Chapter 2
Aquavar: Decision Support System for Surface and Groundwater Management at the Catchment Scale

Qiang Ma, Philippe Gourbesville, and Marc Gaetano

Abstract Due to the impacts of global warming or climate changes, the hazard caused by extreme weather event becomes more frequent and serious. At same time, the last available place such as the floodplain has been strongly encroached by the growing of urbanization, which could lead more citizens to be exposed to flood risks. In current situation, the flood caused by extreme rainfall event could be characterized with shorter response time and higher flood damages. To efficiently manage this kind of flood hazard and effectively reduce the damage cost, the Decision Support System (DSS) applied in urban management has been requested to be able to produce comprehensive view of current situation in real time and further provide accurate forecast as faster and possible. Benefited from the progress of informatics and monitoring techniques, the fast increase of monitoring devices lets the real time data collection become more feasible. And the development of modelling system of hydrology and hydraulic has reach a higher level during last decades, which nowadays is bale to integrated assess the existing catchment water system and further forecast the incoming situation. Integration of those new techniques into DSS, the design of the DSS architecture should be reorganized to make the system become more operational and functional. This paper presents a generic operational DSS approach in order to address the management of natural hazards (floods & draughts) in a sophisticated urban environment and provide both real time assessment and forecast on a Web-based information platform. The proposed approach is illustrated with one model integrated real time DSS application (AquaVar DSS) on Var catchment (2800 km^2) located at French Riviera. Three deterministic distributed model applications of hydrology, hydraulic and groundwater has been integrated into the modelling system at analytic part of the DSS and linked with a Web-based user interface to provide sufficient information for real time risk management in the area. The

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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_2

integrated representation provided by AquaVar DSS has confirmed the feasibility of applying this DSS approach for dealing with extreme hazards. And similar approach could also be implemented in other managements of urban environment and related services such as energy distribution or water distribution.

Keywords DSS · Real time modelling system · Deterministic distributed model applications · Var catchment

2.1 Introduction

Decision Support System (DSS) has been approbated as one of most efficient tools to systematically consider different opinions and demands from various stakeholders then further propose alternative measures that maximize overall satisfactions. The history of DSS progress can be traced back to late 1950s when business companies started to recognize the effective contributions of new techniques on optimizing decision making processes. More theoretical and technological researches in DSS have been implemented from 1960s [1, 21]. The conventional DSS concept has been gradually developed by considering categories of management activities and descriptions of decision making process [5]. With advancement in concept of DSS for specific objectives, its applications in water resource management have been developed in parallel. [14] have made the first attempt of DSS application in water resource management. Follows the box-and-line structure clarified by [21], one DSS has been developed to optimize irrigation plans at central Missouri, USA. The first DSS application in water resource management designed with clear system architecture is built by [10] for alleviating flood problem in Como Lake, Italy. After that, more DSS applications for water resource management have published across the world until 1990s [2, 13, 19, 22].

The Var catchment locates on French Riviera is the largest catchment at French Mediterranean region. The city of Nice (fifth largest in France) is located at the mouth of this catchment. And its recent urban development is currently taking place along the floodplain of the Low Var Valley (last 22 km at the downstream of Var catchment). The challenges of water resource management in this region show higher complexity including security issues of water supply from groundwater resource, inundation risk and environment management under perspective of climate change. Since 1990s, the city of Nice has identified the need of a functional DSS to integrated manage all complicated water-related problems in this area. Unfortunately, at that time, neither the data shortage problem nor the technology limitation has seriously obstructed the DSS development. After 15 years' systematic data collection on topography, meteorological and hydrological variables, which permits to gather significant knowledge and understanding on major hydrological processes within the catchment, in 2014, a new approach is engaged with project of AquaVar aims to develop and implement the first DSS to address a wide diversity of issues in the Var catchment: from resources management to emergency situations management [8, 9].

