MODELING FLOOD ASSESSMENT FOR A NORTHERN WATERSHED IN PAKISTAN

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ABSTRACT

Floods are one of the most devastating natural disasters in recent history of Pakistan, claiming loss in lives and damages to property. This study is a petite effort made in the concerned context to analyze scenarios and generate preventive measures by using models as a core tool. The main objective of this study was modeling flood conditions vis-à-vis generating flood inundation map. The specific objectives of this study were: 1) to calibrate and validate HSPF model for Mangla watershed; and 2) to use HSPF generated stream flow as input to HEC-RAS model to simulate flood scenarios.

The data on land cover, Digital Elevation model (DEM), and climatic conditions (precipitation, temperature) were collected from various sources. The GIS data were imported to a hydrologic model, Hydrological Simulation Program – FORTRAN (HSPF). In addition, the observed stream flow data along with meteorological data for Mangla watershed were used for calibration of the HSPF model. The simulated stream flow was imported to a hydraulic model, Hydrologic Engineering Centre- River Analysis System (HEC-RAS), as input data to simulate flow. The HEC-RAS simulated the inundation map. In addition, WMS (Watershed Management System) is a tool which was used in this study to couple the two models in order to simplify the procedure. Monthly water balance was achieved and statistical analysis was done giving R^2 and NS coefficients as 0.93 and 0.78, respectively. Having analyzed both the models with the incorporation of WMS, the study concluded as modeling to be an effective means of understanding floods, forecasting inundation areas (prone areas), and hence for mitigation measures. HSPF, being a complex model, is recommended to be used for sensitive matters like planning of disaster management and mitigation measures.

Keywords: Hydrologic modeling, stream flow, flood analysis

1. INTRODUCTION

Flood is an intense, naturally occurring hazard having varied causes, which becomes a disaster when the society suffers devastating losses in terms of assets, lives, infrastructure, economy and environment. These damages can be reduced to an extent through proper planning and development of predictive and monitoring capabilities. Historically people have been living in the fertile land of floodplains where their livelihood sets in comfort by virtue of close proximity to sources of food and water. Ironically, the same rivers or streams that endow with sustenance also render these populations vulnerable to periodic flooding. Zhang (2007) suggested that three main factors contribute to a region’s risk to flood: hazard, exposure, and vulnerability. All around the world various measures have taken place to control, forecast floods, and mitigate accordingly.

In Pakistan, the devastating floods of 1973 stimulated the feeling that the flood forecasting arrangements in the country were still derisory and did not meet the country requirements. These floods, thus, paved way to full-fledged activities for the further strengthening of the Flood Forecasting System (FFS). The recent two floods that are 2010 and 2011 have been more than an eye-opener. Though the formation of Provincial and National Disaster Management Authorities (PDMA and NDMA) have made deep inroads towards flood mitigation yet a lot needs to be done. Not much technical studies have been carried out in Pakistan for flood prediction and assessment.

For the evaluation of this hazard, US and some other sources have developed models that can assess historic floods and eventually predict future floods. There are numerous models now possessing various functions to assess floods. Modeling approach has become an effective tool for water resource management. There are two general types of models related to water resources; hydrological and hydraulic models. Hydrological models deal with the properties of water and simulate the stream flows contributing from watersheds into the river whereas hydraulic models deals with the channel properties, simulating flows that how much water would overflow and how much land would inundate. Some hydrological models are Hydrological Simulation Program – FORTRAN (HSPF), Precipitation-Runoff Modeling System (PRMS), Soil and Water Assessment Tool (SWAT), Water Erosion Prediction Project (WEPP), MIKE SHE (originally named SHE – Systéme Hydrologique Européen), Hydrologic Engineering Center’s Hydrologic Modeling System (HEC- 1/HEC-HMS) and Gridded Surface Hydrologic Analysis (GSSHA). Some known hydraulics models are Hydrologic Engineering Centers - River Analysis System (HEC-RAS), StormCAD and Quick2.

For a model to run and estimate scenarios, first it is required to calibrate and validate it. Literature review has shown keen work done regarding calibration and validation of the models. Calibration is a process of aligning the model to replicate the real world with its simulation as close as possible. Validation of a model is a process to confirm the ability of calibrated model (without changing any input parameters) to assess the variables and climatic condition that might impact the quality of the model simulated results. Ahmed et al., (2011) calibrated HSPF model and validated it as well on Wilmot Creek watershed, Ontario. He obtained excellent water budget and performed statistical anaylsis by calculating R^2 and NS coefficients. Functions of the model are comprehensively mentioned including the details of physical parameters present in it. Similarly, Ribarovab et al., (2008) calibrated HSPF model for the Lesnovska River based on the collected meteorological, hydrological and Geographical Information System (GIS) data for the period 2003-2004. The model was verified for year 2005 when also an extreme flood event occurred in August. The water balances were calculated by estimating the volume of the water passing through the reach according to the hydrometric station (observed data). They were compared to the output volume simulated by the HSPF model. The losses in the watershed were accounted assessing the flow paths, the evapotranspiration and the infiltration. Al-Abed & Whiteley (2002) calibrated the HSPF model using automatic calibration and GIS. They found that the coupling of a GIS with automatic calibration produced a realistic and accurate calibration for HSPF with much less effort than there would be for unassisted calibration. This calibration procedure produced very satisfactory results. Current researchers such as Oogathoo (2006) is paying attention on simulating river flows and analyzing flood plains, since this is one natural hazard in which fatalities and damages can be minimized, if predicted. Singh and Woolhiser (2002) , Borah and Bera (2003) have worked a lot on hydrological models. A study was done by Chung et al., (2011) for a South Korean watershed to evaluate the effects of climate change and urbanization on water quantity and quality for nine different scenarios by using the HSPF model.

After working on the hydrological models, stream flows simulated at the outlet of watersheds and river flows are amalgamated in hydraulic models. This is done to generate channel flows.

Ahmed et al., (2010) in their research “Hydrological Modeling and flood hazard mapping of Nullah Lai” have used HEC-RAS and HEC-GeoRAS to delineate the areas vulnerable to flood. HEC-RAS being a user friendly model has become renowned in these last few years. Karki (2011) in his research used HEC-RAS and HEC-GeoRAS for flood hazard mapping on Kankai watershed, East Nepal. Maidment (1999*)* performed floodplain modeling using HEC-RAS hydraulic model on Waller Creek study area in Austin, Texas. He along with his research assistant enlightened that GIS is an effective environment for flood plain modeling and HEC-RAS provides a good representation as an outcome with improved visualization. Limitations of HEC-RAS, not seen in other papers, are also briefly elucidated. The recommendations mentioned regarding HEC-RAS are highly beneficial for other modelers. One of the recommendations is short spacing between cross-sections to attain accuracy.

To study the impact of urbanization on flooding, Suriya and Mudgal (2012) used HEC-RAS for flood zone mapping in the Thirusoolam sub watershed in Chennai.

HSPF and SWAT are continuous simulation models used to analyze long-term effects of hydrological changes and watershed management practices whereas Agricultural Non-point

Source (AGNPS), Kinetic Runoff and Erosion model (KINEROS) and Area Non- point Source Watershed Environment Response Simulation (ANSWERS) are single rainfall event models used to analyze single storm. MIKE SHE and PRMS have both capabilities of analyzing long-term as well as single event simulations. Among these models some are user friendly whereas some are complex. Simple models are sometimes incapable of providing detailed results. Complex models, yet being difficult give more accurate and efficient output. Therefore, finding an appropriate model can be a challenging task. Among these many models, HSPF is chosen as hydrological model for this study since it requires detailed input (daily flows) which in return provide best of all result, closest to the real world, eventually giving more accuracy, and HEC-RAS as hydraulic model as it is user friendly and requires minimum input. HEC-RAS proved to be appropriate for this study since data was very limited and HEC-RAS can generate tremendous results within minimum input.

