



*Addis Ababa University (AAiT) School of civil and Environmental Engineering*

**UPGRADING AND REHABILITATION OF AN EXISTING WATER SUPPLY SCHEM THE CASE OF  
“MIDMAR EMBANKMENT DAM “**

*Adwa, Tigray, Ethiopia*

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A Thesis submitted to School of Graduate in Partials Fulfillment of the Requirement for the degree of  
Master of Science in Civil Engineering.

**(Hydraulic Engineering)**

## Declaration

I, the undersigned, declare that this thesis is my original work, has not been presented for degree in any University and that all sources of material used for this thesis have been duly acknowledged.

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**UPGRADING AND REHABILITATION OF AN EXISTING WATER SUPPLY DAM  
THE CASE OF “MIDMAR EMBANKMENT DAM”**

**TIGRAY REGIONAL STATE, CENTRAL ZONE, ADWA WEREDA**

The undersigned certify I have read and evaluate the thesis entities: Upgrading and Rehabilitation of an existing Water Supply scheme the case of “MIDMAR EMBANKMENT DAM” and hereby recommend for the acceptance by Addis Ababa University in partial fulfillment of the requirements for degree of Master of science.

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As a member of the Board of examiners of the MSc, Thesis Open Defense Examination, we certify that we have read, evaluated the thesis prepared by Berhanu Tesfay and examined the candidate. We recommended that the thesis be accepted as fulfilling the thesis requirement for the degree of Master of Science in Civil Engineering (Hydraulic Engineering).

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## Abstract

Midmar dam was designed as water supply source project for Adwa, small town named Adi-Abun (Currently merged with Adwa town) and for Almeda Textile Factory. However, recently, the dam is also serving as water supply source for Axum town which was not considered during designing phase, Hence, the main objective of this paper is to evaluate the existing and suggest possible remedial engineering measures so as to harvest maximum water as much as possible in a hydrologic year as well as comparing the harvested water with future water demands.

SEEP/W software model is used to analysis quantity of seepage through dam body and foundation at both scenarios (At existing condition and with design modification), when compared with the quantity of seepage estimated at the design document, the designed documents has no problem.

SLOPE/W model is used to computed slope stabilities at different scenarios under different loading conditions as per the analysis results at the existing condition the dam is more stable and the result of SLOPE/W for modified ( after dam height increment by 2m ) shows that the dam is still safe and stable.

As per water demands for Adwa and Axum towns at the existing condition Midmar dam can serve up 2023 G.C safely and when modified as a result 2.5 MCM volume of water can be stored additionally, that is more than 33 % increment in water holding capacity of the dam has been achieved and therefore the dam can serve as water supply source up to 2033G.C safely.

Design modification for existing spill way is not found as such satisfactory as upgrading option as per the second upgrading option additional 22.39ha can be inundated, therefore social, environmental and compensation issues should have to be kept in mind.

## List of symbols and Abbreviations

---

Km /hr.	kilometer per hour
$m^3/day$	meter cubed per a day
<b>AAIT</b>	Adiss Ababa Institute of Technology
m	Meter
E	Easting
N	Northing
$^{\circ}C$	degree Celsius
E.C	Ethiopian calendar
G.C	Gorgerin calendar
WSS	Water Supply and Sanitation
CSA	Ethiopian Central Statistical Agency
PDF	peak day factor
PFH	peak hour factor
PFO	over all peak factor
LPCD	liter per capita demand
IDF	Inflow design flood
$FOS_{min}$	Minimum factor of safety
WWDSE	water works design supervision enterprise
$Km^2$	kilometer square
ha	Hectare
mm	Millimeter
WSSA	Water Supply and Sewerage Authority

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WRDA	Water Resource Development Authority
SDF	Spill way Design flood
MCM	Million cube meter
AWTI	Arba Minch Water Technology Institute
Asl	Above sea level

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## Table of content

<b>DECLARATION .....</b>	<b>I</b>
<b>ACKNOWLEDGEMENT .....</b>	<b>III</b>
<b>ABSTRACT .....</b>	<b>IV</b>
<b>1. INTRODUCTION .....</b>	<b>1</b>
1.1 GENERAL .....	1
1.2 DESCRIPTION OF THE STUDY AREA .....	2
1.2.1. Location .....	2
1.2.2. Topography .....	3
1.2.3. Climate .....	4
1.2.4. Rain fall .....	4
1.2.5. Temperature .....	5
1.2.6. Wind speed .....	6
1.3. STATEMENT OF THE PROBLEM .....	6
1.4. OBJECTIVE OF THE STUDY .....	7
1.4.1. General objective .....	7
1.4.2. Specific Objectives .....	7
<b>2. LITERATURE REVIEW .....</b>	<b>8</b>
2.1 UPGRADING AND REHABILITATION OF DAMS .....	8
2.1.1. Improving spill way safety .....	8
2.1.2. Raise Embankment Crest .....	8
2.1.3. World experience for upgrading and rehabilitation works for Dams .....	9
2.2. STATE OF THE ART OF DAM DESIGN AND CONSTRUCTION .....	9
2.2.1. Over view .....	9
2.2.2. Hydrology studies and influencing factors .....	10
2.2.3. Surface flow estimation / Annual catchment yield .....	10
2.3. WATER SUPPLY SYSTEM DESIGN APPROACHES .....	12
2.3.1. General .....	12
2.3.2. Factors influencing for designing and evaluating of water supply schemes .....	12
2.3.3. Future population and water demand projection .....	12
2.3.4. Population projection and influencing factors .....	13
2.3.5. Population forecasting methods and influencing factors for choice of methods .....	13
2.3.6. Population forecasting methods .....	14
2.3.7. Factors influencing the choice of forecasting methods .....	15
2.4. WATER DEMAND PROJECTION .....	15
2.4.1. Water Demand categories .....	16
2.4.2. Mode and level of services .....	17

2.5. DESIGN PRINCIPLES OF EMBANKMENT DAMS .....	19
2.5.1. <i>Design data (Data requirement)</i> .....	19
2.5.2. <i>Design criteria and free board computation</i> .....	19
2.5.3. <i>Seepage in Embankment dams</i> .....	26
2.6. SLOPE STABILITY ANALYSIS OF EMBANKMENT DAMS .....	28
2.6.1. <i>General considerations for stability</i> .....	28
2.6.2. <i>Stability analysis theory, methods and limitations</i> .....	28
2.6.3. <i>Factor of safety and method of analysis</i> .....	30
2.6.4. <i>Factors of safety and their computations</i> .....	32
2.6.5. <i>Methods and limitations</i> .....	34
<b>3. METHODOLOGY OF THE STUDY .....</b>	<b>35</b>
3.1. GENERAL .....	35
3.2. DATA COLLECTION .....	35
3.2.1. <i>Primary data:</i> .....	35
3.2.2. <i>Secondary data:</i> .....	36
<b>4. ASSESSMENT AND EVALUATION OF THE BASELINE SITUATION .....</b>	<b>37</b>
4.1. ASSESSMENTS .....	37
4.2. SALIENT FEATURES OF MIDMAR DAM, CURRENT AND FORECASTED WATER SUPPLY AND WATER DEMANDS CONDITIONS .....	39
4.2.1. <i>Salient features of Midmar dam</i> .....	39
4.2.2. <i>Current water supply and water demands conditions</i> .....	40
4.3. EVALUATION OF WATER RESOURCE POTENTIAL .....	41
4.3.1. <i>Hydrological investigations</i> .....	41
4.4. GEOTECHNICAL EVALUATION OF MIDMAR DAM .....	43
4.4.1. <i>Dam foundation</i> .....	44
4.4.2. <i>Dam construction materials used</i> .....	44
4.4.2.1. <i>Location of Construction materials</i> .....	44
4.5. SEISMICITY AT MIDAMR DAM .....	46
4.6. MORPHOLOGY AND GEOLOGICAL ASPECTS OF THE STUDY AREA .....	46
4.6. ENGINEERING EVALUATION OF MIDAMR DAM .....	46
4.6.1. <i>Seepage analysis for existing Midamr dam</i> .....	47
4.6.2. <i>Slope stability analysis for Existing Midmar dam</i> .....	49
4.7. SPILL WAY AND FREE BOARD EVALUATION OF EXISTING MIDMAR DAM .....	56
4.7.1. <i>Evaluation of Spill way</i> .....	56
4.7.2. <i>Freeboard evaluation of Midmar dam</i> .....	56

4.8. DAM APPURTENANT STRUCTURES.....	57
4.8.1. Spill way works of Existing Midmar dam .....	57
4.8.2. Intake and bottom out let structures.....	57
4.8.3. Water treatment plant.....	57
4.9. RESULTS AND DISCUSSIONS FOR THE ASSESSMENTS AND EVALUATIONS OF AS IS CONDITIONS .....	58
<b>5. UPGRADING AND REHABILITATION OF MIDAMR DAM .....</b>	<b>59</b>
5.1. OBJECTIVES OF THE UPGRADING AND REHABILITATION.....	59
5.2. SPECIFIC OBJECTIVES OF UPGRADING AND REHABILITATION.....	59
5.3. FACTORS FOR UPGRADING AND REHABILITATION .....	59
5.4. UPGRADING AND REHABILITATION OPTIONS.....	59
5.3. ANALYSIS FOR THE SELECTED OPTIONS .....	60
5.3.1. Redesigning of Midmar dam Spill way .....	60
5.3.2. DAM HEIGHT INCREMENT .....	61
5.3.3. Seepage and Slope stability Analysis for modified dam section .....	61
5.4. UPGRADING AND REHABILITATION DESIGN OF APPURTENANT STRUCTURES.....	70
<b>6. CONCLUSIONS AND RECOMMENDATIONS .....</b>	<b>71</b>
6.1. CONCLUSIONS .....	71
6.2. RECOMMENDATIONS .....	71
<b>REFERENCES.....</b>	<b>73</b>
<b>ANNEX – (A) RAINFALL DATA.....</b>	<b>75</b>
<b>ANNEX – (B) SCREENED AND ADEQUATELY TESTED RAINFALL DATA.....</b>	<b>76</b>
<b>ANNEX-(C): MONTHLY DEPENDABLE RAIN FALL (MM) .....</b>	<b>77</b>
<b>ANNEX-(D):K<sub>N</sub> VALUES USED IN OUTLIER TESTING .....</b>	<b>78</b>
<b>ANNEX-( E ) : ORIGINAL SURVEYING DATA FOR MIDMAR DAM (USED IN DEVELOPMENT FOR CAPACITY – ELEVATION CURVE) .....</b>	<b>79</b>
<b>ANNEX – (F) SCANNED MATERIALS .....</b>	<b>80</b>
<b>ANNEX – (G) WATER DEMAND PROJECTION FOR ADWA PROJECT.....</b>	<b>91</b>
<b>ANNEX – (H) WATER DEMAND PROJECTION FOR AXUM PROJECT .....</b>	<b>92</b>
<b>ANNEX- (I) SUMMARY FOR ANNUAL WATER DEMAND PROJECTION FOR BOTH TOWNS .....</b>	<b>93</b>

List of Figures

Figure1: Location map of Midmar Dam and its catchment ..... 2

Figure2: watershed Area and streams for Midmar dam catchment ..... 3

Figure3: Type of spillway, reservoir and land use cover of Midmar catchment ..... 4

Figure4: Histogram of Monthly Average Rain fall (mm) ..... 5

Figure5: Histogram of Monthly Average temperature (<sup>0</sup>C )..... 5

Figure6: Histogram of wind speed in km/hr ..... 6

Figure7: Methods for calculating of fetch length (Adapted from Saville et al, 1962) ..... 22

Figure 8 : slope and potential slip..... 29

Figure9: Strength envelopes for soils ..... 31

Figure 10 : AUTO CAD modeled for existing dam section ..... 47

Figure 11 : Model for SEEP/W for existing dam..... 48

Figure12: Seepage through dam body and foundation (q) ..... 48

Figure13: Model for SLOPE/W and material properties..... 49

Figure 14: Factor of safety for downstream slope, during steady state (Normal Loading condition) ..... 50

Figure 15:Factor of safety for upstream slope, during steady state (Normal Loading condition) 51

Figure 16: Factor of safety for upstream slope, during sudden draw down (Normal Loading condition) ..... 52

Figure 17: Factor of safety for downstream slope, during steady state (seismic Loading condition) ..... 53

Figure 18:Factor of safety for upstream slope, during steady state (seismic Loading condition) 54

Figure 19:Factor of safety for upstream slope, during steady state (seismic Loading condition) 55

Figure 20: AUTO CAD model for modified dam section ..... 62

Figure 21: Model for modified dam section used in SEEP/W &SLOPE/W ..... 62

Figure 22: Seepage through dam body and foundation (q) ..... 63

Figure 23: Model for SLOPE/W and material properties ..... 64

Figure 24: Factor of safety for downstream slope, during steady state (Normal Loading condition) ..... 64

Figure 25: Factor of safety for upstream slope, during steady state (Normal Loading condition) ..... 65

Figure 26: Factor of safety for upstream slope, during sudden draw down Normal Loading condition) ..... 66

Figure 27: Factor of safety for downstream slope, during steady state (Seismic Loading condition) ..... 67

Figure 28: Factor of safety for upstream slope, during steady state (Seismic Loading condition) ..... 68

Figure 29: Factor of safety for upstream slope, during sudden draw down (Seismic Loading condition) ..... 69

## List of Tables

Table 1: Wind relationship –Water to land (USSR, 1981).....	23
Table 2: Freeboard requirement for preliminary studies (USSR, 1977) .....	25
Table 3: Recommended Minimum factor of safety .....	33
Table 4: Water demand allocation as remedial, 2004 E.C.....	38
Table 5: Summary of Annual water Demand.....	40
Table 7 : Engineering characteristics of soil material .....	45
Table 8: Optimum factor of safety for downstream slope during steady state (Normal loading condition) .....	50
Table 9: Optimum factor of safety for upstream slope, during steady state (Normal loading condition) .....	51
Table 10 : Optimum factor of safety for upstream slope, during sudden draw down (Normal loading condition) .....	52
Table 11: Optimum factor of safety for downstream slope, during steady state (Seismic loading condition) .....	53
Table 12: Optimum factor of safety for upstream slope, during steady state (Seismic loading condition) .....	54
Table 13: Optimum factor of safety for upstream slope, During Sudden draw down (Seismic loading condition) .....	55
Table 14: Optimum factor of safety for downstream slope, during steady state (Normal loading condition) .....	65
Table 15: Optimum factor of safety for upstream slope, during steady state (Normal loading condition) .....	66
Table 16: Optimum factor of safety for upstream slope, during sudden draw down (Normal loading condition) .....	67
Table 17: Optimum factor of safety for downstream slope, during steady state (Seismic loading condition) .....	68
Table 18: Optimum factor of safety for upstream slope, during steady state (Seismic loading condition) .....	69
Table 19: Optimum factor of safety for upstream slope, during sudden draw down (Seismic loading condition) .....	70

## **1. Introduction**

### **1.1 General**

The project area of Midmar dam is located in Tigray National Regional State near Adwa town and is bounded by UTM coordinates of left  $X=488983.936$ , upper- $Y=1568152.068$ , right- $X=501619.910$ , lower  $Y=1576890.10$  and it is located at approximately 1050km from Addis Ababa at the foot of the historical mountain named Soleda, the highest peak in the surrounding.

At this moment there is high and progressive water demand of both towns due to high growth rate of population, industrialization and urbanization and on the other side there is scarce water resource availability, consequently, the city administrations are looking for options, how they are going to satisfy their community demands and achieve further economic development. Therefore, the thesis mainly focuses how to upgrade and rehabilitate Midmar dam just to satisfy demands as much as possible for Adwa, Adi-Abun (Currently merged with Adwa town), Axum towns and Alemeda Textile Factory. It will also evaluate for how many years Midmar dam can be used as a prime water supply source to satisfy all demands with and without any design modification or rehabilitation measures.

## 1.2 Description of the study area

### 1.2.1. Location

The selected study area, Midmar dam water supply project is found in Tigray Region State, central zone, in Adwa Town and it is accessible by all-weather road at a distance of not more than 6 km at a direction of North-East Adwa to Axum main road, the accessibility will help in monitoring of the dam performance and taking some remedial measures easily and timely.

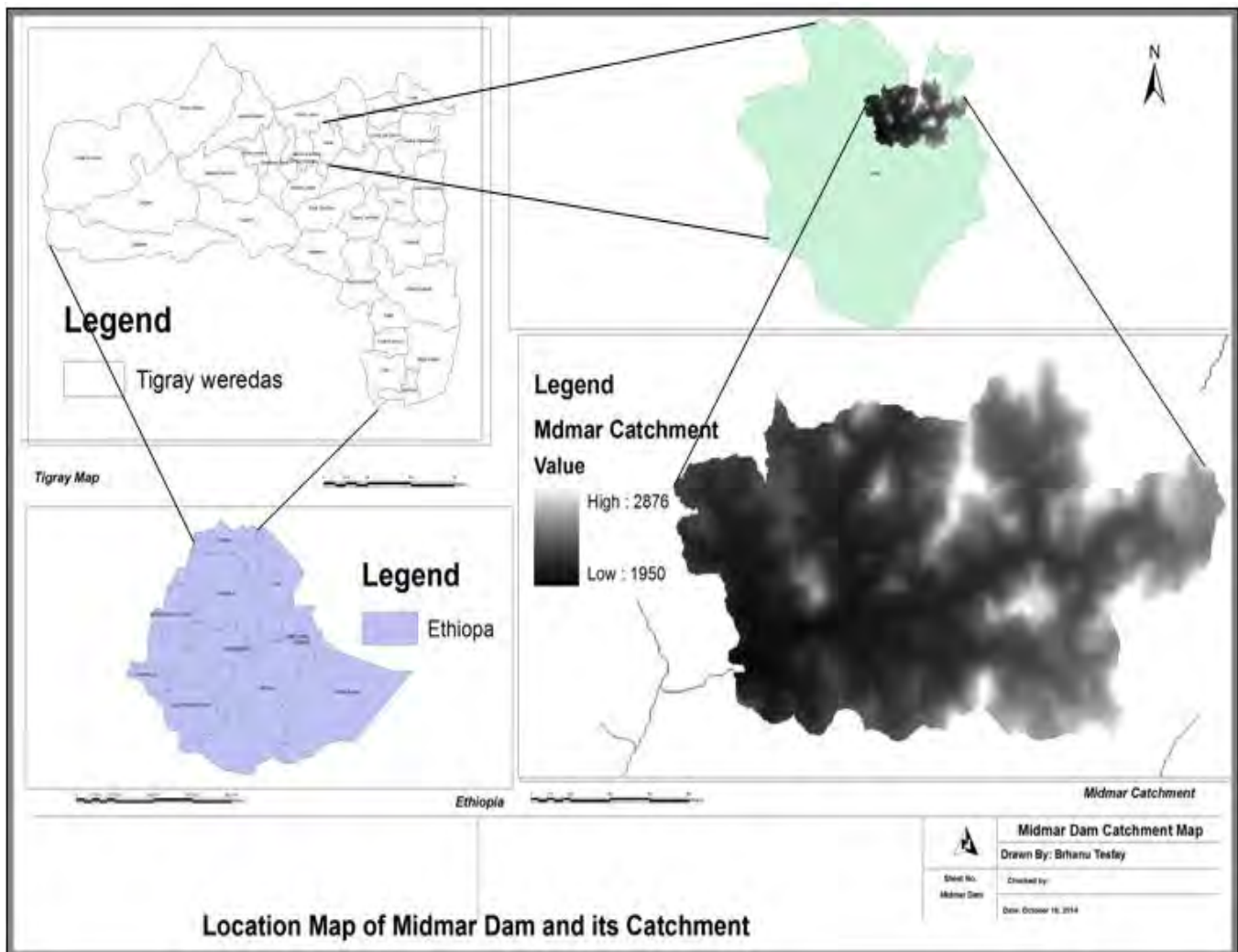


Figure1: Location map of Midmar Dam and its catchment

### 1.2.2. Topography

Catchment for the study area is bounded within the geographic locations left-X=488983.936, upper-Y=1568152.068, right-X=501619.910, lower Y=1576890.10 and has an average slope 21.10% with 1959m and 2826.8m Asl , minimum and maximum elevation respectively, good land coverage for generation of surface run off. At dam axis there is a saddle at the right abutment for locating spillway. Due to this an earth dam type with a hydraulic structure of over flow Ogee shape type of spill way was constructed.

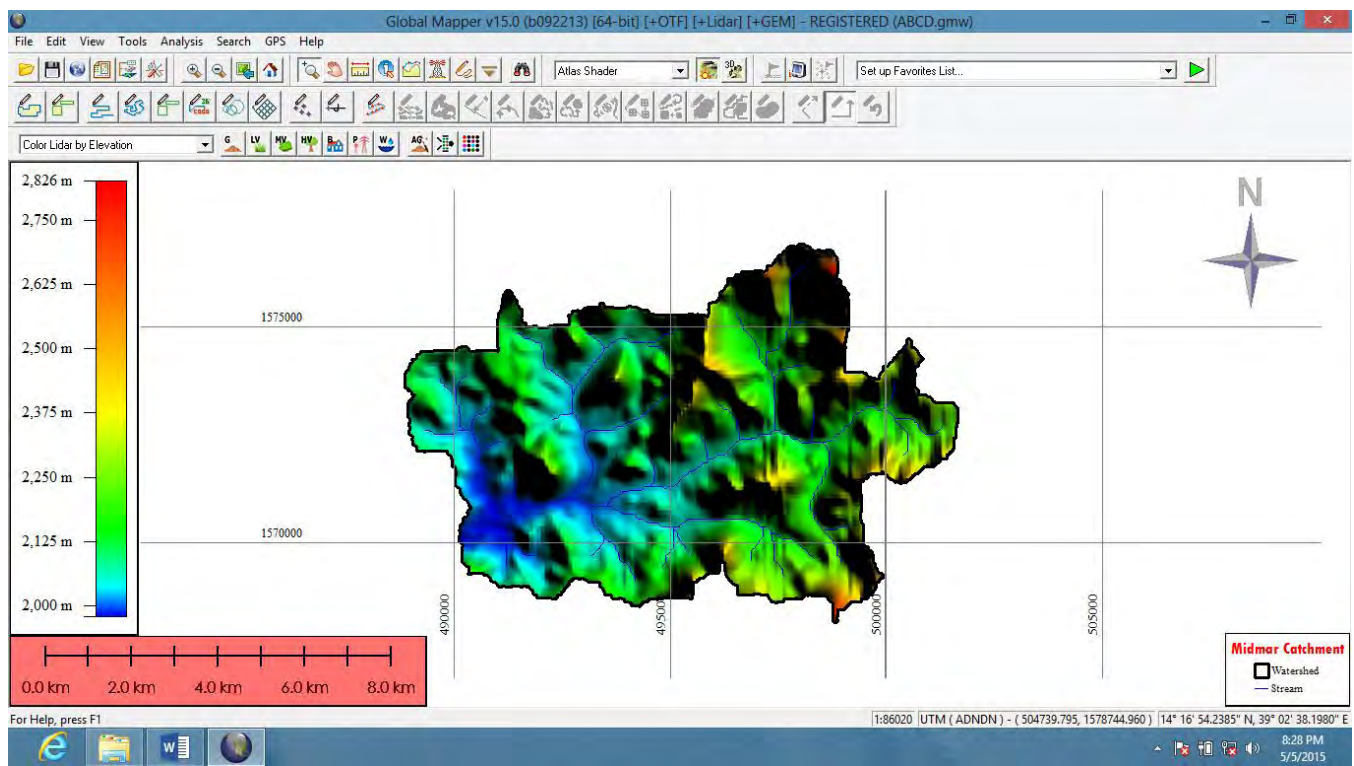


Figure2: watershed Area and streams for Midmar dam catchment



Figure3: Type of spillway, reservoir and land use cover of Midmar catchment

### 1.2.3. Climate

Climate condition with in the project area is classified as continental, with moderately hot and relatively short cold summers. There is a pronounced mono-modal rain fall distribution and more variable in time and space and the average annual precipitation is estimated about 758 mm.

### 1.2.4. Rain fall

For any hydrological analysis and design of hydraulic structures, the following rains falls recorded at Adwa metrological station has been adopted and the station is assumed to be representative.

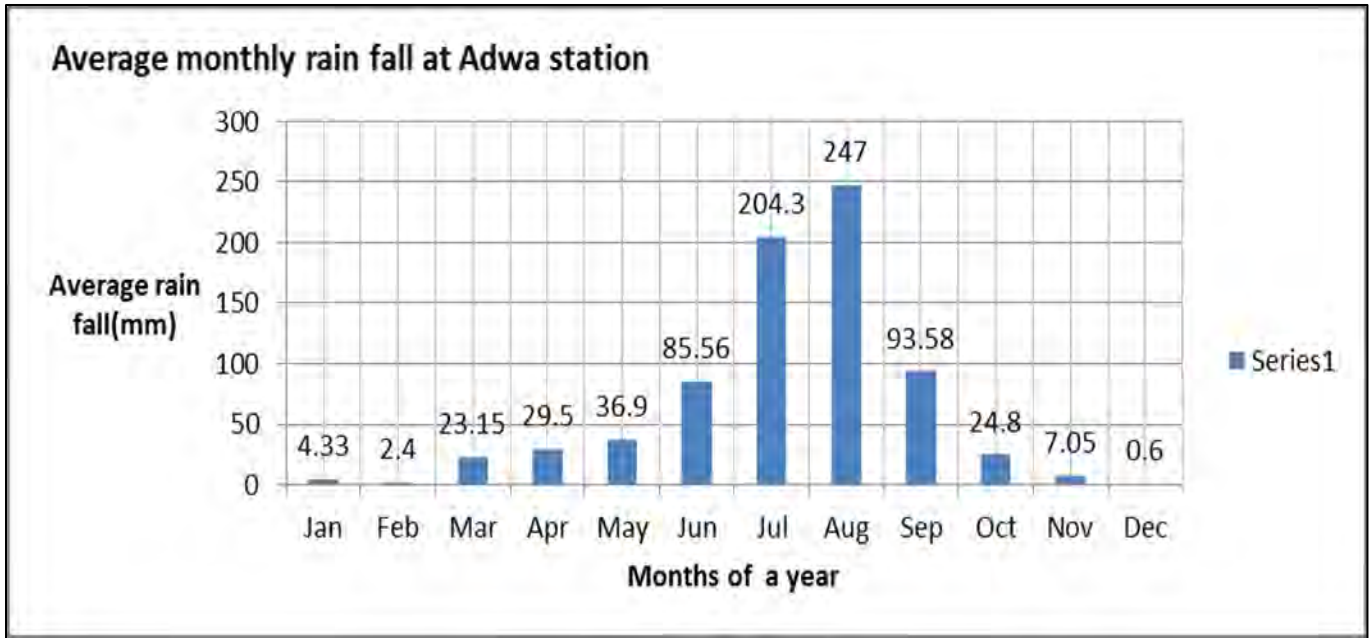


Figure4: Histogram of Monthly Average Rain fall (mm)

**1.2.5. Temperature**

Monthly temperature ranges from 23.6°c to 30.8°c and the average monthly temperature in and around the project area is about 27.6°c.

