ENVIRONMENTAL HYDRAULICS SERIES

Practical Applications in Engineering

Edited by Jean-Michel Tanguy

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volume 4

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Practical Applications in Engineering

Introduction

The first volume of this series on environmental hydraulics consists of a description of the physical processes that are developing, from meteorology to coastal morphodynamics. Volume 2 sets out the mathematical theories that form the basis of the mathematical modeling of these processes. Volume 3 describes the main numerical methods enabling these equations to be solved.

To a certain extent, Volume 4 constitutes a showcase for the series on environmental hydraulics. Its aim is to present a variety of practical examples implemented using tools that are based on the theories presented in Volume 2.

Volume 5 presents a number of software programs used within the water engineering domain.

In keeping with the book's logic, we have differentiated between eight domains, three of which are presented in Parts 1 to 3, followed by five in Parts 4 to 8. Each domain includes a number of studies that are fairly representative of what occurs in the domain concerned. As such, the domains for the first three parts are as follows: operational hydrology, fluvial hydraulics and hydrogeology. A total of 13 technical studies are summarized.

Parts 4 to 8 complete the presentation by offering a summary of 17 technical studies, covering the following domains: flows in an urban environment, estuary hydrodynamics, maritime hydraulics, transportation of dissolved substances – pollution, and fluvial and maritime morphodynamics. Each study has been made the subject of a document covering several pages, presenting, in the following order: the problematic issue to be dealt with, the objective to be reached, the data collected, the digital models implemented and the results obtained.

Introduction written by Jean-Michel TANGUY.

Part 1. Operational hydrology

To begin with, we present how the flood forecasting services and SCHAPI (French National Hydrometeorology and Flood Forecasting Center) estimate, on a daily basis, the hydrometeorological risk across the entire country based on forecasts produced by meteorological models. The following three studies focus on the use of pre-operational or operational models for flood forecasting in the very rapid Mediterranean basins, the Gard and the Aude, which each experienced very heavy flooding, in 2002 and 1999, respectively. Anticipation is thus essential in order to avoid material damage and loss of human life. For this reason, the tools need to be operated very rapidly and be interfaced with meteorological tools upstream and hydrodynamic tools downstream. The last presentation focuses on the approach of the European Community's Joint Research Center (JRC), which produces a hydrological risk estimate on the rivers in Europe in critical situations.

Outline of the studies

	Chapter	Title	Problematic issue	Tool
Operational Hydrology	1	Developing the Flood Alert Map	To use the results of the meteorological models in order to estimate the hydrometeorological risk across the country, on a daily basis	ECMWF ARPEGE ALADIN SYMPOSIUM
	2	Generation of a Flood in a Rapid Basin (Gard 2002)	To simulate the flood that occurred in September 2002 in the Gard area	TOPMODEL (2D hydrologics)
	3	Forecasting a Flood in a Branched Network (Aude 1999)	To estimate the forecast times at a hydrometric station based on the flow rates in the tributaries	SOPHIE (multimodels)
	4	Hydrological Modeling Spatialized on Two Mediterranean River Basins. Application in Flood Forecasting	To determine the parameters that are characteristic of a hydrological model applied on two river basins and to a wide series of events. Application in flood forecasting	MERCEDES (2D hydrologics)

	Chapter	Title	Problematic issue	Tool
	5	Ensemble Hydrological Forecasting and Alert with the European Flood Alert System (EFAS): Case of the Danube Basin Floods in August 2005	To use an ensemble hydrological forecast model in order to forecast the flooding of the Danube, based on the DWD and ECMWF weather forecasts	EFAS

What are the domain's perspectives?

Numerical tools that can be used in forecast mode are indispensable to operational hydrology, notably on rapid basins, where the suddenness of floods can lead to damage and loss of human life.

The forecast models need to be straightforward and must operate rapidly, taking a few minutes at most. For the most part they use limit conditions originating from hydrometric measurement stations: their forecasting is therefore limited to propagation. Anticipation may be increased, however, if rain flow models are used in order to return to the maximum in the river basins so as to simulate flood generation based on the observed rainfall. A further time saving is also possible through the use of rain forecasts upstream of the hydrological models. This is currently being tested with the use of refined meteorological models (AROME), which will enable improved localization and better estimation of the rain's intensity before it falls.

