UNIVERSITY OF ENGINEERING & TECHNOLOGY, PESHAWAR

Department of Civil Engineering

CE 435L: Software Applications in Water Resources & Environmental Engineering (Lab)

Term Project Report - Spring Semester 2026

Flood-Risk Mapping of the Swat River Khwazakhela Gauging Station to Amandara Headworks Using HEC-RAS and RAS Mapper

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Prepared as a professional engineering project report based only on the supplied project document, screenshots, and computed HEC-RAS outputs.

Abstract

This report documents a complete 100-year flood-risk mapping exercise for the Swat River reach extending from the downstream side of Khwazakhela Gauging Station toward Amandara Headworks. The study integrates flood-frequency estimation, terrain-based model geometry development, one-dimensional steady-flow hydraulic simulation, and spatial interpretation of HEC-RAS results in RAS Mapper. The adopted design discharge for the 100-year event is 10,636.67 m3/s, obtained from the Log-Pearson Type III analysis of the supplied annual peak-flow series for 2005-2024.

The final model was prepared in SI units in HEC-RAS 7.0.1 and represents approximately 67.35 km of the Swat River using 34 terrain-derived cross sections. The downstream control is represented by a normal-depth boundary condition with a slope of 0.006414. The computed water-surface elevation for the Q100 profile ranges from 673.82 m at the downstream end to 1,106.64 m near the upstream end. Computed depths range from 1.93 m to 8.71 m, total velocities range from 2.10 m/s to 5.74 m/s, and the interpreted planning-level flood-risk extent is approximately 86.90 km2.

All figures used in this report are taken from the supplied project screenshots, HEC-RAS output windows, RAS Mapper views, and project-derived plots. No AI-generated imagery has been inserted. The Khwazakhela bridge location is discussed as a reference feature only because the dataset does not include the surveyed bridge deck, low chord, pier, abutment, roadway, and opening geometry required for reliable bridge hydraulics in HEC-RAS.

Abbreviations and Symbols

Table 1: Abbreviations and symbols used in the report

Term	Meaning
AEP	Annual exceedance probability
DEM	Digital Elevation Model
EPSG:32643	WGS 84 / UTM Zone 43N coordinate reference system
GEV	Generalized Extreme Value distribution
HEC-RAS	Hydrologic Engineering Center River Analysis System
LP3	Log-Pearson Type III distribution
Q100	Discharge associated with a 100-year return period
RAS Mapper	Geospatial mapping interface within HEC-RAS
SRTM	Shuttle Radar Topography Mission terrain data
WSE	Water-surface elevation

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1. Introduction

Flood-risk mapping converts a hydrologic design flood into engineering information about water levels, depths, velocities, and likely floodplain occupation. For a mountainous river such as the Swat River, these maps are important because high flows may rise rapidly, occupy active bars and overbank areas, and threaten settlements, roads, agricultural land, and hydraulic structures.

This project evaluates the Swat River reach beginning downstream of Khwazakhela Gauging Station and extending toward Amandara Headworks. The available dataset supports a one-dimensional steady-flow HEC-RAS approach. This modelling choice is appropriate for an academic Q100 flood profile where the available information includes annual peak discharges, terrain data, model geometry, and output screenshots, but does not include complete unsteady-flow hydrographs, time-varying boundary conditions, detailed bridge surveys, or calibration-stage records.

The report has been rewritten in a formal engineering-report format. It presents the hydrologic basis of the design flood, explains the hydraulic theory, documents each HEC-RAS modelling step using the supplied screenshots, and interprets the computed Q100 output in terms of water-surface elevation, depth, velocity, Froude number, and flood-risk extent.

2. Aim and Objectives

The aim of the project is to develop and document a planning-level Q100 flood-risk map for the selected Swat River reach using HEC-RAS and RAS Mapper.

- Estimate the 100-year design discharge from the supplied annual peak-flow record.
- Prepare a HEC-RAS model using appropriate project units, reach layout, terrain-derived cross sections, roughness coefficients, and boundary conditions.
- Run the Q100 steady-flow plan and verify successful model computation before interpreting the output.
- Extract and summarize water-surface elevation, hydraulic depth, total velocity, active top width, and Froude number from the computed HEC-RAS results.
- Use the project screenshots to provide a clear step-wise record of the modelling workflow.
- Identify uncertainty sources and recommend improvements required before using the model for final engineering design.

Table 2: Project requirements and report response

Requirement	Professional response in revised report

Q100 flood estimation	The 100-year discharge is adopted as 10,636.67 m3/s from the selected LP3 analysis.
HEC-RAS model setup	The report documents project creation, geometry, flow data, plan setup, computation, and result review.
Reach representation	The 67.35 km Khwazakhela-to-Amandara reach is represented with 34 terrain-derived cross sections.
Screenshots and figures	All original project screenshots are retained and assigned revised professional captions.
Bridge discussion	The bridge is treated only as a reference location because detailed surveyed bridge geometry was not supplied.
Professional formatting	The document uses Times New Roman formatting, structured headings, formal captions, tables, and front matter.

3. Study Area Description

The study reach is located along the Swat River in Khyber Pakhtunkhwa, Pakistan. The upstream portion of the model begins near Khwazakhela Gauging Station, while the downstream model end is located toward Amandara Headworks. The reach was represented in WGS 84 / UTM Zone 43N so that stationing, cross-section width, terrain elevation, and mapped outputs are handled consistently in metric units.

The modelled river length is approximately 67.35 km. The Swat River in this corridor is influenced by steep valley slopes, active sediment movement, floodplain encroachment, and localized constrictions. In such settings, flood-risk mapping is useful for understanding whether high flows remain confined to the main channel or spread into wider overbank areas.

A bridge near Khwazakhela is acknowledged as a reference feature in the analysis. However, it is not inserted as a hydraulic structure because a valid bridge model requires surveyed deck levels, low-chord profile, pier dimensions, abutment geometry, roadway embankment, opening details, and contraction/expansion reach lengths. Without these inputs, modelling the bridge as a structure would introduce unsupported assumptions into the water-surface profile.

4. Theoretical Background

4.1 Flood-Risk Mapping Concept

Flood-risk mapping combines hydrologic estimation, hydraulic computation, and spatial interpretation. Hydrology supplies the design discharge, hydraulics estimates how that flow moves through the channel and floodplain, and mapping presents the computed results in a form that can be interpreted for planning and risk communication. A flood-risk map should not be read only as a wet-or-dry boundary; depth, velocity, Froude number, and the location of hydraulic controls are also important indicators of hazard severity.

4.2 Return Period and Design Flood

A Q100 flood is the discharge associated with a 100-year return period. This does not mean that the event occurs exactly once every century. It means that, under the assumptions of the frequency model, the annual exceedance probability is approximately 1 percent. The relationship can be written as $AEP = 1/T$, where T is the return period in years. Therefore, for $T = 100$ years, $AEP = 0.01$, or 1 percent in any given year.

Because the annual peak-flow record used in this project covers 2005-2024, the Q100 discharge is an extrapolated estimate. A short record can still support an academic frequency analysis, but uncertainty is higher than it would be for a longer, calibrated record. The adopted discharge must therefore be interpreted as a design input for the present model rather than an absolute prediction of future flooding.

4.3 Flood-Frequency Analysis

Flood-frequency analysis uses an annual maximum series to estimate discharges associated with selected return periods. The procedure generally includes organizing annual peak flows, fitting candidate statistical distributions, comparing model behavior, rejecting unrealistic extrapolations, and selecting a discharge value for hydraulic simulation. In this project, Gumbel, Log-Pearson Type III, lognormal, and GEV alternatives were assessed.

The Log-Pearson Type III method applies a Pearson Type III distribution to logarithms of the annual flood peaks. It is suitable for skewed flood records because the logarithmic transformation reduces the influence of large events while retaining the statistical behavior of extreme flows. The quantile is commonly expressed in the form $\log(QT) = \text{mean}[\log(Q)] + KT*SlogQ$, where KT is the frequency factor for the selected return period and skewness condition.

4.4 One-Dimensional Steady-Flow Hydraulic Theory

A one-dimensional steady-flow HEC-RAS model calculates the water-surface profile along a river reach for specified discharge values. The river is represented by a sequence of cross sections, and HEC-RAS solves the energy equation between adjacent sections using the standard-step method. The energy balance includes bed elevation, flow depth, velocity head, friction losses, and contraction or expansion losses.

The general energy equation between two cross sections may be written as $Z_1 + Y_1 + a_1(V_1^2/2g) = Z_2 + Y_2 + a_2(V_2^2/2g) + h_e$, where Z is channel invert elevation, Y is flow depth, V is mean velocity, g is gravitational acceleration, a is the velocity-head coefficient, and h_e is the energy loss between sections. This equation provides the theoretical basis for computed water-surface elevations in a 1-D hydraulic model.

