An Interoperable GIS Oriented Information and Support System for Water Resources Management

Pierluigi Cau
Center for Advance Research and Studies in Sardinia (CRS4), Pula (CA) Italy. plcau@crs4.it

Simone Manca
Center for Advance Research and Studies in Sardinia (CRS4), Pula (CA) Italy.

Costantino Soru,
Center for Advance Research and Studies in Sardinia (CRS4), Pula (CA) Italy.

Davide Muroni
Center for Advance Research and Studies in Sardinia (CRS4), Pula (CA) Italy.

Dorian Gorgan
Technical University of Cluj-Napoca, Cluj-Napoca, Romania

Victor Bacu
Technical University of Cluj-Napoca, Cluj-Napoca, Romania

Anthony Lehman
Institute for Environmental Sciences, enviroSPACE
University of Geneva
1227 Carouge, Switzerland

Nicolas Ray[1,2]
[1]Institute for Environmental Sciences, enviroSPACE
University of Geneva
1227 Carouge, Switzerland
[2]United Nations Environment Programme Global Resource Information Database 1211 Châtelaine, Switzerland

Gregory Giuliani[1,2]
[1]Institute for Environmental Sciences, enviroSPACE
University of Geneva
1227 Carouge, Switzerland
[2]United Nations Environment Programme
Global Resource Information Database
1211 Châtelaine, Switzerland

***Abstract*—Important objectives of the four-year enviroGRIDS project encompass the improvement of transnational cooperation, the use of state of the art Information and Communication Technologies for data analysis and sharing and the application of environmental models for monitoring present and predicting future states of the environment for the Black Sea region. In such a transnational context, there is a dire need for the environmental sciences to evolve from a simple, local-scale vision toward a complex, multi-user, multilayered holistic approach. BASHYT (http://swat.crs4.it/) is a Web based, GIS oriented, information and support tool, part of the Black Sea Catchment – Observation System (BSC-OS). It exposes a set of applications for data management, analysis and visualization and a complete server and client side development framework (wiki like) to create Web contents. The core of the portal relies on the hydrological semi distributed SWAT code to model the water cycle and predict the effect of management decisions on water, sediment, nutrient and pesticide yields on large river basins. Furthermore, BASHYT aims at quantifying the interconnectedness between (human and natural) pressures and states of water body receptors at different space and time scales. The aim is to enhance environmental management capacity to assess water resource and to share and process large amounts of key environmental information. Within an experimental and innovative programming environment, modules have been developed to run near real-time applications based on numerical solvers (SWAT is just one example), run pre- and post-processing codes, query and map results through the Web browser. A set of web OGC services and a complete Application Programming Interface (API) are also exposed by the portal. We expect to improve the ways in which land management systems can operate and improve model usability to aid in making management decisions and watershed-scale modeling.**

Keywords—enviroGRIDS; GIS; SWAT; DSS; Argilla; Black Sea Catchment; Mapserver; BASHYT; Hydrology; Interoperability; OGC; Portal

I. Introduction

Prediction, prevention, or minimization of point and diffuse pollution is an open issue for the Black Sea region. The Black Sea Catchment is going through an ecologically unsustainable development and inadequate resource management, which is leading to severe environmental, social and economic problems. The Black Sea ecosystems are endangered by eutrophication, pollution, and irresponsible exploitation of natural resources which resulted in an steadily decline of biological diversity in ecosystems and in a degradation of landscapes. As a matter of fact point and diffuse pollution from priority sources such as oil spills, or insufficiently treated waters, mismanagement of agricultural lands needs decreasing. The complexity of water resources management in such a complex basin represents an increasing challenge to policy makers of the region, where an interdisciplinary approach is needed to design effective management strategies.

By one side, the use of ICT, such as High Performance Computing (HPC) Infrastructures, Geographical Information System (GIS), numerical models, and web-based applications involves major investments in terms of acquisition of quality data and the development of an interdisciplinary approach to the study. By the other side, such technologies can provide a significant contribution in the description of environmental dynamics, simplifying the management, access, share, and analysis of data and providing efficient report production mechanisms. Web portals [1, 2] are becoming strategic gateways where scientists, citizens, stakeholders, and end users can securely use applications, storage and computational infrastructures and services. Analysis and management tools for the environmental sciences need evolving from a local and single-user oriented approach toward a complex, multi-user, and multilayered global vision.

