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Advances in Hydroinformatics

SimHydro 2019 - Models for Extreme Situations and Crisis Management

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SimHydro 2019 - Models for Extreme Situations and Crisis Management

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ISSN 2364-6934 ISSN 2364-8198 (electronic)
Springer Water
ISBN 978-981-15-5435-3 ISBN 978-981-15-5436-0 (eBook)
https://doi.org/10.1007/978-981-15-5436-0

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Preface

With the current digital development in modern societies, hydroinformatics defined as management of information related to the water sector using ICT tools is becoming a large domain of engineering technology and sciences. Modelling and simulation are historically the points of departure for hydroinformatics and are one of the most important parts of it. Neither the SimHydro cycle of international conferences since 2010 nor the present book has the purpose or ambition to cover thematically the whole extent of the subjects. The main purpose is to concentrate on a limited number of specific areas and subjects that are not usually considered as such during most global international conferences or publications.

Modelling in fluid mechanics, hydraulics and hydrology, whether using digital tools or scale models, has reached sufficient maturity to be in daily use by engineers for analysis, design and for communication. Increasingly, complex cases can be handled thanks to evermore sophisticated tools and increasingly abundant computing power and data resources. The emerging environment populated with the new generation of sensors, using cloud computing resources, producing big data, is challenging the current practices of modelling and requests innovation in methodology and concepts for real integration into the decision-making processes that are more and more requested for crisis management. At the same time, the request to integrate vulnerability and resilience dimension in various engineering approaches is becoming more and more frequent especially for environments directly exposed to major natural hazards like floods and inundations.

With respect to these issues, however, a number of questions still remain open: coupling of models, data acquisition and management, uncertainties (both epistemic and random) of results supplied by models, use of 3D CFD models for complex phenomena and for large-scale problems. All these points are continuously explored and investigated by researchers, scientists and engineers. Like in all scientific domains, most recent and advanced developments have to be discussed and shared regularly in a growing community that has to face every day more challenging and complex situations. The SimHydro 2019 conference, following the four previous editions, has contributed to this objective by providing a platform for exchanges and discussions for the different actors in the water domain.

SimHydro is a permanent cycle of conferences held every 2 years, hosted by Polytech Nice Sophia and organised by the Société Hydrotechnique de France (SHF) and its partners. It aims, as the subject, at recent advances in modelling and hydroinformatics and at the participation and exchanges at European scale (it is open to all other researchers and participants but the purpose is to maintain a specific platform for the region that was a birthplace of both domains).

The latest SimHydro conference was held in Sophia Antipolis, France, from 12 to 14 June 2019. The conference was jointly organised by the Société Hydrotechnique de France (SHF), the Association Française de Mécanique (AFM), the University of Nice Sophia Antipolis/Polytech Nice Sophia and with the support of the International Association for Hydro-Environment Engineering and Research (IAHR), the Environmental and Water Resources Institute (EWRI) of the American Society of Civil Engineers (ASCE) and the Canadian Society for Civil Engineering (CSCE). Several sponsors also supported the conference: EDF, CNR, ARTELIA, SETEC-HYDRATEC and ACRI Group. The conference attracted 166 delegates from 41 countries who participated in 24 sessions where 136 papers were presented. The programme was organised around twelve main themes:

1. Hydro-environmental issues and extreme situations
2. Models for extreme situations
3. Uncertainties and data assimilation
4. Extreme in hydraulics: how to deal with?
5. Crisis management and models
6. Decision support systems and models: concepts, design, challenges, implementation and operation
7. Real-time management and models
8. Hydraulic structures and networks: real-time operation and crisis
9. Scale models in hydraulics and their place and complementarity in simulation concepts
10. Modelling methods and tools for floods management
11. 3D multiphase flows (experiments and modelling)
12. Hydraulic machineries

Within these general themes, topics like coupling of models, data assimilation and uncertainties, urban flooding, data and uncertainties in hydraulic modelling, model efficiency and real situations, new methods for numerical models, hydraulic machinery, 3D flows in the near field of structure and models for complex phenomena have been covered. The conference, by attracting researchers, engineers and decision-makers, has promoted and facilitated the dialogue between various communities especially with a special session dedicated to catastrophe models. The purpose of catastrophe modelling is to help communities and companies anticipate the likelihood and severity of potential future catastrophes before they occur so that they can adequately prepare for their financial impact. Insurances and reinsurance companies at the worldwide scale currently develop these approaches. Catastrophe modelling combines the four components—hazard, inventory, vulnerability and loss—to aid insurers in making their decisions on what type of protection they can offer against a particular risk. Integration of hydroinformatics methods and tools in these approaches is a real challenge. Representatives from insurance and reinsurance companies have presented their approaches of extreme events and their operational implementation through international examples. Exchanges with participants have been very fruitful on crucial questions related to the crisis management during extreme flood events, the needs for operational forecasting systems, the state of the art in research and development in the domain of numerical fluid mechanics, the stakeholder's capacity to understand results, the means for dialogue directly or indirectly between the stakeholders and the model developers and the information's exchange between stakeholders and developers.

