A Research Objectives

Catastrophic flooding endangers human lives and public health, impacts essential services, and transports pathogens. Minor (nuisance) flooding impacts commerce, and causes economic damages - some preventable. Flooding itself is largely unpreventable, but it is possible to get out of the way and mitigate some damages with sufficient warning.

The Harris County Office of Emergency Management (HCOEM) operates a network of precipitation and water level monitoring gages. The network was created to provide data for internal use, but the data has been served to the public for quite some time, and they use the data for making business closure, transportation routing, and other commerce-based decisions. The current network reports to the public the accumulated precipitation and current water depths at over 100 locations throughout the county. The system was recently upgraded, and the new system serves data in a fashion that allows automated capture of the rainfall data.

One meaningful use of the data is to make several hours into the future projections of accumulated water depth based on current conditions and produce inundation probability maps for the general public for commerce related decisions. The concept is to produce on-line maps that answers the question "If the precipitation stopped now, what areas of the county will have a 50% or greater probability of 6 or more of inundation in the next three hours, 75% or greater, and 90% or greater?"

The research objective is simply to develop and deploy and deploy such a tool, using the public data, but otherwise independent of the HCOEM server, to compute and serve in near real-time, inundation probability maps to the general public.

Such a forecasting tool can reduce situations where thousands of commuters leave their jobs early, to avoid inclement weather, but hit the highways at the peak of a minor flooding event creating an enormous traffic problem, impacting commerce, and creating public safety hazards. Inundation forecasts just a few hours into the future are possible using current technologies, are desirable, and can serve as a model for similar communities in Texas.

B Methodology

Conversion of the rainfall signal into a residual depth on the land can be accomplished by a variety of methods, the most intellectually satisfying is with a physics-based hydrodynamic model that incorporates known geometric and friction features [1]. Topologic data for such a models in the form of digital elevation models (DEM) in the Houston region are available to civilians at a resolution of about 1/3 meter, even finer in some cases. The principal problem with direct application of such a model is that computation time would exceed real time, and the tool would be useless for the mapping suggested.

An alternative is a network of transfer functions [2] that can approximate the response.

[1] e.g. GSSHA (Downer and Ogden, 2002), SOBEK (Delft), MIKE (DHI), and others.

[2] This network can be thought of as a neural network, except there is no "hidden" layer.

These can be constructed from historical event data, but using historical records alone is insufficient because we cannot account for physical changes in the built environment[3]. Integration of the approaches is proposed for this work[4]. A physics-based hydrodynamic model is operated in a scenario mode to generate response transfer functions, and these functions are used for the operational aspects of the forecasting problem. The following critical tasks are required for this project to be successful:

1. Mine the existing historical data using the integrated approach. The products will be a transfer function network that simulates the rainfall-depth response at discrete network locations, as well as the historical conditional probabilities of inundation for different inputs. This task requires immense detail as conditional probabilities computations are non-tirvial.

2. Develop automated data capture tools to generate the input time series at each network location during an event. This step is easiest accomplished by direct access to HCOEM database[5]. The rainfall time series from current time backwards, would be updated every 5 minutes. One node of a computer cluster would have the sole task of capturing the data stream every 5 minutes and sending these time series to the controller for real-time computation of the projected responses.

[3]Despite this weakness, these transfer functions are attractive because responses to inputs can be computed extremely fast. The functions can produce very accurate responses when well parameterized by weighting historical and physics-based model data.

[4]This integrated approach is precisely the basis of the work reported by Cleveland and others, 2008

[5]A significant programming task could be avoided with direct access, but it is not a requisite for success

3. These time series are fed into the transfer function network to project future stage at each location in the network. The transfer function network can be decomposed into independent components,thus this computational task is of a highly parallel structure.

