River Siroko Hydrology Assessment

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Executive Summary

A comprehensive hydrology assessment has been carried out on River Siroko, in order to assess the potential of the hydropower site that was identified on the river at coordinates 1˚ 08' 29"N and 34˚ 24' 35" N immediately downstream of the point of confluence of between Siroko and River Guragado.

The drainage basin for Siroko hydropower project comprises of R. Siroko and a tributary known as R. Guragado whose headwaters arise from the Mount Elgon. The total Siroko catchment that would contribute flow to the SHP project would be $60.73km^2$. The average rainfall for the catchment is 1924mm.

Due to the consistent cloud cover, sharp slopes, high altitude and considerable rainfall, the Siroko (SHP) catchment in general should have very low losses due to evapo-transpiration, and a high net yield. The losses due to evapo-transpiration and Ground Water Recharge are conservatively estimated at 45%, with a river runoff of 55% of the incident precipitation.

There is discharge measuring station (ID 82240) on River Siroko maintained by the Ministry of Water and Environment, approximately 25km downstream of the proposed diversion point. This study proposed a relationship between this discharge data and the required data at the proposed abstraction point – based on the catchment characteristics and the spatial rainfall distribution

The daily discharge data of the Mt Elgon Rivers is highly skewed. Even though the average daily discharge of River Siroko (SHP) is 2.03 m^3/s, the median discharge (Q50) of the two sites are $1.14m^3/s$. This is an important note that should carefully be taken into consideration when designing the corresponding hydropower facilities for the sites. The Flow Duration Curve (FDC) for the river shows that a discharge of 3.47m3/s is exceeded 15% of the time while 0.6 m3/s is exceeded 70% of the time.

An environmental flow reserve of $0.2m^3/s$ has been proposed for the river section that will be looped by the canal/penstock system (using the Tennants method).

Given that there are times of the year when the flows at this site are quite low, it is important that a discharge gauge be placed at the site as soon as possible to monitor the flows. The data obtained shall be used to improve the hydrologic estimates at the site – more so if the measurements are compared with those taken [concurrently] at the existing discharge measuring station (ID 82240) 25km downstream.

1 Hydro-Climatology of the River Siroko Catchment

1.1 Background

Due to the amount of rainfall and the many rivers and streams that come down the slopes of the mountain, there is a high potential for hydropower generation in the Mbale region. At the moment (2014) more than twenty small hydropower plants are planned for the Mt Elgon region. Of the twenty-two plants planned, only three will have a capacity larger than one megawatt. The largest of the planned hydropower plants is the Yeriya – Mahoma Sipi-Chebonet hydropower plant which is planned at 33 megawatt. At the moment, no hydropower plants are yet operational, and only the one in Suam is under construction. **Figure 1.1** shows the planned hydropower stations in the Mt. Elgon region.

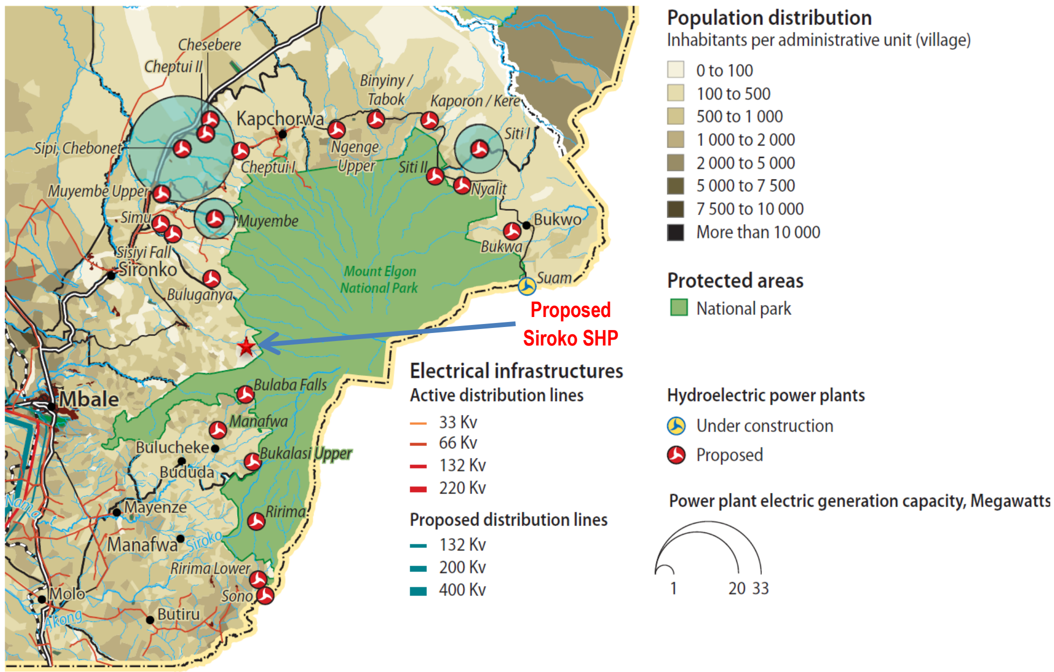

Figure 1.1 The proposed hydropower plants and those under construction in the Mt Elgon districts.
Source: Pravettoni, R. 2012 GRID-Arendal

River Siroko is one of the several perennial rivers that originate from the upper slopes of Mount Elgon flowing down the Western face of the Mountain through Elgon forest reserve, several villages finally droping to reach the dry lowlands where it subsequently discharges into Lake Kyoga. A hydro potential site has been identified on the river approximately 13km downstream of the river source. In order to assess the site's power potential, there is need to analyse the river's catchment characteristics and the discharge patterns including its low and high flows. The results of this analysis will constitute an important input into the design process of the proposed Hydro-electricity facility at the site and provide an indication of its safe capacity and hydrological reliability.

1.2 Siroko Catchment Characteristics

1.2.1 General Geology of the area.

According to Scott (1994), Mt. Elgon, a solitary volcano, is one of the oldest in East Africa. It was built up from lava debris blown out from a greatly enlarged volcanic vent during the Pliocene epoch (Knapen et al., 2006) and rises to a height of about 4320 m above sea level. The geology of the area is dominated by basaltic parent materials and strongly weathered granites of the Basement Complex (Claessens et al., 2007). Carbonatite intrusions on the lower slopes are reported by Knapen et al. (2006) and Claessens et al. (2007) as having caused fenitization of the granites, rendering them sensitive to slope instability. Identified as inorganic clays of high plasticity, the soils of the study area were classified by Mugagga et al. (2011) as vertisols characterised by a clay content exceeding 41%. Such properties qualify the soils as ‘problem soils’ that are susceptible to **landslides**.

1.2.2 Drainage Characteristics

The drainage basin for Siroko hydropower project comprises of R. Siroko and a tributary known as R. Guragado whose headwaters arise from the Mount Elgon. The exact location of the proposed hydraulics take-off point for Siroko hydro-electric power are at coordinates 1˙ 08’ 29”N and 34˙ 24’ 35” N immediately downstream of the point of confluence between Siroko and River Guragado as shown in Figure 1.2. There is a secondary weir on a small tributary that joins the Siroko near the primary weir (see Figure 1.2) which is to be placed there in order to increase the inflow into the head race channel. The areas of catchment upstream of the take-off points for Weir 1 and Weir 2 are 54.9 km² and 5.83km² respectively. Hence the total Siroko catchment that shall contribute flow to the SHP project would be 60.73km².

