REPUBLIC OF KENYA
MINISTRY OF ENVIRONMENT
WATER AND NATURAL RESOURCES
(MEWNR)

COAST WATER
SERVICES BOARD
(CWSB)

Water and Sanitation Service Improvement Project (WaSSIP)

Loan Nos.: IDA 4376-KE and CKE3010-1

Consultancy Services for Water Supply Master Plan for Mombasa and Other Towns Within Coast Province

Volume III
Water Supply Master Plan
Annexes

December 2013

KE-24890-R14-179

TAHAL GROUP

in association with

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ANNEXES

Annexes

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Annex 1

Population Projections

From the "Water Demand and Supply Assessment Report"

Annex 1

Demographic Analysis and Population Forecasts

Population Distribution by Group Sizes – 2009 Census

The sub-locations in each of the 13 districts of the Coast Province (documented in the 2009 census), were sorted and grouped in each district according to ten population group sizes, and the total population in each group was totalled. The results are shown in Table A-1 below.

- 25% of the total 2009 population of 3,316,346 live in 318 villages of the size up to 5,000 inhabitants (62.4% of the total 510 villages and towns)

- 25% live in 119 villages of 5,000–10,000 population.

- 25% live in 57 villages of 10,000–30,000 population each.

- 25% live in 16 towns of 30,000–100,000 population each.

- From the three bullets above, it can be seen that 75% of the population live in 192 villages having populations of more than 5,000.

Table A-1: Population Distribution by Population Group Size – 2009 Census

Pop Group Size		<1,000		1,000-2,000		2,000-3,000		3,000-5,000		5,000-10,000		10,000-15,000		15,000-20,000		20,000-30,000		30,000-50,000		>50,000		Total	
		No	Population	No	Population	No	Population	No	Population	No	Population	No	Population	No	Population	No	Population	No	Population	No	Population	**No**	**Population**
	District																						
1	**Mombasa**			1	1,526					6	48,788	4	45,101	2	35,086	2	53,721	3	112,539	3	226,522	**21**	**523,283**
2	**Kilindini**											3	37,049	1	17,520	4	104,895	2	74,033	3	182,690	**13**	**416,187**
3	**Kwale**	2	1,102	6	9,391	1	2,369	4	15,760	11	75,431	4	47,925									**28**	**151,978**
4	**Kinango**			1	1,443	3	7,601	5	21,039	18	123,727	5	55,750									**32**	**209,560**
5	**Msambweni**	1	841	1	1,637			5	22,481	6	43,043	5	62,603	3	53,626	1	24,024	2	80,138			**24**	**288,393**
6	**Kilifi**	4	2,870	15	22,285	16	38,910	14	58,014	24	171,000	6	69,966	1	15,389	1	27,017			1	50,846	**82**	**456,297**
7	**Kaloleni**							12	47,851	16	119,132	1	13,333	2	33,643	1	29,866					**32**	**243,825**
8	**Malindi**			8	13,957	8	19,642	15	62,542	15	101,349	2	23,490	5	82,479	1	21,591	2	75,502			**56**	**400,552**
9	**Tana River**	9	6,147	23	32,754	12	29,869	8	29,917	5	33,994	1	10,730									**58**	**143,411**
10	**Tana Delta**	6	2,966	6	9,032	10	24,536	10	40,854	3	19,276											**35**	**96,664**
11	**Lamu**	10	5,944	6	8,201	12	26,968	5	19,401	6	41,025											**39**	**101,539**
12	**Taita**	2	1,789	24	37,066	22	55,182	13	47,465	6	37,718			1	17,354	1	20,418					**69**	**216,992**
13	**Taveta**	2	1,114	5	7,042	5	12,892	6	24,247	3	22,370											**21**	**67,665**
Total		**36**	**22,773**	**96**	**144,334**	**89**	**217,969**	**97**	**389,571**	**119**	**836,853**	**31**	**365,947**	**15**	**255,097**	**11**	**281,532**	**9**	**342,212**	**7**	**460,058**	**510**	**3,316,346**
Tot Cumulative		**36**	**22,773**	**132**	**167,107**	**221**	**385,076**	**318**	**774,647**	**437**	**1,611,500**	**468**	**1,977,447**	**483**	**2,232,544**	**494**	**2,514,076**	**503**	**2,856,288**	**510**	**3,316,346**		
%		7.1	**0.7**	**18.8**	**4.4**	**17.5**	**6.6**	**19.0**	**11.7**	**23.3**	**25.2**	**6.1**	**11.0**	**2.9**	**7.7**	**2.2**	**8.5**	**1.8**	**10.3**	**1.4**	**13.9**	**100.0**	**100.0**
% Cumulative		7.1	**0.7**	**25.9**	**5.04**	**43.3**	**11.6**	**62.4**	**23.4**	**85.7**	**48.6**	**91.8**	**59.6**	**94.7**	**67.3**	**96.9**	**75.8**	**98.6**	**86.1**	**100.0**	**100.0**		

Demographic Analysis and Past Population Growth Rates

The 1969, 1979, 1989 and 1999 populations of the respective censuses have been analysed, together with the 2009 population census, to determine population growth rates and long-term projections.

The intercensal population growth rates for the 1969–2009 period have been estimated at the level of sub-location, location, division and district.

It should be emphasised that over a time span of 40 years between the first and last population censuses, the geographical and administrative subdivisions of the Coast Province have been changing, and boundaries of administrative units within regions have also changed. Sub-locations (the sub-location being the smallest population cluster) have been moved from one district to another, and the number of districts has also changed. In addition, several new sub-locations/villages have been created during that period.

The consequences of these changes are inconsistencies in the data at specific locations over time. While the 1999 and 2009 data are generally consistent, the data from the three other census reports, particularly the first two, show inconsistencies that result in negative figures and division by zero, when estimating growth rates between two censuses.

Nonetheless, the total population has been kept as per the censuses at the level of divisions and districts, giving here more significant growth rate figures. In other words, at the level of divisions and districts, the calculated growth rate per period shows positive figures and enables the use of those numbers as a key growth rate for the projection. Thus, the overall regional growth rates in the censuses are consistent, as the boundaries of the regions have remained practically identical during all of the census periods.

The district-wise intercensal growth rates for the five censuses are presented in **Table** on the following page.

Table A-2 District Populations and Intercensal Growth Rates – 1969 to 2009 Censuses

		Population					Inter Censal Growth Rate %			
	Year	1969	1979	1989	1999	2009	1969-79	1979-89	1989-99	1999-2009
	Coast Province	**745,877**	**1,108,974**	**1,653,429**	**2,415,917**	**3,316,346**	**4.05**	**4.07**	**3.87**	**3.22**
	District									
1	**Mombasa**	164,368	236,670	266,631	373,051	523,283	3.71	1.20	3.42	3.44
2	**Kilindini**	52,242	100,405	152,423	224,083	416,187	6.75	4.26	3.93	6.39
3	**Kwale**	44,874	73,377	85,847	117,657	151,978	5.04	1.58	3.20	2.59
4	**Kinango**	65,250	65,884	126,252	174,628	209,560	0.10	6.72	3.30	1.84
5	**Msambweni**	51,503	98,649	127,912	211,714	288,393	6.72	2.63	5.17	3.14
6	**Kilifi**	87,782	131,698	201,678	340,844	456,297	4.14	4.35	5.39	2.96
7	**Kaloleni**	56,929	97,905	142,237	189,807	243,825	5.57	3.81	2.93	2.54
8	**Malindi**	59,862	87,998	190,861	281,552	400,552	3.93	8.05	3.96	3.59
9	**Tana River**	24,068	39,152	89,617	112,968	143,411	4.99	8.63	2.34	2.41
10	**Tana Delta**	17,422	24,750	35,060	67,835	96,664	3.57	3.54	6.82	3.61
11	**Lamu**	11,859	25,920	36,599	72,244	101,539	8.13	3.51	7.04	3.46
12	**Taita**	96,597	101,787	154,072	196,496	216,992	0.52	4.23	2.46	1.00
13	**Taveta**	13,121	24,779	44,240	53,038	67,665	6.56	5.97	1.83	2.47

Population Projections for the Coast Province

Approach and Methodology

Because of the inconsistencies described above, the Consultant has adopted the following procedure in order to analyse and derive the growth rates for Coast Province population projections.

There are two main approaches to performing population projections for an area with a large population (i.e., country /state/ province):

Bottom-up (from the part up to the whole) – a projection is performed for each settlement/city (primary level) that is included in the large area, and summarised for each required clusters and to the entire area; and
Top-down (from whole down to the part) – a projection is first performed for the entire area population, and the population projection for each settlement or a cluster of settlements is calculated as a portion/percentile of the larger area's population projection.

The preferred approach mainly depends on the purpose of the projection. For a Water Supply Master Plan (WSMP), it is most important to estimate at first the overall demand (which is directly related to the overall population) of the area in order to estimate future water balances, and evaluate the need to develop additional water resources for the use of the entire area.

An additional objective is to obtain projections by districts in order to plan the area's main water network that enables efficient use of the water sources. Thus, it is obvious that the water balance for the entire region will differ from that of the master plan, as the latter will be in the scope of 18 cities chosen by CWSB to be the core of the master plan. For those cities, a more detailed projection of population will be carried out in the future, so that the water supply calculations are based on a more accurate projection.

Experience from other WSMPs, shows that a projection for a large population is usually more accurate than a projection for a small population, mainly due to the absence of internal immigration dynamics. Therefore, in order to obtain the abovementioned objectives, a top-down approach was chosen, i.e., a population projection for the entire Coast Province was performed first, and was later used for the calculation of projections for each district. The district projections were then used for calculation of the projections for each division, and so on, down to sub-locations.

Population projections for large sub-locations (>20,000) were calculated by trend analysis. However, either no clear trend was found or insufficient data was available for all of these sub-locations (say the small ones, < 5,000), so projections for small sub-locations were performed using the top-down approach.

The population projections for the province and all clusters were performed for three scenarios – low growth, medium growth and high growth rates.

It should be noted that at the level of a Water Supply Master Plan, division and/or district population projections are enough. Sub-location projections will be revised further during preparation of detailed design of water supply systems for each sub-location.

Population Projections for the Coast Province

The database for the population projections for the Coast Province comprised the five census datasets (sub-location-wise) for the years 1969, 1979, 1989, 1999 and 2009.

The most widely acceptable mathematical function for describing large population changes over time is an S-shaped function, starting with an exponential growth, continuing with a linear growth (which is usually the longest phase) and gradually reaching a saturation point at the third phase. By graphical presentation of Coast Province population data for the years 1969–2009, it is not clear if the province population is at the exponential phase or at the linear phase, since both types of regressions exhibited excellent correlation parameters:

For the exponential regression on the 1969–2009 dataset, it was found:
$R^2 = 0.998$, F-statistic = 1,549 and Probability (F > 1,549) = $1.2 * 10^{-6}$

For the linear regression on the 1969–2009 dataset, it was found (1989–2009):
$R^2 = 0.998$, F-statistic = 436 and Probability (F > 436) = 0.002

By trying to match a constant rate of growth to the population growth curve, the result shows low correlation, where $R^2 < 0.67$.

In both cases (linear and exponential regressions), the R^2 shows extreme significant value, i.e., both of the calculation procedures well explain the rate growth.

However, the exponential regression suggests an annual growth rate of 3.83%, which is significantly higher than the average annual growth rate in the years 1999–2009 (3.22%) (i.e., the difference between year-to-year increase in population and the entire growth rate over the period). On the other hand, the linear extrapolation results in a rapid reduction of the average growth rate, which reaches 2% around the year 2020.

Therefore, the population projections for the low and high scenarios were considered as the continuation of the linear and exponential trends, respectively. For the medium scenario, the projection was calculated according to the average annual growth rate between the years 1999–2009 for the Coast Province which population data and projection to the year 2035, for the three different scenarios are shown in fig A-3 below.

For other growth rate mechanism – such as the Lamu Port, free economic trade zone and others – which may attract people to switch their residence to nearby locations for employment, a separate water demand was calculated in order to reflect their demand for water. Thus, for the case of Mombasa and Lamu free commercial zones, a "block" of demand was added to the balance as an additional demand above local growth rate.

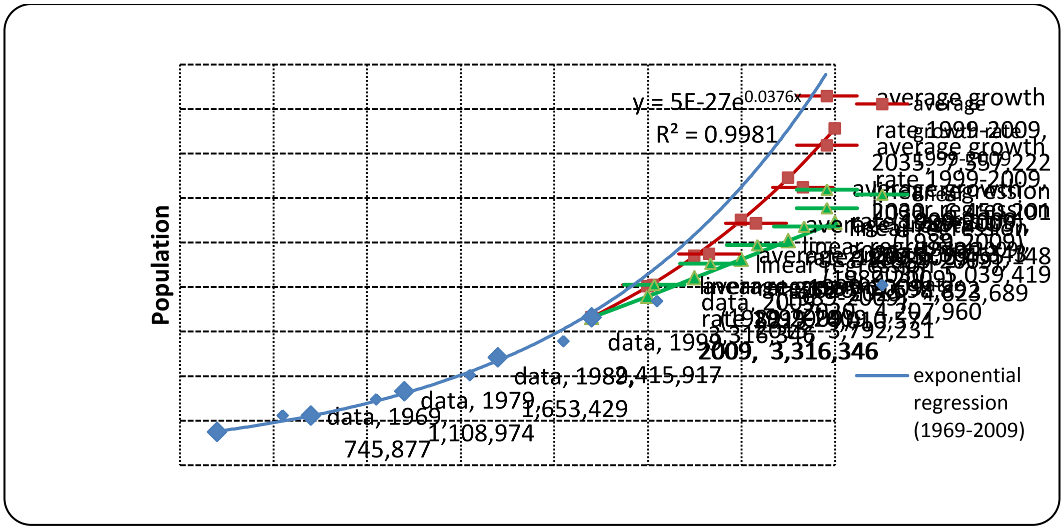

Fig A-3 Coast Province population data and projections to the year 2035

Table A-4 Coast Province – Past Population Data and Projections to 2035

	Low	Medium	High
	Linear	Geometric	Exponential
1969	745,877	745,877	745,877
1979	1,108,974	1,108,974	1,108,974
1989	1,653,429	1,653,429	1,653,429
1999	2,415,917	2,415,917	2,415,917
2009	3,316,346	3,316,346	3,316,346
2015	3,792,231	4,010,574	4,293,595
2020	4,207,960	4,698,892	5,182,370
2025	4,623,689	5,505,343	6,255,121
2030	5,039,419	6,450,201	7,549,931
2035	5,455,148	**7,557,222**	9,112,768

Population Projections by District

For each of the districts of the Coast Province, the projected population (for each year and model) were estimated as a proportion of the province population. The percentage proportion of population of each district was estimated after analysing the current and historic percentage, as follows:

Districts for which the percentage proportion of population (population out of the province population) had a constant trend between the years 1989–2009 were assumed to exhibit the behaviour until 2030.
For districts whose population dynamics compare with the province population had a positive trend (i.e., the population within the district increased more than a province average); it was assumed that the trend will continue in the same manner and with about the same rate of change until 2025, and then will stay constant until 2030.

Each district's percentage of the total Coast Province population is shown in Table A-5 The population projections for the Coast Province, presented by districts, are shown in table A-6.

Table A-5 District Populations as Percentages of Total Coast Province Population

District	1989 *	1999 *	2009 *	2015	2020	2025	2030	2035
Mombasa	16.1%	15.4%	15.8%	15.8%	15.8%	15.8%	15.8%	15.8%
Kilindini	9.2%	9.3%	12.5%	13.2%	13.7%	13.7%	13.7%	13.7%
Kwale	5.2%	4.9%	4.6%	4.5%	4.4%	4.4%	4.4%	4.4%
Kinango	7.6%	7.2%	6.3%	6.0%	5.8%	5.8%	5.8%	5.8%
Msambweni	7.7%	8.8%	8.7%	8.7%	8.7%	8.7%	8.7%	8.7%
Kilifi	12.2%	14.1%	13.8%	13.8%	13.8%	13.8%	13.8%	13.8%
Kaloleni	8.6%	7.9%	7.4%	7.2%	7.0%	7.0%	7.0%	7.0%
Malindi	11.5%	11.7%	12.1%	12.4%	12.6%	12.6%	12.6%	12.6%
Tana River	5.4%	4.7%	4.3%	4.1%	4.0%	4.0%	4.0%	4.0%
Tana Delta	2.1%	2.8%	2.9%	3.0%	3.0%	3.0%	3.0%	3.0%
Lamu	2.2%	3.0%	3.1%	3.2%	3.2%	3.2%	3.2%	3.2%
Taita	9.3%	8.1%	6.5%	6.2%	6.1%	6.1%	6.1%	6.1%
Taveta	2.7%	2.2%	2.0%	1.9%	1.9%	1.9%	1.9%	1.9%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

* data Kenya population census. 2009

Table A-6: Coast Province Population Projections, by District

District	Scenario	2009	2015	2020	2025	2030	2035
Mombasa	Low	523,283	599,172	664,858	730,543	796,228	861,913
	Medium	523,283	633,671	742,425	869,844	1,019,132	1,194,041
	High	523,283	678,388	818,814	988,309	1,192,889	1,439,817
Kilindini	Low	416,187	500,574	576,491	633,445	690,400	747,355
	Medium	416,187	529,396	643,748	754,232	883,678	1,035,339
	High	416,187	566,755	709,985	856,952	1,034,341	1,248,449
Kwale	Low	151,978	170,650	185,150	203,442	221,734	240,027
	Medium	151,978	180,476	206,751	242,235	283,809	332,518
	High	151,978	193,212	228,024	275,225	332,197	400,962
Kinango	Low	209,560	227,534	244,062	268,174	292,286	316,399
	Medium	209,560	240,634	272,536	319,310	374,112	438,319
	High	209,560	257,616	300,577	362,797	437,896	528,541
Msambweni	Low	288,393	329,924	366,093	402,261	438,429	474,598
	Medium	288,393	348,920	408,804	478,965	561,168	657,478
	High	288,393	373,543	450,866	544,196	656,844	792,811
Kilifi	Low	456,297	523,328	580,699	638,069	695,440	752,810
	Medium	456,297	553,459	648,447	759,737	890,128	1,042,897
	High	456,297	592,516	715,167	863,207	1,041,891	1,257,562
Kaloleni	Low	243,825	273,041	294,557	323,658	352,759	381,860
	Medium	243,825	288,761	328,922	385,374	451,514	529,006
	High	243,825	309,139	362,766	437,858	528,495	637,894
Malindi	Low	400,552	470,237	530,203	582,585	634,967	687,349
	Medium	400,552	497,311	592,060	693,673	812,725	952,210
	High	400,552	532,406	652,979	788,145	951,291	1,148,209
Tana River	Low	143,411	155,481	168,318	184,948	201,577	218,206
	Medium	143,411	164,434	187,956	220,214	258,008	302,289
	High	143,411	176,037	207,295	250,205	301,997	364,511
Tana Delta	Low	96,664	113,767	126,239	138,711	151,183	163,654
	Medium	96,664	120,317	140,967	165,160	193,506	226,717
	High	96,664	128,808	155,471	187,654	226,498	273,383
Lamu	Low	101,539	121,351	134,655	147,958	161,261	174,565
	Medium	101,539	128,338	150,365	176,171	206,406	241,831
	High	101,539	137,395	165,836	200,164	241,598	291,609
Taita	Low	216,992	235,118	256,686	282,045	307,405	332,764
	Medium	216,992	248,656	286,632	335,826	393,462	460,991
	High	216,992	266,203	316,125	381,562	460,546	555,879
Taveta	Low	67,665	72,052	79,951	87,850	95,749	103,648
	Medium	67,665	76,201	89,279	104,602	122,554	143,587
	High	67,665	81,578	98,465	118,847	143,449	173,143
Total	Low	3,316,346	3,792,231	4,207,960	4,623,689	5,039,419	5,455,148
	Medium	3,316,346	4,010,574	4,698,892	5,505,343	6,450,201	7,557,222
	High	3,316,346	4,293,595	5,182,370	6,255,121	7,549,931	9,112,768

From the Coast Province population projection, it should be noted that an estimated total population of 7,557,222 inhabitants will live in the area and will demand water supply service at different levels at their locations. This figure is for the medium model for population projection for the horizon year of 2035.

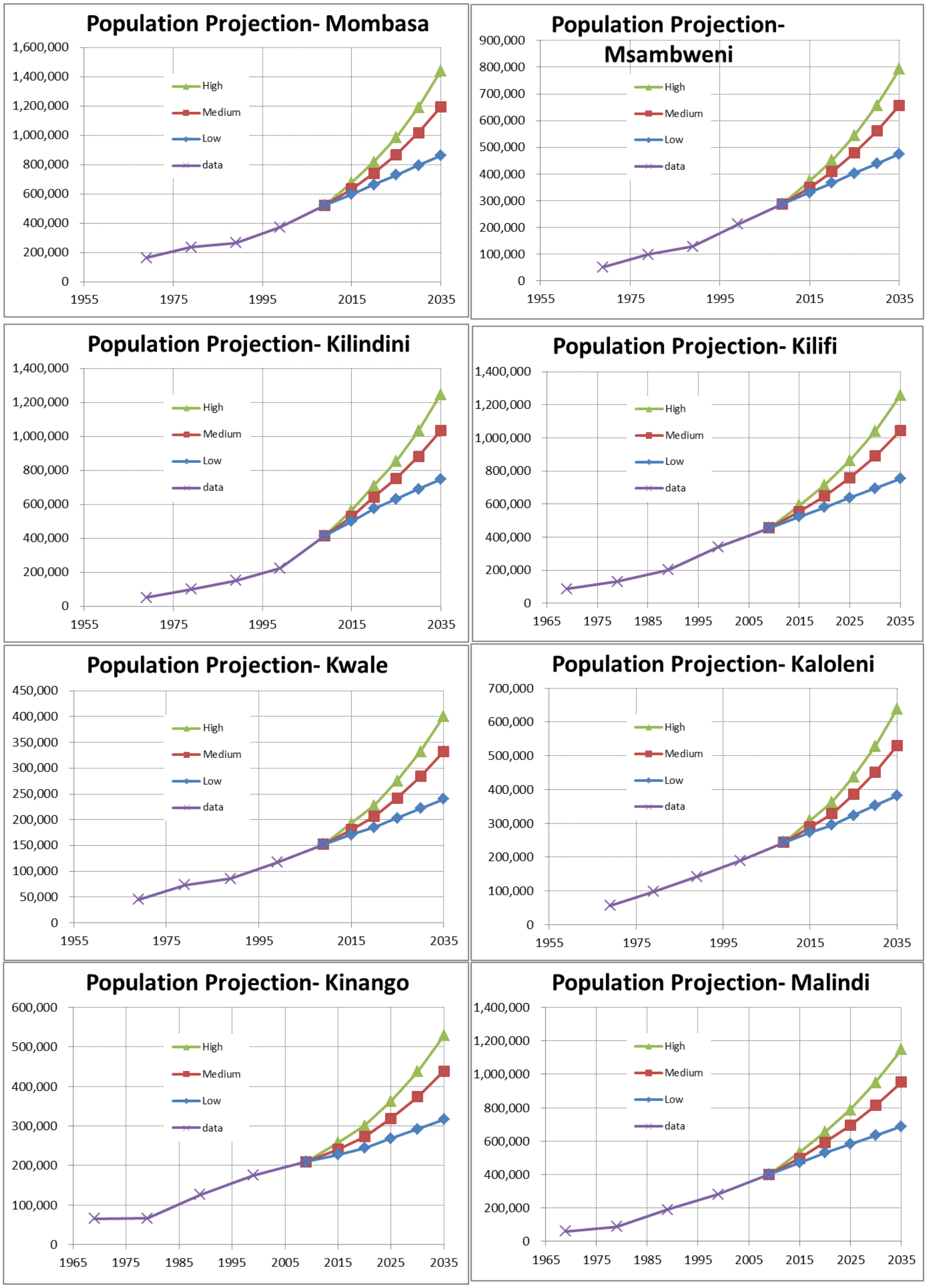

Fig. A-7 Population data projections for the Coast Province districts

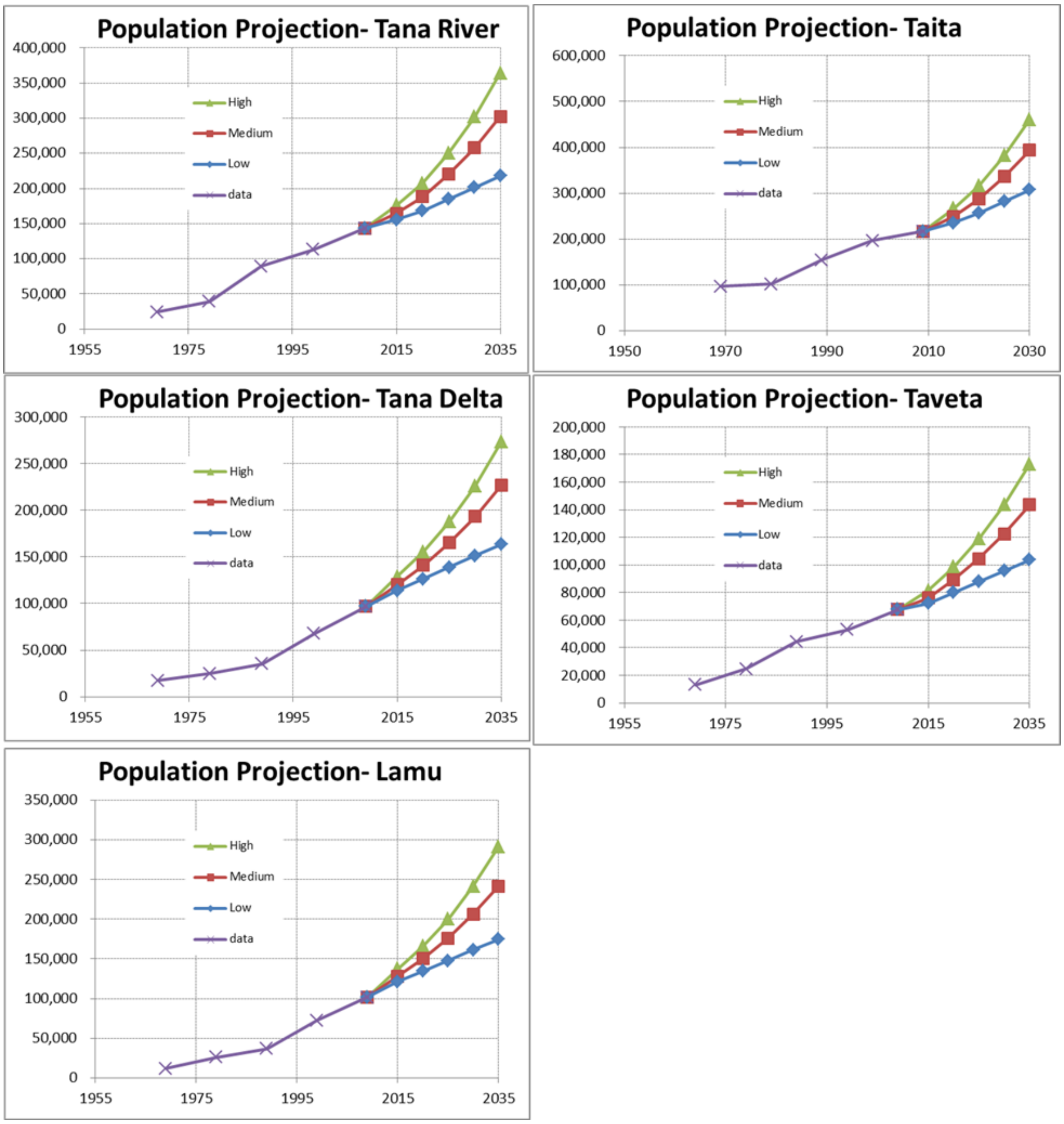

Fig A-7 (cont.) **Population data projections for the Coast Province districts**

Population Projections by Divisions, Locations and Sub-Locations

The population projections by divisions, locations and sub-locations were performed according to the top-down approach using the district population projection as the highest level. The percentage proportion of the division population out of the district population taken from the 2009 census data was assumed to be applicable for the years 2015–2035. The same percentage proportion for the division was taken to be applicable to the locations and sub-locations forming the division.

The "Kenya County Fact Sheets" (Commission on Revenue Allocation, 2011) were used to support the allocation of the population data for the districts, locations and sub-location into urban and rural. This categorization contributed to a more accurate calculation of the water demand.

Annex 2

Water Demand

Annex 2 Water Demand Calculations

<u>Residential and industrial / large consumer surveys</u>

Two types of water demand surveys will be undertaken:

1. A residential water demand survey

In order to collect the necessary information to estimate present residential water consumption in order to represent all types of housing and mode of water supply.

The main objective of the survey will be to check if the type of housing and the mode of water supply could be adopted as relevant indicators to classify domestic consumers.

2. An industrial / large consumer survey

An industrial / large consumer survey will be carried out on a sample of selected consumers with the following main objectives:

1/- assess the water demand by type of industrial activity,

2/- determine current and future water demand of the largest consumers.

The methodology used to assess water demand will be based on an analytical approach aiming at breaking down the demand by different categories of customers with specific consumption / demand behaviours and requirements:

Total demand= Domestic demand + Institutional demand + Commercial demand+ Industrial demand + Tourism demand

The demand of each category of customer can be written as follows:

Domestic demand = Σ Ri x Pi x Di +Σ (1-Ri) x Pi x D'i

Where
i = type of housing
Ri =% of housing i connected to the network
Pi =population living in type of housing i
Di =per capita demand of population in type of housing i connected to the network
D'i =per capita demand of population in type of housing i non connected to the network

Institutional demand= Demand of health sector + Demand of education sector + Demand of other public services =(IDH + IDE + IDO) x P

Where

P = Population
IDH = Per capita demand for health sector
IDE = Per capita demand for education sector
IDO = Per capita demand for other public services

Commercial Demand = CD x P

Where

P = Population
CD = Per capita demand for commercial activities

Industrial Demand = Σ indi x INDi

Where

i = type of industrial activity
indi = relevant indicator for industrial activity i (employees, production ...)
InDi = specific demand for industrial activity i

or

Industrial Demand = InDD1 x S1 + InDD2 x S2

Where

InDD1 = Industrial demand density in m3/ha for intensive industrial activity
S1 = Area occupied by intensive industrial activities
InDD2 = Industrial demand in m3/ha for small scale industrial activity
S2 = Area occupied by small scale industrial activities

Tourism Demand = Σ Bi x BORi x TDi

Where

i = category of accommodation
Bi = Number of beds in category i
BORi = Bed occupancy rate in category i
TDi = Per capita demand per occupied bed in category i

or

Tourism Demand = Σ Si x TDDi

Where

i = category of accommodation

Si = Area occupied by category i
TDi= density of demand in m3/ha for category i

Rate of connection to the network

The decision for a household to connect its house to the network is mainly linked to its capacity and willingness to pay which will depend on:

- The cost of the connection and the conditions of payment
- Its level of income.

Annex 3

Geotechnical Survey

37-2012-4R

November 29, 2012

Annex 3 - Kenya Coast Water Service Board, Water Supply Master Plan

Proposed sites of dams

Geotechnical and Geological Report, for the Feasibility Design Stage

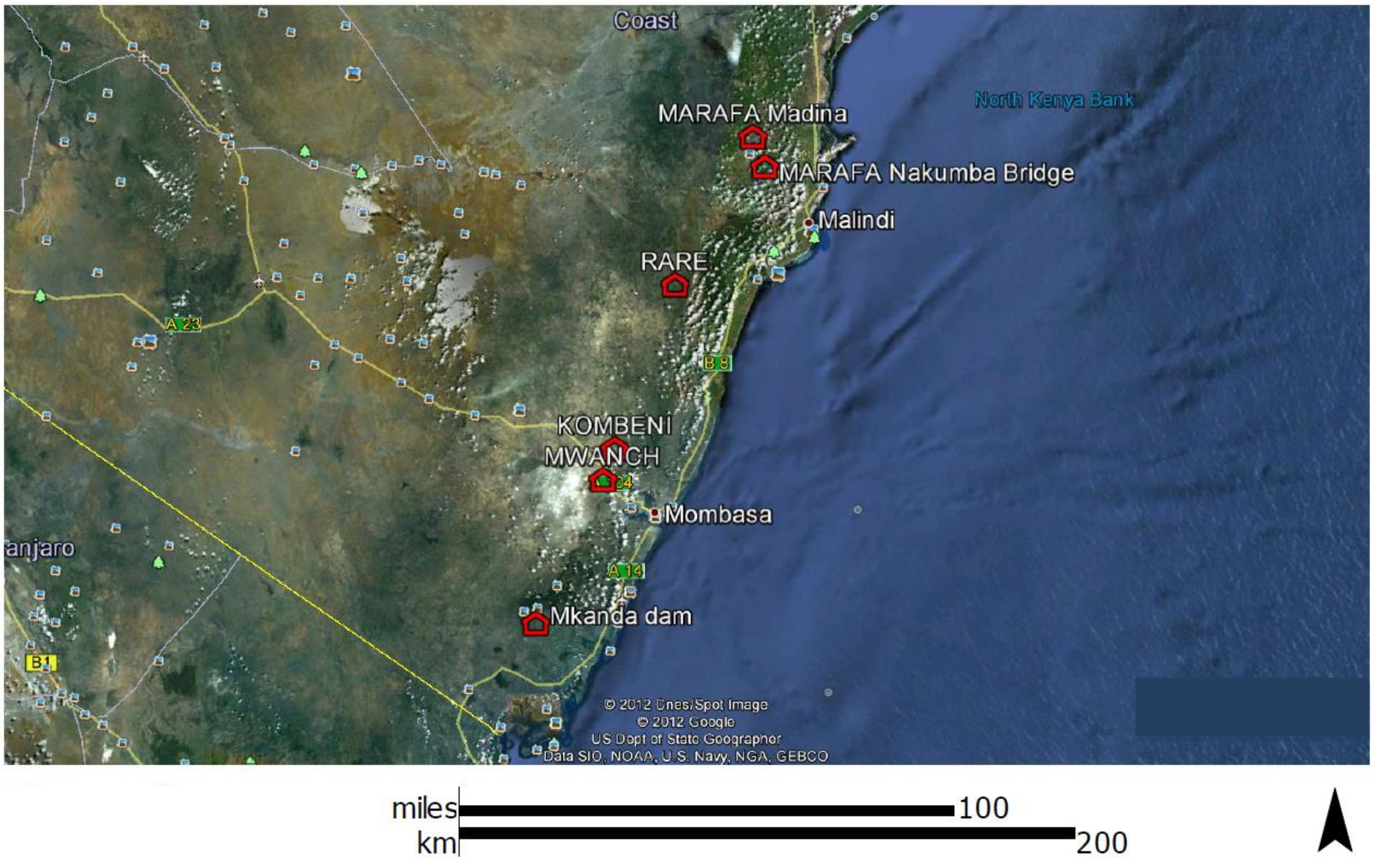

Figure 1 – The location of the proposed site for dams (taken from Google earth)

Dr. Israel Keissar, geotechnical engineer.

Geology – Mr. Moshe Levin, M.Sc

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1 Introduction

This report is a summary of Dr. Israel Keissar's visit to the proposed dam sites, which are part of the water supply master plan for Kenya coast water service board.
The visit took place on October 12 to 19, 2012.

The target of the visit was to prepare a geotechnical / geological preliminary report for the feasibility of constructing dams in the proposed sites.

Available data and maps:

- Geological maps and reports.
- Topographical maps, 1:50,000.
- Reports for Mwacha dam.

After long period of dry climate, heavy rains were poured on the region of Kenya's coast on 11 and 12 of October. During the visit to the proposed dam sites there was flow in the rivers. It was reported by the locals that the rivers were dry or with very low flow before these rains.

Figure 1 shows the location of the sites that were visited.

The geological background of the sites was prepared by Mr. Moshe Levin (M.Sc).

2 The geology of the area

2.1 General geology

The coast area of Kenya, and the areas of the dam sites, are located along the boundary between the western coastal lands and the Duruma-Wazir low lands. The dam sites at the south; Mikanda, Mwache and Kombeni, are located at the western slopes of Shimba hills (see Figure 2). This is being reflected in the geological conditions of Mikanda site, which is located close to the boundaries of the Jurassic-Triassic and Tertiary sediments. The dam sites at Mwache, Kombeni and Rare, are located within the Jurassic-Triassic sequence of sandstone and shale. The dam sites at Marafa are located within the zone of Cainozoic sediments, including Tertiary and Quaternary sediments (see Figure 3).

The general description of the rock units, related to the geological eras:

- The Triassic rocks are known as Duruma Sandstones and are subdivided into three members: Lower, Taru grits. Middle, Mariakani Sandstones and Maji-ya-Chumvi beds. Upper, Mazeras Sandstones and Shimba grits.
  These rocks were deposited under lacustrine and subaerial conditions, with minor marine facies.

- The Jurassic rocks are of marine origin and consist of; limestones, mudstones, shales and thin bands of sandstones. The Jurassic rocks have easterly regional dip, but these are downfaulted against the older Duruma Sandstone Series. Jurassic rocks are subdivided into five stratigraphic units (Caswell, 1956):
  - Changamawe Shales
  - Rabai Shales
  - Maritini Shales
  - Kibiongoni Beds
  - Kambe limestone
- The Cainozoic rocks (Tertiary and Quaternary) occur on the coastal strip of land, which is bordering the Indian Ocean, and include stratigraphic units belonging to Pliocene, Pleistocene and Recent periods. These rocks are composed of sands, dune sands, raised coral reef, crags, red wind-blown sands and raised alluvial deposits. These rocks are flat bedded and rest unconformably upon the older rocks.

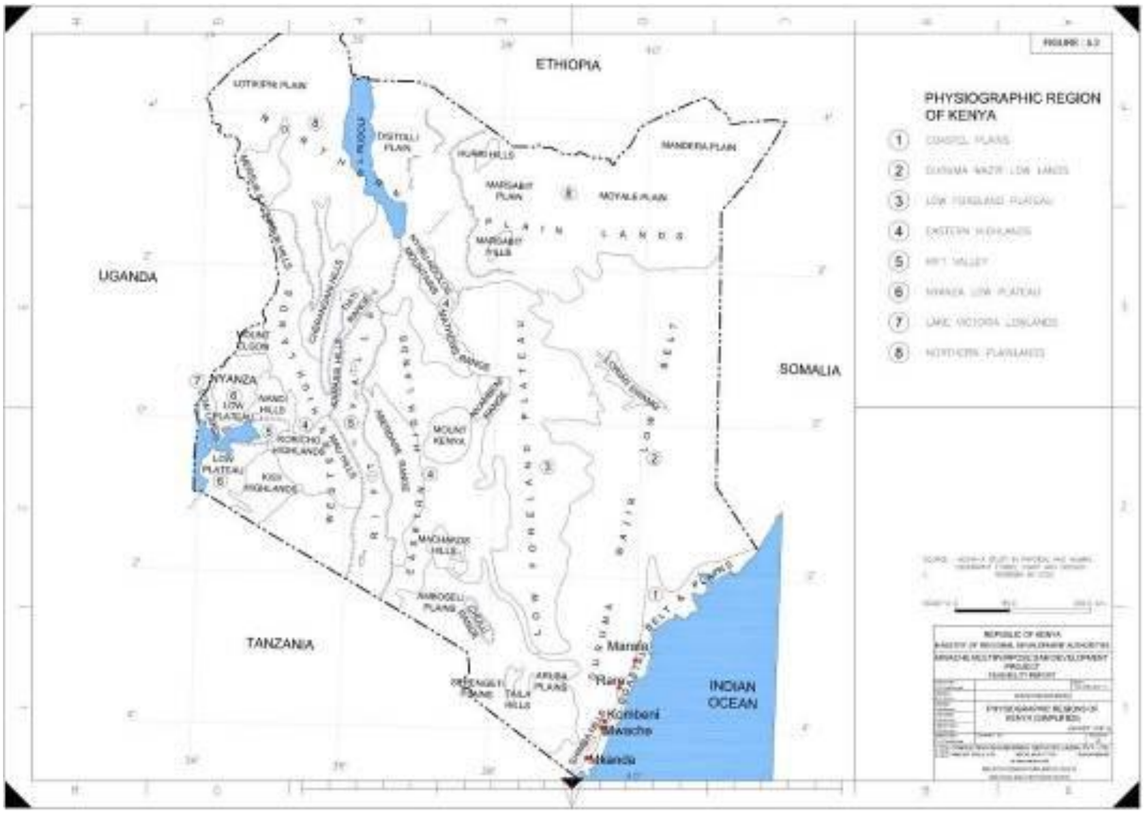

Figure 2 - Location of the dam sites on the Physiographic Regions of Kenya (Source of map - CES report)

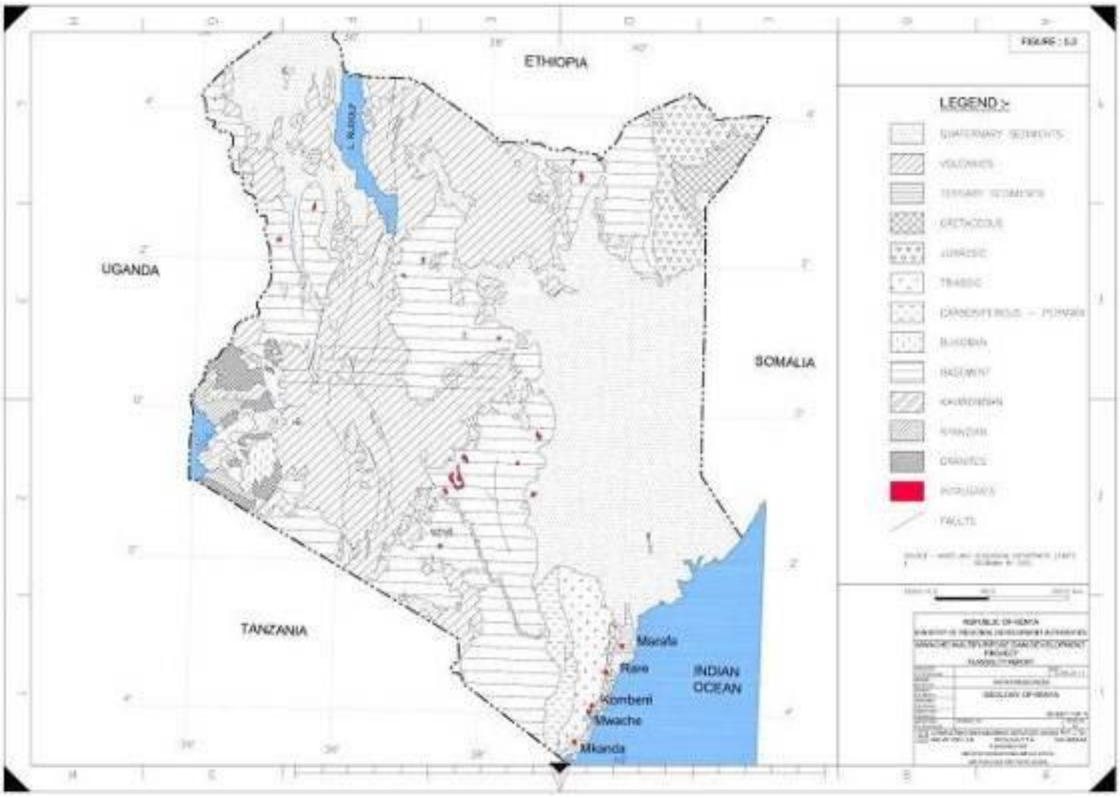

Figure 3 - Location of the dam sites on the Geological Map of Kenya (Source of map - CES report)

2.2 **Seismic Background**

According to the seismic zoning Map of Kenya (Figure 4), the dam sites are located in Zone-VI. In this zone the expected seismic events are of low to medium intensity.
In the “widely felt earthquake map” (Figure 5) there are almost no records of earthquakes in the coastal area. Epicenters of Earthquakes are located mostly in the rift valley. One epicenter is located close to Mikanda site.

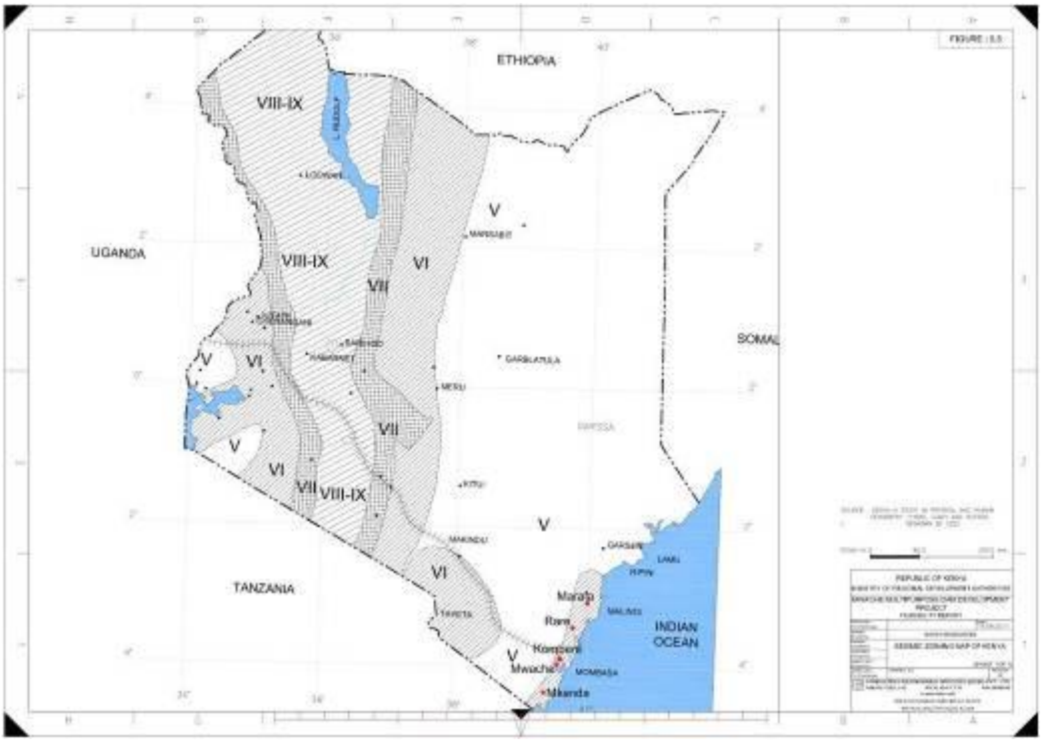

Figure 4 - Location of the 5 sites on the Seismic Zoning Map of Kenya
(Source of map - CES report)

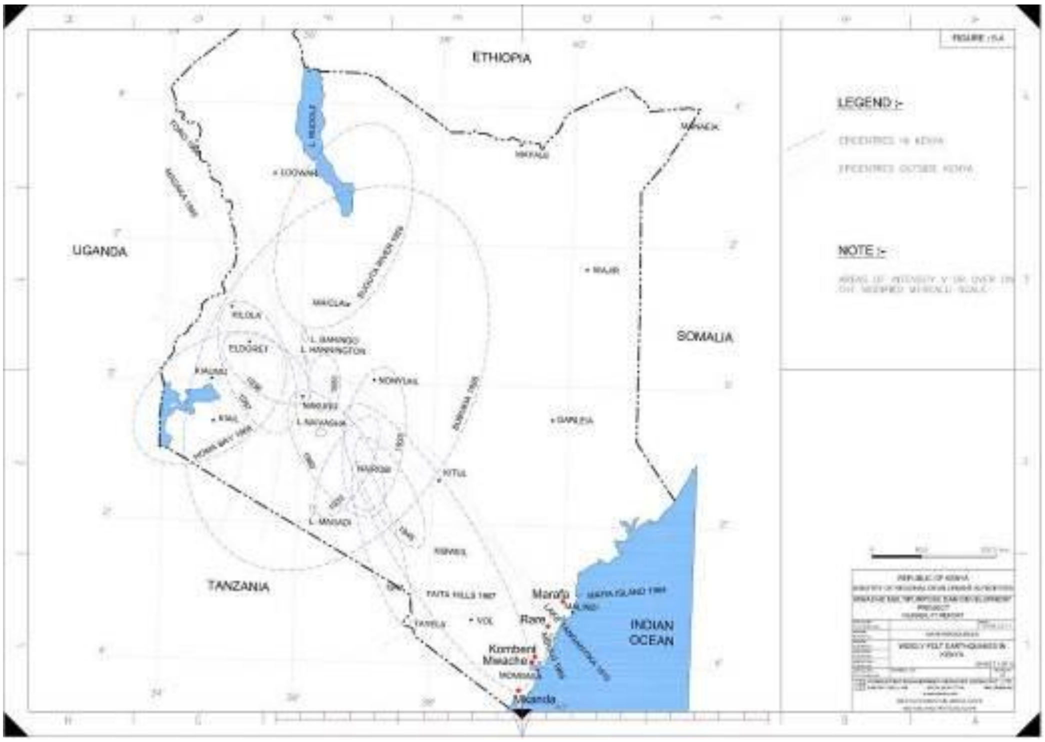

Figure 5 - Location of the 5 sites on the Widely felt Earthquakes in Kenya
(Source of map - CES report)

3 Mwache River

3.1 General

The map of the site is shown in Figure 6. The visit took place on 13.10.2012. The walking trail at the site is shown in Figure 7.

Various reports were issued for this dam and site by Samez Consultants Ltd. The last is, a feasibility study dated September 2011 (here after the "feasibility study"). This report is detailed and includes 8 boreholes.

Three locations for the dam were proposed (see Figure 6). The drilling works that were done as part of the feasibility study were done at location A. We agree that this is the favorable location. The feasibility report suggests a rockfill dam with clay core, 84.5 m high and length of 572 m.

3.2 The geology

The Mwache and Kombeni dam sites are located at the Triassic sequence of rock, which consists of sandstones and shale of the Mariakani and Mazeras formations. The sites were investigated by CES and detailed information exists in their feasibility report.

3.3 **The soil and rock layering**

The findings of the site visit, regarding the soil and rock layering, are similar to the data presented in the feasibility study.

Three main rock layers exist at the site, quoting the feasibility study:

"The Triassic rocks are known as Duruma Sandstones and subdivided into three members – Lower (Taru grits), Middle (Mariakani Sandstones and Maji-ya-Chumvi beds) and Upper (Mazeras Sandstones and Shimba grits). These were deposited under lacustrine and subaerial conditions with minor marine facies."

At the site the soil cover above the rock layers is limited in thickness.

The Durama Sandstones are layered but hard. The lower Taru grits rock, which is found at the river bed, is massive and the contacts between the layers are closed. The upper Mariakani and especially Mazeras layers have open fissures, horizontal and vertical. Yet, as reported in the feasibility study, these layers are zero Lugeon.

3.4 **Type of dam**

Rock fill dam, with impermeable core, is the required dam type for this site.

3.5 **Construction materials**

The lower Taru Sandstone is the main source for construction materials for the dam. This rock is being extensively used at the area for various uses such as; road construction as "bakalsh" and sub-base. Bricks for house construction etc.

Excavation of this rock from the flooded area can provide the required construction materials for the dam: the rock layer, the shale, gravel and sand for filters.

As part of the site visit we visited the near-by Hakika quarry (559940 / 9560970). The manager showed the products of the quarry from blasting and crashing (see photos sheet 1):

- Rocks of various sizes, as required, to be used as rockfill (product of blasting).
- "Balast' - Gravel of various sizes as required (product of crashing).
- "Chips" – Small gravel and sand (product of crashing).
- "Waste" – Silt size particles (maybe even clay) to small gravel (product of crashing). This material has no use or value for the quarry.

The manager claimed that the process of crashing is producing the following proportions: 50% Balast, 25% Flakes, 25% Waste.

Core soils:

The feasibility study claims that clay layers are available at the flooded area and can be used as fill for the dam core.

Our visit concentrated in the area of the dam. At this place it seems that the clay cover over the rock is limited in thickness.

In case adequate clay soil is unavailable, it may be considered using the “waste” of the crushing process (see photos sheet 1). This option is not common and questionable. From visual analysis of this material in Hakika quarry, it seems that it contains large fraction of fines, and that compacted material may have low permeability. Large quantities of this material are available in nearby quarries, and will be produced in the process of the excavation and crushing of rockfill for the dam.

The waste, as well as the clay soils, should be thoroughly tested to prove its adequacy as core material.

3.6 <u>Summary and conclusions</u>

A rock fill dam can be constructed at the proposed location on the Mwache River.

Excavation of rock layers from the flooded area can provide the required construction materials for the dam: the rock layer, the shale, gravel and sand for filters. The relatively thin cover of clay above the local sandstone may be used as core fill. Otherwise clay should be imported.

The layer of the lower Taru grits is a good foundation layer for the dam.

It seems as if this layer is massive and has low permeability. The upper Mariakani and especially Mazeras layers have open fissures, horizontal and vertical. Thus the contact between the dam and the riverbanks should be treated to prevent flow and erosion.

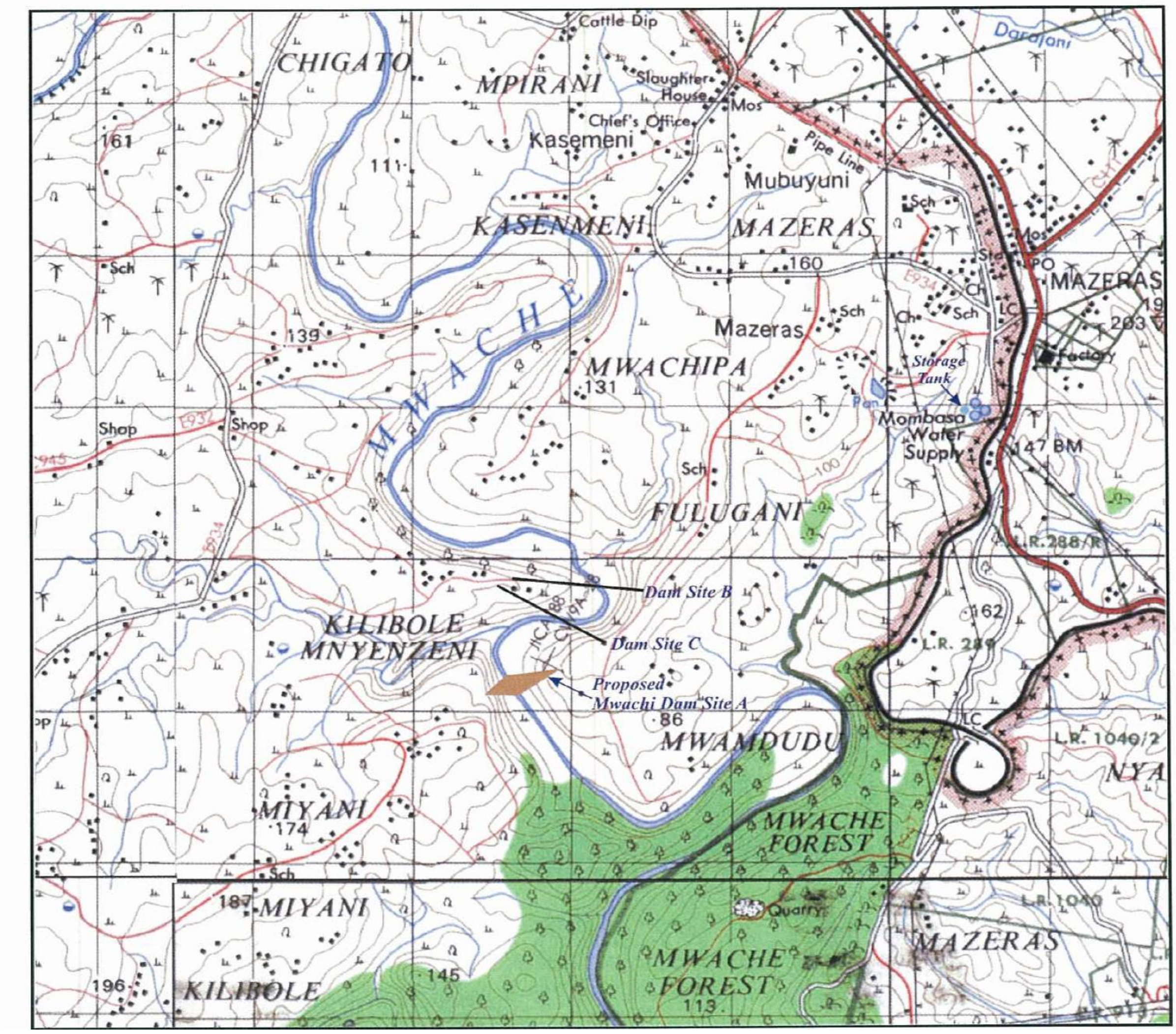

Figure 6 – Mwacha river, the proposed location of the dams

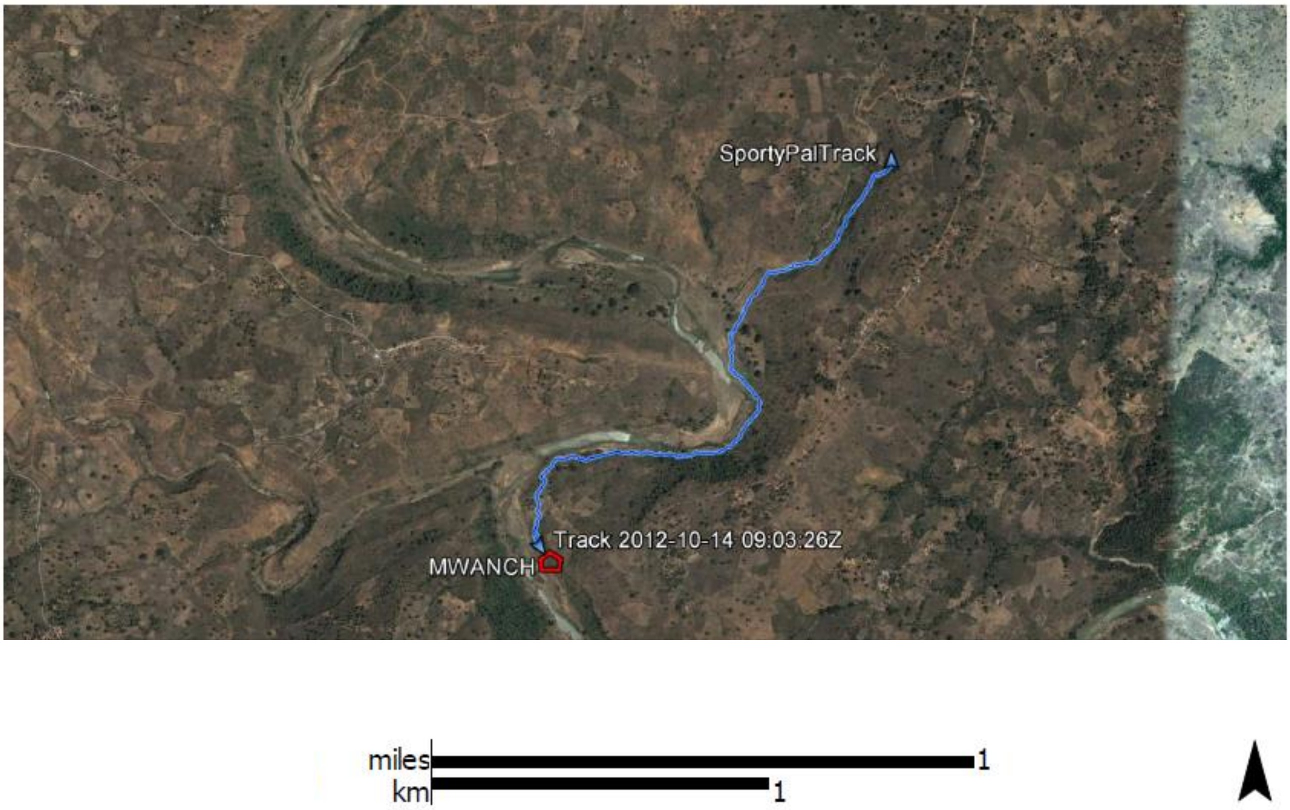

Figure 7 – Mwache river, the walking trail to dam location

Photo sheet 1 – Hakika quarry, products of blasting and crashing

4 Kombeni River

The visit took place on 14.10.2012.
The feasibility report for Mwache dam (Samez Consultants Ltd, September 2011) covers few aspects of Kombeni dam.

Two locations for the dam on Kmobeni River were proposed and visited: Kombeni 1 at 561540 / 9568780, and Kombeni 2 at 562390 / 9568010 (see location and the tour trail in Figure 8).

4.1 The site

See Photo sheet 2. At this section the river flows with a low gradient.
The river embankments are relatively shallow and gently sloped. As a rough visual estimation, the dam height can be up to 30 m and its length is 400 m.
In Kombeni 1 the slopes are similar in both banks. In Kombeni 2 the left bank is steeper.
Although very similar, it seems that the location of Kombeni 2 is favorable.
Construction of a dam at one of these sites will flood the bridge that exists upstream.
For the geology of the area, see paragraph 3.2.

4.2 The soil and rock layering

The geological conditions and rock layering at the Kombeni River are similar to those of Mwache River.
The upper layer of the Mariakani and Mazeras Sandstones are covered by sand and clay and could not be observed. But the lower Duruma Sandstone appears at the riverbed (see Photo sheet 2).

4.3 Type of dam

Rock fill dam, with impermeable core, is the required dam type for this site.

4.4 **Construction materials**

Same as Mwache dam.

4.5 **Summary and conclusions**

A rock fill dam can be constructed at the proposed location on the Kombeni River.
See the Mwache dam.

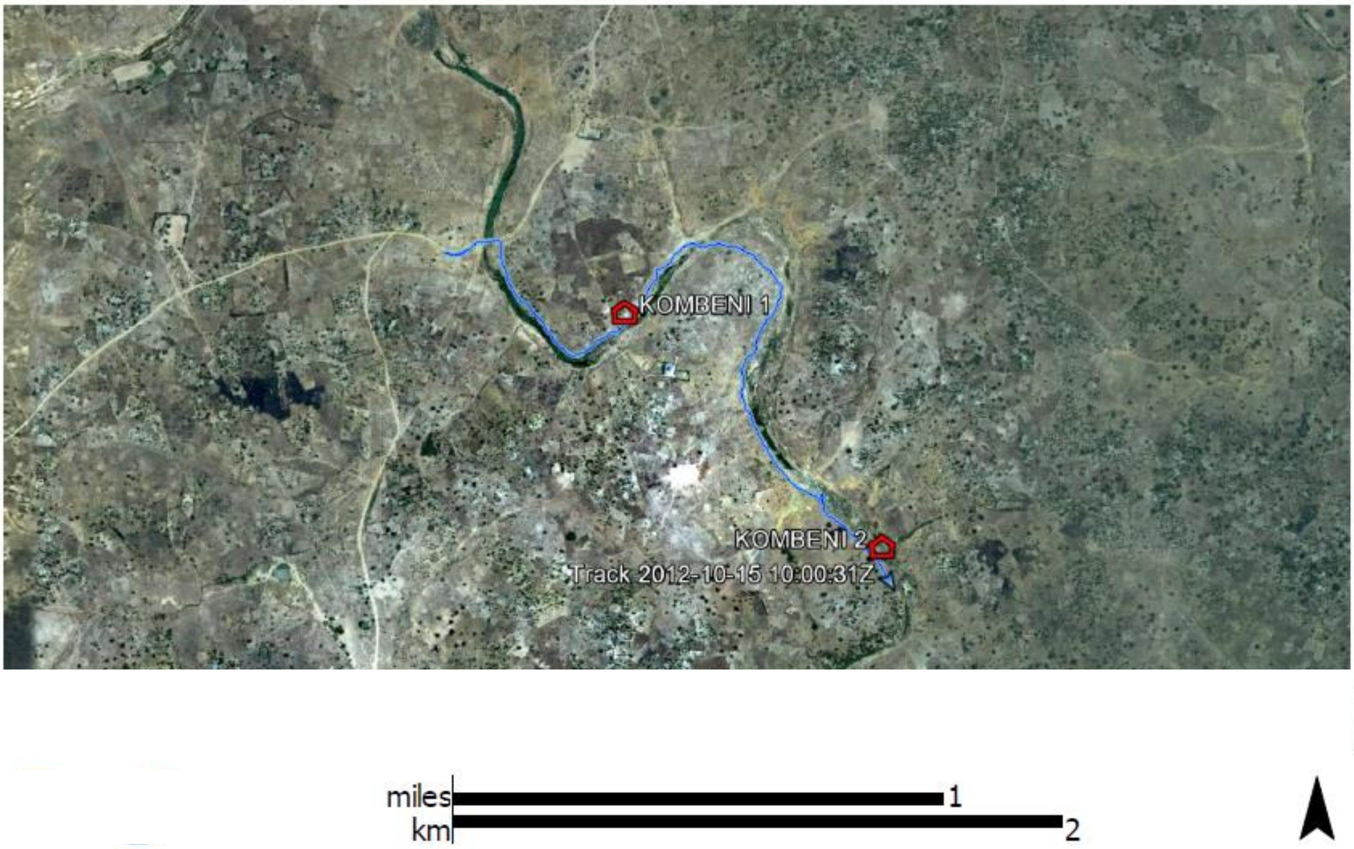

Figure 8 – Kombeni river, the walking trail and the proposed locations for the dam

Kombeni 1

Kombeni 2

Photo sheet 2 – Kombeni river, the two proposed locations for the dam

5 **Rare River**

The visit took place on 15.10.2012, and it was guided by Mr. Gwiya Madubi, the District Water Officer for Ganze.

Three locations for the dam on Rare river were proposed and visited (see location and the tour trail in Figure 9:

"Rare School" at 582100 / 9617030. Close to the local school.

"Rare Mangndo" at 581200 / 9620200. Close to the Mangndo irrigation project.

"Rare Pipe" at 583860 / 9617710. Close to the river crossing of the water pipe.

