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DEVELOPMENT OF A CLOUD APPLICATION FOR SUPPORTING WATER RESOURCES MODELING

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Modeling of water resources is increasingly comprised of multidisciplinary collaborative tasks that in future may rely on development of cloud applications. Cloud applications have the potential to (1) collect all water-related and other relevant data (weather forecasts, climate variations, urbanization, population and economic growth, etc.), (2) create common platform for data access and web service development and (3) develop specialized web services for solving water issues. Data sources and web services can be integrated and used for water modeling tasks via cloud computing applications as the one demonstrated here.
The presented cloud application for supporting water resources modeling is built on three latest advancements in computer science and technology: Cloud Computing, Service Oriented Architecture and web Geographic Information Systems. The cloud application integrates three web services: (1) web service for geospatial data management (2) web service for supporting water resources modeling and (3) web service for water resources optimization. The cloud application advantages over previous technologies are in accessibility, availability, flexibility in adding new components, scalable computational power, internet-based collaboration platform and dissemination of valuable information to stakeholders and general public.

INTRODUCTION

Population growth, higher living standard, power generation, food production and industry are among the main factors for increased water demand. Climate change puts additional pressure on water management for justified and equitable distribution of water resources between all users and functions. Consequently, the main challenges are how to develop and manage water systems starting from small to large scale basins in an integrated and sustainable way. Planning, designing and management of water resources inevitably need advanced modeling for addressing technical, economical, social and ecological aspects.

Water resources modeling (WRM) is usually performed by computer models of the real world. Model structure, input data, objectives and other hypothesis about the real world processes are often uncertain. Future events are unknown and every assumption affects model output e.g. model predictions or forecasts. In the last decade advances in ICT (Information and Communication Technologies) significantly improved WRM leading to improved management of engineering, economic, social, ecological, hydrological and institutional aspects of complex multifunctional water systems. WRM contributes to improved design, implementation, management and knowledge of the water systems.

Most existing water modeling systems are still available as stand-alone applications, frequently relying on GIS (Geographic Information Systems) that provide the framework for management and integration of all geo-spatial data. Recent advances demonstrate transition to web-based applications, using similar GIS frameworks [1]. There are successful examples of open source water modeling solutions [2] [3], while other solutions are combination of open source and commercial software components, creating web services for distributed and interoperable hydro information system [4].

The approach presented in this article is a relatively new concept for development of cloud WRM application. The main objective is to create a cloud application available all the time, accessible from everywhere and requiring only a web browser to be used. The cloud application is conceived to contain all necessary data and information concerning water resources and to provide a platform for development of specialized web services. The created web services can be simultaneously used by multiple users that are geographically dispersed, therefore enabling web-based collaborative environment. All data, models and additional information are stored on the cloud in standardized formats and can be accessed from everywhere at any time. The cloud application is also same for all users using the system. This solves issues of data portability and application versioning. The cloud application can also be flexible for adding additional web services. It can be scalable, interoperable and can work in distributed environment. Such WRM cloud application is one of the most feasible solutions for future development of integrated water modeling systems where all data, services and processing are carried out on one common platform enabling integrated management of the physical system in question that addresses various economic, social, ecological and other objectives.

The WRM cloud application presented here demonstrates the integration of the following web services:

1. Web service for geospatial data management.
2. Web service for supporting WRM.
3. Web service for water resources optimization.

It is a prototype cloud application developed using several programming languages (JavaScript, AJAX, PhP), additional applications (GeoServer, PostgreSQL, PosgGIS), libraries (OpenLayers), geospatial standards (OGC), protocols (WMS, WFS, WFS-T) and others additional components. All components and software packages used in the development of the application are open source. The design and the system components allow easy upgrade of the system and its interoperability, distribution and scalability.

MAIN CONCEPTS AND TECHNOLOGIES

The three main concepts and technologies of (1) Cloud Computing, (2) Service Oriented Architecture (SOA), (3) web GIS and their integration for water management applications motivated the development of the cloud application for supporting WRM.

Cloud computing is the latest buzz word in ICT. The concept of cloud computing is “only a web browser is needed” while everything else is in the cloud. Data, models and processing software are all components that reside in the cloud and are available "on demand" anytime and everywhere. Users only need internet connection and browser to use the system. This concept is somewhat similar to the electricity grid where we just plug in our devices and use them without understanding the infrastructure behind. Cloud computing [5] also creates new possibilities and advantages for companies and users. This is demonstrated by the fact that the largest IT companies like Google, Facebook, Apple, Microsoft, and Amazon are investing in their cloud computing facilities.