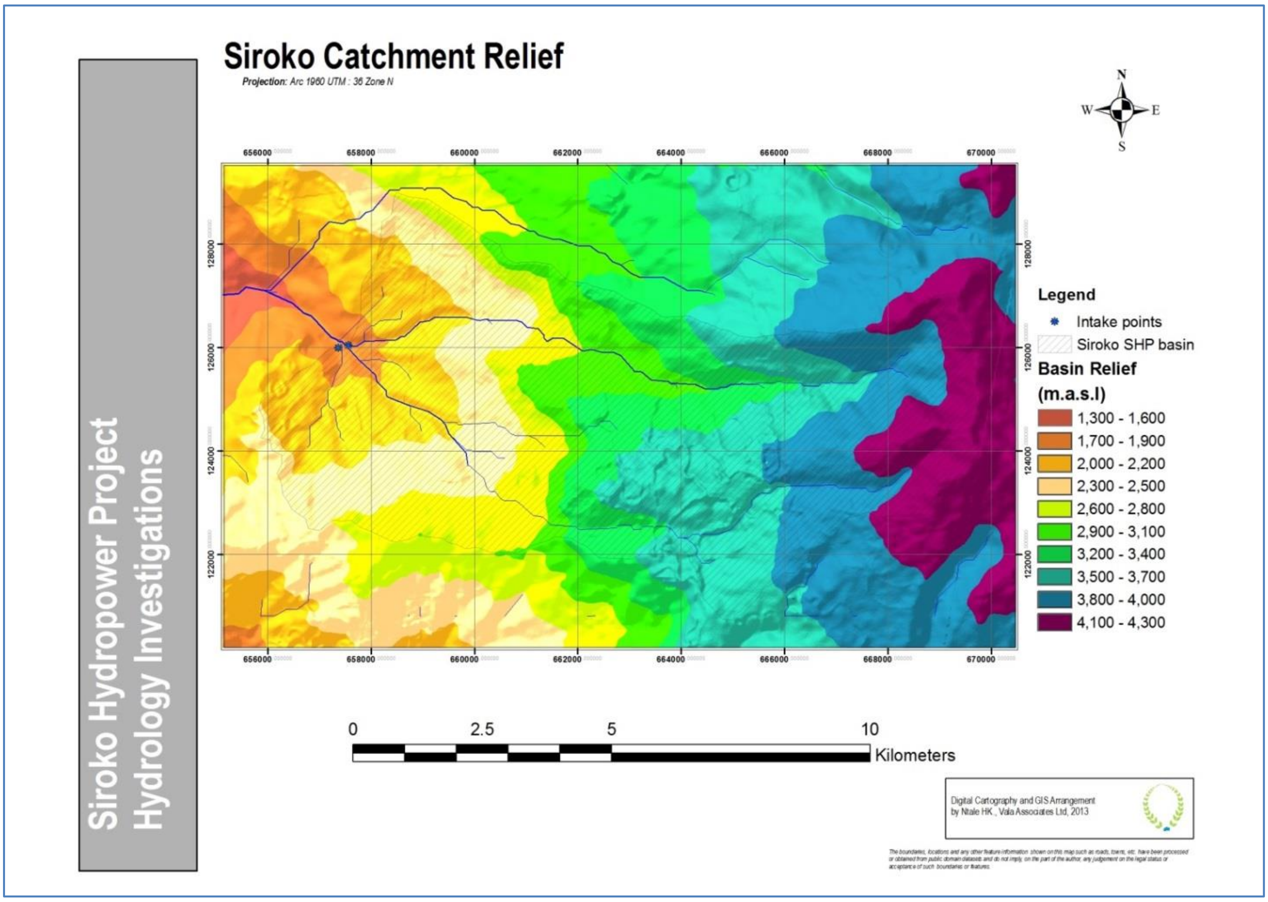

Figure 1.2 General relief profile of the Siroko Catchment

The entire catchment is on Mount Elgon slopes with its highest catchment spot at 4276 masl, while the lowest point is at 1747 masl. The mean catchment slope is approximately 32% although some areas have steep inclines standing at a slope of 210%

1.2.3 River Siroko Profile

River Siroko is a steep river as shown in Figure 1.3 below.

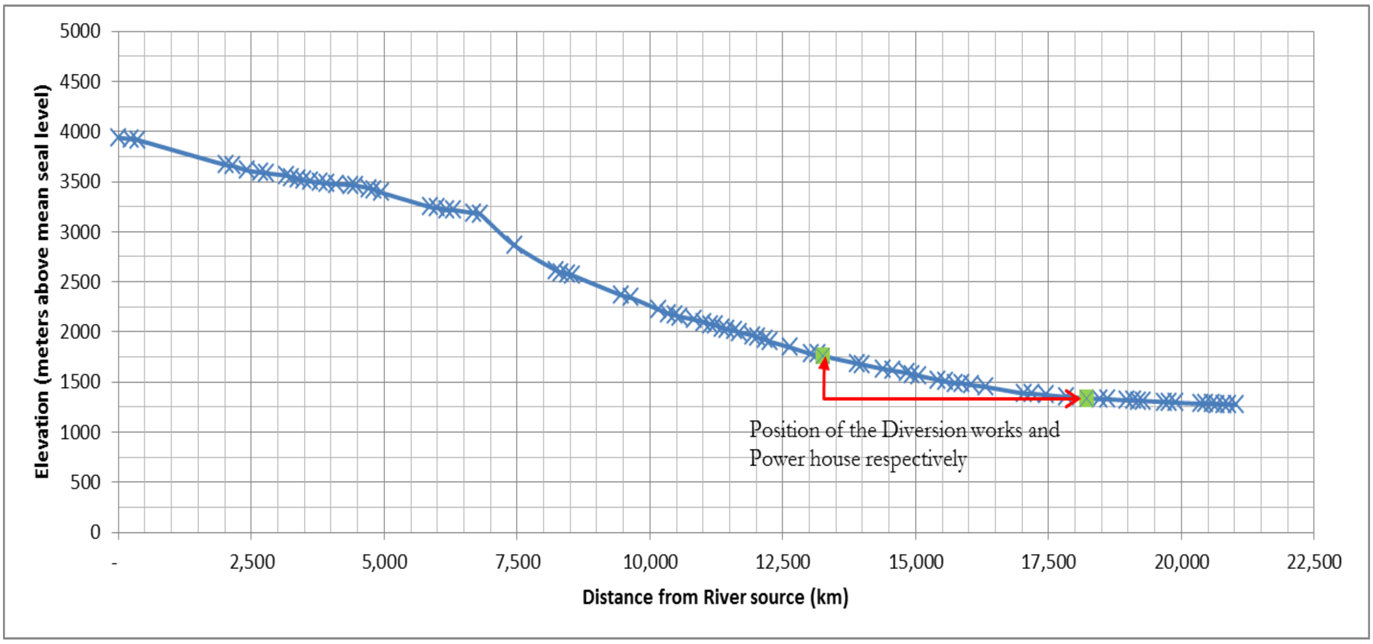

Figure 1.3 Hypsometric curve for River Siroko

1.2.4 Land cover of the Siroko Catchment

Land cover is an important variable in the assessment of potential runoff from a watershed and for River Siroko this is composed of Forest Reserves and Grasslands. Higher up, towards the dormant caldera, the Forest Reserve/woodlands gradually thin down to Grassland (Figure 1.3). Progressing further down the slopes, the vegetation changes to depleted tropical high forest (believed be a result of human activities) and subsistence farmland near the off-take points. Further depletion of tropical forests will no doubt affect the hydrology of the Siroko several ways particularly in the increased frequency of flash floods.

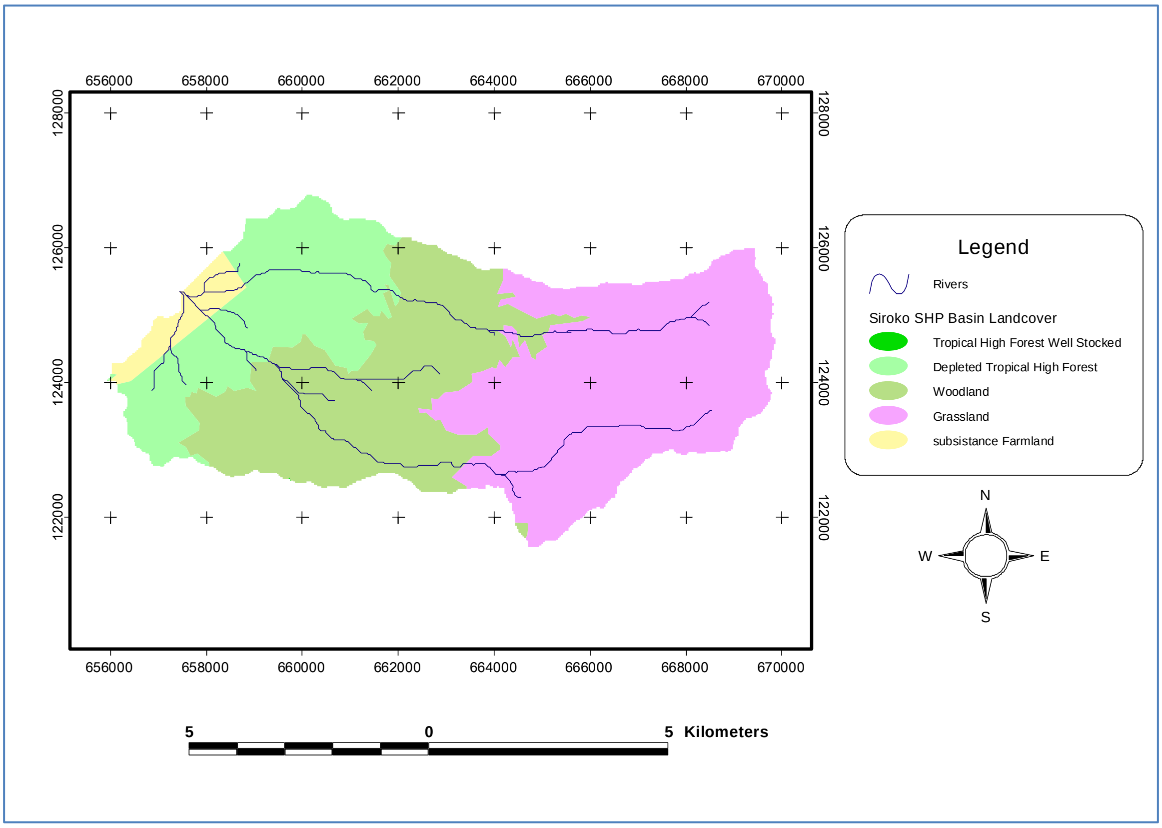

Figure 1.4 Vegetation cover of River Siroko SHP catchment

1.3 Rainfall climatology in the catchment

1.3.1 Rainfall data and patterns for the Siroko Catchment

The Mount Elgon area receives some of the highest rainfall in Uganda with an annual average of 2100mm towards the top of the caldera. However the rainfall decreases as one moves from the top of the mountain to the lower reaches of the Siroko SHP catchment slopes which on average receive 1700mm per annum. Data from the closest rainfall stations (shown in Table 1.1) to the Siroko catchment was obtained and analysed. The location of the stations is shown in Figure 1.4

