# FLOODPLAIN ANALYSIS USING COMPUTATIONAL TOOLS

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***Abstract***

When conducting hydraulic studies or floodplain analysis or when producing DFIRMs for the FEMA map modernization program, two of the more time-consuming processes are setting up the hydraulic model and delineating the floodplain zones. The integration of widely available computational tools with hydrologic and hydraulic modeling and floodplain mapping improves accuracy, effectiveness, and quality. The various tools discussed in this paper include HEC-GeoHMS, HEC-GeoRAS, WISE, CHECK-RAS, and RASPLOT.

In this paper, the county-wide draft DFIRM of Scott County, Minnesota, is used to demonstrate the applications, capabilities, and challenges faced when using these tools. By using Geographic Information Systems (GIS) raster and feature data sets, HEC-GeoHMS and HEC-GeoRAS automate the pre-processing of input data and post-processing of HEC-RAS results. CHECK-RAS is used to verify the validity of hydraulic parameters, structure and cross section data, as well as floodway and flood profile results. RASPLOT facilitates the creation of flood profiles. These tools are successfully linked with HEC-RAS to expedite the production of floodplain mapping and obtain accurate hydraulic results.

***Introduction***

Advances in computer technology for data processing and analysis have resulted in the development and availability of high-resolution topographic data, state-of-the-art Laser Imaging Detection and Ranging (LIDAR), and GIS raster and feature datasets. Interest in geospatial data usage has increased in recent years and GIS applications have become the common approach in engineering analysis and mapping. Local communities, districts, and state agencies are making numerous efforts to collect GIS data that facilitates the development and applications of hydrologic and hydraulic models and floodplain mapping. As a result, extensive, improved and more comprehensive data is currently available.

This trend has prompted the creation of computational aids to process and analyze the substantial amount of data on hand. The need for automation of tasks has become extremely important for managing data efficiently. The preparation or pre-processing of data for hydrologic and hydraulic modeling can be time consuming due to the large amount of data available. When performing floodplain analysis at the regional and state levels, significant amounts of parameters and input data are required for computer models such as the Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) and the Hydrologic Engineering Center's River Analysis System (HEC-RAS).

In addition, the post-processing of hydrologic and hydraulic modeling results can be cumbersome when using improved computer capabilities such as GIS for analysis and visualization. In the past, Flood Insurance Rate Maps (FIRMs) were produced by the Federal Emergency Management Agency (FEMA) and distributed on paper. Presently, FEMA is implementing a map modernization initiative to upgrade and digitize the maps that will be created and distributed in a GIS format. These maps, digital flood insurance rate maps (DFIRMs), utilize state-of-the-art technology to increase the quality, reliability, and accessibility of flood hazard maps and data.

The county-wide draft DFIRM of Scott County, Minnesota, is used in this paper. Hydrologic and hydraulic analysis and preparation of DFIRMs for all major streams within Scott County were performed. Scott County is located just south of Minneapolis, Minnesota, and is bounded on the west and north by the Minnesota River. Approximately 150 miles of streams, draining 350 square miles, were modeled and digital floodplain maps were developed for the county using FEMA's detailed and approximate studies for riverine hydraulics. The studied streams contain segments with significant differences in geometry varying from steep and narrow cross sections to flat and wide river segments over very short distances. In addition, segments of the river cross urban areas where the streams become channelized, narrower, blocked by dams, or bounded by levees. These situations require the use of GIS and computational tools to accurately represent watershed characteristics in the hydrologic model and flow conveyance in the hydraulic model.

### *Computational Tools*

Integrating several computational tools into hydrologic and hydraulic modeling and floodplain mapping improves quality, provides better visualization of results, and decreases processing time. The computational tools discussed in this paper are widely available and include HEC-GeoHMS, HEC-GeoRAS, WISE, CHECK-RAS, and RASPLOT. This analysis was conducted to demonstrate the applicability and efficiency of using computational tools for hydrology, hydraulics, and floodplain mapping.

### *Hydrology*

Scott County hydrology was studied using HEC-HMS (Tetra Tech EM Inc. 2006). HEC-HMS is a rainfall-runoff model developed by the U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center. HEC-HMS is designed to simulate the event-based and continuous precipitation-runoff processes of dendrite watershed systems. Details about the HEC-HMS model are provided in the User's Manual (Scharffenberg 2001).

Setting up the HEC-HMS model requires the use of high-resolution spatial data including topographic, land use, and hydrologic soil conditions data to extract the watershed input parameters needed for the model. The spatial data analysis is performed in Arcview GIS interface using the Geospatial Hydrologic Modeling extension, HEC-GeoHMS, developed by USACE (Doan 2003).

The watershed delineation for Scott County was performed using HEC-GeoHMS. Figure 1 shows the major streams and delineated watersheds in Scott County using HEC-GeoHMS. The basic data requirement for delineation in the HEC-GeoHMS extension is a digital elevation model (DEM) of the study area which is a raster representation of the area's terrain or topography. In the HEC-GeoHMS extension, a terrain-preprocessing tool was used to derive intermediate auxiliary data sets that collectively describe the watershed drainage patterns and allow for stream and sub-watershed delineation.

