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CHANNELIZATION OF NATURAL NULLAHS IN HIMALAYANS FOR FLOOD CONTROL USING HEC RAS

Dr. Engr. Mazhar Hussain, Engr. Muhammad Atif Mian

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By

Dr. Engr. Mazhar Hussain[1], Engr. Muhammad Atif Mian[2]

ABSTRACT

Floods are among the most devastating natural hazards in the world. Pakistan has big rivers and natural nullahs in hilly areas which cause flash flooding in monsoon. This paper concentrates on study of flood analysis of nullahs in Himalayan range and focus on channelization of nullahs to control flash floods. The study area between Nauseri and Thotha is characterized by high mountains which form a water divide between the Neelum and Jhelum River catchment. The range is deeply cut by four big nullahs with steep gradients. The Panjkot and Nausada nullah run towards the Neelum River and the Jandarbain and Agar nullah runs towards the Jhelum River. The Himalayan range is covered with forest. The surface is mostly soil covered but some rock outcrops occur in the form of cliffs. Rock is mostly exposed in deep cut nullahs. The natural nullahs are narrow but have deep valleys. Vegetated terraces occur along the nullahs in the valley bottom. The mountain slopes are partly unstable and slides occur, especially during rains. Channelization of nullahs is based on flood frequency analysis with thirty year return period. Maximum storm rainfall is taken from isohyetal map for calculating the flood. Catchment areas and length of nullahs are assessed using satellite images of Google earth. Rational and Dickens formulas are used for calculating the flood of the catchments. Water surface profiles and water levels are evaluated using computer software HEC-RAS. The study indicates that the channelization of nullahs reduce the impact of potential damages of colossal loss.

Key words: Flood, Himalayans, Modeling, Nullahs, Runoff

INTRODUCTION

Floods in Himalayans are due to glaciers lake outburst and by temporary blocking of the river by large landslides. Flooding is one of the major natural disasters that effect many parts of the world. Besides losing millions of dollars in infrastructure and property damages, thousands of human lives are lost each year due to flooding. With the increasing impacts of climate change and more recent flood events throughout the world, there is a need to establish more useful flood risk management plan and strategies. Flooding can be partially avoided by adequate mitigation techniques, however, flood hazards can never be finished completely. Flash floods can happen everywhere, independently of altitude, longitude or latitude, when large volumes of rainfall happen within a short period of time in the same area. Pakistan has big Rivers and floods are mainly caused by heavy south-westerly monsoon showers and rapid snow melting in the Himalayans areas. However, flash floods occurring in natural streams (called nullahs) as a result of localized intense rains in hilly and pothowar (semi hilly) areas are also very common. Such flash floods have remarkably demonstrated their damage potential in the last few years. Flooding problem in Lai stream, originating from Margalla foot hills in Islamabad area and

[1] Head of Hydraulics Section/Principal Hydraulics, Neelum Jhelum Hydroelectric Project (NJHEP), Pakistan Engineering Congress Member; 2302, maz.civil@gmail.com

[2] Senior Hydraulic Engineer, Neelum Jhelum Hydroelectric Project (NJHEP), Pakistan Engineering Congress Member, *4199: engr.ch_atif@hotmail.com*

passes through the center of Rawalpindi city, has been under discussion for the last 60 years. Floods in the Lai stream basin occur during the monsoon season (July-September). On average there are flood damages almost once every three years in the Rawalpindi. Extreme floods years were 1981, 1988, 1997, 2001 and 2010. Flood of 2001 has been the largest among the recorded events so far and considered as a national disaster on 23rd July, 2001, the rainfall depth recorded at 620 mm in 10 hours from 0600-1600 hours and tragically, 74 human lives were lost while 3,000 houses were completely or partially damaged.

Worldwide many countries are facing the issue of developing methods to address coexisting water shortages and flood inundation in hilly areas. Rainfall-runoff prediction and real-time water resources assessment is essential for addressing such situations. Nowadays computer-modeling techniques have ably assisted scientists and engineers with determining floods as well as flood assessments. Computer models for the determination of flooding effects generally require three parts (1) the hydrological model which develops rainfall-runoff relationship from a design storm or historic storm event, (2) the hydraulic model which routes runoff through stream channels to determine water surface profiles at specific locations along the stream network, (3) a tool for flood plain mapping and visualization. However, point's measurements of stage or discharge are more compatible with models. The purpose of this paper is to provide useful technical information for flood management planners to help in selection and design of flood mitigation measures as well as channelization and side slope protection of nullahs to avoid flood damages by flash flood in hilly areas of Pakistan. Figures 1, 2, 3 and 4 depict damages by floods.