2.2 Context of Var Catchment

With significant elevation variation from 0 m up to 3100 m above sea level, the Var catchment (2800 km^2) is characterized with its steep slope distributed in middle and upper parts of the catchment. The Var river originates from spring at the south mountain pass and flows through a distance nearly 122 km to reach the catchment outlet between city of Nice and Saint Laurent du Var. There are three main tributaries contributed streamflow to the Var river: Estéron, Vésubie and Tinée. More than 90% of streams in this catchment are characterized as typical mountain streams with "V" shaped cross-sections formed by natural erosion (Fig. 2.1). The meteorological condition of this basin is typical Mediterranean climate with hot dry summers and cool wet winters. The annual precipitation in this catchment is around 815 mm, mainly concentrated in 65–80 days over the year. The catchment surface runoff is contributed by instance precipitation, snow melting flow and exchange flow between rivers and aquifers. Two flood periods can be identified in the catchment: spring floods caused by rainfall event combined with snow melting from summits of Alps Mountain and winter floods according to extreme precipitation event covering wide areas. With the runoff records at the Napoléon III Bridge (1985–2014) located at the

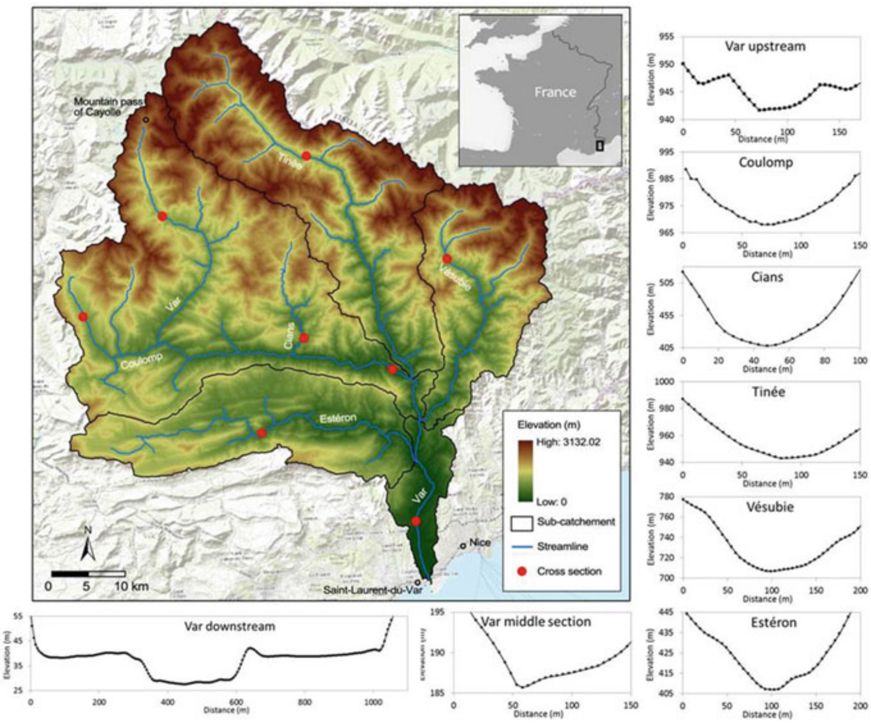

Fig. 2.1 Var catchment at French Mediterranean region

outlet of catchment, the annual average discharge of Var catchment is around 50 m^3/s, while the highest observed instantaneous discharge at flood peak can reach 3750 m^3/s (flood 1994). The downstream part of Var catchment (last 22 km), so called the Lower Var Valley, has connected the mountainous area and the Mediterranean Sea, contains rich groundwater resources [17]. The shallow aquifers in the Lower Var Valley are strongly interacted not only with the rivers but also with the conglomerate bedrock underneath the alluvium [12]. The groundwater in the unconfined alluvial aquifers in the Lower Var Valley is the main resource for supporting the social activities in this region including drinking water supply for around 600,000 inhabitants, industry, and agricultural and domestic consumption [15]. The annual groundwater extraction at public pumping stations is nearly 50 million m^3 [11].

