

Two- and Three Dimensional Visualization of National Weather Service Flood Forecasts Using ArcGIS

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Abstract

As a demonstration project, the National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center, through a partnership with the National Weather Service, has created time series inundation maps for select locations along the Tar River in North Carolina using ArcMap and ArcScene. The project used river gauge data collected and provided by the U.S. Geological Survey during the intense rainfall associated with Hurricane Floyd in September 1999. These time series maps allowed for two- and three-dimensional (2-D and 3-D) visualizations of flood events that were previously only represented in tabular format. This paper seeks to detail the methodologies involved in data collection and processing, creation of geographic data layers, and processes used to export to 2-D and 3-D media.

Background

The NOAA National Weather Service (NWS), in a partnership with the State of North Carolina, and the NOAA Coastal Services Center, is developing flood forecast mapping capability for the Tar River in eastern North Carolina (Figure 1). The goal of this pilot project is to provide customers with visually oriented and easily accessed flood forecast products. Data used includes remotely sensed raster data in the form of LIDAR-derived digital elevation models (DEMs) and digital orthophotography, traditional geographic information system (GIS) vector data layers, as well as in situ measurements of streamflow, precipitation, and ground survey data. Use of partnered data has been a key to developing hydraulic models to accurately predict flooding water surface elevations and mapping these elevations via high resolution DEMs. This project relies on the data provided by North Carolina through a Cooperating Technical State partnership with the Federal Emergency Management Agency (FEMA) National Flood Insurance Program.

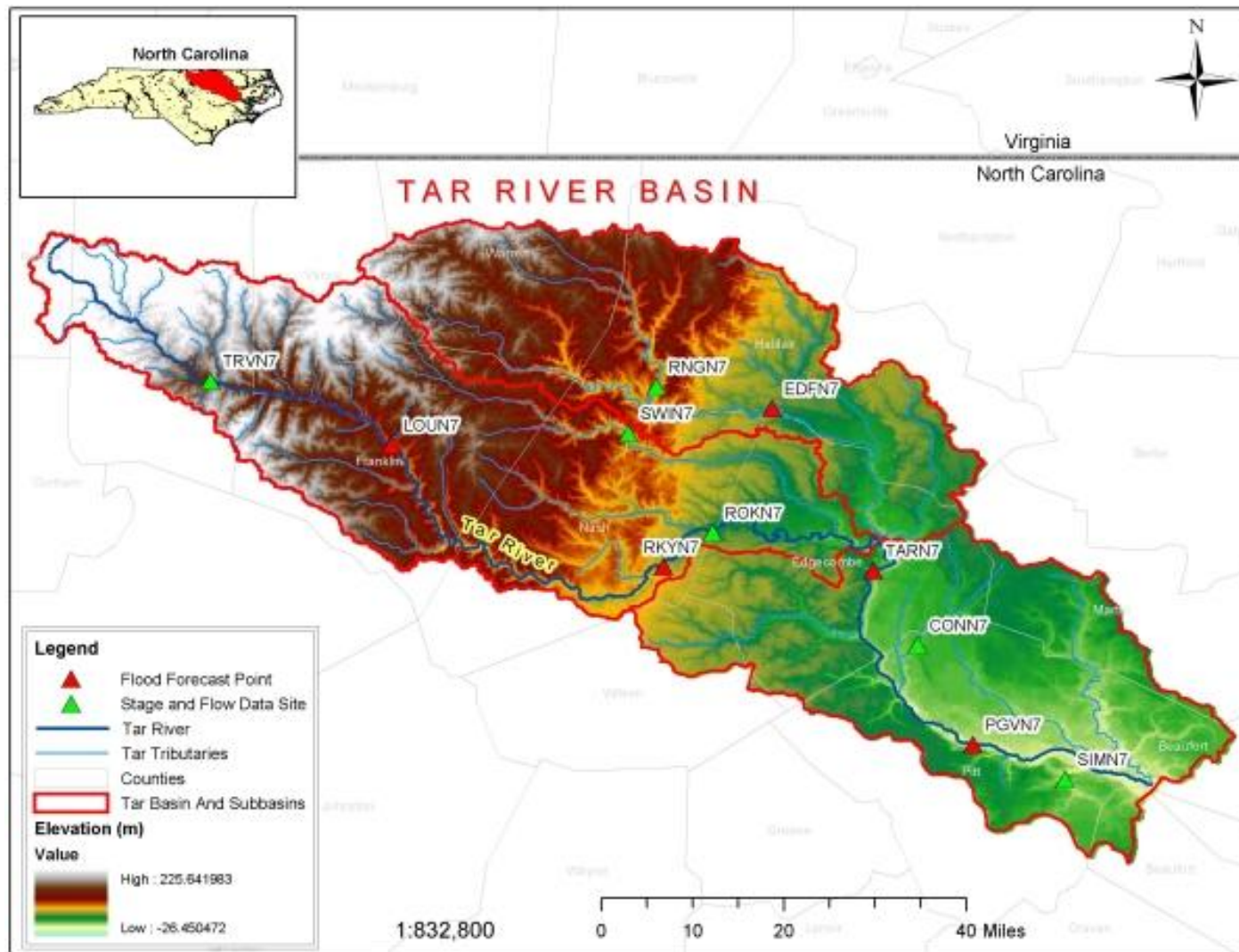


Figure 1. The Tar River Basin, located in eastern North Carolina, drains approximately 2,543 square miles (4.8% of the total area of the state). Shown are digital elevation model, five NWS flood forecast points (red triangles), and other USGS gauges sites used in flood forecasting (green triangles).