In order to contribute to this dialogue and to provide useful references, following the successful experiences of 2012, 2014 and 2017, the organisers of SimHydro 2019 have decided to elaborate this book. This volume gathers a selection of the most significant contributions received and presented during the conference. The objective is to provide the reader with an overview of the on-going developments and the state of the art taking place in four major themes that are as follows:

- Decision support systems and crisis management,
- Flood forecasting,
- Methods and models for hydrology and climate change,
- High performance computing and complex hydraulics applications.

Obviously, all dimensions of these themes cannot be covered in a single book. However, the editors are convinced that the contents may contribute to provide to the reader essential references for understanding the actual challenges and developments in these areas of the hydroinformatics field.

This volume represents the sum of the efforts invested by the authors, members of the scientific committee and members of the organising committee. The editors are also grateful for the dedicated assistance of the reviewers who worked tirelessly behind the scene to ensure the quality of the papers. We hope this book will serve as a reference source on hydroinformatics for researchers, scientists, engineers and managers alike.

Nice, France
Paris, France
August 2019

Philippe Gourbesville
Guy Caignaert

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Part I
Decision Support Systems and Crisis Management

Over the last 20 years, several new paradigms emerged for water resources planning and management. Integrated Water Resources Management (IWRM) has been recognized as an important guideline for effective and sustainable water resources management. According to UNESCO (2009), IWRM can be defined as "a step-by-step process of managing water resources in a harmonious and environmentally sustainable way by gradually uniting stakeholders and involving them in planning and decision-making processes, while accounting for evolving social demands due to such changes as population growth, rising demand for environmental conservation, changes in perspectives of the cultural and economic value of water, and climate change". Although the concept of IWRM was already discussed in the past decades, it is not yet established how to implement IWRM concepts in water management practice. The needs for a holistic approach for water resources management were also highlighted by many actors and were expressed in the European Union Water Framework Directive (WFD) that came into force in 2000.

Despite this effort, water environmental management often falls into an unstructured problem where various stakeholders are involved and multiple criteria have to be evaluated. The decision process for planning or management of water environment therefore tends to become a very complex process. Decision Support Systems (DSS) have been conceptualized and developed to support this unstructured decision making process. Considering the rapid advancement of technologies related to DSSs, the current developments are recently regarded as an iterative process rather than a single procedure. This iterative development with active participation of stakeholders is also considered to make the DSS more sustainable, because the system can be gradually improved by incorporating feedbacks from the stakeholders and end-users. This approach is seen in many recent DSS projects for water resources planning and management. A DSS therefore tends to include a combination of simple and universal models with different functions for sustainable maintenance rather than a single sophisticated model in recent years. On the other hand, advents in computer science and information technology have increased the capability of real-time water resources management. More and more data can potentially be used for real-time water resources management. They include real-time observation data of the target water system, real-time water demand data and real-time meteorological and hydrological forecast data. Although these data can be considered to be very useful in real-time water resources management, it became very challenging task to handle a huge amount of data in real-time. New approaches focused on data management and data technics represent today a major axis for DSSs development. Several papers gathered within this section are addressing the concepts and the operational implementation of DSSs in various environments.

A major application field for DSSs is currently the crisis management. During water related crisis, stakeholders and first responders are looking for tools able to provide an accurate overview of the current situation and also to formulate reasonable forecasts in order to optimize actions and responses. In such context, hydro informatics tools represent some of the key components of the DSSs to develop and to implement in order to answer the crisis challenges. In addition to the classical hydrological and hydraulic models, catastrophe models can be implemented within those environments. The purpose of catastrophe modelling is to help communities and companies anticipate the likelihood and severity of potential future catastrophes before they occur so that they can adequately prepare for their financial impact. Insurances and reinsurance companies at the worldwide scale currently develop these approaches. Catastrophe modelling combines the four components - hazard, inventory, vulnerability, and loss - to aid insurers in making their decisions on what type of protection they can offer against a particular risk. Integration of hydro informatics methods and tools in these approaches is a real challenge is discussed in several contributions of this section.