The experience gathered from many EU initiatives, such as, CLIMB (http://www.climb-fp7.eu/) or DRIHM, (http://www.drihm.eu), that ultimately aim at contributing to Global Earth Observation System of Systems (GEOSS) and Copernicus goals, highlights the need of increasing the interoperability abilities for the sharing of information and knowledge between data repositories and service providers from different sources across Europe. So far, many open standards and interoperability services are being considered, such as Web Map Service (WMS) and Web Feature Service (WFS) proposed by the Open Geospatial Consortium (OGC - http://www.opengeospatial.org/), although their use is still limited. Management and analysis of very large and growing volumes of geo-data is challenging the scientific community without clear long term solutions. The main open issues, tightly bound to technological development are: scalability and flexibility of the application level; web data accessibility and security; limitation use of web services. Important objectives of the four-year enviroGRIDS project (http://envirogrids.net/) include the enhancement of transnational cooperation, the use of web-based technologies for data analysis and sharing and the application of environmental models for monitoring present and predicting future states of the environment for the Black Sea region. One particular objective is to contribute to the achievement of the goals of the intergovernmental Group on Earth Observations (GEO), that is leading a worldwide effort to build a Global Earth Observation System of Systems (GEOSS). Two specific goals are recognized to be of paramount importance: to raise awareness of Societal Benefit Issues of the general public and to build regional capacities on Earth Observations and INSPIRE standards and approaches. Such needs have been addressed by developing a Black Sea catchment Observation System (BSC-OS) [3], that integrates several web-based information technologies to exploit complex models, quality data and the EnviroGRIDS storage and Spatial Data Infrastructure (SDI). The BSC-OS portal is composed of a set of loosely coupled components that aim at addressing specific needs: data and catalogs management is provided by the URM portal; model calibration and execution of scenarios is accomplished by gSWAT; data visualization, scenarios development, and report generation is based on BASHYT; eGLE provides a web-based access to training material and lesson execution.

BASHYT is one important effort to develop and promote a innovative environmental management system particularly targeting observational (e.g., agricultural droughts and water quality measurements) and technological gaps for the water domain. During the EnviroGRIDS project, several hydrological models at the catchment's scale and one large implementation for the whole Black Sea Basin have been set up using the SWAT numerical code. The evaluation of historical changes to support environmental monitoring and reporting has been also carried out, leading to the evaluation of the impact on water resources as a result of natural and/or man-made change. BASHYT aims at using such models to assess the state of the water basin and to identify the reasons affecting the conditions. Furthermore, it aims at fostering integration of expertise from various fields to create a lively system where end-users and scientists can cooperatively work and create applications to assess water quality and quantity status.

In this work, BASHYT is examined, providing a detailed description of the architecture and technologies used, and how it has been applied to real case studies.

II. Description of the Framework

BASHYT is web-based software, which relies on environmental models and state of the art Information and Communication Technologies (ICT) to support decision makers in the field of sustainable water resources management. Initially it was designed to expose hydrological applications based on the Soil and Water Assessment Tool (SWAT) [4]. Currently also other models have been deployed on the system such as the General Estuarine Transport Model / General Ocean Turbulence Model (GETM/GOTM) [5, 6] and the OilSpill Module [7]. In this paper, we will describe the information system particularly focusing on the hydrological applications.

BASHYT is a web-based operational tool to share SWAT model applications on the web and to standardize as much as possible the report production mechanism. The system, for the general user, exposes analysis based on the semi distributed "physically based" hydrological SWAT model and on geo-processing tools that make use of large volumes of geographical data. Free software and in-house technologies are combined to transparently and automatically access to and process SWAT data repositories, run and manage the model, and expose web-based user-friendly environmental applications. The system does not require additional software or plugins, but works directly on any web browser, improving the potential for its utilization by water management administrations, being programmable and assessable directly on the Internet/Intranet through any WEB browser (Internet Explorer, Mozilla Firefox, Opera, ecc.).

A. SWAT – the Soil and Water Assessment Tool

SWAT as described by Neitsch et al. (2005) [8] is a watershed-scale hydrological model, developed by the U.S. Department of Agriculture USDA-ARS and Texas A & M University, which allows to simulate the integrated water cycle and to assess the impact of point and diffuse pollution in the medium/long term. The model has been tested successfully worldwide and is supported and farther developed by a very active community [9]. Its application requires specific information on weather, soil characteristics, topography, vegetation and land use. It is computationally efficient and uses readily available inputs, enabling users to study long-term impacts. The model works on two levels: land and routing phase.

Hydrological processes are first simulated in SWAT for the land phase at the HRU spatial unit. HRUs are Hydrologic Response Unit that represent areas with a unique combination of land cover, soil type and management practice. This yields the water, sediment, nutrient, and pesticide loadings to the main channel in each subbasin. The division of a watershed enables the model to reflect differences in evapotranspiration, runoff, movement and transformation of chemicals, etc., for various crops and soils. This improves accuracy of model predictions and gives a much better physical description of the catchment's water balance and water quality.

In the second phase, the water, sediments, nutrients, etc. are routed through the channel network of the watershed to the outlet. The system incorporates a variety of physical, chemical, and biological (Nitrogen, Phosphorus, Pesticide and sediment fate) processes that control the transport and transformation of pollutants within the water body. The water quality module of the SWAT model, based on Qualk 2E as described by Brown et al. (1987) [10], is driven by hydrodynamics, point and non-point source loadings, and key environmental forcing functions, such as temperature, precipitation, solar radiation, wind speed, and light attenuation coefficients.

