Real Time Flood Modeling Due To The Severe Rainfall During A Hurricane:
The West Fork of the Calcasieu River,
Calcasieu and Beauregard Parishes, Louisiana

Hassan S. Mashriqui, Engineering Director, Natural Systems Modeling Group, CCEER, John C. Pine, Associate Professor, Institute for Environmental Studies, Doug Albert, Graduate Student, Geography Department, Louisiana State University.

INTRODUCTION

Flooding resulting from hurricanes is a major cause of loss of life and property. A new tool in understanding the nature and extent of flooding is now available to local emergency management and other personnel. This tool links hydrologic and hydraulic modeling programs, geographic information systems, and real time weather data. The tool provides local officials information to be used in selecting evacuation routes, buildings to be used as shelters, and areas to be impacted by rising flood waters. In addition, the technology provides local officials with information to mitigate flooding damage including the examination of alternate strategies for identifying drainage area, adding pumping stations, levees, and land use. For the private sector, the flood modeling programs can provide chemical process operations with accurate flood inundation areas, the level of water and flow rate for these areas. For chemical processors who produce, store, transport hazardous substances, this tool provides information on the potential impact for potential or historical storms.

To help illustrate the nature and application of flood modeling technology and its application to emergency management, a fully operational GIS linked hydraulic and hydrologic model was developed to simulate flooding from severe rainfall during a hurricane. The study area for this demonstration is the West Fork of the Calcasieu River in the Calcasieu and Beauregard Parishes in Louisiana. This area was selected because of the interest by local officials in understanding the potential threat of heavy rain in their area. In addition, the study area water basin flows into a heavily developed manufacturing center in Westlake and Lake Charles, Louisiana. The area impacted by the water basin is also a major transportation route for rail, motor carrier, pipeline, and shipping. Figure #1 shows the West Fork Basin area in Calcasieu and Beauregard Parishes.

The demonstration project makes use of National Weather Service forecast information including volume and intensity of rainfall. Flood inundation maps created in the demonstration project will be provided in paper and digital form to State and local officials so that the nature and extent of flooded areas may be understood. Local officials can then use the maps to identify critical building, structures, and transportation routes inside the flood zones. Such a system enables local officials to quickly identify at-risk structures, homes, and organizations. Specific Flood elevation levels for the study area may be used to calculate the most efficient use of pumps, evacuations, or selection of evacuation routes.

