Hydrologic Modeling: Progress and Future Directions

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Briefly tracing the history of hydrologic modeling, this paper will address the progress that has been achieved since the advent of computer and what the future may have in store.

The birth of hydrologic modeling can be traced to the 1850s, with the development of the rational method for computing peak discharge and experiments on flow through sands (Darcy's law). Over the next century, many groundbreaking advances in modeling different components of the hydrologic cycle were made. Some of these advances were based on the laws of mathematical physics and some had their basis in laboratory and/or field experiments. The current state of hydrologic science and engineering owes a great deal to the pre-1960 advances.

The 1960s witnessed the birth of computer revolution, and hydrologic modeling took a giant leap forward. The computer provided a new power for doing computations. As a result, a new branch of hydrology, called digital or numerical hydrology, was born. Several major advances ensued. First, simulation of the entire hydrologic cycle became a reality, as illustrated by the development of the Stanford Watershed Model, and umpteen others that followed. Second, two- and three-dimensional modeling was made possible because of advances in numerical mathematics, which led to such models of channel flow, groundwater, infiltration, and soil water. Third, simultaneous simulation of water flow and sediment and pollutant transport was undertaken, as well as of different phases of flow. Fourth, modeling at large spatial scales (e.g. a large river basin) and at small temporal scales (e.g. minutes) was undertaken. Fifth, integration of hydrology with allied sciences became possible, which led to coupling hydrology with climatology, geomorphology, hydraulics, soil physics, geology, and ecosystems. Climate change became part of hydrologic analysis.

In the decades that followed, computing prowess increased exponentially and hydrology began maturing and expanding both vertically and horizontally. Tools from fluid mechanics, statistics, information theory, and mathematics were employed and became part of hydrology. Further, computer also made possible the development of user friendly software, and tools for date acquisition, storage, retrieval and processing. Remote sensing tools (e.g. radar, satellites) made data acquisition for large areas possible. Geographical information systems (GIS) were developed for processing huge quantities of raster and vector data. The past two decades witnessed the application of artificial neural networks, fuzzy logic, wavelets, entropy theory, copula theory, chaos theory, network theory, and catastrophe theory.

With advances in data capturing, analysis, and transfer, it seems that the future of hydrology will be even brighter, with new tools at its disposal. For example, drones will become commonplace for acquiring spatial data. Hydrologic models will become so user-friendly that little hydrologic knowledge will be needed to operate them, just like one does not need to be an automobile engineer to drive a car or an electrical engineer to operate an electrical system. Each model, however simple or complicated, will be associated with a statement of uncertainty. New frontiers of hydrology will unfold with the use of cell phones. Hydrologic forecasting capability will multiply. There will be greater interaction between the user and the model and the modeler. This has already started to happen through what is now regarded as social hydrology. Hydrology will play an increasing role in meeting grand challenges of this century, such as water security, food security, energy security, environmental security, health security, water-food-energy nexus, and sustainable development.