13$ m3/sec.

H = 1.0. m, maximum allowable flood height above the crest level.

Using the above equation, the length of the spillway is found to be 27m. The dam spillage will all will be through the dam embankment (Dam body).

The total width of the existing spillways is 22m plus the releasing through 2 stop locks equal to 10.77m^3, as calculated by *Pipe Flow Advisor Software* as shown in fig. below

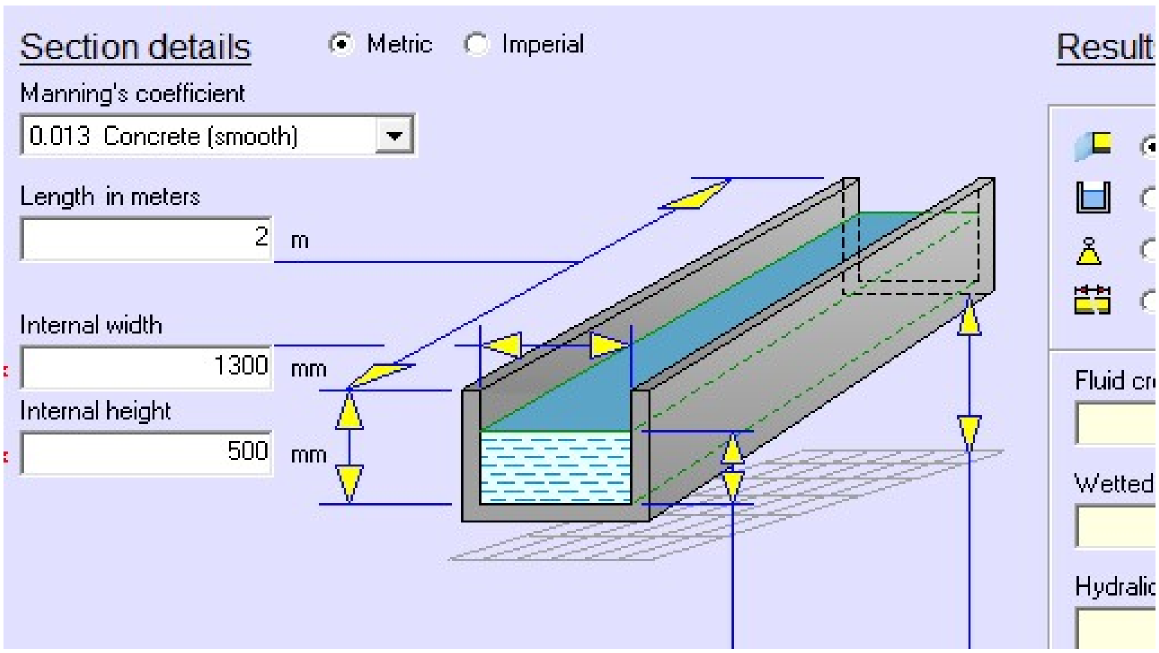

Figure 12: Pipe Flow Advisor Software is used for the calculation of the discharge

There are six outlets from pipe HDPE 250mm diameter. The main function of these outlets are to help in operation, particularly the sediment deposition within the dam reservoir. The discharge of one pipe is calculated using *Pipe Flow Advisor Software* as shown in fig. below