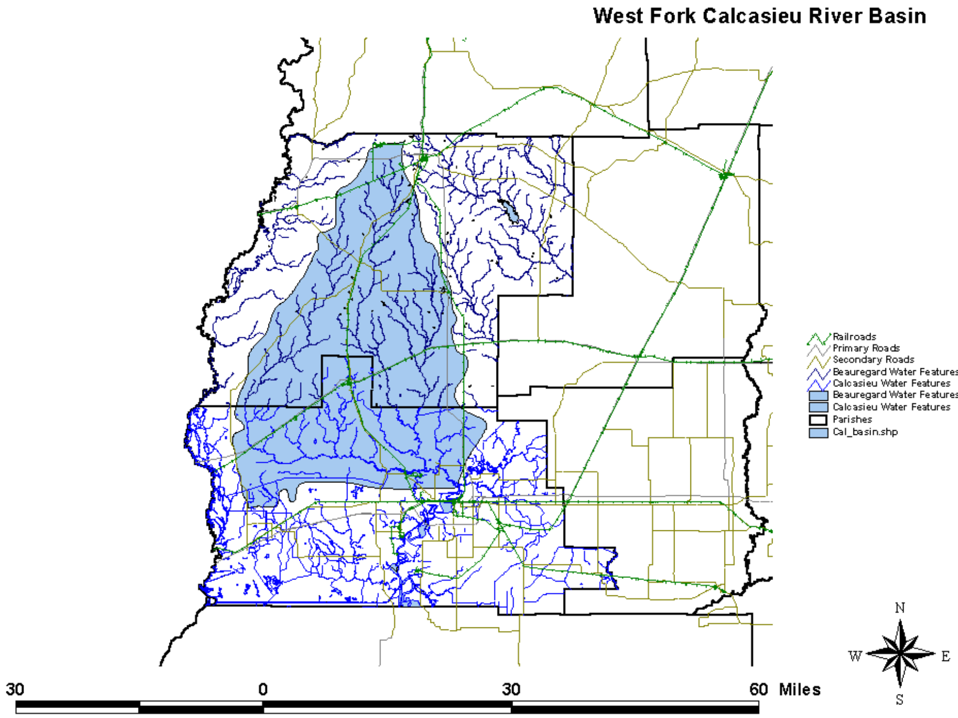

Figure #1
West Fork Calcasieu River Basin

Flood Modeling

Hydrologic and hydraulic modeling was performed using the Watershed Modeling System (WMS) in association with standard FEMA approved hydraulic models including the one-dimensional steady flow model HEC-RAS and the unsteady flow model UNET. These models provide a prediction of real time water surface profiles.

Watershed Modeling System (WMS): WMS is a comprehensive environment for hydrologic analysis. WMS merges information obtained from terrain models and GIS with industry standard hydrologic analysis models. WMS uses three primary data sources for model development including: (1) Geographic Information Systems (GIS) Data; (2) Digital Elevation Models (DEMs); and (3) Triangulated Irregular Networks (TINs). The GIS data includes information on the type of soils in the study area and land use. Surveyed cross sections for water features were prepared in digital form and used as a basis for all flood-modeling programs. The DEM data provides data on the slope of the area as described by land contours; DEM data is drawn from the USGS 1:24,000 Quad sheets.

Terrain models utilize geometric attributes such as area, slope and runoff distances as part of their calculations. WMS takes advantage of many display options to aid in modeling and understanding the drainage characteristics of terrain surfaces. The distinguishing difference between WMS and other applications designed for setting up hydrologic models (like the Corps of Engineers HEC-1 and TR-20 programs) is its unique ability to take advantage of digital terrain data such as the USGS digital elevation model data (DEM) to calculate hydrologic flow development.

Data

The WMS and related programs required extensive data for the water basin. High quality digital elevation model (DEM) files reflecting the slope and contour of an area were used as shown in Figure #2, West Fork of the Calcasieu River, Five-Foot Contours. The watershed and water features were identified and defined using information obtained from EPA's BASIN2 Program as reflected in Figure # 3. A critical part of this project is the display of inundation areas on high quality photos. Data reflecting the nature of soils in the basin was adapted the state soils geographic database (statsgo) as shown in Figure #4. "West Fork Calcasieu River Basin." Finally, the model requires current land use maps classifying areas as cultivated, marshland, forest, or developed. The land use files used in the demonstration was adapted from data provided in the EPA Basin2 Program and other state sources.