Service Oriented Architecture (SOA) [6] defines a group of rules for design, development, integration and implementation of information systems. The key idea behind SOA is how to integrate and connect various information system components. SOA define components interfaces and communications protocols using messages in XML (eXtensible Markup Language) format. SOA enables previously developed components and applications, various programming languages and different platforms to be joined into one integral solution.

Third and crucial concept used in this application is web GIS. GIS provides integration framework for modeling in any domain with geospatial information (water, climate, population, etc.). Almost all information's in WRM are geospatial in nature. Web based GIS latest standards and tools allow development of fully distributed web applications, making the Internet as the new medium for using GIS systems [7]. The presented cloud application for supporting WRM demonstrates one successful implementation of the latest web GIS technologies and standards.

CLOUD APPLICATION WEB SERVICES

The previous sections introduced the main concepts and technologies for development of the cloud application for supporting WRM. In this section we will present the software components, technologies and programming languages used in the development. These were carefully selected to allow further system development and upgrade.

The architecture of the cloud application is based on SOA and presented on Figure 1. The arrows in this figure represent communication between the different web services, as they have been introduced earlier. In the following we will describe the three different web service components, together with the technologies used for their implementation.

1. Web service for geospatial data management.

The web service for geospatial data management is composed of two main components: web application GeoServer and relational database HMak created in PostgreSQL and PostGIS. The relational database HMak stores relevant water resources related data (river network, canals, demand locations, such as towns or cities, or, irrigation fields, etc.) as well as data for the web service for supporting WRM and the web service for water resources optimization.

GeoServer is a middle component that can connect to more data sources and provide data to other components using Open Geospatial Consortium (OGC) standard protocols (WMS, WFS, WFS-T). GeoServer abstracts data sources and provides data access platform for various web services. In the current implementation, the web service for supporting WRM is connected to GeoServer using WFS-T protocol. WFS-T protocol is composed of XML messages and it is asynchronous or “on demand”.

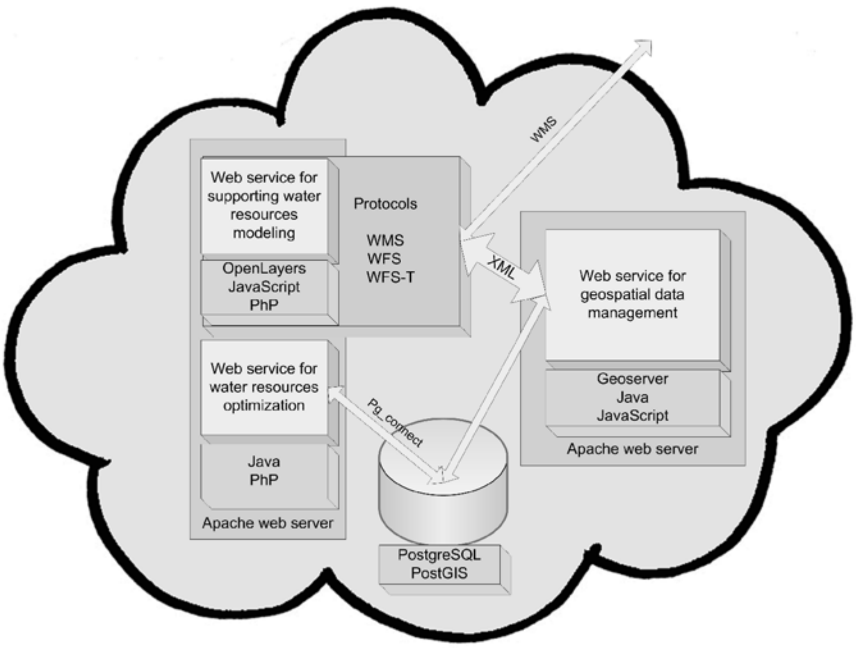

Figure 1. Architecture of the cloud application for supporting WRM.

