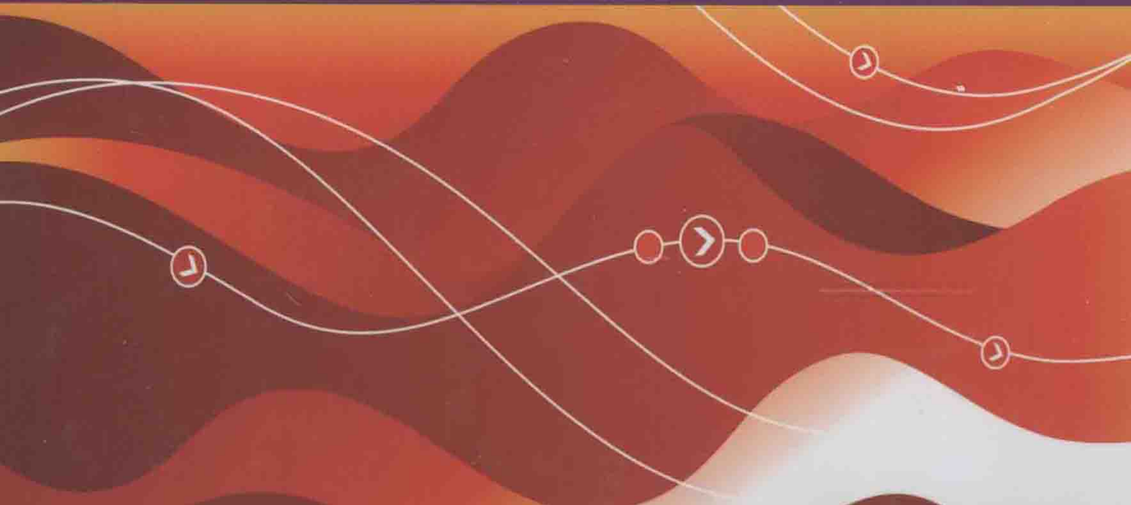
ENVIRONMENTAL HYDRAULICS SERIES

Numerical Methods

Edited by Jean-Michel Tanguy



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volume 3

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Numerical Methods

Introduction

This environmental hydraulics treatise is made up of five volumes: Volume 1 describes the main physical processes and the physical domains where they can be observed and measured.

Volume 2 is dedicated to mathematical modeling in hydraulics and fluvial hydraulics.

In Volume 3, Chapters 1 to 7 constitute an introduction to numerical modeling, and more particularly on finite difference and finite element discretization. It in no way claims to constitute a treatise on the subject, but simply offers an overview of the discretization methods used in the domains covered by this work, which range from meteorology to shore morphodynamics. Chapters 8 to 13 deal with the finite volume discretization method, the spectral approach, numerical schemes and resolution methods.

Lastly, Volume 4 dealing with application examples completes Volume 3, along with a final volume (Volume 5) on operational software.

This volume is made up of three parts and comprises 13 chapters:

Part 1: general considerations concerning numerical tools;

Part 2: discretization methods;

Part 3: introduction to data assimilation.

Set out below is a brief summary of each chapter.

Introduction written by Jean-Michel TANGUY.

Part 1: General considerations concerning numerical tools

We will introduce a number of general concepts regarding models used in engineering and in the operational-forecast domain and detail the ways of constructing numerical models based on mathematical models.

Chapter outline

Part title	Chapter no.	Chapter title	Problematic issue
General Considerations Concerning Numerical Tools	1	Feedback on the Notion of a Model and the Need for Calibration	Placing perspective on the notion of a numerical model in the context of the study of physical phenomena. Importance of calibration
	2	Engineering Model and Real-Time Model	Transposing a model used in engineering into an operational forecast context requires significant computer-science and pairing work to be performed
	3	From Mathematical Model to Numerical Model	Switching from a mathematical model to a numerical model requires approximations to be performed; discretization methods suitable for the types of equations considered and suitable numerical schemes need to be used

What are the domain's perspectives?

