EASTERN NILE IRRIGATION AND DRAINAGE STUDY/FEASIBILITY STUDY
DINGER BEREHA IRRIGATION PROJECT

ANNEX 1: CLIMATE, HYDROLOGY, AND GROUND WATER RESOURCES

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1. CLIMATOLOGY

1.1 INTRODUCTION

There is a first class climatic station at Didessa State Farm with rainfall, temperature (maximum and minimum), wind speed, solar radiation and relative humidity records in the valley plain. The rest of the stations like Arjo and Bedele are nearby stations, which are used to assess the climatic characteristics as regional factors.

1.2 CLIMATE

Mean monthly rainfall data for Arjo, Didessa (former) State Farm (near the bridge under construction) and Bedelle stations were acquired from National Meteorological Service Agency (NMSA) for the project area of Dinger Bereha. Climatic data such as rain-fall, temperature (minimum & maximum), sun-shine hours, Wind speed and relative humidity are made available from the "Arjo-Didessa Climate and Hydrology" report, 2004, prepared by WWDSE and the original data acquired from NMSA. The hydro-meteorological data processing activities are concentrated on acquisition and compilation of available data from the previous studies and the National Metrological Service Agency (NMSA), as the main sources.

Checking of data qualities & compilation activities involved encoding of monthly records, as obtained from WWDSE reports and NMSA raw data, collected in hard copy, verification of climatic stations' location, and elevation and missed data infilling and establishment of a complete database to serve its intended purpose.

Four meteorological observation stations are located in and around the Dinger Bereha Irrigation Project area. The meteorological data for these staitions are obtained from the NMSA. Out of these stations, Jimma station is Class 1 station that included observations of rainfall, temperature, relative humidity, sunshine duration, wind speed and evaporation. Bedele and Didessa stations are also Class 1 stations but do not include data collection of sunshine hrs duration. Jimma station is located at approximately 10 km from the divide of Didessa catchments. Bedele station is located up-stream of the proposed irrigation command area of the project. Didessa State Farm station is located very close and near by to the command area. The details like location, altitude, year of establishment along with their class are shown on Table 1.1. Meteorological data available at the three observation stations have been collected. In summary, climatological data obtained from Bedele, Didessa and Arjo stations were found to be the most reliable and relevant for use in rainfall analysis of the project area. Didessa is geographically the closest station to the project area and is located almost at the same elevation to the project site. The stations' location and the respective data availability at each station are depicted on table 1.2.

Table 1.1: Location of Stations

S.No	Station Name	Latitude North		Longitude East		Altitude (m)
		Deg.	Min.	Deg.	Min.	
1	Arjo	08	27	36	20	2,565
2	Bedele	08	16	36	14	2,090
3	Didessa	09	03	36	04	1,312

Table 1.2: Climatic Data Availability

No	Station name	RF		Tm		RH		WS		SD		1 day		Class
		Yrs	**Avl**	**Yrs**	**Avl**	**Yrs**	**Avl**	**Yrs**	**Avl**	**Yrs**	**Avl**	**Yrs**	**Avl**	
1	Didessa	38	X	47	X	37	X	37	X	37	X	15	X	1
2	Bedele	28	X		X	13	X			18	X			1
3	Arjo	20	X		X	37	X	37	X	37	X			1

Where:

Yrs = rainfall series

RF = monthly rainfall

Tm = average temperature

WS = wind speed

SD = sunshine duration

RH = relative humidity

Avl = availability

1.3 HYDROLOGY

The reliability of a hydrological study is dependent on the quality of the available and recorded data. The latest statistical hydrological models even can not fill the data gaps as required will not substiitute the measured data.

a/ River Flow Data:

Didessa River is the major perennial river, which is bounding the northeast part of the project command area. Perennial tributary rivers are entering from the left bank side of the command area to the Didessa River (when looking downstream) these included Dabena, Boro, Tefisa and many other streams. The measured flow and sediment data of the main Didessa River, just near the bridge located at the road Arjo - Bedele Towns, are acquired from the Hydrology Department of MoWR. The availability of Hydrologic Data in both Didessa and Dabana stations is shown on table 1.3. As is shown on the table, there is also a station named Dabana without a guaged data for use. Thus, as there is no data for this station, no data is acquired from it.

Table 1.3: Hydrological data Availability

Sl No	St. No	Station Name & Location	Lat North	Long East	Flow Record Length (years)			Area (Km^2)
					Mean	Max.	Min.	
1	114001	Didessa near Arjo	8.41	36.25	33	33	29	9,981
2	114005	Dabana near Abasina	9.02	36.03				2,281

b/ Sediment Data

Sediment concentration rate is best decided by actual surveys and observations at specified locations of the concerned catchments. In this study, the sediment concentration at different depths and time are observed near the bridge connecting Arjo and Bedele Towns. The available data are:

- in August 2004 six samples at different depths and time intervals;
- in September 2004 three samples and
- in April 2005 three samples were collected

1.4 CLIMATE IN THE PROJECT AREA

1.4.1 General

Rainfall data, mainly from three stations (Didessa, Arjo and Bedele), with a period of records varying from 20 to 38 years were used for further rainfall analysis. The list of stations for observations of meteorological data along with period of records and availability of data types are given in Table 1.2. Rainfall and temperature have been observed at Didessa, Arjo and Bedele. Climatic data for the Project area such as temperature, relative humidity, sunshine hours, wind speed and rainfall have been collected and reviewed. Consistency tests, data rectification and other adjustments have been performed as deemed necessary, data gaps have been filled in using interpolation and correlations methods as appropriate.

1.4.2 Air temperature

In the project area, the mean monthly temperature varies from 20.1°C in December to 25.4°C in March. The mean monthly temperature of the command area is given in Appendix A. The maximum of mean monthly maximum and the minimum of the mean monthly minimum air temperatures are 35.3°C and 11.5°C that occurred in the months of March and January respectively. Theoretically, the solar radiation absorbed by the atmosphere and the heat emitted by the earth increases the air temperature. The sensible heat of the surrounding air transfers energy to the crop and exerts as such a controlling influence on the rate of evapotranspiration. In sunny, warm weather, the loss of water by evapotranspiration is greater than in cloudy and cool weathers.

1.4.3 Air humidity

Mean monthly humidity values vary between 56% in March to 89% in October. The mean monthly humidity of the command area is given in Table 1.5. Humidity data have been used in estimating evapotranspiration rates from reference crops.

1.4.4 Wind speed

Mean wind speed values vary between 0.48 m/s in December and 1.08 m/s in April. The mean monthly wind speeds of the command area are given in Table 1.4. Average wind speed recorded at the Didessa station is taken as wind speed information relevant for the project area. Wind is characterized by its direction and velocity. Wind direction refers to the direction from which the wind is blowing.

1.4.5 Sunshine Hours

The measured data for Mean sunshine duration is 8.3 hours in December and is reduced to 5.7 hours during August. The mean monthly sunshine durations of the command area are given in Table 1.4. The relative sunshine duration (n/N) is another ratio that expresses the cloudiness of the atmosphere. It is the ratio of the actual duration of sunshine, n, to the maximum possible duration of sunshine or daylight hours N. In the absence of any clouds, the actual duration of sunshine is equal to the daylight hours (n = N) and the ratio is one, while on cloudy days n and consequently the ratio may be zero. In the absence of a direct measurement of Rs, the relative sunshine duration, n/N, is often used to derive solar radiation from extraterrestrial radiation. As with extraterrestrial radiation, the day length N depends on the position of the sun and is hence a function of latitude and date.

The evapotranspiration process is determined by the amount of energy available to vaporize water. Solar radiation is the largest energy source and is able to change large quantities of liquid water into water vapour. The potential amount of radiation that can reach the evaporating surface is determined by its location and time of the year. Due to differences in the position of the sun, the potential radiation differs at various latitudes and in different seasons. The actual solar radiation reaching the evaporating surface depends on the turbidity of the atmosphere and the presence of clouds, which reflect and absorb major parts of the radiation. When assessing the effect of solar radiation on evapotranspiration, one should also bear in mind that not all-available energy is used to vaporize water. Part of the solar energy is used to heat up the atmosphere and the soil profile.

Table 1.4: Summary of Meteorological Characteristics at Project Area/ Relative Humidity (%)

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
	a) Relative Humidity (%)											
Average	64.77	58.97	56.63	67.97	75.72	81.07	87.46	88.52	88.63	84.55	79.36	72.44
CV	0.099	0.127	0.084	0.073	0.053	0.047	0.061	0.048	0.03	0.053	0.070	0.089
Skew	-0.27	-0.27	-0.37	0.474	-0.2	-0.87	-2.92	-2	0.249	0.19	0.287	-0.13
Min	51.5	43.2	45.09	57.42	65.23	65.8	61.77	72.23	82.49	74.24	67.66	55.37
Max	77.3	71.68	64.08	82.17	86.18	90.3	98.1	97.53	95.67	94.73	93.18	85.13
	b) Wind Speed (m/s)											
Average	0.62	0.8	1.0	1.08	1.04	0.86	0.62	0.51	0.5	0.51	0.48	0.51
	c) Sunshine Hours (hrs/day)											
Average	8.155	7.638	7.452	7.287	7.624	6.061	3.703	4.059	6.164	7.855	8.324	8.306
CV	0.125	0.166	0.145	0.165	0.157	0.189	0.243	0.23	0.22	0.139	0.214	0.104
Skew	-0.47	-0.36	-0.27	-1.12	0.141	-0.36	0.248	-0.42	-0.27	0.138	-3.525	0.971
Min	6.05	4.905	4.592	3.304	5.428	3.364	2.277	1.6	2.622	5.778	0.112	6.634
Max	10	9.919	9.744	9.44	10.15	8.12	5.445	6.2	9.12	10.08	10.20	11.02

1.5 Rainfall Analysis

1.5.1 General

The rainfall data obtained from Bedele, Didessa and Arjo stations were found to be the most reliable and relevant for use in the rainfall analysis of Dinger Bereha irrigation project. Didessa station is geographically located within the command area and has the longest recorded rainfall data of the whole stations identified for the purpose of rainfall analysis of the project area.

The rainfall in the project area and its surroundings is a uni-modal type. Most of the rainfall is concentrated for almost six months, which is from May through October. The six wettest months cover 88 percent of the total annual rainfall. The dry season, being from November to February (four months) has a total rainfall of about 4.8% of the mean annual rainfall.

The mean monthly rainfall for stations in the project area is given in Table 1.5 and their pattern is graphically illustrated in Figure 1.1. Didessa and Bedele stations provide more relevant rainfall data that can be adopted for the command area since Didessa is very close to the project area and Bedele station is located outside the project, but it is with in the same catchments area.

Table 1.5: Mean Monthly Rainfall (mm)

Description	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Total
Didessa	3	6	26	49	158	274	312	277	209	104	28	8	1,454
Bedele	18	23	65	105	239	291	310	303	302	156	41	12	1,864
Jimma	33	49	88	133	172	219	208	210	182	103	68	36	1,502

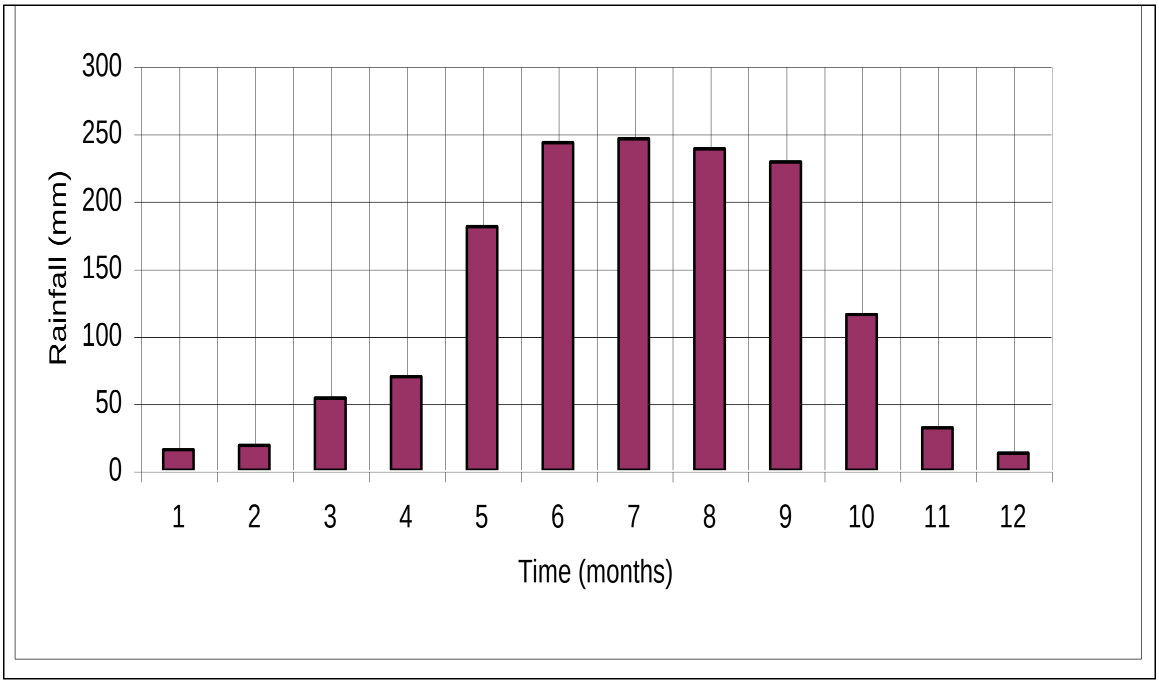


Figure 1.1: Mean Monthly Rainfalls at Arjo Didessa Project Area

1.5.2 Rainfall Internal and External Consistency

Considering the data of the three stations; Didessa, Jimma and Bedele, it is customary in Hydro-meteorological studies to confirm the consistency with statistical analysis. The trend in the annual rainfall pattern is a relevant aspect with respect to the behaviour of the rainfall and to compare such behaviour with those of other relevant stations involved in the study with a view to firm up external consistency. Accordingly, a 3 year moving average analysis was taken up for each of the 3 stations. The results are shown in the figures 4 (a), (b) and (c). It is clearly seen that these show similar trends. Similarly, an analysis with respect to the cross correlation structure among the 3 stations was carried out. The cross correlation matrix depicts the following status (Table 1.6) at annual time resolution level, which is not abnormal. Then, the single mass curve analysis was undertaken for each of these 3 stations and this does not indicate any abnormality to reject this data set. The results of the analysis are shown in Figures 1.3 (a), (b) and (c).

