

Floodplain Modeling in the Kansas River Basin Using Hydrologic Engineering Center (HEC) Models

Impacts of Urbanization and
Wetlands for Mitigation

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1. INTRODUCTION AND BACKGROUND INFORMATION

1.1. OVERVIEW

Flooding is a major natural hazard which every year impacts different regions across the world. Between 2000 and 2008, various types of natural hazards, mainly floods have affected the largest number of people worldwide, averaging 99 million people per year (WDR, 2010). In the United States from 1972 to 2006, the value of property losses due to a catastrophic flood events average about \$80 million (Changnon, 2008). In terms of human life, these catastrophic floods on an average kill about 140 people each year in the US (USGS, 2006). Climate change is expected to enhance the risk of extreme storm events (Milly et al., 2002). In addition, the frequency of flash floods and large-area floods in many regions is very likely to increase (Parry et al., 2007 & Alley et al., 2003). These dangers are exacerbated by rapid urbanization occurring across the world (UN, 2010). In the United States, there was a 34% increase in the amount of land devoted to urban and built-up uses between 1982 and 1997 (USDA, 2001). Urbanization generally increases the size and frequency of floods and may expose communities to increasing flood hazards (Parker, 2000; USGS, 2003). These developments have placed a renewed emphasis on the prediction of flood levels and damages, mainly for the purpose of disaster management and urban and regional planning (Milly et al., 2008).

Studies show that the state of Kansas ranks high among the US states with highest losses due to floods (Changnon, 2008). With increasing population growth and urban development, the likelihood of exposure to flood damage is rising. One of the most effective ways of assessing the flood risk to people and property is through the production of flood models, which show areas prone to flooding events of known return periods. The objectives of this study are: 1) to evaluate the impacts of future land use change in the backdrop of 100 year design storms (considered to be the most extreme storm event), on the peak runoff and flood inundation extents for the Kansas River, and 2) to evaluate the potential role of wetlands in flood attenuation. To mitigate flood risk, reservoirs and levees are used. In recent years, wetlands have been studied for flood attenuation and water quality improvement (Mitsch et al., 2001; Crumpton et al., 2007). Wetlands have the capability of short term surface water storage, and can reduce downstream flood peaks. In addition, wetlands have biological, wildlife habitat and water quality benefits. (Lewis, 1995, Hey and Philippi, 1995, Wamsley et al., 2010).

In this study, Hydrologic Engineering Center (HEC) tools are used to accomplish the research objectives. Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) is used to build the hydrologic model while Hydrologic Engineering Center-River Analysis System (HEC-RAS) is used to build the hydraulic model. These tools are commonly used and have been employed for conducting various types of studies including building flood forecasting and flood inundation models (Knebl et al., 2005; Whiteaker et al., 2006), analyzing different flood control alternatives (Benavides et al., 2001), addressing social impacts of small dam removals (Wyrick et al., 2009), and developing a flood early warning system (Matkan et al., 2009). This study uses these tools to highlight the flooding potential for the Kansas River region as a result of urbanization and extreme rainfall events, and evaluates the potential of using wetlands as a mitigation option.

The Kansas River has been prone to flooding over the last century. It has faced significant flood events in 1951 and 1993. The damages from the 1951 flood were extraordinary. Nineteen people were killed and about 1100 injured with total damage estimates as high as \$2.5 billion. During the height of the flood, on July 13, 1951, nearly 90 percent of the flow in the Missouri River at Kansas City came from the Kansas River, a tributary comprising only 12% of the Missouri's drainage basin (USGS, 2001). The historic 1993 floods affected nine states and resulted in \$15 billion worth of flood damages. From July 22 to July 24, 50 to 330 mm (2 to 13 inches) of rain fell in parts of Kansas and Nebraska, contributing large inflows to already full reservoirs in the Kansas basin. Eighteen of the 163 USGS stream gages in operation in Kansas during 1993 measured record maximum peak daily flows and 69 stations measured the highest mean annual streamflow during their period of record for Water Year 1993 (USGS, 2003).

The remainder of the report is organized as follows. In the next parts of Section 1, the study area and the data sources are discussed. In Section 2, a description of the HEC tools is given, and an outline of the methods and procedures for model building using HEC tools is given in Section 3. In Section 4, scenarios for the future period are discussed, and a description of the results of simulations for those future scenarios is given in Section 5. The conclusions of the study are given in Section 6.

1.2. WATERSHED DESCRIPTION

The Kansas River is located in northeastern corner of the state of Kansas. It is formed by the union of the Republican River and the Smoky Hill River, just east of Junction City, Kansas. From there, the river flows 273 km (170 miles) to Kansas City where it discharges into the Missouri River. The River Valley is 222 km (138 miles) long. The surplus length is due the river meandering across the Valley. The river drops about 98 m (320 ft) from its starting point and has a slope of less than 0.6 m per km (2 feet per mile). The river valley averages 4.2 km (2.6 miles) in width and its widest stretch is between Wamego and Rossville, where it is up to 6.4 km (4 miles) wide. Below Eudora, the valley narrows to less than half the maximum width, 2.4 km (1.5 miles) and in parts of this reach the valley is 1.6 km (1 mile) or less in width (KGS, 1998). Land use throughout the study area is primarily agricultural (cropland and grassland) with some urban areas including Junction City, Manhattan, Topeka, Lawrence, and Kansas City, Kansas. Counties adjacent to the Kansas River support a growing population of nearly 800,000 people (USGS, 2005).

The river is composed of four 8-digit Hydrologic Unit Code (HUC) cataloging units. These include HUC 10270101 Upper Kansas watershed, HUC 10270102 Middle Kansas watershed, HUC 10270103 Delaware River watershed, and HUC 10270104 Lower Kansas watershed. The location of the study area within the USA is shown in Figure 1. Figure 2 shows the location of the Kansas River within the basin, with river flowing from left to right direction.



FIGURE 1. Location of the study area in Kansas state, USA.

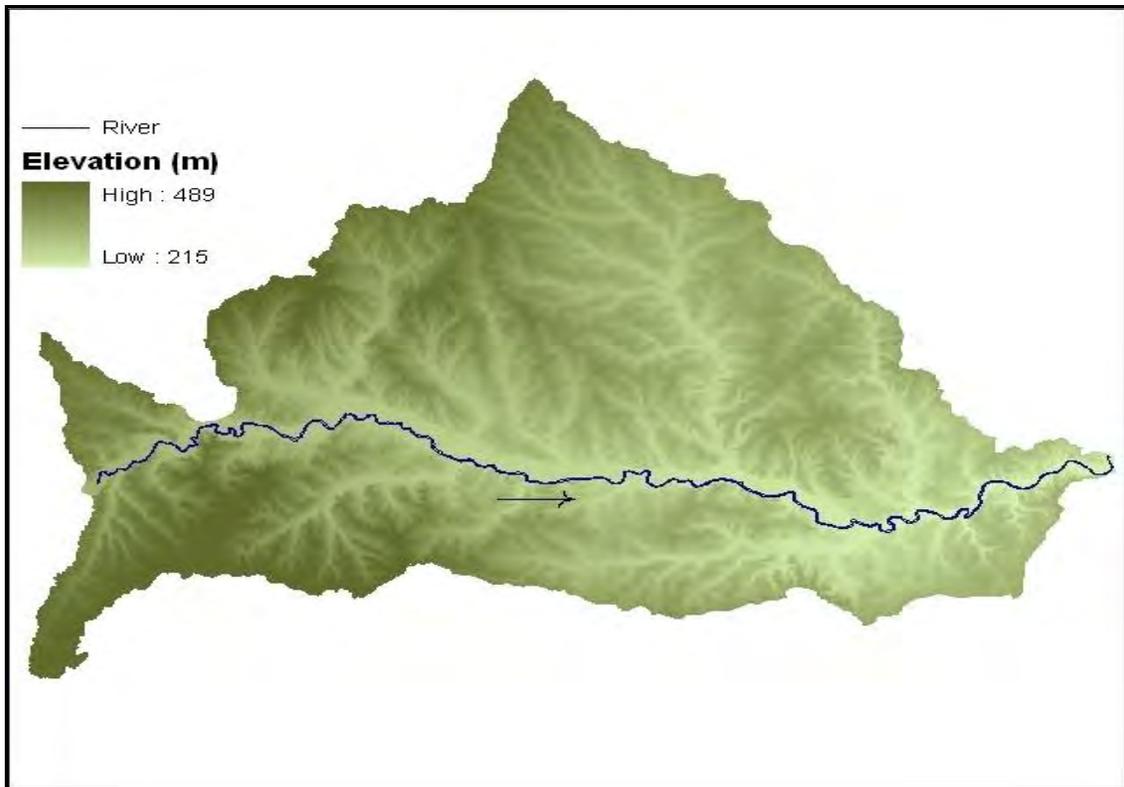


FIGURE 2. Location of the Kansas River within Kansas River basin. Arrow denotes the direction of flow.

1.3. MONITORING & OTHER AVAILABLE INFORMATION

Different datasets were used to build the model. These include the elevation, streamflow, precipitation, soil classification and land use data. The different datasets and their sources are given in Table 1.

TABLE 1. Datasets and their sources used for building the models

Datasets	Source
Elevation	United States Geological Survey (USGS)
Streamflow	United States Geological Survey (USGS)
Precipitation	National Climatic Data Center (NCDC)
Soil Classification	Soil Survey Geographic Database (SSURGO)
Landuse	National Land Cover Database (NLCD)

2. HEC-MODELS-BRIEF OVERVIEW

2.1. HEC-HMS

2.1.1. Tool Description

The Hydrologic Engineering Centers Hydrologic Modeling System (HEC-HMS) simulates the precipitation-runoff processes of watershed systems. HMS uses deterministic mathematical modeling to compute various components of the hydrologic cycle. These are evapotranspiration, precipitation, infiltration, and runoff. Evapotranspiration is the sum of evaporation and plant transpiration from the Earth's surface to the atmosphere: precipitation is the water being released from the clouds as rain: infiltration is the portion of precipitation which after hitting the Earth's surface, seeps through the soil layers: and runoff is precipitation that reaches the Earth's surface but does not infiltrate the soil. HMS is applicable in a wide range of geographic areas for solving the widest possible range of problems including large river basin water supply and flood hydrology, and small urban or natural watershed runoff. Hydrographs produced by HMS are used directly or in conjunction with other software for studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation, and systems operation.

