Integrated Radar and Hydrologic Modeling for a Bridge Scour Monitoring System

1. Introduction

This hydrologic application of radar is being developed for the Oklahoma Department of Transportation. The purpose is to assist Division Engineers in identifying when and where high flow rates may impact scour-critical bridges and manage bridge structure and maintenance information. Knowing when a bridge may have suffered scour during high-flow is an important counter-measure used to combat potentially catastrophic scour and failure of susceptible bridges. Such counter measures are mandated nationwide by the US Federal Highway Administration (FHWA) because of scour risk to transportation infrastructure. This project responds to a national need established by the updated National Bridge Inspection Standards (NBIS) that requires states to develop a plan of action for bridges that are scour critical, i.e., foundations that can be undermined by high flow rates.

The Oklahoma state highway bridge structures of concern include 90 culverts and 66 span bridges. The forecasting system is being implemented for 156 structure locations; input relies on real-time integration of 13 WSR-88D radars (S-band), gauge-correction using 120 mesonet rain gauges, and hydrologic model runs for each bridge location with rainfall input updated every 15 minutes. Actual storm events and comparison to flow quantiles are presented with evaluation of model sensitivity and forecast results.

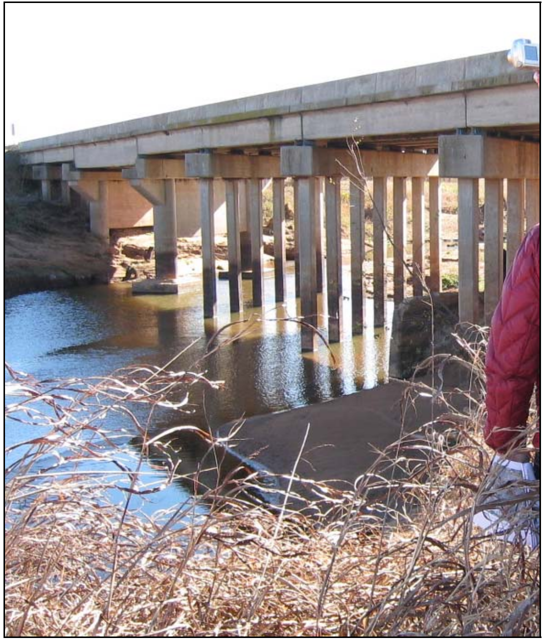

Figure B-1 Bridge scour inspection at a span bridge after a recent high-flow event, 15 November 2007.

2. ScourCast System Design

Operational monitoring of bridges subject to erosion during high flow events using observational systems for detection of heavy rainfall integrated with a hydrologic prediction model is the focus of this presentation. Radar is an important element identifying when a bridge may have experienced a high flow event and related erosion of the bridge foundation through scour. Radar-based monitoring is employed for a state bridge infrastructure maintenance project to combat scour, which is the most common cause of bridge failures in the United States. Monitoring practices include bridge inspection on a regular schedule and during high flow events. Increased monitoring efforts are needed during high flow events such as during flood conditions. Representative rainfall over specific bridge drainage areas is used for input to a physics-based hydrologic model that is capable of generating flow rates at any location in an application area. Most bridges do not have streamflow monitoring stations and must rely on radar-based rainfall for stream flow simulation at ungauged locations. Because few opportunities exist to calibrate the model to observed streamflow, model predictions are compared to regionalized flow quantiles.

3. Components

Besides the graphical interface, the ScourCast system has three main components: 1) Bridge Database; 2) Continuous Distributed Watershed Model; and 3) Rainfall Monitoring. The bridge database is populated with archival bridge characteristics; channel profiles measured after scour events; and span and foundation dimensions. A web-based graphical interface provides access and alerts whenever model flow rates exceed defined thresholds, and to allow queries of rainfall and flow rates for any chosen period. The ScourCast system components are described in following sections.

3.1 Radar Rainfall

The observational network provides continuous real-time rainfall input to the distributed watershed model for tracking runoff and soil moisture. A radar mosaic is formed from 13 S-band radars and operational gauge-correction using 120 rain gauges. Figure 2 presents the distribution of the radars and rain gauges used to produce QPE for model input at the watersheds that drain to each of the bridges. The rainfall is output in 15-minute intervals. Figure 3 is a sample output for a 24-hr period during heavy rainfall in central Oklahoma, 19-August-2007. The upper panel shows the web-based interface used to query rainfall totals and to animate hourly precipitation during any selected day. The lower left panel shows a zoom into an area of heavy precipitation accumulation during re-intensification of remnants from Tropical Storm Erin. The ‘dot’ icons are scour-critical bridge locations. The lower left panel is result of bias correction showing close agreement between gauge and radar accumulations for a selected 6-hour period during this event.