For each subbasin there is one reach, one outlet, and many HRUs. Water quality and quantity state variables are computed for each subbasin at a daily temporal scale. BASHYT interconnects directly to the ARCGIS SWAT [11] and AV SWATX [12] desktop processing software. Such desktop tools are particularly aimed at creating the input files for the SWAT model. A possible data workflow for the system consists of the following phases:

1) Users upload SWAT project (input / output data) to BASHYT. Earth scientists create their model on their local resources, exploiting the GIS functionalities of the desktop AvSWAT or ArcSWAT programs. When the project has been uploaded, users can utilize the BASHYT web interface to analyze each simulation, to compare simulations or to run new scenarios.

2) Once the project is loaded to BASHYT, it can be calibrated over the enviroGRIDS infrastructure exploiting gSWAT [13, 14]. After calibration it can be loaded back to BASHYT. Calibration is a highly computational consuming process and desktop programs may not be efficient.

3) Scenarios can be run on BASHYT exploiting transparently the computational and storage resources granted by the enviroGRIDS SDI: scenarios execution can be also a highly computational consuming processes as well as time consuming.

The gSWAT system allows the calibration of SWAT models in a flexible manner. gSWAT is built as a distributed system composed of a graphical user interface and a service related component. The BASHYT framework enables earth scientists to exploit transparently the whole EnviroGRIDS computational and data storage resources as well as the components of the BSC-OS portal. Interoperability standards and a single sign on authentication mechanism are used to let users have a single entry point.

B. The information and support system

BASHYT is based on the Driving forces-Pressures-State-(DPS) paradigm, introduced by the European Environmental Agency (similar to the PSR model developed by the Organization for Economic Co-operation and Development - OECD [15]) and also adopted in the EU Water Framework Directive (WFD). Whenever a new SWAT project/simulation is loaded to the BASHYT interface, data are automatically digested by the software and a database is created from a fixed schema. The following sections will expose geodata and simulations on the web through thematic applications:

- Driving forces (D) and Pressures (P): this section exposes two main categories where D and P are grouped in: point and diffuse pollution;
- State of the environment (S): water balance and water quality states are analyzed. Results are viewed on various space and temporal scales (e.g., monthly, yearly, subbasin, basin).

The DPS methodological approach is useful to demonstrate the interconnectedness and estimate the effectiveness of the actions aimed (responses) at solving problems at hand. Driving forces stand for processes underlying to environmental changes such as land use or demographic development. Pressure indicators measure the level of environmental impairment (e.g., total quantity of phosphorous in chemical or biological fertilizers applied per hectare of agricultural land). State indicators are the conditions of the environment (e.g., average concentration of phosphorous in surface waters). States have impacts on different receptors causing damages such as loss of biodiversity, eutrophication of surface water or water becoming unsuitable for drinking. Responses (policies and measures) can be manually designed to solve problems and then simulated within BASHYT.

The environmental applications are exposed through a "user friendly" interface, which supports a coherent management of the Driver, Pressure, State indicators as distributed (in space and time) catchment's variables. This approach encourages the user to increase the awareness of the effects of subjective judgments or misjudgments on the final result. Through its thematic sections, users are guided to analyze pressures on the environment from natural (e.g., climate) and anthropogenic (e.g., land use) sources and improve the understanding of the complex watershed system. The DPS "Conceptual Model" represents the causal links between current human activities (D), the pressures they exert (P), and the state (S) of the environment. Responses to the problems at hand or more generally Scenarios of interest can be run on BASHYT and compared to any other scenarios. Water managers can design management strategies to solve environmental problems and evaluate the performance of the choices through the "compare scenario section". The SWAT code is employed to evaluate the performance of the response, on the basis of the chosen indicators. BASHYT reads the SWAT input/output (IO) and dynamically produce standardized reports, making the analysis of the complex SWAT IO considerably easier.

The GIS analysis and visualization tools help identifying critical areas (e.g., the major contributors to nutrient losses or affected by desertification processes) and prioritize critical sub-areas in order to develop a multi-year management analysis. This analysis can be essential, for instance, to reduce the nutrient impact from point and non-point source pollution to downstream water bodies or to design and evaluate sub-regional and regional remediation strategies through the DPS conceptual framework.

BASHYT also exposes an interface to run the SWAT model directly from the Web, where climate change scenarios can be created in an easier way. In the back end, server side procedures:

- Process climate data to produce new input file
- Run the model on the EnviroGRIDS infrastructure (gSWAT) or in the "in house" HPC environment
- Post process results to be viewed in BASHYT

We aim at improving model usability at all levels to aid in making management decisions and watershed-scale modeling.

III. Architecture and Technologies

BASHYT comprises computing and storage resources, data, and a complex software system composed of a relational database management system, visualization software, numerical applications and geo-processing tools. Interoperability is of paramount importance because, in such a system, heterogeneous data sources (databases and filesystem), computing resources and services are shared among the different components of the BSC-OS Portal. Users, logged on BASHYT, transparently access to the shared physical resources, such as a HPC cluster environment to submit jobs, and use catalogs of Geo data or applications found in different domains and organizations. Within BASHYT, the in-house HPC infrastructure is exploited to run the SWAT model as well as all geo-processing phases required by the reporting production mechanism and in particular by the hydrological applications. The data flows, the data storage, and the application workload have been designed in a non-conventional fashion to hide the user the complexity of the infrastructure. The system is more than a simple sum of modules: it is a software to consume and expose Web services for data mapping, querying and sharing, processing and distributing, with a high degree of freedom.