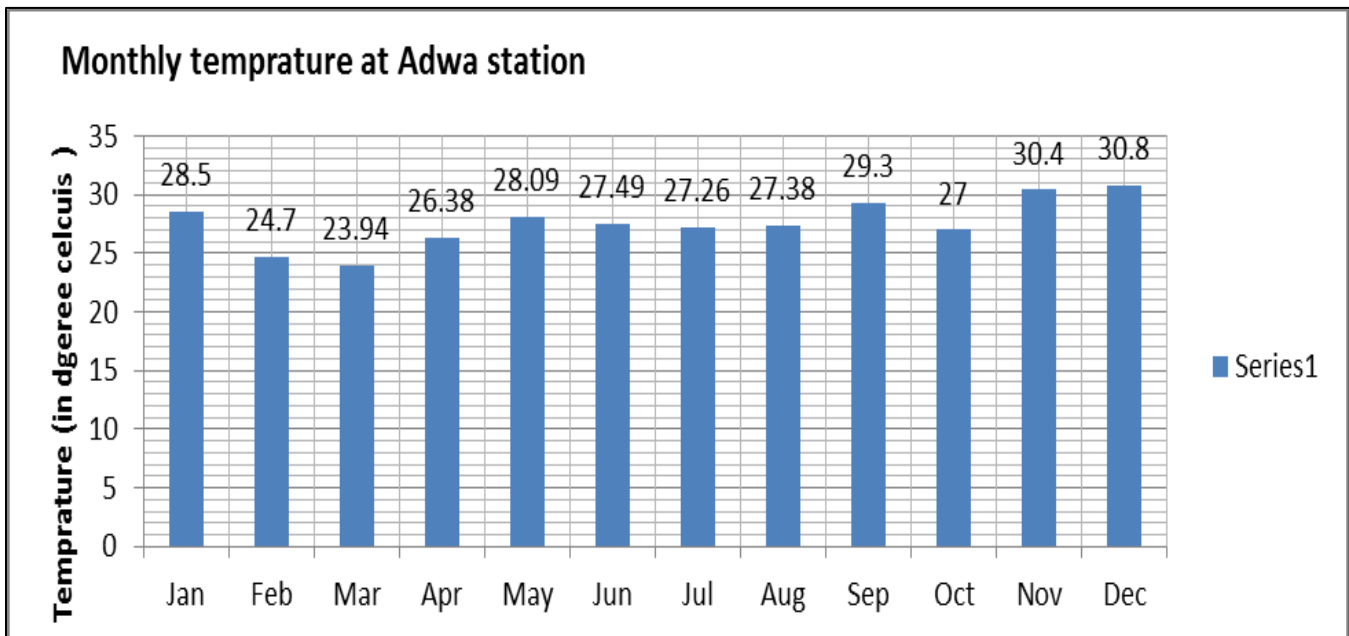


Figure5: Histogram of Monthly Average temperature (°C )

**1.2.6. Wind speed**

Monthly wind speed ranges from 6.228km/hr to 0.576km/hr at Adwa meteorological station and it is assumed to be representative for the project area.

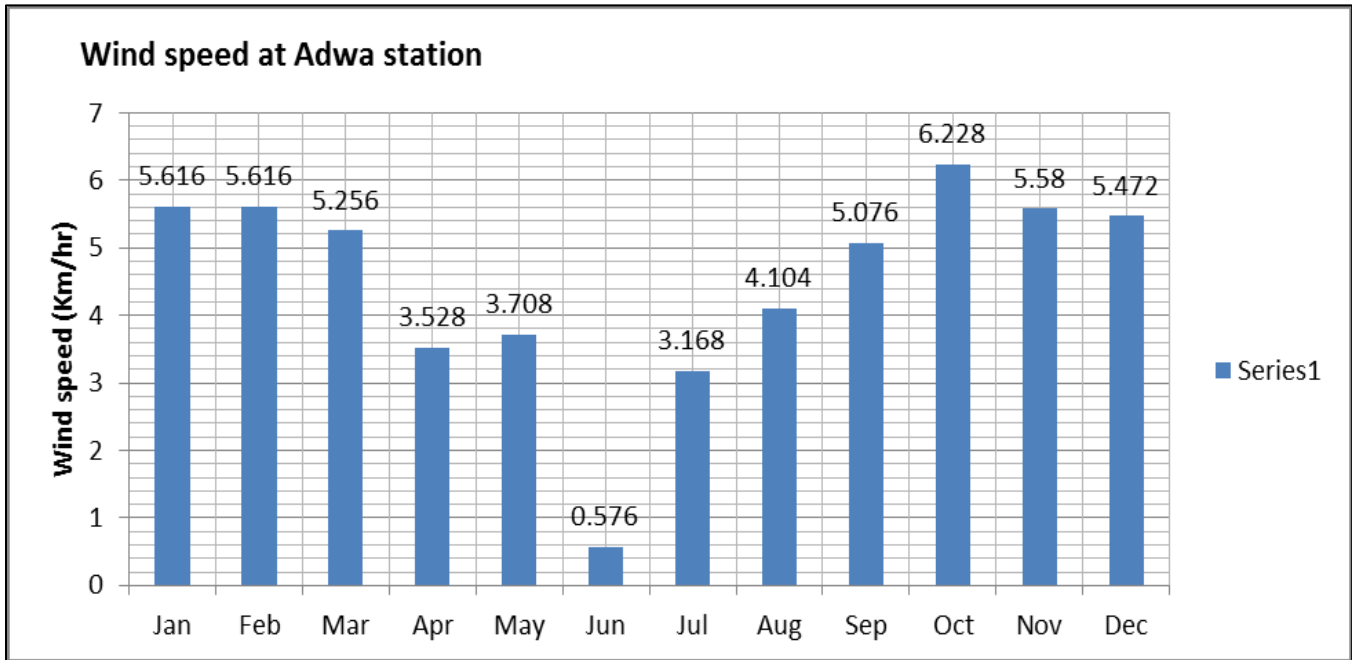


Figure6: Histogram of wind speed in km/hr

**1.3. Statement of the problem**

Several problems of water supply have occurred in Adwa town for long years and to alleviate the problem during transitional government period water supply feasibility study was carried out, accordingly, Midmar dam has been identified and constructed and is serving as a water supply source for Adwa, Adi-Abun and Almeda Textile Factory, however nowadays this dam is also almost a prime water supply source for both towns Adwa and Axum including some beneficiaries of their surrounding rural areas, serving out of its design objectives, therefore, this thesis work will fill the gap on the problems due to shortage of water encountered at the study area.

## **1.4. Objective of the study**

### **1.4.1. General objective**

This main objective of this paper is assessing the existing conditions and forwarding the appropriate upgrading and rehabilitation options of the dam.

### **1.4.2. Specific Objectives**

- Water demand-supply issues
  - To identify whether the existing water resource is adequate or not with future water demand projections.
  - To predict years of conflicts due to shortage of water.
- Evaluation of the base-line situation (Dam, foundation, morphology, hydrology, appurtenant structures)
  - Determine theoretical seepage for Midmar earth dam using a computer program (SEEP/W) and comparing with designed one
  - Determination of annual catchment yield ( Hydrology )
  - Determination of surge head and free board
  - Evaluating and analyzing of slope stabilities of the existing dam using SLOPE/W computer program
- To forward appropriate, better and sustainable recommendations as per the results while evaluating of base line situations, therefore the followings will be concerns of specific objectives of the thesis.
  - The generation of upgrading alternatives
  - Selection of upgrading option (remedial options of the water shortage problem)
  - Design and Analysis of the selected upgrading options
- To select , design and evaluate upgrading and rehabilitation options

## **2. Literature Review**

### **2.1 upgrading and rehabilitation of dams**

Aging of embankment dams, updating of design standards and criteria and the development of conditions affecting the safety of dams have resulted in a need for re- evaluation and, in some instances rehabilitation of dams even to optimize resource utilization upgrading and rehabilitation for existing dam is crucial engineering work. Even if finance is not readily available, rehabilitation or improvement is necessary to protect the asset of the owner of the dam. In this section techniques are presented for rehabilitation of embankment dams.

#### **2.1.1. Improving spill way safety**

A 1981 survey of non-Federal dams in the United States, concluded that 81 % had dam safety shortcomings because their spillways were not adequate to pass the estimated maximum design floods. This often reflects the difference between present-day design flood and the criteria in vogue at the time the dams were constructed.

Embankment dams are particularly sensitive to failure caused by overtopping, both during construction and while in service. Overtopping of a dam often causes dam failures. National statistics show that overtopping due to inadequate spillway design, debris blockage of spillway, or settlement of the dam embankment crests account for approximately 34 % of all U.S. dam failures.

In South West of France, a survey of small embankment dams has been carried out in 1997-1999 on more than 200 dam less than 20 m high [Lautrin, 2003]. 43 % of the spillways of those dams have been raised, ranging from 0.1 to 1.2 m and thereby reducing significantly the spillway capacity. (Source: SMALL DAMS Design, Surveillance and Rehabilitation, PETITS BARRAGES Conception, Surveillance Rehabilitation, 2011)

#### **2.1.2. Raise Embankment Crest**

Generally (but not always) the lowest cost option to overcome inadequate flood handling problem is to increase the total freeboard of the dam by raising the crest of the embankment and raising of dam height is also an engineering option to increase reservoir water holding

capacity This is normally achieved by adding earth fill to the downstream face of the embankment starting from the toe of the embankment. In addition to the fact that the spillway must be designed to accommodate higher “recommended design and safety evaluation check floods:

The stability of the downstream slope (and “in-situ” foundation) must be analyzed taking into account that the existing embankment zones and the raised embankment. The engineering properties of the earth fill materials of the existing embankment and the “new” earth fill section should be determined with reasonable confidence (i.e. a representative (or appropriate) sampling and laboratory testing program) and used in any analyses

### **2.1.3. World experience for upgrading and rehabilitation works for Dams**

- **Hinze Dam Upgrading**

The Hinze Dam is located on the Nerang River, 15km southwest of Nerang in South East Queensland. It provides the major part of the water supply for the Gold Coastal region .the first construction of Hinze dam was made in 1975.The raise during the second stage was in 1985 up to a level of 93.5 meters. During stage three the dam was raised by 15 meters approximately 108 meters and was doubled up the water capacity. The upgrade was provide an additional 79 MCM of flood storage capacity and increase the dam’s yield by at least an additional 16 million liters a day. Within the Hinze dam up grade design stage the permeability on the dam and the foundation was evaluated (Source: BAUER on Large dams [www.bauer.de](http://www.bauer.de))

## **2.2. State of the art of dam design and construction**

### **2.2.1. Over view**

All water scheme projects have to cope with the regional and local conditions. For dam construction and design and evaluation the conditions have to be respected such as, Geology, morphology and topography ,watershed characteristic and hydrology, meteorological and climatic data conditions and social , economic and environment impacts.

**2.2.2. Hydrology studies and influencing factors**

Hydrological studies are based on the available data from pervious times and are influenced by catchment size, land use and cover, slopes of the catchment, rain fall distribution and intensity, availability of rain gauges and their distributions , purpose of the project , proposed service life of the project and economic return of the project and the results of hydrological analysis are vital in estimating reliable volume of water that can be harvested from catchment in a hydrologic year and in designing of appropriate hydraulic structure.

**2.2.3. Surface flow estimation / Annual catchment yield**

The annual yield at a particular out let is the water resource potential of the catchment. This estimation is a function of rain fall, catchment size and weighted runs off coefficient. In general, it is calculated using the following rational formula.

$$\text{Annual yield (m}^3\text{)} = (C) * (Rfdep) * (A) \text{----- Equation 1:( 2.2.3)}$$

Where: C = run off coefficient (unit less)

R<sub>fdep</sub>= Dependable rain fall (mm)

A= catchment size in km<sup>2</sup>, while computing of the annual catchment yield there should be unit consistency.

**2.2.3.1. Determination of dependable rain fall**

Before proceeding of any hydrological analysis the data should have to be checked its adequacy and consistency.To check whether the raw data is adequate or not, the following statistical formula is used and the standard error of the mean is much less than 10 %, thus the available data is adequate enough to carry out further hydrological analysis.

$$\frac{\sigma_{x-1} * 100}{\bar{X} \sqrt{n}} \leq 10\% \text{-----Equation 2:( 2.2.3.1)}$$

Where: n = No of years

$\bar{X}$  = Mean value

$\sigma_{x-1}$  = Standard deviation

The water Resource council method recommends the adjustment be made for outliers. Outlier data are points that depart significantly from the trend of the remaining bulk data, which may be due to error in data collection, or recording or due to natural causes. The presence of outliers in the data causes difficulties when fitting a distribution to the data. The deletion of these data can significantly affect the magnitude of statistical parameters computed from the data, especially for small samples.

According to the water resource council (1981),

- If the station skewness is greater than 0.4 , test for high outlier are considered first
- If the station of the skewness is less than -0.4, test for low outlier first
- If the skewness is between ±0.4, test for both high and low outlier before omitting any data from the data set.

Skewness is defined as lack of symmetry of the distribution and it is a prime factor used to screen the data for further statistical analysis and coefficient of skewness is computed using the following statistical formula.

$$C_s = \frac{N}{(N-1)(N-2)(\sigma_{x-1})^3} \sum (x - \bar{X})^3 \text{ -----Equation 3:( 2.2.3.1)}$$

Where:  $C_s$  = coefficient of skewness

N = sample size

$\bar{X}$  =Mean value

$\sigma_{x-1}$  = Standard deviation

And outlier values are going to computed using the following frequency equation

$$X_{H/L} = \bar{X} \pm K_n * \sigma_{x-1} \text{-----Equation 4:( 2.2.3.1)}$$

Use plus to get high outlier value and minus sign for lower outlier values and  $K_n$  is unit less number and is a function of sample size and read from the next table and it is Annexed, finally the screened and adequate rain fall data obtained after many trials of testing for data adequacy and consistency is used for further hydrological analysis.

## **2.3. Water supply system design approaches**

### **2.3.1. General**

Any water supply system design needs careful and accurate determination of water demands and supplies and numerous factors influence the demand. To reach some conclusions the followings should have to be known and answered.

- For which purpose the water is used?
- Who are users of the water?
- Who or/and How the project is financed?
- For how many years the project will serve?
- What looks like trend of future demands?

### **2.3.2. Factors influencing for designing and evaluating of water supply schemes**

In the design of new water supply project and evaluating of existing schemes it is necessary to estimate the amount of water that is required and the design should have to consider basic assumptions and factors listed here under.

- Source of water supply both at the required quantity and quality
- Cost of the project both availability of financial and economic feasibility
- Technical and environmental feasibility of the site and suitability of the topography
- Market availability of water supply pipes , fittings and any other equipment
- Availability of power of electricity or any other which can substitute.
- Estimation of domestic demand, demand for institutions and factories
- Estimation of future demand , fire extinguishing and other factors

### **2.3.3. Future population and water demand projection**

Ethiopian Water Sector Strategy States that the provision of safe and sufficient water supply and adequate sanitation services are indispensable components in the sustainable development of Ethiopia’s urban and rural socio-economic well-being .At present, most of the population does not have adequate and safe access to water and sanitation facilities. Significant type diseases in the country are water borne diseases and they are due lack of adequate water

supply and sanitation facilities, just provision of access to clean and adequate WSS facilities and improving the performance of this subsector directly reduces the morbidity and mortality rates of the population. (Source Ethiopian Water Sector Strategy, November, 2001).The principal objective of the strategy is to secure for the provision of sustainable, efficient, reliable, affordable and users-acceptable WSS services to the Ethiopian people, including livestock watering. In strategies line with the goals and objectives of relevant national and regional development policies, therefore the thesis addresses performance of Midmar dam.

#### **2.3.4. Population projection and influencing factors**

New design and evaluation of existing water supply schemes involves careful determination of the number of population to be served, evaluation of the master plan of the towns with respect to water demands and re-planning of the master plan when required. population projections involves determination of the base population to be used, the growth rates, and design horizon in which the system is going to be designed as a result sustainable water projects will be owned.

In projecting the population size it is important to consider the following factors

- Fertility and mortality rates and migration
- The economic activities within the town and surrounding areas
- The political and economic significance of the town , Availability of valuable natural resources

Relative location of the town with respect to main high ways and the availability and sufficient urban infrastructures like, electricity, road, water, telecommunication, health, education, financial institutions and so like.

#### **2.3.5. Population forecasting methods and influencing factors for choice of methods**

Knowing the base population alongside with some indication of future growth trends would enable to design a reliable and sustainable water supply systems and used to evaluate adequacy of the existing water supply schemes. Adopting non-reliable base population figure and formulating non-realistic assumptions would eventually lead to either an over designed or under designed water supply scheme that does not meet the purpose it is designed for.

To minimize the risk of over or under designed system that results from mistaken assumptions of base population figure, population data of the beneficiaries of the towns have been taken from Ethiopian Central Statistical Agency (CSA).

### **2.3.6. Population forecasting methods**

#### **Arithmetic increase method**

This method is based on the assumption that the population is increasing of a constant rate. This method gives too low an estimate and can be adopted for forecasting population of large cities which have achieved saturation conditions. That It is generally applicable to large and old cities.

#### **Geometric increase method**

This method assumes that the percentage of increase in population from decade to decade is constant. This method gives high results, as the percentage increase gradually drops when the growth of the cities reach the saturation point. This method is useful for cities which have unlimited scope for expansion and where a constant rate of growth is anticipated.

#### **Decrease or Decline growth method**

In this method, it assumes that the city has some limiting saturation population and its rate of growth is a function of its population deficit.

#### **Logistic method (Saturation method)**

This method has an s-shape combining a geometric rate of growth at low population with declining growth method rate at the city approaching some limiting population, This method is reliable for community with limited land area a for future expansions.

#### **Incremental increase method**

In this technique, the average of the increase in the population is taken as per arithmetic method and to this, is added the average of the net incremental increase, one for every future decade whose population figure is to be estimated. In this method, a progressive increasing or decreasing rate rather than constant rate is adopted.

### **The master plan method**

In this method, the master plan of the city or town is used to determine the future expected population. The town is divided into various zones such as commercial center, industrial areas, residential center, schools, parks etc. thus, the population densities for various zones of the town are fixed and hence the future population of the city when fully developed can easily be worked out. Due to the absence of precise master plan of the towns this method will not be considered for population projection.

### **Methods used by Ethiopian statistical authority**

Out of the population forecasting methods discussed the exponential growth rate is used for population projection in most cases.

#### **2.3.7. Factors influencing the choice of forecasting methods**

Population forecasting methods are mathematical functions and they are mainly dependent on the following factors while adopting for project works.

- Plausibility (Do the outputs make sense?)
- Face validity (availability and quality of the data that is, are the inputs good?)
- Political acceptability (are the outputs acceptable?)
- Resources (money, personnel and time, can we afford it?)
- Need of the users (are users' needs satisfied?)
- Model of complexity (simplicity of application and explanation?)
- Forecast accuracy (is the forecast reasonable accurate?)

Therefore, to minimize the risk of over and under designing and evaluation of existing water supply systems, population growth rates and projects are passed through CSA assumptions and forecasting models, and therefore future population sizes of the project beneficiaries are projected by using an exponential population growth model.

### **2.4. Water Demand projection**

While designing of new water supply systems and evaluating of existing schemes, water demand projection should have to be specified based on water demand categories because

population, access to water, water utilization and facility standard differences are parameters used in defining of water demands.

**2.4.1. Water Demand categories**

For a design and evaluating of a water supply system the amount of water demanded by the community of a town has to be estimated and there are specific water demands are:

- **Domestic water demand**

Demand of a community for drinking, cooking and for sanitary purposes and domestic water consumption varies according to the mode of services, climatic conditions, socio-economic condition and other related factors. The following guide lines are used while designing and evaluating of water supply system schemes. These lists of water demand guide lines are as per Main Report of urban water supply design criteria, January 31, 2006.

Domestic water demand for the following categories of consumer:

	Stage 1	Stage 2
○ House connection (HC),	50 l/c/day	70 l/c/day
○ Yard connection, own (YCO)	25 l/c/day	30 l/c/day
○ Yard connection, shared (YCS)	30 l/c/day	40 l/c/day
○ Public tap supplies (PT)	20 l/c/day	25 l/c/day

- **Institutional and Commercial Demand**

This refers to the water demand of facilities such as schools, hospitals, hotels, etc. and small commercial enterprises, and also public demand where appropriate.

- **Live stoke**(water demand for animals)
- **Water losses** (Non-Revenue Water), even though it not metered as water consumptions, Allowance must be made in the design for water losses, because no distribution system is absolutely tight, in case of Midmar dam there is Non-Revenue water recorded data yet and it is found difficult to say something about confidently.

Therefore, the total average total demand for a water supply scheme is the sum of all domestic, institutional, commercial, industrial and livestock demands including water losses and also it is known that Water demand of towns is dependent on many factors like: - the overall economic

activities of the town, living standard of the society, temperature, water tariff, the availability adequate and good quality of water, distance of water point/s and other social factors.

The estimation of future water demand of a town involves determination of the number of people to be served, the mode of service, per capital water consumption and analysis of the factors that may operate to affect consumptions.

#### **2.4.2. Mode and level of services**

Water supply system of most of the towns the world have four mode of services in which the populations are served.

- House connection (HC)
- Individual yard tap connection (IYTC)
- Shared yard tap connection (SYTC)
- Public tap connection(PTC)

The following guide lines are also used while designing and evaluating of water supply system schemes. The following list of water demand guide lines are as per Main Report Volume II produced by Ministry of Water Resources, Water Sector Development program, Oct 2002.

- Domestic water demand (DWD): Daily per capita water consumption is generally very low throughout the country .DWD is suppressed in almost all towns in the country because of supply shortages. In estimating DWD, general design standards were adopted 30-50 liter per capita daily (lpcd) for Urban centers and 15-25 lpcd for rural areas. The Urban DWD per day is thus projected as being 30 lpcd for short term, 40lpcd for medium term and 50lpcd for long term.
- Commercial and institutional water demands (CIWD): in addition to those of house hold consumers , the water requirement of towns include the needs of such commercial and institution consumers as public , schools , clinics , hospitals , offices , shops , bars , restaurants and hotels is linked directly with population size it was estimated at 5 % of DWD for small-and medium sized towns and for large size towns it was estimated 10 % .

- Industrial water demand (IWD) : for planning purpose , reliable IWD indicators was assumed to be the following percentage of DWD , 30 % of DWD in large and medium towns and 10% of DWD in small towns .
- Livestock water demand (LWD): keeping of livestock is an integral part of the rural community life. And water is an essential commodity for animals just as it is for humans. However it is not advisable to use improved domestic water sources for livestock, it is assumed that most of the animals will be watered from such natural sources as rivers, streams, lakes and ponds and springs in the vicinity. if no such sources are available nearby for the livestock, the animals should be watered from cattle troughs sited below water sources for human consumption , in case potable water schemes are to be used for livestock watering , an allowance of 3 lpcd is an additional to DWD .
- System losses (SL): losses from water supply systems vary considerably according to diverse factors .SL are a function of the quality of construction, type and age of pipes in the distribution network. SL is equivalent / assumed to be 25 % total domestic, commercial, institutional and industrial water demands.
- Average daily demand (ADD): urban ADD is considered to be the combined total of demand from domestic, commercial, institutional, industrial, livestock and water losses or average day demand is the total annual water demand divided by 365 days.
- Maximum daily demand (MDD): Daily water consumption in a town varies according to time of a day, season, and climatic conditions within the entire country and therefore to allow for increasing of water demand during the dry season, MDD was assumed to be 1.15 times the ADD for all towns.

## **2.5. Design principles of Embankment dams**

### **2.5.1. Design data (Data requirement)**

The data required for the design of an earth fill dam are also important while evaluating of existing situations and the followings are the most important among the others.

- Investigation of foundations and sources for construction materials
- Hydrological studies results
- Result of geotechnical investigations
- Topographic surveying data
- Meteorological data
- Source of and availability finance & socio-economic survey data

The required details and accuracy of the data are governed by the nature of the project and immediate purpose of the design; that is the design is for a cost estimate to determine project feasibility, whether the design is for constructions, or whether some other purpose is to be served. The extent of investigations of foundation and sources of construction materials are also governed by the complexity of the situation.

### **2.5.2. Design criteria and free board computation**

The basic principle of design is to produce a satisfactory, functional structure at minimum total cost. Consideration must be given to maintenance requirements so that saving achieved in the initial cost of construction do not result in excessive maintenance cost. Maintenance costs vary with the provision of upstream and downstream slope protections and to achieve minimum cost the dam must be designed for maximum use of the most economical materials available, including material excavated for its foundation and for appurtenant structures.

An earth fill dam must be safe and stable during all phases of construction and operations of the reservoir .To accomplish the following criteria must be met:

- The embankment, foundation, abutments and reservoir rim must be stable and must not developed unacceptable deformation under all loading conditions brought about by construction of the embankment, reservoir operation and earth quake.

- Seepage flow through the embankment, foundation , abutments and reservoir rim must be controlled to prevent excessive uplift pressures, piping , instability , sloughing , removal of materials by solution effects or erosion of materials in to cracks , joints , or cavities .The amount of water lost though seepage must be controlled so that it does not interfere with planned project functions.
- The reservoir rim must be must be stable under all conditions to prevent the triggering of a landslide in to the reservoir that could cause a large wave to overtop the dam.
- The embankment must be safe against overtopping or encroachment of freeboard during occurrence of the IDF (inflow design flood) by the provision of sufficient spillway and out let works capacity.
- Free board must be sufficient to prevent over topping by waves and include and allowable settlement of foundation and embankment as well as for seismic effects where applicable (U.S Army of corps of Engineers, 1993)
- Camber should have to be sufficient to allow for the settlement of the foundation and embankment but not included as part of free board
- The upstream slope must be protected against wave erosion, and the crest and downstream slopes must be protected against wind and rain erosion.
- Adequate spill must be designed and should have to allow safe flooding.
- The slopes of the embankment must be stable during construction and under all conditions of reservoir operation.
- The scheme of zoning of the dam must guarantee the dam’s safety with respect to stability, seepage and cracking. Frequently, different sizing and shaping of the zones result in the same safety. The selection is made with regard to the availability of materials and their most economic handling.

An earth fill dam designed to meet the above criteria will prove permanent safe, provided proper construction methods and controls are achieves, keeping in mind the above guide lines the following remarks are also equivalent important to compute and evaluate free board allowances.

### **Factors which influence selection of freeboard**

- Reliability of design flood estimates
- Assumptions made in flood routing
- Type of dam and susceptibility to erosion by over flow
- Potential changes in design flood estimates , either through changes in flood estimation techniques or due to change catchment condition

### **Freeboard requirement for new embankment dams as per USBR (1992)**

- Free board at maximum reservoir water surface elevation , the minimum freeboard should have to be the greater of (a) 0.9m or (b) the sum of the wind set up and wave run up that should be the generated by the average winds that would be expected to occur during large floods, as determined after seeking advice from local authorities and meteorologists .The point out that for large reservoirs and catchments the wind may be independent of storm event that created the flood , and suggest a wind with a 10% probability exceeding (1 in 10)should be used .

