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NEAR-REAL-TIME FLOOD MODELING AND MAPPING FOR THE INTERNET

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Abstract: The U.S. Geological Survey Urban Geologic and Hydrologic Natural Hazards Initiative project has uniquely combined recently developed tools to produce and publish on the Internet near-real-time maps of forecast or imminent flooding. The tools used by the project include powerful desktop computers, Light Detection and Ranging (LIDAR) topographic data, a robust two-dimensional (2-D) flow model, GIS, and Internet map server software. The pilot study selected a 23-kilometer reach of the Snoqualmie River east of Seattle, Washington, that is between Snoqualmie Falls and Carnation, Washington. The study developed a 2-D model based on LIDAR topographic data. GIS tools were used to process elevation data for the flow model and to process model generated flow information into maps. An Internet map server software package was used to post the flow maps to the Internet. The pilot study demonstrates the feasibility of combining these tools with National Weather Service flow forecasts to produce storm-specific areal flood information maps that are served near-real-time (in a matter of hours, depending on the duration of the forecast hydrograph) on a flexible and user-friendly Internet Web page.

INTRODUCTION

An important component of the U.S. Geological Survey (USGS) Urban Geologic and Hydrologic Natural Hazards Initiative project in the Puget Sound Lowland, Washington, is the monitoring and assessment of hydrologic hazards. This component is developing the capability to map areal flooding from storm-specific point-flow estimates sufficiently quickly to aid emergency managers and the public. To develop this capability, new tools were used that would give relatively inexpensive, high-resolution elevation data for a large area; areally distributed flow information for forecast flows; maps of flow information; and Internet access to the maps. The availability of powerful, inexpensive desktop computers made it possible to use and combine the tools. Tools used to develop the Internet flood maps include LIDAR, a robust 2-D flow model, GIS, and Internet map server software. Each tool was selected to help achieve the goal of presenting near-real-time flood maps on the Internet. Project tasks included development of the flow model (the Snoqualmie River model), flood map construction, and Internet map serving.

FLOW MODEL DEVELOPMENT

For many years, one-dimensional step-backwater models were the only type of model readily available to estimate flood elevations. These models have remained prevalent because of the large expense required to develop the elevation data needed and the questionable robustness of many 2-D flow models. Hydraulic flow models, especially 2-D models, require elevation data of good accuracy and high resolution. Additionally, most 2-D flow models have problems with propagating large flood flows on dry channels with reasonable computational speed. LIDAR and newer numerical schemes in flow modeling are eliminating these constraints on the use of two-dimension flow models.

A 23-kilometer reach of the Snoqualmie River between Snoqualmie Falls and Carnation, Washington, was modeled for this study. This process included developing a 2-D model grid of ground-surface elevations, specifying upstream and downstream hydraulic boundary conditions, selecting an appropriate computational time step for simulations, calibrating the model with data from a 1986 flood, and validating the calibration with data from a 1975 flood.

LIDAR Topography: In the past, elevation data of adequate accuracy and detail for use in hydraulic flow models has been expensive to obtain. Recent developments in LIDAR technology have made very-high-accuracy elevation data (accurate to around one-half foot) relatively affordable (on the order of $500 per square mile). LIDAR is essentially laser range finding using high-pulse rate laser scans from an airplane that is precisely located using state-of-the-art positioning and inertial navigation systems. The resulting data set is a very dense array of elevations. Included in the raw LIDAR data set are data points that reflect unwanted information such as the tops of trees and water surfaces. Collecting the data during leaf-off and at low flow minimizes the number of these unwanted data points. Extensive post-processing is required to arrive at a "bald earth" data set needed for modeling and mapping. Because of cost considerations, no bathymetric surveys of the river were performed for the study. Average channel cross-sections, adjusted by local slope, were placed in the LIDAR data by the use of GIS processing commands as needed to correct obvious errors in channel bathymetry (figure 1). The base 8-meter resolution topography grid used by the flow model was sampled from 2-meter-resolution LIDAR data of the study area.