Table 1.1 Selected Rainfall Gauging stations used to infer River Siroko Catchment rainfall

Station Name	ID	Longitude	Latitude	Elevation (m)
Buwalasi College	88340070	34.283	1.183	1500.0
Bugusege Coffee Res Station	88340260	34.267	1.150	1410.0
Buginyanya Coffee Res	88340590	34.367	1.283	1845.0

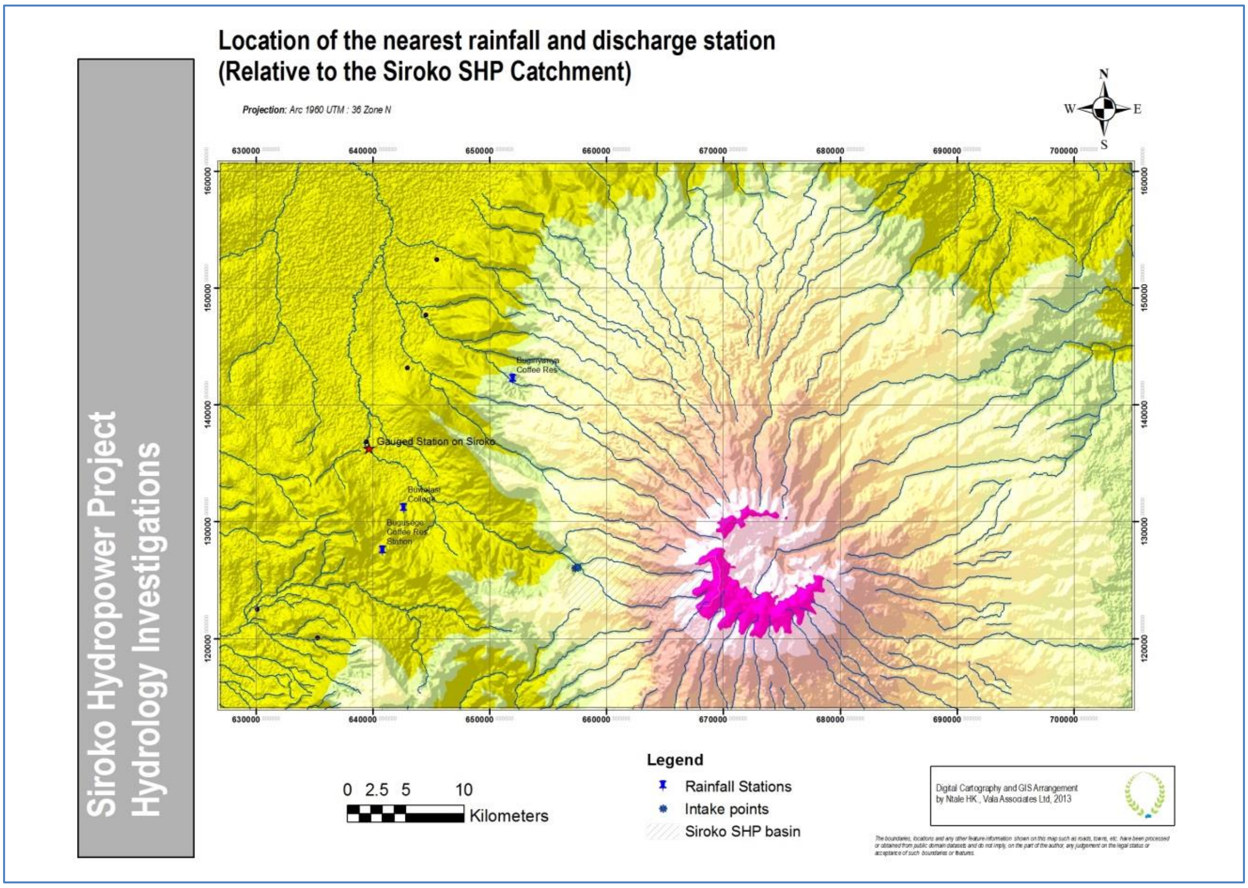

Figure 1.5 Rain and discharge gauging stations

There are no rain gauge stations high in the mountains (Figure 1.4), yet these are the areas with the highest rainfall. The three selected rain stations in Table 1.1 above lie within a radius of 17km of the proposed abstraction point on the Siroko. Even then, these stations cannot be truly representative of the higher Siroko catchment areas. The lengths of the data records for the rain gauging stations are shown in the Timeline below (Figure 1.5).

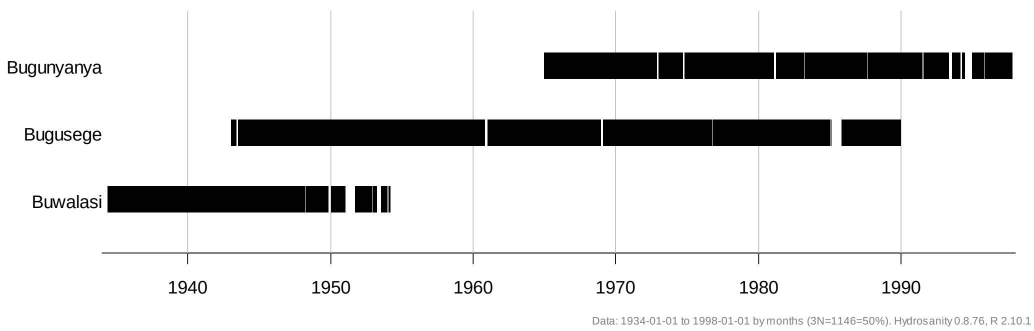

Figure 1.6 Timeline of gauging stations

The seasonal pattern of rainfall regime around River Siroko is such that there are approximately two rain seasons with maximum precipitation occurring between April–June and June-September as demonstrated by the box plots of average monthly rainfall of selected stations (Figure 1.6).

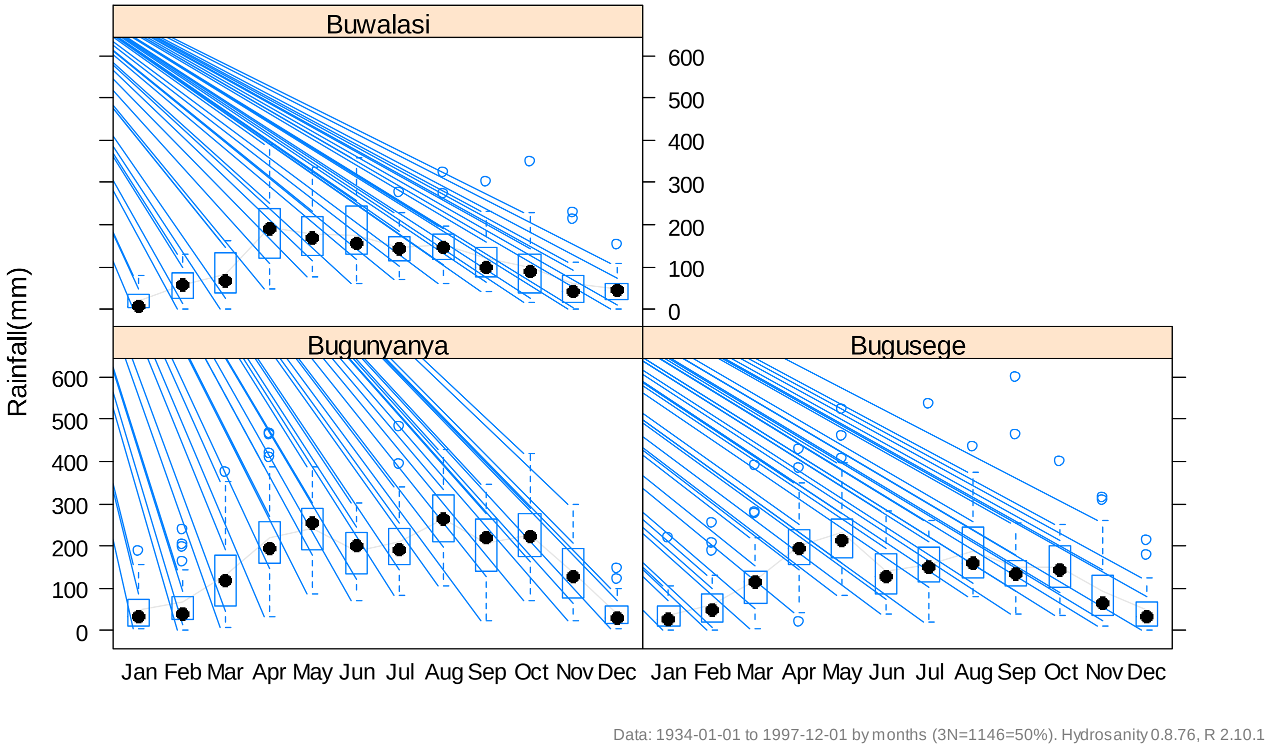

Figure 1.7: Monthly average rainfall for selected gauging stations

The two rain seasons are not so distinct because they are separated by only one month (June) of moderate rainfall. In some years it would appear as if there is one continuous rainfall season starting from April and ending in October.

