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Assessment of Roadside Drainage Capacity on Lamachaur Road

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Abstract

Lamachaur Road, located in a region prone to heavy rainfall and flash floods during the monsoon season, faces recurring waterlogging and roadway obstructions. In response to these challenges, this study examines the efficiency of existing roadside drainage systems in managing runoff and proposes mitigation strategies. The primary objectives included determining peak runoff during rainfall events, assessing the current drainage capacity, and exploring feasible measures to enhance drainage efficiency. Utilizing the Hydrologic Engineering Center's River Analysis System (HEC-RAS) software, a hydrological model was developed to simulate runoff dynamics along the Lamachaur Road. Through rigorous analysis, it was revealed that the existing drainage infrastructure operates at a capacity significantly below the required discharge, with an observed deficiency of 82.7%. Quantitatively, the drainage system had a capacity of approximately 4.5 cumecs, insufficient to manage peak runoff volumes during intense precipitation events adequately. Furthermore, attempts to augment drainage capacity by enlarging the size yielded inconclusive results, as the anticipated reduction in flooding was insignificant. Moreover, the prospect of constructing larger drainage systems was constrained by limited roadway space. In conclusion, this study underscores the pressing need for proactive measures to address the inadequacies of roadside drainage infrastructure along Lamachaur Road. By embracing innovative strategies and integrating sustainable water management approaches, sustainable solutions can be realized, enhancing resilience against the challenges posed by monsoon-induced flash floods.

Keywords**:** Discharge, HEC-RAS, Runoff, Catchment, Drainage.

1. Introduction

More than three-fourths of the annual rainfall in Nepal occurs between June and September under the influence of the summer monsoon (Nayava, 1974). Precipitation is very diverse: the central and western part below the Himalayan belt receives 3000mm of annual rainfall, the central and southern part receives 1500-2000mm, while the high-altitude northern area receives up to 1000mm. Pokhara, one of the highest rainfall-receiving areas of Nepal, has received an average annual rainfall of about 3500 mm over the past decade, of which one-third falls during the monsoon (Paudel & Dawadi, 2022). Stormwater is the runoff from precipitation that does not infiltrate into the ground but flows across impervious surfaces such as rooftops, pavements, and roads, eventually entering storm drains and discharging into nearby water bodies, including lakes, rivers, and streams. Modern drainage design encompasses two principal variables: storage and conveyance. If storage space is limited, the conveyance is set; accordingly, if the conveyance is limited, storage is set to the available conveyance (Hey, 2002). Stormwater management has been a major challenge worldwide in the new urban era.

The drainage channel should carry runoff quickly into the river so it does not affect roads and nearby areas. When creeks overflow or when stormwater accumulates rapidly on streets and is unable to drain efficiently into nearby stream channels, the adjoining roads also become flooded (Lagmay et al., 2017). The discharge capacity of the drainage should be scientifically determined and sufficient to convey the maximum runoff.

Nepal is in a phase of rapid urbanization, and hence, old roads and drainage systems are now insufficient, as infiltration is decreasing day by day. The runoff is only increasing, yet no proper action is being taken to manage it. It is necessary to build a drainage system to ensure the proper functioning of constructed sites and to support public health (Barbosa et al., 2012). Criteria for Roadside Drainage in Nepal regarding discharge include discharge calculation, design of flood and its frequency, and the method of runoff prediction (Rational method). It is precisely accurate and solves the runoff problem if considered carefully. The design flood and its frequency must be considered to ensure the drainage facilities can handle peak runoffs effectively. Overdesigning for the worst possible flood is not economical, and the frequency of the design flood should be chosen based