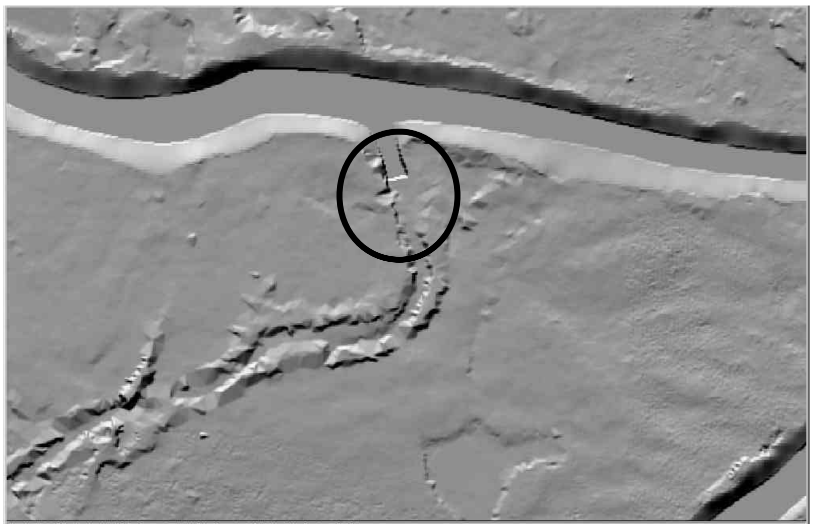

Figure 1. Shaded relief image of LIDAR topography after tree removal and smoothing of main channel, showing elevation errors in tributary.

<u>Robust Flow Model:</u> Most existing 2-D models are constrained by limitations resulting in large part from the robustness of their solution algorithm. The model applied for this pilot study is TrimR2D, a finite-difference depth-averaged model, which, due to a unique solution method, allows simulation of long reaches, remains stable when simulating extreme hydrographs, and is robust enough to handle an input hydrograph without tedious trial-and-error preparation of usable initial conditions. It has been successfully applied to estuarine locations, such as San Francisco Bay (Cheng and others, 1993). Testing has demonstrated that the model is able to flood and dry computational cells easily. Unlike many depth-averaged 2-D flow models, TrimR2D can handle flow regime changes. The model is more stable than traditional finite-element and many finite-difference models used in riverine modeling and is capable of routing flows on steep river systems and simulating wetting and drying. The model currently lacks two important features: the ability to vary roughness coefficients areally (they may be varied with depth), and to simulate the effects of floodwater overtopping bridge decks. These shortcomings were not considered significant for modeling the Snoqualmie River because land cover in the valley is fairly homogeneous, and the flows simulated were of moderate recurrence interval (10 year) and not large enough to inundate bridge decks.

Model Grid: The Snoqualmie River model uses an 8-meter-resolution topographic grid. However, because the model uses a staggered grid scheme in which depth is assigned only at velocity computation points, flow is computed on a 16-meter-resolution numerical grid. For this study flow is computed over a 515-by-825-cell grid that spans the Snoqualmie River from Snoqualmie Falls to just downstream of Carnation, Washington. The flow variables simulated include flow depth and the x and y horizontal velocities. The Snoqualmie River model uses observed discharges at the Raging River near Fall City gage (station no. 12145500), the Tolt River near Carnation gage (station no. 12148500), and the Snoqualmie River near Snoqualmie gage (station no. 12144500) as inflow (upstream) boundary conditions to drive the model application. Observed water-surface elevation at the Snoqualmie River near Carnation gage (station no. 12149000) was used as the outflow (downstream) boundary condition. The computational time-step size for the Snoqualmie River model was set to 1.5 seconds; that time-step size allowed the model to propagate the flow across dry areas while maintaining model stability for the flow events tested.

Model Calibration and Validation: Use of the TrimR2D model required calibration and verification of the roughness values (Manning's roughness coefficients) for the Snoqualmie River model. The flow model was calibrated by adjusting roughness coefficients until computed peak water elevations reasonably matched measured peak water elevations for a November 24, 1986, flood. The application was subsequently validated by comparing computed and measured peak water elevations for a December 3, 1975, flood (figure 2). No data was available to validate the areal extent of flooding. Inflow discharges and outflow water-surface elevations were available at a one-hour time interval for both events. Flood events were simulated for a period that started when the flow went out of bank at Snoqualmie Falls and ended when the peak arrived at Carnation. Measured high-water marks were available for both floods at 5 stations from the U.S. Army Corps of Engineers (COE), but data were not available for comparing simulated and actual inundated areas.

