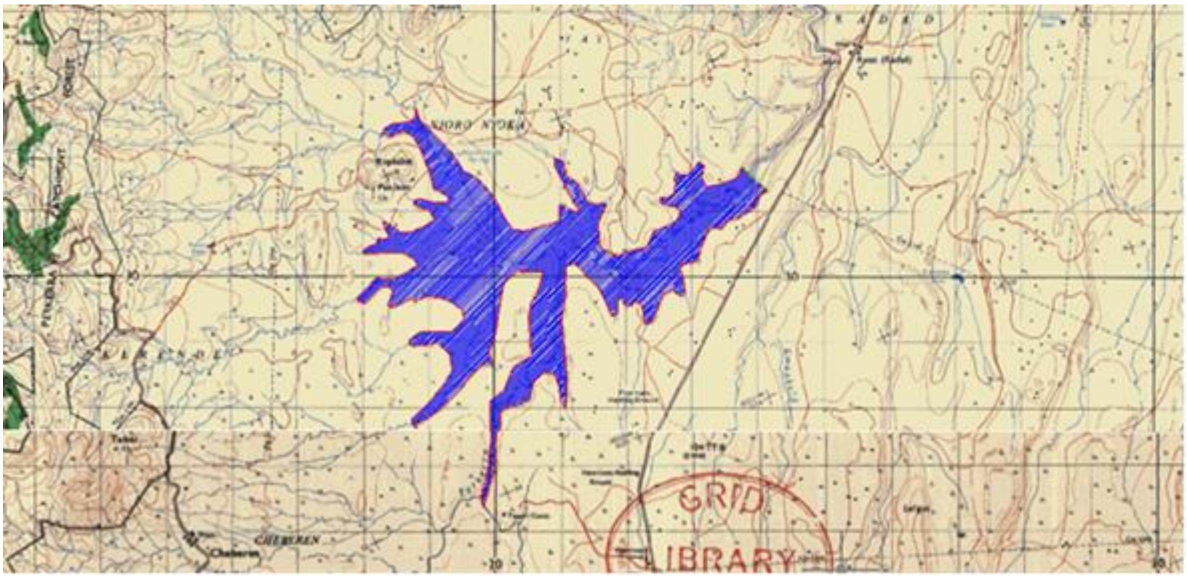
FEASIBILITY STUDY, DETAILED DESIGN AND PREPARATION OF TENDER DOCUMENTS FOR RADAT DAM, BARINGO COUNTY

Contract No. NIB/T/016/2013-14



Feasibility Study Report
Annex II
Hydrological Study Report

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Abbreviations

CAAC	Catchment Area Advisory Committee
CFRD	Concrete Faced Rockfill Dam
DEM	Digital Elevation model
DTM	Digital terrain Model
EAEC	East African Engineering Consultants
EIA	Environmental Impact Assessment
EMCA	Environmental Management and Coordinating Act
FEAM	Federal Emergency Management Agency
IDD	Irrigation and Drainage Department
IPCC	International Panel on Climate Change
ITCZ	Inter-Tropical Convergence Zone
NCWSC	Nairobi City Water and Sewerage Company
NIB	National Irrigation Board
NEMA	National Environmental Management Authority (of Kenya)
NGO	Non-Government Organisation
PAPs	Project Affected Persons
RBDA	River Basin Development Authorities
RGS	River Gauging Station
ToR	Terms of Reference
UNESCO	the United Nations Educational, Scientific and Cultural Organization
WRMA	Water Resources Management Authority
WRUA	Water Resource Users Association
WSP	Water Services Board

1 INTRODUCTION

1.1 Background

The objective of the Radat dam project is to harness, conserve, and control and utilize the flood waters of Perkerra River. The project main target is to enhance development of the expanded Perkerra Irrigation Scheme through the construction of Radat dam, a multipurpose dam with a primary purpose of regulating Perkerra river flow to enhance irrigation development, flood control and hydropower generation. This development will contribute to increase in irrigation area and subsequently agricultural production, improvement of the livelihoods of farmers in the Baringo County and enhanced food self-sufficiency in Kenya as a whole. The proposed dam should meet the expanded irrigation demand of Perkerra irrigation project of 280,000m^3/day.

Pre-Feasibility study identified 5 sites and recommended Radat Dam sites for further investigations. During this stage, focused studies were carried out at the proposed Radat dam site while limited generally studies were carried on the four other sites.

1.2 Perkerra Irrigation Scheme Expansion Project

Perkerra Irrigation Scheme is situated 100Kms North of Nakuru near Marigat Township in Marigat Sub County. It derived its name from the Perkerra River, which is the source of Irrigation Water, and the only permanent river in the District.

The construction of the irrigation Scheme started in 1954 after several feasibility studies, which showed that the Ilchamus flats (Plains) was suitable for Irrigation. The conceptual study was carried out in 1936 but due to financial constraints, construction was shelved until the "state of Emergency" period, when detainees provided labour for construction purposes. Marigat was one of the many detention Camps in the country at that time.

It is estimated that approximately 13,000 people will directly and indirectly benefit from the expanded project in Baringo and neighbouring Nakuru counties. . The Perkerra Irrigation Scheme Expansion Project Study, (Bhundia Associates 2012), proposed to expand the scheme irrigation area to 2020 hectares. The proposed expansion will increase the irrigation area eight times the area currently under irrigation from 254Ha. To achieve this, water sources with an annual yield of 280,000m^3/day is required. The current source of Perkerra irrigation water, the Perkerra River, cam meet irrigation demands of up to 35,424m^3/day.

1.3 Objectives and Scope of the study

The objective of this study is undertaken feasibility studies and detailed design of the proposed Radat dam. The dam to be located in across Perkera river will regulate the in the river while conserving flood flow for reliability utilisation for Perkerra irrigation scheme.

1.4 Scope of the study

The scope of Consultancy Services shall comprise;

a) Feasibility studies at the potential dam sites to select the better alternative and to allow for the design of the dam to determine:

b) carry out detailed investigations and designs of a dam at the selected site in line with established best practice worldwide, and

c) Prepare pre-qualification and tender documents for all civil and supply works arising out of the detailed design including civil/structural works and power plants.

1.5 The feasibility study

Preliminary studies at this stage were undertaken to identify the potential dam sites and select the better alternative. The selected dam will go through detailed investigations and design. The studies herein presented include the following;

1.5.1 Socio- Economic baseline Studies

- To conduct a social baseline in the project area.
- To conduct consultations with relevant stakeholders, including potentially affected persons, to obtain their views and suggestions regarding the environmental and social impacts of the proposed project.
- To identify potential negative and positive social impacts of the Project and propose mitigation measures.
- To prepare an SIA report incorporating results of social analysis

1.5.2 Topographic study

Topographic layout maps of the potential dam sited were prepared from data collected from topographic surveys. The maps are used delineate and to study the dam potential using the digital terrain models.

1.5.3 Hydrology and water management study

Hydrological study involved evaluation basin hydro-meteorological information to derive the following;

- Evaluation of the potential basin runoff yield and potential reservoir size at proposed site
- Carry out water balance study taking into account the proposed irrigation demand and other potential multi-purpose water usage
- Estimate maximum flood occurrences to be used in the reservoir water evacuation structures such as spillway and diversion
- Estimate the reservoir yield and reliability to meet the various water uses
- Estimate sediment load, evaluate reservoir loss and the requirement from dead storage

1.5.4 Geological and geotechnical study

- Undertake geological investigations and geophysical surveys to identify the geological condition, estimate the vertical profile of the underlying strata, identify ground weakness.
- Undertake preliminary material study to identify embankment materiel and recommend a preferred dam type.
- Undertake preliminary geological analysis to recommend and prepare

terms of reference for detailed investigations and studies including core drilling, seismic surveys and borrow pit investigations.

1.5.5 Preliminary dam layout and design

Provide preliminary layout and design of the proposed dam at the recommended site.

1.5.6 Environmental and Social Impact Assessment (ESIA) study

Identify and determine the sizes of affected land for a

1.6 Hydrological Study Report

This section reports on the hydrological and water resources study. Available runoff, reservoir yields and storage requirement and the dam regulation study is also covered.

2 INTRODUCTION

The hydrology of the river basin is essential in planning and design of proposed dam on the river. It is the river flows, its normal seasonal variations as well as its extreme flow events that determine the reservoir capacity, the size and type of the dam and the feasibility of the project. The hydrological study will estimate the river flows; minimum, normal and flood flows to allow optimization of the dam design.

The basis of the hydrologic study is the available hydro-meteorological data. Historical river flow data will form the primary data to be complimented by rainfall records when data is sparse. Rainfall data is modelled to convert to river flows.

2.1 Dam sites

The four identified dam sites are on Perkera River and its tributaries in the middle Perkera river catchment. This hydrological study of the dam sites, seeks to evaluate the water availability to fill the proposed dam development project and to provide adequate water for the proposed irrigation project. Table 2.1 below shows the site location and the catchment sizes at the sites.

Table 2:1 Dam sites – location and catchment areas

Dam site	River	Dam catchment area (Km^2)
Radat	Perkera	1,061.1
Kaplelwo	Perkera/Ainopno	1,148.7
Kopokaplelach	Kapuchara	40.8
Kapng'etuny	Ainopno	143.4

2.2 Perkerra River Basin

The river Perkera and its tributaries form the Perkera River basin which originates from Maji Mazuri ,Timboroa, Lembus, Chemorogok and Metkei forests. The Perkera irrigation scheme falls within the area drained by the Perkera River and its tributaries with a catchment area of about 1,411 km^2. The river basin falls under the Rift valley drainage basin 2E, Kerio Valley sub-basin in the Rift Valley basin. Perkerra borders Molo river basin to the west and to east by Tapuchara river basin, which joins Perkera River at Marigati to form the Tigeri river basin. The table below shows the characteristic of the three sub basins forming the Perkerra river basin.

Table 2:2 Basins details

Name of river	River sub-basins	Catchment area (Km^2)	Length (km)
Eldama/ Perkera	2ED	421	23

Emining	2EF	389	50
Perkera	2EE	601	80
Total		**1,411**	**103**

The proposed Radat dam is located in Radat area in Baringo County in the Northern parts of former Rift Valley province. In terms of drainage, the scheme is within Emining sub-basin in the Perkera river catchment, in drainage area 2, the rift valley drainage basin of Kenya.

The largest single drainage system in the project area is formed by the Perkera River and its tributaries from upstream to downstream. The river Perkera catchment can be divided into five sub catchments as follows.

River Perkera Sub – Catchment: this main catchment and it drains the eastern parts of the basin. The main rivers tributaries include, Kureswa, Magirip, Kirer, Kipsarita, Perkera, Eldama ravine and Kabiet. The main rivers originate from within the Kibimjor ranges from Sekenwo, Sana and Mtarakwa forests, Perkera river drains the central parts of the basin,

River Emining Sub – Catchment: this system drains the Western parts of the basin, the main river tributaries are Narosura, which originates from Mochongoi forest, Esageri , which originates from Kilombe forest and Kipkura , which originates from Kibimoi area and Isanda, which originates from Londian forest. The Emining River enters the Perkera River at Tiggoi area.

River Ainapno Sub – Catchment: this system drains the Western parts of the basin, the main river tributaries are Cheberena, which originates from Chemoge area, and chebsaita, Kibigechi all of which originates from Mukobe forest, there is no gauging station in this sub catchment.

River Lelgel Sub – Catchment: this system drains the Western parts of the basin, the main river tributaries are Chelelach bei, which originates from Maji Mazuri forest, Leigel, which originates from lembus forest and enters Perkera at siloi area.

River Chemususu Sub – Catchment: this system drains the Western parts of the basin, the main river tributaries are Chemusus, Kaplakawa and Tuigoin, Toronga and Markisis, all of which originates from the lembus forest, it enters the Perkera system at Kapchotoi area, there is no river gauging in this sub-catchment.