New operational modeling techniques and GIS raster processing enables the production of spatially referenced flood forecasts for areas between current, point specific river forecast locations. Resulting forecast maps are then displayed in various two- and three-dimensional (2-D and 3-D) graphical formats, including interactive maps and time series animations.

Hurricane Floyd

Hurricane Floyd (1999), the fifth hurricane to impact the State of North Carolina in a four-year period, produced devastating flooding across eastern

North Carolina. Over 4,000 homes and businesses were destroyed, and as a result, the governor requested a program to address flood-mapping deficiencies. In 2000, NOAA formally agreed to participate in the North Carolina Flood Mapping Project by proposing enhancements, such as flood forecast maps, to NWS flood predictions. A demonstration project under the NWS Advanced Hydrologic Prediction Service (AHPS) has been organized for the Tar River Basin in eastern North Carolina. This project is a collaborative effort between the NWS, the U.S. Geological Survey (USGS), the Federal Emergency Management Agency (FEMA), the NOAA Coastal Services Center, and the State of North Carolina.

Data collected from USGS gauge sites during Hurricane Floyd flooding was used to produce example inundation maps and illustrate how flood maps can be displayed in 2-D and 3-D format over the Internet. The processes developed for creating these maps is being used to produce flood forecast maps and the display methods will be used to enhance graphical forecast products. A brief description of the process used to create flood inundation maps follows with example figures.

DEMs from LIDAR Derived Elevation Data

The first step in creating flood inundation maps was to obtain elevation data and create a DEM of the area where mapping was needed. In the case of the Tar River Basin, elevation data was available through the State of North Carolina Floodplain Mapping Information System, accessed through www.ncfloodmaps.com. The elevation data was downloaded in 3.6-square-mile tiles as bare earth mass points and breaklines. The process steps outlined in Figure 2 were used to create the final DEM used for inundation mapping. See Figure 3 for a symbol key for the flow chart in Figure 2. A Triangular Irregular Network (TIN) was created from the mass points and breaklines using ArcMAP and the 3D Analyst "create TIN from features" function. The resulting TIN (ground TIN) was then converted to a raster GRID using the 3-D Analyst "convert TIN to raster" function. A raster cell size of 5 feet was used for detailed inundation mapping to eliminate rough edges associated with lower resolutions. This raw ground DEM excluded bridges, which were necessary to include when mapping flood inundation areas. Therefore, bridge elevations derived from engineering data were burned into the raw ground DEM using ArcGIS and Spatial Analyst. The resulting final ground grid was then ready to be used as the base layer to derive flood inundation maps.

