Lake Skadar-Shkoder Integrated Ecosystem Management Project

Development of a Predictive Hydrological Model for the SS-LBA

Final Report Addendum

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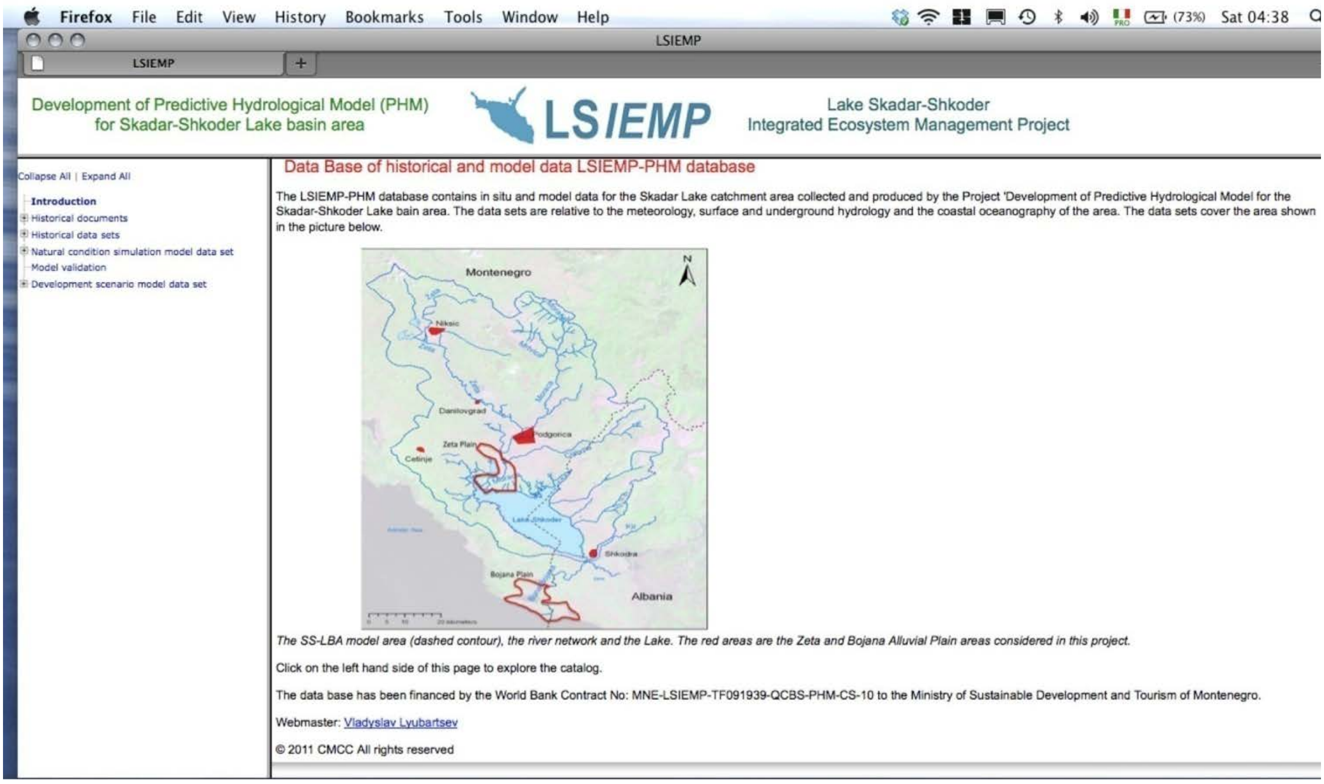
1. Foreword

This Addendum to the Draft Final Report of the Project *Development of a Predictive Hydrological Model (PHM) for the Skadar-Shkoder Lake Basin Area* contains a short review of the LSIEMP-PHM database, the recommendations for future course of actions and the general conclusions of the work.

2. The LSIEMP-PHM database

All observed and model data sets used during the project have been digitized, quality controlled and combined in a unique database platform, the LSIEMP Phm-Data Base (LP-DB) that will be synthetically described in this section. The LP-DB consists of hardware platform composed of an Intel CPU 3.3 GHz with 4GB memory, 1GB disk, 21,5 ‘’ monitor and Microsoft Windows 7 Professional.

The database structure is very simple, consisting of concatenated directories and a series of User Interfaces (UI) to display and search the content of the directories, display maps or time series. The access UI is displayed in Fig. 2.1.



Data Base of historical and model data LSIEMP-PHM database

The LSIEMP-PHM database contains in situ and model data for the Skadar Lake catchment area collected and produced by the Project 'Development of Predictive Hydrological Model for the Skadar-Shkoder Lake bain area. The data sets are relative to the meteorology, surface and underground hydrology and the coastal oceanography of the area. The data sets cover the area shown in the picture below.

The SS-LBA model area (dashed contour), the river network and the Lake. The red areas are the Zeta and Bojana Alluvial Plain areas considered in this project.

Click on the left hand side of this page to explore the catalog.

The data base has been financed by the World Bank Contract No: MNE-LSIEMP-TF091939-QCBS-PHM-CS-10 to the Ministry of Sustainable Development and Tourism of Montenegro.