2.3 Characteristics of the Perkera river basin

The primary watershed characteristics governing stream flow can be divided into four categories: (i) **Precipitation** characteristics and basin area (ii) characteristics that affect hydrologic abstractions and runoff volumes such as land use and vegetation (land cover), soils, and antecedent moisture conditions (iii) topographic characteristics that affect runoff response time, such as watershed shape, drainage pattern, watershed slope, and stream channel slope and (iv) characteristics that affect the subsurface base flow, such as soils, soil moisture, vegetation, channel bed materials, stream channel length, geology and groundwater table. These characteristics affect different aspects of stream flow hydrograph and therefore need to mention briefly in the study. The characteristics of the Perkera river basin are as follows:

2.3.1 Topography and size

The Perkera basin is characterized by undulating terrain with highlands intersected by several valleys. The scheme area is part of the central Rift Valley area and escarpments occur in the East and West. In the upper areas of Emining catchment, some extinct volcanoes rise sharply over the surrounding plateaus such as the Kibimjor range, Tachasis escarpment, Kimata range, Mukobe range. The land slopes from about 3011 m a.s.l to 1000 m,a.s.l figure 2.1. The topography has a direct influence on surface runoff for the Radat, Kaplelwo, Kopokaplelach and Kapng'etuny dam sites.

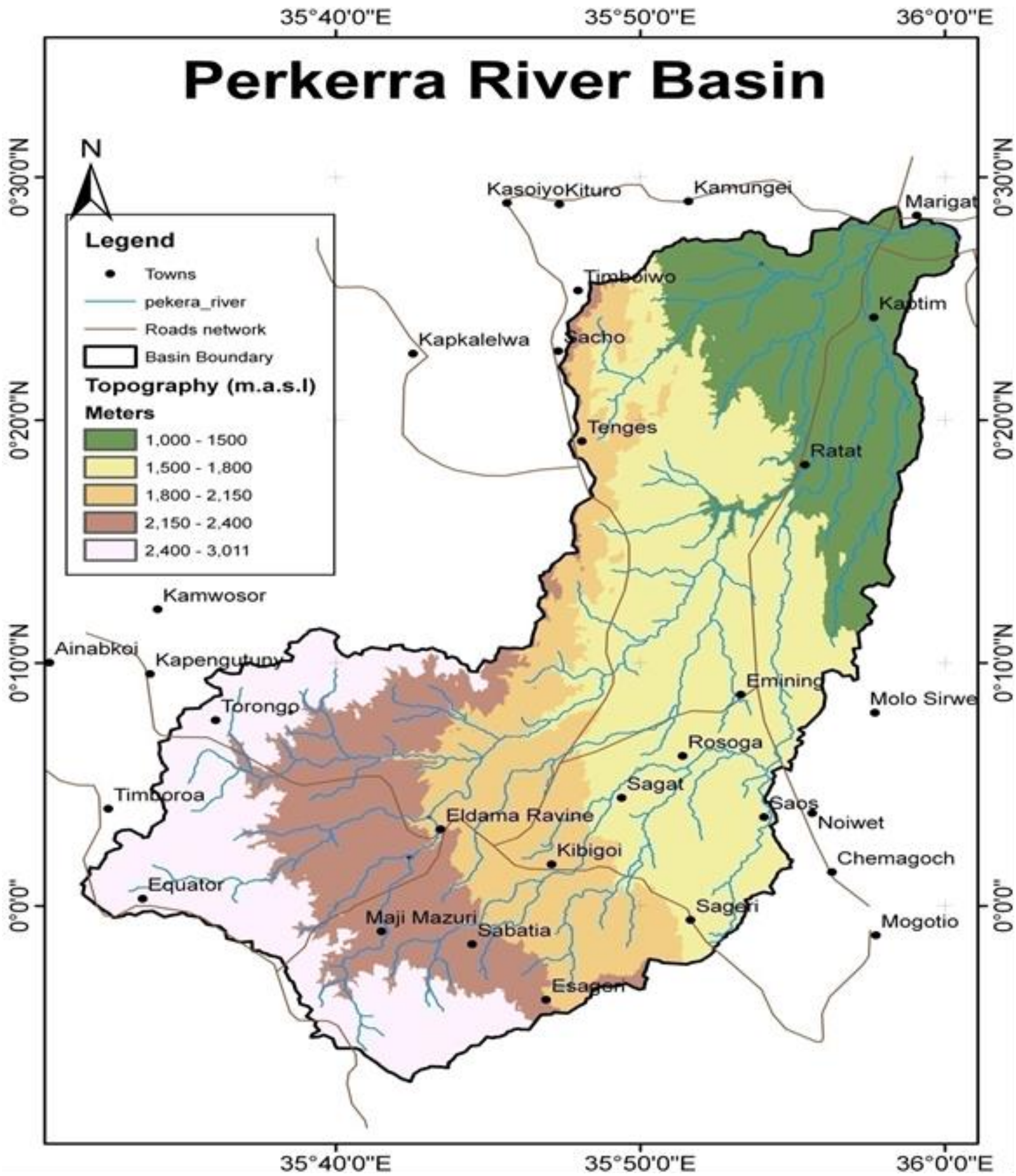


Figure 2:1 The Perkera River basin

2.3.2 Vegetation and Land Cover

Vegetation affects the hydrologic abstractions and runoff volumes through canopy interception, evaporation and evapotranspiration dynamics. The vegetation in the Perkera basin varies from the source areas to downstream as follows: highlands are covered by forest cover has been categorized into: plantation and indigenous, followed by grassland and bush land. Most of the forests are Gazzeted forests and only a few are not. The main exotic tree species found include Cypress, Eucalyptus and Pinus, while Podo, Cedar, Oleafricana and Waibugia are the main indigenous species. The vegetation of the basin was initially of savanna type, but now it is dominated by grassland with scattered forest stands of trees of herbs, shrubs acacia of woody vegetation complex. The plains are dominated by swamp vegetation and acacia of various species. The intense land use has reduced the original wood land to small patches, heavily covered by grassland and bushland, see plates 4.1- 4.3. The ground cover, together the soils influence the infiltration processes and subsequent runoff coefficient and surface runoff.

Plate 2.1: The Radat dam site and catchment area, note sediment deposits on the river bed and high water turbidity due to catchment degradation.

Plate 2.2: The Kopokaplelach dam site on Kapuchara river

Plate 2.3: Kapng'etuny dam catchment on Ainpno River

Plate 2.4:Kapang'etuny dam site and catchment area

2.3.3 Agro ecological and Land use

Land use and land cover affects the runoff characteristic of the basin, the land treatment practices, affect infiltration processes and therefore affects groundwater. The modification of land surface by the various land uses have varying effects on the runoff characteristics of a given drainage area, as it affects the hydrologic abstractions and runoff volumes. The land uses change from upstream to downstream as the ecological conditions change. The Perkera basin falls within three agro-ecological zones and the sequence is as follows: The project area basin falls within the Sunflower-Maize zone.

2.3.4 Climate of the Project Area

Climate is often considered the driving factor for stream flow, and it is spatially and seasonally variable in the Emining catchment in the Perkera River basin. The climate of the project area is heavily influenced by its geographical location and altitude. It varies with from upstream to downstream as follows:

Rainfall upstream areas: The mean annual rainfall is 1241 mm, with 60 % of 1112 mm reliability at Maji mazuri forest station at an altitude of 2331 m a.s.l. The lowest monthly rainfall here is 41 mm in January and the highest is 201 mm in April, see figure 2.2.

Rainfall Midstream: The mean annual rainfall is 652 mm, with 60% reliability of 598 mm at Perkera irrigation scheme at an altitude of 1066 m a.s.l. The lowest monthly is 41 mm in January and the highest is 86 mm in August. Rainfall downstream: The mean annual rainfall is 584 mm, with 60 % reliability of 467 mm at Nginyang health centre. The lowest monthly rainfall is mm in January and the highest is 64 mm in May.

The physical characteristics of the sites are more less the same, especially the topography, geology, soils and ground cover; these are the parameters which influence the runoff coefficient and therefore surface runoff.

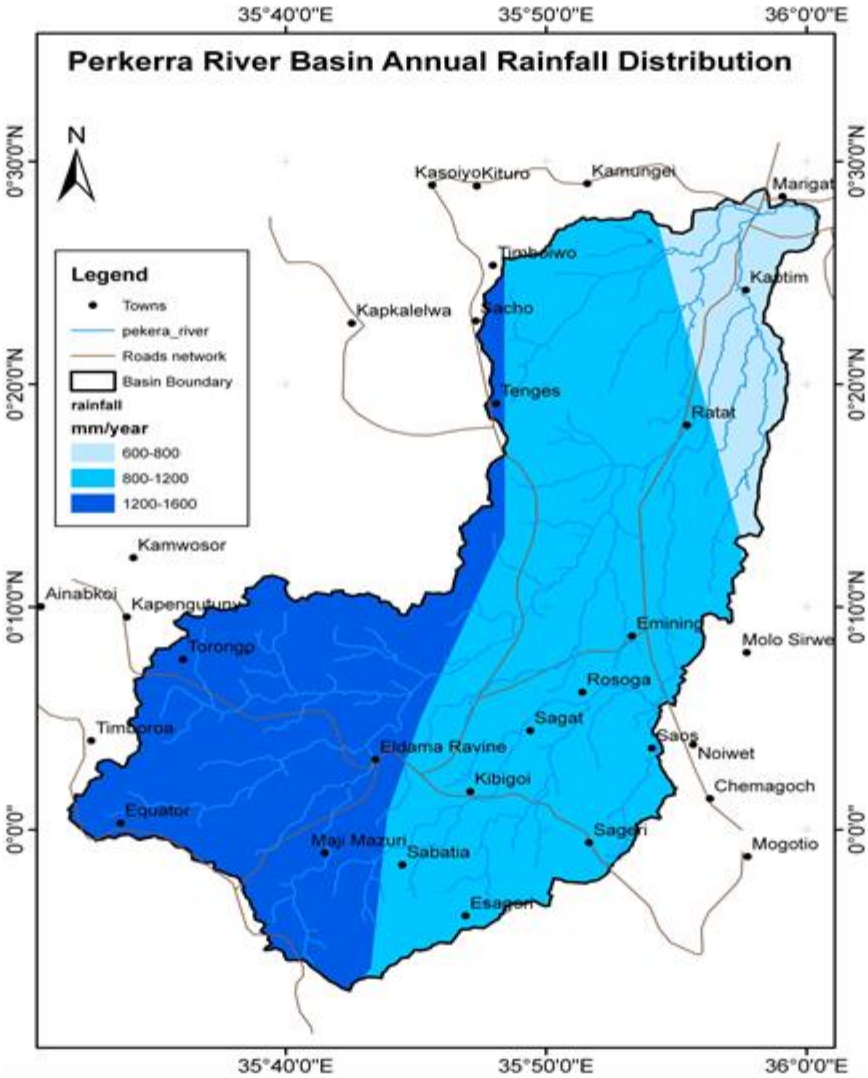


Figure 2:2 Rainfall distributions in the Perkera basin

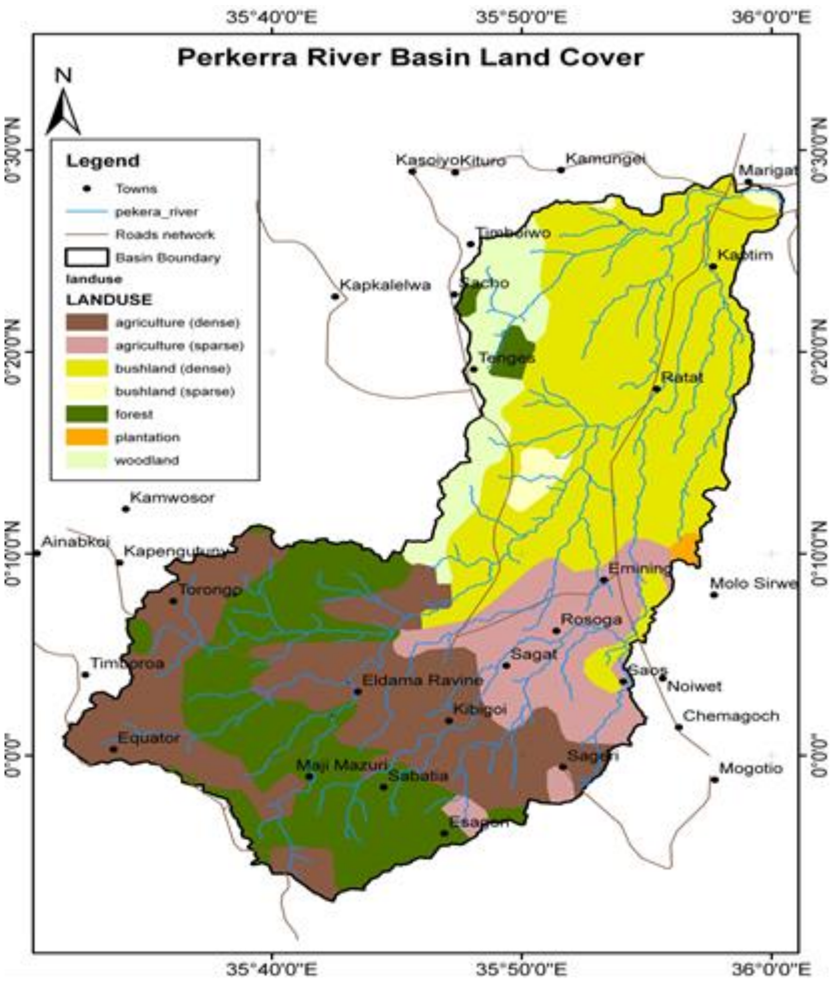


Figure 2:3 Perkera catchment land cover map

Rainfall and Temperature

Rainfall distribution in the project area exhibits a bimodal pattern, long rains in the months of March- April and short rains in June-August. April is the wettest month during the long rains and July during the short rains period, see tables 2.3 and figure 2.3 for Perkera scheme station.

