Integrating Geospatial and Watershed Data Using the Watershed Modeling System (WMS) to Evaluate Flooding Potential of the Clear Fork Watershed in Kentucky and Tennessee[1]

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Abstract. The Office of Surface Mining's Technical Innovation and Professional Services (TIPS) program is currently evaluating several large watershed modeling software programs in order to identify which can best be utilized to support coal mine permitting activities such as the Cumulative Hydrologic Impact Assessment (CHIA) and the determination of Probable Hydrologic Consequences (PHC) of mining. OSM used the WMS software to evaluate the Clear Fork watershed of Kentucky and Tennessee to assist in determining the pre-mine floodplain configuration and assess the changes that surface coal mining operations may have on flooding potential as a result of land use changes. OSM utilized geospatial data from OSM's Knoxville Field Office GIS system along with online information available from the Kentucky Department for Natural Resources GIS and Surface Mining Information System (SMIS) to help identify all existing and proposed surface coal mining operations within the 27.8 square mile (72.0 square kilometers) watershed. Geospatial data was then compiled for land use and soil type utilizing available Digital Orthophoto Quarter Quadrangle (DOQQ) maps, EPA regional land use maps, and NRCS STATSGO soil data. Current land use data for the watershed was also evaluated utilizing IKONOS satellite imagery using a combination of 1-meter panchromatic and 4-meter multispectral bands which can be combined to optimize distinctions in land use. Land use classifications were attempted using ERDAS Image and ArcGIS Spatial Analyst with limited success because of low-flight angle shadowing and snow cover affecting contrast of the ground cover. Drainage areas, routing and runoff information was calculated using 10-meter Digital Elevation Models (DEMs) and the HEC-1 model which can be run inside the WMS software. The resulting peak discharges from a simulated 10-year, 24-hour storm event was then exported to the Army Corps of Engineers HEC-RAS software to determine flood depths in the specified floodplain area. WMS then imported the results from the HEC-RAS and allowed OSM to delineate the depth and extent of flooding as an overlay transparency on both DOQQ and Digital Raster Graphic (DRG) quadrangles to identify structures at risk of flooding. Pre- and postmining conditions were evaluated to document potential changes in water levels which could result in increased flood damage in downstream areas.

Additional Key Words: Hydrologic Routing; Hydrologic Impact Assessment; Composite Curve Number; Hydrologic Soil Group; Risk Assessment; Runoff; Remote Sensing;

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Introduction

The Office of Surface Mining's Technical Innovation and Professional Services (TIPS) program is currently evaluating several large watershed modeling software programs in order to identify which can be best utilized to support coal mine permitting activities such as the Cumulative Hydrologic Impact Assessment (CHIA) and the determination of Probable Hydrologic Consequences (PHC) of mining. The goal of this evaluation effort is to determine each software application's capability to predict flooding and floodplain alteration caused by mining and land use changes; calculate changes in sediment loading or concentrations; and predict water quality changes resulting from mining or other activities within the watershed. In addition, software compatibility with other TIPS and OSM software systems, including Geographical Information Systems (GIS), is being considered. This paper describes the results of the prototyping evaluation of the Environmental Modeling Research Laboratory's Watershed Modeling System (WMS) version 7.0.

The Clear Fork watershed of Tennessee and Kentucky (Figure 1) was chosen as a prototype project area for the evaluation of WMS. This watershed was selected because of the significant, proposed increase in surface coal mining activity over the next 15 to 20 years and the existing quality and quantity of geospatial data within the watershed. By utilizing the available geospatial data, OSM evaluated the WMS software's capability to determine the pre-mine floodplain configuration and assess the changes that surface coal mining operations may have on downstream flooding potential. The sediment loading and water chemistry aspects of WMS were not evaluated during this initial evaluation of the software.

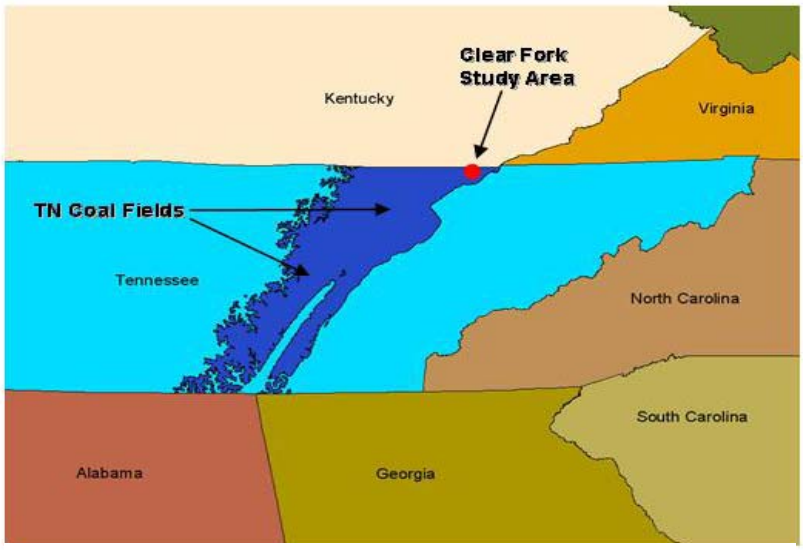


Figure 1. General location of Clear Fork watershed.

Study Area Description and History

The WMS project area consisted of approximately 27.8 square miles in the headwaters of the Clear Fork watershed in Claiborne County, Tennessee and Bell and Whitley Counties of Kentucky (Figure 2). The Clear Fork watershed is located in the Cumberland Mountain section of the Appalachian Plateaus physiographic province which is generally characterized by steep, narrow winding stream valleys, with topographic relief commonly in excess of 2,000 feet (610

m; Griffith, et al., 1997). The natural vegetation is a mixed mesophytic forest with soils generally being acidic, loamy, and well drained.