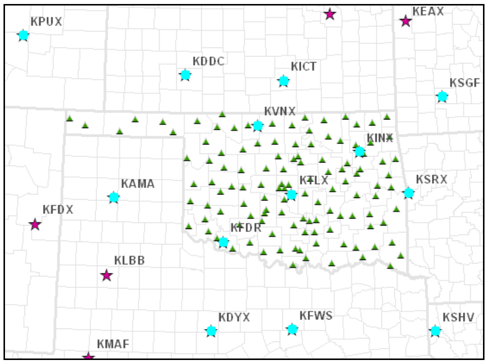

Figure B-2 Observational network composed of 13 NWS Radars and 120 Oklahoma Mesonet Rain Gauges

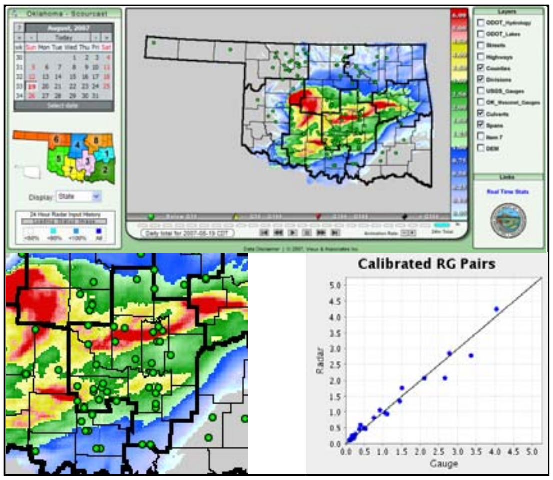

Figure B-3 ScourCast system display showing storm accumulation (upper and lower right zoom) and gauge-radar scatterplot for selected period during event (1 inch = 25.4 mm)

3.2 Runoff Simulation

The distributed modeling of runoff at the bridge locations is accomplished with V*flo*™ (Vieux, 2004). Digital datasets are used to assemble each watershed model. Digital elevation models, stream hydrography and watershed boundaries are used to define the drainage network. The hydrologic response is modeled based on the Green-Ampt infiltration model modified to account for saturation excess. Soil moisture is continuously updated with radar input over each grid cell in the distributed model. Land use/cover defines the spatial distribution of hydraulic roughness parameters.

The distributed model, V*flo*™ ingests radar rainfall operationally and tracks soil moisture and runoff at any location within the watershed. Within a single watershed there may be more than one bridge location that requires simulated hydrographs. One feature of a distributed hydrologic model setup with geospatial data is that multiple locations, not just at the basin outlet, can be defined. The efficiency of a distributed model may be capitalized on with distributed rainfall derived from radar. Without radar, the rain gauge network would be too sparse to support runoff simulation for the watersheds with scour-critical bridges. The distribution of watersheds across the state that contain at least one scour critical bridge is shown in Figure 4. Radar QPE is produced such that all sites are covered.

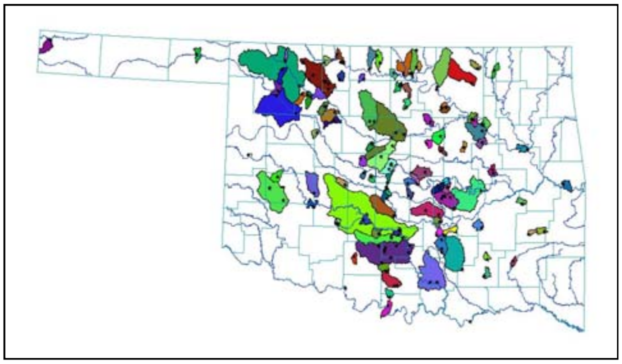

Figure B-4 State-wide distribution of watersheds containing scour-critical bridges

Figure 5 shows a watershed that contains multiple bridge locations, with one near the outlet and the remaining 4 at interior locations.

