

Calculation of Water Surface Elevation Using HECRAS 4.1.0 for Fixing Tailwater Elevation for Powerhouse Site in Planned 37 MW Kabeli “A” Hydroelectric Project, Nepal

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Goal of this HECRAS 4.1.0 model analysis is to find out water surface elevations for safe and optimized layout of powerhouse located in left bank of Tamor river with other protective structures like floodwalls at different flood frequencies for planned 37 MW Kabeli “A” Hydroelectric Project. Powerhouse is costly and vulnerable component of any hydropower facility. Safe location of powerhouse should be prioritized. Any increment in head is related with generation of extra revenue but powerhouse earthwork excavation volume incurs huge part of overall project cost initially. There is some sort of tradeoff between these two parameters to get an optimum design elevation. It is envisioned that 1-D US Army Corp's HEC-RAS model can simulate flow conditions at different flood frequencies. This project is located in Panchthar and Taplejung districts in Eastern Development Region of Nepal. This project utilizes more than 15 km long loop of Kabeli River formed with Tamor River. Kabeli River, which is a tributary of Tamor river is diverted through a 4326.8 m long D-shaped headrace tunnel having internal finished diameter 5.65 m, discharging diverted water into Tamor River for power generation. The gross head of the project is 116.8 m and the design discharge based on 40 percentile flow set by government for power generation from flow duration curve (FDC) in river is 37.73 m³/s.

Kabeli River is one of the tributaries of Tamor River which itself is a major tributary of Sapta Koshi River basin. The catchment area above the proposed intake site of project is 864 km² and at powerhouse site is 3930 km² with elevation ranging from 452 m to 7200 m above mean sea level. In this catchment, monsoon pattern of climate is prevalent. It commences from June to September with heavy rainfall intensity for those four months compared to other months of the year. Rainfall intensity varies in catchment with elevation and runoff is calculated from different methods as powerhouse site is unengaged.

Due to global warming, glacial lake outburst flood (GLOF), known as mountain tsunamies in high Himalayas (Kanchanjunga range) is highly probable. This zone lies in area with high seismic activity with possibility of GLOF, flooding populated areas and infrastructure downstream. Since glacial/snow hydrology study and data collection is still in nascent stage of development, analysis for design flood elevation has been done without taking into account those effects due to unavailability of data.

Introduction

Kabeli River is one of the tributaries of the Tamor River which itself is one of the major tributaries of Sapta Koshi River basin. The catchment area above the proposed intake site of the project is 864 km² and elevation ranges from 550 m to 7200 m above mean sea level. Likewise powerhouse located on left bank of Tamor river has catchment area of 3930 km² with elevation ranging from 452 m to 7200 m above mean sea level. In this geographical region,

monsoon climatic pattern commences from June till September. Rainfall intensity varies in catchment with elevation. Most of annual precipitation takes place during those months compared to other months of the year. In general, amount of precipitation is highest in the south at lower elevation and gradually decreases to the north with the increase in elevation. Average annual precipitation in Kabeli basin is 2135 mm. Average yearly flow at the intake site is 51.75 m³/s with the

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minimum monthly flow of 8.11 m³/s in March and maximum monthly flow of 151.09 m³/s in August. The 100-year return period flood flow at intake site is 1921 m³/s and 5984 m³/s at the intake and powerhouse site respectively.

Hydrology

Since overall civil engineering design is based on hydrology, hydrological study is crucial component to study rainfall pattern, calculate discharging capacity of catchment and to predict design discharge, mean monthly flow, flow duration curve, flood flow and low flow of river. Overall aim of the hydrological and meteorological study of project is to estimate the design flow for required capacity of hydroelectric power plant and to estimate flood and low flows of river.

An accurate assessment of long-term hydrology is essential to any hydropower project. The longer the hydrological record, more reliable is the estimation of design parameters for the project. In case of ungaged (i.e. either limited or no stream flow records) river, direct measurements of hydrological parameters are not available. So, it is necessary to look at catchments that have similar catchment and meteorological characteristics and catchment area ratio (CAR) method is used.

The Kabeli River is one of tributaries of Tamor River and Tamor River is one of major rivers of the Sapta Koshi Basin system. The Kabeli basin is located in between latitudes 27° 16' and 27° 17' N and longitudes 87° 42' and 87° 43' E. The Sapta Gandaki Basin drains Eastern Development Region of Nepal.

The catchment of Kabeli River at proposed project site has characteristics of mountainous catchment. The catchment area of the Kabeli River is 864 km² at the proposed intake site. The catchment area above the permanent snow line (El. 5000m) is about 0.5 km² only. It has elevation ranging from El. 550 m to El. 7200 m.

Above mentioned drainage areas and elevations

are based on latest 1:25000 and 1:50000 scale topographical maps compiled from aerial photogrammetry of 1996 and produced by Survey Department in co-operation with the Government of Finland.

The monsoon commences from June till September. The mean annual precipitation over the project area estimated is 2135 mm.

Methodologies for ungaged catchment

As Kabeli river is an ungaged type river, various methodologies, common for ungaged catchment, are used to determine the hydrology of Kabeli and Tamor River. Followings are widely adopted methods for most of the ungaged catchment in Nepal.

HYDEST

The HYDEST method has been used to estimate mean flow series at the proposed intake and powerhouse site. This method was developed by Water and Energy Commission Secretariat (WECS) and Department of Hydrology & Meteorology (DHM) in 1990 for evaluating the hydrologic characteristics of ungaged catchments. For complete hydrological analysis by this approach, catchment area and its distribution in altitude are essential along with monsoon wetness index of catchments. Monsoon wetness index from isoheytal map for Kabeli catchment is 1500 mm. This approach is used to compute long-term hydrology and extreme hydrology.

MHSP (MEDIUM HYDROPOWER STUDY PROJECT)

The Medium Hydropower Study Project (MHSP) under Nepal Electricity Authority (NEA) in 1997 developed a method to predict long-term flows, flood flows and flow duration curves at ungaged sites through regional regression technique. The MHSP method has been used to estimate mean monthly flow series at proposed intake site. This approach uses both monsoon wetness index and average precipitation of the area along with catchment area of the river.

Catchment correlation

Since there is no availability of hydrological data of project area, an attempt was made to correlate the flows of gaged catchment with the ungaged catchment by using catchment area ratio. During the study, it was found that Tamor River at Majhitar (station no 684) has recorded data of 11 years only. Therefore, catchment characteristics of only two stations: station 690 (Tamor River at Mulghat) and station 795 (Kankai Mai at Mainachuli) are compared. The catchment parameters are presented in Table 2.