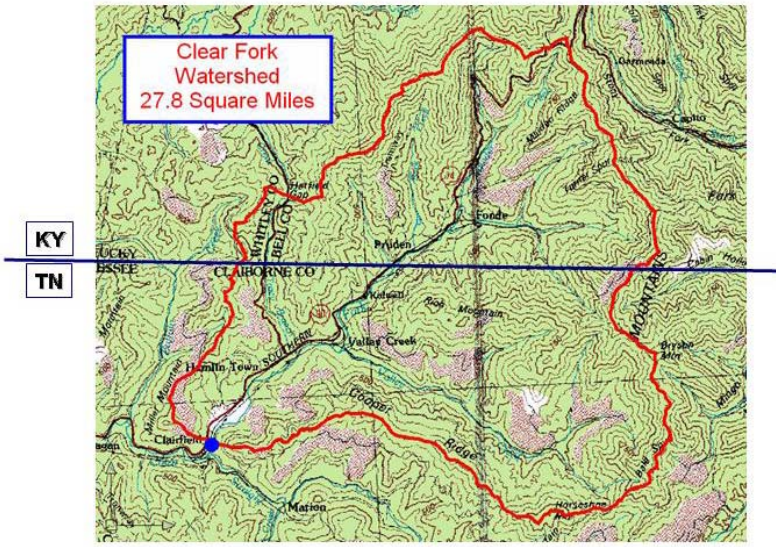


Figure 2. Clear Fork watershed**.**

The project area contains the rural communities of Fonde, Pruden, Hamlin Town, and Clairfield, which are located along the floodplain of Clear Fork. Because of the relatively steep topography in the watershed, most of the development in these communities has historically been in or immediately adjacent to the floodplain of Clear Fork. A public school and a residential area in the Hamlin Town community became the primary focus of this study as shown in Figure 3. A public water supply well field area was also located downstream of this area and was also within the Clear Fork floodplain.

Surface coal mining within the Clear Fork watershed began in the 1960's with the most intense activity occurring during the late 1980's and early 1990's when over 2,000 acres/year (809 hectares/year) of surface disturbance was permitted. Mining activity then declined sharply until 2000 when renewed interest in the area occurred. Figure 4 shows the distribution of proposed and historical mining in the watershed that was used during the WMS evaluation. Most of the older surface mining within the watershed had been reclaimed or naturally revegetated to the point that individual mine plan areas were not delineated.

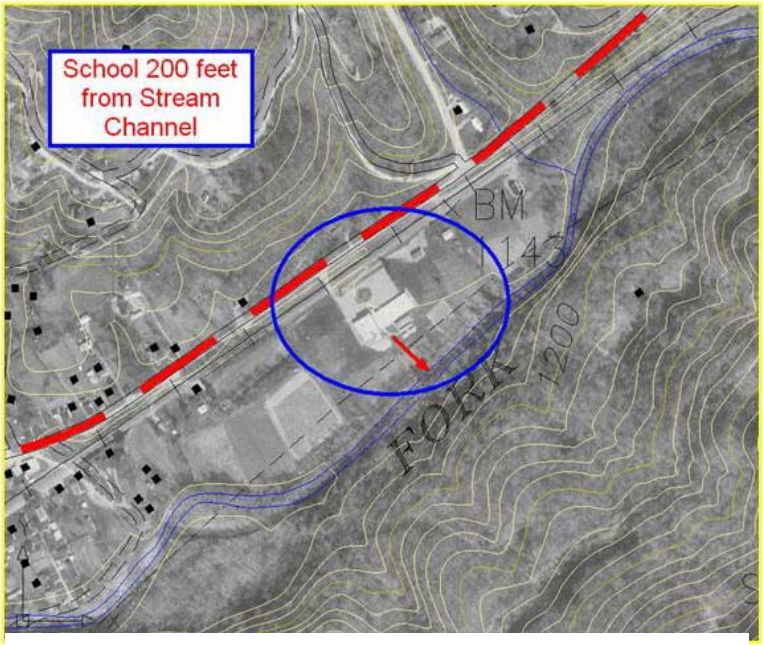


Figure 3. Location of Public School and residential development in relation to Clear Fork.

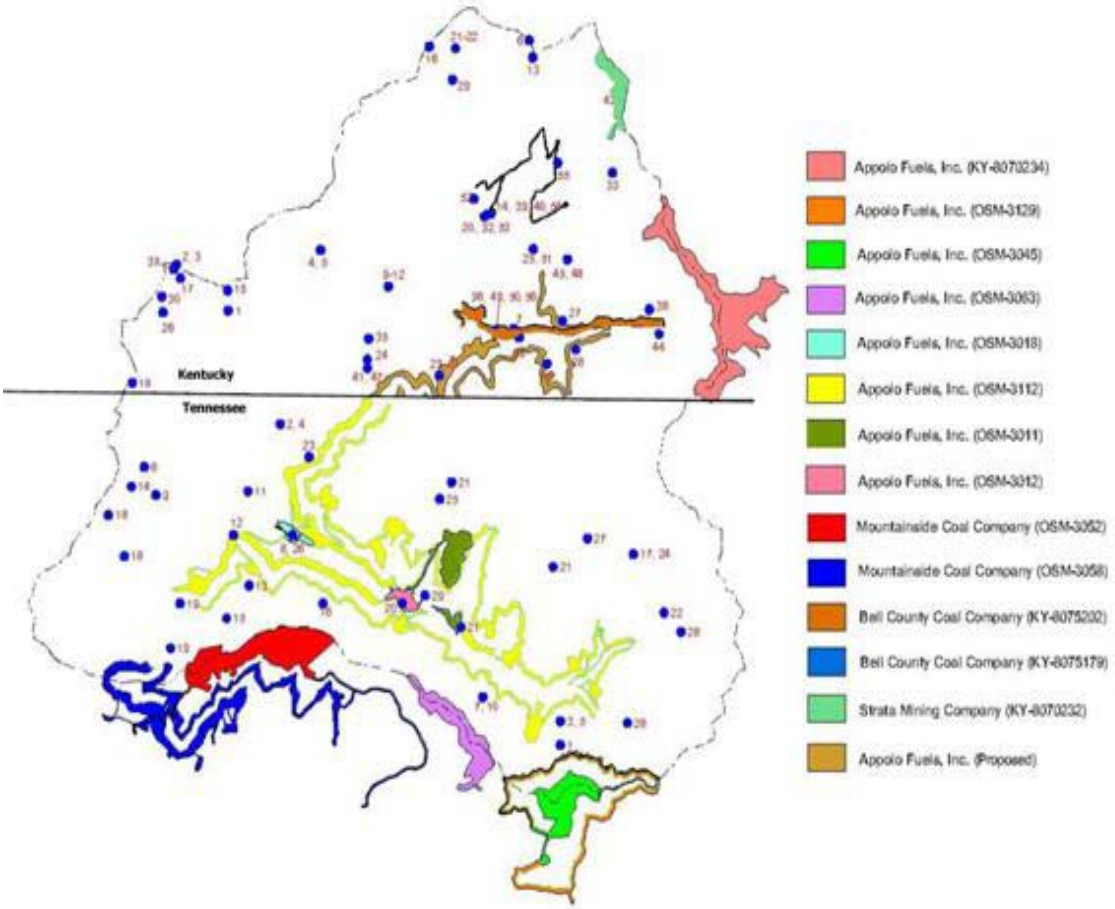


Figure 4. Distribution of historic and proposed mining in Clear Fork watershed**.**

