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SAFEGUARDING HUMANKIND'S HERITAGE, THE GREAT CHALLENGE FOR ENGINEERS

The Web-based Flood Warning System exploiting the JGrass-NewAge

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Abstract
The monitoring and prediction of hydrological extremes is becoming more and more critical in Basilicata region given the increasing number of extremes observed in the last few years. In the present study, we introduce the Web-GIS tool developed for the Civil Protection of the Basilicata region. The tool represents a decision support system aimed at describing the dynamics of the hydrological river system of the region. Hydrological simulations are carried out through the open source semi-distributed hydrological model JGrass-NewAge. Thanks to the modelling framework OMS3, each part of the hydrological cycle is implemented as a component that can be selected, adopted, and connected at run-time to obtain a user customized hydrological model.
JGrass-NewAge was implemented on the Basilicata region starting from a conceptual description of the basins, discretized in Hydrologic Response Units (HRU). At HRU scale, the radiation balance, the water balance, the evapotranspiration and the runoff were estimated after the spatialization of the atmospheric forcings. The flexibility of the model allows to manage the modeling chain by simulating in near real time mode across the regional territory. This will help the management of hydrologic-hydraulic risk, especially at critical points in the hydrographic network for Basilicata territory.

Keywords: hydrological modeling, hydrologic-hydraulic risk, Web-GIS tool

1. Introduction

Basilicata is one of the most exposed region for hydrologic-hydraulic risk with a growing number of extreme events [1,2]. All districts are affected by some form of instability [3]. In particular, the geological characteristics and the dynamics of precipitation caused landslides and floods that affected large areas of the region. Therefore, forecasting of extreme events is essential for the Civil Protection to protect people and structures.
Near real time monitoring and forecasting of these events is essential for the protection of people, environment and infrastructure.
New operational tools such as data analysis methods and new hydrological modeling approaches need to be developed to address water resource prediction and management issues [4].
JGrass-NewAge is a physically based semi-distributed hydrological model of next generation. This system has been designed for prediction and modeling of water resources at basin scale.
The model is open-source, updated by a developer community, and can be run on all major computing platforms [5].
It was already used for water balance definition of Piave [6], Upper Blu Nile [7], Little Washita, Cache La Poudre basins with good results.
JGrass-NewAge will be integrated into the Civil Protection WebGis platform by predicting in real time the assessment of possible hydrological and hydraulic risk scenarios on a regional scale associated with weather phenomena, in support of risk management, forecasting and alert procedures of the Civil Protection system.

2. The modeling Framework OMS3

JGrass-NewAGE system is based on the Object Modelling System v3, (OMS3) [8]. OMS is a component-based Environmental Modeling Framework (EMF). Components are self-contained building blocks, modules or units of code.
Each component implements a single modeling concept, and the components can be joined together to obtain a Modeling Solution (MS) which can accomplish a complicate task, such as simulating the water budget storages and fluxes.
Various OMS components to simulate the relevant hydrological processes and preprocess/postprocess data were implemented.

The list of JGrass-NewAge components is specified in Table 1.

Table 1. JGrass-NewAge Components

Component	Task
Horton Machine	Geomorphic and DEM analyses
Kriging	Interpolation
Shortwave	Radiation budget
Longwave	
Clearness Index	
Net radiation	
Priestley-Taylor	Evapotranspiration
FAO-ETp Model	
Rain Snow Separation	Runoff production
Snow	
Adige	
Embedded Reservoir Model	
Travel times	Travel time analysis
Richards1D	Soil moisture analysis
Muskingum	Discharge propagation
LUCA	Calibration
PSO	

The DEM analysis is performed using the Horton Machine [9, 10, 11], which allow, starting from the DEM, to derive the geomorphic characteristics required by computation.
Meteorological forcing data are interpolated using Kriging techniques; the radiation budget model includes both shortwave and longwave radiation.
Evapotranspiration can be estimated using two different formulations: the Fao-Evapotraspiration model[12], and the Priestly-Taylor model [13].
The component Snow was split in two components, rain-snow separation and snow melting and snow water equivalent.
Two different runoff generation models are implemented, the Adige model and the Embedded Reservoir Model [14].
Two model calibration algorithms are part of the core of OMS3: Let Us CAlibrate (LUCA) and Particle Swarm Optimization (PSO).
Other components can be used to carry out travel time analysis (travel times), to define soil moisture distribution and hillslope stability (Richards1D), to derive the discharge propagation in the network (Muskingum).