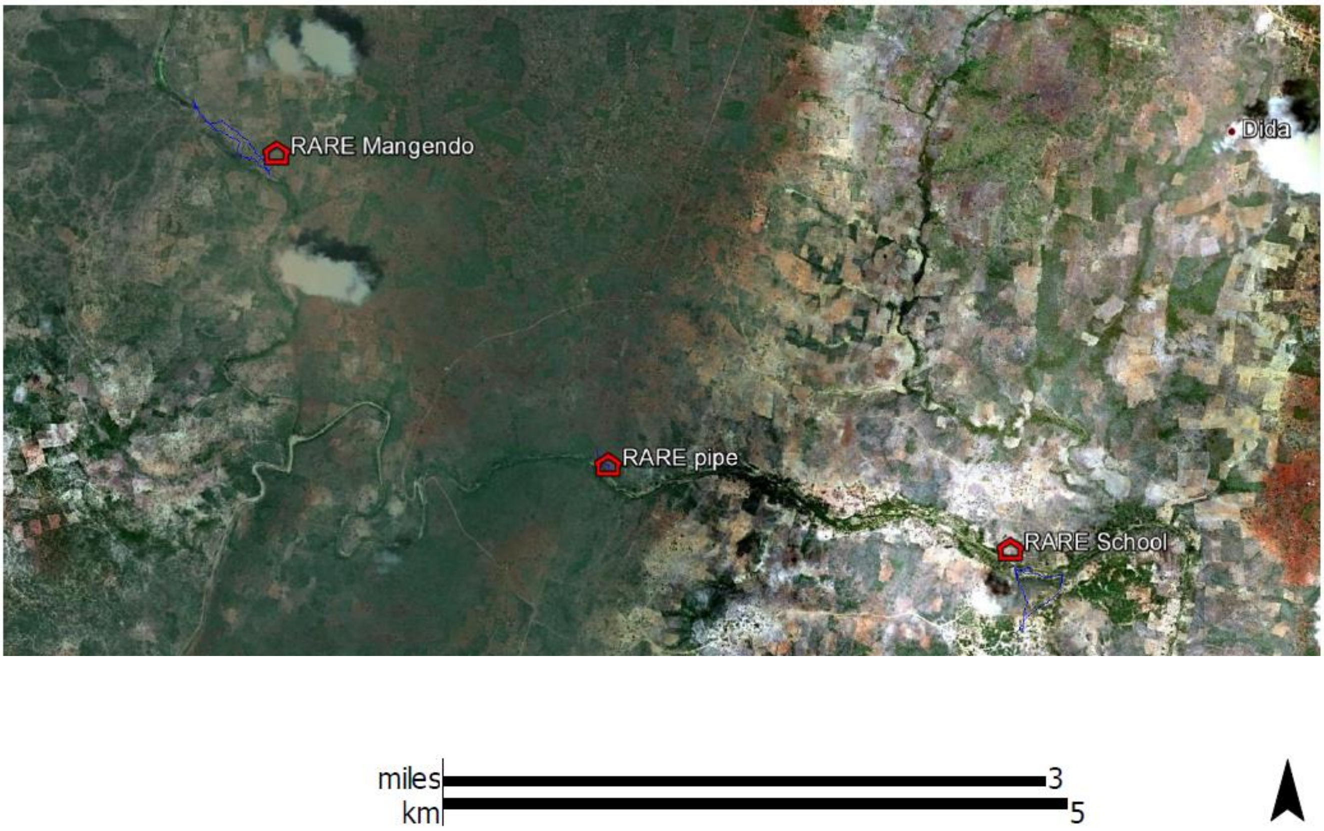

Figure 9 – Rare river, the walking trails and the proposed locations for the dam

5.1 **The geology**

The site is located close to boundary between the Triassic sequence of rocks (TJ-1 of sandstone) and the Jurassic sequence (J2-3 of Posidona shale and Kambe oolitic limestone). Figure 10 (Geology map of Malindi area sheet 66NE&67NW)) shows the Rare area on a 1:125,000 map. According to this map the site is located in the Mazeras and Mariakani sandstone (symbol Kz and Km on the map). The boundary between the two rock sequences is related to the major Lango Baya fault, with north-south direction. The distance between this fault and the dam site is less than 1km to the west. The fault separates between sandstone rock and limestone rock and is presented in the geological cross section (Figure 11). A second fault line, with west-east direction, is also marked on the map 2 km south of the dam site. This fault is probably related to horizontal displacement of the Jurassic rocks.

The area adjacent to the dam site is covered by relatively young Quaternary sediments of Qt1, which are defined as red Magarini sands. Although the dam site is not placed on the fault line it will be necessary to investigate this issue during the design stage

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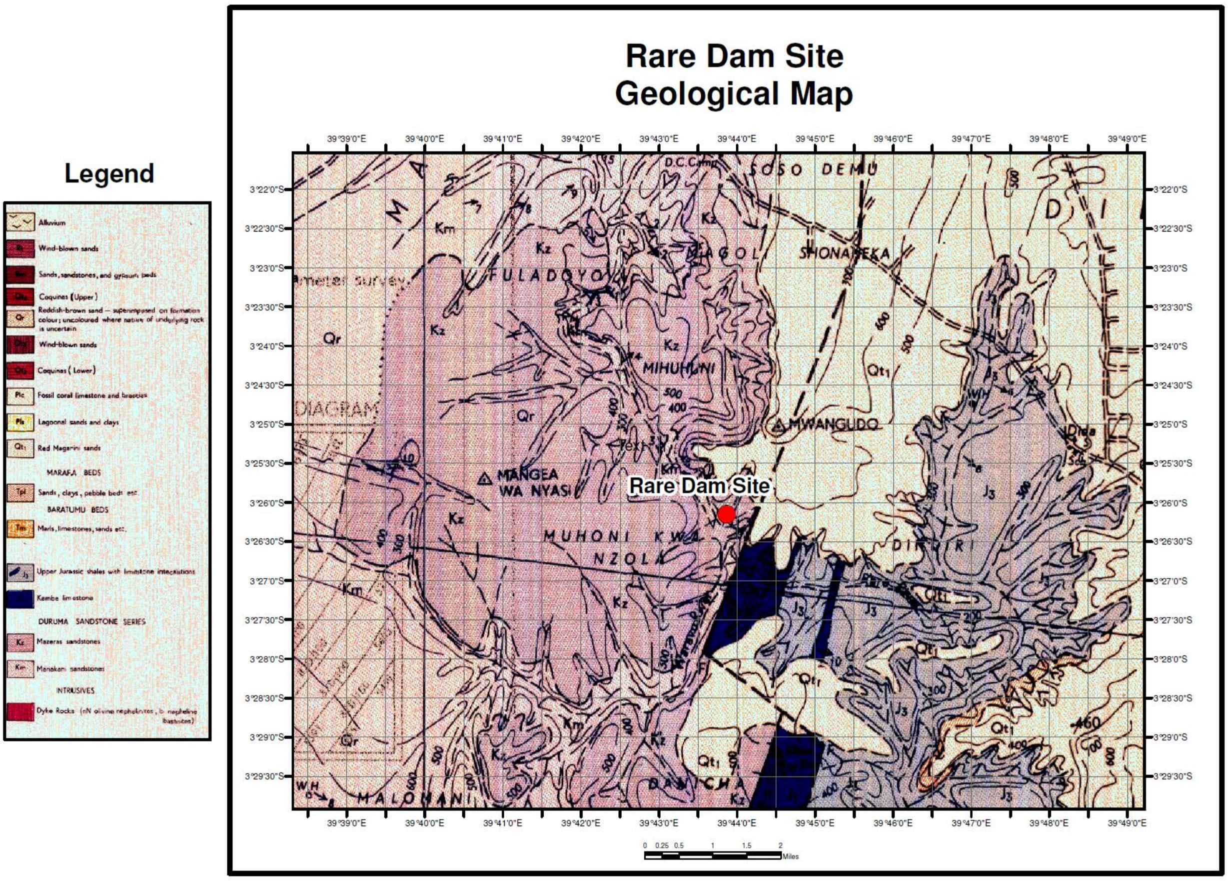


Figure 10 - Rare, Geological Map

(Source map Geological map of Malindi area sheet no. 66 NE and No. 67 NW)

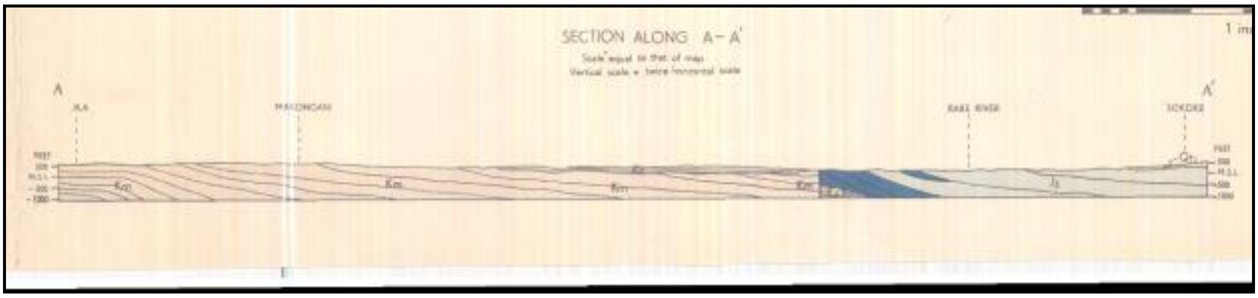


Figure 11 - Geological cross section of Rare area. The dam site is located less than 1 km west of the fault (Source map Geological map of Malindi area)

5.2 ***The site of* "Rare School" (at 582100 / 9617030)**

See Photo sheet 3. At this site the river flows with low gradient.
The right riverbank is steep and high. The left bank is shallow and lower.

The soil and rock layering:

The soil layering, at the river bank and the riverbed, is composed of varved Claystone (see Photo sheet 3).

The soil layering at this site (Claystone) are not favorable for dam construction. It is not recommended to locate the dam at this location.

Photo sheet 3 – Rare River, The site at "Rare School"

5.3 **The site of "Rare Mangndo" (at 581200 / 9620200)**

See Photo sheet 4. At this site the river is wide. There is a point where ridges limit the river width from both banks. Construction of a dam at this site requires a wide dam (estimated by more than 800 m), relatively low (estimated by max. 30 m).
Upstream of the proposed dam site the river widens into a flat, where farms of the Mangndo Irrigation Project are located. Building the dam at this location will flood these farms.

The soil and rock layering:

Two main rock layers exist at the site:
The river banks are composed of red Sandstone. The riverbed is composed of black, massive and hard Sandstone.

It is not recommended to locate the dam at this site, due to the width of the river and the impact on the existing farms.

Photo sheet 4 – Rare River, the site at "Rare Mongndo"

5.4 **The site of "Rare Pipe" (at 583860 / 9617710)**

See Photo sheet 5. At this site the river is narrow with sharp and high banks. As a rough visual estimation, a dam at this location can have the following dimensions: height 30 to 40 m, length 200 to 300 m.
The dam height should be limited so the farms of the Mangndo Irrigation Project, located approximately 5 km upstream, will not be flooded.
The existing main water pipe approximately 0.3 km upstream) and the Road Bridge (approximately 1.5 km upstream) will be flooded but can be rebuilt on the dam.

5.4.1 **The soil and rock layering**

The river banks and riverbed are composed of black, massive, well bedded, hard Sandstone.

5.4.2 **Type of dam**

Rock fill dam with impermeable core is the required dam type for this site.

5.4.3 **Construction materials**

The local black Sandstone is the main source for construction materials for the dam. This rock is being extensively used at the area for various uses such as; road construction as "bakalsh" and sub-base.
Excavation of this rock from the flooded area can provide the required materials for the dam: the rockfill layer, the shale, gravel and sand for filters.

Core soils:
Medium plastic red Clay is abandoned on the highland north of the river. This clay can be used as fill for the dam core. The locals claimed that the thickness of the clay varies. Around 583650 / 9620520 the thickness of the clay is over 6 m.
It should be mentioned that the area with clays are cultivated.

5.5 **Summary and conclusions**

Three sites were visited

"Rare School" at 582100 / 9617030. Close to the local school.

"Rare Mangndo" at 581200 / 9620200. Close to the Mangndo irrigation project.

"Rare Pipe" at 583860 / 9617710. Close to the river crossing of the water pipe.

The "Rare Pipe" site was found to be the most appropriate for the required dam.

A rock fill dam can be constructed at this location.

The local black Sandstone is the main source for construction materials for the dam: the rockfill layer, the shale, gravel and sand for filters. Clay for the core is available at the highland north of the river.

The black sandstone is a good foundation layer for the dam.

The riverbanks and their contact to the dam should be treated to prevent flow and erosion.

Photo sheet 5 – Rare River, "Rare Pipe" site

Photo sheet 6 – Rare River, the clay at plains north of the river

6 Marafa district

The visit to Marafa district took place on 17.10.2012, and was guided by Mr. Hamilton M. Kituri, the District Water Officer.

Three locations were proposed and visited (see location and the tour trail in Figure 12):

"Marafa Medina", on Medina River at 606500 / 9667000.

"Marafa Nakumba village", on Nakumba River at 607900 / 9657200.

"Marafa Nakumba bridge", on Nakumba River at 607870 / 9657750.

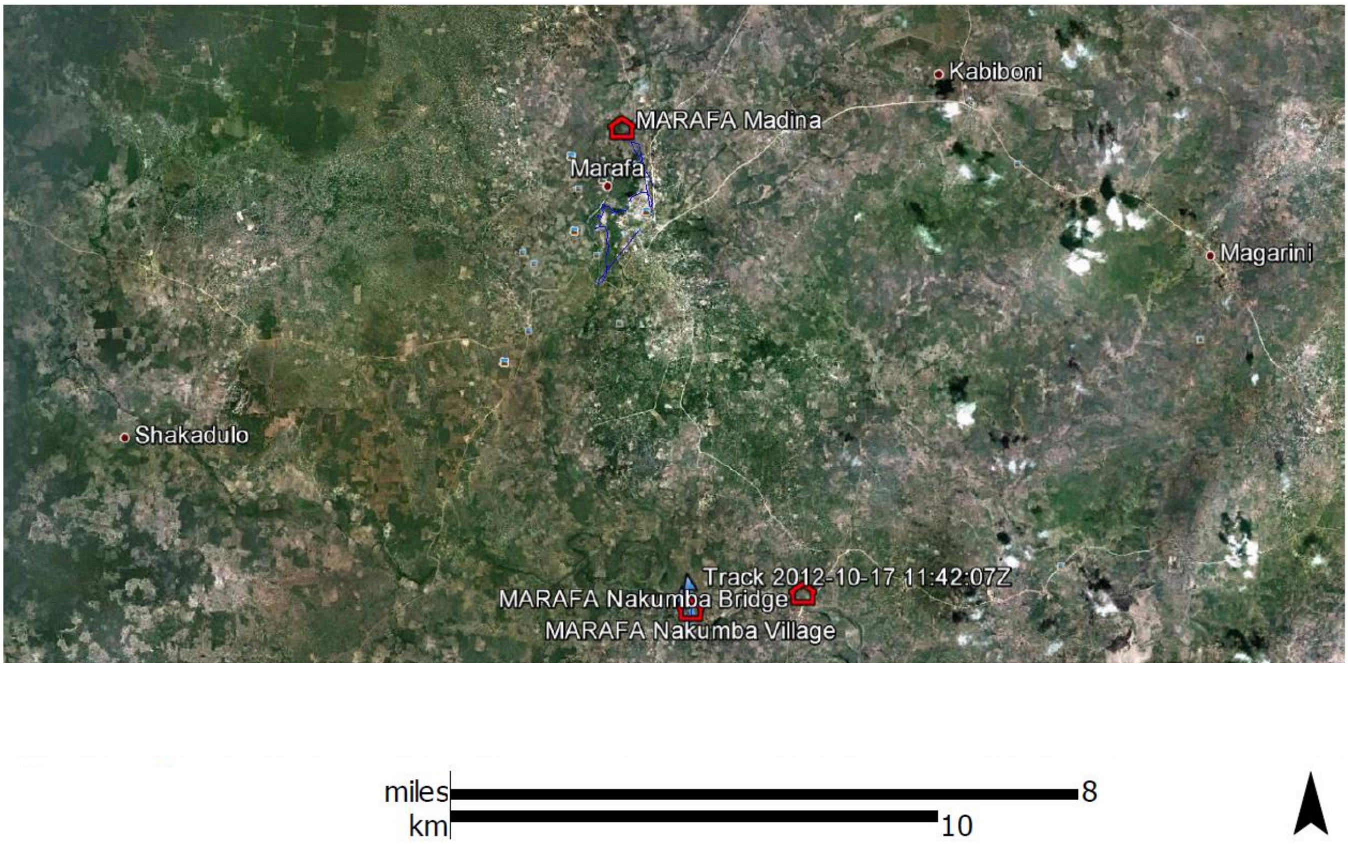


Figure 12 – Marafa district, proposed location of dams, and the walking trails

6.1 **The geology**

The Marafa sites are located in the Tertiary rock sequence, which includes: Sand, clay and pebbles of the Marafa beds (Tpl). Marls, limestone and sands of the Baratumu beds (Tm). The sand is mostly fine silty to clayey sand and has a unique form of erosion. A typical section of 33m of Marafa beds is presented in Report no. 33 (Geology of the Malindi area A.O. Thompson, 1954). It consists of a sequence of red sand with pebbles, greyish-white clayey sand and iron stained brown-yellow and red clayey sand. The Baratumu beds, which are exposed at the eastern side near Nakumba bridge, consists of limy sediment, which can be identified as marly limestone. A typical exposure of 106 m (Geology of the Malindi area A.O. Thompson, 1954) consists of: lower part of 30m marls with many fossils and calcareous nodules (may looks like travertine). Yellow marl and marly limestone of the Baratumu beds, covered by 5m of pebbles and gray clay of the Marafa beds. The top 70 m are layers of quartz pebbles and red Magarini sands (Qr)

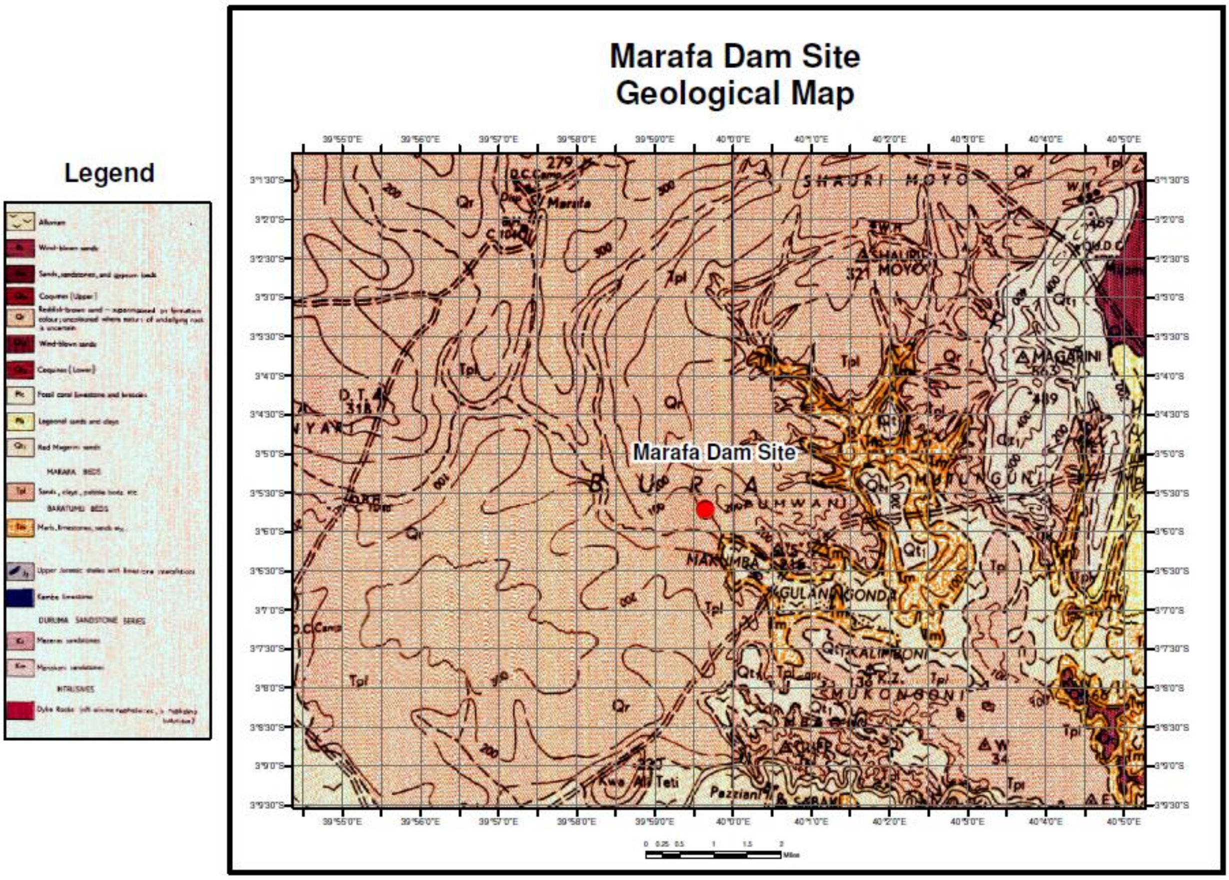


Figure 13 - Location of Marafa site on a geological map

(Source map Geological map of Malindi area sheet no. 66 NE and No. 67 NW)

6.2 **“Marafa Medina” at 606500 / 9667000**

Mr. Kituri, the District Water Officer, proposed this location north-west to Marafa village, on the Medina River. The site is flat with gentle hills (see Photo sheet 7). According to locals, the river basin at this site is flooded. The Medina River is flowing into the Nakumba River. The width of the river basin at this site and the low terrain dictates a very long and low dam.

The soil and rock layering:

The soil layering at the site is composed of layers of sand. Bedrock was not found at the riverbed. Massive erosion is developing at the east banks of the Medina River (see Photo sheet 7). The erosion site is a touristic attraction and called “Hell’s Kitchen”.

This site is not recommended for construction of a dam.

Photo sheet 7 – "Marafa Medina" site, the Medina River and erosion in the sands of its east banks ("Hell's Kitchen")

6.3 **<u>“Marafa Nakumba village” at 607900 / 9657200</u>**

This site, on the Nakumba River, is hilly with gentle slopes (see Photo sheet 8). The riverbed upstream of the proposed location for the dam is a swamp.

As a rough visual estimation, a dam at this location can have the following dimensions: height 20 to 30 m, length 600 to 800 m.

The soil and rock layering:

The soil layering at the site is composed of sand and maybe clay. Bedrock was not found at the river bed.

Dam type:

Earth-fill dam with Rip rap protection can be constructed at this site.

Construction materials:

Local soils, which will be excavated from the flooded area:

Sands, for the external side of the dam. Clays, for the internal side.

Rip-rap stones should be imported.

Photo sheet 8 – “Marafa Nakumba village”, the site

6.4 **"Marafa Nakumba bridge", on Nakumba River at 607870 / 9657750**

This site, on the Nakumba River, is very similar to the upstream site of "Marafa Nakumba village". The site is hilly with gentle slopes (see Photo sheet 9). At this location two ridges narrow the riverbed.

As a rough visual estimation, a dam at this location can have the following dimensions: height 20 to 30 m, length 400 to 600 m.

The soil and rock layering:

The soil layering at the site is composed of sand and maybe clay. Bedrock was not found at the river bed. The ridges at the river banks are formed of Travertine rock.

"Travertine is a form of limestone deposited by mineral springs, especially hot springs. Travertine often has a fibrous or concentric appearance and exists in white, tan, and cream-colored varieties. It is formed by a process of rapid precipitation of calcium carbonate, often at the mouth of a hot spring or in a limestone cave. In the latter, it can form stalactites, stalagmites, and other speleothems." (http://en.wikipedia.org/wiki/Travertine).

Locals use the Travertine as building materials, mainly as sub-base for tarmac roads.

Normally Travertine is a non-homogeneous rock, which contains voids and fissures and thus has relatively high permeability.

Dam type:

Earth-fill dam with Rip rap protection can be constructed at this site.

The quality and formation of the local Travertine is unknown. Thus construction of a dam at this location is questionable.

Construction materials:

Local soils, which will be excavated from the flooded area:

Sands, for the external side of the dam. Clays, for the internal side.

Rip-rap stones should be imported.

Photo sheet 10 - “Marafa Nakumba bridge”, the site

6.5 **Summary and conclusions**

Three locations were proposed and visited:
“Marafa Medina”, on Medina River at 606500 / 9667000.
“Marafa Nakumba village”, on Nakumba River at 607900 / 9657200.
“Marafa Nakumba bridge”, on Nakumba River at 607870 / 9657750.

The “Marafa Medina” site is not recommended for a dam site.
Earth fill dams can be constructed at “Marafa Nakumba village” and “Marafa Nakumba bridge” sites. “Marafa Nakumba village” site seems favorable.

Rock is not available at these sites. The dam can be built with the local soils: sand for the external side of the dam, and clays for the internal side. Rip-rap layer shall protect the embankment against erosion.

7 **Mkanda dam**

The visit to Mkanda dam took place on 18.10.2012, and was guided by the deputy of Mr. Mwidadi, the District Water Officer of Msambweni district. The location of the dam and reservoir is shown in Photo sheet 10. The visit was done only at the area of the dam.

Figure 14 – Mkanda dam and reservoir

7.1 **The geology**

Unit TJ1 (Figure 1 - geological map of Kenya), which is defined as the Triassic-Jurassic sequence of coarse sandstone, dominate the dam site area. Unit Q1, which consists of sands and gravel, is exposed west to the dam. Unit PT (Permian-Lower Triassic), which consists of shale and siltstone, is exposed at the south side of the dam site.

Recent erosion and weathering processes created the upper clay layer, which exists at the riverbed.

7.2 **The Mkanda dam**

The dam was constructed in 1979, after failure of the previous dam.
Based on visual estimation, the dimensions of the dam are: Length 150 to 200 m. Height of the external side up to 15 m.
The local operator of the pumping house claims that the depth of water in the reservoir, adjacent to the dam, is "70 feet".

Photos of the dam, its spillway, the intake and pumping house are shown in Photo sheet 11 and Photo sheet 12.

The soil and rock layering:
Hard and massive Sandstone layer is exposed at the riverbed.
The slopes above the reservoir waters are covered with clay and clayey sand.

The dam:
The dam is built in a narrow section of the river, above a drop in the riverbed.
The local operator said that the dam was not constructed with rocks. The exterior and interior faces of the dam are covered with rip-rap.
It can be concluded that the dam is built with earth-fill and rip-rap. The dam is built on the local Sandstone.
The external slope of the dam was observed. There are no signs of water piping through the dam.

The Spillway:
The spillway, approximately 40 m wide, is built at the left (western) side of the dam. The natural Sandstone is exposed at the spillway.

The Intake:
The intake is composed of 4 pipes (unknown diameter but probably 8") that cross the dam at its base, into a concrete box where 4 valves are located. From the box only two 8" pipes are leading to the pumping house.

The pumping house:

The pumping house contains positions to 3 boasters. At the time of the visit one diesel boaster is operating. An electric motor is installed on the second and hopefully soon will be operating. The total capacity of these 2 pumps is 50 m^3/hr.

Conclusions:

The dam looks stable. Problems were not observed or reported by the local operator.

It seems that Mkanda reservoir is not utilized to its full water potential.

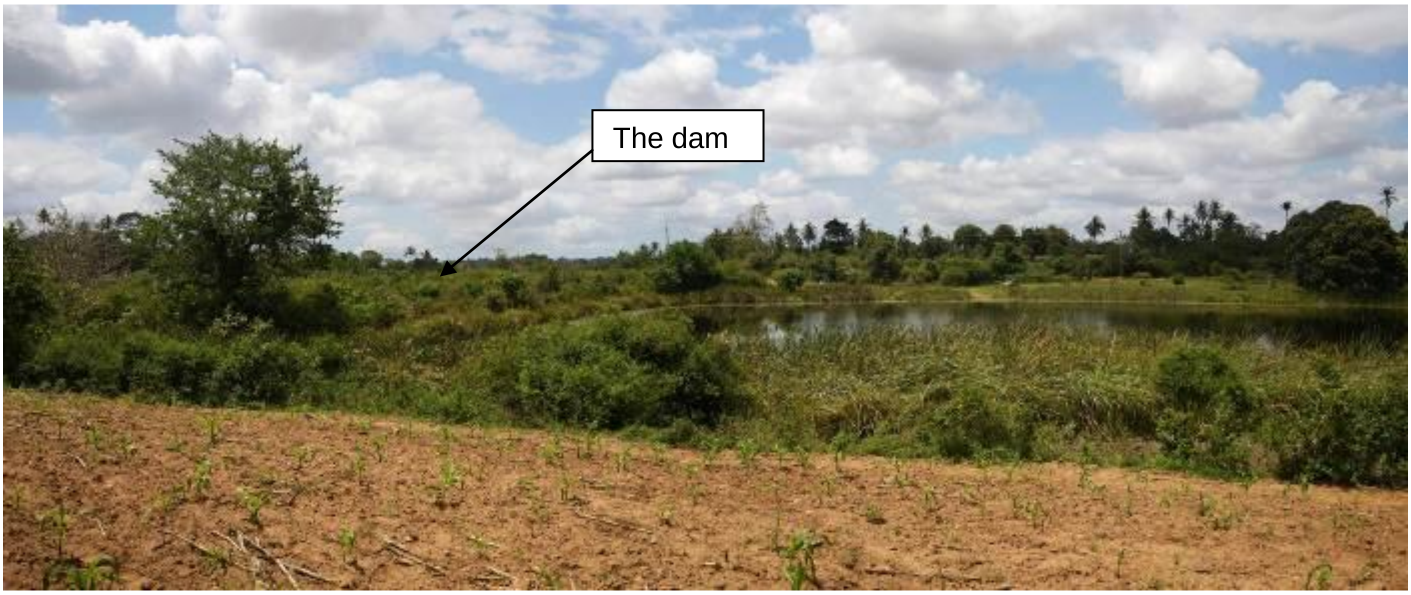


Photo sheet 11 – The Mkanda dam and reservoir

The external slope of the dam

The spillway, the local Sandstone and drop in the riverbed

Photo sheet 12

Photo sheet 13 – The Intake and pumping house

Annex 4

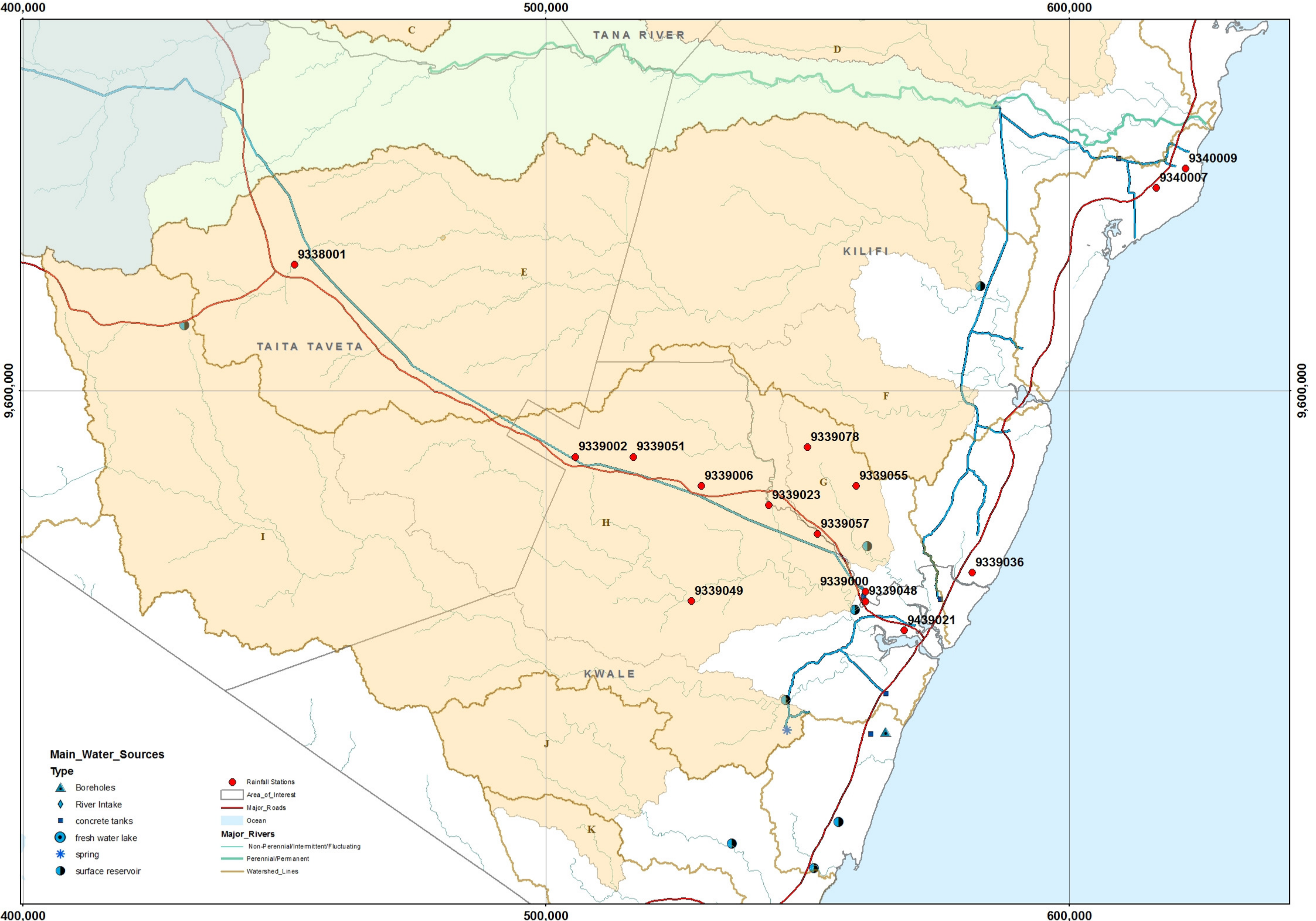
Hydrological and Flow Analyses

Available Rainfall Stations required for the Mombasa Project[3]

Station	Number	Lat.	Lon.	Available Data	Missing data
Lamu	9240001			1965-1988	
Mtwapa Agromet Station	9339036	3.933 S	39.733 E	**1959-2010**	
Msabaha Agromet Station	9340007	3.267 S	40.050 E	**1957-2011**	
Malindi	9340009	3.233 S	40.100 E	**1961-2009**	
Wilson Airport	9136121	257054	9854362	**1959-1988**	
Dagoreti	9136164	249630	9856199	**1959-1988**	
Makindu	9237000	370272	974569	**1959-1988**	
Voi	9338001	3^0 24' S	38^0 34' E	**1956-1988**	Before 1956 & after 1988
Garsen	9240010			**1965-1967; 1971-1988**	1968-1969
Garsen	9240043			1998-2011	
Mazeras Railway	9339000	3^0 58' S	39^0 33' E	**1959-1983;1985;1987;2001-2005**	1984; 1986; 1988-2000
Mombasa Old Observatory	9439002			**1959-1988**	
Mackinnon Road	9439002	3°44' S	39°03' E	**1926-1947; 1963-1994**	1948 – 1962; 1995-2000
Samburu Station	9339006	3°47' S	39°16' E	**1959-1996,2000-2001**	1997-1999
Moi Int. Airport[1]	9439021	4°02' S	39°37' E	**1959-1992**	
Maji Ya Chumvi Railway	9339023	3°49' S	39°23' E	**1959-2002**	
Mazeras Nurseries[2]	9339037			**1977-1988; 1990; 1996-1997**	1989; 1991-1994
Mazeras reservoirs	9339048	3°59' S	39°33' E	**1971-1992**	
Makamini Agr. Office	9339049	3°59' S	39°15' E	**1971-1986**	
Taru Secondary School	9339051	3°44' S	39°09' E	**1972-1991; 1993; 2000-2002**	1992, 1994-1999
Kayafungo Chief's Office	9339055	3°47' S	39°32' E	**1976-1996;1999-2008**	1997-1998
Mariakani Research Station	9339057	3°52' S	39°28' E	**1977-1996;2000-2009**	1997-1999
Tsangatsini Dispensary	9339078	3°43' S	39°27' E	**1982-1992;2000-2010**	1993-1999

[1] CWSSB Report claims that data is available for 1959-2011;[2] CWSSB Report claims that data is available for 1977-1997;
[3] In bold – data already available in hard copy or in EXCEL format

Station	Code	Original Data	Completed Data	Base Station	Comments
Mtwapa	9339036	1959-2009	1959-2009		
Malindi	9340009	1961-2009	1961-2009		
Msabaha	9340007	1957-2009	1957-2009		
Mombasa Port Reitz	9439021	1959-1988	1957-2009	Msabaha	
Mombasa Old Observatory	9439002	1959-1988	1957-2009	Mombasa Port Reitz	
Wilson Airport	9136121	1959-1988	1959-1988	Dagoreti	Gaps filling
Dagoreti	9136164	1959-1988	1959-1988	Wilson Airport	Gaps filling
Makindu	9237000	1959-1988	1959-1988	Self	Gaps filled by AV
Voi	9338001	1956; 1960-1988	1956-2009	Msabaha	
Samburu	9339006	1959-1982;1985-1996	1959-1982;1985-1996	Self	Gaps filled by AV
Maji Ya Railway Station	9339023	1959-1999 with gaps	1959-2009	Kayafungo, Mariakani,Self	Gaps filled by AV
Kayafungo Chief's Office	9339055	1976-2005 with gaps	1959-2009	Maji, Mariakani, Self	Gaps filled by AV
Mariakani Research Station	9339057	1977-2009 with gaps	1959-2009	Maji, Kayafungo, Self	Gaps filled by AV
Mackinnon Road	9439002	1926-1947; 1963-1994	1959-2009	Maji, Kayafungo, Self	Gaps filled by AV
Makamini Agriculture Office	9339049	1971-1985	1959-2009	Maji, Mackinnon	Gaps filled by AV
Mazeras Reservoirs	9339048	1971-1991	1957-2009	Port Reitz, Makamini	Gaps filled by AV
Tsangatsini	9339078	1982-1992; 2000-2009	1959-2009	Kayafungo	Gaps filled by AV
Garsen Development Dep.	9240010	1965-1967; 1971-1988	1959-2009	Msabaha	Gaps filled by AV



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Main_Water_Sources
Type
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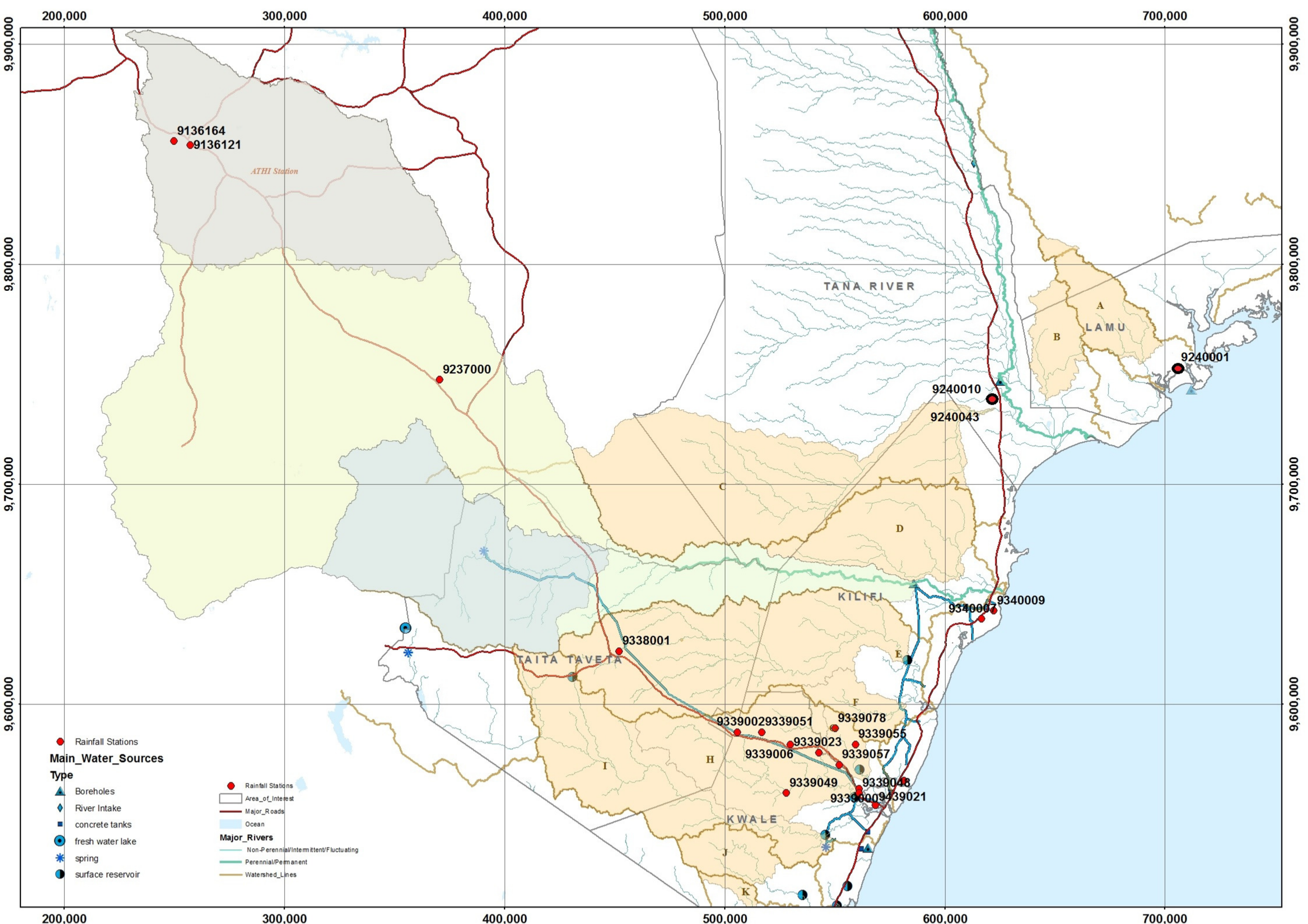
River Intake
concrete tanks
fresh water lake
spring
surface reservoir
Rainfall Stations
Area_of_Interest
Major_Roads
Ocean
Major_Rivers
Non-Perennial/Intermittent/Fluctuating
Perennial/Permanent
Watershed_Lines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ATHI Station
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Rainfall Stations
Main_Water_Sources
Type
Boreholes
River Intake
concrete tanks
fresh water lake
spring
surface reservoir
Rainfall Stations
Area_of_Interest
Major_Roads
Ocean
Major_Rivers
Non-Perennial/Intermittent/Fluctuating
Perennial/Permanent
Watershed_Lines

HYDROLOGY

2.1 GENERAL

Mwache and Kombeni Rivers comprise one of the main drainage basins that drain directly into the Indian Ocean within the Athi River Basin. The two river systems are adjacent to each other and drain areas of similar geographical features whereas Mwache River drains into the Indian Ocean through Mwache Creek at Port Reitz south of Mombasa Island, Kombeni River drains into ocean through Tudor Creek which is immediately north of Mombasa Island.

In order to assess the hydrological trends in the two adjacent sub-catchments, evaluation of the historical climatological and hydrological data was earlier undertaken.

The National Water Master Plan Sectoral Report (B) Hydrology, prepared in July 1992 by Japan International Co-operation Agency mainly covers hydrological analysis carried out for broad national level planning and also deals with formulation of some individual development schemes at national level. However, the Report does not provide complete details at local level. The report recommends that detailed hydrological analysis is necessary and the plan should be examined in subsequent studies on each river basin, district and project basis

Hydrological data for Mwache River exists for the period 1976 to 1990 recorded at River Gauging Station (RGS) 3MA03, which was located a few kilometers upstream of the proposed dam on Mwache River. This station was later abandoned. Since there are no other river gauging stations established on Mwache or Kombeni Rivers, the discharge analysis presented in this report is based on the analyses of rainfall records within the sub-catchment.

The proposed dam location (in the two sub-catchments) falls within the coastal region of Kenya with elevation varying from 0- 300m.a.s.l.

Hydrological studies for Mwache Storage Dam Project have been conducted to:

- Assess the availability of water from Mwache Dam for irrigation, domestic and industrial water supply and hydropower by utilizing available hydrological and hydrometeorological data
- Prepare reservoir Elevation-Area-Capacity curve of Mwache reservoir for determining its capacity and the area of submergence
- Estimate the design flood for dam and spillway design
- Develop rating curves at identified locations
- Assess reservoir sedimentation for fixing the Minimum Drawdown Level of the reservoir

2.2 RIVER SYSTEM AND BASIN CHARACTERISTICS

2.2.1 General

The coastal region is drained by the two major rivers, Tana and Athi (Sabaki) which rise from the central highlands in the interior. Other rivers draining the coastal areas include Mwache, Kombeni, Rare and Ramisi rivers. One of the notable aspects of the drainage of the coastal area is the fact that the water table is very close to the ground surface. Sea water seeps underground from the sea towards the land and as a result, the coastal waters tend to be salty and hard. The coastal areas also experience a general problem of water scarcity due to problems associated with the sandy soils, deficient rainfall and that there are not many perennial rivers flowing within the coastal area.

The Mwache River Basin

Mwache river basin covers an area of 2,250 km^2 within the 3MA sub-catchments of the Athi river drainage basin. Mwache river basin lies between 300 to 14 m.a.s.l.and exhibits gentle slopes in the upper regions and flat in the lower regions. The proposed dam site is located near Fulugani Village of Kasemeni Division, in Kinango District.

Catchment Characteristics of the Mwache River

Drainage Area	= 2250 km^2
Length of river	= 110 km
Average slope (m/100m)	= 0.27

Kombeni River Basin

Kombeni river basin is adjacent to and to the left of Mwache River basin. The diversion dam site has been proposed on this river with a catchment area of 445 km^2. The catchment elevation varies between 260 and 135m.a.s.l.

2.2.2 The Catchment

A plan of the catchment with main river network is shown in **Drawing No. 2010059/WR/MWA/FR/GEN-002**. The catchment upto proposed Mwache Dam site is T- shaped with catchment area of 2250 km^2. This catchment plan has been prepared using 1:50,000 Survey toposheet, Kenya.

Natural vegetation in the project area is reflected through the ecological range of vegetation due to the difference in rainfall and soil zones. Different types of vegetation in the coastal fringes are as under:

- Mangrove vegetation is found in the tidal creeks and in the river estuaries; Immediately behind the mangroves is a vegetation comprising woodlands and bush. Broad-leaved evergreen and deciduous shrubs are characteristic of this vegetation.

- Forest vegetation is found in isolated areas along the coast. In the past, the forests were extensive but have cleared and reduced, as more land has been brought under cultivation,
- The savanna grassland of dry type is found further inland behind the forest belt. This consists of mainly grassland, dotted with a few bushes and shrubs.
- At the western inland margin of the coastal region the Nyika (wildness) area begins. This is the driest part of the coast and it carries its own type of dryland Nyika vegetation consisting of semi-ever green thickets and bushes separated in some parts by grass. The baobab tree is most characteristic of this type of vegetation.

2.2.3 Hydro-Meteorological information

Kenyan coast experiences a warm, humid and moist climate. The climate is influenced by the monsoon wind system, which brings two rainfall seasons. Between January and March, the north-east monsoons blow over the coast due to the low pressure belt over the southern part of the African continent. These winds come from the dry land mass of south-west Asia. They are dry winds also because they blow for only a short distance and for a short time period over the Indian Ocean. The presence of the cold Somali current further reduces the amount of moisture that these winds can pick up over the Indian Ocean.

Between March and September, the direction of the monsoons becomes reversed due to the apparent movement of the sun towards the equator, and the shifting of the low pressure belt. During this period, the south-east monsoons blow over the Kenyan coast. These are the main rain-bearing winds at the coast, as they blow for long distances over the Indian Ocean.

From September, the winds change direction once again and blow directly inland, bringing more rain to the inner coastal zones.

Precipitation Records

The coast region can be sub-divided into four rainfall zones that extend more along the coast than across it, namely;

(i) A narrow stretch extending from north of Mombasa to Shimoni in the south. This zone receives between 1270 and 1500 mm of rain annually;

(ii) Behind this zone and extending from just north of Malindi to the southern border with Tanzania is the second zone that receives between 1015 mm and 1270 mm of annual rainfall

(iii) Further inland and parallel to zone (ii) is third zone which extends from Patta Island in the north to the southern border with Tanzania. This zone receives between 760 mm and 1015 mm of rain annually;

(iv) The forth zone extends between Kolibia in Lamu District south through Hola, past Mackinon Road and south to the Tanzanian border. This zone receives between 510 and 760 mm of rain annually.

The rainfall decreases from the coast moving inland and this moisture gradient is reflected in the change in the vegetation cover, as well as in the type of crops grown. The rainfall decrease is depicted in ***Figure 2.1 and Tables 2.1 & 2.2*** where mean monthly rainfall at Mazeras Railway Station is compared with the rainfall at Tsangstsini Dispensary.

Most of the rainfall at the Kenyan coast occurs between March and July and in October to December with the maximum occurring in May and November as shown on Figure 2.1. The coastal region receives an average annual rainfall ranging from 500mm and 1200mm.

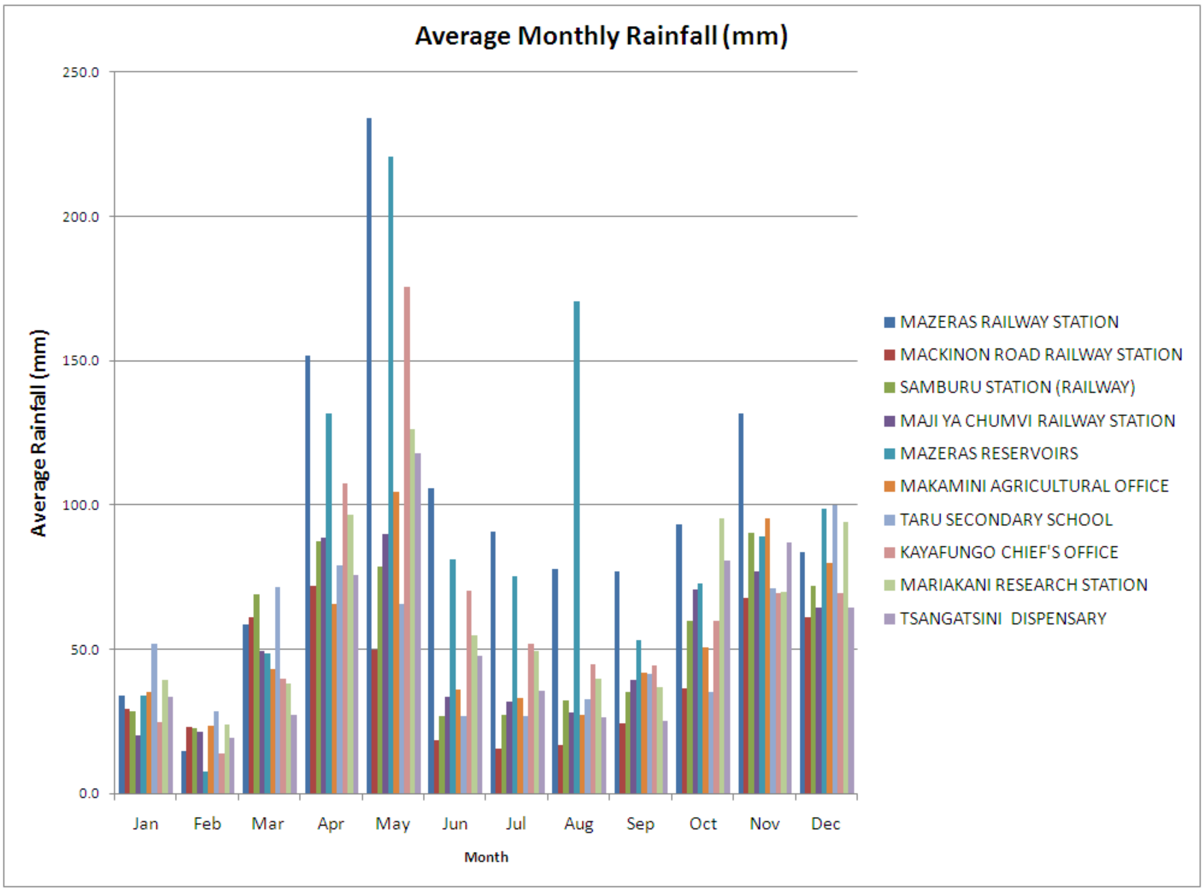

Figure 2.1: Monthly Average Rainfall : 10 Stations in catchment

Table 2.1 : Rain gauge station in Mwache Basin in Kenya

IDENTIFICATION	Name	District	Drainage basin	Latitude	Longitude	Elevation	Period of Data Availability
9339000	MAZERAS RAILWAY STATION	KILIFI	3M	3°58' S	39°33' E	163	1959-1983, 1985,1987, 2001-2005
9339002	MACKINON ROAD RAILWAY STATION	KWALE	3L	3°44' S	39°03' E	358	1962-1994, 2000
9339006	SAMBURU STATION (RAILWAY)	KWALE	3M	3°47' S	39°16' E	280	1959-1996, 2000-2001
9339023	MAJI YA CHUMVI RAILWAY STATION	KWALE	3M	3°49' S	39°23' E	166	1959-2002
9339048	MAZERAS RESERVOIRS	KWALE	3M	3°59' S	39°33' E	163	1971-1992
9339049	MAKAMINI AGRICULTURAL OFFICE	KWALE	3M	3°59' S	39°15' E	122	1791-1986
9339051	TARU SECONDARY SCHOOL	KWALE	3L	3°44' S	39°09' E	305	1972-1991, 1993, 2000-2002
9339055	KAYAFUNGO CHIEF'S OFFICE	KILIFI	3M	3°47' S	39°32' E	229	1976-1996, 1999-2008
9339057	MARIAKANI RESEARCH STATION	KILIFI	3M	3°52' S	39°28' E	183	1977-1996, 2000-2009
9339078	TSANGATSINI DISPENSARY	KWALE	3L	3°43' S	39°27' E	206	1982-1992, 2000-2010

Table 2.2: Monthly Mean precipitation data

Month	MAZERAS RAILWAY STATION	MACKINON ROAD RAILWAY STATION	SAMBURU STATION (RAILWAY)	MAJI YA CHUMVI RAILWAY STATION	MAZERAS RESERVOIRS	MAKAMINI AGRICULTURAL OFFICE	TARU SECONDARY SCHOOL	KAYAFUNGO CHIEF'S OFFICE	MARIAKANI RESEARCH STATION	TSANGATSINI DISPENSARY
Jan	33.8	29.1	28.6	20.1	33.8	35.0	52.0	24.6	39.1	33.5
Feb	14.7	22.9	22.6	21.4	7.7	23.5	28.4	13.7	23.8	19.2
Mar	58.4	61.1	69.1	49.5	48.7	43.2	71.7	39.6	38.0	27.2
Apr	151.9	72.1	87.6	88.4	131.8	65.5	78.9	107.5	96.4	75.5
May	234.2	49.7	78.7	89.8	220.8	104.5	65.6	175.4	126.1	118.0
Jun	105.7	18.4	26.9	33.6	81.0	35.8	26.8	70.3	54.9	47.6
Jul	90.9	15.7	27.3	31.6	75.3	32.9	26.8	51.9	49.3	35.4
Aug	77.8	16.8	32.4	28.0	170.7	27.2	32.7	44.6	39.6	26.3
Sep	77.1	24.3	35.3	39.4	53.2	41.7	41.3	44.1	36.9	24.9
Oct	93.3	36.6	59.8	70.8	72.8	50.7	35.2	59.7	95.3	80.6
Nov	131.6	67.7	90.2	76.8	88.9	95.5	71.1	69.4	69.9	87.1
Dec	83.6	60.9	71.8	64.3	98.5	79.9	99.9	69.6	93.9	64.4

Temperature

The project area experiences hot temperatures throughout the year with minor variations within the months. The maximum temperature varies from 27.8^0 C in July to 32.8^0 C in March. The minimum temperatures vary from 20^{0}C in July to 23.9^{0}C in March. The monthly temperature variation is shown in **Table 2.3 and Figure 2.2.**

Table 2.3: Monthly Temperature data at Kinango

Month	Max.Temp (deg. C)	Mini Temp (deg. C)	Mean Temp (deg. C)
Jan	32.4	22.9	27.65
Feb	32.8	23.1	27.95
Mar	32.8	23.9	28.35
Apr	31.4	23.6	27.5
May	29.8	22.5	26.15
Jun	28.7	21.1	24.9
Jul	27.8	20.2	24
Aug	28	20.1	24.05
Sep	28.7	20.7	24.7
Oct	29.7	21.7	25.7
Nov	30.6	22.7	26.65
Dec	31.9	23.1	27.5
Average	**30.4**	**22.1**	**26.258**

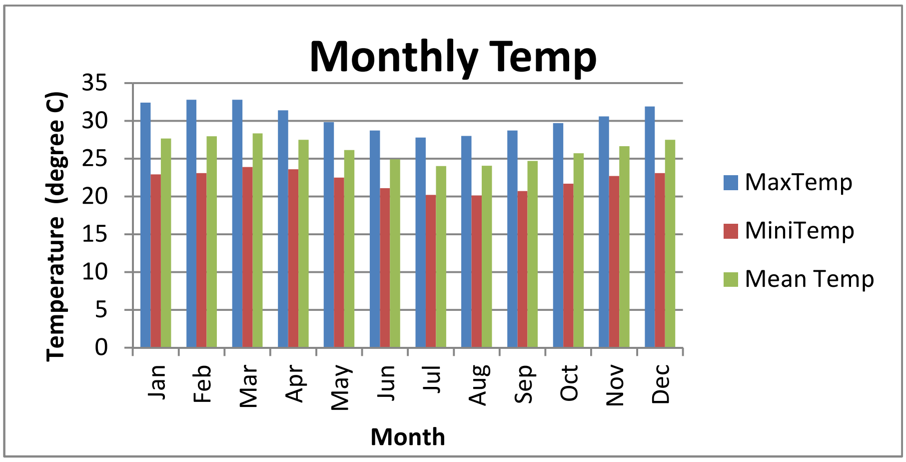

Figure 2.2: Monthly Temperature : Kinango

Relative Humidity

The Relative humidity data shows the Coastal nature of climate. Relative humidity varies between 70% - 75% from January to March and 65% - 67% from April to December. Refer **Table 2.4 and Figure 2.3.**

Table 2.4: Relative Humidity Data at Kinango

Month	Relative Humidity (%)
Jan	67.5
Feb	65.5
Mar	67.9
Apr	73.3
May	76.6
Jun	75.6
Jul	77.3
Aug	75.5
Sep	73.2
Oct	72.9
Nov	73.8
Dec	71.4
Average	**72.54**

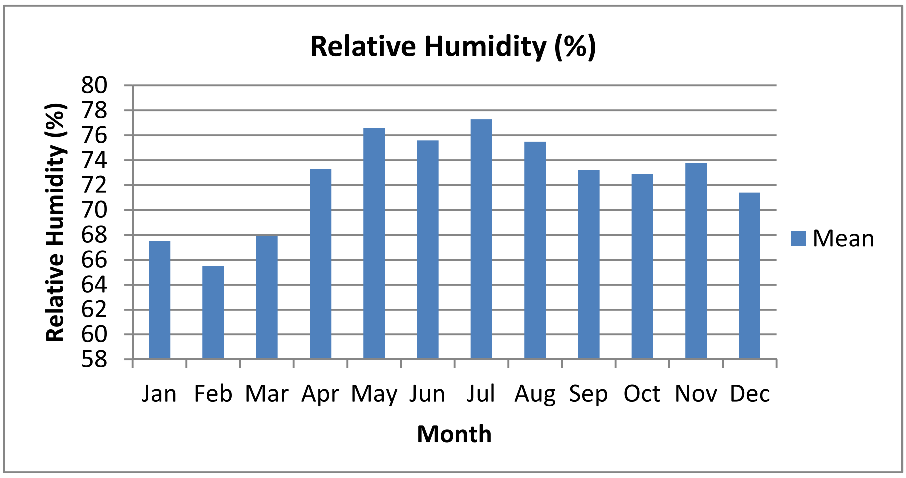

Figure 2.3: Monthly Relative Humidity : Kinago

Wind Speed

The wind speed is high in the coastal areas and is shown in ***Table 2.5 and Figure 2.4***

Table 2.5: Wind Speed Data at Kinango

Month	Wind Speed(Km/day)
Jan	237.5
Feb	230.6
Mar	207
Apr	237.5
May	257.2
Jun	266.1
Jul	258.4
Aug	244.1
Sep	244.1
Oct	231.7
Nov	179.6
Dec	206.3
Average	**233.34**

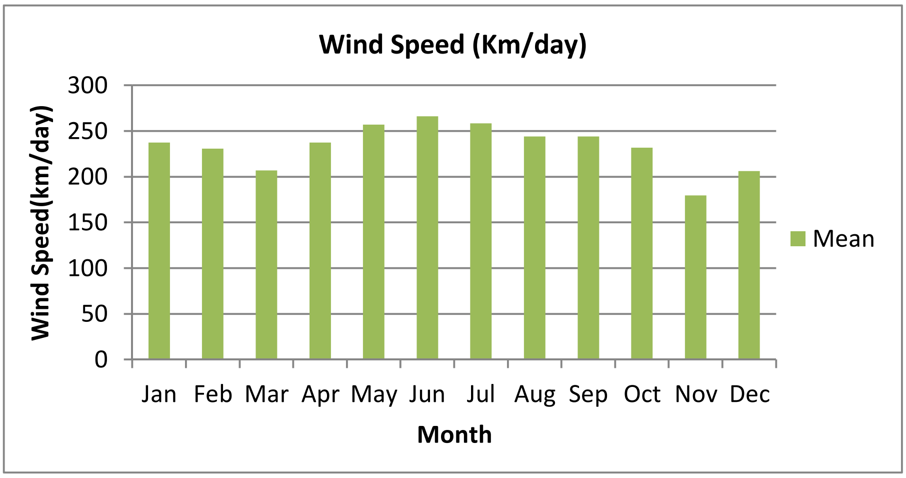

Figure 2.4: Monthly Relative Humidity : Kinango

Precipitation and Evapotranspiration

The precipitation is highest in the months of April and May while no or little precipitation occurs from March to December Annual Average precipitation is 852mm as against 1860mm of Potential Evapotranspiration in the region. 75% Dependable Annual rainfall is 610 mm. (Refer ***Figure 2.5***)

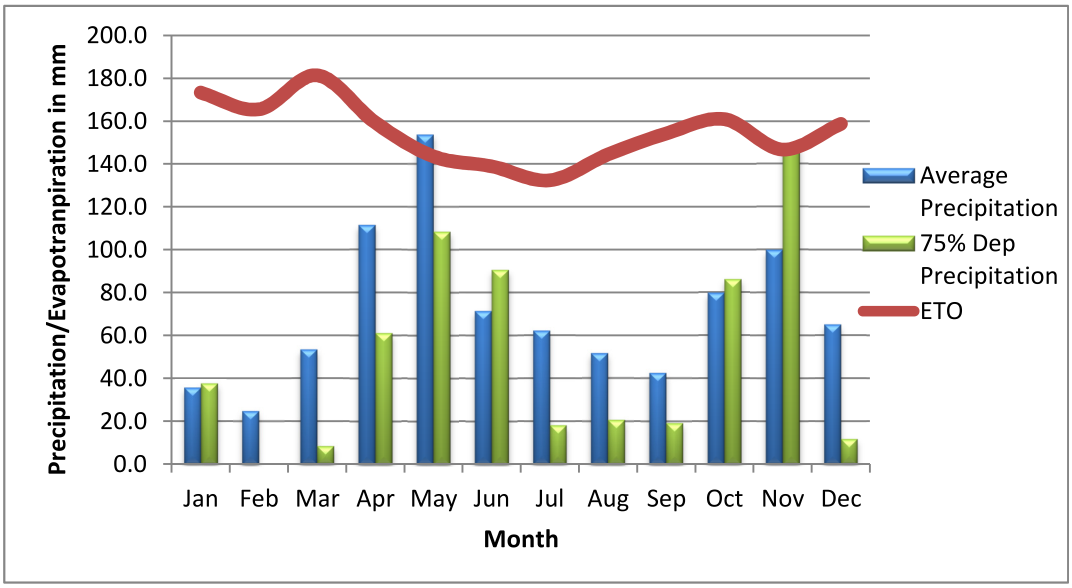

Figure 2.5: 49 year Average and 75% Dependable year Monthly Precipitation/ Evapotranspiration–Kinango District

Evaporation

Evaporation rates recorded at the Moi International Airport provide the appropriate parameter to describe evaporation variation in the project area. The mean monthly evaporation variation in the project area is shown in ***Figure 2.6***. The results indicate that the mean daily evaporation rates vary from 3.5 mm in July to 6.3 mm in February.

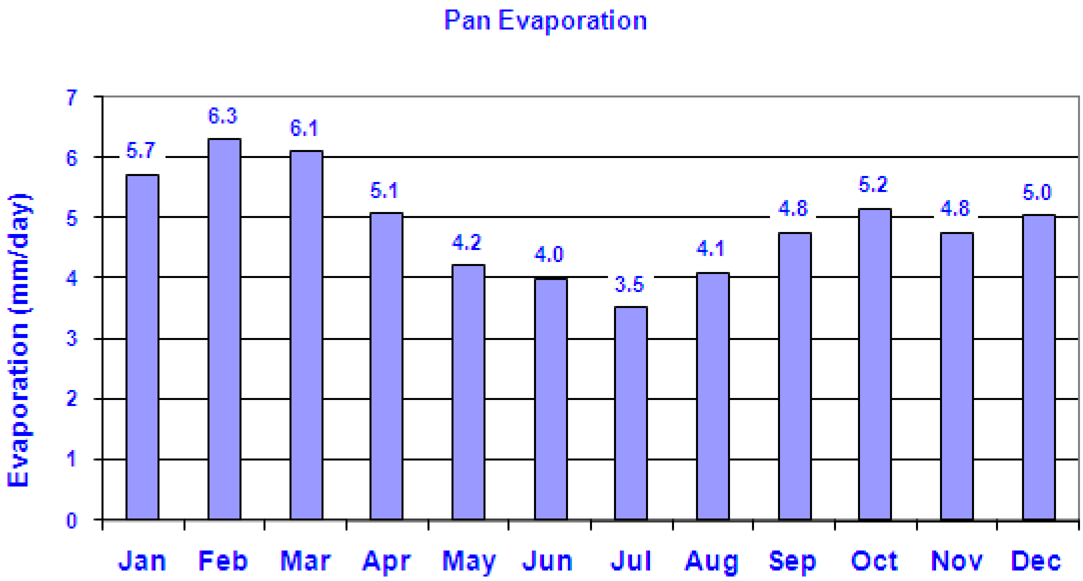

Figure 2.6.: Monthly Evaporation – Moi International Airport

Discharge Data

Daily flow data are available at Flow monitorial station **RGS 3MA03 (long 39.658 E and lat. 3.95 S).** The flow is high in the rainy seasons but becomes low immediately after rains and sometimes nil in extreme dry seasons. The data availability period ranges from 1976 to 1990.

Table 2.6 : Mean Monthly Discharge at Mwache River

Month	Annual Average Discharge (cumec)
JAN	3.0
FEB	2.2
MAR	5.6
APR	5.2
MAY	6.9
JUN	3.4
JUL	2.2
AUG	2.8
SEP	1.5
OCT	1.8
NOV	4.7
DEC	4.9

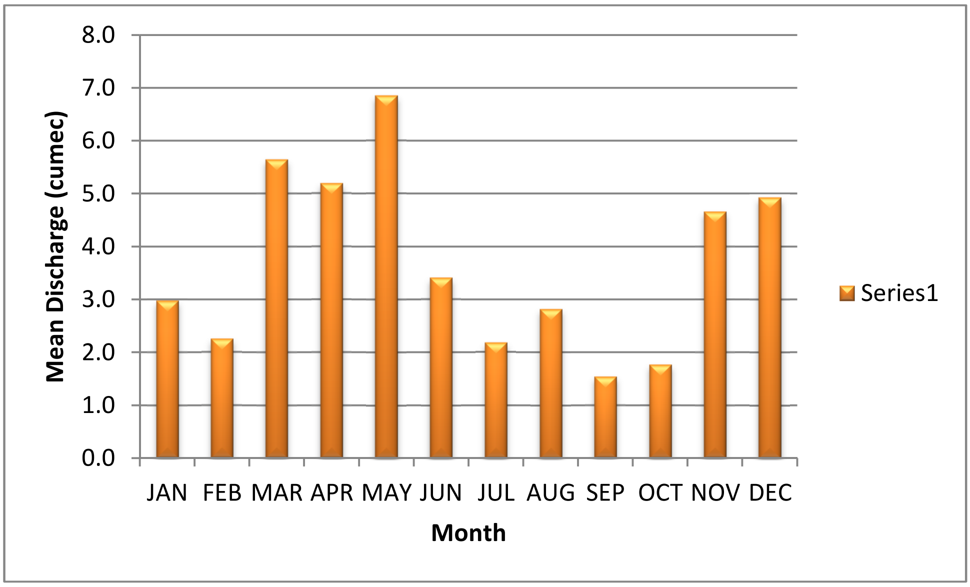

Figure 2.7: Mean Monthly discharge at Mwache River

2.3 WATER AVAILABILITY STUDY

The usual/ desired minimum length of data required for the simulation of the performance of water resource development projects in the face of hydrological variability is given below (Working Group Report, Ministry of Water Resources Govt. of India, 1980):

		Minimum length of data required
(i)	Diversion Project without pondage	10 years
(ii)	Diversion Project with pondage	10 years
(iii)	Within the year storage project	25 years
(iv)	Over the year storage project	40 years
(v)	Complex system involving combination of above	depending upon pre-dominant element

Considering that the Mwache storage dam project is multipurpose reservoir envisaged for irrigation, domestic & industrial benefits, the minimum data required for the hydrological study should not be less than 25 to 40 years.