Purpose and Modeling

The intent of this prototype study was to use WMS to calculate the peak flood discharge for various recurrent interval storms in the watershed using digital elevation information and weighted curve numbers generated from the existing land use and soils data. This information was to be exported into the HEC-RAS software developed by the U.S. Army Corp of Engineers using the WMS interface to delineate the floodplain and flood depths under the various recurrent interval storms. This process was repeated under postmining conditions to determine the change in peak flood discharge resulting from the changes in the weighted curve numbers and associated affects on flood depth and/or floodplain enlargement. It was also a goal of this study to evaluate the ability of WMS to properly import geospatial data from AutoCAD, Environmental Systems Research Institute (ESRI) software Shape files, and ArcGIS coverages formats, and to perform coordinate conversions between different projection systems.

To facilitate this analysis, OSM first compiled proposed and historical surface coal mining data from the OSM Knoxville Field Office (KFO) GIS, and the Kentucky Department for Natural Resources' GIS and Surface Mining Information System (SMIS). Information in the Kentucky systems was readily available for direct download from a web-based internet server and/or FTP servers. Kentucky surface mine data was retrieved in the new Kentucky State Plane, NAD 83, Single Zone, U.S. feet, coordinate system, which was subsequently reprojected. This data was integrated with KFO GIS data, which was in a Tennessee State Plane, NAD 27, feet coordinate system using ArcGIS Toolbox utilities.

Initial land use information for the watershed was obtained from the U.S. Environmental Protection Agency (EPA) GIRAS Land use/Land cover spatial database in an ESRI Shape file at a 1:250,000 scale. The original coordinate system for this GIRAS-data file was geographical using decimal degrees. Land use classifications for the shape file was based on the Anderson Level II land use coding as shown in Table 1. The Anderson Level II classification is generally used for high-altitude data taken at 40,000 feet (12,192 meters) or above at a scale less than 1:80,000 (Anderson, et al, 1976). OSM compared this data to an available copy of a Landsat 5 based, Anderson Level II land use mapping for Tennessee developed by the Tennessee Wildlife Resources Agency in 1995 as part of a statewide coverage. The Landsat thematic mapper utilized 3 visible bands, 3 infrared bands, and a thermal infrared band. The Landsat imagery was more current and of a higher resolution (30 meter except for 120 meters on the thermal infrared) than the EPA GIRAS image, but was clipped at the Tennessee State line so that it provided incomplete coverage of the Clear Fork watershed.

Table 1. Anderson Level I and II Land Use/Land Cover Classes.

1	Urban or built-up land (Level I)
11	Residential
12	Commercial and services
13	Industrial
14	Transportation, communication, utilities
15	Industrial and commercial complexes
16	Mixed urban or built-up land
17	Other urban or built-up land
2	Agricultural land (Level I)
21	Cropland and pasture
22	Orchards, groves, vineyards, nurseries, and ornamental horticultural
23	Confined feeding operations
24	Other agricultural land
3	Rangeland (Level I)
31	Herbaceous rangeland
32	Shrub and brush rangeland
33	Mixed rangeland
4	Forest land
41	Deciduous forest land
42	Evergreen forest land
43	Mixed forest land
5	Water (Level I)
51	Streams and canals
52	Lakes
53	Reservoirs
54	Bays and estuaries
6	Wetland (Level I)
61	Forested wetland
62	Nonforested wetland
7	Barren land (Level I)
71	Dry salt flats
72	Beaches
73	Sandy areas not beaches
74	Bare exposed rock
75	Strip mines, quarries, gravel pits
76	Transitional areas
8	Tundra (Level I)
81	Shrub and brush tundra
82	Herbaceous tundra
83	Bare ground
84	Wet tundra
85	Mixed tundra
9	Perennial snow or ice (Level I)
91	Perennial snowfields
92	Glaciers

Because current baseline land use information was unavailable, TIPS contracted for IKONOS satellite imagery of the Clear Fork watershed using a combination of 1-meter panchromatic and 4-meter multispectral bands, which were designed to be combined to optimize

distinctions in land use (Figure 5). Automated land use classifications were attempted using Earth Resources Data Analysis System (ERDAS) Image and ArcGIS Spatial Analyst software with limited success because of low-flight angle shadowing and snow cover affecting reflection and contrast of the ground cover. As a result, "heads-up" digitizing of the IKONOS image was performed to classify the various land use/land cover in the Anderson Level II classification system described previously (Figure 6.). Curve numbers which were assigned to each land use classification were interactively entered in WMS based on ranges typical for urban and agricultural lands. (USDA, 1986)