Table 2:3 Mean monthly rainfall (mm) at Perkera station

Month	J	F	M	A	M	J	J	A	S	O	N	D
Mean	23.7	24.1	43.5	91.3	67.7	59.1	88.3	71.9	29.7	39.9	41.2	22.1
Minimum	0.0	0.0	0.0	16.0	6.4	0.0	0.0	0.0	0.5	0.0	0.0	0.0

Temperatures: The temperatures at Perkera irrigation scheme are as follows: mean maximum temperature ranges between 30.3 oc in July and 33.7 oc, February, the mean minimum temperature ranges between 16.2 oc in January and 18 oc in April, the mean annual temperature ranges between 23.5 oc in August and 25.7 oc – 22 oc, table 2.2. Absolute temperature ranges between 10.2 oc in June and December to

14.9 of in April, see table 2.4. Evaporation is very high ranging between 2100-2300 mm due low 35 % relative humidity.

Table 2:4 Temperature Perkera irrigation scheme

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Year
Mean. Max	33.2	33.7	33.6	32.6	32.4	32.0	30.3	31.0	33.1	32.9	31.3	31.4	32.3
Mean. Temp	24.7	25.3	25.7	25.3	24.8	24.1	23.7	23.5	24.4	24.8	24.2	23.9	24.5
Mean. Min	16.2	17.0	17.8	18.0	17.2	16.3	17.1	16.1	15.7	16.8	17.2	16.5	16.8
Abs. Min	11.3	10.9	12.5	14.9	13.4	10.2	12.5	11.7	12.1	12.9	12.1	10.2	10.2

2.3.5 The Other Climatic Variables in the Basin

Apart from rainfall, the other climatic parameters are equally important, are as shown in table 2.5 and 2.6.

Table 2:5 Other climatic data for Perkera irrigation scheme (altitude 1148 m)

	Temperature (degree)				Relative humidity (%)						
Month	Daily max	Daily min	Extreme high	Extreme low	Daily max	Daily min	Daily Sunshine (hrs)	Daily wind Run(km)	Monthly Evaporation (mm)	Monthly Mean rainfall (mm)	No. of rainy days
J	33.2	16.3	36.7	10.5	54	31	9.8	73.2	238	36	4
F	34	17	38.1	10.6	53	30	10.0	75.5	233	27	4
M	34	17.6	37.7	10.5	56	32	9.6	76.8	259	56	6
A	33.1	17.8	37.2	13.1	65	39	8.4	67.1	202	76	10
M	32.5	17	36.7	13.0	63	40	9.0	61.9	199	78	9
J	32.2	16.4	35.8	10.2	61	37	9.5	60.0	193	56	7
J	30.4	16.7	34.6	11.0	68	43	8.6	57.9	180	90	9
A	31.1	15.9	35.1	11.0	68	41	8.9	59.9	188	85	10
S	33	15.6	37.3	10.2	58	34	9.4	67.1	216	37	5
O	33.2	16.4	36.7	11.9	55	34	9.0	69.8	227	37	9
N	31.7	17.1	39	11.8	61	39	7.9	67.4	196	46	7
D	32.1	16.4	36.1	10.2	55	37	8.4	70.8	228	34	4
Total	**390.5**	**200.2**	**441.**	**134.0**	**717**	**437**	**108.5**	**807.4**	**2559**	**656**	**84**
Max	**34**	**17.8**	**39**	**13.1**	**68**	**43**	**10.0**	**76.8**	**259**	**90**	**10**
Min	**30.4**	**15.6**	**34.6**	**10.2**	**53**	**30**	**7.9**	**57.9**	**180**	**27**	**4**
Ave	**32.5**	**16.7**	**36.8**	**11.2**	**59**	**36**	**9.0**	**67.3**	**213**	**54**	**7**

Source: Climatological Handbook, KMD

Table 2:6 Climatic data for Marigat Met Station

Station: Marigat 36.03 S, 0.5 E			**Altitude:** 1000 m				**Position:**	
Month	Min Temp [°C]	Max Temp [°C]	Humidity [%]	Wind [km/day]	Sun [hours]	Rad [MJ/m²/day]	ETo [mm/day]	Rain [mm]
January	16.5	33.1	48.45	120.86	10.36	24.64	5.12	48
February	17.0	33.6	46.75	120.6	10.24	25.31	5.45	20
March	18.0	33.8	50.35	120.6	9.57	24.56	5.41	57

April	18.5	32.2	57.11	112.32	8.66	22.47	4.82	64
May	17.0	32.6	59.21	103.68	9.86	23.05	4.67	83
June	16.0	32.0	55.7	112.32	9.93	22.34	4.51	39
July	17.0	30.0	60.48	103.68	8.56	20.64	4.17	77
August	16.0	30.8	59.28	103.68	9.21	22.64	4.48	87
September	15.60	32.5	52.91	112.22	9.81	24.48	4.97	38
October	16.80	33.0	53.15	112.32.	9.12	23.51	4.98	33
November	17.3	31.7	55.11	120.96	8.59	22.09	4.74	50
December	15.8	32.5	54.68	112.32	9.13	22.43	4.63	56
Average							**4.83**	**54.33**
Totals							**57.9**	**652**

Source: FAO CLIMWAT Database

3 RAINFALL ANALYSIS

The purpose of rainfall data collection portion of the hydrological study of the project; was to collect all the available data for parameter that significantly affect stream flows in the basin. Historical rainfall conditions are the best guide to future stream flow conditions in the basin. Because historical data will form the primary basis for predicting future stream flows, in the basin, the rainfall data collection effort was one of the most important steps in completing the hydrological analysis for the project.

To achieve these, data on all seven climatic parameters (rainfall, evaporation, humidity, temperature, sun shine hours, wind, radiation,) were collected. The collected data was then organized, processed and analysed.

3.1 Rainfall data source

The climatological evaluation was based on three rainfall stations, namely Perkera scheme, Marigati, and Baringo farmers training centre (BFTC), see table 3.1.

Table 3:1 Meteorological stations within the project area

Station name	code	Type of station	Elevation (m)
Perkera irrigation	8935163	Full met	1148
Marigati station	8936053	Full met	1000
Baringo F.T.C	8935193	Rainfall	2099

3.1.1 Supplementing of Missing Rainfall Data

The purpose of this task was to use the collected data and reliable data years, to fill in the gap so as to as to develop continuous and consistent records of all parameters needed to estimate the present and future stream flows in the basin. Accurate rainfall analysis requires complete and consistent rainfall data at all critical points in the basins.

3.2 Analysis of Areal Rainfall

The rainfall obtained for particular stations relates to point rainfall. For runoff prediction purposes, the catchment averaged rainfall is required. This will be less than point rainfall; and it reduces as the catchment area increases. The catchment average rainfall can be determined from the point rainfall by applying an area reduction factor or multiplier factor. The Transport and Road Research laboratory (TRRL) gives a reduction factor formula which was used in this case as follows:

$$\mathbf{ARF = 1 - 0.044A^{0.275}}$$

A is the catchment area in km2 = 1,181 Perkera EE07 km2

ARF = (the reduction factor or multiplier factor).

From table 3.2, the mean annual rainfall at, Perkera and Baringo F.T.C stations is 1,295.8 mm and 452.64 respectively .

Table 3:2 Mean monthly rainfall in the project area

Met Station/Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**
Baringo F.T.C	58.90	72.20	115.90	152.90	296.50	132.70
Perkera Agricultural research station	24.84	18.63	38.64	52.44	53.82	38.64
Met Station	Jul	Aug	Sep	Oct	Nov	Dec
Baringo F.T.C	94.80	64.35	68.05	77.40	81.80	80.30
Perkera Agricultural research station	62.10	58.65	25.53	25.53	31.74	23.46

3.2.1 Temporal Distribution of Rainfall

The rainfall analysis is based on actual storms although even design storms can be used, storms differ in a number of characteristics which have a significant effect on the hydrological design. The major characteristics are intensity, duration, volume and frequency which are all interdependent. Rainfall distribution in the project area exhibits a bimodal pattern, long rains in the months of March- April and short rains in June-August. April is the wettest month during the long rains and July during the short rains period, see figure 3.1 for Perkera Agricultural research station.

The rainfall distribution in the upstream parts of the catchment is represented by the Baringo F.T.C, figure 3.2, note the bimodal nature of the distribution, with a single peak in May.

