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DSS Architecture For Water Uses Management

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Abstract

Management of water uses requests to harmonize demands and needs which are getting more and more complex and sophisticated. During the past 3 decades, modelling systems for hydrology, hydraulics and water quality have been used as stand alone products and were used in order to produce an analysis of a current situation and to generate forecast according to different horizons. The current situation, characterized by the fast increase of monitoring devices mainly in the urban environments, requests an integration of the modelling tools in global information systems 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 that may integrated the various components and operate in a sustainable perspective. The modelling systems used for hydrology, hydraulic and water quality have to integrate a common framework allowing modular approach and interoperability. The paper presents a generic operational approach that could be implemented in order to address the management of water uses in a complex urban environment: water supply security issues from groundwater resources, inundation risk and water resources management under the perspective of climate change. The architecture is based on the interoperability of the various models and is integrated in a platform allowing to organize the workflows of data and the production of real time information's used by the decision makers. The current approached is implemented within the AquaVar project on the Var catchment located in the French Riviera.

Keywords: DSS; system architecture; modeling systems; deterministic hydrological modeling; 2D & 3D surface and underground models; Var catchment; France.

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1. Background

Management of water uses requests to harmonize demands and needs which are getting more and more complex and sophisticated. During the past 3 decades, modelling systems for hydrology, hydraulics and water quality have been used as stand alone products and were used in order to produce an analysis of a current situation and to generate forecast according to different horizons. The current situation, characterized by the fast increase of monitoring devices mainly in the urban environments, requests an integration of the modelling tools in global information systems 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 modelling systems used for hydrology, hydraulic and water quality have to integrate a common framework allowing modular approach and interoperability.

2. The Var catchment challenges

2.1. Var catchment characteristics

The Var catchment is located at the southeast part of France with the control area of 2800 km^2 that is the largest river basin in the French Mediterranean Alps region. The elevation variation in this region is conspicuous. The basin raise from 0 m up to 3100 m above the sea level with steep slopes distributed along the branches located in the middle and upper area of the catchment. There are four main tributaries - Var, Estéron, Vésubie, Tinée - cross five main sub-catchments within the catchment (Fig. 1.). The climate conditions in the basin are typical for Mediterranean climate with hot dry summers and cool wet winters. The annual precipitations over the catchment are around 815 mm, mainly concentrated in 65-80 days over the year. The surface discharge is contributed by instance rainfall, snow melting and exchange with the soil and the shallow aqua aquifer. The floods mainly appeared at the spring season with the rainfall events combined with snow melting from the high mountain area and in late autumn / early winter periods with extreme precipitation events covering wide areas. From the discharge records at the Napoléon III Bridge (1985-2014) located at the outlet of the catchment, the annually average discharge of the catchment is around 50 m^3/s while the highest measured instantaneous discharge during flood peak can reach 3750 m^3/s. However the discharges from each tributary contributing to the main branch in the Var Basin are not clear as no measurements are available. The Var low valley – a 22 km long reach - connects the mountainous area and the Mediterranean sea [5].

The groundwater in the unconfined alluvial aquifer is a main water resource for around 600,000 inhabitants who live in the cities and towns near the river mouth such as Nice and St Laurent du Var [1]. Groundwater is used for industrial, agricultural and domestic consumption. The annual groundwater extraction by public pumping stations (Fig. 1.b) is around 50 million m^3 according to the analysis of the records gathered over the recent years [2]. A previous study indicates that the shallow aquifer interacts strongly not only with the river but also with the conglomerate bedrock underneath the alluvium [3].