1.3.2 The spatial rainfall distribution in the Siroko Catchment

Using GIS tools, the rainfall spatial distribution for the Siroko catchment (Figure 1.7) was obtained from the national mean annual rainfall GIS map that was developed by the Water Resources Management department (WRMD) and the Uganda Meteorological Department (UMD) – (MoWE, 2003)

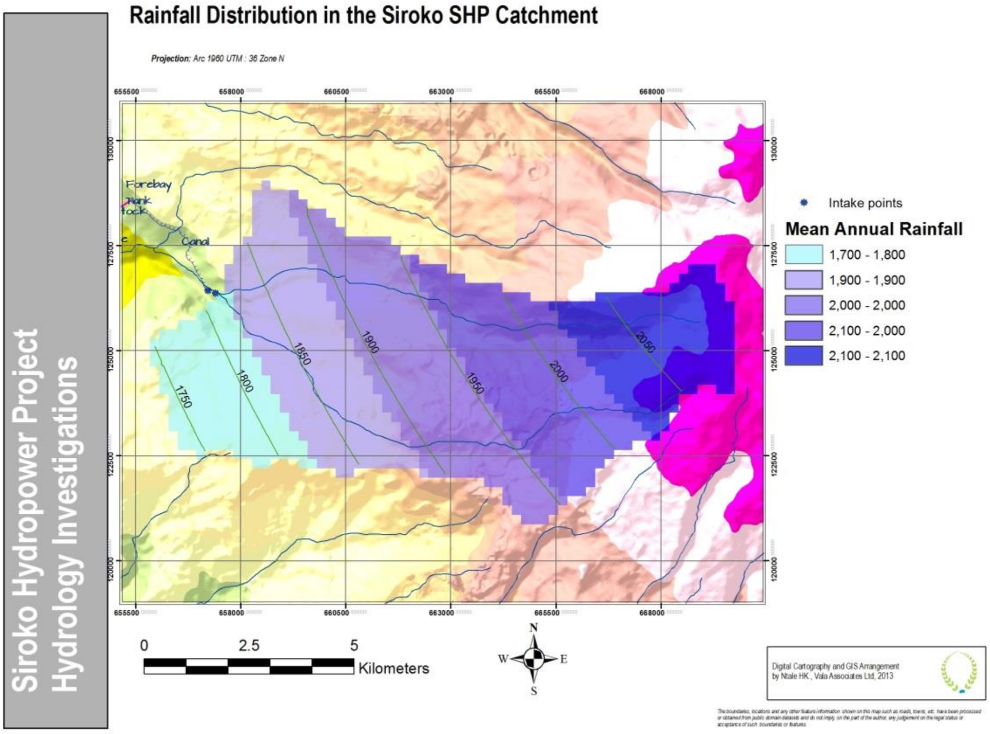

Figure 1.8 Average annual spatial Distribution of rainfall in Siroko basin

From Figure 1.7, one notes that the entire area upstream of the take-off points for the Siroko project is very wet, with annual rainfall ranging between 1750mm-2200mm. There would seem to be some correlation between altitude and rainfall. The average rainfall for the catchment is 1924mm.

2 The Siroko River flow characteristics

2.1 River Discharge data

2.1.1 Siroko (SHP) Catchment Net Yield and ET Losses.

Due to the consistent cloud cover, sharp slopes, high altitude and considerable rainfall, the siroko (SHP) catchment in general should have very low losses due to evapo-transpiration, and a high net yield. The losses due to evapo-transpiration and Ground Water Recharge are conservatively estimated at 45%, with a river runoff of 55% of the incident precipitation. The catchment yield estimates are given in Table 2.1 below.

Table 2.1 Catchment yield estimates for the Siroko SHP basin

Property	Amount	Unit
Catchment Area	60.73	km^2
Average Catchment Rainfall	1924	mm
Catchment Gross Yield	116,844,520	m^3
Less ET and Ground Water Recharge Losses of 45%	-52,580,034	m^3
Catchment Net Yield	64,264,486	m^3
Mean Annual Discharge (MAD)	2.03	m^3/s

2.1.2 Hydrographs of nearby discharge stations

There are several other rivers (Table 2.2) which originate from the Mountain Elgon whose discharge measurements have been recorded for various lengths as shown in Figure 2.1. The hydrographs of these rivers shall be compared with that of the derived Siroko (SHP) flows to discern any relevant properties.

Table 2.2 Discharge stations of selected rivers originating from Mount Elgon

Station ID	Description	Latitude	Longitude	Drainage Area (km^2)	Altitude
82243	R. Sipi at Mbale - Moroto Road	1.3827	34.3144	87.4	1081
82241	R. Simu at Mbale - Moroto Road	1.2985	34.2873	173.9	1091
82240	**R. Siroko at Mbale - Moroto Road**	**1.2362**	**34.2569**	**270.3**	**1118**
82231	R. Kelim (Greek) at Mbale - Moroto Road	1.5982	34.5439	1400	1100

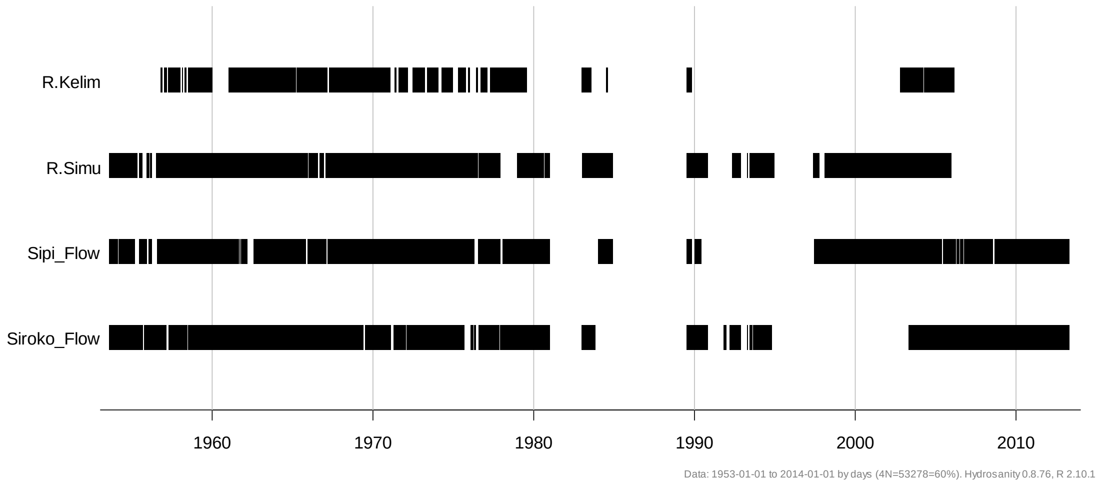

Figure 2.1 Timeline of Selected Gauged rivers flowing from the Elgon Mountain

There are major data gaps in the river discarge time series throught the 80's and 90's. The only window that can be of use in comparative hydrograph analysis for all the rivers is from 1953 to 1980. Figure 2.2 further demonstrates the hydrograph variation of the respective rivers.

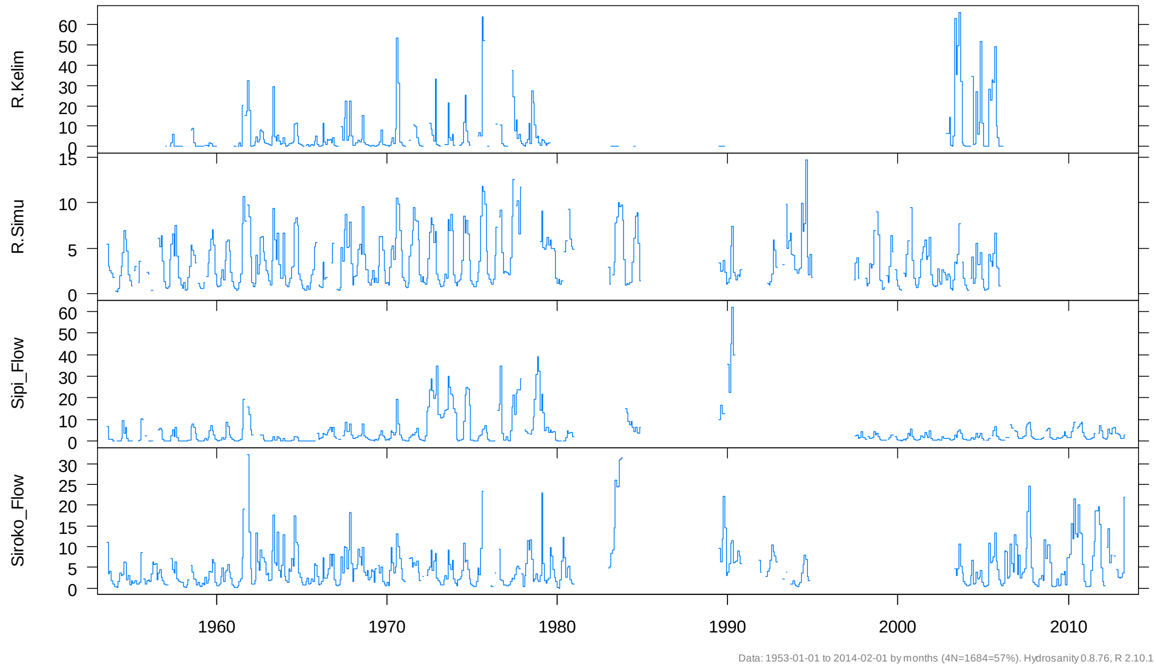

Figure 2.2 Mean monthly flows for River Kelim, Simu, Sipi and Siroko (Gauged)

It will be observed that generally the peaks of the various rivers are coterminous (they happen at the same time). This is to be expected since the waters are originating from catchments of generally similar physical features.