One important component of the system is the Argilla engine [16], a Java development framework to construct web pages and applications. This can be thought of as an open interoperable, and extensible development framework to build spatially enabled web-based applications. It is based on the Model View Controller (MVC) architecture. The MVC architectural pattern has been used to isolate business logic from input and presentation, enabling, for each component, independent development, testing and maintenance [17, 18]. Our MVC software implements the web template system, which is a fast and flexible processing system for web content management and application development, making the programming features available to developers with almost-zero learning curve. This increases developer productivity by reducing scaffolding code when developing web, GUI, database/GIS or any web-based application.

A. The data infrastructure

We have designed a new prototype of a distributed spatial infrastructure based on SpatiaLite (http://www.gaia-gis.it/), particularly useful for large distributed data-intensive applications based on the SWAT model. While sharing many of the same goals as other distributed systems, our design has been driven by observation of our application workload and technological environment, both present and expected. This has led us to reconsider the traditional choice of one comprehensive PostGIS database (which still keeps its validity when dealing with a limited number of watersheds) and explore radically different design points. PostgreSQL/PostGIS system could not be flexible enough to meet the requirements of scalability in a regional/continental context where virtually hundreds and even thousands of basins needed to be simulated.

Given the amount of spatial data required for cases such as the Black Sea watershed scale model, we decided to experiment a solution based on the SQLite technology with spatial extension (SpatiaLite). SQLite is an embedded database engine distributed as a common library; it is widely used on many popular applications like Mozilla Firefox, Apple Mac OS X, Google Apps and many more. Spatialite provides a large set of spatial functions and data structures like what PostGIS does for PostgreSQL.

Inputs and outputs of the SWAT model are stored in SpatiaLite database files. Each DB file contains one model set up (one watershed and many simulations) that is accessed by BASHYT when the user activates the watershed in the portal. This choice guarantees good performance when a large number of simulations/watersheds are accessed from several users at the same time. Within the EnviroGRIDS project, we have set up a test environment of 5 servers with 8 cores each. The application can be scaled and enlarged on a dedicated computing/storage environment (typically using virtualization mechanism) to meet user workload. Each node of the system contains many SpatiaLite DB files that are controlled by dedicated instances of the application framework. BASHYT acts as a workflow manager posting requests and getting results. In this configuration the computing and storing tasks are resolved outside the web framework.

The nature of the SQLite engine (without dependencies) assures high scalable scenarios, since all operations work as in common read/write filesystem. Using this approach, we are gaining the power of a complete transactional RDBMS, without the need of external server process to query and with a useful portability freedom. SQLite offers the capability to load personal or third party extensions (shared libraries), written in C or other languages. This mechanism can be used to straighten the SQL functionalities of the engine or override its functions. This structure, combined with the absence of a dedicated DBMS process, reduces lags and resources needed by network communications. BASHYT commands also the map and graph rendering and other applications for the report production mechanism. The application includes the libsqlite library to manage the whole database repository. When one (or more) SWAT simulation is uploaded or executed in the server, an ETL (Extract, Transform, Load) procedure is run to format the model input/output (IO) and import it into one or more SQLite DB file (internal flow). The SQLite architecture does not impose restrictions on distribution, size or number of files. Each DB file is completely independent from the others. The main issue to consider when using SQLite is its strict dependence on the filesystem. SQLite inherit any fault coming from the layer below without chance for recovery. Distributed network filesystems suffer often from file locking bugs. In general this can cause SQLite data corruption or inconsistency in high traffic volume contexts. In SQLite, one reading operation locks all write requests on files and vice versa. In high concurrency conditions, when read/write actions alternate themselves with high-frequency, this could represent a performance bottleneck. Although our system aims at working in high volume data and traffic situations, the above issues are minor, because end-user operations are read only operations. As a matter of fact all write operations are done by the ETL procedure to import SWAT IO. During this task, the simulation is not available to users for reading.

The SQLite and its SpatiaLite extension engine have been carefully and positively tested in real situations with a large number of competitive access to the web environment. On one hand, this technology can be considered still young and does not have the reliability level or spatial functions of other engines like PostGIS. On the other hand for a limited controlled use, SpatiaLite meets our needs, although some changes on JDBC SQLite driver for Java were needed to let it work on our distributed system.