2.3.1 Approach

RGS 3MA03 is the only operating station in Mwache basin and it is just upstream of the dam site. Its close proximity to the dam site means that the data is representative of the project area than any other. It gives a clear picture about the status of the water resources of the catchment. River Flow data of RGS 3MA03, observed from 1976 to 1990 is shown in ***Annex 2.1.***

Some daily readings are missing in the River flow data. Mean monthly series have been derived from the available river flow data and shown in ***Table 2.7***.

Table 2.7: Mean Monthly Observed Discharge Series of Mwache River

Unit: Cumec

Year	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
1976- 77	4.5	2.5	1.2	4.4	1.9	3.8	6.5	5.5	2.7	5.0	8.9	2.1
1977- 78	1.7	3.7	2.5	4.4	8.8	10.8	11.5	5.0	3.9	7.0	6.8	9.2
1978- 79	2.4	1.7	1.4	**NA**	**NA**	6.4	7.3	4.8	3.4	6.3	4.1	8.5
1979- 80	8.2	2.0	1.8	1.8	1.9	4.5	2.7	1.8	**NA**	**NA** -	3.3	1.9
1980- 81	1.4	**NA**	16.8	1.8	**NA**	6.4	6.0	1.8	**NA**	14.3	6.8	3.1
1981- 82	2.4	1.5	0.7	2.8	3.7	3.7	5.3	1.9	1.2	0.0	4.1	20.3
1982- 83	3.2	2.9	1.7	1.7	4.2	3.8	4.9	1.0	**NA**	**NA**	2.3	6.0
1983- 84	4.6	2.1	1.5	2.0	1.1	1.0	1.6	1.3	**NA**	**NA**	6.8	**NA**
1984- 85	1.8	1.8	0.7	**NA**	1.6	6.3	4.1	3.5	4.6	1.3	2.2	5.2
1985- 86	1.1	3.8	1.8	**NA**	**NA**	3.0	3.8	1.3	1.3	5.4	6.7	11.1
1986- 87	5.6	1.3	**NA**	0.0	1.5	4.9	6.1	2.6	1.0	**NA**	3.9	12.2
1987- 88	1.8	1.7	2.8	1.5	**NA**	**NA**	1.9	4.4	1.1	7.6	8.3	2.4
1988- 89	7.1	1.3	0.9	1.1	**NA**	3.6	3.8	4.3	**NA**	3.9	4.5	4.8
1989- 90	2.0	**NA**	**NA**	**NA**	**NA**	2.6	3.6	2.4	1.1	**NA**	4.1	2.3

Note: NA – Not available

Filling up of the missing data is required to fit the data series suitable for the water availability study.

Three alternative studies have been carried out to fill up the missing data. Alternatives are the following:

1. Missing data is filled with the long term corresponding monthly average
2. As per consultant's visit to the site, it is observed that there is no flow during September and October. As such wherever data is missing during September and October, this is taken as Zero and missing data for remaining months are taken as corresponding long term monthly average.
3. Rainfall data for ten stations is available is shown in ***Table 2.1***. Discharge series and rainfall series for all the corresponding years (1976 to 1990) are compared. Ratio (Discharge/ Rainfall) are derived for the months. Then long term average of monthly discharge-rainfall ratios are calculated. Missing discharge data are filled from rainfall-runoff ratio applied to the corresponding month rainfall. (***Refer Annex 2.2 & Table 2.8***)

Table 2.8 : Mean Monthly discharge series of Mwache River (Option 3)

Unit : cumec

Year	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
1976- 77	4.47	2.46	1.23	4.42	1.87	3.79	6.48	5.46	2.74	5.05	8.88	2.09
1977- 78	1.67	3.69	2.47	4.44	8.77	10.83	11.45	5.00	3.86	7.02	6.78	9.22
1978- 79	2.36	1.71	1.37	1.39	**0.00**	6.37	7.32	4.76	3.41	6.32	4.13	8.51
1979- 80	8.22	2.01	1.77	1.81	1.94	4.53	2.75	1.78	1.50	1.70	3.35	1.85
1980- 81	1.36	2.40	16.75	1.75	0.42	6.37	5.98	1.81	0.00	14.26	6.77	3.12
1981- 82	2.43	1.49	0.69	2.76	3.73	3.68	5.32	1.94	1.19	0.02	4.06	20.33
1982- 83	3.18	2.90	1.73	1.73	4.19	3.76	4.87	1.04	0.00	3.50	2.34	5.99
1983- 84	4.59	2.11	1.53	1.95	1.09	0.97	1.56	1.32	0.00	1.60	6.77	3.47
1984- 85	1.82	1.78	0.74	0.75	1.58	6.28	4.06	3.52	4.56	1.30	2.18	5.24
1985- 86	1.06	3.78	1.84	0.75	0.69	2.99	3.80	1.30	1.26	5.42	6.75	11.08
1986- 87	5.65	1.32	1.50	0.00	1.50	4.88	6.09	2.65	1.02	0.00	3.88	12.18
1987- 88	1.75	1.65	2.75	1.51	1.80	0.51	1.87	4.38	1.13	7.57	8.28	2.41
1988- 89	7.14	1.28	0.89	1.15	1.30	3.61	3.80	4.32	0.00	3.86	4.46	4.76
1989- 90	1.97	0.94	0.94	4.20	5.80	2.61	3.63	2.40	1.07	8.40	4.06	2.29
Average	**3.40**	**2.11**	**2.59**	**2.04**	**2.48**	**4.37**	**4.93**	**2.98**	**1.55**	**4.72**	**5.19**	**6.61**

It would be seen that from the above studies that water availability is the minimum one (***As shown In Table 2.12)***. So for complete 14yrs series, option 3 is adopted. Option 3 also seems to be realistic.

The methodology for option 3 has been discussed in a schematic diagram as outlined below (Refer ***Figure 2.8***).

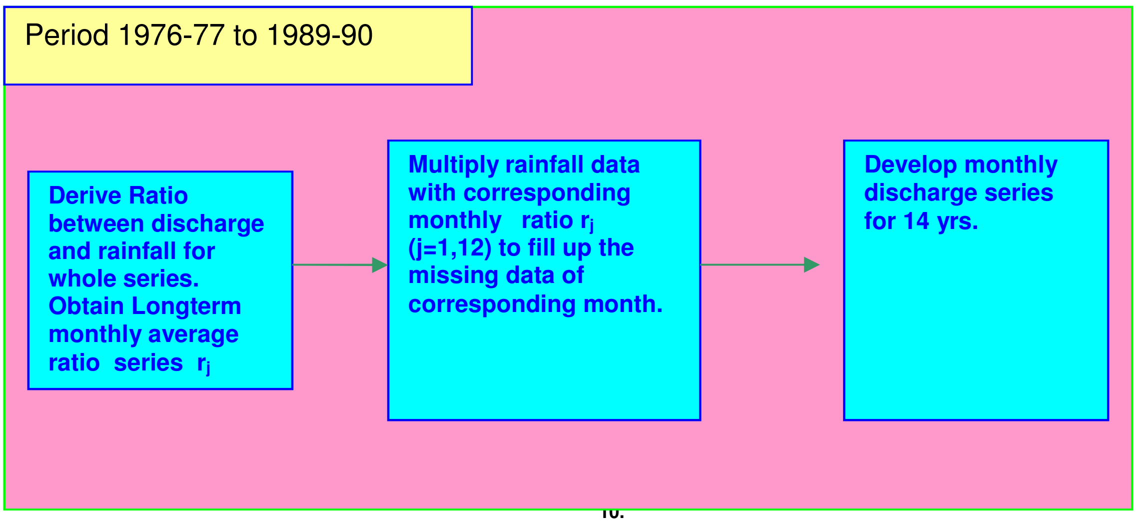

Figure 2.8: Schematic Diagram for developing monthly flow series of Mwache Dam site (Option 3)

Under the data limitations, synthetic generation of monthly stream flow series for Mwache is undertaken based on 14 years of monthly flow pattern besides considering the option of extending the flow series using upstream gauging station discharge data.

2.3.2 Consistency Check

Before conducting the Water Availability study, it is necessary to check the consistency of data of RGS 3MA03 station.

Homogeneity and stationarity of hydrological time series is important for the use of any time series in the hydrological studies. If hydrological time series is non-homogeneous, it is not possible to use the hydrological records for design studies before it is subject to appropriate correction. The cumulative sum plot as well the double mass analysis has been applied to investigate the homogeneity of average annual streamflows for the stations. For the stationary analysis *Sperman's Rank-Correlation method* has been be applied.

The data is therefore checked for internal and external consistency.

Internal consistency check

Mass Curve

The homogeneity test of hydrological time series was conducted for RGS 3MA03 time series by Mass curve analysis. In this method, the cumulative sum of the annual average streamflows is plotted against time. As seen from Mass curve in ***Figure 2.9***, it is clearly seen that the there is no abrupt change in mass curve, hence it is considered consistent internally.

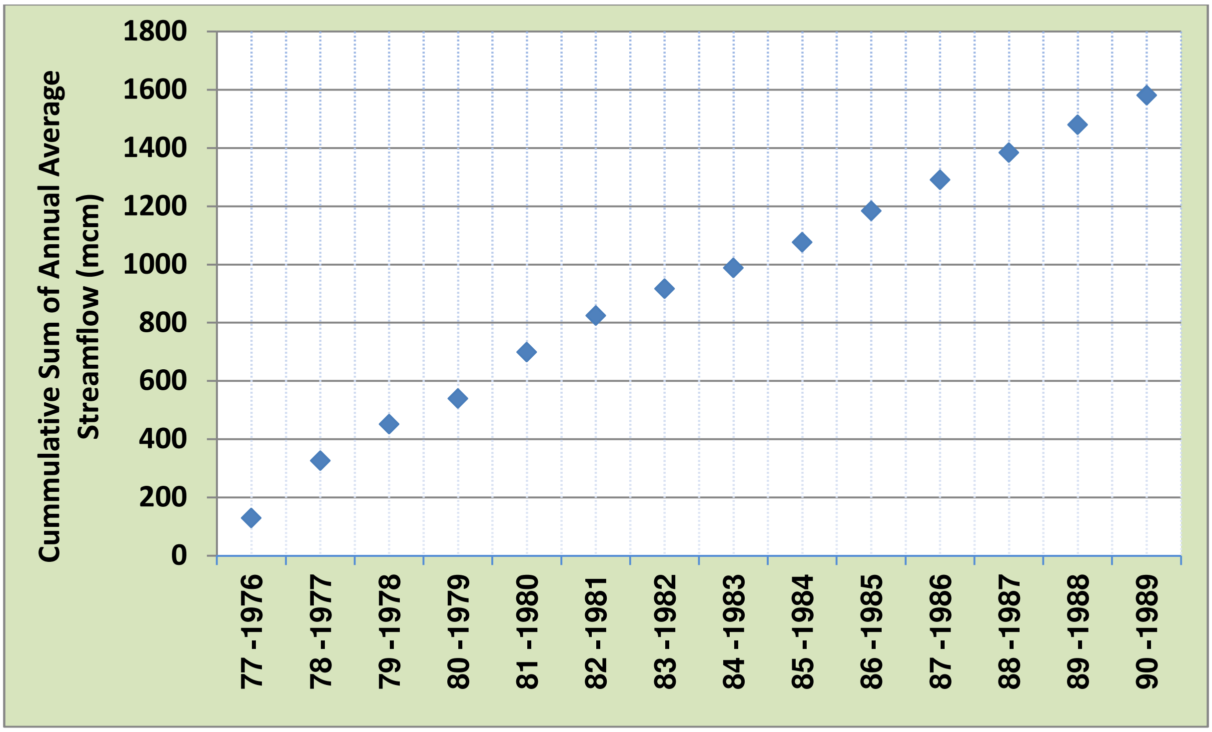

Figure 2.9: Cumulative Sum : RGS3MA03 (MCM)

Trend Analysis

Spearman's Rank-Correlation method was applied for the purpose of trend analysis (Dahmen and Hall, 1990). This method is simple and distribution free; i.e. it does not require the assumption of an underlying statistical distribution. The analysis indicates a downward trend in the streamflow at RGS 3MA03 as evident from ***Figure 2.10.*** This may be attributed to increase in flow diversion in the catchment upstream for irrigation. This behaviour is attributed to gradual increase in drawal for irrigation and domestic water over a period of time. Since after coming up of Mwache Project the area which has already developed will come under assured irrigation command, it is envisaged that the downward trend will stabilise.

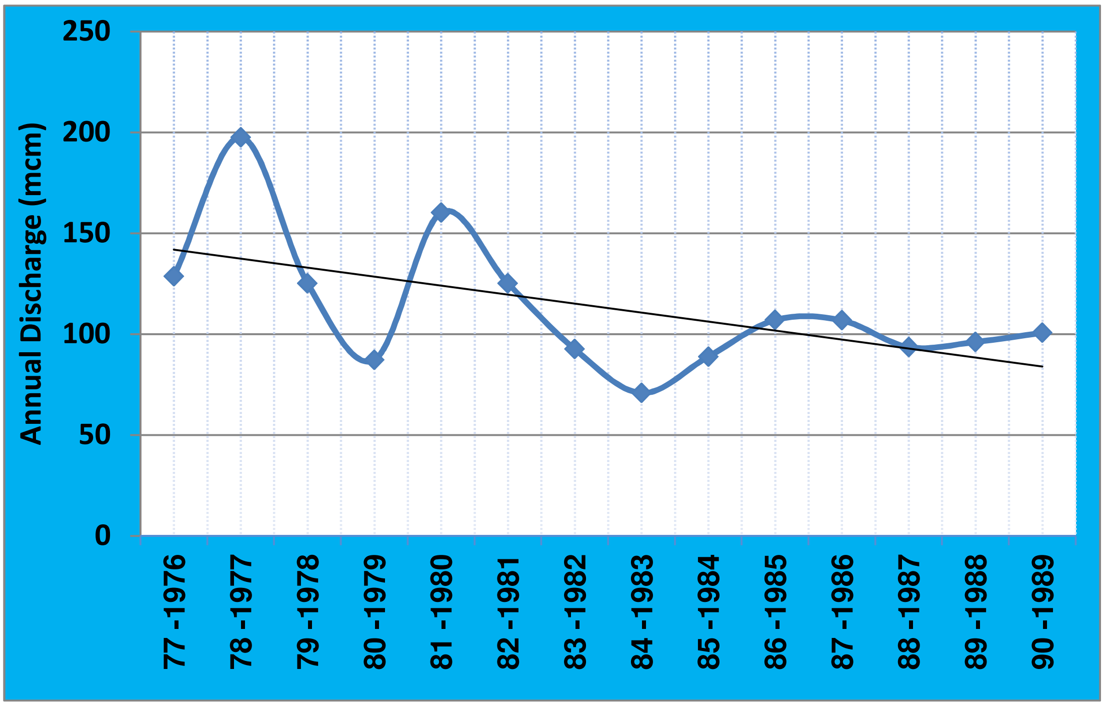

Figure 2.10 : Trend Analysis – RGS3MA03

Monthly Flow

The Monthly flow Pattern of the Mwache Dam site given in **Figure 2.11*.*** shows that the discharge increases from February onwards and reaches peak in May.

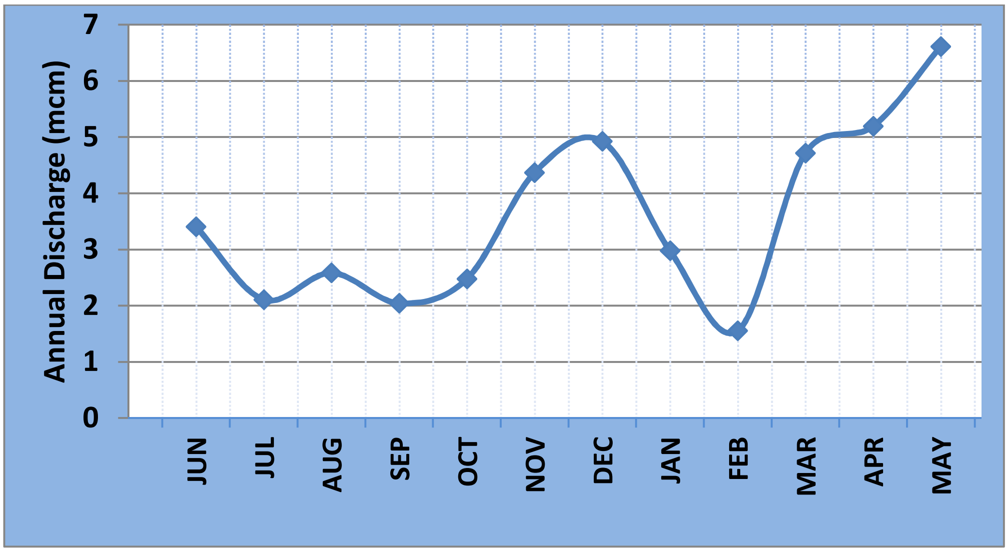

Figure 2.11 : Monthly discharge at Mwache Dam Site

Conclusion of Consistency Checks

From mass curves, Spearman's trend analysis, using average annual flow, monthly average plot, statistical test of 10-day discharge series, it confirms that the recorded discharges at RGS 3MA03 station of Mwache Dam catchment is reasonably consistent and therefore, they can be utilized to conduct water availability studies for the MwacheDam Project.

The observed monthly (period 1976-77 to 1989-90) at Mwache Dam with catchment area of 2250 km^2 are tabulated as **Table 2.11**

Table 2.9: Mean Monthly Observed discharge series of Mwache River

Unit : cumec

Year	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	Annual Average
1976- 77	4.47	2.46	1.23	4.42	1.87	3.79	6.48	5.46	2.74	5.05	8.88	2.09	**4.08**
1977- 78	1.67	3.69	2.47	4.44	8.77	10.83	11.45	5.00	3.86	7.02	6.78	9.22	**6.27**
1978- 79	2.36	1.71	1.37	1.39	**0.00**	6.37	7.32	4.76	3.41	6.32	4.13	8.51	**3.97**
1979- 80	8.22	2.01	1.77	1.81	1.94	4.53	2.75	1.78	1.50	1.70	3.35	1.85	**2.77**
1980- 81	1.36	2.40	16.75	1.75	0.42	6.37	5.98	1.81	0.00	14.26	6.77	3.12	**5.08**
1981- 82	2.43	1.49	0.69	2.76	3.73	3.68	5.32	1.94	1.19	0.02	4.06	20.33	**3.97**
1982- 83	3.18	2.90	1.73	1.73	4.19	3.76	4.87	1.04	0.00	3.50	2.34	5.99	**2.94**
1983- 84	4.59	2.11	1.53	1.95	1.09	0.97	1.56	1.32	0.00	1.60	6.77	3.47	**2.25**
1984- 85	1.82	1.78	0.74	0.75	1.58	6.28	4.06	3.52	4.56	1.30	2.18	5.24	**2.82**
1985- 86	1.06	3.78	1.84	0.75	0.69	2.99	3.80	1.30	1.26	5.42	6.75	11.08	**3.39**
1986- 87	5.65	1.32	1.50	0.00	1.50	4.88	6.09	2.65	1.02	0.00	3.88	12.18	**3.39**
1987- 88	1.75	1.65	2.75	1.51	1.80	0.51	1.87	4.38	1.13	7.57	8.28	2.41	**2.97**
1988- 89	7.14	1.28	0.89	1.15	1.30	3.61	3.80	4.32	0.00	3.86	4.46	4.76	**3.05**
1989- 90	1.97	0.94	0.94	4.20	5.80	2.61	3.63	2.40	1.07	8.40	4.06	2.29	**3.19**
Average	**3.40**	**2.11**	**2.59**	**2.04**	**2.48**	**4.37**	**4.93**	**2.98**	**1.55**	**4.72**	**5.19**	**6.61**	**3.60**

Note : Discharge in italics are derived from monthly rainfall record

2.3.3 Methodology

For developing long term flow series at the proposed dam site, the following two alternatives were considered:

Alternative I – Based on observed discharge data (monthly and daily) of RGS 3MA03 station of Mwache Dam catchment

Alternative II – Synthetic flow series developed for 50 years using Stochastic generation technique based on seasonal parameters of RGS 3MA03 station of Mwache Dam catchment

Alternative I

Daily flow Record at RGS 3MA03 station of Mwache Dam catchment are available for the periods 1976-1977 to 1989-90. Since 10-day discharge is required for analysis of irrigation and power release in case of Mwache dam, the available daily series has been converted to monthly series for the period 1976-1977 to 1989-90. Series for Mwache dam IS shown in ***Table 2.9***.

Alternative II

Time series data comprise a deterministic component and a random component to account for inherent variations in the sample. The statistical parameters to form a deterministic component of this seasonal model are mean, standard deviation and Skewness. Stochastic component is added by using random number generation technique. This random component represents the chance dependent effects in the time series. The synthetic series developed is based on the statistical Parameters of the Mwache Dam flow using the seasonal stochastic model – Thomas Fierring Model. The Thomas Fierring equation is given by:

$$Q_{i,j} = Q_j + \rho_j \frac{\sigma_j}{\sigma_{j-1}}\left(Q_{i-1,j-1} - Q_{j-1}\right) + t_i \sigma_j \sqrt{1-\rho_j^{\,2}}$$

where subscript j defines time period or season. In case of monthly series analysis j varies from 1 to 12 through the year. The subscript i is a serial designation for year and ρ_j is the serial correlation coefficient between Qj and Q_{j-1}.

The discharge series at for Mwache Dam station is available from June, 1976 to June, 1990. Based on the statistical parameters obtained from available historic series like mean, standard deviation, skewness and lag one Auto correlation function (ACF) obtained for historic series as shown in ***Table 2.10,*** the series for another 50 years using Thomas and Fiering model has been generated.

The simulated series are Tabulated as ***Table 2.11*** and the statistical indicators of the observed and generated series are given in Table 2.13 and ***Figure 2.12.*** The statistical indicators mean, standard deviation of simulated series show close values with observed series. Furthermore, the maximum flow of the generated series (25.82

m^3/s) is very close to the observed series (20.33 m^3/s) indicating that the model is generating quite close to the observed one. The flow series (monthly) comprising of observed flow and simulated flow are shown in ***Figure 2.12.***

Table 2.10: Statistical Parameters of historic and simulated series

	Observed Series				Simulated Series			
Month	**Mean**	**Standard Deviation**	**Skewness**	**ACF**	**Mean**	**Standard Deviation**	**Skewness**	**ACF**
Jun	3.404	2.268	1.062	-0.218	2.932	1.936	0.224	-0.056
Jul	2.109	0.862	0.855	-0.332	2.067	0.880	0.243	-0.263
Aug	2.585	4.122	3.603	0.173	3.168	2.897	0.869	-0.274
Sep	2.045	1.410	0.751	-0.055	2.273	1.252	-0.099	0.288
Oct	2.477	2.400	1.666	0.694	2.627	1.458	0.131	0.068
Nov	4.369	2.585	0.968	0.403	4.371	2.431	0.368	0.529
Dec	4.927	2.538	1.184	0.872	4.831	1.777	0.745	0.497
Jan	2.977	1.548	0.326	0.470	2.985	1.956	0.585	0.683
Feb	1.553	1.515	0.832	0.613	1.440	1.302	1.021	0.504
Mar	4.729	3.887	1.001	-0.095	5.234	4.008	1.164	0.485
Apr	5.191	2.141	0.291	0.464	4.934	1.711	0.434	-0.175
May	6.610	5.240	1.518	-0.226	6.200	5.486	1.310	0.282

Table 2.11 : Monthly discharge (cumec) at Mwache river (Simulated)

Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Jun	3.40	2.26	0.00	4.58	5.80	4.22	1.53	5.95	0.71	3.10	1.81	3.19	2.07	0.45	0.25
Jul	2.44	1.39	2.46	1.70	2.40	2.76	0.79	1.41	3.70	1.91	2.53	2.61	2.52	1.67	1.16
Aug	6.22	5.00	3.86	0.00	0.00	2.26	2.65	4.93	0.00	7.17	2.90	2.85	4.19	3.61	4.18
Sept	3.18	0.57	2.93	1.74	1.02	1.76	0.87	4.11	2.01	0.72	4.00	1.48	0.00	3.89	0.00
Oct	0.00	4.96	5.10	1.97	1.94	2.69	3.30	3.38	2.42	5.38	5.12	0.02	3.32	2.01	1.29
Nov	0.00	9.44	8.56	5.03	0.00	6.69	2.92	5.29	5.31	8.74	6.53	3.45	4.07	4.69	2.39
Dec	5.78	11.05	3.49	4.49	2.19	6.13	3.98	5.32	4.14	8.30	1.91	7.16	4.12	6.51	2.65
Jan	3.77	5.53	1.64	0.00	1.99	6.47	4.26	2.26	2.42	5.42	1.47	5.59	1.88	4.59	2.13
Feb	0.00	0.95	0.78	0.69	0.34	2.70	3.62	0.90	4.59	0.00	0.00	4.95	0.49	3.45	1.51
Mar	5.93	5.62	4.50	2.89	3.33	4.37	18.51	4.92	15.43	2.79	0.00	9.70	2.50	5.35	4.56
Apr	6.43	2.62	4.73	3.85	4.48	2.76	3.34	7.37	8.87	3.31	5.29	6.86	5.55	8.52	1.76
May	3.30	0.00	2.03	0.00	0.52	0.00	10.28	4.38	9.92	7.10	14.96	2.66	6.46	9.95	5.80

Year	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
Jun	0.26	5.81	0.50	2.57	2.26	1.75	6.71	0.00	4.92	4.47	5.52	3.36	1.54	0.56	0.12
Jul	3.11	0.90	2.26	1.64	2.98	2.98	1.54	1.11	4.37	0.18	1.26	1.88	2.64	1.71	2.02
Aug	7.10	0.00	0.00	2.37	2.36	0.00	0.00	10.64	7.05	7.98	3.69	9.70	2.80	4.35	3.63
Sept	3.04	3.61	2.75	2.21	0.96	2.62	1.03	3.71	4.78	2.87	3.31	3.16	0.83	1.75	3.94
Oct	4.48	3.50	1.51	4.56	0.75	2.35	2.98	5.02	4.84	1.80	0.00	1.26	4.23	3.37	1.28
Nov	2.82	6.65	6.66	3.76	0.68	2.91	3.65	7.75	1.52	5.33	4.05	3.47	10.09	5.68	5.71
Dec	5.65	5.49	6.91	3.90	3.57	4.69	3.65	5.10	4.76	4.61	2.60	6.54	7.24	4.30	5.02
Jan	5.09	5.21	9.07	0.00	0.45	2.45	0.00	2.42	4.08	3.02	3.27	3.80	4.81	3.26	5.20
Feb	2.28	1.72	3.49	1.38	1.21	1.25	0.71	1.27	2.25	1.63	0.00	0.00	1.95	2.22	2.25
Mar	10.95	6.53	6.95	5.80	7.38	0.00	8.12	7.03	0.00	1.40	3.07	8.42	8.17	8.65	6.11
Apr	4.60	3.95	4.44	4.65	4.00	6.77	6.04	3.36	4.05	6.38	4.57	4.40	4.60	3.37	3.33
May	1.66	1.55	0.00	16.79	0.85	6.68	8.97	0.00	4.61	15.35	7.11	9.36	10.30	3.84	0.00

Year	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
Jun	4.45	5.52	3.44	2.62	4.51	3.72	1.18	1.06	6.96	2.15	3.66	3.28	3.24	3.24	3.23
Jul	1.24	0.93	3.31	0.83	1.85	2.72	2.35	2.95	0.73	3.61	2.33	2.03	2.04	2.03	2.03
Aug	5.30	2.84	0.00	9.48	2.25	0.67	0.00	0.00	0.00	0.00	1.51	2.28	2.27	2.26	2.25
Sept	2.96	0.00	0.65	3.88	3.35	3.51	3.33	1.34	2.06	2.84	2.04	1.88	1.88	1.87	1.87
Oct	2.85	1.75	2.27	3.27	1.39	3.33	2.19	2.02	3.12	0.00	1.97	2.31	2.31	2.30	2.30
Nov	2.57	1.79	5.02	4.23	3.80	2.25	4.08	2.73	2.59	0.00	7.86	4.00	3.99	3.98	3.97
Dec	5.33	1.86	4.29	5.24	4.38	6.58	5.59	4.08	4.77	0.88	4.60	4.65	4.64	4.64	4.63
Jan	0.78	0.00	2.69	2.58	0.73	4.74	3.16	3.42	1.73	0.00	2.25	2.69	2.68	2.67	2.67
Feb	0.89	0.00	3.94	0.51	0.00	3.21	0.99	0.00	0.99	0.00	0.57	1.29	1.29	1.28	1.28
Mar	1.38	5.77	6.20	5.82	13.18	4.42	3.94	0.00	0.34	0.00	0.00	3.91	3.89	3.87	3.85
Apr	3.41	3.63	6.21	3.61	1.72	4.64	6.81	7.33	7.75	7.84	4.75	5.03	5.03	5.03	5.02
May	4.19	6.16	2.08	25.82	0.00	10.77	11.32	5.47	4.09	15.66	5.58	5.89	5.87	5.86	5.84

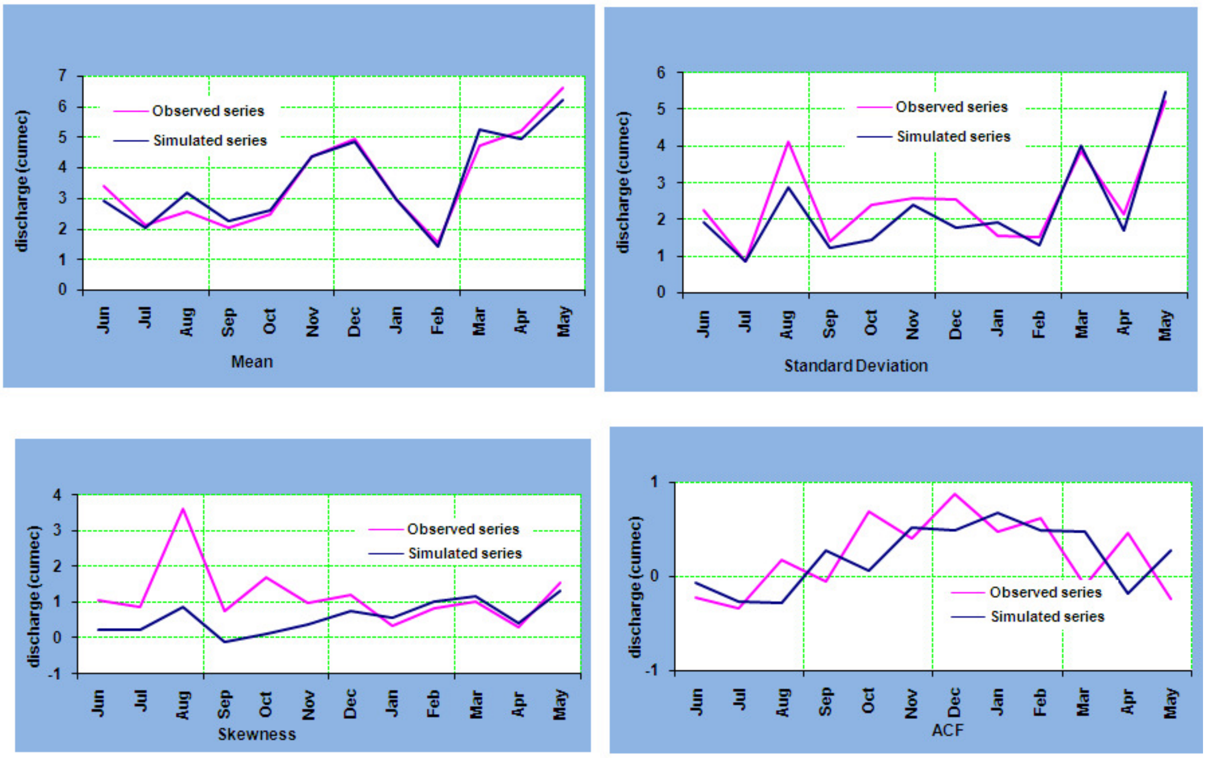

Figure 2.12 : Statistical Parameters of observed (Alternative I)and Simulated (Alternative II) flow series at Mwache

2.3.4 Conclusion and Recommendation

A flow-duration curve of a stream is a plot of discharge that shows the % of time that flow in a stream is likely to equal or exceed any specified value. Annual flow for the two proposed alternatives are subject to dependability analysis. The flow duration curve as shown in ***Figure 2.13*** indicate that while the average annual flow show close values, the values corresponding to 75% and 90% dependable flow vary. Under Alternative I, option 3 is adopted because Dependable discharge is on conservative side and missing discharge data are filled from rainfall-runoff ratio. Under Alternative II, 75% dependable flow is about 93.59 mcum which is little greater than Alternative I and 90% dependable flow is almost same. To be on conservative side, considering all the above facts, Alternative I (option 3) is recommended for Water Planning. The Annual flow at various dependability has been tabulated as ***Table 2.12***. However for planning of irrigation and hydropower potential, simulation using 10-day flow series has been made to derive the 75% dependable release. Dependable curve indicates 1982-83 as closest to 75% dependable year with annual flow of 92.6 M cu m.

Table 2.12 : Percentage dependability of streamflow at Mwache site

Unit: MCM

Method	**% Dependability**			
	Average	**75**	**90**	**100**
Alternative I	**100.69**	**92.60**	**79.00**	**70.80**
Option1	*105.15*	*99.61*	*89.60*	*86.70*
Option2	*103.23*	*98.62*	*81.10*	*75.40*
Option3	*100.69*	*92.60*	*79.00*	*70.80*
Alternative II (extension of data based on option3)	**107.26**	**93.59**	**80.09**	**63.21**

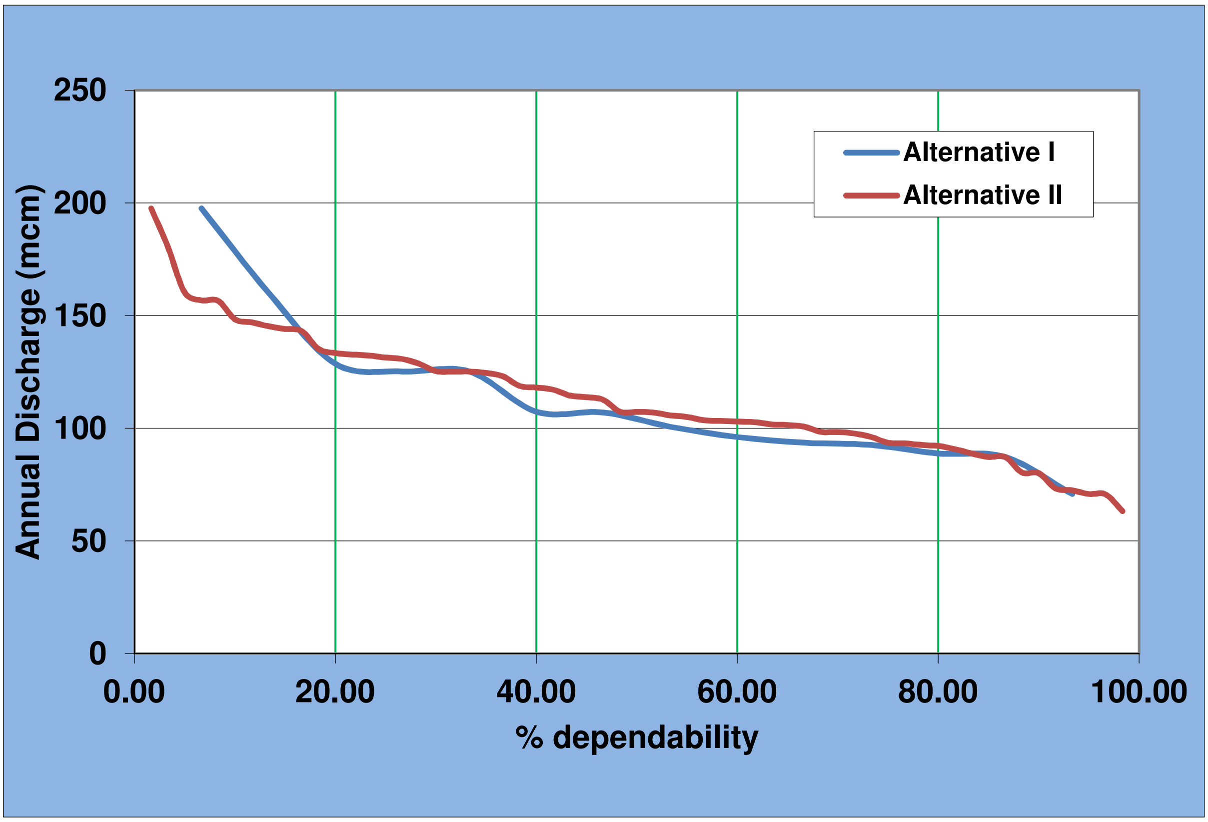

Figure 2.13: Flow Duration curve at Mwache Dam site

Mwache Dam: **Dependable flow:** The average, 75% and 90% dependable annual flows are ***100.69 M cu m***, ***92.6 M cu m*** and ***79.00 M cu m*** respectively and are recommended for Mwache project planning

Water Availability at Kombeni Dam :

The Dependable flow at the Kombeni dam site is developed on the basis of RGS 3MA03 station of Mwache Dam catchment flow by catchment area proportioning The conversion factor obtained is 445/2250 = 0.1978 using the following relationship:

$$Q_{Kombeni} = Q_{Mwache} \frac{CA_{Kombeni}}{CA_{Mwache}} \qquad \text{- (i)}$$

Where, $CA_{Kombeni}$ = Catchment area of the Kombeni dam = 445 km^2; CA_{Mwache} = Catchment Area up to the Mwache Dam= 2250 km^2; Q_{Mwache} = Dependable flow at the Mwache Dam Site; $Q_{Kombeni}$ Dependable flow of the Kombeni Dam site

Kombeni River:
Dependable flow: The average, 75 % and 90 % dependable annual flows are ***19.91 M cu m***, ***18.31 M cu m*** and ***15.63 M cu m*** respectively and are recommended for Kombeni project planning

2.4 RESERVOIR ELEVATION AREA CAPACITY CURVE

The Reservoir Elevation-Area-Capacity relationship for the proposed Mwache dam location has been developed on the basis of topographical surveys carried out by the Consultants. The survey at the proposed dam site shows the deepest bed level at El 14 m. The incremental volume between two consecutive contours is thus computed using following formula.

$$V = \frac{H}{3}\left(A_1 + A_2 + \sqrt{A_1 * A_2}\right)$$

Where,
V = Volume between two contours (m^3)
H = Contour interval/difference in elevation (m)
A_1 = Area at level of first contour (m^2)
A_2 = Area at level of second contour (m^2)
and the volume between different level are added to obtain cumulative volume. The Reservoir Elevation Area Capacity is indicated in **Figure 2.14** and **Table 2.13.** At Full Reservoir Level EL 95 m the reservoir storage is 207.44 Mm^3 and reservoir surface area is 11.08 km^2.

Table 2.13: Elevation-Area–Capacity Table for Mwache Reservoir

Elevation (m)	Area (Sq.km)	Capacity (Mm3)
14	0	0.000
15	0.011	0.004
20	0.102	0.248
25	0.191	0.969
30	0.337	2.272
35	0.59	4.560
40	0.883	8.218
45	1.111	13.192
50	1.384	19.417
55	1.725	27.174
60	2.111	36.748
65	2.57	48.431
70	3.036	62.430
75	3.559	78.900
80	4.259	98.419
85	6.031	124.016
90	8.193	159.438
95	11.08	207.440
100	14.715	271.713

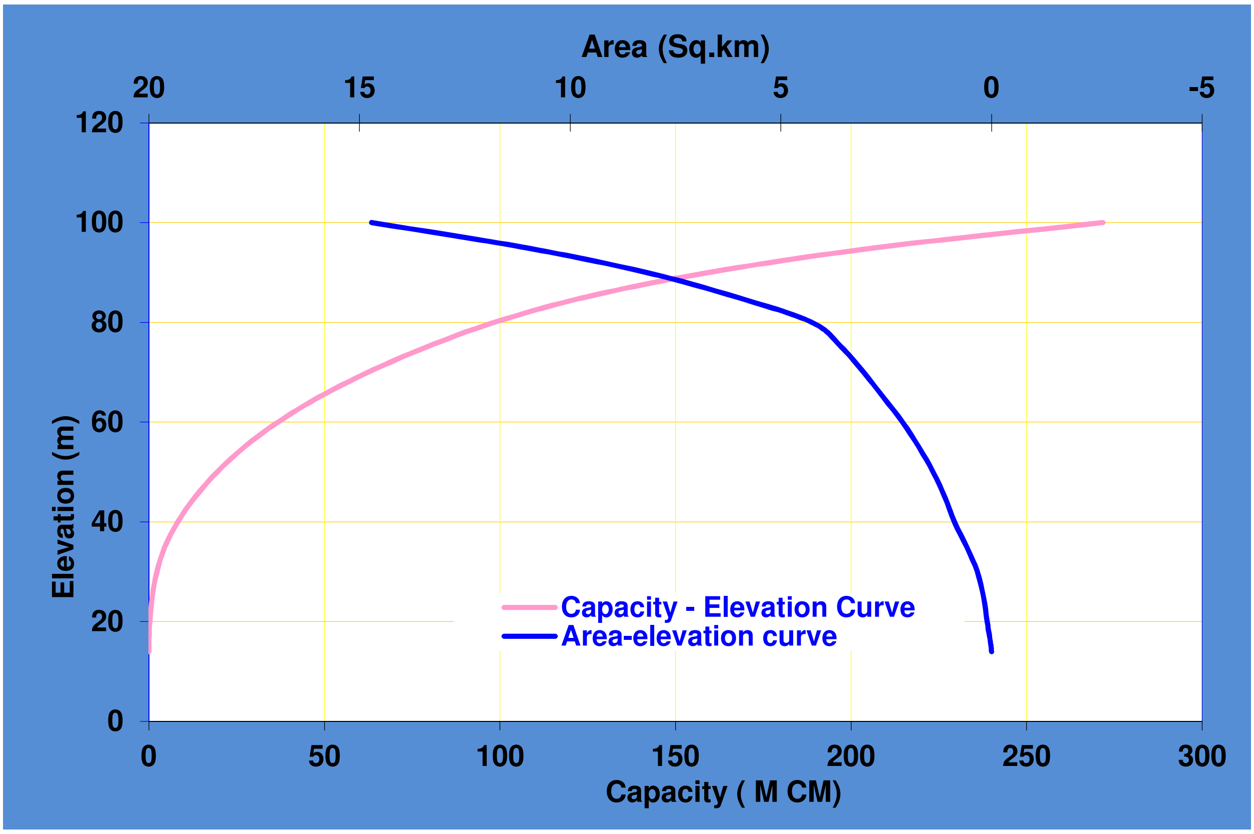

Figure 2.14: Area-Elevation-Capacity for Mwache reservoir

2.5 DESIGN FLOOD

2.5.1 Design Flood Criteria

A 86 m high dam from the deepest bed level is proposed for Mwache dam on river Mwache with gross storage capacity of 207.44 Mm^3 at FRL EL 95.0. The criteria for selection of inflow design flood for safety of dam as per International Standards are:

1. **Indian Standard IS 11223-1985**: As shown below:

Criterion for selection of Design Flood

Classification	Gross storage	Hydraulic head at FRL	Inflow design flood
Small	0.5-10 M. Cum	Between7.5m and 12 m	100 year flood
Intermediate	10-60 M. Cum	Between12m and 30 m	Standard Project Flood
Large	Greater than 60 M. Cum	Greater than 30 m	Probable Maximum Flood

2. **International Commission on Large Dams (ICOLD)** has laid down the norms for categorization as large dams.
   - More than 15 m height measured from the lowest portion of the general foundation area to the crest
   - A dam between 10m and 15m height provided it complies with at least one of the following conditions:
     a) Length of the crest of dam is not less than 500 m
     b) Capacity of reservoir formed by the dam is not less than 1 MCM
     c) Maximum flood discharge dealt by the dam is not less than 2000 m^3/s
     d) The dam had specially difficult foundation problem
     e) The dam is of unusual design
     f) The dam is located on highly seismic zone

3. **FEMA Guidelines**

Flood Selection for Design (or Evaluation)

The selection of the design flood should be based on an evaluation of the relative risks and consequences of flooding, under both present and future conditions. Higher risks may have to be accepted for some existing structures because of irreconcilable conditions. When flooding could cause significant hazards to life or major property damage, the flood selected for design should have virtually no chance of being exceeded. If lesser hazards are involved, a smaller flood may be selected for design. However, all dams should be designed to withstand relatively large flood without failure even when there is apparently no downstream hazard involved under present conditions of development.

Downstream Effects

Safety design includes studies to ascertain areas that would be flooded during occurrence of the design flood and in the event of dam failure. The areas downstream of the project should be evaluated to determine the need for land acquisition, flood plain management, or other methods to prevent major damages. Information should be developed and documented for disseminating to downstream interests regarding the continuing risks of flooding.

Design Flood for Diversion Dam

Prior to commencement of actual construction of any work in the river bed, it becomes necessary to temporarily divert river flows from the proposed area during construction period in the dry or semi-dry season. The standards followed in India have been referred in the absence of International Standards. According to ISO 14815:2000, which lays guidelines for design flood for river diversion works, the flood higher than design flood would pass safely over partially constructed concrete dam. Therefore, it is specified that the diversion flood to be adopted may be maximum of observed flow during the lean period at the dam site or 25 years frequency lean period flow, whichever is higher.

Design Flood for Diversion Barrage

Since important township below Diversion Barrage is located, safety of this township is of paramount importance. Inflow design flood of 1000 year frequency flood is proposed to be adopted for the design of Diversion Barrage.

2.5.2 Data Availability

Due to non-availability of Instantaneous peak discharge records for gauging station in the close proximity of dam site , short interval meteorological data for the region, hydro-meteorological method utilizing catchments characteristics with rainfall were adopted. Considering the nature of data and current available information, the methodology for design flood estimation is discussed as under.

2.5.3 Methodology

i) ***Empirical Formula***

(a) Dicken's Formula

$Q_p = C\ A^{3/4}$

Where, A = Catchment area (2250 km^2)

Q_p= Peak Flood in cumec

$Q_p = 6(2250)^{3/4} = 1960\ m^3/s$

(b) Ryve's Formula

$Q_p = C.A^{2/3}$

Where, A = Catchment area (2250 km^2)

$Q_p = 6.8\ (2250)^{0.67} = 1168\ m^3/s$

(c) Metcalf and Eddy Formula

$Q_p = 6.22\ A^{0.73}$

Where, A = Catchment area = (2250 km^2)

$Q_p = 6.22\ (2250)^{0.73} = 1741\ m^3/s$

(d) Fanning Formula

$Q_p = 2.64\ A^{4/5}$

Where, A = Catchment area = 2250 km^2

$Q_p = 2.64 * (2250)^{4/5} = 1269\ m^3/s$

ii) Unit Hydrograph

For developing unit hydrograph, site specific concurrent short interval rainfall data with automatic SRRG and concurrent runoff data at the catchment outlet for a few flood events are necessary. In the absence of concurrent rainfall & runoff data a triangular unit hydrograph has been developed synthetically following the methodology as outlined in "Design of Small Dams" by the US Bureau of Reclamation (USBR) Publication. The triangular unit hydrograph involves computation of following parameters based on catchment characteristics.

(i) **Time of Concentration, Tc**

The time of concentration is the time required for the surface runoff from the emotest part of the drainage basin to reach an outlet point.

T_c (hour) is computed by the California formula,

$Tc = \{0.87\ L^3/H\}^{0.385}$ where,

L is the length of the main stream from the most remote point to the outlet, in Km, and

H is the elevation difference between the highest point and outlet, in metres

(ii) **Lag Time, Time to Peak and Base Period**

For the derivation of a simple triangular unit hydrograph, the key parameter is the time to peak flow, which may be computed from time of concentration and lag time. The lag time (Ti) is defined as the time interval between mid-point of unit period and peak flow.

Lag time (T_i) $= 0.6\ T_c$

Time to Peak (T_p) $= 0.6\ T_c + D/2$ Where,

T_i and T_p are in hour and D is the unit period, in hour

The base period T_b (in hours) of the triangular unit hydrograph is given by

$T_b = 2.67\ T_p$

(iii) **Peak Flow**

Once T_p and T_b have been computed, the peak flow Q_P of the unit hydrograph can be obtained by the formula.

$Q_p = A/(1.8\ T_b)$ where,

Q_p is peak flood in cumec and A is the catchment area in sq.km.

Considering that the duration of Rainfall is short and the envelop curve shows that significantly high percentage of rainfall occurs in the first few hours, 0.5 hr unit duration has been considered as appropriate for unit hydrograph analysis. Considering longest length of the river from the remotest point to the outlet upto the point under consideration, time of concentration has been determined.

The Unit Hydrograph parameter evolved on the basis of method described above are as follows:

Catchment Parameters				Δ^{hr} Unit Hydrograph Parameters				
Area (Sq. km)	Highest Elev (m)	Lowest Elev (m)	Length of River (km)	Time of Concentration (hr)	Time to Peak (hr)	Unit Duration (hr)	Base Time (hr)	Peak flood (cumec)
2250	320	20	110	24.0	14.9	1	41	30.5

From the Δ^{hr} Unit Hydrograph parameters, the Synthetic Unit hydrograph has been developed based on SCS curve method is shown in ***Fig. 2.15***.

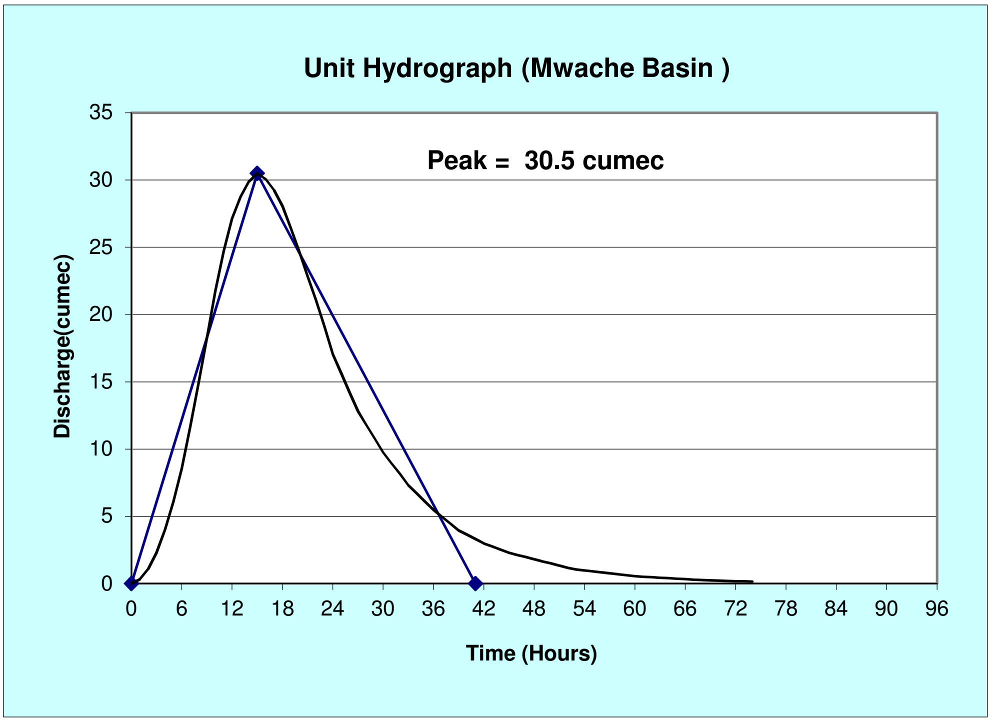

Figure 2.15: Unit Hydrograph for Mwache reservoir

Temporal Distribution of Rainfall

The project site is on the Coastal area. Diurnal pattern shows a distinctive minimum rainfall in the evening. It increases in the midnight and shows a plateau-like distribution until noon. There is a decreasing trend in the afternoon. Mombasa is 20km away from dam site. Diurnal Variation of Hourly rainfall of Mombasa (***Figure 2.16***) is taken for Temporal Distribution of rainfall due to non-availability of short interval rainfall data for the Mwache catchment.

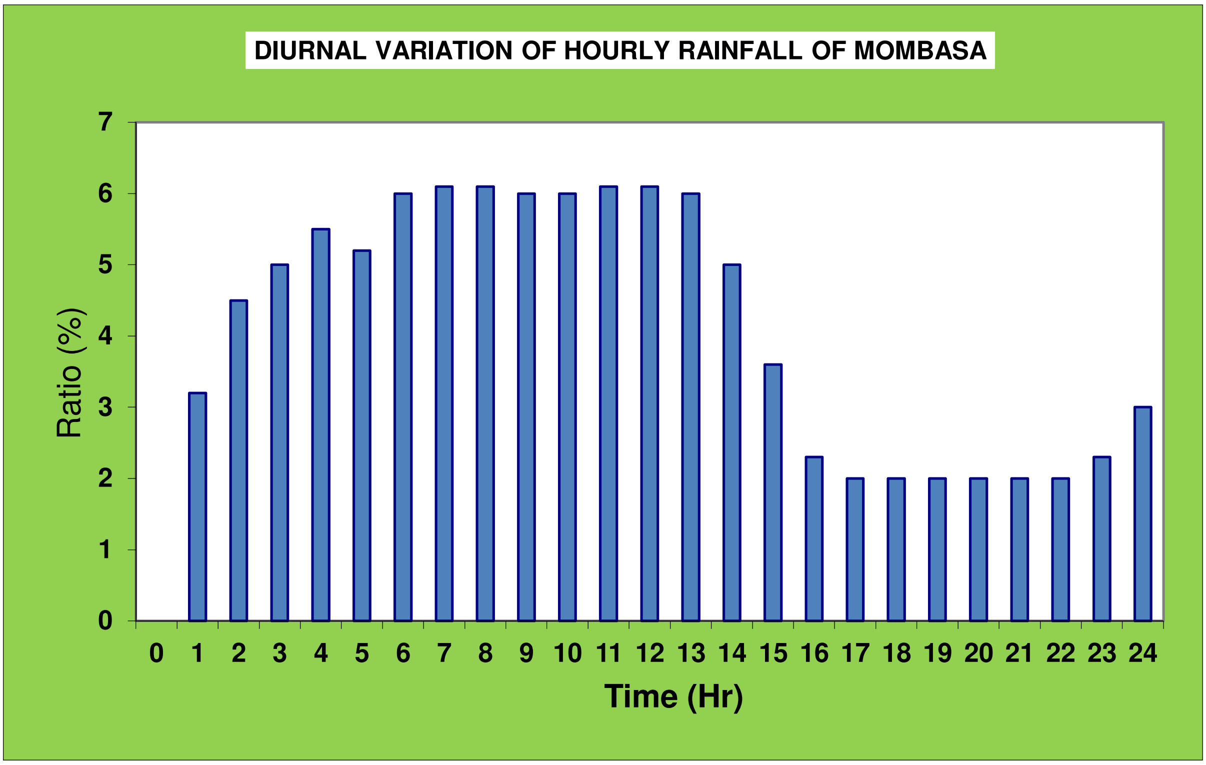

Figure 2.16: Diurnal Variation of Hourly Rainfall of Mombasa

(Source: National Water Master plan of Kenya , 1992, Japan International cooperation agency)

Temporal Distribution Curve for 24 hrs with cumulative % distribution of Rainfall is developed based on above data as shown in **Figure 2.17.**

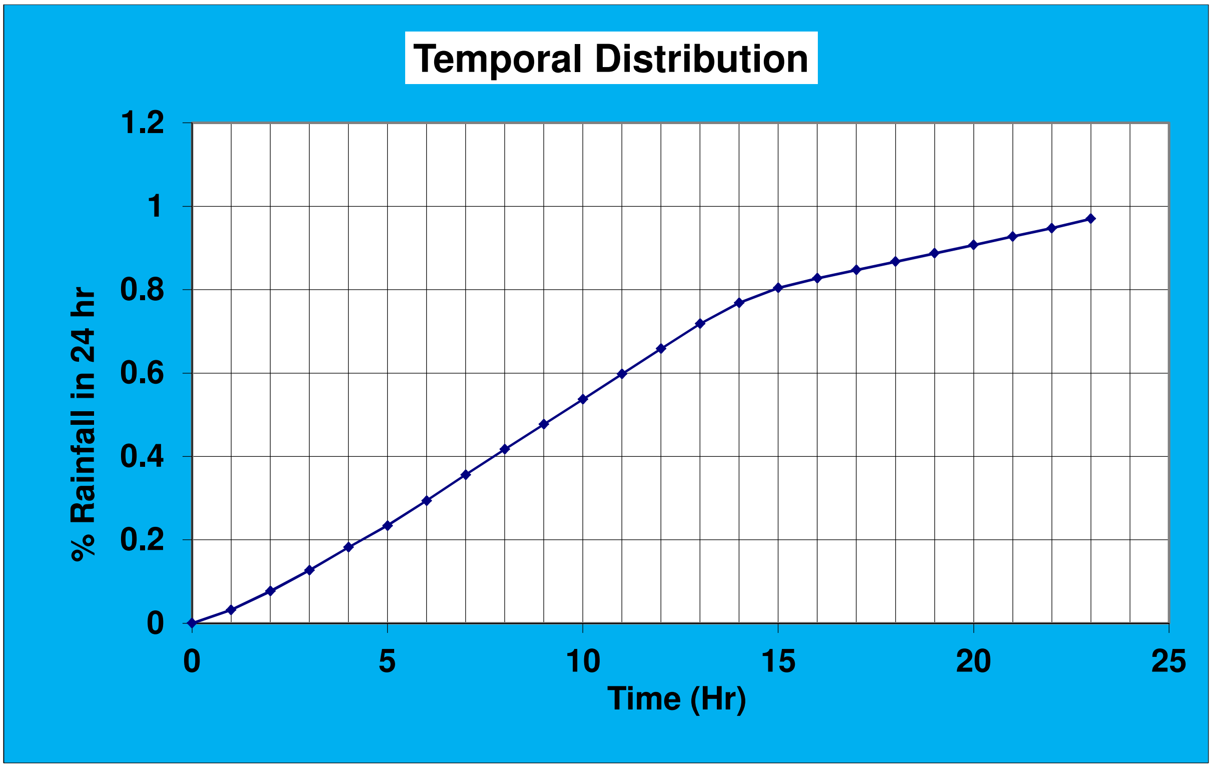

Figure 2.17: Temporal Distribution Curve for 24 Hrs

Frequency Analysis of Rainfall

One day Annual Maximum Rainfall Series for 10 stations are available. Locations of all stations are shown in ***Table 2.1***. Available Length of data of All stations are shown below:

Station ID	**Station Name**	**No of Year Data Available**	**Range of annual Maximum Daily Rainfall**
9339078	TSANGATSINI DISPENSARY	22	1982-2010
9339057	MARIAKANI RESEARCH STATION	30	1977-2009
9339055	KAYAFUNGO CHIEF'S OFFICE	31	1976-2008
9339051	TARU SECONDARY SCHOOL	24	1972-1993 and 2000-2002
9339049	MAKAMINI AGRICULTURE OFFICE	16	1971-1986
9339048	MAZERAS RESERVOIRS	22	1971-1992
9339023	MAJI YA CHUMVI RAILWAY STATION	41	1959-2002
9339006	SAMBURU STATION(RAILWAY)	40	1959-2001
9339002	MACKINON ROAD RAILWAY STATION	34	1962-2000
9339000	MAZERAS RAILWAY STATION	31	1959-1985 & 2001-2005

All the Annual Maximum 24 hr Rainfall series developed are as shown in ***Table 2.14***:

Table 2.14: Annual Maximum 24hr Rainfall Series for 10 Stations

Unit: mm

Station ID	**9339078**	**9339057**	**9339055**	**9339051**	**9339049**	**9339048**	**9339023**	**9339006**	**9339002**	**9339000**
Sr. No										
1	46.00	63.10	71.80	80.20	47.00	47.20	35.60	47.20	39.40	231.10
2	41.00	56.50	55.00	33.00	75.70	73.70	102.60	94.50	50.30	203.20
3	44.40	92.80	113.30	73.10	44.90	62.70	209.60	108.70	38.40	153.70
4	54.50	300.00	73.70	39.60	53.30	67.30	27.90	32.30	124.20	50.80
5	73.50	52.60	79.20	70.00	36.80	53.60	36.80	50.50	83.80	87.60
6	35.30	58.00	67.40	33.70	45.90	74.90	77.50	45.70	105.20	104.10
7	41.20	44.20	85.00	158.00	73.10	103.50	12.70	82.50	66.80	101.60
8	70.80	73.00	54.60	83.30	48.50	67.90	55.60	40.90	65.30	53.60
9	110.00	100.00	49.80	54.40	74.80	87.00	120.60	128.40	80.00	171.40
10	43.50	52.50	61.80	38.70	64.20	400.00	61.70	56.00	36.60	114.30
11	50.00	37.80	76.00	115.50	33.30	73.20	33.30	46.40	70.70	95.20
12	26.00	57.00	10.10	22.30	64.20	81.60	60.70	126.70	101.00	51.10
13	76.10	40.20	70.00	4.00	27.10	68.20	30.00	53.30	94.30	29.00
14	66.80	42.70	49.50	29.00	46.80	46.00	68.50	64.40	45.30	110.40
15	45.00	38.80	100.90	30.00	62.20	62.10	38.60	52.50	52.00	170.00
16	72.10	42.00	60.30	42.00	28.30	71.40	36.20	50.00	40.50	80.70

Station ID	9339078	9339057	9339055	9339051	9339049	9339048	9339023	9339006	9339002	9339000
Sr. No										
17	72.40	35.40	40.50	37.00		51.70	59.30	47.50	47.50	80.50
18	140.40	42.00	34.70	36.00		53.40	60.10	50.00	33.30	10.00
19	100.40	43.90	51.00	53.00		50.80	48.00	50.00	45.50	33.00
20	59.20	48.00	60.00	32.00		52.80	98.30	89.00	50.00	50.70
21	82.60	29.00	69.20	16.30		40.80	50.00	110.00	35.20	93.20
22	24.20	47.80	41.80	51.80		44.40	50.00	73.00	43.60	100.10
23		90.00	42.00	62.30			50.00	73.00	3.20	60.00
24		50.00	95.00	48.30			36.00	42.00	53.00	70.30
25		62.50	40.50				53.00	24.00	31.70	11.90
26		50.00	60.00				49.00	39.00	61.30	25.70
27		180.00	99.50				50.20	83.00	49.30	48.90
28		70.00	41.00				110.00	43.00	51.00	120.00
29		72.20	116.60				55.00	20.00	80.40	60.00
30		55.00	70.50				52.00	51.00	36.00	70.50
31			40.00				65.00	50.30	37.20	87.00
32							58.00	63.50	46.90	
33							40.00	30.70	40.50	
34							49.70	41.50	29.50	
35							65.40	35.00		
36							31.40	43.50		
37							53.70	46.00		
38							40.00	97.00		
39							60.80	28.30		
40							30.30	62.00		
41							37.00			
N	**22**	**30**	**31**	**24**	**16**	**22**	**41**	**40**	**34**	**31**
Mean(Xbar)	**63**	**68**	**64**	**52**	**52**	**79**	**58**	**59**	**55**	**88**
Stdev (σ)	**28**	**52**	**24**	**33**	**16**	**73**	**33**	**27**	**25**	**54**
maximum	**140.4**	**300.0**	**116.6**	**158.0**	**75.7**	**400.0**	**209.6**	**128.4**	**124.2**	**231.1**
Minimum	**24.2**	**29.0**	**10.1**	**4.0**	**27.1**	**40.8**	**12.7**	**20.0**	**3.2**	**10.0**

N = No of Years of data availability

Gumbel (EVI) distributions have *been* fitted to the series. The results are shown in ***Table 2.15:***

Table 2.15: Result of frequency Distribution of rainfall for 10 Stations

Unit: mm

Return Period(T)	9339078	9339057	9339055	9339051	9339049	9339048	9339023	9339006	9339002	9339000
10	99	135	95	94	72	173	100	94	87	157
25	112	159	106	110	80	207	115	107	99	182
50	120	175	114	120	84	229	125	115	106	198
100	128	189	120	129	89	250	135	122	114	213
500	144	218	134	148	98	290	153	137	127	242
1000	150	229	139	155	101	306	160	143	133	254
10000	163	253	150	170	108	339	175	155	144	278

Probable Maximum Precipitation
The probable maximum precipitation is defined as the Greatest or extreme rainfall for a given duration that is physically possible over a station or basin. From the operational point of view, PMP can be defined as that rainfall over a basin which would produce a flood flow with virtually no risk of being exceeded. Determination of PMF begins with the determination of the probable maximum precipitation.

There are two approaches for estimating the PMP. The first approach uses the maximization and transposition of real or model storms which requires a large amount of data, a situation not obtainable in the Mwache River catchment. The second approach utilizes the statistical analysis of the extreme rainfall.

In the statistical approach, the annual series of the observed maximum rainfall depths for given duration are analyzed to yield the mean and standard deviation. PMP is then expressed as the mean of the series plus K times the standard deviation. This is the approach taken to estimate the PMP for Mwache River sub-catchment utilizing 24-hour duration.

The PMP equation is of the form:

$$\mathbf{PMP = \hat{Y} + K \times S_y}$$

Where,

$\hat{Y}$ – The mean of the 24hour maximum annual rainfall

K – A constant equal to 11 for coastal areas *(The study on the National Water Master Plan, 1992)*

S_y - Standard deviation of the maximum annual depths for the 24 hour duration,

Annual maximum series from ten rainfall stations were selected for the computation of the Probable Maximum Precipitation for Mwache River catchment. The stations selected and the results of the analysis are tabulated below.