2.1.3 Brief Discussion of the available discharge data

Station 82240 *R. Siroko at Mbale - Moroto Road:* The catchment area of this river is about four times that of the Siroko (SHP) although the runoff contribution of the latter is much higher. The flows of Gauged Siroko are more subdued compared to the other rivers probably because of a higher base flow component.

Station 82243 *R. Sipi at Mbale - Moroto Road:* The catchment contributing to this discharge is quite narrow in structure. In the period 1953 – 1980, this river had zero flow for 18% of the time.

Station 82241 *R. Simu at Mbale - Moroto Road:* The flows of this catchment are consistent and slightly more attenuated compared to the Sipi flows, owing to the larger length/width ration for the Simu catchment. River Simu is a perennial river which always registers some base flows even during driest seasons.

Station 82231 R. Kelim (Greek) at Mbale - Moroto Road: As earlier stated, River Sipi catchment constitutes 9% of the greater Kelim Catchment. There is wide spatial variation of rainfall in the Kelim catchment ranging from 2200mm to 800mm per annum. Although the Siti and Nyalut Rivers are upstream tributaries of R. Kelim, it is not practical to infer or disaggregate their respective contributions from the total Kelim catchment output.

Table 2.3 shows the catchment characteristics of the nearby gauged rivers alongside the characteristics of the Siroko (SHP) diversion point.

Table 2.3 Catchment characteristics of discharge stations and the Siroko (SHP) project weir diversion point

ID	Area km²	Area/ Perimeter ratio	Slope (%)		Elevation (m)			Length (km)		Ave Q[1] m³/s	Δq[1] l/sec /km²
			Max	Ave	Min	Max	Ave	Max	Equivalent		
Siroko (SHP)	60.73	1.590	211.0	1.2	1761	4275	3052	15.5	14.7	2.0	32.9
Siroko (Gauge)	270.34	2.962	211.0	23.6	1093	4275	1967	41.8	38.6	5.0	18.3
Sipi	87.44	1.173	91.9	18.8	1067	3608	2242	36.7	34.8	2.0	25.5
Simu	173.89	2.296	137.0	27.5	1070	4163	2372	37.1	32.5	3.0	14.5

2.1.4 Generation of the River Siroko Discharge data

There is a discharge measuring station (ID 82240) on River Siroko, approximately 25km downstream of the proposed abstraction point. There must be some relationship between the gauged discharge and the discharge at the point of interest 25km upstream which takes into consideration the river routing and general flow attenuation processes. A simple relationship, between these discharges, is assumed that is dependent on catchment area, land cover and slope, as well as rainfall distribution.

The core considerations held in this regard are the following:-

a) Given that the bulk of the Siroko (SHP) basin (60.73km²) is at high altitudes in the Elgon National Park, with more than 40% of it covered by forest, one would expect high rainfall and reduced evapo-transpiration due to a heavy cloud cover. We have

[1] Calibration assessments for Siroko, Sipi and Simu were done by Water Resources Management Department for the year 2005

conservatively estimated the total losses due to evapo-transpiration and ground water recharge at 45%, with a river runoff of 55% of the incident precipitation.

b) The average runoff from the [gauged] greater Siroko catchment (270.34km^2) is known as well as the mean precipitation (see Table 2.3)

c) The rest of the greater Siroko catchment must necessarily be having larger water losses due to reduced slopes, lower cloud cover, reduced land cover due to extensive farming and higher surface temperatures because of the reduced altitudes. We have conservatively fixed the water loss coefficient for the rest of the Siroko Catchment to 70%.

From the above, we have deduced that the first order estimate of the discharge at the Siroko (SHP) abstraction point is approximately 40% of the observed discharge 25km downstream at the Siroko Gauge. It would therefore seem that the Siroko (SHP) basin acts as an important elevated water tower for the greater Siroko catchment. The Siroko (SHP) discharges have been estimated using a simple linear regression with the gauged discharge at the Siroko. We acknowledge that this is only a first order approximation. In reality, the discharge from the SHP abstraction point to the gauging point 25km downstream (travel time of about 9 hours) goes through some attenuation due to river routing. There is insufficient data to attempt any reverse Hydraulic routing or Hydrologic Muskingums routing to arrive at the input hydrographs. For the quantification of the hydro-eletric potential, the first order estimate of the Siroko (SHP) discharge as outlined above shall be sufficient.

The discharge flows at Siroko (SHP) have been derived taking into consideration the observation above. The derived mean monthly flows for the period 1953 – 2013 are presented in Annex 1 while the annual summary statistics for the catchment are presented in Table 2.4.

Table 2.4 Summary Statistics of the R. Siroko (SHP) derived Flows

Year	Number of missing daily records	Minimum (m^3/s)	Maximum (m^3/s)	Mean (m^3/s)	Median (m^3/s)
1953	200	0.22	18.05	1.64	0.82
1954	0	0.04	11.06	1.02	0.78
1955	30	0.26	12.44	0.85	0.53
1956	0	0.25	5.77	1.33	1.09
1957	32	0.09	14.07	1.26	0.79
1958	20	0.05	7.20	0.75	0.62
1959	0	0.05	15.77	1.04	0.58
1960	0	0.08	9.05	1.07	0.71
1961	6	0.03	31.95	3.22	1.18
1962	0	0.20	30.06	2.20	1.54
1963	0	0.33	20.00	2.83	1.61
1964	0	0.34	42.83	2.41	1.44
1965	0	0.16	7.56	0.91	0.57
1966	0	0.22	17.24	1.55	0.99
1967	0	0.20	19.30	2.46	1.61
1968	0	0.40	9.74	2.06	1.69
1969	30	0.06	11.78	1.25	0.86
1970	0	0.06	17.53	2.27	1.51

Year	Number of missing daily records	Minimum (m^3/s)	Maximum (m^3/s)	Mean (m^3/s)	Median (m^3/s)
1971	56	0.42	7.55	1.87	1.64
1972	27	0.29	15.64	1.78	1.23
1973	0	0.18	11.89	1.34	0.90
1974	0	0.13	11.14	1.50	1.07
1975	122	0.05	26.37	2.24	0.68
1976	121	0.09	5.98	0.96	0.40
1977	30	0.05	3.24	1.08	0.98
1978	0	0.06	7.57	1.96	1.20
1979	0	0.01	12.87	2.11	0.98
1980	0	0.00	5.51	1.51	0.92
1981	365	NA	NA	NA	NA
1982	365	NA	NA	NA	NA
1983	61	1.35	14.63	7.21	8.38
1984	365	NA	NA	NA	NA
1985	365	NA	NA	NA	NA
1986	365	NA	NA	NA	NA
1987	365	NA	NA	NA	NA
1988	365	NA	NA	NA	NA
1989	181	0.71	10.29	4.49	3.86
1990	61	0.69	5.32	2.95	2.84
1991	304	1.12	3.28	2.13	2.09
1992	101	0.93	5.30	2.46	2.43
1993	153	0.19	4.84	0.68	0.44
1994	61	0.14	4.74	1.30	0.84
1995	365	NA	NA	NA	NA
1996	365	NA	NA	NA	NA
1997	365	NA	NA	NA	NA
1998	365	NA	NA	NA	NA
1999	365	NA	NA	NA	NA
2000	365	NA	NA	NA	NA
2001	365	NA	NA	NA	NA
2002	365	NA	NA	NA	NA
2003	114	0.22	14.93	1.77	1.16
2004	0	0.08	12.71	0.94	0.55
2005	0	0.05	26.13	1.99	1.33
2006	0	0.10	16.13	2.33	1.62
2007	0	0.31	22.32	3.22	1.68
2008	0	0.06	17.45	1.91	1.17
2009	0	0.06	10.88	0.81	0.28
2010	0	0.08	25.40	4.81	3.49
2011	0	0.04	20.54	3.41	1.74
2012	1	0.14	11.21	2.39	1.41
2013	245	0.38	20.09	3.05	1.07

The characteristics of the derived Siroko (SHP) time series are demonstrated in Figure 2.3 below. It is observed that there was less variability in the 1988-1994 period. Probably the greater Siroko discharge measurements on which the derived SHP site is based, were done more accurately during that decade.