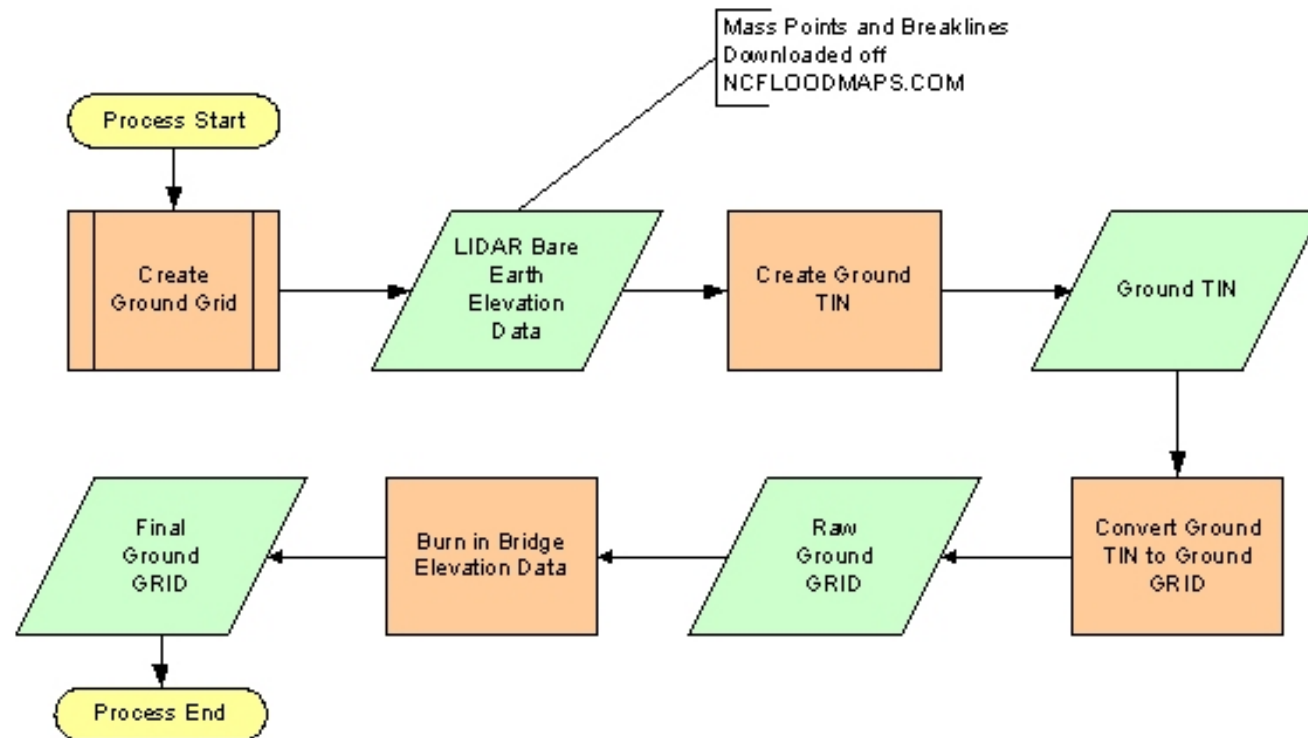


Figure 2. Process steps for creating the final DEM used for flood inundation mapping (see Figure 3 for symbology explanation).

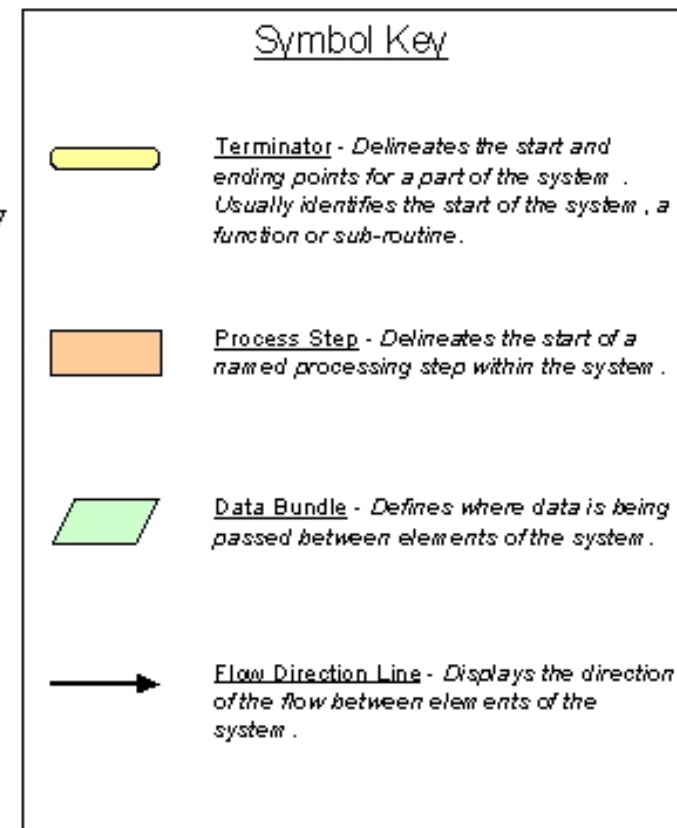


Figure 3. Symbol key for process flow charts in figure 2 and figure 5.

Flood Inundation Mapping

The NOAA Coastal Services Center has used river gauge data (Figure 4), collected by the USGS during the intense rainfall associated with Hurricane Floyd in September 1999, to create time-series inundation maps at select locations along the Tar River. These maps were created primarily using ArcGIS.



Figure 4. USGS gauge located next to highway bridge during flooding flows associated with Hurricane Floyd rainfall (Sept. 1999).

The purpose of this project was to demonstrate a prototype application for flood forecast mapping. The project uses existing data as a model to illustrate the concept of mapping gauge and water surface time-series data in an interactive GIS environment over the Internet. In this interactive format, the user can pan, zoom, and identify data, as well as print maps and view metadata. This prototype shows time-series inundation maps at three urban areas that were most affected by Hurricane Floyd flooding on the Tar River: Rocky Mount, Tarboro, and Greenville.

Each inundation map was created by using a water surface elevation from the USGS stage data and subtracting it in a GIS using spatial analysis techniques from the ground surface, represented by a 5 x 5 ft. DEM, created by the methods discussed previously. Figure 5 shows the process steps for creating inundation maps from USGS gage data in order to create flood inundation polygon shapefiles that are used to depict flooded area. The first step involved collecting stream gauge data to capture the peak flooding associated with Hurricane Floyd. Each USGS gage on the Tar River collects 15 minute stage data and an archive of this data is available upon request. This stage data for the period of September 15th to 17th, 1999 was collected. Stage data from the USGS comes in feet and is referenced to a gage height. A conversion to a consistent elevation datum is required to correctly map the flooding. The NAVD88 datum was selected in order to match the datum used in the LIDAR collection and resulting final ground DEM already created. The result is a time-series dataset with water surface elevations in relation to time and date.