Table 1.6: Cross Correlation Matrix of Annual Rainfall

	Didessa	Jimma	Bedele
Didessa	1	0.11	0.24
Jimma		1	0.48
Bedele			1

Figure 1.2 (a): Trend Analysis of Annual Rainfall at Jimma Station

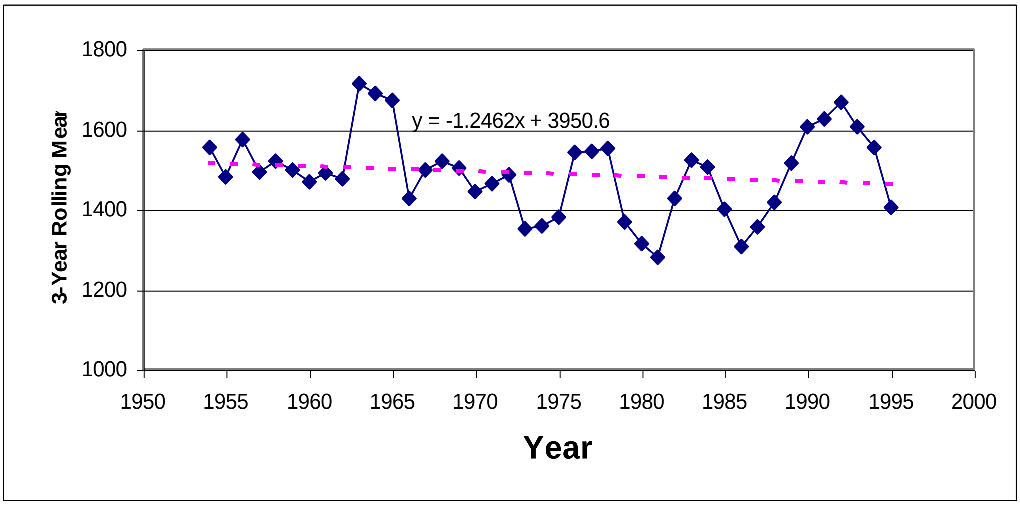


Figure 1.2(b): Trend Analysis of Annual Rainfall at Bedele Station

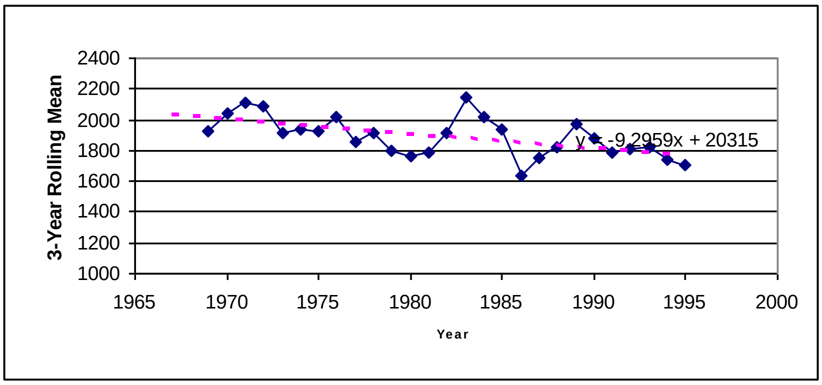


Figure 1.2(c): Trend Analysis of Annual Rainfall at Didessa Station

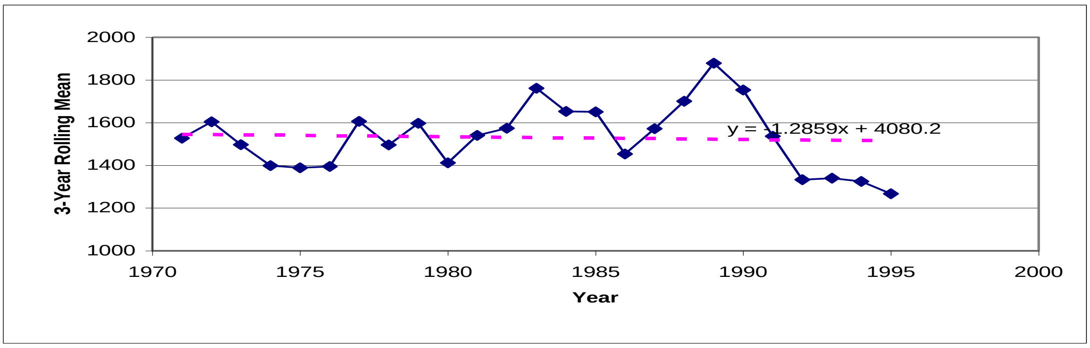


Figure 1.3(a): Single Mass Curve of Jimma Rainfall

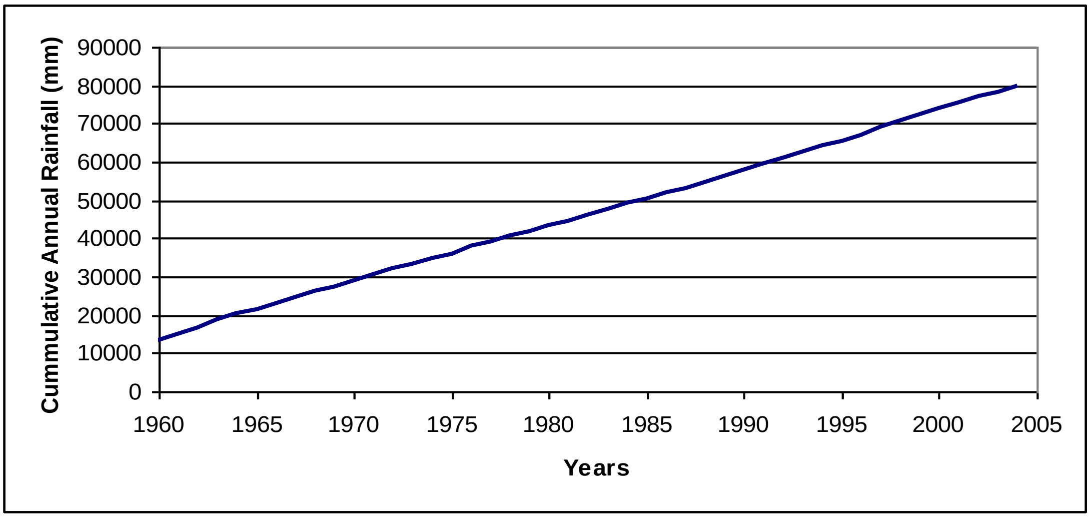


Figure 1.3(b): Single Mass Curve of Bedele Rainfall

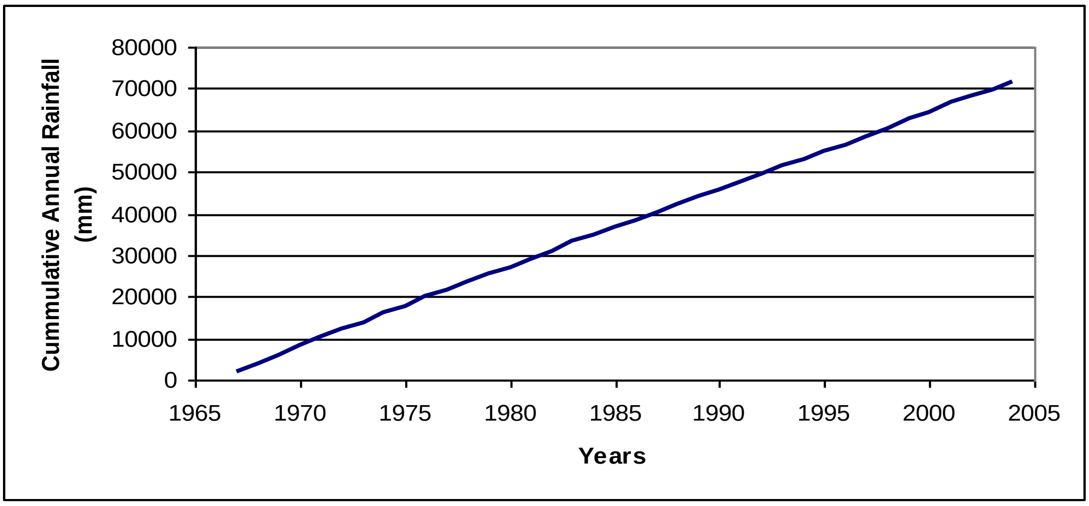
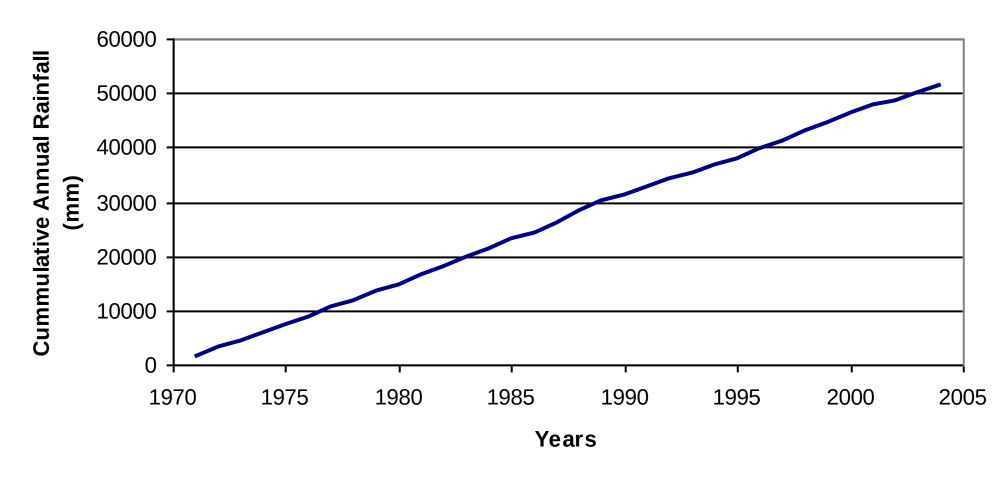


Figure 1.3(c): Single Mass Curve of Didessa Rainfall



1.5.3 Estimation of Rainfall Reliability Level

Irrigation water availability for the command area, corresponding to various rainfall time intervals, requires the magnitude and reliability level of rainfall. Annual and monthly intervals are chosen durations for the concerned irrigation project. Accordingly, rainfall reliability level and magnitude are analyzed by making use of theoretical distributions. In this study, the Extreme Value Type III (minimum) distribution was utilized. The distribution is also known as the Weibull distribution or as Gumbel's limited distribution of the smallest Value. Naturally, zero or other higher values bound rainfalls on the left.

The Weibull (or EV3) distribution can be expressed as:

$$X_p = E + (U-E)\,[-\ln(1-p)]\ 1/A$$

Where:

Xp = magnitude of rainfall corresponding to probability level of p,

The moment estimates of the parameters E (the lower limit), U and a (i.e., E, U and A) can be obtained from the following equation:

U = Xm + Cv.Xm Y(a)
E = U – Cv.Xm.Z(a)

Where:

Xm = mean value,
Cv = coefficient of variation = standard deviation divided by the mean,
Y(a) = (2-Cs)/6
Z(a) = [8+(3-Cs)3]/9, and
A = 3/ (1+Cs)
Cs = skew coefficient calculated from data

The estimated monthly parameter of Weibull Distribution is given in Table 1.8.

The following algorithm is used in the derivation of annual and monthly 55 to 95 percent reliability levels. In the process, the following has been conducted.

1. Averages, standard deviations, skew coefficient of annual and monthly averages were calculated.

2. Weibull Distribution parameters (namely U, E and A) corresponding to annual and monthly rainfalls were calculated from the statistics.

3. Magnitudes of rainfalls corresponding to 55 to 95 percent reliability levels were estimated.

The results so obtained are given in Table 1.7 for monthly time intervals.

Table 1.7: Weibull Probabilities

	Rainfall(mm)	Log of Flows		
Mean	1,421	7.24		
St. Dev	313	0.22		
Skew	0.44	0.03		
Ret.Period	GEV	LN3	LP3	P3
2	1384.87	1377.82	1384.21	1398.58
5	1688.24	1668.45	1664.95	1675.59
10	1870.4	1851.5	1837.05	1833.9
20	2032.34	2021.42	1994.26	1971.95
25	2081.25	2074.4	2042.84	2013.49
50	2224.84	2235.47	2189.44	2135.29
100	2357.41	2393.04	2331.4	2249.01
200	2480.32	2548.65	2470.36	2356.43
500	2629.52	2753.06	2651.29	2490.65
Fit Method	L Moments	Max. Like	Max. Like	Moments
Location	1,279	6.95	2.09	1,421
Scale	295	0.29	0.01	313
Shape	0.1	335.32	562.12	0.44

Fig. 1.4: Probability graph

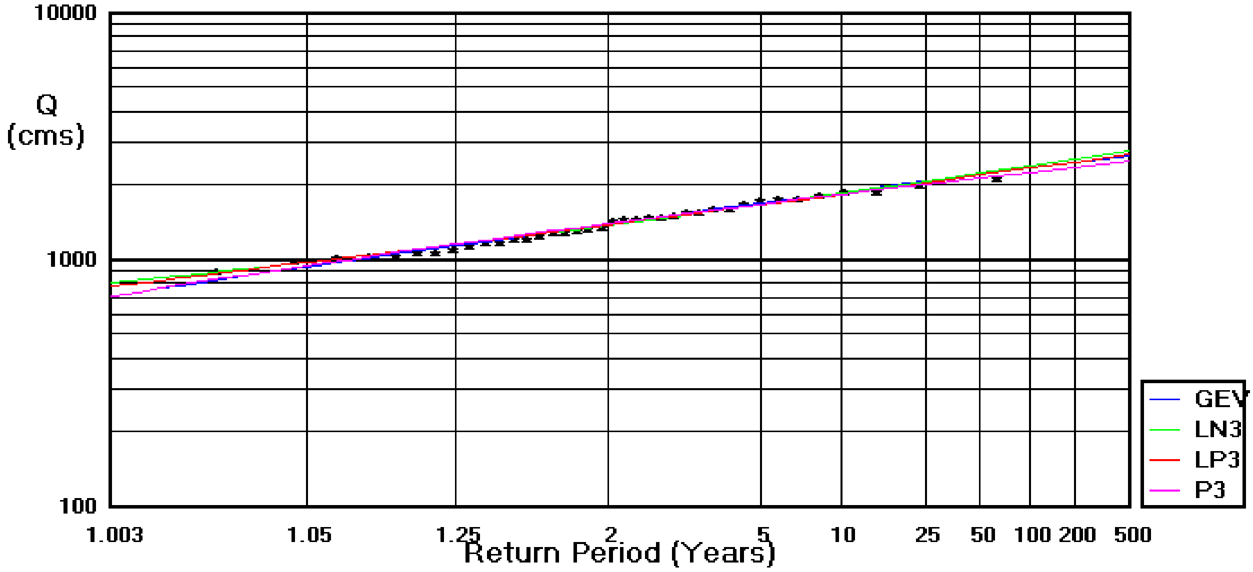


Table 1.8: Parameter Estimates of Weibull Distribution

	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
y(a)	0.5	0.6	0.6	0.4	0.5	0.5	0.8	0.4	0.4	0.5	1.1	0.8	0.4
z(a)	0.2	0.2	0.2	0.3	0.2	0.3	0.1	0.3	0.3	0.2	-0.1	0.1	0.3
U	2.4	2.1	2.2	3.6	2.4	2.9	1.3	3.7	3.4	2.4	0.9	1.3	3.2
E	18.3	21.9	61.2	81.5	201.1	267.3	252.9	257.7	245.0	131.0	30.0	13.9	1541
	-12.9	-15.0	-17.4	-55.3	-9.8	7.3	154.1	35.9	60.9	-29.9	3.8	-4.4	575

U = Xm +Cv*Xm*y(a)   E = U - Cv*Xm*z(a)   X = E + (U-E)*(-ln(1-1/T)^(1/a)

In order to estímate the dependable mean annual rainfall of the project area, the statistical analysis based on Weibul distribution is performed in Table 1.8 and the available dependable rainfall (from 55% to 95%) are presented in Table 1.9 here below. Similarly, monthly rainfalls corresponding to different levels of reliability are depicted on table 1.10.

1.5.4 Estimation of ETo

For the computation of crop reference evapotranspiration (ETo) from meteorological data, a developed and known "Cropwat 4.3" Computer Program is adopted. The "Cropwat 4 Program" is entirely based on FAO Penman-Monteith method, which is maintained as the sole standard method for the computation of crop reference evapotranspiration (ETo) from meteorological data. This section describes how the monthly ETo values are estimated from temperature, humidity, wind-speed and sunshine hours. In order to estimate the mean monthly ETo (mm/month) of the Dinger Bereha project area, the mean monthly data from the years 1961 up to 1993, are acquired from the former feasibility study of Arjo-Didessa Project that is produced some two years back. Furthermore, current data, other data than from Didessa station (1994 up to 2008) are acquired from NMSA for augmenting and updating the current Dinger Bereha irrigation project's ETo determination. The computed average ETo and its magnitude of reliability for each month of the year are also tabulated and presented here under (see for the details tables 1.11, 1.12, and fig 1.5).

Table 1.9: Statistical and dependability analysis of Mean Annual Rainfall

Rank	Rain (mm)	Year	R. P.	Probability (%)
1	2,129	2008	63.67	0.03
2	2,008	1989	23.88	0.05
3	1,903	1988	14.69	0.08
4	1,879	1996	10.61	0.1
5	1,837	2000	8.3	0.13
6	1,785	1987	6.82	0.15
7	1,766	2006	5.79	0.18
8	1,745	1998	5.03	0.2
9	1,697	1992	4.44	0.23
10	1,607	1990	3.98	0.25
11	1,607	1985	3.6	0.28
12	1,572	2003	3.29	0.3
13	1,557	2005	3.03	0.33
14	1,514	1984	2.81	0.35
15	1,486	1997	2.62	0.38
16	1,485	1999	2.45	0.4
17	1,472	2004	2.3	0.43
18	1,464	1991	2.17	0.45
19	1,447	1993	2.05	0.48
20	1,362	1983	1.95	0.5
21	1,345	1986	1.85	0.53
22	1,320	1967	1.77	0.55
23	1,303	1976	1.69	0.58
24	1,292	1974	1.62	0.6
25	1,250	2001	1.55	0.63
26	1,217	1970	1.49	0.65
27	1,210	1971	1.44	0.68
28	1,181	1978	1.38	0.7
29	1,181	1994	1.34	0.73
30	1,132	1969	1.29	0.75
31	1,110	1980	1.25	0.78
32	1,075	1973	1.21	0.8
33	1,070	1968	1.17	0.83
34	1,045	1975	1.14	0.85
35	1,043	1995	1.1	0.88
36	1,024	1979	1.07	0.9
37	991	1972	1.04	0.93
38	905	2002	1.02	0.95

Table 1.10: Monthly Rainfalls Corresponding to Different Reliability Levels

Rel.Level (%)	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
55	10.8	12.2	40.9	58.1	150	213	219	221	212	91.65	18.6	7.58	1,351
60	8.84	9.79	35.8	51.7	137	198	211	210	203	81.66	16.3	6.12	1,303
65	6.92	7.4	30.8	45.3	124	184	204	200	194	71.76	14.2	4.74	1,251
70	5	5.03	25.8	38.6	111	169	197	190	184	61.82	12.2	3.43	1,202
75	3.04	2.63	20.7	31.5	97.9	154	190	178	174	51.68	10.4	2.16	1,144
80	0.99	0.16	15.5	23.8	84.2	138	183	166	164	41.13	8.83	0.92	1,089
85	0	0	9.97	15.2	69.4	120	177	152	152	29.86	7.36	0	1,025
90	0	0	3.87	4.84	52.9	99.7	170	135	138	17.29	6.02	0	951
95	0	0	0	0	32.7	73.7	163	113	119	1.974	4.82	0	848
Avg	15.3	18.4	53.6	69.5	180.8	243.0	245.9	238.3	228.6	115.5	31.4	12.7	1,451

Table 1.11: Summary of Estimated Mean Daily ETo of Dinger Bereha Project Area

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Average (mm/day)	3.7	4.11	4.62	4.51	4.33	3.58	2.96	3.11	3.81	4.03	3.79	3.44
CV	0.05	0.06	0.05	0.07	0.08	0.08	0.08	0.08	0.09	0.06	0.12	0.05
Skew	-0.47	-0.77	0	-0.95	-0.65	-0.19	0.33	-0.51	-0.18	-0.27	-3.11	0.88

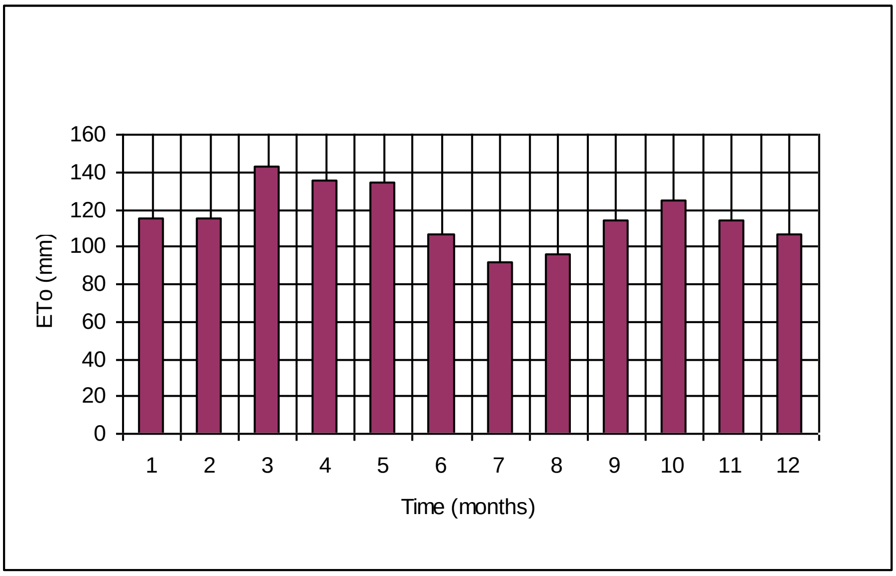
Average (mm/month)	115	115	143	135	134	107	91.8	96.5	114	125	114	107
CV	0.05	0.06	0.05	0.07	0.08	0.08	0.08	0.08	0.09	0.06	0.12	0.05
Skew	-0.47	-0.77	-0	-0.95	-0.65	-0.19	0.33	-0.51	-0.18	-0.27	-3.11	0.88

Note: Total annual ETo = 1,024 mm

Table 1.12: Magnitude of Dependable ETo in mm/month at a given probability level

Probability (%)	Jan	Feb	Mar	April	May	Jun	July	Aug	Sept	Oct	Nov	Dec
70	118	119	147	141	140	112	96	101	120	129	121	110
75	119	120	148	142	142	113	97	102	121	130	123	110
80	120	121	150	144	144	114	98	103	123	131	125	111
85	121	123	151	146	146	116	99	105	125	133	127	112
90	122	125	153	148	149	118	101	107	127	135	131	114
95	125	127	156	152	153	121	104	109	131	137	135	116
Avg	115	115	143	135	134	107	92	96.5	114	125	114	107

Figure 1.5: Bar Graph Showing Mean Monthly ETo at Dinger Bereha project Area



1.5.5 Rainfall Intensity

For internal cross-drainage works, it is found necessary to assume different values of rainfall intensities for various return periods and with different durations. In general, maximum rainfall magnitudes of intensity corresponding to various return periods (or probability levels) are estimated by applying the following equations.

IT = Im [1+ CV.K (T)]

Where:

IT = rainfall intensity corresponding to return period of T years (mm),

Im = mean of annual maximum intensity of rainfall (mm/hr),

CV = coefficient of variation of annual intensity of rainfall,

K (T) = frequency factor

For Extreme Value Type I (or Gumbel) Distribution,

K(T) = -0.779 {0.577 + ln.ln[T/{(T –1}]}

The results of the maximum 24-hrs and 1-hr rainfall frequencies are presented in Table 1.13.

The 1-hr rainfall intensities were estimated using the formula derived for Ethiopian condition and expressed as:

Ih = I24 x (0.523 + 0.15 x ln D)

Where:

Ih = maximum rainfall intensity corresponding to duration D (mm/hr),
ln = natural logarithm
D = duration of Ih (hr),
I24 = maximum rainfall intensity corresponding to duration 24 hours (mm/hr).