2.2. Challenges and expectations

Since the beginning of the 19th century, human activities have been changing the topography of Var river valley. Urbanization of this area has induced increasingly need for constructed area so that land has been reclaimed from river flood plain. The morphology of the river has been reshaped and artificial embankments strictly narrow the riverbed. Today, the width of riverbed varies from 150 to 280 m while the width of natural flood plain is from 600 to 1500 m. This led to an increase of the water velocity thus erosions were gradually happened and observed in many places along the river. Because of the strong connection between the Var river and its aquifer, groundwater table withdrawal has been reported. In 1967, the most severe shortage of groundwater happened in the valley, the groundwater table was 8 m below its static level. In order to decrease the erosion on the riverbed so as to maintain the groundwater level, weirs were built on the riverbed since 1971. By the end of 1986, 11 weirs were finally constructed in different cross sections of the river (Fig. 1.a). On the other hand, the industrial zone and agricultural zone locate on the upstream area of the river while the urban area and some main pumping stations are on the downstream river mouth (Fig. 1.b). For the local inhabitants, there is a potential threat of pollution caused either by industries seepage or by agricultural contaminants. Several studies have been carried out in order to understand the groundwater flow and the river aquifer exchange in order to help the decision-maker on groundwater management. Guglielmi [3] studied the hydraulic conductivity of the Holocene alluvium and the Pliocene conglomerate as well as other hydrogeological characteristics. He applied instantaneous iso-contour map of the groundwater level to infer the direction of river-aquifer exchange in different sections of the valley. Likewise, the same method has been used by Guglielmi and Mudry [4], Emily et al. [5] to describe groundwater flow of the lower Var river valley on different hydrological periods. Potot et al. [3] used trace element analysis along the valley and proved the groundwater exchange between the alluvium and the conglomerate. These studies complete the knowledge of the function of the aquifer. Nevertheless, the methods used in these studies demonstrate a lack of continuity over time. The result, however, indicates only qualitatively the instant direction of the exchange, which is less applicable by the water management services. Knowing that the groundwater management in lower Var river valley faces these challenges, the local water service department has an urgent demand of a physically-based hydraulic model of groundwater flow. The model should be able to consider all the important physical process of groundwater flow such as precipitation recharge, evapotranspiration, groundwater exploitation and river-aquifer exchange etc. This model should also be validated by a long period simulation so that the reliability is ensured.

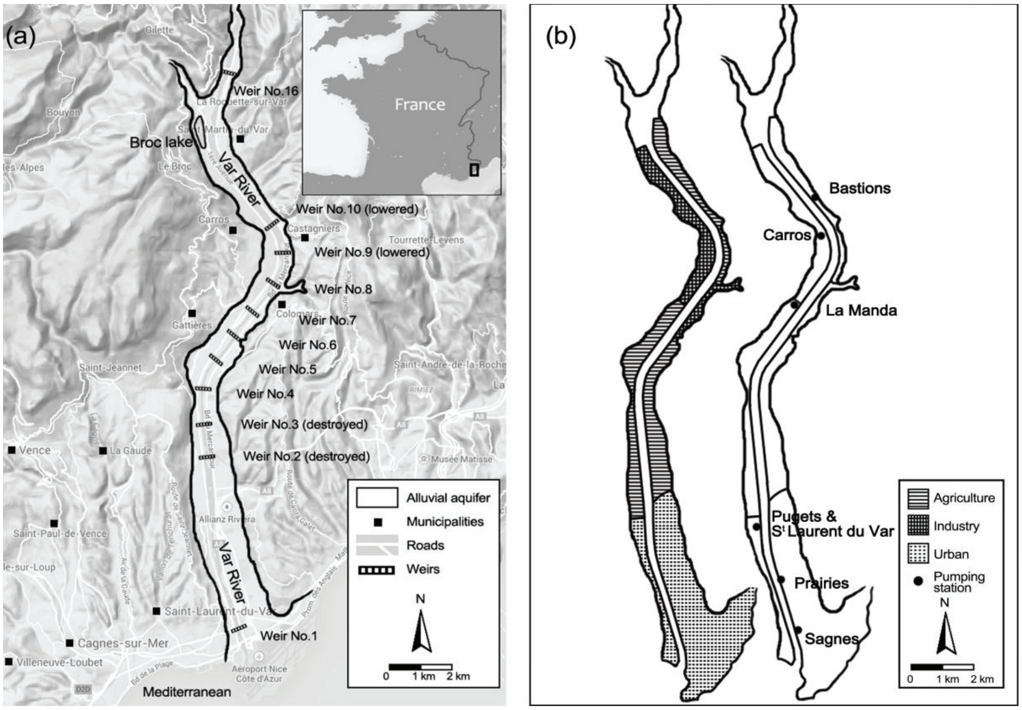

Fig. 1. (a) Study area: the lower Var valley; (b) Land use map and the pumping stations of lower Var river valley.