HEC-HMS is a generalized modeling system capable of representing many different watersheds. A model of the watershed is constructed by separating the hydrologic cycle into manageable pieces and constructing boundaries around the watershed of interest. Any part of the cycle can then be represented with a mathematical model. In most cases, several model choices are available for representing each part. Six choices are available for representing infiltration. Seven methods are included for transforming excess precipitation into runoff. Six routing methods are included for simulating flow in open channels. Each mathematical component model included in the tool is suitable in different environments and under different conditions. Making the correct choice requires knowledge of the watershed, the goals of the hydrologic study, and engineering judgment. The program features a completely integrated work environment including a database, data entry utilities, computation engine, and results reporting tools (HEC, 2010a).

INPUTS

The main inputs to the model include

- Watershed stream network and size,
- Infiltration loss method i.e. Initial and Constant, Deficit and Constant, Exponential, Green-Ampt, Smith Parlange, Soil Moisture Accounting, SCS curve Number,
- Transform method for transforming excess precipitation into runoff i.e. SCS, Clark or Snyder unit hydrographs, Kinematic wave, ModClark, User specified unit hydrograph,

- Routing methods i.e. Muskingum, Kinematic Wave, Lag, Modified Puls, Muskingum-Cunge, and Straddle Stagger,
- Meteorologic data i.e. precipitation, and
- The time span of the simulation.

OUTPUTS

The outputs from the model include

- Hydrographs
- Flow Volume

2.1.2. Why the model was selected

The advantages of using HEC-HMS are that it draws on more than 30 years of experience in hydrologic simulation. It is freely available for download from the HEC website and is supported by the US Army Corps of Engineers. It provides a graphical user interface making it easier to use the software and the program is widely used and accepted for many official purposes, such as floodway determination for the Federal Emergency Management Agency (FEMA).

2.2. HEC-RAS

2.2.1. Tool Description

Hydrologic Engineering Centers River Analysis System (HEC-RAS) is a one-dimensional model, intended for hydraulic analysis of river channels. The model is comprised of a graphical user interface, separate hydraulic analysis components, data storage and management capabilities, graphics and reporting facilities. The HEC-RAS system includes four river analysis components. They include the steady flow water surface profile computations, unsteady flow simulation, sediment transport computations and water quality analysis. In addition to these components, the model contains several hydraulic design features that can be invoked once the basic water surface profiles are computed. HEC-RAS applications include floodplain management studies, bridge and culvert analysis and design, and channel modification studies (HEC, 2010b).

INPUTS

The main inputs to the model are

- River geometric data: width, elevation, shape, location, length,
- River floodplain data: length, elevation,
- The distance between successive river cross-sections,
- Manning 'n' value for the landuse type covering the river and the floodplain area,
- Boundary conditions e.g. slope, critical depth,
- Stream discharge values.

OUTPUTS

The outputs from the model include

- Water surface elevations
- Rating curves
- Hydraulic properties i.e. energy grade line slope and elevation, flow area, velocity
- Visualization of stream flow, which shows the extent of flooding

2.2.2. Why the model was selected

HEC-RAS has been present in the public realm for more than 15 years and has been peer reviewed (HEC, 2010c). It is freely available for download from the HEC website and is supported by the US Army Corps of Engineers. It is also widely used by many government agencies and private firms. For these reasons, HEC-RAS was selected for this study.

3. METHOD AND PROCEDURES

Two models were generated, a hydrologic model using HEC-HMS and a hydraulic model using HEC-RAS. Then using USGS stream gage and NCDC weather station data, the models were calibrated and validated for different historic storm events. Future land use scenarios are developed in GIS for the years 2020, 2030 and 2040 using the ICLUS tool (ICLUS, 2010) with increasing levels of urban land use. To evaluate the impact of land use changes on runoff, the hydrologic model was used to generate runoff for the SCS 100 year 24-hour design storms for different land use scenarios. The hydrologic model runoff estimates were used in the hydraulic model, to generate the flooding extents for the different land use scenarios. Finally, the potential of wetlands for flood mitigation were evaluated. Wetlands were simulated using the hydrologic model.

3.1. HYDROLOGIC MODEL BUILDING

There are multiple ways of creating a watershed stream network and specifying its properties in HEC-HMS. The user can either develop the network manually in HEC-HMS or develop it in GIS or use a combination of the two in which the watershed network is developed in HMS, while its properties are derived in GIS. For developing the watershed properties, topographic data is needed which maybe obtained through a physical site survey or through geospatial datasets such as the Digital Elevation Models (DEM). A DEM is continuous spatial representation of the earth's surface. Traditionally watershed characteristics were obtained from maps or field surveys which are time consuming and expensive. Currently DEMs are widely used for developing the watershed characteristics (Garbrecht and Martz, 1999). For this project, a DEM was used to develop elevation related characteristics for the study site with the help of a GIS based tool called Geospatial Hydrologic Modeling Extension (HEC-GeoHMS).

HEC-GeoHMS is a geospatial hydrology toolkit designed to prepare data for HEC-HMS simulations. The program allows users to visualize spatial information, document watershed characteristics, perform spatial analysis, delineate subbasins and streams, construct inputs to hydrologic models and assist with report preparations. HEC-GeoHMS creates input files which can be used for HEC-HMS simulations. To assist with estimating hydrologic parameters, HEC-GeoHMS can generate tables containing physical characteristics of streams and watersheds which are shown in Table 2 (HEC, 2010d).

TABLE 2. Physical characteristics generated by HEC-GeoHMS

Characteristics	
Stream	Length, Slope, Downstream Connection
Watershed	Area, Slope, Curve Number, Lag Time

HEC-GeoHMS Processing:

For the DEM to be used in GeoHMS, it must first be processed to create certain required layers. These include the flow direction, flow accumulation, stream, stream segments, slope grid, catchment grid delineation, catchment polygon, drainage line and adjoint catchment layers. These layers can be created using either the ArcHydro Tools or the Spatial Analyst extension in

GIS. The layers are used for further GeoHMS processing, for which the procedure is as follows (HEC, 2009): the procedure is helpful to assist in replicating the study.

Starting a Project

- In GeoHMS, select the Data Management function and confirm or define the layers created using the ArcHydro Tools or the Spatial Analyst extension.
- Creating a new project in HEC-GeoHMS by using the Start New Project function which will create two new feature classes, ProjectArea and ProjectPoint.
- Select the Add Project Point tool, define the outlet for the watershed.
- Select the Generate Project function to create a project for the study area.

Deriving Watershed Characteristics

- Use the Batch Subwatershed Delineation command to delineate subbasins at USGS gage points or at any similar points of interest. Then use the Merge Basins command to merge basins upstream of the gages or points of interest, in order to have one subbasin for each gage. The subbasins are stored in the Subbasin layer which is derived from the Catchment Grid layer created earlier.
- Running the River Length function to compute the length of river segments
- Running the River Slope function to compute slope of river segments.
- Running the Basin Slope function to compute the average slope for the subbasins using a slope grid and subbasins polygons.
- Running the Longest Flow Path function to create a polyline layer which stores the longest flowpath for each subbasin.
- Running the Basin Centroid function to create point layer to store the centroid of each subbasin. Choose the center of gravity method from among the options. Check if the centroid locations are reasonable, if not edit them.
- Running the Basin Centroid Elevation function to compute the elevation of each centroid using the underlying DEM.
- Running the Centroidal Flow Path function to create a new polyline layer showing the flowpath of each centroid point along the longest flowpath. This finishes the part of deriving the basin's properties.

HMS Parameters In GeoHMS

- HMS parameters can also be specified in GeoHMS through the Hydrologic Parameters tab. They can be changed later on in HMS if the need arises.
- Select the HMS Processes function, and choose the appropriate loss method, the transform method, the baseflow type and the routing method. The SCS method is selected as the both the loss method, and the transform method because of available inputs and GeoHMS's ability to compute them, baseflow was computed outside HMS using the constant discharge method and Muskingum is selected as the routing method.
- Running the River Auto Name and the Basin Auto Name functions to assign names to river segments and sub-basins for HMS.
- Select Subbasin Parameters from the menu of parameters. Choose the Basin Curve Number and its associated Curve Number Grid file. After the computations are

complete, the attribute table for the sub-basin layer will show a field named BasinCN which is populated with the average curve number for each sub-basin. The curve number grid file for the watershed has to be prepared beforehand. The production of the curve number grid file requires the land use, collected from the NLCD database, and soil classification data, from the SSURGO database. Figure 3 shows a curve number grid for the study region. The curve number calculation is a part of the loss method.

- Running the CN Lag Method function. The BasinLag field in the subbasin feature class will be populated with numbers that represent basin lag time in hours. The lag time parameter is a part of the transform method.
- Running Map to HMS units to convert units and prepare them for use in HMS.
- Use the Check Data function to verify that all the input datasets are in order. A log file is created and the errors if any can be pinpointed and removed.