Figure #2, West Fork Calcasieu River Five-Foot Contours

USGS Digital Elevation Model (DEM

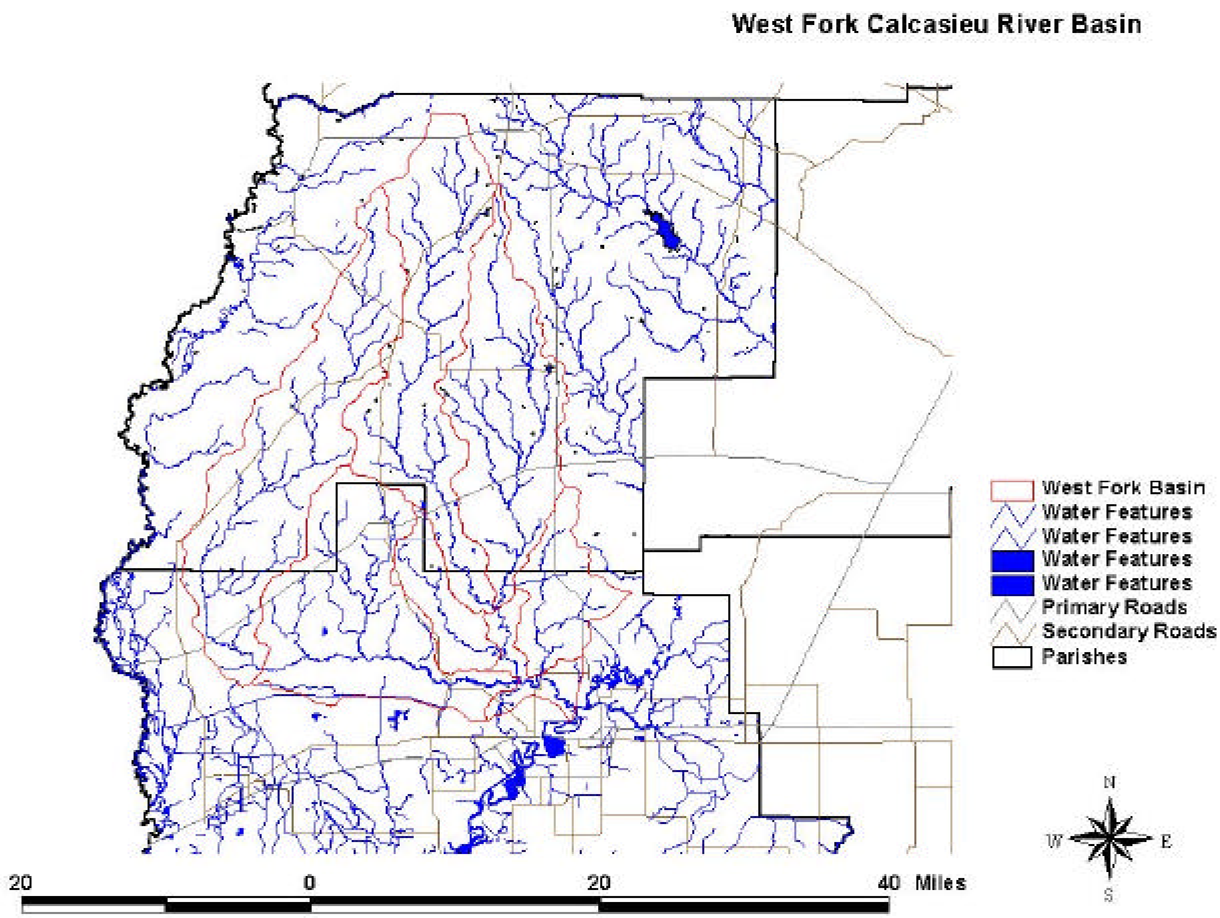

Figure #3
West Fork Calcasieu River Basin

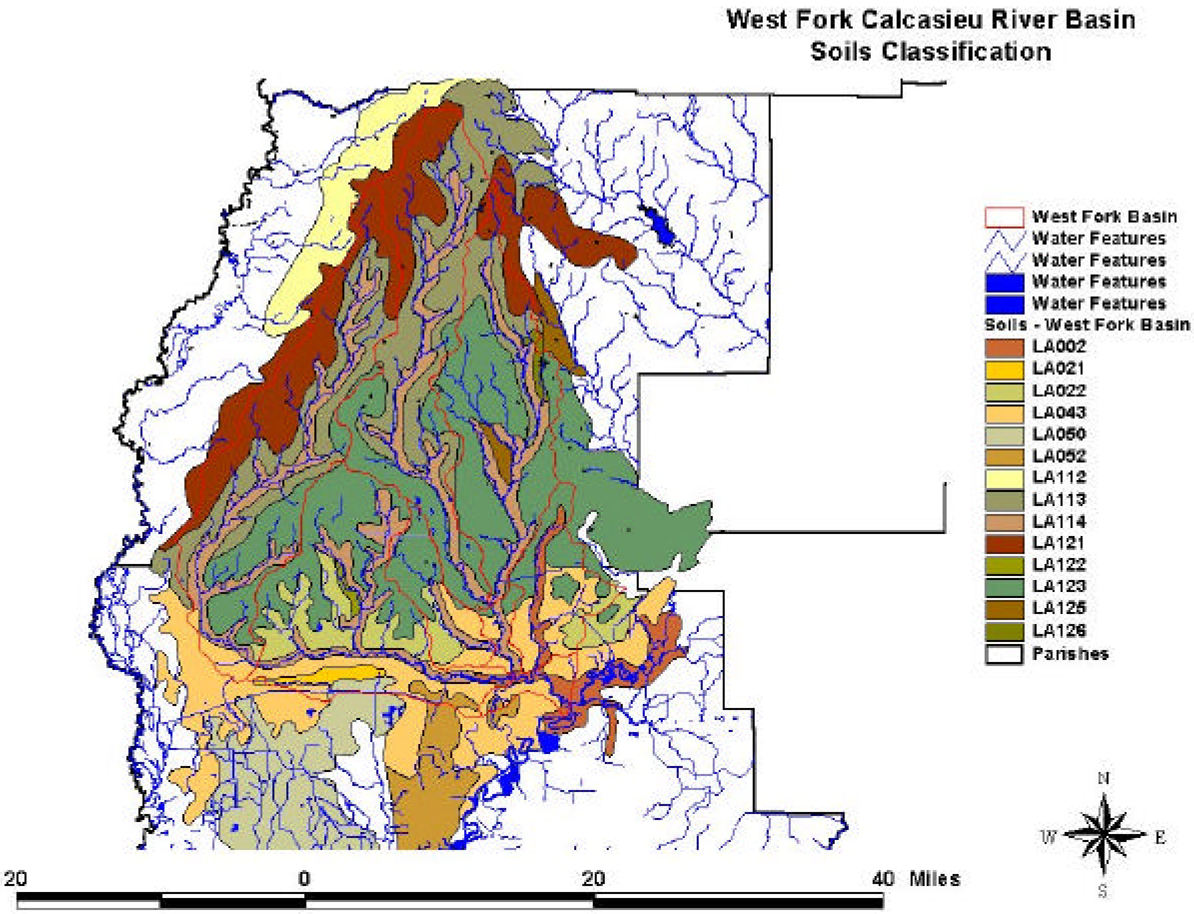

Figure #4, West Fork Basin Soils Data

Color Digital Ortho-Photo Images prepared at a scale of 1:1200 were also used as a part of this demonstration. Figure #5 provides an illustration of how these images could be combined with the water features and DEM layers.