Sophia Antipolis
August 2019

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Chapter 1
Which Models for Decision Support Systems? Proposal for a Methodology

Philippe Gourbesville

Abstract Management of water uses requests to harmonize demands and needs which are getting more and more complex and sophisticated especially with the growing urbanization. Modern cities request a larger number of services for their inhabitants and expect, at the same time, to limit investments in order to constrain the tax pressure. The need of optimization appears at various levels and request the wide spread of monitoring strategies. At the same time, urban growth mobilizes last available spaces that are frequently under the thread of natural hazards like inundations or landslides. The current situation, characterized by the fast increase of monitoring devices mainly in the urban environments, requests an integration of the modeling tools into the Information Systems (IS) that are now dedicated to the global management of urban environments and related services. Decisions Supports Systems (DSSs) that may integrated various components both for real-time monitoring and forecast through model, appear as one of the most relevant answer to the urban environment management's expectations. The models integration is a challenging task that requests to build a global vision that ensures both technical feasibility and sustainability. As demonstrated with the AquaVar approach, several models can be orchestrated within a single environment that can address the diversity of the water related issues handled by local technical services. The models selection has to integrate the evolution of the tools and the possibility to integrate gradually new approaches and methods that are more data oriented and using the results produced from the implemented deterministic tools.

Keywords Water management · Information system · DSS · Monitoring · Real-time · Models · Forecasts · Var catchment

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P. Gourbesville and G. Caignaert (eds.), *Advances in Hydroinformatics*, Springer Water,
https://doi.org/10.1007/978-981-15-5436-0_1

1.1 Introduction

Management of water uses requests to harmonize demands and needs which are getting more and more complex and sophisticated especially with the growing urbanization. Modern cities request a larger number of services for their inhabitants and expect, at the same time, to limit investments in order to constrain the tax pressure. The need of optimization appears at various levels and request the wide spread of monitoring strategies. At the same time, urban growth mobilizes last available spaces that are frequently under the thread of natural hazards like inundations or landslides.

New urban developments appear more vulnerable and request a higher effort for risk management based on systems able to anticipate and analyze situations. The current situation, characterized by the fast increase of monitoring devices mainly in the urban environments, requests an integration of the modeling tools into the Information Systems (IS) that are now dedicated to the global management of urban environments and related services. Energy distribution, water distribution, solid wastes collection, traffic optimization are today major issues for cities that are looking for functional Decisions Supports Systems (DSSs) that may integrated the various components and operate in a sustainable perspective.

The current demand is targeting classical monitoring outputs such as the real time monitoring and request forecasts based on models (analytics) and providing sufficient information for an efficient management. In addition to the analysis of the current situation by visualizing the various information sources, a frequent request is on evolution of the monitored processes in time in order to anticipate reaction and ensure an efficient management. In order to provide a real support to the decision process, several tools dedicated to the data analysis and to the simulation can be interfaced within the core part of the platform. The models used in this analytics domain start with basic statistical tools and go to complex determinist models such as those commonly used in hydroinformatics. This architecture concept for the urban information system is today commonly shared and appears as a consensus solution.

If the concept of DSS is clearly understood, the integration of models is still an important issue that’s not addressed by the modelers’ community. Up to now few operational implementations have been achieved at the international scale and prototypes are just emerging. The availability of computational resources allows today looking at the deterministic models for hydrological and hydraulic issues. Obviously those tools may easily produce massive data that could be used afterward by data mining technics and stochastic models associated to AI protocols. This target architecture requests a specific methodology that describes the various steps to achieve for a successful DSS design and implementation.

1.2 Context, Needs and Methodology

1.2.1 Towards Smart Cities and Smart Water

Several projections confirm that 70% of the world's population will live in a city by 2050. Currently, around half of all urban dwellers live in cities with populations between 100,000 and 500,000 people, and almost 10% of urban dwellers live in megacities, which are defined by UN HABITAT as a city with a population of more than 10 million. As cities around the world experience this massive growth, the need to ensure sustainable expansion, efficient operation and development of high quality of life for residents becomes even greater than it is today. Within this context, the smart city concept has emerged. The term "smart cities" is trending amongst governments, urban planners and even the private sector to address the projected demands of cities in the future. Making cities smarter to support growth is emerging as a key area of focus for governments and the private sector alike. Up to 2030, cities around the world will invest US$ 108 billion in smart city infrastructure, such as smart meters and grids, energy-efficient buildings and data analytics, according to Navigant Research (https://www.navigantresearch.com/news-and-views/global-revenue-from-smart-water-networks-projected-to-reach-72-billion-in-2025).

