

Soil & Water Conservation Engg. 3(2+1)

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Lesson 31 Modeling of Watershed Processes

Global advances in economies and standards of living have resulted in a growing dependency on water resources. Many societies have experienced water scarcity as a result of current patterns with societal advances; these are associated with factors such as population growth, increased urbanization and industrialization, increased energy use, increased irrigation associated with advances in agriculture productivity, desertification, global warming and poor water quality. Improved understanding of how each of these factors influences water supply, demand and quality require improved abilities to understand the underlying processes and their impact on water availability and use. This entails employing a holistic approach which integrates hydrologic processes at the watershed scale to determine an overall watershed response to both user demands and changing climates.

31.1 Model, Watershed Model and Modeling

Watershed modeling is being utilized as a tool to better understand surface and subsurface water movement and the interactions between these water bodies. Models are the simple representations of complicated systems or processes. Some of the oldest forms of models were actual miniature physical representations of natural complicated systems. More importantly, they offer tools to guide decision making on water resources, water quality and related hazard issues. Mathematical models are also representations of systems, but use a series of mathematical equations. The number, form and interconnections of these equations in a model can range from very simple to highly sophisticated.

31.1.1 Watershed Modeling

Watershed models simulate natural processes of the flow of water, sediment, chemicals, nutrients, and microbial organisms within watersheds, as well as quantify the impact of human activities on these processes. Simulation of these processes plays a fundamental role in addressing a range of water resources, environmental and social problems. The current generation of watershed models is quite diverse and varies significantly in sophistication and data and computational requirements. Newly emerging technologies (Geographical Information System, GIS; and Remote Sensing, RS) are being increasingly integrated into watershed models.

31.1.2 Why Modeling?

Modeling is useful for many purposes, but it may not always be the best tool for a given situation. The ability of models to predict future conditions is very useful for projecting the outcome(s) of various possible management measures and strategies. Modeling is thus a tool to aid in selecting the desired management options. Model may help to predict the outcomes of water allocation alternatives, watershed managements, resource management, ecological restoration etc. Two points to be considered while the models are discussed are:

1. Models are a type of tool and are used in combination with many other assessment techniques.
2. Models are a reflection of our understanding of watershed systems. As with any tool, the answers they give are dependent on how we apply them, and the quality of these answers is no better than the quality of our understanding of the system.

31.2 Watershed Modeling-State of Art

The state-of-the-art watershed-scale models and modeling systems include the use of artificial intelligence (AI) for processing of information to improve modeling speed and accuracy, the impact of data resolution and watershed scale on the modeling process. Genetic algorithms (GAs), artificial neural networks (ANN) and fuzzy logic (FL) are currently being employed to assist in processing data, develop improved relationships between hydrologic processes and in some cases, assist in filling voids in the measured data. In addition, tools have evolved to have enhanced modeling capabilities. Two of these tools are Geographic Information Systems (GIS) and Remote Sensing (RS) technologies. Integration of these tools into watershed modeling has improved the spatial and temporal components of watershed models, specifically by reducing model prediction uncertainty due to input data, initial conditions and even parameterization. Advancements in computational efficiencies have also contributed to the increased inclusion of uncertainty analysis in modeling procedures. Uncertainty analysis, which refers to the evaluation of the difference between an observed or calculated value and the true value, generally relies on completing thousands of model simulations using probability distributions to represent model factors (such as inputs or parameters). Advancements in computational efficiency have increased the feasibility of simulating these large datasets and post-processing the output, as is evident by the growing number of researches in this area. Along with the technological advances, the science of watershed modeling has evolved with regard to the calibration and validation process. The most historically common component included in hydrologic calibration-validation is the comparison of predicted and measured downstream flows. With increasing frequency, a more comprehensive flow calibration-validation is presented in modeling applications that include base flow, surface runoff flow and total flow. The inclusion of multiple variables in the calibration process has also led to further development of global sensitivity analyses and automated multi-objective calibration methods. The interest in predicting and calibrating multiple outputs from a watershed model leads to the identification of a multi-objective function for watershed modeling applications. Multi objective functions provide optimization criteria for multiple modeling objectives in a mathematical form. Identification of a multi-objective function is essential for calibrating watersheds with multiple outputs of interest to ensure that all components receive appropriate consideration and there are minimal to no biases among the variables of interest.