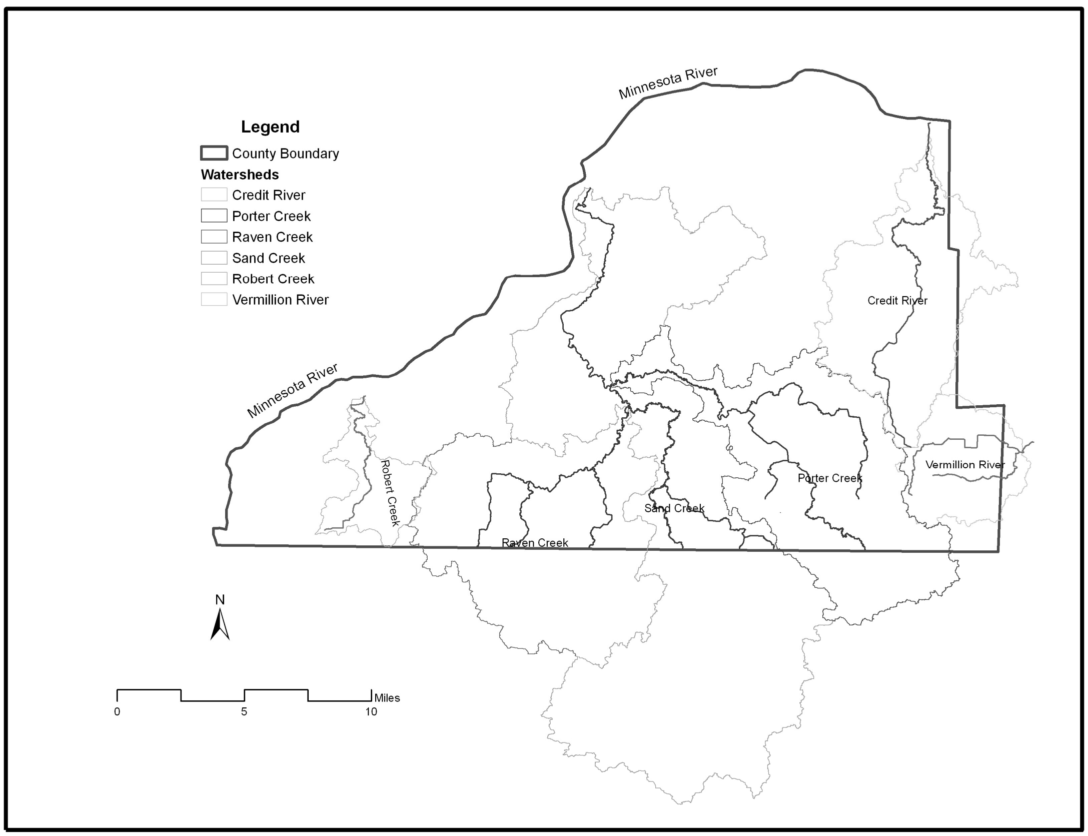


**Figure 1. Watersheds in Scott County, Minnesota**

The first five data sets created were grid representations of flow direction, flow accumulation, stream definition, stream segmentation, and watershed delineation. The next two data sets were the vector representation of watershed polygons and stream polylines. The last data set consisted of aggregated sub-watersheds representing a preliminary delineation based on a specified threshold area. Then, the basin processing function was used to revise the sub-watershed delineation and define the stream reaches.

The basin characteristics function of the HEC-GeoHMS extension was used to derive physical characteristics for the streams and sub-watersheds, such as reach length, slope, and longest flow path, and to attach these characteristics to the attributes table of the sub-watershed GIS layer. These physical characteristics were then used to estimate hydrologic parameters required by HEC-HMS.

The land use analysis was performed using HEC-GeoHMS with two available databases, the existing Minnesota Land Cover Class System (MLCCS) and the Minnesota Gap Analysis Program (GAP). The MLCCS (Richardson 2004) database has a very comprehensive land-cover classification system. However, the GAP database consists of a detailed vegetation cover map produced through computer classification of combined satellite imagery. The MLCCS database was used the majority of Scott County and was combined with the GAP database for areas of the county which have no MLCCS data available. In order to obtain consistent land-use classifications for curve number definition, the more detailed MLCCS data were reclassified into common classes as Level 4 land-use types of GAP data. Figure 2 illustrates the differences between the MLCCS data and the GAP data, as the map for Robert Creek watershed shows more well-defined and smoother land use areas than the map for Vermillion River. Area-weighted composite impervious percentages were then estimated for each land use, based on reference values and professional judgment.