Table 2.16: PMP for 10 Stations

Unit: mm

Return Period(T)	9339078	9339057	9339055	9339051	9339049	9339048	9339023	9339006	9339002	9339000
N	**22**	**30**	**31**	**24**	**16**	**22**	**41**	**40**	**34**	**31**
Mean(Xbar)	63	68	64	52	52	79	58	59	55	88
Stdev (σ)	28	52	24	33	16	73	33	27	25	54
PMP (mm)	**373**	**643**	**330**	**417**	**228**	**886**	**421**	**357**	**331**	**677**

Computation of PMP considering 10 Raingauge station by the Thissen Polygon Method :

There are ten raingauge stations in and around Mwache Catchment. The mean rainfall Pm is computed as follows:

$$Pm = \frac{P1a1 + P2a2 + P3a3 + \ldots\ldots\ldots\ldots + PNaN}{a1 + a2 + a3 + \ldots\ldots\ldots\ldots\ldots + aN}$$

Where

P1, P2, P3…………….PN are rainfall records at individual raingauges

a1, a2,a3………………aN are influence area at the individual raingauge determined by the Thissen polygons

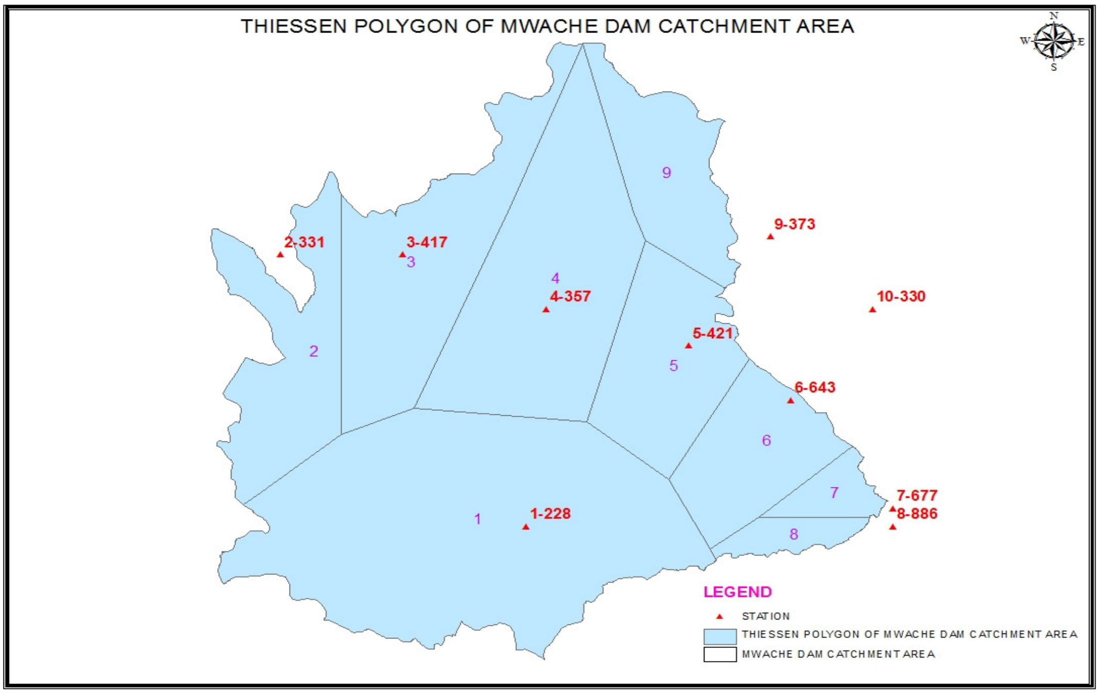

Figure 2.18: Thissen Polygon layout of ten raingauge stations in and around Mwache catchment

Table 2.17: Thissen Weights for 10 stations in and around the Mwache Catchment Area

Thissen Polygon No.	Precipitation, Pi (mm)	Thissen Weight(Ai/A)	Pi *Ai/A
1	228	0.262273	59.79835276
2	331	0.087713	29.03295931
3	417	0.149302	62.25872633
4	357	0.159886	57.07913135
5	421	0.091786	38.64187527
6	643	0.100904	64.88096272
7	677	0.03345	22.64580639
8	886	0.032435	28.73736836
9	373	0.082252	30.67999637
	∑	**1.00**	**393.8**

Based on Thissen Polygon Method as listed in ***Table 2.17***, the weighted Probable Maximum Precipitation is 394mm.**So the Probable Maximum Precipitation for the Mwache River sub-catchment is considered as 400 mm**.

Infiltration Rate of the Project Area

Infiltration is governed by two forces: gravity and capillary action. While smaller pores offer greater resistance to gravity, very small pores pull water through capillary action in addition to and even against the force of gravity.

The rate of infiltration is affected by soil characteristics including ease of entry, storage capacity, and transmission rate through the soil. The soil texture and structure, vegetation types and cover, water content of the soil, soil temperature, and rainfall intensity all play a role in controlling infiltration rate and capacity. For example, coarse-grained sandy soils have large spaces between each grain and allow water to infiltrate quickly. Vegetation creates more porous soils by both protecting the soil from pounding rainfall, which can close natural gaps between soil particles, and loosening soil through root action. This is why forested areas have the highest infiltration rates of any vegetative types.

The top layer of leaf litter that is not decomposed protects the soil from the pounding action of rain, without this the soil can become far less permeable. In chaparral vegetated areas, the hydrophobic oils in the succulent leaves can be spread over the soil surface with fire, creating large areas of hydrophobic soil. Other conditions that can lower infiltration rates or block them include dry plant litter that resists re-wetting, or frost. If soil is saturated at the time of an intense freezing period, the soil can become a concrete frost on which almost no infiltration would occur. Over an entire watershed, there are likely to be gaps in the concrete frost or hydrophobic soil where water can infiltrate.

Once water has infiltrated the soil it remains in the soil, percolates down to the ground water table, or becomes part of the subsurface runoff process.Basic Infiltration rates of various soil are shown in ***Table 2.18***

- **Table 2.18: Basic Infiltration rates for various soil**

Soil Type	**Range of Basic Infiltartion Rate (mm/hr)**
Sand	>30
Sandy Loam	20 to 30
Loam	10 to 20
Clay Loam	5 to 10
Clay	1 to 5

Generalized Values of run-off factor (*Source:* *Guidelines for design, construction and rehabilitation of small dams and pans in Kenya)*

Catchment soil types	Runoff factors (Kr)
Rocky and impermeable	0.8 to 1.0
Slightly permeable, bare	0.6 to 0.8
Slightly permeable, partly cultivated or covered with the vegetation	0.4 to 0.6
Cultivated, absorbent soil	0.3 to 0.4
Sandy bare soil	0.2 to 0.3
Heavy forest	0.1 to 0.2

Considering the soil and catchment characteristics (As discussed in ***para 2.2.2***), rainfall runoff ratio is approximately equal to 0.25. considering all the facts infiltration rate is taken as 15mm/hr.

Effective Rainfall

The Effective Rainfall computed is arranged in critical sequence to get the Direct Runoff Hydrograph (Reference ***Table 2.19 & Table 2.20***). A base flow of 30 m^3/s is added to get the Total Runoff Hydrograph. The Flood Hydrograph is shown as ***Figure 2.19***. The Peak Flood corresponding to PMP of 400 mm is ***2760 Cumec and volume of flood is 180 MCM***.

Table 2.19 : Incremental Rainfall Vs Time

Time (hr)	% Distribution	Incremental Rainfall (mm)
0	0	0.0
1	0.032	12.8
2	0.077	18.0
3	0.127	20.0
4	0.182	22.0
5	0.234	20.8
6	0.294	24.0
7	0.355	24.8
8	0.416	24.4
9	0.476	24.0
10	0.536	24.0
11	0.597	24.2
12	0.658	24.3
13	0.718	24.0
14	0.768	20.0
15	0.804	14.4
16	0.827	9.2
17	0.847	8.0

Time (hr)	% Distribution	Incremental Rainfall (mm)
18	0.867	8.0
19	0.887	8.0
20	0.907	8.0
21	0.927	8.0
22	0.947	8.0
23	0.97	9.1
24	1	12.0

Table 2.20 : Critical Sequence of Excess Rainfall

Incremental Rainfall in Reverse Critical Sequence (mm)	Infiltration Rate (mm)	Excess Rainfall (mm)
8.00	15	0.0
8.00	15	0.0
8.00	15	0.0
8.00	15	0.0
8.00	15	0.0
9.20	15	0.0
12.00	15	0.0
14.40	15	0.0
18.00	15	3.0
20.00	15	5.0
20.80	15	5.8
24.00	15	9.0
24.00	15	9.0
24.20	15	9.2
24.40	15	9.4
24.80	15	9.8
24.32	15	9.3
24.00	15	9.0
24.00	15	9.0
22.00	15	7.0
20.00	15	5.0
12.80	15	0.0
9.08	15	0.0
8.00	15	0.0

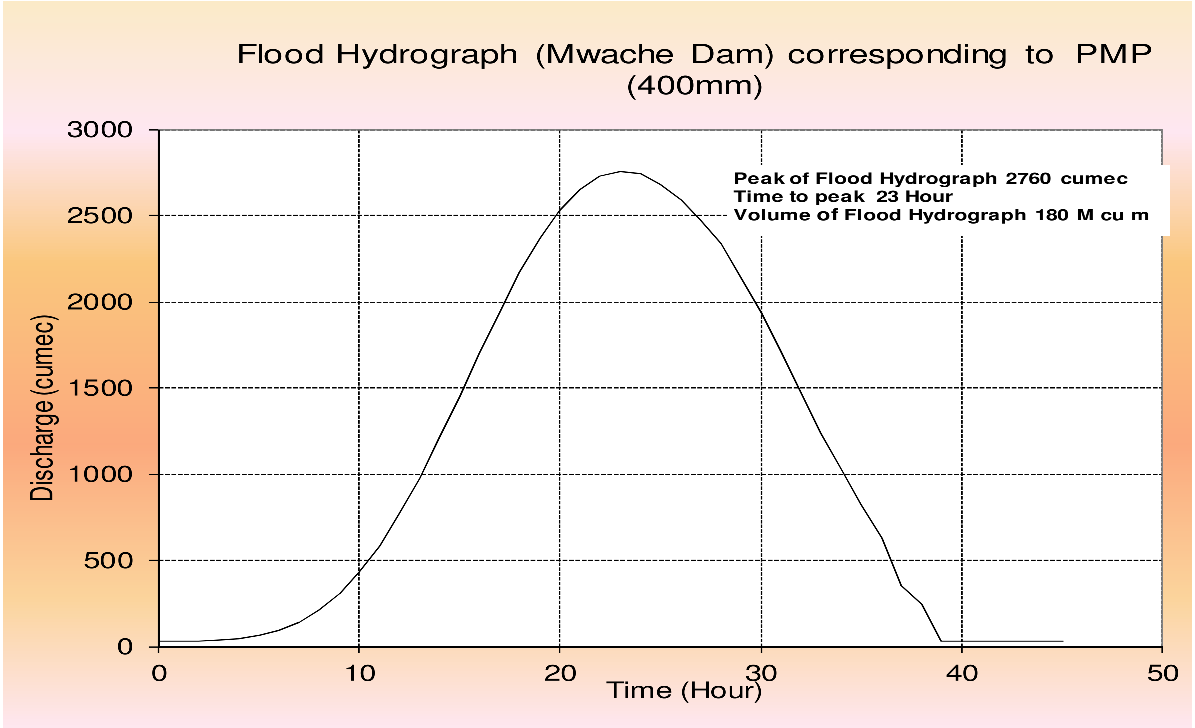

Figure 2.19: Flood Hydrograph corresponding to average PMP (400mm) for Mwache Dam

iii) PMF Computation Based on the National Master plan, 1992:

The project on the Study on the National Water Master Plan, 1992 undertook some major studies to establish a relationship between the PMF, PMP and catchment area. It was established that PMF is proportional to 0.75 power of the catchment area. The relationship is of the form;

PMF = (0.094 x PMP – 9.86) x A^0.75

Where,

PMF – Probable Maximum Flood
PMP - Probable Maximum Precipitation in mm
A – Catchment area in Sq.km

Based on the above relationship, the Probable Maximum Flood,

PMF = (0.094 x 466 – 9.86) x (2250^0.75) m^3/s
=11090 m^3/s

Conclusion:

The flood calculated from the Empirical formulae suggested values in the range of 1168-1960 cumec. As per the relationship developed and applied in National Water Master Plan, 1992, the PMF works out to 11,090 cumec. This reflects a wide variation in the results. The PMF estimated by applying Unit Hydrograph Method is 2760 cumec which is moderate. Considering the above, design peak of **2760cumec** based on Unit Hydrograph Method is proposed with a flood volume of **180 MCM**.

2.6 Diversion Flood

Designing the discharge capacity of the diversion works may be thought of in terms of an optimization calculation taking safety into account. Optimization aims at minising:

- The construction cost of the diversion works
- The cost of the damage that would result from under design not only at the construction site itself but also for property downstream in the event of sudden failure.

As per BIS 14185: 2000, Criteria for Diversion Capacity for Embankment Dams is as follows:

A. For Small and Intermediate Dams

5 to 20 years flood frequency flood is taken to decide the capacity of diversion works. In case the diversion arrangements like tunnels are to be used subsequently as permanent structure like tunnel spillway, the capacity may be equal to the discharging capacity of the permanent structure.

B. For Large Dams

For large dams it is desirable that 100years flood should be adopted for diversion works.

The daily observed data of **RGS 3MA03 (long 39.658 E and lat. 3.95 S)** site for the period 1976-77 to 1989-90 as available was scanned to obtain annual peeks. Following annual peak series were obtained:

Year	Peak Discharge (cumecs)
1976- 77	61.5
1977- 78	51.8
1978- 79	60.2
1979- 80	32.5
1980- 81	27.8
1981- 82	55.6
1982- 83	17.9
1983- 84	27.8
1984- 85	19.3
1985- 86	81.3
1986- 87	37.5
1987- 88	19.3
1988- 89	18.6
1989- 90	6.8

The above series were subjected to frequency distribution by various methods and following results were obtained:

Methods	Return Period	Flood frequency (cumecs)	90% upper confidence limit
Gumbel	100	125	170
LP III	100	124	169.5
P III	100	100	148

The higher of the three i.e. 125 m^3/sec could be considered for100 Yr flood. But this value is very low. So 90% upper confidence limit is considered for the diversion flood. Thus the diversion Flood for Mwache Multipurpose dam development project is considered as **170 cumec.**

2.7 RESERVOIR SEDIMENTATION

2.7.1 General

Storage reservoirs built across rivers or streams tend to lose their capacity progressively with the passage of time on account of sedimentation. After the designated life of a reservoir, sediment affects the regulating capacity of reservoir / dam as the function of water intakes may get affected. It is therefore necessary to make an assessment of reservoir sedimentation and plan for a specified full service time of the reservoir.

Full Service Time and Feasible Service Time are considered as 50 and 100 years respectively as per BIS 12182-1987 "Guidelines for Determination of effects of sedimentation in Planning and Performance of reservoirs" which is based on international practices. Sedimentation studies have been carried out using Modified Empirical Area Reduction method (Borland and Miller, 1960). A suitable rate of sedimentation based on siltation rate observed on river Mwache has been considered for assessing the area capacity for the reservoirs after their Full and Feasible service time. The revised areas and capacities were used for assessing the Minimum Drawdown level of the dam, to meet the desired objectives. The Minimum Drawdown level of the projects need to be planned on the basis of new zero elevation likely to be attained after Feasible service time of reservoir.

2.7.2 Methodology

The Empirical–Area–Reduction Method has been used to obtain the sediment distribution pattern at various depths of reservoir. In this method, reservoirs are classified into four types, namely Lake (Type I), Flood plain-foothill (Type II), Hill (Type III), Gorge (Type IV).

Type of Reservoir

Plot of capacity v/s depth on Log-Log paper was made and slope measured with the linear scale. Inverse of slope m determine the classification of Reservoir type suggested by Borland and Millar of USBR is as under:

M	**Reservoir Type**	**Sediment Classification**
1 - 1.5	Gorge	Type IV
1.5 - 2.5	Hill	Type III
2.5 – 3.5	Flood plain foot hill	Type II
– 4.5	Lake	Type I

New Zero Elevation

Moody's method has been used to determine the new zero elevation. The parameters to be evaluated are:

$$f(p) = \frac{1 - V(p)}{a(p)}$$

$$f'(p) = \frac{S - V(pH)}{H\,A(pH)}$$

Where,

f(p) = function of relative depth of reservoir for the theoretical design curve corresponding to the type of reservoir.

V(p) = relative volume at a given elevation

a(p) = relative area at a given elevation

f'(p) = function of the relative depth of reservoir

S = total sediment of reservoir in Ha-m

V (pH) = reservoir capacity at a given elevation (Ha-m)

H = Total depth of reservoir (m)

A(pH) = Reservoir area at a given elevation (Ha)

Storage design curves (***Figure 2.20***) for various type of reservoir show percentage of sediment deposited versus percentage of reservoir depth developed on the basis of Borland and Millar.

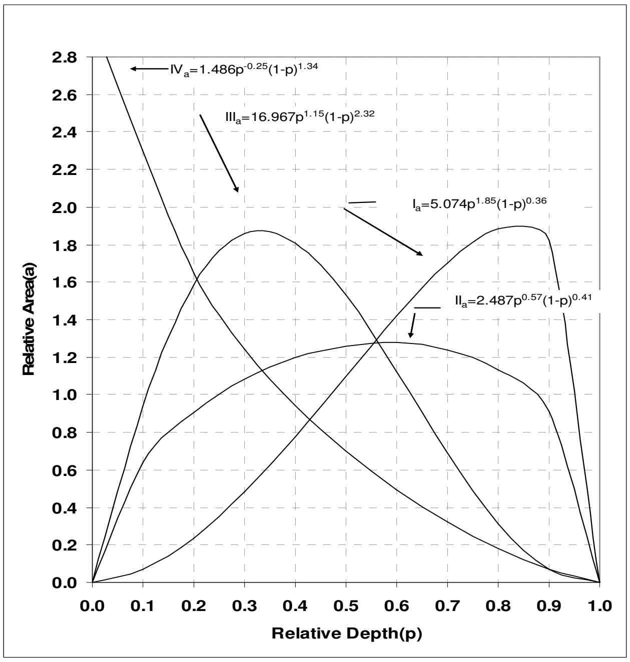

Figure 2.20 : Area Design Curve

2.7.3 Silt Rate and Annual Silt Load

The study held by the Ministry of Water and Irrigation and the Water Resources Management Authority do not contain any sediment load sampling from the two rivers. However, the Practice Manual for Water Supply Services in Kenya provides some guidelines in estimating the sediment load as given in the table below:

Erosion class	Sediment load (m^3/km^2/year)
Low	500
Moderate	1000
Heavy	1500

The fact that the coast region is relatively flat with reasonable coverage of vegetation suggest low levels of soil erosion and consequently low levels of sediment load of 500 m^3/km^2/year

2.7.4 Sediment Distribution Pattern

Based on m factor as shown in ***Figure 2.21***, Mwache reservoir is classified as Type-II Flood Plain Foothill.

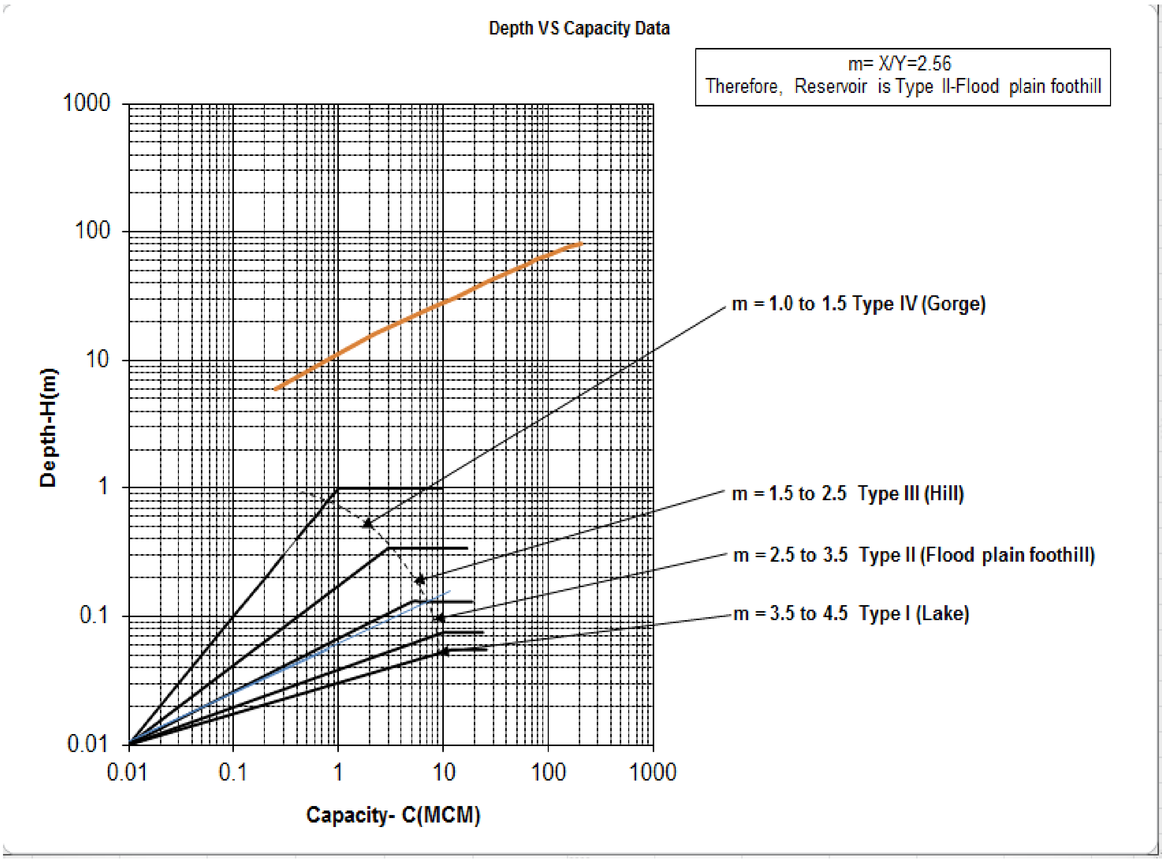

Figure 2.21 : Plot of Depth Vs. Capacity : Mwache

New Zero Elevation

Using Moody's method, New Zero Elevation has been calculated for Full and Feasible life of Mwache reservoir and the results are indicated below :

Time	New Zero Elevation (m)	Reference
50 years	El 39.1 m	***Figure. 2.22***
100 years	El 65.0 m	***Figure. 2.23***

Revised Reservoir Elevation Area Capacity Curve

Sedimentation distribution analysis of Mwache reservoir for 50 and 100 years of sedimentation based on Empirical–Area–Reduction Method have been made. The details are shown in ***Figures 2.24 & 2.25 and Tables 2.21 & 2.22.***

NEW ZERO ELEVATION AFTER 50 YEARS

Sediment Rate (Ham/sq.km./yr.)	0.05	**FRL in m =**		**95**
Trap efficiency	97.83%			
Years	50			
Catchment Area (sq.km.)	2250.00			
sediment Volume (ha.m)	5502.78			
Height(H)	81			
Elevation	Area (ha)	Capacity (ha.m)	Relative Depth (p)	$h'(p)=\frac{S-V(pH)}{H\times A(pH)}$
14	0	0.0	0.000	0.000
20	10.2	24.8	0.074	6.630
25	19.1	96.9	0.136	3.494
30	33.7	227.2	0.198	1.933
35	59	456.0	0.259	1.056
40	88.3	821.8	0.321	0.654
45	111.1	1319.2	0.383	0.465
50	138.4	1941.7	0.444	0.318
55	172.5	2717.4	0.506	0.199
60	211.1	3674.8	0.568	0.107
65	257	4843.1	0.630	0.032
70	303.6	6243.0	0.691	-0.030
75	355.9	7890.0	0.753	-0.083
80	425.9	9841.9	0.815	-0.126
85	603.1	12401.6	0.877	-0.141
90	819.3	15943.8	0.938	-0.157
95	1108	20744.0	1.000	-0.170
100	1471.5	27171.3	1.062	-0.182

Sample Calculation for New Zero Elevation		
Relative Depth Corresponding the Intersection	0.310	
Height Above the bottom =	25.110	m
New zero Elevation After 50 Yrs	**39.1**	m

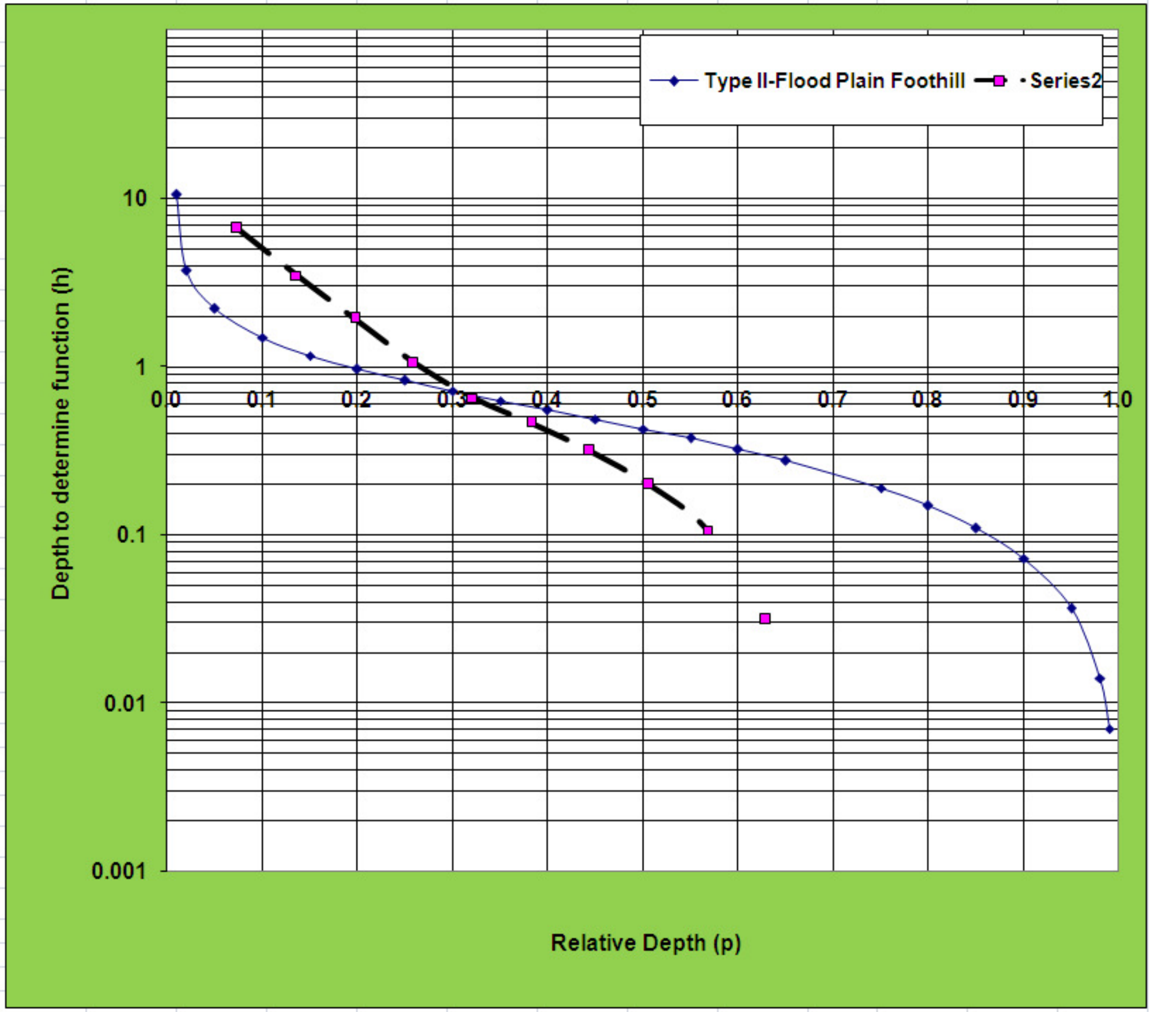

Figure 2.22 : New Zero Elevation of Mwache Reservoir after 50 years

NEW ZERO ELEVATION AFTER 50 YEARS

Sediment Rate (Ham/sq.km./yr.)	0.05	**FRL in m =**		**95**
Trap efficiency	97.83%			
Years	100			
Catchment Area (sq.km.)	2250.00			
sediment Volume (ha.m)	11005.56			
Height(H)	81			
Elevation	Area (ha)	Capacity (ha.m)	Relative Depth (p)	$h'(p)=\frac{S-V(pH)}{H\times A(pH)}$
14	0	0.0	0.000	0.000
20	10.2	24.8	0.074	13.291
25	19.1	96.9	0.136	7.051
30	33.7	227.2	0.198	3.949
35	59	456.0	0.259	2.207
40	88.3	821.8	0.321	1.424
45	111.1	1319.2	0.383	1.076
50	138.4	1941.7	0.444	0.809
55	172.5	2717.4	0.506	0.593
60	211.1	3674.8	0.568	0.429
65	257	4843.1	0.630	0.296
70	303.6	6243.0	0.691	0.194
75	355.9	7890.0	0.753	0.108
80	425.9	9841.9	0.815	0.034
85	603.1	12401.6	0.877	-0.029
90	819.3	15943.8	0.938	-0.074
95	1108	20744.0	1.000	-0.109
100	1471.5	27171.3	1.062	-0.136

Sample Calculation for New Zero Elevation		
Relative Depth Corresponding the Intersection	0.630	
Height Above the bottom =	51.030	m
New zero Elevation After 100 Yrs	**65.0**	m

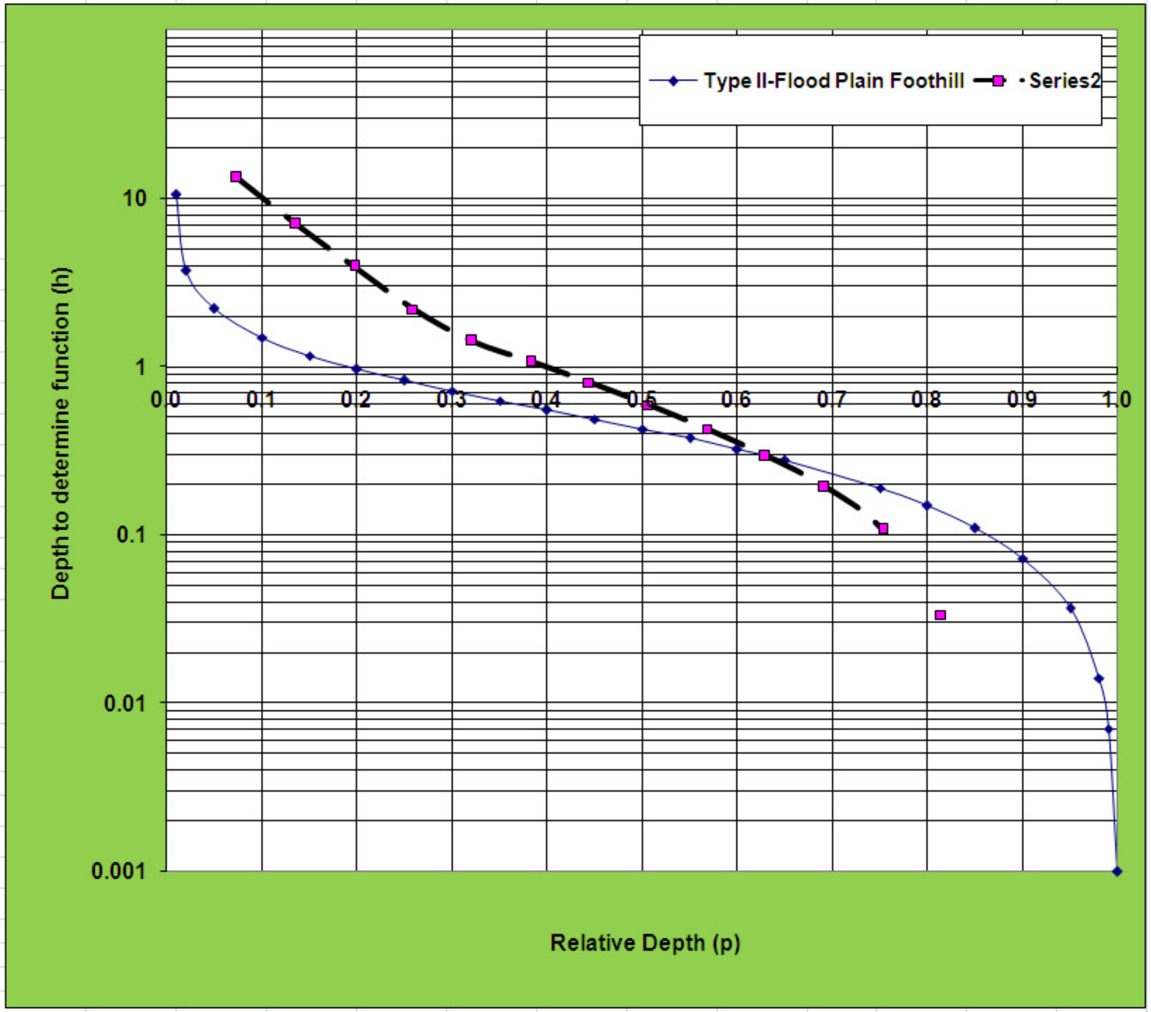

Figure 2.23 : New Zero Elevation of Mwache Reservoir after 100 years

Table 2.21 : Revised Elevation Area Capacity by Empirical Area Reduction Method after 50 Years

Elevation	Original Area	Original Capacity	Relative Distance above the stream bed	Ap (Type II)	Sediment Area	Sediment Volume	Accumulated Sediment Volume	Revised Area	Revised Capacity
m	Ha	Ha-m	m		Ha	Ha-m	Ha-m	Ha	Ha-m
1	2	3	4	5	6	7	8	9	10
95.00	1108.00	20744.0	1.000	0.000	0.0	0.0	5503.6	1108.0	15240.3
90.00	819.30	15943.8	0.938	0.787	59.4	148.5	5355.1	759.9	10588.7
85.00	603.10	12401.6	0.877	0.999	75.4	337.0	5018.2	527.7	7383.4
80.00	425.90	9841.9	0.815	1.127	85.1	401.1	4617.1	340.8	5224.8
75.00	355.90	7890.0	0.753	1.209	91.2	440.7	4176.4	264.7	3713.7
70.00	303.60	6243.0	0.691	1.259	95.0	465.6	3710.8	208.6	2532.3
65.00	257.00	4843.1	0.630	1.284	96.9	479.7	3231.0	160.1	1612.1
60.00	211.10	3674.8	0.568	1.288	97.2	485.1	2745.9	113.9	928.9
55.00	172.50	2717.4	0.506	1.272	96.0	482.9	2263.0	76.5	454.4
50.00	138.40	1941.7	0.444	1.238	93.4	473.5	1789.5	45.0	152.2
45.00	111.10	1319.2	0.383	1.186	89.5	457.3	1332.2	21.6	0.0
40.00	88.30	821.8	0.321	1.115	84.1	434.0	898.2	4.2	0.0
39.10	**83.39**	**768.3**	**0.310**	**1.100**	83.0	**75.2**	**823.0**	**0.4**	**0.0**
30.00	33.70	227.2	0.198	0.904	33.7	589.0	234.1	0.0	0.0
25.00	19.10	96.9	0.136	0.752	19.1	132.0	102.1	0.0	0.0
20.00	10.20	24.8	0.074	0.547	10.2	73.3	28.8	0.0	0.0
15.00	1.10	0.4	0.012	0.202	1.1	28.3	0.6	0.0	0.0
14.00	0.00	0.0	0.000	0.000	0.0	0.6	0.0	0.0	0.0

Total Sediment Volume accumulated in the Reservoir = 5503.63 error = -0.015 % : Therefore Acceptable Ko : 75.45

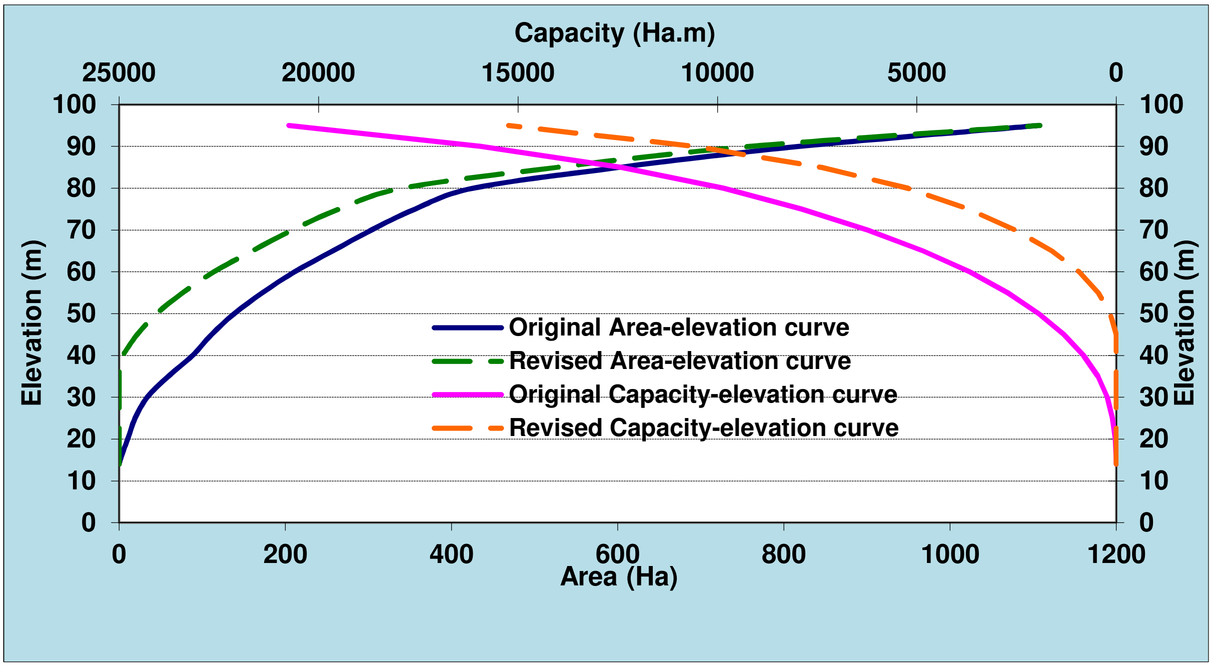

Figure 2.24 : Revised Elevation Area Capacity Curve of Mwache after 50 years

Table 2.22: Revised Elevation Area Capacity by Empirical Area Reduction Method after 100 Years

REVISED AREA AND CAPACITY AFTER 100 YEARS									
Elevation	Original Area	Original Capacity	Relative Distance above the stream bed	Ap (Type II)	Sediment Area	Sediment Volume	Accumulated Sediment Volume	Revised Area	Revised Capacity
m	Ha	Ha-m	m		Ha	Ha-m	Ha-m	Ha	Ha-m
1	2	3	4	5	6	7	8	9	10
95.00	1108.00	20744.0	1.000	0.000	0.0	0.0	11003.2	1108.0	9740.8
90.00	819.30	15943.8	0.938	0.787	160.2	400.5	10602.7	659.1	5341.2
85.00	603.10	12401.6	0.877	0.999	203.3	908.9	9693.8	399.8	2707.8
80.00	425.90	9841.9	0.815	1.127	229.4	1081.8	8612.0	196.5	1229.9
75.00	355.90	7890.0	0.753	1.209	246.1	1188.7	7423.3	109.8	466.7
70.00	303.60	6243.0	0.691	1.259	256.2	1255.8	6167.5	47.4	75.5
65.00	**257.00**	**4843.1**	**0.630**	**1.284**	**261.3**	**1293.9**	**4873.6**	**0.0**	**0.0**
60.00	211.10	3674.8	0.568	1.288	211.1	1181.1	3692.6	0.0	0.0
55.00	172.50	2717.4	0.506	1.272	172.5	959.0	2733.6	0.0	0.0
50.00	138.40	1941.7	0.444	1.238	138.4	777.3	1956.3	0.0	0.0
45.00	111.10	1319.2	0.383	1.186	111.1	623.8	1332.6	0.0	0.0
40.00	88.30	821.8	0.321	1.115	88.3	498.5	834.1	0.0	0.0
35.00	59.00	456.0	0.259	1.022	59.0	368.3	465.8	0.0	0.0
30.00	33.70	227.2	0.198	0.904	33.7	231.8	234.1	0.0	0.0
25.00	19.10	96.9	0.136	0.752	19.1	132.0	102.1	0.0	0.0
20.00	10.20	24.8	0.074	0.547	10.2	73.3	28.8	0.0	0.0
15.00	1.10	0.4	0.012	0.202	1.1	28.3	0.6	0.0	0.0
14.00	0.00	0.0	0.000	0.000	0.0	0.6	0.0	0.0	0.0

Total Sediment Volume accumulated in the Reservoir = 11003.16 error = 0.02 % : Therefore Acceptable Ko : 203.5

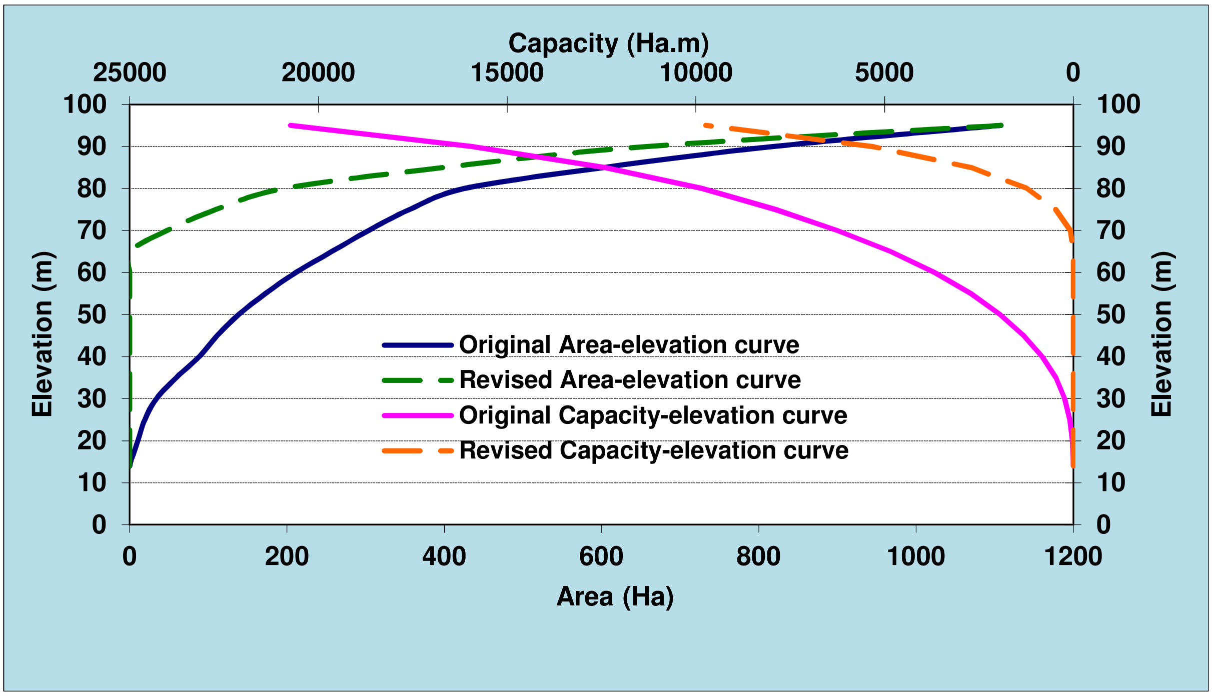

Figure 2.25 : Revised Elevation Area Capacity Curve of Mwache after 100 years

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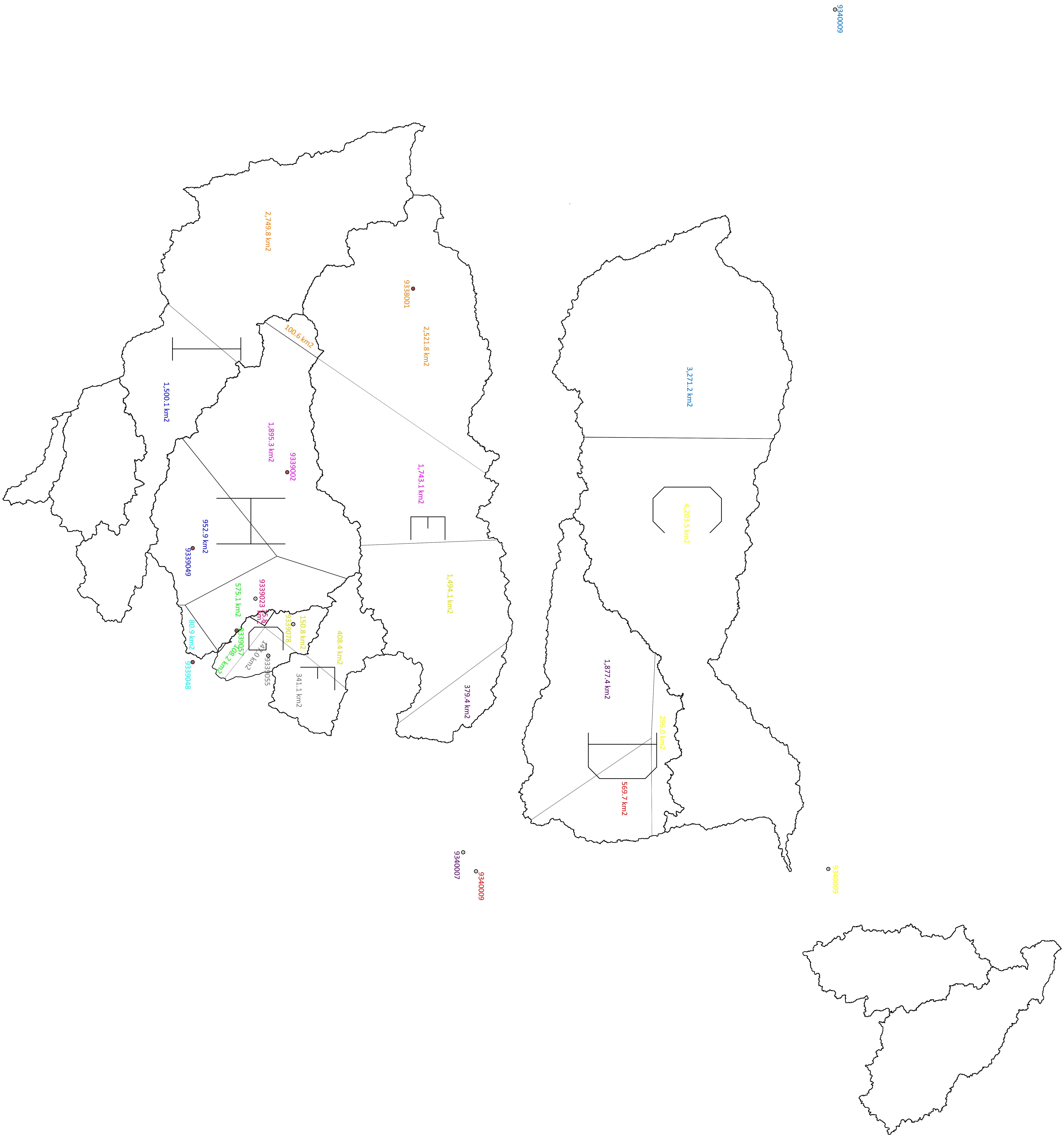


9340009
2,749.8 km2
9338001
2,521.8 km2
100.6 km2
3,271.2 km2
1,500.1 km2
1,895.3 km2
9339002
1,743.1 km2
952.9 km2
9339049
1,494.1 km2
575.1 km2
9339023
150.8 km2
408.4 km2
80.9 km2
9339048
341.1 km2
379.4 km2
1,877.4 km2
569.7 km2
9340007
9340009
9340009

The MRS Model

THE MRS MODEL

1. Introduction

1.1 About the MRS Model

The MRS Model belongs to a class of watershed models whose common base is the conservation of mass principle as applied to a watershed, requiring a balance between all the watershed water components, namely, groundwater replenishment and surface runoff. The models in existence differ in the inter-relationships between their various components, and their computational time-steps. Generally speaking, the shorter the time-step is, the larger is the number of watershed parameters operated on by the model, and the more accurate is the model's output.

Perhaps the most reputable watershed model is that developed by Stanford University, U.S.A., in the sixties. The model operates at hourly time-steps, requiring hourly rainfall as input. The Sacramento model adopted by the U.S. National Weather Services operates at daily time-steps. Having applied these type models in many parts of the world, it became apparent to TAHAL experts that for water resources projects in regions where the number of rainy days in a rainy month is large, the hourly and even the daily time-steps may be replaced by a monthly time-step, without a significant loss in accuracy of the monthly output by the model. Conversely, where the density of rain gauges is low, the monthly model may even produce better results than the daily or hourly ones do. These observations led to the development of the present monthly model, requiring easily accessible monthly rainfall as input. The model has since been successfully used and, its applicability verified in many parts of the world having diverse climatic and geological conditions.

1.2 Computer Requirements

The MRS Program, written in QUICK BASIC 4.5, would run on any PC. Its graphic output requires a graphic adapter such as Hercules in the case of a monochrome monitor, to be used with the MSHERC program, or a EGA/VGA graphic card, in the case of a colored monitor.

1.3 Units

The program operates in metric units as follows:

Rainfall	mm
Streamflow	m^3/sec or $10^6 m^3$ (MCM)
Area	km^2
Volume	MCM

1.4 Limitations

The MRS model was tested in watersheds with diverse climatic and geological conditions and produced good results. Its application is nevertheless limited to rainfall-produced streamflow, rather than snow melt, and to climatic conditions in which monthly rainfalls are generally larger than the month's potential evapotranspiration.

2. The Model

2.1 Overview

The MRS model is a conceptual, deterministic model performing hydrological water balance computations in monthly time-steps. The inputs to the model are monthly rainfalls associated with catchment areas, mean monthly potential evapotranspiration and several empirical parameters such as runoff coefficient and a soil moisture retention capacity. The outputs of the model are the total flow in the river, its surface and baseflow components, and the recharge to groundwater. The MRS model incorporates several applications such as Reservoir Operation and Probability Analysis, which are described in the next chapter.

2.2 Definitions of the Main Variables

PET	=	potential evapotranspiration
RF	=	rainfall
IMP	=	runoff from impervious areas
SRO	=	surface runoff
ET	=	actual evapotranspiration
SM	=	soil moisture
SMAX	=	the upper limit of SM
RCH	=	groundwater recharge
RE	=	recharge excess
GWS	=	groundwater storage contributing to the river
GWMAX	=	the upper limit of GWS
BF	=	baseflow
RB	=	the portion of RCH retained in GWS and becoming BF
RA	=	the portion of RCH leaving GWS and entering the aquifer below
TF	=	total flow in the river

2.3 Basic Relationships

$$IMP = P^{*}RF$$

where:

P = fraction of catchment area with impervious surface (an input parameter)

$$SRO = Z^{*} (SMAV/SMAX)\ ^{*}RF$$

where:

Z = coefficient of runoff (an input parameter)
SMAV = mean soil moisture in the current month, obtained by iterations

$$ET = V^{*}PET \text{ if } SM>= V^{*}PET, \text{ else } ET = SM$$

where:

V = evapotranspiration adjustment factor (an input parameter)

$$SM_2 = SM_1 – SRO + RF – ET$$

where:

SM_1, SM_2 = soil moistures in the beginning and end of month respectively, bounded by zero and SMAX (an input parameter).

RCH is the excess of SM over SMAX.

$$GWS_2 = GWS_1 + RB – BF$$

where:

GWS_1, GWS_2 = groundwater storage in the beginning and end of month, respectively, bounded by zero and GWMAX (input parameter).

RE is the excess of GWS over GWMAX.

$$RB = B^{*} (RCH – RE)$$

where:

B = fraction of recharge becoming baseflow (an input parameter).

RA = RCH – RE – RB

$$BF = RB^{*} (1 – C)\ ^{*}T^{*} (GWS/T – RB) \text{ - theoretically derived}$$

where:

C = baseflow recession constant (an input parameter)
T = -(1/ln C)

TF = IMP + (SRO + RE + BF) * (1 – P)

The computations are conducted in units of mm/month and in the case of TF converted to units of MCM/month by the equation:

$$TFV = TF^{*}CA/1000$$

where:

CA = overall catchment area in km^2.

The model can operate on a large number of sub-watersheds, each assigned a different rainfall input and different parameter values, if so desired.

Rainfall Data

RAINFALL DATA

Table 1: Voi Station - Monthly Rainfall (mm)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1956	0.0	23.5	49.6	114.3	10.1	0.5	2.0	32.3	12.0	7.1	74.2	68.3	393.9
1957	223.0	9.2	81.2	106.6	17.0	2.5	0.7	0.9	10.0	9.5	203.8	178.0	842.4
1958	13.3	10.0	65.7	153.7	15.7	5.7	1.3	5.2	7.8	5.6	73.7	60.1	417.9
1959	118.7	22.7	73.7	**90.1**	3.5	4.2	2.6	8.8	3.4	22.3	72.4	63.2	485.8
1960	11.7	1.3	61.0	67.8	35.2	1.8	0.0	1.5	1.0	76.5	32.3	76.8	366.9
1961	1.0	28.7	76.0	45.7	2.6	0.0	6.6	1.8	90.9	123.4	190.7	170.6	738
1962	98.9	53.2	122.5	17.6	2.9	0.3	0.8	10.7	0.5	0.0	153.3	94.7	555.4
1963	19.9	18.8	104.2	19.8	13.3	19.9	4.4	0.2	11.2	46.8	230.5	184.7	673.7
1964	25.8	34.3	52.8	93.6	11.9	0.0	0.0	2.3	2.5	16.3	3.6	225.5	468.6
1965	54.9	0.0	26.0	61.8	58.5	0.7	0.0	9.6	8.7	42.7	89.6	81.8	434.3
1966	29.6	46.3	223.2	101.1	28.0	6.6	0.0	4.3	1.4	10.7	53.5	53.1	557.8
1967	2.8	36.8	62.3	273.7	16.9	3.9	7.9	30.3	93.1	84.0	97.5	25.3	734.5
1968	0.3	42.2	384.8	87.6	42.6	32.5	0.0	1.5	11.1	27.4	169.8	115.4	915.2
1969	63.8	19.5	159.3	86.4	12.9	4.1	0.9	24.9	8.5	66.2	301.5	23.9	771.9
1970	116.4	0.2	200.2	23.7	16.8	0.2	3.9	1.9	6.0	3.9	51.6	117.5	542.3
1971	2.4	0.2	11.1	114.0	12.7	6.3	4.7	0.0	2.6	4.9	60.2	61.3	280.4
1972	46.0	103.5	60.8	90.7	159.7	0.0	5.0	1.8	36.6	10.9	214.0	114.9	843.9
1973	27.4	36.4	70.0	60.4	30.6	0.2	0.6	1.8	5.1	14.3	203.7	18.4	468.9
1974	12.0	0.8	13.0	200.6	6.1	2.4	11.7	6.0	0.9	16.0	68.4	46.1	384
1975	6.0	4.0	26.3	41.0	25.4	0.0	1.2	0.0	22.0	0.0	102.6	0.0	228.5
1976	19.3	2.6	19.1	59.9	41.2	0.0	0.4	4.5	57.0	1.3	143.3	33.3	381.9
1977	30.0	27.6	29.6	92.7	5.8	9.4	0.0	2.6	19.7	47.1	156.5	207.7	628.7
1978	106.0	35.4	216.0	100.6	14.7	0.5	1.6	0.0	0.8	15.8	334.2	115.8	941.4
1979	144.1	26.5	67.5	165.2	56.2	10.7	5.8	0.3	3.8	23.4	79.4	220.3	803.2
1980	50.4	15.8	54.1	49.0	4.4	0.0	1.5	32.0	8.9	2.6	0.0	96.9	315.6
1981	1.5	0.7	248.4	84.1	22.6	0.0	3.0	2.7	13.8	35.2	62.5	259.1	733.6
1982	4.5	0.0	68.6	82.9	25.9	5.3	10.1	12.9	60.8	106.4	254.0	64.2	695.6
1983	2.7	55.5	89.9	3.1	36.3	2.8	5.6	0.1	4.2	0.0	81.7	43.5	325.4
1984	0.3	0.6	24.5	60.2	1.6	10.0	4.6	0.2	4.1	72.5	120.6	229.2	528.4
1985	37.9	52.3	10.6	69.4	14.3	0.0	6.9	2.5	5.4	18.0	93.9	143.0	454.2
1986	7.6	0.1	24.2	30.0	97.3	0.0	0.0	8.4	0.0	20.4	148.0	218.7	554.7
1987	22.2	2.3	8.3	160.7	44.8	1.6	11.4	17.7	0.0	6.1	53.5	18.5	347.1
1988	110.4	3.5	95.4	65.7	4.8	6.4	0.1	9.9	29.5	27.3	63.1	193.4	609.5
1989	35.1	9.6	49.6	63.4	5.8	4.5	2.3	3.5	7.1	34.7	189.1	104.2	508.9
1990	26.8	18.1	99.1	98.0	20.1	1.3	1.0	0.0	21.3	89.3	126.0	50.8	551.8
1991	13.3	13.1	59.1	141.1	43.8	2.2	3.3	2.5	6.8	21.1	89.8	91.4	487.5
1992	15.6	9.6	30.7	117.1	25.5	0.9	3.0	1.8	9.6	7.6	136.2	125.4	482.9
1993	278.4	9.7	103.8	138.5	11.1	4.9	1.7	2.5	6.1	21.4	85.4	212.4	875.9
1994	21.0	9.3	21.1	32.0	55.9	1.1	3.4	5.0	14.5	39.9	140.1	132.9	476.2
1995	18.7	8.9	67.9	106.6	22.4	0.0	2.3	6.1	6.4	21.2	105.2	144.5	510.1
1996	19.8	15.9	58.3	98.2	25.1	0.4	3.1	0.0	4.2	21.3	146.1	46.5	439.0
1997	13.8	9.3	30.7	0.0	37.6	4.4	4.3	0.0	15.3	262.7	299.0	211.9	889.1
1998	389.0	52.6	62.8	**90.1**	22.9	6.3	2.2	2.7	6.6	10.0	79.7	54.5	779.4
1999	29.0	11.6	29.5	9.1	21.9	3.5	2.7	12.7	15.1	17.4	125.9	51.3	329.7
2000	19.4	8.9	89.4	136.7	32.3	5.5	1.5	4.1	14.3	54.5	81.7	132.8	581.0
2001	42.3	10.9	57.9	109.2	21.5	4.6	1.4	2.9	3.5	7.7	120.6	62.7	445.0
2002	24.8	16.9	142.3	124.5	14.6	0.7	0.5	6.0	26.3	90.0	85.2	127.9	659.9
2003	14.0	8.9	45.1	125.9	26.9	3.2	1.4	5.0	10.4	66.6	125.8	72.6	505.8
2004	64.5	16.6	80.5	136.0	0.0	4.5	1.1	0.0	5.2	58.6	125.8	70.7	563.4
2005	82.9	8.9	54.7	85.7	22.0	3.1	1.2	1.0	8.4	15.6	105.2	35.8	424.4
2006	13.3	10.5	42.5	0.0	7.9	3.2	1.2	7.9	16.9	108.5	208.2	124.9	545.1
2007	32.6	9.8	50.7	109.1	48.2	1.8	1.1	9.9	22.4	32.4	103.9	37.2	459.2
2008	78.8	9.5	97.0	130.3	30.2	5.0	0.7	10.1	3.0	18.7	95.2	57.3	535.7
2009	43.4	28.2	24.8	141.1	8.4	4.7	1.1	0.0	4.5	141.7	94.5	62.0	554.3
Average	**49.8**	**18.7**	**77.4**	**90.1**	**25.9**	**3.8**	**2.7**	**6.0**	**14.3**	**39.0**	**124.2**	**104.3**	**556.1**

Note: Values in red are computed by correlation with Msabaha Rainfall Station; values in bold face are mean values.

Table 2: Mackinnon Road Station - Monthly Rainfall (mm)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1956	**38.9**	15.7	10.6	163.7	14.0	0.0	5.0	22.6	**28.4**	5.6	55.0	86.1	445.6
1957	11.9	4.2	32.5	193.2	**45.4**	11.5	5.1	1.7	0.0	89.5	13.8	63.1	471.8
1958	11.9	27.7	41.6	117.3	6.5	0.0	56.9	62.5	316.7	247.9	391.7	46.9	1327.8
1959	11.9	4.2	58.7	34.6	21.9	3.5	0.9	1.7	0.0	11.7	10.0	46.2	205.4
1960	1.8	56.7	110.3	119.0	81.3	52.6	29.8	9.0	17.8	20.6	103.2	135.4	737.5
1961	61.5	14.7	61.0	133.2	101.7	10.9	14.9	26.1	11.4	54.4	58.2	228.4	776.4
1962	57.2	1.0	79.2	40.7	46.3	22.3	6.6	8.9	48.5	19.3	218.4	30.0	578.4
1963	31.7	62.3	269.9	70.0	91.9	42.7	0.0	13.7	2.8	33.4	26.4	30.5	675.3
1964	0.0	40.2	2.0	75.2	15.2	3.8	80.0	80.0	175.1	250.7	118.1	0.0	840.3
1965	0.0	68.5	94.9	169.3	54.1	90.7	2.1	0.6	8.1	61.5	136.6	51.3	737.7
1966	71.8	76.9	57.7	39.9	39.7	15.2	0.6	64.4	10.9	45.5	124.0	44.9	591.5
1967	101.9	0.0	84.7	7.6	21.5	0.0	21.8	5.5	0.7	0.0	34.8	54.7	333.2
1968	0.0	7.9	0.0	22.9	23.9	50.3	10.7	0.0	27.7	0.0	29.9	76.9	250.2
1969	84.4	0.0	9.8	16.1	95.4	10.4	14.2	5.4	120.7	63.4	68.1	41.5	529.4
1970	15.3	0.0	17.0	199.5	69.1	22.2	5.0	12.8	0.0	22.8	82.1	4.7	450.5
1971	31.2	0.0	74.4	27.2	13.1	17.3	27.1	0.0	16.7	0.0	47.0	106.0	360
1972	47.6	0.0	25.4	90.9	62.5	7.5	9.5	0.0	27.0	10.0	0.0	16.0	296.4
1973	0.0	0.0	20.8	100.0	63.3	26.5	0.0	0.0	72.0	0.0	116.5	61.0	460.1
1974	19.5	30.0	79.0	0.0	0.0	0.0	0.0	0.0	28.0	115.0	57.3	68.0	396.8
1975	10.5	33.3	127.4	54.0	37.0	9.0	5.4	0.0	0.0	29.0	169.9	101.0	576.5
1976	116.8	27.8	29.8	51.6	117.2	14.1	8.5	0.0	16.5	6.2	10.5	36.2	435.2
1977	6.0	41.7	24.1	66.5	2.5	0.0	0.0	1.9	11.8	0.0	33.5	70.7	258.7
1978	8.4	0.0	104.0	85.0	16.2	0.0	8.1	51.6	22.0	29.3	2.1	98.7	425.4
1979	40.2	0.0	57.0	203.1	164.1	9.0	6.2	8.3	18.1	93.0	28.4	26.5	653.9
1980	1.6	13.7	4.2	57.9	64.9	5.8	24.9	0.0	2.4	0.0	12.2	17.9	205.5
1981	0.0	0.0	2.1	5.5	1.8	4.0	2.5	0.0	0.0	37.8	16.1	3.6	73.4
1982	1.6	136.6	61.4	29.3	21.9	0.0	0.8	0.0	4.3	7.8	13.7	13.9	291.3
1983	29.1	4.2	52.2	204.1	78.9	1.0	2.8	1.7	0.0	34.5	69.9	67.2	545.5
1984	89.5	4.2	17.2	98.8	113.8	0.0	110.6	43.1	1.0	15.2	96.1	73.5	663.0
1985	25.8	0.0	141.3	26.7	1.8	39.7	0.0	37.4	54.5	3.5	58.1	113.7	502.5
1986	76.8	0.0	37.2	80.7	47.2	6.6	12.5	40.4	4.2	91.2	42.8	92.3	531.9
1987	16.0	38.0	222.1	126.9	12.8	6.8	4.5	14.0	19.8	**46.6**	24.1	82.6	614.2
1988	0.0	13.1	37.7	65.4	49.5	33.5	26.2	73.4	6.5	19.3	108.0	87.2	519.8
1989	0.0	0.0	0.0	80.4	63.2	12.6	8.5	15.0	17.2	23.4	53.4	72.5	346.2
1990	74.6	14.4	17.0	88.7	16.3	11.1	17.5	21.1	0.0	54.0	10.6	61.4	386.7
1991	0.0	**17.6**	14.9	29.0	38.8	38.7	29.0	12.0	53.0	25.0	142.2	31.6	431.9
1992	11.9	5.7	17.5	162.7	72.7	10.4	50.4	**17.2**	19.4	**46.6**	35.3	64.3	514.1
1993	30.8	12.0	38.9	112.4	81.7	0.0	6.2	12.2	7.7	26.5	20.9	61.4	410.6
1994	30.7	7.3	22.9	**89.9**	64.8	1.0	15.5	9.8	32.1	134.1	51.6	**63.3**	523.0
1995	186.4	9.4	28.6	**89.9**	48.2	2.0	9.1	19.4	32.1	26.3	25.1	**63.3**	539.7
1996	11.9	4.2	19.2	116.1	8.0	3.4	5.9	13.8	0.0	16.2	101.5	68.9	369.2
1997	**38.9**	**17.6**	**51.8**	**89.9**	**45.4**	**13.2**	**14.0**	**17.2**	**28.4**	**46.6**	**67.9**	**63.3**	**494.2**
1998	46.1	5.9	13.5	50.5	40.7	16.4	2.1	19.4	0.0	12.2	74.2	69.9	351.0
1999	96.5	**17.6**	55.3	101.2	21.1	0.9	4.6	38.6	66.2	85.4	51.9	71.4	610.8
2000	11.9	5.9	48.8	89.9	60.6	4.5	2.1	3.3	27.1	24.4	29.9	51.3	359.8
2001	213.8	17.6	13.5	136.0	6.5	9.7	8.5	6.9	0.0	83.1	50.8	59.0	605.5
2002	50.4	5.9	53.0	36.7	23.6	3.7	10.0	12.0	6.1	33.4	74.8	62.2	372.0
2003	11.9	8.7	59.5	325.7	40.6	9.9	8.3	15.7	39.7	130.6	155.4	76.8	883.0
2004	57.3	7.7	21.7	62.8	36.6	1.4	8.1	30.8	34.5	32.1	55.3	71.9	420.2
2005	51.0	7.7	86.8	84.8	33.5	10.7	7.1	20.1	7.8	32.8	54.8	71.9	469.1
2006	**38.9**	8.8	33.8	64.7	18.2	6.1	4.3	4.4	4.3	81.0	30.4	67.6	362.6
2007	**38.9**	**17.6**	**51.8**	**89.9**	**45.4**	**13.2**	**14.0**	**17.2**	**28.4**	**46.6**	**67.9**	**63.3**	**494.3**
2008	**38.9**	15.7	10.6	163.7	14.0	0.0	5.0	22.6	**28.4**	5.6	55.0	86.1	445.6
2009	11.9	4.2	32.5	193.2	**45.4**	11.5	5.1	1.7	0.0	89.5	13.8	63.1	471.8
Average	11.9	27.7	41.6	117.3	6.5	0.0	56.9	62.5	316.7	247.9	391.7	46.9	1327.8

Note: Values in red and blue are computed by correlation with Maji and Kayafungo Rainfall Stations, respectively; values in bold face are mean values.