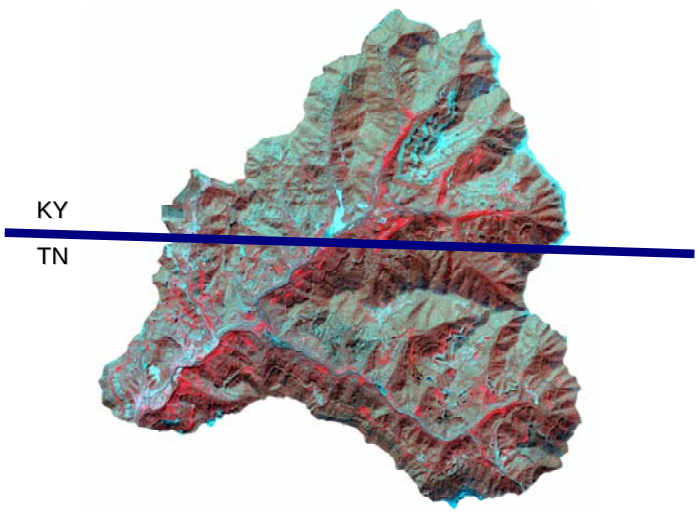


Figure 5. IKONOS image of Clear Fork Study Area

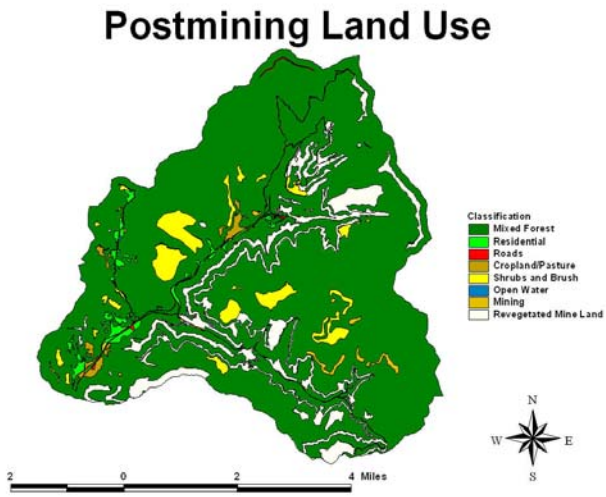


Figure 6. Land use classes based on IKONOS

Hydrologic soil group classes are also used in the computation of runoff by the SCS Curve Number Method which is the WMS module used to calculate flow losses. Soil survey data for Claiborne County, Tennessee was developed in 1948 but had no information relative to current hydrologic soil group classification. State Soil Geographic (STATSGO) soil information was available from the NRCS at a scale of 1:250,000 for the entire watershed. However, at this scale, only one hydrologic "C" type soil was identified within the study area. A review of the Soil Survey Geographic (SSURGO) database revealed large scale soils maps for Bell and Whitley Counties in Kentucky but no mapping for Tennessee (Figure 7). The SSURGO data was mapped at a 1:12,000 to 1:63,360 scale. No correlation was found between the 1948 Claiborne County soil survey and the SSURGO data of Bell and Whitley Counties, Kentucky. As a result, OSM utilized the existing STATSGO data for calculating the hydrologic soil group. Unfortunately, the STATSGO data mapped the entire 27.8 square mile (72.0 square kilometers) watershed as a type "C" hydrologic soil group so, no distinctions in runoff based on soil types were apparent in the WMS model. A hydrologic soil group of "C" is generally considered by the USDA's Urban Hydrology for Small Watersheds, TR-55 (USDA, 1986) as being sandy clay loams with low infiltration and transmission rates.

Modeling Methods

Once all mining, land use, and soils data had been collected and interpreted, OSM staff began to work inside the WMS program to develop the peak flow and flood plain model. WMS integrates multiple hydrologic models within the software that can all be run using the same data sets. These include TR-20, TR-55, NFF, HSPF, MODRAD, HEC-1 (now HEC-HMS), and the Rational method. For the purposes of this evaluation, OSM utilized the HEC-1 model to generate the estimates for peak discharge from a 10-year storm event utilizing a 4.7-inch (119.4-mm) basin-wide average precipitation event and a Type II, 24-hour distribution curve. Although not utilized, options are available within WMS to use multiple rain gage inputs to calculate weighted basin averages and routing for retention structures such as ponds and reservoirs. Peak discharges calculated by the HEC-1 model were compared against results from the U.S. Geological Survey National Flood Frequency (NFF) model and with measured peak discharges from the USGS gaging station on Yellow Creek near Middlesboro, Kentucky (USGS Station 0340200). This gage contains continuous discharge data for 64 years of record and is immediately adjacent to the Clear Fork watershed study area.

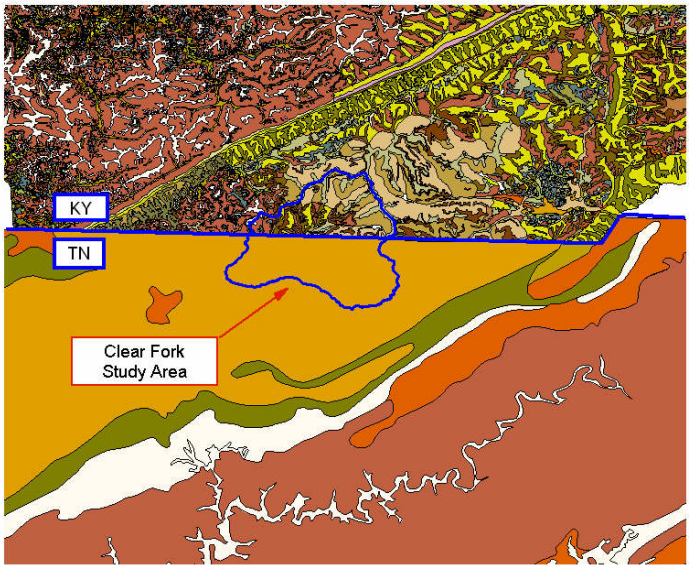


Figure 7. Distribution of STATSGO and SSURGO soils data for the Clear Fork Study Area.

Ten-meter resolution digital elevation models (DEMs) were used as the basis for all of the hydrologic modeling within WMS (Figure 8). Based on this DEM data, WMS generated flow directions using the Topographic Parameterization (TOPAZ) program and automatically delineated the watersheds and stream arcs. WMS then automatically calculated the individual basin data needed to run the various hydrologic models, including basin slopes, flow lengths, elevations, and weighted curve numbers. However, to generate a more distributed type analysis, the Clear Fork watershed was then divided into several sub-basins to more accurately account for routing and lag times. Figure 9 shows the sub-basin configuration used for the HEC-1 model. All

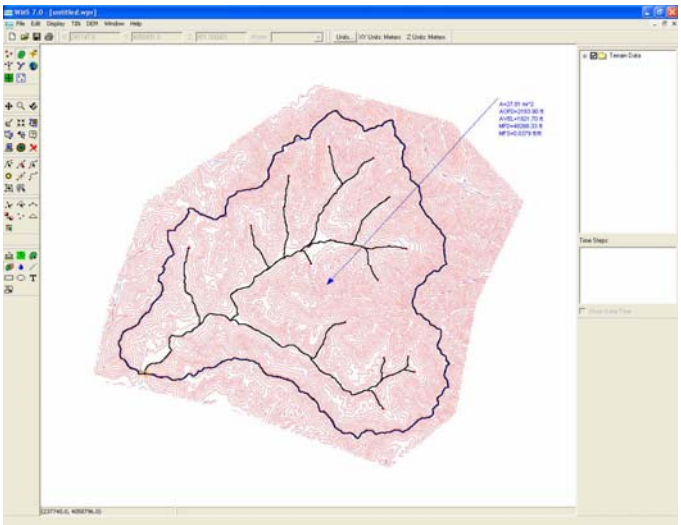


Figure 8. Watershed delineation based on WMS outlet used for the Clear Fork study area

such feature objects can be easily exported to AutoCAD or ESRI formats for use with other programs.