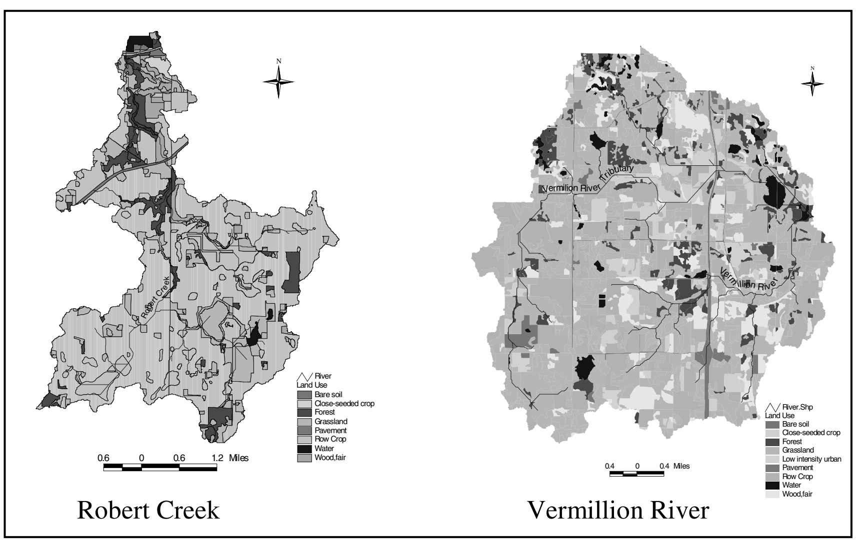


**Figure 2. Land use maps of Robert Creek Watershed (MLCCS) and Vermillion River Watershed (GAP)**

Hydrologic soil data used for Scott County included an updated county soil survey database and the Soil Survey Geographic (SSURGO) data from Natural Resources Conservation Service (NRCS) of the U.S. Department of Agriculture (USDA) for watershed areas outside of the county. The databases were processed in GIS using HEC-GeoHMS and they were merged and clipped to cover the county watersheds. Soil type was represented by polygon shapes with attributes such as soil name, symbol, and area. Each soil group is associated with one of four hydrologic soil groups (A, B, C, or D) based on soil infiltration capacities. Duel assignments such as A/D, B/D, and C/D were redefined based on the assumption of drained conditions because of the prevalent tile drain present in the area. Duel hydrologic soil groups A/D, B/D, and C/D were therefore reassigned as A, B, or C, respectively.

Curve number determines the runoff volume of a watershed. Curve number values were created by NRCS as indices that represent the combination of hydrologic soil groups and land use. Land use and soil data were integrated using HEC-GeoHMS to create the GIS polygons that include unique combinations of land use and hydrologic soil group in each watershed. Because of the heterogeneity of land and soils in the watershed, the curve number of a sub-watershed was calculated as composite curve number based on the area-weighted average of various curve number values for individual sub-watersheds.

A HEC-HMS hydrologic model was then created using the hydrologic parameters developed by HEC-GeoHMS. The Clark Unit Hydrograph (UH) Method was used to compute the unit hydrograph for runoff calculations. The Clark UH method uses time of concentration (Tc) and storage coefficient (K). HEC-GeoHMS provides several tools to estimate these parameters as well. HEC-GeoHMS capabilities extend from processing the digital elevation model to performing spatially intensive analysis of grid-based data to develop and import many of the inputs needed by HEC-HMS. The HEC-HMS model calculates the peak flows for each storm event (Lorenz 1997).

### *Hydraulics*

Hydraulic modeling of surface streams for floodplain analysis is usually performed using the USACE Hydrologic Engineering Center's River Analysis System (HEC-RAS) model. For Scott County, four separate steady state HEC-RAS models were created, thus streams that were hydraulically connected were in the same model (Tetra Tech EM Inc. 2006).

HEC-RAS (Brunner 2002) performs one-dimensional water surface profile calculations using geometric data and steady flow data. The geometric data required for the model includes the stream network, cross-section river stationing, elevation and station information for each cross section, and channel and overbank downstream reach lengths. The flow data required includes peak flows for each flood profile, which are exported from HEC-HMS into HEC-RAS.

The HEC-RAS geometric data was created using the GIS extension HEC-GeoRAS, Version 4.1.1 (Ackerman 2005), developed by USACE in conjunction with the ArcMap GIS application. HEC-GeoRAS is a set of ArcGIS tools designed to process geospatial data for use with the HEC-RAS model. It automates and streamlines a number of GIS operations and eventually creates a HEC-RAS import file containing geometric data based on digital terrain model (DTM) information such as station identifiers, cross-section cut and surface lines, cross-section bank station locations, downstream river reach lengths, main channel alignment, right and left overbank data, ineffective flow areas, storage areas, and cross-section Manning's roughness N-values. In addition, the HEC-GeoRAS tool is used to post-process HEC-RAS modeling results and delineate floodplains and floodways for each stream.

