Project Introduction

Hydrologic considerations can influence the site selection of highway corridors and alternative routes. Hydrology also influences the design of highway-related drainage facilities such as culverts and holding ponds. Information such as peak rate of runoff, volume of runoff, and time distribution of flow is fundamental to drainage facility design.

Models of hydrologic flow attempt to characterize the relationship between precipitation that falls within a drainage basin and the amount of runoff to expect at any given point within the basin, especially during storm flooding events. This information is necessary for planners and engineers to design appropriately-sized drainage structures and to avoid or mitigate flow problems cause by road construction or enhancement projects. Also important are standard methods of calculating where water flows to in a landscape, using elevation data to delineate watershed or basin boundaries.

This report reviews current approaches to modeling hydrologic flow that are typically used by state transportation agencies. It then reviews newer, integrated geospatial approaches, as represented by an MTRI study conducted for the Michigan DOT, and by the relatively new “Watershed Management System” made available by the Federal Highway Administration.

Traditional Approaches

Many methods of analyzing hydrologic flow are available, and method selection is guided by applicable local, state, and national guidelines. Most State Departments of Transportation have drainage manuals that outline hydrologic methods applicable to state legislation and regional land cover/land use (See Appendix A for web links to State Drainage Manuals). These manuals provide, among other information, descriptions as to when each method should be employed. As a general rule, method selection is guided by spatial scale.

Some of the hydrologic methods referenced in the State DOT Drainage Manuals include: Rational Method; USGS (or State approved) Regression Equations; A log-Pearson Type III Probability Stream Gage Analysis; SCS Unit Hydrograph Method; Drainage Area Ratio Method; Computer Models for Hydrograph Generation; NRCS’s TR-55; Michigan’s DEQ’s Computing Flood Discharges for Small Ungaged Watersheds; FEMA Flood Insurance Study Discharge Rates; Stream Channel Encroachment Discharge Rates (SCEL); and Tidal Hydrology.

Many of the State DOT Drainage Manuals are adaptations from the American Association of State Highway and Transportation Officials (AASHTO) Model Drainage Manual (MDM). The Manual compiles generic design policies and procedures and provides a foundation for states to produce a customized drainage manual. There are three editions to the MDM, and the most recent version is from 2005.

Regardless of which hydrologic method is employ, input data will be necessary for model execution, and the input data needs are similar for the different methods. Input data usually includes information on watershed boundaries, elevation, stream discharge, and precipitation. Other types of data inputs may include land cover/land use, soil type, ambient air pressure, and channel cross-sections, among others. For each data type, several different spatial scales may be available, and as a general rule, the highest resolution data source available should be used. Input data can be obtained from a variety of sources. These sources include digital repositories of...
The main source for elevation data is the USGS. Specifically, the National Elevation Dataset (NED) (http://ned.usgs.gov/) from the USGS provides coverage with consistent projection, resolution, and elevation units. Data is available at a 1:24,000-scale (30 m) Digital Elevation Model (DEM) for the conterminous U.S. and at 1:63,360-scale (60 m) DEM for Alaska. Higher resolution data is also available from the USGS in limited areas. The USGS also distributes hard-copy topographic maps at different scales. Other potential sources of elevation data are LiDAR or InSAR.

Watershed boundaries and watercourse information is available as part of the USGS’s National Hydrography Dataset (http://nhd.usgs.gov/). Watershed boundaries could also be manually delineated from elevation data (hardcopy or digital) and watercourse information could be obtained from aerial photographs or hardcopy topographic maps.

Area calculations are examples of data that can be derived from other data sources. Once watershed boundaries are determined, area within these boundaries can be calculated. A more traditional method using hard-copy maps is a square or dot grid area calculation. Area can also be obtained digitally using area queries within GIS software.