CATCHMENT CORRELATION

Mean monthly flows were also computed correlating ungaged Kabeli River with gaged catchment. The catchment area of Tamor at Mulghat (Station Number 690) is 5640 km² while that of Kankai Mai at Mainachuli (Station Number 795) is 1178 km². The station 795 has comparatively smaller catchment area than that of station 690. The catchment area ratio (CAR) of Kabeli to station 795 is 0.73 while that of Kabeli to station 690 is 0.15. As presented in Table 2, station 795 has only 13.8% of total area lying between El 3000 m and 5000 m. But, Kabeli River at the intake site has 20.5% of total area lying between El 3000 m and El. 5000 m. Therefore, correlating the catchment area with station 795 underestimates the flow in Kabeli River during dry seasons. However, station 690 has comparatively bigger catchment area. In one hand, the flow during the dry seasons is of more concern. On other hand, Tamor at Mulghat is mother catchment of Kabeli River, attempts have been made to correlate the flow of this station by applying CAR method to derive the mean monthly flow of Kabeli River at intake site and powerhouse site. In addition, direct catchment correlation with station 690 overestimates the flow during dry seasons in Kabeli River as station 690 has 23.9% of total area lying between elevation 3000 m and 5000 m. Precipitation ratio of 0.937 is also applied along with catchment area ratio (CAR). The mean monthly flow derived from three methods is presented in Table 3.

ADOPTED MEAN MONTHLY FLOW

To compare and check mean monthly flow computed based on station number 690 for Tamor river Mulghat, flow computed by other two methods HYDEST and MSHP are also presented. The above table shows that the mean annual flow derived by later two methods is less than the correlated flow based on station 690. The flow given by HYDEST and MSHP methods is less than the flow given by previous one in wet seasons but seems to be within the reasonable range in dry seasons. Since station 690 being the mother catchment of Kabeli and has long term data of 41 years, mean monthly flow based on catchment correlation and precipitation ratio is adopted. The adopted hydrograph is shown in Figure 2.

There are no water sharing issues of Kabeli River in its licensing area. Therefore whatever flow is available in river can be used for power generation except for downstream release of 10% of driest mean monthly flow as minimum release for environmental flow.

A flow duration curve is a probability discharge curve that shows percentage of time a particular flow is equaled or exceeded. A multiplying factor of 0.14 (CAR=0.15 and Precipitation ratio=0.937) was applied in the daily flow of station 690 to derive the long term daily flow of Kabeli River at the intake site. Based on average daily data from 365 days of each year, flow duration curve was derived. The numerical values of flow duration curve are presented in Table 4.

Since design discharge for project has been calculated based upon 40% exceedance rule from flow duration curve (FDC) for power generation laid by Government of Nepal. Annual 40% exceedance discharge of 37.73m³/s from Kabeli river is diverted through 4326.8 m long D shaped tunnel having internal finished diameter of 5.65m for power generation at powerhouse, which is later added at river section 100 in HECRAS analysis of powerhouse site at tailwater area. It eventually will be discharged

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into Tamor river from powerhouse tailrace area.

Extreme hydrology

Flood flow

In order to estimate the flood flow at intake and powerhouse sites, different methods were used.

CAR method

The maximum instantaneous flow data of Tamor River at Mulghat (station number 690) is available from the year 1965 to year 2006. Three distribution methods; Lognormal, Log Pearson III and Gumbel distribution methods were used to estimate the flow for different return periods. The Log Pearson III method has given the best fit curve, therefore the result given by this method is taken. The flood flows for different return periods at the intake site and powerhouse site of Kabeli-A hydroelectric project were calculated using following formula:

$$Q_{T1} = Q_{T2} \left(\frac{A_1}{A_2} \right)^{3/4}$$

Where,

Q_{T1} = Flow at the intake/Powerhouse site at T-year return period, m^3/s .

Q_{T2} = Flow at the gaging station no 690 at T-year return period, m^3/s .

A_1 = Catchment area at the intake/powerhouse site, Km^2

A_2 = Catchment area at the gaging station no 690 for Tamor river at Mulghat, Km^2

Regression analysis method

In this method, instantaneous maximum flow data from 15 gaging stations (Table 7) all lying within Koshi basin was collected and their individual frequency analysis was carried out. Then, regression equations were developed between the catchment area below elevation 3000 m and T-year return period.

Regional flood frequency analysis method

This method is one of the most widely used methods

for estimating floods for different return periods in an ungaged catchment. The same 15 gaging stations as mentioned in above method were selected for analysis in this method as well. The frequency analysis of maximum instantaneous floods was carried out for each of the station and regression equation between the mean flood discharge ($Q_{2.33}$) and the catchment area was developed. The equation is given as follows:

$Y = 7.792X^{0.623}$ where the coefficient of correlation is 0.775.

And

Y = Mean flood discharge at intake/Powerhouse site, m^3/s

X = catchment area of intake/Powerhouse, Km^2

The mean flood discharge given by above equation was multiplied by the median flood ratio ($Q_T/Q_{2.33}$) to get the flood discharge for T-year return period. The median flood ratio for different return period is shown in Table 7.

The flood flow for different return periods at intake and powerhouse sites using above three methods are presented in Table 8 and Table 9 respectively.

The results given by these three methods are compared. The regression analysis method has overestimated flow for small size catchment like Kabeli since only 4 out of 15 gaging stations taken for this analysis have similar catchment size to Kabeli.

Similarly, regional flood frequency method has underestimated the flow as it has not given the good correlation between mean flood discharge and the catchment area. Therefore, the flood flow derived from CAR method is adopted in HECRAS analysis.

Glacial Lake Outburst Flood (GLOF) Impact Assessment

A glacial lake outburst flood (GLOF) is a type of outburst flood that occurs when the dam containing a glacial lake fails. The dam can

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consist of glacier ice or a terminal moraine. Failure can happen due to erosion, a buildup of water pressure, an avalanche of rock or heavy snow, an earthquake or cryoseism, volcanic eruptions under the ice, or if a large enough portion of a glacier breaks off and massively displaces the waters in a glacial lake at its base. There are few glacier lakes identified in Kabeli basin. All lakes are located below 4500 m altitude. The identified lakes are shown in Table 10.

None of these lakes are identified as potentially dangerous lakes in study conducted by International Center for Integrated Mountain Development (ICIMOD) and United Nations Environment Program (UNEP) in 2001. There is no evidence of glacial lake outburst flood (GLOF) in Kabeli basin in the past. However, possibility of GLOF in the future cannot be ignored. Powerhouse site is located on the left bank of Tamor River which has a number of glacier lakes in its upper catchment. An assessment of a possible GLOF that may impact on the powerhouse of Kabeli-A hydroelectric project is also required.

There is not enough data to make accurate assessment of a possible GLOF impact on the Kabeli-A powerhouse. There are more than eight major glaciers in upper catchment of Tamor river: Chhubuk Glacier, Lonak Glacier, Chhatang Glacier, Pyramid Glacier, Kanchanjangha Glacier, Ramdung glacier, Khumbha Karna Glacier and Yalari Glacier.

There was a GLOF in 1980 and it originated from Lake Nagma Pokhari. The examination of flow records downstream at gauging station 690 indicates that GLOF occurred on 24th June 1980 and the peak discharge was 3,300 m³/s. The flood surge reached 20 m above the river bed of Yangma Khola. It is estimated that the peak flow at Yagma Khola was about 8500 m³/s decreasing to about 3300 m³/s at the gauging station 690. Considering the flood attenuation over this distance, it is estimated that the peak flow at the

tailrace site in Tamor River is about 4500 m³/s which is equivalent to the 1 in 20 year return period flood at the tail race site.

- The average annual flow of Kabeli River at the intake site is 51.75 m³/s.
- The design discharge is 37.73 m³/s corresponding to 40 percentile exceedance flow.
- The 100- year flood discharge is 1921 m³/s at the intake site and 5984 m³/s at the powerhouse site. Additional discharge of 37.73 m³/s has been added from tailrace water coming out near powerhouse mixed with Tamor river station 100 taken for HECRAS analysis.