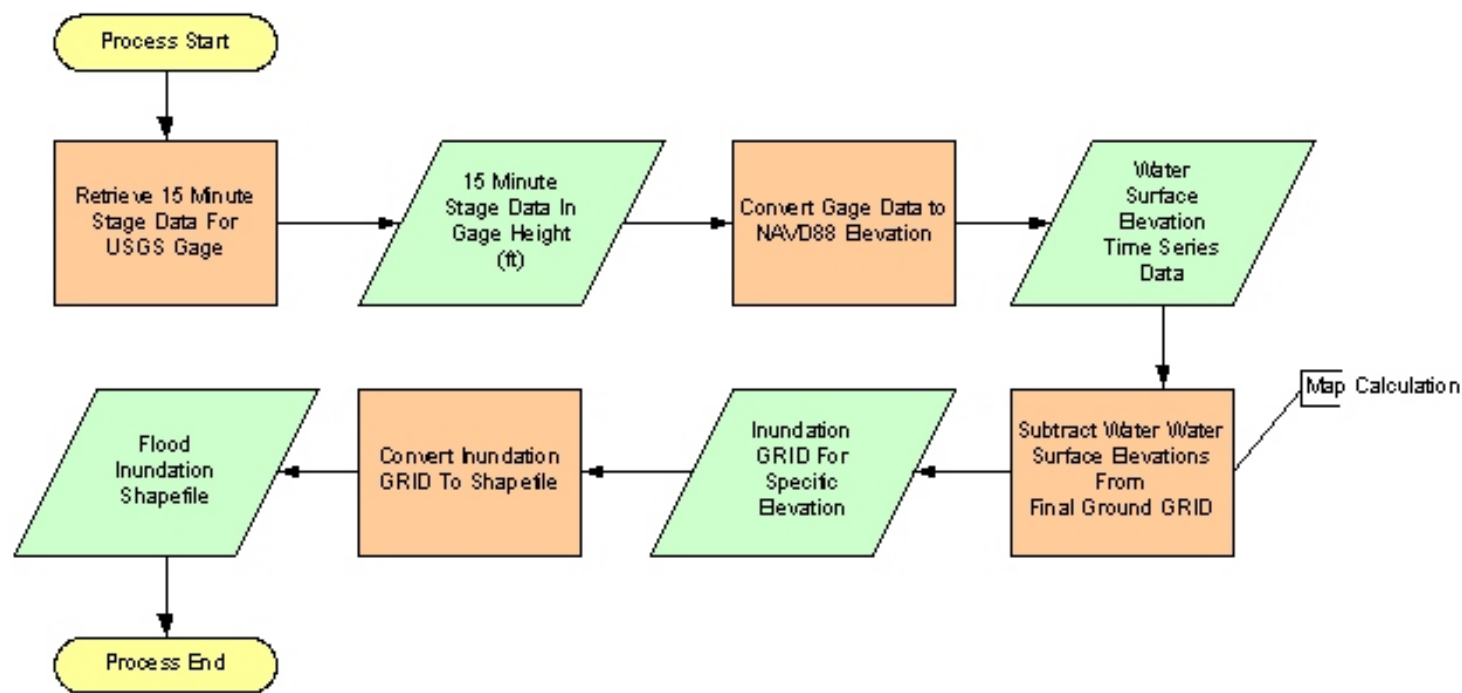


Figure 5. Process steps for creating flood inundation shapefiles from USGS gauge data using final ground DEM (see Figure 3 for symbology explanation)

An elevation for a given time step was then subtracted from the final ground DEM using a Spatial Analyst map calculation in ArcMAP. The result of this calculation was an inundation grid. This inundation grid was then converted to a polygon shapefile. Figure 6 illustrates this process. In some cases the flood inundation shapefile was cleaned to remove outlying inundation areas not connected to the main river. This process was repeated for many time steps, resulting in a series of shapefiles that depict flooding over time.

Digital Elevation Model & Flood Surface

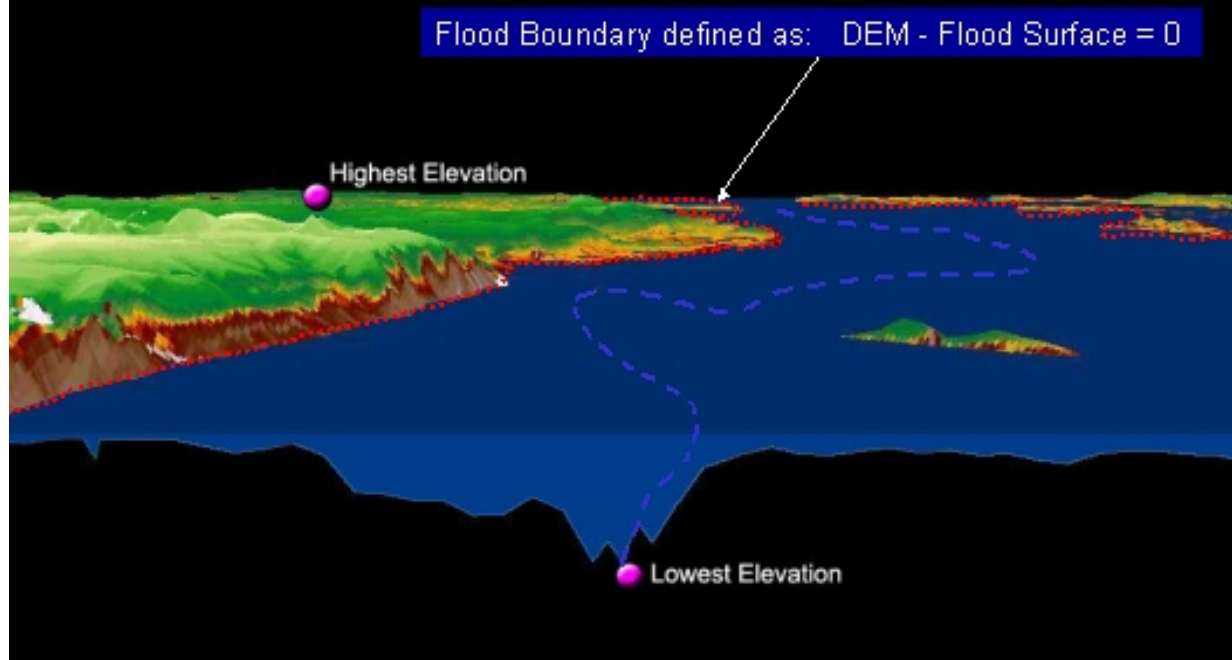


Figure 6. Subtraction of the final ground DEM from the flood surface elevation results in the flood boundary area which is then converted to a polygon shapefile.

