HYDROLOGIC MODELING APPLICATIONS IN NATIONAL FLOOD INSURANCE PROGRAM

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Abstract This paper summarizes applications of hydrologic modeling in the National Flood Insurance Program with emphasis on recent trends and advances. The paper discusses the most popular models used by the effective Flood Insurance Studies, recent trends in applying models supported by GIS and geodatabase, challenges experienced in the transition and lessons learned. It also briefly describes Federal Emergency Management Agency's policy and procedures for approval for use of a hydrologic model for flood insurance studies.

INTRODUCTION

The National Flood Insurance Program (NFIP) currently serves 4.5 million policyholders and provides $650 billion in coverage. Federal Emergency Management Agency (FEMA) initialized Map Modernization to respond to the need to update and maintain flood hazard maps since 2004. This initiative is creating digital flood insurance rate maps (DFIRMs) for more than 20,000 communities across the U.S., is supported by advanced engineering studies, and provides users improved risk information. As a component of the DFIRM Database, use of Geographic Information System (GIS) allows the mapping and engineering data to be linked to physical features of the stream and the watershed, georeferenced, and shared as needed.

There was a heavy backload in updating Flood Insurance Rate Maps (FIRMs) before the Map Modernization began. It is not exceptional for a community with its effective flood insurance study published before 1990, and recent data and engineering methods are not reflected in these studies. The underlying hydrologic methods for ungauged streams are usually regional regression equations for rural communities and small watersheds, or rainfall runoff models for large watersheds or urban areas; the most widely used models are HEC-1 and TR-20 which are event-based parametric models that require less data; however, accurate results depend on effective calibration which was not always conducted. Flood peaks, instead of entire hydrographs then were entered into steady hydraulic models to compute water surface profile.

For purposes of floodplain regulation and insurance rate determination, engineering methods to support flood insurance studies (FIS) are usually based on Federally developed, well-established modeling programs to ensure technical reliability of studies. In addition, public domain models are preferred.

PROGRESS OF TRANSITION

Model modernization provides a good opportunity to introduce advanced engineering technologies into a flood insurance study. Slowly and steadily, the use of better data and better modeling techniques is bringing change.

Lumped Parameter Hydrologic Model GIS technology made it possible to transform lumped parameter models into semi-distributed models and lifted well-established models to a higher level. Methods using parameters to reflect watershed features that can be easily demonstrated by GIS by taking readily available information from the nationwide geodatabase are becoming increasingly popular. For example, the NRCS hydrologic approach which uses curve numbers to compute loss rates has become increasingly popular through application of GIS and Soil Survey Geographic Database (SSURGO), although users still rely on a variety of in-house tools to link the geospatial data with hydrologic models. As end users, hydrologic engineers prefer to create files for direct communication between a specific geospatial data source and a particular hydrologic model rather than to develop and use a data interface model.

With detailed watershed and stream data available at smaller scales, modelers are able to subdivide watersheds into smaller parcels; we have observed some studies with subwatersheds sized as small as five acres and with parameters assigned for each of these subwatersheds. An original lumped parameter model therefore is transformed into spatially distributed parameter model; values of parameters previously finalized by calibration are now obtained directly from the spatially-distributed data source and input into a model where the hydrologic processes can be simulated at a much smaller scale. Does such a model guarantee better results, specifically, in estimating flood peaks and the hydrograph? Our observations show that the models developed with a lumped-parameter concept are not always compatible with such spatially-distributed data. Use of an areal reduction factor to transfer point rainfall into the areal rainfall is an example. Unlike real time simulations that can use NEXRAD data as rainfall input to the model, FIS hydrologic analyses estimate flow peaks and hydrographs from design storms with specified annual exceedance rates. The areal converting factor is based on the concept that rainfall read from a point gage needs to be converted into an areal value and the ratio depends on the size of watershed at the outlet where the hydrograph is generated; however, when the watershed is subdivided into such small parcels and hydrographs are generated for each one, the selection of converting ratio become a debatable issue. There have been many studies discussing how to bridge geodatabase with hydrologic modeling; however, this example shows that the availability of data at smaller scales initiates needs for conceptual changes on lumped parameter hydrologic models. More detailed information does not guarantee greater model accuracy; performance still depends upon the calibration; and value for some crucial parameters such as those for initial moisture conditions still depends on subject engineering judgment.

Continuous Simulation Model Continuous simulation models, such as HSPF, received new life. Traditionally, one of the major challenges in using such a model is the difficulty in calibrating so many parameters, and the lack of a direct link of parameters to the spatially distributed watershed features. The calibration heavily relies on numerical exercise. With establishment of geodatabase, attempts have been made to link model parameters with easily available watershed features such as soil type to improve calibration and overall performance of the model (Lamont, 2005). Like event-based lumped parameter models, these models also need to be reviewed from a new perspective to take advantage of readily available information.