Fig. 1: Flooding due to excessive runoff in Lamachaur Road,2023

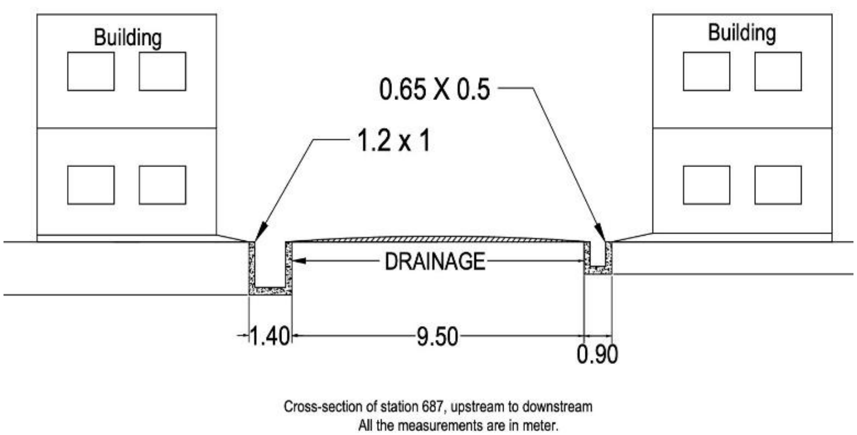

Fig. 2: Typical Cross Section of Road

on the importance of the structure. A proper study of rainfall is required for the accurate design of drainage canals. Lamachaur, Pokhara-16 lies northwards to the city of Pokhara (28°14’54.4” N 83°59’10.6” E to 28°15’41.5” N 83°58’20.0” E). During high rainfall times, the runoff causes an overflow in the drainage canals, resulting in the transformation of roads into temporary streams, which is a common sight during the rainy season in Lamachaur, Pokhara, as well as in many other urban areas across Nepal (Basnet & Neupane, 2018). It is observed that during drain design, a thorough hydrological analysis is absent, resulting in inadequate drainage capacity. Although drainage systems may have been originally designed to manage runoff effectively, the increasing population, unplanned urban expansion, and rapid development have disrupted natural water flow and reduced ground infiltration, thereby heightening the risk of street flooding (Booth, 1991). Vehicles, if not stopped for the runoff to settle down, have a high risk of driving over a pothole on the heavily waterlogged road, while records of pedestrians swept along the flow are also recorded in this road section. Also, the flowing water over the road seeps into the small cracks, which ultimately lead to the formation of large potholes. This stormwater runoff must be managed promptly. This study addresses the issue by analyzing current drainage capacity relative to surface runoff, providing a foundational understanding for effective runoff management.

The study to be conducted analyzes the current status of the drainage system in the Lamachaur area, its capacity to discharge peak runoff safely, and the need for a redesigned drainage channel. The objectives are:

1) To estimate the approximate runoff during a peak flow.
2) To check the present drainage condition.

2. Methodology

The methodology for this study is divided into two subsections: hydrology and hydraulics, with the hydrological section including catchment, precipitation patterns, runoff, and infiltration. Meanwhile, hydraulics includes flow simulation in drainage and road sections, drainage dimensions, and other associated hydraulic parameters.