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Fig. 2.1 The LP-DB access UI to the database

The page is composed of two sections: on the left the catalogue and on the right the maps and the information.

The catalogue contains the following sections:

- Introduction
- Historical documents
- Historical data sets
    - In situ data sets
        - Land and river topography, lake bathymetry
        - Underground water and soil properties

      - Zeta Plain wells
      - Borehole profiles
    - Surface water (river and lake)
      - River and lake water levels
      - River discharge daily time series
      - River discharge climatologies
    - Sea Level
      - Tide gauge stations
    - Meteorological stations
  - Model data sets
    - D1 ERA-INTERIM (meteorological conditions)
    - D2 AFS (oceanographic conditions)
- Natural condition simulation model data set
  - H1 Atmosphere-Land, Surface and near surface hydrology
  - H2 Skadar-Shkoder Lake water level and conditions
  - H3 Zeta Plain undeground water levels
  - H4-H5 Bojana-Drin river discharges and sediment transport
  - H6 Bojana Alluvional Plain water levels

For some of the subdirectories we display the UI in Fig. 2.2 and 2.3. The content of each section of the catalogue will be described in details in the Technical documentation of the Database, prepared for the Training session. We hope this database will serve as the first archive of the historical digital data information for the SS-LBA water levels and discharges.

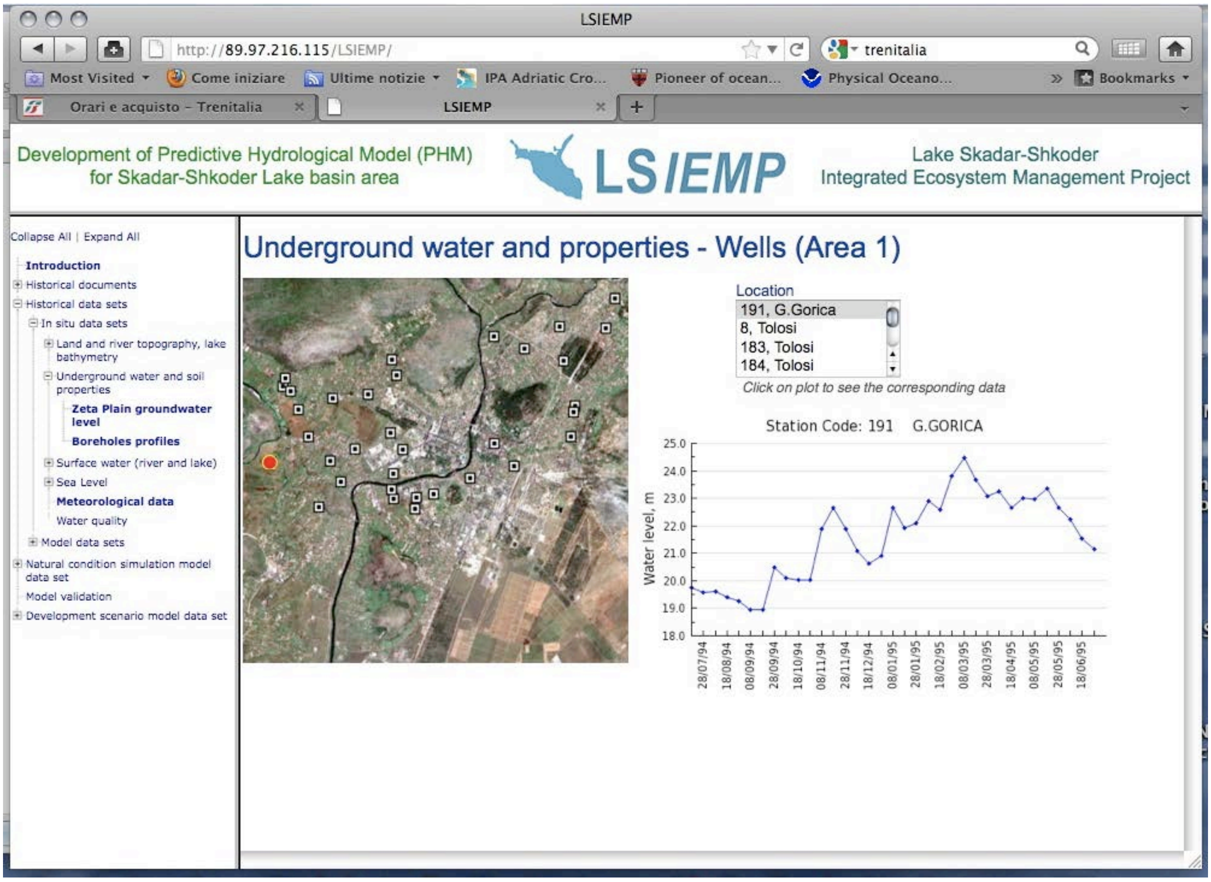

Fig. 2.2 The UI for the Zeta Plain water table data

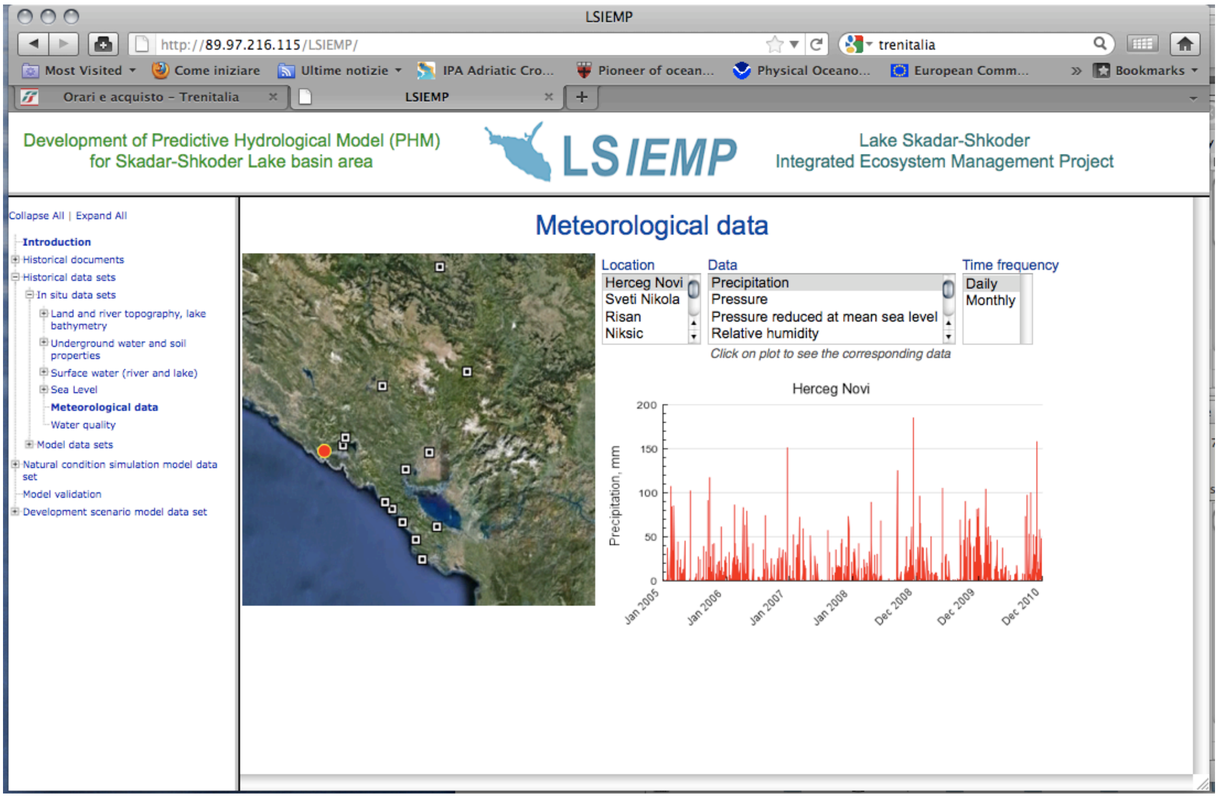

Fig. 2.3 The UI for the meteorological station data

3. Suggestions for future course of actions

The present implementation of the PHM system (Fig. 3.1) needs upgrades in order to improve the natural condition scores and to transform this tool into an early warning flood system for the SS-LBA and the Buna-Bojana-Drin river system. The PHM has the capability to be transformed in an early warning system if it will be streamlined and connected with the real time observational data acquisition system since it contains all the compartments that are needed to nowcast and forecast the SS-LBA and the Buna-Bojana-Drin surface water cycle.