Even with the progress made recently, operational hydrology remains at the construction stage. The models currently on the drawing-board in research laboratories offer an indication of decisive progress to come, through a spatialized response to problems of flood generation and surface run-off in the upstream basins, rarely taken into account by current models.

Part 2. Fluvial hydraulics

This part presents various examples of the usage of fluvial hydraulics numerical models. To begin with, we have chosen a number of 1D examples, where it is a matter of simulating the flood propagation in branched, meshed environments. The corresponding software proved to be particularly well adapted to taking into account complex networks comprising various types of structures in the low-water channel. We then focused on widely overflooding flows, selecting two studies conducted by different teams on the Aude basin for the flood of November 1999. The first study presents the coupling of a spatialized hydrological model with a 2D hydrodynamic model, whereas the second centers around a very accurate close-up view performed to simulate the overflooding by the longitudinal dikes located along the river. These two cases enable the high level of accuracy that may be obtained by these 2D models to be illustrated. The next example deals with the failure mechanism of a longitudinal dike on the Agly, which was conducted by coupling a 2D hydrodynamic model with a procedure simulating the dike failure conditions. This is followed by an example illustrating the propagation of a flood in a confluent that has triggered an upwelling of the groundwater, causing a plant to be flooded. In this example, a 2D hydrodynamic software program has been coupled with a 2D hydrogeological software program in order to represent this complex process. The final example focuses on the simulation of ship paths by a pilot, based on the current field pre-computed by a 2D model. This software may be used both in rivers and in the sea.

Outline of the studies

	Chapter	Title	Problematic issue	Tool
Fluvial Hydraulics	6	Propagation of a Flood in a Branched Network (Marne 1999)	To assess the impact of the correct management of a sector gate at Saint-Maur, a derivation canal serving the Marne, in order to reduce the water line in the event of flooding on the Marne and the Seine	MASCARET (1D hydraulics)
	7	Flood Propagation in a Looped Network (Wateringues)	To design a hydraulic model enabling the simulation of the operation of a Wateringues network during a flood period and optimize management of the network	MAGE (1D hydraulics)
	8	Generation and Propagation of a Flash Flood on a River Basin (Aude 1999)	To study the generation and propagation of the November 2002 flood in the Aude Lower Flatlands	MARINE (2D hydrology) TELEMAC 2D (2D hydraulics)

	Chapter	Title	Problematic issue	Tool
	9	Dynamics of the Flooding of Floodable Flatlands (Aude 1999)	To study the dynamics of the overflooding through the gaps, and the propagation of the November 2002 flood in the Aude Lower Flatlands	ISIS (1D hydraulics, with compartments) REFLUX (2D hydraulics)
	10	Failure of a Dike in a Flood Environment (Agly 1999)	To simulate the failure of a gap and the propagation of a flood wave during the November 1999 flood near Rivesaltes on the Agly	RUBAR 20 (2D hydraulics)
	11	Flooding by Groundwater Upwelling at Remiremont (Moselle)	To explain the flooding conditions of a lateral compartment on the Moselle during the February 1999 flood	REFLUX (2D hydraulics) MARTHE (2D hydrogeological)
	12	NAVMER: Ship Path Simulator	To simulate the ship path based on a 2D current field and orders given by a pilot to the simulator	NAVMER (2D trajectography) + 2D study of currents (REFLUX)

What are the domain's perspectives?

Overall, these examples demonstrate that modeling tools represent a whole range of complementary software *used intensively today* in fluvial engineering studies.

Coupling is produced with other software representing neighboring processes such as hydrology, dike failure and flow in soils.

Engineering and design department needs within this domain are essentially centered on improvements to pre-and post-processing, and to computing times.

Part 3. Hydrogeology

The focus of modeling in hydrogeology concerns what is in store for water located in the soil. It makes use of models capable of representing flows within porous environments in saturated and unsaturated zones. It makes use either of conceptual tools, when the processes are very complex and there is significant soil heterogeneity, or of 2D or 3D tools. Set out below are two case studies using these two types of tools.