Although not required for the HEC-1 model, the DEM had to be converted to a triangulated irregular network (TIN) prior to use in the HEC-RAS software which calculates the floodplain cross sections and flood depth. Therefore, corrections were made in the drainage network and the conversion to a TIN was made prior to running the HEC-1 model. As part of this cleanup, WMS allowed the TIN to be edited to insert topographic breaklines, stream banks, and to allow for corrections in flowlines (such as culvert crossings beneath roadway embankmens).

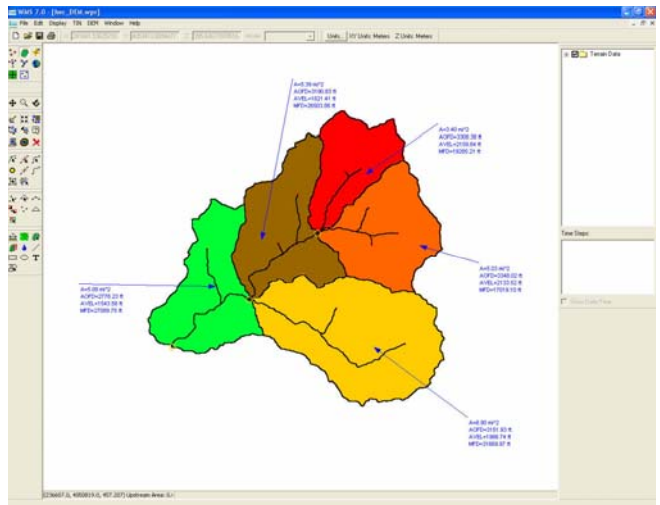


Figure 9. Sub-basin delineations used in Clear Fork

HEC-1 also required information for each of the sub-basins relative to storm-type, precipitation, loss equations, routing method and unit hydrograph methods. Loss methods were described previously using the NRCS/SCS weighted curve number method. Routing was performed using the Muskingum-Cunge method which required stream widths, side slopes and Mannings roughness coefficients (n) for each sub-basin outlet. Mannings numbers were approximated using general information available from the USGS for natural stream channels (Barnes, 1967). Once defined, the HEC-1 model was run; resulting in unit hydrographs and peak flows through each of the sub-basins as shown in Figure 10.

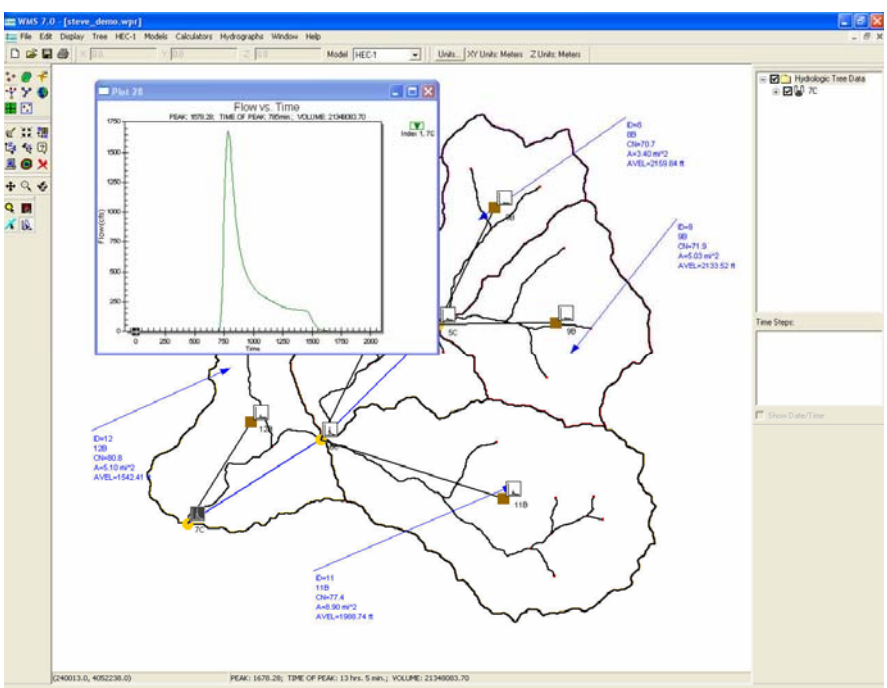


Figure 10. Clear Fork schematic and sub basin hydrograph showing peak discharge

Peak flow in the Clear Fork channel just upstream of the public school was estimated at 10,000 ft^3/sec (283 m^3/sec) in the initial HEC-1 simulation. This discharge was then compared to the National Flood Frequency (NFF) calculations which showed a peak discharge of only 4,500 ft^3/sec (127 m^3/sec). Likewise, the nearest USGS gage showed a maximum instantaneous discharge of only 11,700 ft^3/sec (331 m^3/sec) for an adjacent watershed which had a drainage area of approximately 60.4 square miles (156.4 square kilometers). After correcting several basin parameters, the HEC-1 model was run again in the premine and postmine land use condition. Peak discharges at the upstream point of the floodplain study area were revised to approximately 6,000 ft^3/sec (170 m^3/sec) for the premine condition and 6,100 ft^3/sec (173 m^3/sec) in the postmining condition. This peak discharge became the basis for the analysis to delineate the width of the floodplain and calculate the depth of flow using HEC-RAS.

