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Application of Deterministic Distributed Hydrological Model in Mediterranean Region, Case Study in Var Catchment, France

Qiang MA[1], Ngoc Duong Vo[2], Philippe Gourbesville[1]

[1] Polytech Lab, Nice Sophia Antipolis University, Polytech Nice Sophia, 930 Route de Colles, Sophia Antipolis, 06903, France
[2] Faculty of Water Resource Engineering, University of Science and Technology, the University of Da Nang, Viet Nam

Corresponding author: qma@unice.fr

Abstract. During last decade, due to intensification of urbanization, connections between human and nature become more closed. Through hydro-informatics applications, such as hydrological or hydraulic model simulations, for local water managers, their knowledge and understanding of regional hydrological characteristics can be strongly improved. Among different kinds of hydrological models, the deterministic distributed hydrological model (MIKE SHE), shows obvious advantages in integrate representing multiple hydrological processes in catchment water cycle and producing more accuracy and detail results at any places on the simulation domain. This research is in project of AquaVar, which aims to create one model-based DSS in Var catchment at French Mediterranean Region. The main objective of this study is to build one deterministic distributed hydrological model through one optimized modelling strategy, which is able to overcome to problems caused by missing data, to well represent the complicated hydrological system in Var catchment. Based on a series of hydrological assessments and model testes, under reasonable hypothesized conditions, the model of MIKE SHE was calibrated from 2008 to 2011 and validated from 2011 to 2013 with daily time interval. With high statistical performance and can well presentation of the floods occurred during simulation period, the model results is able to be applied in AquaVar DSS for real time simulation and forecasting further scenarios. Besides, the modelling strategy conceived in this research can be also applied for building deterministic distributed hydrological models in other similar area.

Keywords: Deterministic distributed hydrological model, French Mediterranean Region, MIKE SHE, Var catchment

1 Introduction

During last decade, due to intensification of urbanization, connections between human and nature became more closed. Compared to past, the impacts of flood and drought hazards on human social activities becomes more serious. Recently, diversified and complicated water-related problems let the previous solutions and assessment plans to not be satisfied with the new social development. There is an urgent requirement from regional and local managers, who desire to get an integrate system to comprehensively support their decision making processes. Thus, under this circumstance, the model-integrated and web-based Decision Support System (DSS) gains more interests by those national and city decision makers.

This research work was under the project of AquaVar which aimed to create a model-integrated and web-based DSS in Var catchment (2800 km^2) located at French Mediterranean region used for well representing its complicated hydrological system and water exchange between rivers and shallow aquifers at downstream of the basin. Three deterministic distributed models of hydrology (MIKE SHE), hydraulic (MIKE 21FM) and groundwater (FeFlow) were set up to produce simulations in real time and forecasting the impacts of extreme events such as flood and drought hazards on the cities located at downstream parts of Var. The work in this paper is mainly concentrated on the application of deterministic distributed hydrological model (MIKE SHE) in Var catchment through a reasonable modelling strategy overcoming the difficulties caused by missing field survey.

2 Materials and Modelling Strategy

2.1 Var catchment

The Var catchment is characterized by a conspicuous variation of elevation from 0m (sea level) up to over 3000m at the summits of the Southern Alps Mountain (Figure 1). Black lines presented in the figure have divided Var catchment into 5 sub-catchments named with Estéron, UpVar, Tinée, Vésubie, and LowVar, respectively. The Var River starts at the spring originated from the south of mountain pass of Cayolle and flows through a distance nearly 114km to reach the outlet between NICE and Saint Laurent du Var at Mediterranean sea. The elevation variation in Var River is from 1790m down to the sea level, which forms a steep streamline slope of 1.57% in average. All the streams flows in Var catchment could be characterized as typical mountain stream with "V" shaped cross sections formed by natural erosion effect.