1.1. Objectives

This study focuses on the vulnerability assessment and estimating future inundation for areas that are prone to floods in Mangla watershed. The objectives are as follows:

- To calibrate HSPF model and simulate Mangla watershed based on precipitation, land-use and DEM (Digital Elevation Model) data for the time period 1998 - 2003.
- To simulate river flow and flood inundation in the Indus within Mangla watershed based on flow data and HSPF output using HEC-RAS model.

2. MATERIAL AND METHODS

2.1. Study Area

Mangla watershed is selected for the calibration of HSPF model. The topography consists of steep slopes; this watershed houses the famous Mangla dam at 33.142083˚N and 73.645015˚E. The watershed is spread over an area of 610,411 hectares and mostly consists of light forest, cultivated land, light vegetation and pastures. The soil found in the watershed comprises of sand and silt where 60% area falls in group C of hydrological soil groups and 40% in group B. Figure 1 is showing DEM of the study area.

More data for this watershed or any other watershed were unavailable so Wilmot Creek watershed, Ontario is chosen for validation of this model since it possesses similar topography and climate as that of Mangla. However, the validation is done for the period 1987 – 1995.

2.2. Data Collection

Data collection and compilation is one major task of this project. Lots of corresponding data sets are used to attain the desired results, each of which is equally important.

Following is the list of data sets needed for this study,

- River flow data

- Meteorological data (temperature, precipitation, gauge readings)
- Digital elevation model (DEM)
- Land-use data
- Soil type data

Obtaining data from the concerned authorities took most of the time since it was not readily available. Daily flow data is obtained for 55 years that is from 1955 to 2010. Readings from maximum measuring points on Indus River were required for simulation. Sindh Irrigation and Drainage Authority (SIDA) generously provided heavy amount of data that covered daily flow readings starting from Terbela Dam down to Kotri Barrage, which is the last point where flow is noted. Along with that, flow data for all other rivers that are Jhelum, Chenab, Ravi and Sutlej is also given. Data included gauge readings and upstream and downstream flows for almost all the measuring points. Digitization is another pivotal part. Data from SIDA was in hard copy which is digitized all the way through. Not only this, the daily flow data is compiled in six Excel files comprising of 10 years data each.

2.3. HSPF Model

HSPF is a semi-distributed, continuous model that simulates hydrologic and associated water quality processes on pervious and impervious land surfaces and in streams. Water movements considered in this model are overland flow, interflow, and groundwater flow. It is a complex model simulating much more than other simple models do. Snowpack depth and water content, snowmelt, evapotranspiration, ground-water recharge, dissolved oxygen, biochemical oxygen demand, temperature, pesticides, conservatives, fecal coli forms, sediment detachment and transport, sediment routing by particle, size, channel routing, reservoir routing, constituent routing, pH, ammonia, nitrate-nitrite, organic nitrogen, orthophosphate, organic phosphorous, phytoplankton, and zooplankton are also simulated. HSPF is a watershed model that simulates runoff and nonpoint pollutant loads leaving a watershed.

The HSPF model requires two types of data: GIS based data describing the studied watershed and hourly hydrological and meteorological time series. It was successfully applied for modeling of the river runoff at normal climate conditions as well as for simulation of the first flood event after dry summer period. (Ninov et al., 2004, Ribarova et al., 2005 and Ribarova et al., 2008).

HSPF is comprised of three main modules (PERLND, IMPLND, and RCHRES) and five utility modules. For simulation with HSPF, the watershed has to be represented in terms of land segments (pervious and impervious lands) and reaches. The PERLND module represents hydrology and water quality processes that occur on pervious land segment, while the IMPLND is used for impervious surface area where little or no infiltration occurs. The RCHRES module simulates the processes that occur in a single reach of an open channel. HSPF is extremely data intensive (e.g., hourly rainfall) and over- parameterized model that requires a large amount of site information to accurately represent hydrology and water quality processes in a watershed.

Periods from a few minutes to hundreds of years can be simulated. Simulation results include a time history of the runoff flow rate, sediment load, and nutrient and pesticide concentrations, along with a time history of water quantity and quality at any point in a watershed. HSPF simulates three sediment types (sand, silt, and clay). It is also suiTable for mixed agricultural and urban watersheds. Watershed characteristics and climatic parameters are lumped into several units, and both empirical and physical equations are used to simulate the water flow.

In their effort to evaluate the model, Saleh and Du, (2004) highlighted some issues as they found the calibration process to be strenuous and long.

2.4. Input Data for HSPF

The HSPF model require intensive amount of data, however, due to lack of data only minimum required data are imported to this model to generate stream flows.

The stream flows data are observed data used to compare the simulated flows with real world. Meteorological data which comprises of temperature, precipitation, solar radiation, wind speed, relative humidity, snowmelt equivalence, etc is a requirement. For this study the minimum meteorological data required is temperature and precipitation. Pakistan Council of Research in Water Resources (PCRWR) has provided the aforementioned annual data for Mangla watershed for the time period 1994-2003. The climatic data given is for 12 weather stations out of which seven were of our interest, namely Muzzafarabad, Garhidupata, Kotli, Mangla, Sialkot, Astore and Jhelum. Other data set are Digital Elevation model (DEM), land use layer and soil type layer. DEM is a 3D representation of topography. DEM of Mangla watershed of resolution of 90 meters is obtained from PCRWR. Land-use map used for the calibration of HSPF in this project has 6 categories and it is obtained from global layer. The categories are agricultural land, barren, forests, urban or built up land, wetland and range land. Soil type layer of 1978 obtained from Soil Survey of Pakistan is being used with the assumption that soil type does not change much with respect to time.

2.5. Working towards model; HSPF

For Hydrological Simulation Program-Fortran (HSPF) to run, following steps are followed:

- Streamlining and organizing the historical meteorological data (time series data) by using Watershed Data Management (WDM) utility.
- Delineating watersheds and sub-watersheds using Better Assessment Science Integrating Point and Nonpoint Sources (BASINS).
- Overlaying of land-use/land cover layer, Digital Elevation Model (DEM), rain gauge stations layer.
- Importing all the input data to HSPF.
- Adjusting various parameters for calibration and running the model accordingly.
- Exhibiting output via GenScn in form of graphs, time series data etc.

- Validating HSPF.

The first step is developing .wdm file. WDMUtil program is to develop a utility that provides a variety of features to assist in the compilation of meteorological data and perform needed operations (e.g. editing, aggregation/disaggregation, filling missing data, etc.) to create the input time-series data for the use in HSPF model.

WDM file is formed for Mangla watershed by importing meteorological data into it. For this procedure, flat files are created and scripting is done.

After the collection of data, watersheds are delineated. BASINS is a tool used which is capable of performing watershed and water quality-based studies on regional, state, and local levels. This system performs various functions including; utilities for data management and extraction, watershed boundary delineation, streams delineation, layering (layering of DEM and land use layer or soil type layer) and sub watersheds delineation. DEM of Mangla watershed is imported to BASINS which automatically delineate watershed based on elevations by joining the points of higher elevations to demarcate a visible watershed boundary.

Further, streams are delineated showing the flow route and illustrating an outlet. Rain gauges are then marked on the map by just entering the WGS coordinates of the weather stations.