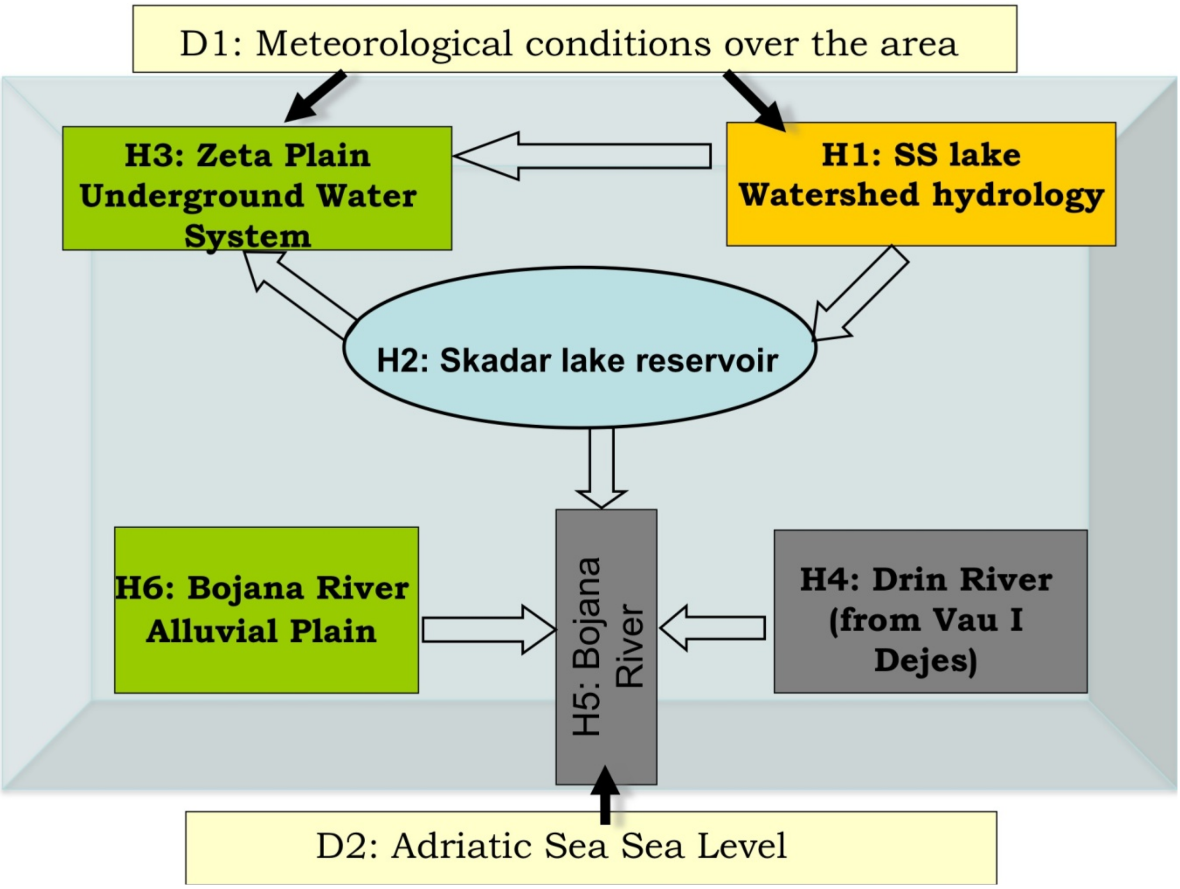

Figure 3.1–The PHM model components, interfaces and external data sets

Many of the required improvements are connected to a better definition of the geomorphological characteristics of the different model compartments since in this high resolution modelling effort landforms play a key role. In addition some processes should be better represented, among them: the snow cover melting and re-freezing, the soil parameters for karstic areas in the Land Surface Model and the spring discharges.

Finally, it is recommended that the future PHM design will be upgraded with:

1. A model coupler interface that could exchange model parameters and fields automatically between the running modules;
2. Data assimilation tools for water level and flow discharges from the real time observing network in order to correct for initial condition model errors.

In addition, it is recommended that a training project will be undertaken to consolidate the operational functioning of the database and the model at the auspices of the HIM and equivalent Institutions in Albania. Such a training project should involve in site visits of scientists to the HIM and Albanian facilities, the implementation of a computational infrastructure and an exchange program for young technicians and scientists at the foreign Institutions that have developed the PHM components.

For each PHM component a list of necessary improvements follows.

3.1 The meteo-hydological model - H1

One of the major problems of the meteohydrological model used in this study was found to be the higher winter and the lower summer discharges of the Moraca river. The reason for that was found to be partially connected to the snow cover production/destruction mechanisms in the Land Surface Model that in turn produced the surface runoff for the river routing module of HYPROM.

Snow acts as a natural reservoir, to redistribute winter precipitation in a delayed mode into spring and summer if realistic. It is noticed that NOAH LSM has a snow depletion bias which gives faster than observed snow melt. In the recent developments of the NOAH LSM (Livneh et al., 2010) the problem is fixed by applying a procedure that accounts for liquid water storage and refreeze within the pore space of the snowpack. Melt-refreeze processes improved the quantity and timing of snow water equivalent and with much better success in redistribution of winter precipitation into spring snow melt and therefore runoff. Unfortunately, above mentioned model was not available for this project.

As an improvement of Skadar-Shkoder watershed model we suggest usage of the improved NOAH LSM model version. To show the importance of proper time distribution of snowmelt runoff in watershed area, winter snow liquid water is retained and used as runoff during spring time by applying a simple parameterization method.

Difference between control run and above mentioned run is shown on Figure 3.1.1 and Table 3.1.1 for scores. The improvement is evident if compared to the scores of Annex 1, Table 3.5.