Since Kabeli and Tamor rivers being ungaged and planned for potential hydropower generation, recordkeeping of daily staff gage readings of river at intake site and tailrace site is highly recommended. Proper hydrology will lead to efficient design of hydraulic structures which ultimately will affect related electrical and mechanical components later. River discharge measurements should also be taken at various gage height so as to develop reliable rating curves at both sites. As gage is already installed at the intake site, hydrology of Kabeli River at intake site should be updated based on recorded data. Staff gage should be installed at powerhouse area with automated hourly recordkeeping of hydrological data too.

The true risk to settlements and infrastructure downstream in the Hindu Kush Himalayan region is difficult to assess. But the Himalayan region is dotted with glacial lakes and is in a seismically active zone. Experts say that, on the basis of past records, a large earthquake in the region is overdue. Many glacial lakes are said to be growing. Some of them alarmingly fast – because of melting glaciers. Some are at risk of rupturing, which would flood areas downstream. There have been at least 35 glacial lake outburst events in Nepal, Pakistan, Bhutan and China during the last century, according to the

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United Nations Environment Program (UNEP). But the increased risk from the quake-induced rupture of glacial lakes has been rarely discussed (Khadka, 2011).

Tail Race Level Optimization Using HECRAS Analysis

The powerhouse area is located near left bank of Tamor river. It has been found that central part of powerhouse is located about 100 m from the bank of the Tamor river. For protection purpose of the powerhouse area from flood, HEC-RAS analysis has been done to know the flow characteristics of the Tamor river so that the river protection structure can be made to withstand worst condition of flood. With the help of HEC-RAS Analysis, 13 cross sections, various water level profiles, rating curves for different years return period at various chainage of river are calculated. Mannings n values for main channel and side channels are chosen as 0.035 and 0.037 taken from document entitled "Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains, United States Geological Survey Water-supply Paper 2339". Values are bit higher owing to fact that large cobbles and boulders present along Tamor river. Tailrace outlet is taken at point 120m from extreme downstream cross section or 480m from extreme upstream cross section in Tamor river chosen for analysis. For tail race waterlevel optimization, rating curve at area near to the outlet of the tailrace canal is found as shown in Figure 8.

Optimization table and plot

The optimization chart is plotted to show the effect of change in tail water level in cost for earthwork excavation and protection of powerhouse and extra revenue obtained from generated energy while changing the tail water level elevation. The chart is plotted by taking TWL elevation along X-axis and cost / revenue along the Y-axis. Two curves a) curve between TWL and cost, b) curve between TWL and revenue has been plotted. The intersection point of these two curves is taken as the optimized point for the tail water level. From chart optimized level is found equal to 458.5 m. The optimization chart is as shown below in Table 13.

Conclusion and basis for finalization of optimization

The main basis for finalization of tailwater elevation (TWL) is the net difference between cumulative incremental revenue and the cost.

The cost is found for earthwork excavation to which TWL is fixed. The total cost is found by adding a) excavation cost b) cost for pumping of seepage water during excavation for powerhouse layout as powerhouse area is very near to the large Tamor river c) cost for diversion work of the river during excavation work plus foundation preparation work of the powerhouse, d) cost for the disposal of the excavated earth.

The incremental change in revenue is found by fluctuating TWL from 457m to 462 m elevation. It is found that revenue increases as the tail water level elevation goes downwards. The earthwork excavation cost also goes on increasing as we go deeper. The optimum point is then chosen where the two curves intersect each other. It comes out as 458.5 m.

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Table 1: Catchment characteristics

Elevation, masl	Intake Area		Powerhouse Area	
	Area in km ²	% of total area	Area in km ²	%
Above 5000	0.5	0.1%	717.0	18.2%
Between 5000 m and 3000 m	177.5	20.5%	1325.0	33.7%
Below 3000 m	686.0	79.4%	1888.0	48.1%
Total Catchment Area	864.0	100.0%	3930.0	100.0%

Table 2: Catchment parameters

Elevation, masl	Tamor at Mulghat		Kankai Mai and Mainachuli	
	Area in km ²	% of total area	Area in km ²	% or total area
Above 5000	717.0	12.7%	0.0	0%
Between 5000 m and 3000 m	1350.0	23.9%	162.0	13.8%
Below 3000 m	3573.0	63.4%	1016.0	86.2%
Total Catchment Area	5640	100.0%	1178.0	100.0%

Table 3: Mean monthly flows for Kabeli River from various mentods, m³/s

Month	Correlation with Tamor at Mulghat	HYDEST	MSHP
Jan	9.93	10.58	10.77
Feb	8.25	9.00	8.98
Mar	8.11	8.34	8.44
Apr	11.83	9.25	11.43
May	25.92	13.38	13.22
Jun	72.42	39.6	40.70
Jul	142.08	123.70	115.21
Aug	151.09	145.96	134.98
Sep	106.31	110.73	103.14
Oct	49.49	48.52	46.98
Nov	21.95	20.32	22.77
Dec	13.61	13.11	14.92
Average	51.75	46.04	44.29

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Table 4: Values of flow duration curve.

% Exceedance	Discharge, m ³ /s
5	154.5
10	143.2
15	131.4
20	111.3
25	90.1
30	72.0
35	48.8
40	37.7
45	27.2
50	23.5
55	19.7

Table 5. Flow Duration Curve based on average daily data (1965-2006)

Percentage of exceedance, %	Month												Annual
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
5	11.39	8.81	9.06	17.38	40.73	105.58	173.28	169.18	135.82	78.34	27.10	17.72	154.47
10	11.01	8.73	8.79	15.31	38.01	101.15	158.80	162.71	129.96	71.08	26.81	16.44	143.24
15	10.97	8.63	8.66	15.02	37.10	96.81	156.76	158.26	154.58	70.93	26.27	16.18	131.45
20	10.84	8.61	8.61	14.26	32.44	92.95	155.44	157.60	123.50	69.00	25.70	15.87	111.25
25	10.60	8.50	8.53	14.01	29.11	90.75	148.93	156.35	116.92	60.04	25.13	15.34	90.12
30	10.47	8.49	8.32	13.31	28.17	86.43	145.42	156.00	112.97	56.33	24.58	14.98	72.00
35	10.24	8.45	8.16	12.54	27.12	83.35	143.18	154.50	111.61	56.04	24.04	14.66	48.77
40	10.06	8.38	8.12	12.18	26.22	80.52	142.24	153.54	109.73	53.68	23.54	14.26	37.73
45	9.97	8.35	8.09	11.90	25.85	76.83	141.65	151.91	108.85	48.39	22.83	13.94	27.17
50	9.88	8.24	8.04	10.91	24.30	73.20	138.14	149.61	108.26	47.09	21.66	13.71	23.48
55	9.82	8.20	7.95	10.77	22.77	68.26	136.86	146.56	105.54	45.63	20.99	13.38	19.66
60	9.71	8.15	7.88	10.44	21.94	64.06	135.89	146.27	100.86	44.65	20.36	13.09	16.33
65	9.53	8.10	7.78	10.20	21.59	59.56	132.39	145.55	96.07	40.38	19.72	12.81	13.72
70	9.44	8.01	7.73	9.98	21.38	52.86	130.39	144.69	90.93	36.15	19.11	12.62	11.90
75	9.32	7.94	7.72	9.85	21.03	44.31	128.85	144.04	88.90	35.13	18.49	12.41	10.30
80	9.29	7.87	7.71	9.39	20.16	44.07	127.12	143.41	85.89	33.14	18.04	12.14	9.36
85	9.16	7.82	7.63	9.30	19.92	42.76	124.02	143.17	84.25	31.84	17.59	11.99	8.78
90	9.11	7.81	7.63	9.18	19.18	41.32	118.59	140.78	82.61	29.96	17.17	11.81	8.28
95	8.95	7.76	7.60	9.00	18.06	39.33	115.36	134.90	77.20	28.72	16.99	11.62	7.89