Results and Discussion

Once the peak flow was determined for the study area, a cross sectional area had to be delineated for the study site and site properties calculated. Figure 11 shows the locations of the cross sections and floodplain area used for the study. Once the cross sections were drawn, the

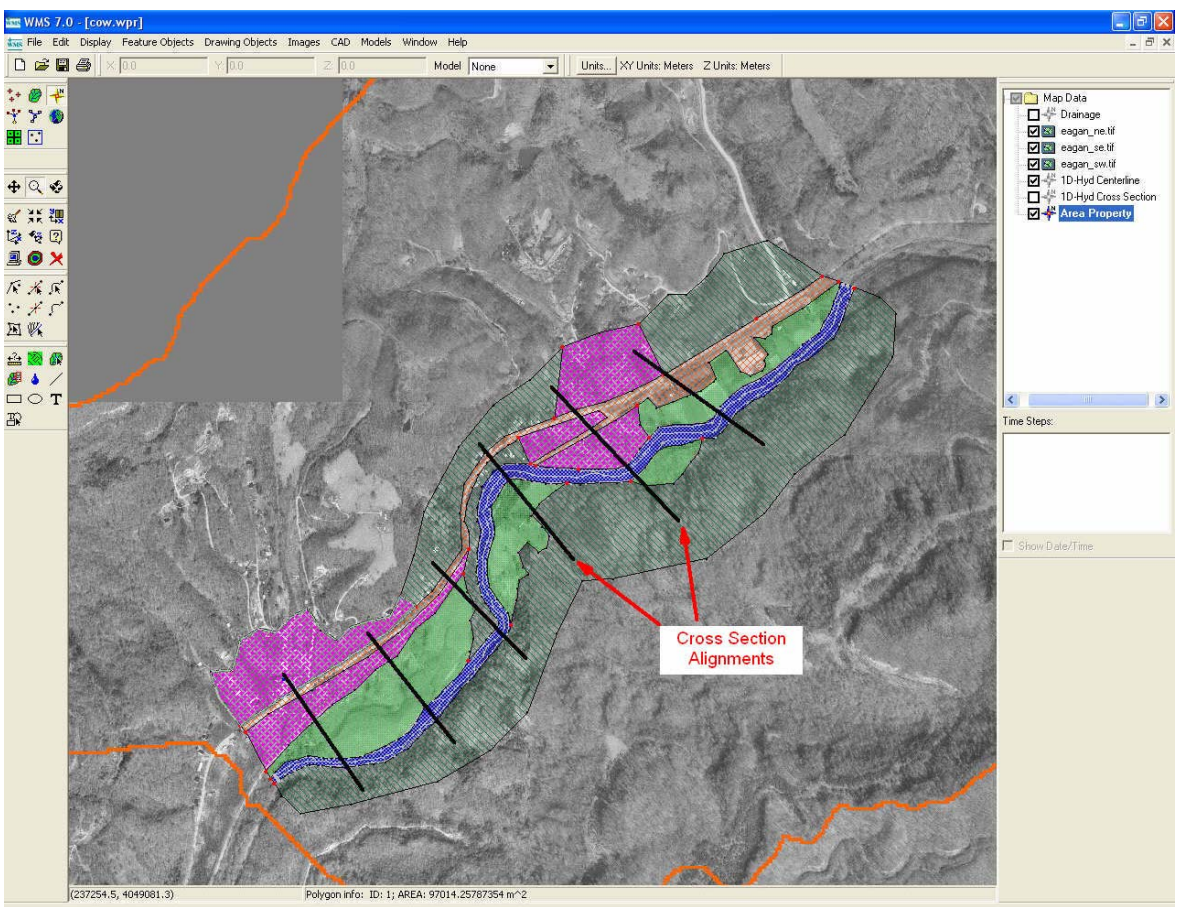
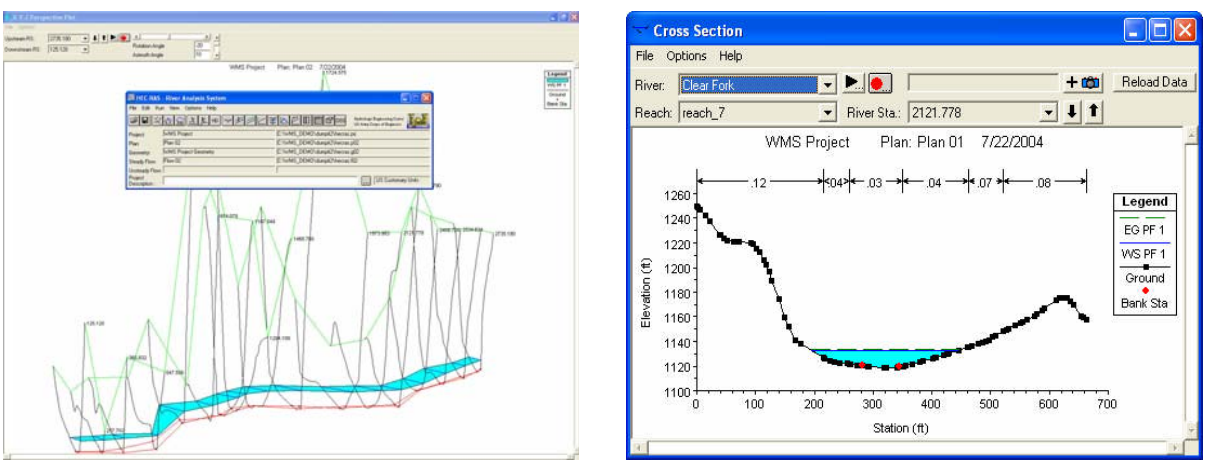


Figure 11. Cross sections and area properties used to develop HEC-RAS section lines

stream centerline and the stream banks had to be delineated for Clear Fork creek. This was performed using digital orthophoto quadrangles (DOQs); reprojected from a UTM, Zone 17, NAD 83 coordinate system to the UTM, Zone 17, NAD 27 coordinate system that the project was developed in. In addition, an area properties coverage of Mannings roughness coefficient had to be generated; based on land use/land cover data for at the cross sections. Based on this information, a Mannings roughness coefficient was assigned to each land use. Although the land use had been delineated for the entire watershed, the area properties was redigitized in this floodplain study area to add additional details available from the DOQ, as shown in Figure 11.

Cross sections were then extracted using the WMS "River Tools" option and edited to ensure alignment between the stream banks and channel. WMS also allows field generated survey data to be added to the DEM or TIN generated data to improve topographic accuracy to the section lines prior to exporting to HEC-RAS. However, no actual field survey was available for the Clear Fork study. Although HEC-RAS can calculate both steady and non-steady state flow, for the purposes of this evaluation, only a steady flow analysis was performed.

