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Composite Web Information System for Management of Water Resources

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Abstract Management of water resources such as lakes and reservoirs involves many stakeholders and a huge amount of data that comes from various information systems and in different formats. These systems are typically very difficult to integrate, analyze and customize. This requires a new breed of information systems capable to answer the challenges of modern water information management. In this paper, we introduce the new application model for designing such systems and accompanying *i*-SeLaR software system - composite, service-oriented and multilayered web information system for management of Serbian lakes and reservoirs. We describe architecture and services of the application model, together with structure and functionalities of the software solution. *i*-SeLaR integrates data, tools and applications for collaboration, data and knowledge management, process automation, and analytics. Architecture and features of *i*-SeLaR provide scalability and flexibility, so the system can be scaled, customized and implemented in organizations of different types and sizes. *i*-SeLaR web portal is the central component which serves as a unique gateway to different data sources and services, and provides a seamless and unified web interface for monitoring and management of water resources. Practical results showed several benefits in terms of better integration and flexibility, enhanced collaboration, higher data quality, knowledge-based analysis and more informed decision making.

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1 Introduction

Effective management of water resources is one of the main prerequisites for sustainable development of any region or country. Information technologies are commonly used in different areas of water management such as data collection, monitoring and analysis.

Especially after introduction of different international and national water policies such as the European Union Water Framework Directive, the design of water resource management information systems and effective information dissemination became some of the most important research and development topics (Roll 2003). The goal of these information systems is to gather and process data from different sources and deliver accurate, relevant and timely information to all parties involved in the process. These include domain experts, scientists, students, water industry, government organizations, and local community.

Knowledge sharing and information exchange between various disciplines and actors are prerequisites for seamless integration of scientific research and technological developments (Quevauviller et al. 2005). This science-policy integration will not be possible without appropriate web-based information technologies which enable effective communication and coordination among participants.

Garcia et al. analyzed the effects of information and communication technologies (including the Decision Support System, Geographical Information System, Supervisory Control and Data Acquisition System, Web and mobile applications) on both the performance of water organization management tasks and the farmers' adaptation to the new services. The main improvements in water management performance were a more efficient and equitable allocation of water resources, the establishment of water traceability, and the improvement in management and transparency (Soto-Garcia et al. 2013).

Building a dynamic and innovative information infrastructure for the water management sector which provides new communication services and tools is prerequisite for sustainable water management (McNamara 2002).

The main issue is how innovative information and communication technologies can support and foster collaboration, information exchange, knowledge management and decision making in the field of water management.

However, most of the existing water management information systems have some of the following problems:

- Specialized, unintegrated and heterogeneous software solutions
- Legacy systems that are difficult to integrate
- Very hard to customize and extend
- Support only certain tasks and activities
- Accessibility problems
- No collaboration and social networking
- Security issues

In this paper, we present a new composite and multilayered infrastructure and application model for managing water resources. *i*-SeLaR (*internet* - Serbian Lakes and Reservoirs) represents a new breed of web information system, which provides many functionalities, tools

and applications for collaboration, data and knowledge management, monitoring, analytics and reporting.

Typically, the traditional water information systems work well internally within a single organization, but they are usually not suitable for data exchange, remote access and coordinated analysis and decision making among different organizations. This requires integration at multiple levels: data, application and user interface. In this context, there is a need to develop appropriate software architecture that comprises different views such as organizational, process, data and functional views (Usländer et al. 2005).

In the case of lakes and reservoir water resource management a large amount of different information needs to be registered, stored and manipulated. This includes various descriptive, qualitative and quantitative information such as general info, physical, chemical and microbiological characteristics, events, soil, population, etc. The best solution for managing this amount of data is a database management system. This approach provides data integrity, transactions, optimized storage and retrieval, as well as security. In this form, data can be integrated more easily and different user applications can be designed over single data model. Database-centric approach has been used successfully in several IT (Information Technology) projects related to lakes and reservoirs (Andreopoulou and Kokkinakis 2006; Radojevic et al. 2007).

Improving collection, storage and processing of data and information are a first step towards improved water governance. Abdullaev et al. used geoinformation systems, remote sensing tools and databases for improving water resources management in five countries of the Central Asia region (Abdullaev et al. 2012). Implementation results show that water management organisations, equipped with data management tools will have better capacities to adapt their decision-making in the changing availability and scarcity of water resources.

Data Warehousing (DW) technologies are best suited for data integration because they offer adequate tools for data extraction and transformation from heterogeneous data sources (relational databases, web services, feeds and files), tools for data cleaning in order to ensure data quality, and tools for loading data into specialized data warehouses which enable multidimensional analysis and data mining. Using web portal technologies, data from the participating data warehouses can be used for reporting and users can access information on water quality in rivers and lakes, ground water, and point sources (Dzemydiene et al. 2008).