The flood inundation shapefiles were then overlaid on existing GIS data to create 2-D maps that illustrate the impact of the flooding area. An example of one of these maps is seen in Figure 7. These maps were used to demonstrate the capability of displaying flood information via the Internet. The NOAA Coastal Services Center also used ArcIMS to develop a site that enabled the user to interactively view flood layers and see the time-series data in animation fashion. The ArcIMS site displays the flood layers on other raster and vector layers and provides the ability to turn on layers based on time intervals. This technology will be used by the State of North Carolina via the North Carolina Floodplain Mapping Information System to display flood inundation layers based on NWS forecasts.



Figure 7. Flood inundation map based on USGS gage data during Hurricane Floyd flooding in Greenville, NC.

Stage - Inundation Mapping for NWS Flooding Categories at Flood Forecast Point

Other products that have been developed using this methodology are stage-inundation maps at NWS flood forecast points. Currently, the NWS makes river forecasts at five points in the Tar River Basin. NWS issues forecasts based on the following flooding categories:

- Record Flooding: Potential for the highest observed river stage or discharge at a given site during the period of record keeping. (Not necessarily the highest known stage)
- Major Flooding: Potential for extensive inundation and property damage. Usually characterized by the evacuation of people and livestock and the closure of primary and secondary roads.
- Moderate Flooding: Potential for closure of secondary roads. Transfer to higher elevation may be necessary to save property. Some evacuations may be required.

- Minor Flooding: Potential for some public inconvenience, but minimal or no property damage likely.
- Flood Stage: A gauge height at which a watercourse overtops its banks and begins to cause damage to any portion of the defined reach. Flood stage is usually higher than or equal to bankfull stage.
- Below Flood Stage: Within Bank Stages (No Damages)

Each forecast point has USGS gauge heights associated with each of the above categories. These gauge heights were converted to the NAVD88 vertical datum and mapped using the same process as described above. The resulting inundation shapefiles correspond to the ranges of flooding categories. These shapefiles were overlaid on existing raster and vector datasets, such as orthophotography, and roads to create stage-inundation maps (Figure 8). In addition, a graphic showing the relationship between gauge height and NAVD88 is provided. These maps have been added to the NWS Southeast River Forecast Center Web pages. The intended audience for this product is the National Weather Service and its customers, especially emergency managers, disaster planners, state transportation officials, town managers, and commercial and residential property owners. These maps illustrate the area that will likely be impacted based on the NWS forecast category.