Outline of the studies

	Chapter	Title	Problematic issue	Tool
Hydrogeology	13	Interaction between Surface and Subsurface Flows: Somme Basin	This application shows how a spatialized subsurface hydrodynamics model, coupled with a hydroclimatic assessment module, enabled the mechanisms at the origin of the 2001 flood to be understood. In addition, a global hydrological model enabled operational forecasts to be produced for the Somme at Abbeville in 2002 and 2003	MARTHE (3D subsurface hydraulics), GARDENIA (reservoir hydrogeology)
	14	Hydrogeo-logical Modeling of the Karst System on the Lez River (Montpellier)	To reproduce the flow rate time series for the source of the Lez near Montpellier, influenced by pumping, and determine the system's level of reaction to precipitation	VENSIM (rain-flow with reservoirs)

What are the domain's perspectives?

Coupling hydrodynamic and hydrogeological models allows a clear understanding of the physical phenomena that occur when a flood is generated as a result of groundwater overspill, with drainage of the water downstream as a result of gravity. Most require a large amount of computing time, but currently allow the simulation of a slow flood over several weeks. Simplified reservoir models are more straightforward and yet are much better suited to the simulation of these floods over several years.

Reservoir models are well adapted to representing the operation of karst systems, but knowledge is not sufficiently advanced at present to enable the use of physical models. The problem also lies in the lack of familiarity with the very heterogeneous make-up of these systems: direction and openings of fractures, preferential flow conduits, etc.

Part 4. Generation and propagation of floods in an urban environment

This part is dedicated to the generation and propagation of flood flows in an urban environment. It presents a description of four cases studied, mainly conducted with the aid of hydrodynamic models, some of which have been completed in order to take account of the rain. As we will demonstrate, this is a domain where model makers are witnessing rapid expansion. Indeed, during the 1990s, studies focusing on flooding in an urban environment generally featured a hydrology element using rain-flow models (rational formula amongst others); these provided hydrographs at the limit conditions of very straightforward hydraulic models (normal flow).

At the early stages, this enabled flows in highly urbanized zones to be presented, using zones with high roughness values to represent these districts. The models were subsequently improved, allowing very dense meshings to be considered, isolating blocks of houses and later houses themselves. The studies offer different modes of representing the urban fabric, ranging from a very precise manner in the Marseille example, to a more simplistic manner in the Amboise example.

Outline of the studies

	Chapter	Title	Problematic issue	Tool
Generation and Propagation of Floods in an Urban Environment	15	Hydraulic Study of the Marseille Vieux-Port River Basin	To reproduce the flood of September 20, 2000 in Marseille with a very finely-tuned modeling of the street geometry and topography	2D REFLUX (2D, hydraulic)
	16	Hydraulic Study of the Aude River in the Carcassonne Crossing	To reproduce the overflooding conditions of the Aude flood waters in 1891 in densely or diffusely urbanized areas of Carcassonne	2D TELEMAC (2D, hydraulic)

	Chapter	Title	Problematic issue	Tool
	17	Failure of a Dike in an Urban Environment: Amboise	To reproduce the 1866 Loire flood wave due to the failure of a dike at Amboise, in order to determine the flooding conditions for a pharmaceutical hangar	2D REFLUX (2D, hydraulic)
	18	Study for the Prevention of Risks Associated with the Dikes of the Rhône and the Saône on Land Belonging to the Lyon Urban Community	Study of the flooding risk to the rear of a longitudinal dike on the Rhône for a thousand-yearly flood. Presenting the unforeseen risks on top of the urban challenges.	2D TELEMAC (2D, hydraulic)

What are the domain's perspectives?

The geometric and topographic complexities of urban road networks mean that *highly sophisticated pre- and post-processing* using geographical information systems (GISs) is needed. There is still a lot of progress to be made in this domain.

These models remain complicated to use. However, they can be used as risk indicators by simulating a variety of different situations, the results of which will feed databases that may be exploited in the form of charts in forecasting mode, when a significant hydrometeorological event is detected.