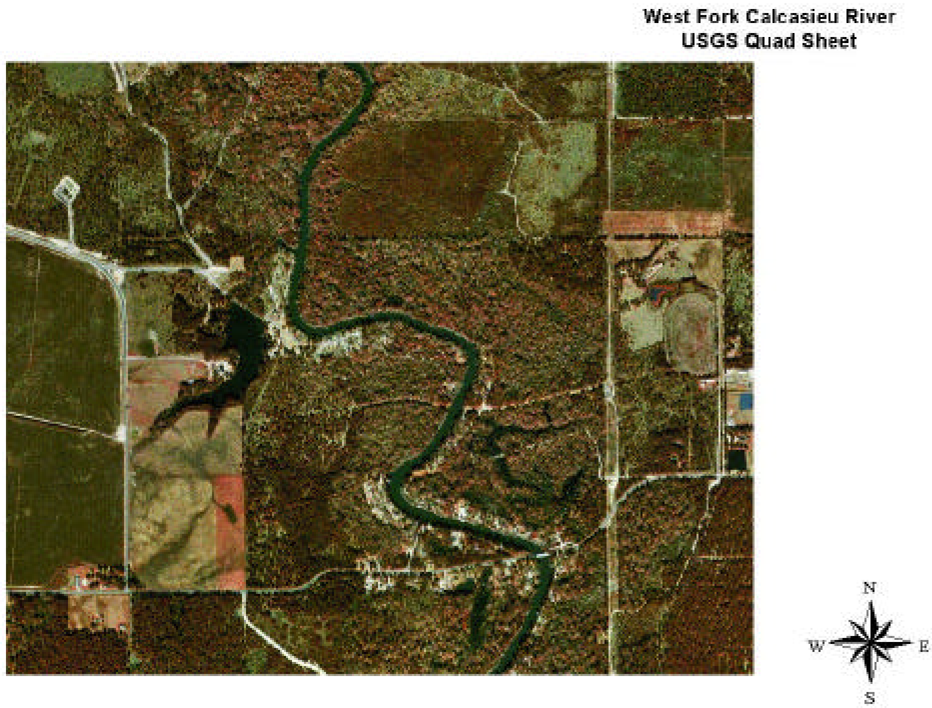

Figure #5, Ortho-Photo Image of Study Area

Calculations used to prepare scenario flooding buffer zones were based on surveyed cross sections of the water features. Displaying the results of the WMS as a buffer zone, however requires accurate elevation contours. Unfortunately, the USGS DEM contour maps are based on a 10-foot elevation range. The GIS programs can estimate contours at even the 1-foot level, but the result is a clear "estimate" and not a true description of the area that could be flooded. As a result, more accurate contours are needed to accurately display the results of WMS.

Map Layers

The analysis completed as a part of this demonstration included a comparison of the flooding buffer zones with selected features of the geographic area. Map layers used in the analysis include the location of hospitals, schools, nursing homes, EPA regulated sites, bridges, USGS landmarks, parks, resident and business addresses from listed phone records, water features, roads, city boundaries, and parish boundaries. Census population files at the county, tract, block group, and block level were also included. Features falling within a specific buffer zone were selected, saved, and grouped by weather scenario. Population counts utilizing the Census Block Group and Block files were made to describe the characteristics of the population in a vulnerability zone.

Images including USGS Quad Sheets in digital form (1:250,000, 1:100,000, and 1:24,000 scale) provided an excellent background for viewing vulnerability zones and map layers in portions of the study area. Figure #6, "West Fork Calcasieu River Resident and Business Locations" provides an illustration of how the display would appear. Black and white photos from Calcasieu Parish and USGS color Quarter Quads were also used as background for the analysis. Figure #5, "Ortho-Photo Image of Study Area" provides an example of the type of image that is available for display and use.

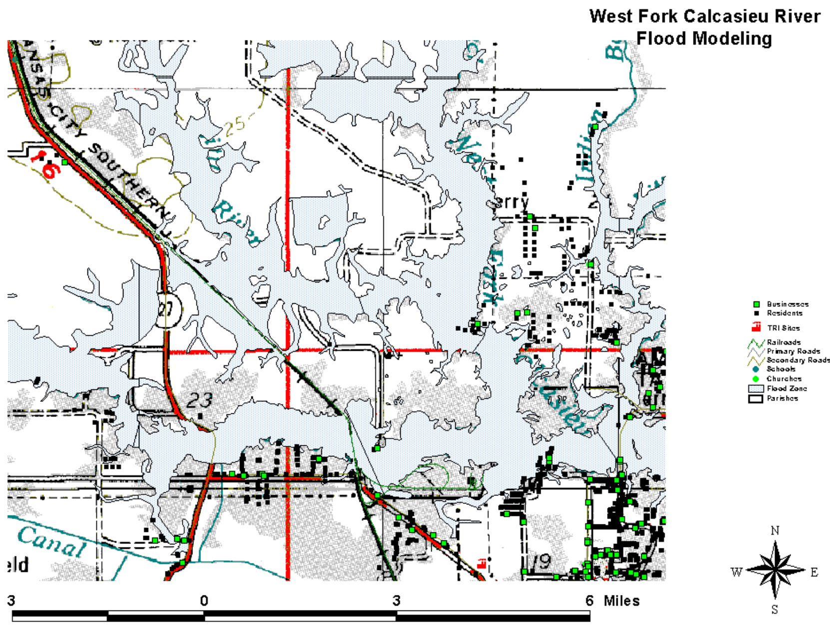

Figure #6 West Fork Calcasieu River
Resident and Business Locations

GIS map layers were provided to the Parish emergency management officials in the study area. Most layers were formatted as ArcView ".shp" files in a UTM 15 projection. The output displays for the functioning hydraulic and flood plain delineation models were also are provided to local emergency management agencies. Multiple scenarios were used to identify buffer zones for potential rainfall events in the West Fork Calcasieu River Basin. Therefore, it will not be necessary for local officials to attempt to run the hydraulic model or create additional flood plain inundation maps for scenarios used in the study.