### **Computation for effective Fetch length**

In reservoirs, fetches are limited by the land surrounding the body of water, the shorelines are irregular and effective fetch is calculated from the following formula :

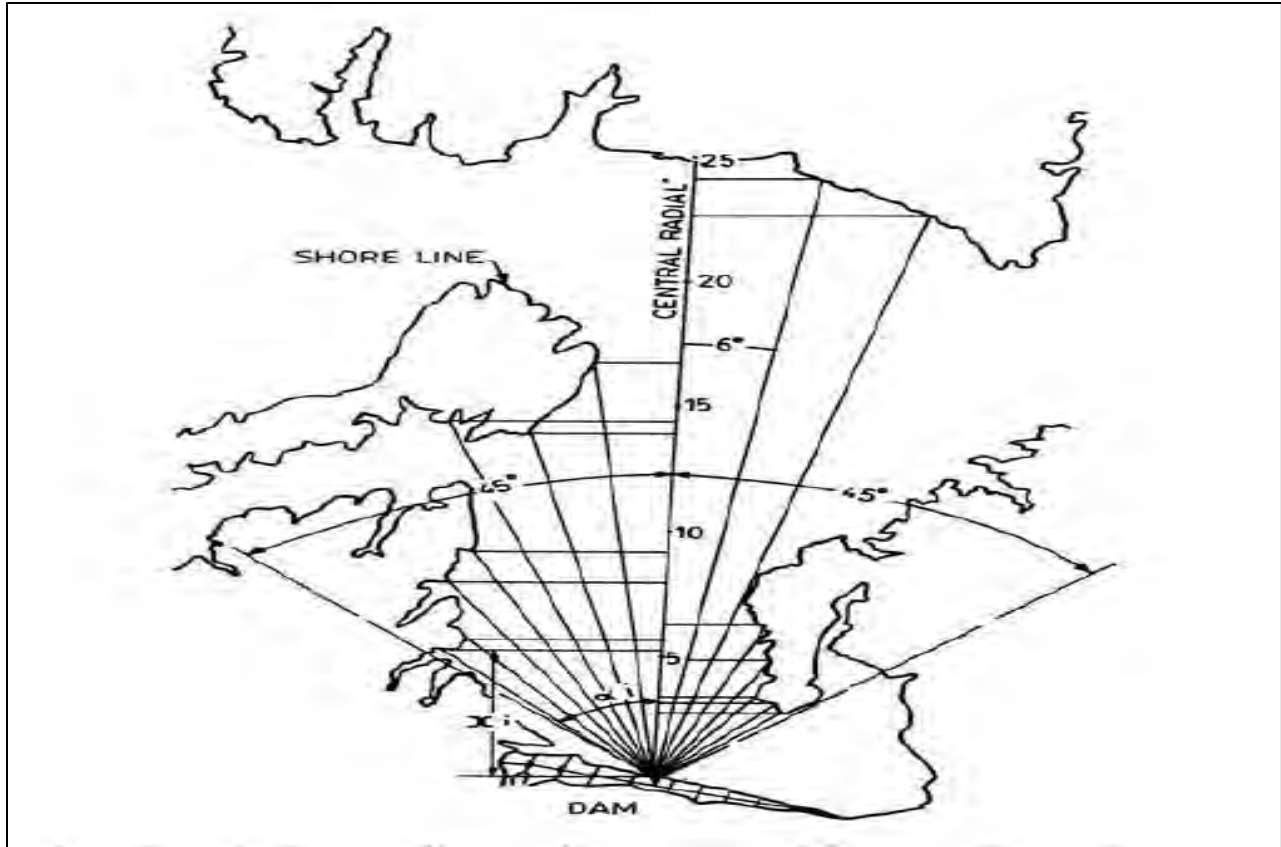


Figure7: Methods for calculating of fetch length (Adapted from Saville et al, 1962)

$$F = \frac{\sum x_i \cos \alpha_i}{\sum \cos \alpha_i} \text{-----Equation 5:( 2.5.2)}$$

Where:  $\alpha_i$  =angle between the central radial from the dam and radial i

$x_i$  = length of projection of radial i on central radial.

A trial and error approach should be used to select the critical position on the dam and direction of the central radial to give the maximum effective fetch.

The radial spanning  $45^\circ$  on each side of the central radial should be used to compute the effective fetch.

### Wind Set-up (Hs)

Wind set-up is the height of water pulled up due to the bellowing of wind and can be estimated for lakes and reservoirs based on the following equation:

$$H_s = \frac{U^2 F \cos^2 \alpha}{K \cdot D_r} \text{-----Equation 6:( 2.5.2)}$$

Where: Hs = Wind set-up in meters above the sill water level that would prevail with zero wind action

U = average wind velocity in kilometres per hour over the fetch distance (F) that influences the designed winds estimates should have to be obtained from the Bureau of Meteorology or equivalent organisation and for effective fetch wind speed over water should have to be corrected as per the following table (1)

Table 1: Wind relationship –Water to land (USSR, 1981)

Effective fetch length(Fe) (km)	0.8	1.6	3.2	4.8	6.4	8(or more)
Wind velocity ratio , over water/over land	1.08	1.13	1.21	1.26	1.28	1.30

**Determination of design wind speed**

Gumbel’s Distribution method is for estimation of deigns wind speed of various recurrence intervals and Extreme values are selected maximum or minimum values of sets of data. This distribution is applicable to the extreme meteorological events, such as maximum daily rainfall, rain intensity and peak flood flows, wind speed. The Gumbel distribution is expressed by the equation:

$$X = \bar{X} + K_T \sigma_x \text{-----Equation 7:( 2.5.2)}$$

Where:X = value of the vitiate X which has a return period T

$\bar{X}$  = Mean of the vitiate

$\sigma_x$  = Standard deviation of the vitiate

K = frequency factor which depends on the assumed frequency distribution, return period, and size of the sample

To determine the values of X for any return period T by using equation (2.5.2) the statistical parameters in the proposed distribution are first determined for the random data series. Then the K value is obtained from the K-T relation of the assumed frequency (Chew, 1951). For the Midmar dam design wind speed estimation, extreme values (daily maximum wind values) has taken for the analysis and the corresponding  $K_T$  is 1.305, and it  $K_T$  can be computed from the following formula.

$$K_T = -\frac{\sqrt{6}}{\pi} [0.5772 + \ln(\ln(\frac{T}{T-1}))] \text{ -----Equation 8:( 2.5.2)}$$

**Wave height**

The maximum wave height is the most important factor for determination of free board which depends on the maximum wind velocity , its duration and fetch length .The most commonly used formula for estimating wave height for fetch lengths (F) less than 32km is (Stevenson’s formula modified by Moliter to include wind velocity )

To determine the wave height, the following formula was used:

$$h_w = 0.0322\sqrt{F.U} + 0.763 - 0.271\sqrt[4]{F} \text{ -----Equation 9:( 2.5.2)}$$

**Wave run up**

When wave strike against a solid surface they climb or run up for a short distance. Rough surface is provided by riprap on face of the dam .the computed wave height is generally increased by 50% to account for wave run up (Sing B. Vars hney R.S. & Varghese B.G (1995).

**Settlement allowance (ΔH) and settlement calculations**

Settlement of the dam between 1.5% and 2% of its total height is considered during its lifetime. Settlement calculation for embankment dam is associated with particle crushing and is greatly increased by saturation. It can be therefore accelerated during construction.

**The construction settlement occurring at crest level is given by:**

$$\text{Settlement (1)} = 0.001H^{(3/2)} \text{ -----Equation 10:( 2.5.2)}$$

Where: H is total dam height excluding settlement,

**Long term post construction settlement is given by:**

$$\text{Settlement (2)} = \delta (\log_{10}(\frac{T_2}{T_1})) \text{ -----Equation 11:( 2.5.2)}$$

Where:  $T_2$  is service life of the dam and  $T_1$  is time of construction,

$\delta$  Ranges from 0.2 to 0.5, take 0.3

Table 2: Freeboard requirement for preliminary studies (USSR, 1977)

S/no	Longest fetch (km)	Normal free board (m)	Minimum free board (m)	Remark
1	Less than 1.6	1.20	0.9	
2	1.6	1.5	1.2	
3	4	1.8	1.5	
4	8	2.4	1.8	
5	16	3.0	2.1	

### Determination of Spill way surcharge head

Hydraulic of spill way is started with the following equation:

$$Q = C * L * (H)^{3/2} \text{ -----Equation 12:( 2.5.2)}$$

Where: Q = Designed routed flood (m<sup>3</sup>/sec)

L = spill way crest length (m)

C= discharge coefficient (unit less) and dependant of shape of the spill way and is obtained from standard figures and it is associated with some iterative computations.

H= depth of flow over crest of the spill way (m),Hence, total free board is equal to the sum of wind set up, wave height, wave run up, settlements and surcharge head and the basic purpose of the spill way is to provide a means of controlling the flow and providing conveyance from reservoir to tail water for all flood discharges up to the spill way design flood (SDF). The importance of safe spill way cannot be over emphasized, many failure of dams have been caused by improperly designed spillways or by spill way of insufficient capacity. Ample capacity of spillway is of paramount importance for earth and rock fill dams, In addition to providing sufficient capacity, the spill way must be hydraulically and structurally adequate and must be located so that spill way discharges do not erode or undermine the downstream toe of the dam. The spillway's bounding surfaces must be erosion resistant to withstand the high scouring

velocities created by the drop from the reservoir surface to the tail water. Usually, advice is required to dissipate the energy of water at the bottom of the drop.

Project functions and their overall social, environmental and economic effects may influence the hydraulic design of spill way .Optimization of the hydraulic design and operation requires awareness by the designer of reliability, accuracy, sensitivity and possible variance of the data used.

### **2.5.3. Seepage in Embankment dams**

Excessive Seepage through the dam body and under foundation results dam failure, Coefficient of permeability also called Darcy's (Engineer's) coefficient of permeability is used in seepage analysis in earth dams and the estimated rate of seepage has great role in zoning of dam body, as result economically, hydraulically and structurally stable dam can be designed.

The coefficient of permeability is defined as the rate of discharge of water at temperature of 20°C under conditions of laminar flow through a unit cross-sectional area of saturated soil medium .The coefficient of permeability has a dimension of velocity and is usually expressed in centimeter per second. Permeability computed on the basis of Darcy's law is limited to the condition of laminar flow and complete saturation of soil. Under condition of partial saturation, the flow is in transient state and is time dependent. To analyze natural flow conditions which depart from the Darcy flow condition, it is sometimes necessary to apply Darcy's law in conditions where it is not strictly valid. When this is done, the effects of turbulent flow and partial saturation on the permeability must be recognized and take into consideration (Cedergren, 1971) and the estimation of quantity of seepage is carried out through principles of Darcy's law, Henry Darcy, a French engineer, conducted a laboratory experiment to study the flow of water in a verticals and filters which he published in his 1856 treatise. The result of his experiment indicated that (Rouse and Ince 1957).

Earth dam should have to be designed to utilize available material to be the best advantages and to conform the actual conditions at site. Sherard et al (1963) say “ The characteristics of the particular site have a great influence on the design of earth dams than do on many other engineering structures “ .Detail design sometimes will be influenced heavily by the strength of

foundation and construction of materials , but the basic features are usually ditched by seepage considerations (P.Novak ,2001),

### **2.5.3.1. Seepage controlling mechanisms in earth dams**

The primary objective of any dam is to impound water behind it and will change the nature balance of conditions at its site , as water is brought into storage , a new seepage pattern will develop in the barrier that confine the reservoir. This water if seeps through the embankment, abutments or through the dam foundation in excessive quantity may damage the dam partly or fully. Therefore it is very important to control the seepage though embankment dam using different controlling mechanisms.

Seepage control is vital to prevent excessive uplift pressures, instability of the down and upstream slopes, piping through the embankment and /or foundation and erosion of material by migration into open joints in the foundation and abutments ([WWW.epa.gov](http://WWW.epa.gov)). The need for seepage control will be depend on the quantity and /or location and it is quite difficult and expensive after construction is finished.

As with other engineering works, earth dams and their foundation can be protected from seepage by two fundamental processes:

- Those which keep the water out or reduce the seepage quantities
  - Cut off trenches or /and Sheet piles
  - Grout curtains
  - Impermeable upstream
- Those which use drainage methods to control that enters
  - Embankment zoning
  - Horizontal drain and blankets ( use application of filters )
  - Chimney drains and Relief wells

## 2.6. Slope stability analysis of Embankment dams

### 2.6.1. General considerations for stability

The stability of an embankment dam depends on the characteristics of the foundation and fill materials, on the geometry of embankment section and additional factors such as presence of water, loading conditions. The up and downstream slopes should have to be stable in all conditions and the slopes are adopted on the following considerations.

- Height of dam
- Type of the dam and properties of the fill material
- Nature of the foundation

According to Terzaghi, side slope for homogenous dams having dam height more than 15m upstream slope of (H)3 : V)1 and downstream slope (H) 2.5:1(V )in general needs to be checked for stability to result in safe and economical design.

### 2.6.2. Stability analysis theory, methods and limitations

#### Conventional approach

Conventional slope stability analyses investigate the equilibrium of a mass of soil bounded below by an assumed potential slip surfaces and above by the surface of slope. Forces and moments tending to cause instability of the mass are compared to those to resist instability. Most procedures assume two dimensional (2-D) cross section and plane strain conditions for analysis .Successive assumptions are made regarding the potential slip surface until the most critical surface (lowest factor of safety) is found .Below figure shows a potential slide mass by a candidate slip surface .If the shear resistance of the soil mass along the slip surface exceeds that necessary to provide equilibrium the mass is stable .If the shear resistance is insufficient the mass is unstable .the stability or instability of the mass depends on its weight , external forces acting on it , the shear strengths and pore water pressures along the slip surface.

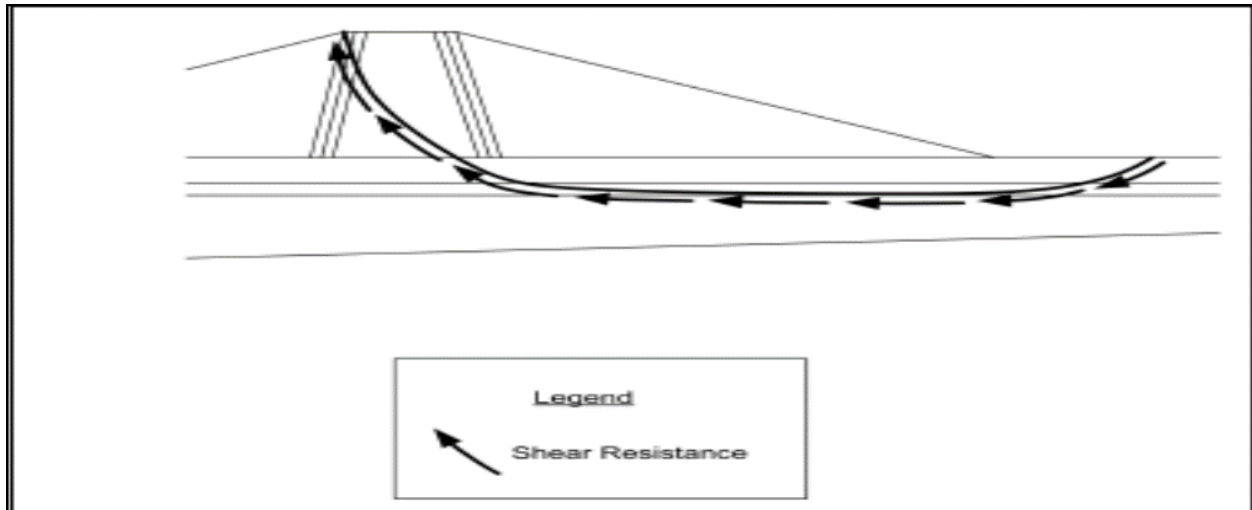


Figure 8 : slope and potential slip

#### Condition for Stability analysis

- Stability analysis of downstream slope during steady seepage.
- Stability of upstream slope during sudden draw down.
- Stability of upstream and downstream slope during and immediately after construction.
- Stability analysis under seismic loading conditions

With a full reservoir the critical region in an earth-fill dam is near the downstream face. If the line of saturation or upper limit of free water in the dam intersects the downstream face, a critical situation may develop. This condition can be avoided by providing a sufficiently wide embankment so that the head loss is great enough to bring the line of saturation out beneath the downstream toe of the dam and Stability analysis during rapid drawdown is an important consideration in the design and evaluating of existing dam embankment dams. During rapid drawdown, the stabilizing effect of the water on the upstream face is lost, but the pore-water pressures within the embankment may remain high. As a result, the stability of the upstream face of the dam can be much reduced. The dissipation of pore-water pressure in the embankment is largely influenced by the permeability and the storage characteristic of the embankment materials.

### 2.6.3. Factor of safety and method of analysis

Conventional analysis procedures characterize the stability of slope by calculating a factor of safety. The factor of safety is defined with respect to the shear strength of the soil as the ratio of the available shear strength ( $S$ ) to the shear required for equilibrium ( $\tau$ ) and many different methods of slope stability analysis have been developed and adopted since many years. The procedure of computation in most methods are very similar, all the methods are targeted to compute the factor of safety. Only the simplest form of the method of slices will be described here. This method assumes a condition of plane strain with failure along a cylindrical surface and the factor of safety against sliding is defined as the ratio of average shear strength, as determined by Coulomb's equation  $s = c + \sigma \tan \Phi$  to the average shearing stress determined by statics on the potential sliding surface. The location of the centre of the failure arc is assumed, the earth mass is divided into a number of vertical segments, and the weight  $W$  of each segment is calculated. The forces between the slices are neglected and each slice is assumed to act independently as a column of soil of unit thickness and width  $b$ . The weight  $W$  of each slice is assumed to act at its centre. When the weight of each slice is resolved in normal ( $N$ ) and tangential ( $T$ ) components, then the normal component will pass through the centre of rotation, and hence does not cause any driving moment on the slice. Shear strength are usually determined from laboratory tri axial tests performed on specimens prepared by compaction in the laboratory samples obtained from exploratory soil borings. The laboratory test data may be supplemented with in situ field tests and corrections between shear strength parameters and other soil properties such as grain size, plasticity and standard penetration resistance ( $N$ ) values. Shear strengths for all of the slope stability analyses described by Mohr-Coulomb failure envelope that relates shear strength to either total or effective normal stress on the failure plane, in the case of total stresses, the shear strength is expressed as;

$$S = c + \sigma \tan \Phi \text{-----Equation 13:( 2.6.3)}$$

Where:  $C$  and  $\Phi$  = cohesion intercept and friction of angle for failure envelope

$\sigma$  = total normal stress on the failure plane

For effective stresses the shear strength is expressed as

$$S = c' + (\sigma - u) \tan \phi' \text{ -----Equation 14:( 2.6.3)}$$

Where:  $C'$  and  $\phi'$  = cohesion intercept and friction of angle for failure envelope plotted in terms of effective stress.

$\sigma$  and  $u$  = total normal stress and pore water pressure respectively on the failure plane

The shear strength parameter,  $C'$  and  $\phi'$  or  $C$  and  $\phi$  are obtained from laboratory shear test data.

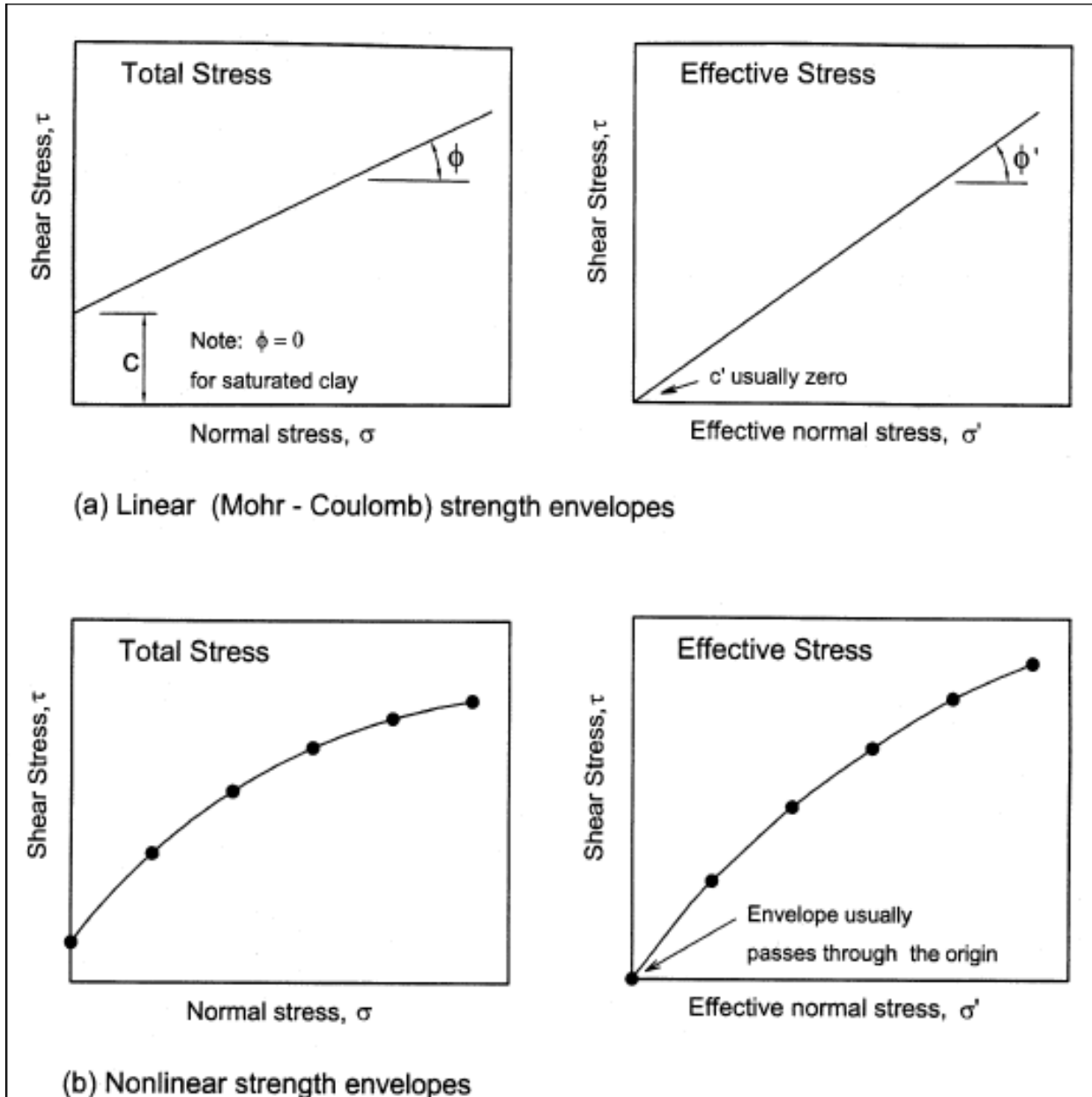


Figure9: Strength envelopes for soils

**2.6.4. Factors of safety and their computations**

Factor of safety is defined by the following relations:

$$F_s = \frac{\text{Available shear strength}}{\text{Equilibrium shear stress}} = \frac{S}{\tau} \text{-----Equation 15:( 2.6.4)}$$

**2.6.4.1. Stability of slopes during end of construction**

Factor of safety is expressed using shear strength parameters in terms of total stress, hence factor of safety is computed using the following formula:

$$F = \frac{M_r}{M_d} = \frac{cL + \tan \phi(\Sigma N)}{\Sigma T} \text{-----Equation 16:( 2.6.4.1)}$$

Where:  $\Sigma T$  = sum of all tangential components

$\Sigma N$  = sum of all normal components

$$\Sigma \Delta L = L = \frac{2\pi r \delta}{360^\circ}, \text{ Length of slip circle----- Equation 17:( 2.6.4.1)}$$

**2.6.4.2. Stability of slopes during steady seepage**

Here the shear strength is defined in terms of effective stress and Critical condition for downstream slope occurs when the reservoir is full and percolation is at its maximum rate. The direction of seepage forces tends to decrease stability. In other words, the saturated line reduces the effective stress responsible for mobilizing shearing resistance.

$$F.S = \frac{cL + \tan \phi \Sigma(N - U)}{\Sigma T} \text{-----Equation 18:( 2.6.4.1)}$$

Where  $\Sigma U$  = the total pore pressure on the slope surface

The pore water pressure at any point is represented by the Piezometric head, ( $h_w$ ) at that point or can be computed by SEEP/W. Thus the variations of pore water pressure along a likely slip surface is obtained by measuring at each of its intersections with an equipotential line, the vertical height from that intersection to the level at which the equipotential line cuts the phreatic line.

**2.6.4.3. Seismic Considerations in stability Analysis**

Seismic forces reduce the margin of safety of an embankment dam. When an embankment dam is located in a seismic region, the stability analysis must consider earthquake forces. During an earthquake, the ground surface oscillates randomly in different directions. This motion can be represented by horizontal and vertical components. An earth dam should be treated as a flexible structure for determining dynamic pressure due to earthquake. However, a simple method to account for earthquake forces in the design of structures is based on seismic coefficients. In this method, basic seismic coefficients or earthquake acceleration coefficients are used as given by:

The factor of safety, therefore, is given as:

$$F = \frac{\Sigma C + \Sigma(N - U - \alpha_h W \sin \alpha) \tan \phi}{\Sigma(W \sin \alpha + \alpha_h W \cos \alpha)} \text{-----Equation 19:( 2.6.4.3)}$$

The geotechnical properties of the available embankment materials are described and therefore, stability analysis of the slopes of the dam will be done and obtained results should have to be compared with the following minimum requirement factors of safety (worldwide guide lines) proposed by USACE are used in world wide.

Table 3: Recommended Minimum factor of safety

S/no	Analysis conditions	Required Minimum factor of safety (NOVAK)	Required factor of safety (USBR )	Required factor of safety (USACE)	Slopes
1	End of construction	1.25	1.4	1.3	Upstream & down stream
2	Long-term(steady seepage)	1.5	1.5	1.5	Upstream & down stream
3	Rapid draw down	1.2	1.3	1.1-1.3	Up stream

---

4	Sudden draw down plus seismic force	1.1	--	1.1	Up stream
5	End of construction & Steady seepage plus seismic force	1.1	--	1.1	Upstream & down stream

---

### 2.6.5. Methods and limitations

Some of the common methods used in computing of factor of safety are the following and they use different assumptions to make the number of equations equal to the number of unknowns, they also differ with regard to which equilibrium equations are satisfied, for example the Ordinary Method of Slices, the Simplified Bishop Method and the U.S.Army Corps of Engineers', Modified Swedish Methods do not satisfy all conditions of static equilibrium. Methods such as Morgenstern and price's and Spencer's do satisfy all static equilibrium conditions. Methods that satisfy static equilibrium fully are referred to as "COMPLET" equilibrium methods and complete equilibrium methods have generally been more accurate than those procedures which do not satisfy and therefore they are preferable and the main limitations of all the methods is that factor of safety is assumed to be constant along the potential slip surface.

### **3. Methodology of the study**

#### **3.1. General**

Due to high water demands of both towns fear for conflicts among users are increasing from time to time, Therefore the method was site visiting , gathering of relevant data on water uses ,water demand and populations, social issues ,hydrologic-hydraulic structures and geotechnical issues related to Midamr dam have been gathered and going to be analysed and interpreted.

#### **3.2. Data collection**

##### **3.2.1. Primary data:**

- Site visiting and visual inspection of project area and assessing of physical performance of the dam (surveillance and performance evaluation, if there is instrumentation).
- Interview with one of site engineers , who had been working as site engineer and supervisor during construction of the dam and other elder people and guards for the dam.
- Discussion with both water supply office managers and staffs , regional water supply , and water resource and regulatory department staffs
- Discussion with zonal and town administrator staff as well as with Almeda Textile factory manger and deptment heads .
- Arranging and organizing list of questionnaires focused on water demand concerns and other relevant topics

Primary data as gathered orally from the surrounding people and water supply offices , and from the answers for the provided questionnaires show that there is high and progressive water demands and on the contrary side limited water resource as a result both towns are under fears of what will be going on in the future, if the existing dam become non-functional , if upgrading and rehabilitation works are not consider and new water projects are not launched timely.