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Table 6: DHM gauging stations within Khosi River basin

S.n	Station No.	River Name	Location	Drainage Area, Km ²			
				Total Area	A<5000 m	A<3000 m	A> 3000 m
1	640	Rosi Khola	Panauti	87	87	87	0
2	650	Khimti Khola	Rasnalu	313	303	213	100
3	620	Balephi Khola	Jalbire	629	543	292	337
4	660	Likhu Khola	Sangutar	823	775	537	286
5	610	Bhote Koshi	Barabise	2410	980	255	2155
6	647	Tamakoshi	Busti	2753	1375	531	2222
7	670	Dudh Koshi	Rabuwa Ghat	4100	2690	1560	2540
8	630	Sun Koshi	Pachuwar Ghat	4920	3348	2093	2827
9	690	Tamor	Mulghat	5640	4923	3573	2067
10	652	Sunkoshi	Khurkot	10000	7040	4851	5149
11	600.1	Arun River	Uwa Gaun	26750	13474	43	26707
12	680	Sunkoshi	Kampughat	17600	13502	9828	7772
13	604.5	Arun River	Turkeghat	28200	14924	1493	26707
14	606	Arun River	Simle	30380	17104	3673	26707
15	695	Sapt Koshi	Chautara-kothu	54100	36009	17512	36588

Table 7: Median Flood ratio for different return period with respect to mean flood (QT/Q2.33)

Station	Q2	Q5	Q10	Q20	Q50	Q100	Q200	Q500	Q1000
640	0.86	1.55	2.01	2.45	3.02	3.44	3.87	4.42	4.85
650	0.82	1.78	2.42	3.03	3.82	4.42	5.01	5.79	6.38
620	0.90	1.43	1.78	2.11	2.55	2.87	3.19	3.62	3.94
660	0.95	1.21	1.39	1.56	1.78	1.94	2.10	2.32	2.48
610	0.87	1.58	2.05	2.50	3.09	3.53	3.96	4.54	4.98
647	0.95	1.20	1.36	1.52	1.72	1.87	2.02	2.22	2.37
670	0.88	1.51	1.93	2.33	2.85	3.23	3.62	4.13	4.52
630	0.94	1.28	1.51	1.72	2.00	2.22	2.43	2.70	2.91
690	0.93	1.30	1.54	1.78	2.08	2.31	2.53	2.83	3.06
652	0.93	1.29	1.53	1.76	2.05	2.27	2.49	2.79	3.00
600.1	0.97	1.13	1.23	1.33	1.45	1.55	1.64	1.77	1.86
680	0.96	1.19	1.35	1.50	1.70	1.85	2.00	2.19	2.34
604.5	0.94	1.25	1.45	1.64	1.89	2.08	2.26	2.51	2.69
606	0.94	1.25	1.45	1.64	1.89	2.08	2.26	2.51	2.69
695	0.93	1.30	1.54	1.77	2.07	2.30	2.53	2.82	3.05
Median flood ratio	0.93	1.29	1.53	1.76	2.05	2.27	2.49	2.79	3.00

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Table 8: Flood flow at intake site (m³/s)

Return Period	Flood Flow, m ³ /s		
	CAR method	Regression analysis	Regional flood frequency
2	710	1238	491
5	1004	1742	680
10	1210	2081	805
20	1417	2403	925
50	1699	2820	1080
100	1921	3133	1196
200	2153	3444	1312
500	2477	3855	1465
1000	2736	4165	1581

Table 9: Flood flow at Powerhouse site (m³/s)

Return Period	Flood Flow, m ³ /s		
	CAR method	Regression analysis	Regional flood frequency
2	2212	1770	1261
5	3126	2451	1746
10	3770	2914	2068
20	4414	3352	2376
50	5292	3918	2775
100	5984	4342	3074
200	6706	4765	3372
500	7715	5322	3765
1000	8523	5745	4062

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Table 10: Hydrological Data Used for HECRAS Analysis

River	At Normal Flow	
	Kabeli and Tamor	Kabeli and Tamor adding Q from Powerhouse
Reach	1	1
RS	600	100
Jan	48.75	86.48
Feb	40.25	77.98
Mar	39.55	77.28
Apr	57.90	95.63
May	127.52	165.25
June	345.29	383.02
July	682.56	720.29
Aug	734.02	771.75
Sept	512.06	549.79
Oct	241.09	278.82
Nov	106.79	144.52
Dec	68.10	105.83
2 Years	2212.00	2250.00
20 Years	4414.00	4452.00
50 Years	5292.00	5329.00
100 Years	5984.00	6022.00
1000 Years	8523.00	8561.00

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Table 11: Profile Output table of Tamor-Kabeli for 20 and 100 years return period flood frequency