The computed 1-hr rainfall intensities and the maximum rainfall magnitudes are shown in table 1.14.

Table 1.13: Didessa Max 24 hr. Rainfall (mm)

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
1993	0	5.5	10.4	16.5	24.2	24.5	40	27.7	37.6	17.8	11.3	0
1994	0.1	0	1.2	30	30.9	57	37.4	38.3	22.3	23.8	13.8	0.3
1995	0	0	12.8	9.5	32.6	23	56	30.3	27.5	18.3	5.2	4.3
1996	11.2	2.2	30.2	15	30	29.7	64.5	38.7	50	21.2	7.2	
1997	12.5	0	3.7	42.4	30	30	40.5	39.4	34.5		28.5	0
1998	0	0	6.4	5.5	60	50	33.5	78	51	30	22.2	0.4
1999	9.8	0.2	0	10.7	28.9	47.7	45	64.1	60.6	28.8	7.8	4.6
2000	0	0	0.4	29.5	59.5	72	19	116.6	52.9	57.4	12.8	0
2001	0	5.7	15	9.2	23.2	30.2	41.5	26.8	55.1	26.5	26.2	10.5
2002	2.5	14.2	20.4	9.9	60.6	40.4	42	25.1	32.8	5.8	0.2	5.6
2003	0	12.5	18.8	0	20	103	93.5	34.2	27.4	23.4	18.5	5.2
2004	0	5.2	4.8	10.2	21.4	34.2	85.9	45.4	21.2	40.8	15.9	1.2
2005	5.2	0.4	35.5	4.2	31.4	32.8	46.5	24.5	26.2	14.2		
2006			8.8			27	67	42.3	79.3	54.6	18.8	12.4
2008	5.3	0	3.8	30	56.4	48.3	80.3	99				

Table 1.14: Maximum 24-hrs Annual Rainfall

Year	(mm/d)		Year	(mm/d)		Year	(mm/d)
1967	47.1		1980	45.6		1993	50.1
1968	47.0		1981			1994	57.8
1969	64.0		1983	50.0		1995	61.0
1970	57.0		1984	51.7		1996	60.1
1971	70.0		1985	62.2		1997	104.5
1972	45.2		1986	64.6		1998	63.5
1973	35.9		1987	58.4		1999	63.0
1974	51.8		1988	53.2		2000	47.9
1975	36.4		1989	46.8		2001	69.0
1976	47.1		1990	49.5		2002	57.0
1978			1991	87.8		2003	
1979	45.0		1992	51.6		2004	39.1
						Average	54.14
						CV	0.306
						Skew	2E-04

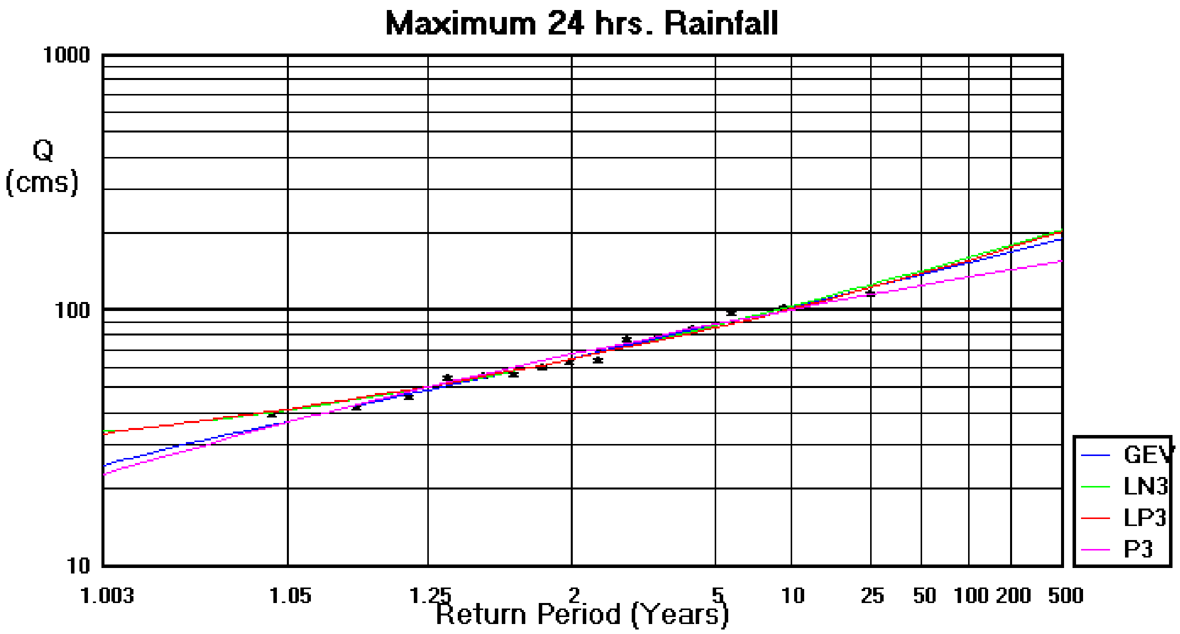
Table 1.15: Maximum Rainfall Magnitudes and Frequencies

Return Peiod (T)	Frequency Factor (K)	Rainfall Magnitude (mm)	
		24-hr	1-hr
2	-0.16	51	27
5	0.72	66	35
10	1.30	76	40
15	1.64	82	43
20	1.86	85	44
25	2.04	88	46
30	2.20	91	48
40	2.40	94	49
50	2.61	98	51

Table 1.16: Maximum Rainfall Magnitudes

Return Period, T (Years)	EVI Factor K(T)	Max. 24 hrs rain (mm)
2	-0.164	65
5	0.719	88
10	1.304	103
25	2.043	124
50	2.591	139
100	3.135	154

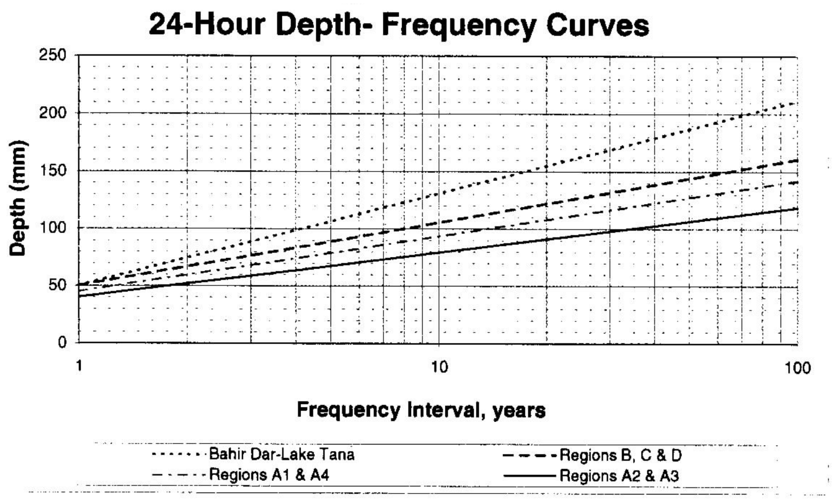
Figure 1.6: Frequency Curve of Maximum Daily Rainfall (mm)



1.5.6 Drainage Design

The Ethiopian Road Authority has established a standard manual for the design of drainage structures and details are presented below.

Figure 1.7: 24 Hour Depth-Frequency Curves



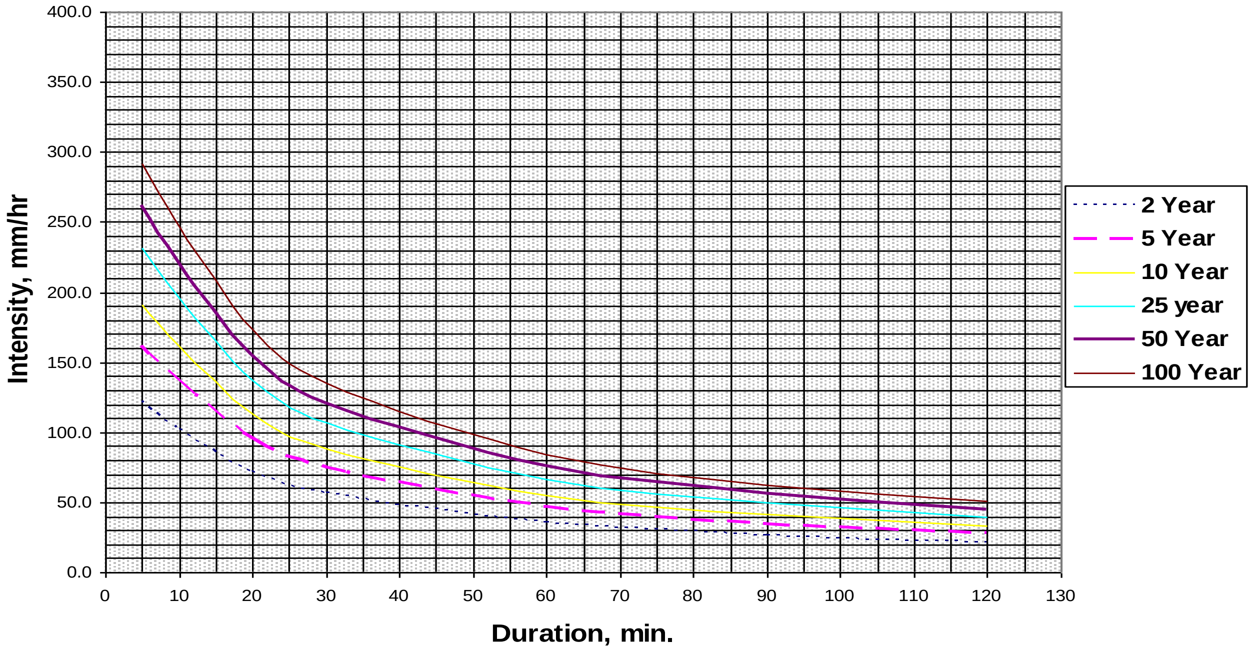
Region	24 HOUR DEPTH (mm) vs. FREQUENCY (yrs) TABLE					
	2	5	10	25	50	100
A1, A4	60	79	93	113	127	142
A2, A3	52	67	79	95	107	118
B and C	65	84	98	118	132	147
D	67	89	105	127	144	161
Bahir Dar	74	106	131	163	187	211

From ERA's Manual, 20 minutes, 1-hour intensity, and 24 hours depth (in mm) are given on figure 1.8 and the attached table. The 24 hours maximum depth (mm) which is estimated by analysis (Table 1.17) does not differ much from the figures given in the Ethiopian Road Authority Manual.

Table 1.17: 1-hr Intensity and 24 hours Depth at different periods

Return Period, T (Years)	20 minutes Intensity (mm/hr)	1 hour Intensity (mm/hr)	24 hours Depth (mm)
2	61	38	65
5	83	42	84
10	108	47	98
25	118	68	118
50	132	76	132
100	150	84	147

Fig. 1.8: Intensity-duration-frequency curve



2. HYDROLOGY

2.1 General

Reliable estimate of the available stream flow is important for any project planning, study and design. In the Dinger Bereha Irrigation project area, there is one major river, which is Didessa River with plenty of rivers/streams systems with their respective sub-catchments and their yields should be properly analyzed with the intention of supplying water for irrigation development. Such estimates can be relied upon on the gauged data if measurements are taken for sufficient periods. With regard to this, guaged data is available only for Didessa River with records of 33 years, which is from the years 1961 up to 2008. Therefore, for the remaining potential tributary rivers or streams, estimates will be achieved from records of the gauged river having similar catchments characteristics.

In line with this, the specific objective of this study is to carry out data collection, assessments, analysis towards hydrology study, which may include surface water such as rivers, streams and springs and study of climate of the project area and its surroundings. So that the principal objective will be provision of sustainable water supply to irrigate the indicated Dinger Bereha command area. The study will provide the development of the surface water resources of the study areas with respect to occurrence, distribution quality and quantity for the lifetime of the project.

The current study, furthermore, aims at development of Irrigation and drainage in the Project area. Generally, the immediate objective of this study is thus, to conduct feasibility study and prepare irrigation system designs at feasibility level for future production of food and cash crops sustainably. The surface water is assessed through conducting hydrological & meteorological studies. In addition, the hydrological study has generated data for both irrigation and drainage studies.

2.1.1 Water Resources Assessment Objectives

The main objective of the hydrological study is to eascertain the availability of surface water for water supply through:

- Analyses & interpretation of hydrometeorological data over the study area;
- Evaluate the availability of surface water for irrigation and drainage;
- assess the possibility of weir sites, so that enough water will be delivered to the command area;

2.1.2 Methodology

The methodology adopted to conduct the hydrology study of the project included among others:

- Collect land use/cover, soil type for further analysis;
- Collect, analyses and interpretation of hydro-meteorological data, consistency of data, trend detection for any climatic change;

- Recommendation for additional surface water sources river and, if required
- Collect information on the existing water sources, which are supplying water for human as well as live-stock consumption.

2.2 AVAILABLE DATA AND DATA RESOURCES

In the project area apart from the Didessa River, there are no data gauged implying that all the major and minor tributaries are remained ungauged. The data from the attributed from gauging station of Didessa river is old enough for the purpose of this study. Totally, there is t 33 years of records, which are presumeably sufficient for further analysis, and this station from the recorded data are collected is located the road crossing Didesa river from Bedele to Arjo town, "Didessa near Arjo town, and is coded as Station No. 114001.

The Hydrology Department of the MoWR is the only organization to supply data and information on river discharge and sediment concentrations. For the un-gauged rivers of particular interest, estimates may be achieved from records of the Didessa River.

2.2.1 Stream Flow Analysis

Station 114001 with a catchment area of 9,981 km² is located about 25 km up-stream of the proposed weir site and has become operational since 1960 where as. By utilizing a topographic map with scale of 1:250,000, the catchment area between station 114001 and the weir site of the Dinger Bereha irrigation project is estimated as 625 km². Before the stream flow analysis, missing data were infilled and then checked for its consistency prior to different analysis. The recorded available flow data at the gauged site shows discontinuity and starting from 1963 up to 2003 there are data missing, which hampers proper statistical analysis; hence, for every missed flow, the "all the years monthly ratio" method is applied and infillings are performed. The station year method of data infilling technique was used for verification, but due to the non-availability of long year records of the Didessa River, it is rejected.

Mean monthly discharges, coefficient of variation of monthly flows, summary of regional monthly flow characteristics, statistics of monthly flows at the weir site are shown on Tables 1.18, 1.19, 1.20, and 1.21 respectively. The monthly stream flows at different reliability level are available in Table 1.18. In order to maintain the historical skewness in the generated flows, the Weibull distribution has been fitted to the standardized residuals of the monthly series.

2.2.2 Flow at the Weir Site

Transposing method has been selected to estimate the flow at the weir site. Since the weir site is located on the Didessa River at some 25 km² down-stream of the gauging site at the bridge near Arjo (114001), then it wise and appropriate to estimate the flow at the weir site by considering area proportionality.

The selected regionalization approach has considered the following characteristics of the catchments:

i) The only recorded one is Didessa River and the weir site also is on the same river, which is near by station 114001;
ii) The two sites have similar Climatological and hydrological characteristics;
iii) They have similar geological setup;
iv) There are adequate rainfall records corresponding and longer reliable station for rainfall-runoff regression.

The relationship between gauged and un-gauged catchments may be stated by using the equation:

$$Q_g / A_g \times p_1 = Q_{ug} / A_{ug} \times p_2$$

where,

- Q_g and Q_{ug} are annual/ monthly flows of the gauged (Didessa River at Station 114001) and un-gauged river flows at weir site respectively,
- p_1 and p_2 are mean weighted annual rainfall of the gauged and un-gauged catchments respectively,

From the above relationship the following formula can be derived:

$$Q_{ug} = \frac{(Q_g) \times A_{ug} \times p_2}{A_g \times p_1}$$

Therefore:

$$Q_{ug} = \frac{(Qg) \times (9{,}981+625) \times 1{,}454}{9{,}981 \times 1{,}680}$$

Based on the above final relationship, the mean annual and monthly flows at the weir sites are estimated and the results are displayed as follows.

Mean dependable flow = 3,232 Mm^3

75 % dependable flow = 2,415 Mm^3

80 % dependable flow = 2,351Mm^3

Table 1.18: Mean monthly discharges

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Total
Mean	48.9	27.6	26.6	35.1	63.5	222.2	659.1	997.1	964.1	620.8	171	99.2	3,948
C.V.	0.52	0.6	0.71	0.64	0.6	0.41	0.37	0.36	0.32	0.58	0.53	0.53	29
Std.dev.	23.72	15.46	17.66	21.02	35.72	86.23	228.84	335.03	290.06	340.42	90.15	49.5	1,059
75%dep.	31.7	16.04	13.9	13.7	36.6	133.2	466.7	652.2	630.7	291.6	112.4	62.7	2,778
80%dep.	28.2	15.04	13.6	12.3	28.9	127.1	424	624	617.2	265.2	95.8	67.7	2,702

Mean dependable flow = 3,232 Mm^3

75 % dependable flow = 2,415 Mm^3

80 % dependable flow = 2,352 Mm^3

Table 1.19: Availability of Streamflow Data in the Region

Sl No	St. No	Station name and Location	Lat North	Long East	Area (Km2)	Flow (Mm3/yr)	Runoff (mm)
1	114001	Didessa near Arjo	8.41	36.25	9,981	3,826	383
3	114005	Dabana near Abasina	9.02	36.03	2,281	1,870	820

Table 1.20: Mean Monthly and Dependable Flows of Didessa at (gauging Station 114001) (MCM)

	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Annual
Mean	46	26	25	33	59.7	209	620	938	907	584	171	93.3	3714
C . V .	0.5	0.6	0.71	0.64	0 . 6	0.41	0.37	0.36	0.32	0.58	0.53	0.53	2 9
Std.dev.	23.72	15.46	17.66	21.02	35.72	86.23	228.84	335.03	290.06	340.42	90.15	49.5	1058.569
75% dep.	31.7	16.04	13.9	13.7	36.6	133.2	466.7	652.2	630.7	291.6	112.4	62.7	2777.6
80% dep.	28.2	15.04	13.6	12.3	28.9	127.1	424	624	617.2	265.2	95.8	67.7	2702

Figure 1.9: Graphical representation of Mean Monthly Flow (MCM)