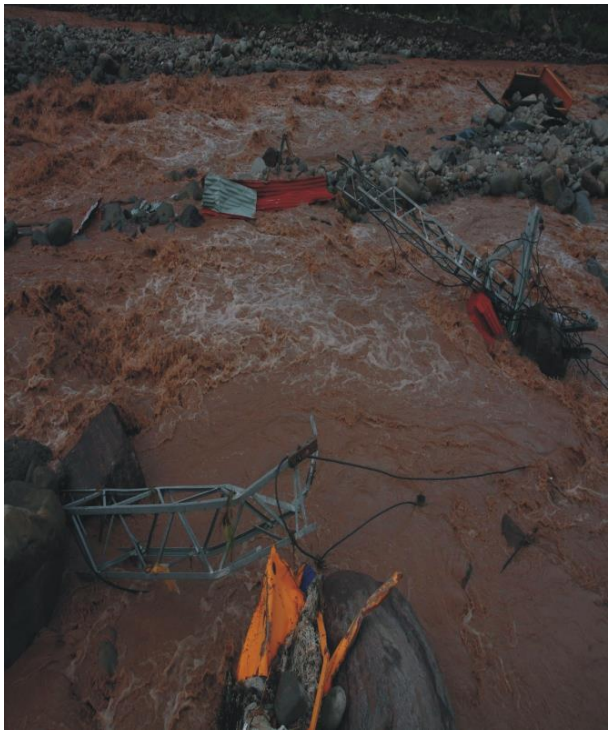


Fig 1: Damages in Agar Nullah, 2010 flood

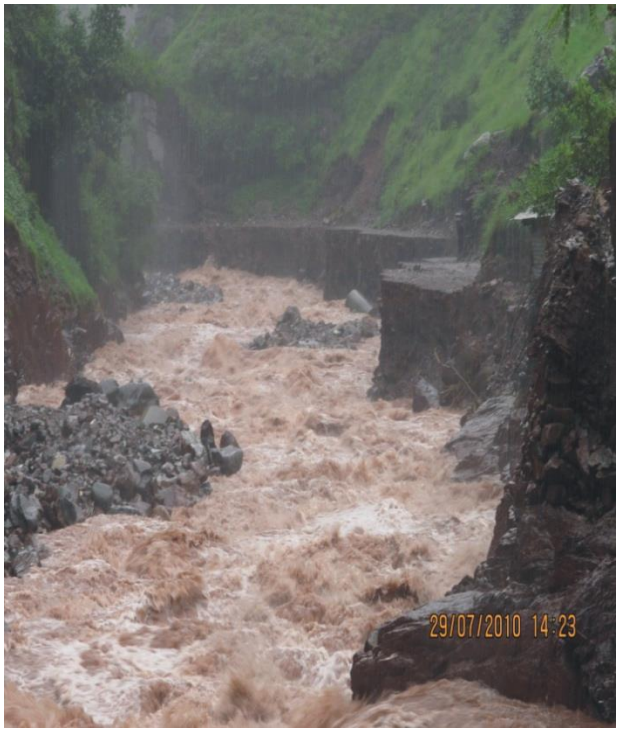


Fig 2: Damages in Jandarbain Nullah, 2010 flood



Fig 3: Road Damages in Panjkot Nullah, 2010 flood



Fig 4: Damages in Nausada Nullah, 2010 flood

2. PHYSICAL CONDITIONS OF THE STUDY AREA

2.1 Topography

Four major nullahs in Himalayans; Agar, Jandarbain, Panjkot and Nausada Nullah at the confluence of Jhelum and Neelum River are considered for the study. Agar Nullah has catchment area of 197 km^2 and length of about 27.3 km. Agar Nullah is located between $34^o13'$ latitude and $74^o53'$ longitude. Jandarbain Nullah has catchment area of 54 km^2 and length of about 11.9 km. Jandarbain Nullah is located between $34^o15'$ latitude and $73^o35'$ longitude at the confluence of Jhelum River. Panjkot Nullah has catchment area of 64 km^2 and length of about 11 km. Panjkot Nullah is located between $34^o23'$ latitude and $75^o6'$ longitude at the confluence of Neelum River. Nausada Nullah has catchment area of 16 km^2 and length of about 5.5 km. Nausada Nullah is located between $34^o25'$ latitude and $75^o6'$ longitude at the confluence of Neelum River.

The gradient of the Nullahs are too much steep which cause high velocities and super critical flow. Cross sections of the valley are too much tight which cause high flow depth, flashing floods and damages. This topography is not favorable with respect to flood regulation. The River flow is therefore expected to respond more or less immediately on heavy rainfall in the catchment. With the topography and existing local road, the study area is divided into three sub areas; namely Nauseri (Panjkot &Nausada Nullah) on the Neelum, Majohi (Jandarbain Nullah) on the upper Jhelum and chattarkalas (Agar Nullah) on the lower Jhelum. The catchment area and length of Nullahs has been calculated from GT sheet which is shown in Figure-5. The longitudinal profiles of nullahs are shown in Figure-13.

2.2 Climate

The climate of the study area is very similar to that of the sub-mountainous tracts of Rawalpindi. It is fairly hot in summer and cold in winter. June and July are the hottest months and temperature rises to more than 101^0F. The temperature during winter seldom falls below the freezing point. The climate in the area is comparatively warm. The surrounding mountains rise to more than 1500 m above the valley floor and have a cool climate.

The maximum temperature during summer months varies between 58^0F and 31^0F. The minimum temperature during winter varies between 37^0F and 72^0F which gives a mean of 55^0F. Although rain occurs in all seasons but the monsoon rain is pronounced. The average annual rainfall at Muzaffarabad is about 1346 mm. These monsoons bring heavy downpours in the catchment areas of Himalayans, resulting in flooding of streams, tributaries and Rivers.

2.3 Relative humidity

The relative humidity data at 08:00 AM to 5:00 PM were available for Muzafarabad Met station. At 08:00 AM the relative humidity for the study area varies from lowest value of 71.6 % in May to highest value of 92.7 % in November. At 05:00 PM the lowest value is 48 % in April to highest value of 88 % in December.

3. RAINFALL ANALYSIS

3.1 Rainfall observation and data availability

The rainfall data for Muzafarabad rain gauge met station was available. For the study it has been considered representative for rainfalls in the catchment areas. The average annual rainfall of the area is about 1443 mm. The maximum rainfall occurs during the months of July, August and September. Precipitation in the study area is characterized by the monsoon season. Winter rains generally occur during the months of January, February and March. Least precipitation occurs in the months of April, May, October and November. There are no gauging stations located on catchment areas of Nullahs, isohyetal map has been used for analysis of flood. Maximum storm rainfall of about 200 mm has been taken from isohyetal map for analysis (Figure 6).

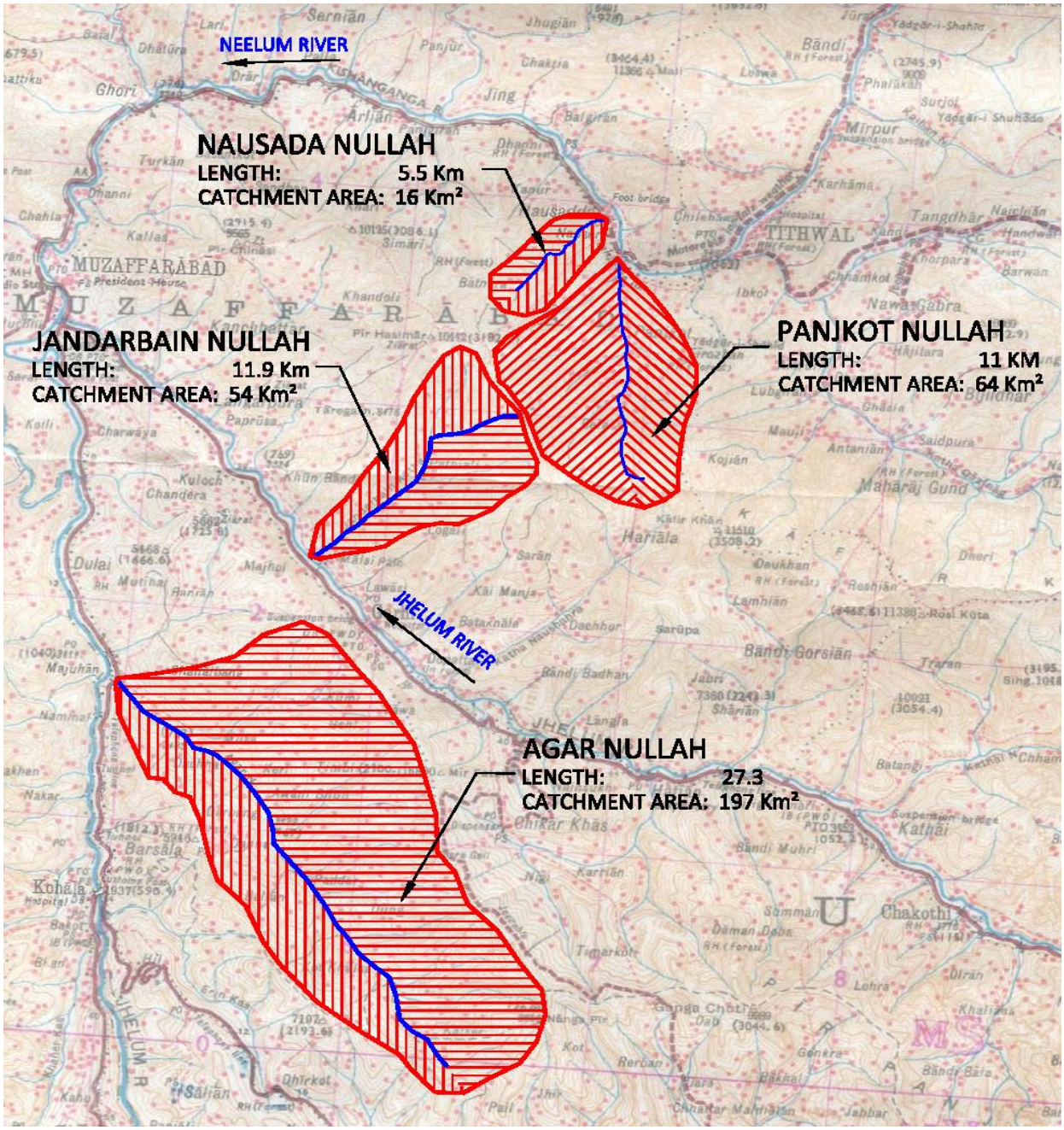


Fig 5: Study area showing catchments (GT Sheets Scale 1:250,000)

3.2 Rainfall characteristics

Using the collected rainfall data of study area, rainfall analysis was made to know general characteristics of the rainfall in the Study Area in terms of duration and distribution in space and time.