The Var low valley is regularly affected by serious flooding events that deeply affect the growing urban development and major infrastructure as the Nice Cote d'Azur airport (2nd busiest airport in France). The different levees systems provide a structural protection for floods with a return period up to 75 years. However, the morphological dynamic of the river, increased by the different weirs, induces a quick evolution of the cross sections in several areas and may significantly reduce the protection level. This situation requests a more careful management in order to ensure a better understanding of the flooding processes and a higher security for exposed persons and goods. The current monitoring is limited to 3 gauging stations located in the downstream area. A more accurate vision on the on-going process and a meaningful forecast are requested and have to be based on accurate hydraulic models.

3. DSS architecture

By definition Decision Support Systems (DSS) are a specific class of computerized information system that supports business and organizational decision-making activities. In cities, the DSSs are supposed to streamline and integrate rules, procedures and decisions needed for solving complex problems: when relationships between required sets of data are unclear, the data comes in multiple formats and/or pertinent problem-solving methods required to be applied are not straightforward [6,8]. The growing complexity of urban environments requests to develop a holistic approach that integrates the dynamic of the various functions and services under various situations like flooding or lack of drinking water. In the water sector, the services provided to the inhabitants have been gradually integrated in various platforms that provide a real time overview of the various business processes. Major water utilities like Suez and Veolia have already produced specific services that are integrated in hypervision platforms promoted by IT providers such as IBM, CISCO, Schneider Electric, etc. In most of the cases, the real-time data on water consumption, potential leakages and quality monitoring are available for the technicians and the decision makers. Several experiments have been conducted successfully in Europe, Asia and USA. One of the most impressive achievements takes place in Malta with the full coverage of the country with a Automated Meters Reader (AMR) solution promoted by Suez and IBM [9].

The current demands are in favor of 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. A synthetic dashboard allows visualizing the current situation. In addition, in order to provide a real support to the decision process, several tools dedicated to the data analysis and to the simulation are interfaced with 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 [8]. However, several serious technical challenges are still there and will request efforts for a real integration and functional interoperability. If the concept is now shared, the maturity has to be gained in particular with the definition of the requested standards for managing the workflows among the various applications.

In the case of the Var low valley, the demands from the local government are targeting the groundwater and flood events management. The 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 will integrate the Analytics domain in the global Information System architecture and will be 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 integrate within the Analytics domain. In order to provide the requested diagnostics and simulations, the flowing 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 from DHI and the Telemac 2D from EDF are used as 2D surface water models and are connected with FEFLOW for the surface/groundwater interaction simulation. In addition, the systems are used for the flood events simulation and for the modeling of the morphological dynamic within the riverbed.
- The MIKE SHE modeling system is used to produce the boundary conditions for FEFLOW and MIKE 21/Telemac systems.