Conjunctive Hydrologic and Hydraulic Models Separate modeling of hydrologic and hydraulic processes has become increasingly recognized as a less favorable approach. Using the entire hydrograph instead of only the peak flow in determining the floodplain is particularly suitable in regions with significant storage areas, such as coastal plains. The demand for models which incorporate both hydrologic and hydraulic processes and are able to either simulate flooding from a single storm event or for a longer period is increasing. In addition, users prefer a model that is able to simulate both flow and stage hydrographs along the stream reach and at storage locations.

Demand for such models introduced some non-Federally developed public domain models and proprietary models into NFIP studies. Interconnected Pond Routing Model (ICPR), which incorporates hydrologic analysis and hydraulic routing into a single model, was the first proprietary model approved by FEMA. It is overwhelmingly popular in Florida where more flood insurance policies are written than in any other state in the nation. The popularity of the model is attributed to its ability to route flow through natural streams, wetlands and stormwater management facilities. Also this model is easy to use, has good technical support and low cost. The model allows users to select well-established methodologies such as NRCS unit hydrograph approach to simulate the rainfall-runoff process, and uses a node-link scheme to route flow though open channel and/or conduit system. The model has been applied to countywide flood insurance studies and mapping, using topographic and other watershed data obtained from the local government's GIS; however, the current version of ICPR does not have capability to import data from geodatabase. The model developer and Southwest Florida Water Management District (SWFWMD) are cooperating to develop bridges that would enable the direct communication between the model and the District's geodatabase.

Similar to ICPR, XP-SWMM is the other proprietary model increasingly used for NFIP studies in urban environment. Its strong capability for communication with outside databases, GIS, CAD and other models make it easy to import a network developed by other tools. We expect that EPA SWMM-5 would provide a low-cost alternative to XP-SWMM.

Distributed Parameter Hydrodynamic Model An emerging approach is to use a spatially distributed hydrologic model and a hydrodynamic model, such as the application of MIKE SHE and MIKE 11 in Broward County, Florida. Such an application extends the FIS study from event-oriented surface water simulations into a long-term simulation including interaction of surface and groundwater. This is particularly important in areas where high ground water table plays a significant role during flooding. In traditional, event-based approaches, the initial condition of groundwater elevation is either subject to engineering judgment or determined according to a local regulatory requirement, which often was not associated with flood frequency but rather developed from environmental or ecologic concerns. As an integrated groundwater and surface water model, MIKE SHE can use either user-defined polygon or program grid file to describe the modeled area. The model offers options from using a simple soil moisture mass balance in the root zone to application of the full Richard's equation to compute infiltration, evaporation, and groundwater recharge in unsaturated zones. It simulates groundwater movements in saturated zones using either traditional finite difference approach or linear reservoir flow routing. Generated interflow hydrographs and Surface runoff hydrographs enter the hydraulic routing model of MIKE 11 for channel routing. The complexity of this approach is beyond the most of NFIP studies; however, the County is planning not only use it for the floodplain determination but also for the countywide stormwater management and planning. Without support of geodatabase, such a complex, spatially distributed parameter model would not be possible.

<u>Model Calibration</u> Calibration of hydrodynamic model can be made easier with the support of geodatabase. NFIP studies use information collected during post disaster flood hazard investigation for model calibration and flood map verification. Such investigation collects high water marks and peak stage data during and/or immediately after flood events. These data have been overlaid on the effective Flood Insurance Rate Maps to evaluate the accuracy of floodplain boundaries and flood elevation. The data can be stored in geodatabase for later use in model calibration (Dewberry, 2001). FEMA's enhanced DFIRM database can store stage gage data (http://www.fema.gov/fhm/dfm_eddb.shtm); however, a bridge still needs to be established between calibration procedures of the model and such data.

In summary, we have observed steady and gradual changes in hydrologic and hydraulic modeling associated with increasing utilization of GIS and geodatabase in NFIP studies. On other side, availability of data also calls for changes in traditional way of conducting hydrologic and hydraulic analyses. Although Federally developed models such as HEC-HMS are used for a majority of studies, proprietary and other non-federally developed models have been employed to fill the gap when these models are not adequate to meet a user's particular needs. With active partnership with local communities in FEMA's map modernization process, we have observed that more locally oriented models were proposed or used for NFIP studies.

FEMA POLICY AND PROCEDURES OF ACCEPTING NON-FEDERALLY DEVELOPED MODELS

Facing increasing demand of using non-federally developed models, FEMA developed policy and procedures to evaluate and approve these models. The process requires cooperation among FEMA, other Federal and local agencies, the community, and model developers.