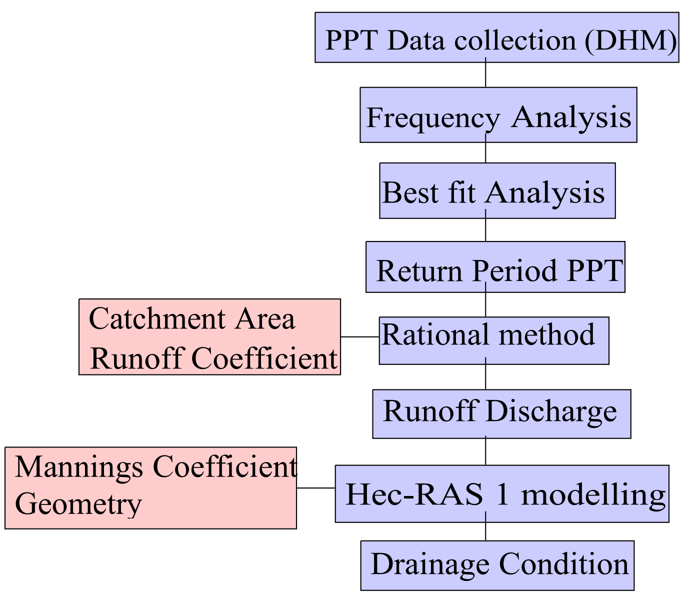

Figure 3: Workflow chart

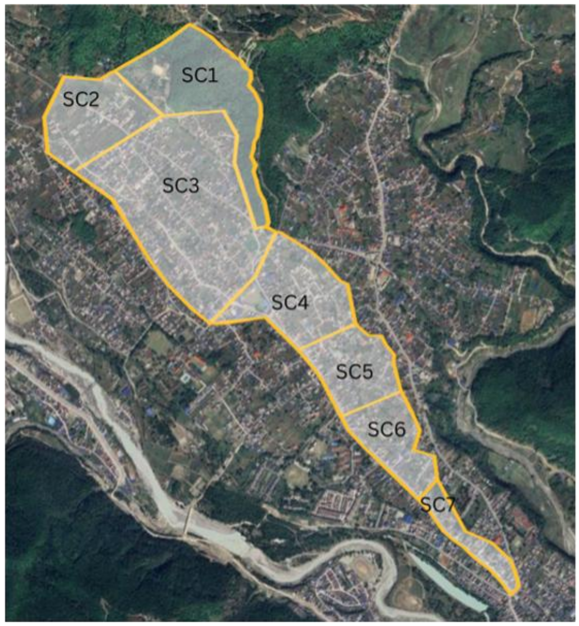

Fig. 4: Catchment area with its sub-catchments.

2.1. Study of Hydrology

With the development of hydrological studies, the rational method has been used extensively lately, as it is more accurate than most conventional methods. The formula for runoff discharge using the rational method is:

$$Q = \frac{CIA}{Z} \qquad (1)$$

Where, Q = peak runoff discharge in cum per second, C = coefficient of runoff, I = mean rainfall intensity in mm per hour, corresponding to the time of concentration of catchment, A=area of draining catchment in hectares, Z = conversion factor (360)

Interception and depressed storage areas in a catchment are those that prevent precipitation from contributing to runoff. During precipitation, a part of the rain is caught by the vegetation, and it evaporates subsequently; that volume of water is the interception (Subramanya, 2021). Relationships between rainfall interval groups and interception loss showed that rainfall magnitude did not relate significantly to the amount of interception loss, stating that it is difficult to predict the volume of interception accurately (Zaw & Oue, 2022). Time of Concentration is the time required for the water in the furthest point of the catchment to reach the basin or reach the inlet of the channel. For constant rainfall intensity, discharge or runoff increases until the time of concentration, then remains constant. The time of concentration of a catchment depends upon the slope and type of soil. So, we calculate the time of concentration of a catchment from the furthest point to the outlet using the soil conditions and slope along the path of flow. Time of concentration is calculated as:

$$T_C = \left(\frac{0{\cdot}87L^3}{H}\right)^{0{\cdot}385} \qquad (2)$$

T in hours, L in kms, H in meters.

Return period is the time when an intensity of rainfall is likely to return or exceed within a certain period. The return period is a probability measure of peak rainfall over a certain region. A 100-year return period of a peak runoff says that there is a 1% probability of peak rainfall occurring this year.

The return period to be considered for Road classes I/II, III, and IV should be 50, 33, and 25 years, respectively (Ministry of Physical Infrastructure & Transport, Department of Roads, 2070).

2.1.1. Gumbel method

Gumbel (1941) proposed this method to find the peak discharge of floods. However, it can also be used for rainfall measurement. The IDF curve for a specific return period can be easily prepared using Gumbel's method.

$$X_T = \bar{X} + K \times \sigma_{\eta-1} \quad (3)$$

where, X_T = the peak value of rainfall, $\bar{X}$ = the mean intensity of rainfall, $\sigma_{\eta-1}$ = standard deviation of n data.

$$K = \frac{Y_T - \overline{Y_n}}{S_n} \quad 4)$$

$$Y_T = -\log\left[\log\left(\frac{T}{T-1}\right)\right] \quad (5)$$

The following process is followed for calculating the data by this method: From the discharge data $\bar{X}$,X and standard deviation $\sigma_{\eta-1}$ is calculated. Then $\overline{Y_\eta}$ (reduced mean) and S_n (reduced standard deviation) are found using Gumbel's table.