– Operational forecast services such as the national meteorological services and flood forecasting services use real-time simulation tools based on numerical tools. *These tools need to be reliable, must not diverge and must be constantly recalibrated with respect to the reality in the field*, allowing civil security services and the general public to be warned of the imminence of a significant unforeseen event. Indeed, society's requirements are evolving towards a strong demand to be given preventative information as to risks, for there to be *greater risk-anticipation* and to be kept out of danger: we can cite as an example the mandatory preventive evacuation of the population of New Orleans when hurricane Gustav arrived in early September 2008, following the catastrophic events of Katrina in late August 2005.

– Significant progress has been made in recent years with respect to numerical modeling, underpinned by developments in computer science. This has enabled *complex geometries for very fine-scale studies* to be taken into account. Choosing appropriate discretization methods and efficient schemes is a major challenge in engineering today. The decision makers of today are demanding increasingly higher standards with regard to technical choices and the use of tried and tested simulation tools, and only the most effective tools will last.

Part two: Discretization methods

We will present the different numerical methods used within the domains covered by this book. Unlike a number of works dealing with these problems, we have opted not to remain focused on conceptual considerations, but to offer the reader a means of understanding the fundamentals of each method and their implementation. In particular, we explain the processing of boundary conditions, which are often overlooked. This lends something of a computational aspect to our presentations, but our aim is to provide the readers with the key principles, enabling them to follow the developments step by step.

Chapter outline

Part title	No.	Section title	Problematic issue
Discretization Methods	4	Problematic Issues Encountered	Highlighting of several difficulties relative to the behavior of computing codes to demonstrate the importance of having efficient numerical schemes
	5	General Presentation of Numerical Methods	Placing perspective on the main existing numerical methods
	6	Finite Differences	Succinct presentation of the method, illustrated using the equation for the diffusion of a pollutant
	7	Introduction to the Finite Element Method	Detailed presentation of the method, illustrated using the equation for swell propagation
	8	Presentation of the Finite Volume Method	Detailed presentation of the method, illustrated using the equation for the development of a water table
	9	Spectral methods in Meteorology	This method is widely used in meteorological computing codes
	10	Numerical-Scheme Study	Each discretization method requires a numerical scheme to be chosen, which must be studied to specify the behavior of the final model.
	11	Resolution Methods	A brief list of the resolution methods

What are the domain's perspectives?

– The recent developments of numerical methods are mainly led by industrial applications. All of these methods, each with different origins, ultimately translate into the resolution of matrix systems. There are numerous links between them, and current research appears to be oriented towards methods, such as discontinuous finite element methods, which present a combination of the advantages of each of them.

– As we have mentioned on a number of occasions in the course of this book, the numerical tools of tomorrow will need to be equipped with high-level processing functionalities to offer the user the possibility of performing a reverse action at any instant on the resolution cycle.

Part three: Introduction to data assimilation

This part presents the data assimilations methods that are most commonly used by forecast services.

The concepts on which these methods are based can appear somewhat abstruse, all the more so as the mathematical formulation is far from simple, but they represent powerful tools that are indispensable to forecasters to enable their models to adjust to the reality in the field.

We can expect these tools to undergo significant development in the coming years.

Chapter outline

Part title	**Chapter no.**	**Chapter title**	**Problematic issue**
Introduction to Data Assimilation	12	Data Assimilation	General presentation of the various applications of the method: meteorology, hydrology and hydraulics
	13	Data Assimilation Methodology	Detailed presentation of the different numerical methods used within the domains covered by this book

What are the domain's perspectives?

– Data assimilation is a method undergoing rapid expansion within our field of application. It is increasingly applied within the framework of computing-code calibration and problematic issues encountered in real time. Meteorology was one of the first disciplines to use these methods owing to the large quantity of measurements and observations resulting from work in the field. It has arrived at a level of maturity that means it can now *serve as a reference to other disciplines such as hydrology and hydraulics*.

– These methods will also be used to install measurement systems that are to be increasingly adapted to simulation models. In hydrology, for example, staff gauge stations were installed in areas presenting high stakes, without the entirety of the forecast chain being taken into account. The installation of new models will be accompanied by an approach aimed at optimizing the measurement systems to be assimilated. Likewise, it will be possible for gauging in rivers, very dangerous in the event of a flood, to be considered in relation to hydrodynamic-model usage in order to be able to optimize their installation and enable measurements at maximum reservoir level to be taken in less exposed locations.

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