Since HSPF entails only one layer so land use map of Mangla watershed is incorporated with the delineated layers on its DEM. The input data of WDM file and ArcGIS layers are imported to WinHSPF. The model is run for a certain extra interlude apart from the simulation period which is termed as the “warm-up” period which is used to harmonize the watershed’s soil and physical conditions in order to make the watershed’s performance more realistic for the actual simulation period being run for the calibration. The warm up period for this study is preceding 3 years that are 1995 – 1997. Next, the model is run without any errors. Parameters present in the Tables of PWATER are adjusted. PWATER is the Table comprising of parameters affecting pervious land. It further comprises of four Tables, PARM1, PARM2, PARM3 and PARM4 which have these different parameters that are adjusted. Other Table is IWATER which signifies parameters that affect impervious land. In the HSPF model, amount of surface runoff is computed by using Philip’s infiltration equation (Philip, 1957).

Philip’s equation is derived from Richard’s equation.

$$q = D\frac{\partial \theta}{\partial x} \qquad (1)$$

Where, q is the evapotranspiration rate.

For the calculation of Evapotranspiration (ET), HSPF has various equations to choose from depending on the data available. For this study ET is calculated by Hamon’s equation.

The output of model is generated through GenScn. GenScn refers to generating scenarios. From this tool, graph of the flow simulated by HSPF is generated. The other output is time series showing simulated flow which is compared with the observed flow by exporting the two into MS Excel and generating graphs in order to do the comparative analysis.

2.6. Water Budget

Water budget is an output file in GenScn showing the water balance of study area for simulated time period. It contains all the components of water balance namely, overland flow, baseflow, ground water, evapotranspiration and precipitation.

The equation of water balance is given below,

$$\Delta S = P - ET_a - SF - DP \qquad (2)$$

Here, ΔS is change in storage in root zone

P is precipitation

ET_a is actual evapotranspiration

SF is stream flow which is combination of surface runoff, interflow and base flow

DP is deep percolation of infiltrated water.

2.7. HSPF physical parameters

As mentioned above, HSPF comprises of certain parameters which affect the flows. These parameters are adjusted once the model is run without errors and there is a need to adjust flows comparative to the observed flows. The output (in terms of flow rate) is then compared with the observed data for calibration. The water budget file is also checked to ascertain that the division of water into various components of the water cycle namely Evapotranspiration, Deep Percolation, Base-flow and Surface-flow is within the scientifically acceptable range. The parameters are then adjusted as per need to match the two curves as well as to balance out the components of the water budget.

Out of a wide range of parameters, some are sensitive.

1. LZSN or Lower Zone Nominal Soil Moisture Storage is a parameter dependent on precipitation, soil type and topography. Increasing the value of LZSN increases ET as there is more water available in the lower zone, it also simultaneously decreases surface runoff and increases probability of water going into deep percolation.
2. INFILT or index to mean soil infiltration rate is the rate at which water infiltrates into the surface after a spell of precipitation. It is directly dependent on precipitation intensity, soil type and topography. Lower values will produce more surface runoff.
3. LSUR or length of assumed overland flow plane is the average distance of relatively higher points in the watershed to the outlet or any other water body such as small streams or swales. Hilly watersheds will have lower values of LSUR and hence have more runoff.

4. SLSUR or average slope of assumed overland flow path is the parameter of average slopes in the watershed. Higher values will be used in watersheds with steep slopes and hence there will be more surface runoff.
5. KVARY or ground water recession flow parameter is used to describe nonlinear ground water recession rate. The unit is /inches. It is usually adjusted at the very end of the calibration. It is used if the output is demonstrating a lot of seasonal variability and constant extreme low flows are being simulated in some of the relatively dry periods and the opposite in the wet periods.
6. AGWRC or ground water recession rate is the ratio of groundwater discharge to that from 24 hours before. The unit is /day. It is very complexly dependent on topography, climate, soil and land-use. It can be adjusted on the basis of historic temporal hydrograph data using differential statistics.
7. DEEPFR or fraction of water that is lost to deep percolation is the parameter which divides the groundwater into active and inactive groundwater. Watersheds with steeper slopes have a higher probability of losing water to deep percolation as well as those areas in the watershed located at a fair distance from the outlet vis-à-vis gauging station.
8. BASETP is a very sensitive parameter BASETP has a default value of zero and should only be adjusted gradually in case significant riparian vegetation exists.
9. AGWETP or fraction of water directly available from groundwater which will be lost to evaporation is a parameter more significant in marshy areas or wetlands. It is also sensitive in areas with relatively higher water Tables. It is very important to check whether wetlands exist as a separate entity in the GIS layer (land-use) or not. If it is, then a separate value for this segment and a zero value for all other land use attributes. If not, then a weighted value for the entire value watershed is used. Like BASETP it affects simulations in low flow periods and helps in obtaining a reasonable water balance.
10. CEPSC is the fraction of precipitation that is retained by vegetation; it never reaches the land surface and is directly evaporated. The unit is inches. It has a significant impact on the annual water budget. Donigian and Davis (1978) determined the values for various categories of land cover.
11. UZSN or nominal upper zone soil moisture storage is the fraction of water stored in the upper zone and directly available for ET. Increasing UZSN increases the amount of water stored in the upper zone, hence making more water available for ET and decreases direct surface run-off while simultaneously increasing the possibility of more base-flow and deep percolation.
12. INTFW or Interflow is the parameter that governs the amount of water that infiltrates deeper from the surface detention zone increases the interflow and decreases the surface run-off while maintaining the same volume at the outlet.

13. IRC or Interflow Recession Coefficient is the parameter which controls the rate of interflow or the rate at which interflow is discharged towards the stream from the storage zone.
14. LZETP or index to lower zone evapotranspiration is the probability of ET from the lower zone or the root zone. It is a direct function of soil type and vegetation.

2.8. HEC-RAS Model

The Hydrologic Engineering Center (HEC) in Davis, California, developed the River Analysis System (RAS) to aid hydraulic engineers in channel flow analysis and flood plain determination. It includes numerous data entry capabilities, hydraulic analysis components, data storage and management capabilities, and graphing capabilities. The program models the hydraulics of water flow through natural rivers and other channels.

This model uses Manning's equation which is given below,

$$Q = VA = \left(\frac{1.00}{n}\right) AR^{\frac{2}{3}} \sqrt{S} \tag{3}$$

Where, Q = flow rate (ft^3/s)

V = velocity (ft/s)

A = cross- sectional flow area (ft^2)

n = manning's roughness co-efficient

R = hydraulic radius (ft)

S = channel slope (ft/ft)

This model performs hydraulic calculations and simulates the water flow through channels. There are five types of calculations that could be done in the current version of HEC-RAS; steady flow analysis, unsteady flow analysis, sediment/transport boundary modeling, water quality analysis and hydraulic design functions.

The first step is importing GIS file into geometric section. Next, the reach is marked and desired cross sections of the channel are generated. Simulated flows are entered in the model and it is run to obtain discharge. The illustration shows if there is inundation or not. Min channel elevation (ft), water surface slope (ft/ft), flow area (sq. ft), top width (ft) are also obtained from HEC-RAS.

2.9. Input Data for HEC-RAS

Following input parameters are notable while doing modeling through HEC-RAS.

- Geometric data which include river reach (from upstream to downstream i.e direction of flow), cross section data and junction data.
- Flow data

2.10. Watershed Modeling Software (WMS)

Watershed Modeling System (WMS), developed by Environmental Modeling Systems, Inc. at Brigham Young University, is a comprehensive graphical modeling environment for all phases of watershed hydrology and hydraulics.