2.1.2. Log Pearson type III

In this distribution, log(x) follows the Pearson type (III) distribution, so the sample variate X_i is first transformed to log(x). It is a statistical model to evaluate the maximum rainfall or flooding. The data set of x-values (rainfall) is converted to logarithmic form, Y = log(x). After that, the mean value (Y) and standard deviation σ_{n-1} of y are to be found. This Y series for the recurrence period T peak value is given by:

$$Y_T = Y + K \cdot \sigma_{n-1} \quad (6)$$

The coefficient of skewness is calculated as:

$$C_s = \frac{\sum_{j=1}^{N}(Y_i - \bar{Y})^3}{(N-1)\cdot(N-2)\cdot\sigma_{n-1}^3} \quad (7)$$

The frequency constant K is then calculated using the log-Pearson type III table. Y_T is then calculated using Equation (A), and then this value is converted into X_T using X_T = antilog (Y_T). This value X_T is the required peak flow.

2.2. Study of Hydraulics

2.2.1. Manning's Equation

Manning's equation is a widely used formula to calculate discharge, flow velocity, and cross-section in an open channel, such as a river, canals, drainage, etc. It is an extensively used equation in the field of channel design. The Manning's equation of discharge is:

$$Q = \frac{1}{n} \cdot A \cdot R^{2/3} \cdot S^{1/2} \quad (8)$$

where

Q is the discharge, n is the Manning's roughness coefficient
A is the cross-sectional area of the drainage
R is the hydraulic radius whose value is $\frac{A}{P}$
S is the slope of the channel.

2.2.2. HEC-RAS

HEC-RAS is a powerful software tool developed by the U.S. Army Corps of Engineers for simulating water flow in rivers, streams, and other channels. This versatile program, used by hydraulic engineers, leverages computational fluid dynamics to analyze water behavior. HEC-RAS incorporates Manning's equation, a widely used principle in open channel flow, to perform these simulations. This capability allows engineers to assess flood risks, design effective flood control measures, and optimize channel modifications. The software's functionalities extend beyond rivers and streams. HEC-RAS can also be used for analyzing drainage line discharge, making it a valuable tool for designing and managing stormwater systems.

3. Results

The results can be studied under two parts: hydrology and hydraulics of open channel flow. Hydrological results include analysis of the precipitation, catchment area, equivalent runoff coefficient, maximum rainfall through the Gumbel and Log Pearson type III method, a statistical approach to choose maximum rainfall between these two methods, and finally calculating the runoff discharge through the Rational method. Then, the hydraulics of open channel flow is studied using HECRAS.

3.1. Hydrological Results X(max)

3.1.1. Maximum Daily Rainfall

Maximum daily rainfall data from 1973 to 2023 of Lamachaur station were obtained from DoHM, Pokhara. The maximum value of daily rainfall was observed in 1978 A.D with 331mm and the minimum value of 120mm was recorded in the years 2006 and 2019 A.D

The mean and standard deviation of this data is calculated and obtained as Mean ($\bar{X}$) = 186.264mm Standard deviation(σ_{n-1}) = 48.079 mm

3.1.2. Gumbel Method

With the data obtained, the Gumbel Method was used to forecast different intensities for respective return periods. A sample calculation is: For T = 50 years, Y_T = 2.056, Y_n = 0.549, S_n = 1.161, K = 1.298

X_T = 186.264 + 1.298 × 48.079 = 248.742mm

Similarly, calculations for various return periods were performed to obtain the return period vs. the maximum projected rainfall plot.

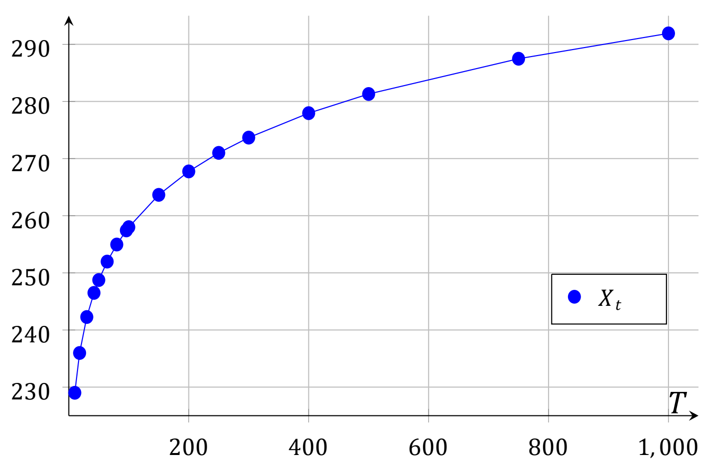

Fig. 4: Gumbel max rainfall vs Return Period

3.1.3. Log Pearson type III

The rainfall data was reduced to Y series (log base 10) and the mean and standard deviation and coefficient of skewness of this Y series were calculated and obtained