Velocity and flow resistance are linked through conveyance and Manning roughness. Manning resistance represents the effect of bed material, channel irregularity, vegetation, floodplain roughness, and alignment. The relationship may be written as $Q = (1/n) A R^{2/3} S^{1/2}$, where Q is discharge, n is Manning roughness, A is wetted area, R is hydraulic radius, and S is the energy slope.

4.5 Roughness, Cross Sections, and Boundary Conditions

Cross-section geometry controls how flow area, wetted perimeter, top width, and hydraulic radius vary with water level. Wide overbank sections may produce larger top widths and lower velocities, while narrow constrictions may cause higher velocities and larger local energy losses. Correct cross-section orientation, bank station placement, and terrain accuracy are therefore essential for a defensible profile.

Boundary conditions are required at model limits. In a subcritical steady-flow analysis, the downstream boundary strongly affects the computed upstream profile. In this project, the downstream condition is represented by normal depth using a slope of 0.006414. This boundary assumes that the energy grade line near the downstream end is approximately parallel to the channel bed slope.

4.6 RAS Mapper and Flood-Inundation Interpretation

RAS Mapper links computed hydraulic output to the terrain and spatial project layers. In a one-dimensional model, the water surface is computed at cross sections, and the map is interpreted by comparing water levels and water-surface station limits with the terrain. Because the model is one-dimensional and terrain-derived, the mapped extent should be treated as a planning-level estimate rather than a final regulatory flood boundary.

5. Project Data and Model Inputs

The revised report is based on the supplied project document and the project outputs already embedded within it. The screenshots and plots are preserved from the original report, while the captions, wording, headings, and report organization have been rewritten for professional presentation. No artificial or AI-generated figure has been introduced.

Table 3: Input data used for hydrologic and hydraulic analysis

Data item	Source / item used	Purpose in the project
Project brief	Term project instruction and supplied report content	Defined project location, Q100 objective, and required HEC-RAS/RAS Mapper workflow.
Annual peak-flow record	Supplied 2005-2024 maximum annual discharge series	Used to estimate the 100-year design flood.
Terrain	SRTM terrain tiles and derived model terrain	Provided elevation basis for cross-section extraction and mapping.
River alignment	Swat River reach alignment used in the HEC-RAS geometry	Established flow direction and cross-section placement.
Cross sections	34 terrain-derived sections over a 67.35 km reach	Represented channel and floodplain geometry in the 1-D model.
HEC-RAS results	Output tables, profile plots, mapper layers, and model screenshots	Provided the hydraulic values and figures used in the report.

6. Hydrologic Analysis and Q100 Adoption

The hydrologic analysis used the annual maximum discharge series for 2005-2024. Candidate probability distributions were fitted to the available peak-flow record. The results show that the Gumbel and lognormal distributions produced lower Q100 estimates, while the GEV fit produced an unrealistically high extrapolated discharge for the available record length. For this reason, the Log-Pearson Type III result was selected as the adopted design discharge for the hydraulic model.

Table 4: Flood-frequency alternatives evaluated for Q100 selection

Frequency model	Evaluation note	Q100 discharge (m3/s)
Gumbel method of moments	Reasonable but lower estimate; KS p = 0.133	6,523.32
Log-Pearson Type III	Adopted model; AIC = 327.36	10,636.67
Lognormal MLE	Alternative low estimate; AIC = 328.25	6,348.32
GEV MLE	Rejected because the short-record extrapolation was unstable	2,819,073.21

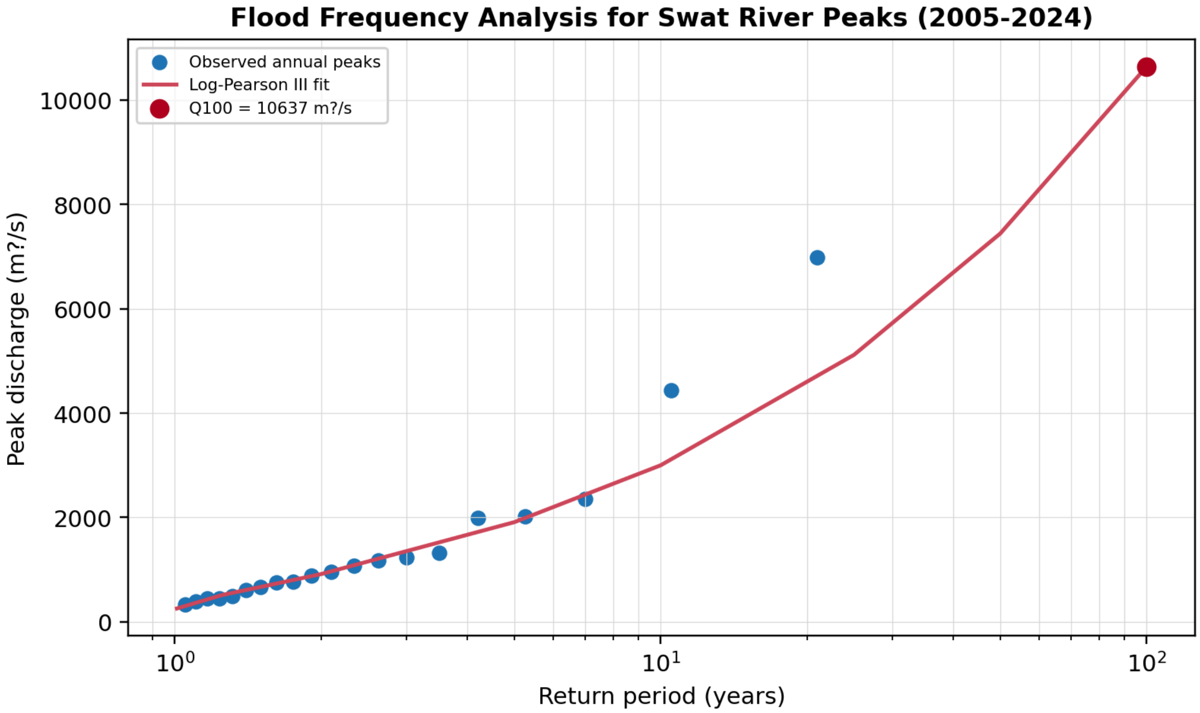


Figure 1: Adopted hydrologic frequency-analysis output showing the Log-Pearson Type III 100-year discharge.

The adopted 100-year discharge is Q100 = 10,636.67 m3/s. This value is entered as the steady upstream inflow in the hydraulic model. Because the model does not include lateral inflow changes or diversions, the same total discharge is carried through the computed output tables.

7. Step-Wise HEC-RAS Modelling Procedure

The HEC-RAS model was prepared in a sequential manner so that each modelling action could be checked before moving to the next stage. The following steps describe the modelling workflow and are supported by the original project screenshots.

Table 5: Adopted HEC-RAS model configuration for the Q100 simulation

Model parameter	Adopted value / description
HEC-RAS version	HEC-RAS 7.0.1
Project title	Swat River Khwazakhela to Amandara
River and reach	Swat River / Khwazakhela-Amandara reach
Modelled reach length	67.35 km
Cross sections	34 terrain-derived cross sections with 101 elevation points per section
Manning roughness	0.035 in the main channel and 0.060 in overbank areas
Loss coefficients	Contraction coefficient = 0.1; expansion coefficient = 0.3
Steady-flow profile	Q100 = 10,636.67 m3/s
Downstream boundary	Normal depth with slope = 0.006414

Projection	EPSG:32643, WGS 84 / UTM Zone 43N

7.1 Step 1 - Project Creation and Unit Setup

A new HEC-RAS project was created for the Swat River reach. The project title, working directory, and SI unit system were confirmed before geometry and flow data were entered. This step is important because all later model files are linked to the project directory and unit settings.

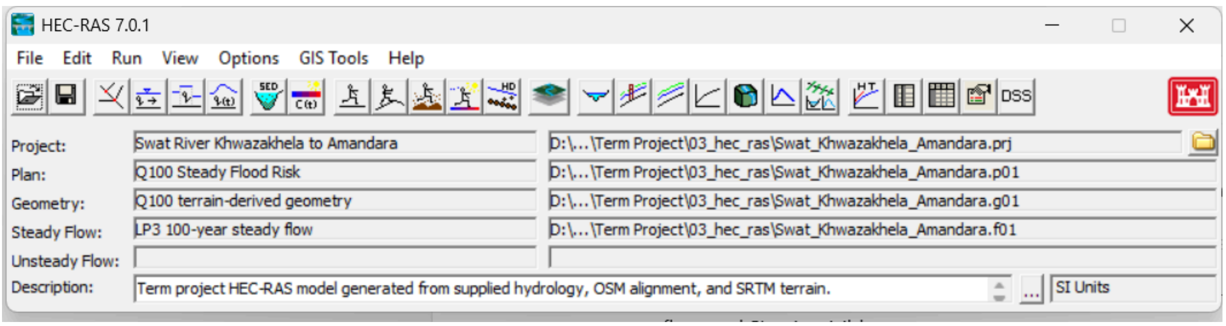


Figure 2: HEC-RAS project environment after creating the Swat River Khwazakhela-to-Amandara project.