B. The GIS visualization

The GIS rendering is optimized using the Open Source MapServer (http://mapserver.org/) technology. This is accomplished, exploiting the scripting languages capabilities to access the MapServer CGI and OGC (WMS, WFS) interfaces. MapServer works as a map engine providing a spatial context where it is required. On the client side, AJAX (web 2.0) technologies, such as the msCross [19] cross-browser interface, is customized to allow users dynamically display and browse the geographical information layers. Our system inherits all the Geographic Information System (GIS) capabilities granted by these technologies. The system aspires to become desktop like for the geospatial data management and analysis, image processing, graphics/maps, spatial modeling, and visualization productions. Complex spatial and alphanumeric query capabilities have been implemented to meet requirements and specifications of the SWAT data structure. GIS functionalities have been also developed from scratch and/or adapted to serve sophisticated applications to query and analyze spatial data produced by the models. In this way users can easily display on maps complex analysis and queries. It is possible, for instance, to execute spatial queries on any simulation map and get a report on the different SWAT output ready to use.

BASHYT supports a multitude of raster and vector data formats (e.g., ESRI Shapefiles, PostGIS, Oracle Spatial, MySQL, OGC web specifications WMS and WFS) exploiting the functionalities of the Geospatial Data Abstraction Library (GDAL - http://www.gdal.org/) and the OGR Simple Feature Library (http://www.gdal.org/ogr/).

C. Interoperability and the web development environment

BASHYT exposes a fully programmable environment accessible directly from the web, wiki like, and an Application Programming Interface (API), that specifies how software components interact with each other (http://swat.crs4.it/Documentation/).

The API we developed is a particular set of rules and specifications that an external software program can follow to access and make use of the services and resources provided by BASHYT. The API defines the "vocabulary" and resources request conventions (e.g., function: getFile()). It includes general specifications for data structures, object classes, and protocols that are to be used to communicate with the framework. The API enables not just to access data but also allows writing and creating new contents exploiting the server side report production mechanism of BASHYT.

The API offers a uniform way of identifying and accessing resources, and thus increasing the interoperability between applications. Web applications are mostly data-driven, and it is easy predictable that they will benefit from the increasing interoperability of our framework. Other web applications of the BSC-OS portal, such as eGLE (http://cgis.utcluj.ro/egle-demo/), exploit our system and its capabilities to merge in new ways information, model outputs, or simply territorial data. The eGLE e-Learning environment is used to support the development and the execution of lessons in Earth Observation domain.

In addition, BASHYT exposes a fast and flexible processing system on the Web (Wiki like) for web content management and application development. On the web, client and server side code can be edited to create complex web applications. Earth scientists, through a dedicated web editor, write their own GUI's and applications. The development process (e.g., layout, connection and query to db, etc.) can be controlled on the fly by switching from edit to view mode. No compilation is required: this increases development or maintenance productivity of web based applications. When ready and validated, applications can be made public by the administrator. Hydrologists, scientists, web designers, and developers are asked to concentrate on generating web contents without getting bogged down in programming matters, making the whole process of developing, updating and maintaining portals significantly easier.

BASHYT development capabilities enable to write services merging server side and client side codes within a uniform web based interface. Dedicated sections of the development framework exposes modules that enable to shape XML objects for the production of graphs, maps, tables, PDF reports, and forms. These modules permit the massive use of preset schemas stored in the database (virtual file system) in a structured form (XML). Each object refers to its schema and describes parameters (e.g., to control layout) and data sources. The development framework exposes GUIs to produce in a easier manner these objects.

IV. THE BLACK SEA CASE STUDY

The Black Sea is suffering from poor water resource management, partially due to the lack of effective transnational cooperation, limited data sharing and the lack of scientific tools to bring together scientists, administrations, social partners, and environment protection agencies. Exchange of information, sharing of good practices, and working together towards common solutions in a multicultural environment are still open challenges. BASHYT aims at contributing to some of these issues by bringing several new emerging information technologies to build a data-driven vision of the planet that is feeding into models and scenarios to explore the past, the present and the future of the Earth and, in the specific context of the enviroGRIDS project, particularly targeting the Black Sea regions. A double objective achieved during the project is the set up of a complex modeling system for inland water analysis and protection exposed on the web by the BSC-OS portal. Within BASHYT, applications are grouped in different thematic sections:

- Data Manager: user can choose which model and watershed to analyze.
- SWAT: users access to the "Watershed" and "Scenarios" sections.

Watersheds in different regions around the word have been deployed on BASHYT, as shown on figure 1, to obtain the needed information and analysis.

In the "SWAT" section, the output of the model is used to produce reports for the watershed organized in the DPS structure, while in the "Basin" section, a physical description of the territory is produced, taking into account topography, land use, soil and climate. In figure 2, the Digital Elevation model for the Black Sea is shown. Reports are based on the SWAT IO data and default parameterization datasets. In figure 3, under current land use and climate condition, the BASHYT exposes the distribution of the water balance components at the subbasin spatial scale for the Black Sea watershed. Over a 38-year simulation period (1970-2008) the main hydrological components assessed on a monthly basis reads as follow (figure 4): average (standard deviation) precipitation is 59.02 mm (16.14). Average evapotranspiration (standard deviation) is 33.9 (20.35). Average water yield (standard deviation) is 23.89 (6.84). Within the same environment, users can assess analysis for the other watersheds in the same standardized fashion.