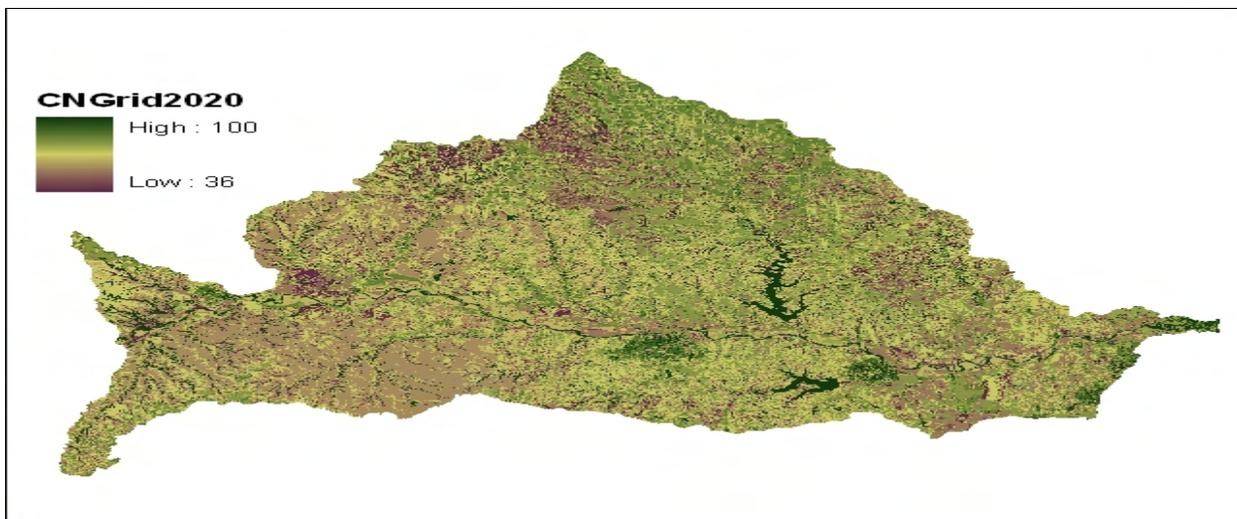


FIGURE 3. Curve Number Grid developed in HEC-GeoHMS for the Kansas River basin.

GeoHMS Data Export to HMS

- Select the HMS Schematic to create a GIS representation of the hydrologic system using a schematic network with basin elements and their connectivity. Two new feature classes HMSLink and HMSNode are added to the map document.
- After the schematic is created, you can see how this model will look like in HEC-HMS by toggling between regular and HMS legend. Select Toggle HMS Legend.
- Select the Add Coordinates function. This tool attaches geographic coordinates (latitude, longitude) to features in HMSLink and HMSNode feature classes.
- Select Prepare Data for Model Export to allow the preparation of subbasin and river features for export.
- Create the Background Map File and the Basin Map File.
- Select HMS Project Setup. This function copies all the project specific files that were created to a specified directory, and creates a .hms file containing information on other files, for input to HMS.
- Open HEC-HMS and locate the .hms file created. The basin file will be added to the program. There is a possibility that the basin file created does not properly represent

the watershed network and has some errors. In that case, create the watershed network manually in HEC-HMS through its toolbar and use the data generated in GeoHMS for the basin, to populate the watershed characteristics in HMS.

3.1.1. HMS Parameters

An HMS model requires three main input process parameters. Among them is the precipitation loss method for overland flow, which accounts for the infiltration losses. There are multiple methods available in HMS including Initial and Constant, Deficit and Constant, Exponential, SCS Curve Number, Green-Ampt, Smith Parlange and Soil Moisture Accounting. As mentioned in the GeoHMS section, the SCS curve number method is selected for this process, whose values are computed from the curve number grid. The curve number values for the different land use classes were taken from KDOT, 2003 and are shown in Table 3.

TABLE 3. Curve Numbers for NLCD land use classes and SSURGO hydrologic soil groups

Land Use Description	NLCD Class	A	B	C	D
Open Water	11	100	100	100	100
Developed Open Space	21	39	61	74	80
Developed, Low Intensity	22	57	72	81	86
Developed, Medium Intensity	23	77	85	90	92
Developed, High Intensity	24	98	98	98	98
Barren Land, Rock, Sand, Clay	31	63	77	85	88
Deciduous Forest	41	36	60	73	79
Mixed Forest	43	36	60	73	79
Scrub/Shrub	52	35	56	70	77
Grasslands, Herbaceous	71	39	61	74	80
Pasture, Hay	81	49	69	79	84
Cultivated Crops	82	67	78	85	89
Woody Wetlands	90	36	60	73	79
Palustrine Forested Wetlands	91	49	69	79	84
Emergent Herbaceous Wetlands	95	49	69	79	84

After the precipitation losses are accounted, a transform method must be specified for transforming overland flow into surface runoff. Different methods are available for the transform method in HMS including SCS, Clark or Snyder unit hydrographs, Kinematic wave, ModClark and User specified unit hydrograph. As mentioned in the GeoHMS section, SCS unit hydrograph method was selected. The Clark and Snyder methods both require two parameters, while SCS method just requires one parameter, as it assumes the shape of the unit hydrograph. The Clark or Snyder methods permit more flexibility in determining the shape of the hydrograph, but the parameters are more difficult to estimate. In the SCS method, 37.5% of the runoff volume occurs before the peak flow, and the lag time can be approximated by taking 60% of the time of concentration. The lag time is the length of time between the centroid of rainfall excess and the peak flow of the resulting hydrograph, whose values were computed using the CN Lag Time function in GeoHMS (HEC, 2010e).

Once excess precipitation has been transformed into overland runoff and routed to the outlet of a subwatershed, it enters the stream at that point and is added to streamflow routed from upstream. There are several methods available in HMS for streamflow routing including Kinematic Wave, Lag, Modified Puls, Muskingum, Muskingum-Cunge, and Straddle Stagger. As mentioned in the GeoHMS section, the Muskingum method was selected for this process.

The Muskingum method has different parameters K , X and number of subreaches (n) which need to be specified. Muskingum K is essentially travel time through the reach. Muskingum X is the weighting between inflow and outflow influence, it ranges from 0 to 0.5. The number of subreaches affects attenuation where one subreach gives more attenuation and increasing the number of sub reaches decreases the attenuation. K (hrs) is approximately equal to $L/3600v$, where L = length of river (m), v = reach velocity (m/s). The minimum number of reaches is estimated by $n = \text{int}(2x(L/60v)/\Delta t)$ and the maximum number of subreaches is estimated by $n = \text{int}((L/60v)/ \Delta t)$, where Δt = time of simulation (Oliviera, 1999).

The rest of the steps necessary for completing an HMS model are described below:

Create a meteorologic model file in HMS from the Meteorologic Model Manager in the Components tab and specify the rainfall. Select the Specified Hyetograph option and then use the Time Series Data Manager in the Components tab to create a Precipitation Gage for the watershed. Specify the rainfall event in the Precipitation Gage. Multiple Precipitation Gages can be created and assigned to the different subbasins in the watershed.

Create the Control specifications from the Control Specifications Manager in the Components tab in order to set the time period of the simulation run.

HMS has an optimization feature which can be used to calibrate the model. To use this feature, a Discharge Gage containing actual flow values is created from the Time Series Data Manager. The simulated flow can be compared against the Discharge Gage values and the optimization function will automatically calibrate various parameters to match the observed values. The parameters that can be calibrated include Loss functions like initial abstraction and curve cumbers, transform functions like SCS lag, routing functions like Muskingum routing parameters. Otherwise calibration can also be done by changing parameters manually and comparing simulated results with field observations.

Validate the model for other events based on the calibrated parameters.

A simplified representation of the HMS model for Kansas River is shown in Figure 4. The figure shows that the model has 12 subbasins and 4 river reaches. A junction represents the confluence of streams from different subbasins.

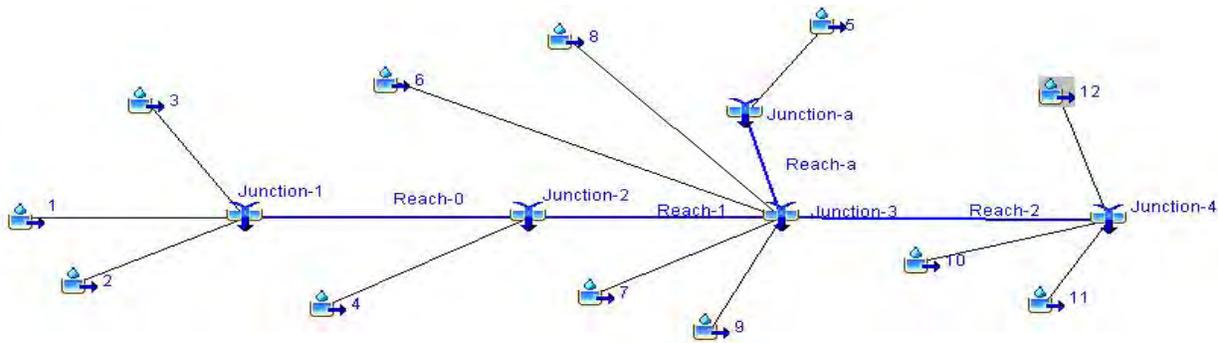


FIGURE 4. Kansas River representation in HMS model.

3.1.2. Soil Data Analysis

As the soil groups in the curve number move from A to D, the difference in curve number values between completely different land use classes decreases. For example, from Table 1, 22 which is developed low intensity and 81 which is pasture/hay, have a curve number difference of 8 for group A but this curve number difference decreases to 2 for group D. So, if the area has a higher number of soil groups C and D, the difference in runoff between the present and future scenarios will be less. Table 4 shows the percentage share of the soil groups for the Kansas River basin.

TABLE 4. Percentage of hydrologic soil groups at the Kansas River Basin

Soil Group	% Area Cover
A	0.278
B	23.81
C	35.933
D	39.39
C/D	0.587

3.1.3. HEC-HMS Calibration Approach

It is difficult to calibrate a hydrologic model, especially for a large watershed. Complete knowledge of antecedent conditions such as soil moisture content and the level of water in wetlands, for instance, are not available. Calibrating on a major flood event does not guarantee that the model will accurately simulate another flood event even when they are of the same magnitude (Bengtson and Padmanabhan, 1999). Keeping this difficulty in mind, multiple peak flow events were selected for calibration. The USGS gage on the downstream most side of the river, Gage 06892350 Kansas River at Desoto, KS, was selected for calibrating the model. Hourly Runoff data was collected from the USGS Instantaneous Data Archive, which had stream flow records available from 1991 onwards. Hourly Precipitation data was collected from the NCDC weather stations.