3. Model application

The model described was applied to the entire territory of Basilicata. The region a surface of about 14000 km^2 divided into 10 basins (Agri, Basento, Bradano, Cavone, Lao, Noce, Ofanto, Noce, Sele, Sinni). Altitude spans from 0m asl to 1970m asl; the region is equipped with a monitoring network of 76 stations that records temperature, rainfall, hydrometric heights, radiation and the main environmental forcing. The river systems flow into the Adriatic Sea and Tyrrhenian Sea.
The 46% of the territory is predominantly mountainous, the remaining 46% is hilly and 8% is flat. The climate is characterized as wet, with a mean annual precipitation of 740 millimeters and annual runoff of 300 millimeters. The average annual temperature is 13.5°C; average monthly temperatures range from 4.9 °C in January and 25 °C in July.
The regional territory is described in Figure 1, where are reported the elevations, the basins and the location of monitoring stations.

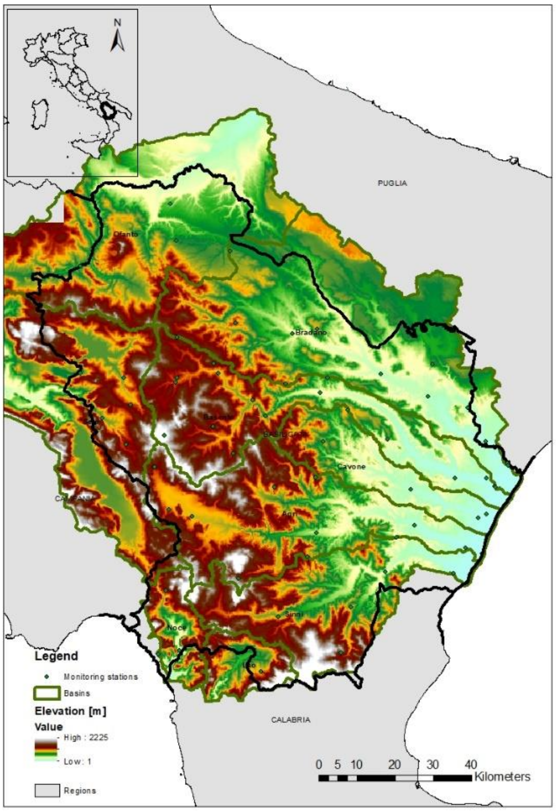

Figure 1. Location of Basilicata region, river basin and monitoring stations.

Regional analysis began with the acquisition of a Digital Terrain Model, as described in [15] which followed the use of model components to perform a complete simulation set.

The analyzes carried out can be divided into two parts, one dedicated to geomorphologic analysis and one dedicated to hydrological analysis.