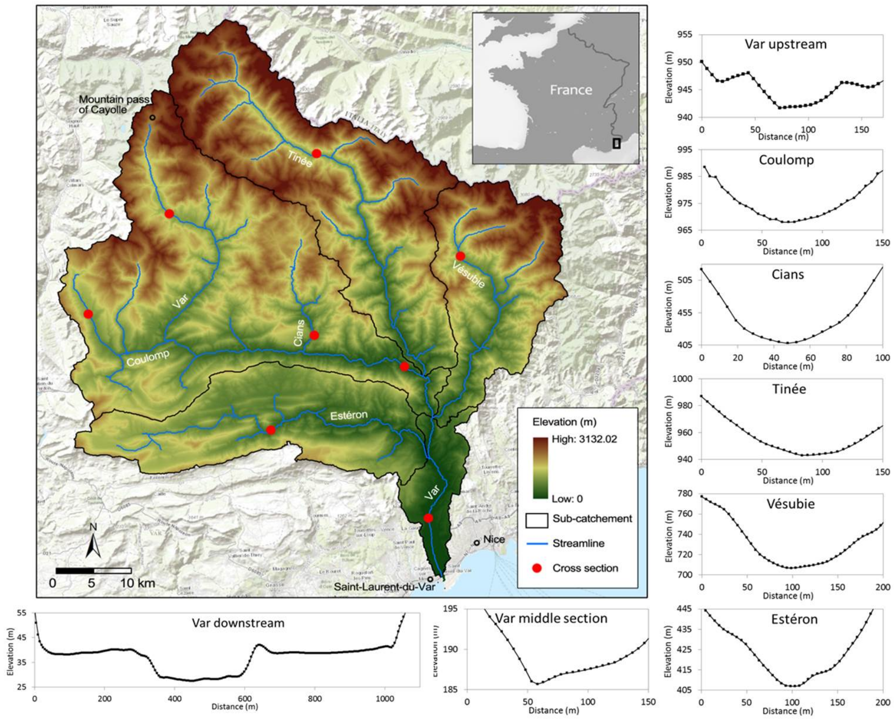


Figure 1 Geography of Var catchment (Source: 5m × 5M DEM, Metropole NICE Côte D'azur).

From the study of Potot et al., (2012), the geological characteristics of Var catchment shows strong heterogeneity consisting in:

- Magmatic and metamorphic rocks located at north-eastern edge of the basin;
- Continental sediments consist mainly as clays and fine micas in the north-western part;
- Marine sediments consist in marl-limestone and sandstones in central and western part;
- Miocene molasses, marls and limestones are found at the south part;
- and at the mouth of the catchment, about 700m thick conglomerates containing the pebbles from rocks outcropping in the whole basin.

Moreover, types of land use in Var catchment could be summarized into 6 main categories including: Forest, Pasture, Agriculture, Open Space (with less vegetation), Artificial Area, and Water Bodies. The top three land use types in Var catchment are Forest (47.80%), Pasture (31.61%) and Open Space with less vegetation (16.88%). Despite, there are some villages located in the upper and middle parts of the catchment, comparing with the urban area contributed by NICE city at downstream part, their artificial area and impacts on catchment hydrological system could be ignored in the assessment.

The meteorological characteristic of Var catchment could be simply identified with typical Mediterranean climate with rainy winters and dry summers. The annual precipitation in Var catchment is around 1154 mm/year with 96 mm/month in average. However, the rainfall temporal distribution in Var catchment shows significantly inhomogeneous phenomenon (Figure 2). The total rainfall amount in the driest period (e.g. from July to September) may take less than 15% of annual rainfall. In contrast, during rainy season, this catchment can receive more than 16% of annual total rainfall in only one month (e.g. November). The rainfall difference between driest and rainiest months could be more than 80%.

Moreover, based on the average monthly rainfall in Var catchment (red line in the figure), the rainy period of Var catchment could be divided into two main parts, named with spring rainy season (from April to May) and winter rainy season (from October to January). Obviously, compared to the spring rainy season, in winter rainy season, either the total amount or the intensity of rainfall shows significant increase. Thus, the extreme rainfall event occurred at winter rainy season is often considered as the main cause of flash flood disaster at the downstream part of the catchment.

