Hydraulic Modeling for Assessing Flood in Soan River under New Scenario of its Catchment

Hashim Nisar Hashmi [1], Habib-ur-Rehman [2], Faisal Mateen [3], Usman Ali Naeem*[4], Abdur Razzaq Ghumman [5], Muhammad Ali Shamim [4]

1) Professor, Department of Civil and Environmental Engineering, UET Taxila, Pakistan
2) Professor, Department of Civil and Environmental Engineering, UET Lahore, Pakistan
3) Senior Engineer, National Engineering Services Pakistan Pvt. Ltd. Islamabad, faisal.civil@gmail.com
4) Assistant Professor, Department of Civil and Environmental Engineering, UET Taxila, Pakistan
usman.naeem@uettaxila.edu.pk

Abstract: The rapid urbanization in the world has tremendous effects of spatial pattern of flows in water channels. If floods are not assessed before the development, this may prove dangerous in terms of life and property. DHA Islamabad Phase I Extension is a new development proposed on right bank of River Soan, Rawalpindi. The objective of this model study is to ensure safety of life and property against any potential flooding, with minimum impact on natural drainage. This research has been limited to data collection, developing the hydrodynamic model using HEC-RAS, firming up the design criteria for flood, model simulation and development of alternatives for flood protection works. A study reach of 11.180 km length is selected. Flood hydrograph at Pindi–Soan gauging station is used as u/s boundary and average river bed slope is used as d/s boundary condition. The flood levels for 5, 10, 50, 100, 150 and 200 years return period are determined at the start of project boundary and two alternates are proposed. In first alternative the level of flood plain is raised to 422.50m for a flood event of 1 in 100 years. For the 2nd alternative the embankment is considered at 423.25m along the boundary of project area. The study of alternatives show that with proposed, during flood events of 100 and 200 years water level rise by 3.5 to 3.75m and backwater effect may go up to 3.5 to 4 km above the start of project area. High velocity i.e. around 3-5 m/s would also be expected with proposed developments. Results of the study reveal that enhancement of the channel capacity is the most feasible solution for the protection of study area.
[Hashim Nisar Hashmi, Habib-ur-Rehman, Faisal Mateen, Usman Ali Naeem, Abdur Razzaq Ghumman, Muhammad Ali Shamim. **Hydraulic Modeling for Assessing Flood in Soan River under New Scenario of its Catchment.** *World Rural Observ* 2018;10(4):60-68]. ISSN: 1944-6543 (Print); ISSN: 1944-6551 (Online). http://www.sciencepub.net/rural. 9. doi:10.7537/marswro100418.09.

Keywords: Soan River, Hydrodynamic Modeling, Flood Protection, DHAI Flooding, HEC- RAS Flood Model

1. Introduction

The rapid environmental changes of the world have made the Hydraulic models most important tool for assessing the floods in different regions of world. Keeping in view the scope of researches that has been done so far in this field; the concentration has been made on the flood assessment through numerical hydraulic modeling for the SOAN River, located in Rawalpindi and Islamabad, Pakistan. Islamabad and Rawalpindi are located over Potohar Plateau as a whole is a hilly area with Margalla hills in the north covered with vegetation. Water courses and nallah are the main characteristic of physical environment of the twin cities. The elevation of is generally more than 500 meter above mean sea level. The main rivers of the area are Soan River, Korang River, Ling River, Sill River and Nullah Lai.

The Soan River is the most important stream of the Potohar region of Pakistan mostly covering the area of Islamabad and Rawalpindi city. It drains much of the water of Islamabad and Rawalpindi through small nullahs. The Soan River starts near a small village Bun in the foothills of Patriata and Murree. It provides water to Simblee Dam, which is the water reservoir for Islamabad. Near Pharwala Fort it cuts through a high mountain range, a wonderful natural phenomenon called Soan Cut. No stream can cut such a high mountain, which proves that the Soan was there before the formation of this range. And as the mountain rose through millions of years, the stream continued its path by cutting the rising mountain. Ling River, following a relatively long course through Lehtrar and Kahuta falls in the Soan near Sihala. Islamabad Highway crosses the Soan River near Sihala, where the famous Cock Pull Bridge is constructed over it. The Nullah Lai, which is most important stream of the Rawalpindi city, joins the Soan River near Soan Camp. After following a meandering path along a big curve, the Soan River falls into the Indus River at Kalabagh. The length of Soan River is more than 250 kilometers *(http://en.wikipedia.org/wiki/Swaan_River).* Figure 1 and Figure 2 shows project location on satellite image and Phase-I Extension at Bank of Soan River respectively.