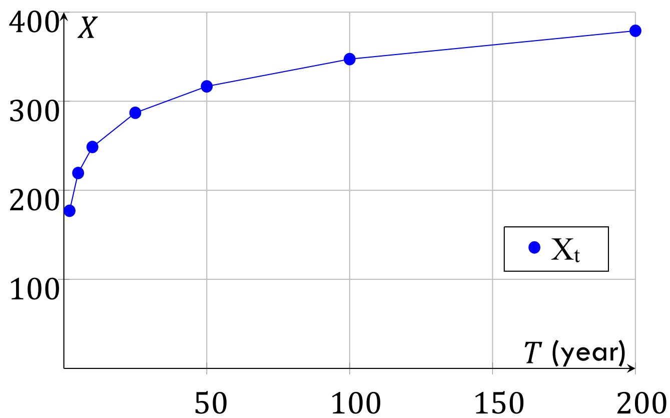

Fig. 5: Log Pearson III Rainfall vs Return Period

as: Mean (Y_m) = 2.257 mm, Standard deviation (σ) = 0.104, C_s = 0.544.
A sample calculation is shown as:
For return period of T = 50 years,
$Y_T = Y_m + K \cdot \sigma_{n-1}$.
K is a value obtained from the Log-Pearson table for the respective coefficient of skewness and return period. $K_{0.5}$ = 2.311, $K_{0.6}$ = 2.359, then by linear interpolation
$K_{0.544}$ = 2.332.
Y_{50} = 2.257 + 2.332 × 0.104 = 2.500,
X_{50} = *antilog* (2.500) = 316.666 mm. A plot of maximum rainfall vs return period was obtained from more similar calculations.

3.1.4. Gumbel vs Log Pearson III

The Log Pearson III Distribution and the Gumbel distribution are approaches to studying probability distributions that use random variables (Desvina, 2019). To better understand which data series should be used for further study, two tests are performed to confirm that one series has a better data set than the other.

- **Coefficient of variance:** Since the coefficient of variance of the Gumbel series is less than that of the Log Pearson Type III. The Gumbel series has more uniform data. It suggests using values from the Gumbel table for further calculations.

- **Chi-Square Method:** It is used to test the goodness of fit.

Degree of freedom = $n - 1 = 7 - 1 = 6$, and the level of significance (α) = 0.995.
From the Chi-square table, χ^2 = 12.592. Since the value of
χ^2 from Gumbel < χ^2 from Log Pearson Type III < 12.592, but the Gumbel test gave a smaller value than the Log Pearson Type III, we conclude that the Gumbel data fits more than the Log Pearson Type III data (Millington et al., 2011).

Table 1: Best fit analysis

Test	Gumbel	Log Pearson III
Coeff. Var (Cv)	0.143	0.254
Chi-Square (χ^2)	2.89	10.98

3.1.5. Peak Rainfall Intensity(mm/hr)

So, the rainfall intensity of the 50-year return period from the Gumbel table is taken for further calculations. i.e., 248.74 mm. The time of concentration is calculated for our catchment as:

$$T_C = 0.87\left(\frac{L^3}{H}\right)^{0.385} \quad t \text{ in hours}, L \text{ in kms}, H \text{ in meters}$$

L = 1.363 km, H = 43 m, T_c = 0.320 hours.

Similarly, $I(D, T_C) = \frac{R(24,T)}{24} \times \left(\frac{24}{T_C}\right)^{2/3}$

= 184.320 *mm/hr*

Here, an intensity of 184.32 mm/hr was obtained and now this intensity is further used to calculate runoff discharge to be carried out by drainage throughout the catchment.

3.1.6. Discharge Calculation along sub-catchments

The sub catchment division and area were obtained using Google Earth. The area was divided into urban pavement, Residential area, and cultivated land through visual inspection and using Google Earth. Interception loss and initial loss that does not contribute to runoff were considered 20% as this does not contribute to the runoff. The water-holding structures, ditches, ponds, etc., were taken into consideration. The coefficient of runoff for the dense forest was taken as 0.1, for cultivated land it was taken as 0.3 and for the Residential area, it was taken as 0.55 (Basnet & Neupane, 2018). Finally, the cumulative discharge was calculated as presented in the table. The equivalent runoff coefficient is also calculated.