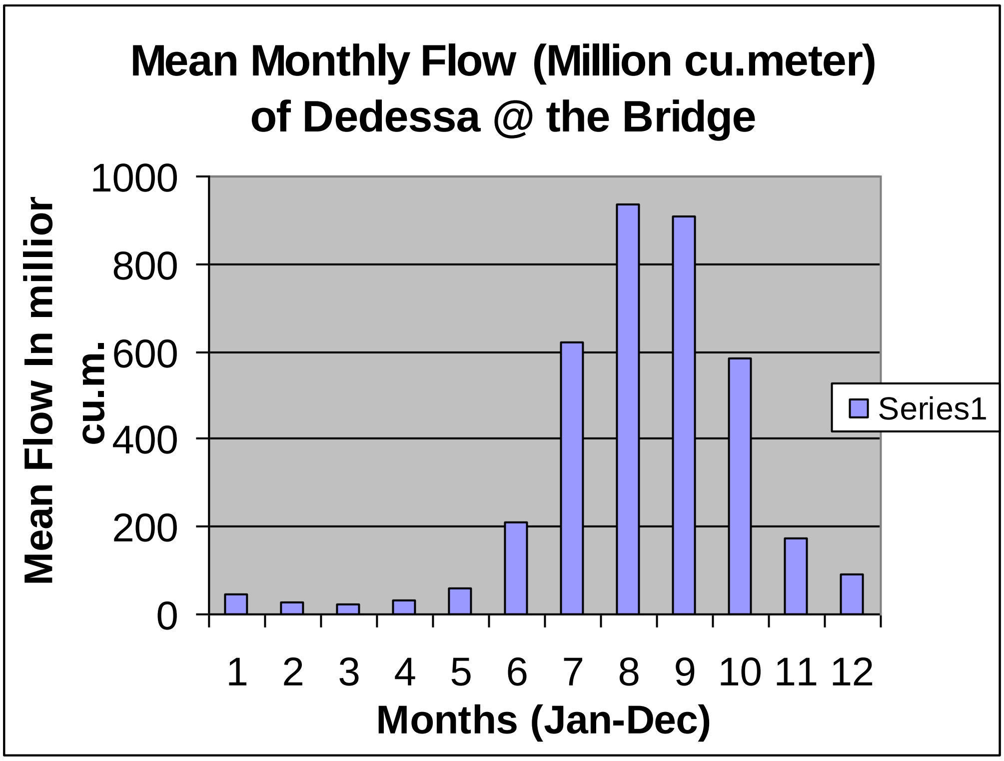
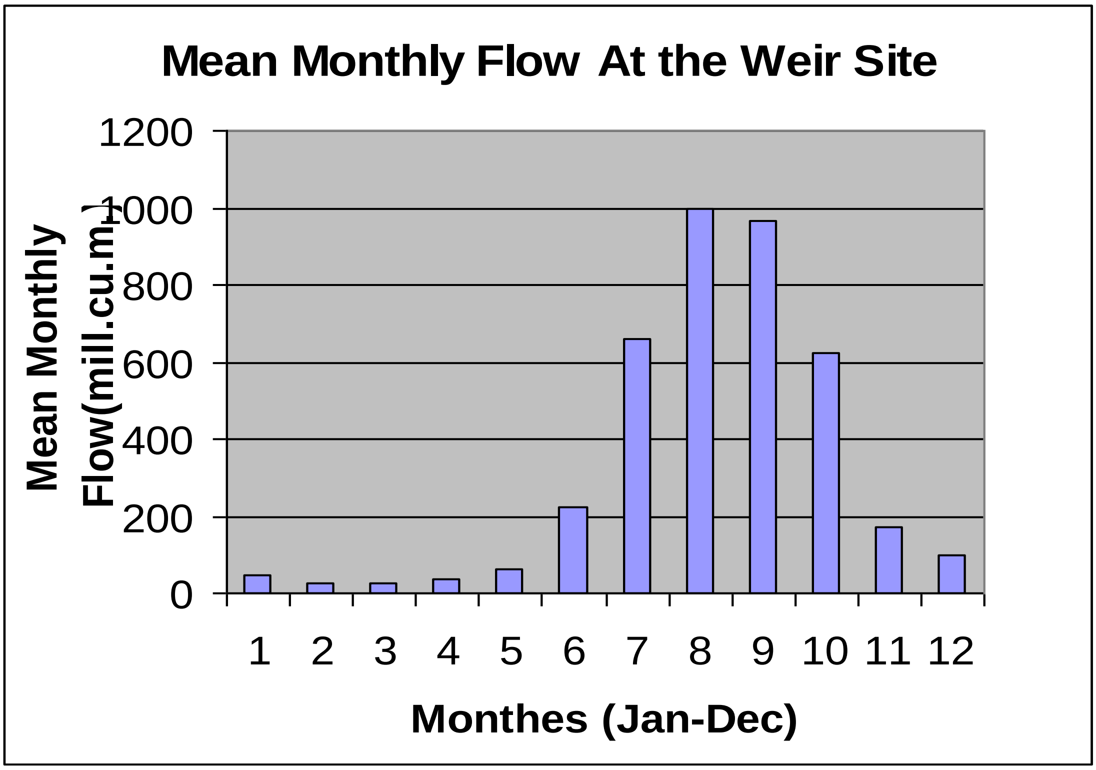


Table 1.21: Statistics of monthly flows at the Weir Site (MCM)

Param	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average	25.00	16.97	17.86	24.21	48.26	157.2	412.8	633	540.6	299.8	105.9	46.11	2,328
Stdev	12.81	9.72	11.82	16.41	29.69	70.67	143.2	189.6	179.2	180.5	89.35	27.17	619.3
Skew	0.626	0.743	1.067	0.937	1.629	0.891	0.126	0.037	0.254	0.585	1.866	0.96	0.498
Max	59.09	40.3	46.01	68.61	144.9	366.1	751.5	1043	905.1	661	400.8	120.1	4,089
Min	6.806	3.462	1.775	4.586	9.685	38.71	143.8	296.2	195.6	49.32	12.69	4.808	1,124
R	0.446	0.828	0.889	0.59	0.298	0.785	0.45	0.529	0.436	0.431	0.796	0.704	
B	0.21	0.628	1.081	0.819	0.54	1.868	0.912	0.701	0.412	0.434	0.394	0.214	

Figure 1.10: Graph Showing Mean Monthly Flow At the Weir Site



2.3 PEAK FLOODS

In the hydrologic analysis of dams, weirs, bridges and drainage structures, there are many factors that affect floods. Some of the factors that need to be recognized and considered on site-by-site basis are:

- rainfall amount and storm distribution;
- catchment area size, shape and orientation;

- ground cover;
- type of soil;
- slopes of terrain and stream(S);
- antecedent moisture condition;
- storage potential (overbank, ponds, wetlands, reservoirs, channel, etc.); and
- Catchments area

In general, three types of estimation floods magnitudes (namely: the Rational Method, SCS method and Transferring Gauged Data method) can be applied for the project area. The purpose of the flood study in this project is to protect the main canal at the head of the irrigation plot and for major rivers if flood occurs from the upstream of the farm. Since there recorded peak discharges are available at station 114001 for frequency analysis, we can easily estimate the peak flows of each river/stream within the command area. Appendix B presents the peak flood calculation for the cross drainage structures. The boundaries of the catchment areas are shown in Volume Drawings.

2.3.1 Peak Flood at the Weir Site

The peak flood at the weir site is estimated by the flood transposing method and this will be performed just by considering the ratio of the areas of the un-gauged to that of the gauged one. This method is very well illustrated in the mean monthly flow estimation for the weir site.

Hydrometric stations on the Didessa river and the neighbouring rivers within the Abbay Basin were identified and data were obtained from the Hydrology Department of the Ministry of Water Resources (MoWR). There are two hydrological observation stations located on the Didessa River. These are Didessa near Arjo town (Station No. 114001) and Didessa near Dembi town (Station No. 114014). Station 114001 with a catchment area of 9,981 km^2 is located about 25 km upstream of the proposed weir site and is operational since 1960, whereas Station 114014 with a catchment area of 1,806 km^2 has become operational since 1985. In addition, the hydrological observation station on the neighboring Dabana near Abasina (Station No. 114005) is considered relevant to the study.

2.3.1.1 Extension of records

Streamflow gauging stations have been installed on the Didessa River near Arjo town (Station 14001) since 1960 and near Dembi town (Station 14014) since 1985. Before the streamflow analysis, data obtained from Station 114001 (Didessa near Arjo) and Station 114014 (Didessa near Dembi) were checked for temporal and spatial homogeneity. The investigation of homogeneity was concentrated mainly on the outliers of the monthly data series of the record. Extremely high or low values of each series that has occurred at time T(i) in each month M(i) were checked against the records of the month M(i-1) and M(i+1) that has occurred at the same year T(i). This approach enabled to judge, whether the relation is still more or less the same as that of the other years. Whenever the outliers were rejected by this test, again another test was performed with other data series of Station 114005 (Dabana near Abasina).

Table 1.22: Maximum Flows (m3/s) of Didessa River near Arjo

Station:- DIDDESSA NEAR ARJO; STATION No.:-114001 Co-Ordinate:- 8d 41'n 34d 25'e

DRAINAGE AREA: 9,981 km2

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	MMD
1961	23.8	32.7	23.8	55.8	43	275	715	899	814	1145	209	154	1145
1962	30.7	16.3	19.1				383	467	525	858	64.2	32.5	858
1963	19.8	13	11.8	30.7	119	213	475	759	563	290	120	129	759
1964		22.2			51.2	131	654	679	677	817	150	35.4	817
1965	32.5	11.8	11.8	25.4	19.8	203	421	507	449	911	192	101.2	911
1966	35.4	40.4	38.4	54.6	65.4		523	598	783	717.5	181.9	78.2	783
1967			22.2	14.2			343	660	618	1070	497	136	1070
1969	24.6	25.4	54.6	38.4	58.2	221	567	752	538	182	55.8	25.4	752
1970	13.6				50.1	265	573	666	527	492.8	126	37.4	666
1971	20.6	8.62	5.2	7.23	50.1	142	565	649	435	467	203	66.6	649
1972	28.9	13.3	11.8	49	44.6	84.4	47.5	57.3	36.1	145	71.5	27.1	145
1973	15	6.4	2.81	4.6	67	125.8			764	487.4	79	35.3	764
1974	20.9	11.29	8.03		92.2	148	310	719					719
1979				18.5	35.3	113.2	264.1	487.4	459	170.5	62	20.9	487
1982	17.81	7.86	10.19	6.15	22.19	125	416.6	502.6	359	510	71.48	43.2	510
1983	12.35	11.46	15.21	6.48	32.31	68.33	359.0	644.6	502.6	1079.8	109.2	39.9	1079.8
1984	21.78	9.78	7.51	5.52	25.49	181.9	439.3	406.7	377.7	114.48			439.3
1985	6.81	4.1	2.88	12.35	38.32	168.8	274.3	555.6	584.5	197.14	42.33	28.1	584.5

Table 1.22: Maximum Flows (m3/s) of Didessa River near Arjo (ctd)

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	MMD
1986	9.78	4.93	14.22	12.35	7.86	91.75	314.15	318.5	614.2	190.27			614.2
1987	6.48	4.64	7.16	12.81	43.99				626.3	299.15	128.2	33.8	626.3
1988	18.35	14.71	14.22	5.52	33.76	190.3	472.03		635.8	605.5	156.2		635.8
1989		13.27	14.22	27.46	21.19	165.6	132.4	387.3	710.6		69.37	80.18	710.6
1990	43.16	17.81	30.88	35.25	25.49	89.38	309.83	630.3	735.9	763.5	216.5	96.6	763.5
1992	9.78	12.35	5.22	21.19	26.79	80.18	225.77	473	436.7	949.68	131	40.7	949.7
1993	20.83	13.08	13.08	40.05	63.52	217.9	399.05	645.6	447.2	258.77	250.4	40.05	645.6
1994	17.55	10.01	6.595	7.3	32.13	132.7	394.97	804.3	522.8	110.69	36.35	32.82	804.28
1995	9.198	5.92	12.17	20.83	23.76	75.99	126.38	353.3	288.3	98.125	30.77	18.62	353.253
1996				21.41	106	205.5	423.9	525.1	403.1				525.1
2001	38.55	32.13	55.47	30.1	82.06	281.2	502.32	588.9	744.4	440.83	168.8	62.61	744.358
2002	44.68	28.13	25.59	34.92	23.76	123.9	240.44	300.8	311.7	167.37	66.31	52.04	311.73
2003	26.85	19.16	30.1	48.71	27.48	92.63		324.7	350.7	348.9	91.5	39.3	350.7
2004	23.16	19.71	13.55	15.49	50.37	164.6	374.85	395	601	438.69	68.2		601
Mean	23.7	16	18	26	49	156	376	534	522	504	129	55.8	680.45
	MMD = Maximum Mean Daily Flow in m^3/sec.												

The data were checked for their consistency before use for different analyses. The investigation concentrated mainly on the outliers of the monthly and daily data series. Extremely high or low values that occurred at a given time were checked against records of other near by rivers (such as Dabana). If the outliers are found to be inconsistent with others, then they were replaced by new values that were generated regionally from data set obtained from other stations.

2.3.1.2 Flood Frequency Analysis

In flood frequency analysis, the objective is to estimate a flood magnitude corresponding to any required return period of occurrence. The resulting relationship between magnitude and return period is referred as the Q-T relationship. Return period, T, may be defined as the time-interval (on the average) for which a particular flood having magnitude QT (also known as qunatile) is expected to be exceeded. A reliable estimate of the entire Q-T relationship cannot be obtained from small samples of at-site data. The benefits of regionalization in flood frequency analysis have been recognized at least since the work of Delrymple (1960).

Nowadays, the regionalization approach to flood frequency analysis (particularly the index-flood method) is becoming more popular. An essential prerequisite for the index-flood method is the standardization of the flood data from sites with different flood magnitudes. The most common practice, used also in this study, is to standardize data by division by an estimate of the at-site mean, thus:

$$Xi = Qi/Qm$$

where Xi is the ith standardized flow, Qi is the ith annual maximum flow, Qm is the average value of at-site annual maximum flow series. Then the quantile QT is estimated as

$$QT = Qm.XT$$

Thus, the mean annual flood is the index-flood. The parameters of the distribution of X are obtained from the combined set of regional data. In this study, two distributions have been used for flood frequency analysis. These distributions are:

- Generalized Extreme Value (GEV) distribution (Jenkinson, 1969)
- Log-Logistic (LLG) distribution (Ahmed et al., 1988)

Table 1.23: Monthly Peak Flow at the Weir Site

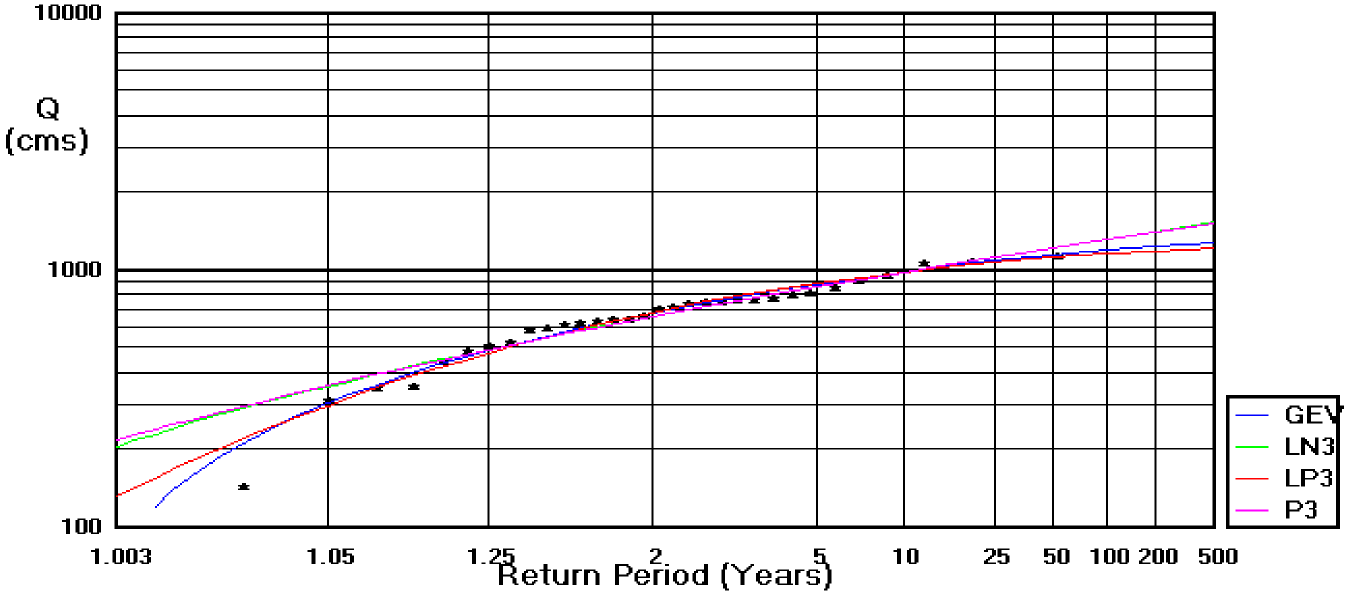
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Mean	25.2	17.0	19.1	27.6	52.1	165.8	399.7	567.6	554.9	535.8	137.1	59.3

2.3.2 Maximum Flow Frequency Analysis

Table 1.24: Flood Frequency at 114001

	Flows	Log of Flows		
Mean	680.46	6.45		
St. Dev	225.39	0.41		
Skew	0.66	-1.64		
RP	GEV	LN3	LP3	P3
2	678.71	656.79	682.58	655.88
5	879.27	857.59	886.06	858.92
10	981.27	978.05	980.74	979.98
20	1061.04	1086.46	1049.71	1088.16
25	1083.19	1119.65	1068.03	1121.16
50	1143.23	1218.99	1115.87	1219.02
100	1192.3	1314.03	1152.88	1311.81
200	1232.58	1406.01	1181.76	1400.64
500	1275.11	1524.29	1210.56	1513.16
Fit Method	L Moments	Moments	Max. Like	Moments
Location	599.14	6.92	7.15	680.46
Scale	228.33	0.21	-0.22	225.39
Shape	0.28	-356.3	3.11	0.66

Figure 1.11 : Flood Frequency Curve



Therefore, the peak floods at the weir site at different return periods are:

25 years = 1,083m³/s
50 years = 1,143m³/s
75 years = 1,187m³/s
100 years = 1,192m³/s
1000 years = 1,335m³/s

2.3.3 Low Flows

Water for Dinger Bereha irrigation area is to be supplied by a diversion structure, which requires a lean flow analysis. Since the minimum flow of the Didessa River is recorded at station 114001 and then the estimated low flow at the weir site is available, statistical method, which is subjected to frequency analysis, can be performed. In line to this, the required probability of exceedence is used in determining the corresponding flow magnitudes. The monthly minimum flows for the period 1961-2004 are presented in Table 1.24 here below. In the case of irrigation by diversion scheme, the water availability depends on the design minimum flow, which should be equal to the scheme irrigation demand. For the scheme demand, see the Agronomy report of DB FS, Annex Agriculture. In order to make sure that the diverted water meets the irrigation demand during the critical period, the simulation of such system is undertaken for a pre-determined critical period or year minimum flow series.