Smart cities encompass six important sectors that need to work in unison to achieve a common goal of making a city more livable, sustainable and efficient for its residents. These sectors are smart energy, smart integration, smart public services, smart mobility, smart buildings, and smart water. Building smart cities upon the six sectors is crucial for sustainable global growth, but the financial, logistical and political challenges are enormous. The conversations about growth of smart cities have historically been dominated by large IT companies that focus on analyzing "big data" taking a top-down, software-centric approach. However, when it comes to the modernization of hundred-year-old systems like water distribution or the power grid, advanced software and networking capabilities are rarely broad enough in scope to make the necessary impact. Conversely, a bottom-up approach to smart city development is based on the belief that the rapid migration to cities will tax municipal infrastructures beyond their breaking points. The cities that succeed in transitioning to "smart" operations will be those that improve their critical systems and infrastructure at a fundamental level as well as integrate their systems through advanced technology. Lastly, smart cities will apply advanced monitoring and analytics to continuously measure and improve performance.

One of a city's most important pieces of critical infrastructure is its water system [1]. With populations in cities growing, it is inevitable that water consumption will grow as well even if the individual use will decrease. The term "smart water" points to water and wastewater infrastructure that ensures this essential resource—and the energy used to transport it—is managed effectively. A smart water system is designed to gather meaningful and actionable data about the flow, pressure and distribution of a city's water. Further, it is critical that the consumption and forecasting of water use is accurate. A city's water distribution and management system must be sound and viable in the long term to maintain its growth and should be equipped with the capacity to be monitored and networked with other critical systems to obtain more sophisticated and granular information on how they are performing and affecting each other. Additional efficiencies are gained when departments are able to share relevant, actionable information. One example is that the watershed management team can automatically share storm water modeling information that indicates probable flooding zones and times based on predictive precipitation intelligence. The transportation department can then reroute traffic accordingly and pre-emptively alert the population using mass notification.

Water systems are often overlooked yet as critical components of energy management in smart cities, typically comprising 50% of a city's total energy spends. Energy is the largest controllable cost in water/wastewater operations; yet optimizing treatment plants and distribution networks has often been overlooked as a source of freeing up operating funds by cash-strapped municipalities. Once facilities are optimized and designed to gather meaningful and actionable data, municipal leaders can make better and faster decisions about their operations, which can result in up to 30% energy savings and up to 15% reduction of water losses. Water loss management is becoming increasingly important as supplies are stressed by population growth or water scarcity. Many regions are experiencing record droughts, and others are depleting aquifers faster than they are being replenished. Incorporating smart water technologies allows water providers to minimize non-revenue water (NRW) by finding leaks quickly and even predicatively using real-time SCADA data and comparing that to model network simulations. Reducing NRW also allows municipalities to recover costs incurred in treatment and pumping. The reduction of NRW is a priority for cities in both developed and developing countries in order to ensure efficient service to population and sustainable use of water resources.

On the wastewater side, there is a move by many water utilities—public and private—to transform wastewater treatment plants into resource recovery facilities, which includes energy. There are several examples of facilities that now produce more energy than required for their operations and sell the excess energy back to the grid. While this is not practical for all treatment plants, it is a worthy ambition for most of the major treatment sites and should be included within the implementation roadmaps or master plans at the national level. However, implementation requests to improve financial capacity of municipalities in order to implement the smart water approach and to contribute to the water security in a global way. One of the biggest obstacles to any capital-intensive project is access to funding. As cities and municipalities look to achieve smarter water, there are a number of options available to help them get started. One very effective path is through leveraging energy-saving performance contracts (ESPCs). ESPCs are a form of a public-private partnership (PPP), a financial model that capitalizes on the flexibility and resources of the private sector to pay for energy-saving capital upgrades using future energy savings. The private financial community provides the initial investment, and services are delivered by Energy Service COmpanies (ESCOs). The financier is paid from the accrued energy savings, with the ESCO guaranteeing the savings amount. An ESPC starts with an energy audit. After identifying opportunities and quantifying the potential savings, the ESCO recommends any number of energy conservation measures, such as equipment retrofits, pumping optimization, demand monitoring and control (DSSs can be created and developed), and/or load-shedding and cogeneration which will save energy through more efficient operations.