Table 3: Makamini Agriculture Office Station - Monthly Rainfall (mm)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1956	**29.0**	43.5	14.0	123.6	30.6	14.1	22.1	24.8	37.4	9.6	57.6	114.4	520.8
1957	6.5	8.3	42.3	151.4	86.6	44.0	22.1	5.4	8.1	125.5	26.5	92.7	619.5
1958	6.5	80.3	54.2	79.9	17.2	14.1	117.6	62.1	285.7	344.5	311.6	77.4	1451.0
1959	6.5	8.3	76.3	1.8	44.6	24.2	14.5	5.4	8.1	18.1	23.6	76.7	308.1
1960	6.5	8.3	69.0	172.8	78.3	108.6	58.0	14.3	32.1	35.0	82.8	161.1	826.8
1961	32.8	41.8	68.3	**74.7**	94.7	41.5	37.9	26.6	23.1	63.8	57.8	249.1	812.2
1962	30.8	13.6	82.8	**74.7**	90.1	59.8	26.7	14.2	75.1	40.0	146.9	61.4	716.1
1963	11.0	28.7	111.1	46.0	119.8	98.1	31.1	10.8	8.1	27.4	14.3	61.8	568.2
1964	6.5	100.1	21.7	181.0	72.9	28.3	14.5	58.2	148.2	118.5	37.5	33.0	820.4
1965	6.5	152.8	95.3	74.4	97.8	169.9	20.7	8.2	18.5	69.9	101.4	81.5	896.8
1966	19.1	193.7	19.3	22.9	83.6	48.4	21.9	77.8	10.1	77.6	106.1	75.5	755.8
1967	30.6	8.3	44.7	34.4	63.3	15.3	16.2	22.6	20.5	14.2	34.6	84.7	389.4
1968	21.1	0.0	16.3	15.3	27.4	85.2	8.1	9.7	0.0	0.0	0.0	71.1	254.2
1969	42.0	14.1	13.5	45.5	210.5	3.8	23.2	14.4	157.3	67.9	129.6	120.4	842.2
1970	15.6	0.0	6.8	37.8	142.4	46.1	11.4	27.9	0.0	31.1	105.2	30.7	455.0
1971	71.7	0.0	17.3	41.6	67.4	24.8	46.5	6.1	5.5	4.9	97.0	13.0	395.8
1972	59.7	5.1	34.1	61.7	78.5	13.5	21.4	7.8	49.1	25.3	49.5	48.1	453.8
1973	0.0	26.5	21.6	87.6	86.9	73.1	37.5	19.6	53.4	12.8	81.6	102.1	602.7
1974	10.5	48.0	83.6	11.3	27.9	43.1	22.7	30.5	69.0	148.8	114.4	147.4	757.2
1975	62.9	31.1	147.2	114.7	69.9	35.6	19.9	22.8	14.0	17.6	102.3	116.9	754.9
1976	85.2	46.3	120.5	91.8	228.8	50.6	22.7	15.8	53.4	42.5	101.2	63.1	921.9
1977	6.5	28.0	18.1	121.3	12.5	9.1	20.9	130.3	10.3	9.6	161.1	49.7	577.4
1978	9.4	8.3	92.7	7.1	38.0	26.6	21.4	54.1	33.0	104.3	78.6	95.1	568.6
1979	0.0	0.0	18.5	45.9	263.8	24.4	89.6	18.3	73.6	117.2	53.3	104.5	809.1
1980	5.8	18.1	14.7	14.2	152.0	54.7	56.9	10.7	30.4	0.0	32.7	45.6	435.8
1981	0.0	0.0	46.8	167.1	64.9	60.8	30.6	0.0	14.9	69.4	184.2	114.1	752.8
1982	111.2	135.0	13.1	68.2	78.5	10.2	60.6	20.2	37.9	42.4	95.5	82.6	755.4
1983	18.4	0.0	0.0	110.8	146.1	17.9	17.9	5.4	8.1	49.5	68.8	96.6	539.5
1984	60.3	8.3	22.6	120.4	137.5	22.4	50.0	44.0	15.2	9.6	21.1	102.5	613.8
1985	20.6	8.3	98.9	93.5	17.2	62.6	25.7	33.7	28.4	9.6	94.6	140.6	633.7
1986	34.6	8.3	13.1	211.6	67.8	29.7	35.9	29.6	20.7	43.5	74.6	120.3	689.6
1987	6.5	101.7	35.9	107.0	51.1	30.2	20.3	10.9	8.1	**62.4**	18.9	111.1	564.2
1988	6.5	35.4	66.9	23.6	178.1	46.0	58.1	9.6	14.5	30.7	42.3	115.5	627.3
1989	6.5	8.3	13.1	23.6	81.8	29.8	40.6	10.6	23.2	37.4	56.4	101.6	432.8
1990	9.3	8.3	29.2	1.8	17.2	14.1	14.5	5.4	8.1	61.5	43.1	91.1	303.6
1991	6.5	**30.9**	44.8	75.0	137.3	26.6	66.2	15.0	78.0	68.6	54.3	62.9	666.0
1992	6.5	12.9	23.0	74.4	135.1	**39.3**	105.5	20.4	26.4	**62.4**	42.7	93.8	642.4
1993	19.6	32.0	50.7	59.0	151.0	14.2	24.2	15.1	16.1	38.4	31.9	91.1	543.5
1994	18.2	10.3	23.4	**74.7**	126.0	36.1	43.9	11.4	**37.0**	221.1	124.9	100.2	827.2
1995	147.2	20.4	32.9	**74.7**	87.7	47.9	28.9	22.1	**37.0**	35.0	53.0	0.0	586.8
1996	6.5	8.3	25.2	74.4	19.9	24.0	23.6	16.7	9.2	24.3	92.6	98.2	423.0
1997	**29.0**	**30.9**	**46.9**	**74.7**	**86.7**	**39.3**	**33.4**	**22.9**	**37.0**	**62.4**	**75.7**	**91.3**	**630.2**
1998	30.2	13.6	17.8	43.4	78.0	56.3	16.8	21.9	8.1	18.8	72.1	99.1	476.2
1999	65.2	**30.9**	71.9	69.1	43.2	17.8	21.3	39.8	67.2	119.9	55.3	100.6	701.9
2000	6.5	13.6	63.4	63.3	113.6	26.8	16.7	6.8	33.0	35.6	38.6	81.6	499.5
2001	146.4	49.3	17.8	86.7	17.2	39.6	28.5	10.2	8.1	116.7	54.4	88.8	663.8
2002	33.2	13.6	68.9	36.5	47.7	24.6	31.2	15.0	14.8	48.0	72.5	91.9	497.7
2003	6.5	22.1	77.3	182.5	77.9	40.2	28.2	18.4	44.1	182.3	133.3	105.7	918.6
2004	38.0	19.0	28.4	49.7	70.7	18.9	27.8	32.5	39.5	46.3	57.8	101.0	529.5
2005	33.6	19.0	112.6	60.8	65.4	42.1	25.9	22.5	16.2	47.2	57.5	101.0	603.7
2006	**29.0**	22.5	44.0	50.6	38.0	30.6	20.8	7.8	13.2	113.8	39.1	97.0	506.4
2007	**29.0**	**30.9**	**46.9**	**74.7**	**86.7**	**39.3**	**33.4**	**22.9**	**37.0**	**62.4**	**75.7**	**91.3**	**630.3**
2008	**29.0**	43.5	14.0	123.6	30.6	14.1	22.1	24.8	37.4	9.6	57.6	114.4	520.8
2009	6.5	8.3	42.3	151.4	86.6	44.0	22.1	5.4	8.1	125.5	26.5	92.7	619.5
Average	6.5	80.3	54.2	79.9	17.2	14.1	117.6	62.1	285.7	344.5	311.6	77.4	1451.0

Note: Values in red and blue are computed by correlation with Maji and MacKinnon Rainfall Stations, respectively; values in bold face are mean values.

Table 4: Mariakani Research Station - Monthly Rainfall (mm)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1956	**34.4**	48.9	22.5	135.7	63.6	33.6	40.8	38.4	**45.1**	0.0	60.7	117.6	641.3
1957	20.0	14.2	29.7	157.1	**128.2**	69.0	40.9	11.4	21.5	162.8	36.7	73.5	765.0
1958	20.0	154.0	32.6	101.9	46.0	33.6	203.1	90.1	307.1	497.7	257.4	42.5	1786.1
1959	20.0	14.2	38.2	41.7	82.0	45.6	27.9	11.4	21.5	0.0	34.5	41.1	378.3
1960	20.0	14.2	36.4	173.6	126.4	**56.0**	**52.1**	**41.2**	**45.1**	**83.8**	**66.6**	**82.9**	**798.3**
1961	**34.4**	**47.5**	**35.9**	**96.8**	147.9	**56.0**	**52.1**	**41.2**	**45.1**	**83.8**	**66.6**	**82.9**	**790.4**
1962	**34.4**	**47.5**	**35.9**	**96.8**	**128.2**	**56.0**	**52.1**	**41.2**	**45.1**	**83.8**	**66.6**	**82.9**	**770.7**
1963	22.7	53.8	47.0	75.8	181.0	132.9	56.1	18.9	21.5	12.7	27.2	9.6	659.3
1964	20.0	192.5	24.5	179.9	119.3	50.5	27.9	84.8	165.6	152.0	45.1	**82.9**	1145.0
1965	20.0	**47.5**	**35.9**	**96.8**	**128.2**	**56.0**	**52.1**	**41.2**	**45.1**	**83.8**	**66.6**	63.3	**736.6**
1966	27.5	374.0	23.9	58.0	**128.2**	**56.0**	40.5	111.9	23.6	89.5	98.3	29.2	1060.5
1967	34.3	14.2	30.3	66.9	106.6	35.1	30.8	35.3	34.3	0.0	42.9	60.4	491.0
1968	**34.4**	**47.5**	**35.9**	**96.8**	**128.2**	**56.0**	**52.1**	**41.2**	28.2	0.0	36.3	209.0	**765.8**
1969	30.8	**47.5**	**35.9**	**96.8**	**128.2**	**56.0**	**52.1**	**41.2**	**45.1**	48.1	64.0	**82.9**	**728.7**
1970	**34.4**	**47.5**	22.3	77.5	151.9	72.0	29.4	31.0	24.3	59.0	63.7	7.3	620.3
1971	23.4	152.3	31.2	70.4	108.8	106.4	88.3	21.6	36.1	0.0	**66.6**	**82.9**	788.0
1972	32.9	14.2	28.9	65.2		47.2	52.6	0.0	63.7	9.6	54.5	**82.9**	451.7
1973	20.0	224.7	29.8	111.2	107.2	61.1	85.5	3.2	91.4	14.2	30.6	50.1	829.0
1974	26.1	9.5	53.4	76.0	30.0	41.9	27.6	82.1	33.1	295.0	97.9	140.5	913.1
1975	48.4	30.4	93.8	184.6	178.1	77.1	33.8	18.4	73.6	18.5	155.2	109.1	1021.0
1976	114.8	54.5	53.7	59.0	371.5	56.7	40.8	28.0	49.6	17.7	77.6	33.6	957.4
1977	12.5	11.3	24.0	16.8	28.4	7.9	51.1	188.4	36.5	302.2	105.5	73.7	858.3
1978	30.8	0.0	134.5	21.2	60.7	52.3	26.0	111.4	35.8	80.3	58.1	147.8	758.9
1979	39.9	0.0	20.4	164.3	322.4	76.1	110.1	26.9	120.8	105.9	73.7	115.3	1175.8
1980	0.0	4.6	0.7	48.6	318.7	60.6	93.4	22.7	13.4	2.2	7.5	19.5	591.9
1981	0.0	0.0	10.2	182.4	141.4	64.7	41.8	7.0	6.7	69.8	54.5	68.7	647.1
1982	76.7	330.0	0.0	64.8	103.4	20.5	162.0	6.6	8.2	24.7	43.4	199.0	1039.3
1983	9.0	0.0	85.3	204.9	272.4	25.7	2.3	67.4	6.7	73.6	141.1	420.7	1309.0
1984	46.3	0.0	35.3	85.9	196.4	27.7	59.0	88.7	15.2	7.6	45.4	11.2	618.7
1985	8.8	3.3	78.1	141.4	29.5	136.6	23.7	44.6	44.7	4.8	117.0	145.5	778.0
1986	58.1	1.0	13.6	227.0	101.0	33.5	20.4	32.4	18.8	52.1	59.7	145.0	762.6
1987	55.6	58.4	36.9	54.5	87.1	66.4	5.7	22.5	19.3	**83.8**	35.4	77.9	603.5
1988	5.4	9.5	72.4	15.2	282.8	73.3	107.9	67.2	21.4	11.1	11.4	48.1	725.7
1989	1.6	0.0	0.0	70.6	124.2	33.0	47.0	24.2	33.3	19.9	78.6	69.8	502.2
1990	105.5	2.0	15.1	40.8	72.4	67.5	17.6	18.5	37.0	30.9	43.0	72.0	522.3
1991	0.0	**47.5**	13.2	97.5	1.5	54.3	75.3	23.2	49.5	38.3	80.8	103.1	584.2
1992	5.0	0.0	26.4	129.0	99.3	**56.0**	36.4	**41.2**	50.4	**83.8**	48.1	54.0	629.6
1993	26.8	69.6	42.4	73.5	238.3	3.2	0.0	20.3	2.8	12.5	0.0	18.5	507.9
1994	27.8	32.8	26.5	**96.8**	182.6	59.2	73.6	21.9	**45.1**	257.2	58.7	**82.9**	965.0
1995	91.9	45.3	28.4	**96.8**	118.1	52.8	53.5	39.3	**45.1**	29.2	41.7	**82.9**	725.0
1996	21.7	9.5	45.7	101.0	154.4	**56.0**	81.9	94.2	17.0	7.2	56.8	70.7	716.2
1997	**34.4**	**47.5**	**35.9**	**96.8**	**128.2**	**56.0**	**52.1**	**41.2**	**45.1**	**83.8**	**66.6**	**82.9**	**770.7**
1998	66.2	24.8	12.5	32.2	94.8	103.3	33.7	16.8	0.0	6.4	64.1	67.3	522.1
1999	47.0	15.8	32.9	60.6	34.2	13.0	34.3	56.1	136.3	231.0	61.8	76.0	799.0
2000	0.0	0.0	43.1	64.7	182.8	35.9	34.8	18.0	0.0	55.3	20.0	0.0	454.6
2001	138.5	31.0	13.0	89.0	10.7	94.6	47.0	14.0	7.5	181.0	51.6	57.2	735.1
2002	50.0	0.0	53.2	62.0	129.7	44.9	111.2	31.3	29.7	55.2	41.0	23.2	631.4
2003	1.0	13.5	47.0	305.5	108.5	76.0	42.0	26.0	97.0	383.6	268.0	107.0	1475.1
2004	47.0	0.0	12.0	51.1	93.1	18.4	40.0	60.5	82.7	51.0	68.5	**82.9**	607.2
2005	41.3	0.0	72.2	72.4	81.6	81.2	30.3	35.9	9.5	53.3	67.6	**82.9**	628.2
2006	**34.4**	15.1	23.2	52.9	23.2	50	4.5	0	0	216.2	19	54.2	492.7
2007	**34.4**	**47.5**	**35.9**	**96.8**	**128.2**	**56.0**	**52.1**	**41.2**	**45.1**	**84.8**	**66.8**	**82.9**	**771.8**
2008	**34.4**	48.9	22.5	135.7	63.6	33.6	40.8	38.4	**45.1**	0.0	60.7	117.6	641.3
2009	20.0	14.2	29.7	157.1	**128.2**	69.0	40.9	11.4	21.5	162.8	36.7	73.5	765.0
Average	20.0	154.0	32.6	101.9	46.0	33.6	203.1	90.1	307.1	497.7	257.4	42.5	1786.1

Note: Values in red and blue are computed by correlation with Kayafungo and Maji Rainfall Stations, respectively; values in bold face are mean values.

Table 5: Mazeras Reservoir Station - Monthly Rainfall (mm)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1956	130.7	1.7	56.3	**121.3**	166.4	62.9	44.8	39.5	**58.8**	40.1	149.9	131.9	1004.2
1957	16.9	1.8	46.6	**121.3**	159.9	125.6	57.5	66.1	**58.8**	32.9	47.6	85.4	820.4
1958	74.1	8.6	40.1	169.0	150.9	63.4	62.1	69.6	60.7	42.7	20.2	112.9	874.3
1959	15.1	6.1	108.6	200.9	255.9	94.1	35.8	26.3	24.0	81.9	45.9	80.6	975.1
1960	16.5	73.8	12.9	118.8	53.0	54.3	194.5	58.8	372.4	164.3	186.5	123.7	1429.5
1961	41.0	0.0	135.7	29.3	123.2	43.4	57.8	71.4	24.0	37.5	49.5	111.3	724.2
1962	18.8	0.0	112.2	225.3	157.1	103.3	68.2	64.0	54.0	56.9	175.2	120.3	1155.5
1963	73.4	4.8	22.1	**121.3**	155.4	29.7	31.0	42.4	42.7	91.8	34.2	142.4	791.3
1964	37.5	0.0	13.1	**121.3**	168.8	87.9	35.1	37.3	108.0	82.9	214.4	66.9	973.2
1965	44.1	11.1	68.9	80.0	268.3	79.7	46.5	71.7	24.0	152.9	77.9	87.1	1012.0
1966	12.9	22.3	15.4	234.8	190.8	78.0	80.4	222.8	199.7	234.1	167.0	67.5	1525.6
1967	12.9	15.7	238.6	112.5	333.2	105.1	113.8	128.2	36.9	71.7	263.4	79.8	1511.9
1968	15.0	75.8	21.6	53.5	88.6	49.2	80.9	119.2	26.5	120.9	99.7	73.6	824.5
1969	46.8	0.0	73.9	66.7	122.3	22.6	54.4	85.3	39.5	36.9	60.7	105.7	714.9
1970	0.0	0.0	26.0	41.3	128.7	112.3	46.9	9.8	14.2	2.3	17.0	85.3	483.8
1971	105.3	7.9	30.7	20.2	341.6	0.8	98.4	82.0	210.3	176.1	79.1	79.9	1232.3
1972	14.7	0.0	0.0	241.9	191.3	139.9	18.9	87.0	18.1	4.9	108.8	76.2	901.7
1973	23.9	1.8	3.6	43.1	215.2	77.2	107.6	19.0	27.6	18.1	52.6	60.3	650.0
1974	46.7	2.0	10.7	207.2	192.0	83.2	92.2	1.8	64.7	33.7	15.4	127.0	876.6
1975	4.0	0.5	131.0	74.9	162.0	97.7	95.7	10.9	104.7	57.7	70.5	165.0	974.6
1976	68.8	0.3	49.2	173.3	83.1	89.6	144.7	214.9	88.4	337.5	141.3	119.9	1511.0
1977	47.9	49.3	39.6	193.8	233.6	123.0	42.9	31.8	24.7	43.5	245.0	138.8	1213.9
1978	75.4	20.4	110.2	130.6	459.3	115.4	58.7	37.7	65.7	70.7	81.4	80.9	1306.4
1979	0.0	0.9	4.0	157.9	46.0	17.5	80.3	212.6	48.2	10.5	104.6	60.3	742.8
1980	36.0	0.6	207.9	67.2	100.1	56.1	46.5	142.6	25.0	113.8	84.0	124.3	1004.1
1981	18.8	0.0	59.2	167.4	512.7	92.9	141.6	43.9	128.7	219.7	102.9	108.2	1596.0
1982	0.0	2.0	44.1	43.6	442.0	119.5	89.3	35.3	101.0	25.7	49.8	85.9	1038.2
1983	0.0	0.0	20.0	233.0	115.9	96.4	86.6	18.6	32.5	7.8	92.5	108.1	811.4
1984	34.1	46.2	28.5	94.6	165.9	24.9	129.3	23.9	18.8	17.4	98.7	146.6	828.9
1985	19.3	0.0	47.6	326.0	360.5	39.9	15.4	51.3	3.6	54.6	67.8	137.7	1123.7
1986	22.0	0.0	5.8	165.3	303.4	22.4	87.9	184.5	19.0	36.3	10.5	38.5	895.5
1987	76.2	1.8	80.0	213.6	55.7	166.7	35.0	45.6	41.7	25.1	63.8	36.3	841.5
1988	43.5	0.0	59.4	138.3	126.6	38.3	28.7	52.5	27.1	145.1	138.4	102.8	900.7
1989	107.3	35.8	93.5	51.6	86.8	59.0	34.0	25.7	19.5	189.0	203.4	185.8	1091.4
1990	0.5	0.0	20.0	13.1	359.3	107.9	112.4	41.0	13.9	27.1	6.1	5.8	707.1
1991	0.0	0.0	0.0	47.1	116.4	42.7	83.4	44.7	42.9	36.7	96.8	111.1	621.9
1992	160.7	1.8	70.4	29.3	136.1	110.0	63.1	49.6	24.0	62.3	56.8	145.5	909.6
1993	21.0	1.7	18.9	113.2	368.6	34.4	89.2	65.0	111.6	96.8	99.8	114.1	1134.4
1994	19.8	1.6	48.0	112.5	194.4	4.5	73.7	71.9	46.8	61.9	72.4	118.7	826.3
1995	20.4	2.7	42.0	94.9	208.4	21.5	85.5	26.9	34.0	62.2	104.5	80.1	783.1
1996	17.1	1.7	24.9	**121.3**	273.6	100.9	100.1	30.3	**58.8**	512.0	224.8	145.3	1611.0
1997	220.7	8.1	44.8	**121.3**	196.9	136.1	72.2	50.7	**58.8**	41.1	52.3	83.2	1086.3
1998	25.4	2.0	24.1	112.5	192.1	82.2	80.2	113.6	24.0	54.9	88.6	81.9	881.7
1999	20.2	1.6	61.4	**121.3**	245.9	121.2	60.0	59.5	**58.8**	124.0	53.9	114.1	1041.9
2000	32.6	1.9	41.8	77.1	190.1	104.3	58.0	51.7	24.0	36.8	84.4	86.4	789.0
2001	23.1	2.8	94.4	106.4	154.3	27.9	39.6	71.4	98.0	190.2	56.6	112.2	976.9
2002	17.3	1.6	33.8	99.9	217.9	77.1	57.8	65.4	55.2	146.6	88.6	90.3	951.4
2003	44.6	2.8	55.9	126.6	78.0	102.3	52.6	31.6	24.0	131.7	88.6	89.6	828.3
2004	54.6	1.6	39.8	69.1	192.4	74.4	53.6	39.9	32.3	51.5	72.3	75.8	757.5
2005	16.9	1.9	32.2	236.5	119.2	78.0	55.4	83.4	69.1	224.8	153.3	111.0	1181.6
2006	27.4	1.8	37.3	84.2	328.6	50.2	52.3	96.0	63.4	82.8	71.3	76.4	971.6
2007	52.4	1.7	66.1	96.9	234.9	111.3	43.9	97.2	34.1	57.4	64.5	84.3	944.8
2008	33.2	4.5	21.2	85.3	121.8	106.3	51.8	32.0	30.3	286.6	64.0	86.2	922.9
2009	**39.8**	**8.2**	**52.7**	**121.3**	**200.8**	**76.7**	**70.3**	**67.1**	**58.8**	**96.7**	**94.7**	**99.4**	**986.6**
Average	130.7	1.7	56.3	**121.3**	166.4	62.9	44.8	39.5	**58.8**	40.1	149.9	131.9	1004.2

Note: Values in red and blue are computed by correlation with Mombasa Air Port and Makamini Rainfall Stations, respectively; values in bold are mean values.

DETERMINATION OF SURFACE RUNOFF COEFFIECIENTS AND CN VALUES

Table 1: Areas of Lithological and Geological Units in the Various Basins (km^2)

Lithology	Code	R%	A	B	C	D	E	F	G	H	I	J	K	Athi at 3F02	Lower Athi	Sabaki	Tsavo at 3G02
Acid metamorphic rock	1	97	0	0	0	0	160	0	0	0	76	0	0	391	766	861	44
Andesite, trachyte, phonolite	2	97	0	0	157	0	0	0	0	0	0	0	0	2583	2876	2955	0
Conglomerate, breccia	3	75	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eolian unconsolidated rock	4	90	0	0	268	115	71	0	0	0	141	0	0	365	788	800	12
Fluvial	5	85	0	21	394	0	322	0	0	59	0	0	0	104	1680	3637	1058
Gneiss rich in ferro-magnesian minerals	6	97	0	0	0	0	655	0	0	3	79	0	0	0	97	155	0
Gneiss, migmatite	7	97	0	0	2606	83	2269	0	0	626	2485	130	10	2645	11473	14688	2276
Granite	8	95	0	0	5	0	21	0	0	29	96	0	0	43	371	462	68
Igneous rock	9	97	0	0	98	0	269	0	0	94	0	0	0	208	477	490	14
Lacustrine unconsolidated rock	10	90	0	0	68	0	0	0	0	0	0	0	0	0	149	149	0
Limestone, other carbonate rocks	11	90	0	0	0	0	80	25	0	0	297	0	0	0	7	109	103
Marine unconsolidated rock	12	75	578	638	1618	391	0	0	0	0	0	0	0	0	0	27	0
Metamorphic rock	13	97	0	0	0	0	30	0	0	9	18	0	0	0	0	9	0
Sandstone, greywacke, arkose	14	90	199	53	2260	2154	1984	659	412	891	515	349	56	0	43	1175	0
Shale	15	97	0	0	0	0	0	0	0	95	129	65	0	0	0	0	0
Siltstone, mudstone, claystone	16	95	0	0	0	0	278	65	10	1799	412	321	112	0	234	241	7
Ultrabasic igneous rock	17	97	560	234	0	0	0	0	0	0	0	0	0	0	0	0	0
Basalt	18	90	0	0	0	0	0	0	0	0	0	0	0	738	3797	5003	1206
Basic igneous rock	19	95	0	0	0	0	0	0	0	0	0	0	0	691	757	2029	1272
Intermediate igneous rock	20	93	0	0	0	0	0	0	0	0	0	0	0	846	1338	1338	0
Pyroclastic unconsolidated rock	21	80	0	0	0	0	0	0	0	0	0	0	0	1041	1810	2370	560
Quartzite	22	93	0	0	0	0	0	0	0	0	0	0	0	437	568	568	0
Water	23	0	0	0	0	0	0	0	0	0	0	0	0	81	81	81	0
Total Area km^2			1,356	946	7,475	2,743	6,138	749	422	3,605	4,250	865	177	10,173	27,311*	37,149*	6,620*
Weighted Basin Value (%)			86.3	81.5	89.2	88.1	93.8	90.4	90.1	94.1	95.2	93.4	93.5	93.0	93.2	92.8	91.8

Note: Parts of the basin areas are located in Tanzania.

Table 2: Basic CN Values of the Various Soil and Land Cover Units

Soil and land cover		Sandy	Loamy	Clayey	Very clayey
		S	L	C	Y
Bushland	*1*	30	58	78	78
Woods/forest	*2*	45	66	83	83
Grassland	*3*	39	61	80	80
Agriculture	*4*	72	81	91	91
Town	*5*	72	82	89	89
Bare Land	*6*	77	86	94	94
Water	*7*	0	0	0	0

Table 3: River Basin A – Definition of Areal Soil and Land Cover Units (km^2) (Total Basin Area 1,356 km^2, Average CN = 59.7)

Soil and land cover unit area		Sandy	Loamy	Clayey	Very clayey
		S	L	C	Y
Bushland	*1*	400.1	120.0	359.5	0.0
Woods/forest	*2*	114.6	41.8	263.0	0.0
Grassland	*3*	7.8	0.0	48.7	0.0
Agriculture	*4*	0.0	0.0	0.0	0.0

Table 4: River Basin B – Definition of Areal Soil and Land Cover Units (km^2) (Total Basin Area 946 km^2, Average CN = 67.8)

Soil and land cover unit area		Sandy	Loamy	Clayey	Very clayey
		S	L	C	Y
Bushland	*1*	85.0	202.0	267.7	0.0
Woods/forest	*2*	48.1	98.8	244.6	0.0
Grassland	*3*	0.0	0.0	0.0	0.0
Agriculture	*4*	0.0	0.0	0.0	0.0

Table 5: River Basin C – Definition of Areal Soil and Land Cover Units (km^2) (Total Basin Area 7,475 km^2, Average CN = 70.4)

Soil and land cover unit area		Sandy	Loamy	Clayey	Very clayey
		S	L	C	Y
Bushland	1	221.1	2249.9	3429.9	1257.6
Woods/forest	2	36.9	11.7	128.2	67.8
Grassland	3	26.2	8.0	10.5	27.0
Agriculture	4	0.0	0.0	0.0	0.0

Table 6: River Basin D – Definition of Areal Soil and Land Cover Units (km^2) (Total Basin Area 2,743 km^2, Average CN = 60.5)

Soil and land cover unit area		Sandy	Loamy	Clayey	Very clayey
		S	L	C	Y
Bushland	1	585.7	400.5	691.6	0.0
Woods/forest	2	415.7	0.9	398.4	0.0
Grassland	3	0.0	80.6	9.8	0.0
Agriculture	4	39.7	0.0	120.3	0.0

Table 7: River Basin E – Definition of Areal Soil and Land Cover Units (km^2) (Total Basin Area 6,138 km^2, Average CN = 74.9)

Soil and land cover unit area		Sandy	Loamy	Clayey	Very clayey
		S	L	C	Y
Bushland	1	0.0	1093.1	3852.3	0.0
Woods/forest	2	0.0	305.2	286.4	0.0
Grassland	3	0.0	8.4	20.8	0.0
Agriculture	4	0.0	240.4	331.8	0.0

Table 8: River Basin F – Definition of Areal Soil and Land Cover Units (km^2) (Total Basin Area 749 km^2, Average CN = 67.7)

Soil and land cover unit area		Sandy	Loamy	Clayey	Very clayey
		S	L	C	Y
Bushland	1	15.0	154.8	27.0	0.0
Woods/forest	2	99.7	145.7	3.6	0.0
Grassland	3	0.0	0.0	0.0	0.0
Agriculture	4	3.7	272.3	27.7	0.0

Table 9: River Basin G – Definition of Areal Soil and Land Cover Units (km^2) (Total Basin Area 422 km^2, Average CN = 81.2)

Soil and land cover unit area		Sandy	Loamy	Clayey	Very clayey
		S	L	C	Y
Bushland	1	0.0	6.8	0.0	0.0
Woods/forest	2	0.0	0.0	0.0	0.0
Grassland	3	0.0	0.0	0.0	0.0
Agriculture	4	7.9	377.4	29.7	0.0

Table 10: River Basin H – Definition of Areal Soil and Land Cover Units (km^2) (Total Basin Area 3,605 km^2, Average CN = 76.0)

Soil and land cover unit area		Sandy	Loamy	Clayey	Very clayey
		S	L	C	Y
Bushland	1	168.2	284.0	1963.4	0.0
Woods/forest	2	8.1	0.6	151.7	0.0
Grassland	3	0.0	8.9	17.8	0.0
Agriculture	4	271.1	183.7	547.2	0.0

Table 11: River Basin I – Definition of Areal Soil and Land Cover Units (km²)
(Total Basin Area 4,250 km², Average CN = 74.3)

Soil and land cover unit area		Sandy	Loamy	Clayey	Very clayey
		S	L	C	Y
Bushland	*1*	124.0	578.2	2928.4	0.0
Woods/forest	*2*	37.4	21.9	273.8	0.0
Grassland	*3*	0.0	0.0	0.0	0.0
Agriculture	*4*	51.4	92.4	142.5	0.0

Table 12: River Basin J – Definition of Areal Soil and Land Cover Units (km²)
(Total Basin Area 865 km², Average CN = 70.4)

Soil and land cover unit area		Sandy	Loamy	Clayey	Very clayey
		S	L	C	Y
Bushland	*1*	71.9	165.8	549.7	0.0
Woods/forest	*2*	0.1	2.7	15.4	0.0
Grassland	*3*	0.0	0.0	0.0	0.0
Agriculture	*4*	4.1	51.3	4.2	0.0

Table 13: River Basin K – Definition of Areal Soil and Land Cover Units (km²)
(Total Basin Area 177 km², Average CN = 75.6)

Soil and land cover unit area		Sandy	Loamy	Clayey	Very clayey
		S	L	C	Y
Bushland	*1*	0.0	17.4	132.2	0.0
Woods/forest	*2*	0.0	12.7	14.9	0.0
Grassland	*3*	0.0	0.0	0.0	0.0
Agriculture	*4*	0.0	0.0	0.0	0.0

Simulated Monthly Flows

SIMULATED MONTHLY FLOWS

Table 1: Basin A – Simulated Monthly Flows, 1958/59-2007/08 (MCM)

YEAR	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	ANNUAL
1958/59	2.6	2.3	2.0	2.0	1.7	1.5	1.5	1.2	1.2	0.9	9.0	6.7	**32.6**
1959/60	2.6	1.2	0.9	0.6	1.7	0.9	0.6	0.6	0.9	0.6	0.6	0.3	**11.4**
1960/61	0.3	4.1	3.2	34.4	67.6	88.2	45.4	34.9	30.9	27.7	25.0	22.4	**384.1**
1961/62	20.1	18.1	16.3	14.9	13.1	11.9	10.8	9.6	8.7	7.9	11.1	11.1	**153.5**
1962/63	9.0	7.0	5.0	4.4	3.8	4.1	7.3	4.1	2.6	2.3	3.2	5.2	**58.0**
1963/64	2.3	1.7	1.5	1.2	1.2	0.9	16.6	5.0	1.2	0.9	0.9	1.5	**34.7**
1964/65	1.2	0.6	0.6	0.6	0.3	10.8	2.6	0.6	0.3	12.8	5.8	7.9	**44.0**
1965/66	6.4	2.0	0.9	0.3	0.6	0.3	0.3	0.3	1.7	0.3	5.0	4.7	**22.7**
1966/67	1.7	0.9	1.2	8.2	25.6	15.7	4.1	3.2	3.8	4.7	7.0	5.8	**81.8**
1967/68	7.6	3.2	2.6	2.0	1.7	4.1	2.6	1.5	9.6	3.5	2.6	2.9	**44.0**
1968/69	2.3	1.7	2.0	1.5	1.5	3.2	1.7	1.2	1.2	1.2	0.9	0.9	**19.2**
1969/70	0.9	0.6	0.6	0.6	0.6	0.3	0.3	0.3	0.3	0.3	0.3	0.9	**5.8**
1970/71	0.6	0.3	0.3	0.0	0.0	0.0	2.3	0.3	0.0	0.0	0.0	6.1	**9.9**
1971/72	0.6	0.6	0.3	3.2	2.0	1.7	2.3	0.3	0.3	0.3	7.0	7.0	**25.6**
1972/73	2.6	0.6	0.6	0.3	0.3	0.6	0.3	0.3	0.6	0.3	0.6	0.6	**7.6**
1973/74	0.9	1.2	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.9	**3.5**
1974/75	0.3	0.6	0.0	0.0	0.0	0.0	0.0	2.3	0.3	0.0	0.0	0.3	**3.8**
1975/76	0.3	0.3	0.0	0.0	0.0	0.9	0.6	0.0	0.0	0.0	0.3	0.3	**2.6**
1976/77	0.3	0.3	0.9	5.0	5.8	7.0	6.4	2.6	1.2	2.6	5.2	3.5	**40.8**
1977/78	1.7	0.9	0.9	0.6	1.2	7.0	7.6	5.5	1.2	0.6	6.7	11.4	**45.1**
1978/79	5.8	3.5	2.6	2.3	2.0	1.7	2.0	1.5	1.2	1.2	1.5	0.9	**26.2**
1979/80	0.9	2.9	2.6	7.3	4.7	5.0	2.6	1.5	1.5	2.0	1.5	1.2	**33.5**
1980/81	0.9	1.2	0.9	0.6	0.6	1.2	1.5	0.6	0.6	0.9	13.7	25.3	**47.8**
1981/82	8.7	7.3	5.8	5.5	4.7	4.7	3.2	2.3	2.3	2.0	6.7	7.0	**60.3**
1982/83	5.8	3.5	2.6	2.3	2.0	1.7	1.5	1.5	1.2	2.0	5.2	3.2	**32.6**
1983/84	1.7	1.2	0.9	0.6	0.6	3.2	4.4	8.2	4.7	1.7	1.2	1.2	**29.4**
1984/85	2.3	1.2	0.9	0.6	0.6	2.6	0.9	0.6	0.3	2.0	14.6	10.2	**36.7**
1985/86	2.3	2.0	1.7	1.5	1.7	9.9	5.8	3.8	3.5	3.2	5.2	6.4	**47.2**
1986/87	2.9	3.8	3.2	2.0	1.7	1.5	1.5	1.2	1.2	1.5	1.5	1.7	**23.6**
1987/88	1.2	0.9	0.6	0.6	0.6	1.2	2.0	0.9	0.3	2.6	5.8	2.6	**19.2**
1988/89	0.6	0.3	0.3	0.3	0.3	1.5	1.2	0.3	0.0	7.0	8.2	0.6	**20.4**
1989/90	0.0	0.0	0.0	0.0	0.3	0.9	0.9	0.3	0.3	0.3	4.4	6.1	**13.4**
1990/91	4.7	3.2	1.2	0.9	0.6	0.9	0.9	0.6	0.6	0.3	0.6	0.6	**14.9**
1991/92	0.3	0.3	0.3	0.3	0.3	0.3	0.3	1.2	0.3	0.3	0.3	0.3	**4.4**
1992/93	0.3	0.3	0.3	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	2.0	**3.5**
1993/94	0.6	0.6	0.3	0.3	0.3	2.3	0.9	0.3	0.3	0.0	3.2	3.8	**12.8**
1994/95	0.6	0.6	0.3	0.0	0.0	0.0	0.3	0.0	0.0	0.0	3.5	2.3	**7.6**
1995/96	0.3	0.3	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	1.5	2.0	**4.4**
1996/97	1.2	0.6	0.3	3.8	8.7	9.6	7.3	13.7	2.9	2.0	2.0	2.0	**54.2**
1997/98	2.0	1.5	1.5	1.2	0.9	0.9	0.9	0.6	0.6	0.6	1.7	1.2	**13.4**
1998/99	0.9	0.9	0.6	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.6	0.9	**5.8**
1999/00	0.6	0.3	0.3	0.3	0.3	0.3	0.3	0.0	0.0	0.0	0.0	0.6	**2.9**
2000/01	0.6	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	**1.2**
2001/02	0.0	0.0	0.6	4.7	2.0	1.5	0.6	0.6	0.3	0.3	1.7	1.5	**13.7**
2002/03	0.6	0.3	0.3	0.3	0.3	0.3	0.6	7.3	0.9	0.0	1.5	0.3	**12.5**
2003/04	0.0	0.0	0.0	1.5	0.6	0.3	0.0	0.0	0.0	0.0	0.3	0.3	**2.9**
2004/05	0.6	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.4	23.0	11.4	**39.6**
2005/06	5.8	4.1	3.8	9.9	16.9	18.9	13.4	6.4	4.7	4.4	3.8	4.1	**96.1**
2006/07	3.5	3.2	2.9	2.6	2.3	2.0	1.7	1.5	1.5	1.2	1.2	1.5	**25.0**
2007/08	1.5	1.2	1.2	0.9	0.6	0.6	0.6	0.6	0.3	0.3	0.3	0.3	**8.2**

Average	**2.4**	**1.9**	**1.5**	**2.6**	**3.7**	**4.6**	**3.4**	**2.6**	**1.9**	**2.1**	**4.1**	**4.0**	**34.9**

Table 2: Basin B – Simulated Monthly Flows, 1958/59-2007/08 (MCM)

YEAR	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	ANNUAL
1958/59	2.0	1.8	1.6	1.6	1.4	1.1	1.1	0.9	0.9	0.7	7.0	5.2	**25.4**
1959/60	2.0	0.9	0.7	0.5	1.4	0.7	0.5	0.5	0.7	0.5	0.5	0.2	**8.8**
1960/61	0.2	3.2	2.5	26.7	52.6	68.7	35.4	27.2	24.0	21.5	19.5	17.5	**298.9**
1961/62	15.6	14.1	12.7	11.6	10.2	9.3	8.4	7.5	6.8	6.1	8.6	8.6	**119.4**
1962/63	7.0	5.4	3.9	3.4	2.9	3.2	5.7	3.2	2.0	1.8	2.5	4.1	**45.1**
1963/64	1.8	1.4	1.1	0.9	0.9	0.7	12.9	3.9	0.9	0.7	0.7	1.1	**27.0**
1964/65	0.9	0.5	0.5	0.5	0.2	8.4	2.0	0.5	0.2	10.0	4.5	6.1	**34.2**
1965/66	5.0	1.6	0.7	0.2	0.5	0.2	0.2	0.2	1.4	0.2	3.9	3.6	**17.7**
1966/67	1.4	0.7	0.9	6.3	19.9	12.2	3.2	2.5	2.9	3.6	5.4	4.5	**63.7**
1967/68	5.9	2.5	2.0	1.6	1.4	3.2	2.0	1.1	7.5	2.7	2.0	2.3	**34.2**
1968/69	1.8	1.4	1.6	1.1	1.1	2.5	1.4	0.9	0.9	0.9	0.7	0.7	**15.0**
1969/70	0.7	0.5	0.5	0.5	0.5	0.2	0.2	0.2	0.2	0.2	0.2	0.7	**4.5**
1970/71	0.5	0.2	0.2	0.0	0.0	0.0	1.8	0.2	0.0	0.0	0.0	4.8	**7.7**
1971/72	0.5	0.5	0.2	2.5	1.6	1.4	1.8	0.2	0.2	0.2	5.4	5.4	**19.9**
1972/73	2.0	0.5	0.5	0.2	0.2	0.5	0.2	0.2	0.5	0.2	0.5	0.5	**5.9**
1973/74	0.7	0.9	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.7	**2.7**
1974/75	0.2	0.5	0.0	0.0	0.0	0.0	0.0	1.8	0.2	0.0	0.0	0.2	**2.9**
1975/76	0.2	0.2	0.0	0.0	0.0	0.7	0.5	0.0	0.0	0.0	0.2	0.2	**2.0**
1976/77	0.2	0.2	0.7	3.9	4.5	5.4	5.0	2.0	0.9	2.0	4.1	2.7	**31.7**
1977/78	1.4	0.7	0.7	0.5	0.9	5.4	5.9	4.3	0.9	0.5	5.2	8.8	**35.1**
1978/79	4.5	2.7	2.0	1.8	1.6	1.4	1.6	1.1	0.9	0.9	1.1	0.7	**20.4**
1979/80	0.7	2.3	2.0	5.7	3.6	3.9	2.0	1.1	1.1	1.6	1.1	0.9	**26.1**
1980/81	0.7	0.9	0.7	0.5	0.5	0.9	1.1	0.5	0.5	0.7	10.7	19.7	**37.2**
1981/82	6.8	5.7	4.5	4.3	3.6	3.6	2.5	1.8	1.8	1.6	5.2	5.4	**46.9**
1982/83	4.5	2.7	2.0	1.8	1.6	1.4	1.1	1.1	0.9	1.6	4.1	2.5	**25.4**
1983/84	1.4	0.9	0.7	0.5	0.5	2.5	3.4	6.3	3.6	1.4	0.9	0.9	**22.9**
1984/85	1.8	0.9	0.7	0.5	0.5	2.0	0.7	0.5	0.2	1.6	11.3	7.9	**28.6**
1985/86	1.8	1.6	1.4	1.1	1.4	7.7	4.5	2.9	2.7	2.5	4.1	5.0	**36.7**
1986/87	2.3	2.9	2.5	1.6	1.4	1.1	1.1	0.9	0.9	1.1	1.1	1.4	**18.4**
1987/88	0.9	0.7	0.5	0.5	0.5	0.9	1.6	0.7	0.2	2.0	4.5	2.0	**15.0**
1988/89	0.5	0.2	0.2	0.2	0.2	1.1	0.9	0.2	0.0	5.4	6.3	0.5	**15.9**
1989/90	0.0	0.0	0.0	0.0	0.2	0.7	0.7	0.2	0.2	0.2	3.4	4.8	**10.4**
1990/91	3.6	2.5	0.9	0.7	0.5	0.7	0.7	0.5	0.5	0.2	0.5	0.5	**11.6**
1991/92	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.9	0.2	0.2	0.2	0.2	**3.4**
1992/93	0.2	0.2	0.2	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	1.6	**2.7**
1993/94	0.5	0.5	0.2	0.2	0.2	1.8	0.7	0.2	0.2	0.0	2.5	2.9	**10.0**
1994/95	0.5	0.5	0.2	0.0	0.0	0.0	0.2	0.0	0.0	0.0	2.7	1.8	**5.9**
1995/96	0.2	0.2	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	1.1	1.6	**3.4**
1996/97	0.9	0.5	0.2	2.9	6.8	7.5	5.7	10.7	2.3	1.6	1.6	1.6	**42.2**
1997/98	1.6	1.1	1.1	0.9	0.7	0.7	0.7	0.5	0.5	0.5	1.4	0.9	**10.4**
1998/99	0.7	0.7	0.5	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.5	0.7	**4.5**
1999/00	0.5	0.2	0.2	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.5	**2.3**
2000/01	0.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	**0.9**
2001/02	0.0	0.0	0.5	3.6	1.6	1.1	0.5	0.5	0.2	0.2	1.4	1.1	**10.7**
2002/03	0.5	0.2	0.2	0.2	0.2	0.2	0.5	5.7	0.7	0.0	1.1	0.2	**9.7**
2003/04	0.0	0.0	0.0	1.1	0.5	0.2	0.0	0.0	0.0	0.0	0.2	0.2	**2.3**
2004/05	0.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.4	17.9	8.8	**30.8**
2005/06	4.5	3.2	2.9	7.7	13.1	14.7	10.4	5.0	3.6	3.4	2.9	3.2	**74.8**
2006/07	2.7	2.5	2.3	2.0	1.8	1.6	1.4	1.1	1.1	0.9	0.9	1.1	**19.5**

2007/08	1.1	0.9	0.9	0.7	0.5	0.5	0.5	0.5	0.2	0.2	0.2	0.2	**6.3**
Average	**1.9**	**1.5**	**1.2**	**2.0**	**2.8**	**3.6**	**2.6**	**2.0**	**1.5**	**1.7**	**3.2**	**3.1**	**27.1**

Table 3: Basin C – Simulated Monthly Flows, 1958/59-2007/08 (MCM)

YEAR	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	ANNUAL
1958/59	17.2	15.3	13.4	13.4	11.5	9.6	9.6	7.6	7.6	5.7	59.2	43.9	**213.9**
1959/60	17.2	7.6	5.7	3.8	11.5	5.7	3.8	3.8	5.7	3.8	3.8	1.9	**74.5**
1960/61	1.9	26.7	21.0	225.4	443.1	578.7	298.0	229.2	202.5	181.5	164.3	147.1	**2519.4**
1961/62	131.8	118.4	107.0	97.4	86.0	78.3	70.7	63.0	57.3	51.6	72.6	72.6	**1006.6**
1962/63	59.2	45.8	32.5	28.7	24.8	26.7	47.8	26.7	17.2	15.3	21.0	34.4	**380.1**
1963/64	15.3	11.5	9.6	7.6	7.6	5.7	108.9	32.5	7.6	5.7	5.7	9.6	**227.3**
1964/65	7.6	3.8	3.8	3.8	1.9	70.7	17.2	3.8	1.9	84.0	38.2	51.6	**288.4**
1965/66	42.0	13.4	5.7	1.9	3.8	1.9	1.9	1.9	11.5	1.9	32.5	30.6	**149.0**
1966/67	11.5	5.7	7.6	53.5	168.1	103.1	26.7	21.0	24.8	30.6	45.8	38.2	**536.7**
1967/68	49.7	21.0	17.2	13.4	11.5	26.7	17.2	9.6	63.0	22.9	17.2	19.1	**288.4**
1968/69	15.3	11.5	13.4	9.6	9.6	21.0	11.5	7.6	7.6	7.6	5.7	5.7	**126.1**
1969/70	5.7	3.8	3.8	3.8	3.8	1.9	1.9	1.9	1.9	1.9	1.9	5.7	**38.2**
1970/71	3.8	1.9	1.9	0.0	0.0	0.0	15.3	1.9	0.0	0.0	0.0	40.1	**64.9**
1971/72	3.8	3.8	1.9	21.0	13.4	11.5	15.3	1.9	1.9	1.9	45.8	45.8	**168.1**
1972/73	17.2	3.8	3.8	1.9	1.9	3.8	1.9	1.9	3.8	1.9	3.8	3.8	**49.7**
1973/74	5.7	7.6	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9	5.7	**22.9**
1974/75	1.9	3.8	0.0	0.0	0.0	0.0	0.0	15.3	1.9	0.0	0.0	1.9	**24.8**
1975/76	1.9	1.9	0.0	0.0	0.0	5.7	3.8	0.0	0.0	0.0	1.9	1.9	**17.2**
1976/77	1.9	1.9	5.7	32.5	38.2	45.8	42.0	17.2	7.6	17.2	34.4	22.9	**267.4**
1977/78	11.5	5.7	5.7	3.8	7.6	45.8	49.7	36.3	7.6	3.8	43.9	74.5	**296.1**
1978/79	38.2	22.9	17.2	15.3	13.4	11.5	13.4	9.6	7.6	7.6	9.6	5.7	**171.9**
1979/80	5.7	19.1	17.2	47.8	30.6	32.5	17.2	9.6	9.6	13.4	9.6	7.6	**219.7**
1980/81	5.7	7.6	5.7	3.8	3.8	7.6	9.6	3.8	3.8	5.7	89.8	166.2	**313.3**
1981/82	57.3	47.8	38.2	36.3	30.6	30.6	21.0	15.3	15.3	13.4	43.9	45.8	**395.4**
1982/83	38.2	22.9	17.2	15.3	13.4	11.5	9.6	9.6	7.6	13.4	34.4	21.0	**213.9**
1983/84	11.5	7.6	5.7	3.8	3.8	21.0	28.7	53.5	30.6	11.5	7.6	7.6	**192.9**
1984/85	15.3	7.6	5.7	3.8	3.8	17.2	5.7	3.8	1.9	13.4	95.5	66.9	**240.7**
1985/86	15.3	13.4	11.5	9.6	11.5	64.9	38.2	24.8	22.9	21.0	34.4	42.0	**309.4**
1986/87	19.1	24.8	21.0	13.4	11.5	9.6	9.6	7.6	7.6	9.6	9.6	11.5	**154.7**
1987/88	7.6	5.7	3.8	3.8	3.8	7.6	13.4	5.7	1.9	17.2	38.2	17.2	**126.1**
1988/89	3.8	1.9	1.9	1.9	1.9	9.6	7.6	1.9	0.0	45.8	53.5	3.8	**133.7**
1989/90	0.0	0.0	0.0	0.0	1.9	5.7	5.7	1.9	1.9	1.9	28.7	40.1	**87.9**
1990/91	30.6	21.0	7.6	5.7	3.8	5.7	5.7	3.8	3.8	1.9	3.8	3.8	**97.4**
1991/92	1.9	1.9	1.9	1.9	1.9	1.9	1.9	7.6	1.9	1.9	1.9	1.9	**28.7**
1992/93	1.9	1.9	1.9	0.0	0.0	0.0	3.8	0.0	0.0	0.0	0.0	13.4	**22.9**
1993/94	3.8	3.8	1.9	1.9	1.9	15.3	5.7	1.9	1.9	0.0	21.0	24.8	**84.0**
1994/95	3.8	3.8	1.9	0.0	0.0	0.0	1.9	0.0	0.0	0.0	22.9	15.3	**49.7**
1995/96	1.9	1.9	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0	9.6	13.4	**28.7**
1996/97	7.6	3.8	1.9	24.8	57.3	63.0	47.8	89.8	19.1	13.4	13.4	13.4	**355.3**
1997/98	13.4	9.6	9.6	7.6	5.7	5.7	5.7	3.8	3.8	3.8	11.5	7.6	**87.9**
1998/99	5.7	5.7	3.8	1.9	1.9	1.9	1.9	1.9	1.9	1.9	3.8	5.7	**38.2**
1999/00	3.8	1.9	1.9	1.9	1.9	1.9	1.9	0.0	0.0	0.0	0.0	3.8	**19.1**
2000/01	3.8	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9	**7.6**
2001/02	0.0	0.0	3.8	30.6	13.4	9.6	3.8	3.8	1.9	1.9	11.5	9.6	**89.8**
2002/03	3.8	1.9	1.9	1.9	1.9	1.9	3.8	47.8	5.7	0.0	9.6	1.9	**82.1**
2003/04	0.0	0.0	0.0	9.6	3.8	1.9	0.0	0.0	0.0	0.0	1.9	1.9	**19.1**
2004/05	3.8	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	28.7	150.9	74.5	**259.8**
2005/06	38.2	26.7	24.8	64.9	110.8	124.2	87.9	42.0	30.6	28.7	24.8	26.7	**630.3**

2006/07	22.9	21.0	19.1	17.2	15.3	13.4	11.5	9.6	9.6	7.6	7.6	9.6	**164.3**
2007/08	9.6	7.6	7.6	5.7	3.8	3.8	3.8	3.8	1.9	1.9	1.9	1.9	**53.5**
Average	**15.9**	**12.3**	**9.9**	**17.0**	**24.0**	**30.5**	**22.2**	**16.9**	**12.5**	**14.1**	**27.0**	**26.5**	**228.7**

Table 4: Basin D (Koromi) – Simulated Monthly Flows, 1958/59-2007/08 (MCM)

YEAR	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	ANNUAL
1958/59	5.3	4.7	4.1	4.1	3.5	2.9	2.9	2.4	2.4	1.8	18.2	13.5	**65.9**
1959/60	5.3	2.4	1.8	1.2	3.5	1.8	1.2	1.2	1.8	1.2	1.2	0.6	**23.0**
1960/61	0.6	8.2	6.5	69.5	136.6	178.4	91.8	70.6	62.4	55.9	50.6	45.3	**776.5**
1961/62	40.6	36.5	33.0	30.0	26.5	24.1	21.8	19.4	17.7	15.9	22.4	22.4	**310.2**
1962/63	18.2	14.1	10.0	8.8	7.7	8.2	14.7	8.2	5.3	4.7	6.5	10.6	**117.2**
1963/64	4.7	3.5	2.9	2.4	2.4	1.8	33.6	10.0	2.4	1.8	1.8	2.9	**70.1**
1964/65	2.4	1.2	1.2	1.2	0.6	21.8	5.3	1.2	0.6	25.9	11.8	15.9	**88.9**
1965/66	13.0	4.1	1.8	0.6	1.2	0.6	0.6	0.6	3.5	0.6	10.0	9.4	**45.9**
1966/67	3.5	1.8	2.4	16.5	51.8	31.8	8.2	6.5	7.7	9.4	14.1	11.8	**165.4**
1967/68	15.3	6.5	5.3	4.1	3.5	8.2	5.3	2.9	19.4	7.1	5.3	5.9	**88.9**
1968/69	4.7	3.5	4.1	2.9	2.9	6.5	3.5	2.4	2.4	2.4	1.8	1.8	**38.9**
1969/70	1.8	1.2	1.2	1.2	1.2	0.6	0.6	0.6	0.6	0.6	0.6	1.8	**11.8**
1970/71	1.2	0.6	0.6	0.0	0.0	0.0	4.7	0.6	0.0	0.0	0.0	12.4	**20.0**
1971/72	1.2	1.2	0.6	6.5	4.1	3.5	4.7	0.6	0.6	0.6	14.1	14.1	**51.8**
1972/73	5.3	1.2	1.2	0.6	0.6	1.2	0.6	0.6	1.2	0.6	1.2	1.2	**15.3**
1973/74	1.8	2.4	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	1.8	**7.1**
1974/75	0.6	1.2	0.0	0.0	0.0	0.0	0.0	4.7	0.6	0.0	0.0	0.6	**7.7**
1975/76	0.6	0.6	0.0	0.0	0.0	1.8	1.2	0.0	0.0	0.0	0.6	0.6	**5.3**
1976/77	0.6	0.6	1.8	10.0	11.8	14.1	13.0	5.3	2.4	5.3	10.6	7.1	**82.4**
1977/78	3.5	1.8	1.8	1.2	2.4	14.1	15.3	11.2	2.4	1.2	13.5	23.0	**91.2**
1978/79	11.8	7.1	5.3	4.7	4.1	3.5	4.1	2.9	2.4	2.4	2.9	1.8	**53.0**
1979/80	1.8	5.9	5.3	14.7	9.4	10.0	5.3	2.9	2.9	4.1	2.9	2.4	**67.7**
1980/81	1.8	2.4	1.8	1.2	1.2	2.4	2.9	1.2	1.2	1.8	27.7	51.2	**96.5**
1981/82	17.7	14.7	11.8	11.2	9.4	9.4	6.5	4.7	4.7	4.1	13.5	14.1	**121.9**
1982/83	11.8	7.1	5.3	4.7	4.1	3.5	2.9	2.9	2.4	4.1	10.6	6.5	**65.9**
1983/84	3.5	2.4	1.8	1.2	1.2	6.5	8.8	16.5	9.4	3.5	2.4	2.4	**59.5**
1984/85	4.7	2.4	1.8	1.2	1.2	5.3	1.8	1.2	0.6	4.1	29.4	20.6	**74.2**
1985/86	4.7	4.1	3.5	2.9	3.5	20.0	11.8	7.7	7.1	6.5	10.6	13.0	**95.4**
1986/87	5.9	7.7	6.5	4.1	3.5	2.9	2.9	2.4	2.4	2.9	2.9	3.5	**47.7**
1987/88	2.4	1.8	1.2	1.2	1.2	2.4	4.1	1.8	0.6	5.3	11.8	5.3	**38.9**
1988/89	1.2	0.6	0.6	0.6	0.6	2.9	2.4	0.6	0.0	14.1	16.5	1.2	**41.2**
1989/90	0.0	0.0	0.0	0.0	0.6	1.8	1.8	0.6	0.6	0.6	8.8	12.4	**27.1**
1990/91	9.4	6.5	2.4	1.8	1.2	1.8	1.8	1.2	1.2	0.6	1.2	1.2	**30.0**
1991/92	0.6	0.6	0.6	0.6	0.6	0.6	0.6	2.4	0.6	0.6	0.6	0.6	**8.8**
1992/93	0.6	0.6	0.6	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	4.1	**7.1**
1993/94	1.2	1.2	0.6	0.6	0.6	4.7	1.8	0.6	0.6	0.0	6.5	7.7	**25.9**
1994/95	1.2	1.2	0.6	0.0	0.0	0.0	0.6	0.0	0.0	0.0	7.1	4.7	**15.3**
1995/96	0.6	0.6	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	2.9	4.1	**8.8**
1996/97	2.4	1.2	0.6	7.7	17.7	19.4	14.7	27.7	5.9	4.1	4.1	4.1	**109.5**
1997/98	4.1	2.9	2.9	2.4	1.8	1.8	1.8	1.2	1.2	1.2	3.5	2.4	**27.1**
1998/99	1.8	1.8	1.2	0.6	0.6	0.6	0.6	0.6	0.6	0.6	1.2	1.8	**11.8**
1999/00	1.2	0.6	0.6	0.6	0.6	0.6	0.6	0.0	0.0	0.0	0.0	1.2	**5.9**
2000/01	1.2	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	**2.4**
2001/02	0.0	0.0	1.2	9.4	4.1	2.9	1.2	1.2	0.6	0.6	3.5	2.9	**27.7**
2002/03	1.2	0.6	0.6	0.6	0.6	0.6	1.2	14.7	1.8	0.0	2.9	0.6	**25.3**
2003/04	0.0	0.0	0.0	2.9	1.2	0.6	0.0	0.0	0.0	0.0	0.6	0.6	**5.9**
2004/05	1.2	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.8	46.5	23.0	**80.1**

2005/06	11.8	8.2	7.7	20.0	34.1	38.3	27.1	13.0	9.4	8.8	7.7	8.2	**194.3**
2006/07	7.1	6.5	5.9	5.3	4.7	4.1	3.5	2.9	2.9	2.4	2.4	2.9	**50.6**
2007/08	2.9	2.4	2.4	1.8	1.2	1.2	1.2	1.2	0.6	0.6	0.6	0.6	**16.5**
Average	**4.9**	**3.8**	**3.1**	**5.3**	**7.4**	**9.4**	**6.8**	**5.2**	**3.9**	**4.3**	**8.3**	**8.2**	**70.5**

Table 5: Basin E (Rare) – Simulated Monthly Flows, 1958/59-2007/08 (MCM)

YEAR	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	ANNUAL
1958/59	14.4	12.8	11.2	11.2	9.6	8.0	8.0	6.4	6.4	4.8	49.6	36.8	179.2
1959/60	14.4	6.4	4.8	3.2	9.6	4.8	3.2	3.2	4.8	3.2	3.2	1.6	62.4
1960/61	1.6	22.4	17.6	188.8	371.3	484.9	249.6	192.0	169.6	152.0	137.6	123.2	2110.8
1961/62	110.4	99.2	89.6	81.6	72.0	65.6	59.2	52.8	48.0	43.2	60.8	60.8	843.4
1962/63	49.6	38.4	27.2	24.0	20.8	22.4	40.0	22.4	14.4	12.8	17.6	28.8	318.5
1963/64	12.8	9.6	8.0	6.4	6.4	4.8	91.2	27.2	6.4	4.8	4.8	8.0	190.4
1964/65	6.4	3.2	3.2	3.2	1.6	59.2	14.4	3.2	1.6	70.4	32.0	43.2	241.6
1965/66	35.2	11.2	4.8	1.6	3.2	1.6	1.6	1.6	9.6	1.6	27.2	25.6	124.8
1966/67	9.6	4.8	6.4	44.8	140.8	86.4	22.4	17.6	20.8	25.6	38.4	32.0	449.7
1967/68	41.6	17.6	14.4	11.2	9.6	22.4	14.4	8.0	52.8	19.2	14.4	16.0	241.6
1968/69	12.8	9.6	11.2	8.0	8.0	17.6	9.6	6.4	6.4	6.4	4.8	4.8	105.6
1969/70	4.8	3.2	3.2	3.2	3.2	1.6	1.6	1.6	1.6	1.6	1.6	4.8	32.0
1970/71	3.2	1.6	1.6	0.0	0.0	0.0	12.8	1.6	0.0	0.0	0.0	33.6	54.4
1971/72	3.2	3.2	1.6	17.6	11.2	9.6	12.8	1.6	1.6	1.6	38.4	38.4	140.8
1972/73	14.4	3.2	3.2	1.6	1.6	3.2	1.6	1.6	3.2	1.6	3.2	3.2	41.6
1973/74	4.8	6.4	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	4.8	19.2
1974/75	1.6	3.2	0.0	0.0	0.0	0.0	0.0	12.8	1.6	0.0	0.0	1.6	20.8
1975/76	1.6	1.6	0.0	0.0	0.0	4.8	3.2	0.0	0.0	0.0	1.6	1.6	14.4
1976/77	1.6	1.6	4.8	27.2	32.0	38.4	35.2	14.4	6.4	14.4	28.8	19.2	224.0
1977/78	9.6	4.8	4.8	3.2	6.4	38.4	41.6	30.4	6.4	3.2	36.8	62.4	248.0
1978/79	32.0	19.2	14.4	12.8	11.2	9.6	11.2	8.0	6.4	6.4	8.0	4.8	144.0
1979/80	4.8	16.0	14.4	40.0	25.6	27.2	14.4	8.0	8.0	11.2	8.0	6.4	184.0
1980/81	4.8	6.4	4.8	3.2	3.2	6.4	8.0	3.2	3.2	4.8	75.2	139.2	262.4
1981/82	48.0	40.0	32.0	30.4	25.6	25.6	17.6	12.8	12.8	11.2	36.8	38.4	331.3
1982/83	32.0	19.2	14.4	12.8	11.2	9.6	8.0	8.0	6.4	11.2	28.8	17.6	179.2
1983/84	9.6	6.4	4.8	3.2	3.2	17.6	24.0	44.8	25.6	9.6	6.4	6.4	161.6
1984/85	12.8	6.4	4.8	3.2	3.2	14.4	4.8	3.2	1.6	11.2	80.0	56.0	201.6
1985/86	12.8	11.2	9.6	8.0	9.6	54.4	32.0	20.8	19.2	17.6	28.8	35.2	259.2
1986/87	16.0	20.8	17.6	11.2	9.6	8.0	8.0	6.4	6.4	8.0	8.0	9.6	129.6
1987/88	6.4	4.8	3.2	3.2	3.2	6.4	11.2	4.8	1.6	14.4	32.0	14.4	105.6
1988/89	3.2	1.6	1.6	1.6	1.6	8.0	6.4	1.6	0.0	38.4	44.8	3.2	112.0
1989/90	0.0	0.0	0.0	0.0	1.6	4.8	4.8	1.6	1.6	1.6	24.0	33.6	73.6
1990/91	25.6	17.6	6.4	4.8	3.2	4.8	4.8	3.2	3.2	1.6	3.2	3.2	81.6
1991/92	1.6	1.6	1.6	1.6	1.6	1.6	1.6	6.4	1.6	1.6	1.6	1.6	24.0
1992/93	1.6	1.6	1.6	0.0	0.0	0.0	3.2	0.0	0.0	0.0	0.0	11.2	19.2
1993/94	3.2	3.2	1.6	1.6	1.6	12.8	4.8	1.6	1.6	0.0	17.6	20.8	70.4
1994/95	3.2	3.2	1.6	0.0	0.0	0.0	1.6	0.0	0.0	0.0	19.2	12.8	41.6
1995/96	1.6	1.6	0.0	0.0	0.0	1.6	0.0	0.0	0.0	0.0	8.0	11.2	24.0
1996/97	6.4	3.2	1.6	20.8	48.0	52.8	40.0	75.2	16.0	11.2	11.2	11.2	297.7
1997/98	11.2	8.0	8.0	6.4	4.8	4.8	4.8	3.2	3.2	3.2	9.6	6.4	73.6
1998/99	4.8	4.8	3.2	1.6	1.6	1.6	1.6	1.6	1.6	1.6	3.2	4.8	32.0
1999/00	3.2	1.6	1.6	1.6	1.6	1.6	1.6	0.0	0.0	0.0	0.0	3.2	16.0
2000/01	3.2	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	6.4
2001/02	0.0	0.0	3.2	25.6	11.2	8.0	3.2	3.2	1.6	1.6	9.6	8.0	75.2
2002/03	3.2	1.6	1.6	1.6	1.6	1.6	3.2	40.0	4.8	0.0	8.0	1.6	68.8
2003/04	0.0	0.0	0.0	8.0	3.2	1.6	0.0	0.0	0.0	0.0	1.6	1.6	16.0

2004/05	**3.2**	**1.6**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**24.0**	**126.4**	**62.4**	**217.6**
2005/06	**32.0**	**22.4**	**20.8**	**54.4**	**92.8**	**104.0**	**73.6**	**35.2**	**25.6**	**24.0**	**20.8**	**22.4**	**528.1**
2006/07	**19.2**	**17.6**	**16.0**	**14.4**	**12.8**	**11.2**	**9.6**	**8.0**	**8.0**	**6.4**	**6.4**	**8.0**	**137.6**
2007/08	**8.0**	**6.4**	**6.4**	**4.8**	**3.2**	**3.2**	**3.2**	**3.2**	**1.6**	**1.6**	**1.6**	**1.6**	**44.8**
Average	**13.3**	**10.3**	**8.3**	**14.3**	**20.1**	**25.5**	**18.6**	**14.2**	**10.5**	**11.8**	**22.6**	**22.2**	**191.7**

Table 6: Basin F (Ndzovuni) – Simulated Monthly Flows, 1958/59-2007/08 (MCM)