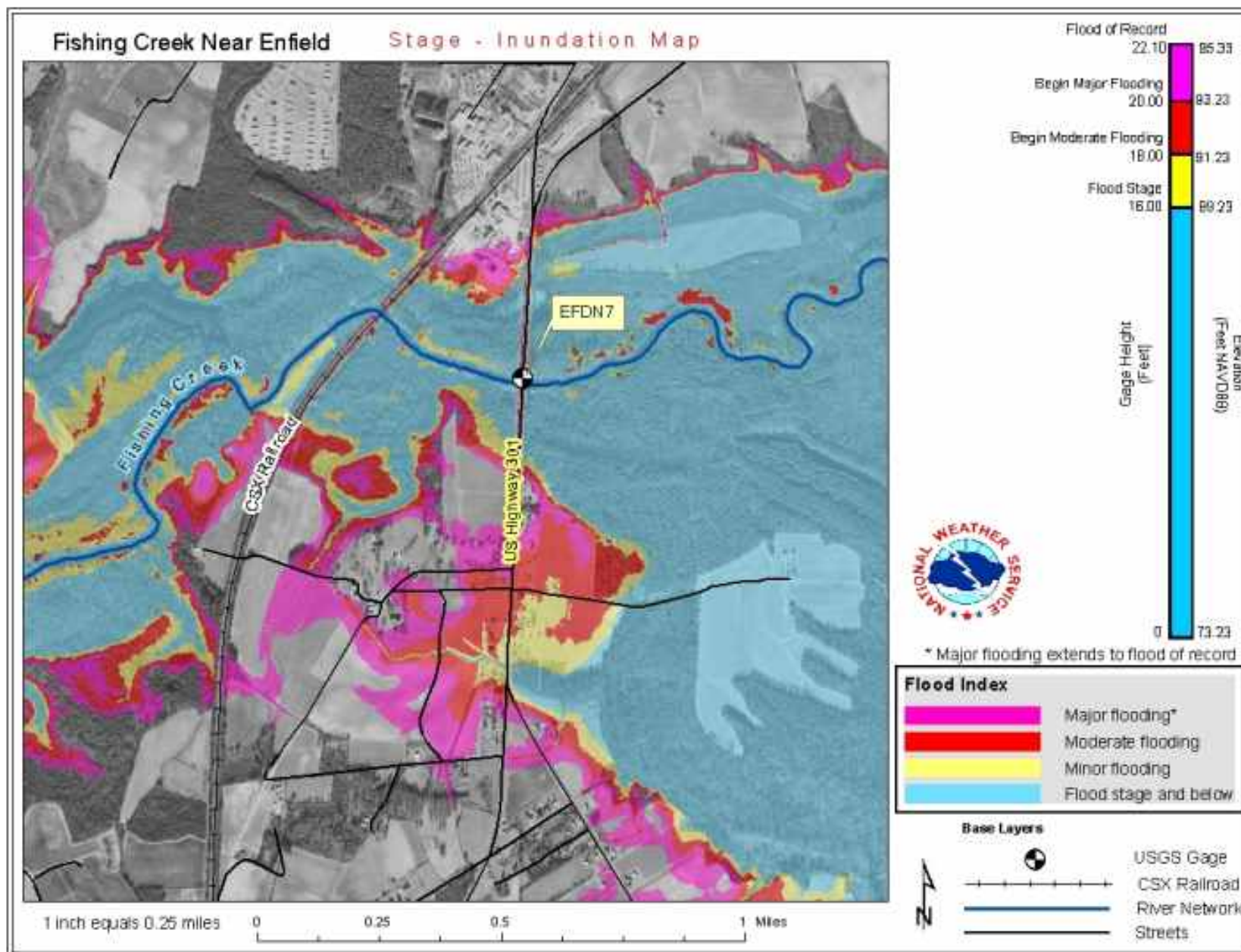


Figure 8. NWS stage inundation (form e-19) map graphically depicting flooding NWS flood definitions and relating river gauge height to actual elevation.

Automating the Map Process

One of the challenges of this project was the dissemination of flood mapping information to those who lack the technical capability to handle output

generated by a GIS. As a result, a need arose for the production of graphical outputs that made use of the previously generated shapefiles. A considerable component of this demonstration project has been the design and creation of an ArcObjects based tool that will aid in automating flood map production. The tool imports flood inundation shapefiles and exports a user defined map extent as a .jpeg image. These .jpeg images can then be incorporated into a variety of display formats including animated .gif images, Web-based mouse-over frames, and movie files such as an .avi or .mpeg. This process eliminates the need for a GIS system and helps broaden the audience of potential users of this data.

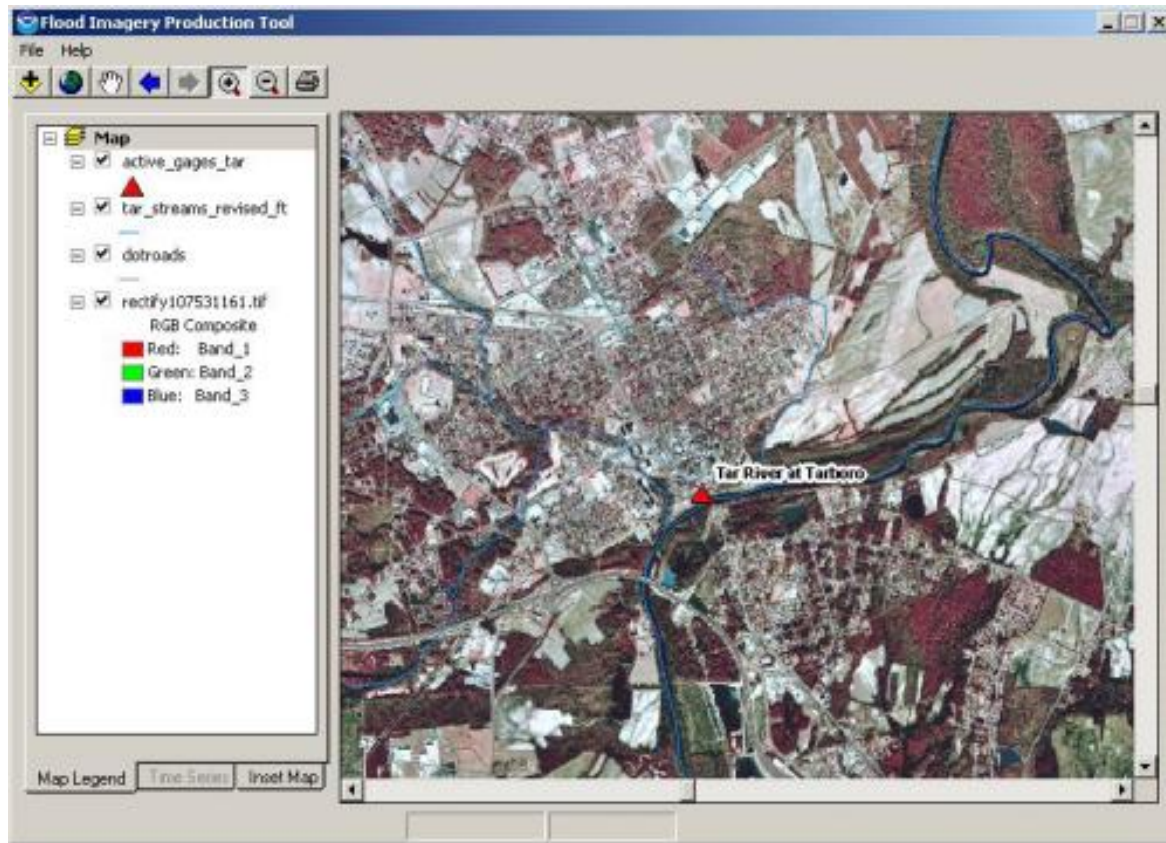


Figure 9. The flood map production tool.