This has proved to be an excellent tool as it has tremendous functions that make modeling very easy. Following are some of the functions of WMS;

- Automatically delineate a watershed and sub-basins.
- Automatically compute area, slope, mean elevation, maximum flow distance etc.
- Automatically cut cross sections and derive Manning's roughness values from elevation.
- Compute hydrologic basin data such as time of concentration, curve number, and infiltration parameters.
- Manipulate stream networks to represent man-made features or proposed changes to the watershed.
- Create flood depth maps.
- Link the peak flow or complete hydrograph from any of the WMS-supported hydrologic models to an HEC-RAS hydraulic model.

WMS is recognized as hydrologic watershed modeling wizard. It’s an all-in-one watershed solution tool executing storm drain modeling, floodplain modeling, hydraulic modeling, etc. WMS animations can also be exported to Google Earth. Manning’s co-efficient can be entered either manually or through land-use layer. For this study, land use layer is used provided with manning’s co-efficient for each category, separately. Figure 2 is a flowchart showing the methodology of HSPF model.

HSPF and HEC-RAS are coupled via WMS. It made the procedure simpler and automatically generated inundation map.

2.11. Statistical Analysis

Statistical analysis is also done for the model by two co-efficients that are coefficient of determination (R^2) and Nash-Sutcliffe coefficient (NS).

- The range of co-efficient of determination is from zero to one. The values closer to one are considered to represent best agreement. R^2 is computed by using the following equation,

$$R^2 = \left[\frac{\sum_{i=1}^{n} (O_i - \overline{O})(P_i - \overline{P})}{\left(\sum_{i=1}^{n} (O_i - \overline{O})^2 \right)^{0.5} \left(\sum_{i=1}^{n} (P_i - \overline{P})^2 \right)^{0.5}} \right]^2 \qquad (4)$$

Where O_i is the observed stream flow at time step I and Ō is the average observed stream flow. P_i is the model simulated stream flow at time step i. $\overline{P}$ is the average model simulated stream flow at time step i simulated by the model.

- Nash and Sutcliffe, (1970) mentioned another method of statistical analysis. This is one of the best approaches and is commonly used for statistical evaluation. Value of NS represents the fraction of the variance in the measured data explained by the model simulation. The value ranges between minus infinity (- ∞) to one, where one represents a perfect fit.

$$NS = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - \overline{O_i})^2} \qquad (5)$$

Where, O_i is the observed stream flow at time step I, and $\overline{O}$ is the average observed stream flow during the calibration period. P_i is the model predicted stream flow at time step *i* simulated by the model.

2.12. Calibration of HSPF

In this context, calibration is the process of matching the stream flows and volume simulated by the HSPF model and the same gauged by Water and Power Development Authority (WAPDA) at a particular point. Table 1 shows the adjusted values used for calibration. The calibration yielded an excellent water budget file (table 2) which was not only within the scientific range for various components but also made physical sense with respect to the topography of the watershed.

The simulated flows (monthly and daily) are compared with the observed flow values and graphs are generated. Figure 4 and 5 are showing graphs of monthly and daily comparison, respectively. The pattern followed by simulated flows is remarkably close to that of observed flows, demonstrating the accuracy in modeling. Graphical representation of monthly flows along with precipitation is shown below. Furthermore, this is also done for daily flows. To make the analysis simpler and understandable, bar chart for monthly flows is also generated which is shown in Figure 6. These graphs show how precise the simulated flow is and the model is running fine for such watersheds. After calibrating HSPF, now this model can be run for any watershed in Pakistan.

2.13. Validation of HSPF

Since no data of any other watershed of Pakistan is available, the same values of parameters have been applied to the Wilmot Creek watershed in Canada for the period of 1987 – 1995 in order to validate the model. Ahmed et al., (2012) has already worked on this watershed so all relative data including meteorological data and GIS layers are obtained at ease. For this watershed there are more number of reaches as compared to Mangla watershed. This particular watershed of Canada is selected because of the similar climatic conditions with that of Mangla watershed. Therefore, it is acceptable to key in the data of Mangla in Wilmot Creek watershed to corroborate that HSPF is running fine as shown in Figure 7.

3. RESULTS AND DISCUSSION

Average precipitation of Mangla watershed is 150mm. To attain inundation, an increment of 100% in precipitation is done. However, no inundation was achieved. The precipitation is increased three folds. This precipitation is put in HSPF to obtain flow of higher values. Next, with the help of WMS these higher flow values are entered in HEC-RAS to generate inundation. Since WMS is used, the inundation map is generated in that software itself. HEC-RAS simulated an inundated area of 8922m^2 and 2650m^2 on the left and right of bank respectively. The model also returns flow depth and other hydraulic parameters as results which are attached as Table 3. Figure 8 shows a two-dimensional overflowing from the river bank.

After running both the models successfully with the help of WMS interface, it is important to analyze the output produced by both the models and their contribution towards achieving the objectives. It is also important to analyze whether or not the results make physical sense.

- After a lot of trial and error plus twigging of hydrological parameters, a sound calibration of HSPF model is achieved for Mangla watershed. At first there were a few anomalies in the curves created using the observed and simulated data but they were removed by averaging out the vague values and removing the cells with zero values as there are missing values in the observed data-set because of the gauging station being closed for maintenance or other reasons. Once the anomalies were removed, a very sound water budget for all land use types and a relatively closer simulated curve vs. observed curve is generated though it is continuously under-estimating. It is giving an average variation of 0.741 for monthly stream flows, an NS and R^2 values of 0.83 and 0.96, respectively. When it comes to hydrological models, R^2 can be misleading at times whereas NS is a very good representation of the accuracy of the model.
- HSPF model validated on Wilmot creek watershed returns an R^2 and NS values of 0.74 and 0.69, respectively. This gives a good check on the versatility of HSPF and the sensitivity of its hydrological parameters. The model is clearly overestimating in high flow seasons which means that the overland flow and base flow are really high which is because of the fact that the hydrological parameters used were that of Mangla where the topography is relatively hilly compared to Wilmot which has a flatter trajectory. Just for the sake of an example, the slopes of overland slopes were set as 18% for Mangla which of course gives the water less time to infiltrate, hence increases runoff, the same would not be the case with Wilmot.
- The Mangla-watershed is located at higher altitude as compared with the usual floodplain areas of Pakistan; hence it is less prone to flooding. Therefore, after observing an escalation of almost 100% more precipitation in flood years, flows were generated. No inundation was seen. Mangla watershed is safe from flooding.
- However for the sake of this learning and study of flood mapping, the precipitation is increased three folds to that of maximum rainfall observed in the watershed. Inundation is

produced on the right and left of the river. The left bank is a relatively low lying area hence it was flooded in a conventional way with the water going over the top of the left bank inundating an area of 8922 m^2. As seen in Figure 8, a pocket of water was observed beyond the right bank. The right bank of the main reach at Mangla is marred by a hilly terrain. The pocket of water observed is actually due to seepage during high flow seasons such as the one produced by extrapolating precipitation. The area inundated by seepage on the right of the river is 2650 m^2. Figure 10 is an inundation map showing flooding in watershed because of overflow in the main reach. This map can be overlaid on Google Earth or DEM to get a better view of inundated area. After such unconventional inundation, the probability of flash flooding in the wake of more precipitation is increased substantially.