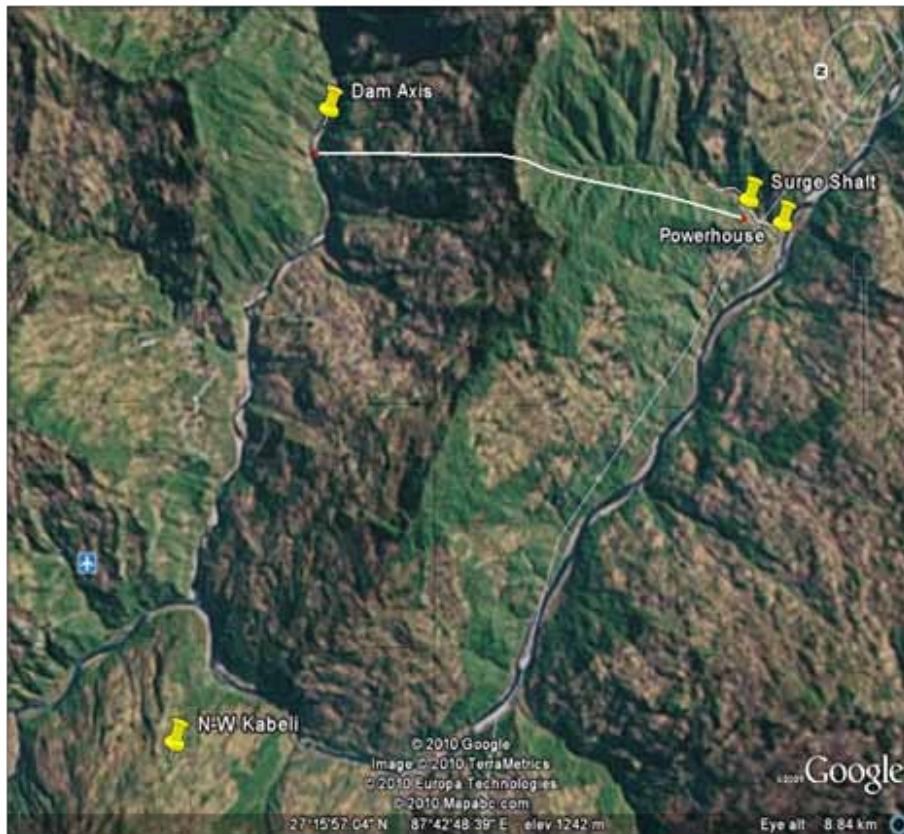
Reach	River Sta	Profile	Q total	Min Ch El	W.S. Elev	Crit W.S	E.G. Elev	E.G. Slap	Vol Chnl	Flow Area	Tap Width	Froudo & Chl
			(m ³ /s)	(m)	(m)	(m)	(m)	(m/m)	(m/s)	(m ²)	(m)	
1	600	20 Years	4414	458.5	467.58	467.58	470.25	0.00475	7.87	669.2	121.92	0.89
1	600	100 Years	5984	458.5	468.83	468.83	472.02	0.00479	8.7	824.44	125.9	0.91
1	550	20 Years	4414	458.18	466.47	466.47	468.96	0.0051	7.44	688.56	144.28	0.9
1	550	100 Years	5984	458.18	468.22	467.77	470.6	0.00377	7.42	957.28	158.28	0.8
1	502.7	20 Years	4414	457.88	466.8		468.45	0.00287	6.01	844.31	159.56	0.69
1	502.7	100 Years	5984	457.88	468.59		470.25	0.0023	6.17	1161.18	187.39	0.64
1	450	20 Years	4414	457.55	467.03		468.18	0.00191	5.06	997.62	172.75	0.56
1	450	100 Years	5984	457.55	468.8		470.02	0.00161	5.3	1343.31	204.57	0.54
1	400	20 Years	4414	457.23	467.14		468.02	0.00139	4.44	1133.23	188.78	0.48
1	400	100 Years	5984	457.23	468.92		469.87	0.0012	4.69	1498.58	211.99	0.47
1	350	20 Years	4414	456.91	467.13		467.93	0.00123	4.31	1181.85	178.99	0.46
1	350	100 Years	5984	456.91	468.9		469.8	0.00111	4.61	1543.93	214.16	0.45
1	300	20 Years	4414	456.59	467.01		467.86	0.00139	4.81	1132.49	157.11	0.5
1	300	100 Years	5984	456.59	468.67		469.72	0.00149	5.52	1458.69	215.81	0.53
1	250	20 Years	4414	456.27	466.71		476.76	0.00182	5.51	1051.84	165.91	0.57
1	250	100 Years	5984	456.27	468.46		469.62	0.00169	5.94	1384.48	204.29	0.56
1	200	20 Years	4414	455.95	466.4		467.64	0.00206	5.8	958.44	145.35	0.6
1	200	100 Years	5984	455.95	468.04		469.5	0.00201	6.37	1225.61	154.52	0.61
1	150	20 years	4414	455.63	465.12		467.39	0.00396	7.67	711.92	113.8	0.82
1	150	100 Years	5984	455.63	465.93	465.78	469.17	0.00507	9.19	804.44	116.4	0.94
1	100	20 Years	4451.73	455.31	464.48	464.45	467.13	0.00495	8.33	678.68	121.94	0.91
1	100	100 Years	6021.73	455.31	465.72	465.72	468.87	0.00502	9.18	832.14	127.18	0.94
1	50	20 Years	4451.73	454.99	464.29	464.29	466.85	0.00477	8.1	697.66	131.33	0.89
1	50	100 Years	6021.73	454.99	465.49	465.49	468.52	0.00483	8.92	858.54	137.35	0.92
1	0	20 Years	4451.73	454.67	463.44	463.44	466.31	0.00545	8.2	635.5	126.63	0.94
1	0	100 Years	6021.73	454.67	465.02	465.02	468.01	0.00461	8.55	869	142.38	0.9

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Table 12: Tailwater Level (TWL) Optimization

Tailwater Level masl	Incremental Energy	Energy Tariff (NRs)	Incremental Revenue discounted for 30 years	Earthwork Excavation Volume in m ³	Total Incremental Excavation Amount NRs	Present value of Energy revenue, NRs	Difference between Incremental Revenue and Cost
462	0.00	4.70	0.00	67717.35	0.00		
461	1.69	4.70	79570271.14	75175.71	6541914.02	79,570,271.14	42,656,491.45
460	1.69	4.70	79570271.14	83219.89	7303407.03	79,570,271.14	38,268,958.70
459	1.40	4.70	65840360.87	92788.50	8982057.96	65,840,360.87	14,993,587.65
458	0.84	4.70	39587412.98	102908.50	9811214.47	39,587,412.98	(16,111,056.91)
457	0.44	4.70	20816784.31	113793.12	10887613.27	20,816,784.31	(41,168,239.39)

Figure 1. Photograph taken in June, 2011, showing trees and developing vegetation. Note debris deposited by winter floods.



Calculation of Water Surface Elevation Using HECRAS 4.1.0 for Fixing Tailwater Elevation for Powerhouse Site in Planned 37 MW Kabeli "A" Hydroelectric Project, Nepal
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Figure 2: Monthly hydrograph