7.2 Step 2 - Reach Layout and Geometry Preparation

The river reach was represented in the geometry editor using the selected Khwazakhela-to-Amandara alignment. Terrain-derived cross sections were placed across the river corridor to convert the spatial river system into the one-dimensional framework required by HEC-RAS.

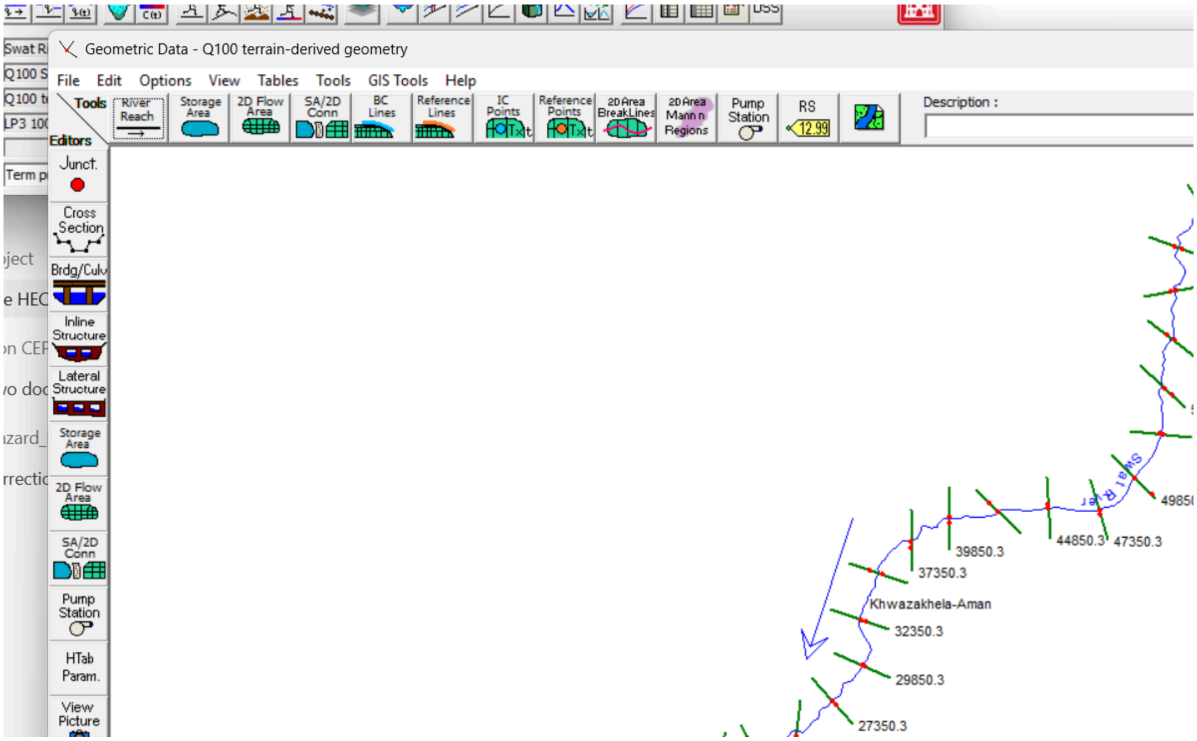


Figure 3: Geometry data editor showing the river reach and terrain-derived cross-section layout.

7.3 Step 3 - Cross-Section Review and Bank-Station Checking

Representative cross-section station-elevation data were checked after geometry generation. Bank stations were reviewed so that the channel and overbank areas were correctly identified. Proper bank-station placement is necessary because HEC-RAS uses these locations to divide the cross section into left overbank, main channel, and right overbank conveyance zones.

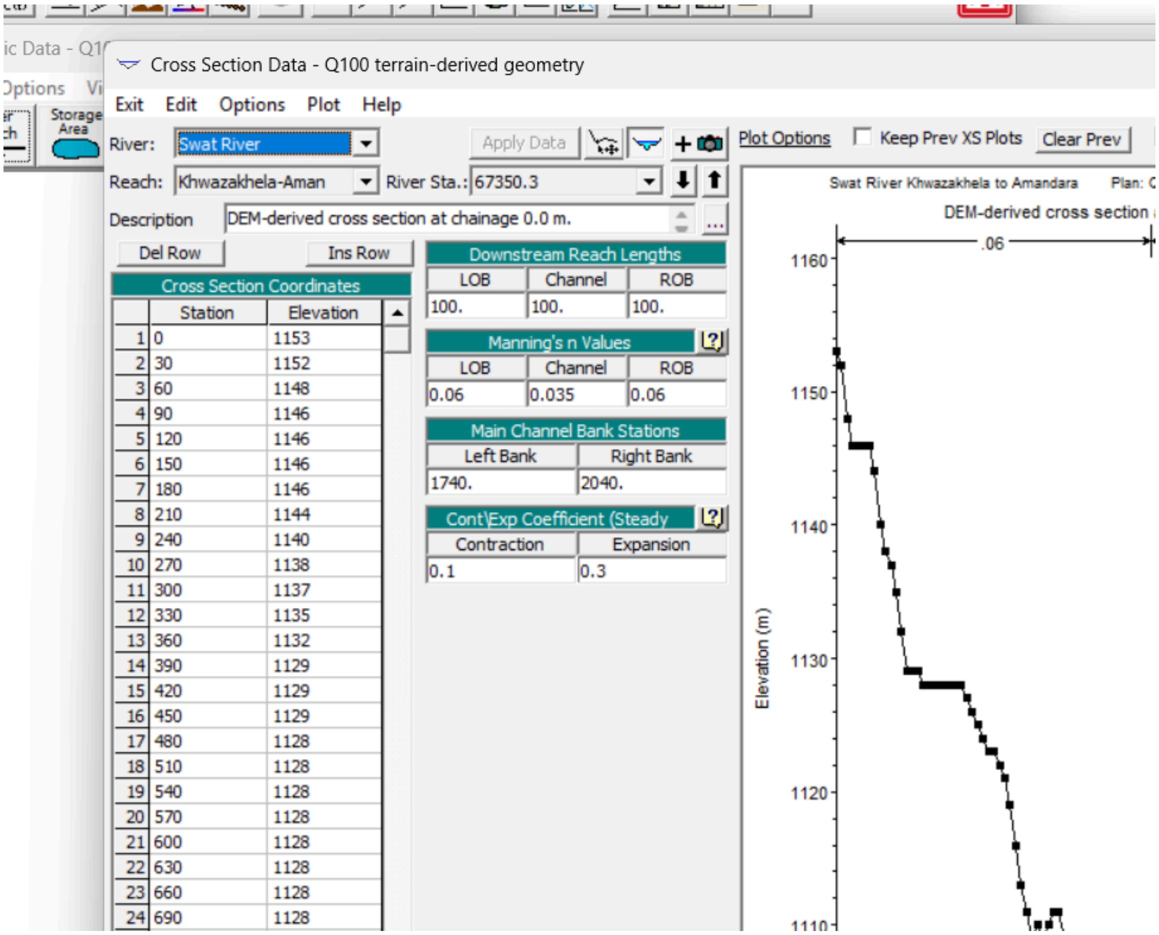


Figure 4: Representative cross-section station-elevation table reviewed during geometry checking.

7.4 Step 4 - Steady-Flow Data Entry

The adopted Q100 discharge was entered in the steady-flow editor as a single design profile. Since the model is steady and no additional tributary inflow data were provided, the discharge remains constant along the reach.