4. CONCLUSIONS AND RECOMMENDATIONS

- The flood extent map produced by WMS using HEC-RAS analysis represents a flood extent polygon on a satellite image. This is essential in planning mitigation/evacuation operations as it gives simple analysis on which settlements are going to be submerged and to what area should the population be relocated as it gives the extents of the flood coverage.
- Data is to be accessible for research work in order to attain a better output. Due to limited data, this study got restricted to Mangla watershed only. However, on the availability of data, similar work can be done for southern part of Pakistan as well since lo lying areas of Sindh are more prone.
- The use of WMS is recommended for future hydrological, hydraulic and floodplain modeling. WMS itself is capable of delineating floodplains on the basis of flow accumulations; however it still needs the aid of hydraulic models to perform flow simulations and model flood events.
- Based on results produced in the wake of flood modeling, the authorities can plan mitigation strategies beforehand to lower the risk of flooding. Planning of evacuation operations will also be made easy with the aid of flood coverage maps.

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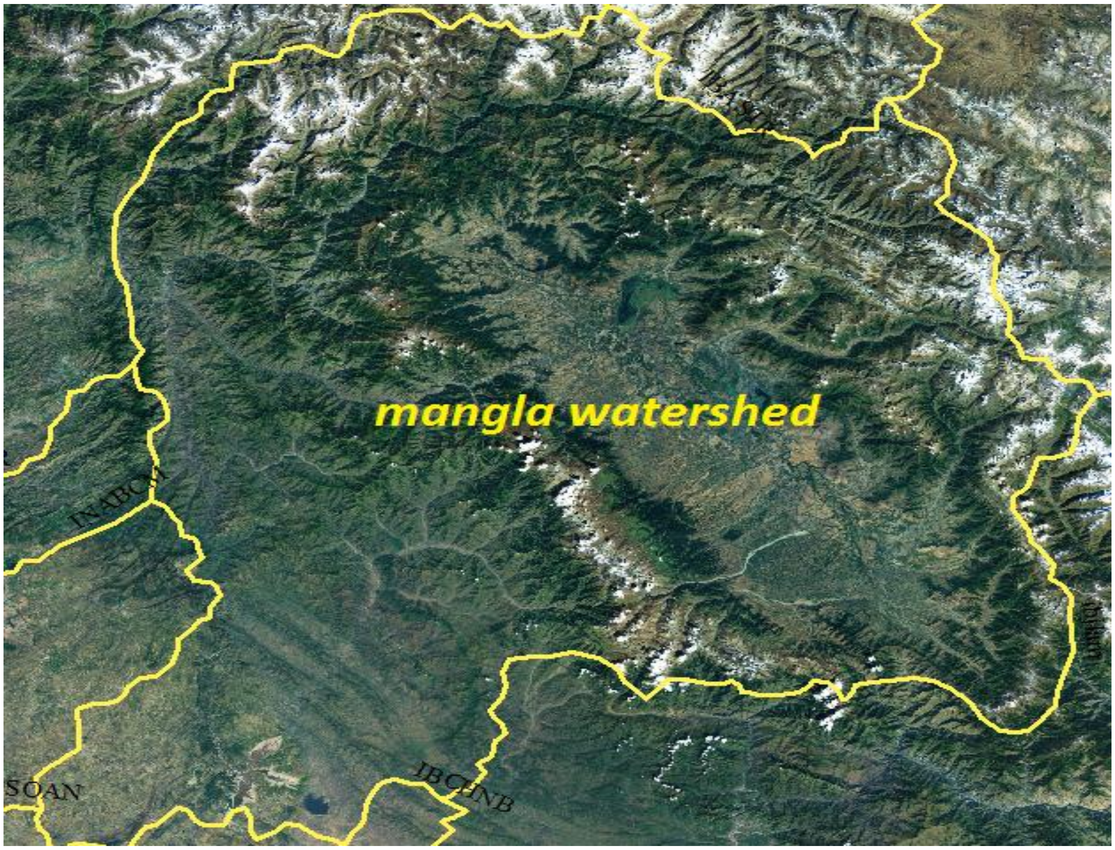


Fig 1. Map of the study area.