3.2. HYDRAULIC MODEL BUILDING

There are two main ways for specifying the inputs to build a model in HEC-RAS. One is to do a physical survey of the study site, and collect data manually regarding the river geometry. The other way is to use geospatial datasets like Digital Elevation Models (DEM) and develop the geometric data in GIS. DEMs are freely available for download online and can be processed relatively easily to extract the geometric data. Accordingly, a DEM was used to prepare geometric data for the study site. This was done using a GIS based tool called HEC-GeoRAS.

HEC-GeoRAS is a set of GIS based utilities for processing geospatial data in ArcGIS using a graphical user interface. The interface aids the preparation of geometric data for import into HEC-RAS and processes simulation results exported from HEC-RAS. The user creates a series of line themes or layers pertinent to developing geometric data for HEC-RAS. The required themes are the Stream Centerline, Flow Path Centerlines, Main Channel Banks, and Cross Section Cut Lines referred to as the RAS Themes. Additional RAS Themes may be created to extract additional geometric data for import in HEC-RAS. These themes include Land Use, Levee Alignment, Ineffective Flow Areas, and Storage Areas (HEC, 2010f).

3.2.1. Hydraulic Geometry Considerations

The hydraulic geometry of the river is essential for accurate model simulations and is basically dependent on the DEM. DEMs are available mainly in two resolutions; 10 m and 30 m. Ten metre profile DEMs capture more geomorphologic detail and have better elevation accuracy than the 30 m DEM (Blackwell & Wells, 2010) as shown in 5. Consequently a 10 m DEM was used for the study.

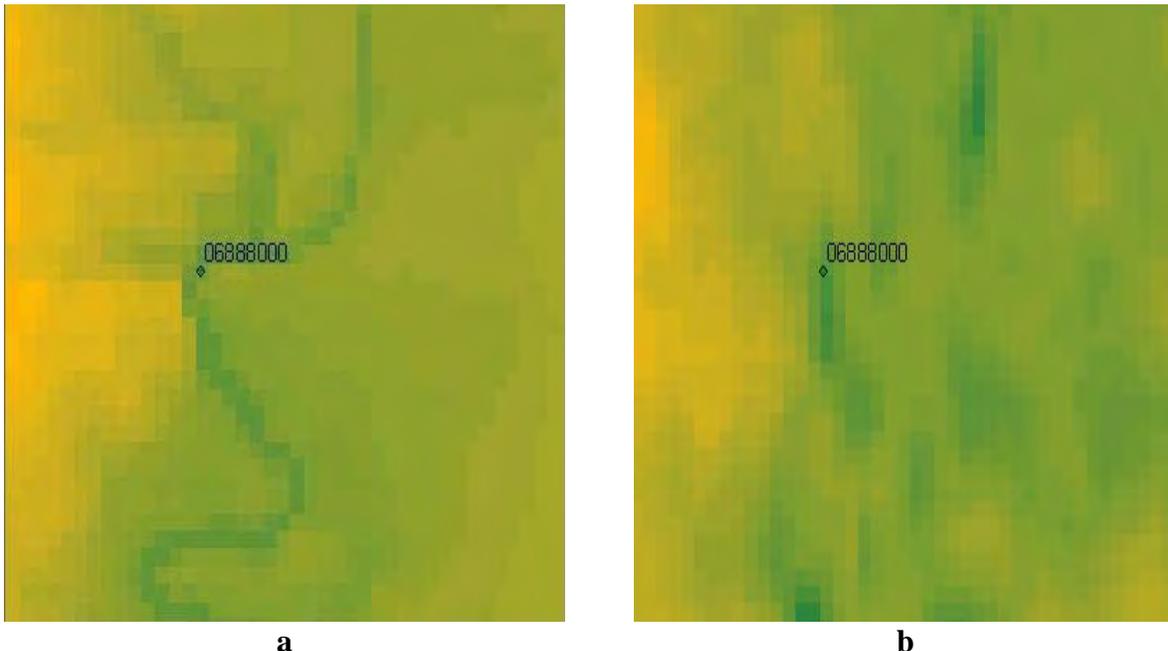


FIGURE 5 (a) Digital Elevation Model example from Kansas River Basin at 10m resolution. **(b)** Digital Elevation Model example from Kansas River Basin at 30m resolution.

3.2.2. HEC-GeoRAS Processing

To create the geometric data file for HEC-RAS, HEC-GeoRAS requires a digital terrain model of the river system in the Triangulated Irregular Network (TIN) format. The DEM file was converted to the TIN format using the 3D Analyst toolbox in ArcGIS. After conversion, the procedure for extracting the geometric data in HEC-GeoRAS is as follows: the procedure is useful if someone would want to conduct a similar study,

River Digitization

- Create empty GIS layers for the Stream Centerline, Bank Lines, Flow Path Centerlines and XS Cut Lines
- In the editor mode, use the Sketch tool to digitize the centerline of the river from upstream to the downstream direction. Aerial photographs and topographical datasets are helpful guides to pinpoint the path of a stream, but usually its path is noticeable on the DEM due to its lower elevation.
- Complete the centerline attributes commands in the RAS Geometry Tab of HEC-GeoRAS to populate the missing fields of the new layer. A river may also have more than one reach.
- Similarly in the editor mode, digitize the River Banks, Flow Path Centerlines and XS Cut Lines using the Sketch tool.
- Complete their attributes commands in the RAS Geometry Tab of HEC-GeoRAS to populate the missing fields of the new layers. Figure 6 shows a sample of the different layers in HEC-GeoRAS.
- Bank lines are used to distinguish the main channel from the overbank floodplain areas. The flow path lines are used to determine the downstream reach lengths between cross-sections in the main channel and over bank areas. Cross-section cutlines are used to extract the elevation data from the terrain to create a ground profile across channel flow. The intersection of cutlines with other RAS layers such as centerline and flow path lines are used to compute HEC-RAS attributes such as bank stations (locations that separate main channel from the floodplain), downstream reach lengths (distance between cross-sections) and Mannings n.

GeoRAS Data Export to RAS

- Assign Mannings n value to cross-sections. Land use data file along with Mannings value for those land use types are needed to assign Mannings value to cross-sections. This is not a compulsory step and can also be performed in HEC-RAS, but it is better to do it GeoRAS as it automatically picks the value from the data.
- Creating the GIS import file for HEC-RAS so that it can read the GIS data and create the river geometry. The Layer Setup is first checked to see if the correct layers are selected, then the Export GIS Data function is used to create an export file for use in HEC-RAS.
- This file is then imported in HEC-RAS for building a floodplain model.
- In HEC-RAS, the river geometry is represented by a sequence of cross-sections called river stations. The numbering of the river stations increases from downstream to the upstream side. The distance between adjacent cross-sections is termed the reach length. Each cross-section is defined by a series of lateral and elevation coordinates, which are typically obtained from land surveys or geospatial datasets. The numbering of the lateral coordinates

begins at the left end of the cross-section, (looking downstream) and increases until reaching the right end. (Tate, 1999)

- Calibrate the model for a real peak flow event. The parameters that can be adjusted are the Mannings n value and the boundary conditions like normal or critical depth. The observed water elevations are compared to the simulated ones.
- Validate the model for other events based on the calibrated parameters.

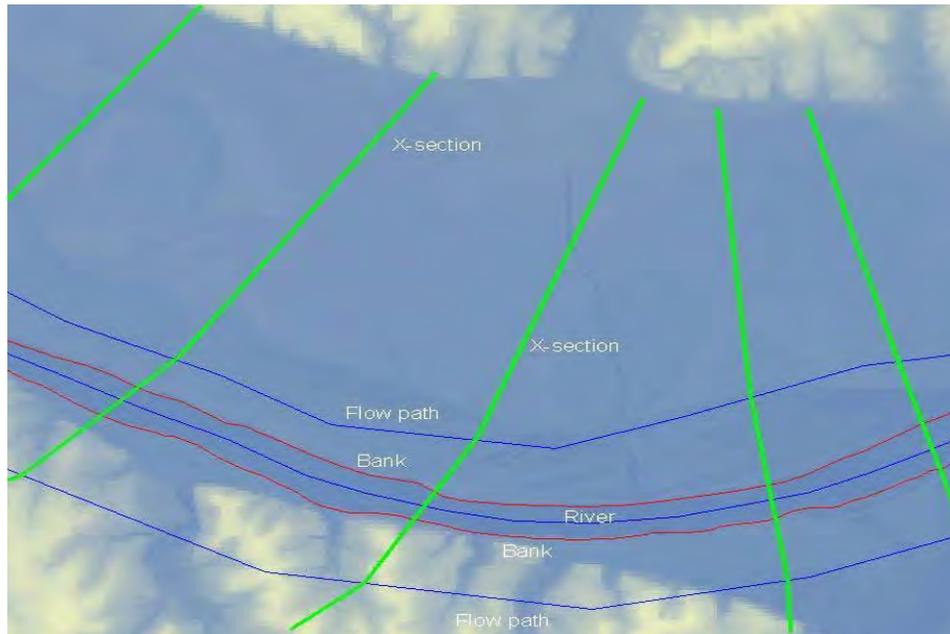


FIGURE 6. A snapshot of River, Banks, Flow Path Centerlines and Cross-section layers for Kansas River in HEC-GeoRAS.

3.2.3. HEC-RAS Calibration Approach

The goal of this project is to create a floodplain model for the Kansas River. This was done in HEC-RAS by setting up a hydraulic model which is to able to simulate historic peak flow water elevations with reasonable accuracy. Once this is completed, the model can be used for floodplain modeling purposes.

USGS flow gages for the Kansas River are used to aid the calibration process. Five gages located on the Kansas River and selected for this process are,

- 06887500 Kansas River at Wamego, KS
- 06888350 Kansas River near Belvue, KS
- 06889000 Kansas River at Topeka, KS
- 06891000 Kansas River at Lecompton, KS
- 06892350 Kansas River at Desoto, KS

The data for a flow gage includes the daily mean flow, the annual peak flow and its associated water surface elevation. Figure 7 shows the location of these gages along the river.