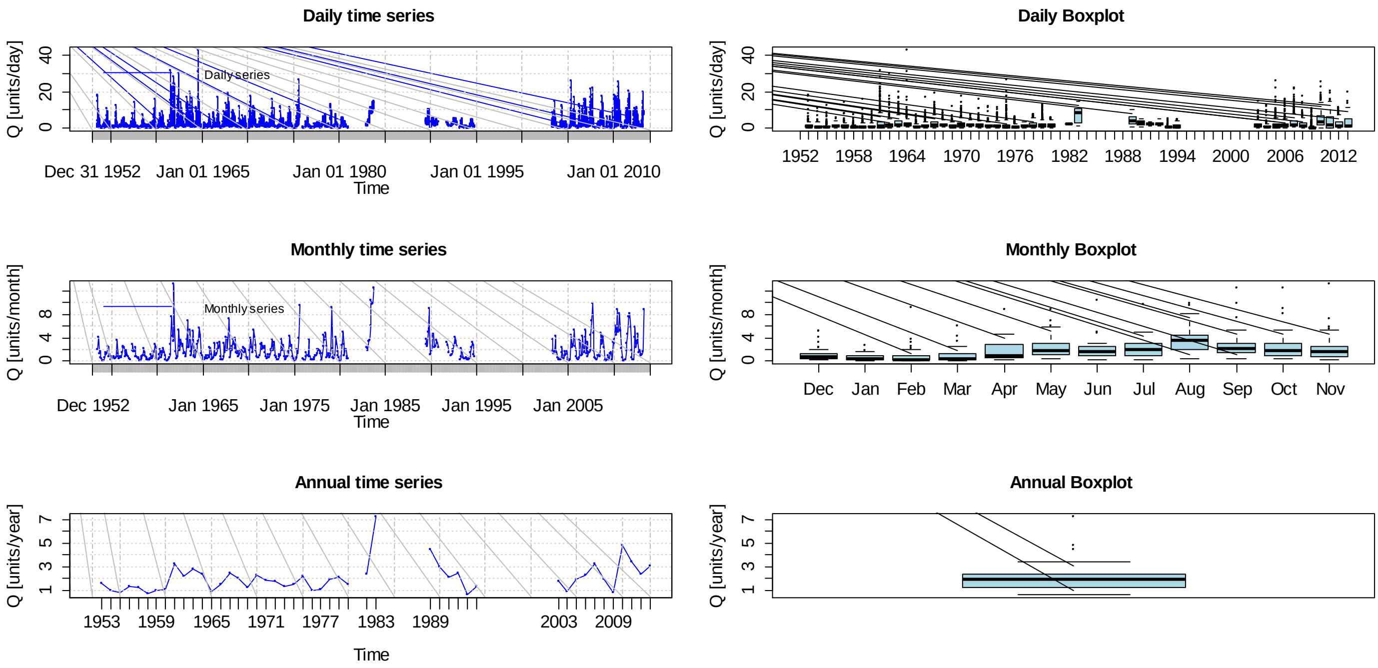

Figure 2.3 Hydroplots of the Derived Siroko SHP discharge

2.1.5 Comparison of derived River Siroko (SHP) water balance with nearby rivers

A rapid water balance was carried out for the River Siroko (SHP) using the derived discharge. A similar exercise was carried out for the nearby rivers. The results are shown in Table 2.5 below.

Table 2.5 Comparison of water balance of R. Siroko (SHP) with nearby rivers

Discharge point	Average Flow (1953-2005) Q (m^3/s)	Average weighted rainfall (mm)	Gross catchment yield (MCM)	Net River Yield (MCM)	Water Loss (ET, interception and Groundwater Recharge)		Δq l/sec/km²
					(MCM)	(mm)	
Siroko Gauge	5.000	1698	459.1	157.7	301.39	1115	18.5
Siroko (SHP)	**2.01**	**1924**	**116.8**	**64.26**	**52.58**	**873**	**32.9**
Sipi Guage	3.280	1752	153.2	103.4	49.76	569	25.5
Simu Guage	3.510	1821	316.7	110.7	205.96	1184	14.5

The discharge yield per km² for all the points is of the same magnitude. However Siroko (SHP) catchment is higher in altitude than the rest of the sites and hence is expected to have less Evapotranspiration losses due to greater cloud and biomass (forest) cover. Using a composite map of mean annual potential open water evaporation for East Africa developed by Dagg et al. (1970), it can be established that the Potential Evapotranspiration (ET) of the Elgon catchments is in the range 1400 – 1600mm. The higher cloudy slopes altitudes over 2,700 m probably have lower potential ET than 1400mm per annum. The actual evapotranspiration would be significantly less, in the range of 60 to 70% of the Potential ET. The rest of the water losses should be attributed to canopy interception and ground water recharge.

2.2 The Siroko (SHP) Flow Duration Curve

The flow duration curve was developed for the derived Siroko (SHP) time series and is shown in Figure 2.4.

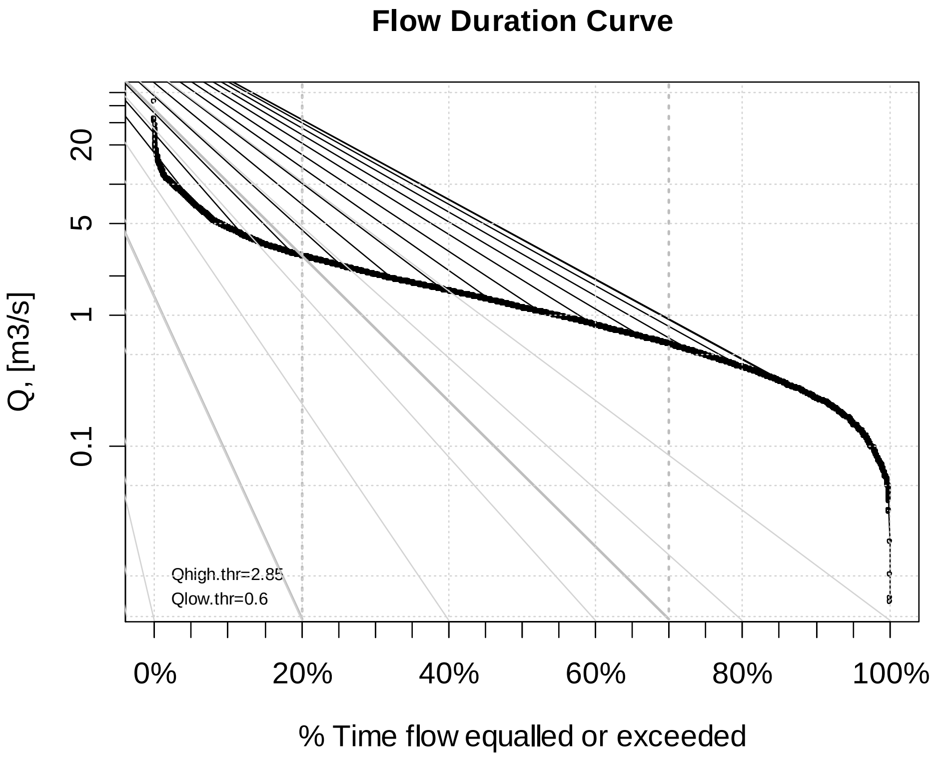

Figure 2.4 Flow duration curve for the Siroko (SHP) data

The threshold flows which are exceeded 20% and 70% of the time are 2.85 and 0.6 m^3/s respectively. The complete table of exceedence values is presented in Table 2.6 below.

Table 2.6 Probability of exceedence of various flows of River Siroko at the abstraction point.

Probability of being exceeded	Siroko (SHP) flow (m^3/s)	Probability of being exceeded	Siroko (SHP) flow flow (m^3/s)
99.9%	0.04	50%	1.14
95%	0.15	45%	1.33
90%	0.23	40%	1.54
85%	0.31	35%	1.77
80%	0.40	30%	2.05
75%	0.49	25%	2.41
70%	0.60	20%	2.85
65%	0.72	15%	3.47
60%	0.84	10%	4.66
55%	0.99	5%	7.51

2.3 Extreme Value Analysis

The annual maximum and minimum flow series was formed by selecting the highest (and lowest) daily mean flow occurring in each year of the record respectively. The set of the derived average maxima (minima) are assumed to be a random statistical sample from the population of all possible maxima (minima) at the site. The Gringorten plotting formula (i-0.44)/(N+0.12), was used in the analysis. This formula is suitable when fitting any of the family of General Extreme Value distributions (GEV) to the data.

2.3.1 Siroko (SHP) Flood Frequency curve

Figure 2.5 demonstrates the results of the successfully fitted the Extreme Value distribution (EV1) to the annual maximum flow series for the derived River Siroko (SHP) data.