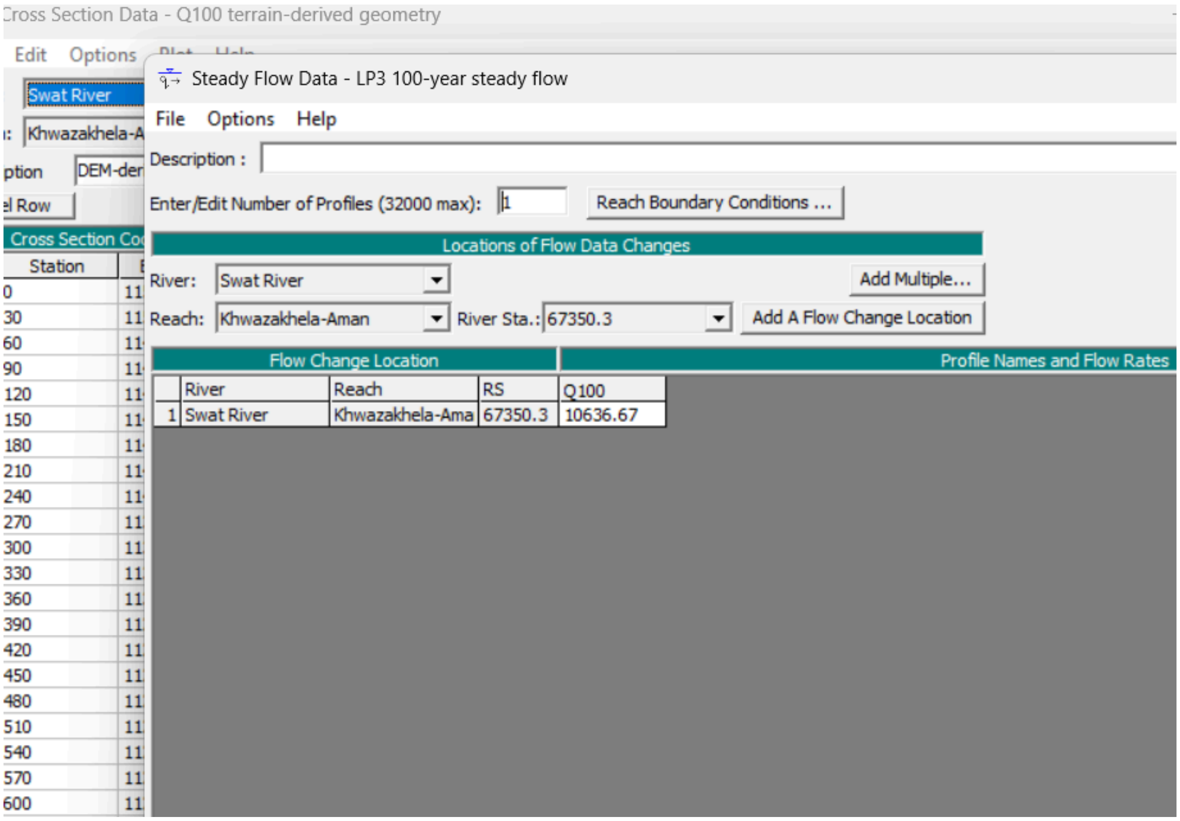


Figure 5: Steady-flow editor showing the single Q100 design profile entered for hydraulic computation.

7.5 Step 5 - Plan Definition and Boundary Condition Assignment

A steady-flow plan was created for the Q100 computation. The plan identifies the geometry file, steady-flow file, flow regime, and boundary condition. The downstream normal-depth slope of 0.006414 was applied to provide the hydraulic control required for the backwater calculation.

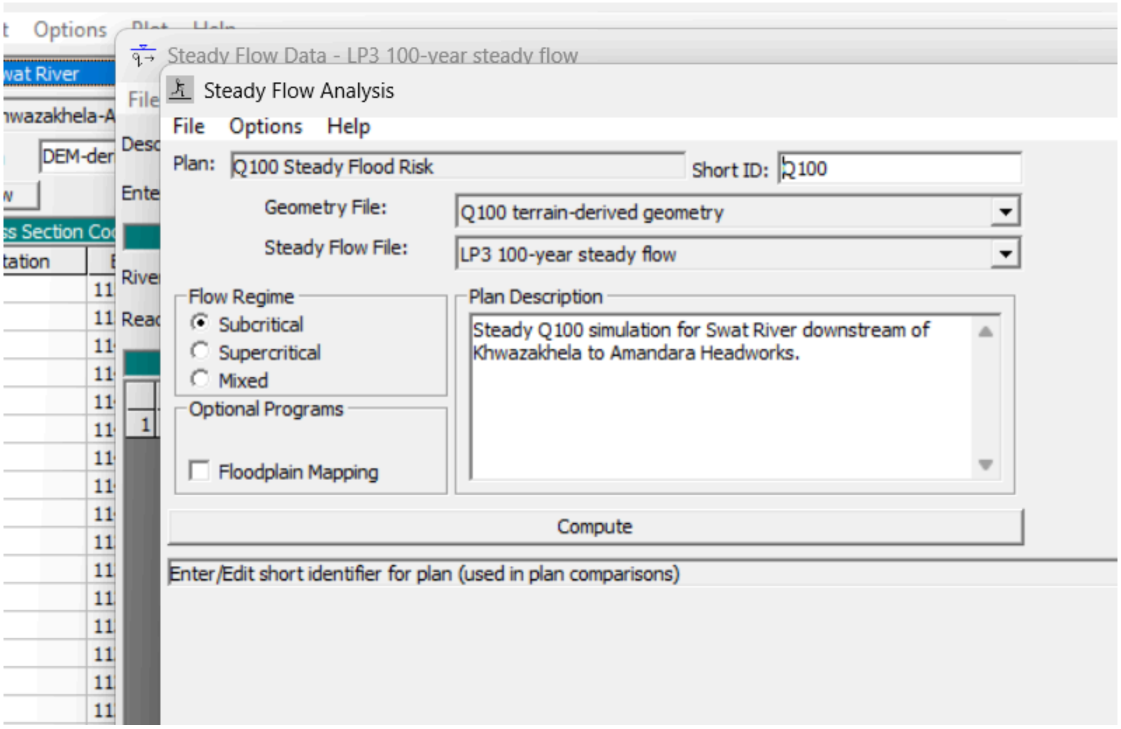


Figure 6: Steady-flow analysis window showing plan selection, flow regime, and compute settings.

7.6 Step 6 - Simulation Execution and Message Review

After saving the geometry, flow, and plan data, the steady-flow computation was executed. The computation messages were reviewed to confirm that the plan completed successfully. Hydraulic output should only be interpreted after the model has finished without fatal errors.

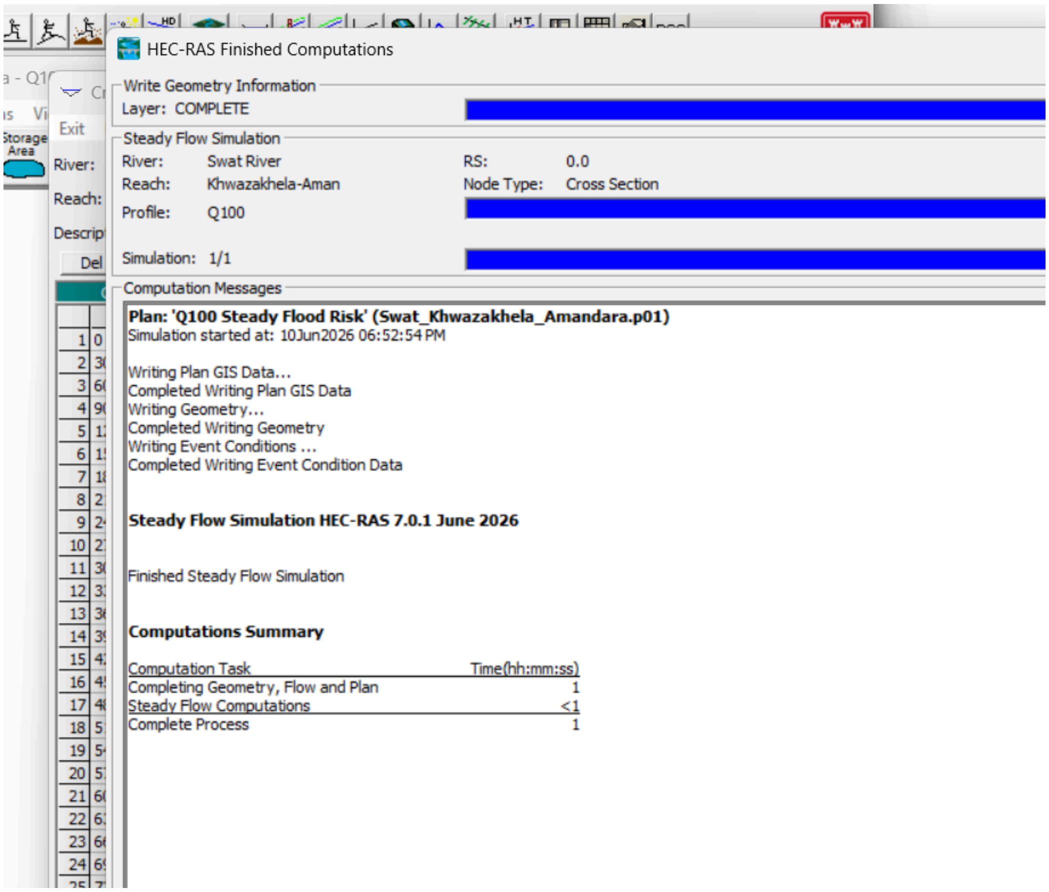


Figure 7: Computation message window confirming successful execution of the Q100 steady-flow plan.

7.7 Step 7 - Output Viewing and Map Preparation

The computed results were inspected using profile plots, cross-section plots, profile output tables, and RAS Mapper layers. These views provide both numerical and visual checks of the Q100 water surface, hydraulic response, and mapped flood-risk boundary.

8. Model Computation and Output Processing

The final plan was computed as a one-dimensional steady-flow simulation. HEC-RAS generated output files and provided profile, cross-section, and tabular results. The output was then processed to summarize the hydraulic variables required for report interpretation.