Since the beginning of 19^{th} century, human activities have been increasing in the Lower Var Valley. On one hand, the growing of urbanization requests more constructed areas reclaimed from river floodplain. And on another hand, with more social activities being implemented in this area, the extraction of groundwater resource is evidently increased. Regarding the frequent interaction between streamflow and groundwater flow, when the river morphology has been strongly reshaped by artificial embankments from 600–1000 m width to 150–280 m, the raise of flow velocity directly leads to the enhancement of river bed erosion and further reduces the groundwater table. It makes the pumping activities become more and more difficult. The most serious groundwater shortage has been recorded at 1967 when the groundwater table was 8 m below its static level. After that, reducing the river bed erosions starts gaining more attention and has been considered as the premier effective measure to maintain the groundwater table in this area. At end of 1980s, 11 weirs were constructed at different cross-sections of the river to reduce the erosion impacts and raise the groundwater level in unconfined aquifers. Today, many industrial and agricultural zones are located at upstream of the Low Var Valley, while the urban area and some main pumping stations are at the outlet (Fig. 2.2). Recognizing the challenges in groundwater management are in aspects of both quantity and quality, the local water service has an urgent demand of a DSS for comprehensively representing major physical processes related to groundwater flow. Moreover, the cities located at lower Var valley are regularly affected by serious flood hazard. The levee system along the river is supposed to defense the flood with return period up to 75 years. However, as result of the river morphological dynamic, their protection level at many places along the river has been strongly reduced. This situation requests more careful management in order to ensure a better understanding of flood mechanism and process and higher security for exposed persons and goods. Therefore, considering those complicated demands in many aspects, one most reasonable and feasible solution is to generate a functional DSS to produce sufficient real time information and forecasts for supporting the decision making process and maximizing the satisfactions of overall stakeholders.