For Scott County streams, the DTMs were created using GIS point layers extracted from LIDAR data. The point layers were converted into Triangular Irregular Network (TIN) layers that represent the ground topography. Field survey data was also obtained around the channel crossings. The TIN layers were merged with field survey data from surveyed cross sections. The river centerline layer was created in ArcMap using U.S. Geological Survey (USGS) National Hydrograph Data (NHD), 2004 aerial photographs, and 2-foot topography.

The cross-section layer consist of cut lines located perpendicular to the stream centerline at: (1) locations that represent the average geometry of the stream reach; (2) road and railroad crossings; and (3) locations of significant changes in geometry, slope, channel conveyance, overbank roughness, and discharge. The locations of the cross sections can be set and edited by the user or can be automated using HEC-GeoRAS. For Scott County, available aerial photographs and contour data were used to lay out the cross-section cut lines. The existing FEMA 100-year floodplain boundary was used as a guide in determining the extent of the cross sections. The average distance between cross sections was 1,000 feet, with smaller distances between cross sections near structures and near abrupt changes in channel conveyance. A total of 533 cross sections were field surveyed and 680 were extracted from the TIN layer. Figure 3 illustrates an example of the stream geometry for Credit River. The figure shows a segment of Credit River with cross-section cut lines upstream and downstream of a roadway crossing. The HEC-GeoRAS extension is showing (near the upper left corner) the menu available to automatically generate the stream geometric data.

Field survey data, including cross sections and structures, was processed using the Watershed Information System (WISE). WISE (Watershed Concepts, 2005) is a tool for managing and utilizing data for watershed studies. WISE consists of several modules that provide integration of GIS with hydrologic and hydraulic programs. The Open Inventory module was used to convert the structure and cross-section data from survey ASCII format into HEC-RAS input data format. The cross sections and structures generated from the TIN layers in HEC-GeoRAS, for which survey data was available, were adjusted in HEC-RAS with the surveyed cross sections and structures data exported from WISE.