Stream discharge and precipitation data are highly correlated, and are probably the two most important datasets for any hydrologic method. Precipitation data can be obtained from local meteorological stations, and most common source of stream discharge data is the USGS (http://water.usgs.gov/). The USGS operates gage stations across the U.S. and provides this data real-time on their website. Data available includes daily, monthly, and annual statistics, as well as peak streamflow, field measurements, and field/lab water quality samples. Stream discharge can also be calculated manually with a field survey team to take channel cross section measurements and the appropriate gear to measure stream velocity.

**Streamlining Approaches**

For modeling hydrologic flow, the suite of methods available to transportation agencies is relatively advanced. What is needed are tools to make these methods more available to project-level agency staff in easier-to-use formats to increase the efficiency of planning and environmental assessment for transportation projects. In particular, desktop software tools that help staff to delineate watersheds, model stream flow in response to storm events, and map multiple floodplain levels appear to be of particular interest to transportation agencies. Additionally, evaluations of whether newer and high resolution elevation formats, such as InSAR and LiDAR data, are needed to see if they can effectively meet agency needs in a cost-effective manner relative to more traditional topographic data sources.

During the TARUT Study for the Michigan DOT (MI-DOT), MTRI researchers built demonstration tools to meet the stated hydrologic flow needs of MI-DOT’s Environmental Section (see TAUT Study Reports Deliverables 4.5 and 5.3-B on the www.tarut.org website for in-depth reviews). MI-DOT staff wanted to know if they could delineate watersheds using a standard methodology through the ESRI ArcGIS software they already had access to. Out of this discussion came interest in having Environmental Section staff be able to have desktop GIS access to calculating storm event stream flow methods, as used by the State’s Hydrologic Studies Unit (part of the Michigan Department of Environmental Quality, MDEQ) and as described in MI-DOT’s Drainage Manual (http://michigan.gov/stormwatermt/0,1607,7-205--93193--,00.html). MTRI staff demonstrated combinations of ArcGIS-based software methods for estimating stream flow of small watersheds (under 1,000 acres in size) for storm events where the Rational Method was applicable. After this demonstration, MI-DOT staff requested demonstrations of calculating different floodplain levels, beyond the normal 100-year and 500-year floodplains that come out of FEMA’s floodplain mapping programs (see http://msc.fema.gov/ and http://www.fema.gov/plan/prevent/fhm/dfm_dfhm.shtm). Using the US Army Corps of Engineer’s HEC-RAS and HEC-GeoRAS software tools, MTRI was able to demonstrate how MI-DOT could model more frequent events such as 25-year floodplains, and compare results to FEMA’s 100-year floodplain designations.

Through these advanced methods, MTRI was able to demonstrate how high-resolution InSAR elevation data could successfully be used to meet a state transportation agencies needs for modeling hydrologic flow. The
InSAR data was of sufficient resolution and of widespread enough availability to be practical, with the benefit of being 1/10 the cost of LiDAR data. Both “bare earth” (digital terrain model, DTM) and “canopy level” (digital surface model, DSM) were available, and the DTM data were used for modeling hydrologic flow in order to analyze where water would flow over the landscape. The DTM data have an RMSE of 0.7-m and a posting (raster cell size) of 5x5m. While not as detailed as LiDAR data, the lower cost and ready availability made the data useful. The InSAR data collection platform was originally developed as a “restricted use” military technology for mapping topography, and is now a dual-use technology available to both civilian and military applications. The civilian program has been commercialized by Intermap Technologies [http://www.intermap.com/] as their “NEXTMap” product [http://www.intermap.com/interior.php/pid/4], with the DTM product costing $30 per square kilometer. Currently, the Intermap elevation is available for approximately 1/3 of the U.S. (18 states), including the Gulf Coast states of Louisiana, Mississippi, Alabama, and Florida; Southeastern Michigan, much of Texas, all of California, and northern Virginia (see Figure 1).

Figure 1: The available extent of high-resolution InSAR elevation data in the Continental U.S. Intermap plans to collect the entire U.S. by the end of 2008.