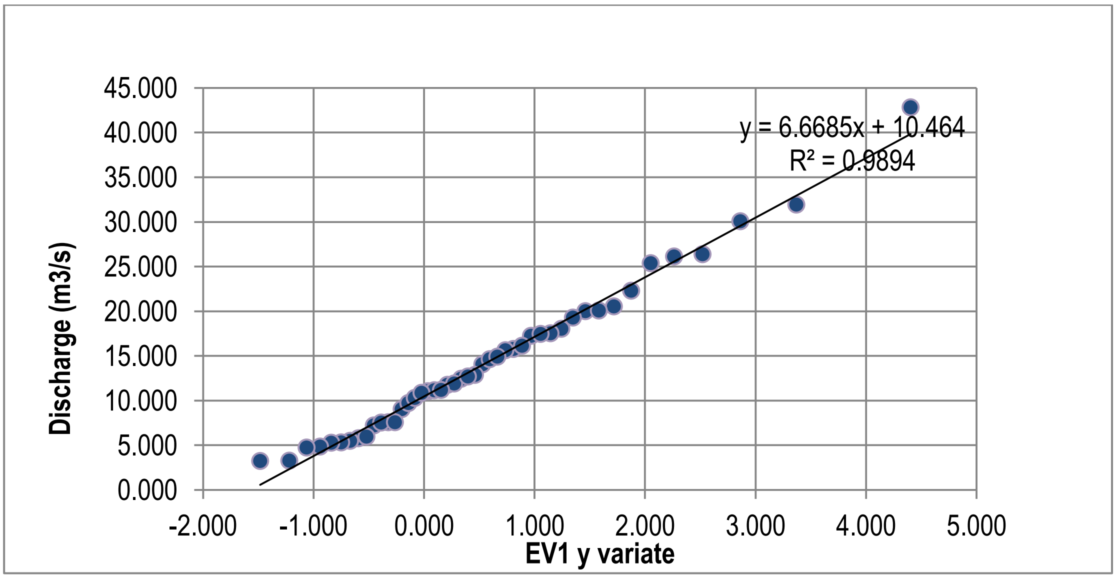

Figure 2.5 R Siroko (SHP) annual maxima discharge fitted with the Gumbel distribution

After fitting the distributions, floods of specific return periods were computed and are given in Table 2.7 below.

Table 2.7 Annual Maximum flows for 2 to 10,000 year return period for R. Siroko (SHP) take off point

Return Period T (Years)	Maximum River Discharge (m^3/sec)
2	12.0
5	20.2
10	26.4
50	42.4
100	50.1
1000	79.9
10000	117.3

2.3.2 Low flow characteristics of R. Siroko (SHP)

The Log-Normal distribution was fitted to the annual minimum series for R. Siroko (SHP) takeoff from which the extreme low flows were computed as shown in **Table 2.8**. From the table, it is expected that once in every 100 years, there is a day with negligible or zero mean flow.

Table 2.8 Annual Minimum flows for 2 to 50 year return period for Siroko Takeoff.

Return Period T (Years)	Minimum River Discharge (m^3/sec)
2	1.91
5	0.52
10	0.23
15	0.17
25	0.10
50	0.05
100	0.02
500	0
1000	0

2.4 A preliminary estimation of the Environment Flow reserves for the R. Siroko (SHP)

The environmental flow is the amount of water that should be kept flowing down a river in order to maintain the river in a "desirable" environmental condition. Environmental flows are all about using the water resources sustainably to maintain the river in a predefined ecological state. The relation between the human need and the ecological need must be decided, and the recognition that there is a limit when a water resource suffers irreversible damage to its ecosystem functions.

2.4.1 Environmental flow methodology

There are mainly four categories of environmental flow determination methodologies, which are :

1. **Hydrological** (Desktop Estimates, Look Up Table) — This is a simple and rapid method that uses hydrological data to derive the environmental flow requirement. A "minimum flow" often represents the flow intended to maintain the recommended river condition. Hydrological methodologies are generally used for the planning level and have been applied widely, both in developed and developing countries. The Tennant Method is the most widely used hydrological method.

2. **Hydraulic Rating** (Rapid Determinations) — These type of methodologies measure changes in various single river hydraulic variables (e.g. depth and velocity) to develop a simple relationship between biota habitat availability and river flow. A common methodology is the Wetted Perimeter Method, developed in Australia.

3. **Habitat Simulation** (Habitat Rating, Expert Panels, Intermediate) — The Habitat Simulation methodology provides links between discharge and available habitat conditions. It uses key target biota to predict habitat discharge curves or habitat time and exceedence services. PHABSIM, developed in U.S.A. is the most commonly applied methodology.

4. **Holistic** (Holistic Approaches, Frameworks, Comprehensive) — In a holistic approach all important flow characteristics (high floods, base flows etc.) are identified. These methodologies incorporate hydrological, hydraulic and habitat simulation models. The Building Block Methodology (BBM) is a holistic methodology and was developed in South Africa.

This assessment has adopted the hydrological method, in particular the Tennant method, owing to its simplicity where by the environmental flow regimes are prescribed on the basis of the average daily discharge or the mean annual flow (MAF). In general cases, 10% of the MAF is recommended as a minimum instantaneous flow to enable most aquatic life to survive, while 30% MAF is recommended to sustain a good habitat.

2.4.2 Siroko SHP flow configuration and Environmental flows

The proposed configuration of the Siroko SHP is such that from the diversion point, the water shall take a detour through a canal, then through a penstock to a power house located 3.8km downstream of the diversion point on the River (Figure 2.6). It will be a run-of-the-river scheme, all the water going through the power house shall return to the river. An issue that concerns us is the amount of [environmental] flows that should be reserved to maintain the ecology of the 3.8km section that will be looped by the canal-penstock system.

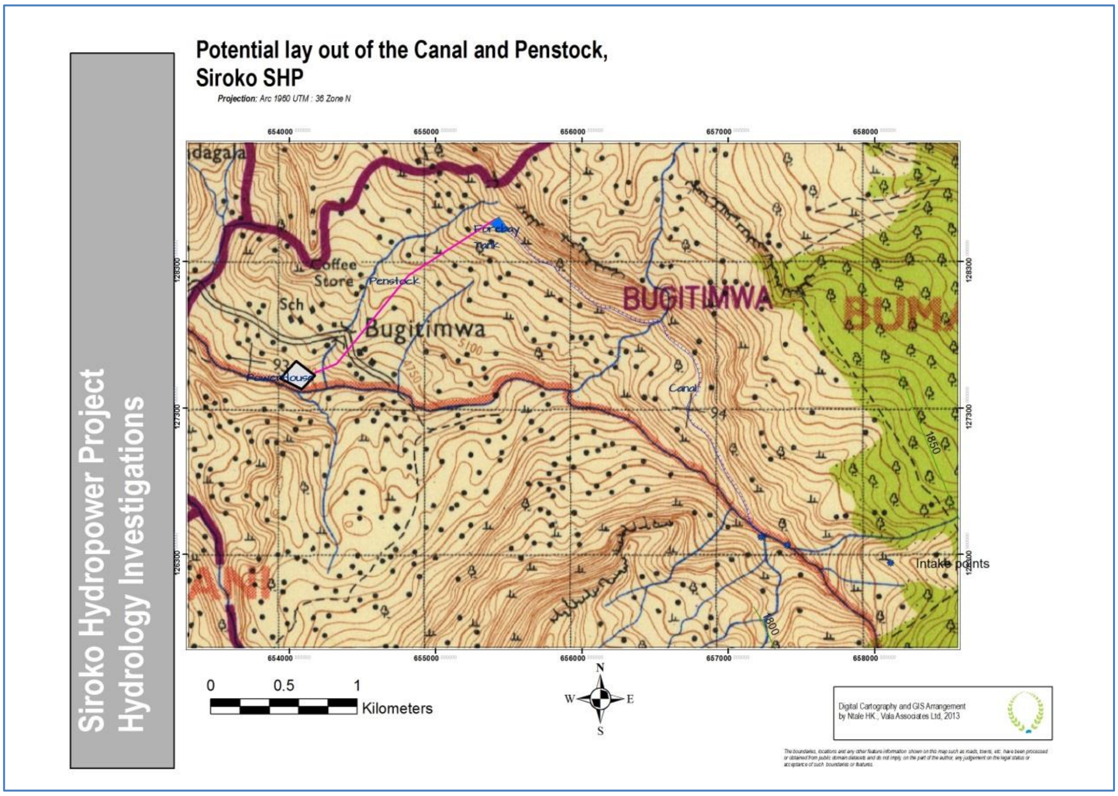

Figure 2.6 Approximate layout of Penstock and canal for the Siroko SHP

Carefully scrutiny of the hydro-morphology of the 3.8km river section to be looped (Figure 2.6) reveals that there are at least three streams contributing to the flow within this section, the largest being Dirigana river. The catchment of R. Dirigana is about a third that of the Siroko SHP basin hence it contributes quite a significant amount of water to the Siroko. Dirigana confluences with Siroko about 1.7km downstream of the proposed diversion point. Basing on the catchment area ratios, R. Dirigana's discharge should be approximately 25% of the Siroko flow at the confluence point. Therefore, when the Siroko SHP scheme is put in place, 2km of the 3.8km looped section will always receive 25% of the original flow – even when no provision for environment flow has been made at the diversion point.