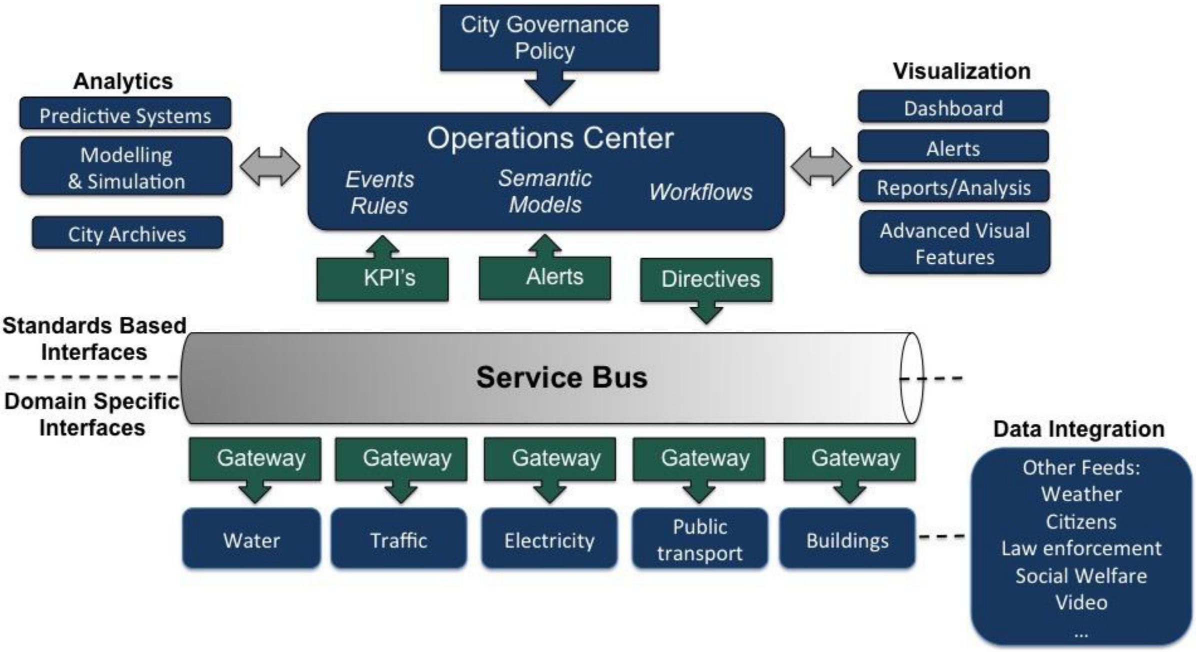

Fig. 2. Concept of hypervision platform dedicated to urban monitoring and management (from IBM).

The combination of the 3 modelling systems allows providing a global overview of the hydrological situation in the catchment and in the low valley. After the initial elaboration and validation steps, the models are used for producing simulations that are integrated within the hypervision platform.

In order to ensure an efficient use of the platform, user profiles have been elaborated. The expert profile allows elaborating a simulation scenario that could be launched on the various models and the consultation profile offers only the visualization of the collected data and the results of the forecast procedure produced by the 3 modelling systems. The public profile is also foreseen in order to provide information to the general public and to improve preparedness / resilience [10] of the population in case of specific and/or extreme situations (flooding, drought, polluted water, etc.

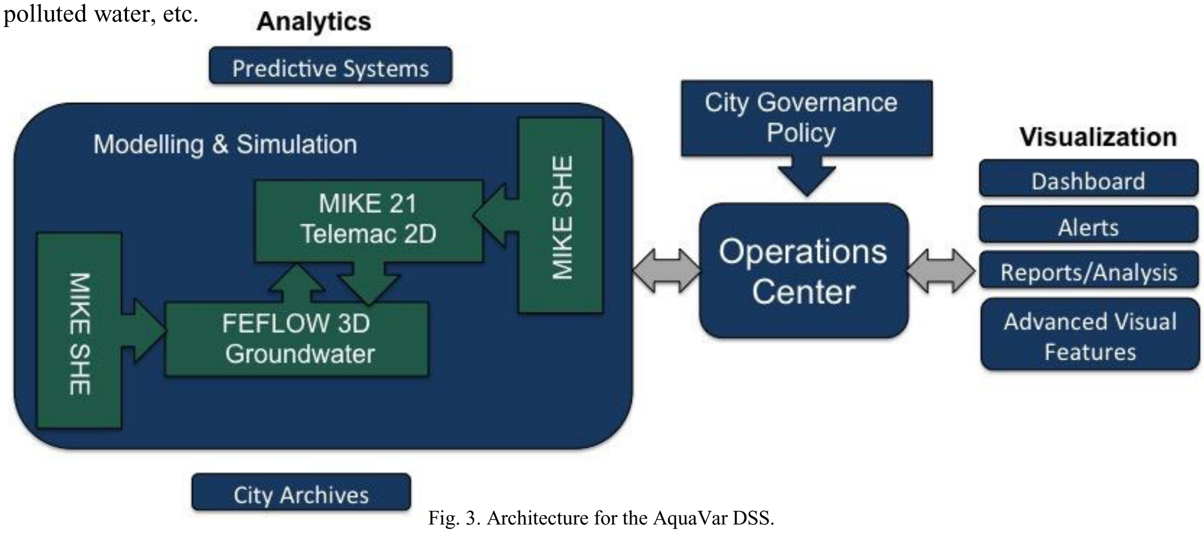

Fig. 3. Architecture for the AquaVar DSS.