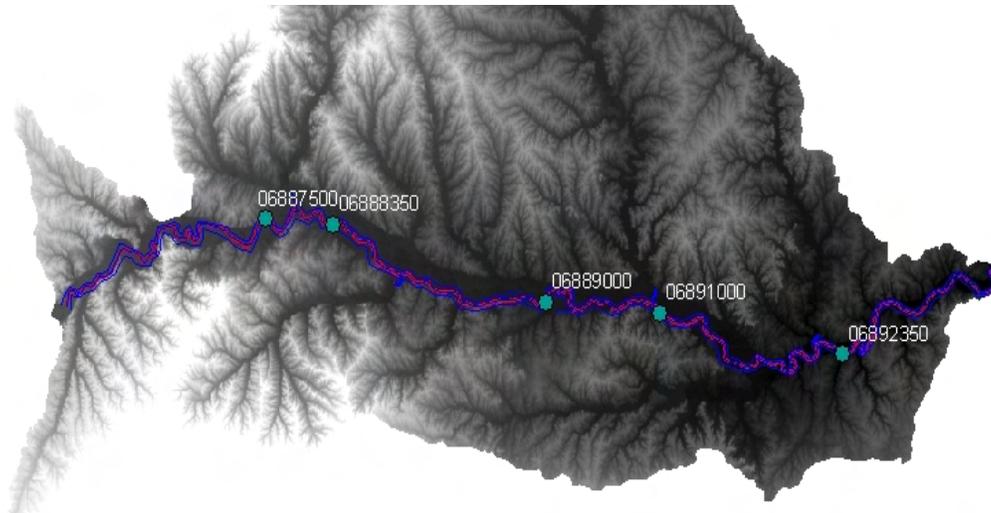


FIGURE 7. Location of USGS gages used for calibration on the Kansas River.

The peak flow data is used for calibrating the model. The main parameter that is changed to calibrate the model is the roughness coefficient, Mannings ‘n’ but boundary conditions like slope can also be changed to calibrate the model. Mannings n values are generalized to a single value for the channel and the over land area, as HEC-RAS has a limitation of 20 points where n values can be specified per cross section and in almost all the instances in this study the cross-sections had more than 20 points. Also, using a Left Bank, Channel, Right Bank simplification makes the calibration process easier and quicker to conduct.

4. FUTURE SCENARIOS

4.1. LAND USE SCENARIOS

To create future land use scenarios, a GIS based tool, Integrated Climate and Land Use Scenarios (ICLUS): ArcGIS Tools and Datasets for Modeling US Housing Density Growth was used. The output from ICLUS was modified to create scenarios representing increasing levels of urban growth and density for the periods 2020, 2030 and 2040. ICLUS was developed by the EPA-ORD-Global Change Research Program at the National Center for Environmental Assessment (ICLUS, 2010). It has multiple scenarios for housing density and population, from which the one giving the highest population was selected. ICLUS output consists of four land use classes, rural, urban, suburban and exurban, while the existing NLCD land use file has 15 land use classes. The ICLUS land use classes exurban, suburban and urban were assumed equal to NLCD urban land use classes 22 (developed low intensity), 23 (developed medium intensity) and 24 (developed high intensity). The ICLUS future output was mosaiced onto the present land use file to create future land use scenarios for simulation.

Four land use scenarios were created for simulation. Baseline scenario used the NLCD 2001 land use file to run the simulation. Scenario 1, used the output from ICLUS for the year 2020, Scenario 2 interchanged the area for the urban land use classes 22 (developed, low intensity) and 23 (developed, medium intensity) for the ICLUS output in 2030. Scenario 3 interchanged the area for the urban land use classes 22 (developed, low intensity) and 24 (developed, high intensity) for the ICLUS output in 2040. When creating the scenarios the focus was on creating scenarios that reflect rising urbanization both in terms of area and density, so that urban land use impacts on surface runoff are discernible. ICLUS outputs for 2030 and 2040 show minimal change in urban land use, which has a negligible impact on future curve numbers, leading to the need for creating more robust urbanization scenarios as represented by Scenarios 2 and 3. Table 5 represents the percentage area share of the different land use classes for the future land use scenarios.

TABLE 5. Percentage area of different NLCD land use classes for the scenarios

Land Use		Scenario (%)			
Class	Description	Baseline	1 (2020)	2 (2030)	3 (2040)
11	Open Water	1.692	1.500	1.496	1.494
21	Developed Open Space	4.961	2.872	2.852	2.845
22	Developed, Low Intensity	2.957	24.742	2.588	0.879
23	Developed, Medium Intensity	0.884	2.497	24.936	2.658
24	Developed, High Intensity	0.368	0.748	0.783	24.947
31	Barren Land, Rock, Sand, Clay	0.153	0.136	0.134	0.134
41	Deciduous Forest	2.502	1.445	1.434	1.430
43	Mixed Forest	4.273	2.512	2.495	2.488
42	Scrub/Shrub	0.799	0.653	0.653	0.652
71	Grasslands, Herbaceous	26.754	22.831	22.801	22.790
81	Pasture, Hay	25.093	17.671	17.560	17.526
82	Cultivated Crops	23.041	17.624	17.520	17.470
90	Woody Wetlands	0.207	0.185	0.185	0.185
91	Palustrine Forested Wetlands	6.183	4.463	4.441	4.433
95	Emergent Herbaceous Wetlands	0.134	0.122	0.122	0.122

4.2. CLIMATE SCENARIOS

For future precipitation, the SCS design storm method was selected. The SCS storm method implements the design storm developed by the Natural Resources Conservation Service (NRCS) (formerly SCS). The SCS hypothetical storm method implements four synthetic rainfall distributions from observed precipitation events. Each distribution is 24 hours long and contains rainfall intensities arranged to maximize the peak runoff for a given total storm depth. The four distributions correspond to different geographical regions. Storms with return periods ranging from 1 to 100 years, and with durations ranging from 30 minutes to 24 hrs are available. The 100 year 24 hour storm is considered to have the severest intensity, and was selected for simulation. Figure 8 shows the approximate geographic boundaries for the rainfall distributions which clearly show that the storm type for Kansas has type 2 distribution. Figure 9 shows the different rainfall depth projections crossing Kansas. The figure shows that the 150, 175 and 200 mm (6, 7 and 8 inch) lines cross the state, and all of them were selected for analysis.

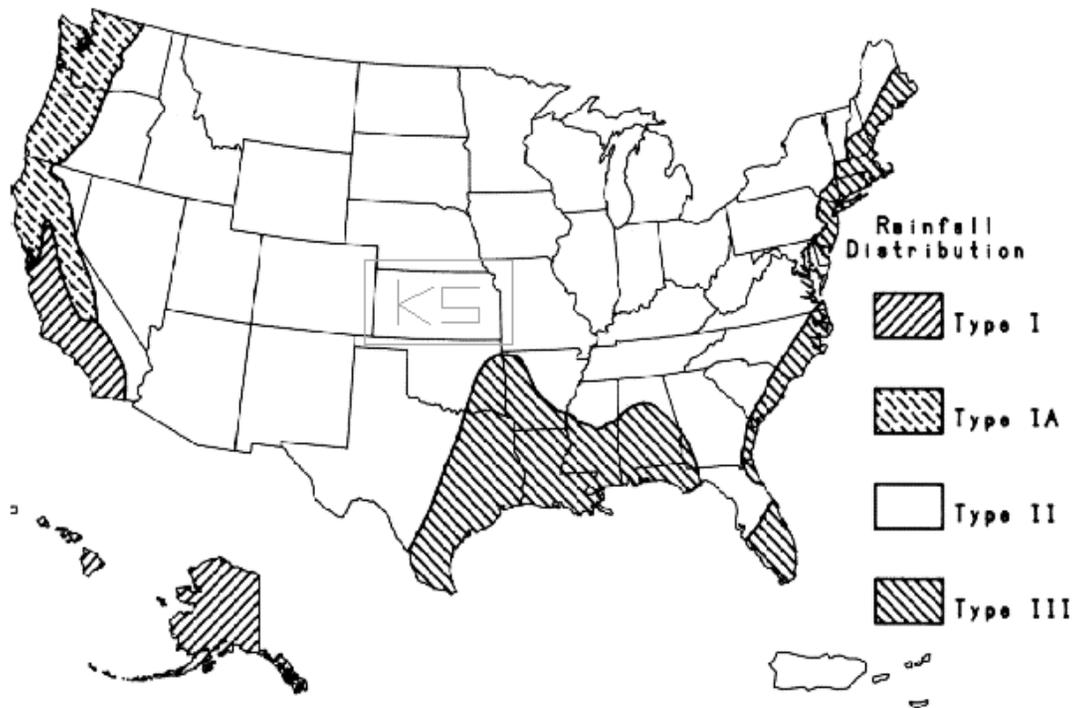


FIGURE 8. Geographic boundaries for Soil Conservation Service (SCS) rainfall distributions