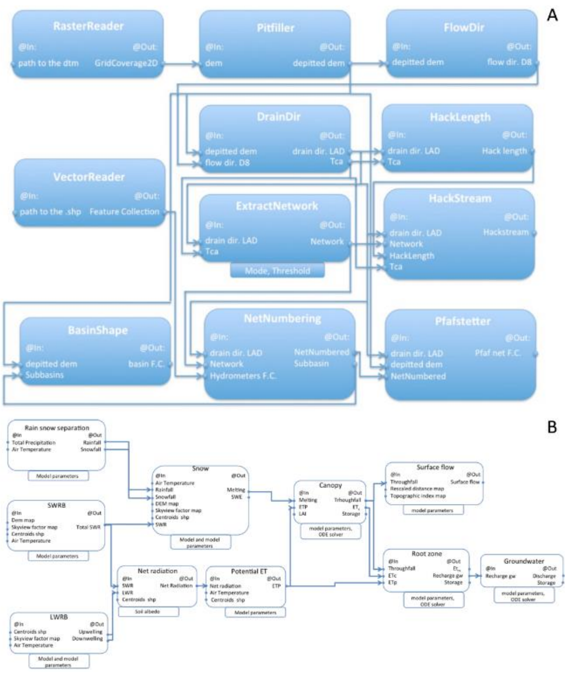

Figure2. Structure of JGrass-NewAge model:
A Geomorphologic analisys, B hydrological analisys

For the model implemented, it was used the Digital Terrain Model of National Geological Service with a spatial resolution of 240 meters.
The basins were split in 151 Hydrologic Response Units and rainfall and temperature data were interpolated for each HRU centroids using Kriging interpolation algorithm.

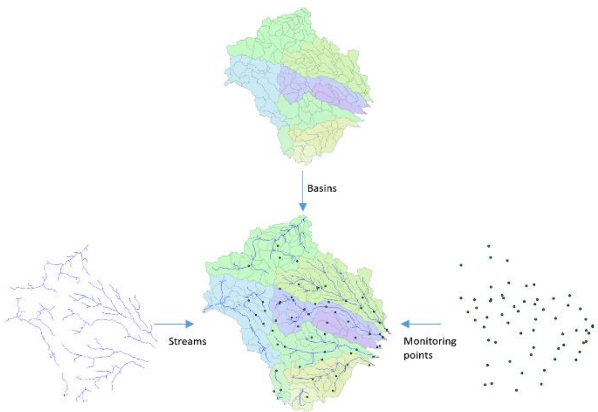

Figure 3. Framework input data

For each HRU, the modeling solution reported in Figure 2B was applied. ShortWave Radiation Balance component (SWRB), was used to estimate the total shortwave radiation. LongWave Radiation Balance component (LWRB), was used to estimate the total longwave radiation. Total longwave and shortwave are the inputs of Net radiation component; Rain-snow separation detects, from total precipitation, rainfall and snowfall while Snow component, allows to simulate the snow water equivalent (SWE) and the snow melting.
Priestley-Taylor model, was used to simulate potential evapotranspiration using the ETp component.
Canopy storage was used to relate interception loss to precipitation and surface flow derive the direct surface flow.
Root zone storage component was used to simulate the drainage toward the groundwater, the evaporation from the bare soil and transpiration from the canopy while the groundwater component was used to simulate the baseflow.

Finally, thanks to a recent enhancement of OMS core, the River Net3 [16], simulation are run in parallel and the discharge produced for each HRU is routed till the closure of each basin.
A preliminary conceptual validation was performed by comparing the historical data of rainfall-runoff at the same stations [17].

4. Results and Discussions

JGrass-NewAge has been implemented on entire regional territory for the last 5 hydrological years (2013-2017). In this paper are reported the first two year, used for calibration.
The model was calibrated against the measured discharge at every hydrometric station for the years 2013-2014 and then validated using the remaining dataset.
The parameters resulted after several tries to find different connections of the storages, the optimal number to describe the hydrological response, at a minimal the computational costs. Although each HRU has different inputs, model parameters are calibrated at catchment scale versus rainfall-runoff data.

The baseflow component has been estimated by interpolation using a baseflow filter applied to the time series of recorded minimum values.
These pre-processing procedures allow to reduce several problems typical of natural and artificial river basin focusing more specifically on the surface hydrology of the river basin. In the present case, such approach allowed to neglect groundwater dynamics without losing in predictive capacity of the model
In particular, the calibration was obtained by decomposing the time series of streamflow in two components: i) the baseflow ii) the sum of surface and sub-surface runoff contributions [18].

Modelling results are showed in Figure 4, where the measured discharge (black line) during the entire calibration period is compared to simulated discharge (red line).