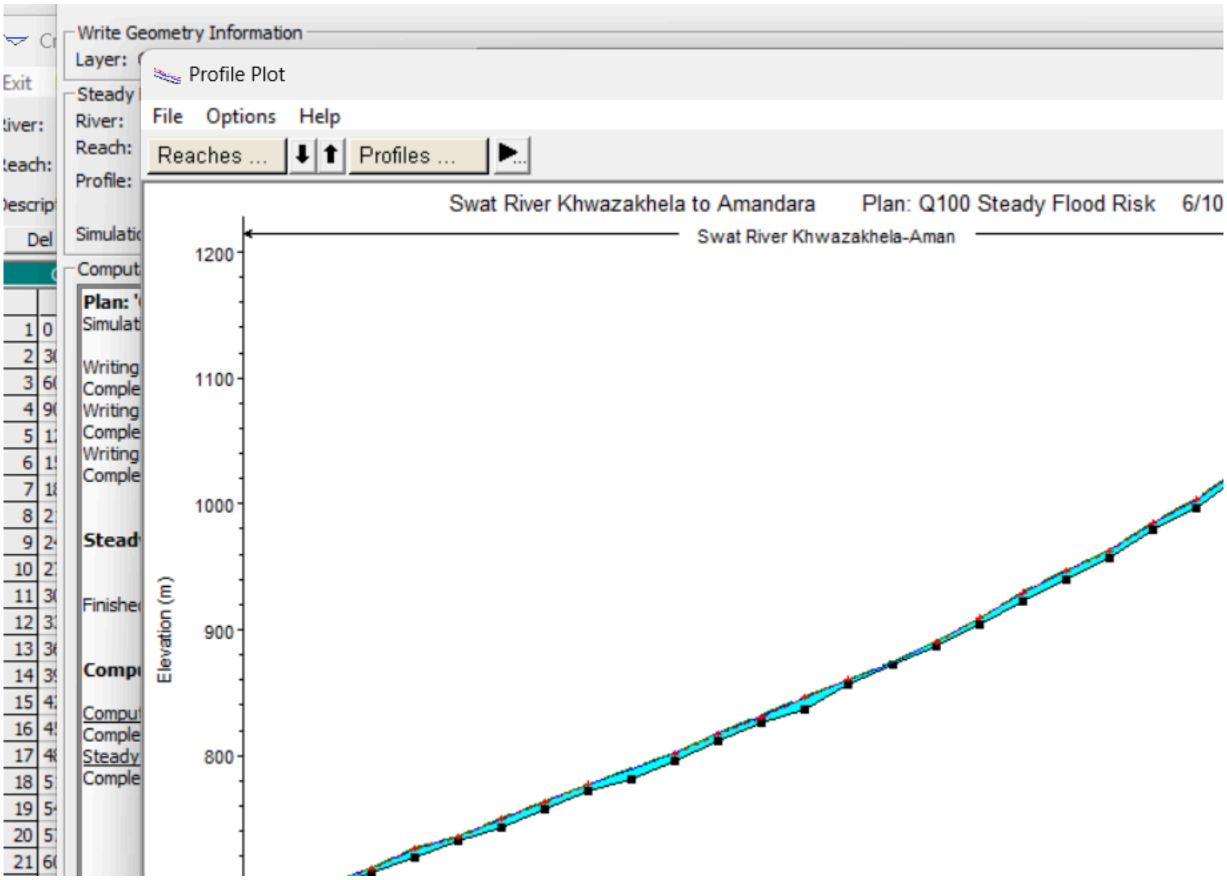
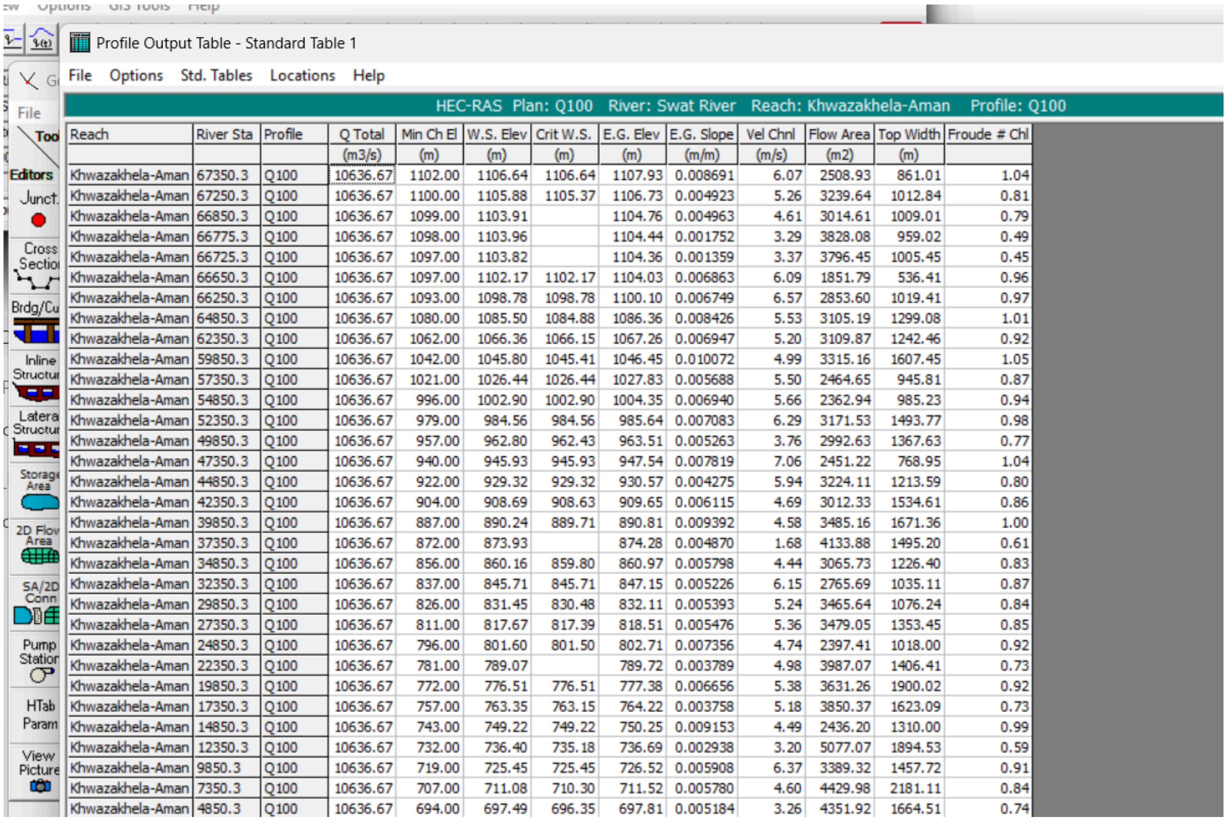


Figure 8: Computed Q100 water-surface profile displayed in the HEC-RAS profile plot window.

The profile output table was used to extract water-surface elevation, energy-grade elevation, flow depth, velocity, top width, energy slope, Froude number, and water-surface station limits. These values form the basis of the result tables included in the next section.