Water resources should be carefully managed by all users instead of by only the water agency. Therefore, a water monitoring system should allow interested parties, such as government representatives, researchers and public users, to participate in managing the water quality. Wang and Guo developed a water quality 2.0 OLAP (On-Line Analytical Processing) system for the South Water Resources Bureau of Taiwan (Wang and Guo 2013). The system utilizes Web 2.0 technologies to integrate qualified data resources and data warehouse system to analyze data from distributed resources to increase the understanding of water quality information of non-experts. This system provides a framework for all users to collaborate in monitoring water quality. Ali Fulazzaky and Akil (2009) describe the application of data and information management for improved water resources management in Indonesia. The study reports improved efficiency and effectiveness in water resources management by implementing information system and water resources data warehouse centre capable to support both tabular and spatial data.

Another common approach for improving management of water resources is the use of DSS (Decision Support Systems). DSS tools aims to contribute to the achievement of improved governance and planning in the field of sustainable water management. Awad et al. (2009) introduced a DSS with web based meta-database about climate, remote sensing and spatial data, which can facilitate decision making by providing an integrated water

resource management system. Zeng et al. developed a decision support system (DSS) for supporting integrated water resources management in Daegu city, Republic of Korea (Zeng et al. 2012). The system contains four subsystems including database, modelbase, and knowledgebase, as well as general user interface (GUI). It is connected with National Water Management Information System and provides several intelligent models such as water demand prediction model. The result indicated that the developed DSS is very useful to deal with complex water resources management problems. Rojek (2014) proposed an integrated and intelligent decision support system that uses several data mining algorithms and artificial intelligence techniques for generating action rules, supervising parameters and preferences for more efficient management of water supply networks. Koutsoyiannis et al. (2003) developed a decision support system to support the management of the water resource system of Athens. The DSS includes information systems that perform data acquisition, management and visualization, and models that perform simulation and optimization of the hydrosystem. The results are utilized to support the new master plan of the hydrosystem management. Chong and El-Shafie (2014) provide a comprehensive review of different computational intelligent models for the improved water management. It is argued that incorporation of advanced self-optimization modelling applications could yield in better water management performance.

Water data are collected and managed by many agencies, scattered in various formats and locations, and cannot be easily accessed by the public. Iwanaga et al. (2013) presented a web-based data management system in support of a unified framework for groundwater data collection and management. The project demonstrates several benefits in terms of better collaboration, faster problem solving and less linguistic ambiguity. Delipetrev et al. (2014) presented a prototype web application for water resources using latest advancements in information and communication technologies, open source software and web GIS (Geographic Information System). The main benefits include availability, accessibility, concurrent multi-users access and interoperability.

Effective water management requires multidisciplinary expertise and collaboration of different actors to make more balanced decisions on water usage. In the area of water resource management, distribution and research organizations usually focus on their local information base without proper coordination and global approach to planning and decision making. This can lead to isolated and suboptimal management of water resources. Collaboration is the key component in overcoming these problems, and information technologies play a central role in this process. Collaboration platforms enable multi-organizational management of water resources, based on information availability and sharing (Hidaka et al. 2011).

Web portals are natural solutions for data exchange, integration, and collaboration among participants. Most existing web portals simply present information from internal and external data sources and do not provide a further analysis of the relationship of web content information. Although web portal technologies are mature and offer user-friendly tools, they have not been widely used in water management domain. There is a lot of space for utilizing web portals in different areas of water management, especially with the advent of the newest web technologies and tools.

There are examples of the effective use of web portals such as the grid portal designed to foster scientific, technical and operational collaboration to improve water resources management (Voorsluys et al. 2007), web portal for environmental research and simulation (Xiang et al. 2004), or web portals that focus on the support of the reporting obligations both at national and international level (Uslander 2005). Zalidis et al. (2013) developed an integrated application portal for environmental spatial information dissemination in the Nestos river basin. The goal of the project is to facilitate the planning and implementation of sustainable water management along with civil protection. Mocanu et al. (2013) stress the necessity of

using modern information technology in water resource management and outline the advantages of using composite applications for this purpose. The authors present architecture of Hydro NETWORK portal together with database and reporting services components.

When it comes to lakes or reservoirs, there are examples of innovative use of web technologies for water resource management of lakes, but there are still a lot of opportunities for the application of advanced web technologies such as business intelligence, knowledge management, application composition, social networking and mobile access. Existing water management information systems are usually focused only at particular segments of water management and used internally within organizations. They are very hard to integrate or customize and also they lack tools for collaboration, document exchange and reporting.