Phase 1 - Extension is an exciting new residential development located adjacent to the right bank of Soan River in Rawalpindi, Pakistan. The project is being proposed by EMAAR (a Dubai based company) DHA Islamabad. The site is part of a larger development project in greater Islamabad developed by the Defense Housing Authority (DHA). The specific site for this portion of land referred to as Phase 1 – Extension that is approximately 500 acres (200 hectare approx) in size, and is comprised of a prominent hill form that gently descends to the river's edge. The River Soan extends along the south-eastern border of the property and makes up the base of a major valley. There is a flatter area of project land immediately adjacent to the river. This project area needs to be protected against any possible flood event that should occur.

The project area is located around 07 (seven) km downstream of the GT road bridge along the river course. Here the river follows a snake like path and sharply meanders as it approaches the project area. The meandering shape shows that the river is flowing in a relatively flat terrain. Just upstream of the DHAI-Phase 1 Extension, the course of the river is channelized by the development of DHAI Phase 1 on right bank and BAHRIA TOWN Phase 9 on the left. The BAHRIA TOWN embankment continues along the left bank of river in front of the project area. At some places natural topographic features mark the banks. The river width varies from as narrow as 120m between hills to several hundred meters wide while passing through the valleys at foothills of Potohar Plateau. The hills forming the banks are covered with vegetation. The river bed along the active course of flow comprises of cobbles and pebbles mixed with gravel, sand and silt.

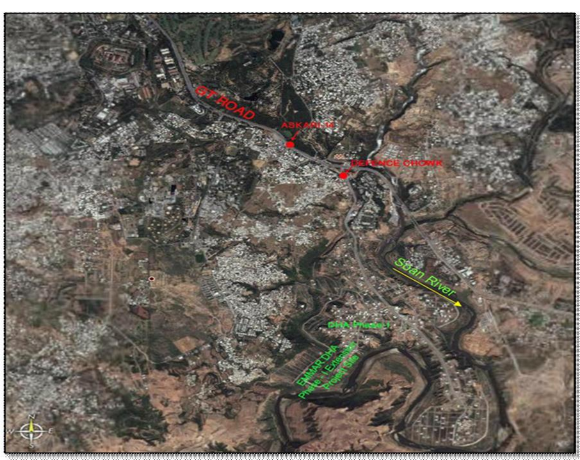

Figure 1: Project Location on Satellite Image

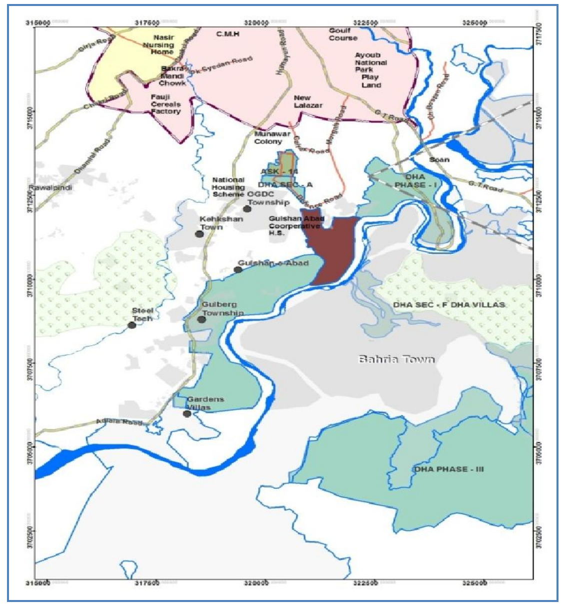

Figure 2: DHAI Phase-I Extension at Bank of Soan River

The objectives of this study are

1) To determine the design flood for the protection of DHA housing project.

2) To assess the flood inundation depths in the DHA housing project, considering occurrence of design flood in the Soan River.

3) To analyze various possible options of the structural measures against flooding of the housing project.

4) To propose best structural measure to protect the DHA from flooding.