The components of the hydrological balance as well as the other SWAT output variables, computed on a daily time step for each HRU, subbasin or river reach are integrated and assessed by BASHYT back-end procedures to expose on the web spatial and temporal analysis (outputs are presented with time series graph, tables and spatial representations by means of dedicated interactive web GIS within the portal).

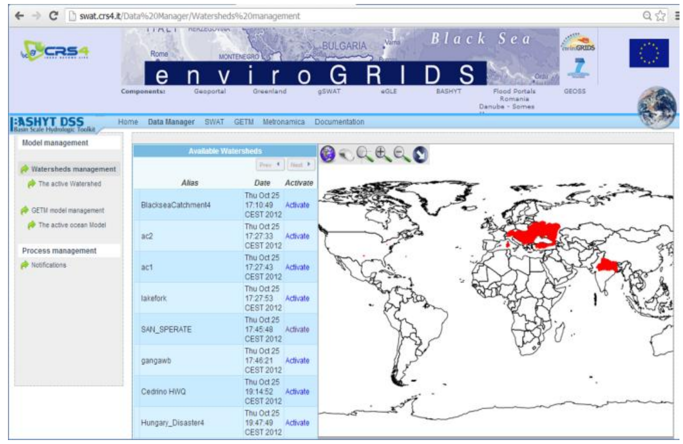

Fig. 1. The data Manager section. The interface shows all watershed that have been deployed on BASHYT. The Black Sea watershed is clearly visible in the center.

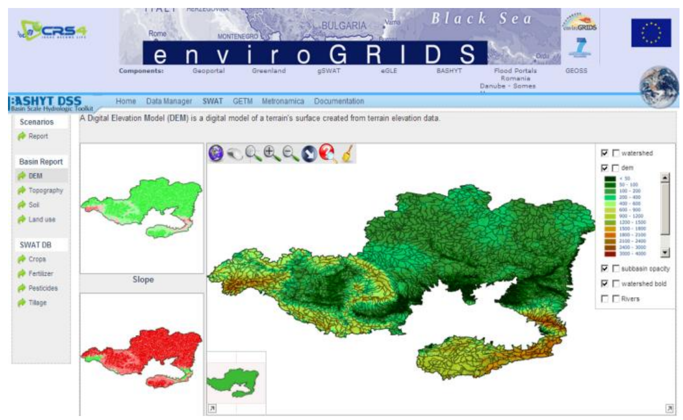

Fig. 2. Digital elevation model viewed on the BASHYT interface for the Black Sea watershed..

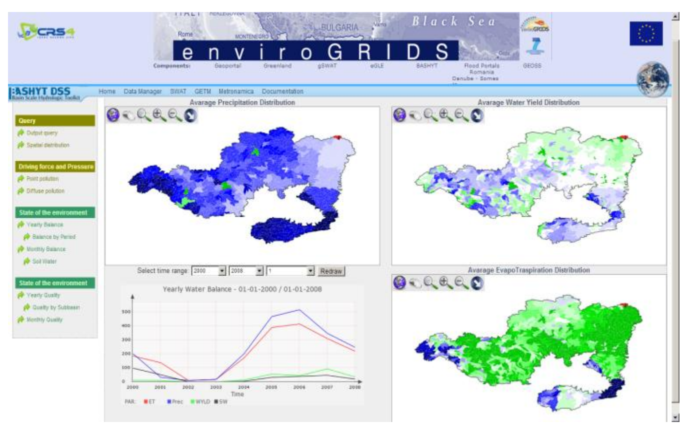

Fig. 3. Water Balance. The water balance is mapped on the Web GIS. Automatic procedures read the SWAT results and produce reports in the form of maps, charts or tables.

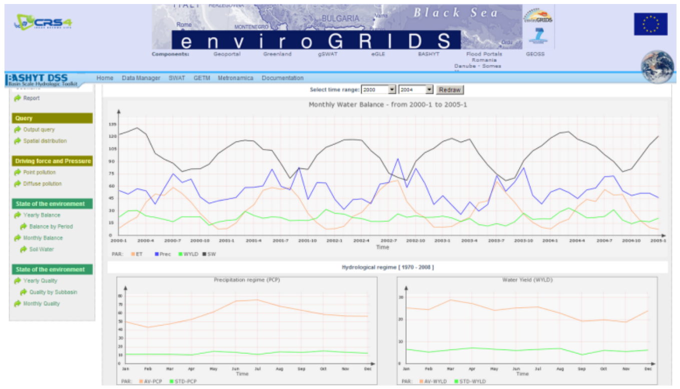

Fig. 4. Water balance for the whole Black Sea basin. Water balance is computed at the subbasin scale and daily time step. Processing algoritm in the back-end integrates these values to assess watershed avarage values.