4. The stage projections are supplied to a high-resolution digital elevation model to draw the inundation boundaries at different conditional probabilities. Figure 1 is an example of what the output product might look like[6]. This step needs to be

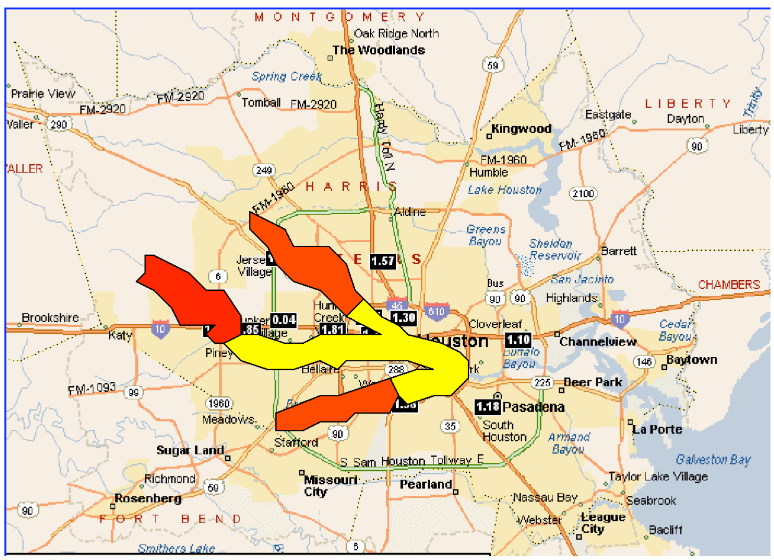

Figure 1: Inundation probability map based on projected hydrographs. Projection of region with 90% probability (red) and 50% probability (yellow) that the indicated areas will experience 6 inundation or larger. (Note: this map is a representation of the kind of product envisioned, it was not generated from data)

automated to the point where the maps can be drawn and served faster than the

[6]This image is built on the older HCOEM map base.

actual event progresses[7].

5. Quality assurance analysis to be convinced that the results are sufficiently correct to be of use to both the general public. The maps need to be archived for post-event analysis; the design goal is an accuracy rate of 75%.

C Research Personnel

The research will be conducted by graduate and undergraduate students selected by the PI based on proven skills in engineering computation. Currently the PI's research team has two members who are qualified to work on this research; one, a BSCE with one year practical experience in the subject is beginning her graduate studies, the other just completing his BSCE[8]. A computer engineering student (undergraduate or graduate) will be recruited to serve as programmer and system administrator. The PI will contribute a significant portion of time in both supervision as well as specialized algorithm development and will be the lead system administrator.

[7] About once every 15-minutes should be useful; this drawing rate allows 3 entire projections to be computed per drawing.

[8] Both students assisted with much of the exploratory work presented in this proposal.

D Student Involvement and Research Education Opportunities in Science and Engineering

The project will provide funding for three to four students at the MS/PhD level, thus assuring some level of continuing production of engineering talent for Texas. The project will provide meaningful case studies examples for undergraduate and graduate hydrology, hydraulics, and computer engineering classes; all of which are taught by the PI. The project will provide a public tool that in addition to being immediately useful, will help in recruiting students into science and engineering to address future regional, state, national and global problems.

E Institutional Commitment and Sources of Additional Support

Resources available includes a 10-node and 24-node cluster computer purpose built and operated by the PI for computationally intensive projects where throughput speed is required (Cleveland and Smith, 2004). The PI also has access to two professional cluster computers operated by the University[9]. The University provides high reliability electricity, and telecommunications, both requisite for the proposed system to work and full-time IT staff members in the college of engineering are available for troubleshooting and assis-

[9]The professional clusters are far more capable then the PI's clusters, but by virtue of needing serve multiple users, even with some of their nodes partitioned for stand-alone use, they would not be ideal for this project. A single, purpose-built, stand-alone, cluster is a more sensible option.

tance.

