IV

Hydraulic Engineering

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IV.1 Introduction

Global freshwater resources comprise 1 million cubic miles. Most of this water is in groundwater, less than 1/2 mile deep within the earth. Of this resource, only 30,300 cubic miles reside in freshwater lakes and streams. However, all of this water is in a continuous movement known as the "hydrologic cycle." The dynamic nature of this movement is quite variable. The response time of urban runoff is minutes to hours and the average residence time of atmospheric moisture is a little more than 9 days, while the global average residence time of freshwater in streams is approximately 10 days, and that of groundwater is 2 weeks to 10,000 years.

As the field of hydraulic engineering enters the third millennium, more noticeable water resources impacts on society are expected. These impacts result from increasing world population, political and economic instabilities, and possibly anthropogenic-driven climatic changes.

Because of the diversity of the amounts of water involved, the variability of the response times, and the myriad of water uses, civil engineers must deal with a multitude of physical and management water problems. Some of these problems are water supply for cities, industries, and agriculture; drainage of urban areas; and the collection of used water. Other problems deal with flows in rivers, channels, and estuaries; and flood protection; while others are concerned with oceans and lakes, hydropower generation, water transportation, etc. Although the emphasis of this section is on water quantity, some aspects of water quality are considered.

Because of the multitude of different types of problems, hydraulic engineering is subdivided into a number of specialties, many of which are the object of separate chapters in this section. These specialties all have fluid mechanics as a common basis. Because the concern is with water, there is little interest in gases, and the fundamental science is hydraulics, which is the science of motion of incompressible fluids.

The chapter on *Fundamentals of Hydraulics* presents properties of fluids, hydrostatics, kinematics, and dynamics of liquids. A separate chapter is devoted to *Open Channel Hydraulics* because of the importance of free surface flows in civil engineering applications. Erosion, deposition, and transport of sediments are important in the design of stable channels and stable structures. Sediment resuspension has important implications for water quality. These problems are treated in the chapter on *Sediment Transport in Open Channels*.

The flow of water in the natural environment such as rainfall and subsequent infiltration, evaporation, flow in rills and streams, etc., is the purview of *Surface Water Hydrology*. Because of the uncertainty of natural events, the analysis of hydrologic data requires the use of statistics such as frequency analysis. *Urban Drainage* is the object of a separate chapter. Because of the importance of the problems associated with urban runoff quality and with the deleterious effects of combined sewer overflows, a new chapter has been added on *Quality of Urban Runoff*.

Hydrology is generally separated into surface water hydrology and subsurface hydrology, depending on whether the emphasis is on surface water or on groundwater. The chapter on *Groundwater Engineering* is concerned with hydraulics of wells, land subsidence due to excessive pumping, contaminant transport, site remediation, and landfills.

Many *Hydraulic Structures* have been developed for the storage, conveyance, and control of natural flows. These structures include dams, spillways, pipes, open channels, outlet works, energy-dissipating structures, turbines, pumps, etc. The interface between land and ocean and lakes is part of *Coastal*

Engineering. The chapter on Coastal Engineering also contains a discussion of the mechanics of ocean waves and their transformation in shallow water and resultant coastal circulation. It also includes a discussion of coastal processes and their influence on coastal structures.

Many forms of software and software packages are available to facilitate the design and analysis tasks. Several of these were originally developed by government agencies and later improved by private companies, which add preprocessors and postprocessors that greatly facilitate the input of data and the plotting of output results. Many of these models, such as SWMM and the HEC series, have well-defined graphical and expert system interfaces associated with model building, calibration, and presentation of results. Several of the public domain packages are listed in the chapter on *Simulation in Hydraulics and Hydrology* and detailed examples of application to urban drainage are also given.

It is not sufficient for civil engineers to deal only with the physical problems associated with water resources. They are also concerned with planning and management of these resources. Conceptualization and implementation of strategies for delivering water of sufficient quantity and quality to meet societal needs in a cost-effective manner are presented in the chapter on *Water Resources Planning and Management*.

As are most engineering sciences, hydraulic engineering is a rapidly moving field. The computer, which was a means of making computations, is now becoming a knowledge processor. The electronic encapsulation of knowledge and information in the form of software, databases, expert systems, and geographical information systems has produced a "Copernican revolution in Hydraulics" (Abbott 1994). The Europeans have coined the word "Hydroinformatics" to designate the association of computational hydraulic modeling and information systems. Thus hydraulic and hydrologic models become part of larger computer-based systems that generate information for the different interests of the water resources managers. For example, the linkage of storm sewer design and analysis packages with databases, geographical information systems, and computer-aided design systems is now becoming routine. Similarly, decision support systems have integrated combinations of water resources simulations and optimization models, databases, geographic information systems, expert- and knowledge-based systems, multiobjective decision tools, and graphical user-friendly interfaces (Watkins et al. 1994). The emphasis has passed from *numerics* to *semiotics* (Abbott et al. 2001).