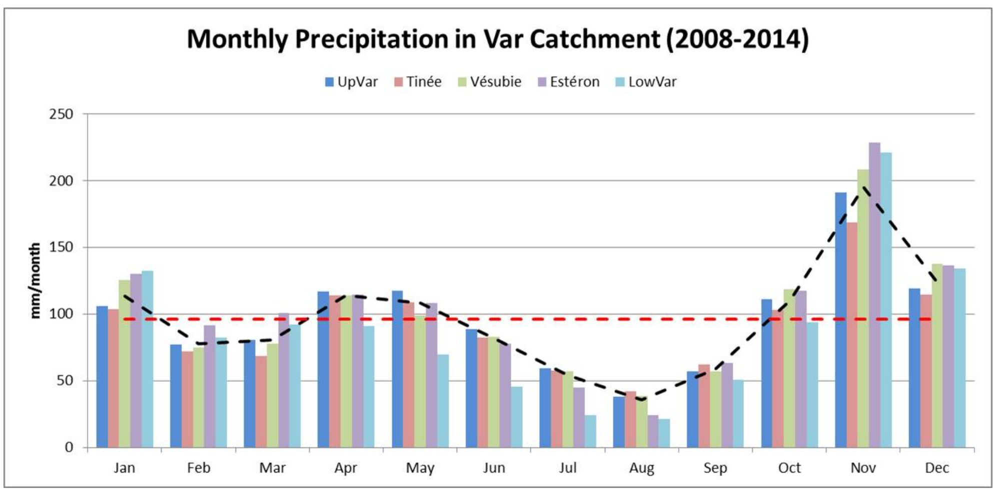


Figure 2: Monthly Precipitation of different sub-catchments in Var catchment (2008-2014).

2.2 MIKE SHE

In 1970s, in Europe, compared to previous models, a new generation of hydrological model, which aimed to provide more scientific information for optimizing water resources management and estimating impacts of increase of social activities such as urbanization, land use changes and infrastructural developments on natural environment, was designed with physical distributed structure. In that period, the Europe Hydrological System –Système Hydrologique Européen (SHE), which originally produced by the cooperation among three European water agencies including British Institute of Hydrology, UK, Danish Hydraulic Institute (DHI), Denmark and SOGREAH, French, under the financial support from European Commission, was developed to satisfy new requirements demanded by water resource managers (Abbott et al., 1986). After getting success in simulating hydrological phenomenon in Europe, many deterministic distributed hydrological models were created based on SHE, such as SHETRAN, SHESED and MIKE SHE (Ewen et al., 2000)

The first version of SHE was became operational in 1982. Since that time, the SHE model has been continued developing and extending by DHI with new mane of MIKE SHE. In recent, MIKE SHE model has been considered as a high performance modelling system for representing water cycle in the catchment. It contains full suite of pre-and post-process tools plus a flexible mix of advanced and simple solution techniques for each processes existed in hydrological cycle. Main hydrological processes, such as rainfall-runoff, evapotranspiration, overland flow and soil flow in unsaturated and saturated zones can be accurately represented in MIKE SHE simulation with different levels of spatial distribution and complexity depends on the modelling proposes, data availability and design of the model application (Butts et al., 2004; Graham and Butts, 2005). One added value of MIKE SHE, compares to other deterministic distributed hydrological models, is it has a user friendly interface, which allows the users to intuitively build the model based on the other modelling applications (e.g. conceptual model). The input data required by MIKE SHE modelling set up is specified in a variety of formats independently. Moreover, during the simulation, the spatial data has been mapped with numerical grids, which makes the changes of spatial discretization become feasible (Graham and Butts, 2005).

The MIKE SHE model is also able to couple with other MIKE series models, such as MIKE 11 and MIKE URBAN to achieve more comprehensive simulation. For instance, in the channel flow represented in MIKE SHE is realized through the coupling process between MIKE SHE and MIKE 11: the channel flow is simulated in MIKE 11 through 1D Saint-Venant equation and linked with overland function in MIKE SHE at certain grid located beside the channel Through one simple comparison between the surface water stages calculated in MIKE SHE and the water level computed in the channels by MIKE 11, the exchange between surface and channel flow is available in the simulation. With this coupling process, the border of MIKE SHE application has been significantly extended. It is also possible to couple the MIKE SHE with MIKE URBAN to simulate surface/subsurface hydrological processes with sewer system in urban area (DHI, 2012).