For the compliance of the objectives, the scope of this study includes the following

- Collection and review of reports, maps and other available data on hydrology and floods in river Soan.
- Hydrological analysis of data to update and firm up the design flood for residential area.
- Topographic survey to prepare river cross sections.
- Define physical boundaries of the system, preparation of the modeling schemes, simulations and results interpretation; this has been performed with setting up a hydrodynamic model using "HEC-RAS", software that is developed by the Hydrologic Engineering Center (HEC) of the U.S. Army Corps of Engineers.
- Development of alternatives for flood protection works.
- Multi-criteria analysis (with and without the project scenarios) of the alternatives taking into technical considerations.

Scientific researches has made the valuable changes in the field of hydraulic modeling, among these Flood Modeling is one aspect. The Flood Modeling has been one of the interesting topics for the researchers. The numerical flood modeling is not only important for the discharge rate calculations but equally important for the flood forecasting and adopting the preventive measures against the flood.

Flooding is a major hazard in both rural and urban areas worldwide, but it is in urban areas that the risks to people and the economic impacts are most severe **[1].** In the UK, for example, over 2 million properties are located in floodplains, with an estimated 200,000 of these being classified as at risk because they do not have protection against a 1-in-75 year flood event. This figure may rise further with global warming, especially given the recent finding that the increase in intensity of heavy rainstorms with temperature rise is larger than that predicted. The majority of these properties are in urban areas.

Flood modeling in urban areas is more complicated than in rural areas **[2]**. While some processes such as channel-floodplain interactions are common to both environments, in urban areas flows interacting with the built environment must also be modelled. Surface flows will be affected not only by the ground topography and vegetation, but also by buildings and other man-made features such as walls, roads, embankments, ditches, kerbs and parked vehicles.

The river level and flood prediction are unquestionably very important factors in the study of hydraulics. One of the common methods is based on using past observed data and forecasting river discharge in the future or time series analysis **[3].**

Continuing advances in computer hardware and the expanding capabilities of modeling software packages, including linked 2D/1D hydraulic models, and multiple 2D domains, have meant that hydraulic models are being applied over ever broadening spatial scales, with modelers continually pushing the boundaries of what these models can achieve **[4]**. These advances have facilitated the development of catchment scale models that are of a geometric size and level of detail that would have been difficult to conceive only five years ago.

Also, the benefits of two-dimensional modeling in flat, rural floodplains have been available for some time, and a number of floodplain hydraulic studies have been undertaken in the past 6 years throughout Australia **[5]**. The increased use of two-dimensional modeling has been made possible due to the improved computational speed of desktop computers as well as the availability of high-quality digital survey information and the ability to readily store and rapidly process this information.

This apparent paradox is tried to be resolved by deriving a dynamic model inspired from financial models, which does not take into account annual maxima only but also threshold exceedances **[6]**. It studies the implications of such a paradox in terms of return period, a notion valid as long as the data.

At present, most river flood forecasts are conducted using a two-step procedure **[7]**. First, flood routing is conducted, normally using hydrological models. The resulting flood peaks are then converted to water level forecasts using a steady flow hydraulic model, such as HEC-RAS. Recently, the HECRAS model has been extended to facilitate unsteady flow analyses, and while the numerical scheme is not robust enough to handle dynamic events (such as ice jam release floods) or supercritical flows, it does have the capability to route simple open water floods and produce water level forecasts at the same time. Here, the viability of the HEC-RAS unsteady flow routine for flood forecasting is examined through an application to the Peace River in Alberta and it is shown that accuracy comparable to more sophisticated hydraulic models can be achieved. Since many agencies already have HEC-RAS models established for floodplain delineation purposes, it would be a simple matter to extend them to the flood forecasting application. An ancillary advantage would be that flood forecasting accuracy could potentially be improved and simplified into a one-step process, without necessitating a time-consuming transition to unfamiliar models.

Hydraulic and Hydrological numerical modeling is a unique dimension of engineering, which covers versatile studies of advance technology. The purpose of hydrodynamic modeling varies from person to person. The scope or extent of hydrodynamic modeling is extended but not limited to the following examples:

- River modeling and analysis
- Watersheds and Catchment area studies
- Water and waste water modeling
- Groundwater modeling
- Flood Risk Assessment
- Open Channel models
- Dams and spillways modeling
- Study for the flood mitigation measures
- Flood predictions/forecasting
- Culverts and aqueduct designs
- River Bank Protections
- Water operated power plant modeling
- Bridges and hydraulic structures
- Hydrodynamic models for water salinity
- Dynamic behavior of Pesticides
- Waste water management planning

- Ocean water movements and study of ecological activities and oceanographic variables (water level, temperature, currents and salinity).