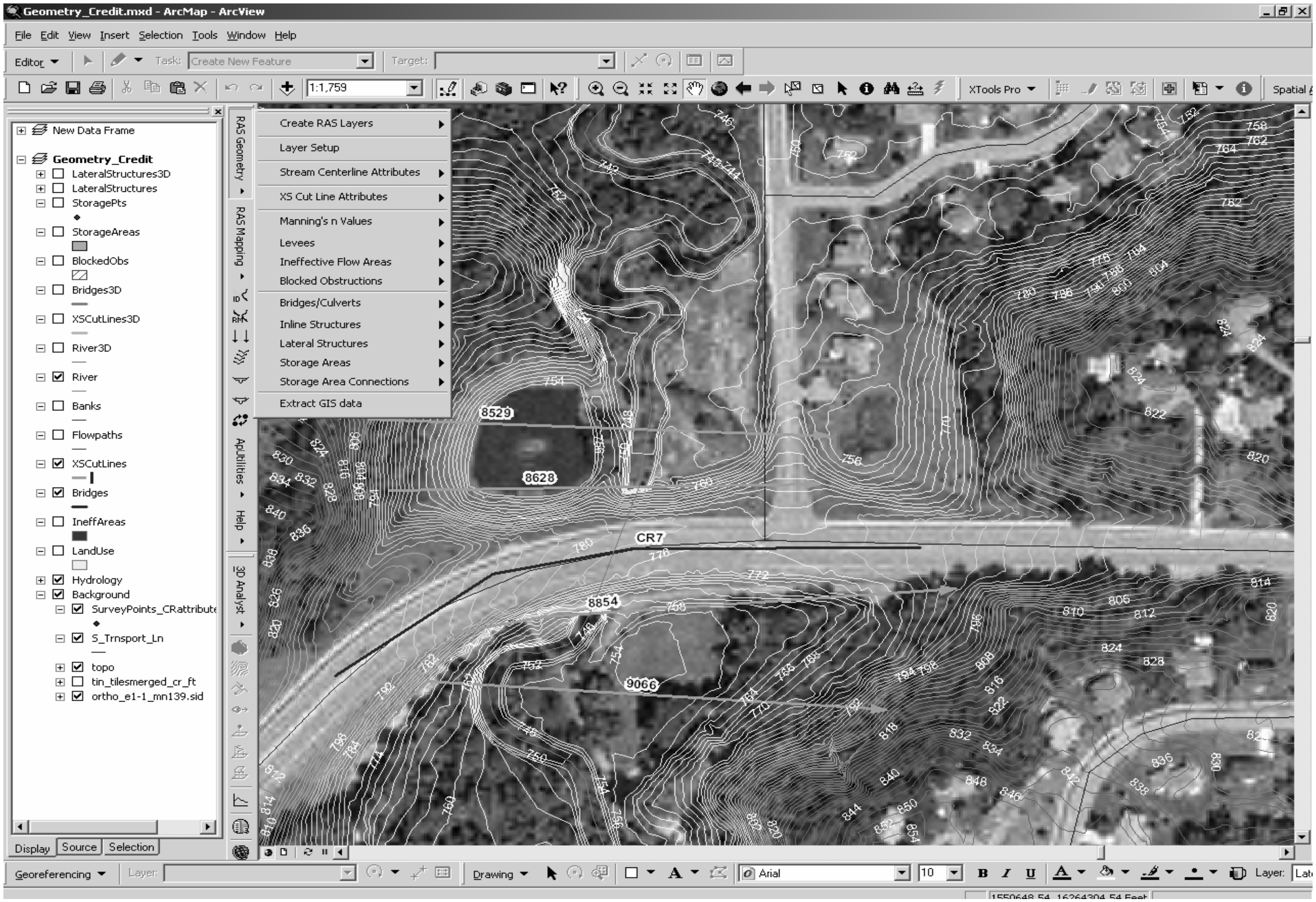


**Figure 3. Example of Stream Geometry for Credit River using ArcMAP with HEC-GeoRAS extension**

The channel banks and overbank flow path layers were drawn in ArcMap using the existing FEMA 100-year floodplain boundary, topographic contours, field survey data, and aerial photographs. HEC-GeoRAS also has an automated tool that offsets the main channel to create the left and right channel banks.

The bridge layer identifies the location of each channel crossing including bridge, roadway, pedestrian bridges, and railroad crossings. The bridge lines were generated in ArcMap based on field survey data, aerial photographs, and street shapefiles. A total of 160 crossings in Scott County main streams were identified, surveyed, and modeled. The flow lengths between the bridge cross sections and the upstream and downstream cross sections were determined by HEC-GeoRAS. The hydraulic structure location, in stream miles, was estimated by intersecting the river centerline layer with the street shapefile and the location of surveyed structures.

Manning's roughness N-values were developed in HEC-GeoRAS based on the MLCCS land use data for most areas in the county and the national GAP database for areas with no MLCCS data. Once the land uses were identified, typical Manning's roughness values were assigned for each land use. Manning's roughness N-values polygon layers were developed by HEC-GeoRAS by intersecting the Manning's roughness N-values layer with the cross-section cut lines These values were imported into HEC-RAS as the starting point. The N-values incorporated into the HEC-RAS hydraulic model were manually refined at the channel bottom utilizing standard Manning's roughness values, field survey observations, field survey photographs, and aerial photographs.

Once the geometric data is prepared in HEC-GeoRAS, the data is imported into the HEC-RAS model. The HEC-RAS model geometry should be reviewed and adjusted using field survey data to correct potential erroneous representations caused by DTM resolution constraints, such as poor resolution in the presence of tree canopy. The HEC-RAS model should be also checked for reasonableness of the hydraulic parameters assumed and water surface profiles obtained. HEC-RAS Automated Review Program, CHECK-RAS (Dewberry & Davis LLC. 2000), was used for this purpose.

CHECK-RAS was applied to assess input data for accuracy and resolve warning messages generated by the HEC-RAS model run. Specifically, CHECK-RAS reviews geometric, steady-flow, and output data to verify that hydraulic parameter estimates and assumptions made in the model are justified and are in accordance with the assumptions and limitations of the HEC-RAS software. CHECK-RAS was run iteratively to verify the reasonableness of Manning's roughness N-values, contraction and expansion coefficients, cross-section geometry, floodway results, structure data, and flood profile results. The four HEC-RAS models developed for Scott County were validated with CHECK-RAS and errors detected were corrected in HEC-RAS to improve the accuracy and quality of the model. Figure 4 shows the selection of profiles in the CHECK-RAS interface.