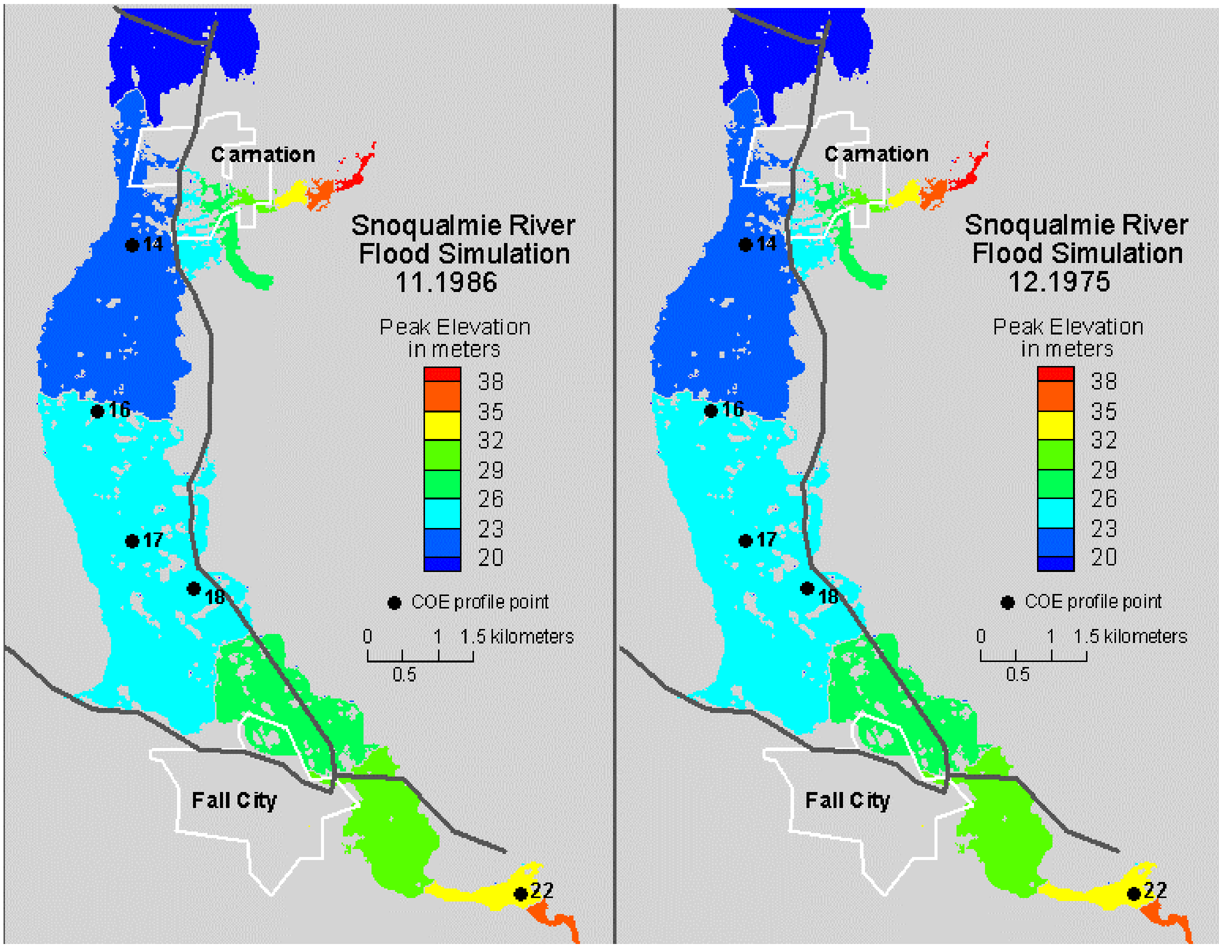

Figure 2. Peak elevations computed by calibration and validation model runs for the study reach.