Once this information was extracted, WMS generates a HEC-RAS geometry file of the floodplain study area and generated depth-of-flow cross sections that can be reviewed and edited within HEC-RAS before pulling them back to WMS as a post-processing file. The 6,000 ft^3/sec (170 m^3/sec) discharge was entered as steady flow. Figure 12a and 12b shows the resulting Clear Fork stream channel profile and of the section lines utilized by WMS.



(a) (b)

Figure 12. (a) Clear Fork stream profile generated by WMS watershed data. (b) Clear Fork stream cross section showing depth of flow resulting from the projected 10-year, 24-hour precipitation event.

The water surface elevations for Clear Fork were processed by HEC-RAS resulted in a set of two-dimensional scatter points with one water surface elevation for each cross-section. Therefore, it was assumed that more cross sections will give better resolution in the floodplain delineation. However, WMS does allow interpolation of water surface elevations along the centerlines and cross section arcs using the "River Tools", assuming that surface water elevation is constant at the cross section lines. The "Interpolate Water Surface Elevations" option was

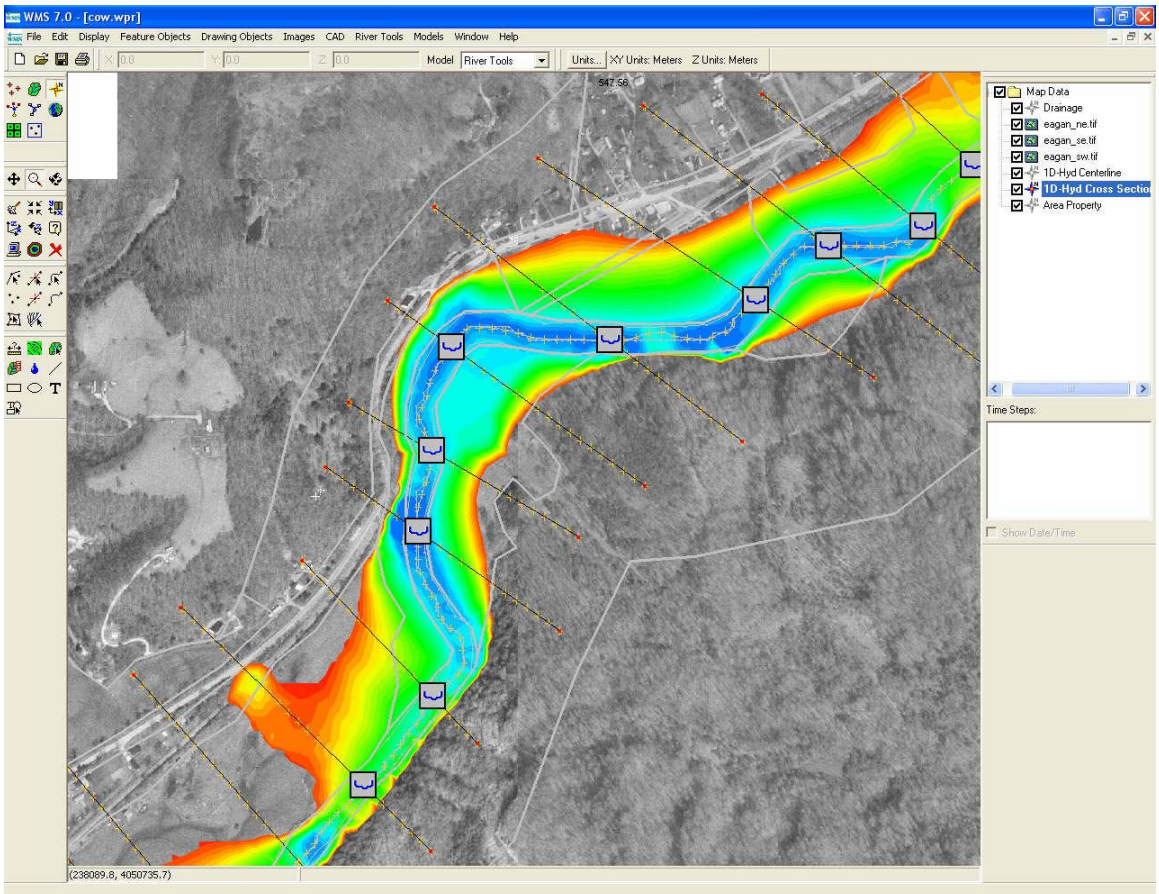


Figure 13. Flood surface water elevation map generated by WMS.

used on a 60-foot (18.3-meters) spacing and was used to generate a TIN contour map of the flood surface elevations as shown in Figure 13.

Using the transparency option (within the contouring options of WMS), the effects of the potential flooding were readily visualized within the WMS workspace. Figure 14 shows the Clairfield School and the residential development immediately downstream of the school lie within the floodplain areas based on the calculated peak flows. However, discussion with the Clairfield School staff revealed that no flooding had ever directly affected the structure. The school was constructed in the 1960's but according to the staff, flood water had risen up to the back of the building on one occasion. They did indicate that water had gone beneath the numerous modular structures behind the building which are visible on the DOQ. They stated that most of the downstream development occurred after this flood which they estimated occurred in the 1970's. Based on the maximum peak flow from the USGS gage in Middlesboro, Kentucky (USGS 0340200), the maximum peak flow ever recorded was 11,700 ft^3/sec (331 m^3/sec) on April 4, 1977. This corresponds within one day (April 5, 1977) of the maximum peak flow for the Clear Fork gage at Saxton, Kentucky (USGS gage 03403910) which is approximately 40 miles downstream of the Clear Fork study area. In the much larger 331 square mile watershed at the Saxton, Kentucky gage, the peak discharge reached 22,800 ft^3/sec (646 m^3/sec).