2.3 Modelling strategy

As we understood, the deterministic distributed hydrological model has advantages of integrate representing multi hydrological processes with higher accuracy and in detail. However, to achieve a better simulation performance, compared to other hydrological models, its data requirement is more difficult to be fully satisfied. Therefore, one reasonable modelling strategy is necessarily requested when the deterministic distributed hydrological model was selected to be applied in one basin, especially the poor gauged or ungauged catchment, which has few data available (Figure 3):

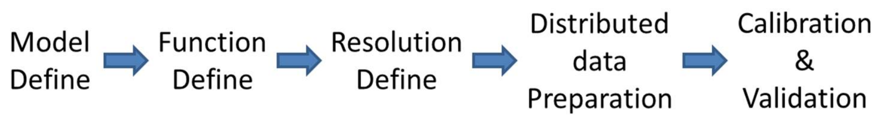


Figure 3: Strategy of deterministic distributed hydrological modelling application.

3 MIKE SHE Application in Var Catchment

3.1 Modelling set up

3.1.1 Distributed rainfall

The accuracy of deterministic distributed hydrological simulation is deeply depended on the quality of input data, especially the precipitation, which is often considered as the key factor in the hydrological process. In this MIKE SHE model application, to get most reasonable distributed rainfall over whole Var catchment, interpolation methods including Inverse Distance Weight (IDW), Spline, Natural Neighbor, Kriging (Ordinary Kriging with Spherical and Linear semivariogram models :Kriging_ S and Kriging_L), and Geographically Weight Regression (GWR) (considering the impacts of elevation (GWR_Z) and elevation and its distance to the sea (GWR_ZD)) were assessed with cross validation method among 10 selected stations evaluated by Nash coefficient (NES). In Table 1, both IDW and Kriging interpolation showed higher statistical performance and considered their statistical coefficients, moreover, referenced the study results of Tao et al., (2009), who assessed the different interpolation methods' effects in small catchment with high density rainfall in Lyon, France, which is not so far from Var catchment, the rainfall distributed map produced by IDW interpolation with 500m resolution was applied in the MIKE SHE simulation in Var catchment.

Table 1: Evaluation among different interpolation approaches through cross validation method.

Interpolation Approach	Average NES
IDW	0.87
Spline	0.73
Natural	0.86
Kriging_S	0.86
Kriging_L	0.85
GWR_Z	0.83
GWR_ZD	0.83

3.1.2 Channel and overland flow

The channel flow in MIKE SHE is represented by the simulation through river network set up in MIKE 11 model. Based on the 5m DEM supported by Metropole NICE Côte D'azur, both the branches and cross sections could be abstracted through ArcMap tools (Figure 4). Moreover, for the overland flow, it could be simulated with distributed Strickler coefficients defined by the distributed land use map collected from Europe European Environment Agency (Table 2).

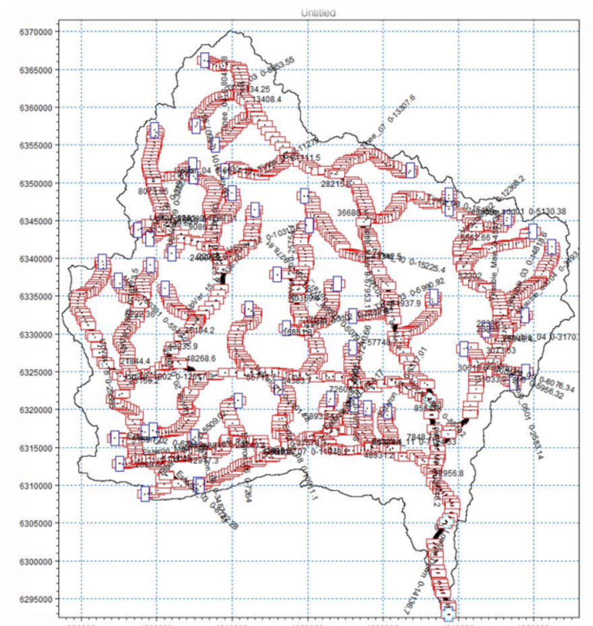


Figure 4: River network set up in MIKE 11.