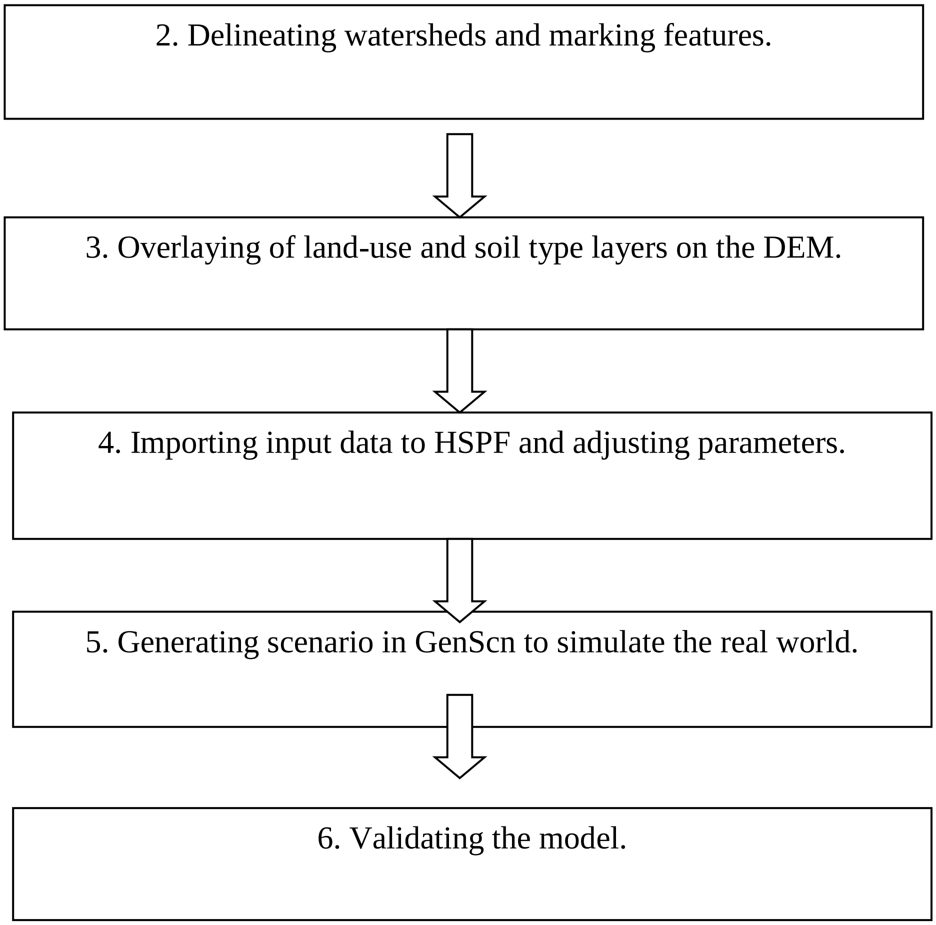


Fig 2. Flowchart showing steps of HSPF modeling

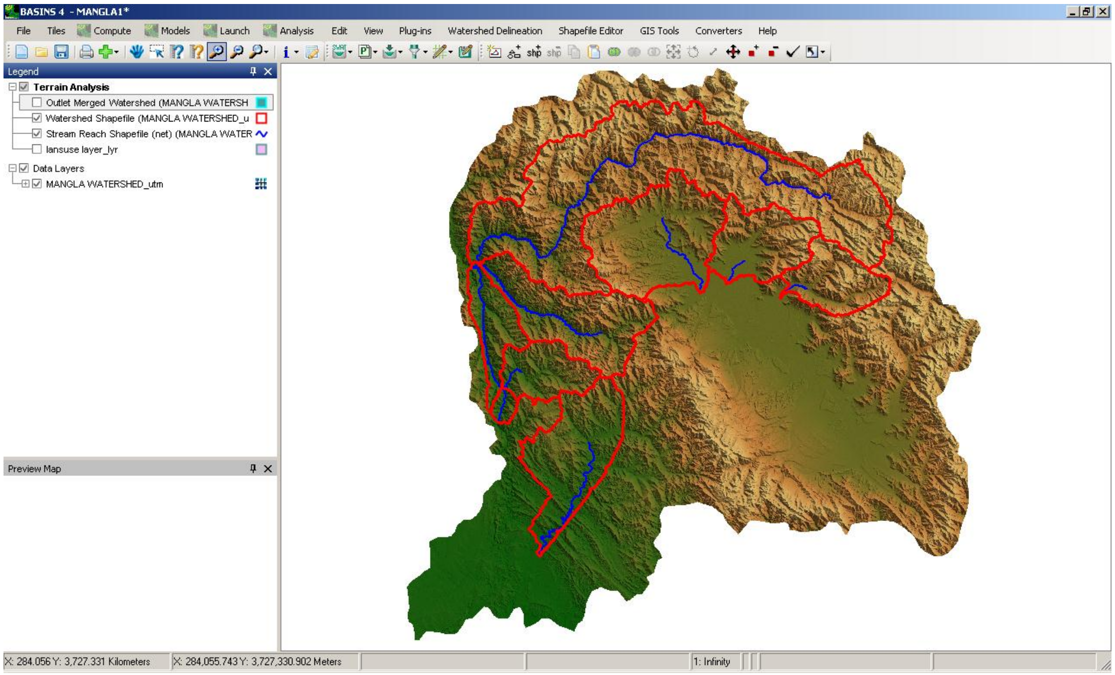


Fig 3. Delineated sub basins and stream lines

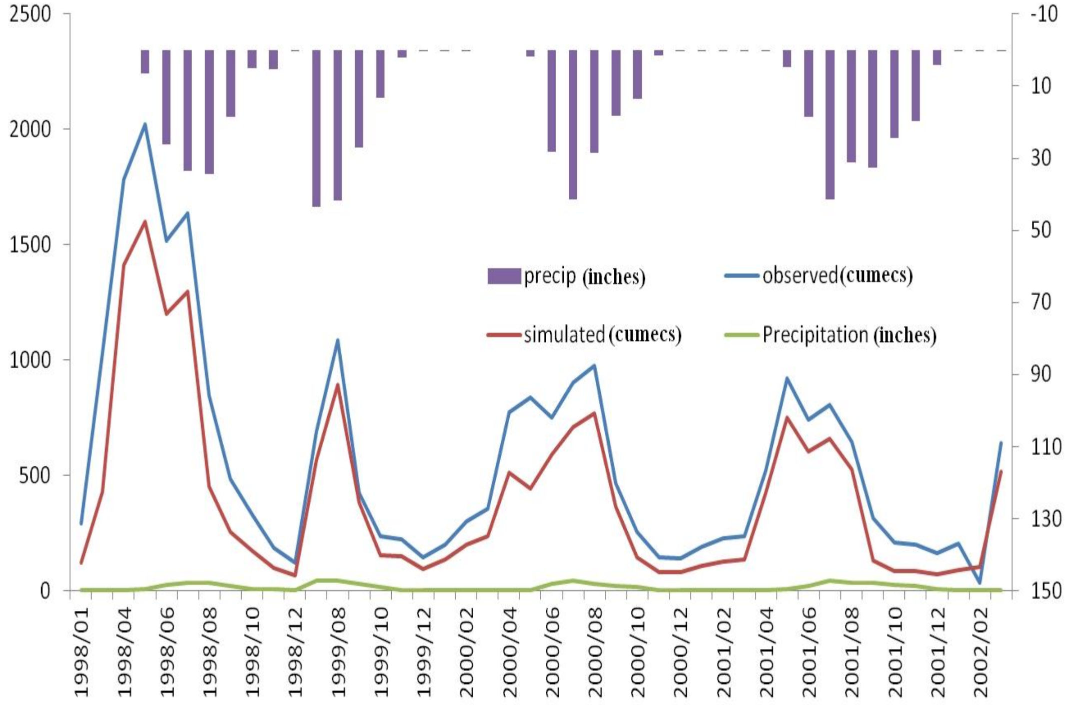


Fig 4. Graph of monthly simulated & observed flows

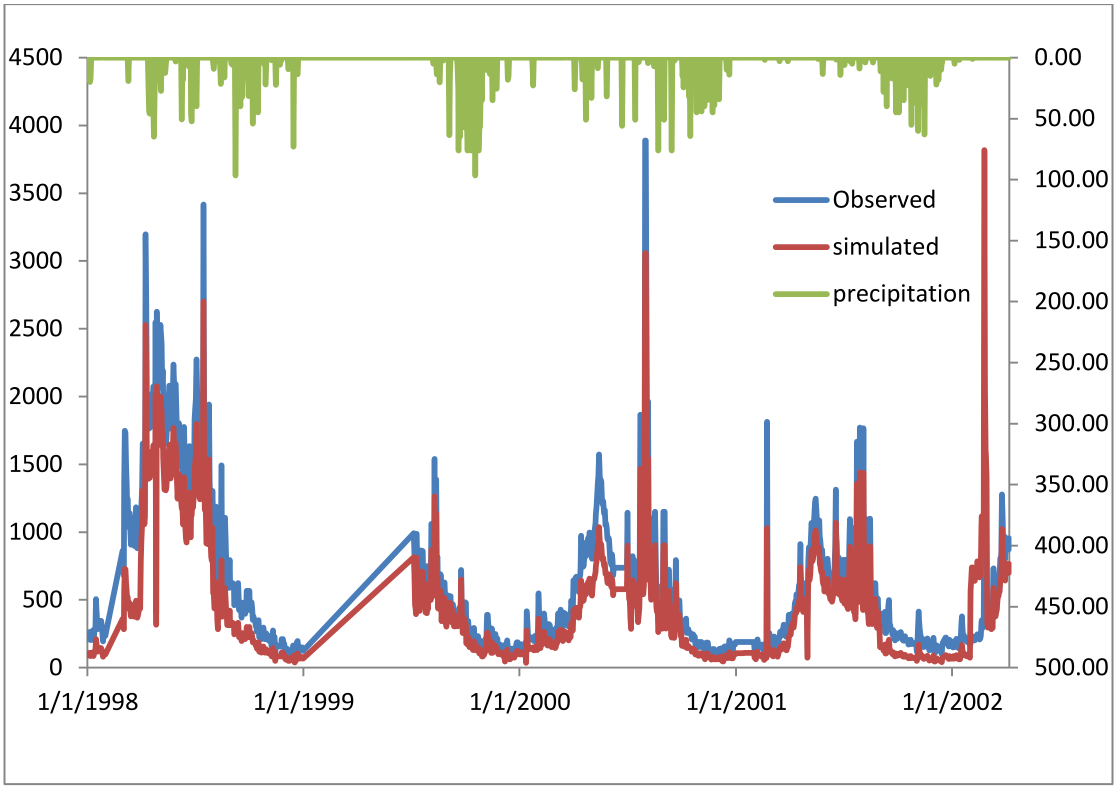