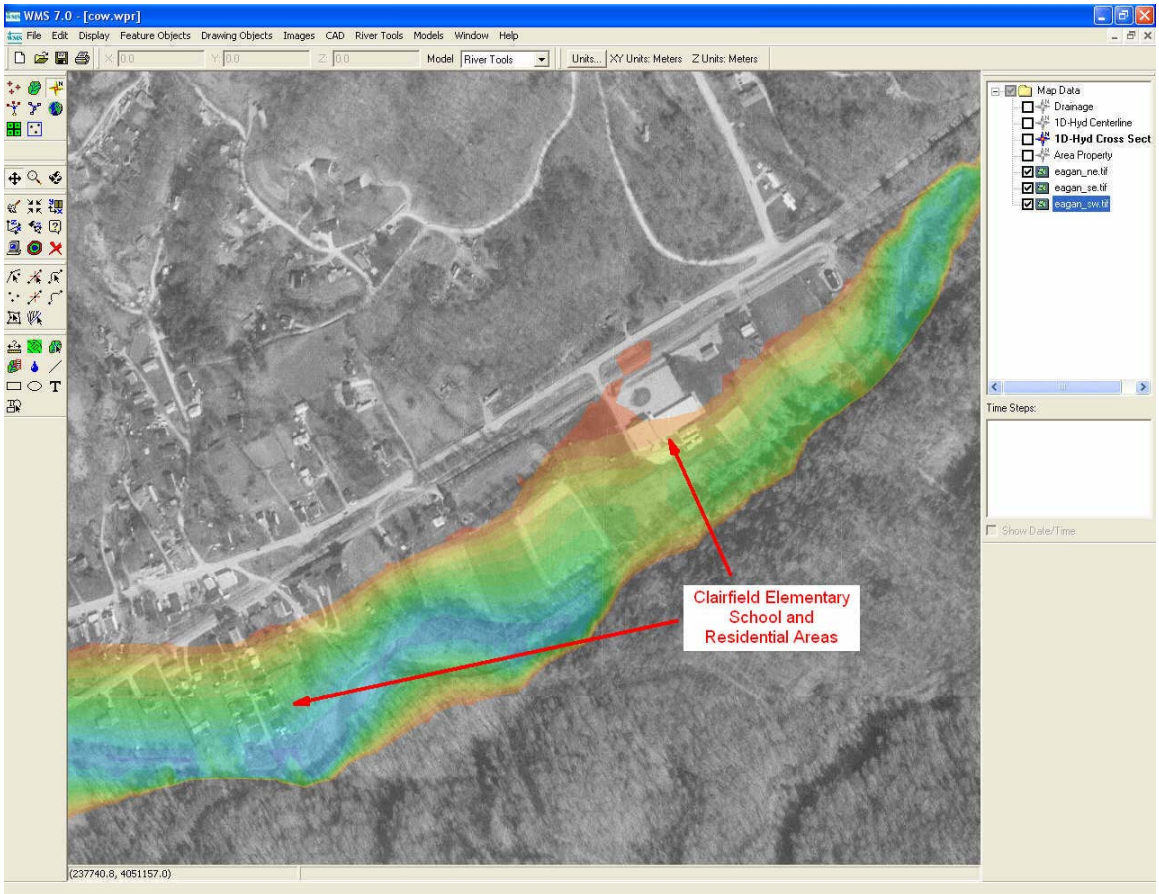


Figure 14. WMS floodplain transparency of downstream Clear Fork study area.

Because of time constraints, a postmining floodplain was not generated as part of this initial prototyping study. It was also not generated because land use changes resulted in less than a 100 ft^3/sec (31 m^3/sec) change in peak flow which was not nearly as significant as the more than 1,500 ft^3/sec (457 m^3/sec) discrepancy between the HEC-1 and the NFF models. Further refinement and calibration of the model is necessary before any conclusion on the validity of this prediction can be made. However, it did provide a very intriguing tool for use by regulatory and urban planning personnel who use geospatial data to determine how changes in the watershed may affect flow changes.

Conclusions and Recommendations

This preliminary evaluation of the WMS version 7.0 modeling software showed that it worked reasonably well with existing OSM geospatial and electronic data sets and has significant potential to be used to integrate this existing data with on-the-ground survey information to refine analyses in critical flow areas and cross sections. However, DEM topographic data resolution (10 meter or 30 meter) was found to be relatively coarse for accurate floodplain and flood-extent delineation in low-order, narrow stream valleys typical of much of the Appalachian coal field. This finding will generally be true for any software using DEM data. Supplemental, higher resolution topographic information may be needed for more accurate analysis in these

types of floodplain areas. WMS and the other modeling software should also be evaluated in areas with flatter, low-relief topography, such as is typical of mining areas in the Midwestern U.S., western Kentucky, southern Tennessee, Alabama, and elsewhere.

Most capabilities of the WMS software may be available in existing TIPS core software or public domain software systems. However, WMS was found to offer a good, single-source tool to integrate and process geospatial data and to interface with commonly used hydrologic and hydraulic models. The graphical user interface worked well with the various hydrologic models and provided excellent pre- and post- processing support for the HEC-RAS program using the WMS-generated hydrologic data. Further refinement, evaluation, and calibration of the prototype model will be required to determine the cause and sources of the discrepancies between hydrologic models. Likewise, no reservoir or pond retention was used in routing flow through the watershed. The capability of WMS to model the effects of these structures should be evaluated further.

In conclusion, as a result of this prototype modeling exercise using the WMS version 7.0 software, the following pros and cons were identified:

Pros

- WMS automates the calculation of basin information needed to run the various hydrologic models, including:
    - Composite Curve Numbers (Loss Coefficients)
    - Channel and Storage Routing, Time of Concentration/Lag Times
    - Basin Elevations, Slopes, Flow Lengths, etc.
- WMS allows for floodplain modeling and mapping based on digital terrain information and hydrologic model results
- WMS interfaces well with other TIPS-supported software (ArcView, ArcGIS, AutoCAD, HEC RAS)
- WMS automates watershed delineations and stream channel generation
- Allows export of modeling results and features objects to other software applications
- Uses common hydrologic models to generate peak flow estimates
- Allows for front end and post-processing for other hydrologic models (e.g., GSSHA, HEC-RAS, CE-QUAL-W2)

Cons

- Some software stability problems were noted during testing – especially during coordinate conversions, TIN generation, and simulations
    - Multiple coordinate systems were often problematic (This project had 7 coordinate systems)
- No “Undo” option which requires frequent “Saves”
- On-screen digitizing capability is somewhat limited (e.g., panning and zooming not available while in digitizer mode)
- AutoCAD Drawings must be version 2002 or older (under current release of WMS)
- The current version of HEC-RAS (version 3.1.2) is not supported – must be 3.1.1 or older

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