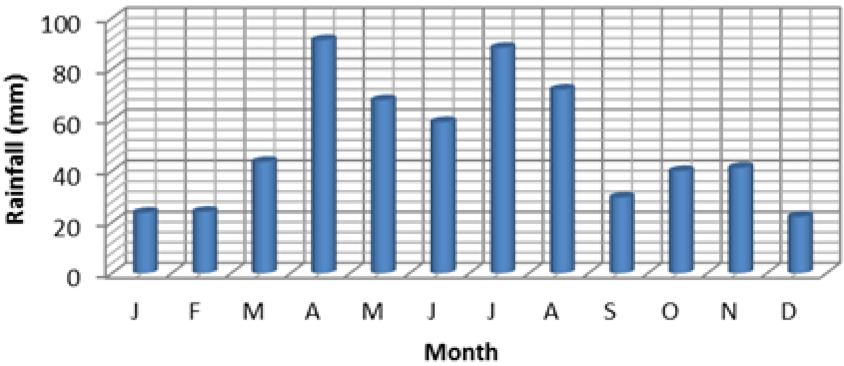


Figure 3:1 Mean monthly rainfall at Perkera Agricultural research station

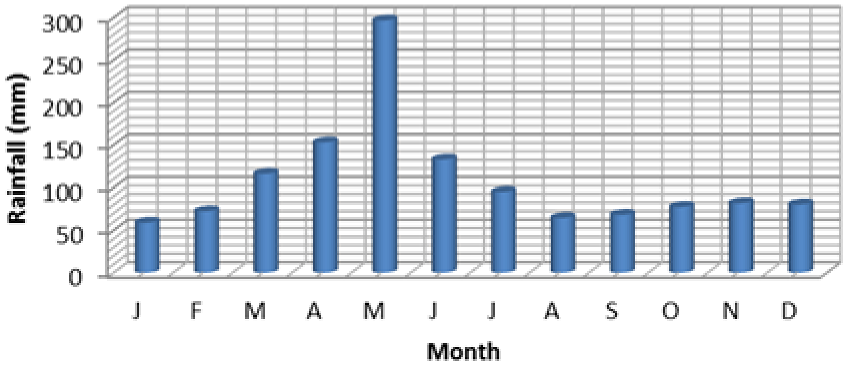


Figure 3:2 Mean monthly rainfall at Baringo F.T.C

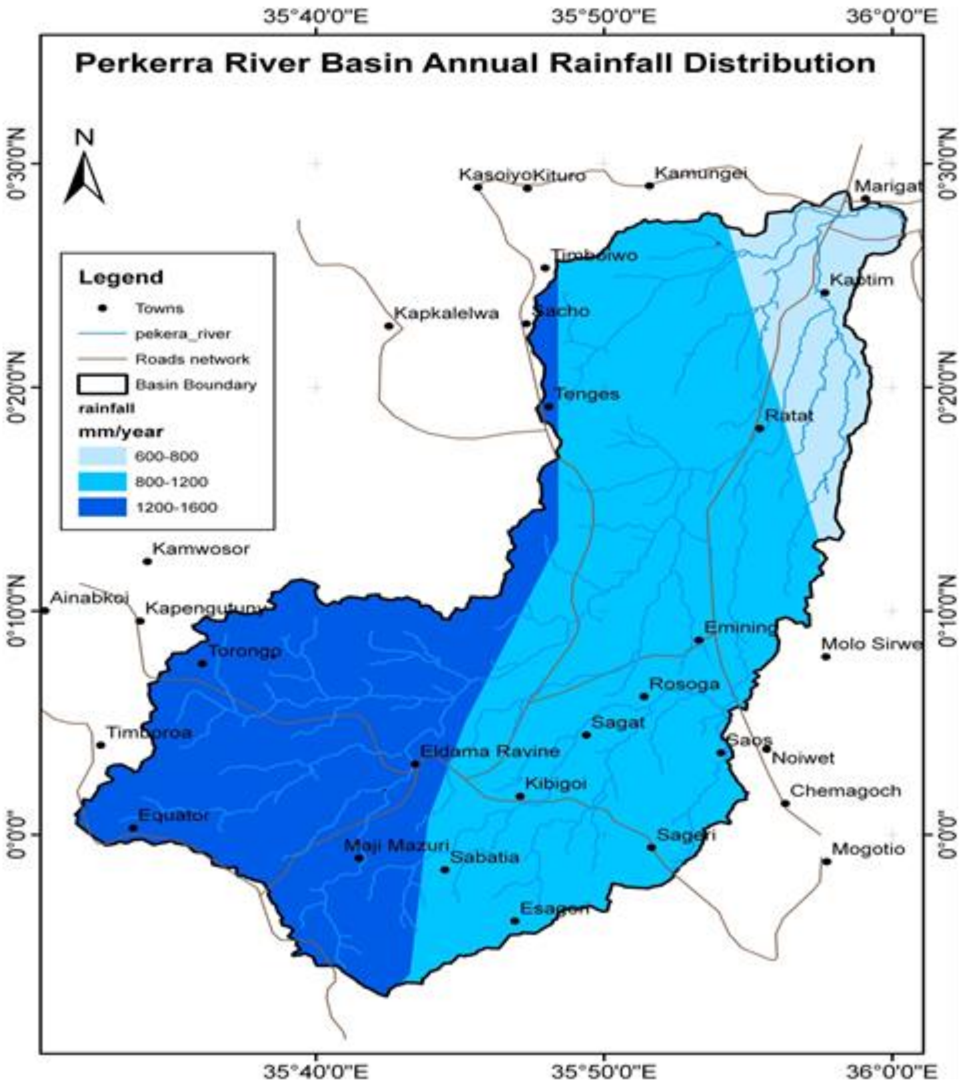


Figure 3:3 Mean annual rainfall spatial distribution in the Perkera basin

3.2.2 Areal Probabilistic Rainfall

The rainfall frequency for the project area depends on the season. It is high during the long rains and low during the short rains season. The rainfall duration also follows the same trend as the frequency, and all of these influence the availability of water supply. Rainfall and runoff are correlated as the amount of rainfall affects runoff as indicated by hydrograph trends, but watershed and channel processes affect the transformation of rainfall to runoff.

Design rainfall is defined as the total amount of rain during the cropping season at which or above which the catchment area will provide sufficient runoff to satisfy the crop water requirements. If the actual rainfall in the cropping season is below the design rainfall, there will be moisture stress in the plants; if the actual rainfall exceeds the design rainfall, there will be surplus runoff which may result in damage to the structures. The design rainfall is usually assigned to a certain probability of occurrence or exceedance, see table 3.3.

Table 3:3 Design rainfall in the project areas based on Perkera station

Probability (%) of exceedance	Rainfall amounts (mm)	Dam site			
	Perkera station	Radat	Kaplelwo	Kopokaplelach	Kapng'etuny
95	3.7	3.33	3.59	0.11	0.44
90	8.6	7.74	8.34	0.26	1.03
80	14.6	13.14	14.16	0.44	1.75
75	**19.2**	**17.28**	**18.62**	**0.58**	**2.30**
60	34.9	31.41	33.85	1.05	4.19
50	44.0	39.6	42.68	1.32	5.28
40	58.0	52.2	56.26	1.74	6.96
30	73.4	66.06	71.20	2.20	8.81
20	99.8	89.82	96.81	2.99	11.98
10	131.8	118.62	127.85	3.95	15.82
5	165.7	149.13	160.73	4.97	19.88

From table 3.3, the monthly design rainfall (75%) exceedance rainfall is 19.2 mm for Perkera station ,17.28 mm for Radat,18.62 mm for Kaplelwo,0.58 mm for Kopokaplelach and 2.30 mm for Kapng;etuny dam site.

3.2.3 Estimation of PMP

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.

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 Perkera River catchment. However the PMP for any part of Kenya can be obtained from PMP Isohyetal map of probable maximum precipitation, Obasi and Nimira, 1977), and for Perkera basin, it was estimated to be 200 mm.

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 analysed 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 to be taken to estimate the PMP for Radat dam 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 15 for highland areas *(The study on the National Water Master Plan, 1992)*

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

4 RUNOFF ANALYSIS

The amount of water harvested from the catchment area is a function of the amount of runoff created by the rainfall on the area. This runoff, for a defined time scale, is calculated by multiplying a "design" rainfall with a runoff coefficient. As not all runoff can be efficiently utilized (because of deep percolation losses, etc.) it must be additionally multiplied with an efficiency factor.

From the catchment topography and land cover evaluation, a runoff coefficient of C= 0.6, is appropriate for the perkera River catchment, and using this, the mean monthly runoff can be estimated using the design rainfall (75% reliability, K = 0.6. Based on Perkera station, the design rainfall is 19.2 mm and design runoff is 11.52 mm and at the dam sites see, table 4.13.

Table 4:1 Design rainfall (mm) (75 %) and runoff at the dam sites

Perkera station		Radat		Kaplelwo		Kopokaplelach		Kapng;etuny	
Rainfall	Runoff	Rainfall	Runoff	Rainfall	Runoff	Rainfall	Runoff	Rainfall	Runoff
19.2	11.52	17.28	10.37	18.62	11.17	0.58	0.35	2.30	1.38

4.1 Effective Rainfall

Effective Precipitation (EP) is the amount of precipitation that is actually added and stored in the soil. During drier periods less than 5mm of daily rainfall would not be considered effective, as this amount of precipitation would likely evaporate from the surface before soaking into the ground. Effective precipitation enters the soil and becomes available to the plant. Effective rainfall (or precipitation) is equal to the difference between total rainfall and actual evapotranspiration. It considers losses due to runoff, evaporation and deep percolation. The equation used in the calculation is:

Effective Precipitation (mm) = (RAIN - 5) x 0.75, or (75 % probability rainfall).

Using this equation, the computation of the effective mean monthly and mean annual rainfall for Perkera station and its corresponding amount at the dam site based on the Perkera data and Marigat data are shown in table 4.2.

Table 4:2 Effective monthly and annual rainfall in the project area (mm)

item	Perkera station	Dam site	Marigat station	Dam site

Mean monthly rainfall	54.83	48.25	54.33	47.81
Effective monthly rainfall	37.37	44.50	37.00	32.78
Mean annual rainfall	658	579.04	652	573.75
Effective annual rainfall	489.75	575.29	485.25	426.57

4.1.1 Infiltration Rate

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. The basic Infiltration rates of various soils are shown in Tables below.

Table 4:3 Basic Infiltration rates for various soils

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

Table 4:4 Generalized Values of run-off factor

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

Source: Guidelines for design, construction and rehabilitation of small dams and pans in Kenya)

4.1.2 Runoff coefficients

The design of water harvesting schemes requires the knowledge of the quantity of runoff to be produced by rainstorms in a given catchment area. It is commonly assumed that the quantity (volume) of runoff is a proportion (percentage) of the rainfall depth.

Runoff [mm] = K x Rainfall depth [mm]

An analysis of the rainfall-runoff relationship and subsequently an assessment of relevant runoff coefficients should best be based on actual, simultaneous measurements of both rainfall and runoff in the project area. As explained above, the runoff coefficient from an individual rainstorm is defined as runoff divided by the corresponding rainfall both expressed as depth over catchment area (mm):

$$K = \frac{\text{Runoff [mm]}}{\text{Rainfall [mm]}}$$

But for the project area, the runoff coefficient has been estimated from the catchment characteristics and using standard runoff tables, the catchment for the proposed dam sites can be described as being slightly permeable, partly cultivated or covered with the vegetation and k= 0.6, was adopted for the study.

4.1.3 Base Flow

Base flow (also called drought flow, groundwater recession flow, low flow, low-water flow, low-water discharge and sustained or fair-weather runoff) is the portion of stream flow that comes from "the sum of deep subsurface flow and delayed shallow subsurface flow". It should not be confused with groundwater flow. It is the discharge into a stream-flow from natural storages, particularly sustaining flow between rainfall events. The base flow can be estimated using the equation:

Direct flow (DF) = total flow (TF) - Base flow (BF)

The base flow can be estimated in two ways; by statistical method or modelling. Using the statistical method, it is estimated using the base flow index (BFI), which is a measure of the amount of low in a river during dry or low flows, used to characterize low flow and groundwater recharge in a catchment. It is calculated as flows:

BFI = Base flow / total flow or Lowest mean monthly flow / mean annual flow x 100. Using the this and the equation above, the base flow index for Perkera at 2EE07 was estimated to be = 0.22, which the used in the equation; Direct flow (DF) = total flow (TF) - Base flow (BF) , to estimate direct flows as 3.596 m^3/sec and total flow 4.61 m^3/sec. These values were then transposed to dam sites using catchment area proportioning method, see table 4.5.

Table 4:5 Flow characteristics at the three dam sites

Dam site	Catchment	Flows (m^3/sec)

	area (km^2)	Total flow	Direct flow	Base flow
Perkera 2EE07	1,181	4.61	3.596	1.05
Radat	1,061.1	4.14	3.23	0.91
Kaplelwo	1,148.7	4.48	3.50	0.98
Kopokaplelach	40.8	0.16	0.12	0.04
Kapng'etuny	143.4	0.56	0.44	0.12

4.1.4 Excess Rainfall

Excess rainfall is the portion of the rainfall that contributes to direct surface runoff (runoff that enters the stream during or soon after the storm). The excess rainfall is the difference between the total rainfall (measured amount) and the rainfall (precipitation losses) due to infiltration and interception (depression storage and canopy interception), this is the rainfall responsible for the peak of the runoff hydrograph.

Excess rainfall = total rainfall – rainfall losses.

4.1.5 Effective runoff

Effective runoff is as a result of the effective rainfall, if the ground is saturated or the catchment is impervious, then a high proportion of the rain becomes effective runoff, see table 4.6.

Table 4:6 Effective runoff in the project area (mm) based on Perkera scheme rainfall

item	Perkera station		Dam site							
			Radat		Kaplelwo		Kopokaplelach		Kapng'etuny	
	Effective rainfall	Runoff (mm)	Effective rainfall	Runoff (mm)	Effective rainfall	Runoff (mm)	Effective rainfall	Runoff (mm)	Effective rainfall	Runoff (mm)
Mean monthly rainfall	54.83	32.90	49.35	29.61	53.19	31.91	1.64	0.99	6.58	3.95
Effective monthly rainfall	37.37	22.42	33.63	20.18	36.25	21.75	1.12	0.67	4.48	2.69
Mean annual rainfall	658	394.8	592.2	355.32	638.26	382.	19.74	11.84	78.96	47.38
Effective annual rainfall	489.75	293.85	440.78	264.47	475.06	285.03	14.69	8.82	58.77	35.26

5 HYDROLOGICAL ANALYSIS

Historical hydrological conditions are the best guide to predict future stream flow conditions in the basin. Relevant historical hydrological data was obtained, reviewed and processed for analysis. The specific hydrologic parameters or data elements collected included, daily and monthly stream flow from existing and discontinued RGs in the basin, daily or monthly diversion records from all significant diversions in the basin, annual summaries, water right data in the basin, sediment transport data and water quality data.