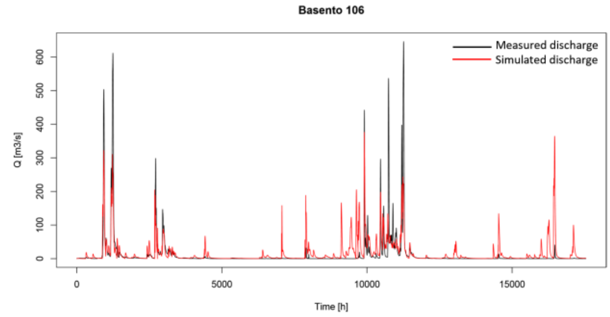

Figura 4. Measured discharge VS Simulated discharges derived from JGrass-NewAge for the calibration period 15/12/2013-15/12/201

The visual inspection of hydrographs, shows the good overall agreement between the discharges provided by JGrass-NewAge and the recorded values.
A quantitative description of model performances is given in Table 2 for the Basento 106 station.

Table 2. Results in terms of goodness of fit in calibration for the station Basento 106

Monitoring station	KGE	NS
Basento 106	0,6	0,7

The objective functions used to evaluate model performances were the Kling-Gupta Efficiency (KGE) [19], and the Nash-Satcliffe Efficiency (NSE) [20].
A qualitative and quantitative improvement of the whole model can be achieved with new hydrometric measurement campaigns for the monitored hydraulic sections, for which no full flow measurements are available, especially during flood.
These measures will allow redefining the rating curve, especially for the floods that causes the most calamitous events.
The analysis of the relative amount of the input and output contributes to the overall water balance, was made using the waterfall charts [21], and are shown in Figure 4 at annual scale.
Green bars represent the mean annual volume of the input of the reservoirs, blue bars represent the mean annual volume output fluxes, and the red bars represent the annual variation of the storage.
The total actual evapotranspiration represents around the 55% of annual input, the remaining part is mainly runoff and a small quantity is storage.

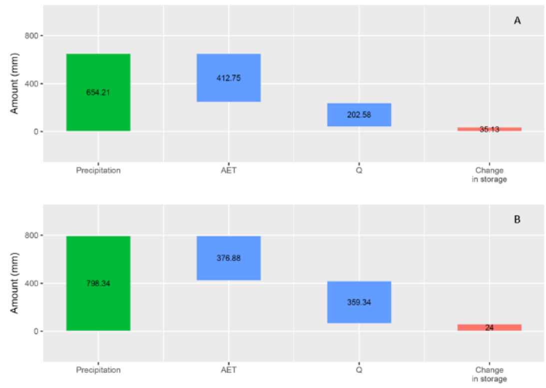

Figure 5. Waterfall charts of the relative contributes of the water balance for Basento basin. A represents the first year of calibration (2013) and B shows the second year of calibration (2014).

The work is still on-going and, therefore, the results are largely preliminary. Further calibrations and validations are upcoming.

5. Conclusions

In this paper we introduce the application of JGrass-NewAge model to Basilicata region.
The model is open source, reproducible, flexible, maintainable and expansible for future investigations. It allows to experiment different representations of spatial variability and hydrologic connectivity, including a broad range of dominant hydrologic processes, with multiple options for each one.
JGrass-NewAge can be used to define the water flow rates in different river sections of interest, to evaluate the soil moisture, to estimate the evaporative flux, to estimate medium-long term water balances, for real-time forecasting of floods, and to forecast long-term runoff.
JGrass-NewAge intends to represent the hydrological model to support Decisions of the Decentralized Functional Center of the Basilicata Region, enabling, through the data transmitted by the thermometric, hydrometric and pluviometric stations present within the basins of interest, to perform real-time simulations of full events to estimate the expected hydrometric levels in certain monitoring sections and compare them with the identified hydrometric alert thresholds.
The versatility of the modeling approach will allow to manage the modeling chain by simulating in near real time on the entire regional territory. This potential will ensure targeted hydrologic-hydraulic risk management especially at critical points of the hydrographic network.

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