The 1986 flood used for model calibration had a 0.1 probability of occurrence (10-year frequency). The peak discharge was 1,591 cubic meters per second (cms) at the Snoqualmie River near Carnation gage (station no. 12149000) and was 1,636 cms at the Snoqualmie River near Snoqualmie gage (station no. 12144500). The flood was simulated for a 36-hour period. The hourly outflow water-surface elevation for the calibration was the measured stage at the Snoqualmie River near Carnation gage (station no. 12149000). During the 1986 flood, flow at the Tolt River peaked before the flows at either of the Snoqualmie River gages. Manning's roughness values were varied from 0.035 to 0.120 (not varied with depth). Computed peak water-surface elevations were compared to high-water mark (HWM) elevations measured by the

COE for the flood at five locations in the modeled reach. The best fit was for a Manning's roughness value of 0.12. Errors for the computed water elevations varied from -0.53 meters (m) to +0.67 m. Water-surface elevation was overestimated by the model at the most upstream observation point and underestimated at the downstream observation points. In the upper reach the valley is not as flat as in the lower reach, and this error may not be significant; in the relatively flatter lower reach, an estimate on the order of 0.5 meter too low may significantly under represent shallow inundation. The average error was -0.11 m and the average absolute error was 0.41 m for the COE observation points.

The 1975 flood used for validation had about a 0.1 probability of occurrence (10-year frequency). The event had multiple peaks at the Snoqualmie River near Snoqualmie gage. The peak discharge was 1,475 cms at the Carnation gage and was 1,467 cms at the Snoqualmie near Snoqualmie gage. The flood event was simulated for a 59-hour period. Peak water-surface elevations were compared to the HWM elevations collected by the COE for the flood at five points in the model reach. Simulation errors varied from -0.37 m to +0.68 m. Similar to the calibration results, water-surface elevations were overestimated at the upstream observation point and underestimated at the other observation points. The average error was -0.09 m and the average absolute error was 0.36 m for the COE observation points.

FLOW MAP INFORMATION

Flow map information available from model simulations includes estimates of time to flood arrival, time to flood crest, and the maximum flow depth. The time to flood arrival is the hour at which each node initially becomes wet; the time to flood crest is the hour at which the maximum depth occurs at each node during the simulation; the maximum flow depths are the maximum depth that occurs at each node during the simulation.

Flood information from the inundation simulations—time to flood arrival, time to crest arrival times, and maximum flow depths—is obtained by post-processing the output files from the TrimR2D model. Flow variables, including flow depth and velocities, are written to the model output file at an hourly interval for every computational node. The resulting output file or files are then processed to select the flood arrival times (figure 3), flood crest arrival times (figure 3), and the peak flow depths from the flood simulation output.