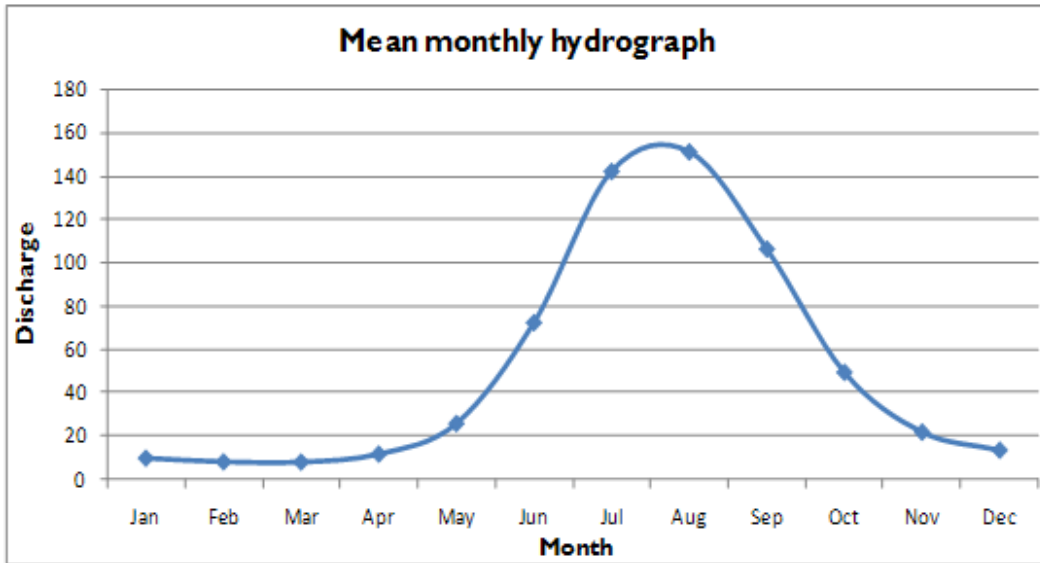
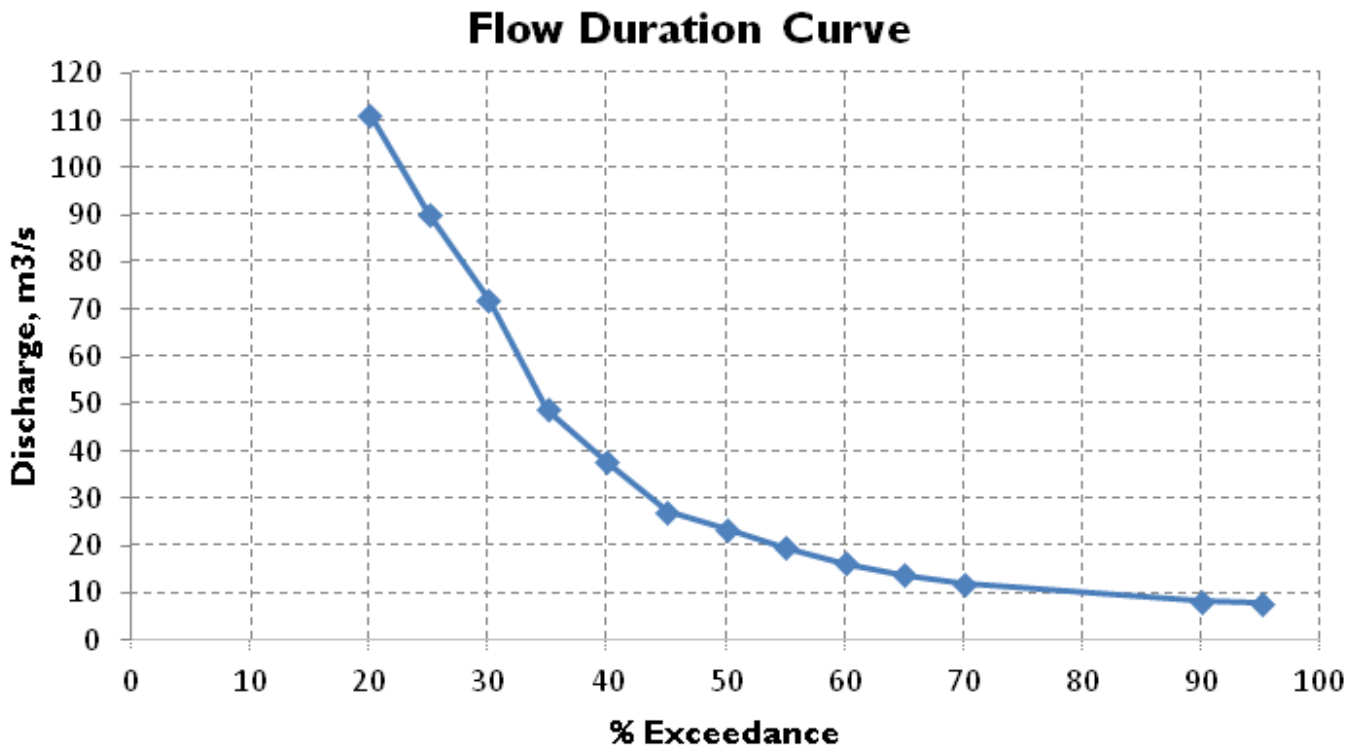


Figure 3: Flow duration curve



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Figure 4: Glacial Lake Outburst Flood (GLOF), know as mountain tsunamis

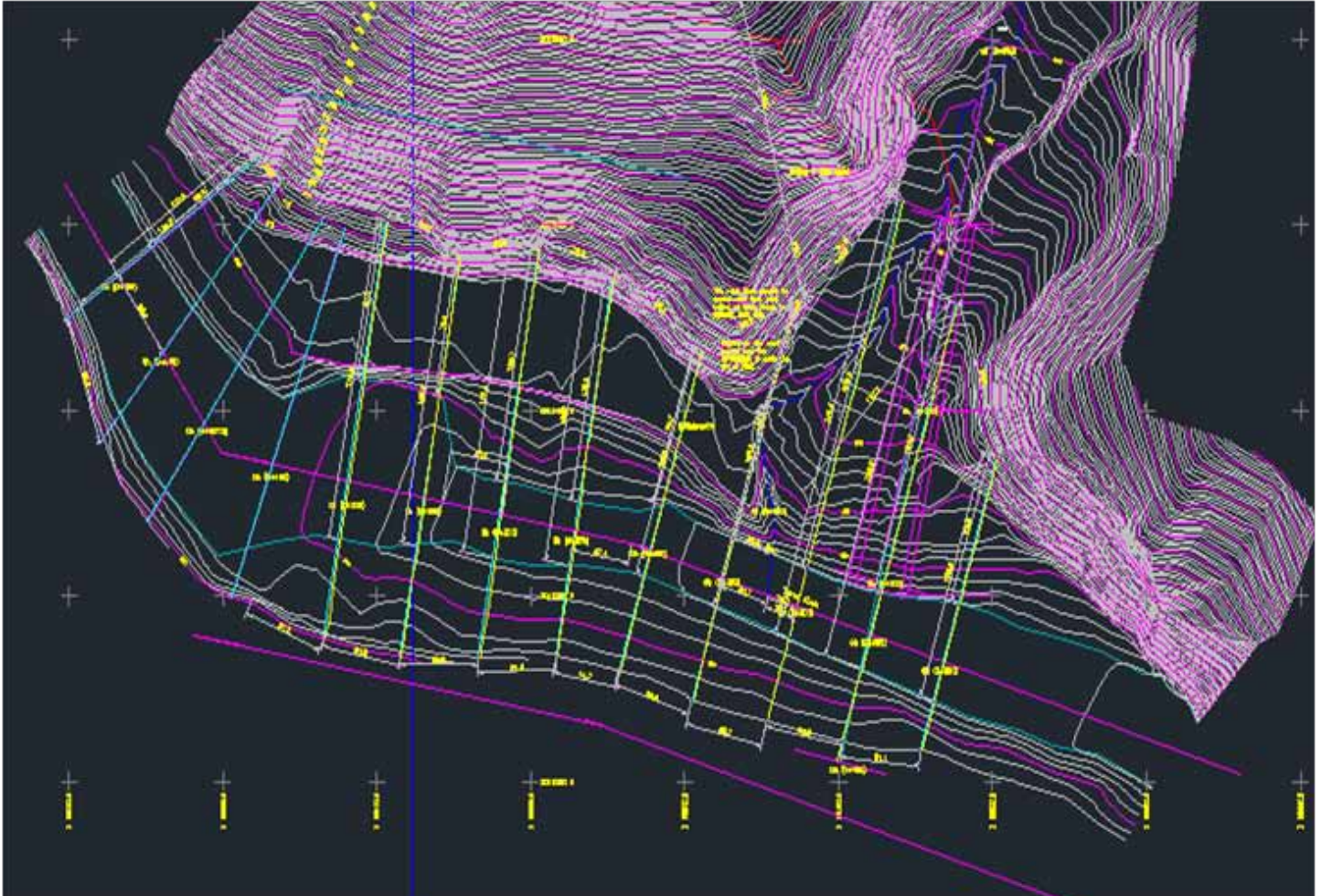


Figure 5: Cross Sections of Tamor river taken for HECRAS analysis



Calculation of Water Surface Elevation Using HECRAS 4.1.0 for Fixing Tailwater Elevation for Powerhouse Site in Planned 37 MW Kabeli "A" Hydroelectric Project, Nepal
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Figure 6: Contour Map along Tamor river with cross sections for input to HECRAS geometry data



