View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by Purdue E-Pubs

Flood Modeling Within the Context of Sustainable Water Resources Management

Venkatesh Merwade, vmerwade@pudue.edu
School of Civil Engineering, Purdue University, West Lafayette, Indiana, USA

ABSTRACT

Flood is one of the costliest natural disasters in the world in terms of economic as well as human losses. Floods also cause epidemics by transmitting water-borne diseases such as typhoid fever, cholera, and diarrhea among others. Flood modeling is one of the tools that can be utilized to create flood inundation maps to prepare communities against flood hazards. This article describes some of the computational methods used for modeling floods and how these methods can then be combined within system dynamics modeling to develop holistic approaches for managing floods and flood-related issues. The methods described here fit well with the overall Sustainable Solution with Appropriate Technological Development and Innovation framework.

Keywords: Flood modeling, hydrologic modeling, hydraulic modeling, system dynamics modeling, SWADIN.

1. INTRODUCTION

While many regions in the developing world face water shortages, the same regions can sometimes be overwhelmed with too much water in the form of flooding. Flood is one of the costliest and most frequently occurring natural disasters in the world. A recent study by Hallegatte, Green, Nicholls, and Corfee-Morlot (2013) shows that future flood losses in coastal cities may increase to $52 billion by 2050, mainly due to climate change. According to the United States National Weather Service, floods in 2011 caused >$8 billion in economic damages and 113 fatalities. Over the last 30 years, the average economic loss in the United States from floods has been $7.82 billion, with 94 deaths per year. Besides causing socioeconomic distress, floods also create and transmit communicable diseases such as typhoid fever, cholera, malaria, and diarrhea among many others. Therefore, flood management should be considered as an integral part of any approach to tackle any water-related issues in developing as well as developed world.

The traditional approach of managing floods is through structural measures in the form of dam or reservoir construction to stop the water, or through building of levees to protect areas from rising water. Despite billions of dollars in investment in structural, the economic and human losses from floods continue to rise. Structural or “hard” measures alter the characteristics of a natural flood to avoid alternation of structures in the floodplain. Because of a false sense of security from a flood-controlling structure, flood-prone areas are exposed to more socioeconomic development, thus increasing the overall damage due to flooding. Therefore, structure measures for reducing flood damages have actually led to more flood damages.

Nonstructural or “soft” flood damage measures involve retaining the natural characteristics of floods, by letting the structures in the floodplain sustain the extra volume of water during a flood. Therefore, there is a growing interest in addressing flood-related issues through nonstructural measures in the form of using floodplain storage or creating wetlands for attenuating flood peaks. Even the United States Army Corps of Engineers, who led the implementation of most structural measures in the United States, is now focusing on implementation of more and more nonstructural measures. This shift in focus from structural to nonstructural measures is driven by the goal to achieve environmental sustainability in flood damage reduction. In the last decade, we can find several examples where structural measures were abandoned to embrace nonstructural measures in the form of wetland restoration or levee removal. These changes have led to flood damage reduction, and revitalized the environmental and ecological heath of the overall system, thus adding recreational value to the area.

Given the above-described background, the objective of this paper is to highlight some of the expertise needed to develop sustainable flood management strategies using nonstructure measures. While this list can be made very elaborate to include hydrologic sciences, engineering, socioeconomics, and political sciences, this paper only focuses on a few areas that the author has experience through recent research projects.