31.3 Benefits of Watershed Modeling

The ability to deliver reliable water resources to a growing population and effectively forecast flooding, drought and surface/groundwater water contamination represent increasingly difficult and interrelated challenges to water resource managers, engineers and researchers. Such challenges necessitate the employment of a more holistic approach that is capable of examining individual processes and systems and the interface between them. The watershed modeling includes an observed shift to a more holistic, watershed-based focus of the regulatory community, various types of watershed-scale models and watershed modeling systems available today, use of artificial intelligence in modeling processes, and issues faced through scale-up of

hydrologic processes and data resolution. The benefits of using these techniques include the ability to assist water resource and watershed managers with a variety of applications such as evaluating and developing TMDLs (Total Maximum Daily Load). Watershed-scale models thus can be employed by water resource managers and decision makers as a screening tool to identify the best management option/strategy for allocating sufficient water for different purposes with reduced problems under the series of possibilities.

31.4 Watershed Models

Watershed models can be grouped into various categories based upon the modeling approaches used. The primary features for distinguishing watershed-scale modeling approaches include the nature of the employed algorithms (empirical, conceptual or physically-based), whether a stochastic or deterministic approach is used for model input or parameter specification and whether the spatial representation is lumped or distributed. The watershed models can be grouped or classified based on different criteria as given below.

1. Based on Nature of Input and Uncertainty

Watershed models can be categorized as *deterministic or stochastic* depending on the techniques involved in the modeling process. *Deterministic models* are mathematical models in which the outcomes are obtained through known relationships among states and events, e.g. Precipitation-Runoff Modeling System (PRMS). *Stochastic models* will have most, if not all, of their inputs or parameters represented by statistical distributions which determine a range of outputs, e.g. Weather Generators.

2. Based on Nature of the Algorithms

Physically-based models are based on the understanding of the physics associated with the hydrological processes which control catchment response and utilize physically based equations to describe these processes, e.g. Soil and Water Assessment Tool (SWAT); MIKE SHE. *Empirical models* consist of functions used to approximate or fit available data. Such models span a range of complexity, from simple regression models to hydro informatics-based models which utilize Artificial Neural Networks (ANNs), Fuzzy Logic, Genetic and other algorithms.

3. Based on Nature of Spatial Representation

Watershed-scale models can further be categorized on a spatial basis as *lumped, semi-distributed or distributed models*. The *lumped modeling* approach considers a watershed as a single unit for computations where the watershed parameters and variables are averaged over this unit. Compared to lumped models, semi-distributed and distributed models account for the spatial variability of hydrologic processes, input, boundary conditions and watershed characteristics. For *semi-distributed models*, the aforementioned quantities are partially allowed to vary in space by dividing the basin into a number of smaller sub-basins which in turn are treated as a single unit, e.g. Hydrological Simulation Program-Fortran (HSPF). These models describe mathematically the relation between rainfall and surface runoff without describing the physical process by which they are related. e.g. Unit Hydrograph approach. Spatial heterogeneity in *distributed models* is represented with a resolution typically defined by the modeler.

4. Based on type of Storm Event

Watershed-scale models can be further subdivided into *event-based* or *continuous-process models*. *Event-based models* simulate individual precipitation-runoff events with a focus on infiltration and surface runoff, while *continuous process models* explicitly account for all runoff components while considering soil moisture redistribution between the storm events.

Keywords: Types of Watershed Models, Geographical Information Systems, Remote Sensing

Suggested Readings

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