What is needed is modular and service-oriented information system capable to fulfill all these requirements. In the following sections, we present the *i*-SeLaR application model and describe the main services and functionalities of the software solution, together with analysis of the key benefits and contributions.

The remainder of the paper is organized as follows. Section 2 describes the architecture of *i*-SeLaR as well as the main services and design methods. We also introduce *i*-SeLaR web portal as the end-user software solution built upon the core services and applications. Finally, in Section 3, the main results, benefits and advantages of the proposed approach and software solution are discussed.

2 Materials and Methods

This section describes methodological approach, software architecture, services and features of *i*-SeLaR software solution, which address important issues that face organizations when designing and implementing water resource management information systems.

i-SeLaR is multi-tiered, multi-layered and composite web system which comprises various technologies, tools and applications. Figure 1 shows the architecture of the system, including the platform stack, main services and functionalities, as well as the web portal structure and features.

2.1 Services and Features of *i*-SeLaR

More complex water management information systems typically require several different servers where each server performs specific role such as database, data warehouse, web server, search, or firewall roles.

In order to provide better manageability, performance, flexibility and consolidation of the system *i*-SeLaR utilizes virtualization technologies.

Operating system services can include 64-bit versions of Windows 2003/2008/2012 Server or Windows 7/8 operating systems, depending on the deployment scenario. IIS (Internet Information Services) web server is used to host SeLaR web applications and portals (sites). Application services are based on the Microsoft .NET technology.

Database services are the core services for data storage, processing, data warehousing, availability and security. Database server stores all the data associated with the system - configuration settings, administration information, service applications data, and user content. This approach facilitates data integration, improves data consistency, security, and makes backup/restore jobs easier.

Web front-end services are based on the SharePoint platform which is used as the foundation for designing *i*-SeLaR service applications, sites and modules (Fig. 2).

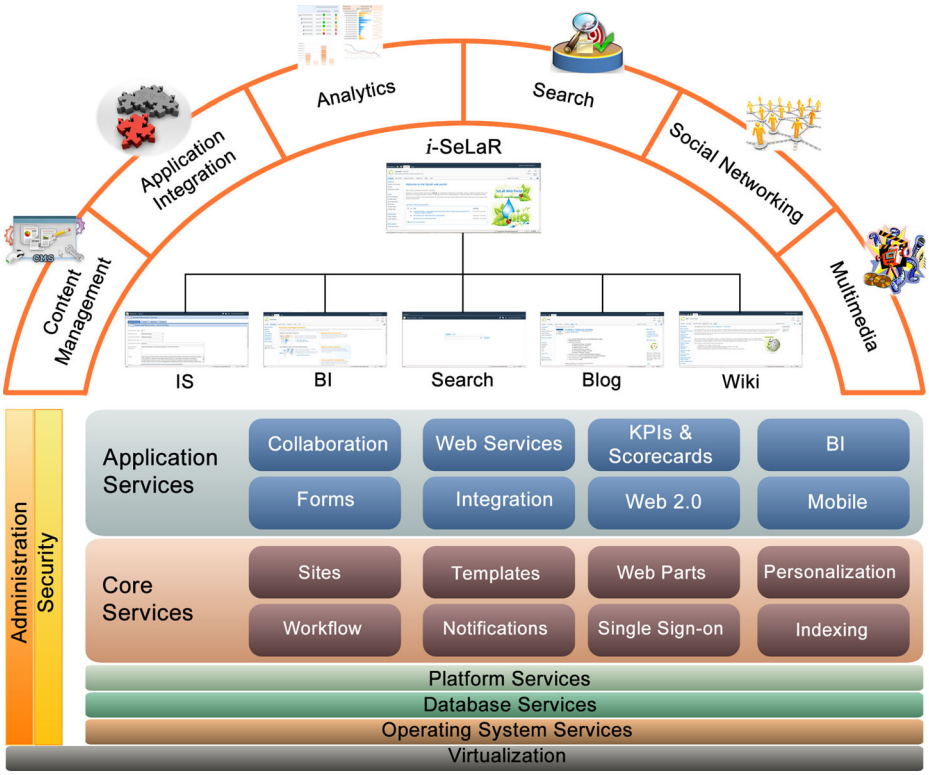

Fig. 1 Architecture of *i*-SeLaR web system

Examples of service applications include business (external) data connectivity (BDC), metadata management, search, analytics, performance monitoring and others. In order to enable services to be shared among different sites and servers, they are published through special service proxies that represent virtual links between service applications and websites.