The NFIP regulations require that all models used to prepare, amend, and revise flood insurance study and flood plain maps must meet the following criteria:

1. The model must be reviewed, tested, and accepted by a government agency responsible for the implementation of programs for flood control and/or regulation of floodplains;
2. The model must be well documented, including source codes and user's manuals; and
3. The model must be available to Federal Emergency Management Agency (FEMA) and all present and future parties affected by flood insurance mapping that is developed or amended through the use of the model.

To ensure consistency in implementing the aforementioned regulation, FEMA created lists collectively titled "Numerical Models Minimum Requirements of the NFIP" to document all public domain and proprietary models, categorized as coastal, hydrologic, statistical, and hydraulic models (http://www.fema.gov/fhm/en_modl.shtm). A separate list was created for models which address location-specific issues and were therefore only approved to be used at certain locations. The current nationwide list includes 15 hydrologic models and 20 hydraulic models, some with several different versions.

Coastal, hydrologic, hydraulic, and hydrodynamic models developed by Federal agencies responsible for the implementation of flood control programs, floodplain regulation, and/or flood hazard analysis clearly meet the above criteria. Approval has also been extended to include models developed by Federal agencies that have been active in developing and advancing hydrologic, hydraulic, and hydrodynamic models.

To comply with first criterion, models developed by non-Federal agencies or private entities must be certified by a governmental agency which is responsible for the implementation of programs for flood control and/or regulation of floodplain lands, and such models must meet the following criteria:

1. The model must be used or planned for use by communities for NFIP studies;
2. The model must provide for new capabilities beyond any non-proprietary model on the existing accepted models lists; and
3. The model must be reviewed, tested, and accepted with respect to its use in the design of flood-control structures or floodplain land use regulation. FEMA requires a written certification from the review agency.

FEMA issued a document titled "Clarification of National Flood Insurance Program Criteria for Certification of Coastal, Hydrologic, and Hydraulic Models" describing certification criteria in detail, to help other agencies performing the review and test. Federal agencies can certify a model for nationwide use, and State or regional agencies can certify a model for use within their jurisdiction. This document has been followed by Federal and by non-federal agencies to certify models developed by local agencies and private entities.

The document indicates that the certifying agency must review the model in sufficient detail to conclude that the model is scientifically correct and technically sound. The certifying agency must assure that the model is based on sound hydrodynamic, hydrologic, or hydraulic principles. The certifying agency may rely on published technical papers or reports authored by a third party, or review reports prepared by the agency's employees, its contractor, or other agencies. It may involve with efforts from several agencies. For example, when evaluating XP-SWMM, St. Louis District of U.S. Army Corp of Engineers (USACE) conducted the initial review and test for the closed conduit analyses, and Environmental Technology Verification Program sponsored by the U.S. Environmental Protection Agency (EPA) and NSF International, an independent, not-for-profit organization, conducted a comprehensive review and test to the model. The review produced a report that summarized testing procedures and detailed testing results (NSF International, 2005). Based on all these works, FEMA was able to approve use of the model for NFIP studies.

The certifying agency may test a model against measured data to determine whether the model can adequately reproduce the measured data, or compare the model with base models, usually Federally developed, that have already been used for flood insurance studies, to evaluate whether it can provide results comparable to the base models. Such a test would assure the accuracy of and consistency of modeling results. As an example, SWFWMD certified CHAN, a one-dimensional unsteady flow routing model. During the testing, SWFWMD used the EPA SWMM as the base model. Its case studies compared performance of CHAN with the EPA SWMM and ICPR models, both accepted by FEMA for nationwide floodplain mapping, and

Network, the SWFWMD's in house model. FEMA approved the CHAN based on SWFWMD's conclusion that the CHAN model is technically sound supported by the test results which showed that flow peak, volume and water surface elevations computed by the CHAN and the other models were comparable.

In addition, FEMA requests that the certifying agency must accept the model for its use in administering programs for flood control structure design and the floodplain regulation. This would avoid misuse of FEMA's acceptance as a marketing tool, and maintain amount of accepted models within a manageable limit.

SUMMARY AND RECOMMENDATIONS

This paper discussed the current situation of hydrologic modeling for a flood insurance study and the trend in using geodatabase to support hydrologic and hydraulic modeling. Broad application of GIS and geodatabase provides detailed data to describe the watersheds and opportunity to improve model accuracy; at the same time it posts challenges to some well-accepted concepts and approaches used by established models. While in past lumped models were cutting edge for their time and have served hydrology well for decades, we have now reached an era where new tools for sensing and positioning can provide a great deal of new valuable information; we will have to evaluate these models from new perspective and make some fundamental revisions to these model to use this information effectively.

A variety of modeling approach has been applied for NFIP studies. Observed trends include applications of models conjunctively that simulate hydrologic and hydraulic processes; incorporating groundwater and surface water into connected distributed-parameter models, and increasing use of location specific models. The paper discussed the FEMA's response to the change, and described FEMA policy and procedures to accept use of non-federally developed models.

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