The *density of the meshes has evolved significantly*: we used 5,000 nodes in 1997 (Amboise), then 30,000 nodes in 2003 (Carcassonne), and a million nodes in 2008 (with substantial computing times). This, along with the evolution we are witnessing in computer capacity, allows us to imagine that by the end of the decade we will be able to access a million, or even 2 million, nodes on desktop computers. Surface run-off in an urban environment is the result of complex interactions between several interactive processes. It will therefore be necessary to couple several models in order to obtain a modeling that is both complete and accurate: surface run-off, underground-network flows, infiltration into soils, storage in retention basins and on roofs, etc.

Part 5. Estuary hydrodynamics

This part presents various examples of the usage of hydrodynamic models at an estuary site. The first two examples are both a first for France, as they concern the "real-time" usage of two hydrodynamic modeling tools – a 1D model (MASCARET) on the Adour and a 2D model (TELEMAC 2D) on the Gironde – for flood forecasting in these two estuaries.

The original nature of these models lies in the fact that they are supplied by maritime boundary conditions downstream (astronomical tide, along with the sea surges and fluvial conditions) and upstream (limited for the time being to discharges measurements provided by limmigraphic stations).

However, estuaries are also home to processes of water mixing and silt-plug circulation, which have an influence on the currents. It became necessary to make use of a 3D hydrodynamic model in the Loire Estuary in order to represent these different phenomena and refine the flow conditions.

Outline of the studies

	Chapter	Title	Problematic issue	Tool
Estuary Hydrodynamics	19	Real-Time Estuary Modeling (Adour Maritime)	To design, implement and exploit a real-time forecasting system on the Adour Maritime, operating based on sea-level forecasts and fluvial flow-rates	MASCARET (1D, hydraulic)
	20	Operational Modeling of the Hydrodynamic Functioning of the Gironde Estuary	To design, implement and exploit a real-time forecasting system on the Gironde estuary, operating based on sea-level forecasts and fluvial discharges	2D TELEMAC (2D, hydraulic)

	Chapter	Title	Problematic issue	Tool
	21	3D Modeling of Salinity and Sediment Suspension in the Loire Estuary: Coupling of Processes	Integrated modeling of the hydrodynamics, salinity and silt plug in the Loire Estuary. The original aspect of this study lies in the fact of updating of the hydrodynamic friction as a function of the local silt deposit amount	3D TELEMAC (hydraulics + salinity + silt transportation)

What are the domain's perspectives?

The hydrodynamic models used for forecasting, whether they are 1D or 2D, have more than proved their *relevance* and *reliability* in representing flood propagation, in the sense that they succeeded in being correctly supplied, in real time, with boundary conditions originating either from measurements provided by limmigraphic stations, or from upstream forecasts obtained by rain-flow models.

Their application in the estuaries, whether small or large, should become *widespread* in the coming years.

It is indispensable to incorporate procedures for correcting the water levels computed using *data-assimilation procedures* which are tentatively beginning to appear in the operational aspect of hydrology (Volume 3, Chapter 13).

One current difficulty that remains is the *significant computing times* presented by 2D models. This is preventing them from being used with refined meshings, which are required for flooding analyses.

The 3D models are expected to be developed on major estuaries in order to take full account of their complexity. They require very fine calibration, however, as a result of extensive, complicated and extremely costly measurements.

Part 6. Maritime hydraulics

This part presents four studies within the maritime hydrodynamics domain, which make use of the different types of models that have arisen from this discipline. Firstly we examine the modeling of sea states for its application in the Iroise Sea in order to study the swell propagation from offshore to the coast. This is followed by its application to determine the sea conditions for the "Route du Rhum" in order to help sailors to optimize their path. We then go on to examine a mixed example: sea states – agitation, with a study focusing on determining agitation conditions within Roscoff marina, based on the swell propagation at high sea. Lastly, we present a study of the agitation within Dunkirk's port.