Table 2: Define the Strickler coefficient based on the different land use types.

Land use Type	Strickler Coefficient (m^(1/3)/s)
Artificial surfaces	50
Agricultural areas	25
Grassland	2.5
Forests	2
Open spaces	5
Water bodies	20

3.1.3 Unsaturated and saturated zone

In the simulation of the unsaturated flow, the soil types should defined in the model simulation. Based on the percentage of soil materials collected from the European

Soil center, through the "Soil Texture triangle", four soil types were defined in the MIKE SHE model of Var catchment (Table 3).

Table 3: Initial values of soil parameters defined in MIKE SHE simulation in Var catchment.

Parameters	Clay Loam	Loam	Sandy Loam	Silt Loam
Water content at saturation (-)	0.5	0.5	0.38	0.46
Water content at field capacity (-)	0.36	0.28	0.18	0.31
Water content at wilting point (-)	0.22	0.14	0.08	0.11
Saturated hydraulic conductivity (m/s)	2.50E-06	6.00E-06	1.00E-03	2.50E-05

In the saturated flow simulation, the characteristic of aquifer is mainly represented by the parameters inputs including depth of the soil, horizontal hydraulic conductivity and vertical conductivity. Due to few field measurements of hydraulic conductivity was available over whole Var catchment, two uniform constant values were respectively defined for horizontal and vertical conductivities with the relationship of horizontal hydraulic conductivity divide by vertical hydraulic conductivity in range from 0.1 to 0.5 (Todd, 1980). And the depth of the soil was also estimated by the surface slope (Table 4).

Table 4: Values of soil depth estimated by surface slope.

Surface slope (°)	Soil Depth (m)
0-10	-12
20-30	-5
20-30	-5
30-40	-5
40-50	-1
50-60	0
60-90	0

3.2 Simulation results

Before the model calibration, the sensitivity analysis of MIKE SHE model application in Var catchment was implemented by evaluating the parameter sensitivity based on its sensitivity rate (SR). Some of the sensitivity analysis results were showed in Figure 5, which indicated the most sensitive parameters in the MIKE SHE application in Var during winter rainy season is the horizontal hydraulic conductivity in the saturated zone.