2. Web service for supporting WRM

The web service for supporting WRM is developed using OpenLayers library and additional code with the programing languages JavaScript, AJAX and PhP. The web service geospatial capabilities are supported by OpenLayers library that support OGC standards (WMS, WFS, WFS-T, etc.). The library gives possibility to draw, edit, delete or modify vector geospatial data online. In the current implementation, the web service is connected over WMS to Google map servers and Open map servers and uses these layers for providing background maps. The web service for supporting WRM over WFS-T connects to the GeoServer and indirectly with the HMak database. HMak database stores six geospatial vector layers: rivers, canals, reservoirs, inflow, users and agricultural areas. Attribute tables are defined and stored for each layer, together with the geospatial data, same as in GIS. The web service provides a toolbar for working with geospatial objects from the six vector layers and developing the water resources model shown on figure 2. Also, the web service provides the interface to enter attributes data to the objects. When a geospatial objects is selected, JavaScript code is activated that reads attributes data from HMak and fills the data under the tab “Attribute Info”. Users can change this data and store it back to HMak. In the current demonstrator implementation attribute data is still relatively simple (e.g. river attributes are Name, GID (unique identification), Id, Category and Goes_in – to indicate flow direction), but the possibilities for extending every object with additional information are possible.

An example model representation using these objects was developed using the web service, by entering rivers, canals, reservoir, users, and agriculture areas, as shown on figure 2. Together with the geospatial data, sample attribute data was provided for every object. Such model representation can in future be extended to provide all inputs needed for invoking computational algorithms for simulation modeling.

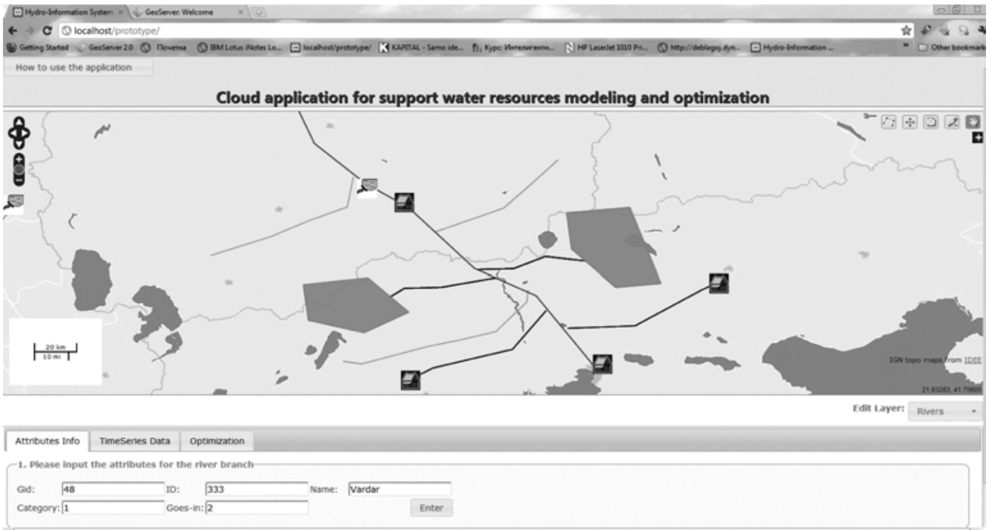

Figure 2. Model representation of a river basin created with the service for WRM.

3. Web service for water resources optimization

The web service for water resources optimization is demonstrated via a custom Dynamic Programming (DP) application developed in Java together with a suitable web interface. This application is based on the dynamic programming algorithm provided in [8] for calculating optimal reservoir operation that simultaneously satisfies the objectives for flood control, downstream water demand and recreation on the lake reservoir. The application works with 5 input tables: reservoir inflow, total demand, upper flood limit, lower recreation limit and reservoir discretization as shown on figure 3. The weight factors in tables Demand, Flood and Recreation describe the relative importance of satisfying the three objectives.

The web service has web interface for entering data, performing basic data quality checks and uploading of the data into HMak database. The execution then starts the dynamic programming (DP) algorithm, which uses the uploaded data and provides the results on a separate web page. Result of this application is optimal reservoir operation in terms of reservoir releases.

Inflow	Demand	Flood	Recreation	Discretization
Int TS	Int TS	Int TS	Int TS	Double Discretization
Double Inflow	Double Demand	Double Flood	Double Recreation	
	Double Weight	Double Weight	Double Weight	

Figure 3. Input tables of the service for water resources optimization.