Rating Curve:

Figure 7: 480 m upstream of Tailrace

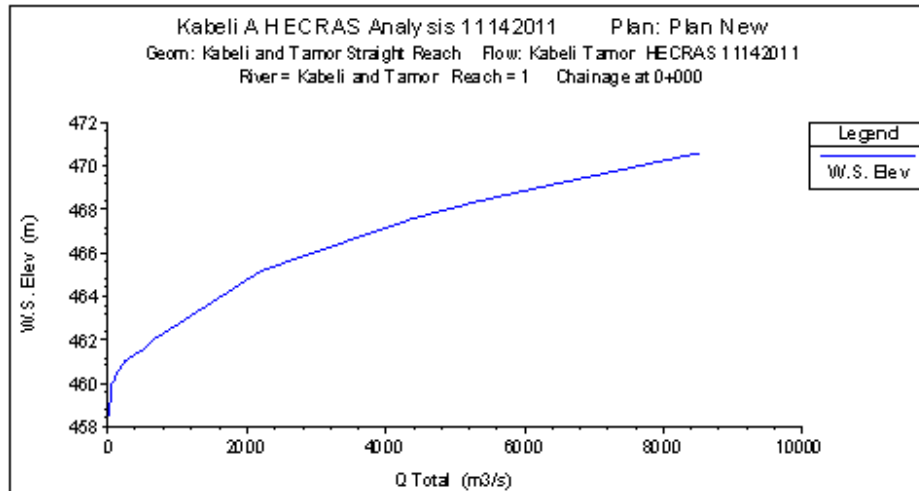


Figure 8: Rating Curve 30 m upstream of Tailrace

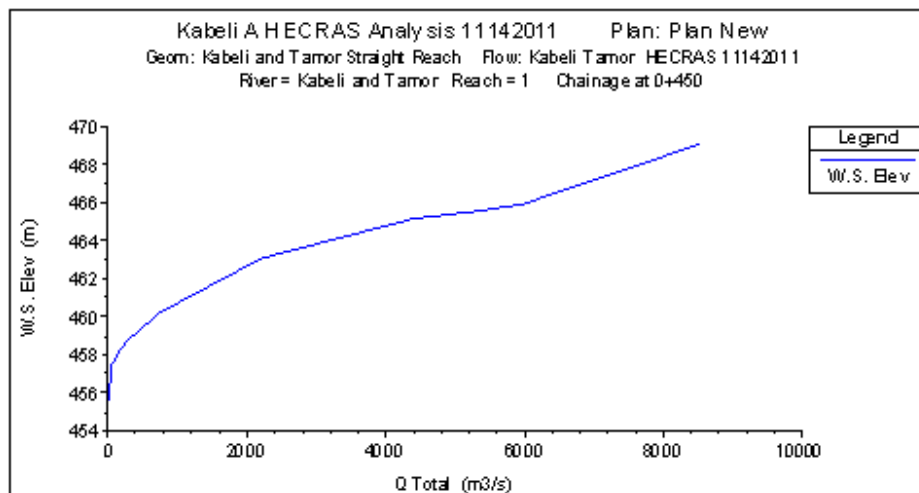
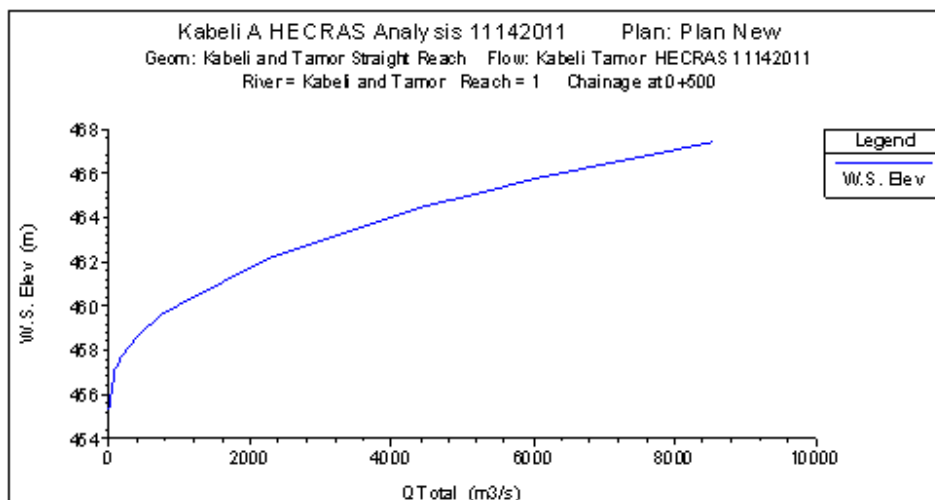


Figure 9: 20 m downstream of Tailrace



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Figure 10: Water Surface Profile for 20 and 100 years flood frequency