4. Implementation of models

A 3D hydraulic model has been set up based on groundwater flow equation (FEFLOW modeling system) 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. The validation of the model has been achieved with a simulation from September 10th 2009 to February 26th 2013, for a total of 1266 days. This period contains two important events: a flood happened on November 2011 followed by a drought on July and August 2012. The equivalent return period of the flood is 10 years (Gumbel law) and the one for the drought is 20 years (Galton law). Considering the exchange between the river and aquifer will be intense during the flood peak, the time step is set to be variable to ensure the accuracy of the result and the stability of the numerical calculation. There are currently 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. 4). The simulation results are shown with the measured data in Fig. 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.

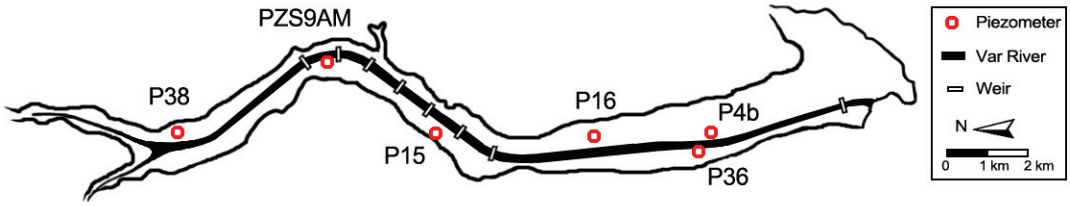

Fig. 4. Piezometers used for model validation.

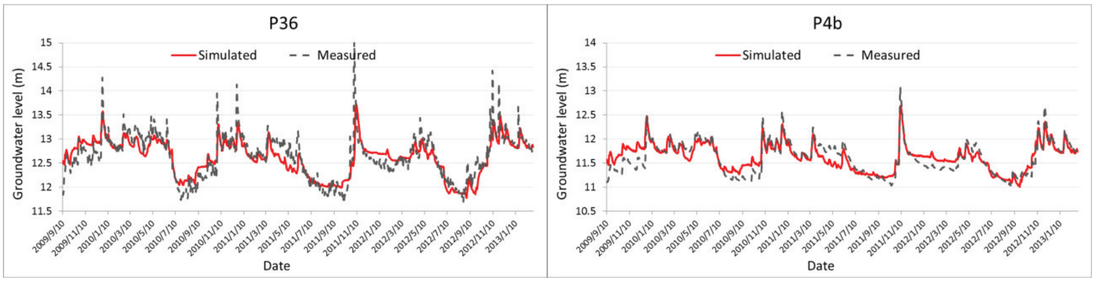

Fig. 5. Comparison between simulated and recorded groundwater levels.

A similar approach has been carried out with MIKE 21 FM regarding the free surface flows simulation and the morphological dynamic. The simulation of 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. ST model takes in account bed load and suspended load. Different geometries have been compared for the simulation of hydrodynamic. The strategy is discussed according to mesh resolution and needs regarding operational management. In order to obtain an efficient MIKE 21FM model, several meshes have been created to simulate the same flood event. The study area has been represented by triangular discretization with different resolutions (5 m, 10 m, 15 m, 20 m and 25 m). Afterwards, triangular mesh has been compared with quadrangular mesh. Finally, hydraulic structures have been implemented with empirical law by entering the characteristics of the weirs. The flood event chosen for this set of tests is from 3rd October 2015 to 6th October 2015, because of the availability of observed data. The comparison of models and observed data (Fig. 6.a) suggests that the 10 m resolution is the most accurate. The triangular discretization is more efficient to simulate the flow over the weir (Fig. 6.b). Implementation of structures requests many parameters and is not really representative of weir effects (Fig. 6.c). Furthermore, regarding to the velocities (Fig. 6.d) the use of empirical law for structures is the least suitable way to simulate weirs effects.