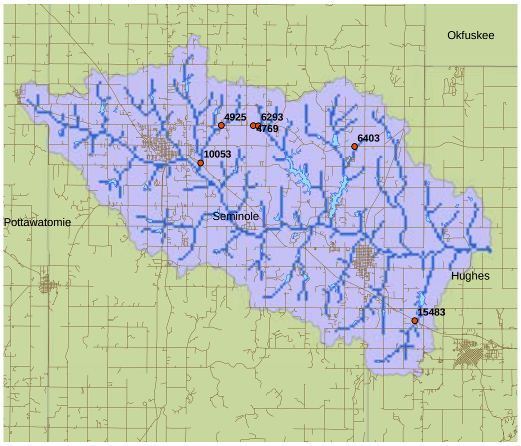

Figure B-5 Multiple sites within a watershed

Evaluation of the simulated and observed flow for a major river with stream flow monitoring provides the opportunity to refine the distributed model to reproduced observed hydrographs. Figure 6 shows an evaluation for a four-month period where streamflow is measured just downstream from the bridge by a gauging station.

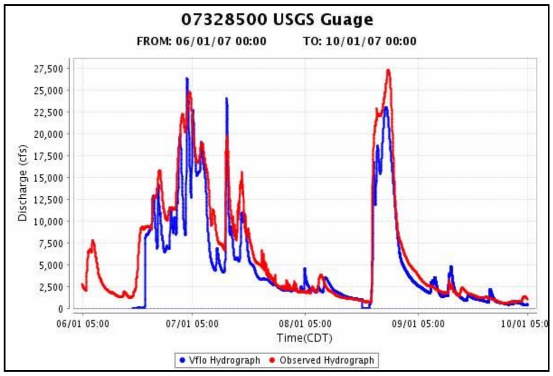

Figure B-6 Simulated and observed hydrographs at a scour critical bridge over the Washita River and Interstate 35 (1cms=35 cfs)

3.3 Information System

The web-based graphical interface links to the bridge database, rainfall monitoring, and flow threshold exceedance. Queries of rainfall and flow rates for any chosen period. In Figure 5, the interface shows bridge data, a current hydrograph, and scour photographs. The channel profile, foundation type footing elevation are shown in the lower panel.

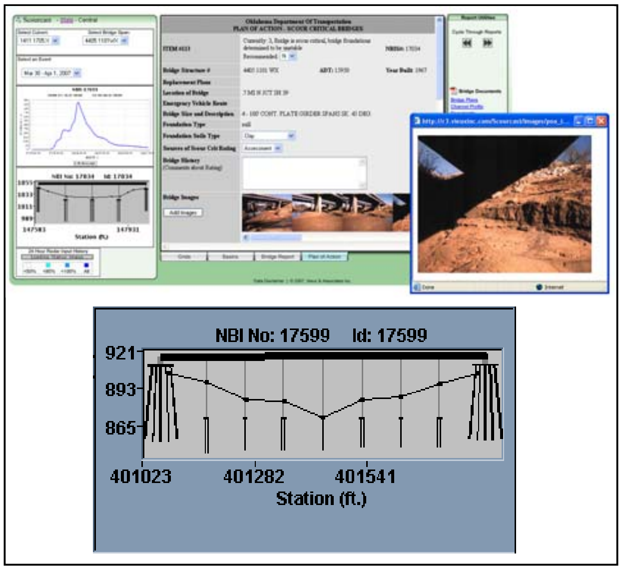

Figure B-7 Web-based interface for accessing bridge data, profile, and photographs of scour

4. Conclusions

The ScourCast system is a *real-time* scour risk identification system that can be used as a countermeasure for scour-critical bridges. The system assists in the identification of elevated risk conditions and helps track agency responses. The system utilizes radar rainfall information to monitor flow conditions at bridges and to effectively communicate the location of scour-critical bridge locations that have recently experienced significant hydrologic events.

The benefit of the ScourCast™ system to FHWA and ODOT Division Engineers is the ability to track the current conditions at a scour-critical bridge and to assemble critical information necessary to take appropriate actions when high flow rates occur at scour-critical bridges. ScourCast™ supports the management and response plan for monitoring scour-critical bridges within the State of Oklahoma to comply with the NBIS regulations to reduce the risk of bridge failure due to foundation scour. The ScourCast system builds on the ability of radar and distributed modeling to provide flow rates in continuous operation at multiple locations within watersheds distributed statewide.

Acknowledgment

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References

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