Fig 5. Graph of daily simulated and observed flows

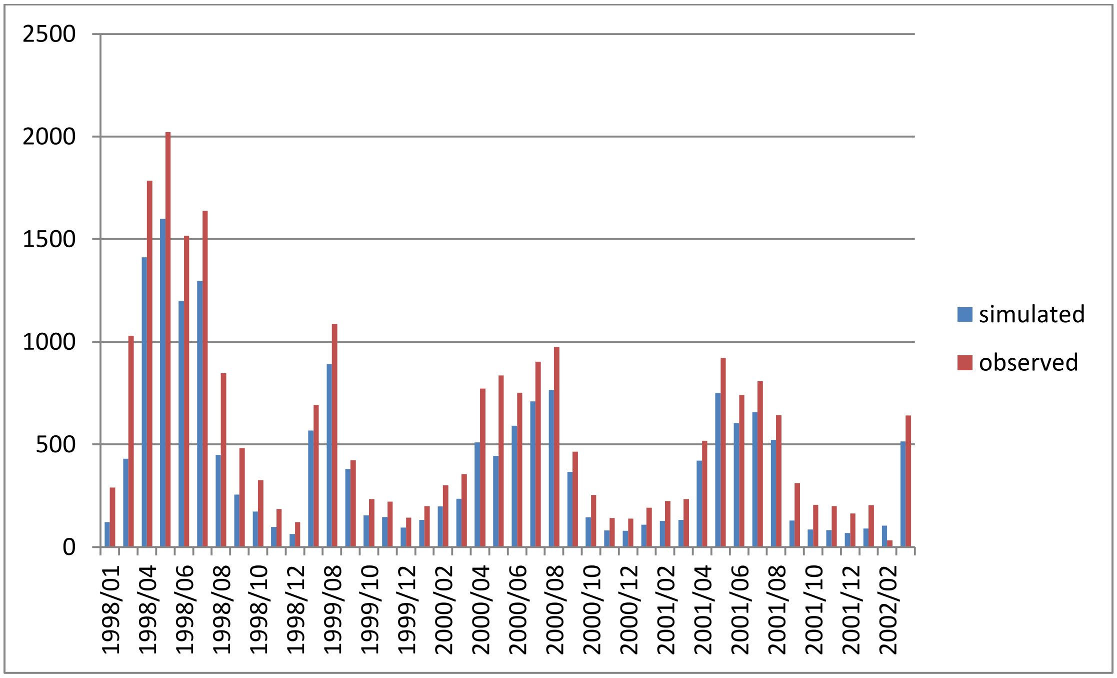


Fig 6. Bar chart showing monthly simulated and observed flows

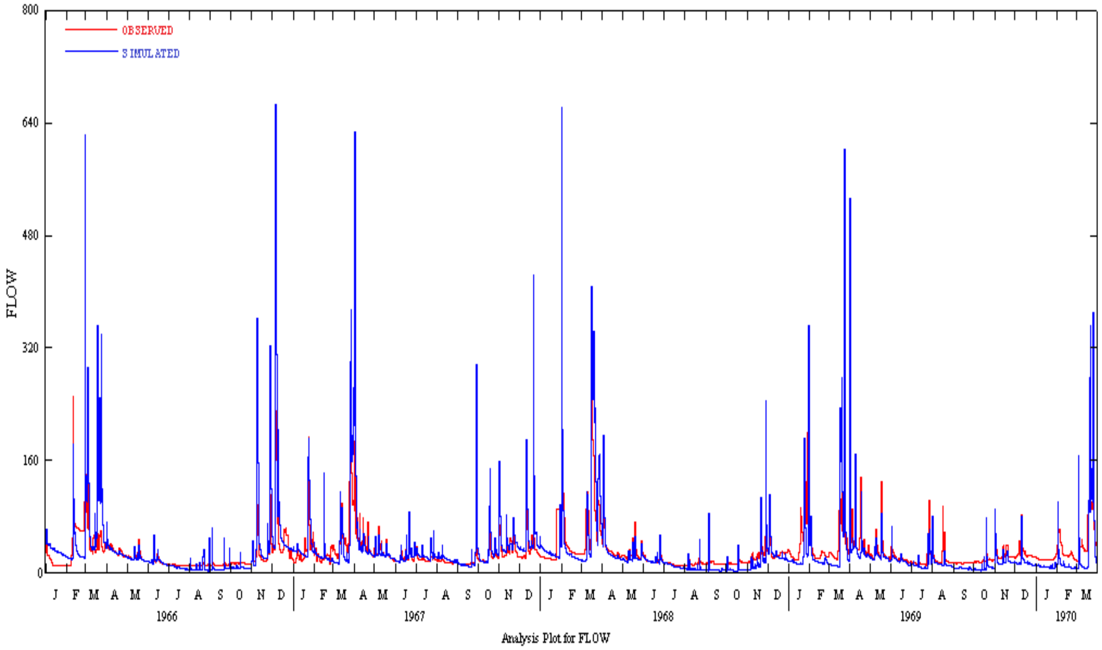
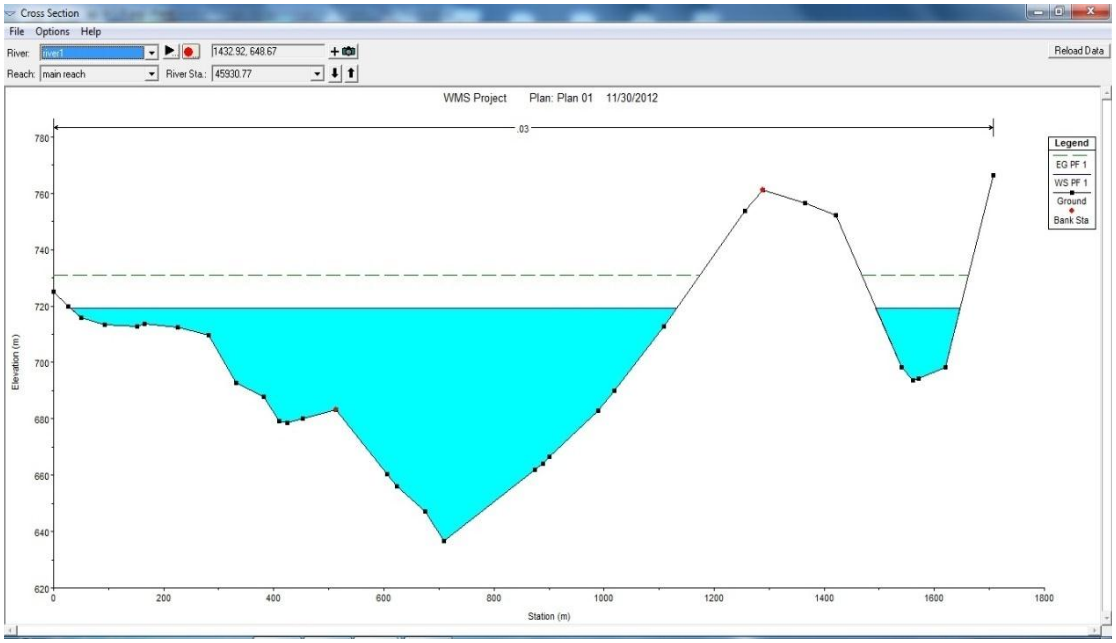


Fig 7. Graph showing comparison between simulated and observed flow for validation period.