Hydroinformatics also introduces new methods to encapsulate existing knowledge often with the goal of accelerating the rate of access to this knowledge. Some of these are data mining, genetic programming, and artificial neural networks (Abbot et al. 2001). For example, artificial neural networks have been used in the real time control of urban drainage systems.

One of the early issues of hydraulic modeling known as *model calibrations* is still an uncertainty, although perhaps less apparent in this new paradigm. For example, if the roughness coefficient is used to fit calculated flows to measured discharges, unrealistic values of Mannings roughness coefficient could hide unknown information or physical phenomena not represented in the model. In that case, the model would not be predictive, even with an excellent calibration (Abbott et al. 2001). However, in some cases, the laws governing roughness coefficients are not complete and new interpretations are needed. For example, in the case of wetlands, as vegetation is deflected to one side and eventually flattened, the values of the roughness coefficient departs markedly from the traditional Manning formulation (Kutija and Hong 1999).

The 1993 extreme floods in the Mississippi and Missouri basins indicated the importance of hydrologic forecasting of the design of flood protection structures and of water management at the basin scale while taking into account the environmental, ecological, and economic impacts. According to Starosolski (1991), the old approach of first designing the engineering project and then considering the ecological effects should be replaced by a systems approach in which the hydraulic, environmental, and ecological aspects are all included in the planning, execution, and operation of water resources projects.

Progress in a topic of hydraulic engineering is presented in the Hunter Rouse Lecture at the annual meeting of the Environmental and Water Resources Institute of the American Society of Civil Engineers and is subsequently published in the *Journal of Hydraulic Engineering*. The proceedings of the Congresses of the International Association of Hydraulic Research, held every 4 years, summarize the advances in the field, primarily in the keynote papers.

Both in surface water and groundwater hydrology, recent researchers have been inspired by the improved ability to observe and model the many heterogeneities of surface and material properties and of transport processes (van Genuchten 1991). Remote sensing now makes it possible to model land surface hydrologic processes at the global scale. Then these processes can be included in general circulation models of the atmosphere (Wood 1991). The research accomplishments in surface water and groundwater hydrology are summarized every 4 years in reports from several countries to the International Union of Geodesy and Geophysics. The U.S. quadrennial report is prepared by the American Geophysical Union and is published in *Reviews of Geophysics.*

Similarly, in coastal engineering, recent mathematical models make it possible to simulate large-scale coastal behavior that is at scales larger than tens of kilometers and time scales of decades. These models include waves, currents, and sediment transport. Models capable of describing the interaction with the bottom topography are under development at least for short-term coastal behavior (De Vriend 1991, Holman 1994). The new techniques mentioned in the previous paragraphs are still in the research stage and are beyond the scope of this handbook, but the references at the end of this introduction provide entry points into several research fields.

References

Abbott, M.B., 1994. Hydroinformatics: a Copernican revolution in hydraulics, *J. Hydraulic Res.*, vol. 32, pp. 1–13, and other papers in this special issue.

Abbott, M.B., Babovic, V.M. and Cunge, L.A., 2001. Towards the hydraulics of the hydroinformatics era, *J. Hydraulic Res.,* vol.39, pp. 339–349.

De Vriend, H.B., 1991. Mathematical modelling and large-scale coastal behavior, *J. Hydraulic Res.*, vol. 29, pp. 727–755.

Holman, R., 1994. Nearshore processes, in U.S. National Report to the International Union of Geodesy and Geophysics 1991–1994, *Rev. Geophys.,* supplement, part 2, pp 1237–1248.

Kutija, V. and Hong, 1996. A numerical model for assessing the additional resistance to flow induced by flexible vegetation, *J. Hydraulic Res.,* vol. 34(1), pp. 99–114.

Starosolski, O. 1991. Hydraulics and the environmental partnership in sustainable development, *J. Hydraulic Res.*, vol. 29 and other papers in this extra issue.

van Genuchten, M.T. 1991. Progress and opportunities in hydrologic research, 1987–1990, in U.S. National Report to the International Union of Geodesy and Geophysics 1991–1994, *Rev. Geophysics*, supplement, April 1991, pp. 189–192.

Watkins Jr., D.W. and McKenney, D.C. 1994. Recent developments associated with decision support systems in water resources, in U.S. National Report to the International Union of Geodesy and Geophysics 1991–1994, *Rev. Geophysics,* supplement, part 2, pp. 941–948.

Wood, E.F., 1991. Global scale hydrology: advances in land surface modelling, in U.S. National Report to the International Union of Geodesy and Geophysics 1987–1990, *Rev. Geophysics,* supplement, pp. 193–201.