5.1 Hydrological Gauging stations

The gauging stations include Eldama 2ED01, 2ED02 and 2ED03, Perkera 2EE01, 2EE02, 2EE03, 2EE04, 2EE05, 2EE06, 2EE07, 2EE08 AND 2EE10 and Emining/Esageri 2EF01, 2EF02, 2EF03, Narosura 2EF04, and Esageri 2EF05 , see table 5.1 and figure 5.1. The analysis of their hisrory and working conditions are shown in table 5.16.

Most of these stations were not visited as they were said to have been closed by WRMA, as the organization started monitoring the main stations in the main rivers, including Perkera 2EE07

Table 5:1 Hydrological network in the Perkera river basin

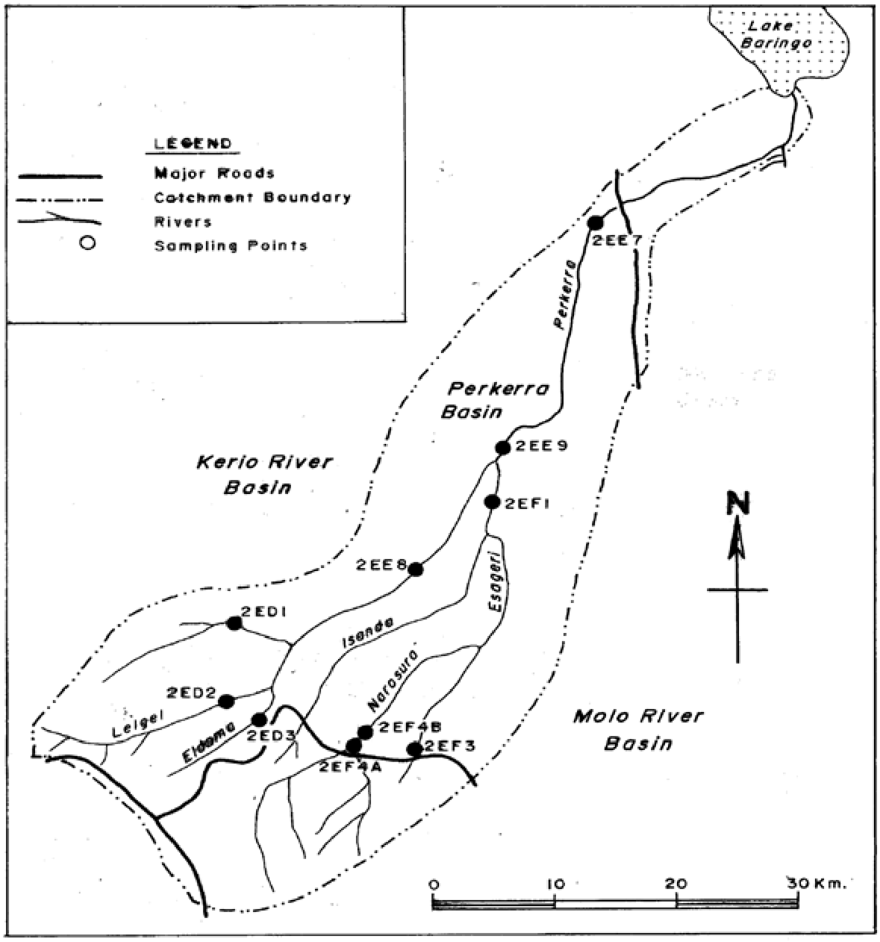
RGS code	River	type	condition	Rating	Catchment area (km^2)
2EE02	Perkera	Staff gauge	Closed	Rated	unkown
2EE03	Perkera	Staff gauge	Closed	rated	1,075
2EE04	Perkera	Staff gauge	Closed	rated	1,339
2EE06	Perkera	Staff gauge	Closed	Not rated	unkown
2EE07A	Perkera	A/ Staff gauge	operational	rated	1,181
2EE08	Perkera			rated	500
2EE09	Perkera	Staff gauge	operational	rated	580
2EE10	Perkera	Staff gauge	closed	Not rated	1,329

Table 5:2 River gauging stations on Emining River catchment

RGS code	River	Type	Condition	Rating	Catchment area (km^2)	Data period
2EF01	Esageri	Staff	Closed	Rated	365	1956-77
2EF02	Esageri	Staff	Closed	Not rated	257	1956-60
2EF03	Esageri	Staff	Closed	rated	60	1956-
2EF04	Narosura	Staff	Closed	rated	90	1956-

Table 5:3 River gauging stations on Eldama Ravine River catchment

2ED01	Tiger	Staff	Closed	Rated	135	1957-
2ED02	Tiger	Staff	Closed	Rated	108	1991-
2ED03	Tiger	staff	Closed	Rated	14	1979-



The Perkerra River Basin and river gauging stations.

Figure 5:1 Map of gauging stations on the Perkera River basin.

Hydrological evaluation for this project was based on daily and monthly river flow data from stations 2EE07 on Perkera, which captures all the flows from the upstream parts of the two basins. This station is downstream of the dam sites and it is representative for the hydrological conditions at the dam sites.

5.2 Evaluation of the existing data

The station RGS 2EE07 was selected because of the following reasons:

- It had good quality and consistent data for some reasonable (28 years) period, 1962-1989
- The data was fairly sufficient to give an indication of the water resources situation in the project area.

5.2.1 Miscellaneous gauging

From the records, there are several current meter gaugings done on the Perkera River at RGS 2EE07, at different times, ranges from 1962 to 2014. These data was used to develop the most recent rating curve for the station, the most recent gaugings are shown in table 5.4 and rating curve figure 5.2.

Table 5:4 The last five years current meter gauging at Perkera 2EE07

Serial No.	Date	Gauge height(m)	Discharge (m^3/sec).
1	12/2/2014	0.60	2.029
2	22/1/2014	0.65	3.146
3	31/1/2014	0.60	9.92
4	3/8/2013	1.09.	50.969
5	13/6/2013	0.65	9.245
6	13/5/2013	0.95	46.17
7	10/5/2013	1.22	60.366
8	8/5/2013	1.24	75.888
9	11/7/2012	0.78	24.570
10	14/6/2012	0.66	22.968
11	12/2/2012	0.48	1.15
12	12/1/2012	0.63	4.027
13	12/10/2011	0.68	3.055
14	3/12/20110	0.39	1.485
15	24/3/20110	0.76	18.24

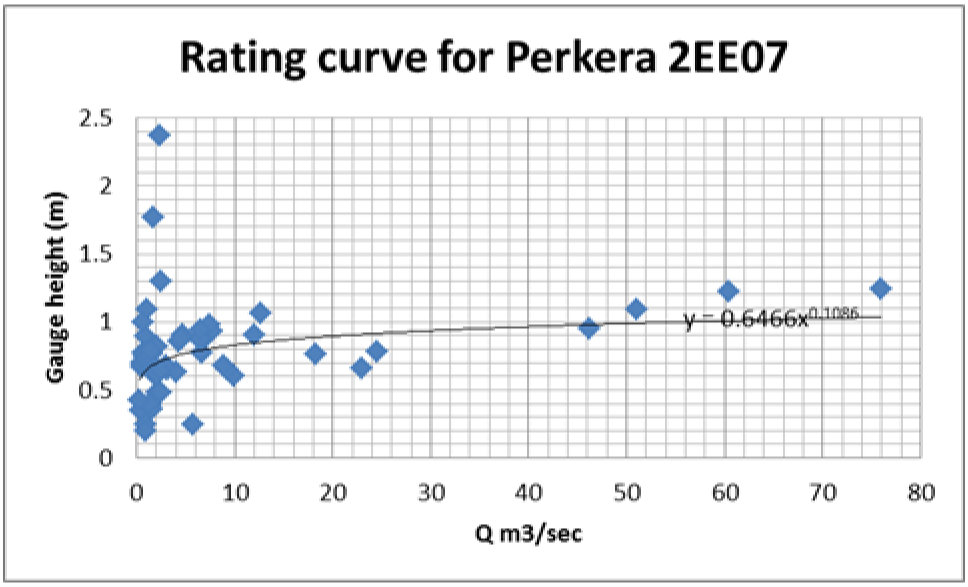


Figure 5:2 Rating curve for Perkera River at 2EE07

5.3 Low Flow Analysis

Flow duration curve were constructed to indicate the available water resources at various time periods. Flood frequency analysis was also carried out, so as to give the probability of occurrence of the various flood levels at the gauging and the dam sites. Low flow analysis was carried out to estimate the low flows in the two Rivers. This is important in the justification of the need for water storage in the two basins. The details of the analysis of the data from the two stations 3CB07 and 3BD03 are discussed below.

The analysis evaluates the available historical hydrologic data for Perkera River basin to deduce the hydrological trends in the project area.

5.3.1 Existing Water rights

There are a total of 25 water rights for Perkera, see table 5.5, a total of 10,692 m^3/day for normal and and 21,228 m^3/day flood water abstractions, for Perkera River.

Table 5:5 Water rights in the Perkera Rivers

Name of river	Normal flow water rights		Flood water rights	
Perkera	m^3/sec	**(m^3/day)**	m^3/sec	**(m^3/day)**
	0.124	10,692	0.247	21,228

5.3.2 Projects upstream of Radat dam site

There are some projects upstream of the proposed dam site and this includes

- Chemususu dam
- Institutional water supplies
- Public water supplies
- Individual abstractor

However more details about them were scanty from WRMA officials in Nakuru, although promised to supply such information latter.

5.4 Naturalized flow

The naturalized river flows for the Perkera and at the dam sites are shown in table 5.6.

Table 5:6 Naturalized flows mean monthly discharge at the dam sites

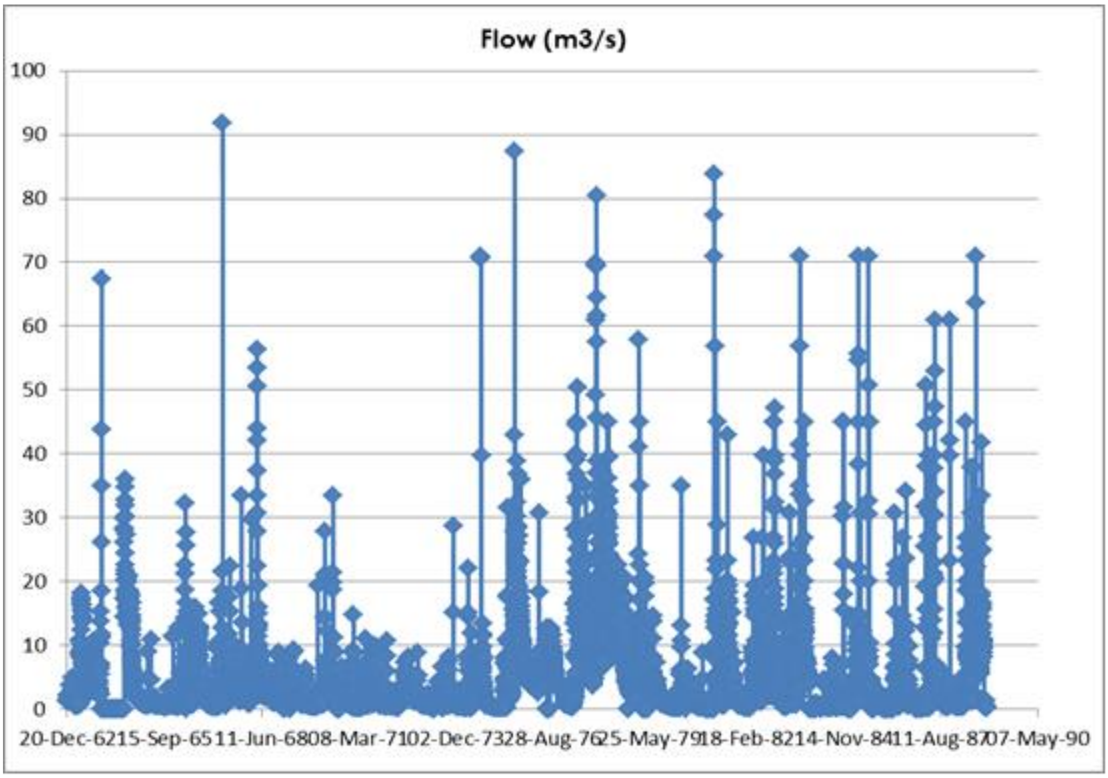
Month	flow m^3/sec				
	Perkera 2EE07	Radat site	Kaplelwo site	Kopokaplelach site	Kapng'etuny site
January	1.507	1.356	1.462	0.045	0.181
February	1.877	1.689	1.821	0.056	0.225
March	3.027	2.724	2.642	0.091	0.363
April	4.717	4.245	4.575	0.142	0.566
May	6.527	5.874	6.331	0.196	0.783
June	4.217	3.795	4.090	0.127	0.506
July	4.817	4.34	4.672	0.133	0.578
August	7.327	6.594	7.107	0.220	0.879
September	5.397	4.857	5.235	0.162	0.648
October	3.447	3.102	3.343	0.103	0.413
November	4.237	3.813	4.109	0.127	0.508
December	3.137	2.823	3.043	0.094	0.376