No doubt most of the above stated numerical models do not reflect the actual site conditions in some cases, but proved to be helpful to compile up and achieve the expected results under a set of control conditions. Concentrating on flood events it can be stated that the Hydraulic modeling and flood inundation mapping are performed in order to predict important information from a flood event including the extent of inundation and water surface elevations at specific locations. A hydraulic model is essentially a representation of the processes that occur during a flood event.

The determination of water surface elevations in a stream/channel, all of the computer programs commonly use ***"Standard Step Method"*** for calculations **[8]**. This is an iterative method, in which the program works for one end of the stream channel to the other, one cross section at a time. At the first cross section, a starting condition is specified as a part of input data. At each succeeding cross section, the program uses the following steps:

- A water surface elevation is estimated and used to compute the cross-sectional flow area. This allows the computation of the flow velocity and velocity head.
- The estimated water surface elevation is also used to compute the wetted perimeter, conveyance, and friction slope.
- The friction slope values of the current and preceding cross section are averaged.
- The average friction slope is multiplied by the weighted average reach length to obtain the total energy loss in this stream reach.
- The energy loss is added to the total energy at the preceding cross section to produce a revised estimate of the total energy at the current cross section.
- The computed total energy elevation is compared to the assumed total energy elevation from the first step.

The above steps are repeated (with additional details to ensure computational stability and convergence, and to account for other factors) until the program determines that no further adjustments are necessary in the energy head at the current cross section. The program then computes various other output values before beginning the same procedure for the next cross section.

At present it is observed that a growing public discussion on increasing damages and loss of life due to flood events is been carried **[9]**. A thorough analysis of the question, is the increased severity of flood damage due to anthropogenic change and, if so, what are the reasons, is yet to come. In this paper only one reason for deterioration of flood conditions is discussed, i.e. the impact of specific landuse changes on flood hydrographs. A model is presented most of whose parameters are determined on the basis of catchment characteristics. Satellite imagery as well as digital elevation models and digital maps are used in order to identify the parameters of the deterministic distributed rainfall-runoff model. It was shown that historical or predicted landuse changes can be identified on digital landuse maps. Based on this information, changes in model parameters can be determined. In the model used here, landuse changes become apparent in a change of the soil water storage capacity distribution functions. Examples are given that show the impact of two types of landuse changes on flood hydrographs. In both cases, increased urbanization and forest diseases, it could be demonstrated that such landuse changes cause significant increases in flood peaks and flood volumes, both of which must be considered as deterioration of flood conditions.

It has been studied that the potential for natural disasters is an important component of landscapes and therefore it is essential to consider this when planning the use of space **[10]**. Using geographical research methods we can identify the presence of potential natural processes in areas, define their effects on nature and society, and using this information in cooperation with other relevant expert input we can look for possibilities for "coexistence" with them through the instruments of spatial and other forms of planning. However, spatial planning is subject to the interests of capital and local communities, and agriculture suffers the blind destruction by urbanization of the highest quality farmland that could produce food in future crisis periods while at the same time placing ever greater demands on limited natural resources (primarily on water for irrigation).

The population existing near the river banks is always subject to flash flooding unless properly secured against extreme conditions; the example of this is observed in flood 2010 in Pakistan.

Numerous computer softwares/packages have been introduced for hydrodynamic modeling. But keeping in view the scope of research of this thesis, only those softwares are discussed which are helpful in river flood models. Among these softwares following names are most prominent:

- FLOWROUTE
- TUFLOW
- MIKE FLOOD
- FLO-2D
- ENVIRONMENTAL FLUID DYNAMICS CODE (EFDC)

- ISIS
- HEC-RAS

Keeping in view the scope of work in this thesis a brief introduction of HEC-RAS and its use is demonstrated herewith prior to develop a river flood model.