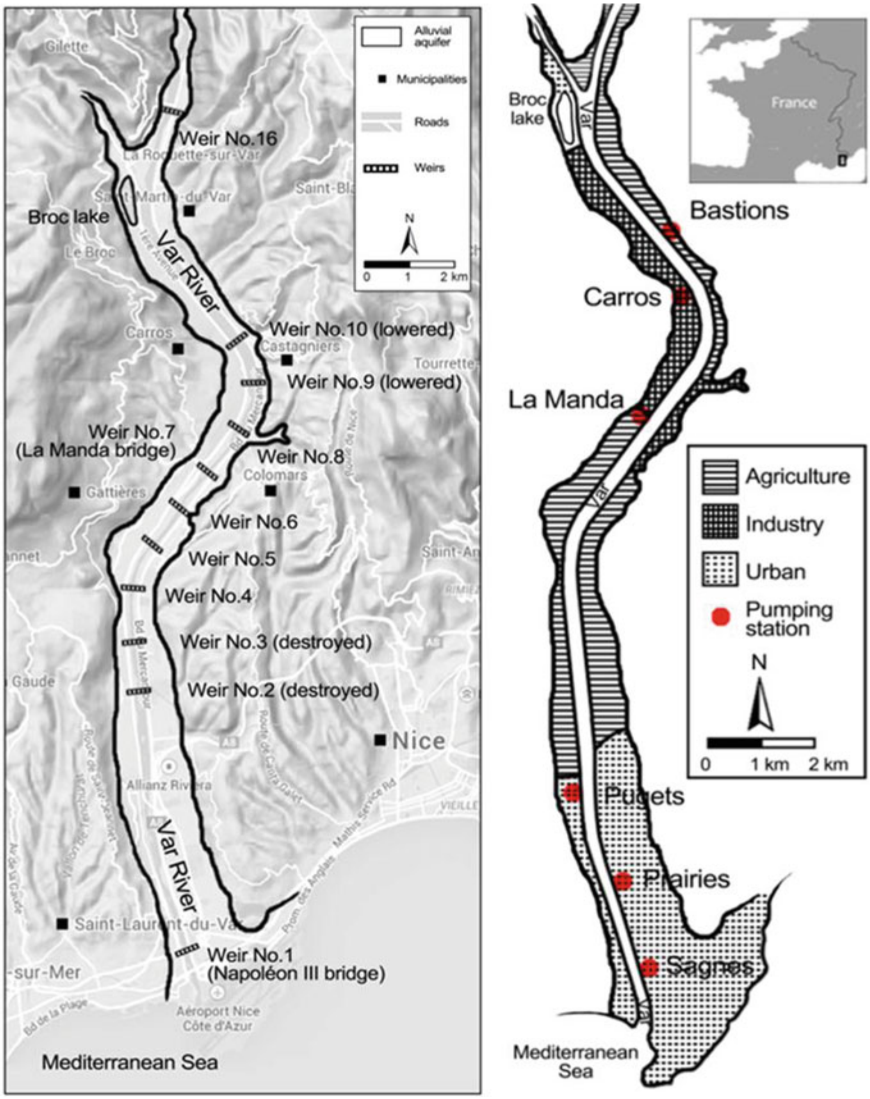

Fig. 2.2 Artificial structures and social activities in lower Var valley

2.3 Aquavar DSS

The AquaVar DSS (Fig. 2.3) [7–9] is based on a platform elaborated over a service bus dedicated to collect and integrate real time information including measurements, forecasts and data related to various processes such as water services and natural hazards. Data are formalized through various standard tools such as Key Performance Indicators (KPIs), predefined alerts and directives and transferred among different

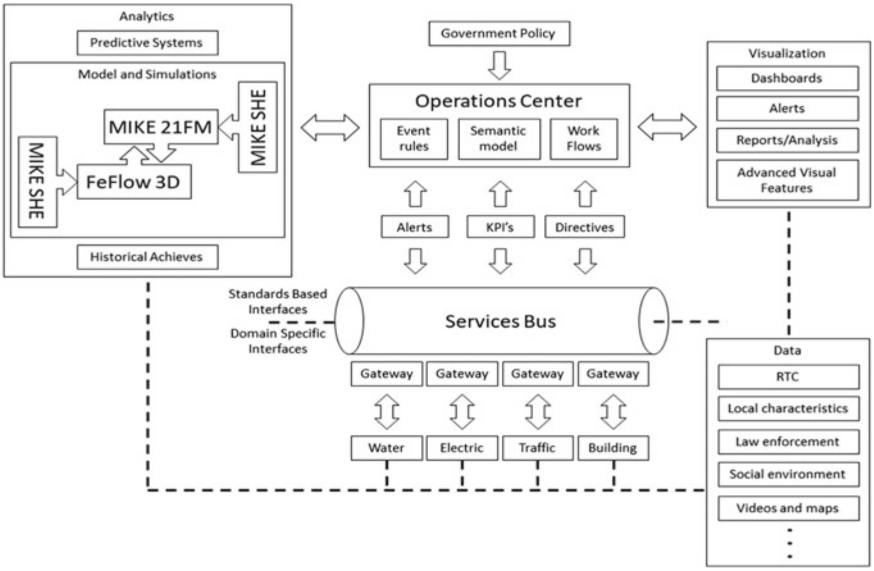

Fig. 2.3 Designed architecture of AquaVar DSS

parts of the system. In the "Analytic" part of AquaVar DSS, three deterministic models have been implemented to produce a comprehensive view of all major physical processes in the catchment water cycle then further support decision making process by answering questions defined from "Operations center". The simplified synthetic dashboard applied in online platforms at "Visualization" part allows all stakeholders, who even don't have strong related background and knowledge, easily understanding the on-going situations and in-coming phenomenon.