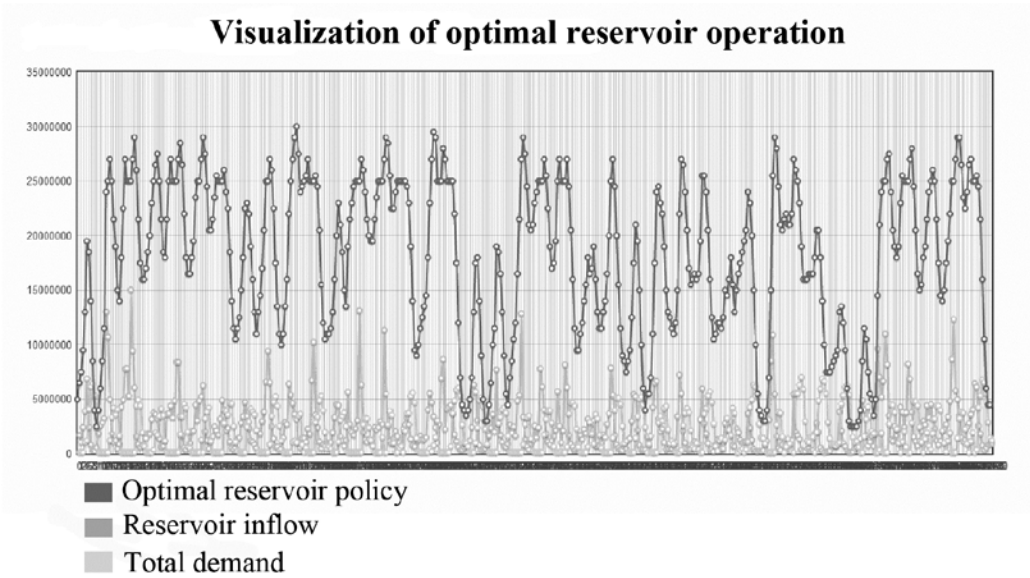

Figure 4. Visualization of optimal reservoir operation.

This service is invoked by selecting a reservoir object from the main working window. When the reservoir object is selected the “TimeSeries Data” tab gives interface for uploading five input tables. After uploading of the five input tables the “Optimization” tab provides the button for starting of the implemented DP algorithm. The execution of the application loads the data from HMak, runs the DP algorithm and provides the results. Such results are shown on figure 4 where reservoir inflow, total demand and optimal reservoir operation curve are plotted together.

DISCUSSION

Development of the cloud application for WRM demonstrates the possibilities of ICT for creation of integrated cloud solution. The main goal of using only web browser for operating the application is accomplished. The presented cloud application is web based, accessible and available all the time and from everywhere. The current implementation of the system is on one physical server with one relational database HMak, one GeoServer instance, and two apache web servers on which three services are working. System components and technologies provide seamless scalability, interoperability and can work in distributed environment. GeoServer can connect to several distributed relational database and other types of data sources. The source code of the cloud application can connect to more instances of GeoServer, which can be distributed on many physical servers. This demonstrates the power of the presented solution to work in heterogeneous server environments and the opportunity to adjust hardware and software resources based on the workload. The cloud application SOA increases the flexibility to add additional web services or upgrading the existing ones. The service for optimizing water resources demonstrates how different applications (using different programing languages) can be connected to the existing services (in this case with the service for supporting WRM) and integrated into cloud application.

The current cloud application for supporting WRM is open to everyone, and anyone with internet connection can use the web services. Users can jointly model the water system, draw rivers, enter attributes, run optimization and view results. Future development plans will create different users and working environments. The cloud application supports creation of collaborative environment for geographically dispersed users. Such collaborative environment can provide interface, data and working windows for the group of users. All services, data and modes are accessible to users at every time and everywhere. Additionally, different working environments can be created for different user categories, such as decision makers, water managers and the general public. These working environments would be based on different services, capabilities and data access. Important advantage of the presented solution is that all services will be based on one common platform.

There are several possibilities for upgrading and improvement of the existing services. The service for supporting WRM can be upgraded with adding new layers and creation of quality attributes tables. The most important part is development of a computational framework that will create an intelligent system, connect different objects and define dependencies between them. Example for this is when a river enters a reservoir the river discharge to be added to the reservoir storage and update the reservoir level. These extensions can lead to the development of a full-fledged water resources modelling system as a cloud application. The service for water resources optimization can be improved by including additional algorithms based on other optimization techniques (reinforcement learning, stochastic dynamic programming etc.) or by improving the existing one with adding additional input information.

CONCLUSION

The shifting of desktop applications, information, and processing power to the cloud has already started. Future applications, software and services will be cloud oriented. The developed cloud application for supporting WRM is a demonstrator of such future orientation. Advantages of the developed application are its availability, accessibility, flexibility, scalability, interoperability included in the design and software components. The prototype cloud application for supporting WRM is just a first step in development of integrated WRM tool. The software components and the web services presented in the article demonstrate that there is software and technologies to develop a robust and complex cloud application. Further development of the application can also include various water related data, population growth, urbanization, climate variations, etc., as they are needed for analysing and solving particular water resources management problems. The platform for development of such applications is already created and future applications will be additional services or modules of the existing cloud application.

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