Hydrologic Engineering Center-River Analysis System (HEC-RES) is a package widely used in the world. It is not only for the river and flood analysis but equally important for the hydraulic analysis of dams, culverts, channels, bridges, weirs, flood ways and other hydraulic structures. The philosophy of software illustrated in the user's manual **[11]** is referred as:

"An integrated system of software, designed for interactive use in a multi-tasking, multi-user network environment comprised of a graphical user interface (GUI), separate hydraulic analysis components, data storage and management capabilities, graphics and reporting facilities."

There are three major components of one dimensional hydraulic models for which HEC-RAS contributes to develop the hydraulic models that are:

1) Steady flow water surface profile computations;

2) Unsteady flow simulation; and

3) Movable boundary sediment transport computations.

The HEC-RAS model can handle a full network of channels, a branching system, or a single river reach. The steady flow component is capable of modeling sub-critical, supercritical and mixed flow regime water surface profiles. The program can also be used to determine the effects of various obstructions such as bridges, culverts, and structures in the flood plain. Flood plain management and flood insurance studies to evaluate floodway encroachments may be evaluated by the steady flow system component of the program. Also, capabilities are available for assessing the change in water surface profiles due to the channel improvements, levees, and ice cover. HEC-RAS supports the river models for one-dimensional analysis under the different scenarios of steady and unsteady flow.

HEC-RAS provides the distinctive environment to perform the analysis and design of hydraulic structures. Numerous optional capabilities are available to model the unique situations. Following are the major applications of the HEC-RAS in the field of hydraulic modeling/engineering:

- Flood routing
- Channel design
- Floodplain studies
- Flood Encroachment analysis
- Analysis and design of bridges, culverts
- Estimation of bridge scour
- Bridge Skew
- Analysis of ice-covered rivers and ice jams.
- Multispan Culverts (Prefabricated Concrete arch with natural stream bottom)
- Multiple "n" values inside of Culverts
- Sediment Transport
- Multiple geometry comparisons for profile & cross section plots
- Modeling gated Spillways, Weirs and Drop Structures.
- Modeling of Back water effects
- Modeling of flumes
- Dam Break modeling

2. Research Methodology

The methodology of the research work is established to address the task of data collection from concerned agencies/sources, data organization in accordance with the inputs required for river modeling.

Figure 3 shows the flow diagram of the adopted methodology in this study.

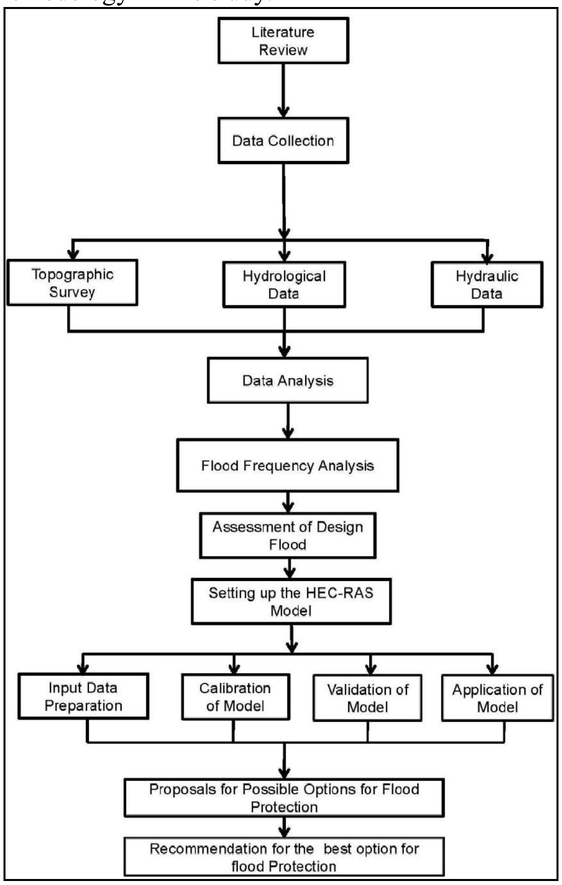

Figure 3: Research Methodology

The data required for preparing a hydrodynamic model can be classified into three categories.

- Topographic Data
- Hydrological Data
- Hydraulic Data

The topographic data includes

i. River geometry for the study reach.

ii. Topographic Maps and Satellite Imagery.

iii. Topographic survey and Mapping.