5.4.1 Hydrological Analysis for Perkera at 2EE07

This is a station on the Perkera River is located at coordinates latitude N 00o 27'27'' E, longtitude 35o 57'57'' S, capturing water from upper and midstream of the basin and its tributaries and has an effective area of about 1,180 km2, see figure 5.3. The station was visited on 15/5/2014 at 11.45 am and the check reading was 0.58 m, giving a discharge 0.61 m^3/sec. The station was found to be a good condition, having been rehabilitated in the year 2005 by WRMA.

According WRMA officials, the station was opened, a visit to the station indicated that the station is presently in a working condition, having rehabilitated in the year 2005

<table>
<tr><td></td><td></td></tr>
<tr><td>Plate 4.5: The first staff gauge at Perkera 2EE07, a check reading taken during the field visit to site was 0.56 m corresponding.</td><td>Plate 4.6:The second and third staff gauges at Perkera 2EE07</td></tr>
</table>



RGS2EE07time series (1962-1988)

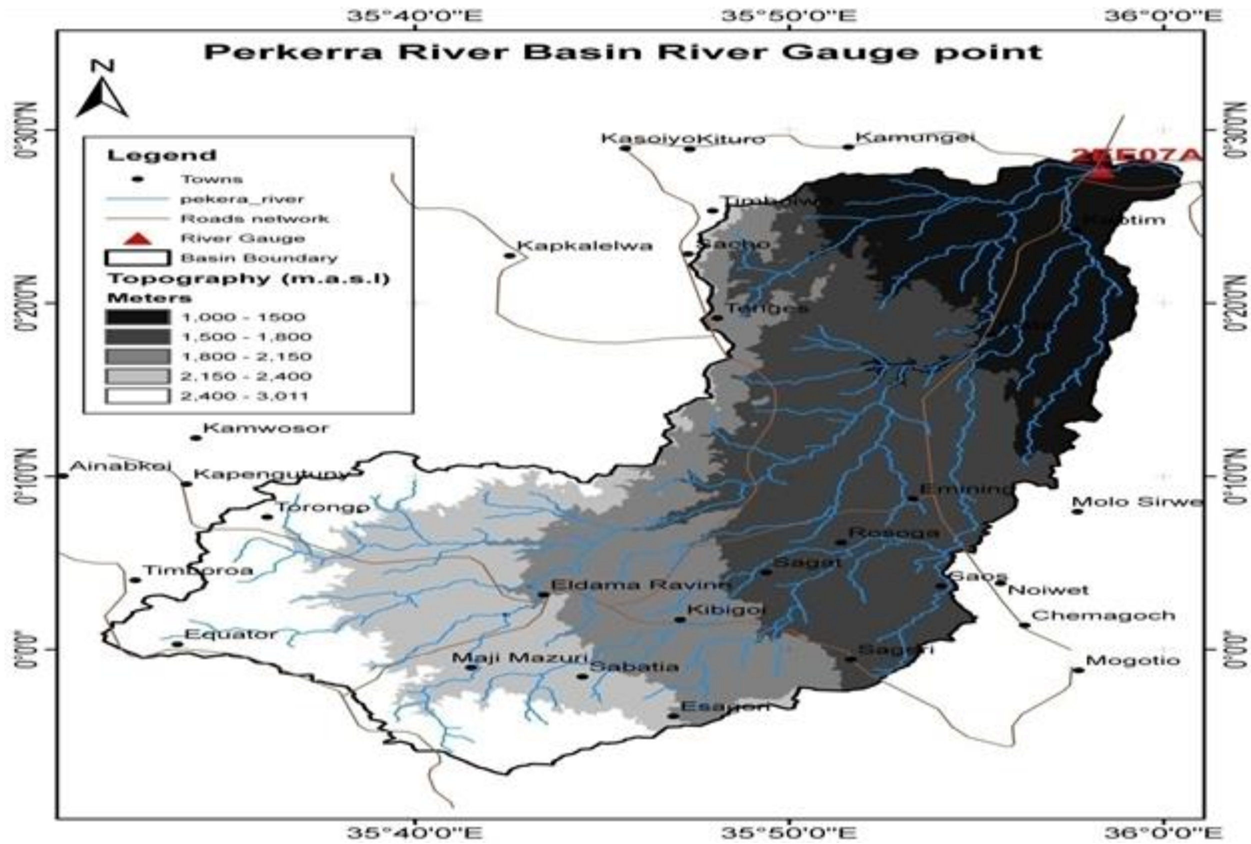


Figure 5:3 *Location* **of RGS 2EE07 in the Perkera river basin. The mean month average**

Table 5:7 4:21 Monthly summary statistic at Perkera 2EE07

Month	J	F	M	A	M	J	J	A	S	O	N	D
Mean	1.63	2.00	3.15	4.84	6.65	4.34	4.97	7.45	5.52	3.57	4.36	3.26
Max	37.43	57.87	83.87	55.65	91.72	60.91	70.96	87.35	36.90	45.03	80.50	67.37
Min	0.23	0.15	0.14	0.15	0.20	0.25	0.21	0.01	0.28	0.28	0.25	0.18

From table 5.7, the mean monthly flow for Perkera River at 2EE07 is lowest 1.63 m^3/sec in January and highest 7.45 m^3/sec in July. The flows from 2EE07 were transposed to the dam sites using the area proportioning method and the results are shown in table 5.8.

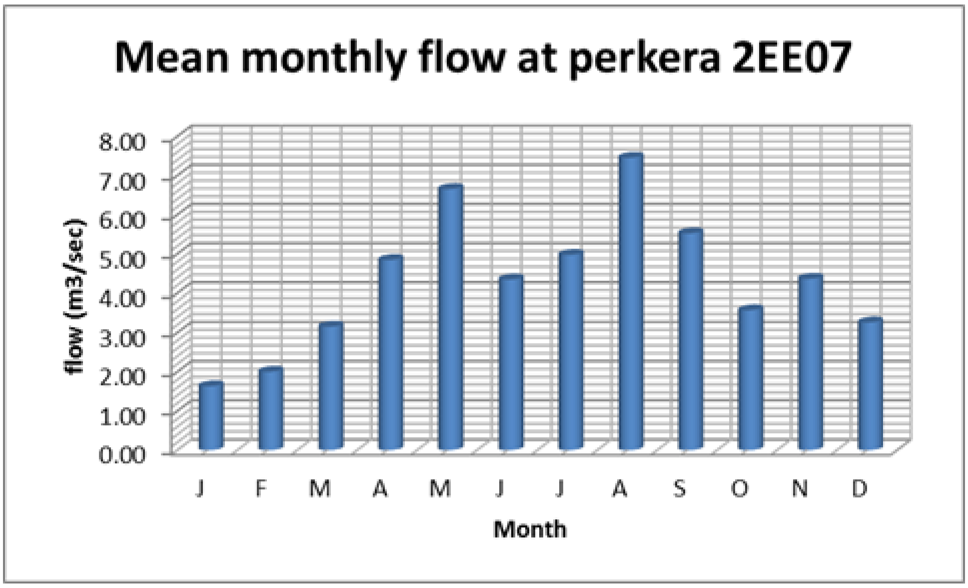


Figure 5:4 Mean monthly River flow at Perkera 2EE07

Table 5:8 The monthly mean flows at the dam sites

Month	**Mean flows at the sites (m³/sec)**				
	2EE07	Radat	Kaplelwo	Kopokaplelach	Kapng'etuny
J	1.63	1.467	1.581	0.049	0.196
F	2.00	1.80	1.94	0.06	0.24
M	3.15	2.835	3.056	0.095	0.011
A	4.84	4.356	4.695	0.145	0.038
M	6.65	5.985	6.451	0.200	0.798
J	4.34	3.906	4.210	0.130	0.521
J	4.97	4.473	4.821	0.149	0.596
A	7.45	6.705	7.227	0.224	0.894
S	5.52	4.968	5.354	0.166	0.662
O	3.52	3.168	3.414	0.106	0.422
N	4.36	3.924	4.229	0.131	0.523
D	3.26	2.934	3.162	0.098	0.391

Table 5:9 The annual accumulated mean flows at the dam sites

Month	**Mean flows at the sites (m³/sec)**				
	2EE07	Radat	Kaplelwo	Kopokaplelach	Kapng'etuny
J	1.63	1.467	1.581	0.049	0.196
F	3.63	3.267	3.521	0.109	0.436
M	6.78	6.102	6.577	0.203	0.814
A	11.62	10.458	11.271	0.338	1.394
M	18.28	16.452	17.732	0.494	2.194
J	22.61	20.349	21.932	0.678	2.713

J	27.58	24.822	26.753	0.827	3.310
A	35.03	31.527	33.979	1.051	4.204
S	40.55	36.495	39.333	1.27	4.866
O	44.07	39.663	42.748	1.322	5.288
N	48.43	43.587	46.977	1.453	5.812
D	51.69	46.521	50.139	1.504	6.203

Based on the mean annual flow in the table above, cumulatively a total of 46.521m³/s at Radat, 50.139m³/s at Kaplelwo, 1.504m³/s at Kopokaplelach and 6.203m³/s at kapng'etuny dam site.

5.4.2 Data gap filling and reliability analysis

The collected data from reliable years was used to fill gaps and develop continuous and consistent records. Accurate hydrological analysis requires complete and consistent stream flow data at all critical points in the basin.

The evaluation of the present water resource situation in the project area was carried out by analyzing mean daily flows over the years. A flow duration curve shows graphically the relationship between any given discharge and the percentage of time that this discharge is equalled or exceeded. A flow duration curve is helpful to provide answers to the following and related questions asked frequently.

- Does the river have uniform flow or does its flow fluctuate widely?
- What are the low-flow and high-flow river characteristics, i.e., is the river flashy?
- What percentage of the time does the river flow at certain discharge levels?
- If the river is to be used for, provide water supply, what percentage of time can the river support such services?

5.4.3 Flow duration analysis

The flow reliability analysis of the Perkera River at 2EE07 at various exceedance levels (flow duration) results are shown in tables 5.10 and in figure 5.11.

Table 5:10 Flow reliability at Perkera 2EE07

Reliability (%)	flow (m³/sec)
2	29.903
5	17.631
10	11.827
50	**1.77**
75	0.676
80	**0.567**
90	0.384
95	**0.291**

From table 5.11 and figure 5.5, at the (Q95) the environmental flow dry weather flow or threshold discharge for river Perkera at 2EE07 0.291 m³/sec, Q80, normal flow is 0.567 m³/sec and the flood flow Q50 is 1.77 m³/sec, from the data analysed (1962- 1989).