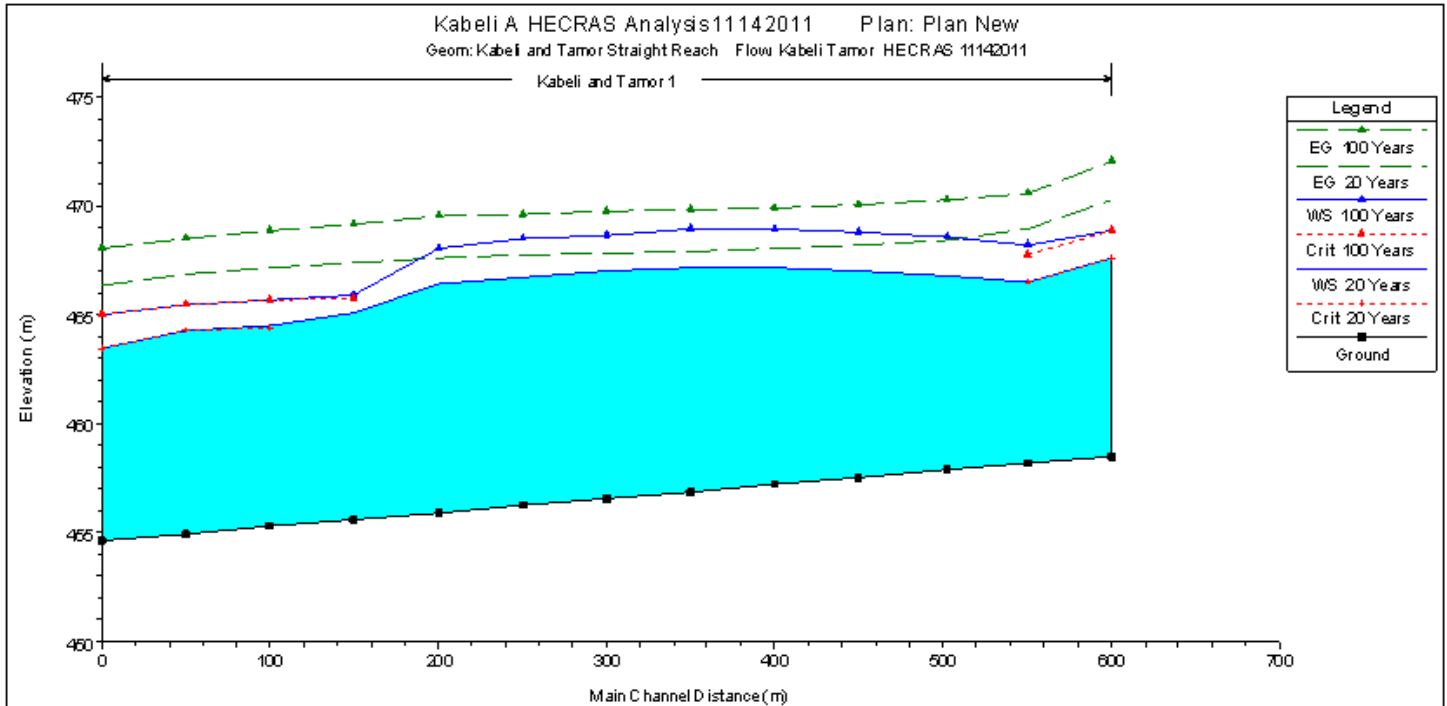


Figure 11: Cross Section Output Table for 100 years flood at extreme upstream river station 600

Plan: Plan New Kabeli and Tamor 1 RS: 600 Profile: 100 Years				
Element		Left OB	Channel	Right OB
E.G. Elev (m)	472.02			
Vel Head (m)	3.18			
W.S. Elev (m)	468.83			
Crit W.S. (m)	468.83			
E.G. Slope (m/m)	0.004785			
Q Total (m3/s)	5984.00	1193.34	4453.49	337.17
Top Width (m)	125.90	55.81	55.10	14.99
Vel Total (m/s)	7.26	4.92	8.70	4.79
Max Chl Dpth (m)	10.33	4.35	9.29	4.69
Conv. Total (m3/s)	86505.3	17251.0	64380.1	4874.2
Length Wtd. (m)	46.29	56.79	55.35	17.12
Min Ch El (m)	458.50	200.39	433.73	192.74
Alpha	1.19	7877.35	0.00	0.00
Frctn Loss (m)	0.20	156.16	352.26	197.87
C & E Loss (m)	0.24	39.80	35.09	29.91
Wt. n-Val.		0.037	0.035	0.037
Reach Len. (m)		20.20	50.00	69.60
Flow Area (m2)		242.50	511.62	70.32
Area (m2)		242.50	511.62	70.32
Flow (m3/s)		1193.34	4453.49	337.17
Top Width (m)		55.81	55.10	14.99
Avg. Vel. (m/s)		4.92	8.70	4.79
Hydr. Depth (m)		4.35	9.29	4.69
Conv. (m3/s)		17251.0	64380.1	4874.2
Wetted Per. (m)		56.79	55.35	17.12
Shear (N/m2)		200.39	433.73	192.74
Stream Power (N/m s)		7877.35	0.00	0.00
Cum Volume (1000 m3)		156.16	352.26	197.87
Cum SA (1000 m2)		39.80	35.09	29.91

Errors, Warnings and Notes	
Warning:	The energy equation could not be balanced within the specified number of iterations. The program used critical depth for the water surface and continued on with the calculations.
Warning:	The velocity head has changed by more than 0.5 ft (0.15 m). This may indicate the need for additional cross sections.
Warning:	The energy loss was greater than 1.0 ft (0.3 m) between the current and previous cross section. This may indicate the need for additional cross sections.
Warning:	During the standard step iterations, when the assumed water surface was set equal to critical depth, the calculated

Calculation of Water Surface Elevation Using HECRAS 4.1.0 for Fixing Tailwater Elevation for Powerhouse Site in Planned 37 MW Kabeli "A" Hydroelectric Project, Nepal
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Figure 12: Cross Section Output Table for 100 years flood at extreme upstream river station 600

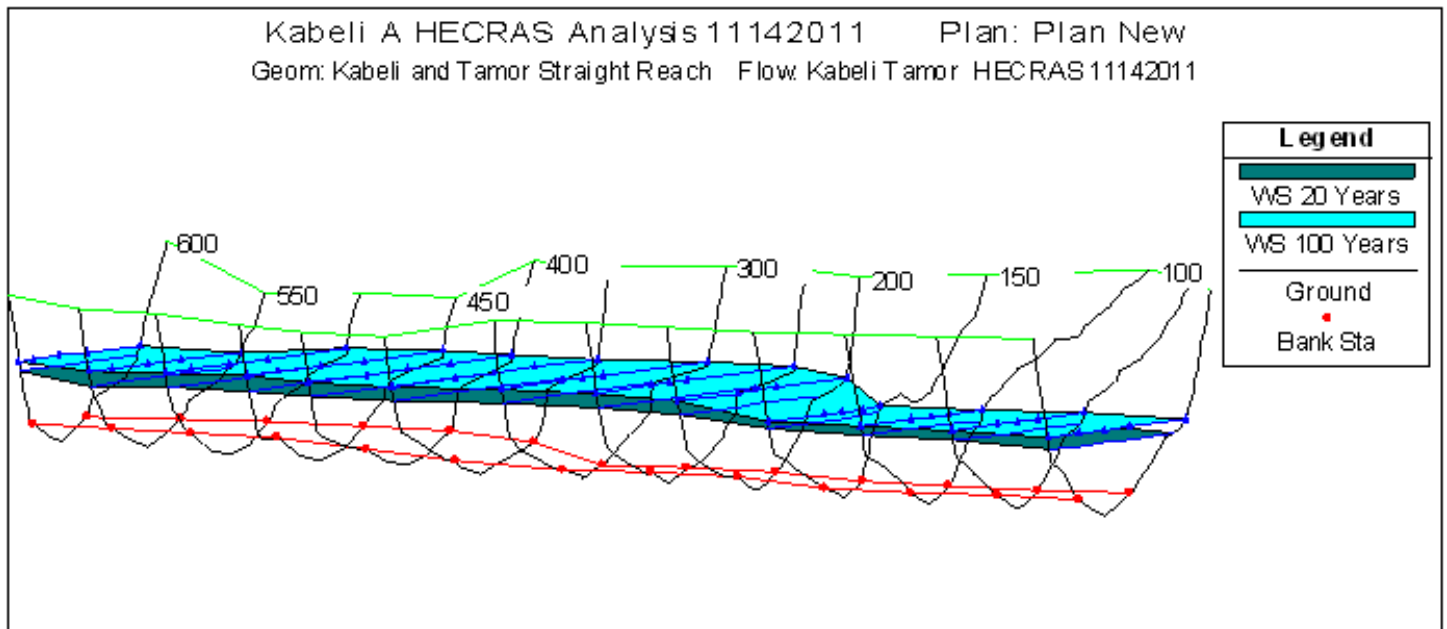


Figure 13: Tailwater level optimization plot