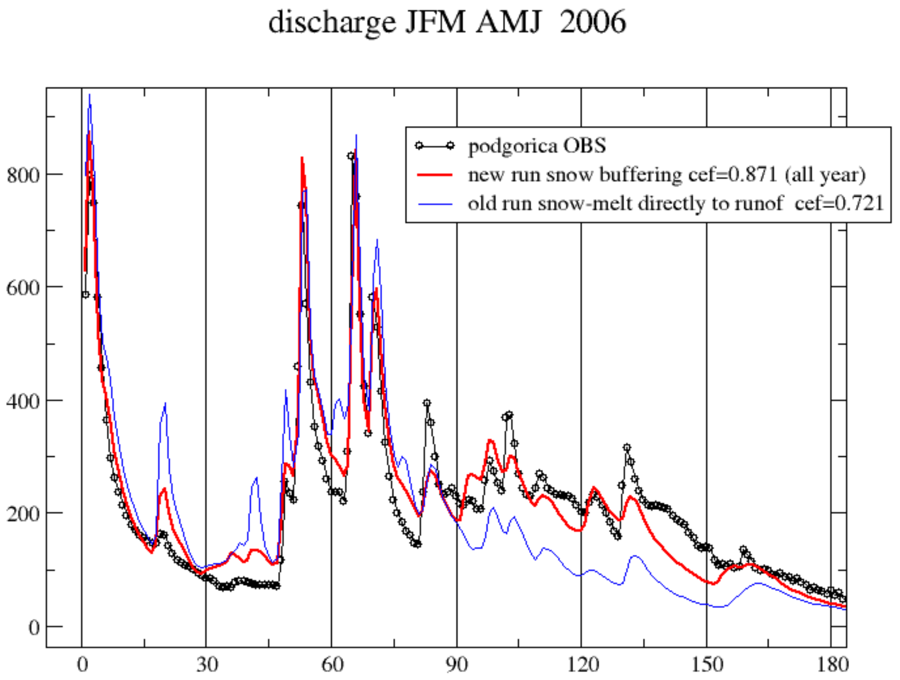

Fig. 3.1.1 Modeled river flow compared to measured flow at Podgorica station on Moraca River; blue line represents natural conditions NOAH-LSM model results, while red line represents new run with parameterized snow melt-refreeze process for the first six months of 2006

Table 3.1.1: Model error scores: modeled river discharge compared to hydrological station data at Podgorica on Moraca River (Mor.Podg.YY) and Danilovgrad on Zeta River (Zet.Dani.YY) for the different natural condition scenario

New snow melting parametrization

Stations and year	**Observed Mean**	**ME %**	**ME**	**MAE**	**RMSE**	**CORR**	**CEFF**	**No of samples**
Mor.Podg.06	140.2	9.5	13.374	38.314	51.399	0.941	0.876	363
Zet.Dani.06	79.2	-7	-5.584	21.811	31.751	0.913	0.827	363
Mor.Podg.07	125.5	7.9	9.904	37.747	65.789	0.858	0.705	363
Zet.Dani.07	77.9	-15.7	-12.196	22.736	37.849	0.861	0.702	363
Mor.Podg.08	142.7	6.5	9.31	38.099	61.559	0.935	0.871	363
Zet.Dani.08	88.5	-15.6	-13.779	21.737	36.728	0.926	0.834	363
Mor.Podg.09	159.3	10.7	16.978	37.21	57.195	0.958	0.91	363

Zet.Dani.09	98.7	-11.1	-10.907	24.274	41.677	0.915	0.812	363
Mor.Podg.10	233.7	3.9	9.058	52.523	86.713	0.953	0.901	345
Zet.Dani.10	146.4	-15.4	-22.599	41.591	54.655	0.914	0.716	345

Natural conditions simulation

Stations and year	**Mean Observed**	**ME %**	**ME**	**MAE**	**RMSE**	**CORR**	**CEFF**	**No of samples**
Mor.Podg.06	140.2	5.7	7.972	63.056	80.218	0.864	0.698	363
Zet.Dani.06	79.2	-10.7	-8.446	30.852	41.971	0.863	0.698	363
Mor.Podg.07	125.3	8.1	10.124	48.737	81.144	0.818	0.55	364
Zet.Dani.07	77.8	-15.9	-12.387	26.709	43.94	0.834	0.598	364
Mor.Podg.08	142.8	6	8.522	44.921	68.29	0.925	0.841	364
Zet.Dani.08	88.7	-16.3	-14.425	23.319	37.573	0.926	0.826	364
Mor.Podg.09	159.3	13.9	22.119	50.595	70.416	0.943	0.864	363
Zet.Dani.09	98.7	-8.2	-8.05	26.86	44.157	0.914	0.789	363
Mor.Podg.10	233.7	2.9	6.748	68.405	105.127	0.924	0.854	345
Zet.Dani.10	146.4	-16.8	-24.553	50.707	62.32	0.902	0.631	345

Another problem of the NOAH LSM model used in this work was the limited number of soil types available in the standard model code. In this work it was chosen to use bedrock because the watershed is predominantly karstic. We noticed that up to 10% more runoff is being generated by NOAH LSM due to higher saturated water conductivity and diffusivity favored by bedrock. However, at least in the Zeta Plain part up to the Skadar-Shkoder watershed area, a combination of two soil types should be used in order to reduce winter runoff and this differentiation should be introduced in the future .

3.2 The Lake hydrodynamics model – H2

Considering the lake model results for the natural condition and the scenario 1 simulations, we have shown that a finite element model such as H2 is capable to simulate a complex geometry system like the Skadar-Shkoder Lake. However the quality of the results was affected by two missing pieces of knowledge: 1) the lake bathymetry and terrain elevation around the lake and 2) the spring discharges and their precise geographical locations.

Regarding the first problem, the lake bathymetry was released to the partnership only by HMI and all the Albanian part of the Lake was missing. Thus the final bathymetry was digitized from an historical map (as described in the Revised First Report) and inserted in the USGS HYDROSHEDS 1 km resolution terrain height digital data set. The connection between the lake and the Buna-Bojana river was also adjusted to match the different data sets but without validation from in situ data. The model area was defined to coincide with the 3 m height above the mean level of the Skadar Lake, taken from the USGS altimetry data set, while it could be more reasonable to enlarge the domain up to 8 meters.