Table 5:11 FDC characteristics at Perkera River basin and at the dam sites (m^3/sec)

Threshold (%)	Description	Basin	Radat site	Kaplelwo site	Kopokaplelach site	Kapng'etuny site
Q95	Reserve	0.291	0.262	0.282	0.009	0.035
Q80	Normal	0.567	0.510	0.545	0.017	0.068
Q75		O.676	0.608	0.656	0.020	0.081
Q50	Flood	1.77	1.593	1.717	0.0531	0.212

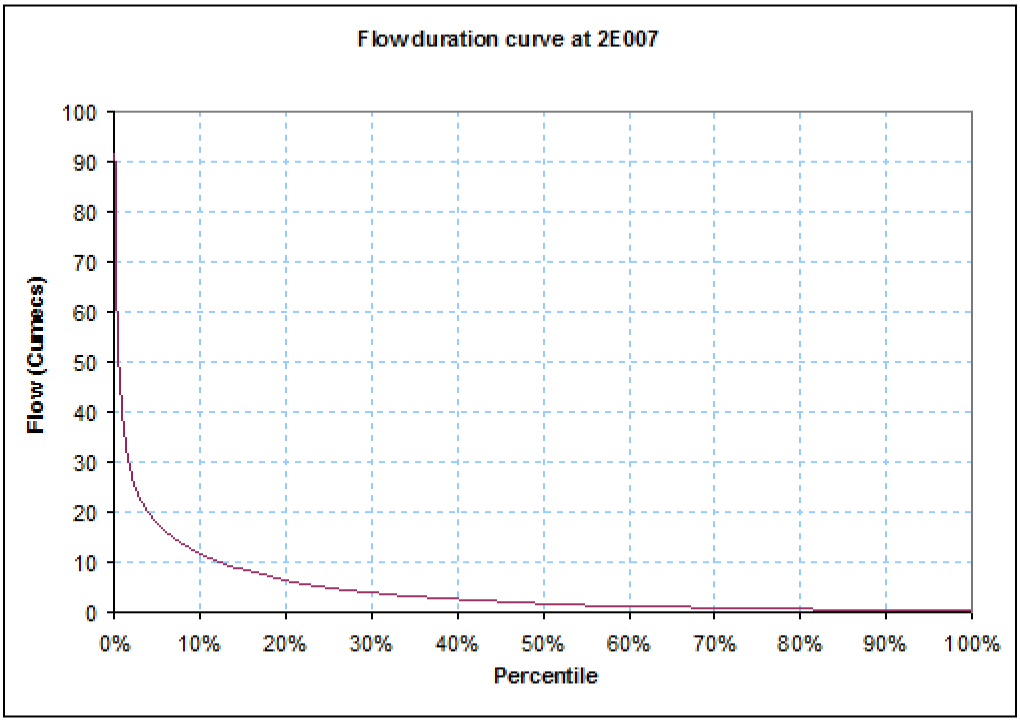


Figure 5:5 Flow duration curve for Perkera River at 2EE07

5.4.4 The Drainage Area Ratio Method

This method was used to interpolate the river flow data from the gauging station at 2EE07 to the proposed dam sites. This method assumes that the stream flow at an ungauged site for the same stream is the same per unit area or at least responds in the same fashion as that of the nearby, hydrologically similar stream gauging station used as an index, in this case 2EE07.

The dam catchment areas are estimated from the topographic maps, digital elevation models or GIS, stream flow statistics were computed for the index stations 2EE07, the statistics were then divided by the basin area to get the stream flow per unit area of the index station, and the value obtained is multiplied by the areas of the ungauged (dam catchments) to get the estimated statistics for the dam site. This method was most suitable for the two basins because the dams are on the respective Rivers as the index station, and has similarities in drainage area, basin characteristics and on climatic characteristics; therefore the river flow per unit area is assumed to be the same.

The general area ratio equation is:

Q ungauged = Q gauge (A ungauged /A gauge)

Where:

Q ungauged: is the flow at the ungauged site (proposed dam site)

Q gauge: is the flow at the gauged site

A ungauged: is the catchment area (km2) of the ungauged site (upstream of the proposed dam in km2)

A gauge: is the catchment area upstream of gauging station (2EE07).

This method allows the estimation of the availability of water at the dam site based on historic long-term information of the gauging station s 2EE07. The catchment area for the station 2EE07 is1,181 km2 and that of the dam sites were 1,061.1,km2, a ratio of = 0.9 for Radat, 1,148.7 km2, a ratio = 0.97 for Kaplelwo, 40.8 km2, a ratio = 0.03 for Kopokaplelach and 143.4 km2, a ratio = 0.12 for Kapng'etuny. These area ratios were then used to interpolate the flow data from the gauging station to the proposed dam sites.

5.5 Flood Frequency analysis

Perkera 2EE07

The objective of flood frequency analysis is to estimate a high (peak) flow corresponding to a specific return period of occurrence, for dam design. This is to ensure that the flood water to be released through the spillway should not create flooding downstream. Thus a balance has to be worked out between the economy, efficiency in regard to flood moderation and safety.

Flood analysis can be based on, (i) Annual maximum peak discharges, (ii) Instantaneous peak flow), the runoff coefficient which is derived from the relationship between recorded flood hydrographs and concurrent rainfall, table 5.12, shows the flood frequency at Perkera 2EE07, based on river flows.

Different methods were used to ensure the results were reliable, as each method has its own strengths and weaknesses based on the assumptions they make. The probability distributions used in the analysis were, Gumbel and the Extreme value index (EVI), each of this probability makes certain assumptions about the catchment's characteristics and hence slightly different results. The goodness of fit test was done using, standard deviation, correlation coefficient and the Chi-square statistic, and the distribution with the lowest standard deviation and highest correlation coefficient, was picked as the best fit of flood data of the river, and was used to generated design floods for the sites, the Gumbel had the best fit to the observed data and therefore gives the most reliable results and was adopted for the study, see table 5.12.

Table 5:12 Design Floods of Perkera River at 2EE07

Return period (Year:T)	Gumbel (m^3/sec)	EVI (m^3/sec)
Q10,000	**251.15**	127.01

Q1,000	**197.44**	108.14
Q500	**181.26**	102.46
Q100	**143.64**	89.24
Q50	**127.35**	83.52
Q20	**105.62**	75.89
Q10	**88.84**	69.99
Q5	**71.34**	63.84
Q2	**44.90**	54.55

The estimated design floods at 2EE07 were then interpolated to the proposed dam sites and the design flood data at the dam site are shown in table 5.13.

Table 5:13 Design floods at the dam sites (m^3/sec)

Return period (Years:T)	Basin 2EE07	Radat site	Kaplelwo site	Kopokaplelach site	Kapng'etuny site
Q10,000	251.15	226.035	243.616	7.545	30.138
Q1,000	197.44	177.696	191.517	5.923	23.693
Q500	181.26	163.134	175.822	5.438	21.751
Q100	**143.64**	**129.276**	**139.33**	**4.309**	**17.237**
Q50	**127.35**	**112.82**	**123.53**	**3.821**	**15.282**
Q20	105.62	95.058	102.451	3.169	12.674
Q10	88.84	79.956	86.175	2.665	10.661
Q5	71.34	64.206	69.20	2.140	8.561
Q2	44.90	40.41	43.553	1.347	5.388

From table 5.13 the (Gumbel) results, which had the best fit on the flood data, the Q100 year flood is 129.276 m^3 /sec for Radat, 139.33 m^3/sec for Kaplelwo, 4.309m^3/sec for Kopokaplelach and 17.237 m^3/sec for Kapng;etuny site . The Q50 year flood is 112.82 m^3 /sec for Radat, 123.53 m^3/sec for Kaplelwo, 3.821 m^3/sec for Kopokaplelach and 15.282 m^3/sec for Kapng'etuny dam site.

5.5.1 Flood Characteristics

Understanding the peak flood characteristics for the project area is a must for the success of the dam project; the various design flood computation methods are discussed as follows:

5.5.2 Inflow Design Flood

The criteria for selection of inflow design flood for safety of dam as per International Standards are:

<u>International Commission on Large Dams (ICOLD)</u>

This commission 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 10 m and 15 m 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

Federal Emergency Management Agency (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.

Kenyan standards

In Kenya, the Water Resources Management Authority (WRMA) recommends minimum design floods for hydraulic design of dam spillways on the basis of risk associated with drainage that may occur downstream on the event of embankment failure. Classification of dams is also based on the height, reservoir impoundment area and the dam catchment. The Tables below show the classification of dams and recommendations for spillway design flood, as per WRMA regulations, see table 5.15 and 4.29.

Table 5:14 Classes of dams

Class of dam	Maximum depths of water at NWL (m)	Reservoir Impoundment (m^3)	Catchment area (m^2)
A (Low risk)	0-4.99	<100,000	<100
B (Medium risk)	5-14.99	100,000 – 1,000,000	100-1,000
C (high risk)	>15.0	>1,000,000	>1,000

Source, Water management rules, draft-June 2006

Table 5:15 Recommended design periods for the design of spillway

Class of dam	Minimum return period (Years)
A (Low risk)	I in 50
B (Medium risk)	1 in 100
C (high risk)	1 in 500

Source, Water management rules, draft-June 2006

The following criteria were adopted in previous studies in Kenya, (TNWS, Long Term Development Plan, Hydrology, Chapter 9, HH, 1986):

- River diversion works – 50 year return period
- Temporary works during dam construction – 50 year return period
- Dam spillway structures – Probable Maximum Flood (PMF)

Data Availability

Due to non-availability of Instantaneous peak discharge records for gauging station in the close proximity of dam site or even at Perkera gauging stations 2EE07, short interval meteorological data for the region, and hydro-meteorological method utilizing catchments characteristics with rainfall was adopted during the study. Considering the nature of data and current available information, the methodology for possible design flood estimation will be as discussed in following section. The runoff coefficient of C = 0.6 was adopted for all the dam sites.

5.6 Estimated Design Flood using empirical formula

The design flood was estimated using different empirical formulae and the highest of the results was adopted and used. Four different used are as follows:

(a) Dicken's Formula

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

Where,

A = Catchment area (km²)
C = runoff coefficient
Qp= Peak Flood in m³/s

(b) **Ryve's Formula**

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

Where,

A = Catchment area (km²)
C = runoff coefficient
Qp= Peak Flood in m³/s

(c) **Metcalf and Eddy Formula**

$$Q_p = C\,A^{0.73}$$

Where,

A = Catchment area (km^2)
C = runoff coefficient
Qp= Peak Flood in m^3/s

(d) **Fanning Formula**

$$Q_p = C\,A^{4/5}$$

Where;

C = runoff coefficient
Where, A = Catchment area (km^2)
Qp= Peak Flood in m^3/s

These formulae are more useful because they do not experience application restrictions based on catchment size as the case with the rational formula.

(E) **The rational formula**

$$Q_{pF} = CIA$$

Where:

QpF is the flood peak in m^3/s

C is the runoff coefficient (proportion of precipitation that contributes to runoff

I is the rainfall /storm intensity in mm/hr

A is the catchment area in km^2

However this was not applicable to the study as the three of the four dam sites, had catchment high above the 50 km2 limit for its application. The summary of estimated peak flows using different methods are shown in table 5.15.

Table 5:16 Summary of peak flows estimates based on empirical formula

Empirical formula	**Peak discharge estimate (m^3/sec)**			
	Radat site	Kaplelwo site	Kopokaplelach site	Kapng'etuny site
Dicken's formula	111.55	118.39	9.69	24.86
Ryve's Formula	63.89	67.37	7.20	16.71
Metcalf and Eddy Formula	97.04	102.83	8.99	22.51

Fanning Formula	158.04	168.39	11.66	31.87

Based on empirical formulae results in table 5.15, the peak flow at the Radat dam site ranges between 63.89- 158.04 m^3/sec, and hence the higher value is adopted, 158.04 m^3/sec. For Kaplelwo, the peak flow ranges between 67.37- 168.39 m^3/sec and 168.39 m^3/sec is adopted, for Kopokaplelach, the peak flow ranges between 7.2- 11.66 m^3/sec and 11.66 m^3/sec is adopted and for Kapng'etuny, the peak flow ranges from 16.71-31.87 m3/sec, and 31.87 m^3/sec is adopted.