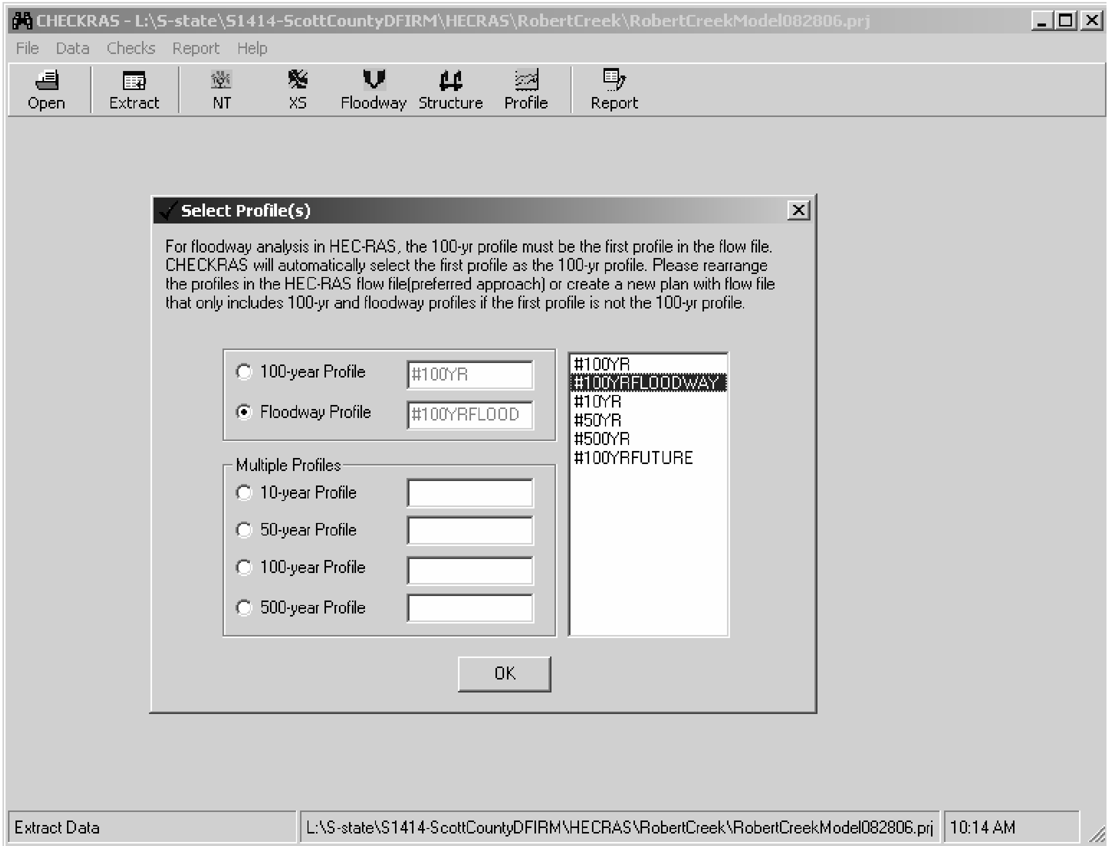


**Figure 4. CHECK-RAS Interface Showing Selection of Profiles**

There are two ways to visualize the HEC-RAS modeling results. Results can be displayed as X/Y coordinate plots or in spatial graphical maps. X/Y coordinate plots are two-dimensional graphs of the flooding profiles that show the relationship between distance along the stream and water surface elevations. X/Y coordinate plots of flood profiles can be automatically generated using RASPLOT. Spatial graphical maps are two-dimensional representations of flooding areas. These maps can be automatically generated using HEC-GeoRAS.

RASPLOT (Dewberry & Davis LLC. 2005) is a computer program that creates flood profiles by automatically extracting data from HEC-RAS input and output files. The final product from RASPLOT is in DXF file format (drawing interchange format) which allows for editing and printing of profiles as necessary. Flood profiles for the 10-, 50-, 100-, and 500-year events were generated for the study streams in Scott County. Figure 5 shows the flood profile for a segment of Sand Creek. RASPLOT offers great flexibility in the plots because they can be edited using a computer aided design software such AutoCAD. The RASPLOT profile's quality is superior to those profiles generated using HEC-RAS. Names for the river crossings (e.g. roadway, bridges, and railroad) and cross sections can be added to the profile to provide a more descriptive plot of the area and surroundings. The RASPLOT profiles also follow the guidelines required by FEMA for Flood Insurance Study (FIS) profiles.