3.3 Duration

To judge the general duration of rainfall, significant past rainfall events was studied based on the records of Muzaffarabad rain gauge station and isohyetal map. Considering past 30 year rainfall data, the rainstorms of 24 hours have been adopted for analysis.

4. RUNOFF CALCULATION BY RATIONAL FORMULA

4.1 Estimation of area and length of Nullah

Area and length of Nullahs have been calculated by using GT Sheets with AutoCAD software. GT sheets of scale 1: 250000 & 1:50000 have been used for this purpose. Based on survey data, the longitudinal profiles of Nullahs in the catchment areas were generated and are shown in Figure 13.

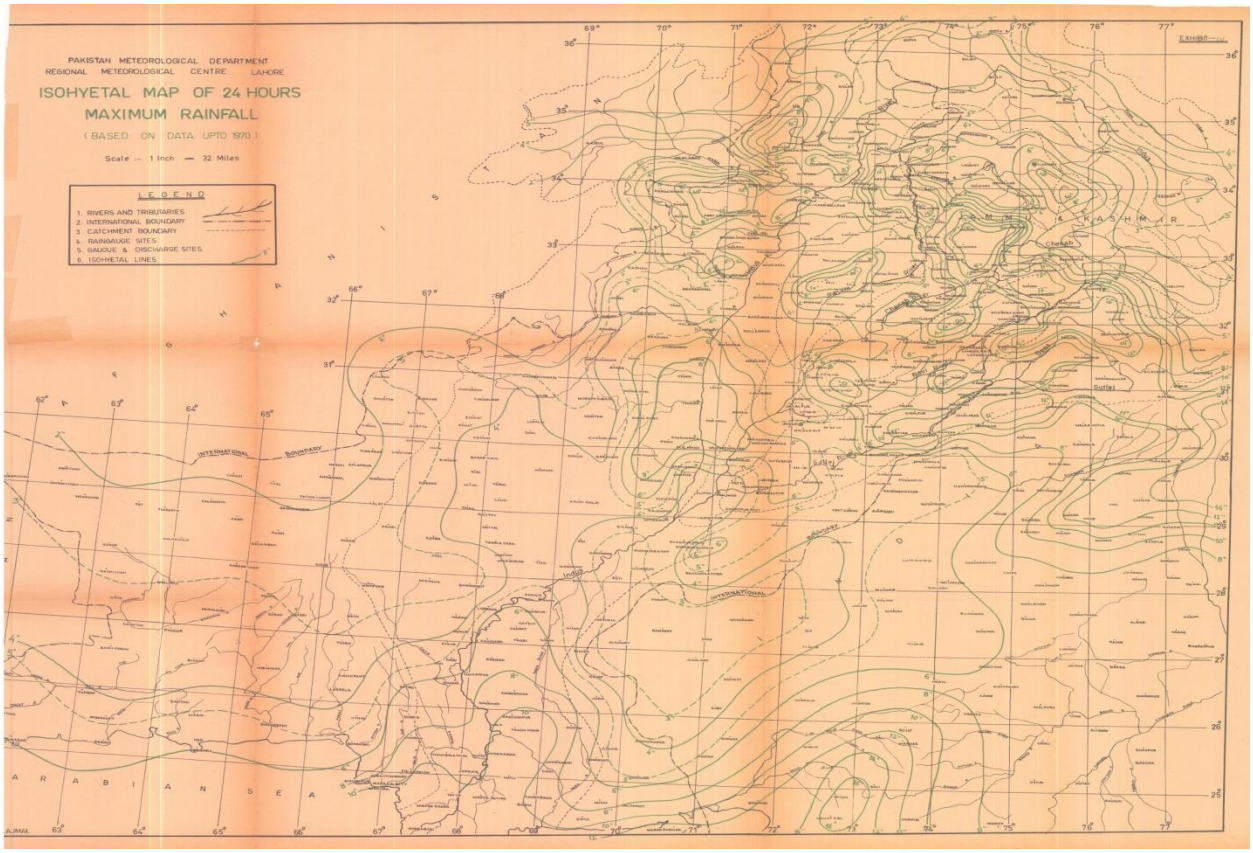


Fig 6: Isohyetal map of 24 hours maximum rainfall

4.2 Time of concentration

Time of concentration has been calculated by following formula

T_c = L/3600……(Eq-1)

Where

T_c = Time of concentration in hrs

L = Length of Nullah in meter

4.3 Intensity of rainfall (I)

Maximum storm rainfall used for estimation of design flood is 203.2 mm for Muzaffarabad region which is for the storm duration of 24 hours. This maximum storm rainfall is for 30 year return period. This maximum storm has been taken from isohyetal map collected from Pakistan Meteorological Department. Intensity of rainfall (I) has been calculated by following formula:

$I = (P/T_r)^* (T_r+1/T_C+1)$…….. (Eq-2)

Where

P = Maximum storm rainfall, mm

T_r= Duration of Storm, hour

T_c= Time of concentration, hour

I = Intensity cm/hr

4.4 Flood Estimation

Runoff coefficient has been taken 0.4 for hilly areas. Design flood discharge for 30 year return period has been calculated by rational formula which is given below.

Q = CIA……. (Eq-3)

Where

C = Runoff Coefficient, 0.4

I = Intensity of rainfall, cm/hr

A = Watershed Area, km^2

5. FLOOD FREQUENCY ANALYSIS

Data series of 32 years of annual flood peaks at Muzaffarabad has been used for flood frequency analysis for different return periods by Gumbel extreme value distribution.

6. CHANNELIZATION OF NULLAHS

Channelization of Nullahs has been designed by following formulas. Velocity of Nullah has been calculated by Manning's formula. Flood frequency analysis of Nullah for different return periods has been performed by ratio of return period of Muzaffarabad. 30 year flood return period has been used for channelization of Nullahs. Flood analysis is also performed for low flow analysis like 20, 50 and 80 m^3/s for channelization of Nullahs.

$$\mathbf{V = \frac{1}{n} R^{\frac{2}{3}} S^{\frac{1}{2}}}$$ ……..... (Eq-4)

Where

V = Velocity of Nullah in m/s

n = Manning Coefficient used 0.035 for unlined Nullah and for lined channel used 0.015.