1.2.2 Towards the Water Information System

In the coming years the new technologies from the IT sector will affect the full water cycle and the management of the water related services. However, the impact of these new technologies—from sensors to Decision Support Systems (DSSs)—could be stronger and really significant if priorities are properly defined and implemented within the R&D and deployment strategies. The main driver of the strategy has to be to achieve a comprehensive architecture of an Information System (IS) dedicated to water uses and connected to others systems involved in human activities. This is the operational formulation of the smart water concept.

By definition, Information Systems are implemented within an organization for the purpose of improving the effectiveness and efficiency of that organization [2]. Capabilities of the IS and characteristics of the organization, its work systems, its people, and its development and implementation methodologies together determine the extent to which that purpose is achieved. The IS is associated to an architecture which provides a formal definition of the business processes and rules, systems structure, technical framework, and product technologies for a business or organizational information system.

In order to elaborate a specific IS for the management of the water cycle, a methodology is needed for identifying priorities and strategic investments to do in the ICT domain. The requested approach has to investigate all domains and provide a map of the various process taking places in the different domains of the water uses cycle. This formalization exercise, using mainly concepts and processes, is requested in order to ensure the coherence of technical choices in a holistic approach.

Most of municipalities are currently engaged to this approach in an explicit or implicit way: monitoring activities are gradually introduced and allow improving the efficiency of water management, from resources to treatment operations and environment quality monitoring [3–5]. The availability of the real time monitoring systems provides a significant improvement within the management of water related services. One of the key challenges is to ensure that each specific monitoring system can integrate a wider system covering all the urban management actions. This step is highly challenging as it requests to address the legacy of each system within the target one. High financial investments can be requested and efficiency may suggest completely forgetting an existing technical solution in order to move to a more open and interoperable approach.

In addition to the development of real time monitoring systems (dashboards), the need for forecasts is the following step and requests to implement modeling tools that can operate in real time too and produce realistic forecasts on the various processes that have to be managed: water consumption, pressure, flood and associated inundation [6], urban runoff, accidental pollutant behavior, etc. The models integrate an analytics domain that is added to the classical dashboard and provide the added value to the stakeholders. The shared information helps to consolidate a common approach especially for the crisis management and the optimization of the mitigation actions.

1.2.3 Methodology for Models Selection

At first, the main target should be the creation and the development of a Water Information System (IS) [3] that provides the relevant resources for the services managers. The global architecture for this IS has to become explicit and a roadmap for the urbanization of this IS has to be produced by the relevant entity (most of time Municipalities and associated technical services). In most of the cases, the definition of the target IS—at the city scale—integrates existing monitoring systems in order to consolidate the current architecture and to address the legacy issues. When the global roadmap is defined and covering the forecast objectives/expectations, the design of the specific water IS can be addressed and the selection of required models can be initiated.

Obviously, the consolidation of the Water IS cannot be achieved at the initial stage and it requests a continuous efforts. When the water IS roadmap is clarified with relevant objectives, the selection of models can be done based on the requested added value of the forecasts and the availability of data and computational resources. In order to maximize the efficiency of the DSS, a common format/standard for the data and for exchanges among the different tools is highly recommended and contribute to the sustainability of the Water IS. The implementation of standardized workflows ensures interoperability with the global IS that covers the various urban services.

The modeling tools have to be selected for their performance to provide in the define timing the relevant forecasts: running a deterministic tool requesting a computational time larger that the process to forecast is obviously irrelevant. The modeler task is then to assess both quality of delivered results and operational implementation within the management procedures. If data and real-time monitoring systems are operating, and according to the processes to address, the key principle is to select the model that is allowing to deliver the relevant answer in the minimum of time. The deterministic models for both hydrological and hydraulic processes (surface and underground) represents a meaningful approach as relevant results can be obtained with limited data sets and assumptions that are based on physical laws. The use of these models within the operational phase will generate results that could be used afterwards as inputs data for stochastic models using AI technics such as ANN or multi agents. This last step may contribute to reduce significantly the computational efforts and the simulation time. This new performance can be very helpful for managing services (Fig. 1.1).