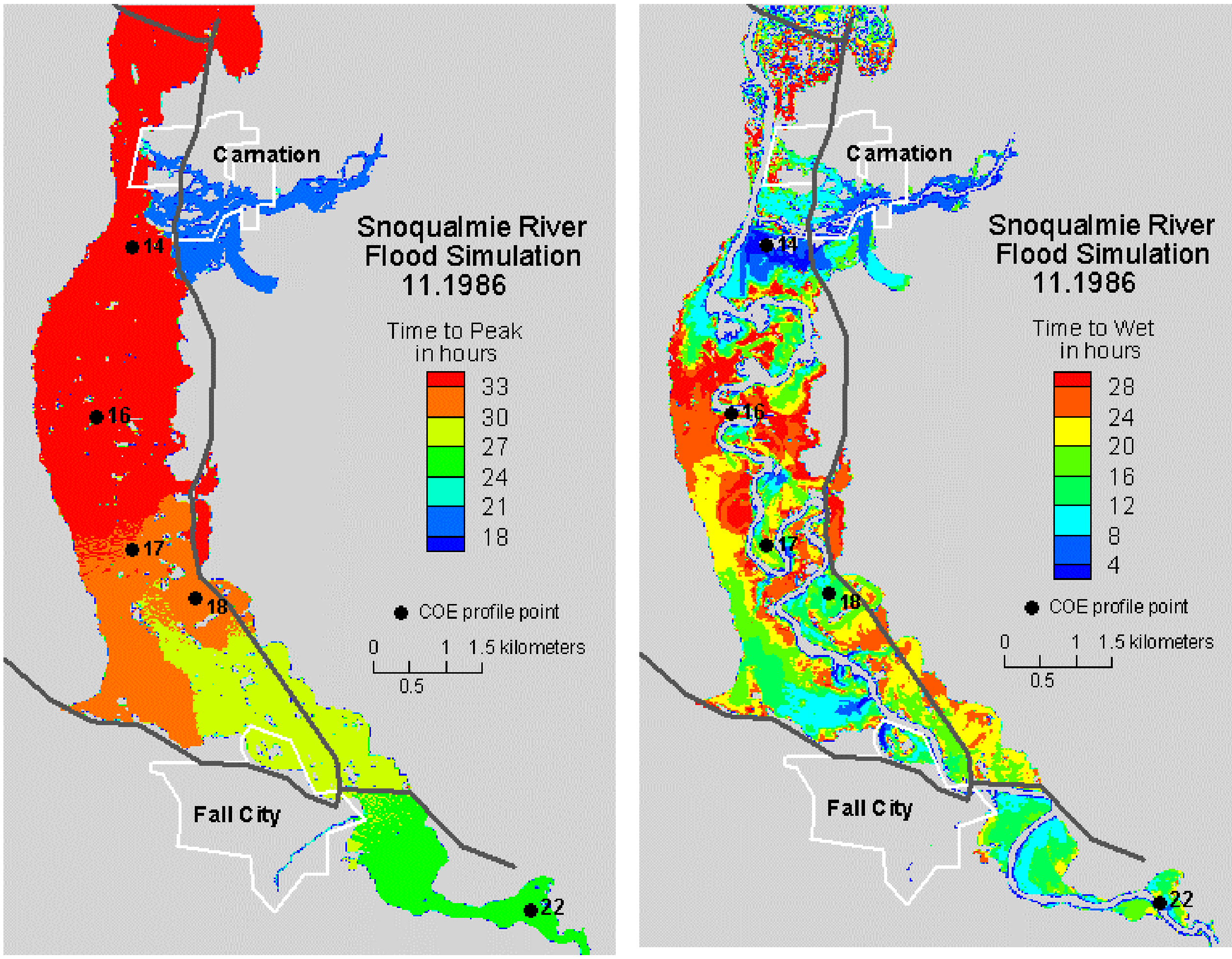

Figure 3. Peak arrival times and flood arrival times (time to wet) for the study reach.

INTERNET MAP SERVING

Many steps are required to serve flow maps on the Internet, including: transforming the National Weather Service (NWS) forecast data into the model input file, timebc.dat; running of the flow model; GIS processing of the model results; and finally, presentation on the Internet using a map server (figure 4).

Forecast Flows and Model Computations: The model is applied to estimate flood inundation that would result in the Snoqualmie River valley from flow volumes forecast by a National Weather Service River Forecast Center (NWS-RFC). Flow and water-surface elevation forecasts for several locations on the river are generated by the NWS-RFC located in Portland, Oregon daily when storms are imminent. The forecasts are based on regional rainfall-runoff relations and comprise six-hour forecasts over a period of three to five days. NWS forecast locations in the model reach include the Snoqualmie River near Snoqualmie, the Tolt River near Carnation, and the Snoqualmie River near Carnation. These data are automatically downloaded from the NWS-RFC computers and processed for input into the Snoqualmie River model. Preparation of the NWS river forecast data includes the estimation of flows in the Raging River because the NWS forecast locations do not include the Raging River. The flows for the 1975 and 1986 floods were used to determine an equation for estimating the Raging River flows based on flows at the Snoqualmie River near Snoqualmie gage.