Figure 2 shows where MTRI processed the high-resolution InSAR data into an ArcGIS-compatible format that could be combined with the Archydro Desktop ArcGIS extension for calculating watersheds. In this case, five small (<120 hectares) watersheds were calculated through user-selected points within the boundaries of a sample InSAR elevation dataset that covered the Novi area in Oakland County, Michigan. These same watersheds were evaluated by MTRI for potential peak stream flow in response to a “one inch in one hour” rainfall event, and the estimated peak stream flow calculations reached through application of the Rational Method are shown in Table 1. Figure 3 shows a more detailed example of a watershed calculated within the ArcGIS environment. A 16.3-ha watershed was calculated as a demonstration to see what area might be impacted by a potential road project.
Figure 2: Five custom watersheds calculated using InSAR elevation data and the ArcHydro extension for ArcGIS. Note the precise yellow borders showing the boundaries of the watersheds (automatically delineated with the combination of InSAR elevations and ArcHydro), and the red circles showing the user-selected watershed delineation points. Sizes in hectares and acres are labeled for each watershed; the ArcHydro extension is available as a no-cost add-on to Desktop ArcGIS and is capable of handling high-resolution elevation data.

Table 1: Watershed size, coefficients, rainfall intensity, and predicted peak discharge for the five custom watersheds derived for the Novi area InSAR elevation data. Note the increasing peak discharge associated with larger watersheds, using a suburban housing runoff coefficient and a one inch in one hour storm event.

<table>
<thead>
<tr>
<th>Watershed Area in hectares</th>
<th>Watershed Area in Acres, A</th>
<th>Coefficient of Runoff, C</th>
<th>Intensity of rainfall, inches per hour, I</th>
<th>Peak discharge in cubic feet per second, Q</th>
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</thead>
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<tr>
<td>16.3</td>
<td>40.3</td>
<td>0.35</td>
<td>1</td>
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<tr>
<td>114.8</td>
<td>283.7</td>
<td>0.35</td>
<td>1</td>
<td>99.3</td>
</tr>
</tbody>
</table>
Figure 3: The delineated 16.3-ha Watershed A area derived from InSAR elevation data and ArcHydro. Note the custom watershed boundary calculated with ArcHydro (dark green outline) and the user-selected watershed delineation point (red circle). This shows how high-resolution elevation data and geospatial tools can calculate precise watershed boundaries and analyze the location of a road project in a watershed.

Figure 4 shows an example of using high-resolution elevation data (again, 5x5-m data, this time derived from stereo-pair ADS 40 imagery) to calculate custom floodplain extents. MTRI researched southeastern Michigan rainfall events using National Weather Service data and relating these to local USGS stream gauge patterns. From this, HEC-RAS and HEC-GeoRAS were applied to model the floodplain extent of a 25-year storm event; a 100-year event was also calculated and found to be similar to available FEMA data. By using high-resolution data and these tools, transportation agencies could see what road areas would be impacted by any storm event, especially for potential corridor alignments where roads did not yet exist.
Figure 4: The extent of estimated floodplains for 25-year and 100-year storm events for an area of Wayne County, MI, modeled using high-resolution elevation data and HEC-RAS software. The 100-year extent (in green) is close to the 25-year extent (in blue), meaning that flooding has the potential to impact most of the floodplain during more frequent storm events. Road maintenance in similar areas could take this feature into account with geospatial tools such as the floodplain modeling methods demonstrated here. Note the nearby location of the USGS stream gauge site used to provide input data on historical storm events.

Similar in spirit to MTRI’s work, a new software package that may meet transportation agency hydrologic flow needs is the Watershed Modeling System, developed by Brigham Young University’s Environmental Modeling Research Lab (EMRL) in collaboration with the Federal Highway Administration Resource Center, and released in the Fall of 2007 (http://www.ems-i.com/WMS/WMS_Overview/wms_overview.html). While the normal commercial cost is $3700 for a complete license, FHWA has arranged for the software to be available at no cost to state DOTs and the U.S. DOT. The stand-alone windows software includes the ability to delineate basins, calculate flood frequency discharges, and estimate storm runoff curves. It can run hydrologic models such as HEC-1, HEC-HMS, TR-20, TR-55, and the Rational Method. Figure 5 shows an example of the WMS interface being used to delineate watersheds using USGS DEM data.
Recommendations for Research Opportunities