The challenge then is preserving the ecology of the river in the 1.7km section between the diversion weir and the confluence with R. Dirigana. In regards to this aspect, the observation from the site visit was that:-

- there were no large-scale human water uses within this river reach;
- there were no sacred sites for prayers, swearing or taking oaths, circumcision, etc. within the river reach
- there was no small holder irrigation use of the water within the river reach
- The area has a gravity flow water supply scheme whose source is much higher up in the highlands. Hence the water supply of the area will not be affected by the diversion for the Siroko SHP.

Since there are no significant water uses in the 1.7km reach before the R. Dirigana joins the Siroko, we recommend that an environmental flow amounting to 10% of the Mean Annual Flow (MAF) be allowed to maintain the riverine system. The Mean Annual Flow for River Siroko SHP is 2.01 m^3/s. Therefore at least 0.2 m^3/s should be allowed to pass thru at all times to maintain the 1.7km riverine section.

Provision should be made at the diversion weir to allow for seasonal flushing to rejuvenate the 1.7km section.

3 Summary and conclusion

A comprehensive hydrology assessment has been carried out on River Siroko, in order to assess the potential of the hydropower site that was identified on the river at coordinates 1˚ 08’ 29”N and 34˚ 24’ 35” N immediately downstream of the point of confluence of between Siroko and River Guragado. The following are the principal findings:

- The drainage basin for Siroko hydropower project comprises of R. Siroko and a tributary known as R. Guragado whose headwaters arise from the Mount Elgon.
- The total Siroko catchment that would contribute flow to the SHP project would be 60.73km². The average rainfall for the catchment is 1924mm.
- The losses due to evapo-transpiration and Ground Water Recharge are conservatively estimated at 45%, with a river runoff of 55% of the incident precipitation.
- There is discharge measuring station (ID 82240) on River Siroko maintained by the Ministry of Water and Environment, approximately 25km downstream of the proposed diversion point. This study proposed a relationship between this discharge data and the required data at the proposed abstraction point – based on the catchment characteristics and the spatial rainfall distribution
- The daily discharge data of the Mt Elgon Rivers is highly skewed. Even though the average daily discharge of River Siroko (SHP) is 2.03 m^3/s, the median discharge (Q_{50}) of the site is 1.14m^3/s.
- The Flow Duration Curve (FDC) for the river was computed; the discharge of 3.47m^3/s is exceeded 15% of the time while 0.6 m^3/s is exceeded 70% of the time.
- An environmental flow reserve of 0.2m^3/s has been proposed for the river section that will be looped by the canal/penstock system.

Given that there are times of the year when the flows at this site are quite low, it is important that a discharge gauge be placed at the site as soon as possible to monitor the flows. The data obtained shall be used to improve the hydrologic estimates at the site – more so if the measurements are compared with those taken [concurrently] at the existing discharge measuring station (ID 82240) 25 km downstream.

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Appendix 1: Derived R. Siroko (SHP) flows (Average Monthly flows).

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1953	NA	NA	NA	NA	NA	NA	NA	4.44	1.35	1.58	0.69	0.42
1954	0.15	0.13	0.09	0.61	1.41	1.17	1.33	2.54	2.44	0.83	1.18	0.26
1955	0.75	0.51	0.55	0.73	0.42	0.36	0.54	3.46	NA	0.89	0.36	0.75
1956	0.78	0.60	1.36	2.49	2.30	2.33	0.80	1.45	1.77	1.01	0.70	0.35
1957	0.33	0.31	NA	NA	2.86	1.76	1.43	2.56	0.87	0.71	0.66	0.51
1958	0.57	0.14	0.07	0.34	0.78	NA	2.18	1.52	0.90	0.81	0.26	0.54
1959	0.21	0.16	0.43	0.29	1.05	0.48	0.82	1.61	1.55	2.78	2.46	0.53
1960	0.26	0.26	0.39	1.09	1.93	0.65	1.55	1.66	2.24	1.54	0.93	0.30
1961	0.12	0.08	0.07	0.26	0.64	0.90	2.90	7.63	NA	NA	12.93	5.38
1962	1.90	0.37	0.35	0.75	5.32	2.53	1.72	3.68	2.90	2.91	2.51	1.32
1963	1.47	0.71	0.80	3.63	7.02	2.47	2.23	5.40	1.67	1.01	2.16	5.18
1964	1.13	0.73	0.54	1.87	1.62	2.87	2.15	7.01	4.39	4.14	1.43	1.02
1965	0.53	0.28	0.29	0.64	0.94	0.38	0.50	0.91	0.67	2.35	2.18	1.16
1966	0.34	0.35	0.62	2.97	0.93	0.94	1.29	1.86	3.23	2.11	3.24	0.76
1967	0.33	0.25	0.30	0.81	3.03	1.49	4.02	3.92	1.87	3.64	7.32	2.34
1968	0.65	1.87	1.86	2.29	3.77	3.00	2.16	3.95	1.55	1.22	1.71	0.75
1969	1.08	1.78	1.60	0.53	1.85	NA	2.21	1.44	2.06	0.60	0.39	0.25
1970	0.52	0.21	1.68	3.92	2.45	1.46	2.01	5.22	4.04	2.87	1.86	0.82
1971	0.65	NA	NA	NA	2.82	2.97	2.02	2.46	2.22	2.58	1.54	0.71
1972	NA	1.11	NA	NA	1.21	1.76	2.06	3.71	1.71	2.58	3.33	0.93
1973	0.74	0.53	0.28	0.32	0.80	1.19	0.86	3.71	2.30	1.76	2.70	0.86
1974	0.46	0.26	0.78	0.91	1.15	1.73	4.33	2.51	2.69	1.77	0.86	0.42
1975	0.21	0.12	0.17	0.62	1.98	1.31	3.81	9.37	NA	NA	NA	NA
1976	NA	0.21	0.13	NA	1.42	NA	NA	3.74	0.82	0.73	0.33	0.27
1977	0.20	0.24	0.30	0.61	0.98	0.91	1.32	1.96	2.09	1.88	NA	1.34
1978	0.13	1.18	2.35	4.55	3.65	4.70	2.76	0.60	0.87	1.39	0.76	0.59
1979	1.18	9.17	2.37	0.68	0.44	0.76	0.95	3.96	3.06	1.75	1.03	0.61
1980	0.08	0.00	0.78	2.59	4.95	2.95	1.05	1.97	2.08	0.82	0.45	0.35
1981	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1982	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1983	1.92	2.08	3.35	3.64	5.81	10.46	9.73	9.81	12.42	12.58	NA	NA
1984	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1985	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1986	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1987	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1988	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1989	NA	NA	NA	NA	NA	NA	3.85	2.52	4.77	8.90	5.78	1.18
1990	1.57	2.38	4.34	4.62	2.42	2.50	2.57	3.58	3.07	2.39	NA	NA
1991	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	2.71	1.57
1992	NA	NA	NA	1.12	1.63	1.90	2.69	4.14	3.51	3.10	2.53	NA
1993	NA	NA	NA	0.84	NA	1.49	NA	NA	0.36	0.41	0.69	0.36
1994	0.23	0.17	0.36	0.52	1.42	2.31	3.22	2.78	1.16	0.74	NA	NA
1995	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1996	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1997	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1998	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1999	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2000	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2001	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2002	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2003	NA	NA	NA	NA	1.90	1.19	1.87	4.26	2.07	1.44	0.61	0.41
2004	0.26	0.21	0.32	1.18	2.71	0.39	0.48	1.57	0.86	1.00	1.67	0.54
2005	0.23	0.11	0.24	0.26	4.32	2.43	2.59	3.04	5.35	2.58	1.80	0.80
2006	0.36	0.22	0.50	3.60	3.54	0.95	1.11	4.27	2.38	1.52	5.19	4.20
2007	1.32	3.17	0.94	1.37	1.50	1.87	3.88	7.42	9.84	4.88	1.93	0.59
2008	0.36	0.33	0.16	0.86	0.84	1.22	0.75	4.69	2.83	4.17	4.21	2.45
2009	0.18	0.14	0.13	0.24	0.91	0.21	0.32	1.37	1.28	1.63	0.31	2.92
2010	2.96	3.29	6.24	4.73	8.65	5.28	4.88	8.02	5.35	5.24	2.24	0.62
2011	0.10	0.10	0.15	0.18	1.72	3.10	4.53	7.44	7.46	7.90	6.13	1.91
2012	0.60	0.23	NA	3.94	5.72	2.46	3.20	NA	3.12	NA	1.80	1.07
2013	0.96	1.05	1.42	8.76	NA	NA	NA	NA	NA	NA	NA	NA
Average	0.68	0.90	1.01	1.83	2.46	2.02	2.31	3.79	2.86	2.55	2.29	1.18