YEAR	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	ANNUAL
1958/59	2.0	1.8	1.6	1.6	1.4	1.1	1.1	0.9	0.9	0.7	7.0	5.2	**25.2**
1959/60	2.0	0.9	0.7	0.5	1.4	0.7	0.5	0.5	0.7	0.5	0.5	0.2	**8.8**
1960/61	0.2	3.2	2.5	26.6	52.2	68.2	35.1	27.0	23.9	21.4	19.4	17.3	**297.0**
1961/62	15.5	14.0	12.6	11.5	10.1	9.2	8.3	7.4	6.8	6.1	8.6	8.6	**118.7**
1962/63	7.0	5.4	3.8	3.4	2.9	3.2	5.6	3.2	2.0	1.8	2.5	4.1	**44.8**
1963/64	1.8	1.4	1.1	0.9	0.9	0.7	12.8	3.8	0.9	0.7	0.7	1.1	**26.8**
1964/65	0.9	0.5	0.5	0.5	0.2	8.3	2.0	0.5	0.2	9.9	4.5	6.1	**34.0**
1965/66	5.0	1.6	0.7	0.2	0.5	0.2	0.2	0.2	1.4	0.2	3.8	3.6	**17.6**
1966/67	1.4	0.7	0.9	6.3	19.8	12.2	3.2	2.5	2.9	3.6	5.4	4.5	**63.3**
1967/68	5.9	2.5	2.0	1.6	1.4	3.2	2.0	1.1	7.4	2.7	2.0	2.3	**34.0**
1968/69	1.8	1.4	1.6	1.1	1.1	2.5	1.4	0.9	0.9	0.9	0.7	0.7	**14.9**
1969/70	0.7	0.5	0.5	0.5	0.5	0.2	0.2	0.2	0.2	0.2	0.2	0.7	**4.5**
1970/71	0.5	0.2	0.2	0.0	0.0	0.0	1.8	0.2	0.0	0.0	0.0	4.7	**7.7**
1971/72	0.5	0.5	0.2	2.5	1.6	1.4	1.8	0.2	0.2	0.2	5.4	5.4	**19.8**
1972/73	2.0	0.5	0.5	0.2	0.2	0.5	0.2	0.2	0.5	0.2	0.5	0.5	**5.9**
1973/74	0.7	0.9	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.7	**2.7**
1974/75	0.2	0.5	0.0	0.0	0.0	0.0	0.0	1.8	0.2	0.0	0.0	0.2	**2.9**
1975/76	0.2	0.2	0.0	0.0	0.0	0.7	0.5	0.0	0.0	0.0	0.2	0.2	**2.0**
1976/77	0.2	0.2	0.7	3.8	4.5	5.4	5.0	2.0	0.9	2.0	4.1	2.7	**31.5**
1977/78	1.4	0.7	0.7	0.5	0.9	5.4	5.9	4.3	0.9	0.5	5.2	8.8	**34.9**
1978/79	4.5	2.7	2.0	1.8	1.6	1.4	1.6	1.1	0.9	0.9	1.1	0.7	**20.3**
1979/80	0.7	2.3	2.0	5.6	3.6	3.8	2.0	1.1	1.1	1.6	1.1	0.9	**25.9**
1980/81	0.7	0.9	0.7	0.5	0.5	0.9	1.1	0.5	0.5	0.7	10.6	19.6	**36.9**
1981/82	6.8	5.6	4.5	4.3	3.6	3.6	2.5	1.8	1.8	1.6	5.2	5.4	**46.6**
1982/83	4.5	2.7	2.0	1.8	1.6	1.4	1.1	1.1	0.9	1.6	4.1	2.5	**25.2**
1983/84	1.4	0.9	0.7	0.5	0.5	2.5	3.4	6.3	3.6	1.4	0.9	0.9	**22.7**
1984/85	1.8	0.9	0.7	0.5	0.5	2.0	0.7	0.5	0.2	1.6	11.3	7.9	**28.4**
1985/86	1.8	1.6	1.4	1.1	1.4	7.7	4.5	2.9	2.7	2.5	4.1	5.0	**36.5**
1986/87	2.3	2.9	2.5	1.6	1.4	1.1	1.1	0.9	0.9	1.1	1.1	1.4	**18.2**
1987/88	0.9	0.7	0.5	0.5	0.5	0.9	1.6	0.7	0.2	2.0	4.5	2.0	**14.9**
1988/89	0.5	0.2	0.2	0.2	0.2	1.1	0.9	0.2	0.0	5.4	6.3	0.5	**15.8**
1989/90	0.0	0.0	0.0	0.0	0.2	0.7	0.7	0.2	0.2	0.2	3.4	4.7	**10.4**
1990/91	3.6	2.5	0.9	0.7	0.5	0.7	0.7	0.5	0.5	0.2	0.5	0.5	**11.5**
1991/92	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.9	0.2	0.2	0.2	0.2	**3.4**
1992/93	0.2	0.2	0.2	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	1.6	**2.7**
1993/94	0.5	0.5	0.2	0.2	0.2	1.8	0.7	0.2	0.2	0.0	2.5	2.9	**9.9**
1994/95	0.5	0.5	0.2	0.0	0.0	0.0	0.2	0.0	0.0	0.0	2.7	1.8	**5.9**
1995/96	0.2	0.2	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	1.1	1.6	**3.4**
1996/97	0.9	0.5	0.2	2.9	6.8	7.4	5.6	10.6	2.3	1.6	1.6	1.6	**41.9**
1997/98	1.6	1.1	1.1	0.9	0.7	0.7	0.7	0.5	0.5	0.5	1.4	0.9	**10.4**
1998/99	0.7	0.7	0.5	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.5	0.7	**4.5**
1999/00	0.5	0.2	0.2	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.5	**2.3**
2000/01	0.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	**0.9**
2001/02	0.0	0.0	0.5	3.6	1.6	1.1	0.5	0.5	0.2	0.2	1.4	1.1	**10.6**
2002/03	0.5	0.2	0.2	0.2	0.2	0.2	0.5	5.6	0.7	0.0	1.1	0.2	**9.7**

2003/04	0.0	0.0	0.0	1.1	0.5	0.2	0.0	0.0	0.0	0.0	0.2	0.2	**2.3**
2004/05	0.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.4	17.8	8.8	**30.6**
2005/06	4.5	3.2	2.9	7.7	13.1	14.6	10.4	5.0	3.6	3.4	2.9	3.2	**74.3**
2006/07	2.7	2.5	2.3	2.0	1.8	1.6	1.4	1.1	1.1	0.9	0.9	1.1	**19.4**
2007/08	1.1	0.9	0.9	0.7	0.5	0.5	0.5	0.5	0.2	0.2	0.2	0.2	**6.3**
Average	**1.9**	**1.4**	**1.2**	**2.0**	**2.8**	**3.6**	**2.6**	**2.0**	**1.5**	**1.7**	**3.2**	**3.1**	**27.0**

Table 7: Basin G (Kombeni) – Simulated Monthly Flows, 1958/59-2007/08 (MCM)

YEAR	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	ANNUAL
1958/59	1.4	1.3	1.1	1.1	1.0	0.8	0.8	0.6	0.6	0.5	4.9	3.7	**17.9**
1959/60	1.4	0.6	0.5	0.3	1.0	0.5	0.3	0.3	0.5	0.3	0.3	0.2	**6.2**
1960/61	0.2	2.2	1.8	18.8	37.0	48.4	24.9	19.2	16.9	15.2	13.7	12.3	**210.5**
1961/62	11.0	9.9	8.9	8.1	7.2	6.5	5.9	5.3	4.8	4.3	6.1	6.1	**84.1**
1962/63	4.9	3.8	2.7	2.4	2.1	2.2	4.0	2.2	1.4	1.3	1.8	2.9	**31.8**
1963/64	1.3	1.0	0.8	0.6	0.6	0.5	9.1	2.7	0.6	0.5	0.5	0.8	**19.0**
1964/65	0.6	0.3	0.3	0.3	0.2	5.9	1.4	0.3	0.2	7.0	3.2	4.3	**24.1**
1965/66	3.5	1.1	0.5	0.2	0.3	0.2	0.2	0.2	1.0	0.2	2.7	2.6	**12.4**
1966/67	1.0	0.5	0.6	4.5	14.0	8.6	2.2	1.8	2.1	2.6	3.8	3.2	**44.9**
1967/68	4.1	1.8	1.4	1.1	1.0	2.2	1.4	0.8	5.3	1.9	1.4	1.6	**24.1**
1968/69	1.3	1.0	1.1	0.8	0.8	1.8	1.0	0.6	0.6	0.6	0.5	0.5	**10.5**
1969/70	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.5	**3.2**
1970/71	0.3	0.2	0.2	0.0	0.0	0.0	1.3	0.2	0.0	0.0	0.0	3.4	**5.4**
1971/72	0.3	0.3	0.2	1.8	1.1	1.0	1.3	0.2	0.2	0.2	3.8	3.8	**14.0**
1972/73	1.4	0.3	0.3	0.2	0.2	0.3	0.2	0.2	0.3	0.2	0.3	0.3	**4.1**
1973/74	0.5	0.6	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.5	**1.9**
1974/75	0.2	0.3	0.0	0.0	0.0	0.0	0.0	1.3	0.2	0.0	0.0	0.2	**2.1**
1975/76	0.2	0.2	0.0	0.0	0.0	0.5	0.3	0.0	0.0	0.0	0.2	0.2	**1.4**
1976/77	0.2	0.2	0.5	2.7	3.2	3.8	3.5	1.4	0.6	1.4	2.9	1.9	**22.3**
1977/78	1.0	0.5	0.5	0.3	0.6	3.8	4.1	3.0	0.6	0.3	3.7	6.2	**24.7**
1978/79	3.2	1.9	1.4	1.3	1.1	1.0	1.1	0.8	0.6	0.6	0.8	0.5	**14.4**
1979/80	0.5	1.6	1.4	4.0	2.6	2.7	1.4	0.8	0.8	1.1	0.8	0.6	**18.4**
1980/81	0.5	0.6	0.5	0.3	0.3	0.6	0.8	0.3	0.3	0.5	7.5	13.9	**26.2**
1981/82	4.8	4.0	3.2	3.0	2.6	2.6	1.8	1.3	1.3	1.1	3.7	3.8	**33.0**
1982/83	3.2	1.9	1.4	1.3	1.1	1.0	0.8	0.8	0.6	1.1	2.9	1.8	**17.9**
1983/84	1.0	0.6	0.5	0.3	0.3	1.8	2.4	4.5	2.6	1.0	0.6	0.6	**16.1**
1984/85	1.3	0.6	0.5	0.3	0.3	1.4	0.5	0.3	0.2	1.1	8.0	5.6	**20.1**
1985/86	1.3	1.1	1.0	0.8	1.0	5.4	3.2	2.1	1.9	1.8	2.9	3.5	**25.9**
1986/87	1.6	2.1	1.8	1.1	1.0	0.8	0.8	0.6	0.6	0.8	0.8	1.0	**12.9**
1987/88	0.6	0.5	0.3	0.3	0.3	0.6	1.1	0.5	0.2	1.4	3.2	1.4	**10.5**
1988/89	0.3	0.2	0.2	0.2	0.2	0.8	0.6	0.2	0.0	3.8	4.5	0.3	**11.2**
1989/90	0.0	0.0	0.0	0.0	0.2	0.5	0.5	0.2	0.2	0.2	2.4	3.4	**7.3**
1990/91	2.6	1.8	0.6	0.5	0.3	0.5	0.5	0.3	0.3	0.2	0.3	0.3	**8.1**
1991/92	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.6	0.2	0.2	0.2	0.2	**2.4**
1992/93	0.2	0.2	0.2	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	1.1	**1.9**
1993/94	0.3	0.3	0.2	0.2	0.2	1.3	0.5	0.2	0.2	0.0	1.8	2.1	**7.0**
1994/95	0.3	0.3	0.2	0.0	0.0	0.0	0.2	0.0	0.0	0.0	1.9	1.3	**4.1**
1995/96	0.2	0.2	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.8	1.1	**2.4**
1996/97	0.6	0.3	0.2	2.1	4.8	5.3	4.0	7.5	1.6	1.1	1.1	1.1	**29.7**
1997/98	1.1	0.8	0.8	0.6	0.5	0.5	0.5	0.3	0.3	0.3	1.0	0.6	**7.3**
1998/99	0.5	0.5	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.5	**3.2**
1999/00	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.3	**1.6**
2000/01	0.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	**0.6**
2001/02	0.0	0.0	0.3	2.6	1.1	0.8	0.3	0.3	0.2	0.2	1.0	0.8	**7.5**

2002/03	0.3	0.2	0.2	0.2	0.2	0.2	0.3	4.0	0.5	0.0	0.8	0.2	**6.9**
2003/04	0.0	0.0	0.0	0.8	0.3	0.2	0.0	0.0	0.0	0.0	0.2	0.2	**1.6**
2004/05	0.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.4	12.6	6.2	**21.7**
2005/06	3.2	2.2	2.1	5.4	9.3	10.4	7.3	3.5	2.6	2.4	2.1	2.2	**52.7**
2006/07	1.9	1.8	1.6	1.4	1.3	1.1	1.0	0.8	0.8	0.6	0.6	0.8	**13.7**
2007/08	0.8	0.6	0.6	0.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	**4.5**
Average	**1.3**	**1.0**	**0.8**	**1.4**	**2.0**	**2.5**	**1.9**	**1.4**	**1.0**	**1.2**	**2.3**	**2.2**	**19.1**

Table 8: Basin I (Pemba) – Simulated Monthly Flows, 1958/59-2007/08 (MCM)

YEAR	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	ANNUAL
1958/59	1.6	1.4	1.3	1.3	1.1	0.9	0.9	0.7	0.7	0.5	5.5	4.1	**20.0**
1959/60	1.6	0.7	0.5	0.4	1.1	0.5	0.4	0.4	0.5	0.4	0.4	0.2	**7.0**
1960/61	0.2	2.5	2.0	21.1	41.4	54.1	27.9	21.4	18.9	17.0	15.4	13.8	**235.7**
1961/62	12.3	11.1	10.0	9.1	8.0	7.3	6.6	5.9	5.4	4.8	6.8	6.8	**94.2**
1962/63	5.5	4.3	3.0	2.7	2.3	2.5	4.5	2.5	1.6	1.4	2.0	3.2	**35.6**
1963/64	1.4	1.1	0.9	0.7	0.7	0.5	10.2	3.0	0.7	0.5	0.5	0.9	**21.3**
1964/65	0.7	0.4	0.4	0.4	0.2	6.6	1.6	0.4	0.2	7.9	3.6	4.8	**27.0**
1965/66	3.9	1.3	0.5	0.2	0.4	0.2	0.2	0.2	1.1	0.2	3.0	2.9	**13.9**
1966/67	1.1	0.5	0.7	5.0	15.7	9.6	2.5	2.0	2.3	2.9	4.3	3.6	**50.2**
1967/68	4.6	2.0	1.6	1.3	1.1	2.5	1.6	0.9	5.9	2.1	1.6	1.8	**27.0**
1968/69	1.4	1.1	1.3	0.9	0.9	2.0	1.1	0.7	0.7	0.7	0.5	0.5	**11.8**
1969/70	0.5	0.4	0.4	0.4	0.4	0.2	0.2	0.2	0.2	0.2	0.2	0.5	**3.6**
1970/71	0.4	0.2	0.2	0.0	0.0	0.0	1.4	0.2	0.0	0.0	0.0	3.7	**6.1**
1971/72	0.4	0.4	0.2	2.0	1.3	1.1	1.4	0.2	0.2	0.2	4.3	4.3	**15.7**
1972/73	1.6	0.4	0.4	0.2	0.2	0.4	0.2	0.2	0.4	0.2	0.4	0.4	**4.6**
1973/74	0.5	0.7	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.5	**2.1**
1974/75	0.2	0.4	0.0	0.0	0.0	0.0	0.0	1.4	0.2	0.0	0.0	0.2	**2.3**
1975/76	0.2	0.2	0.0	0.0	0.0	0.5	0.4	0.0	0.0	0.0	0.2	0.2	**1.6**
1976/77	0.2	0.2	0.5	3.0	3.6	4.3	3.9	1.6	0.7	1.6	3.2	2.1	**25.0**
1977/78	1.1	0.5	0.5	0.4	0.7	4.3	4.6	3.4	0.7	0.4	4.1	7.0	**27.7**
1978/79	3.6	2.1	1.6	1.4	1.3	1.1	1.3	0.9	0.7	0.7	0.9	0.5	**16.1**
1979/80	0.5	1.8	1.6	4.5	2.9	3.0	1.6	0.9	0.9	1.3	0.9	0.7	**20.5**
1980/81	0.5	0.7	0.5	0.4	0.4	0.7	0.9	0.4	0.4	0.5	8.4	15.5	**29.3**
1981/82	5.4	4.5	3.6	3.4	2.9	2.9	2.0	1.4	1.4	1.3	4.1	4.3	**37.0**
1982/83	3.6	2.1	1.6	1.4	1.3	1.1	0.9	0.9	0.7	1.3	3.2	2.0	**20.0**
1983/84	1.1	0.7	0.5	0.4	0.4	2.0	2.7	5.0	2.9	1.1	0.7	0.7	**18.0**
1984/85	1.4	0.7	0.5	0.4	0.4	1.6	0.5	0.4	0.2	1.3	8.9	6.3	**22.5**
1985/86	1.4	1.3	1.1	0.9	1.1	6.1	3.6	2.3	2.1	2.0	3.2	3.9	**28.9**
1986/87	1.8	2.3	2.0	1.3	1.1	0.9	0.9	0.7	0.7	0.9	0.9	1.1	**14.5**
1987/88	0.7	0.5	0.4	0.4	0.4	0.7	1.3	0.5	0.2	1.6	3.6	1.6	**11.8**
1988/89	0.4	0.2	0.2	0.2	0.2	0.9	0.7	0.2	0.0	4.3	5.0	0.4	**12.5**
1989/90	0.0	0.0	0.0	0.0	0.2	0.5	0.5	0.2	0.2	0.2	2.7	3.7	**8.2**
1990/91	2.9	2.0	0.7	0.5	0.4	0.5	0.5	0.4	0.4	0.2	0.4	0.4	**9.1**
1991/92	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.7	0.2	0.2	0.2	0.2	**2.7**
1992/93	0.2	0.2	0.2	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	1.3	**2.1**
1993/94	0.4	0.4	0.2	0.2	0.2	1.4	0.5	0.2	0.2	0.0	2.0	2.3	**7.9**
1994/95	0.4	0.4	0.2	0.0	0.0	0.0	0.2	0.0	0.0	0.0	2.1	1.4	**4.6**
1995/96	0.2	0.2	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.9	1.3	**2.7**
1996/97	0.7	0.4	0.2	2.3	5.4	5.9	4.5	8.4	1.8	1.3	1.3	1.3	**33.2**
1997/98	1.3	0.9	0.9	0.7	0.5	0.5	0.5	0.4	0.4	0.4	1.1	0.7	**8.2**
1998/99	0.5	0.5	0.4	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.4	0.5	**3.6**
1999/00	0.4	0.2	0.2	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.4	**1.8**
2000/01	0.4	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	**0.7**
2001/02	0.0	0.0	0.4	2.9	1.3	0.9	0.4	0.4	0.2	0.2	1.1	0.9	**8.4**
2002/03	0.4	0.2	0.2	0.2	0.2	0.2	0.4	4.5	0.5	0.0	0.9	0.2	**7.7**

2003/04	0.0	0.0	0.0	0.9	0.4	0.2	0.0	0.0	0.0	0.0	0.2	0.2	**1.8**
2004/05	0.4	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.7	14.1	7.0	**24.3**
2005/06	3.6	2.5	2.3	6.1	10.4	11.6	8.2	3.9	2.9	2.7	2.3	2.5	**59.0**
2006/07	2.1	2.0	1.8	1.6	1.4	1.3	1.1	0.9	0.9	0.7	0.7	0.9	**15.4**
2007/08	0.9	0.7	0.7	0.5	0.4	0.4	0.4	0.4	0.2	0.2	0.2	0.2	**5.0**
Average	**1.5**	**1.2**	**0.9**	**1.6**	**2.2**	**2.8**	**2.1**	**1.6**	**1.2**	**1.3**	**2.5**	**2.5**	**21.4**

Table 9: Basin J (Ramisi) – Simulated Monthly Flows, 1958/59-2007/08 (MCM)

YEAR	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	ANNUAL
1958/59	2.2	1.9	1.7	1.7	1.5	1.2	1.2	1.0	1.0	0.7	7.5	5.6	**27.2**
1959/60	2.2	1.0	0.7	0.5	1.5	0.7	0.5	0.5	0.7	0.5	0.5	0.2	**9.5**
1960/61	0.2	3.4	2.7	28.6	56.3	73.5	37.8	29.1	25.7	23.0	20.9	18.7	**320.0**
1961/62	16.7	15.0	13.6	12.4	10.9	9.9	9.0	8.0	7.3	6.5	9.2	9.2	**127.8**
1962/63	7.5	5.8	4.1	3.6	3.2	3.4	6.1	3.4	2.2	1.9	2.7	4.4	**48.3**
1963/64	1.9	1.5	1.2	1.0	1.0	0.7	13.8	4.1	1.0	0.7	0.7	1.2	**28.9**
1964/65	1.0	0.5	0.5	0.5	0.2	9.0	2.2	0.5	0.2	10.7	4.9	6.5	**36.6**
1965/66	5.3	1.7	0.7	0.2	0.5	0.2	0.2	0.2	1.5	0.2	4.1	3.9	**18.9**
1966/67	1.5	0.7	1.0	6.8	21.3	13.1	3.4	2.7	3.2	3.9	5.8	4.9	**68.2**
1967/68	6.3	2.7	2.2	1.7	1.5	3.4	2.2	1.2	8.0	2.9	2.2	2.4	**36.6**
1968/69	1.9	1.5	1.7	1.2	1.2	2.7	1.5	1.0	1.0	1.0	0.7	0.7	**16.0**
1969/70	0.7	0.5	0.5	0.5	0.5	0.2	0.2	0.2	0.2	0.2	0.2	0.7	**4.9**
1970/71	0.5	0.2	0.2	0.0	0.0	0.0	1.9	0.2	0.0	0.0	0.0	5.1	**8.2**
1971/72	0.5	0.5	0.2	2.7	1.7	1.5	1.9	0.2	0.2	0.2	5.8	5.8	**21.3**
1972/73	2.2	0.5	0.5	0.2	0.2	0.5	0.2	0.2	0.5	0.2	0.5	0.5	**6.3**
1973/74	0.7	1.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.7	**2.9**
1974/75	0.2	0.5	0.0	0.0	0.0	0.0	0.0	1.9	0.2	0.0	0.0	0.2	**3.2**
1975/76	0.2	0.2	0.0	0.0	0.0	0.7	0.5	0.0	0.0	0.0	0.2	0.2	**2.2**
1976/77	0.2	0.2	0.7	4.1	4.9	5.8	5.3	2.2	1.0	2.2	4.4	2.9	**34.0**
1977/78	1.5	0.7	0.7	0.5	1.0	5.8	6.3	4.6	1.0	0.5	5.6	9.5	**37.6**
1978/79	4.9	2.9	2.2	1.9	1.7	1.5	1.7	1.2	1.0	1.0	1.2	0.7	**21.8**
1979/80	0.7	2.4	2.2	6.1	3.9	4.1	2.2	1.2	1.2	1.7	1.2	1.0	**27.9**
1980/81	0.7	1.0	0.7	0.5	0.5	1.0	1.2	0.5	0.5	0.7	11.4	21.1	**39.8**
1981/82	7.3	6.1	4.9	4.6	3.9	3.9	2.7	1.9	1.9	1.7	5.6	5.8	**50.2**
1982/83	4.9	2.9	2.2	1.9	1.7	1.5	1.2	1.2	1.0	1.7	4.4	2.7	**27.2**
1983/84	1.5	1.0	0.7	0.5	0.5	2.7	3.6	6.8	3.9	1.5	1.0	1.0	**24.5**
1984/85	1.9	1.0	0.7	0.5	0.5	2.2	0.7	0.5	0.2	1.7	12.1	8.5	**30.6**
1985/86	1.9	1.7	1.5	1.2	1.5	8.2	4.9	3.2	2.9	2.7	4.4	5.3	**39.3**
1986/87	2.4	3.2	2.7	1.7	1.5	1.2	1.2	1.0	1.0	1.2	1.2	1.5	**19.6**
1987/88	1.0	0.7	0.5	0.5	0.5	1.0	1.7	0.7	0.2	2.2	4.9	2.2	**16.0**
1988/89	0.5	0.2	0.2	0.2	0.2	1.2	1.0	0.2	0.0	5.8	6.8	0.5	**17.0**
1989/90	0.0	0.0	0.0	0.0	0.2	0.7	0.7	0.2	0.2	0.2	3.6	5.1	**11.2**
1990/91	3.9	2.7	1.0	0.7	0.5	0.7	0.7	0.5	0.5	0.2	0.5	0.5	**12.4**
1991/92	0.2	0.2	0.2	0.2	0.2	0.2	0.2	1.0	0.2	0.2	0.2	0.2	**3.6**
1992/93	0.2	0.2	0.2	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	1.7	**2.9**
1993/94	0.5	0.5	0.2	0.2	0.2	1.9	0.7	0.2	0.2	0.0	2.7	3.2	**10.7**
1994/95	0.5	0.5	0.2	0.0	0.0	0.0	0.2	0.0	0.0	0.0	2.9	1.9	**6.3**
1995/96	0.2	0.2	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	1.2	1.7	**3.6**
1996/97	1.0	0.5	0.2	3.2	7.3	8.0	6.1	11.4	2.4	1.7	1.7	1.7	**45.1**
1997/98	1.7	1.2	1.2	1.0	0.7	0.7	0.7	0.5	0.5	0.5	1.5	1.0	**11.2**
1998/99	0.7	0.7	0.5	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.5	0.7	**4.9**
1999/00	0.5	0.2	0.2	0.2	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.5	**2.4**

2000/01	0.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	**1.0**
2001/02	0.0	0.0	0.5	3.9	1.7	1.2	0.5	0.5	0.2	0.2	1.5	1.2	**11.4**
2002/03	0.5	0.2	0.2	0.2	0.2	0.2	0.5	6.1	0.7	0.0	1.2	0.2	**10.4**
2003/04	0.0	0.0	0.0	1.2	0.5	0.2	0.0	0.0	0.0	0.0	0.2	0.2	**2.4**
2004/05	0.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.6	19.2	9.5	**33.0**
2005/06	4.9	3.4	3.2	8.2	14.1	15.8	11.2	5.3	3.9	3.6	3.2	3.4	**80.0**
2006/07	2.9	2.7	2.4	2.2	1.9	1.7	1.5	1.2	1.2	1.0	1.0	1.2	**20.9**
2007/08	1.2	1.0	1.0	0.7	0.5	0.5	0.5	0.5	0.2	0.2	0.2	0.2	**6.8**
Average	**2.0**	**1.6**	**1.3**	**2.2**	**3.0**	**3.9**	**2.8**	**2.1**	**1.6**	**1.8**	**3.4**	**3.4**	**29.1**

Table 10: Basin K (Mwena) – Simulated Monthly Flows, 1958/59-2007/08 (MCM)

YEAR	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	ANNUAL
1958/59	0.5	0.4	0.4	0.4	0.3	0.3	0.3	0.2	0.2	0.2	1.7	1.3	**6.1**
1959/60	0.5	0.2	0.2	0.1	0.3	0.2	0.1	0.1	0.2	0.1	0.1	0.1	**2.1**
1960/61	0.1	0.8	0.6	6.4	12.7	16.6	8.5	6.6	5.8	5.2	4.7	4.2	**72.1**
1961/62	3.8	3.4	3.1	2.8	2.5	2.2	2.0	1.8	1.6	1.5	2.1	2.1	**28.8**
1962/63	1.7	1.3	0.9	0.8	0.7	0.8	1.4	0.8	0.5	0.4	0.6	1.0	**10.9**
1963/64	0.4	0.3	0.3	0.2	0.2	0.2	3.1	0.9	0.2	0.2	0.2	0.3	**6.5**
1964/65	0.2	0.1	0.1	0.1	0.1	2.0	0.5	0.1	0.1	2.4	1.1	1.5	**8.3**
1965/66	1.2	0.4	0.2	0.1	0.1	0.1	0.1	0.1	0.3	0.1	0.9	0.9	**4.3**
1966/67	0.3	0.2	0.2	1.5	4.8	3.0	0.8	0.6	0.7	0.9	1.3	1.1	**15.4**
1967/68	1.4	0.6	0.5	0.4	0.3	0.8	0.5	0.3	1.8	0.7	0.5	0.5	**8.3**
1968/69	0.4	0.3	0.4	0.3	0.3	0.6	0.3	0.2	0.2	0.2	0.2	0.2	**3.6**
1969/70	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	**1.1**
1970/71	0.1	0.1	0.1	0.0	0.0	0.0	0.4	0.1	0.0	0.0	0.0	1.1	**1.9**
1971/72	0.1	0.1	0.1	0.6	0.4	0.3	0.4	0.1	0.1	0.1	1.3	1.3	**4.8**
1972/73	0.5	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	**1.4**
1973/74	0.2	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	**0.7**
1974/75	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.4	0.1	0.0	0.0	0.1	**0.7**
1975/76	0.1	0.1	0.0	0.0	0.0	0.2	0.1	0.0	0.0	0.0	0.1	0.1	**0.5**
1976/77	0.1	0.1	0.2	0.9	1.1	1.3	1.2	0.5	0.2	0.5	1.0	0.7	**7.6**
1977/78	0.3	0.2	0.2	0.1	0.2	1.3	1.4	1.0	0.2	0.1	1.3	2.1	**8.5**
1978/79	1.1	0.7	0.5	0.4	0.4	0.3	0.4	0.3	0.2	0.2	0.3	0.2	**4.9**
1979/80	0.2	0.5	0.5	1.4	0.9	0.9	0.5	0.3	0.3	0.4	0.3	0.2	**6.3**
1980/81	0.2	0.2	0.2	0.1	0.1	0.2	0.3	0.1	0.1	0.2	2.6	4.8	**9.0**
1981/82	1.6	1.4	1.1	1.0	0.9	0.9	0.6	0.4	0.4	0.4	1.3	1.3	**11.3**
1982/83	1.1	0.7	0.5	0.4	0.4	0.3	0.3	0.3	0.2	0.4	1.0	0.6	**6.1**
1983/84	0.3	0.2	0.2	0.1	0.1	0.6	0.8	1.5	0.9	0.3	0.2	0.2	**5.5**
1984/85	0.4	0.2	0.2	0.1	0.1	0.5	0.2	0.1	0.1	0.4	2.7	1.9	**6.9**
1985/86	0.4	0.4	0.3	0.3	0.3	1.9	1.1	0.7	0.7	0.6	1.0	1.2	**8.9**
1986/87	0.5	0.7	0.6	0.4	0.3	0.3	0.3	0.2	0.2	0.3	0.3	0.3	**4.4**
1987/88	0.2	0.2	0.1	0.1	0.1	0.2	0.4	0.2	0.1	0.5	1.1	0.5	**3.6**
1988/89	0.1	0.1	0.1	0.1	0.1	0.3	0.2	0.1	0.0	1.3	1.5	0.1	**3.8**
1989/90	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.1	0.1	0.1	0.8	1.1	**2.5**
1990/91	0.9	0.6	0.2	0.2	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0.1	**2.8**
1991/92	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	**0.8**
1992/93	0.1	0.1	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.4	**0.7**
1993/94	0.1	0.1	0.1	0.1	0.1	0.4	0.2	0.1	0.1	0.0	0.6	0.7	**2.4**
1994/95	0.1	0.1	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.7	0.4	**1.4**
1995/96	0.1	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.3	0.4	**0.8**
1996/97	0.2	0.1	0.1	0.7	1.6	1.8	1.4	2.6	0.5	0.4	0.4	0.4	**10.2**
1997/98	0.4	0.3	0.3	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.3	0.2	**2.5**
1998/99	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	**1.1**

1999/00	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.1	**0.5**
2000/01	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	**0.2**
2001/02	0.0	0.0	0.1	0.9	0.4	0.3	0.1	0.1	0.1	0.1	0.3	0.3	**2.6**
2002/03	0.1	0.1	0.1	0.1	0.1	0.1	0.1	1.4	0.2	0.0	0.3	0.1	**2.3**
2003/04	0.0	0.0	0.0	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.1	**0.5**
2004/05	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	4.3	2.1	**7.4**
2005/06	1.1	0.8	0.7	1.9	3.2	3.6	2.5	1.2	0.9	0.8	0.7	0.8	**18.0**
2006/07	0.7	0.6	0.5	0.5	0.4	0.4	0.3	0.3	0.3	0.2	0.2	0.3	**4.7**
2007/08	0.3	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	**1.5**
Average	**0.5**	**0.4**	**0.3**	**0.5**	**0.7**	**0.9**	**0.6**	**0.5**	**0.4**	**0.4**	**0.8**	**0.8**	**6.5**

Results of Groundwater Model Runs

3. Model Results – Stage 1

3.1 Initial Run

An initial run was performed in order to understand the flow regime in the area of the Tiwi and Msambweni well fields. All parameters of the simulation were described in the previous section. The simulation was conducted without any pumping taking place in order to establish a "natural" baseline for the aquifer system.

Results are reported as water levels, flow vectors and flow budget.

3.2 Results of Initial Run

The flow regime of the initial run ("natural" case) is presented in Fig. 1. Flow is in general from west to east, from the mountains to the ocean. Flow vectors are perpendicular to the shoreline. The "natural" water levels in Tiwi and Msambweni are 15 and 30-40 m, respectively. Note the "red" cells on the mountains west of Tiwi wells, an area that cannot sustain an aquifer. However, there is some flow in the deeper parts of this region into Tiwi field.

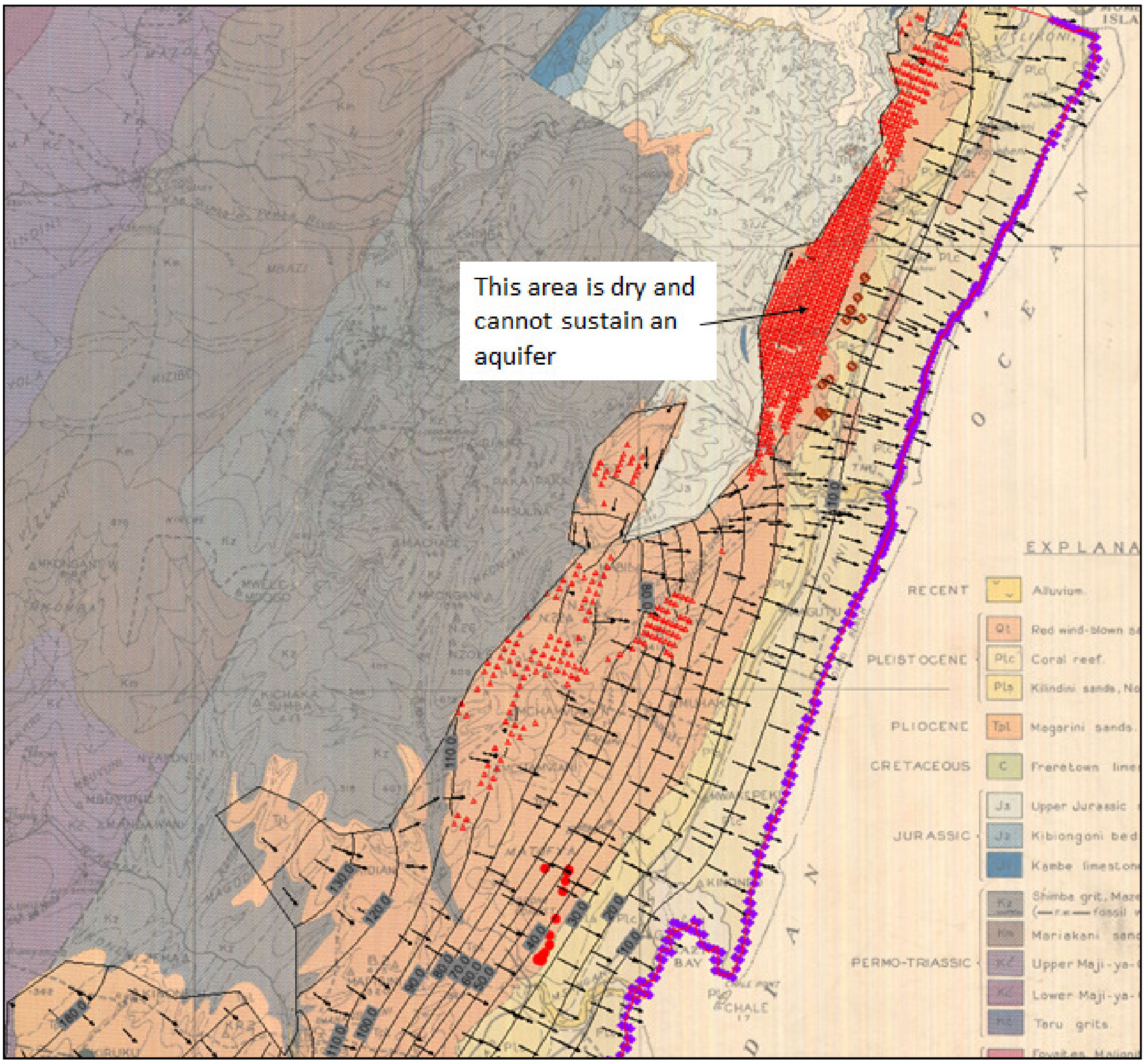


Fig. 1: Flow regime of initial run - reference "natural" case

The water balance (referred to as "flow budget" in GMS software) for Tiwi aquifer was calculated for each simulation. The extent of the Tiwi area was determined based on the flow directions and water level contours, and are presented in Fig. 2. The flow budget components are also shown: recharge from rainfall, recharge from rainfall on the mountains (Mts.) entering Tiwi from the west, flow to the ocean, flow from south and north, pumping.

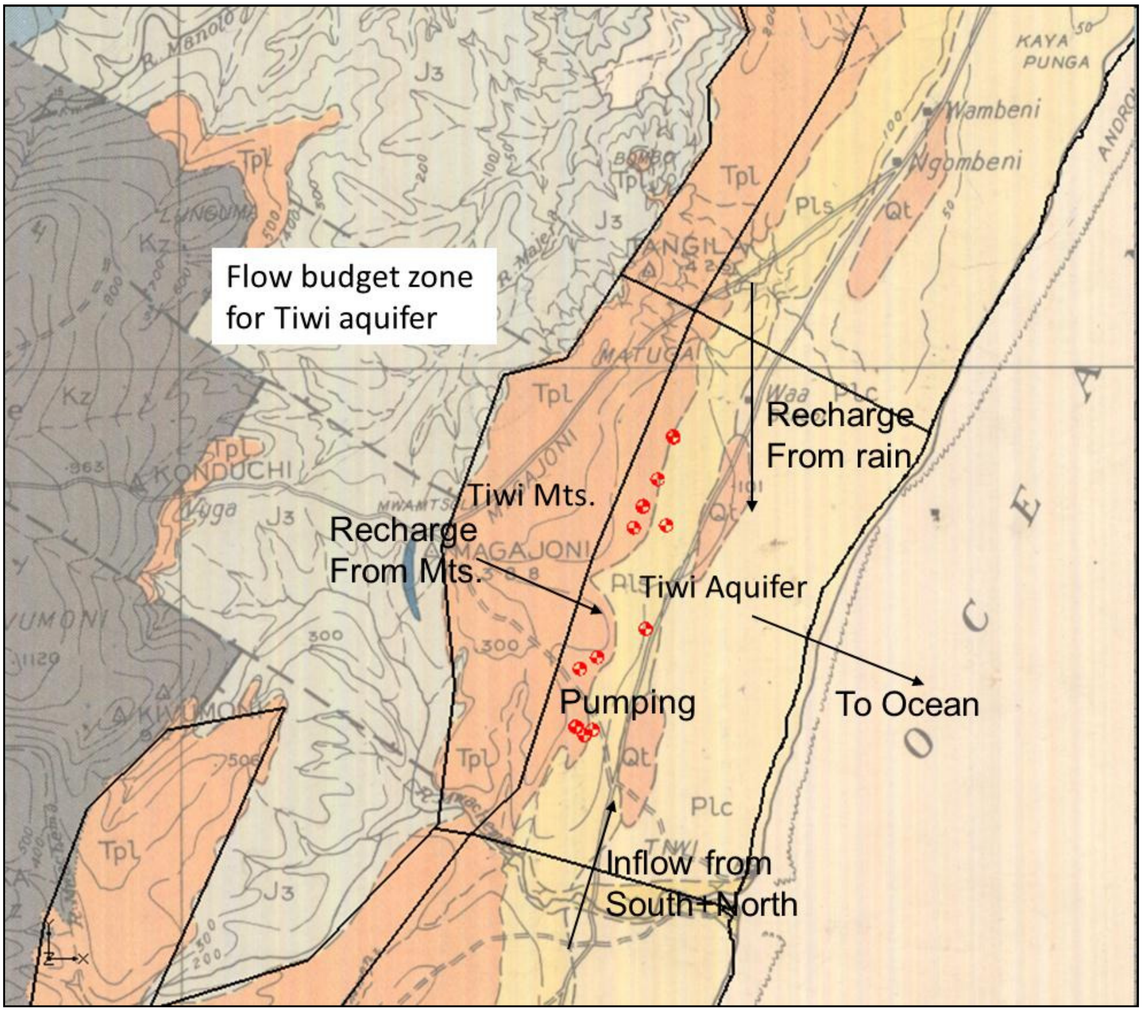


Fig. 2: Flow budget zone for Tiwi Aquifer

The flow budget for Tiwi aquifer is presented in Table 1. The total recharge on Tiwi aquifer is about 30,000 m^3/d (11 MCM per year), while about 16,000 m^3/d (6 MCM/y) is recharged in the mountains and enters from the west.

Table 1: Flow Budget for the Reference "Natural" Case – High Recharge and No Pumping (Run Tiwi 1)

	m^3/d
INFLOW	
Recharge	30,474
Recharge Mt. to coast	16,559
From south/north	2,859
Total INFLOW	49,892
OUTFLOW	
Pumping	0
Ocean boundary	49,892
Total OUTFLOW	49,892
% Pumping from total inflow	0%
% Budget discrepancy	0.0000%

Fig. 3 presents the water levels and flow directions for production of 13,127 m^3/d (4.8 MCM/y) in Tiwi. Water levels drop to 8-9 m, but all flow is still in the direction of the ocean. It can be seen that Tiwi field attracts some of the water from the southwest. The effect of pumping is noted to be about 1 km west and south of Tiwi wells. The flow budget shows that pumping is 25% of the total inflow to this portion of the aquifer. No seawater intrusion occurs.

Table 2 shows the flow budget for Tiwi aquifer for high recharge and low pumping.

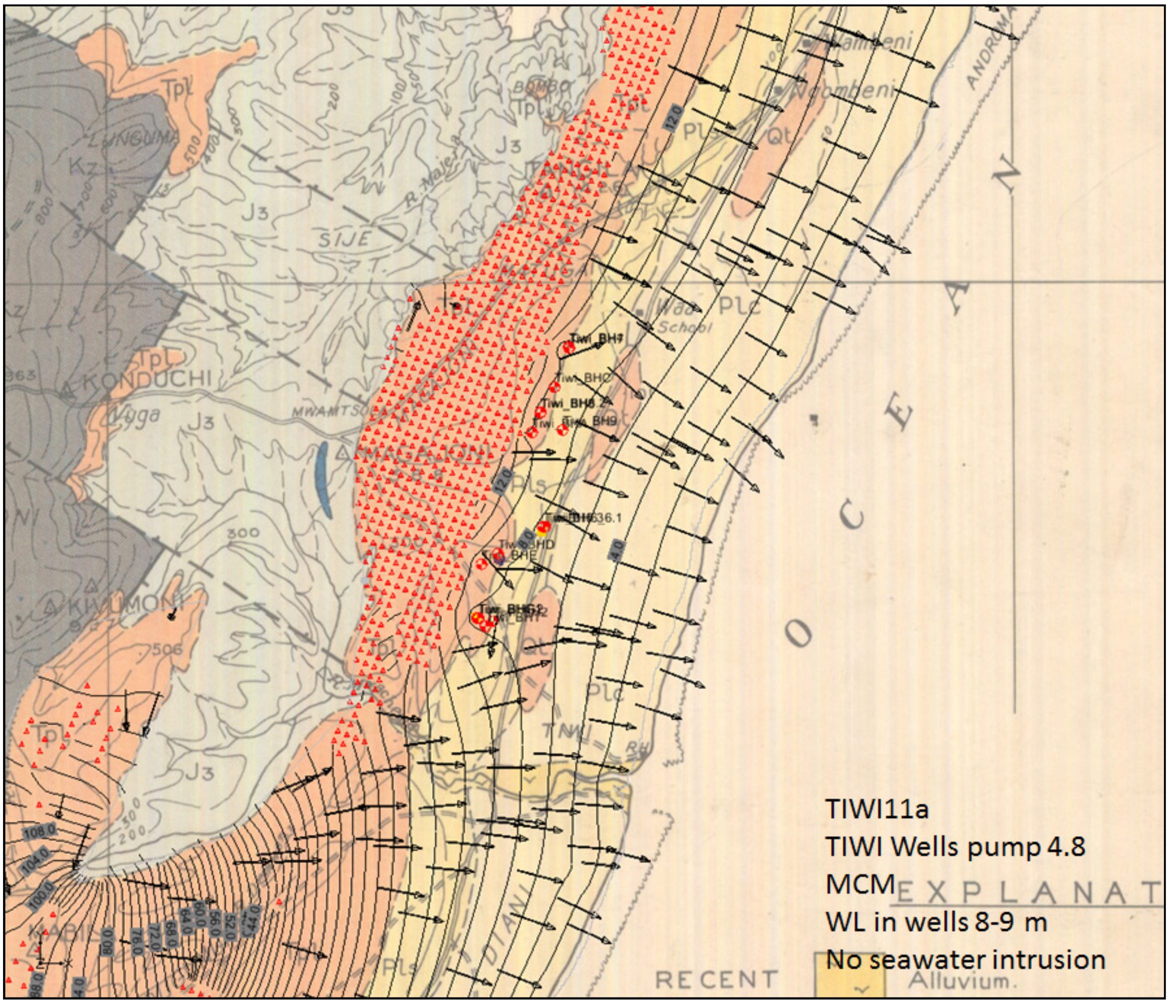


Fig. 3: Water levels and flow directions (run Tiwi 11a)

Table 2: Flow Budget for Tiwi Aquifer – High Recharge and Low Pumping (Run Tiwi 11a)

	m^3/d
INFLOW	
Recharge	30,474
Recharge Mt. to coast	16,666
From south/north	5,716
Total INFLOW	52,856
OUTFLOW	
Pumping	13,127
Ocean boundary	39,729
Total OUTFLOW	52,856

% Pumping from total inflow	25%
% Budget discrepancy	0.0000%

Fig. 4 presents the water levels and flow directions for production of 13,824 m^3/d (5 MCM/y) in Msambweni. Water levels drop to 25-35 m, and still all flow is mostly eastward.

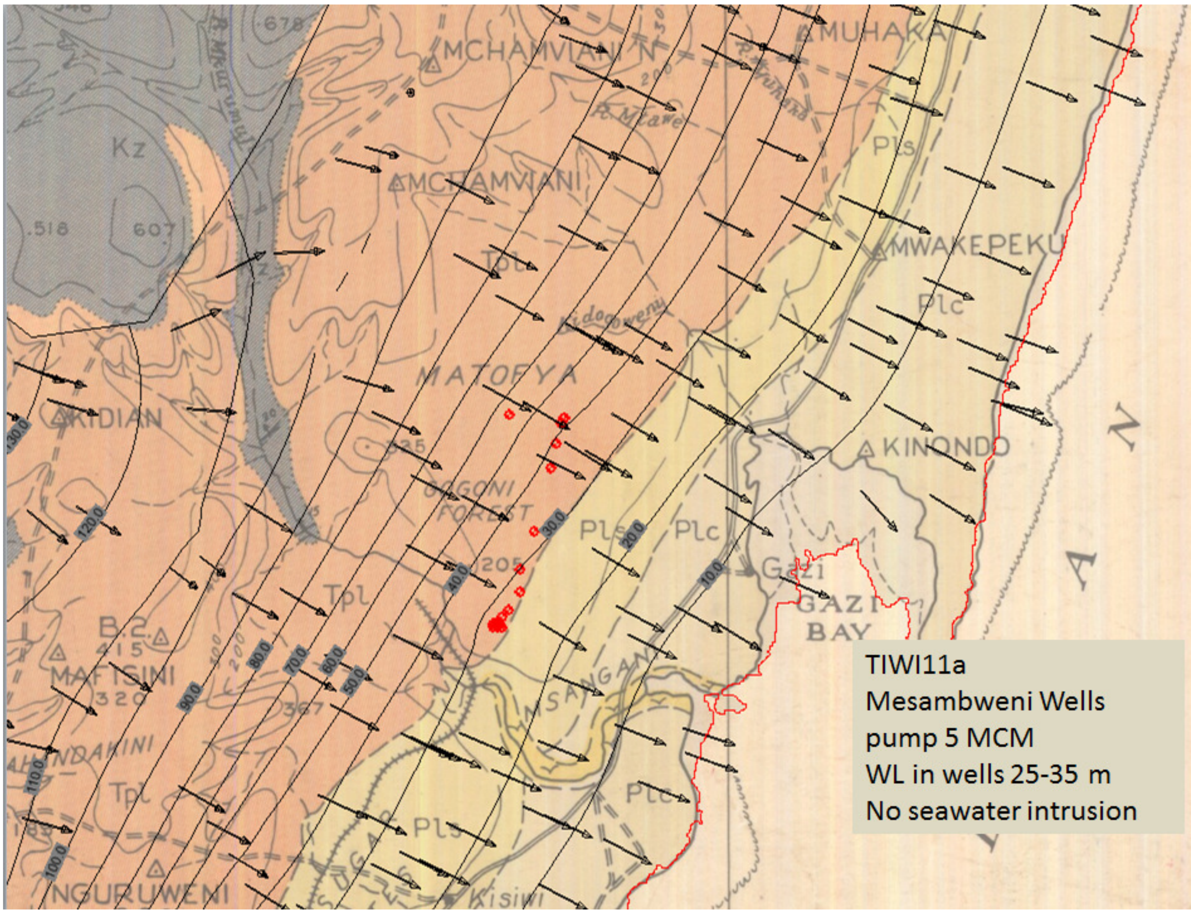


Fig. 4: Water levels and flow directions in Msambweni Aquifer (run Tiwi 11a)

The resultant water levels in Tiwi do not resemble the current situation, where water levels are more or less at sea level or even lower. The two main reasons for this could be:

- Total production in the wells or in an adjacent part of the aquifer is not considered.
- Recharge to the mountains west of the well fields is exaggerated.

4. Additional Simulations

Additional simulations are intended to examine:

- Effect of increased production in Tiwi.
- Effect of lower recharge to the aquifer.
- Effect of well distance from the ocean.

4.1 Effect of Increased Production in Tiwi

Tiwi well production is increased threefold to 14.4 MCM/y. All other parameters stay the same.

Fig. 5 presents water levels and flow directions for this situation. The water levels in the wells are now mostly below sea level, -1 to -8 m. Depression cones around the wells are created. Nevertheless, no seawater intrusion takes place. A groundwater divide is created halfway between the wells and the ocean, with a water level of about +1-1.3 m at the divide.

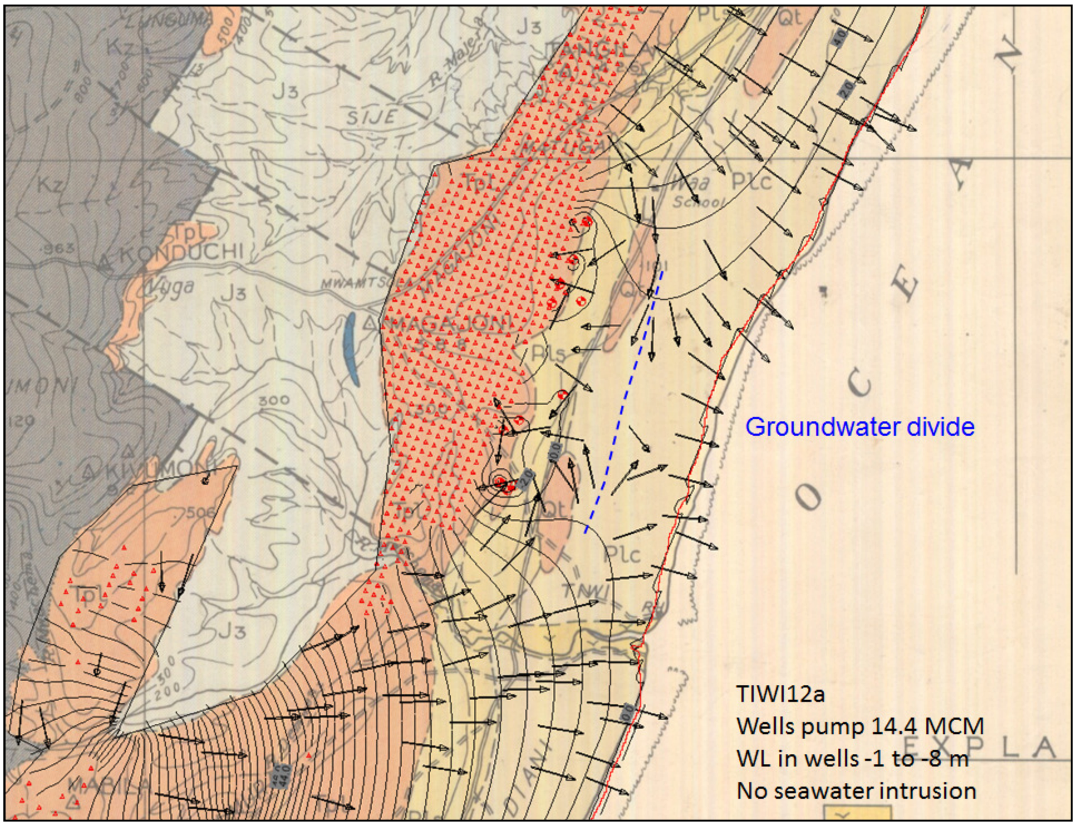


Fig. 5: Water levels and flow directions (run Tiwi 12a)

The flow budget is presented in Table 3. Pumping in Tiwi is 67% of the total inflow. Outflow to the ocean is about 19,400 m^3/d. Many seawater intrusion studies relate to the outflow to the sea per 1 km length. In this case, the Tiwi aquifer budget zone defined here is about 10 km long. Therefore, the outflow per 1 km is 1,940 m^3/d. This amount of outflow is related to prevention of seawater intrusion.

Table 3: Flow Budget for Tiwi Aquifer – High Recharge and High Pumping (Run Tiwi 12a)

	m³/d
INFLOW	
Recharge	30,474
Recharge Mt. to coast	16,863
From south/north	11,446
Total INFLOW	58,783
OUTFLOW	
Pumping	39,381
Ocean boundary	19,403
Total OUTFLOW	58,784
% Pumping from total inflow	67%
% Budget discrepancy	0.0003%

4.2 Effect of Lower Recharge to the Aquifer

Rain coefficients in the mountains adjacent to Tiwi and Msambweni were lowered, such that the total recharge in the mountains decreased to about 25% of the initial value, and recharge on the Tiwi aquifer itself decreased to about 85%. Altogether recharge decreased to 64% of the original. Tiwi and Msambweni well productions were set back to the original values of 4.8 and 5 MCM/y.

Fig. 6 presents the water levels and flow directions for Tiwi area for a lower amount of recharge. Water levels in Tiwi field are 0-3 m. A groundwater divide is created here, but is located closer to the wells than to the ocean. The water level at the water divide is about 3 m. In this case, no seawater intrusion takes place. In Msambweni field water levels decrease to 15-25 m, compared to 25-35 m for the same production, but for higher recharge rates in the catchment areas.

Table 4 shows the flow budget for Tiwi aquifer for low recharge and low production. The flow budget for Tiwi aquifer for low recharge and high production is shown in Table 5.

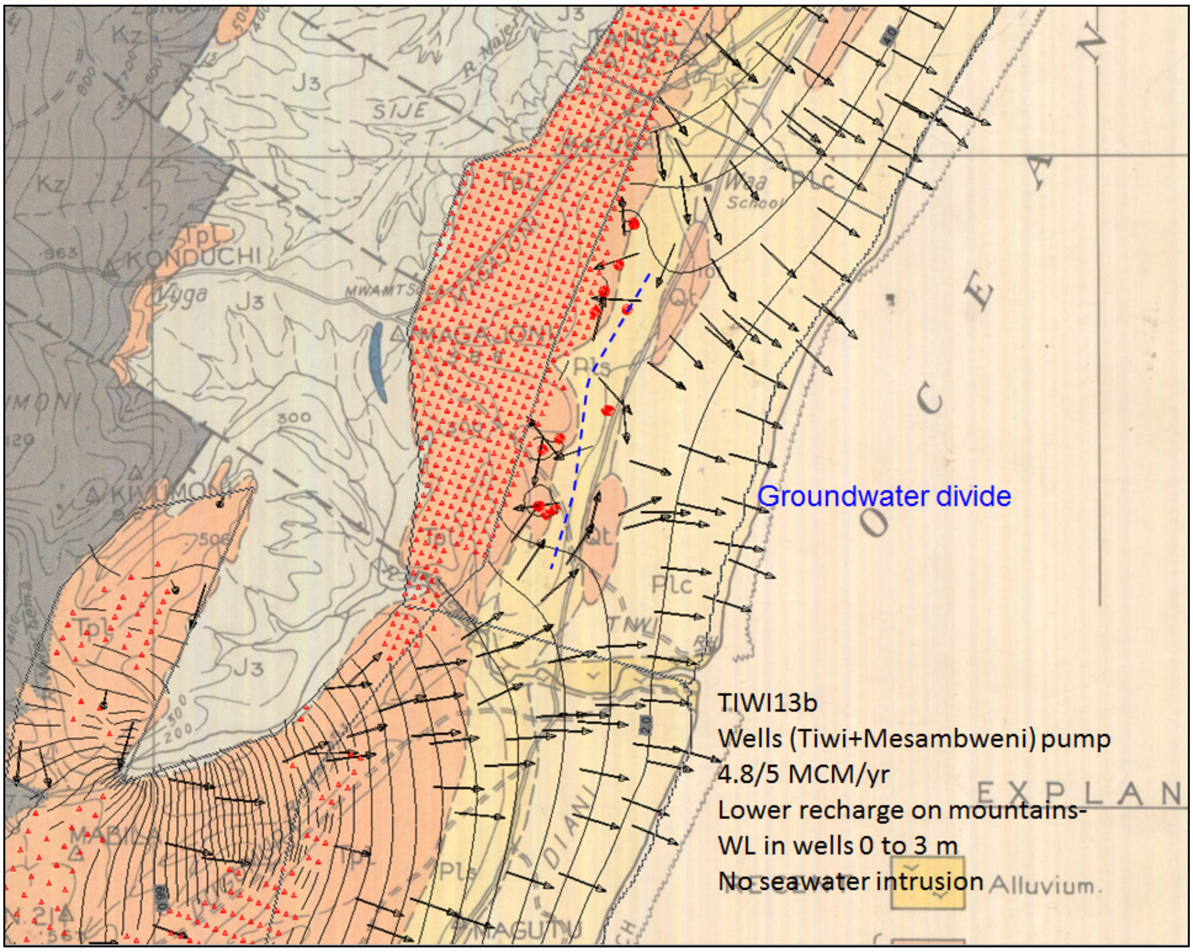


Fig. 6: Water levels and flow directions (run Tiwi 13b)

Table 4: Flow Budget for Tiwi Aquifer – Low Recharge and Low Pumping (Run Tiwi 13b)

	m^3/d
INFLOW	
Recharge	26,130
Recharge Mt. to coast	3,979
From south/north	6,205
Total INFLOW	36,314
OUTFLOW	
Pumping	13,127
Ocean boundary	23,187
Total OUTFLOW	36,314
% Pumping from total inflow	36%
% Budget discrepancy	0.0000%

Fig. 7 presents the water levels and flow directions for Tiwi area, for a lower amount of recharge, but three times the production of 14.4 MCM/y. Water levels in the wells decreased dramatically to -8 to -17 m, and significant seawater intrusion takes place. The flow budget shows that pumping in this case is 88% of total inflow. Outflow to the ocean is very small, 520 m^3/d per km.

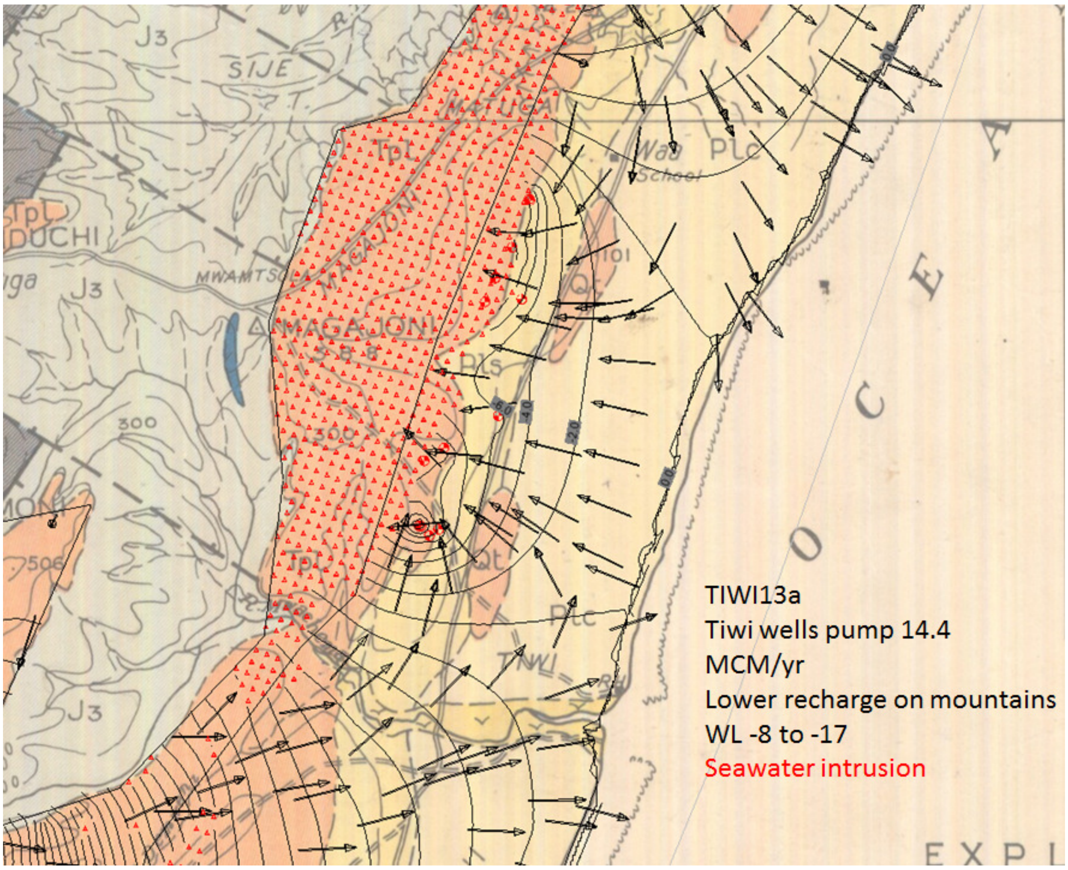


Fig. 7: Water levels and flow directions (run Tiwi 13a)

Table 5: Flow Budget for Tiwi Aquifer – Low Recharge and High Pumping (Run Tiwi 13a)

	m^3/d
INFLOW	
Recharge	26,130
Recharge Mt. to coast	4,200
From south/north	11,883
Seawater intrusion	2,378
Total INFLOW	44,590
OUTFLOW	
Pumping	39,381
Ocean boundary	5,209
Total OUTFLOW	44,590
% Pumping from total inflow	88%
% Seawater intrusion from total inflow	5%
% Budget discrepancy	-0.0001%

4.3 Effect of Well Distance from the Ocean

All Tiwi wells were moved about 2 km toward the ocean, such that the distance from the ocean is about 2.5 km instead of about 4-5 km (halfway from the ocean). The low recharge conditions, together with the low pumping rate of 13,127 m3/d (4.8 MCM/y) were simulated.

Water levels and flow directions for this simulation appear very similar to the case where the Tiwi wells are located in their original place. Water levels at the new well locations are about 3-3.5 m, while somewhat lower water levels result (2.7-3 m) for the simulation with the original location. Also, there is no seawater intrusion for these conditions. The flow budget for this run is very similar to the flow budget of the Tiwi13b run (Table 6).

Table 6: Flow Budget for Tiwi Aquifer – Low Recharge, Low Pumping and Wells Closer to the Ocean (Run Tiwi 14a)

	m³/d
INFLOW	
Recharge	26,130
Recharge Mt. to coast	3,911
From south/north	5,402
Total INFLOW	35,443
OUTFLOW	
Pumping	13,127
Ocean boundary	22,316
Total OUTFLOW	35,443
% Pumping from total inflow	37%
% Budget discrepancy	0.0000%

5. Model Summary

Six model simulations were performed in order to study the flow regime and conditions that will cause seawater intrusion of the South Coastal Aquifer, and specifically of Tiwi well field.

The parameters studied are:

- Amount of pumping.
- Amount of recharge from rain to the aquifer and recharge on the mountains west of the aquifer.
- Distance of the well field from the shoreline.

A summary of the simulations and results is presented in Table 7.

Table 7: Summary of Simulations, Conditions and Results

Conditions	Run			Tiwi 1	Tiwi 11a	Tiwi 12a	Tiwi 13b	Tiwi 13a	Tiwi 14a
		Value	Unit						
Recharge (Tiwi+ Mt)	High	17.2	MCM/y	V	V	V			
	Low	11.0					V	V	V
Pumping	None	0.0		V					
	High	14.4				V		V	
	Low	4.8			V		V		V
% Pumping from total inflow				0%	25%	67%	36%	88%	37%
Distance from ocean	Large	4.5	km	NA	V	V	V	V	
	Small	2.5		NA					V
Water levels in wells			m	15	8: 9	-1: -8	0: 3	-8: -17	3:3.5
Seawater intrusion				NO	NO	NO	NO	YES	NO

The conclusions of the numerical modelling study include:

- Two different simulations resulted in "close to reality" water levels, Tiwi12a WL= -1 to -8, and Tiwi13b WL=0 to 3. Even though the recharge and pumping amounts between these simulations varied greatly, both showed no seawater intrusion. The outflow values of groundwater to the ocean in the two simulations were 1,940 and 2,300 m^3/d per km of coast, respectively.
- Seawater intrusion did take place for pumping of 88% of the total inflow to the aquifer.
- The location of the wells in relation to the coast is a less sensitive parameter when pumping amount and outflow to the ocean are kept within a certain reasonable range.
- The simulations may indicate that Msambweni area has very promising water amounts and quality. This area should be further investigated for proper design of the groundwater use.
- This study is very general in nature and is intended to provide an understanding of the flow regime and certain parameters that appear to affect the issue of safe yield and seawater intrusion. For more accurate predictions and results, a large amount of consistent data on water levels, well discharges and water chemistry in the area should be measured, reported accurately for several years.
- This study may indicate that seawater intrusion is not necessarily the most problematic process that may occur with respect to Tiwi well field, or other areas of the South Coast. Further data collection and measurements should be performed in order to verify if seawater intrusion is of concern.
- Pollution due to untreated waste should be taken very seriously as a major threat to aquifer quality.