Figure 9 above shows the layout of the flood map production tool. From the File menu a user can add a series of flood shapefiles to the map view. Once the shapefiles are added, the tool places them in chronological order using the values in an attribute field. The user can then click on the Time Series tab and create the output .jpeg images. The .jpeg images are saved to a user-specified directory, and a time stamp is automatically added as seen in Figure 10. The finished .jpeg files are then ready for use in a variety of Web applications.

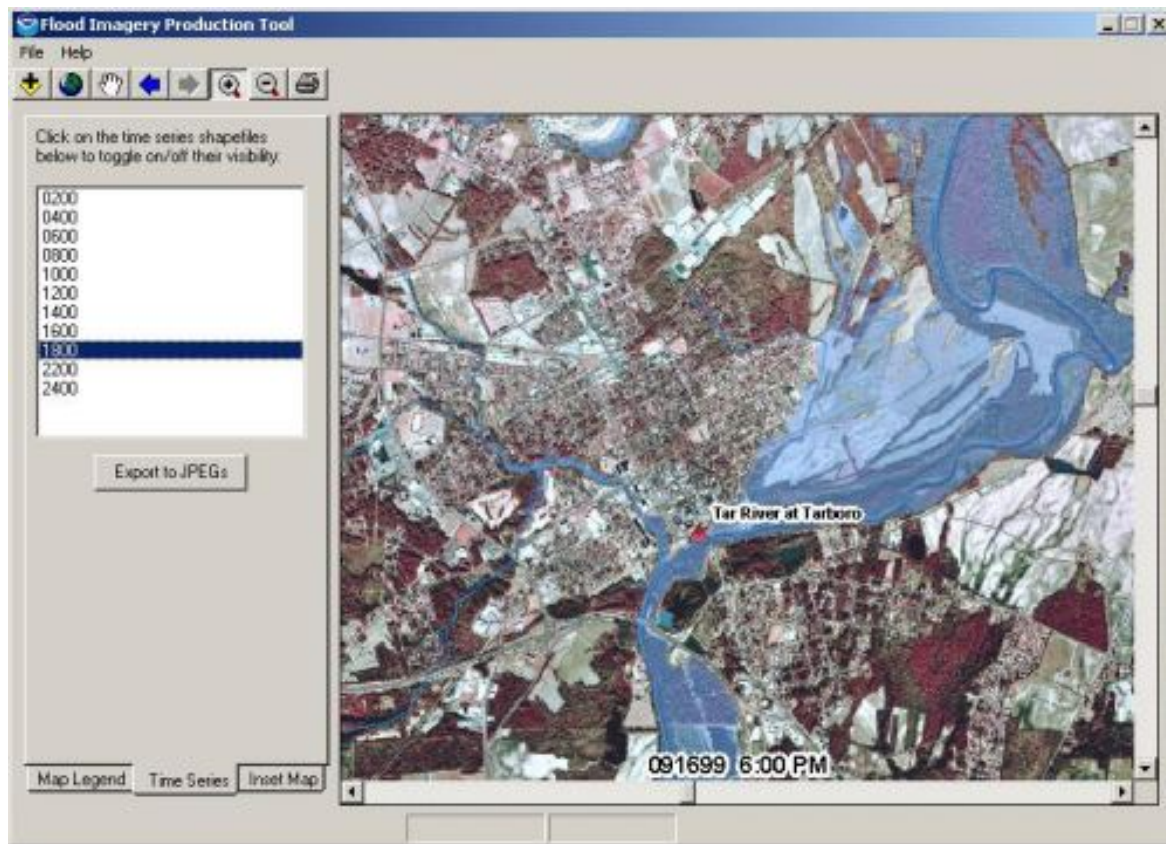


Figure 10. JPEG production with a time stamp

Eventually, this tool will be modified to work as either a background process or Web service. The goal is to eliminate the manual handling of shapefiles and simply provide the location of model output for automated map production. The maps can then be easily incorporated into a Web site template for immediate display during an expected flood event.

3-D Visualization of Flood Inundation

A secondary output of the flood inundation shapefiles was created in ArcScene. Using the beginning and end elevations of the flood event, a macro was written in Visual Basic for Applications to simulate rising water. At each interval increase in water height, the ArcScene map extent was exported as a .jpeg image. The resulting .jpeg images were then compiled to create a movie in .avi and animated .gif format.

At this stage in the project, these 3-D visualizations provide a good synopsis of a flood event and the areas affected, but are not hydraulically correct. Currently, a plane of water is passed through the DEM to give the illusion of flooding without taking into account channel slope, hydraulic structures, and man-made features that affect water flow. The challenge that lies ahead is to produce animations that accurately depict flood events taking into account features such as dams, dykes, and the upstream and downstream elevations of the river. Until then, such animations will prove to be valuable tools to visually depict the end results of flood events and the specific areas they impact.