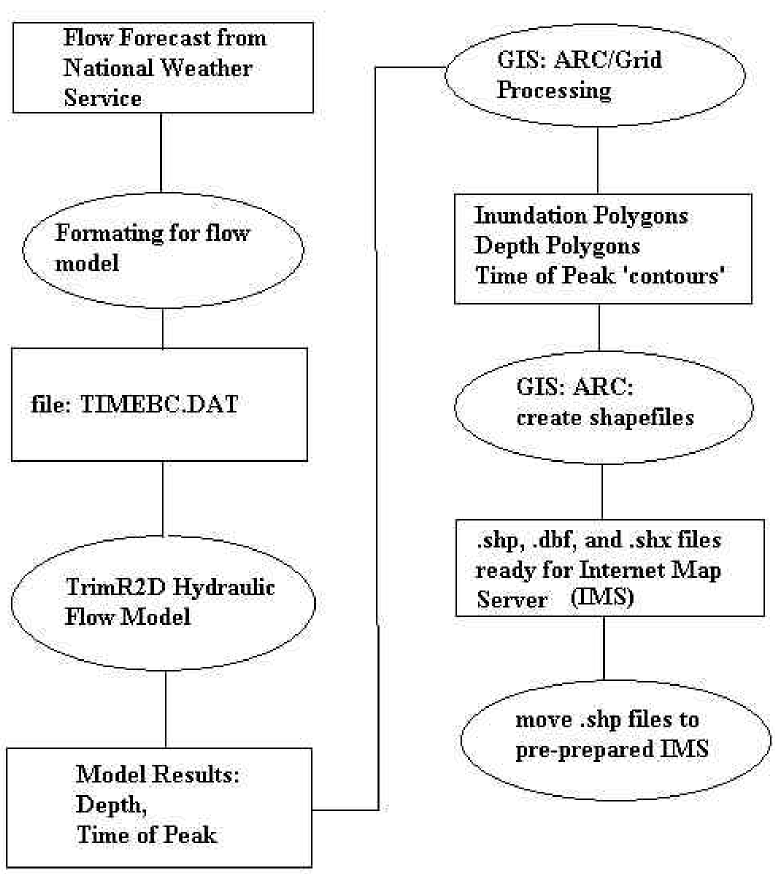

Figure 4. Diagram of process to create near-real-time flood maps.

Mapping and Internet Publishing: Automated post-processing routines created for the pilot study use a geographic information system (GIS) to produce map files suitable for Internet map-server software that presents the information in a flexible, user-friendly map in near real time over the Internet. A file-processing program performs two file conversion processes: retrieving and preparing NWS forecast data for input to the hydraulic model, and post-processing the model results into depth and time information layers and preparing them for input to the Internet map server. The retrieval program uses the Internet file-transfer-protocol, FTP, to access the forecasts, processes the information into the appropriate time and dimension units, and prepares the input files according to the model requirements. For this demonstration project, the model is run as a stand-alone application in order to monitor its performance. Another automated application processes the three output files created by TrimR2D: a file with maximum flood depths for all locations in the study area, a file with flood crest arrival times, and a file with flood arrival times. The three files generated by TrimR2D are ASCII files and need to be converted to a spatial data format that can be displayed on the Internet. Initially, a Visual Basic program starts a GIS (Arc/INFO®) and runs an Arc Macro Language program, shape.aml that converts the TrimR2D output files from ASCII format to shape files (a georeferenced graphics exchange file). First, the ASCIIGRID command in shape.aml converts the ASCII files from TrimR2D into GRIDs, a spatial data format for raster data. Commands then execute to aggregate the values for the maximum flood depth into three categories (0 to 2 foot depth, 2 to 5 foot depth, and greater than a 5 foot depth). Finally, the GRIDPOLY and ARCSHAPE commands execute and convert the GRIDs into three shape files. The Visual Basic program then copies the shape files to a directory where the internet map server can display them on the Internet.

Internet map servers are an emerging software technology developed specifically to allow greater flexibility for the authors and viewers of maps. The authors have the ability to control the map components and their appearance according to the scale the user selects to view the map. The users have the ability to select which components to view. For example, a map component of a residential road network would be too detailed for a small-scale map (perhaps an area covering several counties), so the author would not offer that road network at that scale, but may make it active at larger scales where the network would not clutter the map. The user may be given the choice of a topographic map or an aerial photograph to use as the background. Once a map component is imported into the internet map server, the author of the map application has the ability to select the scales at which it is viewable. The author also has the ability to change the appearance of the component at specific scales—a highway map, for example, may be made to appear as a single red line at the smallest scale, while at larger scales it may appear as a composite red-and-black line to distinguish it from local roads. Images may be compressed for viewing at small (regional) scales for quick Internet transfer, and progressively be delivered at greater and greater resolution as smaller geographic areas are selected for viewing. Figure 5 is a screen shot showing flood depths from the calibration model run at a moderately small scale (about 1:16,000 as viewed on screen).