Table 2: Equivalent Runoff

S. N.	Area (ha)	CA
1	23.1	2.768
2	16.8	6.174
3	53.9	28.012
4	20.4	9.909
5	13.5	6.819
6	12.2	5.917
7	6.56	3.739
Sum	146.46	63.338
Ceq	0.432	

The equivalent runoff coefficient of the overall catchment is found to be 0.432.

Table I: Discharge Calculation Along Subcatchment

S.C	Land Type	Area (%)	Area (ha)	C	Cum (Q-I)
SC1	Forest	90	20.763	0.1	0.850
	Cultivated	10	2.307	0.3	1.134
SC2	Pavement	5	0.840	0.9	1.444
	Residential	15	2.520	0.55	2.011
	Cultivated	80	13.440	0.3	3.663
SC3	Pavement	20	10.774	0.9	7.635
	Residential	40	21.548	0.55	12.489
	Cultivated	40	21.548	0.3	15.137
SC4	Pavement	10	2.043	0.9	15.890
	Residential	50	10.215	0.55	18.191
	Cultivated	40	8.172	0.3	19.195
SC5	Pavement	10	1.337	0.9	19.688
	Residential	60	8.022	0.55	21.495
	Cultivated	30	4.011	0.3	21.988
SC6	Pavement	10	1.220	0.9	22.438
	Residential	50	6.100	0.55	23.812
	Cultivated	40	4.880	0.3	24.412
SC7	Pavement	20	1.312	0.9	24.895
	Residential	60	3.936	0.55	25.782
	Cultivated	20	1.312	0.3	25.943

3.2. Hydraulic Results

3.2.1. Existing Drainage

The data needed for processing in HEC-RAS was collected and data input was done in software with manually applied corrections in the data to find the output of sufficient drainage size. HEC-RAS involves the software part of the project, which presents the drainage condition under different conditions of stormwater discharge. The following list of tables shows the data of cross-section along the Lamachaur road flow path of water at different station intervals with a steady flow for the existing drainage situation, with a discharge input of almost 26 cumecs as obtained from hydrological analysis. It is found that the existing drainage is insufficient for the proper management of the stormwater discharge during peak rainfall time. So, a study was done to find out the maximum carrying capacity of the existing drainage system. By running trials in HEC-RAS for different discharges, it was estimated that drainage systems could carry a 4.5 cumecs discharge of stormwater from adjacent catchments effectively.

3.2.2. Increment in Drainage Size

The current flood situation and the maximum capacity of the drainage network is illustrated above. One of the objectives of this project is to determine the optimum drainage size for stormwater management. So, considering all the economic, standard road regulation, and other factors, the drainage of a width of 1.5m from upstream to downstream was adopted, keeping the depth constant. After changing the cross-section of the roadside drain, the flow simulation was run in HEC-RAS, and no distinct change in flood over the roadway was observed.

4. Discussion

A few stations were compared and observed for flow depth with various discharges and geometric sizes. For a discharge of 26 cumecs, the flow was observed to fully inundate the roadway with depths ranging from a few centimeters to almost a meter along various stations upstream to downstream. It is evident that the drainage size is extremely insufficient to handle the discharge. On substantially reducing the discharge through a trial process, a discharge of 4.5 cumecs was observed to be accommodated by the drainage up to its full capacity, with a very small amount of flow on the roadway in a few sections. The maximum capacity of the existing drainage was determined to be 4.5 cumecs. After that, the size of the drainage was increased to 1.5m in width with a constant depth from upstream to downstream. This change in dimension was run for a discharge of 26 cumecs to check whether it could accommodate it or not and the result is that it is still insufficient and no drastic reduction in flood depth over the roadway was observed. Further increment in drainage size would result in reduced road width, which is not a feasible solution.