### 3.2.2. Secondary data:

- Geological and geotechnical reports and Engineering design documents of Midmar dam project data are collected from Tigray regional water resource bureau and federal Ministry of water , Ethiopia
- Petition prepared and its temporary remedial measures proposed for both towns has been collected ( Officially Axum town has got right to use MidmarDam as water supply source )
- Collection of design guide lines , manuals and standards used in designing of earth dams
- Collection of water supply design document for Axum town
- Collection of study documents at Midmar dam project by Water works design supervision enterprise ( Federal WWDSE)
- Collection of M.Sc. thesis document done related to the thesis work

(THE CASE OF MAYKOKOEARTH DAM BY G.B.Gebreegiabher & THE CASE OF ZANAMED, AMHARAREGION BY Tigist Anteneh Mekonenen)

## 4. Assessment and evaluation of the baseline situation

### 4.1. Assessments

- During assessments in the study area, the major finding was the co-existence of high water demands and availability of scarce water resource and such happenings greatly affects rate of the rapid economic development in the area,
- Eventhough regional water bureau had formed group of experts to asses and forward remedial measures in 2004 E.C to resolve the conflict due shortage of water , the conflict resolving committee members put temporary solution and they never considered future water demand projections , beside this they never proposed for how many years their temporarily solution is valid.
- There is an interest to increase dam height from water supply office managers, experts, political leaders and communities ,however,they never think of slope stability conditions.
- From water office managers and their staffs and communities there is questions for increments in plant treatment capacities.
- Need for construction of additional water supply projects
- Axum town has suffered more than Adwa due to shortage of water
- Neither thesis nor paper has worked yet , the communities , community leadreds know nothing about the existing conditions of the dam and they are too much concerned.
- Need for thesis and other research works at Midmar dam project

As per study and common understanding of the assigned committee members ( Reference letter written WRD/24677/W-3:, at March ,21 ,2004 E.C) the following table shows clearly what they had suggested as remedials.

Table 4: Water demand allocation as remedial, 2004 E.C

S/No	Name of the Town	Type of Water demands	Allocated water Demand (m <sup>3</sup> ) per a day	Remark
1	Adwa	<ul style="list-style-type: none"> <li>• Domestic demand</li> <li>• Institutional Demand</li> <li>• Industrialwater Demand &amp; others</li> </ul>	3104.12	Adwa will fully get water from Midmar dam project
2	Axum	<ul style="list-style-type: none"> <li>• Domestic demand</li> <li>• Institutional Demand</li> <li>• Industrialwater Demand &amp; others</li> <li>• Total water Demand</li> </ul>	3417.15	Axum town will go to get 933.1 m <sup>3</sup> per a day from ground water of Axum areas
			6521.27	

## 4.2. Salient features of Midmar dam, current and forecasted water supply and water demands conditions

### 4.2.1. Salient features of Midmar dam

- **Hydrology**
  - Catchment area =75 km<sup>2</sup>
  - Mean annual Rain fall =746mm
  - Mean Annual flow =11.9MCM
  - Annual sediment load =65,100m<sup>3</sup>
  - Dependable rain fall = 735mm
  - Design routed flood =260m<sup>3</sup>/sec
- **Reservoirs**
  - Live storage =7.5MCM
  - Dead storage =2.5MCM
  - Total design storage =10CMC
  - Dead storage level= 1044.34m
  - Normal storage level=1054m
- **Dam (Zoned type Embankment dam)**
  - Maximum dam height=32.7m
  - Crest length =310m
  - Crest width =8m
  - Depth of trench =8m
  - Crest length of spill way =60m
- **Intake and out let capacities (Designed )**
  - Intake capacity =380lit/sec
  - Out let capacity =40m<sup>3</sup>/sec
- **Treatment plant capacity**
  - Designed capacity = 83 lit /sec
  - Current capacity =94lit/se

#### 4.2.2. Current water supply and water demands conditions

##### Water demands for Adwa and Axum

Water demand projection is key engineering activity while designing and evaluating of water supply project/s and helps to own technically, economically and socially sounded projects. Hence , principles of water demand projection in this their work is going to show the relationship between summary of water demands and existing capacity of Midmar dam , to do so Population Projections is crucial and Population figures are available from the 1994 population and housing census of Ethiopia, published by the Central Statistical Authority (CSA), Office of Population and Housing Census Commission. The CSA makes population projections for towns (urban) and rural areas by region.

##### Population size and water demands for Adwa and Axum towns

Based on population forecasting methods and inputs data from CSA, populations sizes are used in water demand projections and the annual water demand projections for both towns is done based on water demand guide lines produced by Ministry of water resource ( Urban Water Supply Design Criteria ,January 31, 2006 and Water sector Development program ,Oct 2002)

##### Annual water demands & Capacity of Existing Midmar dam

The following table shows that annual water demand of Midmar dam project beneficiaries , Hence , as per project annual water demands Capacity of Midmar dam can be evaluated .

Table 5: Summary of Annual water Demand

s/no	year (G.C)	Adwa project		Axum project		Total annual water demand for the project	
		Maximum	Minimum	Maximum	Minimum	Minimum	Maximum
1	2014	3,896,808	4,619,475	1,991,291	2,787,808	5,888,234	7,407,283
2	2015	3,967,700	4,718,536	2,069,294	2,897,012	6,036,994	7,615,548
3	2016	4,041,229	4,821,477	2,150,353	3,010,494	6,191,582	7,831,971

4	2017	4,117,639	4,928,451	2,234,586	3,128,421	6,352,226	8,056,872
5	2018	4,197,042	5,039,615	2,322,120	3,250,968	6,519,162	8,290,582
6	2019	4,279,555	5,155,133	2,413,082	3,378,315	6,692,637	8,533,448
7	2020	4,365,301	5,275,177	2,507,607	3,510,650	6,872,908	8,785,827
8	2021	4,454,405	5,399,922	2,605,835	3,648,169	7,060,240	9,048,092
9	2022	4,546,999	5,529,555	2,707,911	3,791,075	7,254,910	9,320,630
10	<b>2023</b>	<b>4,643,221</b>	<b>5,664,265</b>	<b>2,813,985</b>	<b>3,939,579</b>	<b>7,457,206</b>	9,603,845
11	2024	4,743,212	5,804,253	2,924,215	4,093,901	7,667,427	9,898,153
12	<b>2025</b>	<b>4,847,120</b>	<b>5,949,723</b>	<b>3,038,762</b>	<b>4,254,267</b>	<b>7,885,882</b>	<b>10,203,991</b>
13	2026	4,955,098	6,100,893	3,157,797	4,420,915	8,112,895	10,521,808
14	2027	5,067,306	6,257,984	3,281,494	4,594,092	8,348,800	10,852,075
15	2028	5,183,909	6,421,228	3,410,037	4,774,051	8,593,945	11,195,279
16	2029	5,305,080	6,590,867	3,543,615	4,961,061	8,848,694	11,551,928
17	2030	5,430,997	6,767,151	3,682,425	5,155,395	9,113,422	11,922,547
18	2031	5,561,846	6,950,341	3,826,673	5,357,343	9,388,520	12,307,684
19	2032	5,697,822	7,140,706	3,976,572	5,567,201	9,674,394	12,707,907
20	<b>2033</b>	<b>5,839,124</b>	<b>7,338,529</b>	<b>4,132,342</b>	<b>5,785,279</b>	<b>9,971,466</b>	13,123,808

### 4.3. Evaluation of water resource potential

#### 4.3.1. Hydrological investigations

These investigations are very important in reservoir planning as the reservoir size, fixing of height of dam, and determination of other engineering parameters which depends on the available water resource and purpose of the project.

#### **4.3.1.1. Hydrological analysis at Midmar dam axis**

Though there are many activities in doing of hydrological studies, in this case, the most important hydrological studies are just determination of water resource potential and in flow sediments to the existing reservoir, hence, the annual Water resource potential in the study area is going to be quantified using rational formula.

#### **4.3.1.2. Water Resource Potential /Assessment**

Screened rain fall data which was tested for both outlier values is also checked for adequacy and the revised standard error is 2.44 % which is less than 10% therefore, 75 % dependable rainfall of the annual precipitation of the catchment has been considered and is computed through the principle of least square method(plotting position method) after interpolating it is 735.30mm,just using rational formula and assuming reasonable run off coefficient 0.250 as per experiences in Tigray region , annual run off volume from the catchment is estimated 13.78MCM and during my site visiting elder people and guards of the dam confirmed that water is spilling over the spill way during rain seasons.

#### **4.3.1.3. Sedimentation and Distribution investigations**

The average annual sediment production from a catchment is dependent on many factors such as soil type, land use cover, topography and climate and in most cases adequate data for a complete analysis of all factors are difficult to observe.

The Midmar dam design project prepared by water Resource Development Authority (1992, WRDA, Adiss Ababa) has considered sedimentation rate ranging from 3733 to 434 m<sup>3</sup>/km<sup>2</sup>/ year with average rate of 1764 m<sup>3</sup>/km<sup>2</sup>/year but as per the study and detail design of additional treatment plant for Midmar project, January, 2014,by Water Works Design and Supervision Enterprise (WWDSE), the reservoir sediment deposition has been concluded and summarized as follow.

- The reservoir in 1992 has an original total capacity of 10.15 MCM at an elevation of 1054.7 m Asl
- Total capacity of Midmar reservoir deceases from 10.15 MCM to 9.60MCM with in the period of 1992 to 2003

- The total loss of reservoir storage is 0.55 MCM and the dead storage of the reservoir decreases from 2.5 MCM to 2.04 MCM. During 2003 the survey the sediment deposition was 0.41 MCM.
- The result of as per 2013 survey the sediment deposition has only increased to 0.14 MCM
- From the sediment survey results, the rate of sediment deposition reduces in consequence the transport sediment load over the watershed also decreases. The reduction of sediment of sediment deposition could be due to intensive soil and water conservation work undertaken over the catchments (pictures from agriculture office of Adwa, which shows conservation practices)
- Because of effective watershed management the annual sediment yield /inflow has reduced to 0.014 MCM that is  $199.43 \text{ m}^3/\text{km}^2/\text{year}$  and this shows the sediment deposition rate is decreasing progressively, further the sediment load transported to the reservoir will be reduced by constructing of check dams to the tributaries.
- From the survey result about 74.6 % of sediment deposition for the period of 1992 to 2003, while for the period from 2003 to 2013, 25.4 % of sediment has deposited.
- Thus, as long as there is no sediment load record on the tributary rivers the prediction of sediment deposition will be based on the survey results, so if the deposition sediment in the future continues the prediction of sediment volume will be 0.83 MCM in 20 service life of the reservoir.

#### 4.4. Geotechnical evaluation of Midmar dam

Geotechnical evaluation is crucial concern while designing and evaluating of existing embankment dam/s, hence, earth dam should have to be satisfy the basic requirements; slope stability, appropriate zoning of dam body, durability, limited deformation and limitation of damage to nearby structures or services, hence geotechnical analysis of earth dam can answer some of the following failure criteria.

- Loss of overall stability
- Failure due to internal erosion or /and surface erosion or scour (over topping)
- Failure due to hydraulic uplift

- Deformation due to slope and their foundation which causes structural damage in adjacent structures, roads or services.
- In general geotechnical analysis and evaluation of existing earth dam will help in designing of the most economical and structurally stable earth dams. .

Geotechnical investigations were carried out to decide the appropriate dam axis location and to locate construction material sites and among the investigation, test pits excavations, drilling of boreholes, in situ water pressure tests, and laboratory testing of soils samples were carried out. The available geotechnical information is obtained from detail Design Report volume -2 (WRDA, September, 1993)

#### **4.4.1. Dam foundation**

The dam foundation, abutments and the reservoir bed were investigated for water tightness, The investigation was carried out by drilling of total of 13 boreholes , out of which 8 were located on the dam axis and abutments while the remaining 5 were located in the reservoir bed ,and it was done to investigate the foundation conditions at the dam site and reservoir ,the boreholes were drilled up to a maximum depth of 31 m .The alluvial deposit along the dam axis comprises sandy silt clay (0-2.5m) of medium to high plasticity and from 2.5-8m consists of gravelly sandy silt with significant proportion of boulders and cobble, the permeability in this section is high ( Source : Study and Detail Design of Additional Treatment Plant for Midmar Dam ,Geotechnical investigation Draft Report , February ,2014 By Water Works Design and Supervision Enterprise , Addis Ababa , Ethiopia ) and during construction phase grouting was exercised .

#### **4.4.2. Dam construction materials used**

##### **4.4.2.1. Location of Construction materials**

##### **Location of core material**

The locations of core materials for Midmar dam were located on three borrow sites, namely, Tekejeba borrow site (6.1km far from dam site), Adi-Elbal borrow site (7km far from dam site

along the former Adi Abun- Asmera road ) and Mai-Shana borrow site (9.4km far from dam site along the former Adi Abun-Asmera road).

#### **Location of shell material**

Abundant shell material within the project area was identified during the study and the borrow sites were located about 5 km upstream of dam and 1.4km downstream of the dam.

#### **Location of transition and filter materials**

Sand used for concrete works , filter drains and transition materials were found and located on the former Adwa –Asmera road at 38km-40km far from dam site within three dry river beds ( Weabu , GualKoarNebric and Endamariam )

#### **4.2.2.2. Construction materials used**

The following are soil engineering characteristic adopted in Midmar dam construction (Source MidmarDam Project Final Design Report , September 1993, Study and Detail Design of Additional Treatment plant for Midmar Project , Geotechnical investigation Draft report February ,2014 & and hydraulic conductivity for shell material is assumed reasonably from literatures )

Table 6 : Engineering characteristics of soil material

S/N	Engineering characteristics of soil material	Category of Construction materials for Midmar dam		
		foundation	Core	Shell
1	Dry density	16KN/m <sup>3</sup>	15.696KN/m <sup>3</sup>	17.658KN/m <sup>2</sup>
2	Internal angle of friction (Total)	24.65 <sup>0</sup>	16 <sup>0</sup>	28 <sup>0</sup>
3	Cohesion	26.12KN/m <sup>2</sup>	64.746KN/m <sup>2</sup>	34.335KN/m <sup>2</sup>
4	hydraulic conductivity	10 <sup>-7</sup> m/sec	1.415*10 <sup>-10</sup> m/sec	10 <sup>-4</sup> m/sec

#### 4.5. Seismicity at Midamr dam

The Adwa region, where the dam found is situated on the boundary of zone 1 and zone 2 on seismic risk map of the country. And during designing of Midmar dam it was found necessary to consider the effect of seismicity, while designing of the dam it was recommended to take account 0.11 for horizontal seismic coefficient and scaling factor of 2/3 was used for so as to determine vertical seismic coefficient.

(Source:Midamr Dam project Detail Design Report, Draft Volume 2,Geotechnical,September,1993)

#### 4.6. Morphology and geological aspects of the study area

The dam axis extends within the gentle valley of the stream with particular geological formations of recent alluvial and fluvial deposits, residual soils,colluvium materials, and metamorphic rocks and some other minor geological occurrences such as quartz vein and dykes of igneous origins

The geological formations of the spill way sites is similar to that of the right abutment of the dam structure which is mainly phyletic rock under lain by schist, here again the geological formations for outlet structures is similar to that of the spill way but an extensive and deeper alluvial deposit was investigated during geotechnical investigations carried out before construction of the dam.

#### 4.6. Engineering evaluation of Midamr dam

Height of Midamr dam was fixes based on the storage requirements for the projected water demands and the dead storage requirement for sediment deposition .The overall storage requirement corresponds to 10MCM and from reservoir area capacity storage capacity curve, the height of the dam required for this storage was found 30m with crest length of 310m.The head over the spill way to discharge a flood of 280 m<sup>3</sup>/sec capacity was found to be 1.7m using crest length of 60m & free board of 1m was provided taking wave height and other factors , Thus , the overall height of the dam was fixed to 32.7m and upstream ( 3:1 ) and downstream (2.5:1 ) were proposed and accordingly the dam was constructed.

#### 4.6.1. Seepage analysis for existing Midamr dam

Seepage Analysis is one of the basic requirements for designing and evaluating of embankment dams, just to ensure safety against internal erosion, piping and development of excessive pore pressures in the dam, Hence, Seepage analyses through dam body and foundation is conducted using the state of the art of computer program – SEEP/W and the existing dimension of the dam is modelled using AUTO CAD and is exported to GEO-STUDIO computer program.

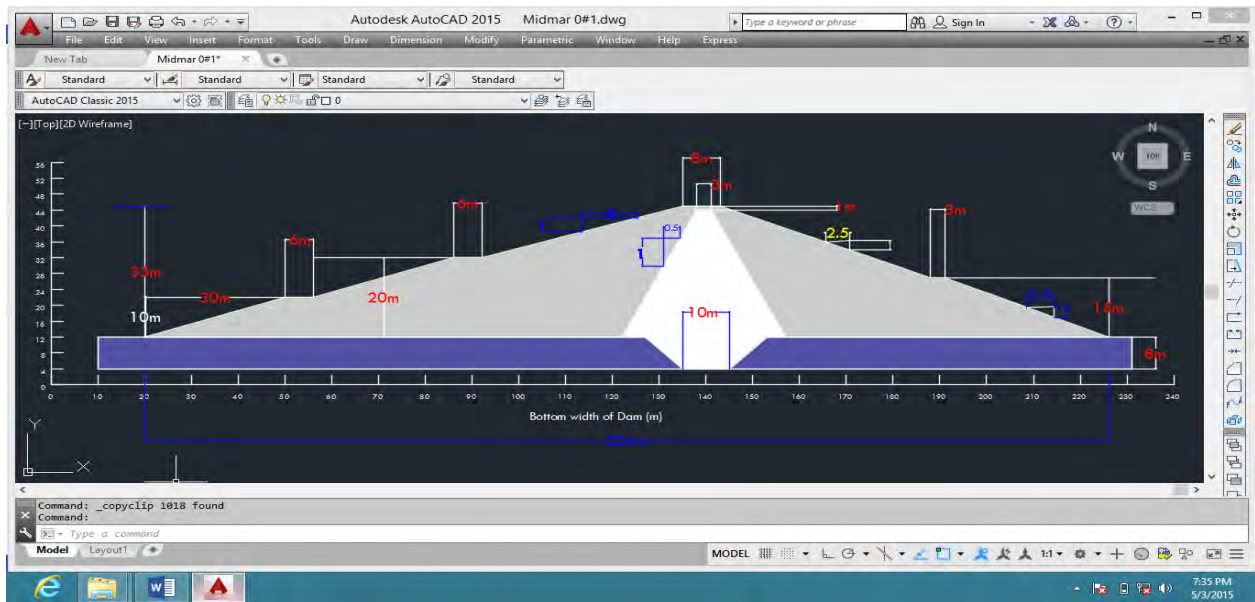


Figure 10 : AUTO CAD modeled for existing dam section

In the model: Depth of foundation =8m

- Top width of the dam =8m
- Top width of core material =3m
- Dam height =33m,
- Depth of foundation =8m
- Width of upstream berms=6m but width for downstream berm =3m, upstream slopes (3:1), Downstream slopes (2.5:1)

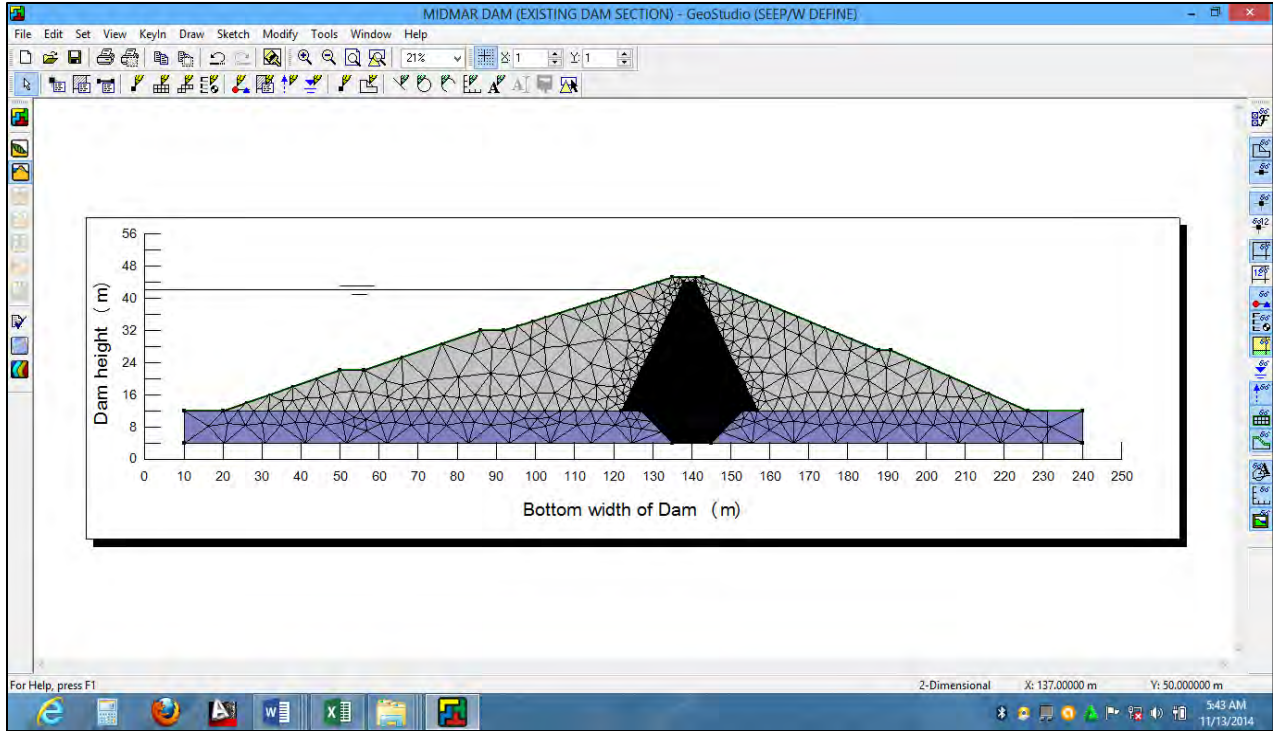


Figure 11 : Model for SEEP/W for existing dam

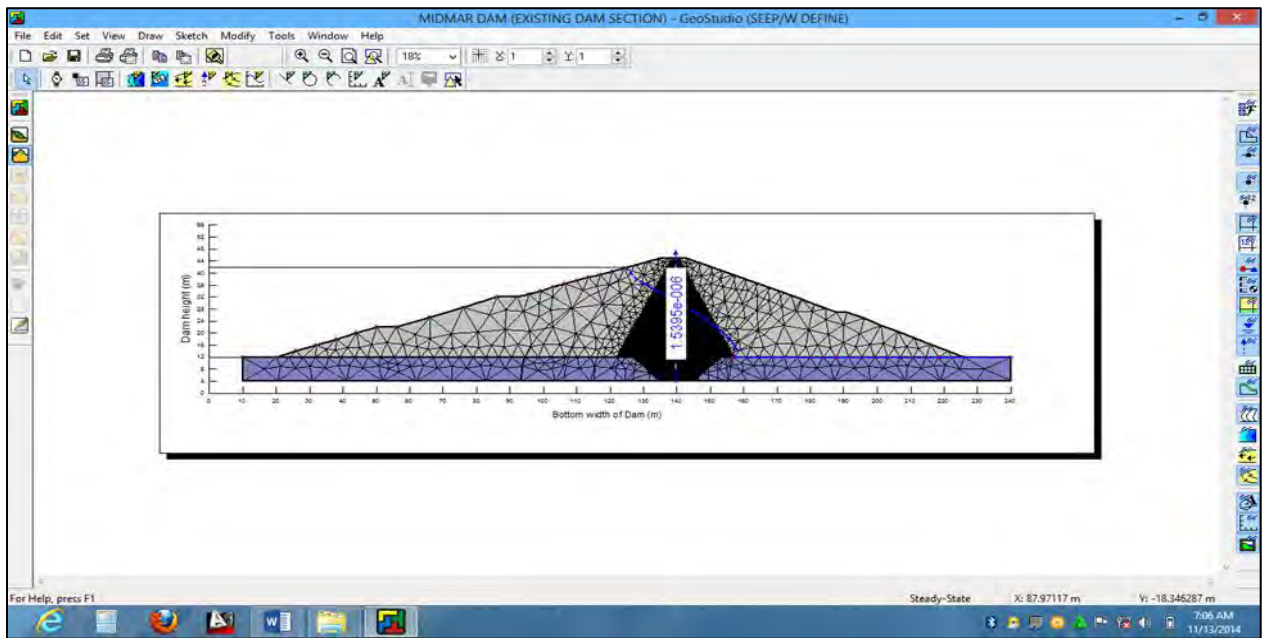


Figure12: Seepage through dam body and foundation (q)

#### 4.6.1.1. Results SEEP/W and Discussions

When the expected quantity of seepage (q) estimated using SEEP/W is  $1.5369 \times 10^{-6}$  m<sup>3</sup>/sec/m length is compared with the designed seepage that is  $2 \times 10^{-5}$  m<sup>3</sup>/sec/m/length, therefore the

design document has no problem of quantifying the expected quantity of seepage, Hence filter materials of the dam had been designed safely, and also during my site visiting, I never came across seepage through the dam body. And at maximum scenario 15024.980m<sup>3</sup> of water will lost be in a year as seepage from reservoir, which is not as such significant in working of water balance.

#### 4.6.2. Slope stability analysis for Existing Midmar dam

The stability of an embankment depends on the characteristics of the foundation and fill materials, on the geometry of the embankment section, and additional factors such as presence of water, loading conditions etc. The stability of existing Dam has been analyzed using state of the art software – SLOPE/W.

##### 4.6.2.1. Stability analysis under normal loading conditions

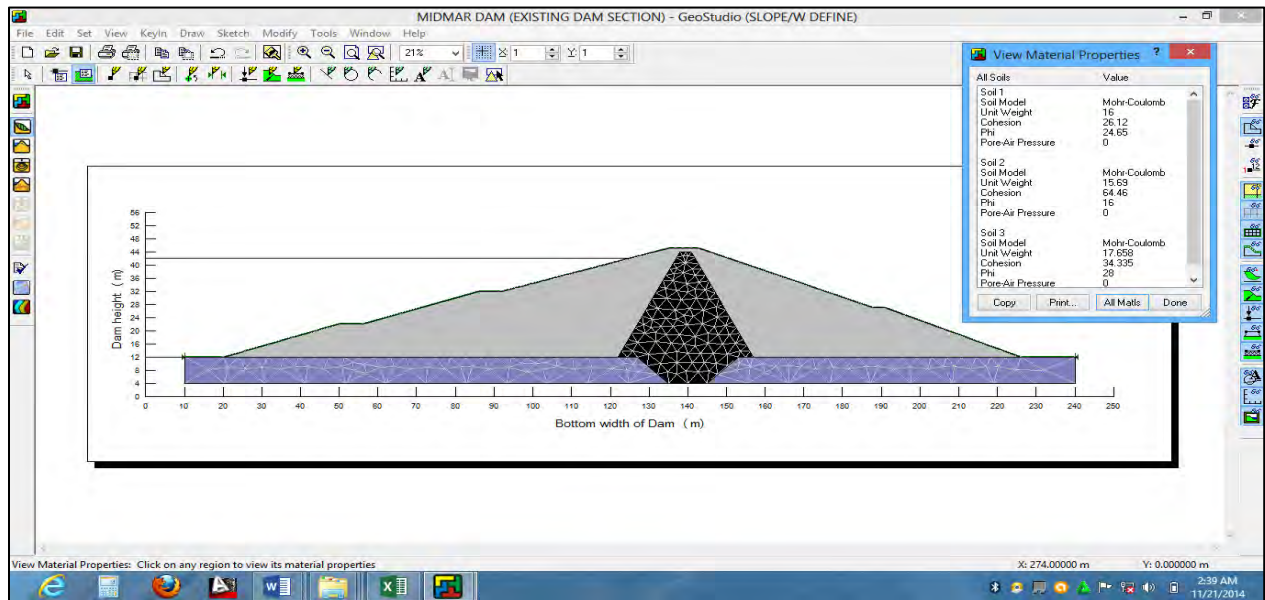


Figure13: Model for SLOPE/W and material properties

Stability analysis for existing Midmardam, under normal loading conations is computed under the following scenarios being the dam already stored water.