2. HYDROLOGIC MODELING

Hydrologic modeling involves simulation of hydrologic cycle at scales ranging from a small field (few square kilometers) to continental basins (millions of square kilometers). In many cases, a watershed scale model covering an area of ten to hundreds of kilometers is most effective in simulating the local hydrology of a system with more confidence. Such a model can be useful in rainfall-runoff forecasting of individual events, or can be used to simulate the hydrology of the entire system for several years for water resources management and planning. Depending on the temporal frame of the project, a hydrologic model can be categorized as "event based" or continuous. One of the commonly used event-based models is the Hydrologic Engineering Center's (HEC) Hydrologic Modeling System (HMS) from the United States Army Corps of Engineers. HEC-HMS is a nonproprietary model available for free to use. Similarly, one of the commonly used continuous models is Soil Water Assessment Tool (SWAT) jointly developed by the United States Department of Agriculture's Agricultural Research Service and Texas A&M University. SWAT is a nonproprietary open source model that is available for use for any watershed. While HEC-HMS is a purely rainfall-runoff model, SWAT is a comprehensive hydrology and water quality model that can simulate hydrology, sediment and contaminant transport, and agricultural management practices. The main input data required for simulating hydrology in both HEC-HMS and SWAT include climate information, land use and soil, and topography.

3. HYDRAULIC MODELING

A hydrologic model will produce a hydrograph that shows the flow rate of water with respect to time at a given location on a stream. A hydraulic model uses either the peak of this hydrograph or the entire hydrograph as the input to produce the water velocity and surface elevation at any desired locations along the stream. One of the commonly used hydraulic models for such purpose is the HEC River Analysis System (RAS) from the United States Army Corps of Engineers. HEC-RAS is a nonproprietary one-dimensional (1-D) hydraulic model that uses topography and flow data to produce water surface elevations and velocities. While 1-D is common for modeling river hydraulics during high floods, two-dimensional models are also commonly used in many parts of the world for modeling floods. Two-dimensional models require more detailed topography data compared to a 1-D model and also produce slightly different results for various flow conditions (Cook & Merwade, 2009).

4. FLOOD INUNDATION MAPPING

After hydrologic and hydraulic modeling, the water surface elevations are then used to create a water surface. The topography in the form of a digital elevation model is then subtracted from the water surface to get the extent of the flood inundated area. Geographic Information System is commonly used to pre- and postprocess various datasets in hydrologic, hydraulic, and flood inundation mapping to create the final flood inundation maps. Flood inundation mapping is a resource-intensive process, and depending on the quality of input data and modeling approaches, it can have various levels of uncertainties associated with the final output (Merwade, Olivera, Arabi, & Edleman, 2008). Additionally, because of the extensive data and resources requirements, it is not always possible to follow the standard engineering approach to create flood hazard maps for many rural and developing areas of the world. The author is currently working on alternative cost- and time-effective approaches for creating flood hazard maps. One such approach uses the soil data to create flood inundation map for any county in the United States. A visual comparison (Figure 1) of a map created by using soil data and engineering analysis shows that the approach using soil data has potential to create flood hazard maps for many areas in the world where detailed soil maps are available.

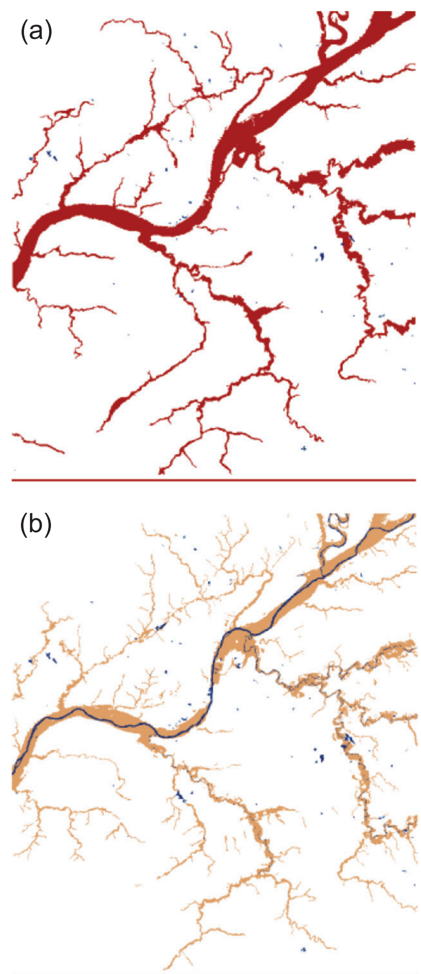

Figure 1. Flood hazard maps for Tippecanoe County in Indiana from (a) engineering analysis and (b) soil data.