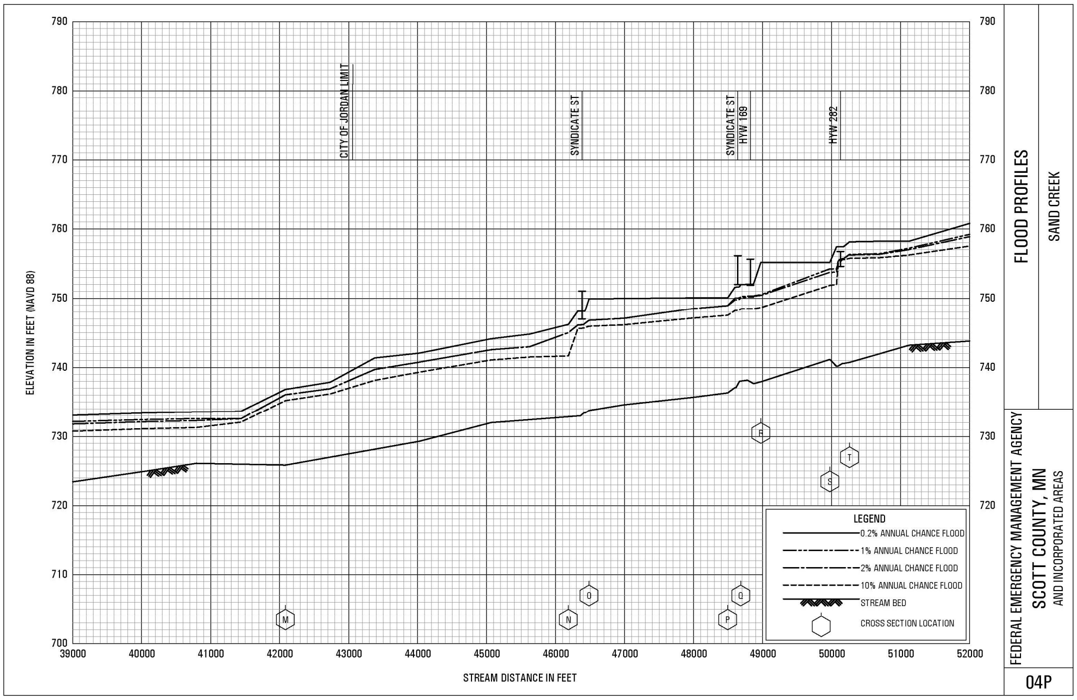


**Figure 5. Typical Flood Profile of Sand Creek Generated by RASPLOT**

### *Floodplain Mapping*

Water surface elevation data exported from HEC-RAS simulations can be processed by HEC-GeoRAS for GIS analysis. HEC-GeoRAS facilitates the generation of floodplain maps by reading the spatial data format (SDF) file from HEC-RAS, creating a geodatabase that contains the terrain data and water surface information extracted from the SDF, and intersecting these layers to create a polygon of the floodplain.

During the post-processing of HEC-RAS results, GIS layers for inundation depth and floodplain boundary are created including water surface, terrain surface, and cross section cut lines with flood elevation data. All GIS layers developed during the post-processing are based on the content of the HEC-RAS export file and the terrain data (TIN layer). HEC-GeoRAS allows selecting multiple water surface profiles and creates a floodplain polygon for each profile. The floodplain polygon is generated by intersecting the water surface elevations with the cross-section cut lines to generate a water surface TIN. Then, the water surface TIN is intersected with the terrain surface to create the floodplain polygon. HEC-GeoRAS performs this automatic process and produces the floodplain of the selected flood profile. The process can be iteratively done to obtain the floodway boundary, 100-year flood zone, and 500-year flood zone. Figure 6 displays the floodway, 100-year and 500-year flood zones delineated using HEC-GeoRAS for Credit River. The HEC-GeoRAS extension is showing the menu available to automatically generate the floodplain delineation.