Another major uncertainty in the modelling exercise is connected to the unknown discharge and location of springs. This is a serious lack of information that should be considered in future mapping and monitoring programs.

In the H2 model grid, the presence of a blocking bridge (Lesendro Bridge not suspended but built on a sediment-filled street bridge) between the two Maraca river branches was not considered (see Annex 2, page 10) and this aspect can affect the hydrodynamics in the area even if probably not the water volume far from the bridge. This missing obstacle influence the results presented in the Scenario 3 simulation especially for what concerns the spreading of pollution from the left branch of the Moraca and the Rijeka Crnojevica river so that these simulations have not been included in the final report.

3.3 The Alluvial Plain underground water models – H3 and H6

The modelling of the Zeta and Bojana Alluvial Plains has been greatly affected by the scarcity of stratigraphic information from deep wells and the almost totally missing information about water table levels in the Bojana plain. In the future modelling efforts it is recommended to get new updated information about the hydrogeology, lithology and geology of the Alluvial Plains.

3.4 The Buna-Bojana-Drin river models – H4 and H5

The modelling of the Buna-Bojana-Drin river system was affected by two major uncertainties/unknowns: the first connected to the unknown Drin river topography and the second the unknown sedimentological characterization of the river bed and the suspended sediments.

In the future, constructions and obstructions along the rivers should be considered at several river sections (an example is shown in Fig. 3.4.1). Last but not least, digital terrain model information at high resolution should be merged with the topographic sections of the Buna-Bojana in order to use river models with flooding model options.

Fig. 4.4.1 Google images of the Buna-Bojana river branch showing the presence of partially obstructing dams and bridges on the two sides of the island

The dredging of the Buna-Bojana river should be carefully considered in a future project since our experiments showed that there is missing information about the sediment composition of the river bed and the dredging could be enhancing the flood risk of these areas.

4. Final discussion and conclusions

The Predictive Hydrological Model for the Skadar-Shkoder Lake basin area and the Buna-Bojana-Drin after the Vau-I-Dejes dam river system, has been used to model the 2005-2010 natural environmental conditions of the area and the impacts of three development scenarios. In Fig. 4.1 the overall structure of the terrain, alluvial and water system of the Skadar Lake is represented from satellite altimetry. The picture shows the low level of the Skadar Lake and Bojana river alluvial plains so that the height for the latter part is lower than the estimated error of 1 m in the satellite image. It is clear from this picture that the flooding of the lake and the Buna-Bojana-Drin river system nearby areas is likely to occur for completely natural reasons and that the future development scenarios should address the problem of harmonizing these natural conditions with protection of human assets and activities from flooding.