Table 1.25: Minimum Flow (m³/sec) Of Dedessa at the Bridge Near Arjo

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	Minimum flow
1961	13.8	12.6	11.3	17.2	12.6	45	316	331	448	120	81	40	11.3
1962	17	7.23	7.79	7.7	10.7	40.4	125	216	317	67.8	31.6	13	7.23
1963	7.7	4.83	2.2	2.69	14.9	66.6	145	320	233	72.7	54.6	37.4	2.2
1964	13.4	9.65	7.3	7.2	9.12	60.6	138	270	310	163	37.4	24.6	7.2
1965	11.2	5.97	2.69	9.12	2.69	20.6	195	262	157	115	88.6	36.4	2.7
1966	22.2	21.4	13	14.9	13.6	59.4	153	268	151	107	66.1	40.5	13
1967	26.5	10.2	1.82	2.95	4.2	29.2	147	369	334	112	84.4	52.4	1.8
1969	15.6	11.8	17	6.79	11.8	66.6	185	365	195	52.4	25.4	13.6	11.8
1971	7.68	2	0.44	0.93	0.81	50.1	128	299	280	153	67.8	30.7	0.44
1972	12.8	10.2	5.1	5.1	9.4	17	10.5	28.3	15.7	46.8	28.9	11	5.1
1973	6.79	2.54	0.73	0.73	2.27	57	204	349	293	82.3	36.1	17.9	0.73
1979	4.1	3	2.6	3.08	3.36	18.5	86.7	222.3	147	68	20.9	7.6	3.1
1982	8.23	4.93	2.44	1.07	2.88	21.8	109	200.6	87	75.8	30.2	12.8	1.1
1983	6.48	3.83	2.44	2.88	1.86	18.9	76.9	147	264	96.6	41.5	22.4	1.9
1984	8.99	4.1	2.88	2.24	2.24	30.9	140	200.6	100	21.2	16.4	12.3	2.3
1985	3.1	1.21	0.59	2.24	5.22	28.8	125	286.6	169	43.2	17.3	9.78	0.6
1986	3.83	3.1	2.44	3.1	2.24	3.83	91.8	125.2	158	35.3	16.8	8.8	2.2
1987	2.88	1.69	2.05	2.44	2.05	12	51.2	130.3	177	80.2	33.8	15.7	1.7
1988	11	8.99	5.52	2.05	1.86	32.3	167	252.2	204	78.5	38.3	21.6	2.1
1989	10.7	5.52	4.93	4.36	4.36	14.7	74.7	133.8	350	95.4	25.5	26.1	4.4
1990	11.9	8.61	7.16	10.6	8.99	24.9	88.2	193	186	78.3	40.2	23.5	7.2
1992	7.86	5.83	4.36	3.58	13.3	39.1	75.8	227.6	120	104	40.7	19.5	4.4
1993	12.6	10	6.94	12.2	17.5	47.1	133	313.6	182	70.1	33.5	19.7	6.9
1994	10.4	6.6	4.67	4.38	10.4	25	133	299	136	36.4	19.7	16.5	4.4
1995	5.92	4.67	3.04	3.04	10.9	15.5	64.4	132.7	118	33.5	16.5	9.2	3.1
2001	26.8	20.8	17	4.38	20.8	82.1	185	276	182	156	52	39.3	4.4
2002	28.8	15.5	15.5	17.5	13.1	23.2	123	157.7	154	57.2	34.2	36.4	13.1
2003	16.5	12.6	12.6	15.5	14	13.1	45	173	162	69.1	39.4	26.8	13.1
2004	17	11.7	9.6	9.2	14.5	46.3	99.2	146.9	185	66.3	45.5	29.9	9.2
Mean	12	8	6	6.2	8	35	125	231	200	81	40	23	5.128
Std.dev.	7.01	5.25	4.98	5.06	5.66	19.9	59.6	85.01	92	36.7	20.4	11.8	4.08
C.V	0.58	0.66	0.82	0.82	0.68	0.57	0.48	0.37	0.46	0.45	0.51	0.52	0.8

Table 1.26: Probability of minimum flows (m3/s)

Year	Minimum Flow (m³/sec)-Q	Rank	P
1961	13.1	1	0.03
1962	13.1	2	0.07
1963	13	3	0.1
1964	11.8	4	0.13
1965	11.3	5	0.16
1966	9.2	6	0.19
1967	7.23	7	0.23
1969	7.2	8	0.26
1971	7.2	9	0.29
1972	6.9	10	0.33
1973	5.1	11	0.36
1979	4.4	12	0.39
1982	4.4	13	0.42
1983	4.4	14	0.45
1984	4.4	15	0.48
1985	3.1	16	0.51
1986	3.1	17	0.54
1987	2.7	18	0.57
1988	2.3	19	0.6
1989	2.2	20	0.63
1990	2.2	21	0.66
1992	2.1	22	0.69
1993	1.9	23	0.72
1994	1.8	24	0.75
1995	1.7	25	0.79
2001	1.1	26	0.81
2002	0.73	27	0.84
2003	0.6	28	0.87
2004	0.44	29	0.91

The 75% exceedence probability year, which is 1994 (see Table 1.26) has been adopted as the critical period to be sufficient to analyse the degree of reliability of flows for the proposed irrigation scheme.

2.4 SEDIMENT LOADS AND WATER QUALITY

2.4.1 Sediment Loads

Suspended sediment data from Station 14001 is obtained to see the sediment status of the weir site. Suspended concentration rates varying between 162 mg/l at a depth of 3.3 feet to 1740 mg/l at a depth of 9 feet were observed from Didessa River at station 114001. Relationships between water discharge and sediment loads at various sites in the region are presented in Table 1.27. At-site and regional approach has been used to estimate sediment rates from the estimated stream flows at the weir site. Accordingly, the following relationship has been derived:

Gs = 0.078*Q1.5

Where:

Gs = sediment load (in gm)
Q = monthly mean discharge (in l/s/km^2).

Careful assessment regarding reservoir sedimentation will be required in the site as the weir is dependant of the sedimentation situation. Accordingly, water diversion planning will include assessment of the probable rate of sedimentation. In estimating sedimentation, materials originating as bed load will be assumed to have a density of 1.4 gm/cc and material carried in suspension will be assumed to have a density of 1.2 gm/cc. The bed load at the weir sites would be assumed 15 percent of the suspended load. Monthly total sediment load (suspended and bed load), and accumulated total sediment load at the weir site are given on Tables 1.28 and 1.29 respectively.

Table 1.27: Relationships between water discharge and sediment load

No	Station	Area (km^2)	Module '000 t/yr	Loss t/km2/y	Values of C in: Qs =C x (Qw)1.5
114001	Didessa near Arjo	9,981	49,354	287	*0.14*
4005	Dabana near Abasina	2,881	453	157	0.059
4002	Anagar near Neqemte	4,674	702	150	0.061
6002	Abbay at Sudan Border	172,254	335,170	1,946	0.165
	Weir site	10,606	52,444	305	0.15

Table 1.28: Monthly Total Sediment Load at the Weir Site (in '000 m3)

	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Annual
Avg	3.79	2.05	1.76	2.63	6.95	41.90	201.7	382.7	327.7	185	29.71	10.58	1196
Std dev	1.71	1.01	1.11	1.72	4.2	17.6	62.72	98.19	92.6	99.01	14.7	4.95	304.5
CV	3.63	4.01	5.15	5.31	4.91	3.42	2.526	2.086	2.311	4.349	4.024	3.8	2.07
Skew	7.36	6.29	8.83	7.54	11.4	7.48	3.696	0.678	3.509	7.051	10.92	8.77	4.57

Table 1.29: Accumulated Total Sediment Load at the Weirsite (in MCM)

Ret.Per (Yrs)	Jan	Feb	Marc	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Annual
25	0.09	0.05	0.05	0.06	0.17	1.05	5.05	9.55	8.15	4.62	0.74	0.26	30.32
50	0.18	0.15	0.09	0.14	0.35	2.04	9.9	18.7	16.1	9.12	1.02	0.53	56.97
75	0.29	0.16	0.14	0.21	0.53	3.04	14.8	38.1	23.2	13.8	2.3	0.79	97.36
100	0.38	0.20	0.17	0.26	0.68	4.04	19.7	37.4	31.7	18.2	2.90	1.05	116.7

From the above table, it can be concluded that the total annual sediment concentration at the weir site is 1.197 million cubic meters, which is 113kg/km²/year. Out of the total annual sediment load, 15 percent is assumed as bed load, which is 17kg/km²/year the remaining 98kg/km²/year is the estimated of suspended load at the proposed weir site.

2.5 WATER QUALITY

The water quality status of the Didessa River is evaluated using the data collected from MoWR, Abbay River Basin Master Plan Study Report (1998). The samples were taken as part of the supporting measurement for the aquatic study, and appear to represent the only available data on water quality within the catchment. Table 30 shows water quality measurements taken for Didessa at two sites. The samples shown in this table were taken after the start of the rainy season and presumably, all tributaries of the river exhibited adequate water quality at the time of sampling. Total dissolved solids characterized mainly by major anions and cations are directly related to the electrical conductivity of the water. The low Electrical Conductivity (EC) and TDS value in general shows that the water is soft in nature and has low salinity. Moreover, the low conductivity is sign of low fertility of the water with regard to aquatic life. Electrical conductivity (EC) measurements were very low at all the sampled sites. EC is the ability of the water to conduct electric current and directly related to the amount of cations and anions in the water. The pH value is the measure of the concentration of hydrogen (H+) and hydroxyl (OH-) ions in the water. It is to determine the acidity or alkalinity of the substance. The Na+ and K+ reading expressed in terms of Sodium Adsorption Ratio (SAR) is the useful parameter for the evaluation of the water body for irrigation purpose.

For irrigation water, it is important to measure the sodium adsorption ratio as follows:-

$$SAR = \frac{Na^+}{[(Ca^{++} + Mg^{++}) / 2]^{0.5}}$$

The higher the SAR value of the water the less suitable will be for irrigation purposes. The maximum computed value among the readings is 0.29, which is less than 10. This illustrates that the water is very much suitable for irrigation purpose interms of SAR. The chloride concentration of the rivers stipulated in is very low (1.0 to 2.0 mg/l), at times of sampling. Hence, the parameter was in conformity with the standard set by EPA (250mg/l for aquatic species).

From the above description, it can be concluded that the Didessa River water is fit and can be used with out harm for irrigation in the Dinger Bereha project area.

Table 1.30: Water quality results for sites on the Didessa River

Sampling	Near Arjo bridge	at Gimbi bridge	Comment
Sample date	13/08/96	14/08/96	
Elevation (m asl)	1300	1200	
TDS (gm/l)	20	20	N
EC (□s/cm)	60	50	N
PH	6.74	6.97	N
Na++	3.3	3.0	N
K+	1.9	2.5	N
Ca++ (mg/l)	6.4	9.6	N
Mg++ (mg/l)	2.43	1.4	N
Cl- (mg/l)	1.0	2.0	N
SAR	0.29	0.25	N

Source: Water Quality Result for Major Rivers (BCEOM, 1996, Cited By BCEOM Abbay River Basin Study, 1998)

2.6 WATER AVAILABILITY IN THE PROJECT AREA

Since the Didessa River is gauged at the station near Arjo Bridge and has more than 30 years of recorded flow data, the availability of surface water at the proposed weir site is assessed and analyzed. The frequency analysis of the mean monthly flow of the Didessa River at the proposed weir site is performed and presented in table 1.32 below.

Table 1.31: Monthly Dependable flows (MCM) at the Weir Site

	Jan	Feb	Mar	Mar	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Total
50% Dep.	38.2	20.3	18.3	16.5	38.6	170.3	568.4	836.4	827.3	355.5	127.6	76.7	3,592
75% Dep.	31.7	16.04	13.9	13.7	36.6	133.2	466.7	652.2	630.7	291.6	112.4	62.7	2,738
80% Dep.	28.2	15.04	13.6	12.3	28.9	127.1	424	624	617.2	265.2	95.8	67.7	2,650
85% Dep.	27.6	14.7	13.3	11.9	28	123.3	411.3	605.3	598.7	257.2	92.3	65.7	2,591
90% Dep.	27.1	14.4	13	11.7	27.4	120.8	403.1	593.2	586.7	252.1	90.5	54.4	2,556

In the project area, the dry season starts in the month of November and extends up to the end of May and the available dependable monthly flow is given in Table 1.32 below.

Table 1.32: Dry Season Available Dependable Flow (MCM)

	Jan	Feb	Mar	Mar	May	Nov	Dec	Total	% to the Annual
50% Dep.	38.2	20.3	18.3	16.5	38.6	127.6	76.7	336.2	9.4 %
75% Dep.	31.7	16.04	13.9	13.7	36.6	112.4	62.7	287.1	10.5 %
80% Dep.	28.2	15.04	13.6	12.3	28.9	95.8	67.7	261.5	10 %
85% Dep.	27.6	14.7	13.3	11.9	28	92.3	65.7	253.5	9.8 %
90% Dep.	27.1	14.4	13	11.7	27.4	90.5	54.4	238.5	9.3 %

Table 1.33: Probability of the Mean Flow at the Weir Site

Rank	Flow (m3/s)	Year	R. P.	Prob.(%)
1	6,860	1961	55.33	2.9
2	5,541	1964	20.75	5.8
3	4,939	1970	12.77	8.7
4	4,878	1966	9.22	11.6
5	4,719	1974	7.22	14.5
6	4,612	2001	5.93	17.4
7	4,530	1973	5.03	20.3
8	4,357	1971	4.37	23.2
9	4,295	1963	3.86	26.1
10	4,265	1969	3.46	29
11	4,236	1965	3.13	31.9
12	4,216	1967	2.86	34.8
13	4,097	1978	2.63	37.7
14	4,093	1983	2.44	40.6
15	4,026	1962	2.27	43.5
16	3,790	1988	2.13	46.4
17	3,613	1993	2	49.3
18	3,526	1989	1.89	52.2
19	3,408	1972	1.78	55.1
20	3,358	1996	1.69	58
21	3,271	1994	1.61	60.9
22	3,264	1985	1.54	63.8
23	2,980	2004	1.47	66.7
24	2,938	1992	1.41	69.6
25	2,778	1984	1.35	72.5
26	2,741	1987	1.3	75.4
27	2,678	2003	1.25	78.3
28	2,629	1982	1.2	81.2
29	2,603	1979	1.16	84.1
30	2,565	1990	1.12	87
31	2,559	2002	1.08	89.9
32	2,460	1986	1.05	92.8
33	1,721	1995	1.02	97.7

2.7 Peak Flows from the Sub Catchments in and near the Project area

2.7.1 General

In the hydrologic analysis, for dams, weirs, bridges and drainage structures, it must be recognized that there are many variable factors that affect floods. Some of the factors that need to be considered to an individual site-by-site basis are:

- rainfall amount and storm distribution;

- catchments area size, shape and orientation;
- ground cover;
- type of soil;
- slopes of terrain and stream;
- antecedent moisture condition;
- storage potential (overbank, ponds, wetlands, reservoirs, channel, etc.);
- Catchments area.

In general, three types of estimation of floods magnitudes; namely the Rational Method, SCS method and Transferring Gauged Data method can be applied for the project area. These methods are described as follows.

2.7.2 Rational Method

The Rational Method can be applied to small catchments if they do not exceed 12.8 km2 (or 5 square mile) at the most (Gray, 1971). The consequences of applying the Rational Method to larger catchments is to produce an over estimate of discharge and a conservative design. The method is nevertheless frequently used in standard or modified form for much larger catchments. This is because of its relatively simplicity. The vast majority of catchments producing floods imposed on the command drainage system lie within the validity of the Rational Method and it has been used as the principal method of estimating design discharges of dykes, culverts, drainage channels and any other cross drainage works.

The Rational Method is based on the following formula:

$$Qm = 0.2778 \times C \times I \times A \times Fr$$

Where:

Qm = peak flow corresponding to return period of T years in m^3/sec;
C = a 'runoff' coefficient expressing the ratio of rate of runoff to rate of rainfall;
I = average maximum intensity of rainfall in mm/hr, for a duration equal to the time of concentration;

A = drainage area in km^2;

Fr = is the areal reduction factor (this factors improves the catchment limitations imposed on the use of rational method).

Coefficient of runoff C is given by many soil and water conservation texts. Information on rainfall intensity I in a time of concentration (time period required for flow to reach the outlet from the most remote point in the catchment) is required and can be estimated by the following formula. The selection of the correct value of ‘C’ presents some difficulty. It represents a parameter that can influence runoff including: soils type, antecedent soil conditions, land use, vegetation and seasonal growth. Therefore, the value of ‘C’ can vary from one moment to another according to changes, especially soil moisture conditions.

2.7.3 Time of Concentration

The time of concentration is calculated according the Kirpich equation

$$Tc = (1/3{,}080) \times L1 \times 155 \times H^{-0.385}$$

Where:

Tc = time of concentration (in hours),
L = maximum length of main stream (in meters),
H = elevation difference of upper and outlet of catchment, (in meters).

The area reduction factor (Fr) is introduced to account for the spatial variability of point rainfall over the catchment. This is not significant for small catchments but becomes so as catchment size increases. The relationship adopted for 'Fr' is based on that developed for the East African condition (Fiddes, 1997). The relationship can be expressed as:

$Fr = 1 - 0.02\ D^{-0.33}\ A^{0.50}$

Where:

D = duration in hours;
A = drainage area in km^2;

This equation applies for storms of up to 8 hours duration. For longer durations on large catchments the value of D can be taken as 8 for use in the above formula.

2.7.4 SCS Method

A relationship between accumulated rainfall and accumulated runoff is derived by SCS (Soil Conservation Service). The SCS runoff equation is therefore a method of estimating direct runoff from 24-hour or 1-day storm rainfall.

The equation is:

$Q = (P - Ia)\ 2 / (P - Ia) + S$

Where:

Q = accumulated direct runoff, (mm)
P = accumulated rainfall (potential maximum runoff), (mm)
Ia = initial abstraction including surface storage, inception, and infiltration prior to runoff, (mm)

S = potential maximum retention, mm

The relationship between Ia and S was developed from experimental catchment area data. It removes the necessity for estimating Ia for common usage. The empirical relationship used in the SCS runoff equation is:

$Ia = 0.2 \times S$

$Q = (P - 0.2S)^{2} / (P+0.8S)$

S is related to soil and cover conditions of the catchment area through CN. CN has a range of 0 to 100 and S is related to CN by:

$S = 254 \times [(100/CN) - 1]$

Conversion from average antecedent moisture conditions to wet conditions can be done by multiplying the average CN values by Cf [where Cf = (CN/100)-0.4].

2.7.5 Transferring Gauged Data

Gauged data may be transferred to an un-gauged site of interest provided such data are nearby (i.e., within the same hydrologic region, and there are no major tributaries or diversions between the gage and the site of interest). These procedures make use of the constants obtained in developing the regression equations. These procedures are adopted from the work of Admasu (1989) as follows:

$Qu = Qg \times (Au/Ag)^{0.70}$

where:

Qu = mean annual daily maximum flow at ungauged site (m^3/s),
Qg = mean annual daily maximum flow at nearby gauged site (m^3/s),
Au = ungauged site catchment area (km^2),
Ag = gauged site catchment area (km^2),

The estimate daily (or the 24-hr) annual maximum flood could be converted into a momentary peak as:

$Qp = Cf \times Qu$

Here, Cf is a factor estimated as Cf = 1 + 0.5/Tc where Tc is time of concentration.

2.7.6 Estimation of Weighted Average

In general, the rational method, SCS method and Transferring Gauged Data are recommended for relatively small, medium and large catchments respectively. However, it is very important to establish a smooth pattern of transition from small to medium and from medium to large catchments. Accordingly, the recommended weighted average estimate of peak flood can be given as:

$Qw = W1 \times Q1 + W2 \times Q2 + W3 \times Q3$

where:

Q1, Q2, and Q3 are mean annual momentary peaks estimated by Rational, SCS and Transferring Gauged Data methods, respectively
W1, W2 and W3 are weighing factors of mean momentary peak estimates by Rational, SCS and Transferring Gauged Data methods, respectively, and
$W1 = 12.5/(12.5+Au)$
$W2 = 1 - (W1 + W3)$
$W3 = (Au/Ag)^{0.70}$
Where Ag and Au are gauged and un-gauged site catchment areas, respectively.