A methodology to evaluate agricultural drought conditions, applied also to the Black Sea basin, has been set up during the project. Drought is a temporary condition of relative scarcity of water resource compared to values that can be considered normal for a period of time and on a region [20]. We may distinguish between meteorological, agricultural, hydrological and operational drought [21, 22, 23]. While the meteorological drought is identified on the basis of a deficit of precipitation, the agricultural drought depends on the soil moisture deficit, which is dependent on many factors such as the precipitation regime and weather, the soil characteristics and the evapotranspiration rate. The persistence of agricultural drought condition produces negative effects both on natural vegetation and agriculture. Drought periods have an important impact on water supply system causing water shortage, negatively affecting the economic and social system.

The Soil Moistures Deficit (SMD) agricultural drought index implemented in BASHYT is a variation of the approach proposed by Narasimhan [24]. SMD is calculated on a monthly basis as proposed in the formula (1) and at the subbasin spatial scale. For the given month the index expresses the ratio between the anomaly of the monthly value compared to the average multi-annual data, and the difference between the maximum and minimum values for the entire time series available (for the Black Sea: 1970-2008).

The SMD index reads as follows:

$$SMD_i = \frac{SW_i - SW_i^{mean}}{SW_i^{\max} - SW_i^{\min}} \qquad (1)$$

where SMDi is the deficit of soil water content of months i, SW_i the monthly average soil water content of month i, SW_i^{mean} the long-term average of the soil water content of month i, SW_i^{min} and SW_i^{max} respectively the minimum and the maximum soil water content of month i for the entire simulation.

The index can be positive or negative, signifying for a given month a surplus and a deficit of water content respectively for a given soil. BASHYT automatically quantifies the anomaly magnitude of the SMD drought index, mediated on each month and on a subbasin spatial scale. In figure 5, for July 2002, the spatial distribution of the monthly SMD index is provided. Yellow/orange colors represent area under water stress while green colors show high water content values.

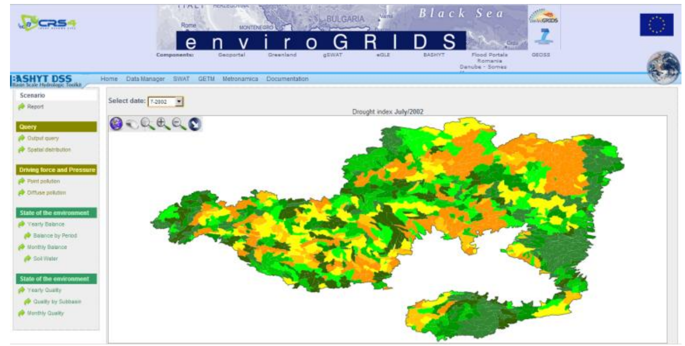

Fig. 5. Spatial distribution of the monthly SMD index (July 2002). BASHYT automatically quantify the SMD drought index. Yellow/orange areas show drought conditions while green colors show high water content values.

The correct characterization of the spatial and temporal distribution of rainfall, of the land use, soil and anthropogenic pressures are strategic to represent the complex dynamic of surface and ground water resources and to design its sustainable use.

V. Conclusions and Future Work

The BASHYT provides a framework for analyzing management scenarios based on valuable data and computing resources over the Web. The system is based on client/server architecture and can be used within the Internet/Intranet cyberspace, offering to the community services to extract meaningful information about the environment. The DPS conceptual model can be used as a base for environmental management allowing the linkage between pressures and state-indicators. The application of this causality model and the use of GIS capabilities in combination with the SWAT hydrological model have the advantage of allowing the spatial visualization and complex analysis and better integration/exploitation of the different indicators on which water and territorial management is based.

In general, the web interoperability is of paramount importance to control the redundancy of replicated datasets, and it allows users to retrieve updated certified information, avoiding the latency due to administrative and technological barriers.

As a matter of fact, environmental analysis will benefit from near real-time data processing, making territorial management and planning more efficient. The BASHYT system can contribute to the development and the exchange of information relative to the environment, offering administrations standardized procedures to manage, control and study water resources. The development of a web-based framework such as BASHYT offers an infrastructure for optimizing data-sharing and solving application development problems in a multi-user environment. It improves model(s) usability by simplifying data I/O flow management and application development to aid in making management decisions.

The current version of the software has been used to expose on the web various SWAT model implementations for different regions of the world. The Black Sea case study is just one example. The system address the subjects related to SWAT data archiving, distribution and interpretation on a web-based environment through the use of interoperability standards and automated procedures. Improved capabilities for coordinating, accessing, sharing, and using environmental and geo-data have been also implemented in the system. Building web applications cooperatively through the web development environment contributes to the creation of enlarged multi-cultural working groups to improve public consciousness for environmental problems and strategic remediation strategies on a transnational scale.

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REFERENCES

[1] Berners-Lee, T.: Weaving the Web – The Past, Present and Future of the World Wide Web by its Inventor. Texere (2000)

[2] Berners-Lee, T., Hall, W., Hendler, J.A.: A Framework for Web Science (Foundations and Trends(R) in Web Science). Now Publishers Inc., (2006)

[3] D. Gorgan, P. Cau, K. Charvat, D. Rodila, V. Bacu, A. Jonoski, A. Van Griensven, P. Horak, K. Abbaspour, S. Manca, G. Giuliani, N. Ray, A. Lehmann, 2010. Requirements and specifications for the development of BSC-OS Portal. Technical report (enviroGRIDS_D61) enviroGRIDS – FP7 European project.