This project builds upon work sponsored by the Texas Department of Transportation, and the Harris County F lood Control District. It is probable that during the project duration will materialize as the usefulness of the products become apparent. The ATP/ARP funding will provide the means to demonstrate the principle, and after trial deployment the project will be self supporting.

F Budget Justification

The major budget elements are salary and supplies, including computing supplies to maintain the server cluster to perform the computations and generate the maps. The current computer systems maintained by the PI are likely to have many years of service remaining, parts for the older machines are abundant. The supplies category includes funds to purchase replacement computer parts and specialized software as needed.

G Bibliography

Asquith, W.H. Thomson, D.B., Cleveland, T.G., and X. Fang. 2004. Synthesis of Rainfall and Runoff Data Used for Texas Department of Transportation Research Projects 0-4193 and 0-4194. U.S. Geological Survey Open-File Report 2004-1035, 1050 p.

Asquith, W.H., Roussel, M.C., Cleveland, T.G., Fang, Xing, and Thompson, D.B., 2006. Statistical characteristics of storm interevent time, depth, and duration for eastern New mexico, Oklahoma, and Texas. U.S. Geological Survey Professional paper 1725, 299p. ISBN 1-411-31041-1

Asquith W.H., Thompson, D.B., Cleveland, T.G., Fang, X. 2006. "Unit hydrograph estimation for applicable Texas watersheds." Report 0-4193-4, Texas Department of Transportation.

Cleveland, T.G., Thompson, D.B., Fang, X., and He, X. 2008 "Synthesis of Unit Hydrographs from a Digital Elevation Model" *in press* American Society of Civil Engineers, J. of Irrigation and Drainage Engineering. IRENG-06-5147

Cleveland, T.G., X. He, W.H. Asquith, X. Fang, and D.B. Thompson, 2006. "Instantaneous Unit Hydrograph Selection for Rainfall-RunoffModeling of Small Watersheds in North and South Central Texas." American Society of Civil Engineers, J. of Irrigation and Drainage Engineering, Vol. 132, No. 5, pp 479-485.

Cleveland, T.G., He, X., Fang, X., Thompson, D.B. 2006. "Regressions Relating Watershed Physical Characteristics to Unit Hydrograph Parameters for Rainfall-Runoff Modeling in Central Texas" Costal Hydrology and Processes, Singh, V.P., and Xu, Y.J. eds. Water Resources Publications, Highlands Ranch, CO. pp 465-478.

Cleveland, T.G., and Smith M.T. (2004). Darkstar Cluster Computer.
< http://cleveland1.cive.uh.edu/computing/darkstar/index.html> (Nov. 16, 2006).

Cleveland, T.G. 2003. Determination of Instantaneous Unit Hydrographs for Houston from HCOEM and USGS OFR 96-250 Report to the Environmental Institute of Houston, University of Houston http://cleveland1.cive.uh.edu/Reports/EIH2002.pdf

Delft Hydraulics. URL: http://delftsoftware.wldelft.nl/

DHI group. URL: http://www.dhigroup.com/

Downer, C.W., and F.L. Ogden. 2002. GSSHA users manual, gridded surface subsurface hydrologic analysis version 1.43 for WMS 6.1. ERDC Technical Report, Engineering Research and Development Center, Vicksburg, MS.

Fang, X., Thompson, D.B., Cleveland, T.G., and Pradhan, P. 2007 "Variations of Time of Concentration Estimates Using the NRCS Velocity Method" American Society of Civil Engineers, Journal of Irrigation and Drainage Engineering, Vol. 133, No. 4, pp 314-322.

Leinhard, J.H. 1972. Prediction of the dimensionless unit hydrograph. Nordic Hydrology, 3, pp 107-109

Williams-Sether, T., Asquith, W.H., Thompson, D.B., Cleveland, T.G., and X. Fang. 2004. Empirical, Dimensionless, Cumulative-Rainfall Hyetographs for Texas. U.S. Geological Survey Scientific Investigations Report 2004-5075, 138p.