Profile Output Table - Standard Table 1

File Options Std. Tables Locations Help

HEC-RAS Plan: Q100 River: Swat River Reach: Khwazakhela-Aman Profile: Q100

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(m3/s)	(m)	(m)	(m)	(m)	(m/m)	(m/s)	(m2)	(m)	
Khwazakhela-Aman	67350.3	Q100	10636.67	1102.00	1106.64	1106.64	1107.93	0.008691	6.07	2508.93	861.01	1.04
Khwazakhela-Aman	67250.3	Q100	10636.67	1100.00	1105.88	1105.37	1106.73	0.004923	5.26	3239.64	1012.84	0.81
Khwazakhela-Aman	66850.3	Q100	10636.67	1099.00	1103.91		1104.76	0.004963	4.61	3014.61	1009.01	0.79
Khwazakhela-Aman	66775.3	Q100	10636.67	1098.00	1103.96		1104.44	0.001752	3.29	3828.08	959.02	0.49
Khwazakhela-Aman	66725.3	Q100	10636.67	1097.00	1103.82		1104.36	0.001359	3.37	3796.45	1005.45	0.45
Khwazakhela-Aman	66650.3	Q100	10636.67	1097.00	1102.17	1102.17	1104.03	0.006863	6.09	1851.79	536.41	0.96
Khwazakhela-Aman	66250.3	Q100	10636.67	1093.00	1098.78	1098.78	1100.10	0.006749	6.57	2853.60	1019.41	0.97
Khwazakhela-Aman	64850.3	Q100	10636.67	1080.00	1085.50	1084.88	1086.36	0.008426	5.53	3105.19	1299.08	1.01
Khwazakhela-Aman	62350.3	Q100	10636.67	1062.00	1066.36	1066.15	1067.26	0.006947	5.20	3109.87	1242.46	0.92
Khwazakhela-Aman	59850.3	Q100	10636.67	1042.00	1045.80	1045.41	1046.45	0.010072	4.99	3315.16	1607.45	1.05
Khwazakhela-Aman	57350.3	Q100	10636.67	1021.00	1026.44	1026.44	1027.83	0.005688	5.50	2464.65	945.81	0.87
Khwazakhela-Aman	54850.3	Q100	10636.67	996.00	1002.90	1002.90	1004.35	0.006940	5.66	2362.94	985.23	0.94
Khwazakhela-Aman	52350.3	Q100	10636.67	979.00	984.56	984.56	985.64	0.007083	6.29	3171.53	1493.77	0.98
Khwazakhela-Aman	49850.3	Q100	10636.67	957.00	962.80	962.43	963.51	0.005263	3.76	2992.63	1367.63	0.77
Khwazakhela-Aman	47350.3	Q100	10636.67	940.00	945.93	945.93	947.54	0.007819	7.06	2451.22	768.95	1.04
Khwazakhela-Aman	44850.3	Q100	10636.67	922.00	929.32	929.32	930.57	0.004275	5.94	3224.11	1213.59	0.80
Khwazakhela-Aman	42350.3	Q100	10636.67	904.00	908.69	908.63	909.65	0.006115	4.69	3012.33	1534.61	0.86
Khwazakhela-Aman	39850.3	Q100	10636.67	887.00	890.24	889.71	890.81	0.009392	4.58	3485.16	1671.36	1.00
Khwazakhela-Aman	37350.3	Q100	10636.67	872.00	873.93		874.28	0.004870	1.68	4133.88	1495.20	0.61
Khwazakhela-Aman	34850.3	Q100	10636.67	856.00	860.16	859.80	860.97	0.005798	4.44	3065.73	1226.40	0.83
Khwazakhela-Aman	32350.3	Q100	10636.67	837.00	845.71	845.71	847.15	0.005226	6.15	2765.69	1035.11	0.87
Khwazakhela-Aman	29850.3	Q100	10636.67	826.00	831.45	830.48	832.11	0.005393	5.24	3465.64	1076.24	0.84
Khwazakhela-Aman	27350.3	Q100	10636.67	811.00	817.67	817.39	818.51	0.005476	5.36	3479.05	1353.45	0.85
Khwazakhela-Aman	24850.3	Q100	10636.67	796.00	801.60	801.50	802.71	0.007356	4.74	2397.41	1018.00	0.92
Khwazakhela-Aman	22350.3	Q100	10636.67	781.00	789.07		789.72	0.003789	4.98	3987.07	1406.41	0.73
Khwazakhela-Aman	19850.3	Q100	10636.67	772.00	776.51	776.51	777.38	0.006656	5.38	3631.26	1900.02	0.92
Khwazakhela-Aman	17350.3	Q100	10636.67	757.00	763.35	763.15	764.22	0.003758	5.18	3850.37	1623.09	0.73
Khwazakhela-Aman	14850.3	Q100	10636.67	743.00	749.22	749.22	750.25	0.009153	4.49	2436.20	1310.00	0.99
Khwazakhela-Aman	12350.3	Q100	10636.67	732.00	736.40	735.18	736.69	0.002938	3.20	5077.07	1894.53	0.59
Khwazakhela-Aman	9850.3	Q100	10636.67	719.00	725.45	725.45	726.52	0.005908	6.37	3389.32	1457.72	0.91
Khwazakhela-Aman	7350.3	Q100	10636.67	707.00	711.08	710.30	711.52	0.005780	4.60	4429.98	2181.11	0.84
Khwazakhela-Aman	4850.3	Q100	10636.67	694.00	697.49	696.35	697.81	0.005184	3.26	4351.92	1664.51	0.74

Figure 9: Profile output table used to extract hydraulic variables for the selected river stations.

Cross-section output plots provided a visual check of the computed water surface relative to the terrain section. This helps identify unusual hydraulic behavior, abrupt changes in top width, or sections where the water surface approaches critical conditions.

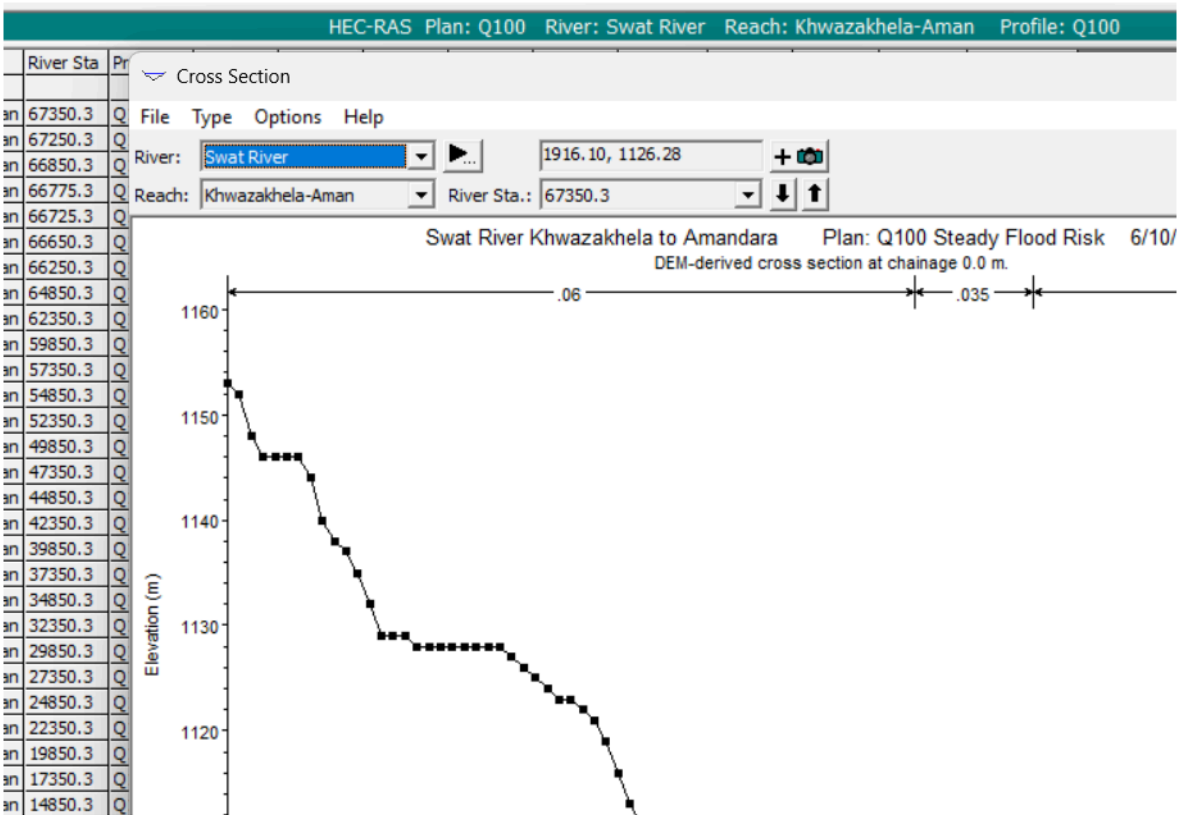


Figure 10: Representative cross-section output plot showing the computed Q100 water surface over terrain.

RAS Mapper was used to display the model geometry and output layers spatially. This view confirms that terrain, river alignment, cross sections, results, and map layers are organized correctly within the HEC-RAS project.