5. SYSTEM DYNAMICS MODELING

The above-mentioned methods will produce a flood inundation or hazard maps for a given input condition. In most cases, flood inundation maps are used as a primary source of information for relief and rescue operations during a flood event. Within the context of water resources management or water-borne epidemics planning, flood inundation maps can also be used as a tool in decision making, or for drafting policies. Under such circumstances, it is important to know the consequences or related effects of a decision or policy for a given flood inundation extent. For example, what communities need to be evacuated, and how this evacuation will affect other community infrastructures? What are the effects of a particular flood control strategy on one type of infrastructure versus others? To enable such scenario analysis in making decisions, it is necessary to link the flood inundation models with other models such as socioeconomics and policy. One way to link different models and simulate the inter-relationships among them is through system dynamics modeling. Figure 2 shows a system dynamics model developed for Kenya to study the effect of drought and related hydraulic policies on agricultural production and population dynamics. Such a model can be easily adopted and modified to include health epidemics and social sciences.

6. SUMMARY AND CONCLUSIONS

Flood management involves the use of a variety of models including hydrologic, hydraulic, and system dynamics modeling. While computational modeling for flood hazards can be resources intensive, flood maps derived from cheaper alternatives such as through soil data show potential for using flood management. While the data requirements for creating hydrologic and hydraulic models can be extensive, an approximate model can be easily created for any watershed in the world by using public domain data from the United States Geological Survey, ASTER Global Digital Elevation Model, and Food and Agricultural Organizations soil data base. The system dynamics modeling approach discussed in this paper fits with the Sustainable Solution with Appropriate Technological Development and Innovation (SWADIN) framework (SWADIN, 2013). By working with various group members within the