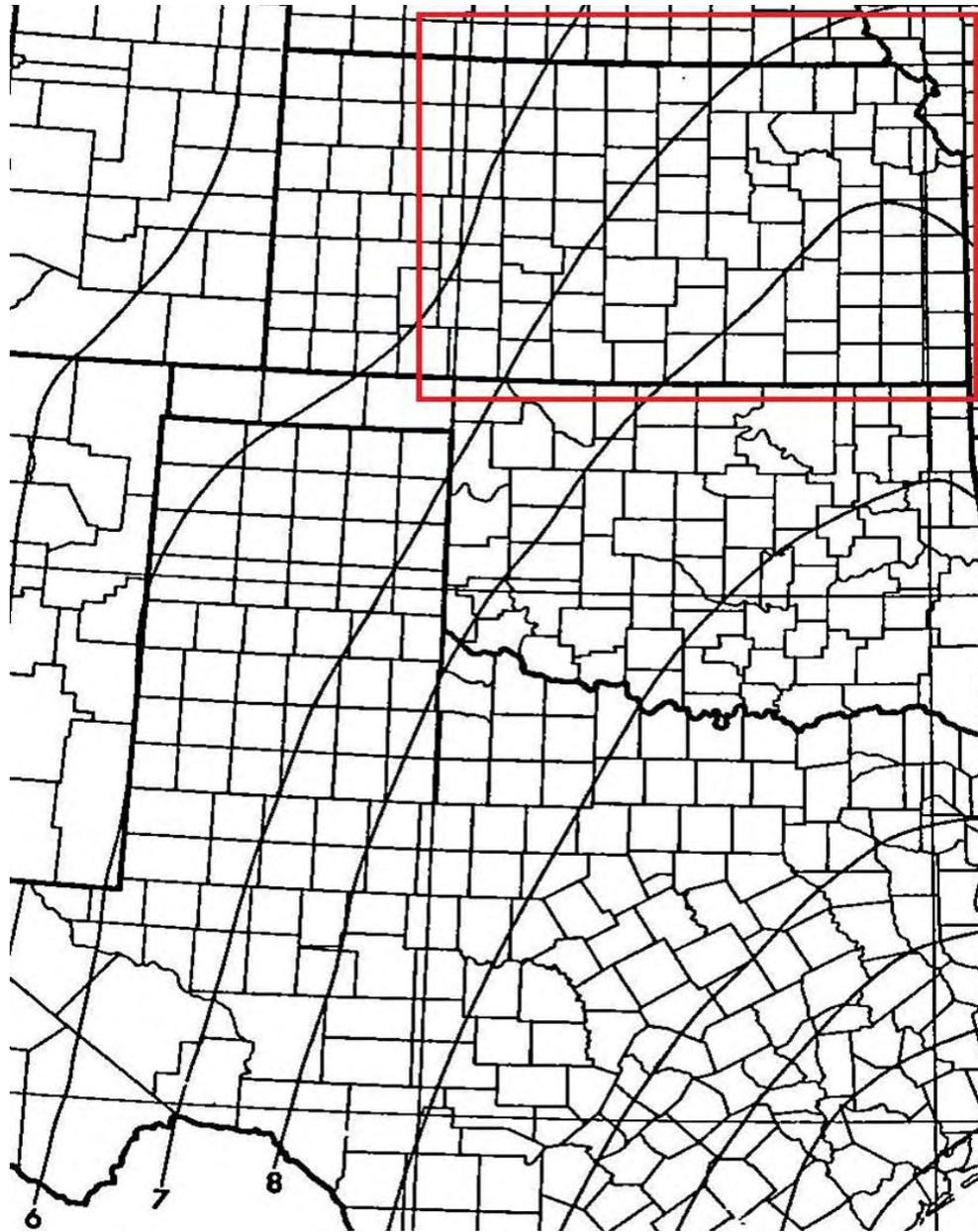


FIGURE 9. 100 Year Return Period, 24 hour duration Precipitation map for Kansas, inches. The red rectangle highlights Kansas state with precipitation contour lines.

4.3. FUTURE WETLANDS SCENARIOS

From ICLUS simulations over the three periods 2020, 2030 and 2040, the average percentage area of wetlands is about 5%, as shown in Table 5, which is obtained by adding the three wetland classes; 90, 91 and 95. Three scenarios were created for the future periods for modeling the effect of wetlands on flooding. The wetland area was increased gradually to 6 % in 2020, 8 % in 2030 and 10 % in 2040. These three scenarios were simulated for the 150 mm (6 inch) storm only and a uniform depth of 0.30 m (1 ft) was assumed for all wetlands for calculating flow volume.

There is no specific module or component for representing wetlands in HMS. They can be represented as a reservoir at the end of a subwatershed, but this would require assuming that all flows in a subwatershed will be caught by the reservoir. In our case, wetlands at different locations in the basin were combined together to simplify their representation in the model. Also, modeling a reservoir would require making some assumptions as the appropriate data for creating a storage-discharge relationship and other factors required for adequately modeling a reservoir in HMS are not available. Wetlands were subsequently modeled using the diversion component in HMS (Bengtson and Padmanabhan, 1999).

A diversion allows a user specified portion of the flow to be diverted and taken out of the system. Diversions permit considerable flexibility in setting the rate of diverted flow to incoming flow and various rates can be modeled. Fixing diversions as a rate of incoming flow can mirror the subwatershed area that contributes to the wetlands. The timing of diversions can be controlled by not allowing water to be diverted until a specific flow is reached. There are two options for diverting water, either flow can start being diverted as soon as runoff is generated, or it can be diverted after a flow magnitude is exceeded. The second case is hypothetical and it would mean assuming that the flows to the wetlands are controlled through some structural adjustments in the watershed. The volume diverted in both the cases would be the same but changing the timing of the diversion would have a different impact on the flood hydrograph. Since our interest is in gauging the effect of wetlands on flood attenuation, the second option was chosen (Juliano and Simonovic, 1999). The total amount of diversion can be set equal to the storage capacity of the wetlands. Once the wetland storage capacity was satisfied, all remaining flow was routed downstream. For modeling diversions, 25 % of the subwatershed peak runoff was set as the diversion rate. Since wetlands cover a maximum of 10 % of the watershed area in the scenarios, this assumption is sufficient for filling the volume of the wetlands. The flow hydrographs from the earlier runs were used as a guide for developing inflow diversion relationships that are required for diversions, with the timing being adjusted in such a manner that the peak flow is impacted.

5. MODEL SIMULATION RESULTS AND DISCUSSION

5.1. HEC-HMS CALIBRATION/VALIDATION

HEC-HMS has an optimization feature which can be used to match the simulated flow with observed flow. The optimization feature was used to carry out the calibration process. It allows for multiple parameter calibration at the same time. Three parameters were selected for calibration. They were the curve number, Muskingum K and Muskingum X parameters. A sample of an optimization run is shown in figure 10 a, b and c. Five different events were calibrated using the data, and the average of those calibrated parameters was taken to develop the final calibrated parameter values.