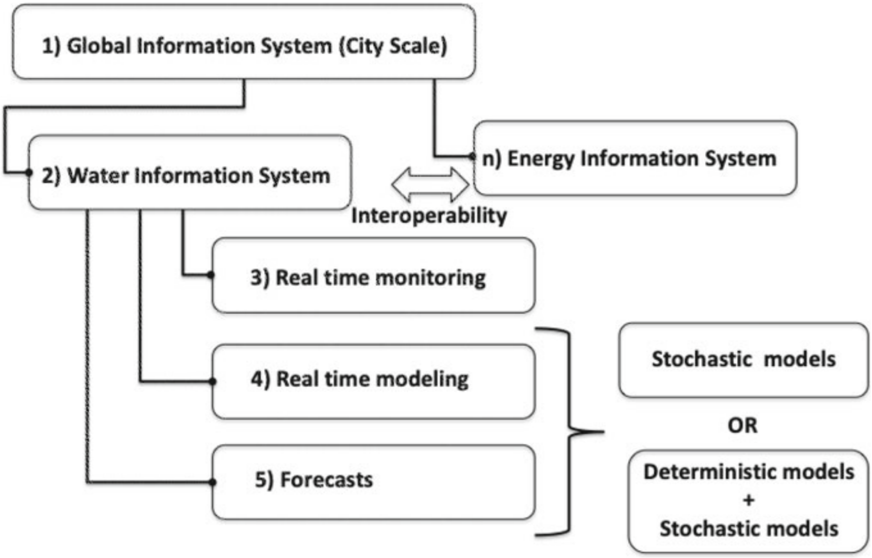

Fig. 1.1 Methodology for models integration within City IS

1.3 Aquavar Approach

1.3.1 Nice and Var Catchment Context

The city of Nice is located on the French Riviera at the mouth of the Var catchment. The recent urban development of the fifth largest French city is currently taking place in the last available space along the Var low valley and over about 20 km of floodplain. Due to the complexity of challenges—water supply security issues from groundwater resources, inundation risk and water resources management under the perspective of climate change—the need for a DSS has been identified since the late 90’s. Unfortunately, at such time, both availability of data and technical tools (from communication protocols to modeling tools) has not permitted to engage the development of such system. However, during the last 15 years, systematic data collection on topography, climate and hydrological variables has permitted to gather a significant knowledge on the main hydrological processes within the Var catchment. Since 2014, a new approach has been engaged with the AquaVar project dedicated to the development and implementation of a first DSS able to address a wide diversity of issues: from resources management to emergency situations management [5].

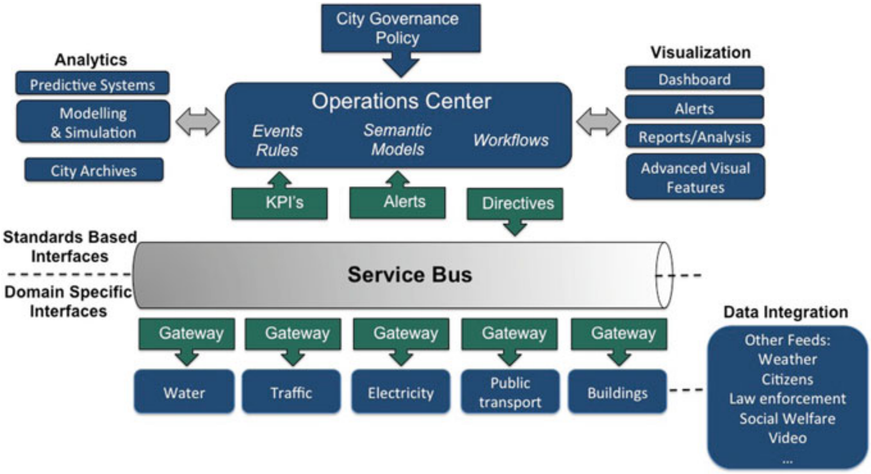

Fig. 1.2 Global architecture for the Nice Metroplis IS and the integration of AquaVar DSS within the Analytics domain [5]

1.3.2 Global Architecture

The selected architecture for the AquaVar DSS is based on a platform elaborated over a service bus dedicated to collect and integrate field data that are related to various processes including the water services and the natural hazards. Data are formalizes through various tools such as Key Performance Indicators (KPIs), predefined alerts and directives. The synthetic dashboard allows visualizing the current situation. In addition, with the analytics components, the platform integrates deterministic modeling solutions which allow to have a full simulation of the hydrological cycle at the catchment scale, a 3D simulation of complex underground aquifer and associated relationships with 2D/3D surface flow model including pollutants exchanges. The modeling system integrated within the hypervision platform is based on 3 deterministic modeling systems (Fig. 1.2).