R = Hydraulic Radius = $\overline{P}$, Area = A= $by + ZY^2$, Wetted Perimeter=P = $b + 2y\sqrt{1 + z^2}$

S = Bed slope of nullah in %

Z = Side slope of nullah

b = Bed Width in m

Y = Flow Depth in m

Flow depth has been calculated by trial and error adjustment in manual calculations. And this flow depth has been calibrated by running HEC-RAS model which closely match with manual calculations.

6.1 Protection works

For channelization of nullahs, the protection works play an important role to save infrastructures. The few flood protections arrangements are shown in Figure 7 and 8 in Himalayan region.

6.2 Types of Protections

Important infrastructure like residence buildings, agriculture lands, shops etc exists on both the banks of nullahs which require to be protected against floods. The following three types of flood protection arrangements are proposed for protection works:



Fig 7: Retaining wall for road & bridge protection

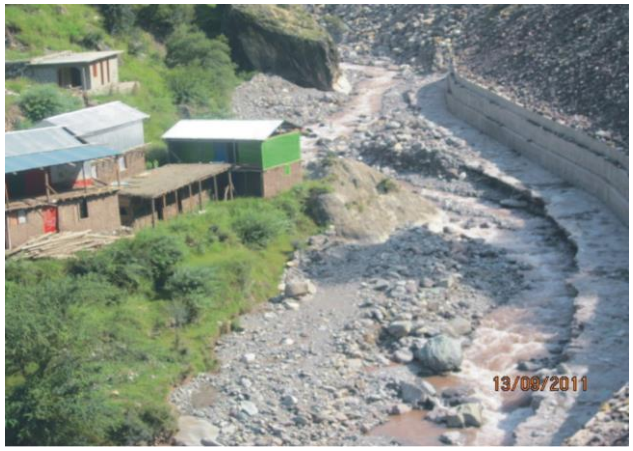


Fig 8: Grouted riprap for houses & road protection

Type -1 Rip rap concrete grouted

For the side slope protection of Nullahs where bed width of nullah more than 20 m, concrete grouted riprap protection are proposed. The design is given below in Figure-9:

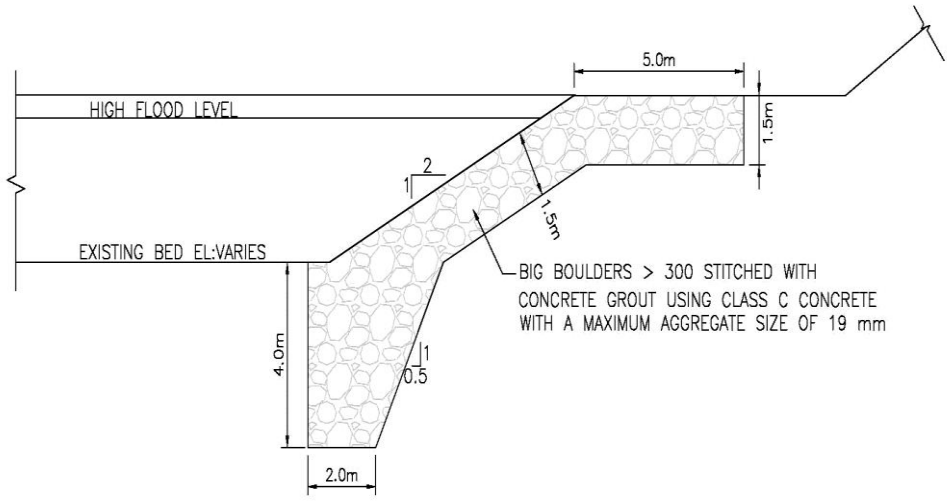


Fig 9: Grouted riprap concrete

Type -2 Concrete Blocks

Protection arrangement consisting of plain cement concrete blocks of concrete type A can be proposed along the curvilinear lengths of the right and left banks of nullah where bed

width of nullah less than 20 m & more than 10 m and the critical stretch of right bank where the access road comes close to the nullah bed. Concrete blocks design is shown in Figure-10.

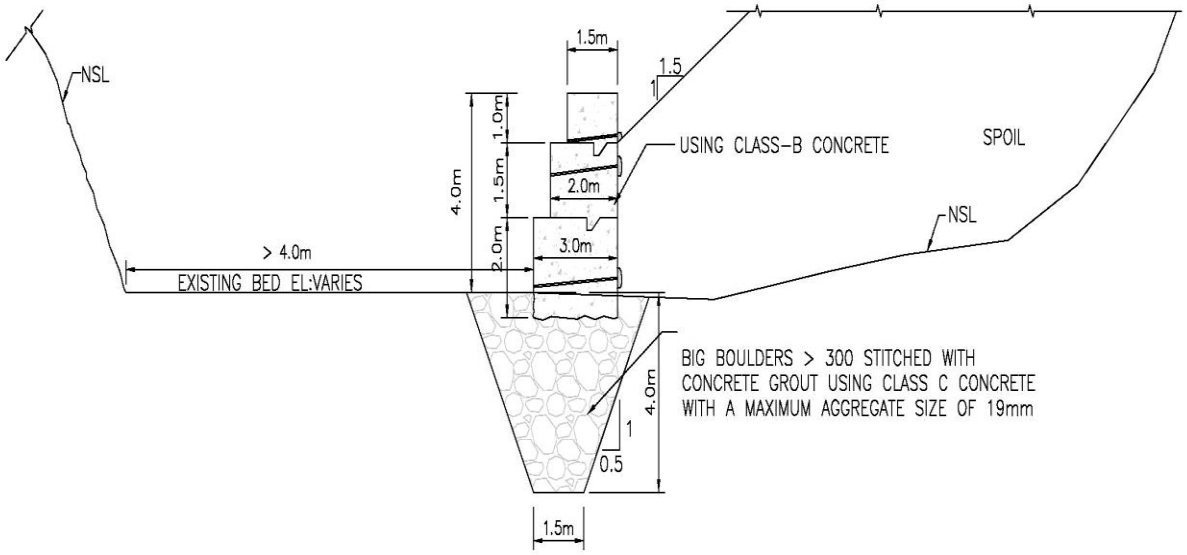


Fig 10: Concrete Blocks protection design

Type -3 Reinforced Concrete retaining wall

RCC Retaining Wall is proposed where sections are very tight bed width less than 10 m along the important infrastructure like houses, etc, and design is shown in Figure-11:

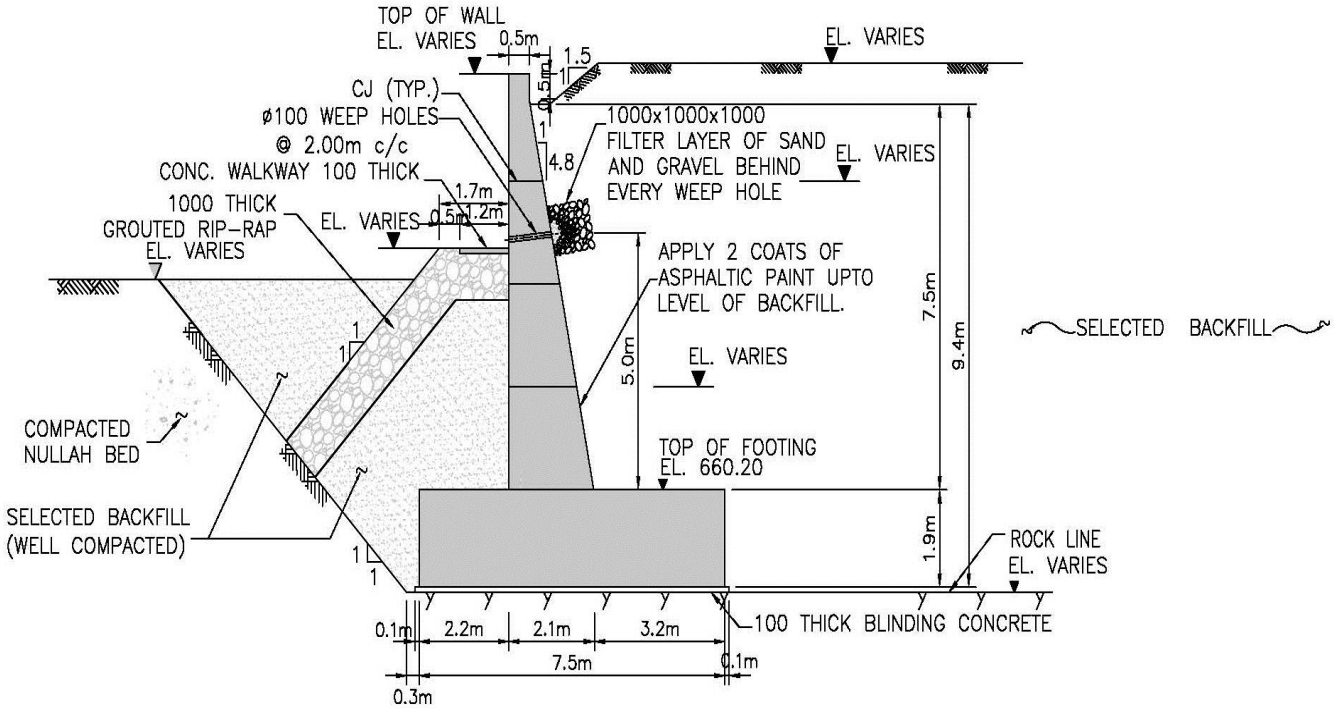


Fig 11: Reinforced concrete retaining wall

7. HEC-RAS ONE- DIMENSIONAL FLOW CALCULATION

HEC-RAS is capable of performing one-dimensional water surface profiles calculations for steady gradually varied flow in natural or constructed channels. Subcritical, supercritical and mixed flow regime water surface profiles of study nullahs have been calculated by using HEC-RAS model. Water surface profiles are computed from one cross section to the next by solving the energy equation. The energy equation is given below.

$$Z_2 + Y_2 + \frac{a_2 V_2^2}{2g} = Z_1 + Y_1 + \frac{a_1 V_1^2}{2g} + h_e \quad \text{..... (Eq-5)}$$

Where: Z1, Z2 = elevation of the main channel inverts in m

Y_1, Y_2 = depth of water at cross sections in m

V_1, V_2 = average velocities (total discharge/total flow area) in m/s

a_1, a_2 = velocity weighting coefficients

g = gravitational acceleration in m/s^2

h_e = energy head loss in m

The equation for energy head loss (he) is as follows:

$$h_e = L \bar{S}f + C \left| \frac{a_2 V_2^2}{2g} - \frac{a_1 V_1^2}{2g} \right| \quad \text{..... (Eq-6)}$$

Where: L = discharge weighted reach length in m

$\bar{S}f$ = representative friction slope between two sections

C = contraction or expansion loss coefficient

8. CALIBRATION AND VALIDATION OF MODEL

The flood on 27th July, 2010 that could provide the richest hydrological data, was selected for the model calibration. Hydraulic parameters calculated by using HEC-RAS model were very similar to existing flood of 2010. Figures 12, 13, 14, 15 and 16 depict calibrated and validated water profiles of nullahs.

9. RESULTS AND DISCUSSIONS

Channelization and side slope protections of nullahs are based on water surface profiles calculated by using HEC-RAS model. Channelization of nullahs is important for control flow and protection of flood.

9.1 Agar Nullah

The existing slope of Nullah is 0.0275 m/m and velocity after running the HEC RAS model is about 8 m/sec. For calibration purpose, Manning roughness' coefficient is taken as 0.035. The water surface profiles are shown in Figure 12. The validation results are shown in Figure 13. For validation purpose, the flood levels 2010 are used. The results are summarized in Table 1. Average flow depth by model is 2.5m and flow is found as supercritical. In flood 2010, the flow depth was about 2.7 m.

9.2 Jandarbain Nullah

The existing slope of Nullah is 0.0549 m/m and velocity after running the HEC RAS model is about 8 m/sec. For calibration purpose, Manning roughness' coefficient is taken as 0.035. The water surface profiles are shown in Figure 12. The validation results are shown in

Figure 13. For validation purpose, the flood levels 2010 are used. The results are summarized in Table 2. Average flow depth by model is 3.2m and flow is found as supercritical. In flood 2010, the flow depth was about 3.6 m.

9.3 Nausada Nullah

The existing slope of Nullah is 0.0677 m/m and velocity after running the HEC RAS model is about 9 m/sec. For calibration purpose, Manning roughness' coefficient is taken as 0.035. The water surface profiles are shown in Figure 12. The validation results are shown in Figure 16. For validation purpose, the flood levels 2010 are used. The results are summarized in Table 3. Average flow depth by model is 1.4m and flow is found as supercritical. In flood 2010, the flow depth was about 1.6 m.

9.4 Panjkot Nullah

The existing slope of Nullah is 0.0928 m/m and velocity after running the HEC RAS model is about 12 m/sec. For calibration purpose, Manning roughness' coefficient is taken as 0.035. The water surface profiles are shown in Figure 12. The validation results are shown in Figure 15. For validation purpose, the flood levels 2010 are used. The results are summarized in Table 4. Average flow depth by model is 2.8 m and flow is found as supercritical. In flood 2010, the flow depth was about 3.1 m.

10. CONCLUSIONS

Based on the results of the study, following conclusions are drawn:

- The localization of rainfall is quite significant and the spatial distribution pattern is different from flood to flood. Therefore, basin mean rainfall is more important than the point rainfalls for flood assessments.
- The calibrated /validated water surface levels are closely matched with floods 2010 water surface levels. The model has been applied for estimation of standard flood discharge.
- Due to channelization and protection works in nullahs damages can be reduced nearest populous abadies to save human life.
- Due to channelization of nullahs, infrastructure can be protected and hence colossal loss can be avoided to save national money.
- Four types of protections works are proposed along the nullahs at critical locations (at permanent infrastructures) based on HEC RAS model results.

11. RECOMMENDATIONS

Based on this study, following recommendations are made:

- More rainfall gauging stations in Himalayans should be established and at the same time proper attention should be given to arrange the gauged data for future use. As there was no gauging station located in study area, so existing hydrological gauging data of Muzaffarabad was used, it is also recommended to establish a net work of rain gauge stations in the study area.
- The data used is quite inadequate, which is a great hindrance for formulation of the flood mitigation plan in the area.
- A water gauging station preferably with automatic recorder should be installed in Himalayans for calibration of model results.

- An efficient flood warning & forecasting system needs to be established in the area to safeguard the public life and property in the event of flood in nullahs.
- Based on the results of flood modeling, the preparation of flood hazard map should be taken up for hilly areas.
- Runoff modeling of various streams should be taken up to avert flood damages due to flash floods in other parts of Pakistan especially in Khyber Pukhtunkhawa (KPK) nullahs.