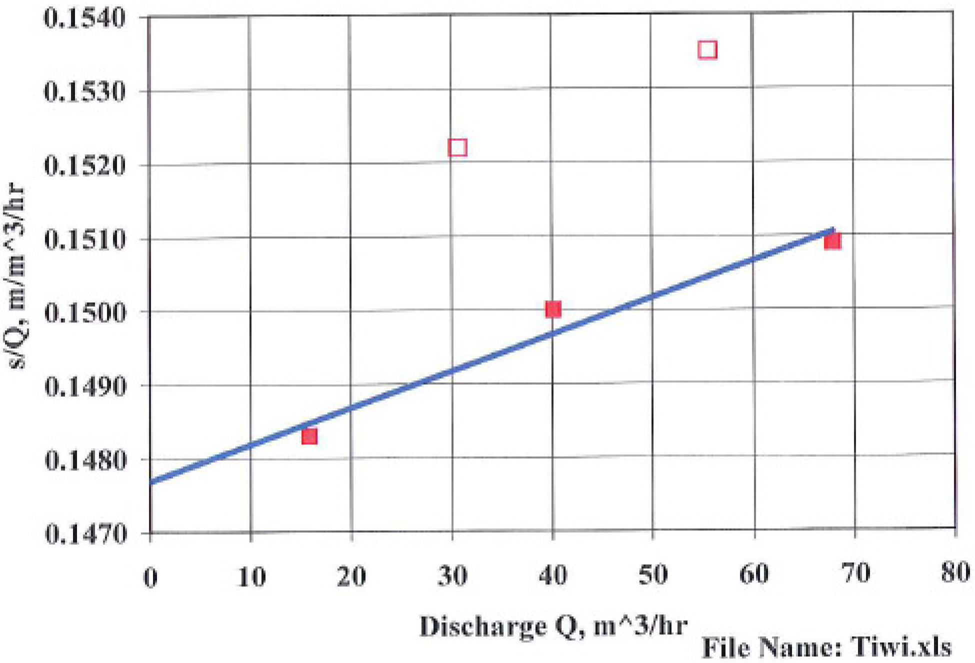
ANALYSIS OF PUMPING TESTS ON TIWI BOREHOLES

Step Drawdown Test

A = 1.476E-1
B = 4.951E-5

Well Name: BH-C
Date of Test: 1.10.2011
SWL, m: 33.95

Discharge m^3/hr	Drawdow m	Q/s, m^3/hr/m	s/Q, m/m^3/hr	Efficiency, %
16	2.35	6.74	0.1483	99.5
31	4.67			
40	6.02	6.66	0.1500	98.7
56	8.55			
68	10.25	6.62	0.1509	97.8



File Name: Tiwi.xls

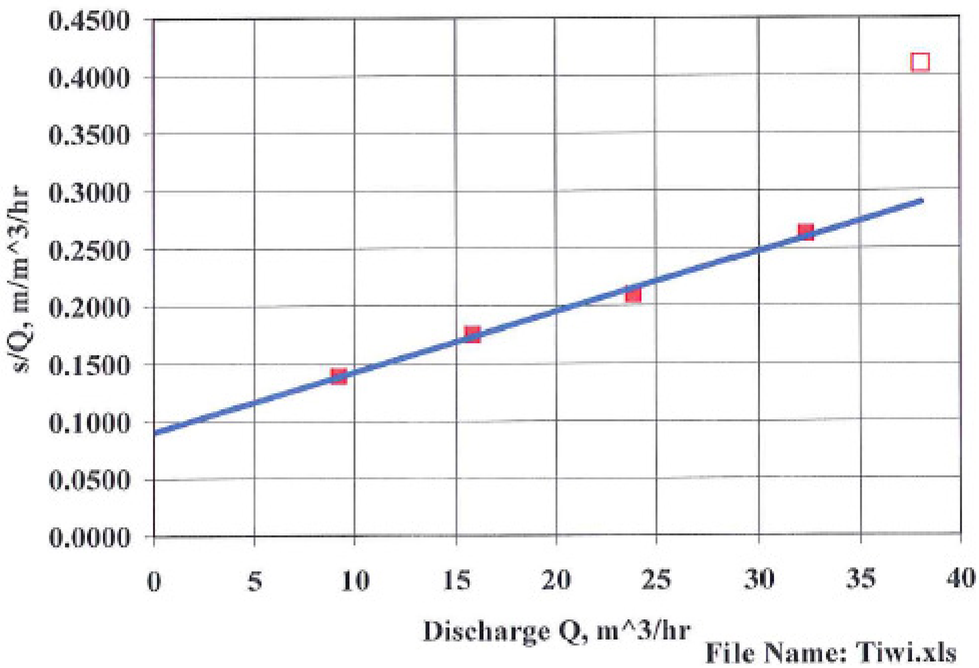
Step Drawdown Test

Well Name: BH-6

A = 9.027E-2 Date of Test: 9.9.2011

B = 5.231E-3 SWL, m: 35.64

Discharge m^3/hr	Drawdow m	Q/s, m^3/hr/m	s/Q, m/m^3/hr	Efficiency, %
9	1.28	7.18	0.1391	65.2
16	2.77	5.71	0.1749	52.2
24	5.01	4.76	0.2097	41.9
32	8.48	3.81	0.2623	34.8
38	15.61			



File Name: Tiwi.xls

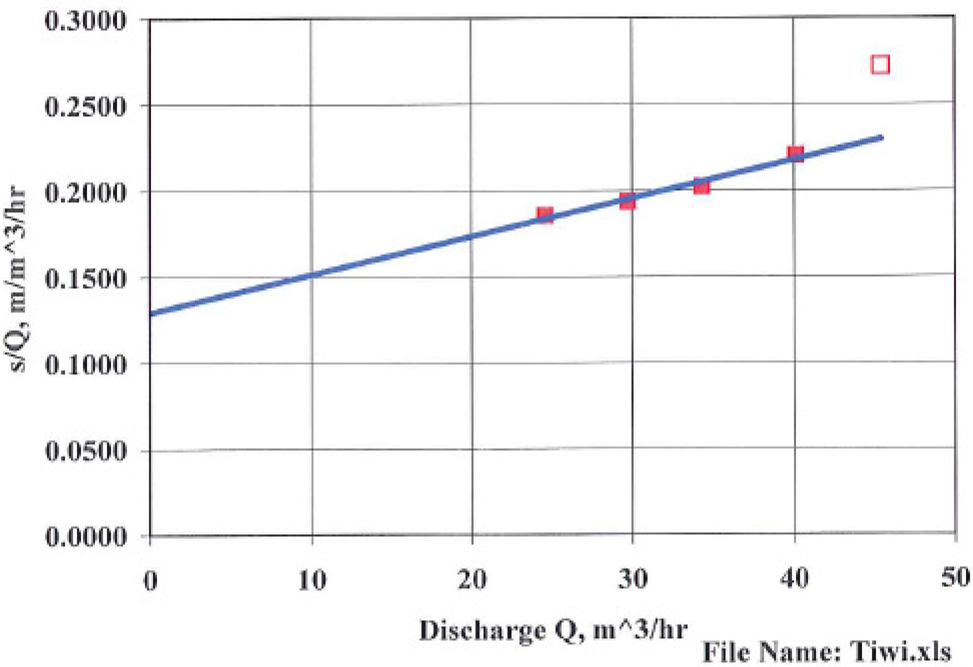
Step Drawdown Test

Well Name: BH-8.2

A = 1.292E-1
Date of Test: 2.7.2011

B = 2.21E-3
SWL, m: 43.72

Discharge m^3/hr	Drawdow m	Q/s, m^3/hr/m	s/Q, m/m^3/hr	Efficiency, %
25	4.56	5.38	0.1855	70.4
30	5.76	5.16	0.1936	66.3
34	6.94	4.94	0.2021	63.0
40	8.84	4.53	0.2202	59.3
45	12.36			



File Name: Tiwi.xls

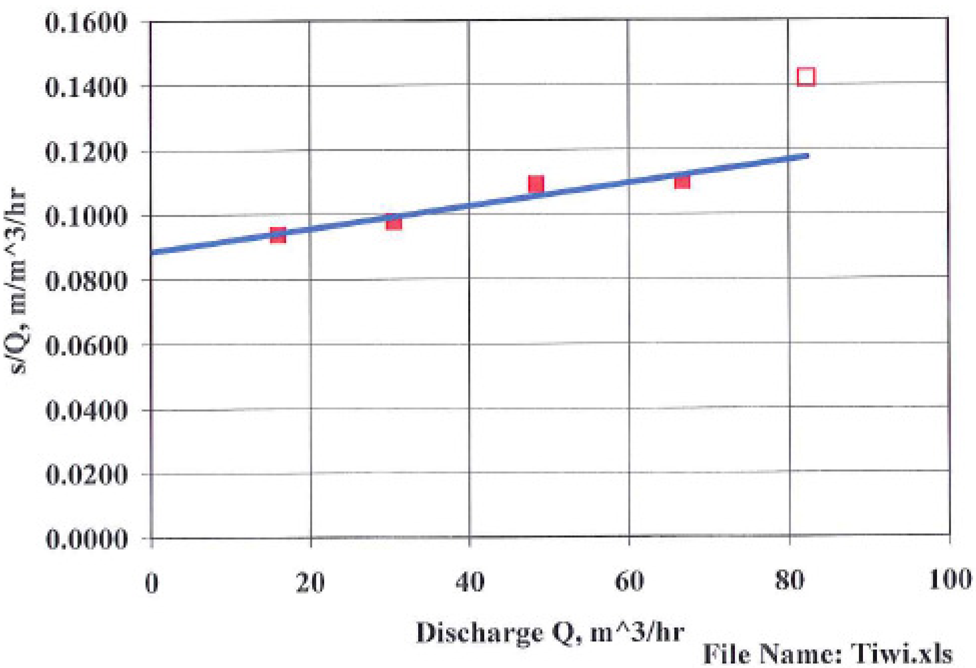
Step Drawdown Test

Well Name: BH-G.1

A = 8.847E-2 | Date of Test: 5.10.2011

B = 3.526E-4 | SWL, m: 28.59

Discharge m^3/hr	Drawdow m	Q/s, m^3/hr/m	s/Q, m/m^3/hr	Efficiency, %
16	1.50	10.65	0.0938	94.0
31	2.99	10.22	0.0978	89.1
48	5.28	9.15	0.1092	83.8
67	7.36	9.07	0.1101	79.0
82	11.68			



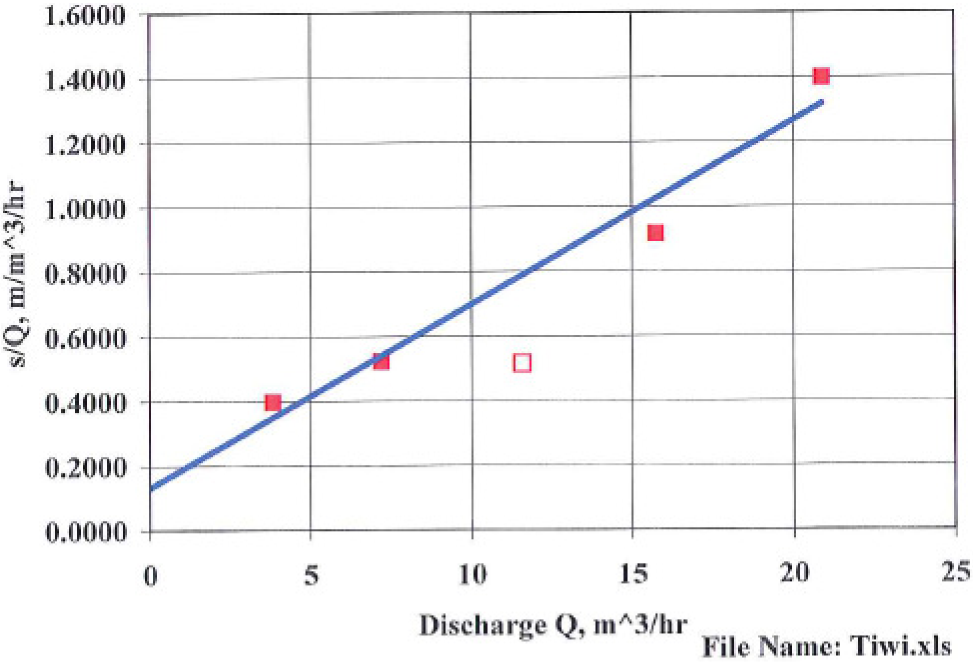
File Name: Tiwi.xls

Step Drawdown Test

A = 1.321E-1
B = 5.668E-2

Well Name: BH-8.3
Date of Test: 26.10.2011
SWL, m: 43.3

Discharge m^3/hr	Drawdow m	Q/s, m^3/hr/m	s/Q, m/m^3/hr	Efficiency, %
4	1.52	2.51	0.3968	37.8
7	3.76	1.91	0.5222	24.5
12	5.97			
16	14.43	1.09	0.9156	12.9
21	29.20	0.71	1.3971	10.0



File Name: Tiwi.xls

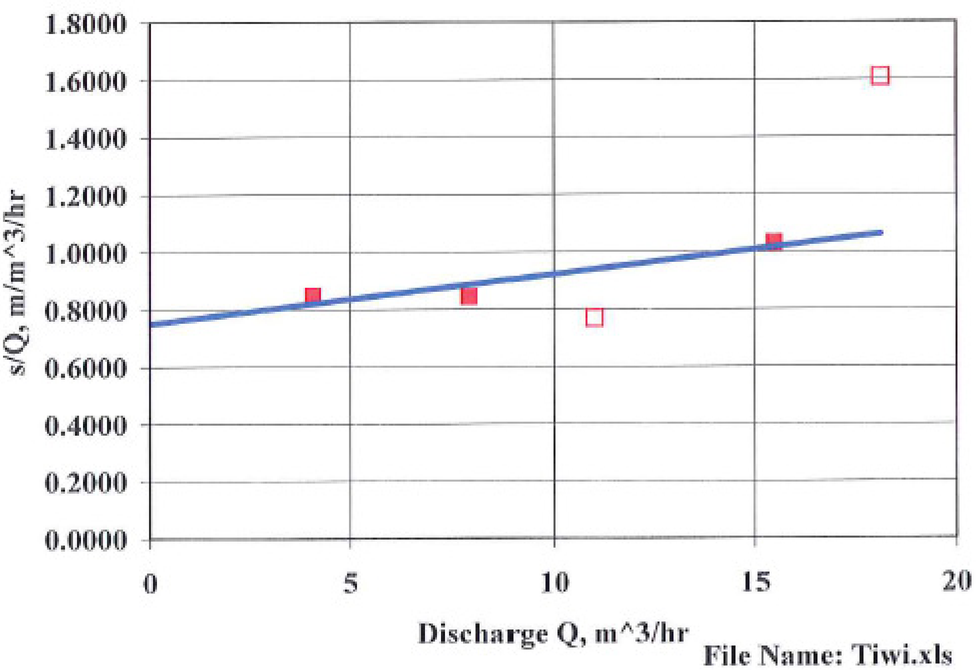
Step Drawdown Test

Well Name: BH-6.3

A = 7.495E-1 Date of Test: 26.10.2011

B = 1.72E-2 SWL, m: 35.62

Discharge m^3/hr	Drawdow m	Q/s, m^3/hr/m	s/Q, m/m^3/hr	Efficiency, %
4	3.45	1.17	0.8476	91.5
8	6.70	1.18	0.8438	84.6
11	8.48			
15	15.95	0.97	1.0303	73.8
18	29.11			



File Name: Tiwi.xls

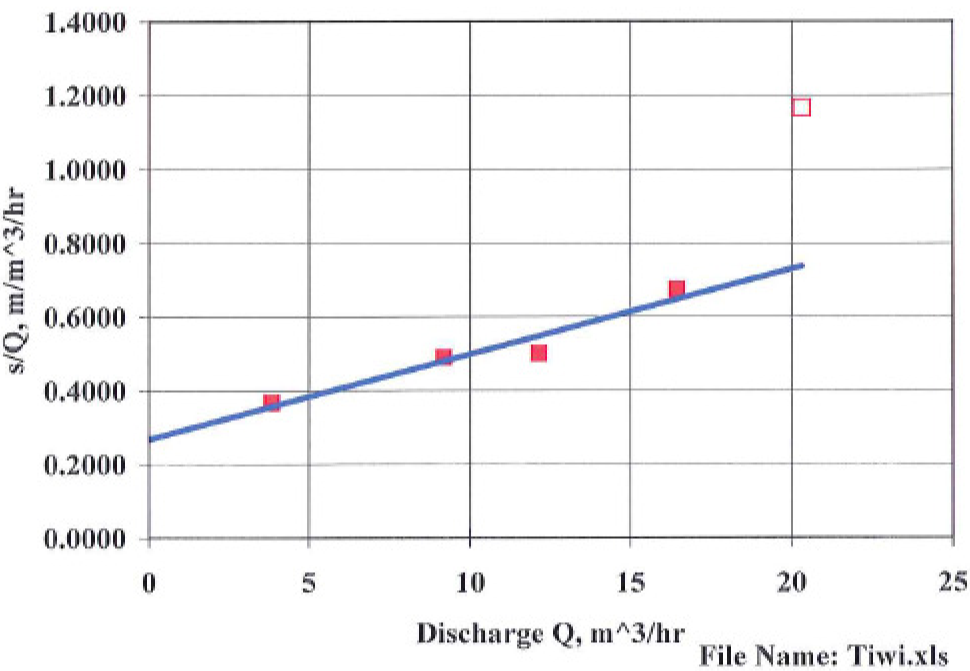
Step Drawdown Test

Well Name: BH-6.3

A = 2.681E-1 Date of Test: 1.7.2011

B = 2.309E-2 SWL, m: 35.91

Discharge m^3/hr	Drawdow m	Q/s, m^3/hr/m	s/Q, m/m^3/hr	Efficiency, %
4	1.41	2.72	0.3671	75.1
9	4.50	2.04	0.4901	55.8
12	6.09	1.99	0.5016	48.9
16	11.09	1.48	0.6745	41.4
20	23.67			



File Name: Tiwi.xls

Data for Climate Change Analysis

DATA FOR CLIMATE CHANGE ANALYSIS

TABLE 1: MSABAHA RAINFALL STATION MONTHLY & ANNUAL PRECIPITATION (mm)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL	Minimum	Maximum	Mean
1957	93.5	0.3	49.8	122.7	243.6	129.3	43.9	32.0	44.5	12.7	197.6	126.7	1096.6	0.3	243.6	91.4
1958	0.0	1.0	37.1	18.0	231.9	262.6	73.7	68.6	31.0	3.3	14.2	22.1	763.5	0.0	262.6	63.6
1959	47.0	11.9	43.7	471.4	118.4	199.6	135.6	100.3	3.8	43.9	12.4	24.9	1212.9	3.8	471.4	101.1
1960	0.0	0.8	67.8	224.0	269.0	222.0	74.4	24.1	27.9	100.3	7.1	26.9	1044.3	0.0	269.0	87.0
1961	0.0	27.2	19.3	129.3	141.2	112.8	358.1	108.5	598.2	211.8	296.2	129.0	2131.6	0.0	598.2	177.6
1962	22.6	0.0	23.6	61.7	317.5	81.8	51.0	52.1	38.3	6.4	0.5	76.7	732.2	0.0	317.5	61.0
1963	9.6	1.8	59.8	295.2	284.9	146.0	65.6	54.9	40.0	57.2	102.1	77.8	1194.9	1.8	295.2	99.6
1964	41.2	0.0	44.7	221.4	415.5	140.5	38.6	61.7	24.7	19.1	2.6	162.8	1172.8	0.0	415.5	97.7
1965	14.0	0.5	1.5	29.7	200.5	181.9	49.7	49.7	55.7	103.7	140.5	4.4	831.8	0.5	200.5	69.3
1966	33.0	1.5	54.1	265.0	336.3	247.1	48.2	110.7	27.0	65.5	187.6	17.5	1393.5	1.5	336.3	116.1
1967	0.0	0.8	1.1	237.3	249.1	95.1	81.6	176.1	172.1	229.5	142.1	3.3	1388.1	0.0	249.1	115.7
1968	0.0	115.5	193.1	289.0	437.2	292.5	403.7	93.9	71.7	197.0	347.5	40.2	2481.3	0.0	437.2	206.8
1969	0.0	9.3	2.6	118.3	174.0	87.8	79.2	45.3	14.7	77.1	73.5	12.3	694.1	0.0	174.0	57.8
1970	2.3	2.5	163.2	260.9	356.2	52.0	84.9	39.0	16.8	67.1	23.3	35.2	1103.4	2.3	356.2	92.0
1971	0.0	0.0	41.8	63.8	318.7	316.2	111.9	21.5	40.4	4.9	26.4	1.0	946.6	0.0	318.7	78.9
1972	51.6	58.9	10.6	82.3	462.4	9.2	98.8	53.9	109.8	181.4	102.9	83.3	1305.1	9.2	462.4	108.8
1973	0.0	0.5	36.7	242.4	408.5	278.5	12.7	83.4	7.5	58.7	61.9	27.0	1217.8	0.0	408.5	101.5
1974	11.0	0.0	0.0	79.7	166.0	150.2	227.4	1.0	8.4	11.4	11.0	9.5	675.6	0.0	227.4	56.3
1975	0.0	0.0	33.7	126.7	245.7	241.9	131.2	23.3	37.4	9.5	24.0	1.8	875.2	0.0	245.7	72.9
1976	4.5	0.0	4.8	146.9	261.1	118.9	144.8	49.1	186.4	12.4	56.5	3.6	989.0	0.0	261.1	82.4
1977	7.5	0.0	14.4	192.7	99.5	145.8	32.7	178.8	84.2	179.0	236.1	43.1	1213.8	0.0	236.1	101.2
1978	5.3	2.3	111.1	181.0	493.5	110.2	78.8	28.7	14.9	81.2	175.2	108.7	1390.9	2.3	493.5	115.9
1979	42.0	41.1	105.3	100.7	508.9	157.9	197.8	40.8	59.3	22.9	13.5	32.5	1322.7	13.5	508.9	110.2
1980	0.0	54.6	0.9	57.7	83.4	57.7	168.1	235.6	16.4	32.9	186.8	20.3	914.4	0.0	235.6	76.2
1981	8.1	0.0	222.0	118.6	181.1	72.3	47.6	86.5	41.6	65.0	32.0	74.8	949.6	0.0	222.0	79.1
1982	0.0	0.0	76.2	240.1	559.6	255.0	115.6	36.4	75.3	251.8	117.4	28.3	1755.7	0.0	559.6	146.3
1983	1.4	11.3	10.5	200.8	425.2	305.7	129.9	30.9	23.1	18.7	33.8	16.8	1208.1	1.4	425.2	100.7
1984	1.3	0.0	10.2	161.2	344.5	289.8	242.0	18.6	24.4	97.8	73.8	45.7	1309.3	0.0	344.5	109.1
1985	0.3	8.0	45.9	224.8	315.3	61.6	77.6	107.0	33.5	13.1	62.8	11.4	961.3	0.3	315.3	80.1
1986	0.1	0.0	36.5	242.4	656.1	54.1	46.8	37.9	44.9	14.9	103.9	56.6	1294.2	0.0	656.1	107.9
1987	3.0	0.7	0.0	153.2	226.6	61.2	119.0	227.1	13.4	44.2	18.3	21.0	887.7	0.0	227.1	74.0
1988	17.0	1.1	39.6	149.9	120.7	251.5	25.2	48.9	66.2	8.8	108.9	127.7	965.5	1.1	251.5	80.5
1989	9.7	0.6	23.9	218.6	139.6	211.6	121.7	54.5	26.4	74.1	177.0	61.2	1118.9	0.6	218.6	93.2
1990	6.0	7.9	64.5	141.8	272.9	80.0	55.7	9.3	113.9	206.9	88.0	13.9	1060.8	6.0	272.9	88.4
1991	0.0	3.6	31.7	46.1	494.2	116.6	172.0	45.3	25.0	41.0	36.9	49.9	1062.3	0.0	494.2	88.5
1992	1.0	0.6	8.4	99.3	323.0	65.1	154.6	39.2	41.8	8.2	102.4	80.0	923.6	0.6	323.0	77.0
1993	118.2	0.7	68.4	51.9	189.2	229.1	88.9	46.0	20.4	41.6	30.8	157.2	1042.4	0.7	229.1	86.9
1994	3.4	0.4	0.5	288.3	607.1	70.6	176.2	67.1	71.9	86.7	107.9	86.7	1566.8	0.4	607.1	130.6
1995	2.4	0.0	38.9	122.7	293.9	12.0	121.3	76.6	22.1	41.1	58.7	97.0	886.7	0.0	293.9	73.9
1996	2.9	6.0	31.0	141.2	319.2	44.8	162.3	14.7	9.0	41.5	116.3	10.1	899.0	2.9	319.2	74.9
1997	0.2	0.4	8.4	372.8	436.4	209.6	220.3	19.4	77.0	628.4	331.9	156.8	2461.6	0.2	628.4	205.1
1998	167.5	37.5	34.7	424.5	298.5	285.3	116.4	47.5	23.8	13.9	22.7	17.2	1489.5	13.9	424.5	124.1
1999	7.0	2.3	7.4	339.2	289.9	169.7	143.2	133.9	75.9	32.0	87.8	14.3	1302.6	2.3	339.2	108.6
2000	2.7	0.0	56.6	55.9	386.5	253.0	80.4	59.6	70.9	122.1	25.5	86.6	1199.8	0.0	386.5	100.0
2001	12.9	1.7	30.7	116.8	286.2	216.8	75.0	48.8	4.7	8.3	80.3	24.4	906.6	1.7	286.2	75.6
2002	5.1	6.9	100.0	82.8	221.9	57.4	33.8	75.9	144.6	208.5	30.4	82.3	1049.6	5.1	221.9	87.5

2003	0.3	0.0	20.2	79.7	336.2	158.9	74.5	67.6	47.1	151.6	87.7	33.2	1057.0	0.0	336.2	88.1
2004	22.8	6.6	49.3	57.4	84.7	212.6	61.5	21.2	14.8	132.2	87.7	31.5	782.3	6.6	212.6	65.2
2005	31.0	0.0	28.1	169.0	290.4	153.4	63.9	32.6	34.8	27.5	58.6	0.6	889.9	0.0	290.4	74.2
2006	0.0	1.4	18.1	361.5	158.8	160.8	68.4	92.4	86.6	253.6	203.8	79.6	1485.0	0.0	361.5	123.8
2007	8.6	0.8	24.8	117.0	535.1	102.9	60.8	109.7	120.5	68.4	56.8	1.8	1207.2	0.8	535.1	100.6
2008	29.2	0.5	62.8	70	366.7	231.8	42.1	111.4	1.7	35.2	44.5	19.6	1015.5	0.5	366.7	84.6
2009	13.4	16.6	3.5	46.1	163.4	221	59.4	21.7	10.6	334.3	43.6	23.8	957.4	3.5	334.3	79.8
Average	**16.2**	**8.4**	**42.9**	**168.1**	**304.6**	**159.5**	**108.5**	**66.4**	**58.4**	**91.7**	**91.9**	**49.1**	**1165.8**			

TABLE 2: MELANI RAINFALL STATION MONTHLY & ANNUAL PRECIPITATION (mm)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL	Minimum	Maximum	Mean
1961	100.5	23.8	17.5	124.5	141.1	106.7	309.2	100.5	467.5	179.9	219.8	85.3	1876.3	17.5	467.5	156.4
1962	17.5	1.0	86.1	47.0	369.4	66.1	60.5	47.9	29.3	9.6	0.0	57.7	792.1	0.0	369.4	66.0
1963	7.2	0.0	52.9	428.2	298.6	159.8	75.5	59.9	39.6	63.9	53.7	39.4	1278.7	0.0	428.2	106.6
1964	27.5	0.0	12.8	191.8	427.5	132.7	48.6	54.2	38.6	29.7	4.1	108.7	1076.2	0.0	427.5	89.7
1965	10.5	1.3	4.0	45.5	223.0	129.5	35.2	52.0	40.2	118.0	122.6	6.5	788.3	1.3	223.0	65.7
1966	33.9	1.3	29.5	269.5	262.1	219.1	46.0	97.9	24.3	77.6	215.7	19.7	1296.6	1.3	269.5	108.1
1967	1.1	0.0	2.0	211.5	252.4	134.7	85.3	175.1	173.3	272.6	153.7	0.2	1461.9	0.0	272.6	121.8
1968	0.2	137.7	101.0	355.2	374.1	291.7	137.4	39.6	49.6	28.6	160.0	41.3	1716.4	0.2	374.1	143.0
1969	0.0	6.6	15.8	3.9	246.0	81.0	74.0	57.8	10.1	100.7	60.3	6.2	662.4	0.0	246.0	55.2
1970	11.7	0.0	81.1	218.3	370.8	50.8	79.7	49.0	9.8	4.7	2.4	18.0	896.3	0.0	370.8	74.7
1971	0.0	0.0	42.5	96.8	362.0	325.2	113.1	23.0	48.4	15.3	21.9	1.0	1049.2	0.0	362.0	87.4
1972	14.1	84.6	6.6	39.2	394.1	14.3	114.1	58.1	102.8	181.1	107.7	81.5	1198.2	6.6	394.1	99.9
1973	0.0	0.0	18.6	270.9	300.7	267.3	11.1	104.6	11.2	72.8	46.1	4.3	1107.6	0.0	300.7	92.3
1974	1.6	0.0	1.9	118.6	142.4	149.9	227.6	10.3	0.8	5.5	3.4	0.9	662.9	0.0	227.6	55.2
1975	0.0	0.0	9.5	136.0	315.4	187.5	145.2	23.3	19.4	21.7	11.8	11.1	880.9	0.0	315.4	73.4
1976	2.9	0.0	11.2	171.2	273.1	116.8	120.2	40.6	155.9	8.3	41.0	0.0	941.2	0.0	273.1	78.4
1977	1.1	0.2	10.4	157.2	130.8	146.9	22.0	140.9	43.6	227.2	98.6	41.0	1019.9	0.2	227.2	85.0
1978	7.0	0.7	129.7	196.7	455.5	99.7	47.2	31.1	12.2	52.1	155.7	104.6	1292.2	0.7	455.5	107.7
1979	44.9	7.4	58.5	78.6	521.2	245.4	193.6	35.1	48.6	5.0	35.0	42.4	1315.7	5.0	521.2	109.6
1980	0.0	3.0	6.4	32.3	68.4	109.4	128.5	205.8	33.9	10.9	152.5	54.3	805.4	0.0	205.8	67.1
1981	5.7	0.2	274.7	87.2	220.5	122.9	59.5	79.9	48.5	52.5	34.2	17.2	1003.0	0.2	274.7	83.6
1982	2.0	0.0	79.2	185.1	581.1	181.0	158.3	19.7	49.3	279.2	85.1	92.2	1712.2	0.0	581.1	142.7
1983	0.0	4.3	8.6	142.2	463.2	201.2	126.8	36.6	68.5	37.3	6.1	19.4	1114.2	0.0	463.2	92.9
1984	0.6	0.0	11.2	240.4	320.5	254.0	172.4	24.3	33.4	74.2	81.7	19.3	1232.0	0.0	320.5	102.7
1985	0.3	6.7	31.4	207.4	286.2	55.5	67.9	89.4	31.9	27.0	17.9	7.3	828.9	0.3	286.2	69.1
1986	7.9	0.0	26.0	243.7	600.6	34.1	37.1	49.6	25.7	15.6	41.6	8.8	1090.7	0.0	600.6	90.9
1987	5.2	1.1	0.0	175.7	263.6	104.5	150.0	237.3	17.5	47.5	20.8	7.1	1030.3	0.0	263.6	85.9
1988	2.3	1.8	39.2	116.1	94.0	186.3	33.8	42.8	55.9	36.6	92.6	48.4	749.8	1.8	186.3	62.5
1989	4.0	0.2	12.6	187.6	184.4	216.7	117.6	45.1	30.7	49.3	140.6	24.3	1013.1	0.2	216.7	84.4
1990	6.9	10.0	98.9	130.3	223.0	67.1	29.6	14.5	57.2	154.8	10.3	44.1	846.7	6.9	223.0	70.6
1991	0.0	1.0	29.2	89.8	515.2	78.3	160.9	42.5	17.6	12.3	7.3	17.9	972.0	0.0	515.2	81.0
1992	0.6	0.3	1.5	81.3	225.5	113.1	146.3	38.8	35.6	9.9	37.4	64.4	754.7	0.3	225.5	62.9
1993	91.1	0.0	25.7	129.2	203.4	263.1	57.8	32.9	18.5	46.8	22.1	54.3	944.9	0.0	263.1	78.7
1994	0.4	0.0	0.0	249.3	518.5	42.2	181.7	63.6	100.2	99.4	123.1	56.1	1434.5	0.0	518.5	119.5
1995	3.8	0.0	28.5	96.1	245.4	7.9	94.9	57.3	17.7	76.6	86.0	60.3	774.5	0.0	245.4	64.5
1996	1.8	10.2	49.9	176.9	374.5	74.9	93.5	14.3	31.7	7.2	35.7	0.0	870.6	0.0	374.5	72.6

1997	**0.0**	**0.0**	**23.9**	**275.2**	**357.2**	**207.2**	**203.2**	**13.9**	**84.8**	**111.8**	**264.2**	**143.6**	**1685.0**	**0.0**	**357.2**	**140.4**
1998	**89.5**	**44.3**	**24.5**	**430.4**	**232.3**	**268.4**	**63.2**	**35.0**	**16.1**	**12.8**	**54.2**	**6.1**	**1276.8**	**6.1**	**430.4**	**106.4**
1999	**6.5**	**0.3**	**16.3**	**310.4**	**316.6**	**121.4**	**130.1**	**108.6**	**81.2**	**21.4**	**99.4**	**18.6**	**1230.8**	**0.3**	**316.6**	**102.6**
2000	**0.0**	**0.0**	**118.0**	**34.6**	**353.6**	**192.1**	**65.0**	**39.1**	**31.2**	**120.9**	**33.0**	**3.3**	**990.8**	**0.0**	**353.6**	**82.6**
2001	**0.0**	**0.7**	**33.7**	**123.2**	**270.6**	**241.5**	**83.9**	**32.0**	**1.8**	**4.5**	**83.4**	**4.6**	**879.9**	**0.0**	**270.6**	**73.3**
2002	**2.1**	**5.5**	**99.3**	**127.8**	**154.0**	**65.0**	**52.0**	**120.5**	**159.6**	**171.0**	**16.9**	**98.6**	**1072.3**	**2.1**	**171.0**	**89.4**
2003	**0.0**	**0.7**	**7.7**	**114.6**	**332.4**	**113.1**	**82.5**	**35.1**	**45.1**	**140.7**	**70.1**	**4.8**	**946.8**	**0.0**	**332.4**	**78.9**
2004	**4.2**	**5.5**	**6.5**	**115.4**	**109.8**	**204.7**	**74.6**	**28.8**	**27.2**	**177.7**	**53.1**	**22.2**	**829.7**	**4.2**	**204.7**	**69.1**
2005	**21.3**	**0.0**	**46.0**	**122.7**	**266.6**	**150.0**	**64.6**	**31.6**	**13.9**	**20.1**	**59.8**	**1.4**	**798.0**	**0.0**	**266.6**	**66.5**
2006	**1.4**	**0.4**	**24.1**	**304.5**	**219.5**	**225.0**	**103.2**	**93.9**	**92.7**	**268.8**	**134.4**	**37.3**	**1505.2**	**0.4**	**304.5**	**125.4**
2007	**10.0**	**0.5**	**18.5**	**155.4**	**607.5**	**132.0**	**78.7**	**141.7**	**173.5**	**48.4**	**15.7**	**11.2**	**1393.1**	**0.5**	**607.5**	**116.1**
2008	**14.6**	**0**	**93.4**	**59.5**	**369.6**	**163.5**	**70.8**	**99.7**	**11.1**	**49.1**	**49.6**	**1.2**	**982.1**	**0.0**	**369.6**	**81.8**
2009	**0.0**	**7.5**	**0.0**	**82.6**	**126.3**	**204.1**	**28.5**	**23.3**	**9**	**390.5**	**28.3**	**2.3**	**902.4**	**0.0**	**390.5**	**75.2**
Average	**11.5**	**7.5**	**39.3**	**163.0**	**305.4**	**149.5**	**99.2**	**63.2**	**56.0**	**82.6**	**70.8**	**33.1**	**1081.3**			

TABLE 3: MTWAPA RAINFALL STATION MONTHLY & ANNUAL PRECIPITATION (mm)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL	Minimum	Maximum	Mean
1959	16.3	27.9	0.0	608.8	163.8	127.3	177.8	88.4	11.4	32.8	3.3	61.2	1319.0	0.0	608.8	109.9
1960	10.2	0.0	62.0	213.4	378.2	204.0	95.3	37.1	10.2	40.1	5.1	13.2	1068.8	0.0	378.2	89.1
1961	0.0	36.6	26.7	178.1	26.2	82.8	300.0	81.5	311.7	241.0	247.1	113.8	1645.5	0.0	311.7	137.1
1962	96.5	0.0	85.9	158.7	118.1	55.6	69.1	39.4	39.1	24.6	24.9	55.1	767.0	0.0	158.7	63.9
1963	9.6	0.0	90.9	401.1	243.7	186.3	60.9	97.6	55.9	66.7	119.9	30.7	1363.3	0.0	401.1	113.6
1964	13.6	15.2	67.6	224.9	231.6	70.2	26.6	62.6	31.7	17.1	16.2	73.6	850.9	13.6	231.6	70.9
1965	50.1	0.0	16.0	100.7	188.3	147.5	53.1	39.7	92.3	110.3	325.7	1.0	1124.7	0.0	325.7	93.7
1966	59.0	7.7	95.7	362.1	375.7	281.3	54.5	80.4	18.6	107.7	142.6	31.0	1616.3	7.7	375.7	134.7
1967	2.0	61.2	9.9	152.2	253.1	108.9	77.9	229.6	143.7	471.2	215.5	11.7	1736.9	2.0	471.2	144.7
1968	0.0	118.6	124.8	250.8	579.8	273.5	159.1	85.5	81.7	115.0	295.0	24.4	2108.2	0.0	579.8	175.7
1969	11.5	76.4	57.0	55.0	137.5	206.5	122.0	124.0	32.5	105.0	163.5	8.0	1098.9	8.0	206.5	91.6
1970	7.5	0.0	34.0	195.0	243.7	56.0	60.8	35.2	35.2	19.2	15.5	19.9	722.0	0.0	243.7	60.2
1971	2.5	0.0	56.5	154.6	257.5	267.0	124.2	36.5	45.2	5.9	25.0	86.0	1060.9	0.0	267.0	88.4
1972	35.1	16.5	19.0	64.4	513.4	32.2	107.1	86.1	163.2	258.0	103.1	9.1	1407.2	9.1	513.4	117.3
1973	1.1	5.6	0.8	432.2	327.2	195.9	17.3	105.2	23.3	38.6	79.6	33.8	1260.6	0.8	432.2	105.1
1974	9.8	4.6	29.4	132.5	115.5	148.8	106.1	21.2	50.8	8.2	40.4	15.9	683.2	4.6	148.8	56.9
1975	24.1	0.0	32.4	237.1	324.8	193.7	112.3	13.8	70.2	29.8	15.6	75.2	1129.0	0.0	324.8	94.1
1976	7.3	1.9	13.9	159.8	155.2	186.9	125.2	19.8	152.7	25.7	65.3	22.8	936.5	1.9	186.9	78.0
1977	0.0	0.0	59.8	166.8	73.4	112.5	60.9	118.4	126.1	298.7	150.6	125.5	1292.7	0.0	298.7	107.7
1978	41.0	48.5	64.6	237.8	350.7	155.3	106.7	66.7	22.6	55.2	172.0	157.1	1478.2	22.6	350.7	123.2
1979	130.0	37.2	140.1	162.3	578.3	65.2	77.1	73.1	122.7	26.5	59.4	126.1	1598.0	26.5	578.3	133.2
1980	2.3	8.8	25.5	308.0	93.6	56.1	100.0	271.5	22.0	20.7	42.0	26.4	976.9	2.3	308.0	81.4
1981	21.3	0.2	170.2	107.1	161.4	90.2	54.6	74.6	39.2	132.8	144.8	90.0	1086.4	0.2	170.2	90.5
1982	1.4	0.0	38.2	281.3	660.4	118.2	193.3	72.5	110.1	176.7	57.6	28.0	1737.7	0.0	660.4	144.8
1983	1.4	5.0	67.4	165.5	544.9	223.3	163.1	22.9	64.5	32.2	21.6	10.6	1322.4	1.4	544.9	110.2
1984	0.2	0.0	26.3	296.9	321.5	169.6	117.3	18.6	90.9	299.4	163.5	28.1	1532.3	0.0	321.5	127.7
1985	20.3	50.6	48.3	209.9	277.5	54.0	151.2	91.3	38.3	43.2	51.7	69.3	1105.6	20.3	277.5	92.1
1986	45.0	1.0	103.8	346.9	678.7	58.1	14.4	52.8	27.0	70.0	116.9	133.9	1648.5	1.0	678.7	137.4
1987	16.9	3.3	19.2	192.1	340.9	22.7	85.6	259.1	56.2	35.8	25.0	37.7	1094.5	3.3	340.9	91.2
1988	33.2	10.7	94.0	449.1	98.4	292.7	38.2	75.3	58.1	31.2	140.1	126.5	1447.5	10.7	449.1	120.6

1989	39.2	0.2	32.1	270.3	262.8	109.1	101.4	51.9	65.7	143.4	51.1	111.6	1238.8	0.2	270.3	103.2
1990	33.8	18.7	151.8	219.3	126.9	146.2	47.6	64.7	67.8	168.7	57.1	65.2	1167.8	18.7	219.3	97.3
1991	11.7	0.7	55.2	12.1	563.2	129.4	245.2	78.1	23.2	19.2	53.8	11.4	1203.2	0.7	563.2	100.3
1992	0.3	0.4	11.7	137.6	408.4	106.5	153.2	34.2	57.1	39.7	87.0	98.8	1134.9	0.3	408.4	94.6
1993	47.0	1.1	19.0	91.4	271.3	184.4	78.5	62.4	71.2	81.3	90.0	96.3	1093.9	1.1	271.3	91.2
1994	0.2	0.0	7.7	328.7	435.5	154.5	169.6	103.4	107.7	64.6	125.2	167.4	1664.5	0.0	435.5	138.7
1995	0.9	0.0	70.6	366.6	453.7	13.8	99.1	114.9	26.6	224.5	288.9	24.2	1683.8	0.0	453.7	140.3
1996	0.0	6.7	113.6	164.3	742.1	24.4	104.8	10.2	12.6	29.3	88.0	0.3	1296.3	0.0	742.1	108.0
1997	0.2	0.4	20.9	327.8	332.1	207.9	101.2	115.7	33.7	991.4	314.5	99.1	2544.9	0.2	991.4	212.1
1998	155.2	130.3	68.8	365.1	302.6	70.6	163.0	32.9	37.4	58.2	82.2	28.0	1494.3	28.0	365.1	124.5
1999	31.1	0.0	29.4	349.2	299.1	182.3	163.7	94.0	94.2	72.3	144.2	13.1	1472.6	0.0	349.2	122.7
2000	2.8	0.2	40.7	231.9	459.2	291.7	125.8	60.1	57.1	110.2	149.0	62.4	1591.1	0.2	459.2	132.6
2001	5.7	5.4	14.4	224.3	193.3	214.7	80.1	47.6	5.4	22.7	77.4	31.7	922.7	5.4	224.3	76.9
2002	37.3	25.8	28.3	202.3	153.7	60.9	98.5	70.2	111.5	182.6	173.2	80.4	1224.7	25.8	202.3	102.1
2003	2.0	6.2	31.8	160.9	278.8	102.2	61.6	53.3	79.9	134.4	20.4	24.3	955.8	2.0	278.8	79.7
2004	101.9	3.5	19.3	198.3	44.3	175.0	127.6	31.8	20.4	195.0	153.4	30.1	1100.6	3.5	198.3	91.7
2005	39.5	0.0	51.0	228.9	222.5	142.7	47.5	71.9	42.4	29.4	92.0	4.6	972.4	0.0	228.9	81.0
2006	1.0	2.4	49.7	348.9	305.9	158.6	103.0	88.0	86.2	282.6	367.1	49.7	1843.1	1.0	367.1	153.6
2007	3.2	1.4	21.0	228.8	802.7	142.1	116.4	181.2	147.3	54.8	149.3	84.8	1933.0	1.4	802.7	161.1
2008	12.7	0.0	82.1	133.9	228.6	162.2	75.9	34.2	44.8	50.4	52.9	21.5	899.2	0.0	228.6	74.9
2009	5.5	6.2	59.4	43.6	171.1	212.8	51.4	60.2	5.4	321.8	83.5	71.5	1092.4	5.4	321.8	91.0
Average	**23.5**	**14.6**	**52.1**	**228.2**	**311.2**	**141.8**	**104.4**	**77.3**	**65.6**	**121.9**	**112.7**	**55.3**	**1308.8**			

Annex 5

Bills of Quantities (BOQs)

DO NOT DELETE THIS SECTION BREAK

Annexes

Annex 5

Bills of Quantities (BOQs)

IMMEDIATE PHASE

1			Baricho Waterworks Extension	Unit	Qty	Unit Cost (US$)	Total Cost (US$)
	1.1		**Civil engineering works**				
		1.100	Drilling new boreholes at the Baricho site, 5 m diameter	No.	2	500,000	1,000,000
		1.101	Concrete works for the borehole cover and pump installation	LS	2	80,000	160,000
		1.102	Conducting geohydrological study to determine civil engineering works needed for future abstraction of water from the buried Sabaki River palaeochannel	LS	1	130,000	260,000
		1.103	Civil construction works for new non-asphalt access road to site, and upgrade of existing non-asphalt road	km	0.5	433,322	216,661
						Subtotal	**1,636,661**
	1.2		**Electromechanical works**				
		1.200	Supply of borehole pumps, 480 m^3/h, 60 m head	No.	2	85,000	170,000
		1.201	Installation of the above borehole pumps	No.	2	12,000	24,000
		1.202	Electrical installation for pumps	LS	2	8,200	16,400
						Subtotal	**210,400**
	1.3		**Pipe and manifolds**				
		1.300	Pipes to borehole pump manifolds, steel, 16", DN400	m	40	278	11,115
		1.301	Pipe for main manifolds from borehole pumps to main conveyer, steel, 20", DN500	m	300	338	101,335
		1.302	Main gate valve for borehole manifolds, 12", DN300	No.	2	1,190	2,380
		1.303	Main non-return valve for borehole manifolds, 12", DN300	No.	2	450	900
		1.304	Suction chamber main valve, 24", DN600	No.	1	2,125	2,125
		1.305	Suction chamber secondary valve, 12", DN300	No.	3	1,190	3,570
						Subtotal	**121,425**
	1.4		**Accessories**				
		1.400	Air valve, static + dynamic, 6", DN150	No.	4	231	924
		1.401	Air valve, static + dynamic, 4", DN100	No.	2	222	444
		1.402	Air valve, static + dynamic, 3", DN80	No.	2	158	316
		1.403	Surge rapid pressure release valve, 12," DN300	No.	2	14,516	29,032
		1.404	Surge rapid pressure release valve, 10", DN250	No.	2	8,050	16,100
		1.405	Surge rapid pressure release valve, 6", DN150	No.	4	3,942	15,768
		1.406	Pressure sustain valve, 16", DN400	No.	2	42,278	84,556
		1.407	Pressure sustain valve, 12", DN300	No.	1	14,646	14,646
		1.408	Pressure sustain valve, 10", DN250	No.	1	8,138	8,138
		1.409	Flowmeter for each borehole, DN400	No.	2	8,450	16,900
		1.410	Gate valve for flowmeters, DN400	No.	4	1,241	4,964
						Subtotal	**191,788**
			Total – Section 1				**2,160,274**

2			Baricho-Nguu Tatu Pipeline (segment rehabilitation)	Unit	Qty	Unit Cost (US$)	Total Cost (US$)
	2.1		**Pipe and manifolds**				
		2.100	Rare-Jaribuni parallel force main pipe, steel, DN800, PN 25	m	600	753	451,800
		2.101	Lower Ribe-Nguu Tatu parallel force main pipe, steel, DN800, PN 16	m	12,000	753	9,036,000
						Subtotal	**9,487,800**
	2.2		**Accessories**				
		2.200	Air valve, static + dynamic, 6", DN150	No.	42	231	9,702
		2.201	Gate valve for the main pipeline, 32", DN800	No.	10	4,477	44,770
		2.202	Drain valve for the main pipeline, 8", DN200	No.	9	1,250	11,250
						Subtotal	**59,180**
	2.3		**Water distribution chambers**				
		2.300	Gate valve chamber for main valve, 32", 2 m x 3 m	No.	42	657	27,598
		2.301	Air valve chamber, 1.5 m x 1.5 m	No.	10	570	5,699
		2.302	Chamber for drainage valves, 2 m x 3 m	No.	9	570	5,129
						Subtotal	**38,427**
2			**Total – Section 2**				**9,591,949**

3			Kakuyuni-Kilifi and Malindi-Gongoni Pipelines	Unit	Qty	Unit Cost (US$)	Total Cost (US$)
	3.1		**Pipe and manifolds**				
		3.100	New Kakuyuni-Kilifi gravity main, PE pipe, DN500, PN 10	m	50,500	307	15,503,500
		3.101	New Malindi-Gongoni gravity main, PE pipe, DN300, PN 10	m	25,000	124	3,100,000
						Subtotal	**18,603,500**
	3.2		**Accessories**				
		3.200	Air valve, static + dynamic, 6", DN150	No.	62	231	14,322
		3.201	Gate valve for the main pipe, 20", DN500	No.	10	1,681	16,810
		3.202	Gate valve for the main pipe, 12", DN300	No.	5	1,470	7,350
						Subtotal	**38,482**
	3.3		**Water distribution chambers**				
		3.300	Gate valve chamber for main valves, 20", 2 m x 3 m	No.	10	657	6,571
		3.301	Gate valve chamber for main valves, 12", 2 m x 3 m	No.	5	657	3,285
		3.302	Air valve chamber, 1.5 m x 1.5 m	No.	62	570	35,336
						Subtotal	**45,192**
	3.4		**Water tanks**				
		3.400	New water tank at Kakuyuni	m^3	2,500	450	1,125,000
		3.401	New water tank at Kilifi	m^3	5,000	350	1,750,000
		3.402	New water tank at Gongoni	m^3	1,000	600	600,000
						Subtotal	**3,475,000**
	3.5		**Water pumps**				
		3.500	New pumping station at the Gongoni Water Tank (150 m^3/h, 40 m)	LS	1	220,000	220,000
						Subtotal	**220,000**
			Total – Section 3				**22,382,174**

4			Deep Neogenic Aquifer Investigation in the Lamu Region (Neogenic Aquifer)	Unit	Qty	Unit Cost (US$)	Total Cost (US$)
	4.1		**Deep Aquifer Investigation**				
		4.100	Conducting a survey of the deep Neogenic aquifer in the Lamu Region	LS	1	2,500,000	2,500,000
			Total – Section 4				**2,500,000**
			Total – Immediate Phase (emergency works to improve supply to Mombasa)				**36,634,396**

PHASE I

1			Mwache Waterworks (excluding dam and water treatment plant works)	Unit	Qty	Rate (US$)	Total (US$)
	1.1		**Civil engineering works**				
			Pumping station at Mwache				
		1.100	Construction of new pumping station, 90 m x 30 m x 7 m (L x W x H)	m^2	2,700	1,540	4,158,000
		1.101	Construction of new auxiliary building, 30 m x 20 m x 5 m (L x W x H)	m^2	600	1,200	720,000
		1.102	Construction of new electrical building, 25 m x 15 m x 7 m (L x W x H)	m^2	375	500	187,500
		1.103	Construction of new administration building, 20 m x 15 m x 3 m (L x W x H)	m^2	300	500	150,000
		1.104	Construction of guardhouse, 10 m x 6 m x 3 m (L x W x H)	m^2	60	500	30,000
		1.105	Fire protection system for the new pumping station	LS	1	25,000	25,000
		1.106	Fire protection system for the new auxiliary building	LS	1	25,000	25,000
		1.107	Fire protection system with foam for the new electrical building	LS	1	30,000	30,000
		1.108	Lighting system for all buildings	LS	1	15,000	15,000
						Subtotal	**5,340,500**
	1.2		**Water tanks and works**				
		1.200	New Mwache Tank (NMT)	m^3	20,000	400	8,000,000
		1.201	New Nguu Tatu Water Tank (extension)	m^3	40,000	400	16,000,000
		1.202	New Kaya Bombo Water Tank	m^3	30,000	400	12,000,000
		1.203	New water tank at Lunga Lunga	m^3	3,000	500	1,500,000
		1.204	New water tank at Msambweni	m^3	6,000	400	2,400,000
		1.205	Inlet/outlet flowmeter and regulating valve chamber, 6 m x 3 m x 4 m (L x W x H)	No.	12	2,171	26,048
		1.206	Outlet valve chamber, 3 m x 2 m x 2.5 m (L x W x H)	No.	5	657	3,285
		1.207	Line valve chamber, 2.5 m x 2 m x 2 m (L x W x H)	No.	44	570	25,077
		1.208	Air valve chamber, 2 m x 2 m x 2.5 m (L x W x H)	No.	316	483	152,557
		1.209	Washout chamber, 3 m x 2 m x 2.5 m (L x W x H)	No.	33	657	21,684
						Subtotal	**40,128,652**
	1.3		**Electromechanical works**				
			Mwache Pumping Station pumps to +120 NMT				
		1.300	Supply of delivery pumps, 865 m^3/h, 110 m head	No.	6	146,147	876,882
		1.301	Installation of the above delivery pumps	No.	6	12,500	75,000
		1.302	Electrical installation for pumps	LS	6	25,000	150,000
		1.303	Accessories for the new +120 delivery pumps	LS	6	65,000	390,000
		1.304	Accessories installation for the new +120 delivery pumps	LS	6	50,000	300,000
		1.305	Provide electricity to the site (proportional cost)	LS	1	788,246	788,246
						Subtotal	**2,580,128**
			Pumps to Changamwe				
		1.306	Supply of delivery pumps, 600 m^3/h, 65 m head	No.	6	126,000	756,000
		1.307	Installation of the above delivery pumps	No.	6	12,500	75,000
		1.308	Electrical installation for pumps	LS	6	19,500	117,000
		1.309	Accessories materials for the new +75 delivery pumps	LS	6	65,000	390,000

1			Mwache Waterworks (excluding dam and water treatment plant works)	Unit	Qty	Rate (US$)	Total (US$)
		1.310	Accessories installation for the new +75 delivery pumps	LS	6	50,000	300,000
		1.311	Provide electricity to the site (proportional cost)	LS	1	788,246	788,246
						Subtotal	**2,186,246**
			Pumps to Kaya Bombo				
		1.312	Supply of delivery pumps, 865 m^3/h, 70 m head	No.	6	146,147	876,882
		1.313	Installation of the above delivery pumps	No.	6	12,500	75,000
		1.314	Electrical installation for pumps	LS	6	19,500	117,000
		1.315	Accessories materials for the Kaya Bombo delivery pumps	LS	6	65,000	390,000
		1.316	Accessories installation for the Kaya Bombo delivery pumps	LS	6	50,000	300,000
		1.317	Provide electricity to the site (proportional cost)	LS	1	788,246	788,246
						Subtotal	**2,547,128**
			Total – Section 1				**50,538,222**

2			Mwache Transmission Pipelines	Unit	Qty	Unit Cost (US$)	Total Cost (US$)
	2.1		**Transmission pipe**				
		2.100	Pipe (Mwache-Kaya Bombo), steel, DN800	m	22,000	653	14,366,000
		2.101	Pipe (Kaya Bombo-Likoni), steel, DN500	m	11,000	338	3,715,617
		2.102	Pipe (Kaya Bombo-Tiwi), steel, DN500	m	20,000	338	6,755,667
		2.103	Pipe (Tiwi-Ukunda), steel, DN400	m	6,000	278	1,667,250
		2.104	Pipe (Ukunda-Msambweni), steel, DN300	m	22,000	228	5,012,150
		2.106	Pipe (Mwache-Changamwe), steel, DN700	m	15,000	653	9,795,000
		2.107	Pipe (New Mwache Tank -Nguu Tatu), steel, DN1000	m	35,000	850	29,750,000
		2.108	Pipe (Mwache-New Mwache Tank), steel, DN1000	m	4,500	850	3,825,000
		2.109	Pipe for manifold section, steel, DN1000	m	150	850	127,500
		2.109	Pipe for manifold section, steel, DN800	m	150	653	97,878
		2.110	Pipe for manifold section, steel, DN700	m	150	532	79,853
		2.111	Pipe for manifold section, steel, DN500	m	150	338	50,668
		2.112	Pipe for manifold section, steel, DN300	m	150	228	34,174
		2.113	Pipe for manifold section, steel, DN250	m	150	200	30,000
		2.114	Drainage pipe for manifold sections, steel, DN300	m	500	338	168,892
		2.115	Excavation for pipelines	m	135,500	10	1,355,000
		2.116	Access road, non-asphalt	km	15	433,322	6,499,830
						Subtotal	**83,330,477**
	2.2		**Accessories**				
			Flowmeters				
		2.200	Electromagnetic flowmeter, DN800	No.	6	13,415	80,488
		2.201	Electromagnetic flowmeter, DN700	No.	2	8,328	16,657
		2.202	Electromagnetic flowmeter, DN500	No.	2	4,359	8,718
		2.203	Electromagnetic flowmeter, DN300	No.	2	2,924	5,848
						Subtotal	**111,710**
			Accessories				
		2.204	Manual butterfly valve, DN500	No.	45	24,169	1,087,605
		2.205	Manual butterfly valve, DN700	No.	3	46,114	138,342
		2.206	Manual butterfly valve, DN800	No.	27	53,723	1,450,521
		2.207	Manual butterfly valve, DN400	No.	2	19,013	38,027
		2.208	Gate valve (on pipeline and on drain pipes), DN300	No.	3	6,744	20,232
		2.209	Gate valve (on pipeline and on drain pipes), DN250	No.	37	4,127	152,699
		2.210	Air valve, DN200	No.	316	3,000	948,000
		2.211	Pressure-reducing valve for kiosk lines, DN300	No.	32	14,516	464,512
						Subtotal	**4,299,937**
			Total – Section 2				**87,742,124**

3			Taveta Springs Rehabilitation + Taveta Local Water Supply Scheme	Unit	Qty	Unit Cost (US$)	Total Cost (US$)
	3.1		**Civil engineering works**				
			Water intake system				
		3.100	Intake – civil works	m³/d	7,300	9	65,700
		3.101	Construction of new pumping station, 25 m x 12 m x 5 m (L x W x H)	m²	300	350	105,000
		3.102	Construction of new electrical building, 5 m x 12 m x 5 m (L x W x H)	m²	60	350	21,000
		3.103	Fencing, chain link	m	50	11	550
						Subtotal	**192,250**
			Water treatment plant				
		3.104	Treatment works, full conventional train – primary sedimentation + coagulation + secondary sedimentation + filtration + disinfection	m³/d	7,300	2	14,600
		3.105	Fencing, chain link	m	500	40	20,000
		3.106	Construction of new high-lift pumping station (HLPS), 12 m x 25 m x 7 m (L x W x H)	m²	300	500	150,000
		3.107	Construction of new administration building, 18 m x 12 m x 3 m (L x W x H)	m²	216	500	108,000
		3.108	Construction of guardhouse, 6 m x 5 m x 3 m (L x W x H)	m²	30	500	15,000
		3.109	Treated water flowmeter and regulating valve chamber, 6 m x 3 m x 4 m (L x W x H)	No.	1	350	350
		3.110	Treated water outlet valve chamber, 3 m x 2 m x 2.5 (L x W x H)	No.	1	650	650
						Subtotal	**308,600**
		3.111	**Transmission pipe chambers**				
		3.112	Line valve chamber, 2.5 m x 2 m x 2.5 m (L x W x H)	No.	19	570	10,829
		3.113	Air valve chamber, 2 m x 2 m x 2.5 m (L x W x H)	No.	75	483	36,208
		3.114	Washout chamber, 3 m x 2 m x 2.5 m (L x W x H)	No.	15	657	9,856
		3.115	Access road, non-asphalt	km	5	433,322	2,166,610
						Subtotal	**2,223,503**
	3.2		**Transmission pipe**				
		3.200	Raw water pump suction pipe, steel, DN300	m	100	315	31,500
		3.201	Raw water pump delivery pipe, steel, DN400	m	150	520	78,000
		3.202	High-lift suction pipe, steel, DN300	m	50	315	15,750
		3.203	Treated water pump delivery pipe to main conveyor, steel, DN400	m	200	520	104,000
		3.204	Transmission pipe, steel, DN500	m	2,500	653	1,632,500
		3.205	Pipeline excavation	m	3,000	12	36,000
						Subtotal	**1,897,750**
	3.3		**Electromechanical works**				
		3.300	Supply of raw water delivery pumps, 360 m³/h, 45 m head	No.	6	85,000	255,000
		3.301	Installation of the above raw water delivery pumps	No.	3	5,500	16,500
		3.302	Installation of the above treated water delivery pumps	No.	3	1,205	3,615
		3.303	Electrical installation for pumps	LS	1	35,000	35,000
		3.304	Provide electricity to the site	LS	1	50,000	50,000
						Subtotal	**360,115**
	3.4		**Accessories**				

3			Taveta Springs Rehabilitation + Taveta Local Water Supply Scheme	Unit	Qty	Unit Cost (US$)	Total Cost (US$)
		3.400	Air valve, DN200	No.	12	3,000	36,000
		3.401	Manual gate valve (drain valve), DN300	No.	4	9,756	39,023
		3.402	Electromagnetic flowmeter, DN400	No.	2	36,089	72,177
						Subtotal	**147,200**
			Total Section 3				**5,129,419**
			Total – Phase I works				**143,409,768**

PHASE II

Phase II – Baricho 2 Expansion + Supply Schemes

1			Baricho 2 Scheme (Inner Stages A–D)	Unit	Qty	Unit Cost (US$)	Total Cost (US$)
	1.1		**Civil engineering works**				
		1.100	Drilling new boreholes at the Baricho site, 9 m diameter, RHC-type	No.	5	400,000	2,000,000
		1.101	Concrete works for the borehole cover and pump installation	LS	5	50,000	250,000
		1.102	Horizontal drilling for "gallery"-type suction shaft	No.	5	130,000	650,000
		1.103	Civil construction works for new non-asphalt access road to site, and upgrade of existing non-asphalt road	km	1	433,322	433,322
		1.104	Construction of new pumping station, 60 m x 25 m, 7 m (L x W x H)	m^2	1,500	1,540	2,310,000
		1.105	Construction on new auxiliary building, 20 m x 15 m x 5 m (L x W x H)	m^2	300	580	174,000
		1.106	Construction of new electrical building, 20 m x 12 m, 7 m (L x W x H)	m^2	240	350	84,000
		1.107	New receiving tank with chlorination chamber	m^3	5,000	400	2,000,000
						Subtotal	**7,901,322**
	1.2		**Electromechanical works**				
		1.200	Supply of borehole pumps, 900 m^3/h, 60 m head	No.	5	73,965	369,824
		1.201	Installation of the above borehole pumps	No.	5	1,205	6,025
		1.202	Supply of delivery pumps, 833 m^3/h, 240 m head	No.	4	240,405	961,621
		1.203	Installation of the above delivery pumps	No.	4	1,205	4,820
		1.204	Supply of delivery pumps, 700 m^3/h, 110 m head	No.	6	146,147	876,882
		1.205	Installation of the above delivery pumps	No.	6	1,205	7,320
		1.206	Electrical installation for pumps	LS	1	66,147	66,147
		1.207	Provide electricity to the site	LS	1	788,246	788,246
						Subtotal	**3,080,885**
	1.3		**Pipe and manifolds**				
		1.300	Pipes to borehole pump manifolds, steel, DN400	m	160	278	44,460
		1.301	Pipe main manifolds from borehole pumps to main conveyer, steel, DN500	m	120	338	40,534
		1.302	Pipe from manifolds to water treatment tank, steel, DN600	m	350	570	199,500
		1.303	Pipe from water treatment tank to suction chamber, steel, DN750	m	150	650	97,500
		1.304	Overflow pipe from treatment tank, steel, DN600	m	200	448	89,603
		1.305	Main gate valve for borehole manifolds, 12", DN300	No.	5	14,280	71,400
		1.306	Main non-return valve for borehole manifolds, 12", DN300	No.	5	5,400	27,000
		1.307	Treatment water tank valve, 24", DN600	No.	2	25,500	51,000
		1.308	Suction chamber main valve, 24", DN600	No.	1	25,500	25,500
		1.309	Suction chamber secondary valve, 16", DN400	No.	5	14,892	74,460
		1.310	Suction chamber secondary valve, 12", DN300	No.	3	14,280	42,840
						Subtotal	**763,797**
	1.4		**Accessories**				

1			Baricho 2 Scheme (Inner Stages A–D)	Unit	Qty	Unit Cost (US$)	Total Cost (US$)
		1.400	Air valve static + dynamic, 6", DN150	No.	12	231	2,772
		1.401	Air valve static + dynamic, 4", DN100	No.	5	222	1,110
		1.402	Air valve static + dynamic, 3", DN80	No.	5	158	790
		1.403	Surge rapid pressure release valve, 12", DN300	No.	5	14,516	72,580
		1.404	Surge rapid pressure release valve, 10", DN250	No.	2	8,050	16,100
		1.405	Surge rapid pressure release valve, 6", DN150	No.	4	3,942	15,768
		1.406	Pressure sustain valve, 16", DN400	No.	5	42,278	211,390
		1.407	Pressure sustain valve, 12", DN300	No.	4	14,646	58,584
		1.408	Pressure sustain valve, 10", DN250	No.	4	8,138	32,552
		1.409	Flowmeter for each borehole, DN400	No.	5	8,450	42,251
		1.410	Gate valve for flowmeters, DN400	No.	12	1,241	14,892
						Subtotal	**468,789**
	1.5		**Auxiliary systems**				
		1.500	Surge protection system and all accessories needed – surge protection tank, pressure valves, system control, interface with existing system, etc.	LS	1	1,528,130	1,528,130
		1.502	Fire protection system for the new pumping station	LS	1	25,000	25,000
		1.503	Fire protection system for the new auxiliary building	LS	1	25,000	25,000
		1.504	Fire protection system with foam for the new electrical building	LS	1	30,000	30,000
		1.505	Lighting system for all buildings	LS	1	15,000	15,000
						Subtotal	**1,623,130**
	1.6		**Treatment systems**				
		1.600	Chlorination system for the disinfection	LS	2	125,000	250,000
						Subtotal	**250,000**
			Total – Section 1				**14,087,923**