Since the Dinger Bereha sub-catchments (the Project Area) is hydrologically similar and also directly draining to the gauged Didessa River, then the peak flow of the Didessa River can be transposed to the command project area and is fairly estimated by the method of the analyzed gauged data to that of ungauged ones.. Therefore:

$Qu = Qg \times (Au/Ag)^{0.70}$

Where:

Qu = mean annual daily maximum flow at un-gauged sub-catchments (m^3/s),
Qg = mean annual daily maximum flow at nearby weir site (m^3/s),
Au = Area of un-gauged sub-catchments (km^2),
Ag = 10,606 km^2 = Area of gauged weir site (km^2),

The peak daily maximum flow at the proposed weir site at different return periods (section 2.3.1) are given as below:

25 years = 1,083 m^3/s
50 years = 1,143 m^3/s
75 years = 1,187 m^3/s
100 years = 1,192 m^3/s
1000 years = 1,335 m^3/s

Based on "Transposing Gauged Data" method, the peak flow the individual sub-catchments of the Project area at different return periods are tabulated in Appendix A.

2.7.7 Conclusions regarding peakflows for cross drainage structures

In general, the command area peak flow (QP) at different return periods can be generalized as peak flow per area, so that in case there is a change in the locations of cross drainage works, easily the peak flow can be determined. Then, command area peak flow QP at different return periods are:

Qp at 25 year return period = 0.28 $m^3/s/km^2$
Qp at 50 years return period = 0.3 $m^3/s/km^2$
Qp at 75 years return period = 0.315 $m^3/s/km^2$
Qp at 100 years return period = 0.32 $m^3/s/km^2$

The calculation of weighted average using the rational, SCS and transferring data from gauged catchments is not a considered to be a good practice, since the rational and SCS methods are much more precise than the method involving the transfer of a very large catchment to very small catchment. There, the peak flows as calculated in Appendix B have been retained for dimensioning the cross drainage structures.

3. GROUNDWATER RESOURCES

3.1 Introduction

3.1.1 Scope of Work Stipulated in the TOR

The scope of work in the hydrogeological study includes:

- Data Collection (Location and characteristics of water wells and springs; hydrogeological condition of the project area);
- Estimation of quantities of groundwater that can be made available through wells;
- Determination of quality of groundwater; and
- Estimation of quantities of water actually available for irrigation

3.1.2 Method of Approach

Relevant data from previous works were collected and analyzed and further geological and hydro-geological field survey was conducted. Details of methods applied, documents and maps used to undertake the assessment of groundwater source potential were as follows:

1) Topographic maps at a scale of 1:50,000 are used to review the relief of the area and used as a base map

2) The 1:2,000,000 geological and hydrogeological maps of Ethiopia was collected and used for the identification of major structures and geological units

3) Regional geological and hydrogeological maps and reports were collected and reviewed to understand the regional geology

4) National reports on water resources and hydro meteorological were collected and studied for recharge potentials to groundwater.

5) Existing water well data were collected and studied for general overview of their status, the drilling depth, water quality, water table, yield and other aquifer parameters.

6) Hydrogeological field assessment was conducted to understand the hydrogeological configuration and groundwater resources of the area.

7) Analyses and interpretation of the geological, hydrogeological, well data available was conducted to assess the general groundwater potential.

The major assessment in the hydrogeological investigation includes the nature of the aquifer material, formation type, weathering and fracturing condition, geological structures such as faults, joints, bedding planes and other features which have impact on the storage and movement of groundwater, drainage system and geomorphology.

3.1.3 Review of previous work

A number of regional works have been undertaken in the assessment of the geological history of the country in general and Abbay Basin in particular. Most of the studies are however at regional and reconnaissance level regarding the project areas under consideration. The relevant documents available at regional level with respect to geology and hydrogeology considerations of the proposed project sites are the following:

- Land and Water Resources for the Blue Nile Basin, USBR 1964;
- Preliminary Water Resources Development Master Plan for Ethiopia, WAPCOS 1990;
- Abbay River Basin Integrated Development Master Plan Project, BCEOM 1998; and
- Geological Map of Ethiopia, EIGS 1996
- Hydrogeological map of Ethiopia, EIGS 1987

USBR's study identified and suggested a number of dam sites but made detailed assessment on upper Didessa River and designated. Moreover, the study made assessment for potential dam sites at about 4 km upstream of Didessa-Wama junction and designated it as Dula dam site, DD-13. The report further mentioned another potential dam site close to the Didessa-Wama junction. According to USBR, the main stream Didessa flows on volcanic rocks from the headwaters to the approximate area of Didessa-Wama junction to the bend where the river turns to the northwest and then entrenched in metamorphic rocks to the rest of the way to the Blue Nile. Another regional study at the area is the one undertaken by WAPCOS. WAPCOS proposed a number of hydropower sites on Didessa River and its tributaries in its report and made general assessment of the geology of the Didessa River. According to WAPCOS, the flow of the river in the NNW direction is controlled by faults. In the higher reaches, the bedrock constituting the valley is older volcanics of Tertiary age up to latitude 8029' and thereafter, Precambrian group of rocks. BCEOM is the third important study in the basin. BCEOM reviewed the studies by USBR 1964. The work of EIGS group is regional, describing geological and hydrogeological setup of the country. The report accompanying the hydro geological and Geological maps did mot give any special emphasis to the proposed sites.

3.2 GENERAL GEOLOGY OF THE BASIN

3.2.1 General

The geology of the valley is mapped as metamorphic rock in the Geological Map of Ethiopia, 1996 by EIGS. However, field observation and regional correlation shows that apart from the metamorphic rock, volcanic rocks have also covered the project area. Accordingly, from field observation and correlation with the geological map of Ethiopia the regional geology of the area under consideration is briefly described in the following paragraphs.

3.2.2 Metamorphic Rock

Field observation of the metamorphic rock was made along the road from Bedele to Arjo and towards the weir site through the dry weather road.

According to the geological map of Ethiopia by Tefera etal, 1996, the metamorphic rock of the project area is the Alghe Group. This group of rock consists of grey gneiss with variable colour index showing development of layering. Much of this unit is relatively uniform and poorly layered orthogenesis, representing deformed and metamorphosed plutonic rocks of diorite and quartz diorite and tonolitic composition.

3.2.3 Tertiary Volcanic rocks

3.2.3.1 Jimma Volcanics

As cited in the explanation bulletin of Geological map of Ethiopia, 1996, the volcanic rocks are analogous to the Main Volcanic Sequence of Davidson 1983. They form a thick succession of basalts and felsic rocks with basalts dominating the lower part of the volcanic. Davidson has reported K/Ar age of 42.7 to 30.5 Ma for the Jimma volcanics. These rocks outcrop in the upstream areas

3.2.3.2 Mekonen Basalt

These are thick sub-horizontal flood basalts mapped by Davidson 1983. The Mekonen basalt mostly directly overly the basement complex in the southwestern plateau and are dated K/Ar age of 34.8 to 23.1 Ma (late Oligocene-early Miocene). The Mekonen Basalts are considered analogous to the Wolega Basalts, which are outcropping in Wolega area.

3.2.4 Quaternary Plateau Basalts

These basalts outcrop at localized spots in the valley floor of the upper Didessa, mainly in the command and reservoir sites areas of the Arjo-Didessa Irrigation Project. They are strongly fractured and weathered. These Quaternary alkaline basalts and trachytes were erupted along pre-existing structures. The area is characterized by NE-SW trending major lineaments which is observable on the satellite imagery. The eruption of these localized alkaline basalts and trachytes is expected to be through these major fissure directions. The rocks are believed to be Pleistocene in age.

3.3 GEOMORPHOLOGY AND GEOLOGY OF THE DINGER BEREHA AREA

3.3.1 Location

Dinger Bereha Irrigation Project Site is located in Didessa valley in Oromia Regional State, Illubabor zone. The centre of the project currently named Ilu Harar (Gudiru or Chewaka) town is 60 km NNW of Bedele Town.

3.3.2 Geomorphology and Drainage

The command area is characterised by undulating landform. Quite a number of streams which are tributaries of Didessa River dissect the area. The average elevation of the site is about 1248 m. The elevation ranges from about 1100 m to 1260 m at the valley floor and is as high as 1990 m in the surrounding highlands. The general geomorphology is depicted in Figure 3.1.

Among the many intermittent and perennial streams include like Boro, Mimite and Guracha which are flowing to Dabana and Didessa Rivers. In addition to these there are many incised streams that dissect most of the command areas. The major rivers draining the area are depicted in Figure 3.1.

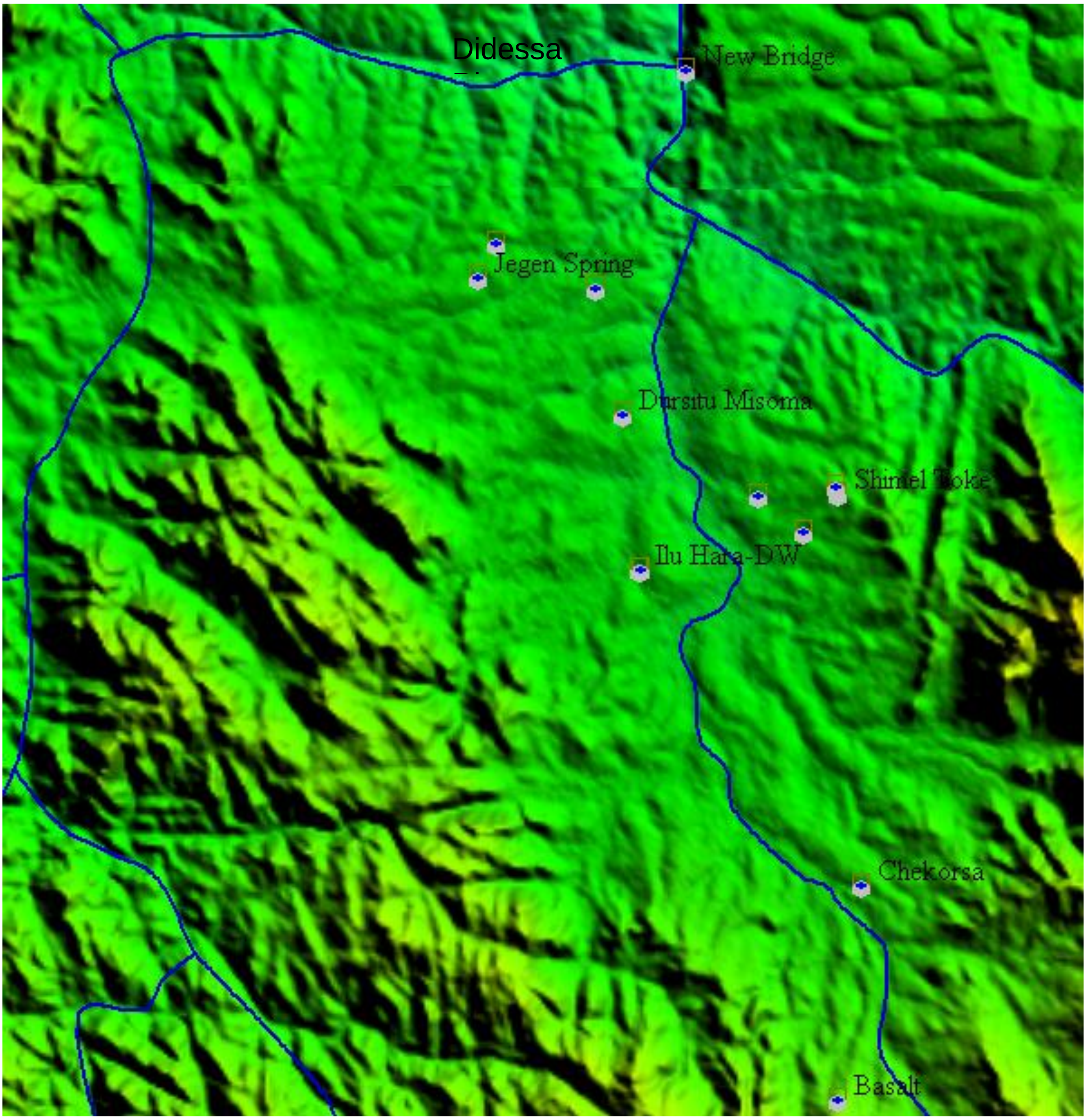


Figure 3.1: Geomorphology and Drainage map

3.3.3 Geology

Regionally the project area can be characterised by metamorphic rock basement overlain by different volcanic flows and basaltic dikes through the regional faults on the metamorphic basement and localised fissures for recent alkaline dikes. According to the field observation the geology of the project area can be described by crystalline rocks (igneous and metamorphic), which are covered by alluvial and colluvial deposits, residual soils and flood plain deposits. The upstream side of the command area is covered by both volcanic at the top and metamorphic rock at the bottom while the downstream area of the command area is covered by metamorphic rock under the soil cover. Volcanic rocks cover the abutment of the Didessa valley while going close to the valley bottom the metamorphic rock is outcropping. The escarpments of the valley are covered with Makonen basalt. The major volcanic piles are cropping out at the escarpments and observable on the plateau and escarpments of the Didessa valley. The geological map of the area is depicted in Figure 3.2. Therefore, the general stratigraphy of the valley can be summarized as follows:

- Colluvial-Alluvial sediments
- Residual soils
- Basalts
- Metamorphic rock/Alghe Group

3.3.3.1 Alluvial deposits

These deposits have been transported long with the help of water forces. The soils are deposited along the riverbank and are about 2 to 3 m thick in the command area. The soil is loose, brownish to reddish in colour composed predominantly of fine sand and silt with gravel and clay. The clayey silt soil predominates in the depressions and flat areas where springs appear and marshy nature of the area is revealed for some time after the rainy season.

3.3.3.2 Colluvial soils

These soils are with minor transportation from their place of formation. The slight movement across the slope is due to gravity. Colluvial soils are available at slopes and at the foothills. The soils are mixed ranging in grain size from clayey to boulders with no stratification or horizons.

3.3.3.3 Residual soils

They are soils developed insitu by the decomposition of rocks on which it lies. The residual soils identified in the field are associated with the decomposition of rocks. These soils cover gently sloping areas where recent settlements/villages are established. The soils at the site are mixed with some gravely, pebbly residues at the contact with country rock.

3.3.3.4 Basalts and Metamorphic rocks

The basaltic rock covers the upland areas mainly above 1,400 m elevation. It is observable on the way from Kone to Chekorsa. The metamorphic rock outcrops in river course and cover the lowland area under the veneer soil cover. The generalised geology of the project area is shown in Figure 3.2.

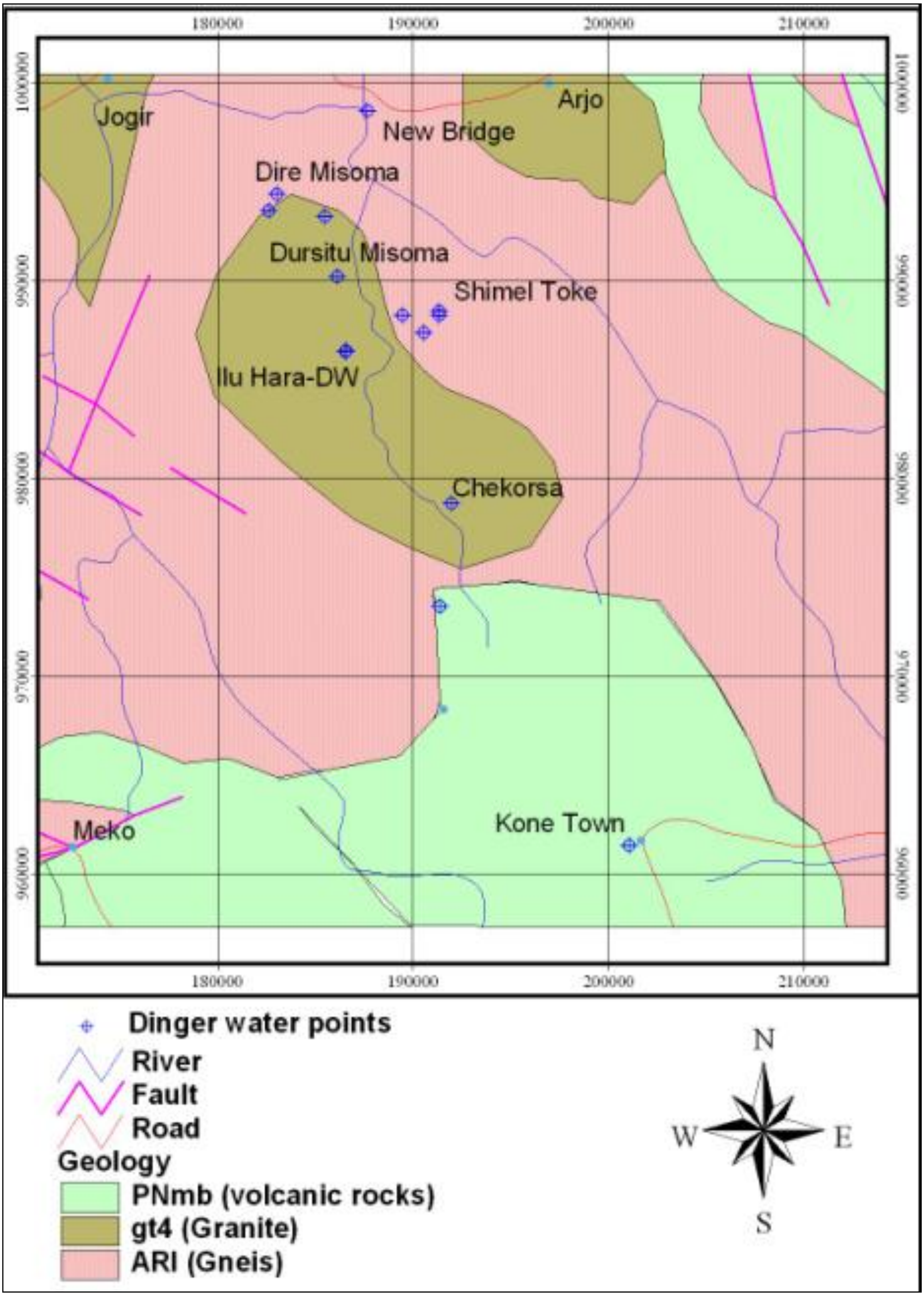


Figure 3.2: Geological map of Dinger Bereha

3.4 HYDROGEOLOGY

3.4.1 General

The hydrogeology of an area depends necessarily on the geomorphology and geological setups in addition to the hydro-metrology. The geomorphology of the area as depicted above is characterized by northerly inclining landform and the geology is typical of crystalline rock terrain where no stratification is observable rather undulation predominates. The recharge and discharge relationship partly depends on the geomorphology and geology. Granites and gneisses have groundwater accumulation potential in their weathered zone. For the weathering zone to develop and be potential storage and transmission zone for groundwater, the geometry of the land is also critically important. Besides, the composition of the metamorphic rock is also another important factor in the formation of aquifers in their weathered upper zone.

Considering the geometry of the land in Dinger Bereha and analyzing the existing data on groundwater, the groundwater potential for rural water supply source is grouped into three forms, namely:

1. High potential area, which includes depressions, the stream banks on different parts of the project area
2. Moderate potential area which includes the rugged terrain and inter-hill valleys and riverbanks
3. Low potential area which encompasses the mountain and rugged terrain areas

It is noted that the flat and depression areas have relatively thicker saprolite zones than the rugged terrain areas. The localized riverbank and inter-hill valley deposits are also considered to have high deposition of granular material, which can serve as localized groundwater storage and transmission reservoirs. The lower part of the saprolite/weathered zone forms the primary water bearing strata and groundwater storage.