The hydrological data includes

i. Flood hydrograph at the start of the reach.

ii. Any inflow or outflow data for streams joining to the river.

The hydraulic data includes

iii. Average bed slope of the channel reach.

iv. Average value of the Manning's roughness coefficient for the channel reaches.

The topographic survey was ascertained to get the horizontal and vertical control of the project area, and collected from the concerned office. The collected data was formatted in a way to be used for modeling in HEC-RAS. The data was processed to:

v. Develop river cross-sections.

vi. Determine the centre-line distances for each section.

vii. Determine the Thalweg points.

Flood peaks in rivers and drainage channels depend on various factors such as rainfall intensity, catchment area, its shape, vegetation cover, topographical features and inflows from the streams joining its course. Accordingly hydrological studies were carried out to determine flood discharge in the river Soan for a return period of 200 years. The analysis carried out includes:

a) Determination of flood inflow hydrograph for the river Soan. The hydrographs are synthesized using USSCS (United States Soil Conservation Service) method **[12]**.

b) Runoff frequency analysis to determine flood peak in river Soan. Gumbel's method is used for the frequency analysis and flood peak is computed for different return periods. A summary of peak flood discharge against various return periods is given in Table 1. Figure 4 shows the flood hydrographs of the Soan River.

Table 1: Peak Discharges at Project Area

Return Period (Years)	Peak Discharge (Cumecs)
5	2536.38
10	3125.00
20	3713.62
50	4491.73
100	5080.35
150	5424.67
200	5669.00

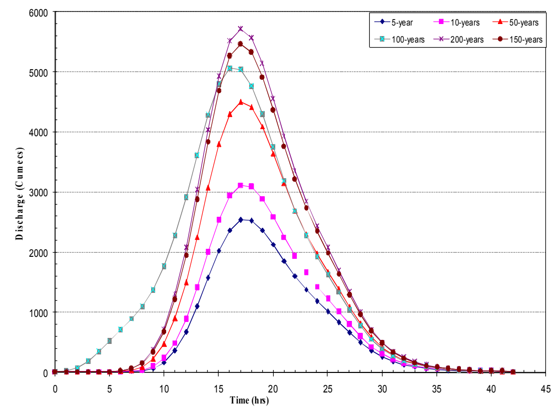

Figure 4: Flood Hydrograph for Soan River

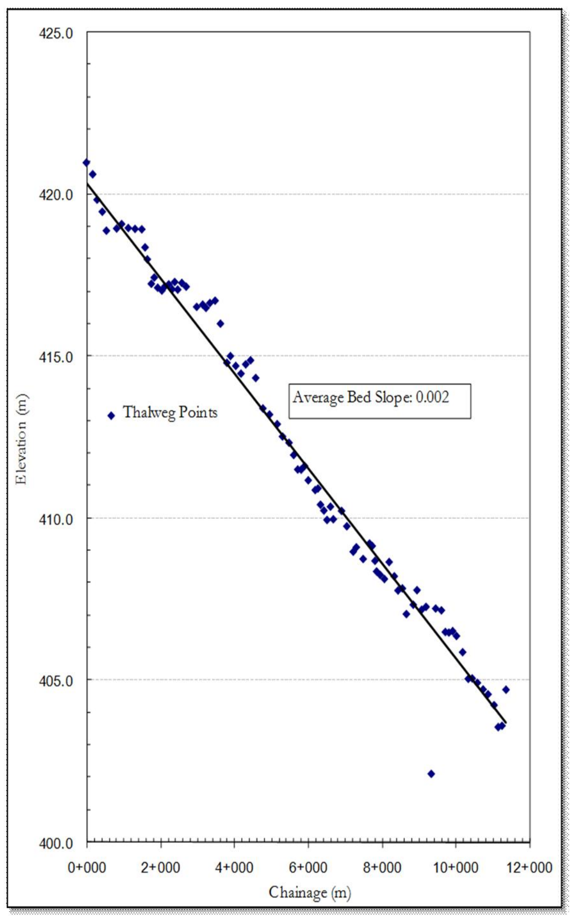

Figure 5: Average Bed Slope of Soan River understudy

The hydraulic parameters required for the model input are water area, wetted perimeter and hydraulic radius. This is determined by HEC-RAS model using river cross-sections obtained from topographical data.