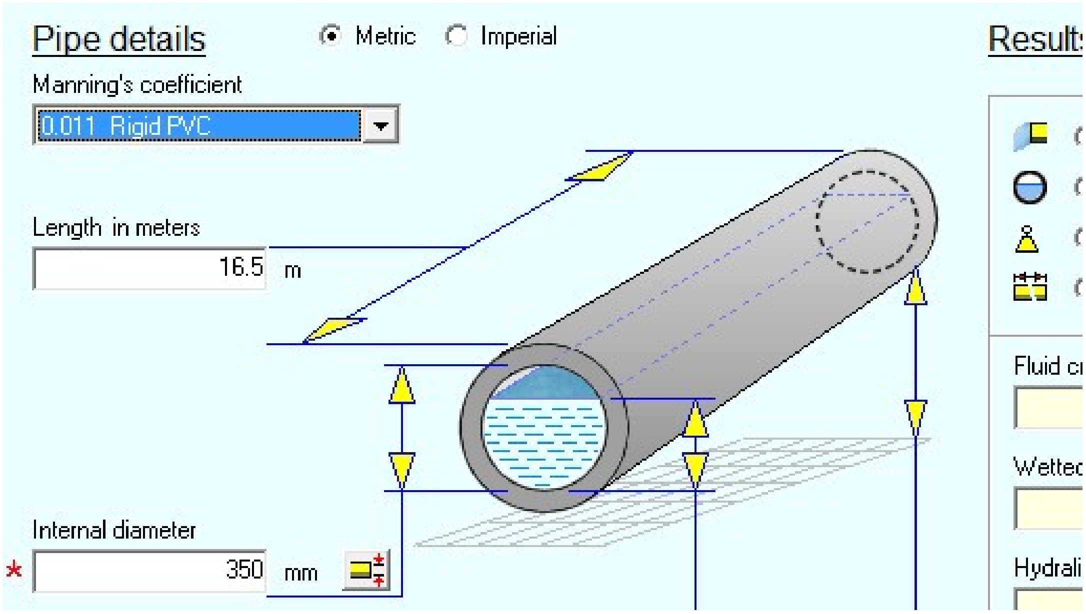

Figure 13: Pipe Flow Advisor Software is used for the calculation of the discharge

7. Construction Local Materials (Location and transportation REPORT)

7.1 Sand materials

Such materials are available within the vicinity of the dam location.

7.2 Stones Material

Stone is available in the hills surrounding and adjacent to the dam location.

7.3 Construction of the DAM :

Both skilled Labors and unskilled labors are available in Azagarfa village and its surrounding areas.

8. BILL OF QUANTITIES

Table 11: Bill of Quantities

Item	Description	Unit	Quantity	Rate USD	Amount USD
1.0	**Mobilization :**				
1.1	This item extends to include physical mobilization and demobilization of the equipment & manpower including camping.	Job	1.00		
2.0	**Site Clearance:**				
2.1	Site Cleaning from trees, bushes, boulders and derbies from reservoir area 800 m X 1000 m and demolishing of the remained damaged spillway and cart away as instructed by the Engineer.	Ha	5		
3	**Earth Works:**				
3.1	Excavate of in the existing dam reservoir to the dimensions and depths 1m upstream the main spillway 100x100m, and 50x100m u/s the secondary spillway as shown in the drawings to reach the volume of 15000m$^{3.}$ The excavated material shall be spread and compacted to fill the wadi u/s the repaired breach, as per drawings, specifications and instructed by the Engineer	M^3	15,000		
3.2	Excavate and cart away the sandy soil to the bed rock and excavate for key trench at two breaches as shown in the drawing and cross section No.9 & 10 and instructed by the Engineer.	M^3	1,900		
3.3	Provide materials and repair the existing embankment including the fill of the breaches by construct of compacted homogenous clay soil in layers not to exceed 30 cm and not less than 95% of the modified proctor test to form the main Dam embankments, as shown in the drawings and instructed by the Engineer	M^3	7280		
3.4	Provide materials and repair the dry stone pitching on the upstream and downstream the existing embankment including the new build of embankment at breaches. as shown in the	M^3	252		

	drawings and instructed by the Engineer				
4.	**Irrigation Pipes and valve Installation Works:**				
4. 1	Supply and lay HDPE or UPVC Pipes of 10" inner Diameter Single **line length of 18m**. For the out of the Hafir , not less than 10 bars, with complete fittings and as shown in the drawings and instructed by the Engineer	No.	6		
4. 2	Repair of the existing 14’’ 4 valves at main spillway, and supply of stop locks from timber wood pieces dimension as shown in the drawings and instructed by the Engineer	Job	1		
5	**Masonry**				
	Provide material and construct of rubber masonry stone for spillway mortar mix 4:1 sand-cement as per drawings and specifications.				
5.1	Repair the damaged part of the spillway stilling basin	M^3	10		
5.2	Embankment end protection	M^3	50		
5.3	Repair the damaged part of the spillway apron	M^3	10		
	Total				
	17% VAT				
	Grand Total				