Project Summary

Texas Department of Transportation

0-6382: Establish Effective Lower Bounds of Watershed Slope for Traditional Hydrologic Methods

Background

The Texas Department of Transportation (TxDOT) designs roadways and proximal infrastructure with substantial transportation dollars spent on drainage and conveyance infrastructure. Methods currently used to estimate watershed timing parameters contain some form of watershed slope as a principal parameter, and the time response (often thought of as a travel time) is usually inversely proportional to topographic slope. Therefore, as topographic slope decreases, the watershed timing parameter increases. In a hydrologic model, the decrease in topographic slope produces a rightward shift in time of the equilibrium and/or peak discharge and a commensurate reduction in the computed peak discharge. Furthermore, conservation of mass requires that the reduced peak discharge be accommodated by storage (drainage is stored by the system for a longer time). Effectively, this increases the time base of runoff, which distributes (stretches) the output hydrograph.

The ability to estimate travel time appropriately for watersheds where topographic slope is small will reduce uncertainty in predicting design peak discharges; a result is improved decisions on structure size and corresponding cost. The net result is improved use of financial resources, reduced risk of costly overestimation of design peak discharge (size of structure), and reduced risk of underestimation (size of structure) and the potential resulting damage to highway infrastructure and adjacent real property.

The purposes of this research project were to identify — from literature, data, modeling, and experiments — the dimensionless topographic slope where conventional hydrologic methods become suspect and alternate approaches should be considered, to develop and document such alternate approaches, and to explore technologies (instrumentation selection and/or invention) for more intensive study of low-slope hydrology should further work and supporting data be deemed necessary.

What the Researchers Did

The researchers conducted a detailed examination of the professional literature and extended an existing database of watershed responses in Texas and elsewhere. Two small (1/4 acre) field sites were instrumented for rainfall-runoff data collection. The plots are referred to in the report as impervious and pervious surfaces.

Research Performed by:

Center for Multidisciplinary Research in Transportation (TechMRT),
Texas Tech University

Texas Transportation Institute (TTI),
The Texas A&M University System

U.S. Geological Survey (USGS)

Research Supervisor:
Theodore G. Cleveland, TechMRT

Researchers:
David B. Thompson, TechMRT
Li Ming-Han, TTI
William H. Asquith, USGS

Project Completed: 8-31-11

An indoor rainfall-simulator study was also conducted. These simulator studies allowed control of slope and rainfall rate. These field studies were used to validate a two-dimensional diffusion-hydrodynamic (DHM) overland flow model. DHM was then used in a parametric study to examine the effect of slope (and several other variables) on watershed response. Model responses from the parametric study were interpreted in the context of a timing equation (as one might apply in a typical hydrologic design situation).

What They Found

The researchers determined from the literature and the extended database including field and rainfall simulator studies that low-slope behavior appears to begin at a dimensionless slope of about 0.002, and occurs unequivocally at slopes one order of magnitude smaller (0.0002).

The parametric studies for impervious surfaces using DHM showed that watershed-timing response was asymptotic with regard to slope at a dimensionless slope of 0.0005 and at this slope (or even smaller) the watershed-timing response was the same.

The parametric studies for pervious surfaces using DHM showed an overwhelming dependence on rainfall intensity. This dependency is problematic and requires a subtle understanding of the conceptualization of the underlying mathematics. Timing estimates are used to estimate rainfall intensity, yet if intensity is part of the estimation then a circular dependence is established (which requires iteration to resolve). The dependence on intensity is because low slopes increase both ponding depth and exposure time for infiltration, and these factors have a demonstrable impact on watershed timing.

The project team also found that the small-field studies produced results that were different from studies at many other locations, and from the simulator studies. Results from the two small plot studies in the research lie outside the anticipated region for their area and slope configuration. The researchers' interpretations of these two experiments (in the context of dozens of other sites) are that currently established or conventional streamgaging techniques for watersheds as small as these are not well suited to low-slope hydrologic studies and different measuring methods are indicated.

What This Means

Although several equations from the DHM studies are presented in the report and could be used, the researchers instead suggest an adjustment of existing technology. The suggested adjustment is applied at a dimensionless slope of 0.003 and all slopes less than this threshold. This value is selected to create a smooth transition from typical slope to low-slope conditions and the overlap with the declared "low slope" above is intentional.

The Kerby-Kirpich methods presented in TxDOT research report 0-4696-2 are adjusted in this regime (slope less than 0.003) by adding an offset to the actual slope of 0.0005. Other parts of the methodology are left unchanged.

For More Information:
Research Engineer - Wade Odell, TxDOT, 512-416-4730
Project Director - Jaime Villena-Morales, TxDOT, 806-748-4345
Research Supervisor - Theodore G. Cleveland, TechMRT, 806-742-2801

Technical reports when published are available at:
http://library.ctr.utexas.edu/index.html

www.txdot.gov
keyword: research

Texas Department of Transportation
Research and Technology Implementation Office
P.O. Box 5080
Austin, Texas 78763-5080
512-416-4730