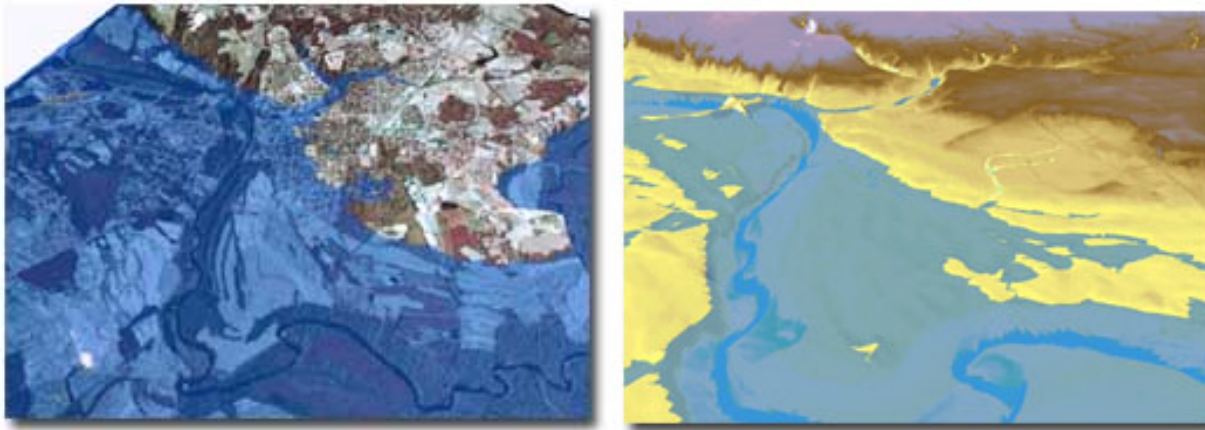


Figure 11. Example outputs of ArcScene animations showing transparent flood layer on aerial photo and bare earth DEM.

Conclusions

In an effort to assist the National Weather Service in producing more graphical forecasts in a GIS format, the NOAA Coastal Services Center has been developing the capability to map river forecasts. The goal is to convert traditionally text-based river forecasts to GIS layers (Figure 12) that can be overlaid on other GIS raster and vector datasets and used to make critical emergency management decisions by state and local officials.

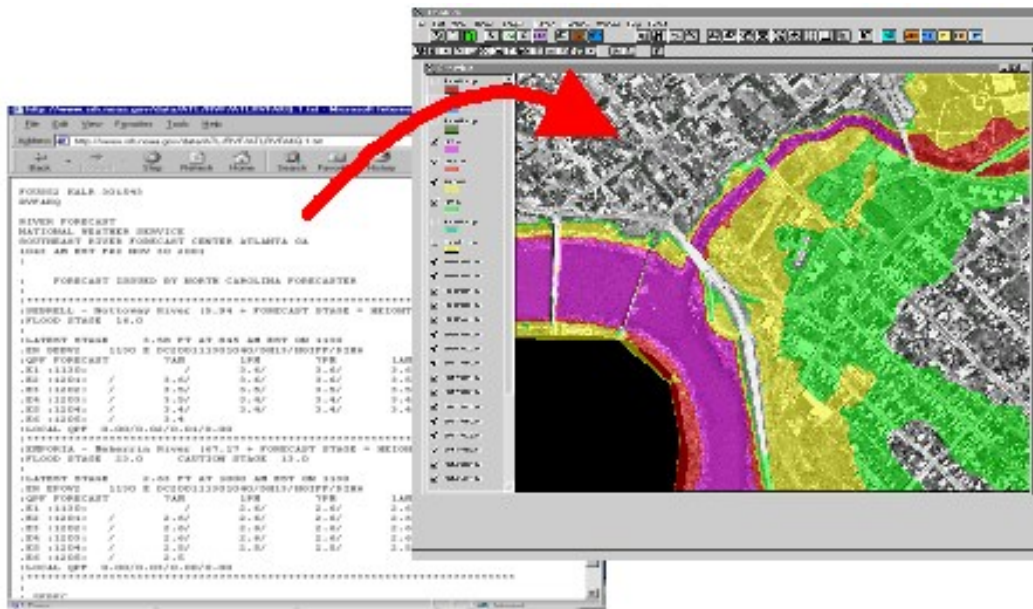


Figure 12. Text based forecast (on left) and a GIS based map showing forecasted flood inundation over an aerial photo (on right).

This paper has described the methods of producing GIS inundation maps from historical data (Hurricane Floyd) used to demonstrate effective 2-D and 3-D visualization and dissemination of flood data over the Internet. The next step in this project is to map NWS river forecasts using a dynamic hydraulic routing model that will enable prediction of flood stages between current river forecast points, areal depiction of forecasted peak flooding, and the ability to show predicted flooded areas as a snapshot in time. A system to map these forecasts and provide GIS layers to the State of North Carolina is being developed to run as part of the NWS Southeast River Forecast Center forecasting operations. Products from this project should be appearing on the Internet in early fall of this year.

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To view the demonstration web site visit:

www.csc.noaa.gov/ncflood

To view the Southeast River Forecast Center Tar River Basin AHPS pages visit:

www.srh.noaa.gov/atr/ahps/tar/tar.htm

North Carolina Floodplain Mapping Program

www.ncfloodmaps.com

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