1. Steady state condition
2. Sudden draw dawn

1. During steady state condition

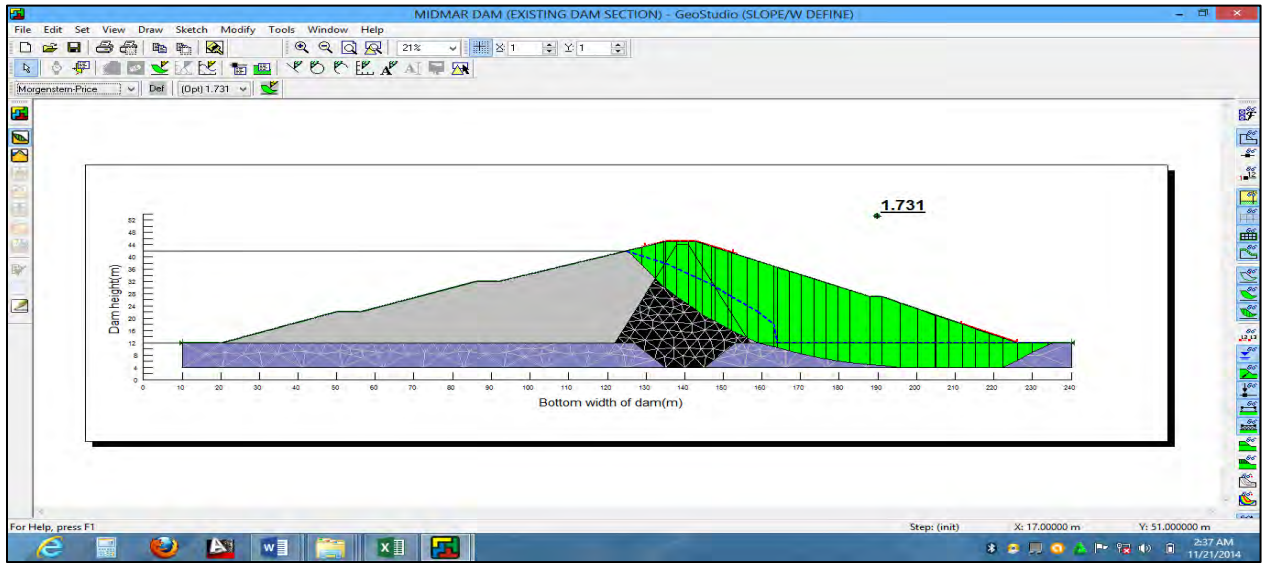


Figure 14: Factor of safety for downstream slope, during steady state (Normal Loading condition)

Table 7: Optimum factor of safety for downstream slope during steady state (Normal loading condition)

S/no	Method	Optimum factor of safety	Minimum required FS	Remark
1	Ordinary	1.587		
2	Bishop	1.736	1.5	Downstream slope, SAFE!
3	Janbu	1.579		
4	Morgenstern-price	1.731		

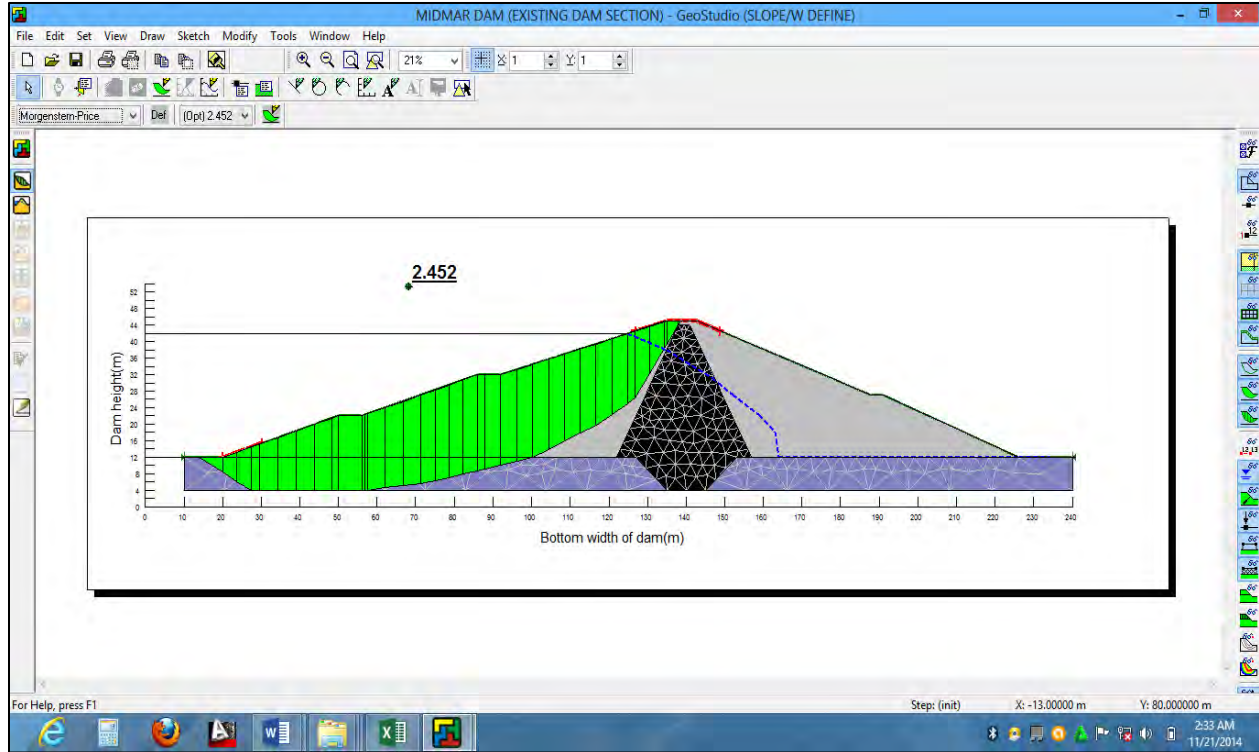


Figure 15:Factor of safety for upstream slope, during steady state (Normal Loading condition)

Table 8: Optimum factor of safety for upstream slope, during steady state (Normal loading condition)

S/no	Method	Optimum factor of safety	Minimum required FS	Remark
1	Ordinary	2.346		
2	Bishop	2.535	1.5	Upstream slope, SAFE!
3	Janbu	2.295		
4	Morgenstern-price	2.452		

2. ) During sudden draw down condition

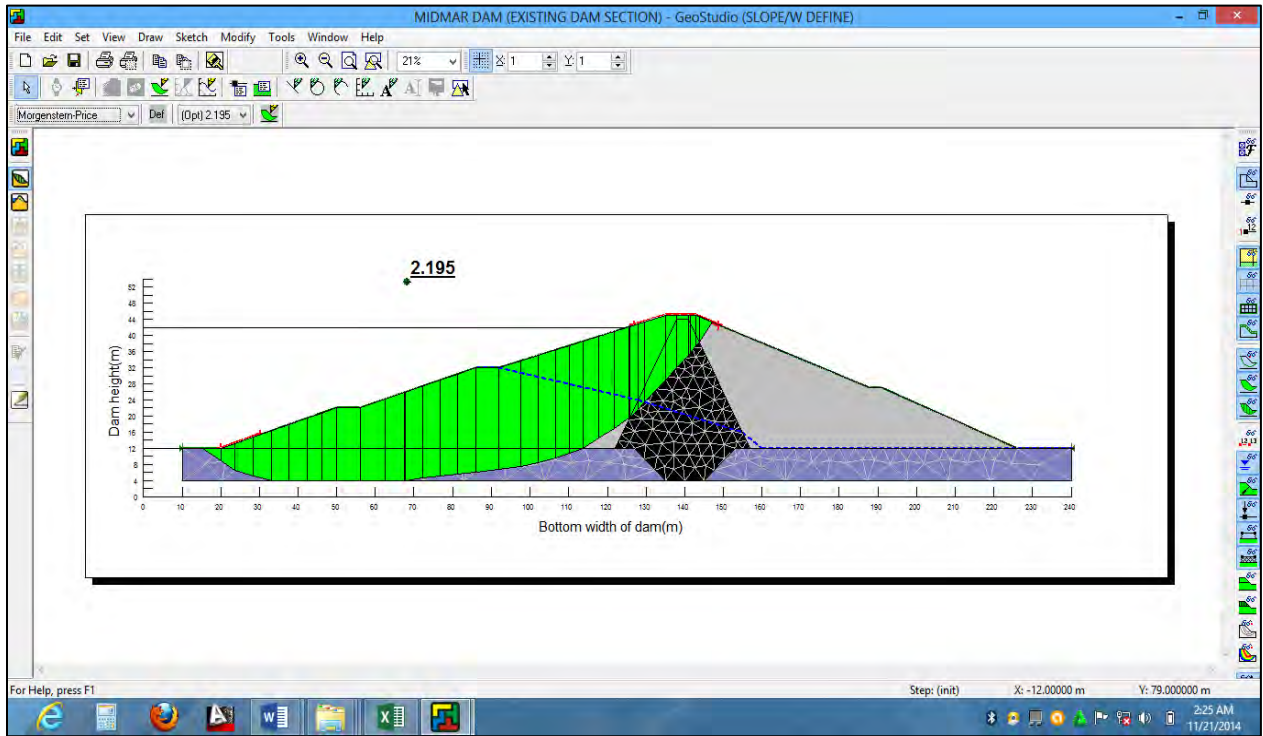


Figure 16: Factor of safety for upstream slope, during sudden draw down (Normal Loading condition)

Table 9 : Optimum factor of safety for upstream slope, during sudden draw down (Normal loading condition)

S/no	Method	Optimum factor of safety	Minimum required FS	Remark
1	Ordinary	2.105		
2	Bishop	2.249	1.1-1.3	Upstream slope, SAFE!
3	Janbu	2.048		
4	Morgenstern-price	2.195		

### 4.6.2.2. Stability analysis under seismic condition

#### 1) During steady state condition

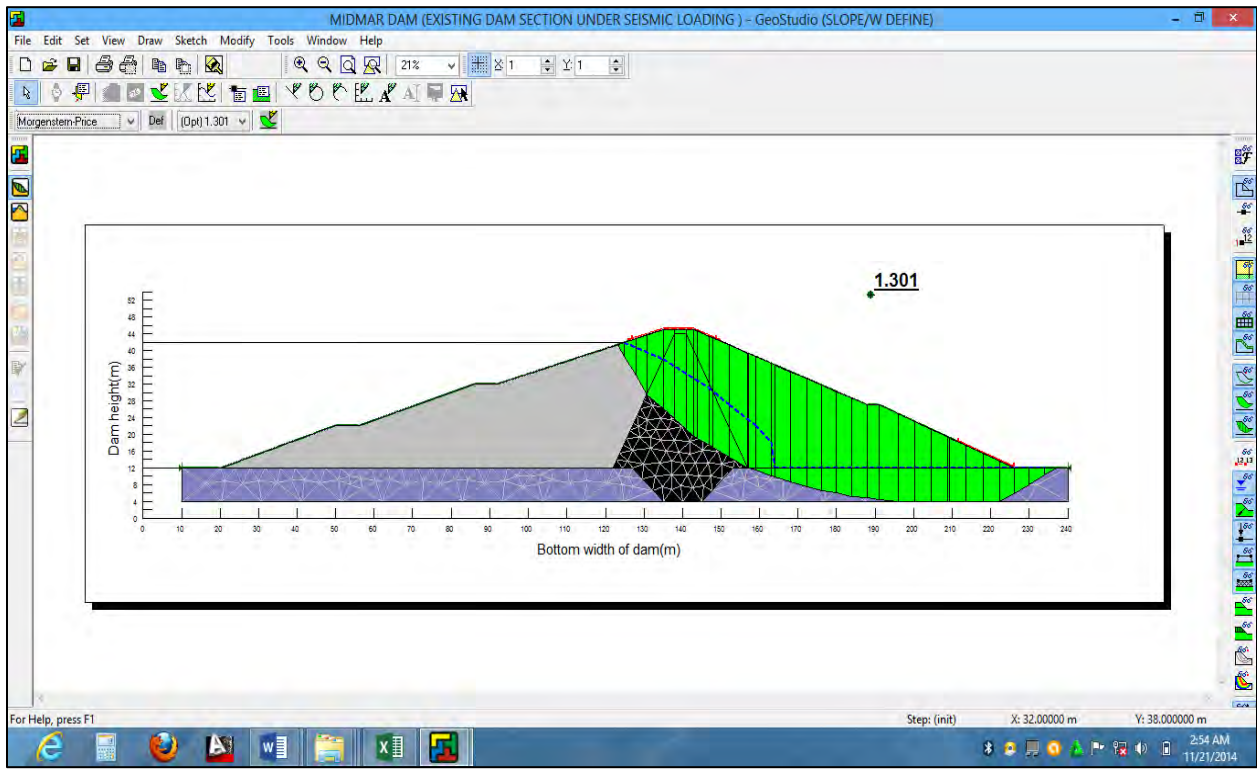


Figure 17: Factor of safety for downstream slope, during steady state (seismic Loading condition)

Table 10: Optimum factor of safety for downstream slope, during steady state (Seismic loading condition)

S/no	Method	Optimum factor of safety	Minimum required FS	Remark
1	Ordinary	1.197		
2	Bishop	1.311	1.1	Upstream slope, SAFE!
3	Janbu	1.170		
4	Morgenstern-price	1.301		

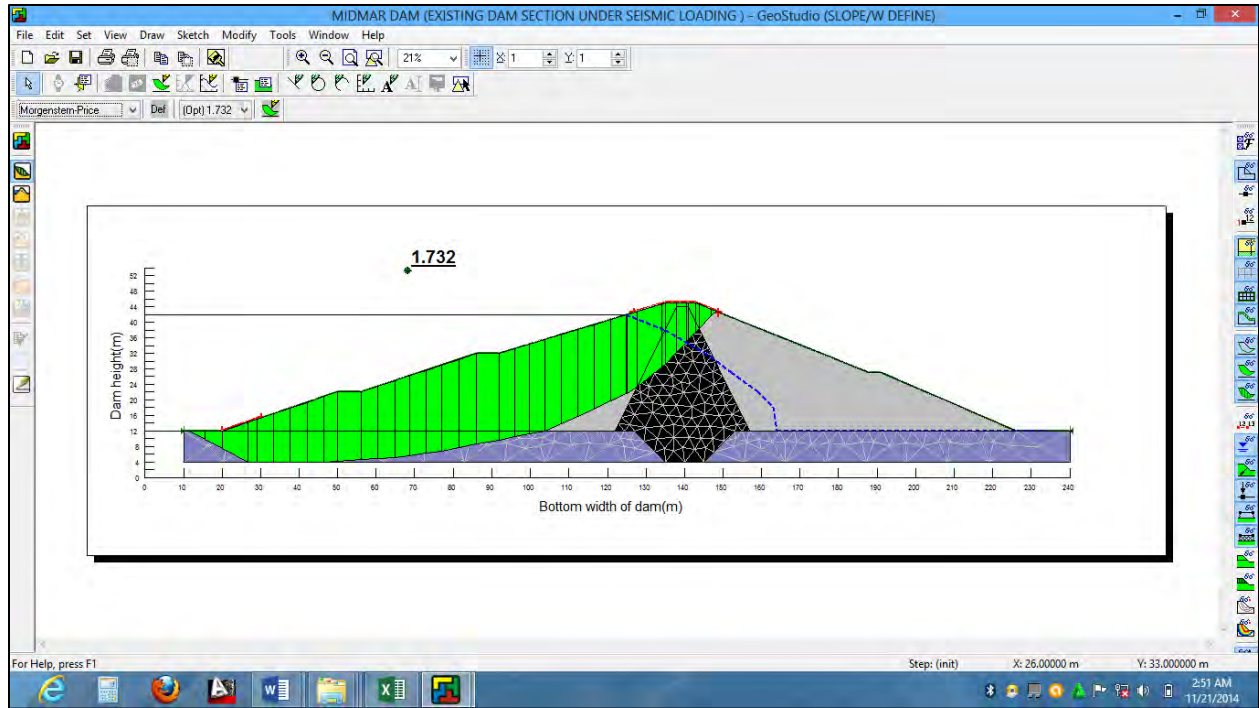


Figure 18:Factor of safety for upstream slope, during steady state (seismic Loading condition)

Table 11: Optimum factor of safety for upstream slope, during steady state (Seismic loading condition)

S/no	Method	Optimum factor of safety	Minimum required FS	Remark
1	Ordinary	1.650		
2	Bishop	1.715	1.1	Upstream slope, SAFE!
3	Janbu	1.627		
4	Morgenstern-price	1.732		

2) Sudden draw down condition

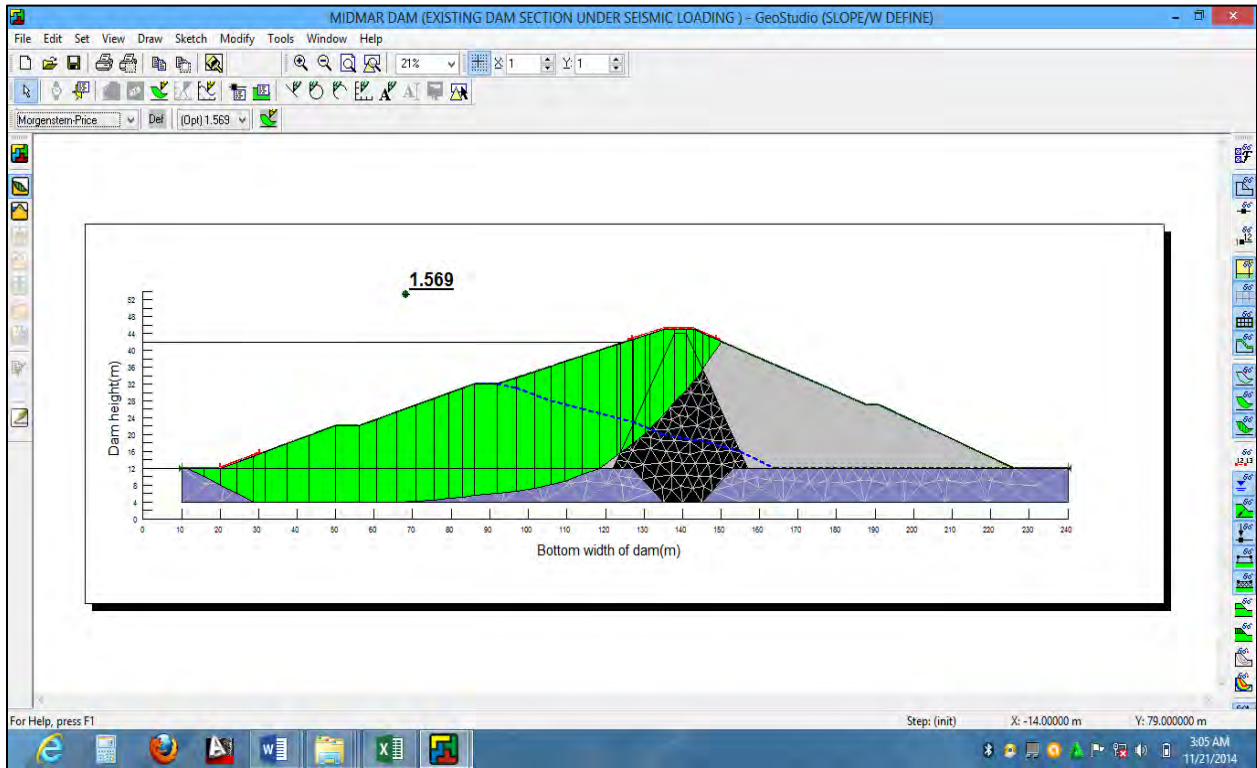


Figure 19:Factor of safety for upstream slope, during steady state (seismic Loading condition)

Table 12: Optimum factor of safety for upstream slope, During Sudden draw down (Seismic loading condition)

S/no	Method	Optimum factor of safety	Minimum required FS	Remark
1	Ordinary	1.499		
2	Bishop	1.618	1.1	Upstream slope, SAFE!
3	Janbu	1.455		
4	Morgenstern-price	1.569		

## 4.7. Spill way and Free board evaluation of Existing Midmar dam

### 4.7.1. Evaluation of Spill way

During this evaluation the surcharge head should have to be checked whether it was designed properly or not, hence spill way designed values are going to computed for the routed flood and the assumed spill way crest length using the following spill way formula.

$$Q = C * L * (H)^{3/2} \text{ -----Equation 20 :(4.7.1)}$$

Where: Q = Designed routed flood (m<sup>3</sup>/sec)

L = spill way crest length (m)

C= discharge coefficient (unit less) and dependant of shape of the spill way

H= depth of flow over crest of the spill way (m)

For the designed and existing spill way crest length (60m), Discharge coefficient (C=2.2) the surcharge head is 1.57m and the designer had adopted surcharge head 1.7m , therefore the existing surcharge head is more safe.

### 4.7.2. Freeboard evaluation of Midmar dam

Effective fetch length for Midmar dam is 1.5km (Source, Midmar Dam project final Design report Volume -3, September 1993), following free board computation principles and taking of wind speed corresponding to 10years return period (6.544km/hr) , average depth of water along the fetch line (15m ) Wind Set-up (H<sub>s</sub>) is 0.02m , Wave height (h<sub>w</sub>) is 0.6m , wave run up is 0.9m Thus, total free board height without camber (height of free board excluding of settlement) and surcharge head will be = 0.002+0.9= 0.902m , still to be on the safest side settlement should have to be computed and hence the overall free board will be the sum of surcharge head , wind set up , total wave height and settlement.

### Settlement allowance (ΔH) and settlement calculations

Settlement of the dam lies between 1.5% and 2% of its total height is considered during its lifetime. Therefore, for the case of Midmar dam site take 1.5% settlement, or Settlement calculation for embankment dam is associated with particle crushing and is greatly increased by saturation. It can be therefore accelerated during construction .The construction settlement

occurring at crest level is 0.186m and long term post construction settlement is 0.42m (service life of Midmar is assumed 50years and 2years for construction elapsed)Hence, total settlement is equal to 0.6055m and the overall free board without surcharge head is 1.51m, and design of the dam has satisfied more or less this criteria.

#### **4.8. Dam appurtenant structures**

##### **4.8.1. Spill way works of Existing Midmar dam**

Spill way is a hydraulic structure, part of a dam and its main function is to discharge major floods (Design routed flood) without damaging to the dam body and its appurtenant structures and at the same time keeping the reservoirs below some predetermined maximum level and type of the spill way adopt is an ogee shape type and is designed to pass  $260\text{m}^3/\text{sec}$  flood, and the computed corresponding discharge head is 1.7m.

##### **4.8.2. Intake and bottom out let structures**

As per the study conducted by Water Supply and Sewerage Authority, (Adwa town preliminary study for Textile Factory and Town Water supply November, 1991) the design maximum daily demand for the municipal and industrial use was 192 lit/sec .To satisfy the probable peak hourly demand, the discharge capacity of the intake at the minimum reservoir level was adopted to meet twice as much as the design maximum daily demand, Therefore, the designed intake capacity of the dam is 380 let/sec.

To satisfy the water demand for the prior right users located downstream and at the same time to maintain the prevalence for maintenance of a live stream and preservation of aquatic life, discharge of 20lit/sec was considered during designing and to pass flood discharge in conjunction with spill way or evacuate the reservoir for inspection or maintenance, the out let was designed to accommodate maximum discharge of  $40\text{m}^3/\text{sec}$ .

##### **4.8.3. Water treatment plant**

The present source of water supply to Adwa is surface water from Midmar dam , the design production capacity of the treatment plant was  $7200\text{m}^3/\text{day}$  , however the treatment plant

currently produces 8256m<sup>3</sup>/day (Source : Study and Detail Design of Additional Treatment Plant for Midmar Dam project , Water Works Design and Supervision Enterprise , January ,2014)

#### **4.9. Results and Discussions for the assessments and evaluations of as is conditions**

There is high water demands and Midmar Dam will not satisfy more and the results of SEEP/W and SLOPE /W for the as is situations show that the dam is designed more safely. Though computation of annual catchment yield, shows that the catchment can generate more run off volume, however, to be confident 2.5MCM of water which is equivalent to the designed dead storage volume can be harvested from the catchment, therefore options for upgrading and maintaining of scheme rehabilitation and upgrading works are found to be unquestionable .

## **5. Upgrading and Rehabilitation of Midamr dam**

### **5.1. Objectives of the upgrading and rehabilitation**

The main objectives of upgrading and rehabilitation of Midamr dam is to harvest additional volume of water in a hydrologic year so as to alleviate the acute shortage of water supply for both towns as much as possible.

### **5.2. Specific objectives of upgrading and rehabilitation**

The specific objectives of this upgrading & rehabilitation is to asses and fix appropriate dam height increment and to estimate how much additional volume of water can be stored as a result of dam heightening ,and also to examine this additional volume of water to what extent can satisfy the water demands.

### **5.3. Factors for upgrading and rehabilitation**

Factors which are considering during dam height increment are availability and suitability of topographic reservoir area ,amount of water demand to be harvested additionally, availability of surface water resource potential, hydraulic dam design criteria and slope stability analyses of the dam , in case of Midamr dam , Storage capacity is found the most governing factor to perform the remain engineering tasks that is the dam do have a room to store 2.5MCM additional volume of water and as per capacity elevation curve of the dam the expected additional dam height increment is only 2m.

### **5.4.Upgrading and rehabilitation options**

So as to harvest additional volume of water on the top of existing capacity, the following options are adopted as engineering measures.

- Widening of spill way width , reducing of designed surcharge head
- Increment of dam height

### 5.3. Analysis for the selected options

During the assessment and evaluation of Midamr dam, there is water resource potential to be harvested, and reservoir area to accommodate 2.5MCM volume of water, the analysis options are targeting how to harvest this amount of water logically.

#### 5.3.1. Redesigning of Midmar dam Spill way

Hydraulic design of Spill way, is dependant of the following factors and other assumptions.

- Topography
- The nature and strength of over burdens
- The alignment of dam axis at the upstream end ;and
- The nature of river & channel alignment at the downstream end
- Hydrology (Routed flood), and the proposed and constructed type of spill way and its

Hydraulic is started with the following equation:

$$Q = C * L * (H)^{3/2} \text{ -----Equation 21 :(5.3.1)}$$

Where: Q = Designed routed flood (m<sup>3</sup>/sec)

L =spill way crest length (m)

C= discharge coefficient (unit less) and dependant of shape of the spill way

H= depth of flow over crest of the spill way (m)

In general this option is widening of spill way crest length, that is reducing of surcharge head (for Q=260m<sup>3</sup>/sec, Ogee shape type, C=2.2, Weir Height=1.5, maximum trial crest length =100m, computed surcharge head=1.2m, Revised C=2.15, Revised Q=264 m<sup>3</sup>/sec, flow type is subcritical) thus weir height of spill way can increase by 0.5m as a result Midmar dam can get a room to harvest additional volume of water for 461,482 m<sup>3</sup> (Read from Capacity Elevation Curve), therefore this is not as such significant and satisfactory upgrading and rehabilitation options.

### 5.3.2. Dam height increment

Dam height increment is a function of many factors which mentioned above, even though Midamr dam satisfy many of the factors, dam heightening is not as simple as raising of the height, but the dam should have to be checked for its stability.

### 5.3.3. Seepage and Slope stability Analysis for modified dam section

For evaluation of slope stabilities at different critical conditions, the following modified section has been adopted and the analysis of the program is based on soil characteristics, and crest width determined as per the following recommendation and this top width is generally governed by minimum roadway width requirements.