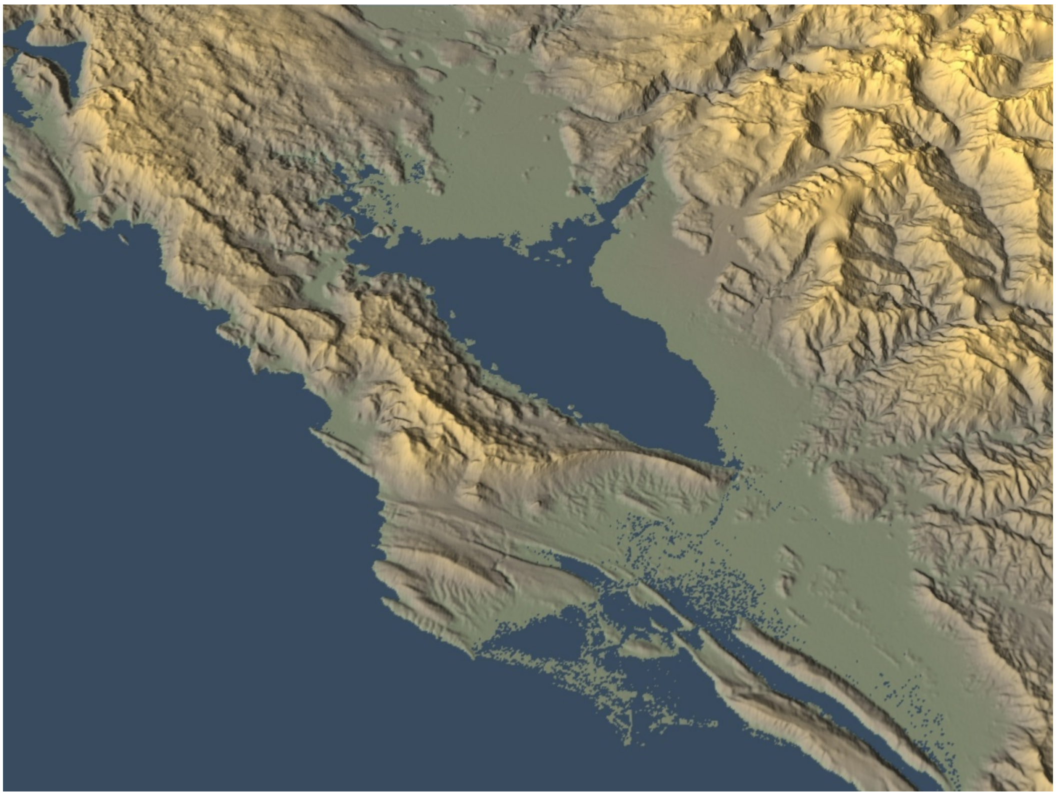

Fig. 4.1 The 3-D visualization of the terrain from altimetry data

In situ meteorological and river discharge data were used throughout the project to validate and calibrate the PHM components. It was found that the HMI meteo-hydrological monitoring network was quite extensive and of good quality, giving essential data to validate the model results even if more stations would be needed in the future to monitor the eastern side affluents of the Moraca river, such as the Cijevna river, Gostiljska, Mrka and Urelja. Furthermore, it is recommended also to have an equivalent monitoring system for the northern Skadar lake Albanian rivers such as Proni-i-Tat, Rjolit and Banus Sica. They have comparable discharges to their Montenegrin river counterparts and contribute substantially to the lake water volume.

The Zeta Plain underground water and stratigraphic information was ensured by CETI and the Geological Survey of Montenegro. Here the lack of recent and higher resolution data was a serious drawback for the modelling exercise, especially the lack of recent and well documented observations on spring locations and discharges near the Malo Blato. Even more fundamentally, the Bojana river Alluvial plain lack of comprehensive stratigraphic and underground water table level observations was a serious disadvantage.

The Skadar lake water level data that are part of the HMI network (stations of Plavnica and Ckla) seem to be sufficient to monitor the water lake levels even if temperature measurements should be added to the sensor suite. It is clear from our analysis that both the Plavnica and Ckla water levels are not very different from the Buna bridge water levels so that the three stations completely define the lake levels. The northern part of the Lake, where Rijeka Crnojevica and the Karatuna inflows take place should be better monitored given the importance of the discharges and the obstruction of the Lisendro bridge.

Regarding the Buna-Bojana-Drin river monitoring system, it is recommended that all stations available, such as the Buna bridge, Bahcallek, Dajc and Fraskanjel will be upgraded and maintained as well as protocols for data exchange developed between Montenegro and Albania that will ensure timely release of data in case of flooding. These data will allow to set up a flood alert system based upon the real time data and the model forecasts. Additionally stations at the Bojana river mouths should also be considered especially for the monitoring of sediment transport and quality.

Thus in conclusion, the present in situ water cycle stations seems to fit the need of a flood alert system if real time protocols will be developed for the timely exchange of data between Albania and Montenegro and the north-eastern river and spring inflow monitoring will be upgraded.

From the natural system condition simulations we have shown that anomalous precipitation conditions can induce flooding of the lake and the Buna-Bojana-Drin river adjacent areas. During the reference time period, Jan. 2006-Dec. 2010, low precipitation and water level winters occurred, in 2007 and 2008, followed by two high precipitation and water level winters, 2009 and 2010. In October 2009 and 2010, anomalous precipitation over the Skadar Lake basin area (see Fig. 3.1.4 and 7.2.1 of Draft Final Report) occurred which induced 200 m^3 s^{-1} flow rate anomalies at the Buna-bridge station (from 800 to 1000 m^3 s^{-1} winter peaks, see Fig. 3.2.30 of Draft Final Report).

The lake flooded areas in the north-eastern part doubled between 2007-2008 and 2009-2010 years. The circulation of the lake is highly variable between years and it is clearly wind driven with important contributions from the river inflows. The large scale circulation is formed by a combination of two gyres, one cyclonic in the northern and the other anticyclonic in the southern part of the lake basin.