GIS provides a unique tool to merge and display geographic images. Figure #7 provides a display of a portion of the West Fork Calcasieu River using 3D technology. A USGS Quarter Quad in the Moss Bluff area is draped over the USGS DEM contour map creating a 3D image of the area. This type of image is useful to local officials and businesses for it can display the impact of flooding in a 3D image. The 3D image has the capacity to show the elevation of the water and its impact on buildings, bridges, roads, land, and levees.

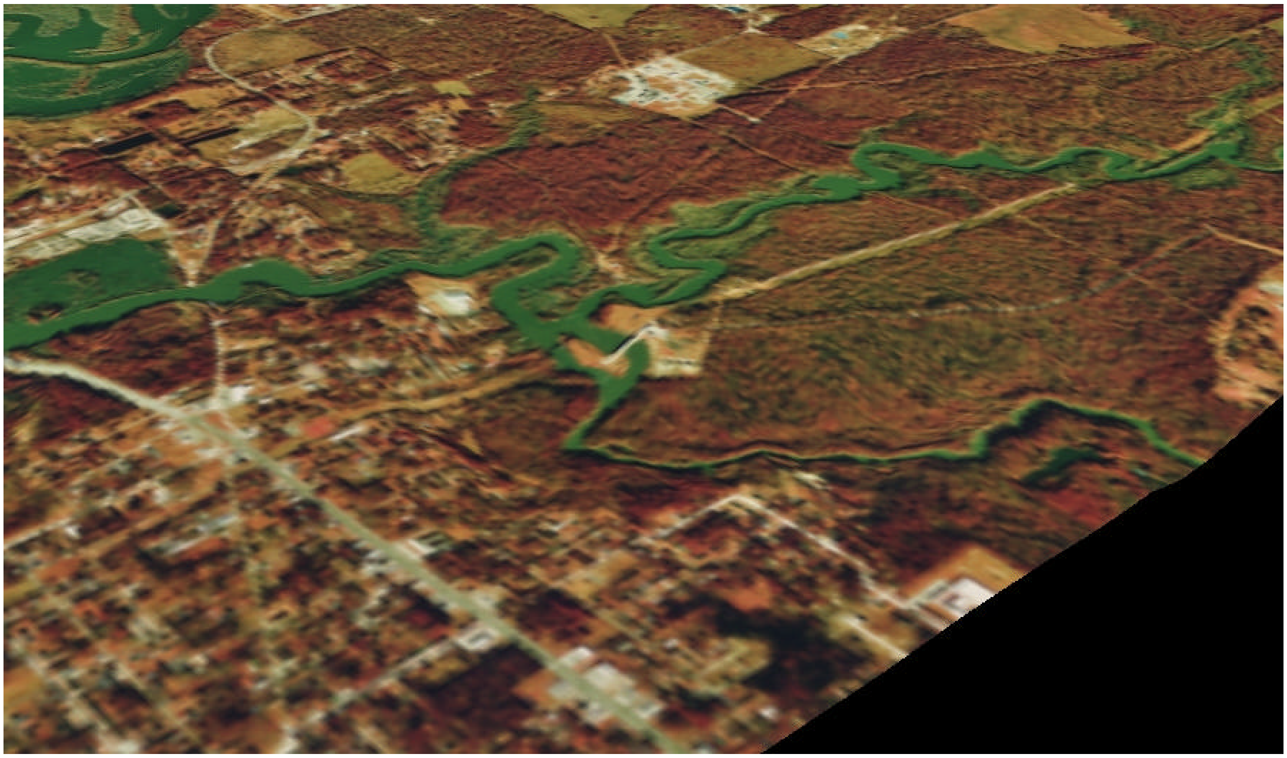

Figure #7, West Fork Calcasieu River
3 D Image

Future Data Needs

The next phase of the project will be to prepare more accurate elevation contours for the local area. These data should include but are not limited to:

- Existing digital elevation that may be available from the county, state or local agency
- Surveyed cross-section data used in conjunction with the HEC-RAS and UNET model for developing water surface profiles along the course of the river under study
- Surveyed information about the extents of the flood of record. This data will be collected from digital map sources as well as field surveys where necessary.
- Base map information including available aerial photography, scanned maps or digital raster graphic files, location and ownership of critical structures within the flood plain boundaries. Both existing data sources (where available) and field surveys will be used to compile the base map information.

Conclusions

Hydraulic models for predicting water surface profiles and flood inundation may be used by local emergency management, public works, planning, flood management, and public safety personnel to identify at-risk structures and organizations. The models also provide a basis for predicting the area to be impacted, the water level, and flow rate. The most convenient and user-friendly method to display and query this information is through the use of a Geographic Information System (GIS). Base map information including an aerial photograph or digital map and point features for critical structures may be used as a backdrop for inundation maps. Each different inundation map (corresponding to water surface profiles from selected flows and or high water elevations) may be a separate layer (polygon) in the GIS. Parish or county personnel will then be able to select the inundation map corresponding to a forecasted condition, overlay it on the base map and query the layer for structures inside the selected inundation area.

Household and business information, including phone numbers or other emergency contact information, may be stored as part of the GIS database. A simple query process may be used to alert households as well as business facilities of a potential flood zone that could affect their home or business. Figure #6, "West Fork Calcasieu River, Resident and Business Locations" provides an illustration of how WMS could create a buffer zone to reflect a weather scenario and be used to identify residents and businesses vulnerable to flooding.

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Appendix A
Supported Hydrologic Models with WMS

HEC-1 Interface in WMS: The HEC-1 model is designed to simulate the surface runoff response of a river basin to precipitation by representing the basin as an interconnected system of hydrologic and hydraulic components. A river basin is represented as an interconnected group of sub-areas. The assumption is made that the hydrologic processes can be represented by model parameters which reflect average conditions within a sub-area. WMS includes a comprehensive interface to the HEC-1 flood hydrograph program used by many hydrologic engineers to model the rainfall-runoff process. The interface has been created in such a way that models can be built from TINs used to delineate basin boundaries and compute geometric data, or by manually constructing a series of outlets and basins to form a topologic representation of the watershed. When a TIN is used the topologic model is automatically constructed as outlets are added and basins defined. Hydrographs from different sub basins or from different runs of HEC-1 can also be overlaid for comparison.

TR-20 Interface in WMS: TR-20 Computer Program (Project Formulation Hydrology, TR-20: TECHNICAL RELEASE 20 Computer Program For Project Formulation Hydrology February, 1992 Revised by The Hydrology Unit & the Technology Development Support Staff Soil Conservation Service.). The TR-20 computer program assists the engineer in hydrologic evaluation of flood events for use in analysis of water resource projects. The program is a physically based event model, which computes direct runoff resulting from any synthetic or natural rainstorm. There is no provision for recovery of initial abstraction or infiltration during periods of no rainfall within an event. The program develops flood hydrographs from runoff and routes the flow through stream channels and reservoirs. Routed hydrographs are combined with those from tributaries. Procedures for hydrograph separation by branching or diversion of flow and for adding base flow are provided. The program uses procedures described in the SCS National Engineering Handbook, Section 4, Hydrology (NEH-4) except for the reach flood routing procedure. Peak discharges, the times of occurrence, water surface elevations and duration of flows can be computed at any desired cross section or structure. Complete discharge hydrographs, as well as discharge hydrograph elevations, can be obtained if requested. The program provides for the analysis of up to nine different rainstorm distributions over a watershed under various combinations of land treatment, floodwater retarding structures, diversions, and channel modifications. Such analysis can be performed on as many as 200 sub-watersheds or reaches and 99 structures in any one continuous run. WMS includes a comprehensive interface to the TR-20 hydrologic program used by many hydrologic engineers to model the rainfall-runoff process. The interface has been created in such a way that models can be built from TINs used to delineate basin boundaries and compute geometric data, or by manually constructing a series of outlets and basins to form a topologic representation of the watershed. When a TIN is used the topologic model is automatically constructed as outlets are added and basins defined. Also, any geometric parameters computed by WMS are supplied to corresponding TR-20 input fields. Once a TR-20 model has been defined the TR-20 model checker can be run to try and identify potential problems in the data prior to actually running the TR-20 model. The model checker provides several hints (although it does not guarantee a successful run or that the answers will be correct) for correcting the data prior to running TR-20. TR-20 can be launched from within WMS and after completion hydrographs can be displayed on the TIN, the topologic model and blown up within the hydrograph window.