River: river1

1432.92, 648.67

Reach: main reach

River Sta.: 45930.77

WMS Project Plan: Plan 01 11/30/2012

Fig 8. Cross section of River Indus showing inundation

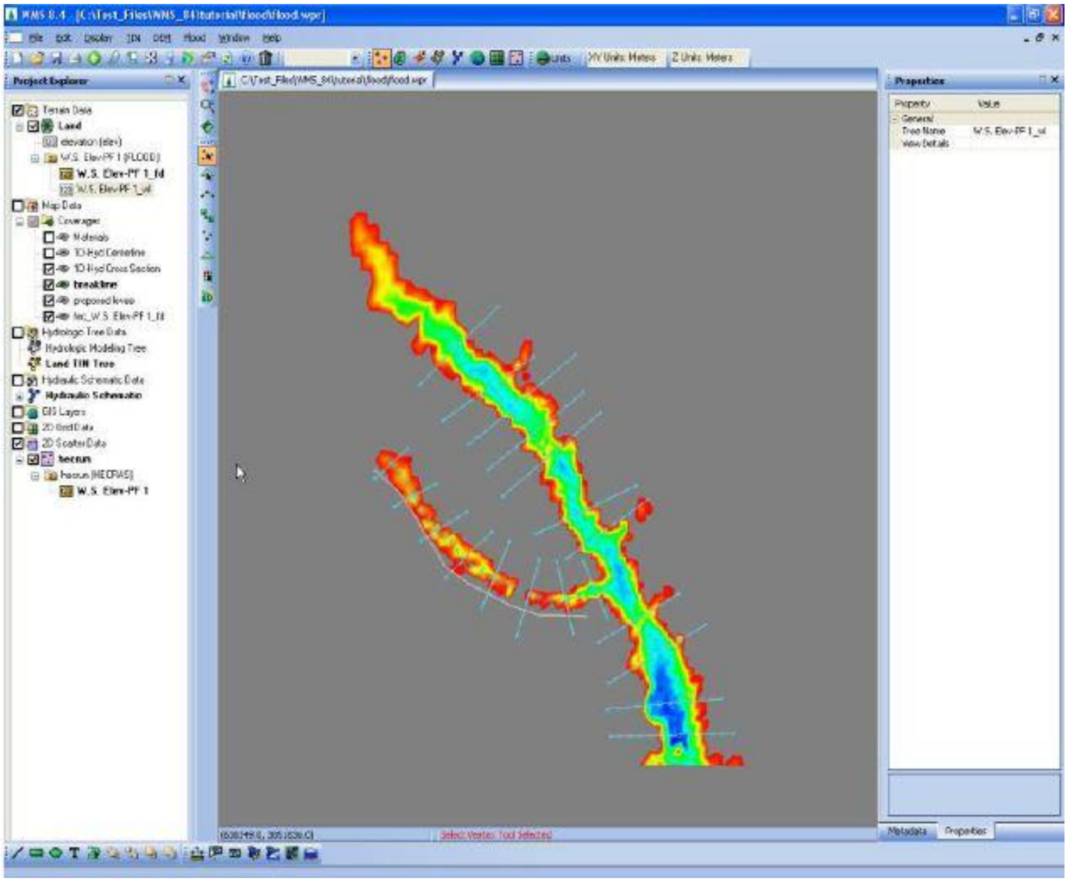


Fig 9. Inundation map of the study area.

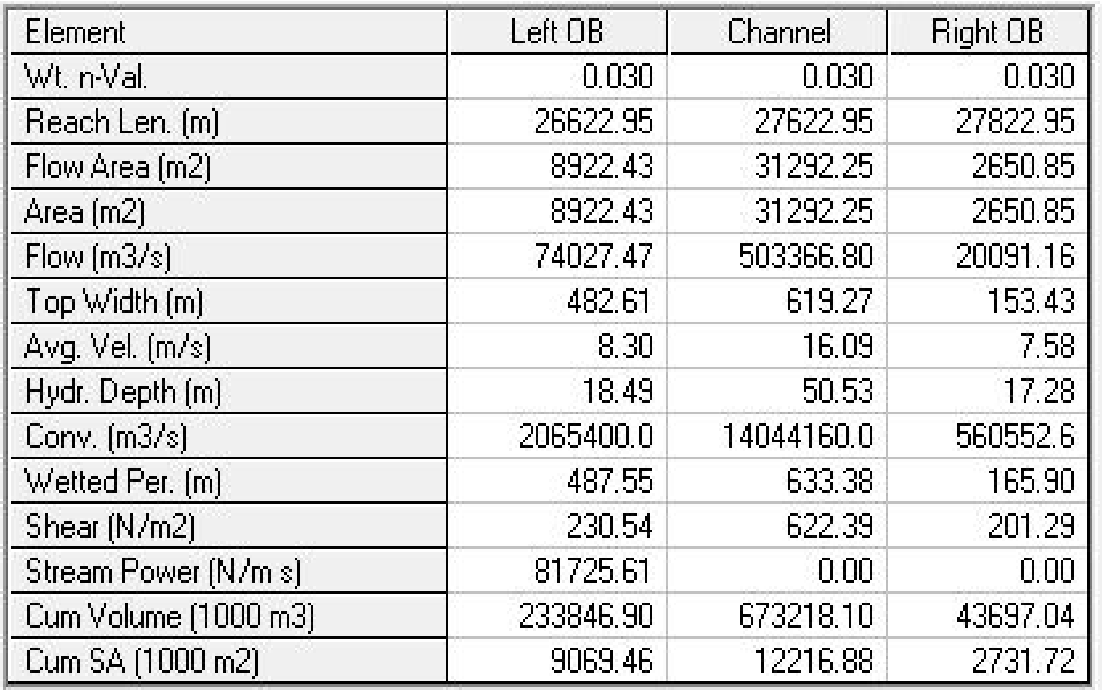
Table 1. Adjusted values of parameters in PWATER used for calibration of HSPF

PARAMETER	FUNCTION	VALUE
LZSN	Lower zone nominal moisture storage	6.5
INFILT	Index to mean soil infiltration rate	0.16
LSUR	Length of overland flow plane	150
SLSUR	Slope of overland flow plane	0.56
KVARY	Ground water recession flow meter	0.0
AGWRC	Ground water recession rate	0.98
DEEPFR	Fraction of water lost to deep percolation	0.1
BASETP	ET due to riparian vegetation	0.02
AGWETP	ET directly from ground water	0.0
CEPSC	Fraction of precipitation retained by vegetation	0.1
UZSN	Upper zone nominal moisture storage	1.128
NSUR	Manning’s ‘n’ for overland flow	0.2
INTFW	Water infiltrated for interflow	0.75
IRC	Interflow recession coefficient	0.5
LZETP	ET directly from the lower zone	0.1

Table 2. Average annual water budget

HYDROLOGIC COMPONENT (in)	YEAR				
	1998	1999	2000	2001	2002
RAINFALL	10.8	14.24	11.19	11.36	11.11
SURFACE	1.8	2.53	2.14	1.78	0.33
INTERFLOW	1.77	2.4	2.1	2.65	1.32
BASEFLOW	0.67	0.84	0.6	0.97	0.69
DEEP GROUNDWATER	0.98	1.21	0.94	1.18	1.12
TOTAL ET	5.56	7.28	5.39	4.72	7.71
% ET	51.48	51.12	48.1	41.54	69.39

Table 3. HEC-RAS output showing inundation area and other parameters



Element	Left OB	Channel	Right OB
Wt. n-Val.	0.030	0.030	0.030
Reach Len. (m)	26622.95	27622.95	27822.95
Flow Area (m2)	8922.43	31292.25	2650.85
Area (m2)	8922.43	31292.25	2650.85
Flow (m3/s)	74027.47	503366.80	20091.16
Top Width (m)	482.61	619.27	153.43
Avg. Vel. (m/s)	8.30	16.09	7.58
Hydr. Depth (m)	18.49	50.53	17.28
Conv. (m3/s)	2065400.0	14044160.0	560552.6
Wetted Per. (m)	487.55	633.38	165.90
Shear (N/m2)	230.54	622.39	201.29
Stream Power (N/m s)	81725.61	0.00	0.00
Cum Volume (1000 m3)	233846.90	673218.10	43697.04
Cum SA (1000 m2)	9069.46	12216.88	2731.72