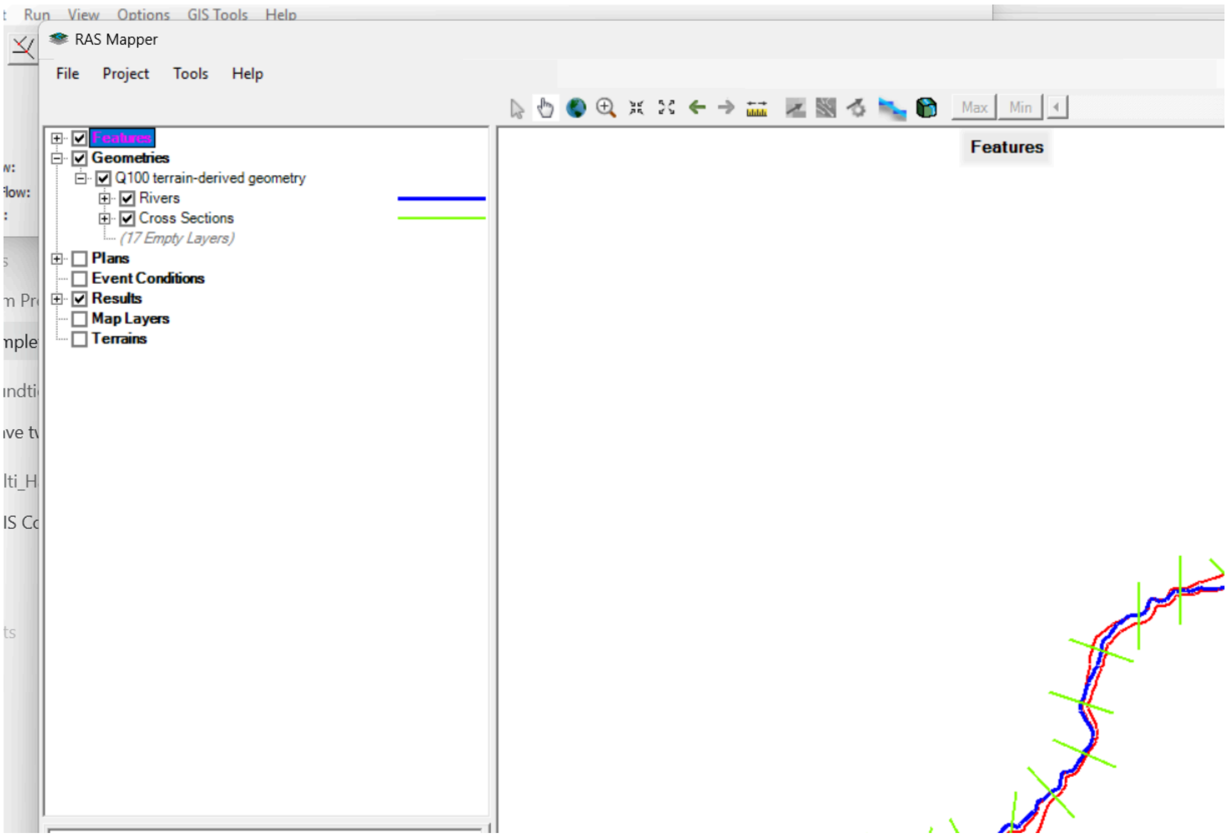


Figure 11: RAS Mapper interface displaying project geometry, terrain, results, and output map layers.

9. Results and Interpretation

9.1 Overall Hydraulic Response

The computed Q100 profile shows a continuous water surface along the modelled reach. The total discharge remains 10,636.67 m3/s in the output because the model is a steady single-profile simulation without lateral inflows or diversions. Water-surface elevation decreases downstream in response to the river-bed gradient, while local depth and velocity vary according to cross-section shape and floodplain width.

Table 6: Overall hydraulic output range for the Q100 profile

Hydraulic variable	Minimum	Maximum
Total discharge, Q (m3/s)	10,636.67	10,636.67
Water-surface elevation, WSE (m)	673.82	1,106.64
Computed hydraulic depth (m)	1.93	8.71
Total velocity (m/s)	2.10	5.74
Active top width (m)	536.41	2,181.11
Froude number at cross section	0.47	1.10
Derived flood-risk extent (km2)	86.90	86.90

9.2 Selected Cross-Section Results

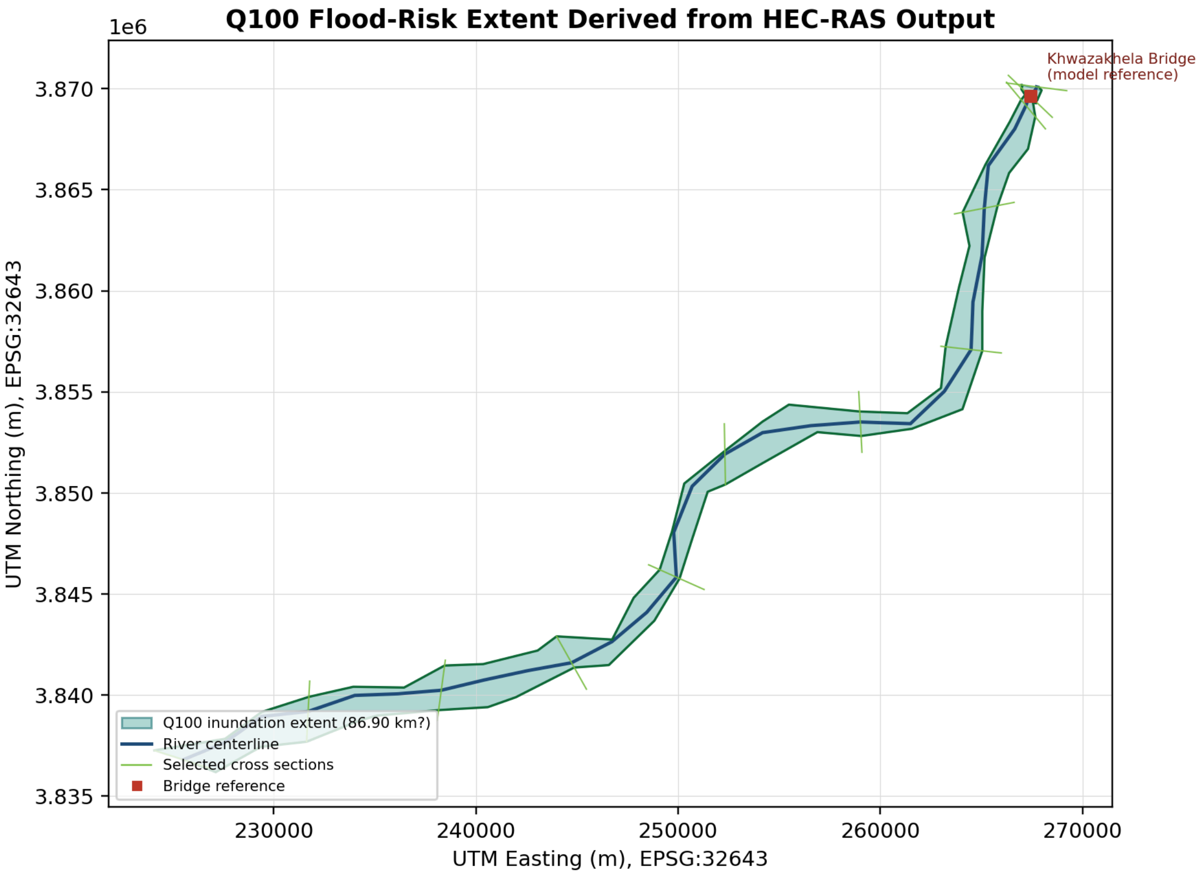
Selected cross-section results are presented to show hydraulic variation along the reach. The upstream and downstream sections represent model limits, while the bridge vicinity, maximum-depth location, and maximum-velocity location highlight important local model behavior. The bridge-vicinity row should be read as a nearby channel result, not as a formal bridge hydraulic computation.

Table 7: Selected cross-section results from the computed Q100 profile

Location	River station (m)	WSE (m)	Depth (m)	Velocity (m/s)	Froude	Top width (m)
Upstream reach	67,350.3	1,106.64	4.64	4.24	0.94	861.01
Bridge vicinity	66,775.3	1,103.96	5.96	2.78	0.49	959.02
Maximum-depth section	32,350.3	845.71	8.71	3.85	1.04	1,035.11
Maximum-velocity section	66,650.3	1,102.17	5.17	5.74	1.04	536.41
Downstream reach	0.0	673.82	3.82	3.22	0.65	1,156.89

9.3 Flood-Risk Extent and Longitudinal Trends

The interpreted Q100 flood-risk extent is approximately 86.90 km2. This boundary is derived from the HEC-RAS output and should be considered a planning-level representation because the model is one-dimensional and relies on terrain-derived geometry. The mapped result is still useful for academic flood-risk screening and for identifying areas where more detailed survey and modelling may be required.



Source: HEC-RAS 7.0.1 Q100 profile output; flood boundary from Sta W.S. Lft/Rgt at modeled cross sections.

Figure 12: Planning-level Q100 flood-risk boundary derived from the computed HEC-RAS output.

The longitudinal profile confirms a consistent downstream reduction in bed elevation and water-surface elevation. Local changes in depth and velocity depend on cross-section width, channel slope, and resistance rather than discharge alone.

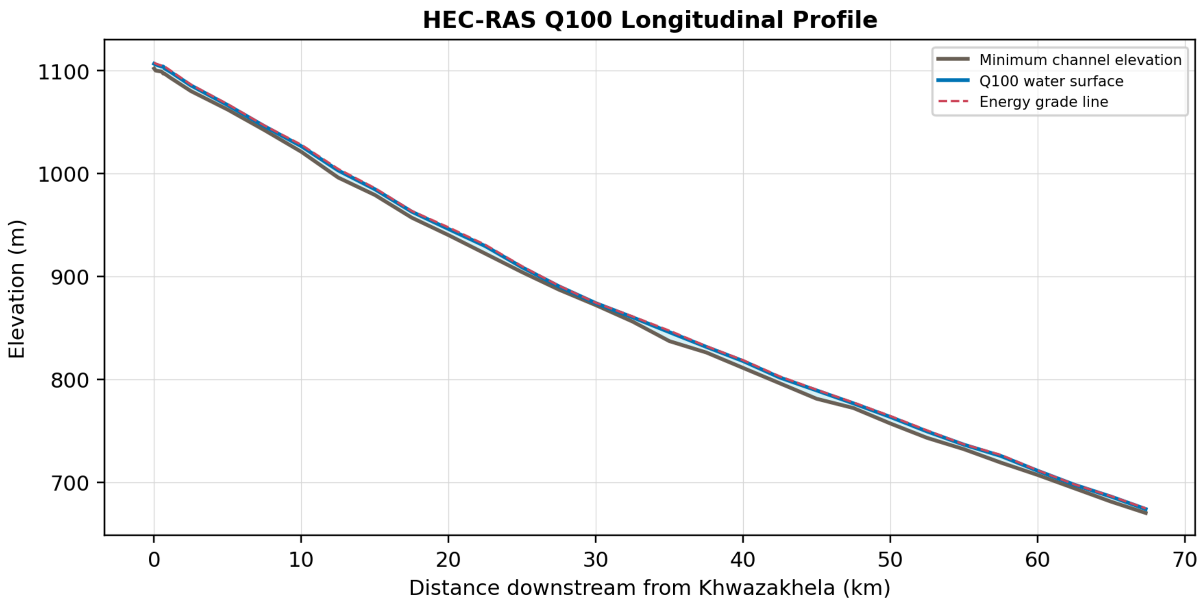


Figure 13: Longitudinal variation of bed elevation and computed Q100 water-surface elevation.