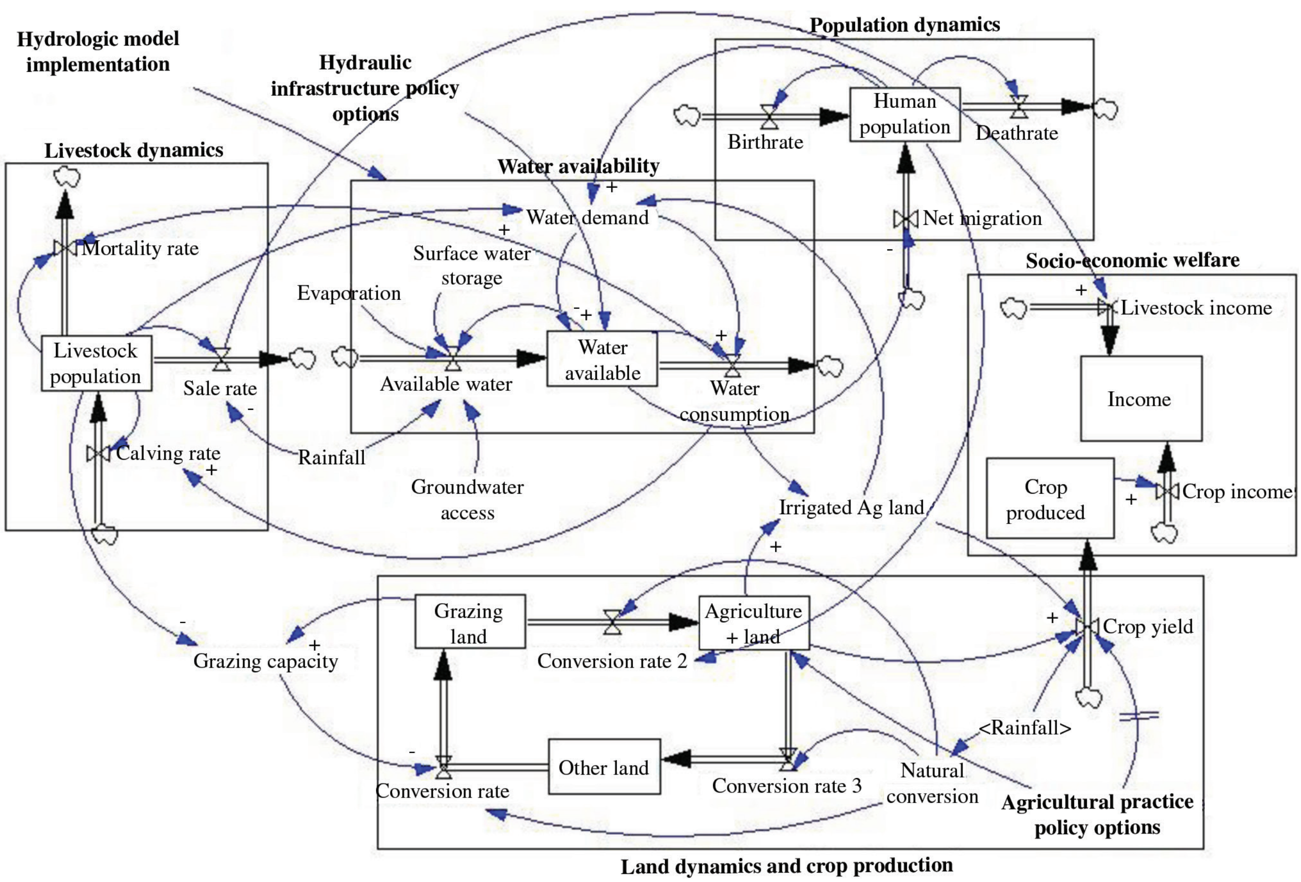

Figure 2. System dynamics framework for linking the systems affected by drought.

Source: Gies (2013).

SWADIN team, the food, environment, and health systems can be easily integrated to study the effect of floods and other water-related issues on a community.

REFERENCES

Cook, A., & Merwade, V. (2009). Effect of topographic data, geometric configuration and modeling approach on flood inundation mapping. *Journal of Hydrology, 377*, 131–142.

Gies, L. (2013). Drought policy development and assessment in East Africa using Hydrologic and system dynamics modeling (Masters thesis, Faculty of Purdue University) 121 p. Retrieved from http://web.ics.purdue.edu/~vmerwade/reports/2013_01.pdf

Hallegatte, S., Green, C., Nicholls, R. J., & Corfee-Morlot, J. (2013). Future flood losses in major coastal cities. *Nature Climate Change, 3*, 802–806.

Merwade, V. M., Olivera, F., Arabi, M., & Edleman, S. (2008). Uncertainty in flood inundation mapping – Current issues and future directions. *ASCE Journal of Hydrologic Engineering, 13*(7), 608–620.

SWADIN. (2013). *Systems dynamic modeling approach discussed in this paper fits with the te sustainable solution with appropriate technological development and innovation*. Retrieved from https://tech.purdue.edu/swadin.

Dr. Venkatesh Merwade is an Associate Professor in the School of Civil Engineering at Purdue University. His research and teaching interests include addressing water resources issues by using geographic information systems, computer modeling, and hydrologic information systems. Currently he is working on projects related to flood modeling and mapping, soil moisture data assimilation, and cyberinfrastructure development for hydrology. Prior to joining Purdue University, Dr. Merwade worked as a postdoctoral fellow at the Center for Research in Water Resources at the University of Texas at Austin. Dr. Merwade obtained his B.E. in Environmental Engineering from Shivaji University, India, M.Sc. in Hydrology from the National University of Ireland, Galway, and Ph.D. in Civil Engineering from the University of Texas at Austin.