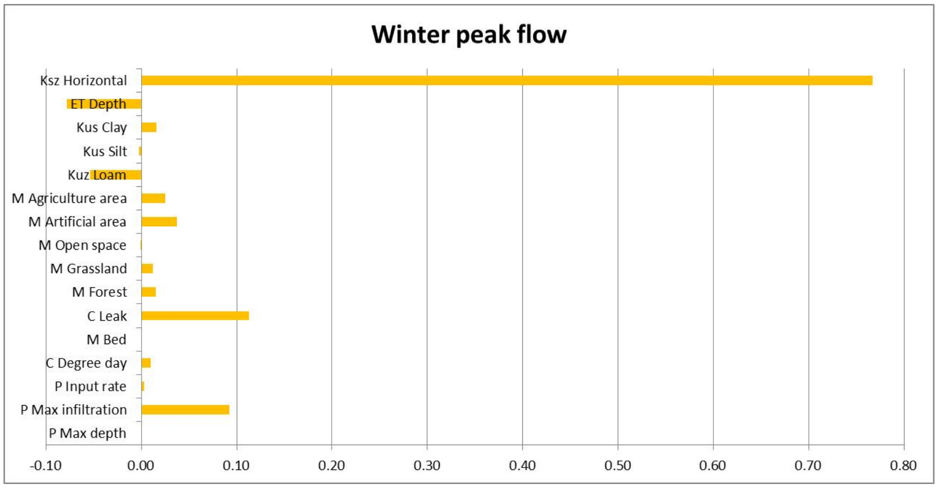
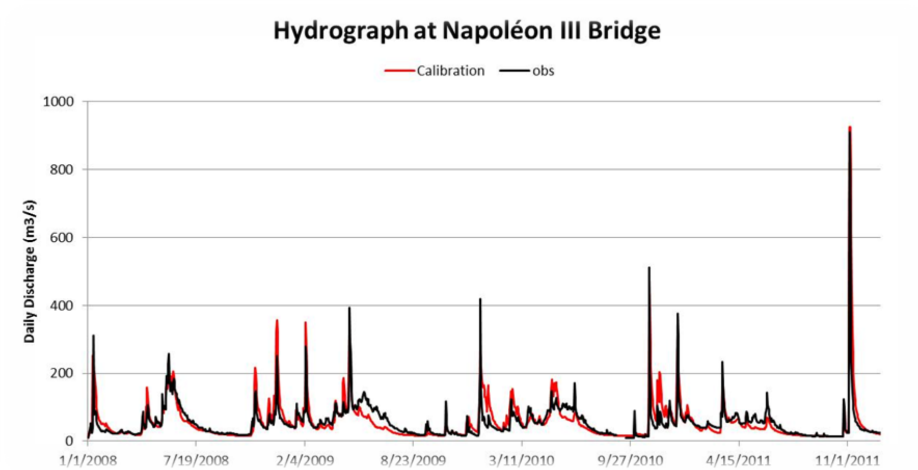


Figure 5: SR of all the tested parameters for peak flow of winter floods.

The calibration and validation of MIKE SHE application in Var catchment were respectively set up from 2008 to 2011 and from 2011 to 2014 with daily time interval (Figure 6).



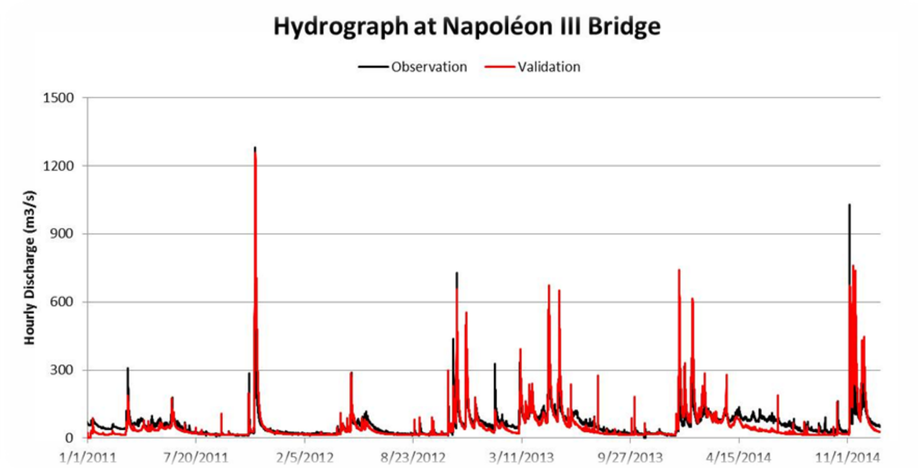


Figure 6: Calibration and validation of the MIKE SHE simulation in Var catchment.

4 General Conclusion

Compared to other type of hydrological models like conceptual model, the deterministic distributed hydrological model has advantage of detail and accurately representing the multi-hydrological processes in the catchment. At same time, it high data requirement in the modelling set up process often limits it application in the ungauged or poor gauged catchment with less field data available. Thus, followed the modelling strategy we defined in this study, many hypothesize were conceived during the modelling set up process to fill the gap between model requirements and field data collection. The reasonable modelling results proved that for representing the complex catchment hydrological system like Var catchment, the minimum modelling requirement could be more concentrated on the data collection among topography and precipitation which linked with the most effective hydrological processes in the catchment: rainfall-runoff process.

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