- Manning roughness co-efficient is established using observed discharge versus gauge data. The data calibration was carried out within the

HEC-RAS environment, keeping in view the available data of gauge station and "n" value of 0.05 has been adopted for the purpose of analysis.

- The average bed slope for the study reach is determined using thalweg points of the cross-section. The average bed slope is computed as 0.002 shown in Figure 5. Since bed slope varies in different reaches, however above stated value has been considered in this thesis. Figure 4 shows the relation for Thalweg points in the project area.

The heart of the project is setting up a Hydrodynamic Model for hydraulic simulation and floods analysis of the Soan River under different scenarios. HEC-RAS has been chosen for this purpose. As a rational approach for Model Schematization and in order to establish the physical boundaries for the flood routing of River Soan, the study reach selected starts from the gauge station named "Soan-Pindi". This gauge station was located ¼ km downstream of the GT road bridge just below the confluence of nullah Lei and river Soan. The station was established in 1960 to monitor discharge in the river Soan. A rating curve is developed 1 km downstream of the project area to form the lower boundary for the flood routing study. The total length of reach is around 11 km. The average bed slope varies from 2 – 4 m/km. Rajwal Kas and Gurba Kas are the two major tributaries that inflows in the river Soan from the left bank within the modeled reach. River cross-sections surveyed at different locations are incorporated and their centre-line chainage is established. Cross-section X90 (chainage 0+00) marks the inflow boundary and cross-section X01 (chainage 11+180) marks the outflow boundary. A schematic diagram of the hydrodynamic model is shown in Figure 6.

The information is then put as Geometric Data in HEC-RAS and river reaches are identified, the said cross sections were Geo referenced to recognize the exact location on maps etc. The contraction and expansion coefficients are taken as 0.1 and 0.3 respectively.

After completing the Geometric data entries, the steady flow data is then entered. The inflow data for different profiles is entered and a run is made. The results then calibrated to Gauge Station data to have a concurrent and most realistic value of Manning's Coefficient "n", the said values comes as 0.05 after numerous iterations and profile results.

The obtained value of "n" is then used for each cross section and to obtain detailed analysis results for unsteady flow conditions. It is necessary to define the boundary conditions before hydraulic computation. Flow Hydrographs (as defined earlier) are used as upstream boundary condition and a river slope has been used as downstream boundary condition. Please note we may establish a hydrodynamic model without defining the downstream boundary conditions.

Similarly, Initial Flow Conditions are defined and different flows at change locations such as Rajwal Kas & Garba Kas have been entered at specific locations. It is to be noted that the hydrographs for different return periods (e.g 5, 10, 50, 100, 150 and 200 yrs) have been used to run the model under different scenarios.

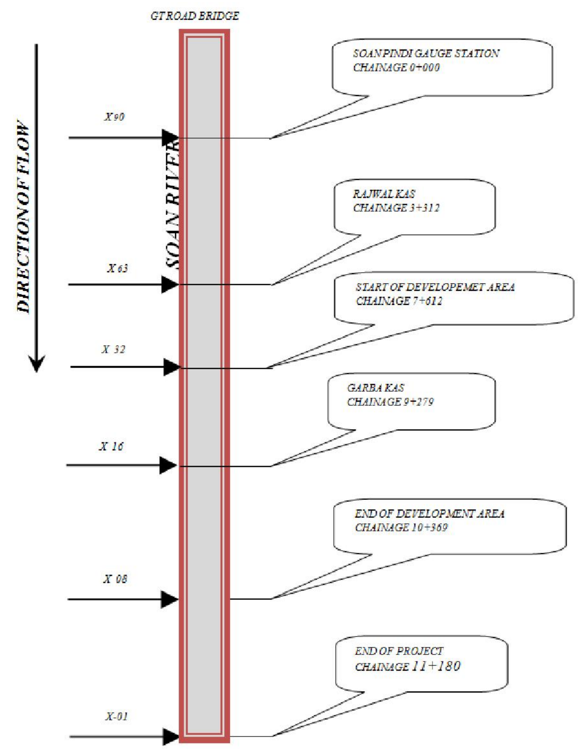

Figure 6: Schematization of Hydrodynamic Model

3. Model Analysis and Results

The completion of hydrodynamic model leads to the model run, the subject model is run under for various return periods and results are obtained for steady and unsteady flow conditions. The affects in flooded area are studied and flood prone areas were identified within certain reaches in the project area based on the most critical scenario. Table 2 & 3 represents the computed results.