12. ACKNOWLEDGEMENT

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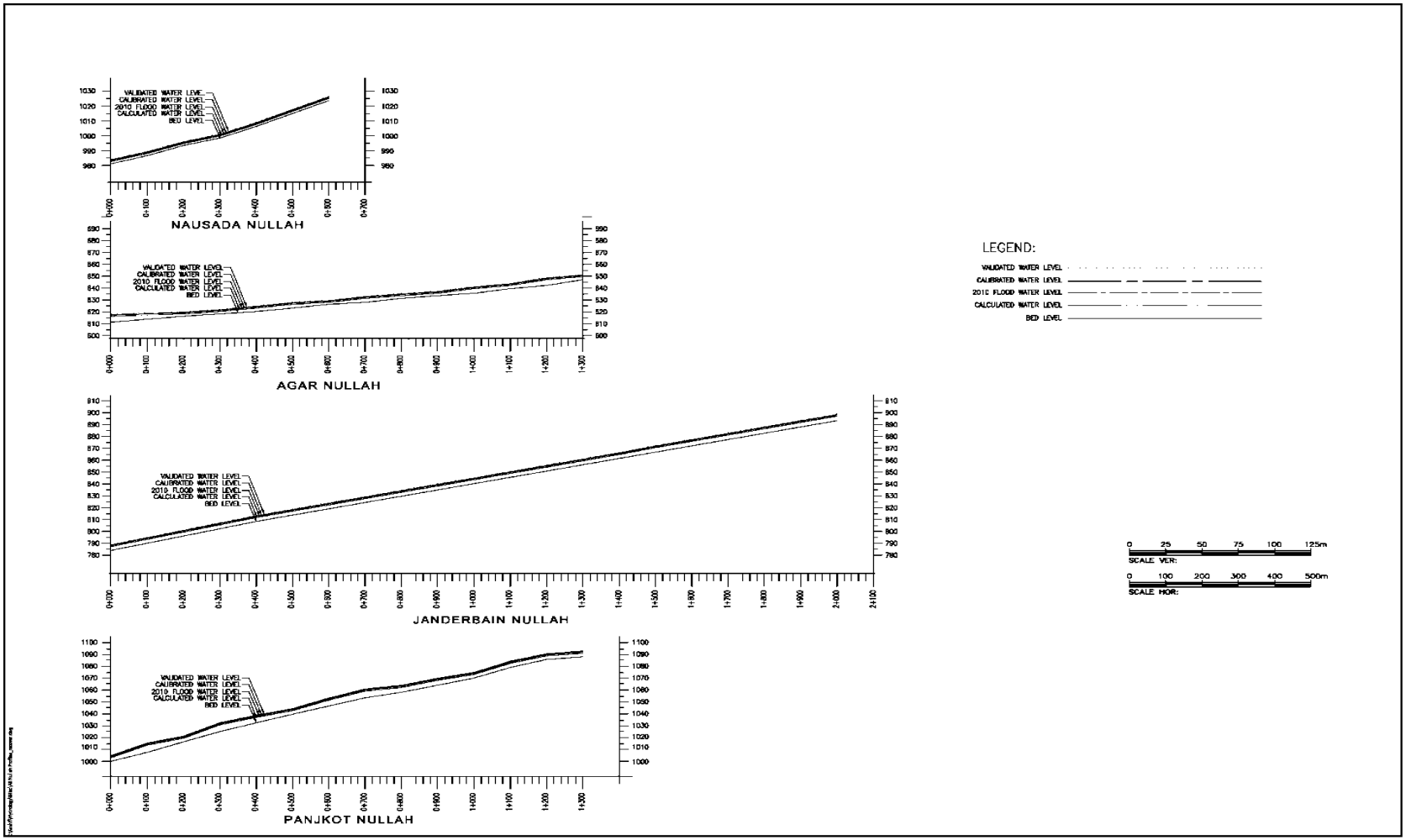


Fig 12: Calibrated & Validated Profiles of Nullah

Table-1: Calibrated & Validated Hydraulic Parameters of Agar Nullah

RD	BED Level	Calculated Water Level	2010 Flood Water Level	Calibrated Water Level	Validated Water Level	Velocity	Calibrated Manning's Coefficients
(-)	(masl)	(masl)	(masl)	(masl)	(masl)	(m/sec)	(-)
100	611.3	616.3	617.2	617.7	618.1	8.3	0.035
200	616.3	618.3	619.2	619.7	620.1	7.9	0.035
300	618.3	620.3	621.2	621.7	622.1	8.0	0.035
400	620.3	623.2	624.1	624.6	625.0	8.0	0.035
500	623.2	626.4	627.3	627.8	628.2	8.2	0.035
600	626.4	628.0	628.9	629.4	629.8	8.2	0.035
700	628.0	631.4	632.3	632.8	633.2	8.6	0.035
800	631.4	633.7	634.6	635.1	635.5	9.0	0.035
900	633.7	635.7	636.6	637.1	637.5	9.1	0.035
1000	635.7	639.5	640.4	640.9	641.3	8.5	0.035
1100	639.5	642.3	643.2	643.7	644.1	7.9	0.035
1200	642.3	647.1	648.0	648.5	648.9	7.6	0.035
1300	647.1	649.7	650.6	651.1	651.5	6.6	0.035

Table-2: Calibrated & Validated Hydraulic Parameters of Jandarbain Nullah

RD	BED Level	Calculated Water Level	2010 Flood Water Level	Calibrated Water Level	Validated Water Level	Velocity	Calibrated Manning's Coefficients
(-)	(masl)	(masl)	(masl)	(masl)	(masl)	(m/sec)	(-)
0	790.1	793.4	794.3	794.8	795.2	10.3	0.035
100	796.2	799.5	800.4	800.9	801.3	9.4	0.035
200	802.3	805.6	806.5	807.0	807.4	8.7	0.035
300	808.4	811.7	812.6	813.1	813.5	8.9	0.035
400	813.7	817.0	817.9	818.4	818.8	8.9	0.035
500	819.1	822.3	823.2	823.7	824.1	7.0	0.035
600	824.4	827.6	828.5	829.0	829.4	8.2	0.035
700	829.7	832.9	833.8	834.3	834.7	9.2	0.035
800	835.0	838.2	839.1	839.6	840.0	8.7	0.035
900	840.3	843.5	844.4	844.9	845.3	9.5	0.035
1000	845.6	848.8	849.7	850.2	850.6	8.8	0.035
1100	850.9	854.2	855.1	855.6	856.0	8.7	0.035
1200	856.2	859.5	860.4	860.9	861.3	8.5	0.035
1300	861.5	864.8	865.7	866.2	866.6	8.9	0.035
1400	866.8	870.6	871.5	872.0	872.4	8.3	0.035
1500	872.1	875.9	876.8	877.3	877.7	9.3	0.035
1600	877.4	881.2	882.1	882.6	883.0	9.4	0.035
1700	882.7	886.5	887.4	887.9	888.3	9.6	0.035
1800	888.0	891.8	892.7	893.2	893.6	8.2	0.035
1900	893.3	897.1	898.0	898.5	898.9	8.6	0.035