3.4.2 Aquifer Systems

In Dinger Bereha area, there are three main aquifer systems. These aquifers are:

1. Alluvial-colluvial sediments aquifers, which are localized to river valleys and depressions
2. Volcanic aquifers
3. Saprolith zone of the metamorphic rock

The Alluvial-colluvial and metamorphic aquifers are usually localised systems while the volcanic aquifers are regional. However, the volcanic aquifers occur mainly in the highlands outside the project area under consideration.

3.4.3 Groundwater Occurrence in Dinger Bereha Project Site

Groundwater in the project area occurs in water table and semi confined aquifer system. Because of thin clay inter-layering in the alluvial deposits and clay overburdens over the saprolite zone in the depression areas, the groundwater storage in most of the plateau areas appear in semi-confined conditions and at places where there is no soil cover on the saprolite zone and in the marshes it appears as water table aquifer.

Generally, the aquifer system is associated with two major units, which are expected to store exploitable amount of groundwater in the command area of the project site. These are:

- The weathered and fractured basement: The weathered and fractured top zone of a basement rock like gneiss available in the area can often have good water bearing and transmitting capacity. This type of formation characterizes the flat and depression areas.

- The localized alluvial and colluvial sediments near the riverbanks and inter-hill valleys: These sediments are loose and composed mainly of sands, gravel, silts and clays that they store subsurface water in their primary openings. These sediments are much localized to the river valleys and inter-hill valleys.

Therefore, the major rock units that are expected to store adequate volume of potable water for the purpose of rural water supply in the project area, the saprolite and fractured zone and alluvial deposits along major river valleys and inter hill areas serve as sources. Generally, it is noted that the saprolite and fractured zone at Dinger area is well developed. The possibility of finding adequate amount of potable subsurface water storage within the weathered basement is high. Moreover, due to the presence of alluvial and colluvial deposits on river valleys and inter-hill valleys, subsurface storage of water for rural water supply is possible in most places of the project area.

3.4.4 Existing Groundwater Development Situation in the area

The Dinger Bereha area is a recently developed area for settlers from Hararghe zone of Oromia Regional State. The main water supply source of the villages is groundwater in the form of springs, shallow-drilled wells, deep-drilled wells, hand dug wells. According to the data from Woreda water office, 91 springs, 13 shallow wells, one deep well and 2 hand dug wells are developed in the 23 Kebeles of the project area. However, the data does not contain details on the well and aquifer parameters. Rural water supply per capita in Ethiopia is assumed to be 25 l/s and the service population of each rural water supply scheme is as shown in Table 3.1. Assuming that all the schemes are functioning and all the population designed for the schemes uses these schemes, the annual groundwater abstraction/consumption is estimated to be 30,112 m3. This value is very small as compared to the anticipated annual recharge in the area.

3.4.5 Recharge-Discharge

The knowledge of groundwater replenishment is very important in the planning of groundwater development. The recharge potential of groundwater can be estimated by different methods, which includes hydrograph analysis (base flow separation), groundwater table fluctuation, groundwater flow (Darcy approach) and catchment water balance. As the area is newly developed for settlement from drought affected areas in the country, no well establish groundwater data is available for determining groundwater table fluctuation. The minimum flow which will be taken as base flow of Didesa at the Bridge and the water balance estimates of recharge from previous studies and groundwater flow (Darcy approach) are adopted in this study for the approximation of recharge in the command area. Recharge in the area is mainly from direct infiltration of part of the water from precipitation. Infiltration occurs mainly through the sandy clay overburden, at the foothills of mountains and hills through exposed fractures, broken quartz and pegmatite veins. There is also possibility for local aquifer to be recharged from rivers, streams and marshes. The estimates of recharge made during the hydrogeological study of Arjo-Dedesa Irrigation Project work by Water Works Design and Supervision Enterprise, 2007 is about 17 % of the annual precipitation. Arjo-Dedesa Irigation project site is just upstream of Dinger Bereha specifically located on the eastern (upstream) side of the Bedele-Arjo main road. The recharge estimated for this project area quantitatively was **246.99** mm. The same percentage of annual precipitation to infiltration is taken for Dinger Bereha as similar climatological and physiographic setup prevails in Dinger too. According to the metrological data at Didessa Bridge, the annual precipitation for the period 1963-2008 is 1505 mm (from hydrology report). Therefore, the annual recharge to groundwater is **255.85** mm.

Table 3.1 : Water Supply Schemes in the command area of Dinger Bereha Irrigation Project

No	Kebele	Spring	Hand Dug Wells	Shallow Wells	Deep Wells
1	Dabana	4		1	
2	Ada Kebena		1	2	
3	Jiru Bedena	2	1		
4	Sere Gudo	4			
5	Burka Anani	3			
6	Dire Misoma	2		2	
7	Woltasis	4		1	
8	Dursitu Misoma	4		1	
9	Haro Chewaka	4		1	
10	Arjo Oromia	5		1	
11	Chefe Megertu	4		1	
12	Biftu Ayana	3		1	
13	Burka Berisa	3			
14	Demiksa	6			
15	Ilu Harar/Godure	6		1	1
16	Shimel Toki	6			
17	Duki	5			
18	Tokuma Harar	5			
19	Terkenfeta Misoma	2		1	
20	Boha Biftu	6			
21	Boneya	4			
22	Kenini Denta	5			
23	Chamen	4			
	Total	**91**	**2**	**13**	**1**

Table 3.2: Technologies, Design population and possible annual consumption of Rural Water Supply Schemes in the command area of Dinger Bereha Irrigation Project

No	Scheme	Design population	Annual consumption
1	Hand-dug Wells + HP	500	4,562.50
2	Spring Development on spot	800	7,300.00
3	Shallow Wells	800	7,300.00
4	Deep Wells	1200	10,950.00
	Sum	**3,300**	**30,112.50**

It is however to be noted that the metamorphic aquifer system is not regional.

The potential groundwater storage and movement is believed to be in the alluvial sediments and saprolith zone. Major groundwater out flow out of the area is westwards. Darcy Approach considers groundwater flux through a flow width perpendicular to the general gradient of groundwater flow. There is a single deep well at Chewaka town (Ilu Harar) where pump testing is conducted to determine hydraulic parameters. According to the well completion report of this well, the aquifer has transmissivity value of 40 m^2/day. The annual flux/discharge from in the northerly direction from Chewaka can be estimated using Darcy's Approach applying the following formula:

$$Q = 365 \times T \times I \times B$$

Where Q, T, B and I denote discharge (m^3/year), Transmisivity (m^2/day), hydraulic gradient (-) and groundwater flow channel width (m).

From the general geomorphology the average gradient of the ground surface is determined to be about 2%. The gradient of the water table is assumed to take the gradient of the ground surface. Using these hydraulic values the Darcy recharge/discharge in 1 km width is estimated to be 292 mm if constant flow is to be assumed for the whole project area. This estimation is only to give general impression. Exact evaluation of the annual recharge requires delineation of specific wellfields as it is well mentioned in the previous section that the aquifer system in the project area is more of localized system.

3.4.6 Ground Water Quality

3.4.6.1 Drinking Water Quality

At the area there are no many water supply schemes which have water quality test data. The physico-chemical data of 3 well samples was collected from the IIubabore Zone Water Office. The three (Ilu Harar, Urji and Dabana wells) water quality data analysis showed slight differences from one another (see Table 3.3). The water sample from Ilu Harar, Urji and Dabana are classified as Ca-HCO3, Ca-Na-HCO3 and Mg-Na-HCO3 type, respectively. The ranges of values of water quality data are compared with WHO and Ethiopian Drinking Water Standards. Generally, the groundwater quality in Dinger Bereha is within acceptable limits compared to these drinking water quality standards. The comparison of concentration values of chemicals and other physical parameters for ground water in Dinger Bereha are shown in Table 3.4.

Table 3.3: Water quality data of three wells in Dinger Bereha area

CLIENTS ID NO.	Ilu Harar	Urjii	Daabana
SOURCE OF SAMPLE	Well	Well	Well
LOCATION	ILUHARAR	URJI	DABANA
DATE RECEIVED	31/05/06	26/03/08	26/03/08
LAB. ID NO.	926/98	1509/2000	1511/2000
Turbidity (NTU)	5	18	5
Total Solids 1050C (mg/l)	292	324	162
T.Dissolved Solid 1050C (mg/l)	280	292	150
Electrical Conductivity (us/cm	428	442	229
PH	6.97	7.44	6.83
Ammonia (mg/l NH3	0.26	0.23	0.13
Sodium (mg/l Na)	19.5	30	13.5
Potassium (mg/l K)	4.9	4.4	2.8
Total Hardness (mg/l Ca CO3)	202.4	195.3	105
Calcium (mg/l Ca)	58.7	62.16	4.2
Magnesium (mg/l Mg)	10.04	9.69	22.95
Total Iron (mg/l Fe)	0.43	0.14	0.32
Manganese (mg/l Mn)	0.15	0.1	0.1
Fluoride (mg/l F)	0.4	1.2	0.62
Chloride (mg/l Cl)	1.9	4.97	2.98
Nitrite (mg/l NO2)		0.02	0.015
Nitrate (mg/l NO3)	0.19	5.78	6.12
Alkalinity (mg/l CaCO3)	232.5	224	122
Carbonate (mg/l CO3)	Trace	Trace	Trace
Bicarbonate (mg/l HCO3)	283.6	273.28	148.84
Sulphate (mg/l SO4)	6.1	23.3	1.52
Phosphate (mg/l PO4)	0.346	0.2	0.33

Table 3.4: Comparison of water quality data of three wells in Dinger Bereha with WHO, European and Ethiopian Standards

Variable	WHO(1984)	European Union	Ethiopian (2002)	Dinger Bereha wells
Colour (TCU)	15	20	50	
TDS (mg/l)	1000		1500	150 -292
Turbidity (NTU)	5	4	25	5 - 18
pH	<8.0	6.5-8.5	7-8.5	6.8 – 7.4
Ammonia			0.1	0.13 -0.26
Nitrate	50	50	50	0.19 – 6.12
Phosphorus		5		
Sodium	200	500		13.5 – 30
Chloride	250	25	600	1.9 – 4.9
Sulfate	400		483	1.52 – 23.3
Fluoride	1.5	1.5	1.5	0.4 – 1.2
Arsenic	0.01	0.05	0.05	

Variable	WHO(1984)	European Union	Ethiopian (2002)	Dinger Bereha wells
Cadmium	0.003	0.005	0.01	
Chromium	0.05	0.05	0.05	
Copper	2	0.1-3.0	1.5	
Iron	0.3	0.2	1	0.14 - 0.43
Lead	0.01	0.05	0.1	
Manganese	0.5	0.05	0.5	0.1 - 0.15
Mercury	0.001	0.001	0.001	
Nickel	0.02	0.05		
Zinc	3	0.01-5.0	15	

3.4.7 Water Quality for Irrigation

3.4.7.1 General

Irrigation water criteria are dependent on the types of plants, amount of irrigation water used, soil and climate. Clayey soil will cause most difficulty with water quality because drainage is poor and the opportunity for leaching of excess salts is thereby lessened. If plants are struggling against adverse conditions, they will be susceptible to injury by poor irrigation water. Also, plants in a hot dry climate will abstract more moisture and thereby concentrate dissolved solids in the soil moisture faster than in a cool, moist climate (Devis & De Wiest, 1991).

3.4.7.2 Classification of Irrigation Water Quality

The most damaging effects of poor-quality irrigation water are excessive accumulation of soluble salts and/or sodium in soil. The salinity hazard can be estimated by measuring the electrical conductivity (EC) directly or the Total Dissolved Solid (TDS). According to Wilcox 1955, EC (µS/cm) values less than250, 250-750, 750-2,250 and greater than 2,250 are categorized as low, medium, high and very high salinity hazard respectively.

Beside the potential dangers from high salinity, sodium hazard sometime exists. The two principal effect of sodium are a reduction in soil permeability and a hardening of the soil. Both effects are caused by the replacement of calcium and magnesium ions by sodium ions on the soil clays and colloids. The extent of this replacement can be estimated by sodium adsorption ratio (SAR) which is expressed by the following formula:

$$SAR = \frac{Na_{meq/l}}{\sqrt{\frac{Ca_{meq/l} + Mg_{meq/l}}{2}}}$$

The SAR values 0-10, 10-18 and 18-26 and >26 represent low, medium, high and very high sodium hazard, respectively, Wilcox 1955 in Driscoll (1991). The SAR values determined from the existing data are tabulated in Table 4-6. The SAR values of these three samples in Dinger Bereha show low hazard.

Table 3.5 : Summary of SAR values for the three wells in Dinger Bereha

Parameter	Station Code	pH	TDS	El. Conductivity	SAR
Unit			Mg/l	uS/cm	meq/l
1	Well1	6.97	280	428	0.62
2	Well3	6.83	150	229	0.57
3	Well2	7.44	292	442	0.93

Further, the 3 wells water quality data collected from Ilubabor Zone water Office are plotted on Wilcox Diagram for the classification of irrigation waters (Figure 3.3). The diagram shows that Dabana well (Well 3) water sample analysis lie in the C1-S1 Type in the 16 classifications of irrigation water based on SAR and sodium hazard and those from Ilu Harar and Urji Oromiya lie in C2-S1. C2 (medium salinity) means the water can be used in moderate amount of leaching areas and plants with moderate salt tolerance and can be grown in most cases without special practices for salinity control. Moreover, S1 (Low-sodium water) can be used with little danger on nearly all soils and sodium-sensitive crops.

3.5 Groundwater Potential for Future Use

3.5.1 Water Well

There are a number of drilled shallow and hand dug wells for community water supply source. The aquifer system in such metamorphic rocks is dependent on fracturing and mainly weathering and development of saprolite zone which is usually localized. It is the weathering of the basement complex in its upper part that can be potential storage zone for groundwater. Crystalline rocks when weathered can give different types of products depending on the extent and type of weathering. Common weathering products and their water bearing capacity of some of the crystalline rocks, which are typical in Dinger Bereha, are shown in Table 3.6. The texture of the weathered zone of the basement complex depends very largely on the parent rock composition and the crystal type and size. The weathered basement can be broadly considered as one aquifer regardless of parent lithology as the final weathering products for gneissic and granite is always clay minerals with residual quartz fragments. The lateral extent, depth and weathering products in the saprolite zone determine the storage and movement of groundwater. In the particular area under consideration, the aquifer is found to be localized in different pocket weathered zones. This means that as such no high quantity of groundwater to be abstracted using wells for irrigation. For very small irrigation schemes at house hold level it may be thinkable to use hand pumps to irrigate horticultures. The quantity of water is not so promising to install motorized system for augmenting the surface water irrigation intended at Dinger Bereha.

3.5.2 Spring Developments

The main water supply sources for the community in Dinger Bereha are springs. Many springs have been protected for the rural water supply sources in the Woreda. There are still unprotected springs in the area. The unprotected springs and over flows, and night flows of protected springs can be used for house hold level irrigation.

Table 3.6 : Summary of Weathering Products and Water Bearing Capacity of some Common Metamorphic and Igneous Rocks

Parent rock	Texture	Jointing	Weathering products	Depth of weathering	Water bearing capacity
Gneiss	Coarse grained	Moderate	Clay minerals, Quartz Persists	Moderate to deep	Good
Schists	Foliated	Cleavage	Clay minerals	Deep	Poor
Quartzite	Fine coarse grained	Strong	Mechanically weathered quartzite	Shallow	Poor to very good
Granite & Granodiorite	Coarse grained	Strong	Clay minerals Quartz and some mica persist	Deep	Good
Syenite	Coarse grained	Moderate	Clay minerals	Moderate	Poor
Gabbro	Coarse grained	Little	Clay minerals	Moderate	Poor