Given the current state of existing methods and tools, the greatest opportunity in helping transportation agencies to meet their hydrologic flow needs may be two-fold: 1) assessing and applying newer sources of elevation data to hydrologic flow analyses, and 2) developing focused user-friendly tools where existing tools do not yet meet transportation agency needs. WMS may meet many needs, but no formal evaluation has been published assessing its abilities to handle larger and high-resolution data sets that are becoming more available to transportation agencies. We recommend that the Streamlining Environmental and Planning Processes project perform such an evaluation to test the practicality of using newer, high-resolution elevation data in WMS and similar software.

We also recommend that the SEPP project test to see if a focused tool can rapidly be created that meets the highest priority of state transportation agency needs, based on the feedback of the SEPP Advisory Group. This tool would be user-friendly, work within the most common transportation agency GIS software environments, and enable agency staff to accomplish hydrologic flow analysis tasks that they cannot currently do easily or quickly. The 3-year TARUT project leads us to believe these needs will focus on watershed delineation, stream flow estimation, and floodplain modeling, but we look forward to integrating Advisory Group input to ensure than any tool development meets pressing transportation agency needs. Finally, the proposed hydrologic flow tool would be able to use latest elevation data derived from advanced remote sensing sources as part of this study’s evaluation of new and innovative geospatial methods.
Appendix A: Links State Drainage Manuals that Describe Current State Methods of Calculating Hydrologic Flow

Arizona DOT  

*California DOT  
http://www.dot.ca.gov/hq/oppd/hdm/hdmtoc.htm

Colorado DOT  
http://www.dot.state.co.us/environmental/envWaterQual/wqms4.asp

Connecticut DOT  

Florida DOT  
http://www.dot.state.fl.us/rrdesign/dr/Manualsandhandbooks.htm

Georgia DOT  
http://www.dot.state.ga.us/doingbusiness/PoliciesManuals/roads/documents/designpolicies/GA8-ALL.pdf

*Idaho Transportation Dept.  

Illinois DOT  
http://www.dot.state.il.us/bridges/brmanuals.html

*Indiana DOT  
http://www.in.gov/dot/div/contracts/standards/dm/index.html

*Iowa DOT  
http://www.dot.state.ia.us/design/desman.htm

Kentucky Transportation Cabinet  
http://transportation.ky.gov/design/drainage/drainage.html

Louisiana DOTD  

Maryland DOT  

*Massachusetts Highway Dept.  
http://www.mhd.state.ma.us/default.asp?pgid=content/designGuide&sid=about

Michigan DOT  

Minnesota DOT  

Mississippi DOT  
http://www.dot.state.mn.us/bridge/Hydraulics/default.html

*Missouri DOT  
http://www.modot.mo.gov/business/manuals/projectdevelopment.htm
Montana DOT

Nebraska Dept. of Roads
http://www.dor.state.ne.us/roadway-design/download/draindes-eroscontman.pdf

Nevada DOT

New Jersey DOT
http://www.state.nj.us/transportation/eng/documents/drainage/drainage.shtml

New Mexico DOT
http://nmshtd.state.nm.us/main.asp?secid=15697


North Carolina DOT
http://www.ncdot.org/doh/preconstruct/highway/hydro/gl0399web/

North Dakota DOT
http://www.dot.nd.gov/designmanual.html

*Pennsylvania DOT

*South Dakota DOT

Tennessee DOT
http://www.tdot.state.tn.us/Chief_Engineer/assistant_engineer_design/design/DrainManpdf/Chapter%201.pdf

Utah DOT


West Virginia DOT
http://www.wvdot.com/engineering/TOC_engineering.htm

Wisconsin DOT

* State incorporates drainage manual as part of a larger design manual.