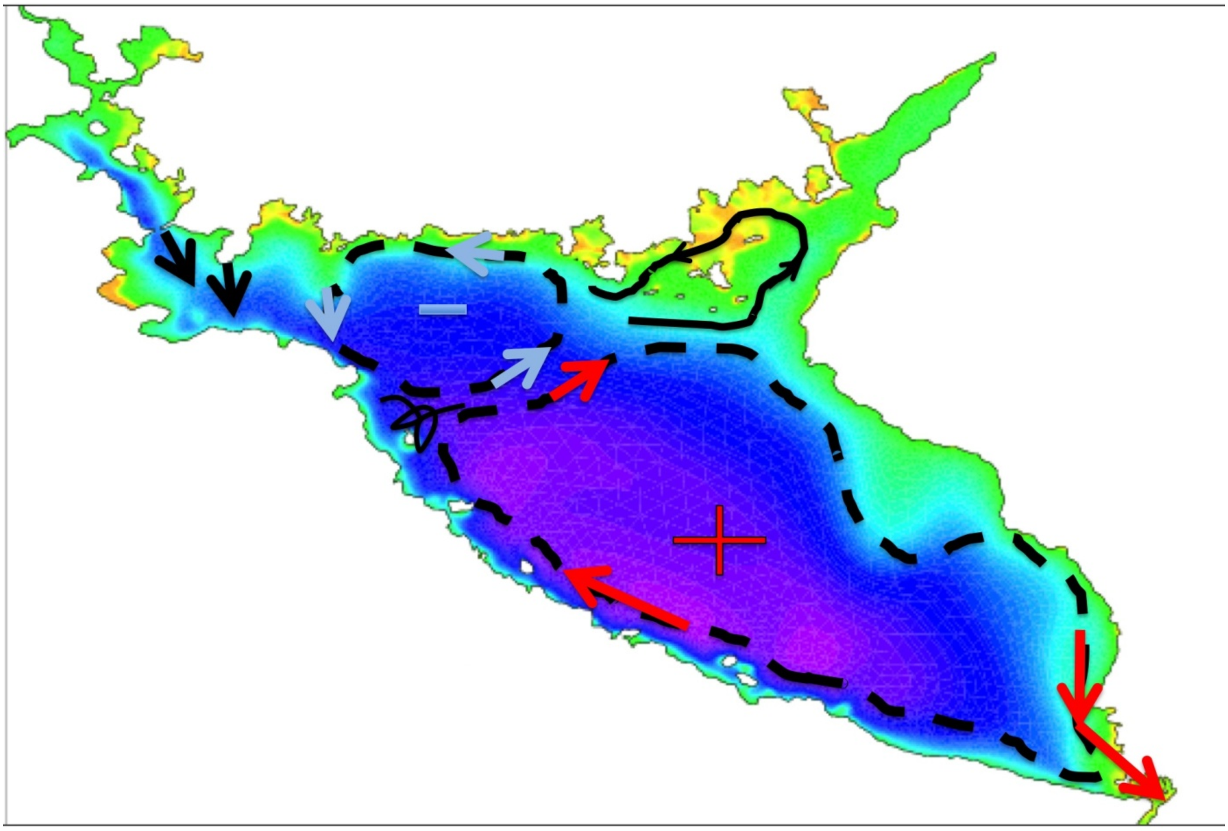

Fig. 4.2 The schematic of the lake circulation showing: the northern cyclonic gyre indicated by the blue arrow, the southern anticyclonic gyre indicated by the red arrows.

The strength and magnitude of these two gyres varies between years: in general we can say that there is a boundary intensified current along the south-western border (See Fig. 4.2 red large arrow) that in some years weakens and a north-eastern border (Albanian) current strengthens. Some years (like 2010) the winter circulation seems not to close into the two gyres but the southern and northern intensified boundary currents remain. Lake temperatures are rather uniform and they vary between 25-27 degrees in September and 5-7 degrees in winter.

The underground water levels in the Zeta Plain show a large seasonal cycle and interannual variability. The Zeta Plain water Table is around 20 m a.s.l., average over the seasons, with a plus or minus 5 meter excursion between winter and summer respectively. The interannual variability is about 2 meters, i.e. half of the natural seasonal cycle and it is associated to the large precipitation anomalies of winters 2009 and 2010. In the Bojana Alluvial Plain the water Table is around 1 m a.s.l and it is clearly connected to the surface river water level regime, especially during flooding events.

The Buna-Bojana-Drin water level regimes are regulated by the Buna bridge outflow which during the winter arrives to a discharge of 800 $m^3 s^{-1}$ in the years 2006-2008 and the Vau-I-Dejes discharges. The latter increases the lake outflow contribution to the flow at Fraskanjel of about 300 $m^3 s^{-1}$ except for the winters 2009-2010 where the flow at Fraskanjel reached 3000 $m^3 s^{-1}$, due to an anomalous discharges at the Vau-I-Dejes dam.

The development scenarios that we have examined show that the Moraca HPP dam system will not impact significantly the natural water cycle regimes, even if the Moraca discharges are up to 300% their natural values during summer (from about 20 to 70 $m^3 s^{-1}$ at the Podgorica station). The lake water level changes during summer are only few percent of the mean water level (20-30 cm differences) and the natural flooding cycles of the lake are marginally changed.

The development scenario 2 shows a highly sensitive response of the Buna-Bojana-Drin river system to the dredging and, given the limited information available, the specific dredging scheme should be carefully tested since it seems to impact the high flood risk of these areas. The conclusions from our experiments do not support the river dredging to be carried out in the short term. Instead different containment efforts should be examined possibly in a future project that should be dedicated to this specific development aspect of the area.

The scenario 3 experiments show that the rivers, considered as lake sources of

pollution, could eventually affect large areas of the lake. In particular the left branch of the Moraca river affect all the northern and central lake areas, especially during the winter months when the circulation is stronger. Urelja and Banus Sica also affect large areas and the latter can affect the water quality of the Buna-Bojana-Drin river system.
Last but not least, the scenario 4 study clearly defined the response of the overall water cycle system to precipitation events occurring the Skadar-Shkoder Lake Basin Area: precipitation events in October-November-December of 2009 and 2010 give rise to Moraca lake water discharges of the order of 1200-1400 m^3 s^{-1} that in turn build with a delay of few days an outflow at the Buna bridge of about 1000 m^3 s^{-1}. Downstream of the lake outflow the flooding is controlled by the Vau-I-Dejes dam system which in January 2010 and November-December 2010 added 2000 m^3 s^{-1} instead of 300 m^3 s^{-1} as normally registered in the 2006-2009 period.