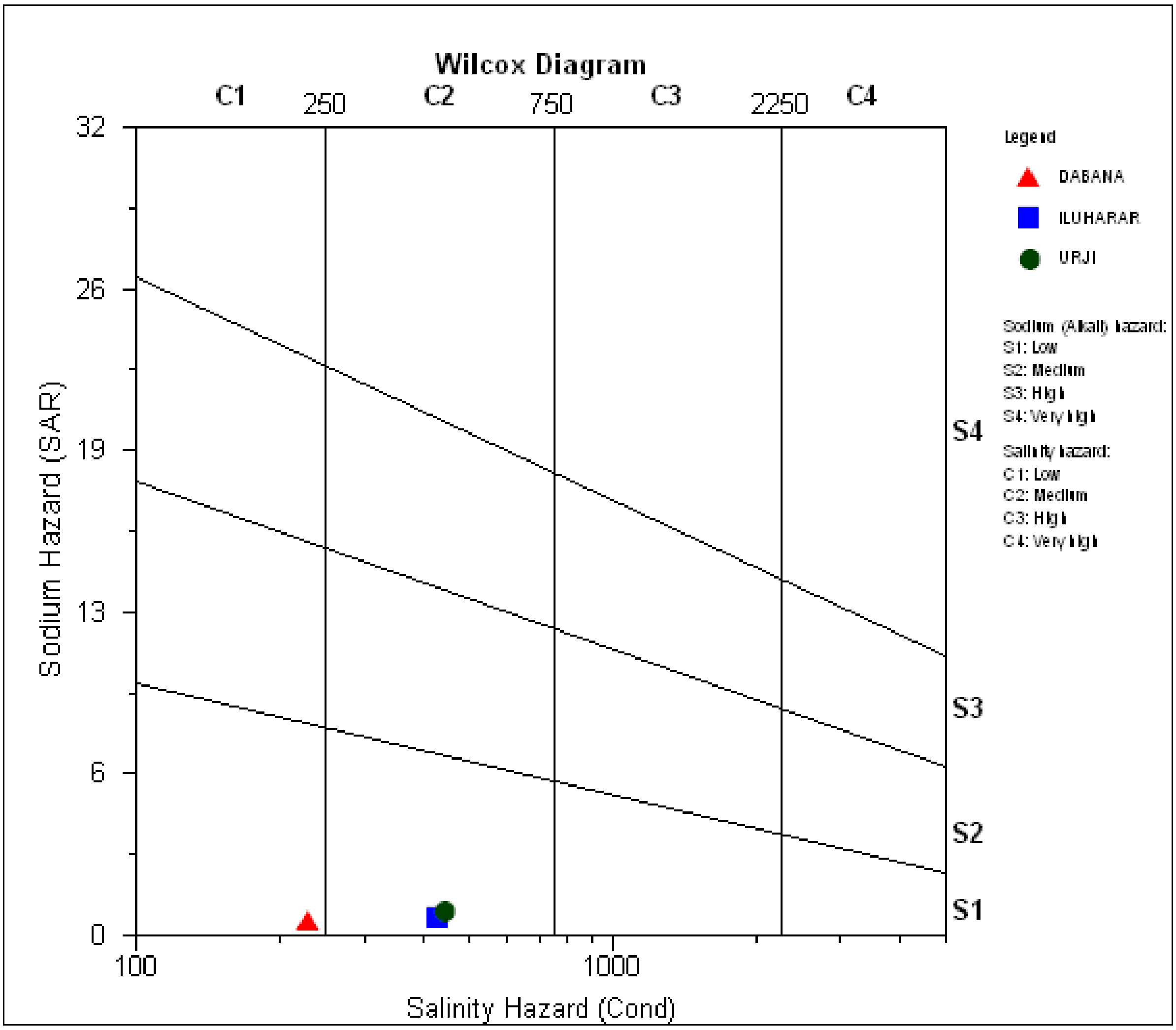


Figure 3.3: Wilcox Diagram for water quality for irrigation

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APPENDIX A: TABLES WITH CLIMATIC AND HYDROLOGICAL DATA

Average Monthly Temperature at Didessa Station (°C) from the year 1961-2008

Year	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1961	22.2	21.8	24.7	24	23.2	21.5	20.7	20.2	21.6	22	21.9	19.7
1962	20	21.8	24.9	22.5	23.2	21	20	20	21.3	22.1	20.2	19
1963	21.7	23.2	24.3	16.3	15.9	21.6	21.1	20.8	21.4	21.7	24.6	21.3
1964	21.7	22.9	25.4	24.6	23.7	21.5	20.4	20.4	21.4	22	21.5	20.8
1965	21.5	21.8	24.8	24.8	23.5	21.6	21.3	20.8	21.5	22.4	23.2	20.5
1966	22.7	23.6	25.3	24.8	24.1	21.7	21.4	20.8	21.5	22.3	22	18.8
1967	19.5	22.5	25.1	24.8	23.7	21.2	20.7	20.5	21.3	21.1	23	18.7
1968	19.9	22.4	23.6	24.5	24.1	21.6	21.6	21.1	21.2	21.4	21.2	19.6
1969	22.4	23.2	25.1	24.6	24	22	20.7	20.7	21.5	21.7	21.2	16.9
1970	21.5	22.9	25	24.9	24.3	22	21.4	20.8	21.6	22.8	19.8	18.2
1971	21.6	20.4	23.9	24.7	23.7	21.1	21	19.9	21.1	22.4	21.7	18.2
1972	21.5	23.1	24.2	24.9	23.2	21	21.8	21.3	21.6	22.3	22.8	20.2
1973	22.7	22.6	25.8	26.8	24.1	21.8	21.3	20.8	21.5	21.7	21.7	17.4
1974	21.2	23.3	25.3	23.9	23.9	21.8	20.8	21.3	21.3	21.2	19.1	19
1975	21	23.6	25.9	24.8	23.7	21.7	20.5	20.2	21.3	21.9	20.4	18.9
1976	20.6	23.9	24.8	24.3	23.1	21	21	20.8	21.6	22.4	22.5	19.7
1977	23	23.5	24.9	25.3	24.4	21.4	21	21.3	21.9	23.5	23	20.9
1978	21.1	22.8	26.1	25.6	23.8	21.9	20.9	21.2	21.1	22.3	20.9	20.4
1979	22.2	23.5	24.7	24.2	24.2	21.9	21.3	21.6	22	22.3	21.6	20.9
1980	22.3	24.1	26.1	25.8	24.4	22.3	21.1	20.8	22	22	22	19.5
1981	22.4	22.6	26.2	25.1	24.7	22.3	20.6	21.1	21.5	22	21.6	19.2
1982	22.7	22.3	23.8	24.9	23.5	21.9	21.2	20.7	21.6	21.8	23	20.6
1983	20.3	23.6	26.1	25.6	25	22.8	22.3	21.8	21.7	22.4	22.3	18.6
1984	20.6	20.6	25.4	26.2	24.5	21.9	20.9	20.7	21.1	20.2	23.4	20.6
1985	21.5	22.9	25.7	25.1	24	21.7	20.6	20.4	21.5	21.5	22.1	19.7
1986	21.5	24.7	23.9	24.6	24.6	22	21.3	21.1	21.2	21.7	22	20.4
1987	21.8	23	25.4	25.1	24.2	22.6	22.2	21.6	21.9	23.1	22.7	20.2
1988	22.4	24.5	25.1	25.8	25.3	22.5	21.3	21.6	21.9	22.5	20.6	18.8
1989	21.3	22.3	24.6	24.5	23.3	21.9	21.3	21.6	21.7	22	21.9	21.6
1990	21	21.9	24.8	25.1	18.6	22.4	21.4	21.4	21.9	22.1	22.4	20.9
1991	23	23.6	25.1	25.1	24.6	22.6	21.3	20.8	22	21.4	21.4	18.2
1992	22.1	24.1	25.2	25.2	24.6	22.3	21.1	21.3	21.8	22.7	21.8	21.3
1993	22.6	23.5	24.3	25.6	24.4	22.7	21.4	21.4	21.8	22.9	21.7	19.6
1994	21.6	24.2	26.8	24.9	24.3	22.3	21.1	21.5	21.8	22	23.3	20
1995	22.3	24.5	26.4	26.5	25.3	23.1	21.9	22.1	22.3	23	23.3	22.2
1996	22.6	24.1	26.3	25.9	24.7	21.9	21.7	21.8	22.4	22.4	22	20.2
1997	23.4	22.4	26.9	25.5	24.4	23.1	22.3	22.3	23.2	24	25.1	22.9
1998	24.6	24.9	27.4	27.7	26.2	23.4	22.4	22.3	23.1	24.2	22	19.1
1999	21.9	22.8	26.2	26.3	24.9	22.8	21.6	21.3	22.9	23.5	21	19.8
2000	21.6	22.9	26.6	26.6	25.5	22.6	21.9	21.8	23	24	23.5	20.8
2001	23	24.3	26	26.4	25.5	23	22	22.2	23	24.2	23.6	21.6

Contd.

Year	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
2002	23.2	23.6	26.9	25.9	25.8	22.8	22.7	22.2	22.8	23.3	23.1	22.7
2003	21.9	24.5	26.4	25.7	25.8	23.2	22	22.2	22.7	23	23.5	20.6
2004	24.2	24.2	26.2	26.5	25.6	22.8	21.5	22.1	22.5	22.6	23.2	21.8
2006	21.1	22	24	23.3	22.1	20.8	19.3	18.8	22.6	23.5	22.7	22.2
2007	19.1	19.4	25.2	25.7	24.9	24.9	24.8	22.3	22.6	23.1	22.2	22.2
2008	22.8	23.5	25.7	24.8	21	22.6	21.3	21.5	22.4	22.9	22.1	22
Mean	21.85	23.06	25.4	25	23.9	22.14	21.3	21.17	21.89	22.4	22.2	20.1
Std.dev.	1.114	1.137	0.92	1.6	1.74	0.769	0.82	0.737	0.597	0.85	1.17	1.74
C.v.	0.05	0.05	0.04	0.06	0.07	0.04	0.04	0.04	0.03	0.04	0.05	0.09
Max.	246	24.9	27.4	27.7	26.2	24.9	24.8	22.3	23.2	24.2	25.1	22.9
Min.	19.1	19.4	23.6	16.3	15.9	20.8	19.3	18.8	21.1	20.2	19.1	16.9

Estimated Mean Monthly ETo of the Project Area (mm) from the year 1961-1992

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1961	116	110	139	128	116	109	94.2	110	133	132	116	100	1403
1962	100	105	144	130	137	105	81.6	77.4	112	112	104	99	1308
1963	108	104	145	103	104	93.2	84	92.9	109	124	127	110	1303
1964	122	117	144	140	140	104	84.3	86.6	116	132	116	119	1420
1965	119	116	150	128	137	89	96.2	106	124	120	118	107	1410
1966	114	118	138	142	135	102	95.1	93.1	111	134	123	104	1408
1967	107	124	148	133	143	118	97.7	103	127	125	111	107	1444
1968	109	114	140	139	127	111	81.4	89.9	108	111	122	105	1358
1969	115	114	140	133	133	107	90.1	94.8	112	122	111	99	1369
1970	124	124	157	137	148	120	99.4	99.7	122	125	107	102	1466
1971	113	109	139	135	132	105	90.8	93.2	111	124	113	102	1366
1972	120	122	140	151	135	106	105	102	125	131	126	104	1466
1973	118	120	151	148	152	115	87.2	95.9	119	134	120	104	1464
1974	111	117	140	127	143	105	102	102	109	126	58.6	104	1346
1975	118	120	144	130	127	99	84.7	75.7	96	120	109	108	1332
1976	116	123	144	143	125	111	90.8	94.8	105	115	104	105	1375
1977	105	108	135	135	132	104	90	96	113	120	116	109	1362
1978	119	101	144	141	136	107	80	94.2	106	116	114	100	1359
1979	104	109	130	131	126	101	81.9	95.3	98.9	109	109	104	1299
1980	102	102	130	132	134	107	90.9	94.5	111	123	110	107	1343
1981	117	119	124	124	137	106	90.1	99.2	86.5	113	120	102	1338
1982	112	105	144	129	128	113	92.3	92.5	116	120	105	102	1358
1983	110	116	141	143	129	122	106	94	108	115	115	103	1401
1984	111	121	146	151	127	107	97.4	96.6	116	133	120	107	1432
1985	116	113	142	131	122	106	84.1	87.1	109	120	116	103	1349
1986	106	110	134	121	131	91.3	88.2	95.6	96.5	118	120	107	1320
1987	114	116	134	142	119	105	101	98	122	124	115	123	1412
1988	117	118	156	145	142	113	84.2	103	108	129	121	108	1443
1989	115	117	137	132	144	115	92	105	113	126	112	100	1408
1990	118	94.8	133	107	104	97.4	90.6	95	111	136	117	114	1318
1991	117	113	137	129	118	112	94.8	111	135	131	115	96.4	1411
1992	106	110	146	139	144	109	84.5	80.3	113	115	108	105	1360

Estimated Mean Monthly ETo of the Project Area (in mm/day)

Month	ETo	Total Rainfall	Effective Rain
	(mm/d)	(mm/month)	(mm/month)
January	4.15	12.0	11.8
February	5.15	14.5	14.2
March	6.24	44.8	41.6
April	6.95	58.5	53.0
May	8.07	172.5	124.9
June	7.17	264.8	151.5
July	5.75	293.1	154.3
August	5.48	249.0	149.8
September	4.88	227.0	144.6
October	4.71	126.2	100.7
November	3.75	30.8	29.3
December	3.47	11.8	11.6

Maximum Flow (m^3/s) of Didessa at 114001

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	MMD
1961	23.8	32.7	23.8	55.8	43	275	715	899	814	1145	209	154	1145
1962	30.7	16.3	19.1				383	467	525	858	64.2	32.5	858
1963	19.8	13	11.8	30.7	119	213	475	759	563	290	120	129	759
1964		22.2			51.2	131	654	679	677	817	150	35.4	817
1965	32.5	11.8	11.8	25.4	19.8	203	421	507	449	911	192	101.2	911
1966	35.4	40.4	38.4	54.6	65.4		523	598	783	717.5	181.9	78.2	783
1967			22.2	14.2			343	660	618	1070	497	136	1070
1969	24.6	25.4	54.6	38.4	58.2	221	567	752	538	182	55.8	25.4	752
1970	13.6				50.1	265	573	665.8	526.8	492.8	126	37.4	665.8
1971	20.6	8.62	5.2	7.23	50.1	142	565	649	435	467	203	66.6	649
1972	28.9	13.3	11.8	49	44.6	84.4	47.5	57.3	36.1	145	71.5	27.1	145
1973	15	6.4	2.81	4.6	67	125.8			764	487.4	79	35.3	764
1974	20.9	11.29	8.03		92.2	148	310	719					719
1979				18.5	35.3	113.2	264.1	487.4	459	170.5	62	20.9	487
1982	17.81	7.86	10.19	6.15	22.19	125	416.58	502.6	359	510	71.48	43.16	510
1983	12.35	11.46	15.21	6.48	32.31	68.33	358.98	644.6	502.6	1079.8	109.2	39.9	1079.77
1984	21.78	9.78	7.51	5.52	25.49	181.9	439.25	406.7	377.7	114.48			439.3
1985	6.81	4.1	2.88	12.35	38.32	168.8	274.25	555.6	584.5	197.14	42.33	28.13	584.53
1986	9.78	4.93	14.22	12.35	7.86	91.75	314.15	318.5	614.2	190.27			614.2
1987	6.48	4.64	7.16	12.81	43.99				626.3	299.15	128.2	33.76	626.3
1988	18.35	14.71	14.22	5.52	33.76	190.3	472.03		635.8	605.5	156.2		635.8
1989		13.27	14.22	27.46	21.19	165.6	132.4	387.3	710.6		69.37	80.18	710.6
1990	43.16	17.81	30.88	35.25	25.49	89.38	309.83	630.3	735.9	763.5	216.5	96.6	763.5
1992	9.78	12.35	5.22	21.19	26.79	80.18	225.77	473	436.7	949.68	131	40.7	949.68
1993	20.83	13.08	13.08	40.05	63.52	217.9	399.05	645.6	447.2	258.77	250.4	40.05	645.632
1994	17.55	10.01	6.595	7.3	32.13	132.7	394.97	804.3	522.8	110.69	36.35	32.82	804.28
1995	9.198	5.92	12.17	20.83	23.76	75.99	126.38	353.3	288.3	98.125	30.77	18.62	353.253
1996				21.41	106	205.5	423.9	525.1	403.1				525.1
2001	38.55	32.13	55.47	30.1	82.06	281.2	502.32	588.9	744.4	440.83	168.8	62.61	744.358
2002	44.68	28.13	25.59	34.92	23.76	123.9	240.44	300.8	311.7	167.37	66.31	52.04	311.73
2003	26.85	19.16	30.1	48.71	27.48	92.63		324.7	350.7	348.9	91.5	39.3	350.7
2004	23.16	19.71	13.55	15.49	50.37	164.6	374.85	395	601	438.69	68.2		601
Mean	23.7	16	18	26	49	156	376	534	522	504	129	55.8	680.45

Statistics of Maximum Flow

Rank	Flow	Year	R. P.
1	1,145	1961	53.67
2	1,080	1983	20.13
3	1,070	1967	12.38
4	950	1992	8.94
5	911	1965	7
6	858	1962	5.75
7	817	1964	4.88
8	804	1994	4.24
9	783	1966	3.74
10	764	1973	3.35
11	764	1990	3.04
12	759	1963	2.78
13	752	1969	2.56
14	744	2001	2.37
15	719	1974	2.21
16	711	1989	2.06
17	666	1970	1.94
18	649	1971	1.83
19	646	1993	1.73
20	636	1988	1.64
21	626	1987	1.56
22	614	1986	1.49
23	601	2004	1.42
24	585	1985	1.36
25	525	1996	1.31
26	510	1982	1.26
27	487	1979	1.21
28	439	1984	1.17
29	353	1995	1.13
30	351	2003	1.09
31	312	2002	1.05
32	145	1972	1.02

Peak Flow of the Command Area at different Return Periods

Catchment	Area	*Peak flow (QP) (m^3P/s)*				
ID #	(km^2)	At different Return Periods				
		25	50	75	100	1000
1	1.2	1.8	2	2.2	2.3	2.4
2	5.1	4.9	5.4	5.8	6.03	6.2
3	1.6	2.2	2.42	2.6	2.7	2.8
4	3.1	3.5	3.9	4.2	4.34	4.5
5	1.6	2.2	2.42	4.2	4.34	4.5
6	4.9	4.8	5.3	5.7	5.9	6.1
7	53.3	25.2	27.7	29.6	30.8	31.8
8	3.1	3.5	3.9	4.2	4.34	4.5
9	1.3	2	2.2	2.4	2.5	2.52
10	32.0	17.5	19.3	20.7	21.5	22.1
11	1.3	2	2.2	2.4	2.5	2.52
12	1.2	1.8	2	2.2	2.3	2.4
13	4.3	4,3	4.73	5.1	5.3	5.4
14	2.3	2.8	3.1	3.32	3.5	3.6
15	3.7	4	4.4	4.7	4.9	5.1
16	3.9	4.1	4.5	4.8	5	5.2
17	3.3	3.6	4	4.3	4.5	4.6
18	3.1	3.5	3.9	4.2	4.34	4.5
19	4.0	4.1	4.5	4.8	5	5.2
20	13.8	9.8	10.8	11.6	12	12.4
21	48.8	23.7	26.1	28	29	30
22	21.2	13.2	14.5	15.5	16.2	16.6
23	27.1	15.7	17.3	18.5	19.3	20
24	99.2	39	43	46	47.9	49.3
25	6.6	6	6.6	7.1	7.4	7.6
26	4.3	4.3	4.73	5.1	5.3	5.4
27	4.1	4.2	4.62	5	5.2	5.4
28	5.5	5.2	5.72	6.1	6.4	6.6
29	1.5	2.1	2.31	2.5	2.6	2.7

Total Area = 366.4 km^2

APPENDIX B: CALCULATION OF PEAKFLOWS AT CROSS DRAINAGE STRUCTURES

Calculation of peakflows at X drainage structures

If area less than 10 km2 use CIA, if more than 10 km2 use SCS method

Catchment area #	Area (km2)	Length of water course (km)	Highest elevation (m)	Lowest elevation (m)	Fall H (m)	Slope S (%)	Tc BW (min)	Tc SCS Kirpich (hr)	(min)	Design rainfall I (mm/hr) (acc to IDF curve regions) T = 25	T = 50	T = 100	Runoff coeff C	Peak runoff (m3/s) (Q = CIA/360) T = 25	T = 50	T = 100
1	1.6	1.5	1550	1240	310	20.7	29	0.17	10	90	110	135	0.35	14	17	21
2	5.1	4.6	1840	1240	600	13.0	86	0.47	28	51	59	69	0.35	25	29	34
3	1.5	1.7	1430	1240	190	11.2	37	0.23	14	91.5	108.5	129	0.35	13	16	19
4	3.1	3.0	1680	1240	440	14.7	57	0.32	19	73	79.5	89.5	0.35	22	24	27
5	1.6	1.8	1480	1240	240	13.1	38	0.23	14	91	101	119	0.35	14	16	18
6	4.8	3.9	1880	1240	640	16.4	70	0.38	23	61	66	76	0.35	28	31	35
7	53.0	15.0	2090	1240	850	5.7	261	1.61	97	35	40	45	SCS	24	37	53
8	3.4	4.8	1600	1240	360	7.5	104	0.60	36	49	54	59	0.35	16	18	20
9	1.1	1.8	1330	1240	90	5.1	46	0.32	19	85	97.5	107.5	0.35	9	10	11
10	13.8	6.7	1930	1240	690	10.3	118	0.68	41	41	46	51	SCS	17	23	31
11	3.8	4.1	1360	1240	120	2.9	106	0.77	46	48	53	58	0.35	18	20	22
12	1.4	2.0	1410	1240	170	8.6	45	0.29	17	83	95	105	0.35	12	13	15
13	0.7	1.0	1300	1240	60	6.1	26	0.19	12	145	139	154	0.35	9	9	10
14	0.5	1.7	1395	1240	155	9.1	43	0.25	15	73	80	90	0.35	4	4	5
15	0.9	1.3	1290	1240	50	3.8	37	0.28	17	93	103	125	0.35	8	9	11
16	0.6	0.8	1305	1240	65	8.1	20	0.15	9	126	141	158	0.35	7	8	9
17	2.9	1.8	1390	1240	150	8.3	39	0.27	16	90	105	115	0.35	26	30	33
18	0.5	0.9	1290	1240	50	5.6	25	0.19	11	97	118	139	0.35	5	6	7
19	0.6	1.3	1310	1240	70	5.4	36	0.25	15	90	105	116	0.35	6	7	7