2			Baricho-Nguu Tatu Pipeline	Unit	Qty	Unit Cost (US$)	Total Cost (US$)
	2.1		**Pipe and manifolds (including excavation)**				
		2.100	Parallel force main pipe, steel, DN800, PN 40	m	28,000	653	18,270,525
		2.101	Parallel force main pipe, steel, DN800, PN 25	m	28,000	623	17,444,000
		2.102	Parallel force main pipe, steel, DN800, PN 16	m	26,000	603	15,678,000
		2.103	Parallel force main pipe, steel, DN800, PN 12	m	25,000	578	14,450,000
		2.104	Branch pipes for connecting kiosks, PE pipe, DN400, PN 25	m	300	500	150,000
		2.105	Branch pipes for connecting other points, PE pipe, DN300, PN 25	m	500	312	156,000
		2.106	Branch pipes for connecting other points, PE pipe, DN250, PN 25	m	500	180	90,000
						Subtotal	**66,238,525**
	2.2		**Accessories**				
		1.200	Air valve, static + dynamic, 6", DN150	No.	50	231	11,550
		1.201	Air valve, static + dynamic, 4", DN100	No.	30	222	6,660
		1.202	Air valve, static + dynamic, 3", DN80	No.	20	158	3,160
		1.203	Surge rapid pressure relief valve, 12", DN300	No.	10	14,516	145,160
		1.204	Surge rapid pressure relief valve, 10", DN250	No.	8	8,050	64,400
		1.205	Surge rapid pressure relief valve, 6", DN150	No.	6	3,942	23,652
		1.206	Pressure sustain valve, 16", DN400	No.	12	24,278	291,336
		1.207	Pressure sustain valve, 12", DN300	No.	12	14,646	175,752
		1.208	Pressure sustain valve, 10", DN250	No.	12	8,138	97,656
		1.209	Gate valve for the main pipe, 24", DN600	No.	15	2,125	31,875
		1.210	Gate valve for the secondary pipe, 20", DN500	No.	15	1,681	25,215
		1.211	Gate valve for the secondary pipe, 16", DN400	No.	8	1,241	9,928
		1.212	Gate valve for the secondary pipe, 12", DN300	No.	12	1,190	14,280
						Subtotal	**900,624**
	2.3		**Water distribution chambers**				
		2.300	Gate valve chamber for main valve, 24", 2 m x 3 m	No.	15	657	9,856
		2.301	Gate valve chamber for secondary valves, 20", 2 m x 3 m	No.	15	657	9,856
		2.302	Gate valve chamber for secondary valves, 16", 2 m x 2 m	No.	8	570	4,559
		2.303	Gate valve chamber for main valve, 12", 1 m x 2 m	No.	12	483	5,793
		2.304	Drainage valve for the main line, 12", DN300	No.	20	1,190	23,800
		2.305	Drainage valve for the secondary lines, 10", DN250	No.	10	905	9,050
		2.306	Drainage valve for the secondary lines, 8", DN200	No.	10	600	6,000
		2.307	Drainage valve for the secondary lines, 6", DN150	No.	10	307	3,070
		2.308	Chamber for drainage valves	No.	50	570	28,497
						Subtotal	**100,482**
			Total – Section 2				**67,239,631**

3			Baricho–Kakuyuni Pipeline	Unit	Qty	Unit Cost (US$)	Total Cost (US$)
	3.1		**Pipe and manifolds (including excavation)**				
		3.100	Parallel force main, PE pipe, DN600, PN 16	m	24,000	605	14,520,000
		3.101	Parallel force main, PE pipe, DN600, PN 12	m	21,000	605	12,705,000
		3.102	Branch pipes for connecting kiosks, PE pipe, DN400, PN 12	m	300	500	150,000
		3.103	Branch pipes for connecting other points, PE pipe, DN300, PN 12	m	300	312	93,600
		3.104	Branch pipes for connecting other points, PE pipe, DN250, PN 12	m	300	180	54,000
						Subtotal	**27,522,600**
	3.2		**Accessories**				
		3.200	Air valve, static + dynamic, 6", DN150	No.	20	2,772	55,440
		3.201	Air valve, static + dynamic, 4", DN100	No.	20	2,664	53,280
		3.202	Air valve, static + dynamic, 3", DN80	No.	20	1,896	37,920
		3.203	Surge rapid pressure relief valve, 10", DN250	No.	6	8,050	48,300
		3.204	Surge rapid pressure relief valve, 6", DN150	No.	6	3,942	23,652
		3.205	Pressure sustain valve, 12", DN300	No.	6	14,646	87,876
		3.206	Pressure sustain valve, 10", DN250	No.	6	8,138	48,828
		3.207	Gate valve for the main pipe, 20", DN500	No.	10	20,172	201,720
		3.208	Gate valve for the secondary pipe, 12", DN300	No.	8	14,280	114,240
		3.209	Gate valve for the secondary pipe, 10", DN250	No.	12	10,860	130,320
						Subtotal	**801,576**
	3.3		**Water distribution chambers**				
		3.300	Gate valve chamber for secondary valves, 20", 2 m x 3 m	No.	10	657	6,571
		3.301	Gate valve chamber for secondary valves, 12", 2 m x 2 m	No.	8	657	5,257
		3.302	Gate valve chamber for secondary valves, 10", 2 m x 2 m	No.	12	570	6,839
		3.303	Drainage valve for the main line, 12", DN300	No.	6	1,190	7,140
		3.304	Drainage valve for the secondary lines, 10", DN250	No.	6	10,860	65,160
		3.305	Drainage valve for the secondary lines, 8", DN200	No.	4	7,200	28,800
		3.306	Drainage valve for the secondary lines, 6", DN150	No.	4	3,684	14,736
		3.307	Chamber for drainage valves	No.	20	570	11,399
						Subtotal	**145,902**
			Total – Section 3				**28,470,078**

4			Kakuyuni-Marafa Pipeline	Unit	Qty	Unit Cost (US$)	Total Cost (US$)
	4.1		**Pipe and manifolds (including excavation)**				
		4.100	Force main, PE pipe, DN300, PN 24	m	10,000	312	3,120,000
		4.101	Force main, PE pipe, DN300, PN 16	m	6,000	250	1,500,000
		4.102	Force main, PE pipe, DN300, PN 12	m	4,500	200	900,000
		4.103	Branch pipes for connecting other points, PE pipe, DN300, PN 12	m	300	150	45,000
		4.104	Branch pipes for connecting other points, PE pipe, DN250, PN 12	m	300	120	36,000
						Subtotal	**5,601,000**
	4.2		**Accessories**				
		4.200	Air valve, static + dynamic, 6", DN150	No.	12	2,772	33,264
		4.201	Air valve, static + dynamic, 4", DN100	No.	10	2,664	26,640
		4.202	Air valve, static + dynamic, 3", DN80	No.	10	1,896	18,960
		4.203	Surge rapid pressure relief valve, 10", DN250	No.	4	8,050	32,200
		4.204	Surge rapid pressure relief valve, 6", DN150	No.	4	3,942	15,768
		4.205	Pressure sustain valve, 12", DN300	No.	4	14,646	58,584
		4.206	Pressure sustain valve, 10", DN250	No.	6	8,138	48,828
		4.207	Gate valve for the main pipe, 12", DN300	No.	10	14,280	142,800
		4.208	Gate valve for the secondary pipe, 10", DN250	No.	8	10,860	86,880
						Subtotal	**463,924**
	4.3		**Water distribution chambers**				
		4.300	Gate valve chamber for secondary valves, 12", 2 m x 2 m	No.	10	657	6,571
		4.301	Gate valve chamber for secondary valves, 10", 2 m x 2 m	No.	8	570	4,559
		4.302	Drainage valve for the secondary lines, 10", DN250	No.	6	905	5,430
		4.303	Drainage valve for the secondary lines, 8", DN200	No.	8	750	6,000
		4.304	Drainage valve for the secondary lines, 6", DN150	No.	8	505	4,040
		4.305	Chamber for drainage valves	No.	14	570	7,979
						Subtotal	**34,580**
	4.4		**Water tanks**				
		4.400	New water tank at Marafa	m^3	1,500	500	750,000
						Subtotal	**750,000**
	4.5		**Water booster for Marafa**				
		4.500	Supply booster pump, 50 m^3/h, 60 m head	No.	4	16,950	67,800
		4.501	Install booster pumps	No.	4	600	2,400
		4.501	Construction of new pumping station, 6 m x 10 m x 7 m (L x W x H)	m^2	60	500	30,000
		4.502	Construction of guardhouse, 6 m x 5 m x 3 m (L x W x H)	m^2	30	500	15,000
		4.504	Electrical system to connect Marafa Pumping Station	LS	1	60,000	60,000
						Subtotal	**175,200**
			Total – Section 4				**7,024,704**
			Total for first part of Phase II works – Baricho 2 expansion + supply schemes				**116,822,334**

Phase II – Water Supply to Lamu and Tana River Counties

1			Garsen-Lamu Water Supply Scheme	Unit	Qty	Unit Cost (US$)	Total Cost (US$)
	1.1		**Civil engineering works**				
			Water intake system				
		1.100	Intake – civil works	m^3/d	120,000	9	1,080,000
		1.101	Construction of new pumping station, 65 m x 20 m x 7 m (L x W x H)	m^2	1,300	350	455,000
		1.102	Construction of new electrical building, 20 m x 12 m x 5 m (L x W x H)	m^2	240	350	84,000
		1.103	Construction of new administration building, 20 m x 10 m x 3 m (L x W x H)	m^2	200	350	70,000
		1.104	Fencing, chain link	m	400	11	4,400
		1.105	Fire protection system for the new pumping station	LS	1	30,000	30,000
		1.106	Fire protection system with foam for the new electrical building	LS	1	20,000	20,000
		1.107	Fire protection system for the new administration building	LS	1	15,000	15,000
		1.108	Lighting system for all buildings	LS	1	25,000	25,000
						Subtotal	**1,783,400**
			Water treatment plant				
		1.109	Treatment works, full conventional train – primary sedimentation + coagulation + secondary sedimentation + filtration + disinfection (Note: 3 trains, 40,000 m^3/d each)	LS	3	1,000,000	3,000,000
		1.110	Fencing, chain link	m	500	11	5,500
		1.111	Construction of new high-lift pumping station (HLPS), 60 m x 25 m x 7 m (L x W x H)	m^2	1,500	350	525,000
		1.112	Construction of new administration building, 18 m x 12 x 3 m (L x W x H)	m^2	216	350	75,600
		1.113	Construction of guardhouse, 12 m x 9 m x 3 m (L x W x H) x 3 No.	m^2	324	350	113,400
		1.114	Fire protection system for the new pumping station	LS	1	30,000	30,000
		1.115	Treated water flowmeter and regulating valve chamber, 6 m x 3 m x 4 m (L x W x H)	No.	1	1,793	1,793
		1.116	Treated water outlet valve chamber, 3 m x 2 m x 2.5 m (L x W x H)	No.	1	657	657
						Subtotal	**3,751,950**
			Transmission pipe chambers				
		1.117	Line valve chamber, 2.5 m x 2 m x 2.5 m (L x W x H)	No.	19	570	10,829
		1.118	Air valve chamber 2 m x 2 m x 2.5 m (L x W x H)	No.	75	483	36,208
		1.119	Washout chamber 3 m x 2 m x 2.5 m (L x W x H)	No.	15	657	9,856
						Subtotal	**56,893**
	1.2		**Transmission pipe**				
		1.200	Raw water pump suction pipe, steel, DN300	m	100	228	22,783
		1.201	Raw water pump delivery pipe, steel, DN400	m	150	278	41,681
		1.202	Raw water main conveyance pipe, steel, DN1200	m	150	1,767	265,050
		1.203	High-lift suction pipe, steel, DN300	m	50	228	11,391
		1.204	Treated water pump delivery pipe to main conveyor, steel, DN400	m	200	278	55,575

1			Garsen-Lamu Water Supply Scheme	Unit	Qty	Unit Cost (US$)	Total Cost (US$)
		1.205	Transmission pipe, steel, DN1200	m	78,000	1,700	132,525,000
		1.206	Pipeline excavation	m	78,000	12	900,000
		1.207	Access road, non-asphalt	km	75	433,322	32,499,150
						Subtotal	**166,320,630**
	1.3		**Electromechanical works**				
		1.300	Supply of raw water delivery pumps, 800 m³/h, 135 m head	No.	8	146,147	1,169,176
		1.301	Installation of the above raw water delivery pumps	No.	8	1,205	9,640
		1.302	Supply of treated water delivery pumps, 800 m³/h, 220 m head	No.	8	240,405	1,923,241
		1.303	Installation of the above treated water delivery pumps	No.	8	1,205	9,640
		1.304	Electrical installation for pumps	LS	1	101,166	101,166
		1.305	Provide electricity to the site	LS	1	1,205,552	1,205,552
						Subtotal	**4,418,415**
	1.4		**Accessories**				
		1.400	Manual butterfly valve (line), DN1200	No.	16	84,520	1,352,320
		1.401	Air valve, DN200	No.	150	3,000	450,000
		1.402	Manual gate valve (drain valve), DN300	No.	15	9,756	146,338
		1.403	Electromagnetic flowmeter, DN1200	No.	1	36,089	36,089
		1.404	Pipe, steel, DN1200	m	80	1,466	117,299
		1.405	Pipe, steel, DN1000	m	80	1,102	88,160
		1.406	Drainage pipe, steel, DN500	m	500	338	168,892
						Subtotal	**2,359,098**
	1.5		**Auxiliary systems**				
		1.501	Surge protection system and all accessories needed – surge protection tank, pressure valves, system control, interface with existing system, etc.	LS	1	2,337,140	2,337,140
						Subtotal	**2,337,140**
			Total – Section 1				**181,027,526**

2			Hola Local Water Supply Scheme	Unit	Qty	Unit Cost (US$)	Total Cost (US$)
	2.1		**Civil engineering works**				
			Water intake system				
		2.100	Intake – civil works	m^3/d	2,700	25	67,500
		2.101	Pumping station, 16 m x 10 m x 5 m (L x W x H)	m^2	160	350	56,000
		2.102	Construction of new electrical building, 12 m x 5 m x 5 m (L x W x H)	m^2	60	350	21,000
		2.103	Fencing, chain link	m	50	11	550
						Subtotal	**145,050**
			Water treatment plant				
		2.104	Treatment works, full conventional train – primary sedimentation + coagulation + secondary sedimentation + filtration + disinfection	m^3/d	2,700	5	13,500
		2.105	Fencing, chain link	m	500	40	20,000
		2.106	Administration building, 12 m x 10 m x 3 m (L x W x H)	m^2	120	350	42,000
		2.107	Guardhouse, 8 m x 5 m x 3 m (L x W x H)	m^2	40	350	14,000
		2.108	Treated water flowmeter and regulating valve chamber, 6 m x 3 m x 4 m (L x W x H)	No.	1	350	350
		2.109	Treated water outlet valve chamber, 3 m x 2 m x 2.5 m (L x W x H)	No.	1	650	650
						Subtotal	**77,000**
		2.111	**Transmission pipe chambers**				
		2.112	Line valve chamber, 2.5 m x 2 m x 2.5 m (L x W x H)	No.	19	570	4,559
		2.113	Air valve chamber, 2 m x 2 m x 2.5 m (L x W x H)	No.	75	483	5,793
		2.114	Washout chamber, 3 m x 2 m x 2.5 m (L x W x H)	No.	15	657	3,285
						Subtotal	**13,638**
	2.2		**Transmission pipe**				
		2.200	Raw water pump suction pipe, steel, DN300	m	400	315	126,000
		2.201	Raw water pump delivery pipe, steel, DN400	m	150	520	78,000
		2.202	High-lift suction pipe, steel, DN300	m	50	315	15,750
		2.203	Treated water pump delivery pipe to main conveyor, steel, DN400	m	200	520	104,000
		2.204	Installation of manifolds for pumps	LS	1	24,000	24,000
		2.205	Access road, non-asphalt	km	2	129,997	259,993
						Subtotal	**607,743**
	2.3		**Electromechanical works**				
		2.300	Supply of raw water and treated water delivery pumps, 250 m^3/h, 45 m head	No.	6	42,500	255,000
		2.301	Installation of the above raw water delivery pumps	No.	3	5,500	16,500
		2.302	Installation of the above treated water delivery pumps	No.	3	1,205	3,615
		2.303	Electrical installation for 6 pumps	LS	1	35,000	35,000
		2.304	Provide electricity to the site	LS	1	50,000	50,000
						Subtotal	**360,115**
	2.4		**Accessories**				
		2.400	Air valve, DN200	No.	10	3,000	30,000
		2.401	Manual gate valve (drain valve), DN300	No.	4	9,756	39,023
		2.402	Electromagnetic flowmeter, DN400	No.	1	12,500	12,500
						Subtotal	**81,523**
			Total – Section 2				**1,285,070**

3			Bura Local Water Supply Scheme	Unit	Qty	Unit Cost (US$)	Total Cost (US$)
	3.1		**Civil engineering works**				
			Water intake system				
		3.100	Intake – civil works	m^3/d	3,300	25	82,500
		3.101	Pumping station, 12 m x 10 m x 5 m (L x W x H)	m^2	120	350	42,000
		3.102	Construction of new electrical building, 12 m x 5 m x 5 m (L x W x H)	m^2	60	350	21,000
		3.103	Fencing, chain link	m	120	11	1,320
						Subtotal	**146,820**
			Water Treatment Plant				
		3.104	Treatment works, full conventional train – primary sedimentation + coagulation + secondary sedimentation + filtration + disinfection	m^3/d	3,300	5	16,500
		3.105	Fencing, chain link	m	400	40	16,000
		3.106	Administration building, 12 m x 10 m x 3 m (L x W x H)	m^2	120	350	42,000
		3.107	Guardhouse, 8 m x 5 m x 3 m (L x W x H)	m^2	40	350	14,000
		3.108	Treated water flowmeter and regulating valve chamber, 6 m x 3 m x 4 m (L x W x H)	No.	1	350	350
		3.109	Treated water outlet valve chamber, 3 m x 2 m x 2.5 m (L x W x H)	No.	1	650	650
						Subtotal	**73,000**
			Transmission pipe chambers				
		3.110	Line valve chamber, 2.5 m x 2 m x 2.5 m (L x W x H)	No.	8	570	4,559
		3.111	Air valve chamber, 2 m x 2 m x 2.5 m (L x W x H)	No.	12	483	5,793
		3.112	Washout chamber, 3 m x 2 m x 2.5 m (L x W x H)	No.	5	657	3,285
						Subtotal	**13,638**
	3.2		**Transmission pipe**				
		3.200	Raw water pump suction pipe, steel, DN300	m	400	315	126,000
		3.201	Raw water pump delivery pipe, steel, DN400	m	150	520	78,000
		3.202	High-lift suction pipe, steel, DN300	m	50	315	15,750
		3.203	Treated water pump delivery pipe to main conveyor, steel, DN400	m	200	520	104,000
		3.204	Installation of manifolds for pumps	LS	1	9,600	9,600
		3.205	Access road, non-asphalt	km	2	129,997	259,993
						Subtotal	**593,343**
	3.3		**Electromechanical works**				
		3.300	Supply of raw water and treated water delivery pumps, 250 m^3/h, 45 m head	No.	6	42,500	255,000
		3.301	Installation of the above raw water delivery pumps	No.	3	5,500	16,500
		3.302	Installation of the above treated water delivery pumps	No.	3	1,205	3,615
		3.303	Electrical installation for 6 pumps	LS	1	35,000	35,000
		3.304	Provide electricity to the site	LS	1	50,000	50,000
						Subtotal	**360,115**
	3.4		**Accessories**				
		3.400	Air valve, DN200	No.	12	3,000	36,000
		3.401	Manual gate valve (drain valve), DN300	No.	4	9,756	39,023
		3.402	Electromagnetic flowmeter, DN400	No.	1	12,500	12,500
						Subtotal	**87,523**
			Total – Section 3				**1,290,940**

			Total for second part of Phase II works – Water supply to Lamu and Tana River counties					**182,223,445**
			Total – Phase II works					**299,045,700**

PHASE III

1			Mzima Waterworks + Mzima 2 Pipeline	Unit	Qty	Unit Cost (US$)	Total Cost (US$)
	1.1		**Civil engineering works**				
		1.100	Transmission pipe, steel, DN1200 (48"), including excavation	m	1,300	1,676	2,178,800
		1.101	Water tank, rectangular, 2,000 m³ x 3 No.	m³	6,000	500	3,000,000
		1.102	Inlet flowmeter and regulating valve chamber, 6 m x 3 m x 4 m (L x W x H)	No.	4	1,793	7,171
		1.103	Outlet valve chamber, 3 m x 2 m x 2.5 m (L x W x H)	No.	6	657	3,943
		1.104	Construction of guardhouse, 10 m x 5 m x 3 m (L x W x H)	m²	50	350	17,500
		1.105	Fencing, chain link	m	305	100	30,500
						Subtotal	**5,237,9**
			Mazeras Water Tanks				
		1.105	Inlet flowmeter and regulating valve chamber, 6 m x 3 m x 4 m (L x W x H)	No.	1	1,793	1,793
						Subtotal	**1,793**
			Transmission pipe chambers				
		1.106	Line valve chamber, 2.5 m x 2 m x 2.5 m (L x W x H)	No.	50	570	26,497
		1.107	Air valve chamber, 2 m x 2 m x 2.5 m (L x W x H)	No.	200	483	96,555
		1.108	Washout chamber, 3 m x 2 m x 2.5 m (L x W x H)	No.	100	657	65,710
						Subtotal	**188,762**
	1.2		**Transmission pipeline**				
		1.200	Pipe, steel, DN1200	m	78,200	1,676	131,063,200
		1.201	Pipe, steel, DN1000	m	142,028	1,202	170,717,656
		1.202	Manual butterfly valve, DN1200	No.	34	95,000	3,230,000
		1.203	Manual butterfly valve, DN1000	No.	80	67,731	5,418,480
		1.204	Air valve, DN200	No.	450	3,000	1,350,000
		1.205	Manual gate valve, DN300	No.	400	14,280	5,712,000
		1.206	Pipeline excavation	m	220,000	12	2,640,000
		1.207	Rehabilitate/supplement existing access road, non-asphalt	km	220	216,661	47,665,420
						Subtotal	**367,796,756**
	1.3		**Accessories**				
		1.300	Manual butterfly valve, DN1200	No.	8	7,616	60,924
		1.301	Manual butterfly valve, DN1000	No.	12	5,644	67,731
		1.302	Electromagnetic flowmeter, DN1000	No.	5	27,172	135,859
		1.303	Electromagnetic flowmeter, DN1200	No.	2	36,089	72,177
		1.304	Pipe, steel, DN1200	m	100	1,466	146,624
		1.305	Pipe, steel, DN1000	m	200	1,102	220,480
		1.306	Drainage pipe, steel, DN500	m	500	338	168,892
						Subtotal	**872,687**
			Mazeras Water Tanks				
		1.307	Manual butterfly valve, DN1000	No.	4	8,444	33,776
						Subtotal	**33,776**
	1.4		**Water tank rehabilitation**				
		1.400	Water tank rehabilitation	No.	8	100,000	800,000

						Subtotal	**800,000**
			Total – Section 1				**374,931,688**

2			Voi-Mwatate-Wundanyi Branch	Unit	Qty	Unit Cost (US$)	Total Cost (US$)
	2.1		**Civil engineering works**				
		2.100	Construction of new pumping station, 10 m x 10 m x 5 m (L x W x H)	m^2	100	550	55,000
		2.101	Construction of new electrical building, 8 m x 5 m x 5 m (L x W x H)	m^2	40	350	14,000
		2.102	Construction of new administration building, 8 m x 6 m x 3 m (L x W x H)	m^2	48	350	16,800
		2.103	Valve chambers, 3 m x 2 m x 2.5 m (L x W x H)	No.	84	657	55,196
		2.104	Fire protection system for new pumping station	LS.	1	15,000	15,000
		2.105	Lighting system for all buildings	LS	1	15,000	15,000
						Subtotal	**170,996**
	2.2		**Electromechanical works**				
		2.200	Supply and installation of delivery pumps, 210 m^3/h, 240 m head	No.	5	45,500	227,500
		2.201	Main low-voltage (LV) panel board, complete with a 150 kVAr power factor corrections capacitor, 7-step LOVATO controller and automatic changeover switch, as a complete package	No.	1	31,500	31,500
		2.202	Transformer, 415 kVA, 11 kV/433 V, and metering equipment for pumping station	LS	1	60,000	60,000
						Subtotal	**319,000**
	2.3		**Pipe and manifolds**				
		2.300	Suction pipe from sump to pumps, steel, DN250	m	100	188	18,828
		2.301	Delivery pipe from pump to main pipeline, steel, DN300	m	100	188	18,828
		2.302	Pipe to Mwatate, steel, DN400, PN 20, including excavation	m	30,000	310	9,300,000
		2.303	Pipe to Wundanyi, steel, DN250, PN 24, including excavation	m	12,000	278	3,336,000
						Subtotal	**12,673,657**
	2.4		**Accessories**				
		2.400	Main gate valve for Mwatate Pipeline, DN400	No.	4	1,584	6,336
		2.401	Main gate valve for Wundanyi Pipeline, DN250	No.	4	1,285	5,140
		2.402	Air valve, static + dynamic, 4", DN100	No.	60	2,664	159,840
		2.403	Surge rapid pressure release valve, 6", DN150	No.	6	3,942	23,652
		2.404	Pressure sustain valve, 12", DN300	No.	4	14,646	58,584
		2.405	Flowmeter for Mwatate Pipeline, DN400	No.	1	8,450	8,450
		2.406	Flowmeter for Wundanyi Pipeline, DN250	No.	1	6,500	6,500
		2.407	Gate valve for Mwatate flowmeters, DN400	No.	2	14,892	29,784
		2.408	Gate valve for Wundanyi flowmeters, DN250	No.	2	11,500	23,000
						Subtotal	**321,286**
	2.5		**Auxiliary systems**				
		2.500	Surge protection system and all accessories needed – surge protection tank, pressure valves, system control, interface with existing system, etc.	LS	1	60,000	60,000
						Subtotal	**60,000**
			Total – Section 2				**13,544,938**

3			Msambweni Waterworks + connection to bulk water supply system	Unit	Qty	Unit Cost (US$)	Total Cost (US$)
	3.1		**Civil engineering works**				
		3.100	Drilling new boreholes at the Msambweni site, 250 mm diameter	No.	15	12,000	180,000
		3.101	Concrete works for the borehole cover and pump installation	LS	15	2,500	37,500
		3.102	Civil construction works for tertiary road	km	20	129,997	2,599,932
		3.103	Construction of new electricity panel sheds 5 m x 2 m (L x W) x 16 No.	No.	16	15,400	246,400
		3.104	Valve chambers, 3 m x 2 m x 2.5 m (L x W x H)	No.	116	657	76,223
						Subtotal	**3,140,055**
	3.2		**Electromechanical works**				
		3.200	Supply and install borehole pumps, 55.5 m^3/h, 150 m head	No.	15	30,488	457,317
		3.201	Supply and install electrical systems for borehole pumps	LS	15	4,500	67,500
		3.202	Provision of power to the borehole sites (transformer and high-tension transmission cable)	LS	1	150,000	150,000
						Subtotal	**674,817**
	3.3		**Transmission pipeline (including excavation)**				
		3.300	Pipe (Msambweni-Lunga Lunga), steel, DN300	m	46,000	228	10,488,000
		3.300	Pipe (Tiwi-Msambweni), steel, DN500	m	35,000	338	1,183,000
						Subtotal	**11,671,000**
	3.4		**Pipe and manifolds (including excavation)**				
		3.400	Pipe to borehole pump manifolds, steel, DN100	m	1,500	165	247,500
		3.401	Main manifold pipe from borehole pumps to main conveyer, steel, DN100	m	150	165	24,750
		3.402	Pipe from manifolds to water treatment tank, steel, DN500	m	1,000	635	635,000
		3.403	Main gate valve for borehole manifolds, DN100	No.	12	1,302	15,624
		3.404	Main non-return valve for borehole manifolds, DN100	No.	12	300	3,600
		3.405	Treatment water tank outlet valve, DN500	No.	1	19,078	19,078
		3.406	Pipe from treatment tank to Msambweni Reservoir, steel, DN500	m	6,500	635	4,127,500
						Subtotal	**5,073,052**
	3.5		**Msambweni Pumping Station to Lunga Lunga**				
		3.500	Supply of delivery pumps, 170 m^3/h, 160 m head	No.	5	12,500	62,500
		3.501	Installation of the above delivery pumps	No.	5	7,500	37,500
		3.502	Electrical installation for pumps	LS	1	15,000	15,000
		3.503	Accessories for the new pumps	LS	5	12,000	60,000
		3.504	Installation of accessories for the new pumps	LS	5	10,000	50,000
		3.505	Provide electricity to the site	LS	1	300,000	300,000
						Subtotal	**525,000**
	3.6		**Accessories**				
		3.600	Air valve, static + dynamic, 4", DN100	No.	56	2,664	149,184
		3.601	Air valve, static + dynamic, 3", DN80	No.	15	1,896	28,440
		3.602	Flowmeter for each borehole, DN100	No.	15	1,454	21,803
		3.603	Gate valve for flowmeters, DN100	No.	30	1,302	39,060
						Subtotal	**238,487**
	3.7		**Auxiliary systems**				

		3.700	Surge protection system and all accessories needed – surge protection tank, pressure valves, system control, interface with existing system, etc.	LS	1	359,560	359,560
						Subtotal	**359,560**
	3.8		**Treatment systems**				
		3.800	Construction of receiving tank for chlorination	m^3	500	400	200,000
						Subtotal	**200,000**
	3.9		**Auxiliary systems (Msambweni Pumping Station for Lunga Lunga)**				
		3.900	Surge protection system and all accessories needed – surge protection tank, pressure valves, system control, interface with existing system, etc.	LS	1	2,908,206	2,908,206
						Subtotal	**2,908,206**
			Total – Section 3				**24,790,177**
			Total – Phase III works				**413,266,803**
			GRAND TOTAL – All works for Immediate Phase and Phases I, II and III				**893,750,333**

Annex 6

Financial and Economic Analyses

Annex 6a

Financial Analysis Cash Flow

Year		2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Investment US$ (Millions)		0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	3.43	3.43	5.35	5.31	5.28	6.41
Grants US$ (Millions)															
Investments after grants deduction		0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	3.43	3.43	5.35	5.31	5.28	6.41
Interest rate for capitalization		1	1.2	1.3	1.5	1.6	1.8	1.9	2.1	2.4	2.6	2.9	3.1	3.5	3.8
Annual Investment after capitalization		0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	1.5	1.3	1.9	1.7	1.5	1.7
Total Investment (NPV)	71.32														
Annual water capacity (mcm)	525.36	-	-	7.30	7.30	7.30	7.30	7.30	75.19	75.19	75.19	75.19	75.19	100.74	100.74
Annual water demand (mcm)	640.77	22.35	25.90	29.45	33.61	37.77	41.92	46.08	50.24	57.14	64.05	70.95	77.86	84.77	89.99
Annual water supply (mcm) min(capacity,	489.46	-	-	7.30	7.30	7.30	7.30	7.30	50.24	57.14	64.05	70.95	75.19	84.77	89.99
Average Capital Cost per m3 (US$/m3)	525.36	-	-	7.30	7.30	7.30	7.30	7.30	75.19	75.19	75.19	75.19	75.19	100.74	100.74

Continued Financial analysis cash flow

2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041
15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
6.37	6.33	6.30	6.26	22.27	21.92	25.71	25.37	25.03	30.80	30.34	29.88	29.42	28.96	28.50
6.37	6.33	6.30	6.26	22.27	21.92	25.71	25.37	25.03	30.80	30.34	29.88	29.42	28.96	28.50
4.2	4.6	5.1	5.6	6.1	6.7	7.4	8.1	9.0	9.8	10.8	11.9	13.1	14.4	15.9
1.5	1.4	1.2	1.1	3.6	3.3	3.5	3.1	2.8	3.1	2.8	2.5	2.2	2.0	1.8
100.74	100.74	100.74	100.74	100.74	100.74	100.74	100.74	139.07	139.07	139.07	139.07	139.07	139.07	139.07
95.20697	100.4279	105.6489	110.8698	116.1638	121.4578	126.7517	132.0457	137.3396	137.3396	137.3396	137.3396	137.3396	137.3396	137.3396
95.20697	100.4279	100.74	100.74	100.74	100.74	100.74	100.74	137.3396	137.3396	137.3396	137.3396	137.3396	137.3396	137.3396

Continued Financial analysis cash flow

2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056
30	31	32	33	34	35	36	37	38	39	40	41	42	43	44
28.04	49.21	48.33	47.46	46.59	45.71	44.84	43.97	43.09	42.22	41.35	39.29	38.45	37.61	36.78
28.04	49.21	48.33	47.46	46.59	45.71	44.84	43.97	43.09	42.22	41.35	39.29	38.45	37.61	36.78
17.4	19.2	21.1	23.2	25.5	28.1	30.9	34.0	37.4	41.1	45.3	49.8	54.8	60.2	66.3
1.6	2.6	2.3	2.0	1.8	1.6	1.5	1.3	1.2	1.0	0.9	0.8	0.7	0.6	0.6
139.07	139.07	139.07	139.07	139.07	139.07	139.07	139.07	139.07	139.07	139.07	139.07	139.07	139.07	139.07
137.3396	137.3396	137.3396	137.3396	137.3396	137.3396	137.3396	137.3396	137.3396	137.3396	137.3396	137.3396	137.3396	137.3396	137.3396
137.3396	137.3396	137.3396	137.3396	137.3396	137.3396	137.3396	137.3396	137.3396	137.3396	137.3396	137.3396	137.3396	137.3396	137.3396

Continued Financial analysis cash flow

2057	2058	2059	2060	2061	2062
45	46	47	48	49	50
35.94	35.10	34.27	33.43	22.68	167.10
35.94	35.10	34.27	33.43	22.68	167.10
72.9	80.2	88.2	97.0	106.7	117.4
0.5	0.4	0.4	0.3	0.2	1.4
139.07	139.07	139.07	139.07	139.07	139.07
137.3396	137.3396	137.3396	137.3396	137.3396	137.3396
137.3396	137.3396	137.3396	137.3396	137.3396	137.3396

Annex 6 A Financial Analysis O&M

Year		2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
O&M annual costs US$ (Millions)		0.24	1.08	1.69	2.29	2.90	2.90	2.90	2.90	2.90	3.35	3.80	3.80	3.80	4.22
Energy annual costs US$ (Millions)		-	-	1.44	1.44	1.44	1.44	1.44	5.17	5.17	5.17	5.17	8.11	8.11	8.11
Sum of O&M + energy annual costs US$ (Mill.)		0.24	1.08	3.12	3.73	4.33	4.33	4.33	8.06	8.06	8.51	8.96	11.91	11.91	12.34
Interest rate for capitalization		1.10	1.21	1.33	1.46	1.61	1.77	1.95	2.14	2.36	2.59	2.85	3.14	3.45	3.80
Annual O&M + energy after capitalization		0.22	0.89	2.35	2.55	2.69	2.45	2.22	3.76	3.42	3.28	3.14	3.79	3.45	3.25
Total Costs O&M (NPV)	30.43														
Total Costs energy (NPV)	42.04														
Annual water supply (mcm)	489.45	0	0	7.3	7.3	7.3	7.3	7.3	50.23	57.14	64.04	70.95	75.19	84.76	89.98
Average O&M per m3 (US$/m3)	0.062														
Average energy per m3 (US$/m3)	0.085														

Continued Financial Analysis O&M

2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041
15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
4.6498	5.07	5.07	5.07	5.07	5.07	5.119	5.16	5.16	5.16	5.16	5.16	5.16	5.16	5.16
8.113	8.1	8.11	8.62	8.62	8.62	8.62	8.62	8.99	8.99	8.99	8.99	8.99	8.99	8.99
12.763	13.18	13.18	13.70	13.70	13.70	13.74	13.78	14.15	14.15	14.15	14.15	14.15	14.15	14.15
4.1772	4.59	5.05	5.55	6.11	6.72	7.40	8.14	8.95	9.84	10.83	11.91	13.11	14.42	15.86
3.0553	2.87	2.61	2.46	2.24	2.03	1.85	1.69	1.58	1.43	1.30	1.18	1.07	0.98	0.89
95.20	100.42	100.74	100.74	100.74	100.74	100.74	100.74	137.33	137.33	137.33	137.33	137.33	137.33	137.33

Continued Financial Analysis O&M

2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056
30	31	32	33	34	35	36	37	38	39	40	41	42	43	44
5.16	5.16	5.16	5.16	5.16	5.16	5.16	5.16	5.16	5.16	5.16	5.16	5.16	5.16	5.16
8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99
14.15	14.15	14.15	14.15	14.15	14.15	14.15	14.15	14.15	14.15	14.15	14.15	14.15	14.15	14.15
17.44	17.44	17.44	17.44	17.44	17.44	17.44	17.44	17.44	17.44	17.44	17.44	17.44	17.44	17.44
0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81
137.33	137.33	137.33	137.33	137.33	137.33	137.33	137.33	137.33	137.33	137.33	137.33	137.33	137.33	137.33

Continued Financial Analysis O&M

2057	2058	2059	2060	2061	2062
45	46	47	48	49	50
5.16	5.16	5.16	5.16	5.16	5.16
8.99	8.99	8.99	8.99	8.99	8.99
14.15	14.15	14.15	14.15	14.15	14.15
72.89	80.17	88.19	97.01	106.71	117.39
0.194	0.17	0.16	0.14	0.13	0.120
137.33	137.33	137.33	137.33	137.33	137.33

Appendix 6A Amortization

Loan 1

Sum of Loan (M. U.S. $)	36.630				
Year	Annual Refund (Fund only)	Accumulated Refund (fund	Annual Balance for Interest	Annual Interest	Sum of annual refund (Fund &
2013	-	-	36.6	0.4	0.4
2014	-	-	36.6	0.4	0.4
2015	-	-	36.6	0.4	0.4
2016	-	-	36.6	0.4	0.4
2017	-	-	36.6	0.4	0.4
2018	-	-	36.6	0.4	0.4
2019	-	-	36.6	0.4	0.4
2020	-	-	36.6	0.4	0.4
2021	-	-	36.6	0.4	0.4
2022	-	-	36.6	0.4	0.4
2023	1.2	1.2	35.4	1.1	2.3
2024	1.2	2.4	34.2	1.0	2.2
2025	1.2	3.7	33.0	1.0	2.2
2026	1.2	4.9	31.7	1.0	2.2
2027	1.2	6.1	30.5	0.9	2.1
2028	1.2	7.3	29.3	0.9	2.1
2029	1.2	8.5	28.1	0.8	2.1
2030	1.2	9.8	26.9	0.8	2.0
2031	1.2	11.0	25.6	0.8	2.0
2032	1.2	12.2	24.4	0.7	2.0
2033	1.2	13.4	23.2	0.7	1.9
2034	1.2	14.7	22.0	0.7	1.9
2035	1.2	15.9	20.8	0.6	1.8
2036	1.2	17.1	19.5	0.6	1.8
2037	1.2	18.3	18.3	0.5	1.8
2038	1.2	19.5	17.1	0.5	1.7
2039	1.2	20.8	15.9	0.5	1.7
2040	1.2	22.0	14.7	0.4	1.7
2041	1.2	23.2	13.4	0.4	1.6
2042	1.2	24.4	12.2	0.4	1.6
2043	1.2	25.6	11.0	0.3	1.6
2044	1.2	26.9	9.8	0.3	1.5
2045	1.2	28.1	8.5	0.3	1.5
2046	1.2	29.3	7.3	0.2	1.4
2047	1.2	30.5	6.1	0.2	1.4
2048	1.2	31.7	4.9	0.1	1.4
2049	1.2	33.0	3.7	0.1	1.3
2050	1.2	34.2	2.4	0.1	1.3
2051	1.2	35.4	1.2	0.0	1.3
2052	1.2	36.6	-	-	1.2
SUM					56

Loan 2

Sum of Loan (M. U.S. $)	306.57				
Year	Annual Refund (Fund only)	Accumulated Refund (fund	Annual Balance for Interest	Annual Interest	Sum of annual refund (Fund &
2021	0	0	3.06	3.06	3.06
2022	0	0	3.06	3.06	3.06
2023	0	0	3.06	3.06	3.06
2024	0	0	3.06	3.06	3.06
2025	0	0	3.06	3.06	3.06
2026	0	0	3.06	3.06	3.06
2027	0	0	3.06	3.06	3.06
2028	0	0	3.06	3.06	3.06
2029	0	0	3.06	3.06	3.06
2030	0	0	3.06	3.06	3.06
2031	10.21	10.21	296.35	8.89	19.10
2032	10.21	20.43	286.13	8.58	18.80
2033	10.21	30.65	275.91	8.27	18.49
2034	10.21	40.87	265.69	7.97	18.18
2035	10.21	51.09	255.47	7.66	17.88
2036	10.21	61.31	245.25	7.35	17.57
2037	10.21	71.53	235.03	7.05	17.27
2038	10.21	81.75	224.81	6.74	16.96
2039	10.21	91.97	214.59	6.43	16.65
2040	10.21	102.19	204.38	6.13	16.35
2041	10.21	112.40	194.16	5.82	16.04
2042	10.21	122.62	183.94	5.51	15.73
2043	10.21	132.84	173.72	5.21	15.43
2044	10.21	143.06	163.50	4.90	15.12
2045	10.21	153.28	153.28	4.59	14.81
2046	10.21	163.50	143.06	4.29	14.51
2047	10.21	173.72	132.84	3.98	14.20
2048	10.21	183.94	122.62	3.67	13.89
2049	10.21	194.16	112.40	3.37	13.59
2050	10.21	204.38	102.19	3.06	13.28
2051	10.21	214.59	91.97	2.75	12.97
2052	10.21	224.81	81.75	2.45	12.67
2053	10.21	235.03	71.53	2.14	12.36
2054	10.21	245.25	61.31	1.83	12.05
2055	10.21	255.47	51.09	1.53	11.75
2056	10.21	265.69	40.87	1.22	11.44
2057	10.21	275.91	30.65	0.91	11.13
2058	10.21	286.13	20.43	0.61	10.83
2059	10.21	296.35	10.21	0.30	10.52
2060	10.21	306.57	0	0	10.21
SUM					470.58

Loan 3

Sum of Loan (M. U.S. $)	116.82				
Year	Annual Refund (Fund only)	Accumulated Refund (fund	Annual Balance for Interest	Annual Interest	Sum of annual refund (Fund & Interest)
2026	0	0	116.82	1.16	1.16
2027	0	0	116.82	1.16	1.16
2028	0	0	116.82	1.16	1.16
2029	0	0	116.82	1.16	1.16
2030	0	0	116.82	1.16	1.16
2031	0	0	116.82	1.16	1.16
2032	0	0	116.82	1.16	1.16
2033	0	0	116.82	1.16	1.16
2034	0	0	116.82	1.16	1.16
2035	0	0	116.82	1.16	1.16
2036	3.89	3.89	112.92	3.38	7.28
2037	3.89	7.78	109.03	3.27	7.16
2038	3.89	11.68	105.13	3.15	7.04
2039	3.89	15.57	101.24	3.03	6.93
2040	3.89	19.47	97.35	2.92	6.81
2041	3.89	23.36	93.45	2.80	6.69
2042	3.89	27.25	89.56	2.68	6.58
2043	3.89	31.15	85.66	2.57	6.46
2044	3.89	35.04	81.77	2.45	6.34
2045	3.89	38.94	77.88	2.33	6.23
2046	3.89	42.83	73.98	2.21	6.11
2047	3.89	46.72	70.09	2.10	5.99
2048	3.89	50.62	66.19	1.98	5.87
2049	3.89	54.51	62.30	1.86	5.76
2050	3.89	58.41	58.41	1.75	5.64
2051	3.89	62.30	54.51	1.63	5.52
2052	3.89	66.19	50.62	1.51	5.41
2053	3.89	70.09	46.72	1.40	5.29
2054	3.89	73.98	42.83	1.28	5.17
2055	3.89	77.88	38.94	1.16	5.06
2056	3.89	81.77	35.04	1.05	4.94
2057	3.89	85.66	31.15	0.93	4.82
2058	3.89	89.56	27.25	0.81	4.71
2059	3.89	93.45	23.36	0.70	4.59
2060	3.89	97.35	19.47	0.58	4.47
2061	3.89	101.24	15.57	0.46	4.36
2062	15.57	116.82	0	0	15.57
2063					
2064					
2065					
SUM					178.61

Loan 4

Sum of Loan (M. U.S. $)	413.26				
Year	Annual Refund (Fund only)	Accumulated Refund (fund	Annual Balance for Interest	Annual Interest	Sum of annual refund (Fund & Interest)
2033	0	0	413.26	4.13	4.13
2034	0	0	413.26	4.13	4.13
2035	0	0	413.26	4.13	4.13
2036	0	0	413.26	4.13	4.13
2037	0	0	413.26	4.13	4.13
2038	0	0	413.26	4.13	4.13
2039	0	0	413.26	4.13	4.13
2040	0	0	413.26	4.13	4.13
2041	0	0	413.26	4.13	4.13
2042	0	0	413.26	4.13	4.13
2043	13.77	13.77	399.48	11.98	25.75
2044	13.77	27.55	385.70	11.57	25.34
2045	13.77	41.32	371.93	11.15	24.93
2046	13.77	55.10	358.15	10.74	24.52
2047	13.77	68.87	344.38	10.3	24.10
2048	13.77	82.65	330.60	9.91	23.69
2049	13.77	96.42	316.83	9.50	23.28
2050	13.77	110.20	303.05	9.09	22.86
2051	13.77	123.97	289.28	8.67	22.45
2052	13.77	137.75	275.50	8.26	22.04
2053	13.77	151.52	261.73	7.85	21.62
2054	13.77	165.30	247.95	7.43	21.21
2055	13.77	179.07	234.18	7.02	20.80
2056	13.77	192.85	220.40	6.61	20.38
2057	13.77	206.63	206.63	6.19	19.97
2058	13.77	220.40	192.85	5.78	19.56
2059	13.77	234.18	179.07	5.37	19.14
2060	13.77	247.95	165.30	4.95	18.73
2061	13.77	261.73	151.52	4.54	18.32
2062	151.52	413.26	0	0	151.52
2063					
2064					
2065					
2066					
2067					
2068					
2069					
2070					
2071					
2072					
SUM					611.6248

Annex 6 B

Economic Analysis Cash Flow

Year		2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Investment US$ (Millions)			12.2	12.2	12.2			46.09	102.19	102.19	56.09		38.94	38.94	38.94
Investment US$ (Millions) after SCF		0	10.98	10.98	10.98	0	0	41.48	91.97	91.97	50.48	0	35.04	35.04	35.04
Interest rate for capitalization		1.1	1.21	1.331	1.46	1.61	1.77	1.94	2.14	2.35	2.59	2.85	3.13	3.45	3.79
Annual Investment after capitalization		0	9.07	8.24	7.49	0	0	21.28	42.90	39.00	19.46	0	11.16	10.15	9.22
Total Investment (NPV)	219.69														
Annual water capacity (mcm)	525.36	0	0	7.3	7.3	7.3	7.3	7.3	75.19	75.19	75.19	75.19	75.19	100.74	100.74
Annual water demand (mcm)	640.77	22.35	25.90	29.45	33.61	37.76	41.92	46.08	50.23	57.14	64.04	70.95	77.85	84.76	89.98
Annual water supply (mcm) min(capacity,	489.45	0	0	7.3	7.3	7.3	7.3	7.3	50.23	57.14	64.04	70.95	75.19	84.76	89.98
Average Capital Cost per m3 (US$/m3)	0.44														

Continued Economic Analysis Cash Flow

2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041
15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
							137.75	137.75	137.75					
0	0	0	0	0	0	0	123.97	123.97	123.97	0	0	0	0	0
4.17	4.59	5.05	5.55	6.11	6.72	7.40	8.14	8.95	9.84	10.83	11.91	13.10	14.42	15.86
0	0	0	0	0	0	0	15.23	13.84	12.58	0	0	0	0	0
15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
100.74	100.74	100.74	100.74	100.74	100.74	100.74	100.74	139.07	139.07	139.07	139.07	139.07	139.07	139.07
95.20	100.42	105.64	110.86	116.16	121.45	126.75	132.04	137.33	137.33	137.3	137.33	137.33	137.33	137.33
95.20	100.42	100.74	100.74	100.74	100.74	100.74	100.74	137.33	137.33	137.33	137.33	137.33	137.33	137.33

Continued Economic Analysis Cash Flow

2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056
30	31	32	33	34	35	36	37	38	39	40	41	42	43	44
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17.44	19.19	21.11	23.22	25.54	28.10	30.91	34.00	37.40	41.14	45.25	49.78	54.76	60.240	66.26
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
139.07	139.07	139.07	139.07	139.07	139.07	139.07	139.07	139.07	139.07	139.07	139.07	139.07	139.07	139.07
137.33	137.33	137.33	137.33	137.3	137.33	137.33	137.33	137.33	137.33	137.33	137.33	137.33	137.33	137.33
137.33	137.33	137.33	137.33	137.33	137.33	137.33	137.33	137.33	137.33	137.33	137.33	137.33	137.33	137.33

Continued Economic Analysis Cash Flow

2057	2058	2059	2060	2061	2062
45	46	47	48	49	50
0	0	0	0	0	0
72.89	80.17953205	88.19	97.017	106.71	117.39
0	0	0	0	0	0
139.07	139.07	139.07	139.07	139.07	139.07
137.33	137.33	137.33	137.33	137.33	137.33
137.33	137.33	137.33	137.33	137.33	137.33

Economic Analysis O&M

Year		2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
O&M annual costs US$ (Millions)		0.24	1.08	1.69	2.29	2.90	2.90	2.90	2.90	2.90	3.35	3.80	3.80	3.80	4.22
Energy annual costs US$ (Millions)		-	-	1.44	1.44	1.44	1.44	1.44	5.17	5.17	5.17	5.17	8.11	8.11	8.11
Sum of O&M + energy annual costs US$ (Millions)		0.24	1.08	3.12	3.73	4.33	4.33	4.33	8.06	8.06	8.51	8.96	11.91	11.91	12.34
Interest rate for capitalization		1.10	1.21	1.33	1.46	1.61	1.77	1.95	2.14	2.36	2.59	2.85	3.14	3.45	3.80
Annual O&M + energy after capitalization		0.22	0.89	2.35	2.55	2.69	2.45	2.22	3.76	3.42	3.28	3.14	3.79	3.45	3.25
Total Costs O&M (NPV) after SCF	27.39														
Total Costs energy (NPV) after SCF	37.84														
Annual water supply (mcm)	489.46	-	-	7.30	7.30	7.30		7.30							89.99
Average O&M per m3 (US$/m3)	0.06														
Average energy per m3 (US$/m3)	0.08														

Continued Economic Analysis O&M

2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041
15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
4.65	5.08	5.08	5.08	5.08	5.08	5.12	5.16	5.16	5.16	5.16	5.16	5.16	5.16	5.16
8.11	8.11	8.11	8.63	8.63	8.63	8.63	8.63	8.99	8.99	8.99	8.99	8.99	8.99	8.99
12.76	13.19	13.19	13.70	13.70	13.70	13.75	13.79	14.15	14.15	14.15	14.15	14.15	14.15	14.15
4.18	4.59	5.05	5.56	6.12	6.73	7.40	8.14	8.95	9.85	10.83	11.92	13.11	14.42	15.86
3.06	2.87	2.61	2.46	2.24	2.04	1.86	1.69	1.58	1.44	1.31	1.19	1.08	0.98	0.89
95.21	100.43	100.74	100.74	100.74	100.74	100.74	100.74	137.34	137.34	137.34	137.34	137.34	137.34	137.34

Continued Economic Analysis O&M

2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056
30	31	32	33	34	35	36	37	38	39	40	41	42	43	44
5.16	5.16	5.16	5.16	5.16	5.16	5.16	5.16	5.16	5.16	5.16	5.16	5.16	5.16	5.16
8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99	8.99
14.15	14.15	14.15	14.15	14.15	14.15	14.15	14.15	14.15	14.15	14.15	14.15	14.15	14.15	14.15
17.45	19.19	21.11	23.23	25.55	28.10	30.91	34.00	37.40	41.14	45.26	49.79	54.76	60.24	66.26
0.81	0.74	0.67	0.61	0.55	0.50	0.46	0.42	0.38	0.34	0.31	0.28	0.26	0.23	0.21
137.33	137.33	137.33	137.33	137.33	137.33	137.33	137.33	137.33	137.33	137.33	137.33	137.33	137.33	137.33

Continued Economic Analysis O&M

2057	2058	2059	2060	2061	2062
45	46	47	48	49	50
5.16	5.16	5.16	5.16	5.16	5.16
8.99	8.99	8.99	8.99	8.99	8.99
14.15	14.15	14.15	14.15	14.15	14.15
72.89	80.18	88.20	97.02	106.72	117.39
0.19	0.18	0.16	0.15	0.13	0.12
137.34	137.34	137.34	137.34	137.34	137.34

Appendix 6B

Economic Criteria NPV IRR

Year	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Investment US$ (Millions) after SCF	-	10.98	10.98	10.98	-	-	41.48	91.97	91.97	50.49	-	35.05	35.05	35.05
Annual O&M Costs (Millions)	0.21	0.97	2.81	3.36	3.90	3.90	3.90	7.26	7.26	7.66	8.07	10.72	10.72	11.10
Total Annual Costs US$ (Millions)	0.21	11.95	13.79	14.34	3.90	3.90	45.38	99.23	99.23	58.15	8.07	45.76	45.76	46.15
Annual water supply (mcm)	-	-	7.30	7.30	7.30	7.30	7.30	50.24	57.14	64.05	70.95	75.19	84.77	89.99
M3 Unit Price (US$)	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Total Annual Income US$ (Millions)	0	0	2.1681	2.1681	2.1681	2.1681	2.1681	14.9205	16.97	19.02	21.07	22.33	25.17	26.7258
Net Income	-0.21	-11.95	-11.62	-12.17	-1.73	-1.73	-43.22	-84.31	-82.26	-39.13	13.01	-23.43	-20.59	-19.42
Interest rate for capitalization	90.9%	82.6%	75.1%	68.30%	62.0%	56.4%	51.3%	46.6%	42.4%	38.5%	35.0%	31.8%	28.9%	26.33%
Annual Costs after capitalization	-0.20	-9.88	-8.73	-8.31	-1.08	-0.98	-22.18	-39.33	-34.88	-15.09	4.56	-7.47	-5.96	-5.11

ENPV	-140		Interest Rate
EIRR	1.5%		10%

Continued Economic Criteria NPV IRR

2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041
15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
-	-	-	-	-	-	-	123.98	123.98	123.98	-	-	-	-	-
11.49	11.87	11.87	12.33	12.33	12.33	12.37	12.41	12.74	12.74	12.74	12.74	12.74	12.74	12.74
11.49	11.87	11.87	12.33	12.33	12.33	12.37	136	137	137	13	13	13	13	13
95.21	100.43	100.74	100.74	100.74	100.74	100.74	100.74	137.34	137.34	137.34	137.34	137.34	137.34	137.34
0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
28.27	29.82	29.91	29.91	29.91	29.91	29.91	29.91	40.78	40.78	40.78	40.78	40.78	40.78	40.78
16.79	17.96	18.05	17.59	17.59	17.59	17.55	-106.47	-95.93	-95.93	28.05	28.05	28.05	28.05	28.05
23.9%	21.7%	19.7%	17.9%	16.3%	14.8%	13.5%	12.2%	11.1%	10.1%	9.2%	8.3%	7.6%	6.9%	6.3%

Continued Economic Criteria NPV IRR

2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056
30	31	32	33	34	35	36	37	38	39	40	41	42	43	44
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12.74	12.74	12.74	12.74	12.74	12.74	12.74	12.74	12.74	12.74	12.74	12.74	12.74	12.74	12.74
13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
137.34	137.34	137.34	137.34	137.34	137.34	137.34	137.34	137.34	137.34	137.34	137.34	137.34	137.34	137.34
0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
40.78	40.78	40.78	40.78	40.78	40.78	40.78	40.78	40.78	40.78	40.78	40.78	40.78	40.78	40.78
28.05	28.05	28.05	28.05	28.05	28.05	28.05	28.05	28.05	28.05	28.05	28.05	28.05	28.05	28.05
5.73%	5.21%	4.74%	4.31%	3.91%	3.56%	3.23%	2.94%	2.67%	2.43%	2.21%	2.01%	1.83%	1.66%	1.51%
1.61	1.46	1.33	1.21	1.10	1.00	0.91	0.82	0.75	0.68	0.62	0.56	0.51	0.47	0.42

Continued Economic Criteria NPV IRR

2057	2058	2059	2060	2061	2062
45	46	47	48	49	50
-	-	-	-	-	-
12.74	12.74	12.74	12.74	12.74	12.74
13	13	13	13	13	13
137.34	137.34	137.34	137.34	137.34	137.34
0.30	0.30	0.30	0.30	0.30	0.30
40.78	40.78	40.78	40.78	40.78	40.78
28.05	28.05	28.05	28.05	28.05	28.05
1.37%	1.25%	1.13%	1.03%	0.94%	0.85%
0.38	0.35	0.32	0.29	0.26	0.24

Annex 7

Storage Capacity

Appendix 7: Analysis and Estimation of the Required Storage Capacity of a Water System

The required storage (reservoir) capacity of the water system is estimated according to the following factors:

- The size of the locality/town,
- The number of daily hours of production,
- The demand pattern.

The size of the town is the main governing parameter of the demand pattern, or the hourly distribution of the ratio between the effective demand Q_h and the average demand Q_{av} throughout the day; this ratio may vary between 0.15-2.4 for towns with population < 5,000 inhabitants to 0.35-1.7 for towns with population < 100,000 inhabitants.

- The required storage volume V_{st} is calculated as the sum of the following two components:

- Net required storage capacity; this is the minimum required storage capacity of the reservoir which abides by the condition that it does not run dry;

Reserve capacity; this an additional capacity which represents 1-2 hours of the average demand Q_{av}: 1h for 20 hours of daily production and 2h for 12 hours of daily production.

Four categories have been selected for the pattern of production: 24, 20, 16 and 12 hours/day. With all the above assumptions, the calculations show that:

- V_{st}/ $V_{d\ av}$ varies between 0.24-0.17 for 20 hours of daily production and is bigger for small towns;
- V_{st}/ $V_{d\ av}$ varies between 0.31-0.37 for 12 hours of daily production and is bigger for big towns.

The detailed results and steps involved in the estimations are shown in the table below.

Required System Storage Capacity Calculations

n	Required Net Storage Capacity $V_{av}/V_{d\,av}$					Reserve Capacity $V_{res}/V_{d\,av}$	Required Total Storage Capacity $V_{st}/V_{d\,av}$				
	Town population < 5,000	Town population 5,000-10,000	Town population 10,000-50,000	Town population 50,000-100,000	Town population > 100,000		Town population < 5,000	Town population 5,000-10,000	Town population 10,000-50,000	Town population 50,000-100,000	Town population > 100,000
24	0.306	0.281	0.261	0.243	0.234	0.041	0.347	0.322	0.302	0.284	0.275
20	0.199	0.170	0.159	0.146	0.128	0.041	0.240	0.211	0.200	0.187	0.169
16	0.111	0.129	0.129	0.129	0.129	0.062	0.173	0.191	0.191	0.191	0.191
12	0.228	0.241	0.255	0.263	0.282	0.083	0.311	0.324	0.338	0.346	0.365

LEGEND

Q_{av} - average demand flowrate

$Q_{d\,av}$ – average daily demand flowrate

Q_h - demand flowrate

Q_s - supplied flowrate

V_{av}- available/necessary water volume in storage capacity

V_d- daily average water demand

V_{res}- emergency reserve water demand

V_{st}- necessary storage volume

n- number of operation daily hours of water supply

Peak Hour Demand Coefficient (Q_h/Q_{av})

Hour	Town population < 5,000	Town population 5,000-10,000	Town population 10,000-50,000	Town population 50,000-100,000	Town population > 100,000
0-1	0.15	0.2	0.25	0.3	0.35
1-2	0.15	0.2	0.25	0.3	0.35
2-3	0.15	0.2	0.25	0.3	0.35
3-4	0.15	0.2	0.25	0.3	0.35
4-5	0.2	0.3	0.3	0.3	0.3
5-6	0.5	0.55	0.6	0.6	0.6
6-7	1	1	1	1	1
7-8	2.4	2.2	2	1.9	1.7
8-9	1.8	1.7	1.7	1.7	1.7
9-10	1.6	1.6	1.6	1.6	1.55
10-11	1.5	1.5	1.5	1.5	1.45
11-12	1.4	1.4	1.4	1.4	1.4
12-13	1.4	1.4	1.4	1.4	1.4
13-14	1.3	1.3	1.3	1.3	1.3
14-15	1.3	1.3	1.3	1.3	1.3
15-16	1.6	1.5	1.45	1.4	1.4
16-17	1.7	1.6	1.6	1.5	1.5
17-18	1.7	1.65	1.6	1.5	1.4
18-19	1.4	1.3	1.25	1.2	1.2
19-20	1.1	1.1	1.1	1.1	1.1
20-21	0.5	0.55	0.6	0.7	0.8
21-22	0.5	0.55	0.6	0.7	0.8
22-23	0.3	0.4	0.4	0.4	0.4
23-24	0.2	0.3	0.3	0.3	0.3
Total	**24**	**24**	**24**	**24**	**24**

Annex 8

Multicriteria Analysis

Annex 8 – Multi-Criteria Analysis

(originally submitted in Full Feasibility Report)

1.1 Background

Selection of the optimal water supply solution entails issues which are beyond the traditional engineering and economic considerations.

The Multi Criteria analysis provides a systematic approach that enables a more objective evaluation of the scenarios on disciplines which are not quantitative such as environmental or social parameters. In recent years, multi-criteria analysis has become an invaluable tool for the evaluation of different scenarios. Each indicator of the design is allocated a different weight that reflects the importance that the stakeholder or the expert assigns to it.

Four main filed of interests (also called "parameters") were selected for comparison and weighting. They are deemed the most appropriate by the stakeholders and the experts: variables within each one of the parameters are named indicators:

- Engineering aspects.
- Financial and economic considerations.
- Environmental considerations.
- Social & Political aspects.

Table 0-1: Classification and Weighting of Parameters and Indicators for

Criteria / Parameter	**Assigned Weights**
A. Engineering Sustainability	**30%**
Feasibility of implementation	40%
Reliability of Resources	30%
Diversity of Resources	30%
B. Economic Considerations	**40%**
NPV	20%
IRR	35%
O&M Costs	10%
Calculated Water Cost	35%
C. Environmental Issues	**15%**
Water Quality	30%
Downstream Impact	30%
Energy Consumption	30%
Construction Effects	10%
D. Social & Political aspects	**15%**
Supply Coverage	30%
Resettlement / Income Loss	40%
Political acceptability	30%

1.2 Results

Table 0-2 presents the final results and the weighted average of each scenario. Scenario B1 has the highest overall score of 76.8, followed by B5.

Table 0-2: Multi-Criteria Analysis for Bulk Water Supply

Item	Criteria / Parameter	Classification	Inner Weighting	Scenario				
				B1	B1.1	B3	B5	C1
1.0	**Engineering Sustainability**	30%						
1.1	Feasibility of implementation		40%	80	70	50	65	50
1.2	Reliability of Resources		30%	90	70	70	60	90
1.3	Diversity of Resources		30%	90	80	80	20	100
	Engineering Summary			86	73	65	50	77
2.0	**Economic Considerations**	40%						
2.1	NPV		20%	47	13	0	100	26
2.2	IRR		35%	80	31	19	100	0
2.3	O&M Costs		10%	83	76	85	100	31
2.4	Calculated Water Cost		35%	86	79	78	100	79
	Economic Summary			76	49	42	100	36
3.0	**Environmental Issues**	15%						
3.1	Water Quality		30%	90	70	70	50	95
3.2	Downstream Impact		30%	60	60	70	50	60
3.3	Energy Consumption		30%	90	70	70	80	50
3.4	Construction Effects		10%	60	60	70	80	50
	Environmental Summary			78	66	70	62	67
4.0	**Social & Political Aspects**	15%						
4.1	Supply Coverage		30%	100	80	80	80	80
4.2	Resettlement / Income Loss		40%	80	70	70	50	60
4.3	Political acceptability		30%	100	90	50	50	30
	Social Summary			**60**	**51**	**39**	**39**	**33**
	Total	**100%**		**76.8**	**59.0**	**52.8**	**70.2**	**52.4**
	Rank			**1**	**3**	**4**	**2**	**5**

Scenario B5 has the highest score regarding financial & economic aspects (lowest investment and lowest O&M costs), but the lowest engineering and environmental score.

Table 0-3: Multi-Criteria Analysis for Bulk Water Supply (Engineering priority)

Criteria	Classification	Scenario B1	Scenario B1.1	Scenario B3	Scenario B5	Scenario C2
Engineering Sustainability	**45%**	**86**	**73**	**65**	**50**	**77**
Economic Considerations	**25%**	**76**	**49**	**42**	**100**	**36**
Environmental Issues	**15%**	**78**	**66**	**70**	**62**	**66.5**
Social & Political Issues	**15%**	**60**	**51**	**39**	**39**	**33**
Total	**100%**	**78.4**	**62.6**	**56.2**	**62.7**	**58.6**
Rank		**1**	**3**	**5**	**2**	**4**

Table 0-4: Multi-Criteria Analysis for Bulk Water Supply (Environmental priority)

Criteria	Classification	Scenario B1	Scenario B1.1	Scenario B3	Scenario B5	Scenario C2
Engineering Sustainability	20%	86	73	65	50	77
Economic Considerations	30%	76	49	42	100	36
Environmental Issues	**40%**	78	66	70	62	66.5
Social & Political Issues	10%	60	51	39	39	33
Total	**100%**	**77.1**	**60.8**	**57.6**	**68.7**	**56.1**
Rank		**1**	**3**	**4**	**2**	**5**

Table 0-5: Multi-Criteria Analysis for Bulk Water Supply (Social & Political priority)

Criteria	Classification	Scenario B1	Scenario B1.1	Scenario B3	Scenario B5	Scenario C2
Engineering Sustainability	20%	86	73	65	50	77
Economic Considerations	30%	76	49	42	100	36
Environmental Issues	10%	78	66	70	62	66.5
Social & Political Issues	**40%**	60	51	39	39	33
Total	**100%**	**71.7**	**56.3**	**48.3**	**61.8**	**46.1**
Rank		**1**	**3**	**4**	**2**	**5**

Table 6.6 presents the final results and the weighted average of the development scenarios for the Lamu area. The Garsen scenario has the highest overall score of 64.6, followed by the Nanighi scenario with an overall score of 49.4.

Table 0-6: Multi-Criteria Analysis for the Lamu Area

Item	Criteria	Classification	Inner Weighting	Nanighi Scenario	Garsen Scenario	Desalination Scenario
1.0	**Engineering Sustainability**	30%				
1.1	Feasibility of implementation		40%	40	60	100
1.3	Reliability of resources		30%	80	70	100
1.4	Diversity of resources		30%	0	0	0
	Engineering Summary		100%	**40**	**45**	**70**
2.0	**Economic Considerations**	40%				
2.1	NPV		20%	32	100	0
2.2	IRR		35%	86	100	0
2.3	O&M costs		10%	36	100	47
2.4	Calculated water cost		35%	95	100	57
	Economic Summary		100%	**40**	**65**	**5**
3.0	**Environmental Issues**	15%				
3.1	Water quality		30%	80	70	100
3.2	Downstream impact		30%	50	70	70
3.3	Energy consumption		30%	100	60	40
3.4	Construction period		10%	60	60	50
	Environmental Summary		100%	**75**	**66**	**68**
4.0	**Social Issues**	15%				
4.1	Supply coverage		30%	100	90	70
4.2	Resettlement / income loss		40%	80	70	70
4.3	Political acceptability		30%	90	80	50
	Social Summary		100%	**90**	**86**	**56**
	Total	**100%**		**52.8**	**62.3**	**41.5**
	Rank			**2**	**1**	**3**