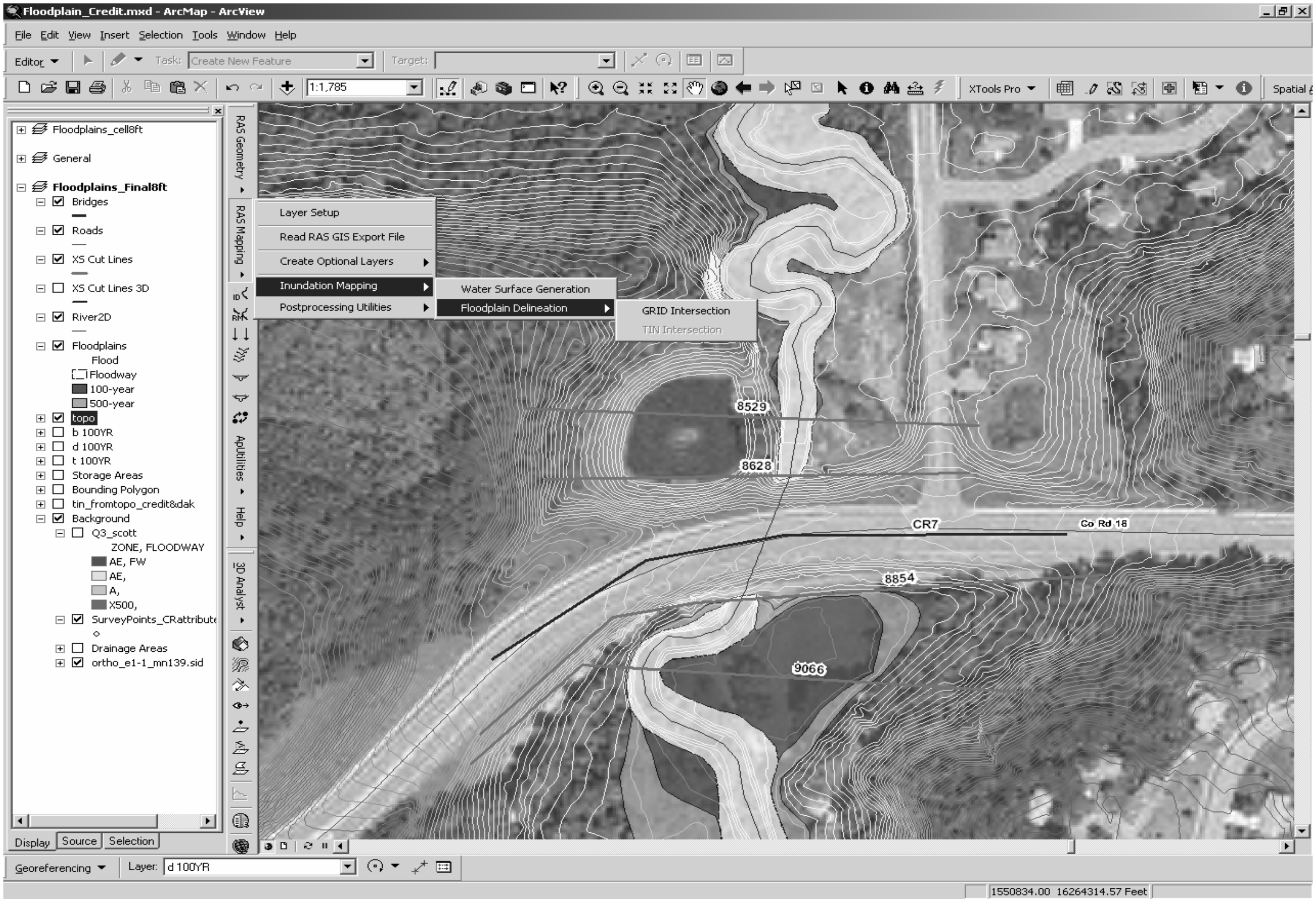


**Figure 6. Floodplain Mapping of Credit River using ArcMAP with HEC-GeoRAS extension**

The floodplain boundary is created based on the TIN surface. The resolution of the floodplain boundary varies depending on the resolution of the TIN. The floodplain generated by HEC-GeoRAS should be carefully reviewed against topographic or survey data.

Floodplain delineation of the 100-year storm event, 500-year storm event, and floodway was performed for the major Scott County stream. The floodplain polygon obtained automatically by HEC-GeoRAS was “smooth out” to follow the contours properly. The polygon was also adjusted using topography and survey data in areas where the resolution of the TIN was poor.

***Conclusion***

The usage and availability of high-resolution geospatial data has increased in recent years along with continuous advances in computer technology for data processing. Therefore, the use of automotive tools that facilitate the development of hydrologic and hydraulic models and floodplain mapping is essential. This paper discusses several computational tools that are widely available. Among these tools are HEC-GeoHMS, HEC-GeoRAS, WISE, CHECK-RAS, and RASPLOT.

The county-wide draft DFIRM of Scott County, Minnesota, was used to illustrate the applications, capabilities, and challenges faced when using these tools. There was a substantial amount of data needed to conduct the floodplain analysis. Because most geospatial data is not centralized in one clearinghouse, the data used in this analysis came in different resolutions and formats and was obtained from various sources. Using GIS tools such as HEC-GeoHMS and HEC-GeoRAS proved very effective. The hydrologic and hydraulic modeling was optimized and the floodplains were mapped efficiently to produce high quality maps.

***References***

Ackerman, Cameron T. (2005). “HEC-GeoRAS GIS Tools for Support of HEC-RAS Using ArcGIS, User’s Manual, Version 4”. USACE Hydrologic Engineering Center. Davis, CA.

Brunner, Gary W. (2002). “HEC-RAS River Analysis System Hydraulic Reference Manual, Version 3.1”. USACE Hydrologic Engineering Center. Davis, CA.

Doan, James H., et al. (2003). “Geospatial Hydrologic Modeling Extension HEC-GeoHMS: User’s Manual, Version 1.1”. USACE Hydrologic Engineering Center. Davis, CA.

Dewberry & Davis LLC. (2000). “CHECK-RAS, HEC-RAS Automated Review Program User’s Manual, Version 1.1”. Federal Emergency Management Agency, Washington, DC.

Dewberry & Davis LLC. (2005). "RASPLOT, Flood Insurance Study Profile Plot Program User's Guide, Version 2.5". Federal Emergency Management Agency, Washington, DC.

Lorenz, David L, et al. (1997). "Techniques for Estimating Peak Flow on Small Streams in Minnesota". U.S. Geological Survey Water-Resources Investigation Report 97-4249, Prepared in Cooperation with the Minnesota Department of Transportation, Mounds View, Minnesota.

Richardson, Bart, et al. (2004). "Minnesota Land Cover Classification System User Manual, Version 5.4". Minnesota Department of Natural Resources, Central Region.

Scharffenberg, William A. (2001). "Hydrologic Modeling System HEC-HMS: User's Manual." USACE Hydrologic Engineering Center, Davis, CA.

Tetra Tech EM Inc. (2006). "Credit River, Robert Creek, and Vermillion River Hydrologic Analysis for Digital Flood Insurance Rate Map (DFIRM), Draft". Prepared for the Natural Resource Department, Scott County, MN.

Tetra Tech EM Inc. (2006). "Hydraulic Analysis of Sand Creek and Tributaries for Digital Flood Insurance Rate Map (DFIRM)". Prepared for the Natural Resource Department, Scott County, MN.

Watershed Concepts. (2005). "A User Guide for Watershed Information System Manual, Version 3.0". Federal Emergency Management Agency, Washington, DC.