Site services provide functionalities like site creation, management and taxonomy. Sites can have a range of features and functionalities. The highest level object is called a site collection. It has one root site and many subsites at the lower levels. Each of these sites can use specific service applications and contain specific modules, pages and web parts. Web parts are the basic composition blocks of each web page; they are stored in the portal database and available through online gallery. Additionally, *i*-SeLaR architecture enables software-as-a-service (SaaS) model through the specialized application catalog site. This site serves as an extensibility point that hosts applications developed by various parties. These apps run in an isolated application domain and can be installed by authorized users on different sites.

Users and team members can also personalize websites and individual web parts in order to make them more effective and useful. Audience targeting can be used to filter information based on different user categories such as membership, job position, interests, geographic location, or language. Each user has his own personal website for content management, information exchange and social networking. These sites also aggregate information generated by other users.

In addition to using web forms, users can trigger workflows. Workflows are groups of defined activities such as sending emails or collecting data from users. These activities are

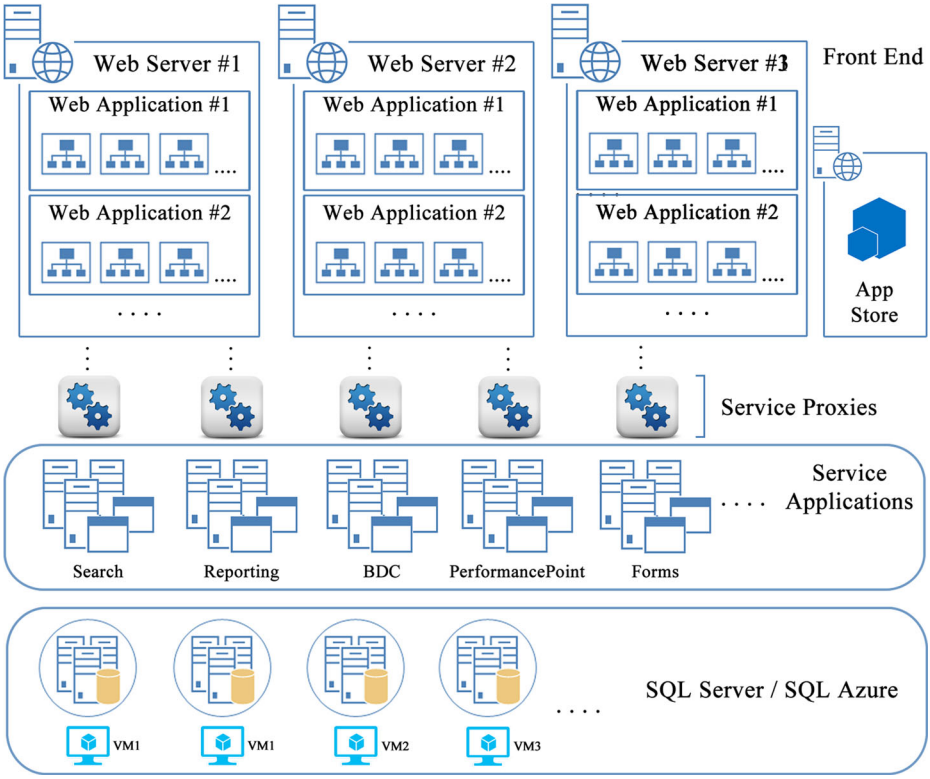

Fig. 2 Logical schema of the *i*-SeLaR platform with n-tier topology

linked together using rules that govern the logic and flow of the workflow. This enables business process automation in whole or part. For example, water examination process can be automated with workflows starting from water sampling, through processing, all the way to analysis. During workflow execution, information, documents and tasks are distributed between users for actions. Workflow services contribute to increased efficiency and accuracy, as well as better work tracking and compliance.

Notification services provide management and delivery of alerts via email or SMS (Short Message Service). Users can subscribe to modules or items in order to receive alerts about certain actions (adding, deleting or updating data).

Indexing services provide content indexing (structured, unstructured, internal and external data sources and services) that is used for searching. Indexing jobs can be scheduled at different intervals depending on business requirements. Indexing engine can index content inside documents, as well as external data sources connected to *i*-SeLaR web system.

Having in mind the increasing demand for collaboration and coordination of activities related to water resource management, collaboration service layer is added to *i*-SeLaR architecture. Collaboration services connect and empower users to better coordinate their activities and to make joint decisions. Collaboration features enable users to share information and work together on documents, projects, and other content. There are special collaboration site templates, modules and web parts which can support various collaboration scenarios ranging from two people document authoring, discussions, and announcements, to a project or program management.