5.7 Probable maximum flood (PMF)

Determination of PMF begins with the determination of the probable maximum precipitation, the PMF is the flood which is a direct result of PMP or is the highest flood a region will ever experience or Flood that may be expected from the most severe combination of the critical meteorological and hydrological conditions that are reasonably possible in a particular area.

PMF is the flood which is a direct result of PMP or is the highest flood a region will ever experience or Flood that may be expected from the most severe combination of the critical meteorological and hydrological conditions that are reasonably possible in a particular area. According to Obasi and Nimira (1977), the probable maximum flood PMF, is given by the following regression curve formulae:

PMF = (0.094 pmp –9.86) A 0.75

Where:

PMF: Probable Maximum Flood m^3/s

A: Catchment area (km2) of the project.

PMP: Probable Maximum Precipitation for upper Perkera = 200 mm (obtained from PMP Isohyets map Obasi and Nimira, 1977); m^3/sec as the PMF for the project area, using the above equation, see the results in table 5.17.

Table 5:17 Probable maximum flood at the dam sites

Dam Site	Catchment area (km^2)	PMF (m^3/s)
Radat	1,061.1	1,662.09
Kaplelwo	1148.7	1,763.98
Kopokaplelach	40.8	144.32
Kapng'etuny	143.4	370.47

From table 5.17, Radat dam site has a peak flow of 158.04m^3/s and a PMF of 1,662.09 m^3/s, Kaplelwo dam site has a peak flow of 168.39 m^3/sec and the PMF is 1,763.98 m^3/s. For Kopokaplelach, the peak flow is 11.66m^3/s and the PMF is 144.32 m^3/s, for Kapng'etuny, the peak flow is 31.87 m^3/sec and the PMF is 370.47 m^3/sec, see the flood summary in table 5.18.

Table 5:18 Summary of flood estimates based on empirical formula

Dam Site	Peak discharge estimate (	PMF (m^3/sec)

	m^3/sec)	
Radat	158.04	1,662.09
Kaplelwo	168.39	1,763.98
Kopokalelach	11.66	144.32
Kapng'etuny	31.87	370.47

5.7.1 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 minimizing:

- 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:

5.7.2 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, see table 5.19.

Table 5:19 Diversion floods (m^3/sec)

Dam Site	5 year flood estimate (m^3/sec)	10 year flood (m^3/sec)	20 year flood (m^3/sec)
Radat	64.21	79.96	95.06
Kaplelwo	69.20	86.18	102.45
Kopokalelach	2.14	2.67	3.17
Kapng'etuny	8.56	10.66	12.67

The return period adopted between 5 year and 20 years depends on the flow characteristic during the diversion time.

<u>B: For Large Dams</u>

For large dams it is desirable that 100 years flood should be adopted for diversion works, table 5.20.

Table 5:20 Diversion floods for large dams (m^3/sec)

Dam Site	100 year flood estimate (m^3/sec)
Radat	129.28
Kaplelwo	123.53
Kopokalelach	4.31
Kapng'etuny	12.67

From table 4.28, the 100 year flood for radat is 129.28 m^3/sec, Kaplelwo 139.33 m^3/sec, Kopokalelach 4.31 m^3/sec and Kapng'etuny 12.67 m^3/sec.

6 BASIN WATER BALANCE

The water balance of the Perkera river basin at the dam sites is shown in table 6.1

Table 6:1 Flow reliability at the Perkera 2EE07 and dam sites

Reliability level	Flows (m3/sec)									
	2EE07(m3/sec)		Radat		Kaplelwo		Kopokaplelach		Kapng'etuny	
	Existing	available	Existing	available	Existing	available	Existing	available	Existing	available
Q50	1.77	1.523	1.593	1.346	1.717	1.47	0.053	-0.194	0.212	-0.035
Q75	0.676	0.552	0.608	0.484	0.656	0.532	0.02	-0.104	0.081	-0.043
Q80	0.567	0.443	0.51	0.386	0.545	0.421	0.017	-0.107	0.068	-0.056
Q95	0.291	0.291	0.262	0.262	0.282	0.282	0.009	0.009	0.035	0.035

Given the existing water rights in the basin, the dam sites at Kopokaplelach and Kapng'etuny will experience water deficits, while there is water surplus in the Radat and Kaplelwo dam sites.

6.1 Basin Water Yield

The water yield of a watershed may either be measured directly on a single outlet on the main stream or be calculated through empirical equations based on important physical properties of a particular watershed. Using the directly measured runoff values is, of course, the best way, but since it takes a long time and investments are delayed, the empirical method is preferred in applications.

The annual water yield expressed in the Turc method as reported by Shaw:

V = h.A.10

Where, V is the annual water yield of the basins (m^3 year-1), A is the area of the basin (hectare) and h = -1,903 is the surface runoff height that occurred in the basin (mm year-

The surface runoff height is calculated as:

h = P – ET

ET is the areal evapotranspiration (mm year-1) and P is the mean precipitation (mm year-1). The estimated basin water yields at the dam sites aere shown in table 6.2..

Table 6:2 Basin/ dam site water yields

River/ dam site	Basin area (km^2)	Basin area (ha)	Water yield (m^3/year)
Perkera 2EE07	1181	118,100	-1,152,632,380
Radat	1,061.1	106,110	-1,035,612,378
Kaplelwo	1,148.7	114,870	-1,121,108,226
Kopokalelach	40.8	4,080	-39,819,984
Kapng'etuny	143.4	14,340	-14,054,175

From table 6.2, it is evident that the Perkera basin as a whole experiences large water deficits as water losses through evaporation at 1,631.98 mm annually, is far more compared to annual precipitation of 656 mm at the Kari met station.

6.2 Basin Groundwater Recharge

Groundwater recharge has been defined as the process of addition of water to the saturated zone. Because it is almost impossible to measure directly, recharge is usually estimated by indirect means. The Relationship of Krishna Rao was used as follows:

Krishna Rao gave the following empirical relationship to determine the ground water recharge in limited climatological homogenous areas, the equation is: R = K (P - X)

R is net recharge (mm) and P is mean annual precipitation (mm)The following relation is stated to hold good for different rainfall amounts; R = 0.20 (P - 400) for areas with P between 400 and 600 mm R = 0.25 (P - 400) for areas with P between 600 and 1000 mm R = 0.35 (P - 600) for areas with P above 2000 mm where, R & P are expressed in millimeters

P = 656 mm

R = 0.20(656-400)

R = 51.2 mm (the net ground water recharge(R) in the project area is 51.2 mm)

6.3 Evapotranspiration

Evapotranspiration (ETo) is the total amount of water lost through evaporation in the soil and transpiration ("breathing") of the plants. The annual evapo-transpiration is 1631.98 mm, see table 6.3.

This is quite high water losses, which has an implication on the water availability in the basin..

Table 6:3 Mean monthly Evapotranspiration (mm) at Kari research station Met.

Month	ET_0
	mm/month
January	158.72
February	152.6
March	167.71
April	162.3

Month	ET_0
	mm/month
May	144.77
June	135.30
July	129.27
August	134.30
September	149.10
October	154.38
November	142.38
December	143.53
Total	**1,631.98**

6.4 Net Evaporation from the Reservoir

Because of its nature, evaporation from water surfaces is rarely measured directly, except over relatively small spatial and temporal scales (Jones 1992). Evaporation from water is most commonly computed indirectly by one or more techniques. These include:

- pan coefficients × measured pan evaporation,
- water balance,
- energy balance,
- mass transfer,
- a combination of energy balance and aerodynamic techniques

The selection of the "best" technique to use for a particular computation is largely a function of the data availability, type or size of the water body, depth and the required accuracy of the estimated evaporation.

The most commonly used method in the Kenya for estimating evaporation from small, shallow water bodies, is to measure evaporation from a standard pan and then multiply by a coefficient.

6.4.1 Evaporation Pan Method:

E = Kp Epan

A pan Where Kp is the pan coefficient, = 0.7 and Epan is the evaporation from A Class. Based in the above equation, the net evaporation for the dams sites is 1631.98 x 0.7 = 1,142.4 mm, based on the Kari station and 2559 x 0.7 = 1,791.3 mm based on Perkera scheme station.

7 SEDIMENTATION

The rate of sedimentation rate depends on the soil erodability of the soils of the basin, precipitation and the river capacity.

7.1 Reservoir Sedimentation

There is little existing records of sediment flow rates for Perkera River at RGS 2EE07 and none at the proposed dam sites and hence the sediment loading rate used in the study was estimated from another RGS on Perkera 2EE04. The National Water master plan (1992) Sectorial report B: on hydrology, provides sedimentation rates for major rivers in the country. The equation for the Perkera River basin is as follows:

Qs = aQb ,

Where:

Qs: is suspended load (ppm)

Q: is the discharge (cms)

a and b are constants, derived from data,

see table 7.1 for Perkera 2EE04.

Table 7:1 Perkera River at RGS 2EE04 rating equation of suspended load and its volume

RGS	River	Catchment area (km2)	Annual mean discharge (m3/sec)	Rating equation		Mean (ppm)	Annual (ton/year
				a	b		
2EE04	Perkera	1,334	2.8	1197.201	1.010	3,387	390,033

From the table 7.1, the annual suspended load discharge at from the Perkera basin at 2EE04 is 390,033 tonnes/ year. Since the area of the Perkera basin is at 2EE04 is 1,334 km2, then the mean sediment yields for Perkera basin at 2EE07, with an area of 1,181 km2, is 345,299.08 tons/year or is 292.4 tones/km2/yr. When this is transposed to the dam sites, the results are as shown in table 7.2.

Table 7:2 Estimated sedimentation rates at the dam sites

Site	Catchment area (km2)	Sediment load (m3/year)	Yield (tones/km2/yr)
Perkera at 2EE07	1,181	345,299.08	292.4
Radat site	1,061.1	310,769.82	292.87
Kaplelwo site	1,148.7	334,940.11	291.58
Kopokaplelach site	40.8	10,358.97	253.90
Kapng'etuny site	143.4	41,435.89	288.95

From table 4.39, Radat dam site experiences sedimentation rates of 310,769.82 m³/year or 292.4 tones/km2/year, Kaplelwo 334,940.11 m³/year or 292.87 tonnes/km²/year, Kopokaplelach 10,358.97 m³/year or 253.9 tonnes/km2/year and Kapng'etuny 41,435.89 m³/year or 288.95/km2/year.

7.2 Estimation of Sedimentation Level

The sedimentation levels in the Perkera basin and at the proposed dam sites are quite high and hence siltation problems for the dams is real and there is need for increased efforts in catchment conservation. During the field visits, there was evidence of serious watershed degradation evidenced by intensive charcoal burning as witnessed by several bags of charcoal along the roads in the area.

8 HYDROLOGICAL IMPACTS OF THE PROPOSED DAMS ON THE RIVER BASINS

There are several hydrological impacts of dam construction in a river basin, this includes;

- Magnitude of the extremes: Dams are quite effective at accomplishing what they were designed to do as the most dramatic shifts occur in the decreased magnitude of 1-day maximum flows. A somewhat different pattern emerges for minimum flows, minimum flows tend to increase following impoundment, but this is most true for the longer duration events.
- Changes in hydrograph variability equally profound effects have occurred in parameters associated with the shape of the hydrograph. The characteristics of the hydrograph, as revealed by show significant changes in the number of reversals and in mean rise rates and fall rates. Besides greatly modifying the sequencing of hydrograph peaks, the day-to-day rate of change is also dramatically affected, especially for the rise rate of the hydrograph.
- The pulsing response of flows serves critical riparian functions, Changes in the frequency and duration of flows of a particular stage and discharge can significantly disrupt terrestrial and aquatic ecology.
- Changes in the timing of flows whether these dams are flood control, irrigation, or hydropower, they are all associated with storing water for subsequent releases. This storing component significantly affects the release timing and greatly disrupts the pre-impact natural flow regime's expected timing of flows. This effect occurs on the scale of total monthly stream flow and in the timing of extreme maximum and minimum flows in the river, especially during rain seasons, as they reduce to allow reservoir storage (filling).
- Modifies temperature and local climatic conditions, like temperature

Appendices

Appendix I: Rainfall Data

Appendix II: -River Flow Data