Outline of the studies

Domain	Chapter	Title	Problematic issue	Tool
Maritime Hydraulics	22	Numerical Modeling of Sea States	To study the swell conditions on the shore based on the sea states off the Iroise Sea in order to approach the sedimentary dynamics of the beaches	TOMAWAC (sea states)
	23	Taking Sea States into Account in Offshore Racing	To provide sailors with precise information regarding the sea states: swell and currents to enable them to optimize their course	VAG (sea states)
	24	Agitation Study for Roscoff-Bloscon Marina	To determine the swell agitation conditions within Roscoff marina within the framework of an extension in order to ensure that the maximum agitation threshold was not reached	SWAN (swell propagation) + REFONDE (agitation)
	25	Swell Agitation at Dunkirk's Western Port	To determine the agitation conditions within Dunkirk's port, in order to determine the maximum agitation threshold	REFONDE (agitation)

What are the domain's perspectives?

The use of sea-state models has been developed considerably within the context of engineering studies. The latest generations of models are much more efficient. They now enable us to study *wide-ranging domains* and obtain a high level of accuracy with regard to the swell conditions on the shore.

Agitation models have also made significant progress over the last few decades. The new finite element models use complex geometric domains, an accurate presentation of structures and extremely precise bed bathymetries. They require *very dense meshes*, however, (several million nodes), due to the very short wavelengths of the swell.

Hydrodynamic model couplings have also been simplified. It is enough to supply the meshes with suitable boundary conditions, particularly sea-state models, which are very sensitive to parasitic reflections.

The interactions between the swell and currents have not yet been well quantified and will need to be studied further on physical models.

The battery of codes: sea states + agitation thus constitutes a consistent, compatible whole, which enables interfacing with current-study models and sedimentology models that may be used in shore morphodynamics.

Part 7. Transportation of dissolved substances, pollution

Studies exploring water quality have progressed significantly since the appearance of numerical models. They were based on hydrodynamic models, then incorporated dissolved-substance transportation processes, sediment transportation-erosion-deposit processes and lastly, fairly complex biochemical processes.

The applications presented in this chapter are relatively original: the first focuses on large-scale modeling with the aid of a complete chain incorporating anthropic pollution and biochemical stresses in a flood environment; the second concerns the oil-spill drift forecasts produced in response to the Prestige and Erika accidents. They illustrate the fairly wide spectrum of these models.

Outline of the studies

	Chapter	Title	Problematic issue	Tool
Transportation of Dissolved Substances, Pollution	26	Study of Water Quality in the Seine	Simulation of the Seine hydrosystem as it is currently, and that predicted for 2015. Estimation of the evolution in the quality of the water bodies	PROSE (1D, hydraulic + transportation of substances + biochemical modules)

	Chapter	Title	Problematic issue	Tool
	27	Drift Forecasts for the Erika and Prestige Oil-Spills	To predict how substances spilled in oil-tanker accidents will develop over time and space in order to alert the professionals responsible for safety and the pollution response	MOTHY (hydrocarbon oil-spills)

What are the domain's perspectives?

These applications show that the pollution, whether progressive or occasional in nature, needs to be accurately simulated in order to assess its repercussions on the environment on one hand and in order to bring it under control on the other hand. The *toughening of the rules regarding environmental evaluation* is likely to galvanize the scientific community and produce high-performance simulation systems.

The marine problems also require *simulations to be triggered as soon as possible* in order to predict the pollutant trajectory and take safeguard actions on the marine life and the shore. These modeling systems, which were already highly effective, will no doubt be improved further and their usage intensified and made commonplace, for frequent use.

Part 8. Fluvial and maritime morphodynamics

Morphodynamics is a fairly complex science because it incorporates hydrodynamics, sediment transport and bed evolutions. Each of these processes is intimately interdependent and their modelings are still posing a number of problems today. The applications that we present here concern the flood environment and the maritime domain. The fluvial sedimentology modeling is still in its early stages: it is very difficult at the present time to represent the river bed evolutions. The sole application on the Arc river that we present uses a hydrodynamic model coupled to a 1D river bed development model. The remaining three applications relate to the shore. The first uses a 3D modeling system to quantify the movement of suspended sediment. The second uses a family of 2D models, but ventures further by representing the evolutions of the beds in the vicinity of a small sedimentary cell. The third and final application is a major study that implements a numerical hydrodynamic model and physical sedimentological model integrated approach on the bay of the Mont-Saint-Michel.