Top width (A) of the earth dam can be also selected as per the following recommendations:

$$A = \frac{H}{5} + 3 \text{-----Equation 22 :( 5.3.2) for very low dams}$$

$$A = 0.55(H)^{0.5} + 0.2H \text{----- Equation 23 :( 5.3.2) for dams lower than 30m}$$

$$A = 1.65(H + 1.5)^{1/3} \text{-----Equation 24 :( 5.3.2)for dams higher than 30m}$$

Where H is the height of the dam.

(Source: Irrigation Engineering and hydraulic structures by Santosh Kumar Garg)

From the capacity elevation curve and topographic nature of the reservoir area so as to harvest 2.5MCM volume of water the dam should have to increase its height by 2m , the topographic map shows that it is impossible to increase dam height beyond 2m.

Therefore, top width for modified dam is 5.4m, take 6m , the modified section is modelled using AUTO CAD and is exported to GEO-STUDIO computer program for further analysis.

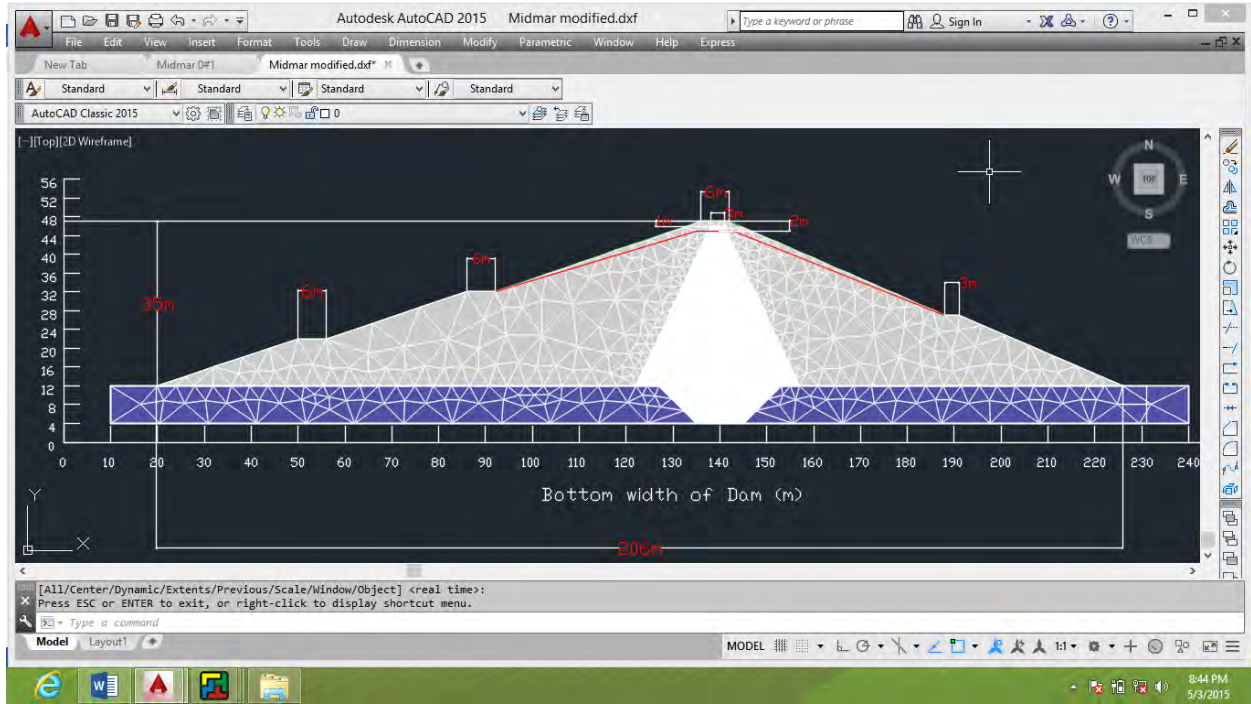


Figure 20: AUTO CAD model for modified dam section

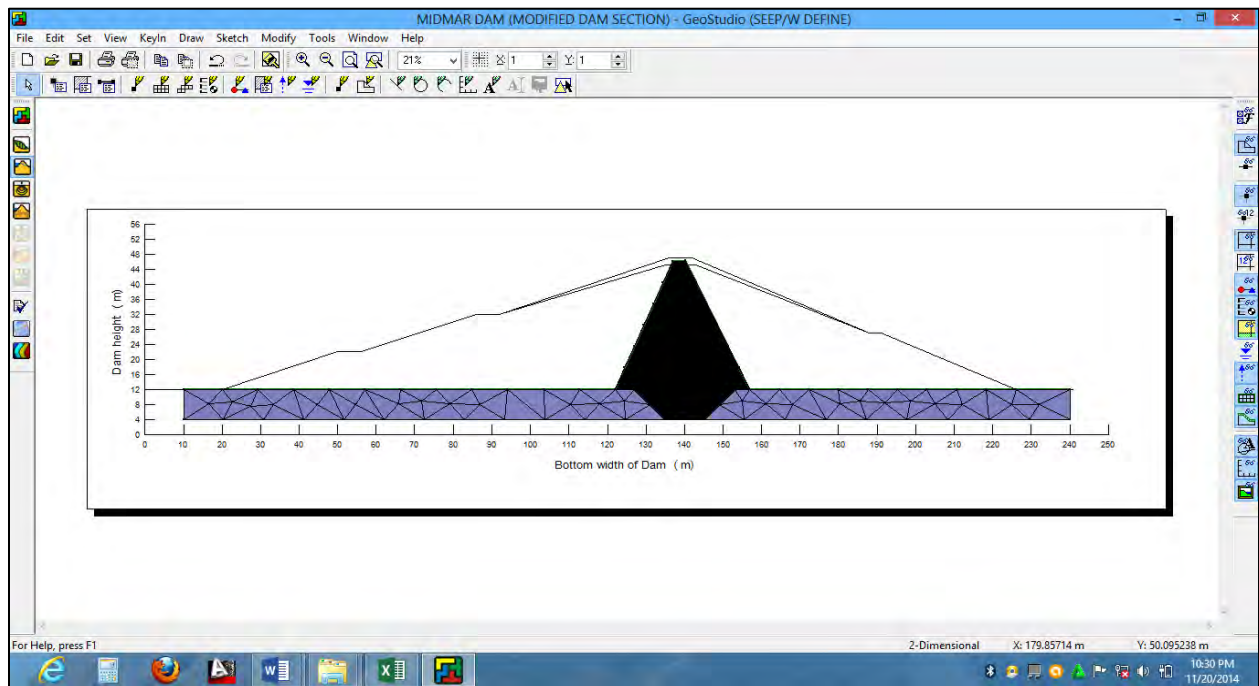


Figure 21: Model for modified dam section used in SEEP/W &SLOPE/W

### 5.3.3.1. Seepage analysis using SEEP/W, results & discussions

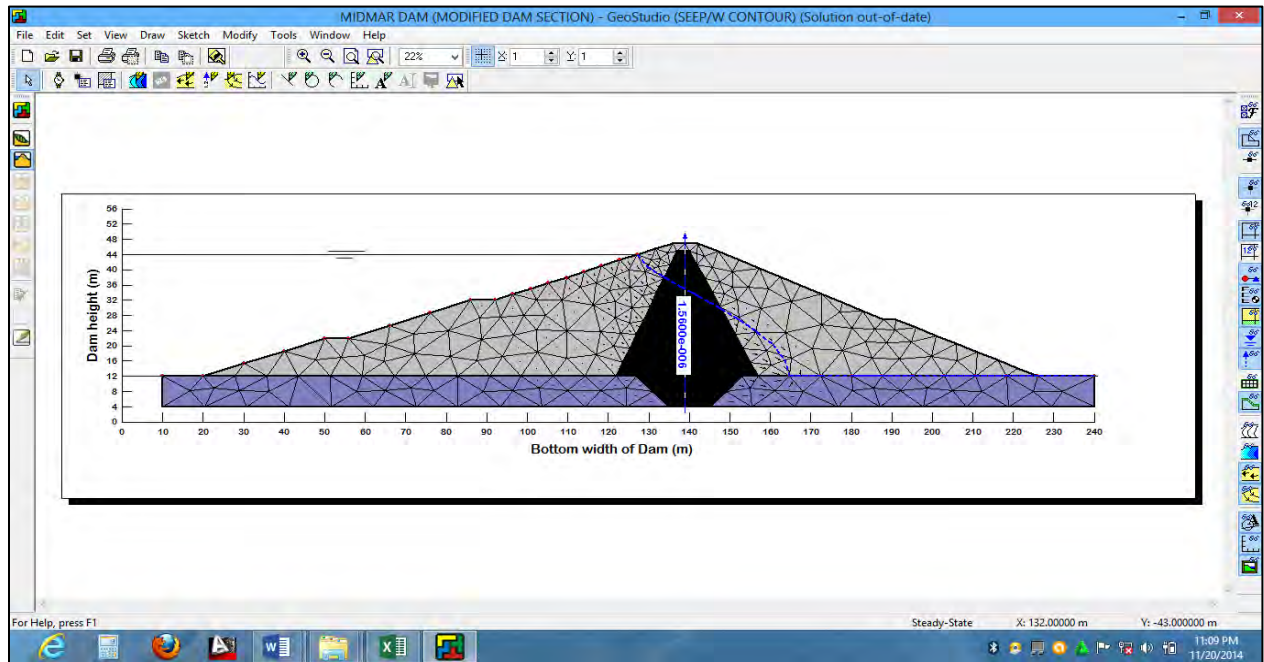


Figure 22: Seepage through dam body and foundation (q)

#### Results SEEP/W and Discussions

When the expected quantity of seepage (q) estimated using SEEP/W is  $1.560 \times 10^{-06} \text{ m}^3/\text{sec}/\text{m}$  length is compared with the designed seepage that is  $2 \times 10^{-05} \text{ m}^3/\text{sec}/\text{m}/\text{length}$ , therefore the design document has no problem of quantifying the expected quantity of seepage, Hence filter materials of the dam had been designed safely, And at maximum scenario  $15250.80 \text{ m}^3$  of water will lost be in a year as seepage from reservoir, which is not as such significant in working of water balance.

### 5.3.3.2. Slope stability analysis under Normal loading condition

Slope stability for this modified dam is done as that of the existing situations of dam ,here the only difference is that height of the dam has been increased as a result top width of has been reduced, later the computed factors of safety under different loading conditions and circumstances are going to checked with the minimum standard recommended factor of safeties.

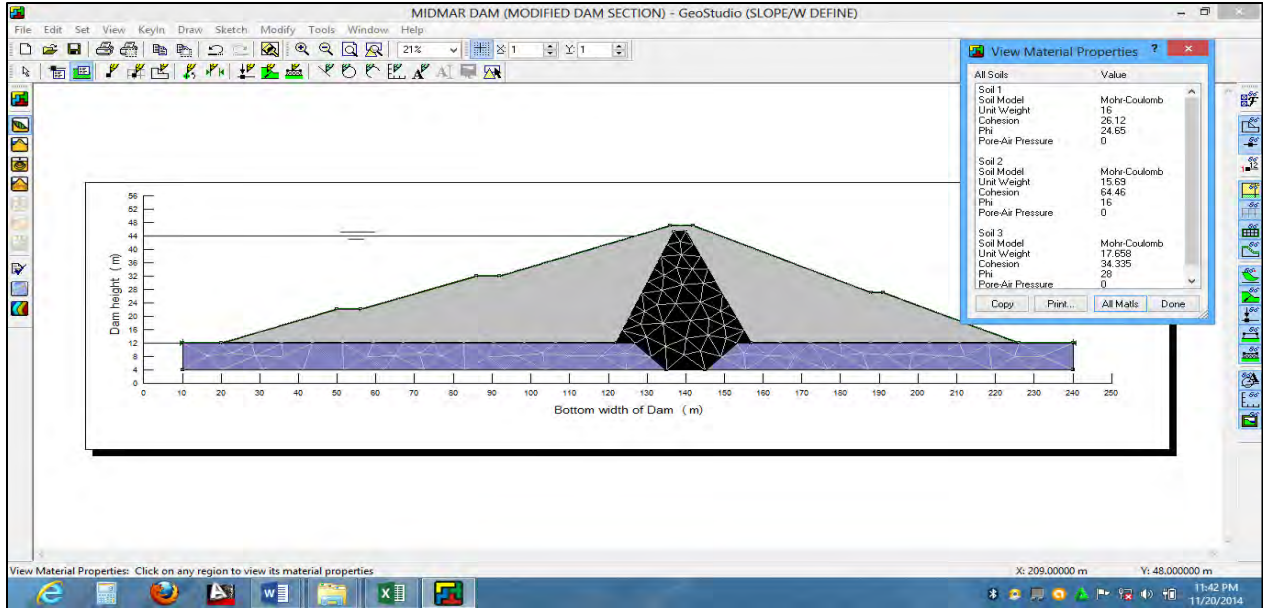


Figure 23: Model for SLOPE/W and material properties

### 1) During Steady state

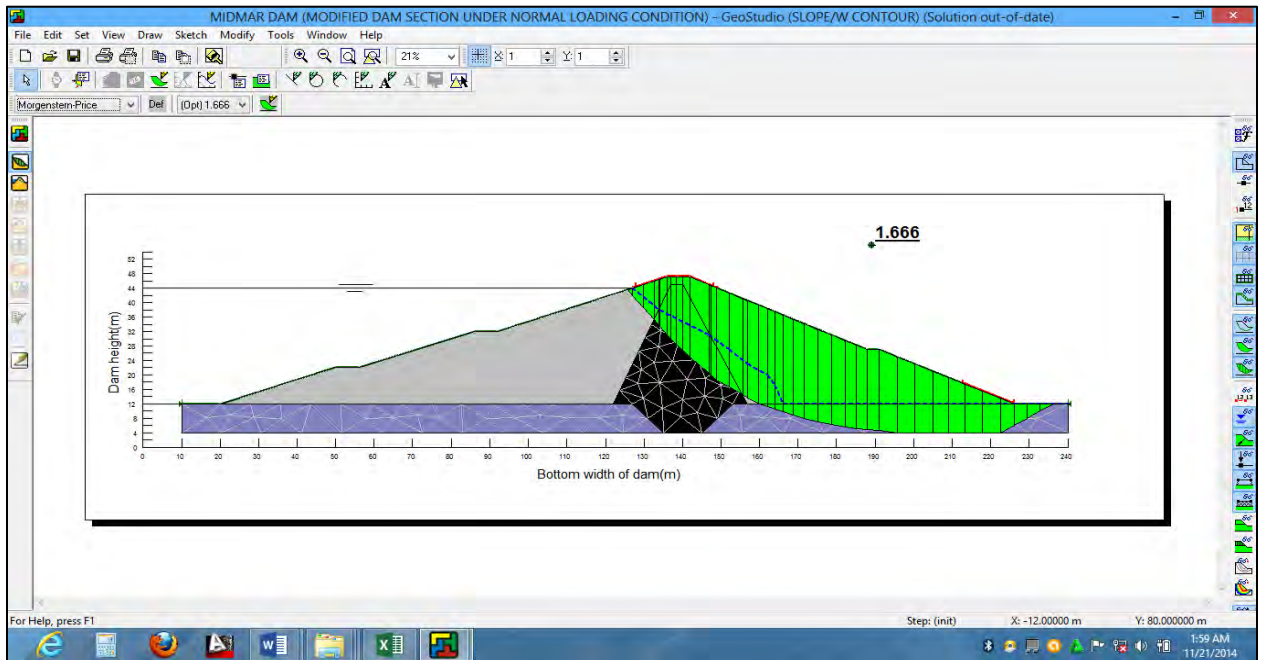


Figure 24: Factor of safety for downstream slope, during steady state (Normal Loading condition)

Table 13: Optimum factor of safety for downstream slope, during steady state (Normal loading condition)

S/no	Method	Optimum factor of safety	Minimum required FS	Remark
1	Ordinary	1.544		
2	Bishop	1.660	1.5	Downstream slope, SAFE!
3	Janbu	1.512		
4	Morgenstern-price	1.666		

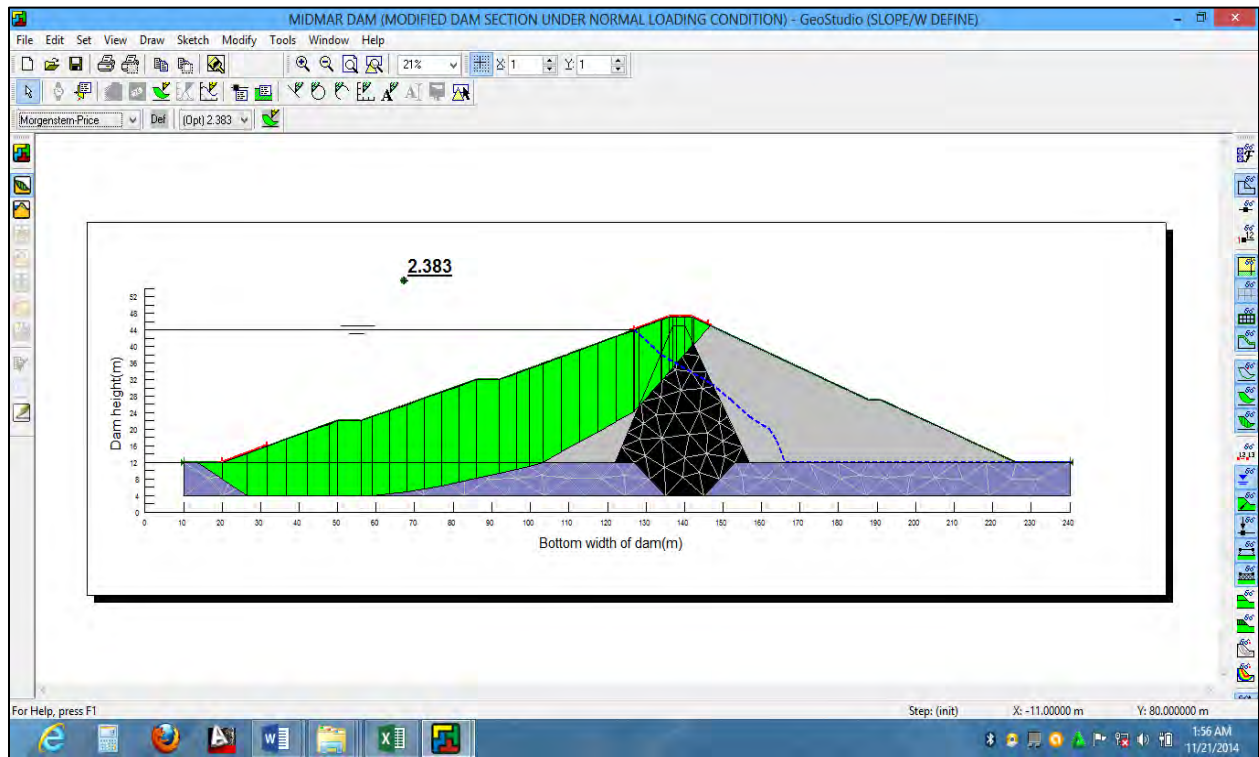


Figure 25: Factor of safety for upstream slope, during steady state (Normal Loading condition)

Table 14: Optimum factor of safety for upstream slope, during steady state (Normal loading condition)

S/no	Method	Optimum factor of safety	Minimum required FS	Remark
1	Ordinary	2.275		
2	Bishop	2.447	1.5	Upstream slope, SAFE!
3	Janbu	2.229		
4	Morgenstern-price	2.383		

2) During sudden draw down

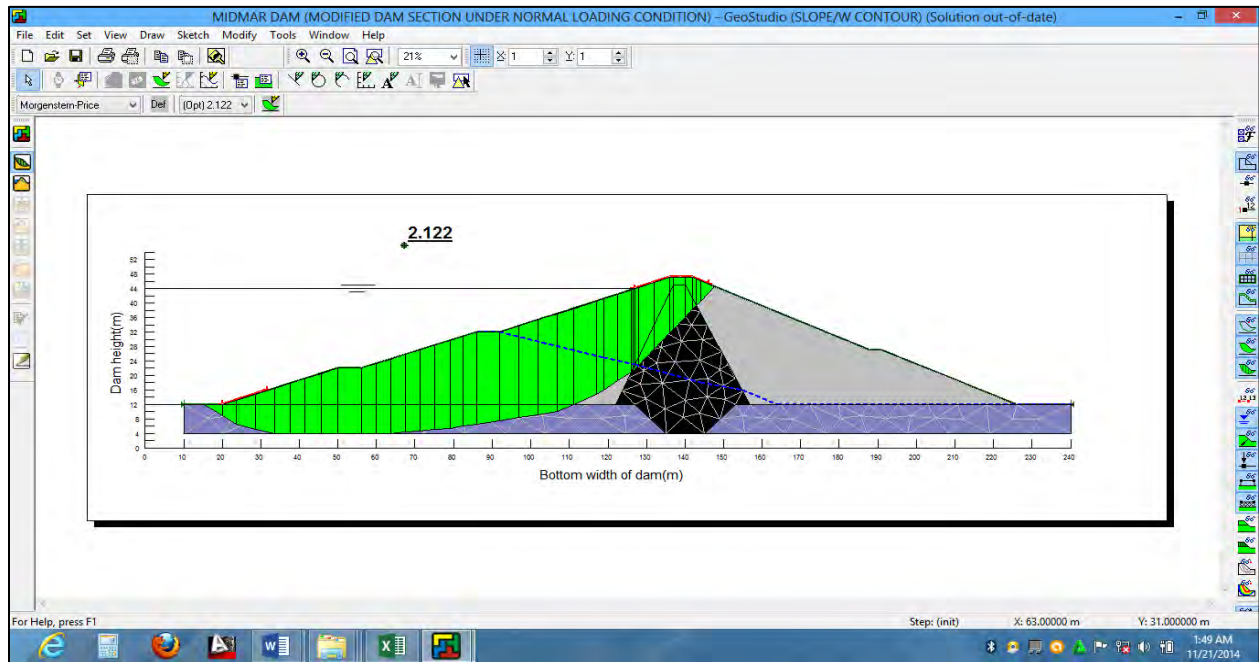


Figure 26: Factor of safety for upstream slope, during sudden draw down Normal Loading condition)

Table 15: Optimum factor of safety for upstream slope, during sudden draw down (Normal loading condition)

S/no	Method	Optimum factor of safety	Minimum required FS	Remark
1	Ordinary	2.021		
2	Bishop	2.168	1.3(1.2)	Upstream slope, SAFE!
3	Janbu	1.973		
4	Morgenstern-price	2.122		

**5.3.3.3. Stability analysis under seismic loading conditions**

1) During steady state

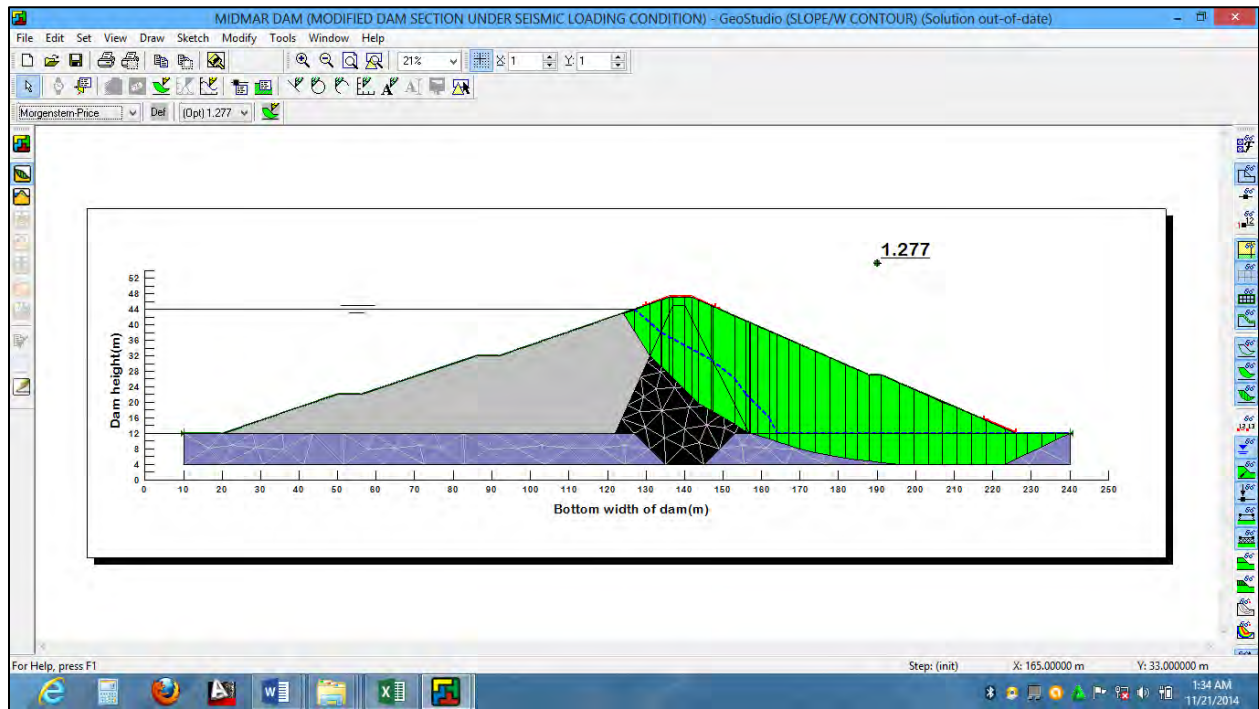


Figure 27: Factor of safety for downstream slope, during steady state (Seismic Loading condition)

Table 16: Optimum factor of safety for downstream slope, during steady state (Seismic loading condition)

S/no	Method	Optimum factor of safety	Minimum required FS	Remark
1	Ordinary	1.175		
2	Bishop	1.277	1.1	Downstream slope, SAFE!
3	Janbu	1.141		
4	Morgenstern-price	1.277		

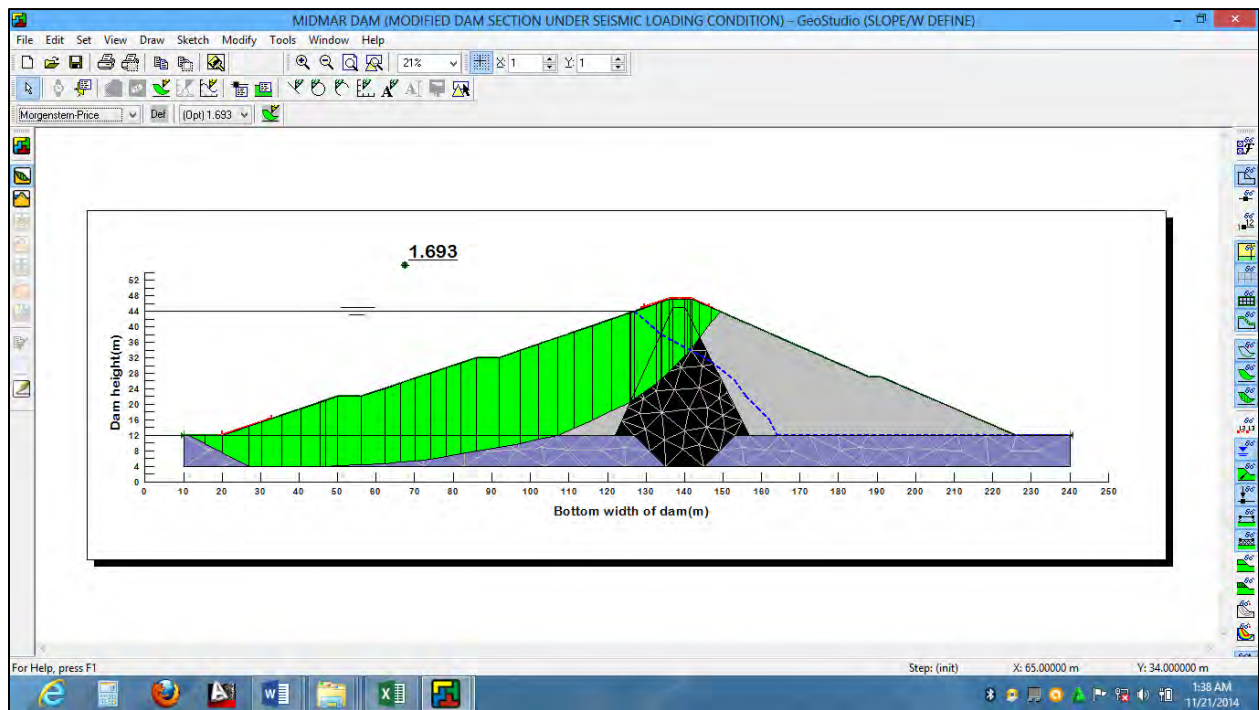


Figure 28: Factor of safety for upstream slope, during steady state (Seismic Loading condition)