1.3.3 Implementation of Models

For the Var low valley, the demands from the local government are targeting the water resources with the groundwater located within the low valley, the exchanges between the surface flows and the groundwater especially in case of accidental pollution and the flood events that could generate inundations and impacts on urban and commercial areas. The main requests are both for a real-time information on the current processes and on the possibility to assess a future situation through modeling tools. The models integrate the Analytics domain in the global Information System (IS) architecture and are connected through the Service Bus to the various data sources such as water levels, discharges and water quality parameters. The hypervision interface allows to display the measurements and to interact with the modeling tools that produce the simulations.

One of the key questions is obviously on the choice for the modeling tools to be integrated within the Analytics domain. In order to provide the requested diagnostics and simulations, the following modeling systems have been chosen and interconnected:

- The FEFLOW modeling system, developed by DHI, for the 3D simulation of the groundwater resources simulation. In order to represent the interactions between the river and the groundwater table, the FEFLOW model is combined with a 2D surface water model;
- The MIKE 21 system (DHI) is used as 2D surface water model and is connected with FEFLOW for the surface/groundwater interaction simulation. In addition, the system is used for flood events simulation and for the modeling of the morphological dynamic within the riverbed;
- The MIKE SHE system (DHI) produces the hydrological data to be used as boundary conditions for FEFLOW and MIKE 21 systems (Fig. 1.3).

A 3D hydraulic model based on FEFLOW modeling system has been set up over the 22 km of the Var low valley. The detailed geological structure has been integrated within the model in order to have an accurate representation of the processes [7–10]. The validation of the model has been achieved with a simulation from September 10th 2009 to February 26th 2013. Among the 24 piezometers with automatic recorder which have been set up to monitor the daily groundwater level along the valley, 6 of them have been chosen to validate the model thanks to their fully digital recording during the simulation period. Their location enables a holistic view from the upstream to the downstream (Fig. 1.4). The simulation results are shown with the measured data

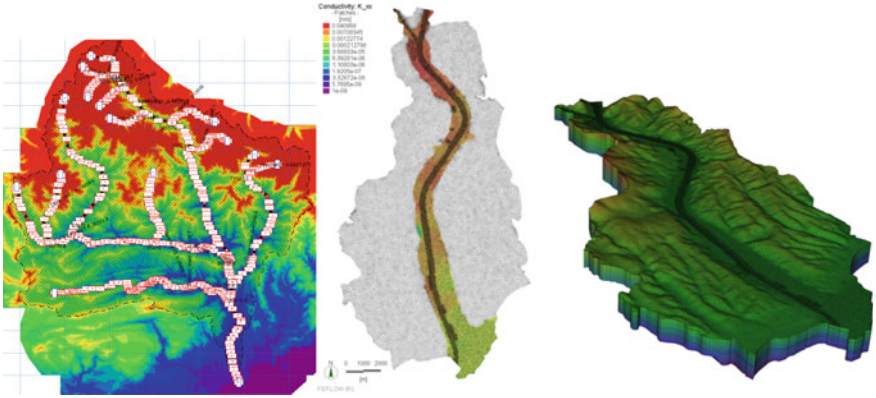

Fig. 1.3 Extension of the MIKE SHE, MIKE 21 and FEFLOW models integrated within the AquaVar DSS

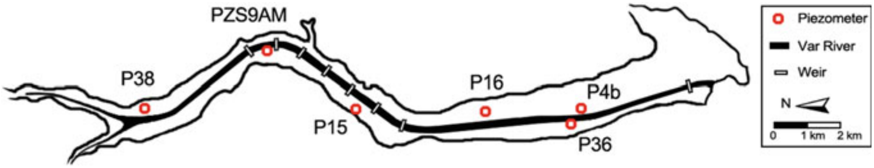

Fig. 1.4 Piezometers used for FEFLOW model validation

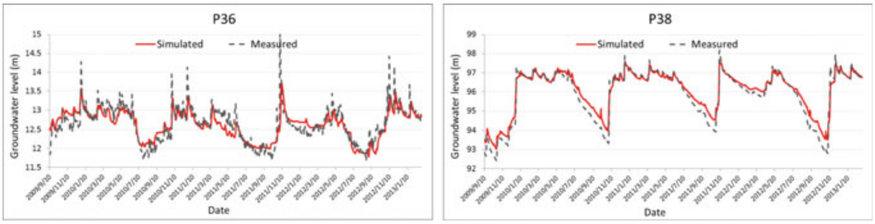

Fig. 1.5 Comparison between simulated (FEFLOW model) and recorded groundwater levels

in Fig. 1.5. The results demonstrate that the model is able to represent the dynamics of the groundwater flow by considering direct water recharge, river-aquifer exchange as well as the groundwater extraction. Consequently, the model can be used as a groundwater management tool and integrated within the hypervision platform.