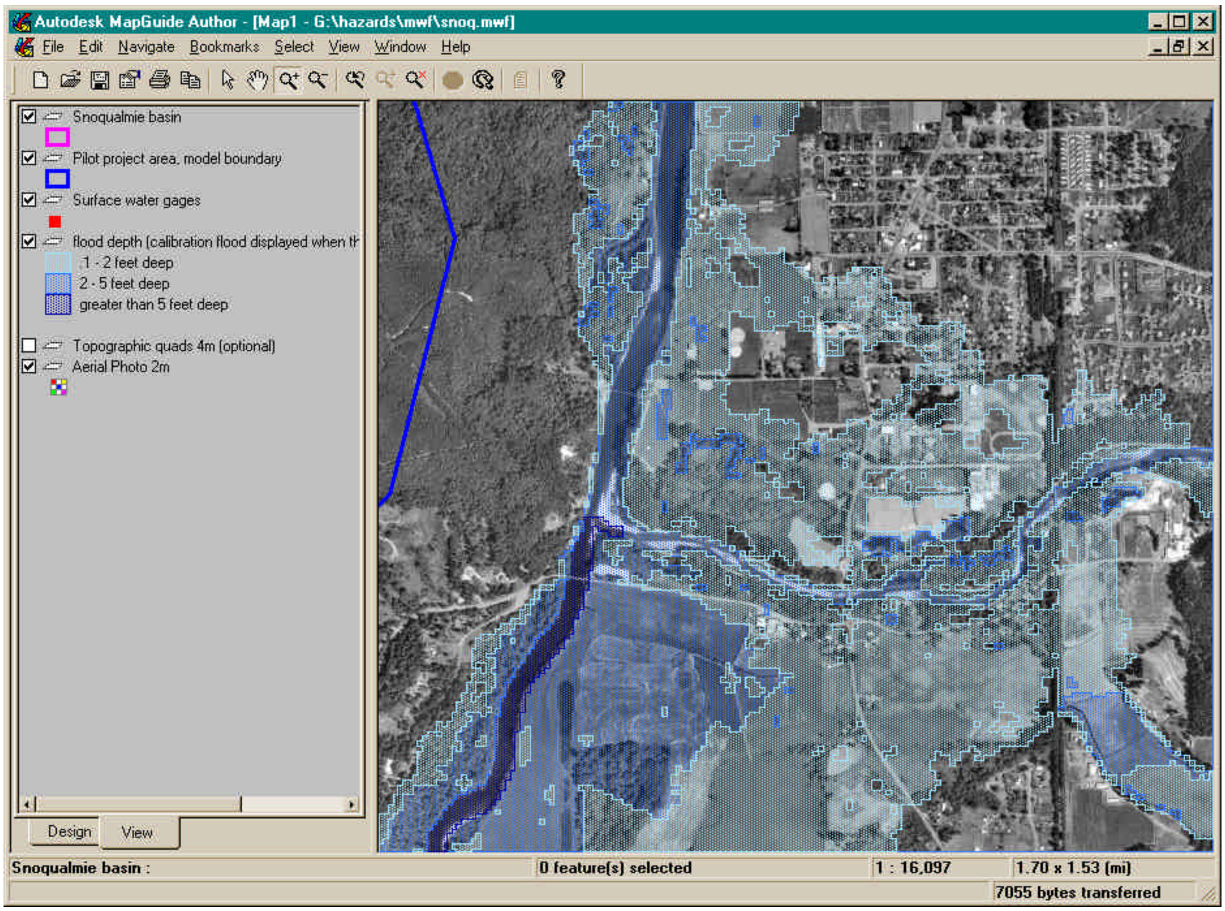

Figure 5. Computer screen shot of Snoqualmie River flood information presented by the Internet map server.

CONCLUSIONS

Currently available tools can be used to provide near-real-time maps of forecast flood discharges for delivery via the Internet. The pilot study has created a process to automatically retrieve and process NWS flood forecasts for input into a 2-D hydraulic model. Results for the 23-kilometer reach of the Snoqualmie River are subsequently automatically processed into maps of depth of flood, time until arrival, and time until peak maps ready for input to the Internet map server. The map server presents the information over the Internet in an interactive mapping format.

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