Table 17: Optimum factor of safety for upstream slope, during steady state (Seismic loading condition)

S/no	Method	Optimum factor of safety	Minimum required FS	Remark
1	Ordinary	1.632		
2	Bishop	1.755	1.1	Upstream slope, SAFE!
3	Janbu	1.583		
4	Morgenstern-price	1.693		

2) During Sudden draw down

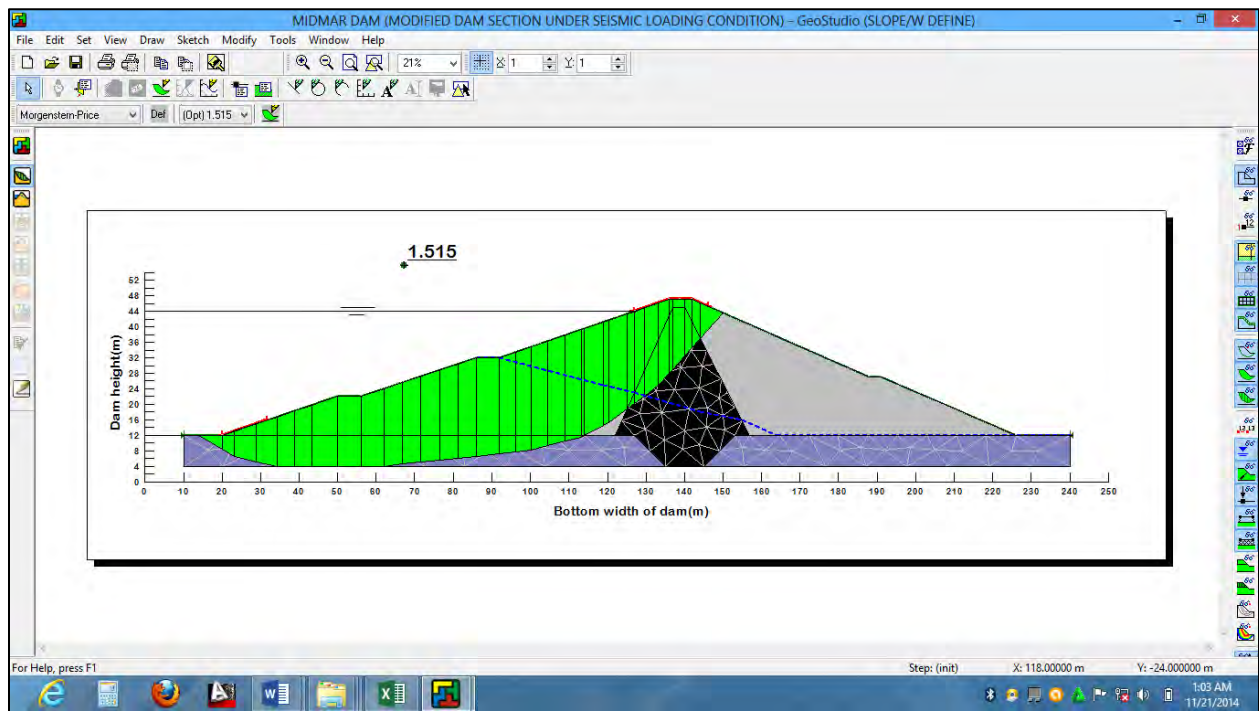


Figure 29: Factor of safety for upstream slope, during sudden draw down (Seismic Loading condition)

Table 18: Optimum factor of safety for upstream slope, during sudden draw down (Seismic loading condition)

S/no	Method	Optimum factor of safety	Minimum required FS	Remark
1	Ordinary	1.439		
2	Bishop	1.562	1.1	Upstream slope, SAFE!
3	Janbu	1.407		
4	Morgenstern-price	1.515		

#### 5.4. Upgrading and rehabilitation design of appurtenant structures

During the assessment and evaluation of Midmar existing water supply scheme the appurtenant structures are found at the most safest side design approaches. For example the designed intake capacity is 380lit/sec and the maximum intake capacity to satisfy the water demand after dam height increment is 340 lit/sec.

## 6. Conclusions and recommendations

### 6.1. Conclusions

Assessments, evaluations and results of redesign (Modification) , shows that Midmar dam can increase its height by 2m, as a result 2.5MCM water can be harvested additionally in a hydrologic year, and therefore the dam can serve as water supply source to satisfy water demands of both towns safely up to 2033G.C, if dam heightening is not taken as an opportunity the dam will satisfy all water demand for both town up to 2023 G.C beyond these years if nothing is done finally project beneficiaries will be faced to high economic ,social and developmental crisis.

### 6.2. Recommendations

- Upgrading and Rehabilitation of Midamr dam is an opportunity to harvest additional volume of water ,Hence, before any planning and implementing of water supply projects around Adwa and Axum area , any considered body or organization better to refer this thesis work.
- Dam height increment for Midmar dam should have to be done under the guidance of the thesis work, just selection of dam heightening options & construction materials, the materials should have to fulfil the minimum requirements of soil engineering characteristics which have considered in evaluating and upgrading of this scheme.
- Ground water potential assessment at downstream of Midmar dam should have to be investigated as well as construction of new water supply scheme/s should have to be facilitated soon.
- Being the designed capacity of plant treatment was restricted to 94.1 lit/sec and currently, the treatment plant is redesign to meet maximum demand about 243lit/sec, however, while if dam heightening is taken as remedial option upgrading for treatment plant capacity should have to consider so as to produce 340lit/sec even beyond more.
- Due to 2m dam height increment 22.39 ha is going to be inundated by water, therefore social ,environmental and, compensational issues should have to be thought and handled before implementing of dam heightening activities.

- Water conservation practices in the catchment should have to be kept and scaled up.
- Financial and economic feasibility study for the Dam heightening option should have to be done before implanting the option and should have to be compared with other possible water resource development projects alternatives. Then after the most sounded alternative will be selected.

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**Annex – (A) Rainfall Data****Annex-1 Monthly rain fall (mm)**

Monthly Rain fall (mm) at Adwa rain gauge station														
s/no	year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1	1972	0	0	0	11.6	12.6	125	260.2	225.7	36	112.5	2.5	0	786.1
2	1973	0	0	0	29.7	44.6	17	237	234.5	147	34	2.5	0	746.3
3	1974	0	10	7	0	45.5	110.7	151	302.7	118	0	0	0	744.9
4	1992			0	18.4	0	36.5	63.2	76.4	3.8	0	1	0	199.3
5	1993	3.4	2.7	42	68.1	61.2	42.2	199.2	176	130.3	32	0	0	757.1
6	1994	0	6	0	17	44.4	122.8	200	369.8	132.8	0	17.8	1	911.6
7	1995	0	0	30.7	31.8	81.5	39.6	213.3	214.7	174.2	8.5	11.2	0	805.5
8	1996	13.2	0	110	62.6	97	151.9	205.1	243.2	176.1	2.4	39	1.6	1102.1
9	1997	0	0	27.3	0	79.6	88	186	152.4	0	149.3	23.9	0	706.5
10	2001	0	0	14.9	2.9	9.8	81.7	264.6	430.7	39.5	16.5	0	0	860.6
11	2002	0	1.5	17.3	10.8	0.9	51.7	132.3	236.1	80.8	5.7	0	1.1	538.2
12	2003	0	9.6	9.2	8.2	4.5	149.3	312.8	223.5	145	3.1	0.8	0	866
13	2004	20.8	8	0	24.4	0	105	222.1	272.7	24.7	24.2	1	0	702.9
14	2005	0	0	101.5	97.8	38.3	74.5	149.2	273	105.4	0.8	2.4	0	842.9
15	2006	0	0	16.9	34.6	50.8	106.1	191.1	341.9	85.2	27.7	2	6.5	862.8
16	2007	0.1	0	16.8	45.4	19.4	71	283	253.8	100.6	2.2	1.5	0	793.8
17	2008	31.8	0	0	37.7	37.5	81.5	203.1	172.7	91.4	2	14.3	0	672
<i>monthly mean</i>		4.331	2.36	23.153	29.47	36.92	85.559	204.31	247.05	93.576	24.76	7.053	0.6	
Mean														758.74

**Annex – (B) Screened and adequately tested rainfall data**

Monthly Rain fall (mm) at Adwa rain gauge station														
s/no	year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1	1972	0	0	0	11.6	12.6	125	260.2	225.7	36	112.5	2.5	0	786.1
2	1973	0	0	0	29.7	44.6	17	237	234.5	147	34	2.5	0	746.3
3	1974	0	10	7	0	45.5	110.7	151	302.7	118	0	0	0	744.9
4	1992			0	18.4	0	36.5	63.2	76.4	3.8	0	1	0	199.3
5	1993	3.4	2.7	42	68.1	61.2	42.2	199.2	176	130.3	32	0	0	757.1
6	1994	0	6	0	17	44.4	122.8	200	369.8	132.8	0	17.8	1	911.6
7	1995	0	0	30.7	31.8	81.5	39.6	213.3	214.7	174.2	8.5	11.2	0	805.5
8	1996	13.2	0	110	62.6	97	151.9	205.1	243.2	176.1	2.4	39	1.6	1102.1
9	1997	0	0	27.3	0	79.6	88	186	152.4	0	149.3	23.9	0	706.5
10	2001	0	0	14.9	2.9	9.8	81.7	264.6	430.7	39.5	16.5	0	0	860.6
11	2002	0	1.5	17.3	10.8	0.9	51.7	132.3	236.1	80.8	5.7	0	1.1	538.2
12	2003	0	9.6	9.2	8.2	4.5	149.3	312.8	223.5	145	3.1	0.8	0	866
13	2004	20.8	8	0	24.4	0	105	222.1	272.7	24.7	24.2	1	0	702.9
14	2005	0	0	101.5	97.8	38.3	74.5	149.2	273	105.4	0.8	2.4	0	842.9
15	2006	0	0	16.9	34.6	50.8	106.1	191.1	341.9	85.2	27.7	2	6.5	862.8
16	2007	0.1	0	16.8	45.4	19.4	71	283	253.8	100.6	2.2	1.5	0	793.8
17	2008	31.8	0	0	37.7	37.5	81.5	203.1	172.7	91.4	2	14.3	0	672
<i>monthly mean</i>		4.331	2.36	23.153	29.47	36.92	85.559	204.31	247.05	93.576	24.76	7.053	0.6	
Mean														758.74
Standard Deviation														187.17
Coefficient of skewness														-1.4967
High outlier value														1190.927
Low outlier vaue														326.5551
Minimum value of rain fall data														199.3
Maximum value of the rain fall data														1102.1

**Annex-(C): Monthly Dependable rain fall (mm)**

Dependable rain fall for Monthly Rain fall (mm) at Adwa rain gauge station															Rain fall in descending order	Rank	Probability of exceedence m/(N+1) in %
s/no	year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual			
1	1972	0	0	0	11.6	12.6	125	260.2	225.7	36	113	2.5	0	786.1	911.6	1	6.67
2	1973	0	0	0	29.7	44.6	17	237	234.5	147	34	2.5	0	746.3	866	2	13.33
3	1974	0	10	7	0	45.5	110.7	151	302.7	118	0	0	0	744.9	862.8	3	20.00
4	1993	3.4	2.7	42	68.1	61.2	42.2	199.2	176	130.3	32	0	0	757.1	860.6	4	26.67
5	1994	0	6	0	17	44.4	122.8	200	369.8	132.8	0	17.8	1	911.6	842.9	5	33.33
6	1995	0	0	30.7	31.8	81.5	39.6	213.3	214.7	174.2	8.5	11.2	0	805.5	805.5	6	40.00
7	1997	0	0	27.3	0	79.6	88	186	152.4	0	149	23.9	0	706.5	793.8	7	46.67
8	2001	0	0	14.9	2.9	9.8	81.7	264.6	430.7	39.5	16.5	0	0	860.6	786.1	8	53.33
9	2003	0	9.6	9.2	8.2	4.5	149.3	312.8	223.5	145	3.1	0.8	0	866	757.1	9	60.00
10	2004	20.8	8	0	24.4	0	105	222.1	272.7	24.7	24.2	1	0	702.9	746.3	10	66.67
11	2005	0	0	101.5	97.8	38.3	74.5	149.2	273	105.4	0.8	2.4	0	842.9	744.9	11	73.33
12	2006	0	0	16.9	34.6	50.8	106.1	191.1	341.9	85.2	27.7	2	6.5	862.8	706.5	12	80.00
13	2007	0.1	0	16.8	45.4	19.4	71	283	253.8	100.6	2.2	1.5	0	793.8	702.9	13	86.67
14	2008	31.8	0	0	37.7	37.5	81.5	203.1	172.7	91.4	2	14.3	0	672	672	14	93.33

**Annex-(D):K<sub>n</sub> values used in outlier testing**

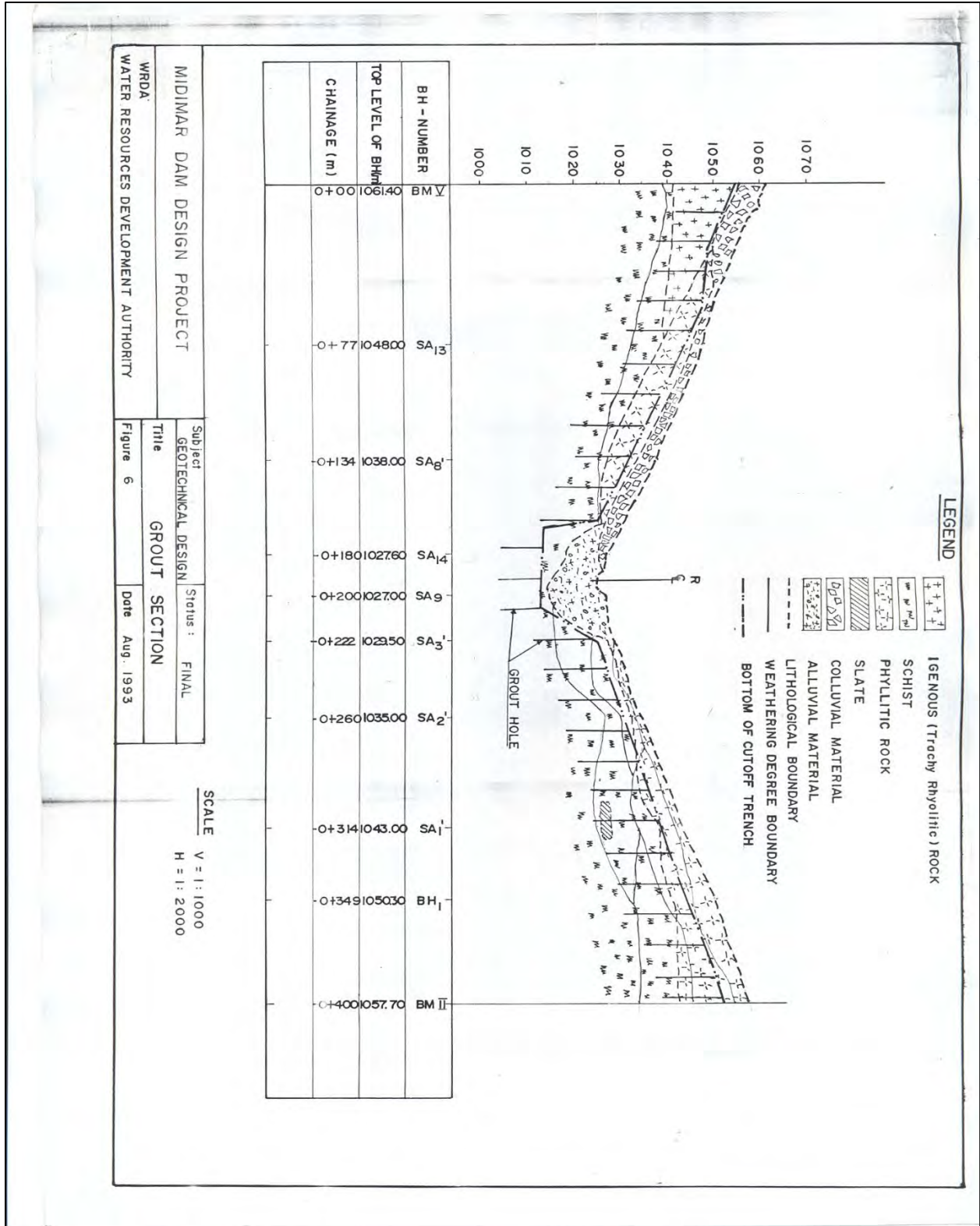
Sample size(N)	K <sub>n</sub>	Sample size (N)	K <sub>n</sub>	Sample size(N)	K <sub>n</sub>	Sample size(N)	K <sub>n</sub>
10	2.036	24	2.467	38	2.661	60	2.837
11	2.088	25	2.486	39	2.671	65	2.866
12	2.134	26	2.502	40	2.682	70	2.893
13	2.175	27	2.519	41	2.692	75	2.917
14	2.213	28	2.534	42	2.7	80	2.94
15	2.247	29	2.549	43	2.71	90	2.981
16	2.279	30	2.563	44	2.719	95	3
17	2.309	31	2.577	45	2.727	100	3.017
18	2.335	32	2.591	46	2.736	110	3.049
19	2.361	33	2.604	47	2.744	120	3.078
20	2.385	34	2.616	48	2.753	130	3.104
21	2.408	35	2.628	49	2.76	140	3.129
22	2.429	36	2.639	50	2.768		
23	2.448	37	2.65	55	2.804		

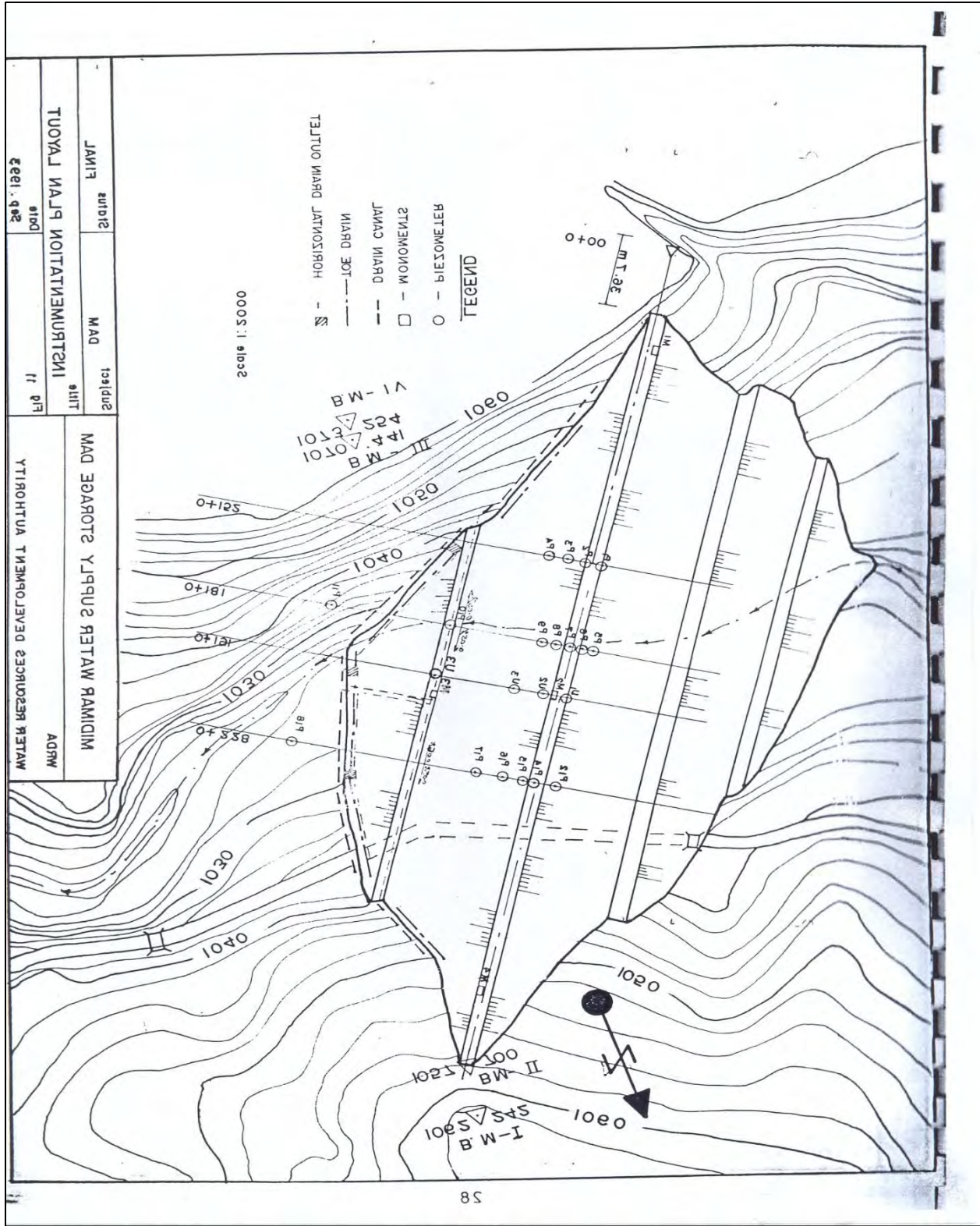
**Annex-( E ) : Original surveying data for Midmar dam (Used in development for Capacity – Elevation Curve)**

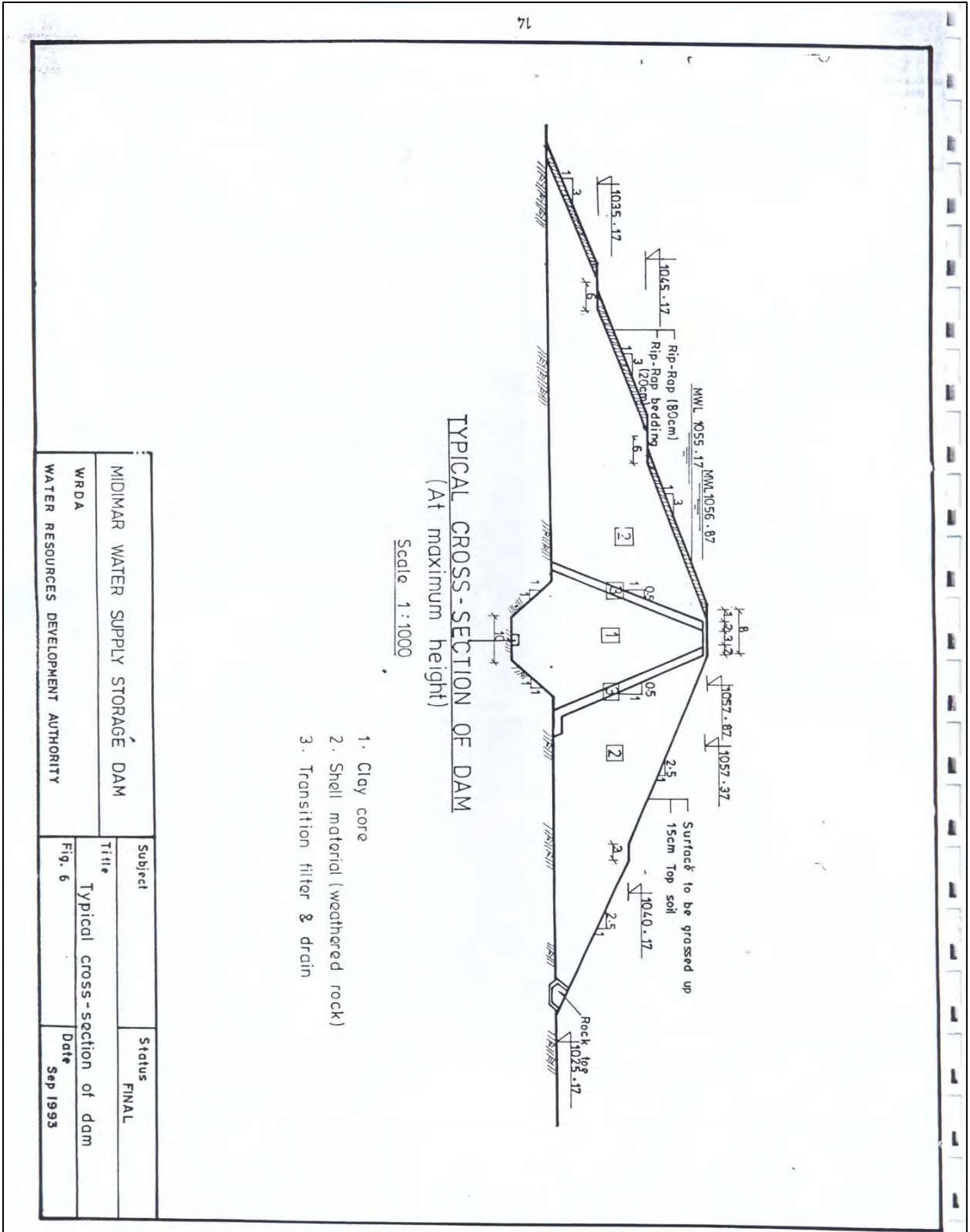
Capacity Elevation curve developed by frustum formula					
Original Capacity Area Elevation survey data			Incremental volume ( 10 <sup>6</sup> m <sup>3</sup> )	cumulative volume (10 <sup>6</sup> m <sup>3</sup> )	Remark
s/no	Elevation	Area (ha)			
1	1024	0.00	0.00		
2	1026	0.13	0.0009	0.0009	
3	1028	0.6	0.0067	0.0076	
4	1031.6	2.85	0.0571	0.0647	
5	1032	3.54	0.0128	0.0774	
6	1034	6.05	0.0948	0.1722	
7	1036	10.81	0.1663	0.3385	
8	1038	16.07	0.2671	0.6056	
9	1040	24.1	0.3990	1.0046	
10	1042	32.81	0.5669	1.5715	
11	<b>1044.4</b>	<b>45</b>	<b>0.9299</b>	<b>2.5013</b>	<b>Dead storage</b>
12	1046	55.41	0.8018	3.3032	
13	1048	70.5	1.2561	4.5593	
14	1050	86.91	1.5712	6.1305	
15	1052	100.3	1.8705	8.0010	
16	<b>1054</b>	<b>113.86</b>	<b>2.1402</b>	<b>10.1412</b>	<b>Design capacity</b>
17	<b>1056.7</b>	<b>136.25</b>	<b>3.3720</b>	<b>13.5131</b>	<b>Maximum capacity of the reservoir</b>

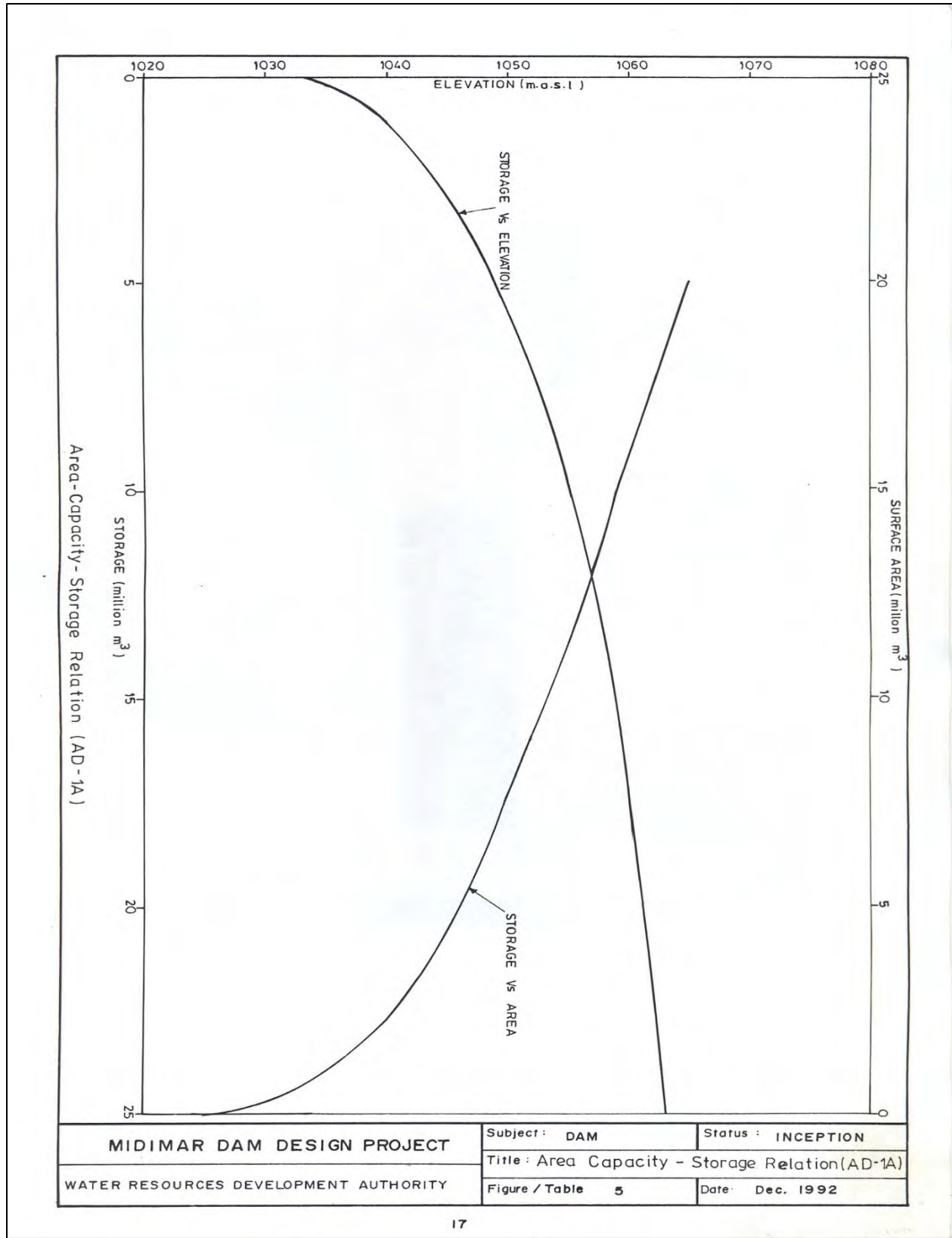














List of questions for Midmar water supply

Prepared by: Birtanu Tesfay

ADIWA/AXUM TOWN

1. What is the source of water for your town?

MIDMAR DAM WATER SUPPLY PROJECT AND FIVE SHALLOW WELLS, MAINLY FROM MIDMAR DAM WATER SUPPLY PROJECT.