The main demands of local government in the Lower Var Valley are targeting on the groundwater and flood managements. The requests are both for a real-time information of current processes and of the possibility to assess a future situation through modelling simulations. Models integrated in "Analytic" parts are set up and updated by the data collected and transferred through service bus. One of the key issues in setting up this DSS is the model selection. In order to provide sufficient information to well represent the physical processes at any locations in the catchment, three deterministic distributed models have been applied in the analytic system (Fig. 2.4):

- The MIKE SHE model system, developed by DHI, for simulating all major hydrological processes covered whole Var catchment area. Based on real time data collected through service bus, the model simulation is aimed to produce accurate boundaries for lunching more detail simulations in lower Var valley.
- The MIKE 21FM model system is applied as 2D high resolution surface flow simulation in connected with FeFlow for representing the flow exchange between

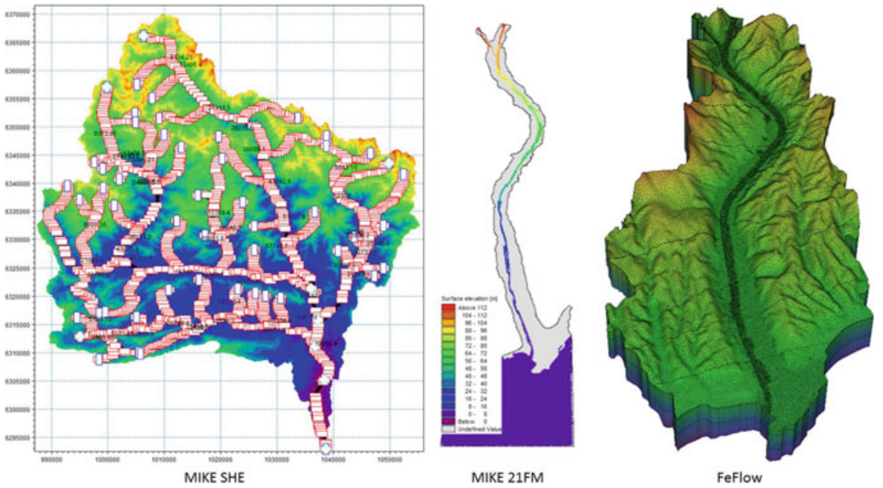

Fig. 2.4 Integrated three deterministic distributed models in AquaVar DSS

rivers and shallow aquifers. In addition, this model is also used independently for simulating the flood hazards and morphological dynamic of riverbed.

- The FeFlow model system applied in AquaVar DSS is responsible to provide 3D view of groundwater resources at lower Var valley. With detail geological structure described in the model, its simulations are able to produce accurate representation of all underground processes. Moreover, by coupling with 2D surface hydraulic model (MIKE 21FM), the interactions between river and groundwater table can be also well simulated.

2.4 Results

The modelling process starts from MIKE SHE simulation of the catchment hydrological cycle. Based on high resolution simulation within daily and hourly time interval respectively, the MKE SHE applications in the Var catchment are able to provide precise descriptions of most of major hydrological and hydrogeological characteristics at any places in the catchment and further to support the applications of MIKE 21FM and FeFlow to have more detail simulation of the Lower Var Valley. The 3D groundwater model of FeFlow could be highlighted with detail geological structure data of the Lower Var Valley. The simulation has been validated from September 2009 to February 2013, which covered one serious flood hazard happened at November 2011 and one drought event recorded at summer 2012. There are 24 piezometers with automatic recorder for monitoring daily groundwater table. From the upstream to the downstream, 6 piezometers have been applied for validated the simulation (Fig. 2.5). The results demonstrate that the model system is able to represent the dynamics of