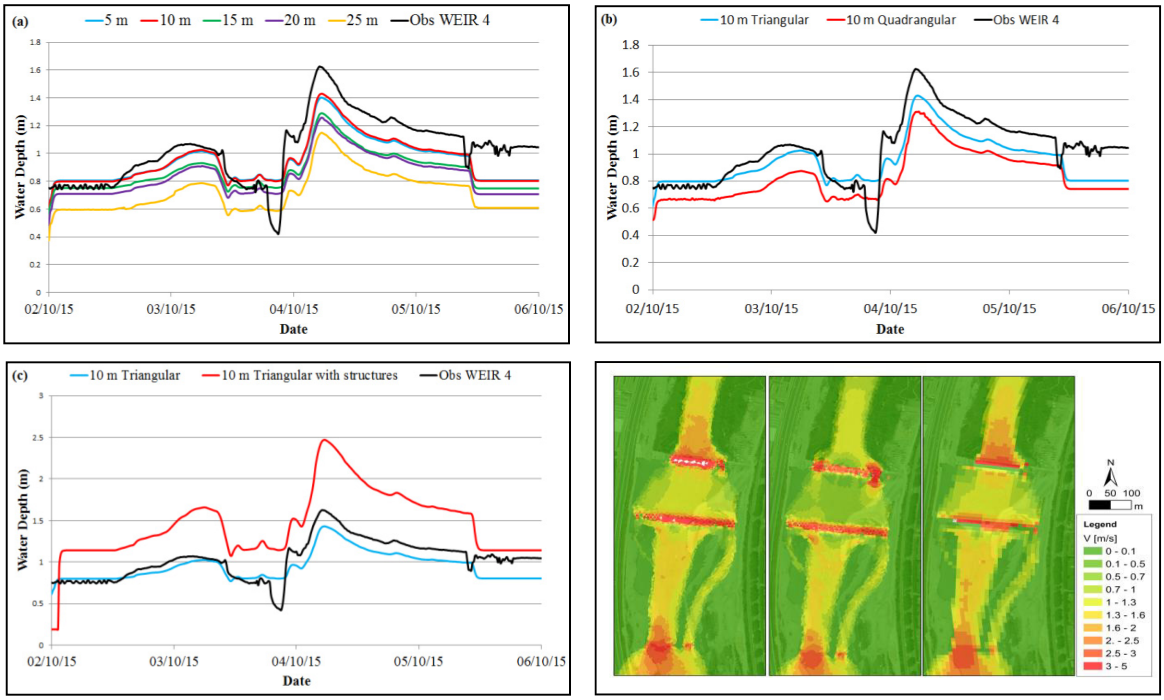

Fig. 6: Comparison of water depth for (a) different resolutions; (b) different types of mesh; (c) different implementations of weirs; (d) comparison of velocities for triangular mesh, triangular mesh with structures and quadrangular mesh.

For the hydrological modelling, 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 modeling system that provides the input data for FEFLOW and MIKE 21 / Telemac 2D systems.

The 3 modelling systems are currently integrated with the hypervision platform for the operational implementation.

5. Conclusion and perspectives

The proposed generic operational approach developed in the AquaVar project could be implemented in order to address the management of water uses in a complex urban environment: water supply security issues from groundwater resources, inundation risk and water resources management under the perspective of climate change. The proposed approached is based on a hypervision environment integrating 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 with the hypervision platform is based on Feflow, Mike SHE, Mike21 FM and Telemac 2D. The architecture is based on the interoperability of the various models and is integrated in a platform allowing to organize the workflows of data and the production of real time information’s used by the decision makers and different stakeholders. One of the main interests of the approach is to integrate an existing hypervision platform already implemented and used for urban monitoring.

The current approached is implemented within the AquaVar project, on the Var catchment located in the French Riviera and for an area close to 3,000 km^2. Obviously the concept can be extended to various catchments and for various priorities such as flood management, groundwater resources management, etc. The obtained results demonstrate both the efficiency of the approach and the interest from the management point of view.

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