Interface to the National Flood Frequency (NFF) Program in WMS: For many years, the U.S. Geological Survey (USGS) has been involved in the development of regional regression equations for estimating flood magnitude and frequency at identified sites. These regression equations are used to transfer flood characteristics from gauged to ungauged sites through the use of watershed and climatic characteristics as explanatory or predictor variables. Generally these equations have been developed on a statewide or metropolitan area basis as part of cooperative study programs with specific State Departments of Transportation or specific cities. The USGS, in cooperation with the Federal Highway Administration and the Federal Emergency Management Agency, has compiled all the current (as of September 1993) statewide and metropolitan area regression equations into a microcomputer program titled the National Flood Insurance Program. As many as 7 multiple regression equations (2-, 5-, 10-, 25-, 50-, 100-, and 500-year) are defined for each of 200 plus flood regions across the US. Methods are also available for estimating a typical flood hydrograph corresponding to a given T-year peak discharge.

Interface to the Rational Method in WMS: The Rational method main dialog will include the capability to generate Intensity-Duration-Frequency (IDF) curves from HYDRO-35 maps (eastern US), NOAA Atlas maps (western US), or user specified data of rainfall intensities. A kinematics wave equation, used by the Federal Highways

Administration (FHA) design handbook, can be used to estimate the time of concentration from the catchment length, slope, and a Manning's roughness coefficient.

HEC-RAS (River Analysis System): HEC-RAS is an integrated system of software, designed for interactive use in a multi-tasking, multi-user network environment. The system is comprised of a graphical user interface (GUI), separate hydraulic analysis components, data storage and management capabilities, graphics and reporting facilities. The current version of HEC-RAS only supports Steady Flow water surface profile calculations. HEC-RAS is designed to perform one-dimensional hydraulic calculations for a full network of natural and constructed channels. The program is intended for calculating water surface profiles for steady gradually varied flow in natural or man-made channels. Both sub-critical and supercritical flow profiles can be calculated. The effects of various obstructions such as bridges, culverts, weirs, and structures in the floodplain may be considered in the computations. The computational procedure is based on the solution of the one-dimensional energy equation with energy loss due to friction evaluated with Manning's equation. The computational procedure is generally known as the standard step method. The program is also designed for application in floodplain management and flood insurance studies to evaluate floodway encroachments. Also, capabilities are available for assessing the effects of channel improvements and levees on water surface profiles. Input and output may be either English or metric units.

UNET (one-dimensional Unsteady Flow through A Full Network of Open Channels): UNET simulates one-dimensional unsteady flow through a full network of open channels. One basic element of a full network problem which is the split of flow into two or more channels. For sub-critical flow, the division of flow depends on the stages in each of the receiving channels. These stages are a function of channel geometry and downstream backwater effects. In addition to solving the one-dimensional unsteady flow equations in a network system, UNET provides the user with the ability to apply several external and internal boundary conditions, including; flow and stage hydrographs, gated and uncontrolled spillways, bridges, culverts, and levee systems. All input, output and calculations are performed in U.S. Foot- Pound Units.