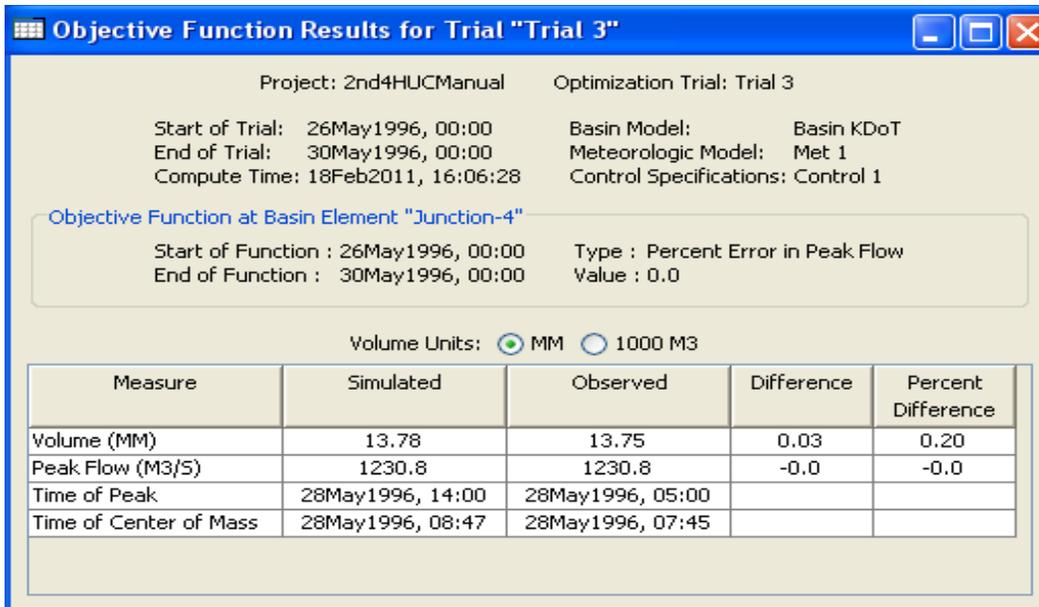


FIGURE 10a. HMS Optimization Summary

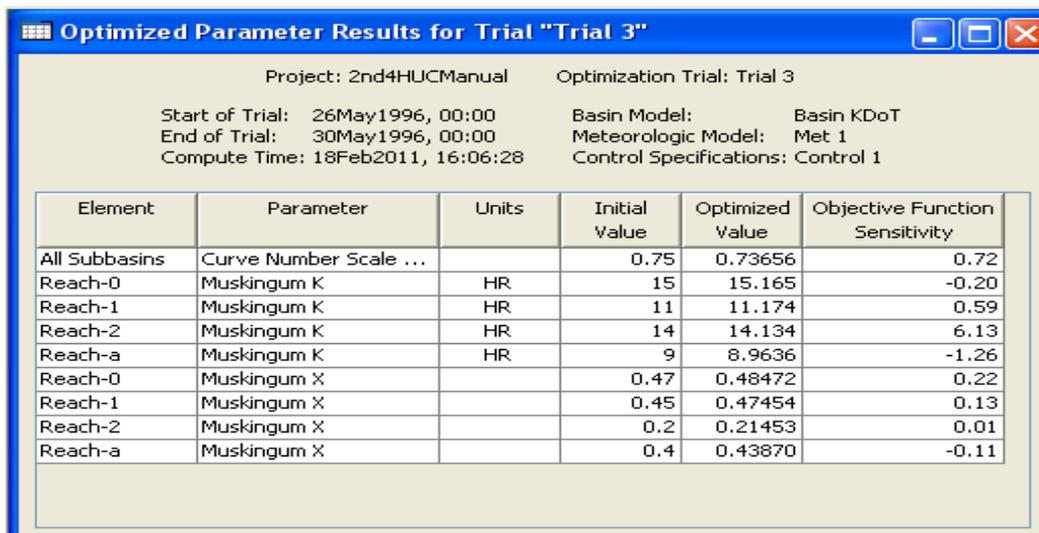


FIGURE 10b. HMS Optimized Parameters

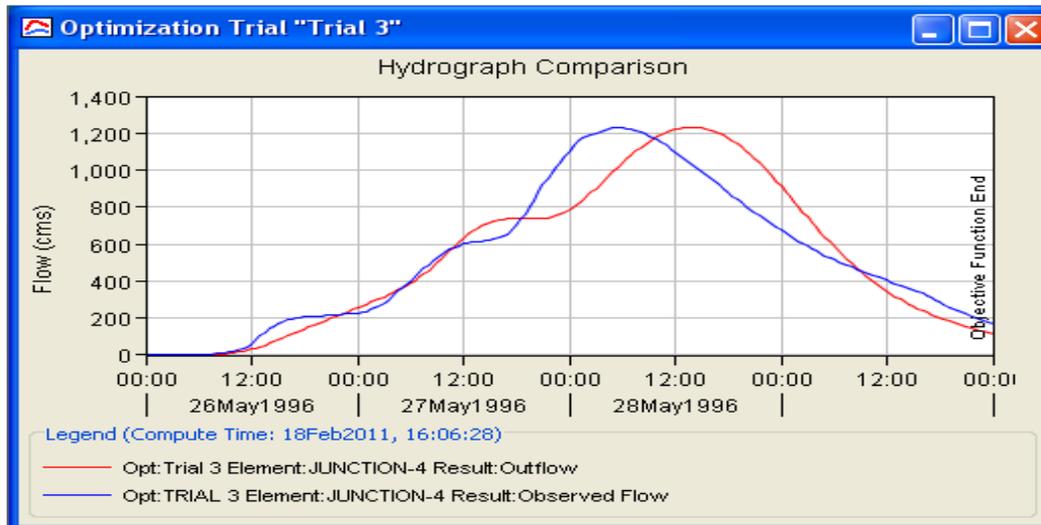


FIGURE 10c. HMS Hydrograph Comparison

The calibrated parameters were then validated for another storm event. Results from the calibration and validation process are shown in Tables 6 and 7 respectively.

Figure 10a shows a summary of an optimization run comparing simulated and observed runoff and volumes. Figure 10b shows the optimization results for the different calibration parameters. Figure 10c shows a comparison of the simulated and observed hydrographs. Five different events were successfully calibrated and the final parameter values developed from that process were validated for another storm event. The hydrologic model and the calibrated parameters were then used to simulate future scenarios.

TABLE 6. HMS Calibration parameters Curve Number scale factor all subbasins, Routing parameters (K, X) for river reaches.

Curve Number Scale	K for Reaches				X for Reaches			
	0	1	2	a	0	1	2	a
0.893	13.678	10.089	12.564	8.894	0.401	0.360	0.339	0.342

TABLE 7. Flow, Time of Peak and Volume for HMS Validation event

Event	Flow (m ³ /s)			Time of Peak		Volume (mm)	
	Observed	Simulated	% Diff.	Observed	Simulated	Observed	Simulated
19-Nov-92	761.55	763.4	-0.24	20 Nov1992, 17:00	20 Nov1992, 18:00	4.51	4.44

5.2. HEC-RAS CALIBRATION/VALIDATION

The five selected USGS gages are calibrated individually by adjusting their Mannings n values until the model water surface elevations match that of USGS gages. Then the calibrated parameters i.e. Mannings roughness coefficient, are validated for four different peak events over the last 10 years to determine if the water surface elevations are comparable. The results of the

calibration and validation process are close in values with percent difference ranging from -6.73 % to 8.43 % (Table 8).

TABLE 8. HEC-RAS Model Calibration and Validation Calibration

Event 2005-06-05	Flow (m ³ /s)	Water Elevation			Mannings n	
		Observed (m)	Simulated (m)	% Difference	Main Channel	Overbanks
Gage 06887500	1064	4.55	4.53	0.34	0.056	
Gage 06888350	1596	5.37	5.37	0.06	0.1	0.14
Gage 06889000	1913	7.38	7.34	0.58	0.07	0.08
Gage 06891000	2072	5.18	5.20	-0.35	0.033	
Gage 06892350	2001	5.99	6.02	-0.41	0.02	

The calibration results have negligible difference between the observed and the simulated values. The validation results are also satisfactory with the difference in water surface elevations being small. The overall validation process R² and Nash-Sutcliffe model efficiency co-efficient are 0.971 and 0.96 respectively, so the model is performing reasonably well, and can be used to assess the changes in land use on flooding.

VALIDATION				
Gage 06887500	Flow (m ³ /s)	Observed (m)	Simulated (m)	% Difference
Event 2001-06-21	880	3.99	4.09	-2.44
Event 2009-04-27	690	3.63	3.61	0.42
Event 2008-06-20	908	4.16	4.23	-1.54
Event 2007-05-07	1049	4.39	4.69	-6.73
Gage 06888350	Flow (m ³ /s)	Observed (m)	Simulated (m)	% Difference
Event 2001-06-21	934	4.45	4.45	0.00
Event 2009-04-27	843	4.41	4.29	2.70
Event 2008-06-20	962	4.63	4.49	2.96
Event 2007-05-07	1760	5.47	5.57	-1.78
Gage 06889000	Flow (m ³ /s)	Observed (m)	Simulated (m)	% Difference
Event 2001-06-21	1268	6.02	6.35	-5.52
Event 2009-04-27	1661	7.00	7.01	-0.13
Event 2008-06-20	1035	5.51	5.85	-6.08
Event 2007-05-07	2592	8.75	8.01	8.43
Gage 06891000	Flow (m ³ /s)	Observed (m)	Simulated (m)	% Difference
Event 2001-06-21	1534	4.46	4.60	-3.01
Event 2009-04-27	2216	5.36	5.33	0.51
Event 2008-06-20	1194	3.93	4.11	-4.66
Event 2007-05-07	3481	6.67	6.24	6.44
Gage 06892350	Flow (m ³ /s)	Observed (m)	Simulated (m)	% Difference
Event 2001-06-21	2287	6.40	6.33	1.05
Event 2009-04-27	2157	6.10	6.19	-1.50
Event 2008-06-20	1106	4.58	4.84	-5.73
Event 2007-05-07	3396	7.92	7.40	6.62

5.3. FUTURE SCENARIOS

For the new land use scenarios, the corresponding new curve numbers were generated to be used along with the future storms, and wetland scenarios in the HMS model to generate runoff estimates. Those runoff estimates were used in the RAS model to generate water elevations and flood inundation extents. The analysis of these simulations is presented in the next sections.

5.3.1. Kansas River Streamflow for Different Landuse Scenarios

The HMS model was run for the future scenarios to generate runoff estimates. The modeling results for the different landuse scenarios, the Baseline scenario, Scenario 1 (ICLUS output for 2020), Scenario 2 (interchanging low and medium, developed intensity classes for 2030) and Scenario 3 (interchanging low and high, developed intensity classes) are shown in Table 9.

TABLE 9. Peak Runoff estimates for different land use scenarios for the 150, 175, 200 mm (6, 7 and 8 inch) storms

Storm		Runoff (m ³ /s)			
(in)	(mm)	Baseline	Scenario 1, 2020	Scenario 2, 2030	Scenario 3, 2040
6	152.4	5162.1	5208.7	5551.4	6144.2
7	177.8	6675.9	6723.6	7022.1	7681.2
8	203.2	8252.9	8300.1	8532.9	9250.2

The table shows that the runoff values increase with time. The 200 mm (8 inch) storm as expected generates more runoff compared to the 175 and 150 mm (7 and 6 inch) storms. The increase is small in 2020, and grows more pronounced in 2030 and 2040. The runoff values show a marked increase with the shift in time from a low intensity development to a higher intensity development. The probable reason for the subtle increase between the present and the 2020 scenarios is the small difference between the curve numbers for low intensity development and other land use classes like cultivated crops, pasture, forest etc. and the majority of soil cover for the area being of groups C or D as mentioned in Table 2.

5.3.2. Impact of wetlands on Kansas River Streamflow

The model was simulated again for the future scenarios (Scenarios 1, 2 and 3), after incorporating the wetlands into it. Wetlands are 6 %, 8 % and 10 % of the total basin area in 2020, 2030 and 2040, respectively. Wetlands can intercept runoff and reduce the flow volume; in addition to that, they have been modeled in such a manner that they also impact the peak flow. For simulations, only the 150 mm storm was selected and the results are shown in Table 10. Comparison for the original and wetland scenarios is given in Table 11.

TABLE 10. Peak Runoff estimates with incorporated wetlands for different land use scenarios for 150 mm (6 inch) storm

Storm		Runoff (m ³ /s)		
(in)	(mm)	Scenario 1, 2020	Scenario 2, 2030	Scenario 3, 2040
6	152.4	4606	4744.2	5060.6

Table 11 shows the impacts of increasing the area of wetlands on flood attenuation. The peak flow and the volume of the storm event are reduced by varying degrees over the different scenarios. For the runoff, a high of 17.64 % reduction is obtained while for volume a high of 36.83 % reduction is obtained. As the area of wetlands increases, the volume of water that can be retained increases. The peak runoff increases over the future due to urbanization, and it is noted that the higher the runoff the higher the flow reduction due to increase in area of wetlands. Incorporating wetlands result in an average 14 % reduction in peak flow and an average 31 % reduction in flow volume for the Kansas River basin.