Table-3: Calibrated & Validated Hydraulic Parameters of Nausada Nullah

RD	BED Level	Calculated Water Level	2010 Flood Water Level	Calibrated Water Level	Validated Water Level	Velocity	Calibrated Manning's Coefficients
(-)	(masl)	(masl)	(masl)	(masl)	(masl)	(m/sec)	(-)
0	988.2	990.0	990.9	991.4	991.8	10.5	0.035
100	996.8	998.4	999.3	999.8	1000.2	12.3	0.035
200	1003.0	1004.7	1005.6	1006.1	1006.5	13.3	0.035
300	1012.8	1014.5	1015.4	1015.9	1016.3	12.1	0.035
400	1023.7	1025.5	1026.4	1026.9	1027.3	13.2	0.035
500	1034.6	1036.4	1037.3	1037.8	1038.2	12.1	0.035

Table-4: Calibrated & Validated Hydraulic Parameters of Panjkot Nullah

RD	BED Level	Calculated Water Level	2010 Flood Water Level	Calibrated Water Level	Validated Water Level	Velocity	Calibrated Manning's Coefficients
(-)	(masl)	(masl)	(masl)	(masl)	(masl)	(m/sec)	(-)
0	1000.1	1003.1	1004.0	1004.5	1004.9	10.1	0.035
100	1007.6	1013.7	1014.6	1015.1	1015.5	10.5	0.035
200	1016.5	1019.5	1020.4	1020.9	1021.3	9.2	0.035
300	1025.1	1030.8	1031.7	1032.2	1032.6	8.3	0.035
400	1032.5	1037.1	1038.0	1038.5	1038.9	10.6	0.035
500	1039.7	1042.7	1043.6	1044.1	1044.5	9.3	0.035
600	1046.7	1051.6	1052.5	1053.0	1053.4	8.8	0.035
700	1053.6	1059.3	1060.2	1060.7	1061.1	9.7	0.035
800	1058.2	1062.3	1063.2	1063.7	1064.1	9.5	0.035
900	1064.2	1068.3	1069.2	1069.7	1070.1	8.5	0.035
1000	1070.2	1073.2	1074.1	1074.6	1075.0	10.0	0.035
1100	1079.1	1082.6	1083.5	1084.0	1084.4	10.4	0.035
1200	1085.9	1088.9	1089.8	1090.3	1090.7	9.8	0.035
1300	1088.2	1091.2	1092.1	1092.6	1093.0	9.6	0.035

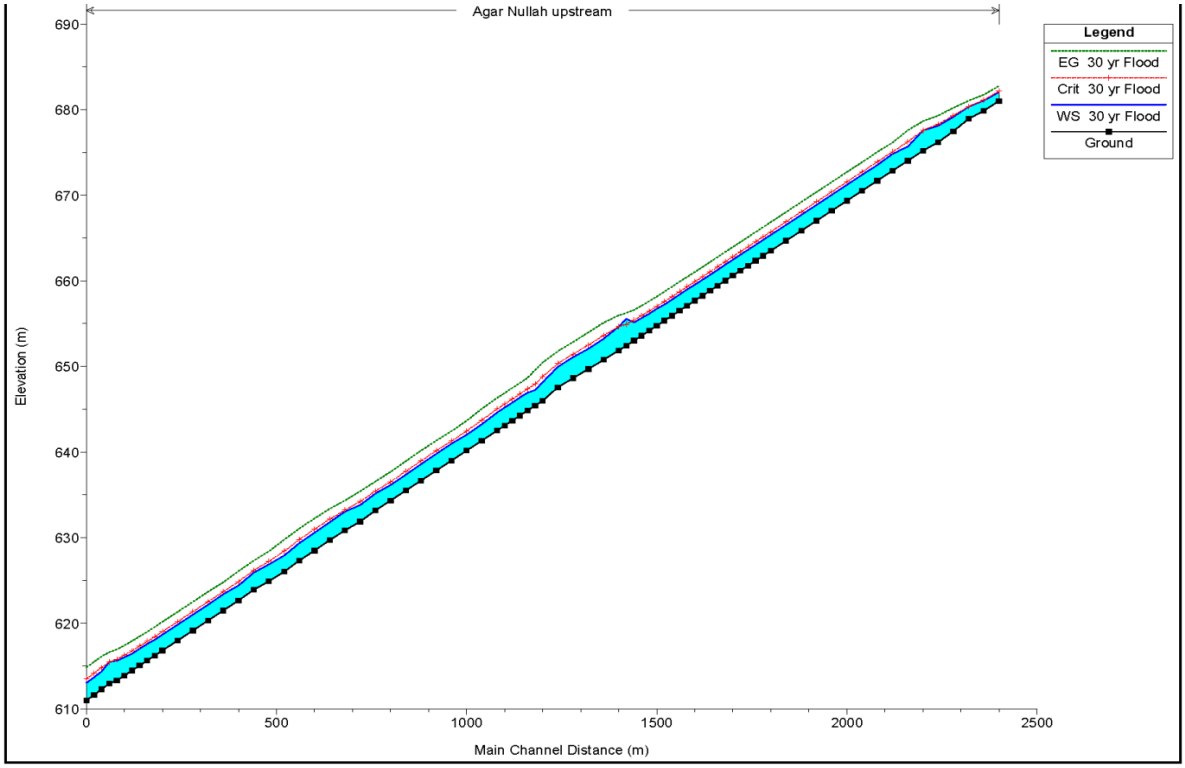


Fig 13: Water Surface Profile of Agar Nullah (HEC-RAS)