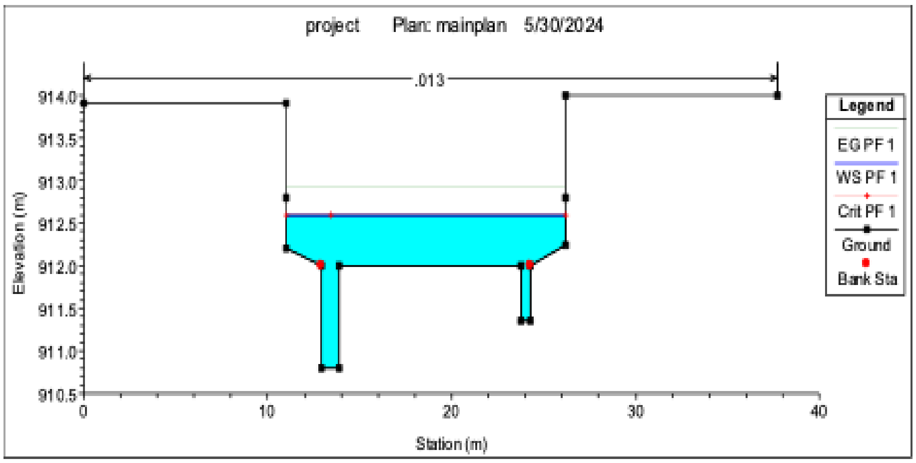

Fig. 6: Maximum Flow Condition

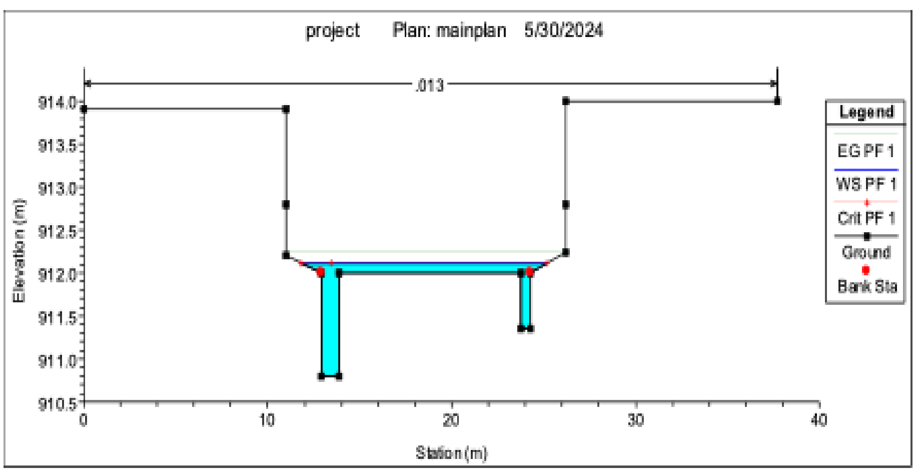

Fig. 7: Existing Flow Capacity

5. Conclusion

In conclusion, this study looked closely at the drainage problems along Lamachaur Road using detailed water flow models and simulations based on heavy rain expected for a 50-year return period. We found that the peak runoff hits about 26 cubic meters per second, but the current drains can only handle 4.5 cumecs, leaving a huge 82.7% gap that turns the road into a stream during monsoons. Interestingly, even if we tried making the drains much bigger in our tests with HEC-RAS software, it barely helped to reduce flooding, thanks to the limited space available, reminding us that increasing size is not always the smart fix. Instead, we need to turn to smart, eco-friendly, nature-based ideas like low-impact development techniques and redirecting water elsewhere to make these growing urban areas tougher against heavy rains.

6. Recommendation

Instead of altering drainage dimensions, the focus should be on removing excess runoff from various points within the catchment area. This can involve strategically implementing cross-drainage structures to divert runoff to designated outlets, such as the Seti River, thereby preventing the drainage system from being overwhelmed. LID techniques such as rain gardens, green roofs, and rain barrels are effective and sustainable methods to reduce runoff by allowing water to infiltrate into the ground or be captured and reused. These methods help to mimic natural hydrological processes, reducing the burden on traditional drainage infrastructure. Introducing permeable pavements in open spaces, such as parking lots, can significantly reduce runoff by allowing water to permeate through the surface and infiltrate into the ground below. This helps to mitigate stormwater runoff and reduces the strain on drainage systems during heavy rainfall events.

7. Acknowledgment

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