[4] Neitsch, S. l., J. G. Arnold, J. R. Kiniry and J. R. Williams. 2005. Soil and Water Assessment Tool. Theoretical documentation. Version 2005. Blackland research center - Texas agricultural experiment station. Grassland, soil and water research laboratory - USDA agricultural research service.

[5] H.Burchard, K.Bolding, L.Umlauf. GETM, source code and test case documentation. Version pre 1.8, http://getm.eu.

[6] L.Umlauf,H.Burchard,K.Bolding.GOTM, sourcecode and test case documentation. Version 4.0. , http://www.gotm.net.

[7] A. Vargiu, E. Peneva, S. Manca, M. G. Mulas, F. Murgia, M. Pintus, C. Soru,R. Biella, P. Cau, 2010. A web based interface for coastal zones modelling: a test case for the Orosei Gulf in Sardinia (Italy). Procedings of the Phisics and Estuaries and Coastal Seas (PECS) Conference, Sri Lanka – Colombo, 09-2010.

[8] S.L. Neitsch, J.G. Arnold, J.R. Kiniry, R. Srinivasan, J.R. Williams, "Soil and Water Assessment Tool, User's Manual". Published 2002 by Texas Water Resources Institute, College Station, Texas

[9] Jayakrishnan, R., R. Srinivasan, C. Santhi, and J.G. Arnold. 2005. Advances in the application of the SWAT model for water resources management. Hydrol. Process. 19(3):749-762.

[10] Brown, L.C. and T.O. Barnwell, Jr.. 1987. The enhanced water quality models QUAL2E and QUAL2E-UNCAS documentation and user manual. EPA document. EPA/600/3-87/007. USEPA, Athens, GA.

[11] Francisco O., V. Milver, R. Srinivasan, and C. Janghwoan, ARCGIS-SWAT: a geodata model and GIS interface for SWAT. 2006. Journal of the American Water Resources Association.

[12] Di Luzio, M., R. Srinivasan, and J. G. Arnold. 2002. Integration of watershed tools and SWAT model into BASINS. J. of the American Water Resources Association. 38(4):1127-1141.

[13] Mihon D., Stefanut T., Bacu V., Rodila D., Abbaspour K., Kokoszkiewicz L., Rouholahnejad E., van Griensven A., and Gorgan D., Grid Based Hydrologic Model Calibration and Execution. CSCS-18, International Conference on Control Systems and Computer Science, Bucharest, Romania, 24-27 May, 2011.

[14] Bacu V., Mihon D., Rodila D., Stefanut T., Gorgan D., gSWAT Platform for Grid based Hydrological Model Calibration and Execution. ISPDC 2011 Conference, Cluj-Napoca, July 2011.

[15] OECD. OECD –Environmental Indicators- Development, Measurement and Use. Organization for Economic Co-operation and Development. http://www.oecd.org/dataoecd/7/47/24993546.pdf.

[16] P. Cau, G. C. Meloni, S. Manca, C. Soru, D. Muroni. A Java Based Framework Optimized for Scientific Modeling and Analysis, International MultiConference of Engineers and Computer Scientists 2011 Vol. 1 (IMECS), Hong Kong (2011), ISBN: 978-988-18210-3-4.

[17] Burbeck, S.: Applications Programming in Smalltalk-80: How to use Model–View–Controller (1987)

[18] Reenskaug, T.: Models, views, controllers. Tech. rep., Xerox PARC (1979)

[19] S. Manca, P. Cau, E. Bonomi, A. Mazzella. 2006. The Datacrossing DSS: a Data-GRID Based Decision Support System for Groundwater Management. Second IEEE International Conference on e-Science, Amsterdam, December 4-6. ISBN: 0-7695-2734-5.

[20] Rossi G.. 2000. Drought Mitigation Measures: a Comprehensive Framework. In Vogt J.V. e Somma F. (eds.), Drought and Drought Mitigation, Kluwer Academic Publishers, pp. 233-246.

[21] Palmer, W.C., (1965). Meteorological Drought. Research Paper No. 45, U.S. Department of Commerce Weather Bureau, Washington, D.C., 58 pp.

[22] Gibbs, W.J., Maher J.V., (1967). Rainfull deciles as drought indicators. Bureau of Meteorology Bulletin No. 48, Commonwealth of Australia, Melbourne.

[23] McKee, T.B., N.J. Doesken and J. Kleist. 1993. The relationship of drought frequency and duration to time scales. Preprints, 8th Conference on Applied Climatology, 17-22 January, Anaheim, CA, Amer. Meteor. Soc., 179-184.

[24] Narasimhan, B., and R. Srinivasan. 2002. Development of a Soil Moisture Index for Agricultural Drought Monitoring Using a Hydrologic Model (SWAT), GIS and Remote Sensing. Texas Water Monitoring Congress. September 9-11, 2002. Austin, TX.