It is important to note that the Project area is located at chainage around 7+612 to 10+369 (X-32 to X-08). It partially covers the flood plain of the river Soan. The level of flood plain varies around 410m (X-32) to 406m (X-08), reported from site conditions. It is obvious from the river cross-sections (X32 – X08) attached in appendix A and water levels given in cross section data for bed elevation that even for a discharge of 1 in 10 years the water spills out of the main channel onto the flood plain/project area. The depth of flow is around 6m to 12m within the flood plain area.

Table 2: Analysis Results for Unsteady Flow Conditions

Return Period (Years)	X-91 m	X-32 m	X-8 m	X-1 m
5	428.9	417.5	412.0	410.6
10	430.2	418.6	412.8	411.3
50	433.2	420.8	414.3	412.8
100	434.7	421.8	415.0	413.5
150	435.5	422.3	415.3	413.8
200	436.0	422.6	415.59	414.0

Table 3: Inundation Depths for Different Return Periods

Return Period (Years)	Start of Project X-32		End of Project X-08	
	Min (m)	Max (m)	Min (m)	Max (m)
5	0.45	7.58	0.47	6.05
10	0.45	8.61	0.47	6.80
50	0.45	10.86	0.47	8.37
100	0.45	11.83	0.47	9.02
150	0.45	12.33	0.47	9.35
200	0.45	12.69	0.47	9.59

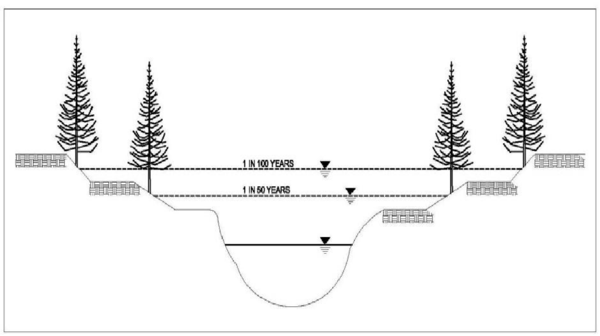

Figure 7: Enhancement of Channel Capacity

4. Discussions and Conclusions

The analysis results are concluded as follows:

a) Within the project area the flood plain varies from 410m to 406m.

b) The project area is subject to flooding for 1 in 50, 1 in 100 and 1 in 200 the design floods are 420.86, 421.83 & 422.69 respectively.

c) The inundation depth varies from 6m to 12m in the selected reach.

d) There is need of protection works to avoid flooding in the project area.

e) The protection works are required to be addressed the flooding for 1 in 100 years flood to be most economical option.

Flood Protection Measures

Four possible options are ascertained for the flood protections which are enlisted hereunder:Raising the ground level.

✓ Construction of peripheral dike along the project area.

✓ Construction of RCC retaining wall.

✓ Enhancing the Channel Capacity.

Following Cost Estimates have been worked out for these options:

Table 4: Cost Estimates for Flood Protection Measures

Proposed Option	Approx Cost (Millions Rs.)
Raising of ground level	1409
Construction of peripheral dike (earthen) along project area	476
Construction of RCC wall	1500
Enhancing of channel capacity	300

Recommendations

On the basis of analysis, model study and the consequences of flooding following recommendations are made:

a) A developed ground level of 422.50 m for flood plains is determined to be safe against 1 in 100 year flood. This incorporates a free-board of 0.7m as a margin of safety.

b) A flood embankment level of 423.25 m is safe against 1 in 200 year flood. This incorporates a free-board of 0.5m as a margin of safety.

c) Re-allocation of land use for the flood plains (non-residential facilities at relatively low level developed ground) through changes in Master Plan may help to reduce the impact of flood in the vicinity of project.

d) The most economical and viable solution is enhancing the channel capacity, against 1 in 100 year flood as shown in Fig 6, hence recommended for the protection of study area against flooding, moreover the option will improve the aesthetics of the society.

Corresponding Author:
Usman Ali Naeem
Assistant Professor
Civil Engineering Department, University of Engineering and Technology Taxila. Pakistan
usman.naeem@uettaxila.edu.pk

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12/25/2018