A similar approach has been carried out with MIKE 21 FM regarding the free surface flows simulation and the morphological dynamic. The simulation of the bed evolution has been carried out with Sand Transport module in MIKE 21 FM that calculates the sediment transport capacity, the initial rates of bed level changes and the morphological changes for non-cohesive sediment due to currents. The sediment transport computation is based on hydrodynamics conditions and sediment properties. In order to obtain an efficient MIKE 21 FM model, several meshes have been created to simulate the same flood event (3rd October 2015 to 6th October 2015). The built model with a 10 m resolution combining triangular and quadrangular elements has demonstrated efficiency and well reproduced observed values. High-resolution mesh has been implemented in order to represent properly the hydraulic structures and their effects (Fig. 1.6).

For the hydrological modeling, a similar approach has been implemented with MIKE SHE over the full catchment. The validation has been carried out over a period of 3 years after the validation of the numerical grid to use for the surface runoff estimation. Good results have been also obtained with this deterministic approach that provides the input data for FEFLOW and MIKE 21 systems. The 3 modeling systems are currently integrated within the AquaVar engine that is deployed with the Information System operated by Nice Côte d'Azur Metropolis services.

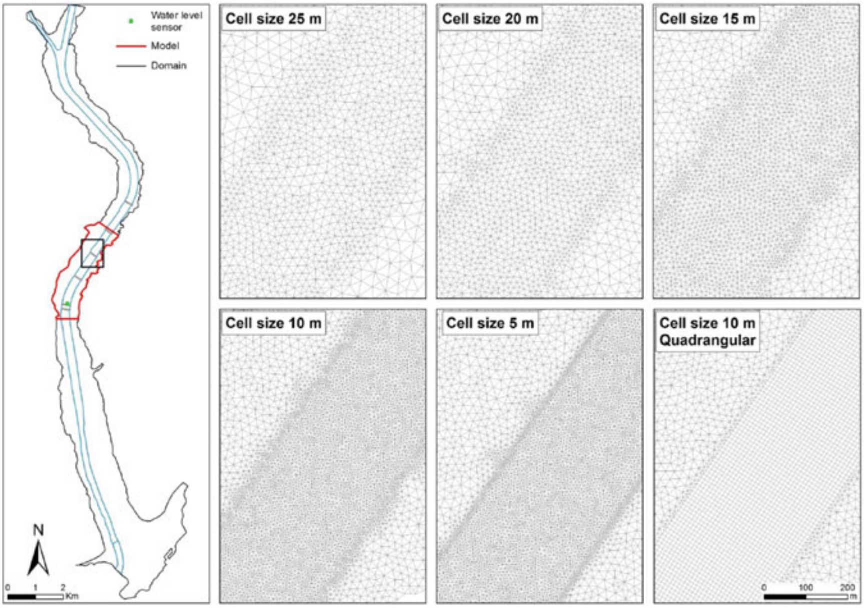

Fig. 1.6 Various mesh sizes tested within the 2D hydraulic model (MIKE 21)

1.3.4 AquaVar Orchestration

One selected approach for the AquaVar DSS is the use of common modeling software as non-interactive services. Modeling systems like Mike SHE, Mike 21 or FEFLOW are commonly used on the desktop computer as highly interactive applications where the user can take advantage of the numerous visualization features available. Conversely, in the AquaVar DSS, these models are used in batch mode and are viewed as modules managed by a program named the orchestrator. The AquaVar engine (Fig. 1.7) automates the management of the modeling services by coordinating the exchange of data through their interactions.

The engine consists in the following modules:

- Simulation engines: a simulation engine is a wrapper around specific simulation software like Mike SHE, Mike 21 or FEFLOW. The wrapper makes it easy to add a new simulation engine with no change in the architecture;
- Configuration modules: each simulation engine relies on a corresponding configuration module to automatically set up the simulation parameters. The configuration module is also able to perform data format conversion when necessary;
- Scheduler: the scheduler allows running automatically the simulation engines in the background at regular intervals. The scheduler uses a table similar to a Unix crontab which can be set up by the user;