2. How much water your town is demanded per a day currently? And what is your future water demand per a day?

OUR WATER DEMAND IS BASED ON WATER DEMAND CITED IN GUIDE LINE MANUALS PRODUCED BY BIAWR. AND OUR FUTURE DEMAND WILL BE BASED ON BTP-TWO REVISED.

3. Are you satisfied with the current water service delivered?

NO, OUR DAILY DEMAND IS HIGHER THAN THE WATER PRODUCED/ALLOWED FROM MIDMAR AND THE WELLS, THIS IS DUE TO HIGH GROWTH RATE OF URBANIZATION.

4. Have you remembered any conflict raised (due shortage of water)?

~~YES IN THE YEAR 2005 E.C. THERE WAS CONFLICT BETWEEN US AND ADWA~~

5. What is/are your recommendation/s so as to solve the current water demands?

- I. Construction of new dam is
- II. Drilling of wells
- III. Upgrading and rehabilitation of existing water supply schemes
- IV. All or any other options



6. Have you observed that Midmar Dam is spilling?

SPECIALLY UP GRADING AND REHABILITATION WORKS IN MIDMAR DAM IS VERY VITAL, AND ALSO WE NEED ADDITIONAL PIPE LINES. INSTALLATION FOR

7. ~~What~~ is your observation concerning water demand rates?

FROM YEAR TO YEAR OUR DEMAND IS INCREASING PROGRESSIVELY THIS IS DUE TO HIGH GROWTH RATE OF OUR TOWN, WATER DEMAND FOR THE UNIVERSITY IS ALSO INCREASING PROGRESSIVELY.

8. Do you believe that there was serious and continuous supervision during construction?

9. When did start service of Midmar Dam water supply project for your town?

WE GET WATER SERVICE FROM MIDMAR SINCE 2002, E.C,

10. What is the maximum depth of foundation of water supply construction?

11. What do you know about construction materials from which they were come?

12. What is your expectation from my thesis work?

- THE THESIS WILL SUGGEST CONSTRUCTION OF NEW DAMS AND OPTIONS FOR REHABILITATION & UPGRADING OF EXISTING SCHEMES
- THE THESIS WILL TELL US FOR HOW MANY YEAR MIDMAR DAM CAN SERVE US SAFELY BEFORE UPGRADING AND AFTER UPGRADING.



TELEFAX - 0347713626

List of questions for Midmar water supply project

Prepared by : Berhanu Teslay

ADWA/AXUM TOWN

1. What is the source of water for your town?

MIDMAR DAM WATER SUPPLY PROJECT & THREE SHALLOW WELLS

2. How much water your town is demanded per a day currently? And what is your future water demand per a day?

OUR WATER DEMAND IS BASED ON WATER DEMANDS CITED IN GUIDE LINE MANNAULS PRODUCED BY MOWR, AND OUR FUTURE DEMAND WILL BE BASED ON THE REVISED GTP - TWO REVISED.

3. Are you satisfied with the current water service delivered?

NO OUR ONLY DEMAND IS HIGHER THAN THE WATER PRODUCED FROM MIDMAR DAM PROJECT & THE WELLS DUE HIGH GROWTH RATE OF URBANIZATION.

Have you remembered any conflict raised due shortage of water?

YES, IN THE YEAR 2004 ERIC THERE WAS CONFLICT BETWEEN US & AXUM TOWN BUT IT IS NOT AS SUCH SIGNIFICANT AND WAS SOLVED WISELY & PROPERLY.

5. What is/are your recommendation/s so as to satisfy your future water demands?

- (i) Construction of new dam /s
- (ii) Drilling of wells
- (iii) Upgrading and rehabilitation of existing water supply schemes

IV. All or any other options, DEVELOPING OF EXISTING WELLS

6. Have you observed that Midmar Dam is spilling?

YES, DURING THE RAIN SEASON WATER IS SPILING.



7. What is your observation concerning water demand rates?  
FROM YEAR TO YEAR OUR WATER DEMAND IS INCREASING PROGRESSIVELY


8. Do you believe that there was serious and continuous supervision during construction?  
YES THERE WAS, AS A RESULT THE DAM HAD CONSTRUCTED AT MOST OF THE MOST EFFICIENT QUALITY.

9. When did start service of Midmar Dam water supply project for your town?  
NOVEMBER, 1993 E.C

10. What is the maximum depth of foundation excavated during construction?  
12m

11. What do you know about construction materials from where they were come?  
THE CONSTRUCTION MATERIAL HAVE COME FROM THE STUDIED AREA, DURING (FROM IDENTIFIED SITES)

12. What is your expectation from my thesis work?  
- WE ARE EXPECTED FOR HOW MANY YEARS MIDMAR CAN GIVE FULL SERVICE, THE OPTIONS FOR UPGRADING & REHABILITATION WILL BE FORWARDED. OTHER WATER PROJECTS WILL BE RECOMANDED



Annex – (G) Water demand projection for Adwa project

Water Demand projection in m <sup>3</sup> for Adwa Project														
Adwa Town and Almeida Textile Factory														
Year	Population (Thous)	Basic Demand (liters/Person/Day)	Commercial/Industrial Demand (liters/Person/Day)	Leakage/loss (liters/Person/Day)	System loss (liters/Person/Day)	Total Daily water demand or required (liters/Person/Day)	Annual water Demand (liters/Person/Year)	All India Per Capita Demand (liters/Person/Day)	Actual per Capita Demand (liters/Person/Day)	Water Demand for domestic use (liters/Person/Day)	Water Demand for industrial (liters/Person/Day)	Water Demand for irrigation (liters/Person/Day)	Total Annual water Demand (liters/Person/Year)	
1977	41000	2015	2053	112	596	821	428	124273	176070	100000	72588	28040	200000	407440
1978	41500	2056	2123	117	601	839	439	126130	180854	100000	74765	28500	203812	411970
1979	42000	2100	2193	122	606	857	450	128187	185638	100000	76942	28960	207624	416500
1980	42500	2145	2263	127	611	875	461	130244	190422	100000	79119	29420	211436	421030
1981	43000	2190	2333	132	616	893	472	132301	195206	100000	81296	29880	215248	425560
1982	43500	2235	2403	137	621	911	483	134358	200000	100000	83473	30340	219060	430090
1983	44000	2280	2473	142	626	929	494	136415	204784	100000	85650	30800	222872	434620
1984	44500	2325	2543	147	631	947	505	138472	209568	100000	87827	31260	226684	439150
1985	45000	2370	2613	152	636	965	516	140529	214352	100000	90004	31720	230496	443680
1986	45500	2415	2683	157	641	983	527	142586	219136	100000	92181	32180	234308	448210
1987	46000	2460	2753	162	646	1001	538	144643	223920	100000	94358	32640	238120	452740
1988	46500	2505	2823	167	651	1019	549	146700	228704	100000	96535	33100	241932	457270
1989	47000	2550	2893	172	656	1037	560	148757	233488	100000	98712	33560	245744	461800
1990	47500	2595	2963	177	661	1055	571	150814	238272	100000	100889	34020	249556	466330
1991	48000	2640	3033	182	666	1073	582	152871	243056	100000	103066	34480	253368	470860
1992	48500	2685	3103	187	671	1091	593	154928	247840	100000	105243	34940	257180	475390
1993	49000	2730	3173	192	676	1109	604	156985	252624	100000	107420	35400	261000	479920
1994	49500	2775	3243	197	681	1127	615	159042	257408	100000	109597	35860	264812	484450
1995	50000	2820	3313	202	686	1145	626	161099	262192	100000	111774	36320	268624	488980
1996	50500	2865	3383	207	691	1163	637	163156	266976	100000	113951	36780	272436	493510
1997	51000	2910	3453	212	696	1181	648	165213	271760	100000	116128	37240	276248	498040
1998	51500	2955	3523	217	701	1199	659	167270	276544	100000	118305	37700	280060	502570
1999	52000	3000	3593	222	706	1217	670	169327	281328	100000	120482	38160	283872	507100
2000	52500	3045	3663	227	711	1235	681	171384	286112	100000	122659	38620	287684	511630
2001	53000	3090	3733	232	716	1253	692	173441	290896	100000	124836	39080	291496	516160
2002	53500	3135	3803	237	721	1271	703	175498	295680	100000	127013	39540	295308	520720
2003	54000	3180	3873	242	726	1289	714	177555	300464	100000	129190	40000	299120	525250
2004	54500	3225	3943	247	731	1307	725	179612	305248	100000	131367	40460	302932	529780
2005	55000	3270	4013	252	736	1325	736	181669	310032	100000	133544	40920	306744	534310
2006	55500	3315	4083	257	741	1343	747	183726	314816	100000	135721	41380	310556	538840
2007	56000	3360	4153	262	746	1361	758	185783	319600	100000	137898	41840	314368	543370
2008	56500	3405	4223	267	751	1379	769	187840	324384	100000	140075	42300	318180	547900
2009	57000	3450	4293	272	756	1397	780	189897	329168	100000	142252	42760	321992	552430
2010	57500	3495	4363	277	761	1415	791	191954	333952	100000	144429	43220	325804	556960
2011	58000	3540	4433	282	766	1433	802	194011	338736	100000	146606	43680	329616	561490
2012	58500	3585	4503	287	771	1451	813	196068	343520	100000	148783	44140	333428	566020
2013	59000	3630	4573	292	776	1469	824	198125	348304	100000	150960	44600	337240	570550
2014	59500	3675	4643	297	781	1487	835	200182	353088	100000	153137	45060	341052	575080
2015	60000	3720	4713	302	786	1505	846	202239	357872	100000	155314	45520	344864	579610
2016	60500	3765	4783	307	791	1523	857	204296	362656	100000	157491	45980	348676	584140
2017	61000	3810	4853	312	796	1541	868	206353	367440	100000	159668	46440	352488	588670
2018	61500	3855	4923	317	801	1559	879	208410	372224	100000	161845	46900	356300	593200
2019	62000	3900	4993	322	806	1577	890	210467	377008	100000	164022	47360	360112	597730
2020	62500	3945	5063	327	811	1595	901	212524	381792	100000	166199	47820	363924	602260
2021	63000	3990	5133	332	816	1613	912	214581	386576	100000	168376	48280	367736	606790
2022	63500	4035	5203	337	821	1631	923	216638	391360	100000	170553	48740	371548	611320
2023	64000	4080	5273	342	826	1649	934	218695	396144	100000	172730	49200	375360	615850
2024	64500	4125	5343	347	831	1667	945	220752	400928	100000	174907	49660	379172	620380
2025	65000	4170	5413	352	836	1685	956	222809	405712	100000	177084	50120	382984	624910
2026	65500	4215	5483	357	841	1703	967	224866	410496	100000	179261	50580	386796	629440
2027	66000	4260	5553	362	846	1721	978	226923	415280	100000	181438	51040	390608	633970
2028	66500	4305	5623	367	851	1739	989	228980	420064	100000	183615	51500	394420	638500
2029	67000	4350	5693	372	856	1757	1000	231037	424848	100000	185792	51960	398232	643030
2030	67500	4395	5763	377	861	1775	1011	233094	429632	100000	187969	52420	402044	647560

Annex – (H) Water demand projection for Axum project

Sl.No	Water Demand projection in m <sup>3</sup> for Axum Projects											
	Axum Towns					Axum Towns						
	Year	Population (2011)	Water Demand (m <sup>3</sup> /day)	Water Demand (m <sup>3</sup> /day)	Water Demand (m <sup>3</sup> /day)	Water Demand (m <sup>3</sup> /day)	Water Demand (m <sup>3</sup> /day)	Water Demand (m <sup>3</sup> /day)	Water Demand (m <sup>3</sup> /day)	Water Demand (m <sup>3</sup> /day)		
1	2012	46,647	2,142	1,178	112	136	102	97	29	102	1,178	112
2	2014	58,202	2,630	1,474	147	186	132	124	39	132	1,474	147
3	2016	69,757	3,118	1,670	167	210	156	48	156	1,670	167	
4	2018	81,312	3,606	1,866	186	234	176	54	176	1,866	186	
5	2020	92,867	4,094	2,062	206	258	196	60	196	2,062	206	
6	2022	104,422	4,582	2,258	225	282	216	66	216	2,258	225	
7	2024	115,977	5,070	2,454	245	306	230	72	230	2,454	245	
8	2026	127,532	5,558	2,650	265	330	254	78	254	2,650	265	
9	2028	139,087	6,046	2,846	284	354	278	84	278	2,846	284	
10	2030	150,642	6,534	3,042	304	378	302	90	302	3,042	304	
11	2032	162,197	7,022	3,238	323	402	326	96	326	3,238	323	
12	2034	173,752	7,510	3,434	343	426	350	102	350	3,434	343	
13	2036	185,307	8,000	3,630	363	450	374	108	374	3,630	363	
14	2038	196,862	8,488	3,826	382	474	398	114	398	3,826	382	
15	2040	208,417	8,976	4,022	402	498	422	120	422	4,022	402	
16	2042	220,000	9,464	4,218	421	522	446	126	446	4,218	421	
17	2044	231,555	9,952	4,414	441	546	470	132	470	4,414	441	
18	2046	243,110	10,440	4,610	460	570	494	138	494	4,610	460	
19	2048	254,665	10,928	4,806	480	594	518	144	518	4,806	480	
20	2050	266,220	11,416	5,002	500	618	542	150	542	5,002	500	
21	2052	277,775	11,904	5,198	519	642	566	156	566	5,198	519	
22	2054	289,330	12,392	5,394	539	666	590	162	590	5,394	539	
23	2056	300,885	12,880	5,590	559	690	614	168	614	5,590	559	
24	2058	312,440	13,368	5,786	578	714	638	174	638	5,786	578	
25	2060	323,995	13,856	5,982	598	738	662	180	662	5,982	598	
26	2062	335,550	14,344	6,178	617	762	686	186	686	6,178	617	
27	2064	347,105	14,832	6,374	637	786	710	192	710	6,374	637	
28	2066	358,660	15,320	6,570	656	810	734	198	734	6,570	656	
29	2068	370,215	15,808	6,766	675	834	758	204	758	6,766	675	
30	2070	381,770	16,296	6,962	694	858	782	210	782	6,962	694	
31	2072	393,325	16,784	7,158	713	882	806	216	806	7,158	713	
32	2074	404,880	17,272	7,354	732	906	830	222	830	7,354	732	
33	2076	416,435	17,760	7,550	751	930	854	228	854	7,550	751	
34	2078	427,990	18,248	7,746	770	954	878	234	878	7,746	770	
35	2080	439,545	18,736	7,942	789	978	902	240	902	7,942	789	
36	2082	451,100	19,224	8,138	808	1,002	926	246	926	8,138	808	
37	2084	462,655	19,712	8,334	827	1,026	950	252	950	8,334	827	
38	2086	474,210	20,200	8,530	846	1,050	974	258	974	8,530	846	
39	2088	485,765	20,688	8,726	865	1,074	998	264	998	8,726	865	
40	2090	497,320	21,176	8,922	884	1,098	1,022	270	1,022	8,922	884	
41	2092	508,875	21,664	9,118	903	1,122	1,046	276	1,046	9,118	903	
42	2094	520,430	22,152	9,314	922	1,146	1,070	282	1,070	9,314	922	
43	2096	531,985	22,640	9,510	941	1,170	1,094	288	1,094	9,510	941	
44	2098	543,540	23,128	9,706	960	1,194	1,118	294	1,118	9,706	960	
45	2100	555,095	23,616	9,902	979	1,218	1,142	300	1,142	9,902	979	
46	2102	566,650	24,104	10,098	998	1,242	1,166	306	1,166	10,098	998	
47	2104	578,205	24,592	10,294	1,017	1,266	1,190	312	1,190	10,294	1,017	
48	2106	589,760	25,080	10,490	1,036	1,290	1,214	318	1,214	10,490	1,036	
49	2108	601,315	25,568	10,686	1,055	1,314	1,238	324	1,238	10,686	1,055	
50	2110	612,870	26,056	10,882	1,074	1,338	1,262	330	1,262	10,882	1,074	
51	2112	624,425	26,544	11,078	1,093	1,362	1,286	336	1,286	11,078	1,093	
52	2114	635,980	27,032	11,274	1,112	1,386	1,310	342	1,310	11,274	1,112	
53	2116	647,535	27,520	11,470	1,131	1,410	1,334	348	1,334	11,470	1,131	
54	2118	659,090	28,008	11,666	1,150	1,434	1,358	354	1,358	11,666	1,150	
55	2120	670,645	28,496	11,862	1,169	1,458	1,382	360	1,382	11,862	1,169	
56	2122	682,200	28,984	12,058	1,188	1,482	1,406	366	1,406	12,058	1,188	
57	2124	693,755	29,472	12,254	1,207	1,506	1,430	372	1,430	12,254	1,207	
58	2126	705,310	29,960	12,450	1,226	1,530	1,454	378	1,454	12,450	1,226	
59	2128	716,865	30,448	12,646	1,245	1,554	1,478	384	1,478	12,646	1,245	
60	2130	728,420	30,936	12,842	1,264	1,578	1,502	390	1,502	12,842	1,264	
61	2132	739,975	31,424	13,038	1,283	1,602	1,526	396	1,526	13,038	1,283	
62	2134	751,530	31,912	13,234	1,302	1,626	1,550	402	1,550	13,234	1,302	
63	2136	763,085	32,400	13,430	1,321	1,650	1,574	408	1,574	13,430	1,321	
64	2138	774,640	32,888	13,626	1,340	1,674	1,598	414	1,598	13,626	1,340	
65	2140	786,195	33,376	13,822	1,359	1,698	1,622	420	1,622	13,822	1,359	
66	2142	797,750	33,864	14,018	1,378	1,722	1,646	426	1,646	14,018	1,378	
67	2144	809,305	34,352	14,214	1,397	1,746	1,670	432	1,670	14,214	1,397	
68	2146	820,860	34,840	14,410	1,416	1,770	1,694	438	1,694	14,410	1,416	
69	2148	832,415	35,328	14,606	1,435	1,794	1,718	444	1,718	14,606	1,435	
70	2150	843,970	35,816	14,802	1,454	1,818	1,742	450	1,742	14,802	1,454	
71	2152	855,525	36,304	15,000	1,473	1,842	1,766	456	1,766	15,000	1,473	
72	2154	867,080	36,792	15,196	1,492	1,866	1,790	462	1,790	15,196	1,492	
73	2156	878,635	37,280	15,392	1,511	1,890	1,814	468	1,814	15,392	1,511	
74	2158	890,190	37,768	15,590	1,530	1,914	1,838	474	1,838	15,590	1,530	
75	2160	901,745	38,256	15,786	1,549	1,938	1,862	480	1,862	15,786	1,549	
76	2162	913,300	38,744	15,982	1,568	1,962	1,886	486	1,886	15,982	1,568	
77	2164	924,855	39,232	16,180	1,587	1,986	1,910	492	1,910	16,180	1,587	
78	2166	936,410	39,720	16,376	1,606	2,010	1,934	498	1,934	16,376	1,606	
79	2168	947,965	40,208	16,572	1,625	2,034	1,958	504	1,958	16,572	1,625	
80	2170	959,520	40,696	16,770	1,644	2,058	1,982	510	1,982	16,770	1,644	
81	2172	971,075	41,184	16,966	1,663	2,082	2,006	516	2,006	16,966	1,663	
82	2174	982,630	41,672	17,162	1,682	2,106	2,030	522	2,030	17,162	1,682	
83	2176	994,185	42,160	17,360	1,701	2,130	2,054	528	2,054	17,360	1,701	
84	2178	1,005,740	42,648	17,556	1,720	2,154	2,078	534	2,078	17,556	1,720	
85	2180	1,017,295	43,136	17,752	1,739	2,178	2,102	540	2,102	17,752	1,739	
86	2182	1,028,850	43,624	17,950	1,758	2,202	2,126	546	2,126	17,950	1,758	
87	2184	1,040,405	44,112	18,146	1,777	2,226	2,150	552	2,150	18,146	1,777	
88	2186	1,051,960	44,600	18,342	1,796	2,250	2,174	558	2,174	18,342	1,796	
89	2188	1,063,515	45,088	18,540	1,815	2,274	2,198	564	2,198	18,540	1,815	
90	2190	1,075,070	45,576	18,736	1,834	2,298	2,222	570	2,222	18,736	1,834	
91	2192	1,086,625	46,064	18,9								

Annex- (I) Summary for Annual Water demand projection for both towns

Water Demand projection in m <sup>3</sup> for Adwa and Axum Projects																		
Adwa and Axum Towns																		
S/N	Year	Total population (Town)	Annual water Demand		Commercial (business) Water Demand		Industrial water Demand		System loss		Total Daily water Demand in per stream/line		Annual water Demand for Axum		Total annual Demand for Adwa project		Total Annual Demand for both towns	
			50 l/cd	70 l/cd	55/DHO	30% DHO	30% DHO	30% DHO	30% DHO	30% DHO	30% DHO	30% DHO	30% DHO	30% DHO	30% DHO	30% DHO	30% DHO	30% DHO
			2237	3175	112	156	670	908	357	493	1307	5726	1572487	1224983	2970040	3057469	4021536	817531
1	2014	55,701	2495	4115	147	208	882	1204	882	1389	4981	6044	1470345	1491291	3888044	4619475	5888239	7407283
2	2015	61,003	3054	4726	153	214	916	1231	1011	1445	5154	7415	1891172	2033647	3967209	4718530	6006094	7615548
3	2016	65,476	3288	4443	159	222	952	1300	1071	1500	5356	7498	1954869	2236813	4091359	4821477	6191582	7813197
4	2017	65,563	3288	4477	165	231	983	1305	1115	1530	5566	7707	2059442	2334586	4176649	4928451	6352286	8056672
5	2018	68,546	3502	4986	171	240	1008	1409	1159	1619	5784	8097	2111018	2392120	4192041	5039615	6519160	8280382
6	2019	71,222	3701	5181	185	259	1068	1488	1202	1683	6010	8414	2193714	2473083	4279555	5155131	6692627	8533448
7	2020	74,072	3701	5181	185	259	1068	1488	1202	1683	6010	8414	2279443	2597487	4365301	5235177	6872408	8789837
8	2021	76,921	3846	5384	197	269	1154	1615	1286	1812	6480	9086	2369341	2716517	4451405	5399923	7060240	9098092
9	2022	79,695	3997	5588	201	280	1198	1679	1340	1884	6744	9445	2461337	2876385	4546939	5529535	7284470	9326670
10	2023	83,006	4153	5818	208	291	1236	1744	1402	1982	7008	9811	2550468	3093485	4641221	5664365	7467246	9493445
11	2024	86,320	4316	6042	216	302	1285	1811	1457	2039	7305	10197	2638371	3234215	4740212	5804355	7667427	9889153
12	2025	89,701	4483	6279	224	314	1346	1884	1514	2119	7569	10596	2732014	3384307	4847120	5949723	7885882	10225497
13	2026	93,215	4661	6528	233	326	1408	1959	1573	2202	7865	11011	2830314	3537797	4955068	6008895	8112895	10321408
14	2027	96,908	4852	6781	242	339	1453	2034	1635	2308	8127	11442	2934476	3691494	5067300	6072984	8248800	10432075
15	2028	100,601	5053	7046	252	352	1510	2114	1689	2408	8489	11891	3040033	3848087	5183499	6201228	8393945	11195779
16	2029	104,404	5261	7314	262	366	1569	2197	1765	2471	8806	12330	3148055	4010057	5305080	6309867	8568694	11551928
17	2030	108,300	5489	7609	272	380	1631	2283	1834	2568	9172	12840	3258623	4182455	5431097	6427151	8713427	11927547
18	2031	112,300	5649	7907	282	395	1694	2372	1906	2669	9571	13345	3378394	4363319	5559860	6550341	8868300	12307682
19	2032	117,384	5889	8213	293	411	1761	2465	1991	2772	9964	13866	3505085	4556082	5697822	6687300	9074304	12707207
20	2033	121,482	6099	8538	303	427	1830	2561	2082	2882	10409	14409	3638465	4749349	5839124	6838539	9271466	13125088