The hydraulic summary plot shows how depth, velocity, and Froude number change along the model. Sections with Froude number approaching or slightly exceeding 1.0 should be interpreted carefully because they may be sensitive to cross-section geometry, roughness values, and local bed-slope representation.

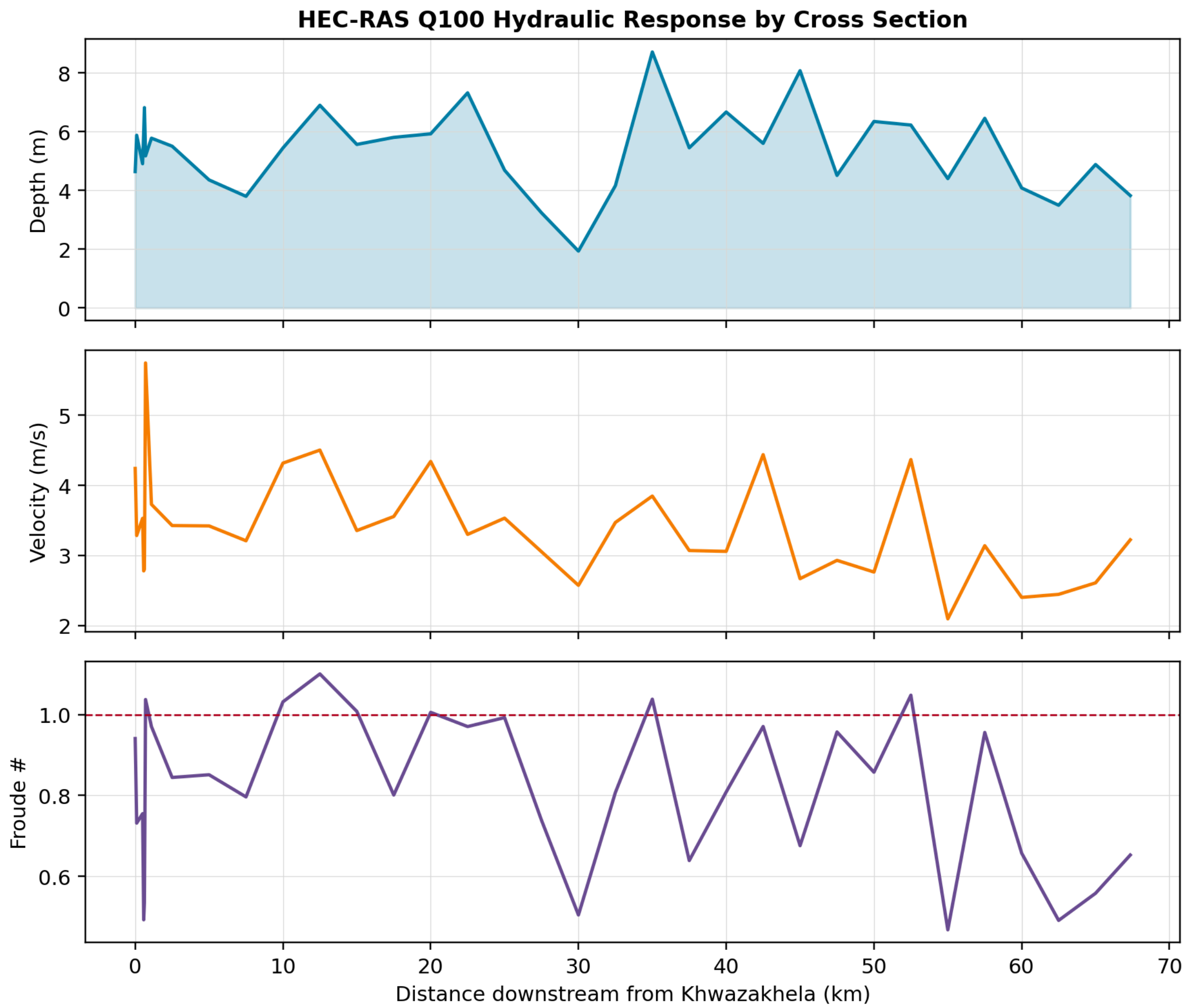


Figure 14: Summary plot of computed depth, velocity, and Froude-number response along the model reach.

10. Discussion

10.1 Reliability of the Computed Flood Profile

The model completed the Q100 steady-flow computation and produced internally consistent results. The constant total discharge confirms that the model is operating as a single-profile steady-flow simulation. The range of computed water-surface elevation, depth, velocity, and active top width indicates that the Q100 event would occupy a broad corridor in several portions of the reach.

The Froude number ranges from 0.47 to 1.10. Most of the model behaves as subcritical flow, but some sections approach critical conditions. These locations require caution because minor changes in terrain, bank stations, roughness, or boundary slope may affect the computed profile.

10.2 Bridge Representation

The bridge near Khwazakhela was not modelled as a hydraulic structure. This is an appropriate modelling decision for the available dataset because formal bridge hydraulics require surveyed deck levels, low-chord profile, pier and abutment geometry, roadway embankment profile, ineffective-flow limits, and approach/exit cross sections. Adding a bridge without these data would create artificial losses and could distort the computed water surface.

10.3 Main Uncertainties

The main sources of uncertainty are the limited length of the annual peak-flow record, use of SRTM-based terrain, absence of surveyed channel cross sections, approximate roughness assignment, cross-section spacing, and lack of calibration against measured water levels. These limitations do not prevent the report from demonstrating the required workflow, but they do restrict the use of the output for final design or legal flood zoning.

Table 8: Main modelling limitations and recommended improvements

Limitation	Effect on results	Recommended improvement
Short peak-flow record	Increases uncertainty in extrapolated Q100 discharge.	Extend the record or apply regional flood-frequency analysis.
Terrain-derived geometry	May miss small levees, embankments, and channel details.	Use surveyed sections, UAV photogrammetry, or lidar where possible.
Approximate Manning roughness	Affects depth, velocity, and water-surface elevation.	Calibrate roughness using measured stage-discharge data.
1-D steady-flow method	Cannot fully represent lateral storage and unsteady flood-wave behavior.	Develop a 2-D or unsteady-flow model for detailed mapping.
Bridge not surveyed	Bridge backwater and opening losses are not quantified.	Survey bridge deck, low chord, piers, abutments, and roadway profile.

11. Conclusions

- The adopted 100-year design discharge for the HEC-RAS simulation is 10,636.67 m3/s, based on the selected Log-Pearson Type III frequency analysis.
- The HEC-RAS model represents approximately 67.35 km of the Swat River from Khwazakhela toward Amandara using 34 terrain-derived cross sections.
- The computed Q100 water-surface elevation ranges from 673.82 m at the downstream end to 1,106.64 m near the upstream end.

- Computed hydraulic depth ranges from 1.93 m to 8.71 m, while total velocity ranges from 2.10 m/s to 5.74 m/s.
- The interpreted planning-level Q100 flood-risk extent is approximately 86.90 km2.
- The bridge was treated as a reference feature only because complete surveyed bridge-structure data were not available.

12. Recommendations

- Survey Khwazakhela Bridge before adding bridge hydraulics to HEC-RAS, including deck profile, low-chord elevations, pier dimensions, abutments, and roadway embankment.
- Replace SRTM terrain with surveyed cross sections, lidar, or UAV-derived terrain to improve channel and floodplain representation.
- Calibrate Manning roughness using observed water-surface elevations or reliable stage-discharge data from a nearby gauge.
- Prepare an unsteady-flow or two-dimensional model if flood hydrographs, lateral inflow hydrographs, and time-varying downstream boundary conditions become available.
- Review the mapped flood-risk boundary in GIS against settlements, roads, field evidence, and known hydraulic controls before using it for planning decisions.
- Maintain a transparent model archive that records all assumptions, parameter values, data sources, and output files for future audit and revision.

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