TABLE 11. Comparison between runoff and volume estimates for original and wetlands scenarios for 150 mm (6 inch)

Scenario	Original Runoff (m ³ /s)	Runoff with Wetlands (m ³ /s)	% Diff. (m ³ /s)
Scenario 1 (6%)	5208.7	4606	-11.57
Scenario 2 (8%)	5551.4	4744.2	-14.54
Scenario 3 (10%)	6144.2	5060.6	-17.64
Scenario	Original Volume (mm)	Volume with Wetlands (mm)	% Diff. (mm)
Scenario 1 (6%)	72.71	54.69	-24.78
Scenario 2 (8%)	76.93	52.91	-31.22
Scenario 3 (10%)	81.52	51.5	-36.83

5.3.3. Kansas River Water Elevations for Different Landuse Scenarios

The estimates of the peak runoff from the HMS model for the future scenarios are used in the hydraulic model built in HEC-RAS. Flow values at the location of the five calibration gages were selected. The RAS model was then simulated to obtain water elevation levels and flood inundation extent estimates. The water elevation results for the different landuse and storm scenarios, at the calibration gage locations are shown in Table 12.

TABLE 12. Kansas River Water Elevation Estimates for the different land use and SCS storm scenarios at USGS gage locations

SCS Storm	Water elevation (m)			
	Baseline	Scenario 1	Scenario 2	Scenario 3
150 mm				
6887500	4.68	4.75	4.88	5.03
6888350	5.56	5.62	5.75	5.89
6889000	8.74	8.79	8.9	9.03
6891000	7.01	7.04	7.11	7.18
6892350	8.82	8.85	9.08	9.44
175 mm				
6887500	5.21	5.27	5.39	5.51
6888350	6.09	6.15	6.26	6.38
6889000	9.36	9.41	9.51	9.63
6891000	7.59	7.62	7.67	7.73
6892350	9.75	9.78	9.94	10.28
200 mm				
6887500	5.62	5.66	5.77	5.88
6888350	6.57	6.57	6.68	6.81
6889000	9.86	9.91	10.04	10.13
6891000	8.05	8.07	8.12	8.2
6892350	10.54	10.56	10.67	10.98

The results depict a gradual increase in water elevation levels in the future. The increase is small between the present and 2020 scenarios, but grows more pronounced when the present and 2040 scenarios are compared. The highest water elevations are obtained from the 200 mm (8 inch) which is understandable since it has the highest runoff. The largest increase in elevations is observed for the last calibration gage where the difference between the present and 2040 scenarios is 0.62 m for the 150 mm storm, 0.53 m for the 175 mm storm and 0.44 m for the 200 mm storm. This decreasing difference trend illustrates the effect of the topography of the river basin, which is usually funnel shaped, meaning with increase in elevation there is an increase in basin area. Among the calibration validation data, the highest water elevation level observed was 8.75 m (Table 8). Compared to that, the results show a maximum increase of 2.23 m in 2040.

5.3.4. Impact of Wetlands on Kansas River Water Elevations

The effect of wetland on the water elevation levels was evaluated using the wetland incorporated runoff estimates generated from the HMS model for the 150 mm storm. Table 13 shows a comparison between the original and wetland scenarios.

TABLE 13. Comparison between water elevations estimates for original and wetlands scenarios for 150 mm (6 inch) storm

SCS 150 mm	Scenario 1, 6% (m)			Scenario 2, 8% (m)			Scenario 3, 10% (m)		
	Original Elevation	Wetland Elevation	% Diff.	Original Elevation	Wetland Elevation	% Diff.	Original Elevation	Wetland Elevation	% Diff.
6887500	4.75	4.71	0.84	4.88	4.84	0.82	5.03	4.99	0.80
6888350	5.62	5.4	3.91	5.75	5.46	5.04	5.89	5.57	5.43
6889000	8.79	7.78	11.49	8.9	7.6	14.61	9.03	7.63	15.50
6891000	7.04	6.24	11.36	7.11	6.22	12.52	7.18	6.14	14.48
6892350	8.85	8.43	4.75	9.08	8.53	6.06	9.44	8.75	7.31

The table shows a decrease in water elevations when wetlands are simulated. The difference varies at the different locations on the river but it is considerable with a maximum decrease of 15.50 % and 1.4 m being observed.

5.3.5. Kansas River Inundation Extents for Different Land Use Scenarios

The area that gets inundated in the river basin can be modeled in HEC-GeoRAS by using the RAS model results as inputs. The extent of the inundation can be calculated and the vulnerable segments of the river basin where flooding is severe, can be identified in GeoRAS. The inundation area results for the different future land use and storm scenarios are shown in Table 14.

SCS Storm		Area (km ²)			
(in)	(mm)	Baseline	Scenario 1	Scenario 2	Scenario 3
6	152.4	350.83	354.82	366.35	379.91
7	177.8	409.16	413.59	424.02	436.27
8	203.2	458.69	461.61	473.11	484.49

The table shows that with increasing storm depth and urbanization over the future, the flood inundation area also increases. The difference in inundation area between any two consecutive storms for any scenario is not the same. The difference is higher between 150 mm and 175 mm storms than compared to 175 mm and 200 mm storms. An average decrease of 58 km² is simulated between 150 mm and 175 mm storms and an average decrease of 48 km² is observed between the 175 mm and 200 mm storms, for all the scenarios. This is due to the funnel shaped topography of a watershed. Figure 11 shows the flooding visualization in GeoRAS and how it can allow for comparing the effects of different storm events and tracing which location along the river is more susceptible to flooding.

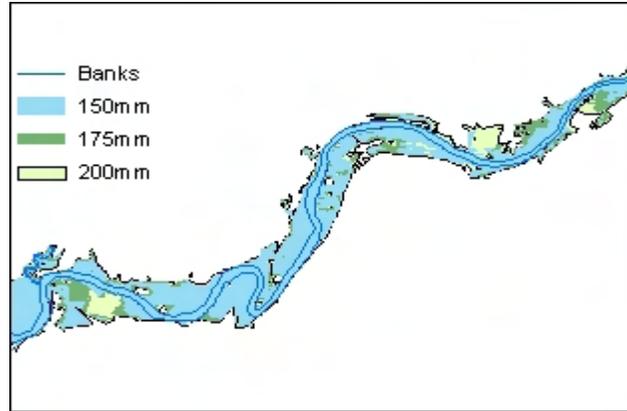


FIGURE 11. GeoRAS inundation area for comparing the different storm events 150, 175 and 200 mm (6, 7 and 8 inch) for the 2040 scenario.

A snapshot of the simulated flooding along the Kansas River for the different storm scenarios in 2040 is shown in figure 11. The locations at which the 175 and 200 mm start having an impact can be easily observed.

5.3.6. Impact of Wetlands on Kansas River Inundation Areas

The effect of wetlands on flood inundation for the 150 mm storm and the land use scenarios is shown in Table 15.

TABLE 15. Comparison between inundation areas estimates for original and wetlands scenarios for 150 mm (6 inch) storm

SCS 150 mm	Original Area (km ²)	Area with Wetland (km ²)	% Diff.
Scenario 1 (6%)	354.82	300.13	15.41
Scenario 2 (8%)	366.35	301.33	17.75
Scenario 3 (10%)	379.91	306.9	19.22

The table shows that inundation areas decrease when runoff with wetlands is simulated. The presence of wetlands reduces the extent of flooding, on average by about 17.5 %.

6. CONCLUSIONS

The Kansas River basin was modeled using HEC-HMS and HEC-RAS to determine the effects of increasing urbanization on peak flood runoff over future periods. A GIS tool ICLUS's projections of urban land use densities for 2020 were modified to represent increasing densification of urban areas, by converting low intensity development to medium intensity in 2030 and to high intensity developments in 2040. Design storms of 100 year return periods for the region were simulated. The watershed was also modeled to evaluate the impact of wetlands on flood attenuation. Wetlands were assumed to have a storage depth of 0.3 m (1 ft) and their percentage area share of the watershed was 6 % in 2020, 8 % in 2030 and 10 % in 2040. Wetlands were also modeled in such a manner that the peak flow was affected, for this an assumption was made that there would be some control structure for regulating flows in and out of wetlands, which is typical of many restored wetland designs.

The HEC-HMS and HEC-RAS models were both calibrated and validated for historic flow events. The HMS model was then used to generate estimates of peak flows for the design storms for different land use scenarios. The output from HMS was then used to run the RAS model. The RAS model then generated estimates of water elevations and flood inundation extents for those design storms and land use scenarios. The wetlands were modeled as diversions in HMS. The amount of flow diverted to wetlands was set in such a manner that the volume of storage available in the wetlands was filled. Comparisons were made for gauging the impacts of wetlands, between the original runs without wetlands for the 150 mm (6 inch) storm for all the land use scenarios, then running the models after incorporating wetlands.

The results show an appreciable increase in peak runoff and flood inundation extents for the various scenarios. There is about a 1000 cms increase in peak runoff for the different storms from the baseline scenario to the 2040 one, as a consequence of increasing urbanization and densification. This is about an average 15% increase in runoff for all the land use and design storm scenarios. The maximum increase in water elevations between the present and 2040 scenarios is about 0.62 m for 150 mm storm, 0.53 m for the 7 inch storm and 0.44 m for the 8 inch storm. This is about an average maximum increase of 5 % in the water elevations for all scenarios. The flood inundation extents for the watershed also increase correspondingly. There is an average inundation area increase of 6.85 % between the present to the 2040 scenario for the various design storms.

The presence of wetlands reduced peak flows and inundation extents. For the different scenarios, an average decline of 14 % was achieved in the peak runoff, while for the flood volumes; an average decline of 31 % was noted. Modeling the different wetlands scenarios resulted in an average decrease of 8.7 % in the water elevations with a maximum decrease of 15.5 % at one location. An average decrease of 17.5 % was obtained in the inundation area extents.

The models created can be used to test the impacts of land use changes, rainfall predictions, and channel modifications in the Kansas River basin. One limitation of the model is that it is built on a macro scale, and if the results are applied to a small segment on the watershed, they might not be accurate. Also, an economic analysis would be needed to determine whether the savings in damages obtained from flood reductions as a result of increasing wetland volumes justify the cost of constructing and maintaining those wetlands. Environmental managers and practitioners in USEPA's regional offices are evaluating this approach to prioritize and inform decisions about ecological restoration in specific watersheds and for the implementation and assessment of Best Management Practices within the floodplains of the Kansas River and other rivers of the Midwest.

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