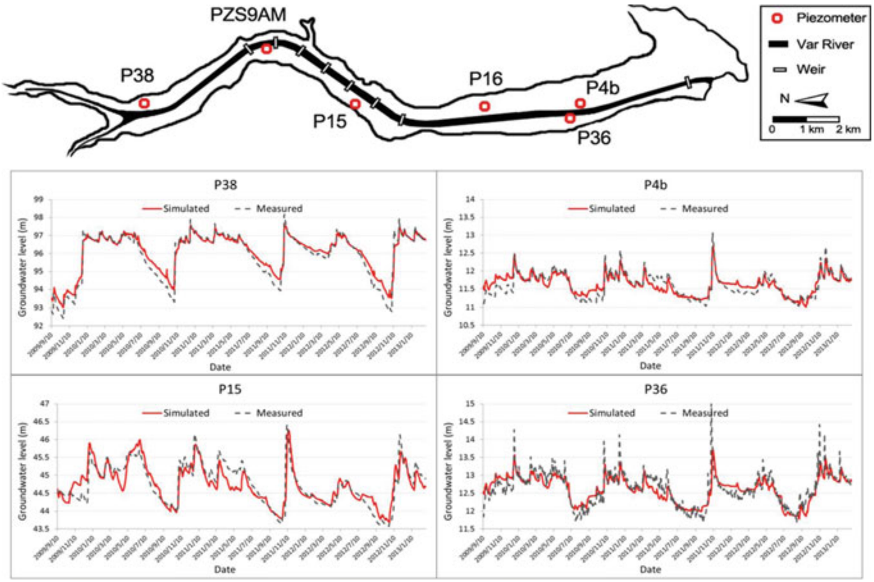

Fig. 2.5 FeFlow application in lower Var valley

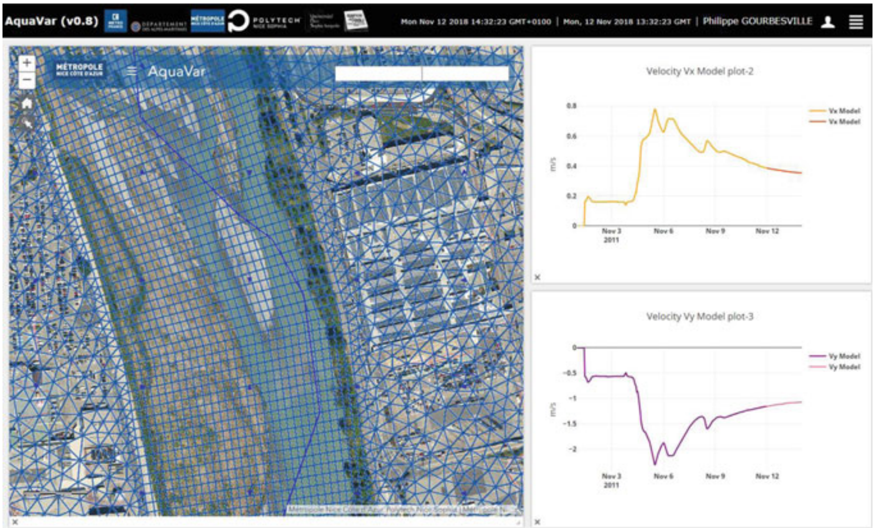

Fig. 2.6 Example of AquaVar web interface

the groundwater flow by considering direct water recharge, river-aquifer exchange as well as the groundwater extraction. Moreover, the designed DSS is implemented as one online service, which allows all the users visiting the web-site to obtain the detail simulation results at each mesh cell (Fig. 2.6).

2.5 Conclusion

Benefited from advancements of new techniques such as real time monitoring, Information System (IS) and hydro-informatics tools, the DSS can produce sufficient and accurate information for optimizing the decision making process then maximizing the satisfactions of overall stakeholders. However, to achieve this objective, the DSS architecture has to be designed for enlarging the effects of new technological applications. This paper has proposed a functional DSS architecture based on the interoperability of various models and integrated in online platforms allowing efficiently managing massive data and producing real time simulation and forecasts. The current approach has been well implemented within the AquaVar project in the Var catchment at the French Riviera. Three deterministic distributed models have been integrated in the analytic part of DSS to provide a comprehensive view of all major physical processes in the catchment water cycle. The AquaVar DSS is designed as one web service allows all stakeholders participating the management activities. The achievements of AquaVar DSS demonstrate both the efficiency of the approach and the interests from the management point of view. Moreover, the developed concept for the DSS could also be extended to various catchments and for other objectives.

Acknowledgements This research is currently developed within the AquaVar project with the support of Metropole Nice Côte d'Azur, Agence de l'Eau Rhone Mediterranéen, Nice Sophia Antipolis University, Conseil Départemental 06 and Meteo France. The work benefited from the data provided by the Metropole Nice Côte d'Azur, Conseil Départemental 06, Meteo France and H2EA.

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