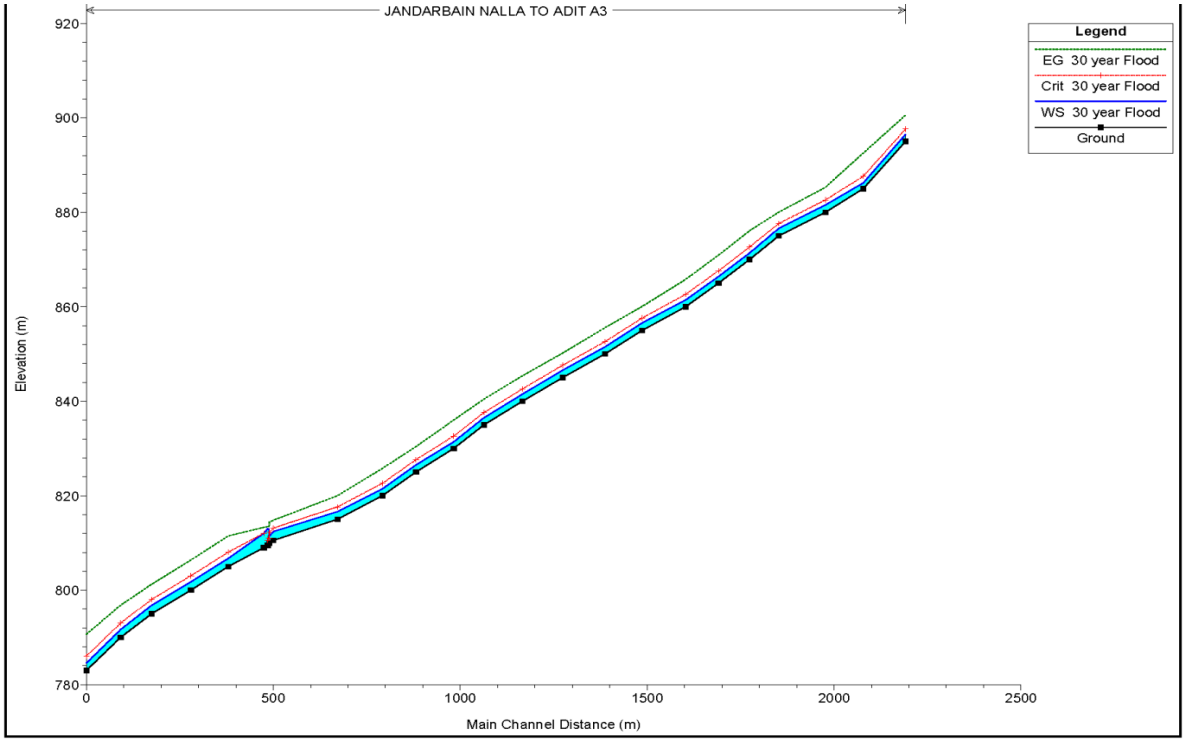


Fig 14: Water Surface Profile of Jandarbain Nullah (HEC-RAS)

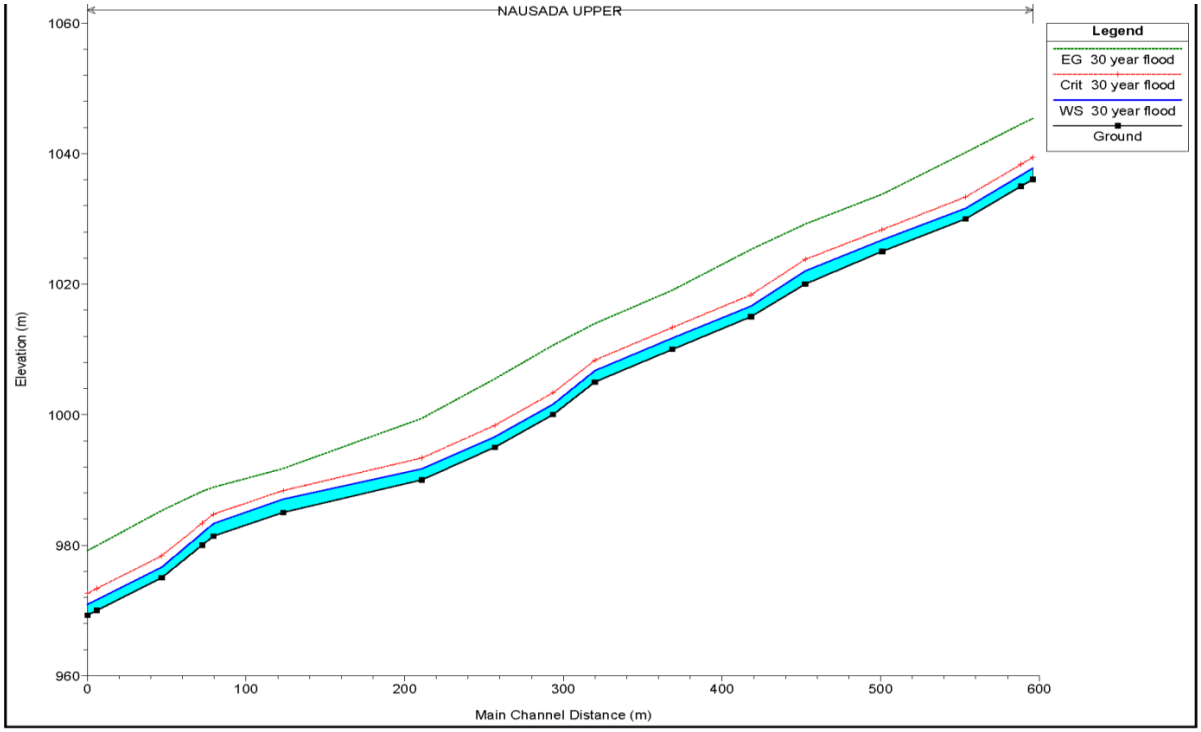


Fig 15: Water Surface Profile of Nausada Nullah (HEC RAS)

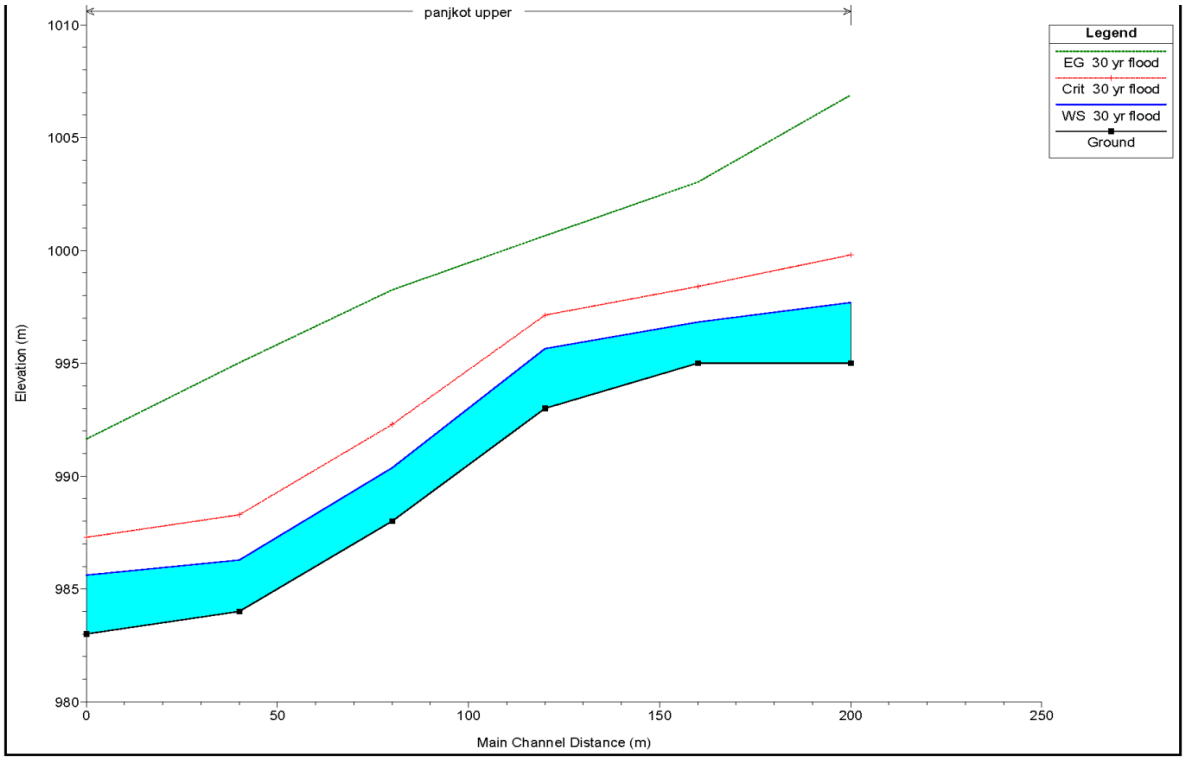


Fig 16: Water Surface Profile of Panjkot Nullah (HEC-RAS)