Forms services are critical services that are extensively used in *i*-SeLaR web system as the primary mean of interaction. Forms are web browser compatible and data entered into the forms is stored as an XML (Extensible markup Language) file that can be passed to one of many types of back-end systems, including the SeLaR web portal databases, e-mail, web services and external databases. Forms can be used as the front-end for workflow-driven applications.

Integration services enable integration of external data sources, applications, and web services into *i*-SeLaR web portal. These services allow users to define external entities (systems), create models that represent the data in those systems, and then extract that data for use in the web portal. Integration services work seamlessly with other services like search, composites, forms and authentication.

i-SeLaR web portal supports Enterprise 2.0 concept through implementation of various Web 2.0 tools and technologies. These include AJAX (Asynchronous JavaScript and XML) support, rich internet applications (RIA), blogs, wikis, note boards, discussion forums, RSS (Rich Site Summary) feeds, content tagging, ratings, and social networking. Web 2.0 features facilitate many activities like collaboration, data manipulation, analysis, and multimedia.

Business intelligence (BI) services include collection of technologies and tools used for data extraction, transformation, loading, data warehousing and reporting. *i*-SeLaR web system contains BI site template, BI modules (reports, analytics, scorecards, etc.) and BI web parts (reporting, filtering, KPI, etc.). BI web portal can serve as single point for data analysis, performance monitoring and decision making.

With increasing proliferation of mobile devices, mobile access became prerequisite in today's environment. Mobile services deliver a mobile experience which allows users to easily access content from any mobile device. This broadens the accessibility of content beyond the capabilities of traditional desktop-based web sites.

Additional important aspects of *i*-SeLaR web system are security features and models. The security model is realized through managed accounts, service applications such as Single Sign-On (SSO), authentication mechanisms (like database or claims-based authentication) and fine-grained authorization. SSO is one of the most important technologies for application integration since it provides storage of user credentials (user names and password) and mapping these credentials to other applications and services. Access can be configured at different levels – server, service application, site, web page, module and item. This mechanism can support any business scenario – multitude of users, roles, organizations, data sources, etc.

The following section describes the concrete web system designed for management of Serbian lakes and reservoirs.

2.2 Structure and Functionalities of *i*-SeLaR Web Portal

i-SeLaR web system is based on the presented architecture and application model, and utilizes various services and features. The central component of *i*-SeLaR web system is the web portal. It represents a composite web application consisted of different structural elements. These elements can be viewed at four levels: presentation, collaboration, business logic, and data.

Structure, modules and services of the web portal are designed and composed in a way which supports most of the activities related to management of lakes and reservoirs in Serbia.

There are six web portals – one top-level portal and five subportals, each of them having the specific organization, configuration, modules, web parts, and services. These portals share the same software architecture, some of the services and web parts, but also have unique features and capabilities.

2.2.1 The Main Web Portal

Top-level web portal is the starting point of *i*-SeLaR system (Fig. 3). It contains various modules and web parts that can be grouped in the following categories:

- Information management

– News and announcement – Used to deliver and disseminate important messages and news to visitors and/or the team members. It is possible to put expiration dates, insert attachments, and enter keywords for a better search.
– Events calendar – Allows maintaining lists of events like meetings, workshops, conferences, deadlines, milestones, etc. When creating new events it is possible to create meeting or document workspaces (available site templates) to organize attendees, agendas, documents, minutes, and other event details.
– Links – Used to create personal/public internal or external links to relevant resources, which speeds up navigation throughout the portals.

- Document management – These modules are specially designed for document management with support for document creation, editing, versioning, sharing, workflows and retention.

– Project documents – Documents related to the SeLaR project.
– Papers – Papers related to water resources.
– Legal documents – Library of legal documents related to water resources and ecology.

- Project management

– Team members – List of team members with personal data.
– Project tasks – Special module for project management with abilities to define phases, tasks, links between tasks, priorities, dates, assignments and status. It provides Gantt chart view as well as export options to MS (Microsoft) Excel and MS Project.

- Integration of external web services

– RSS news – Aggregates news from different external web feeds related to ecology and water management.
– Twitter news related to the project – Displays tweets related to water resource management.
– Weather info – Shows weather info with 3 days forecast for certain lakes and reservoirs. It uses MSN weather web service.
– SeLaR tweets – Shows tweets from SeLaR account.
– Google maps – It uses Google Maps API and data from SeLaR database (geolocation) to display lakes and reservoirs.

- Social networking

– Discussions - The purpose of this module is to provide a place for discussions, to organize messages around similar topics and to facilitate an online exchange of ideas.
– Site surveys – Questionnaires used to gather feedback on various topics from users.

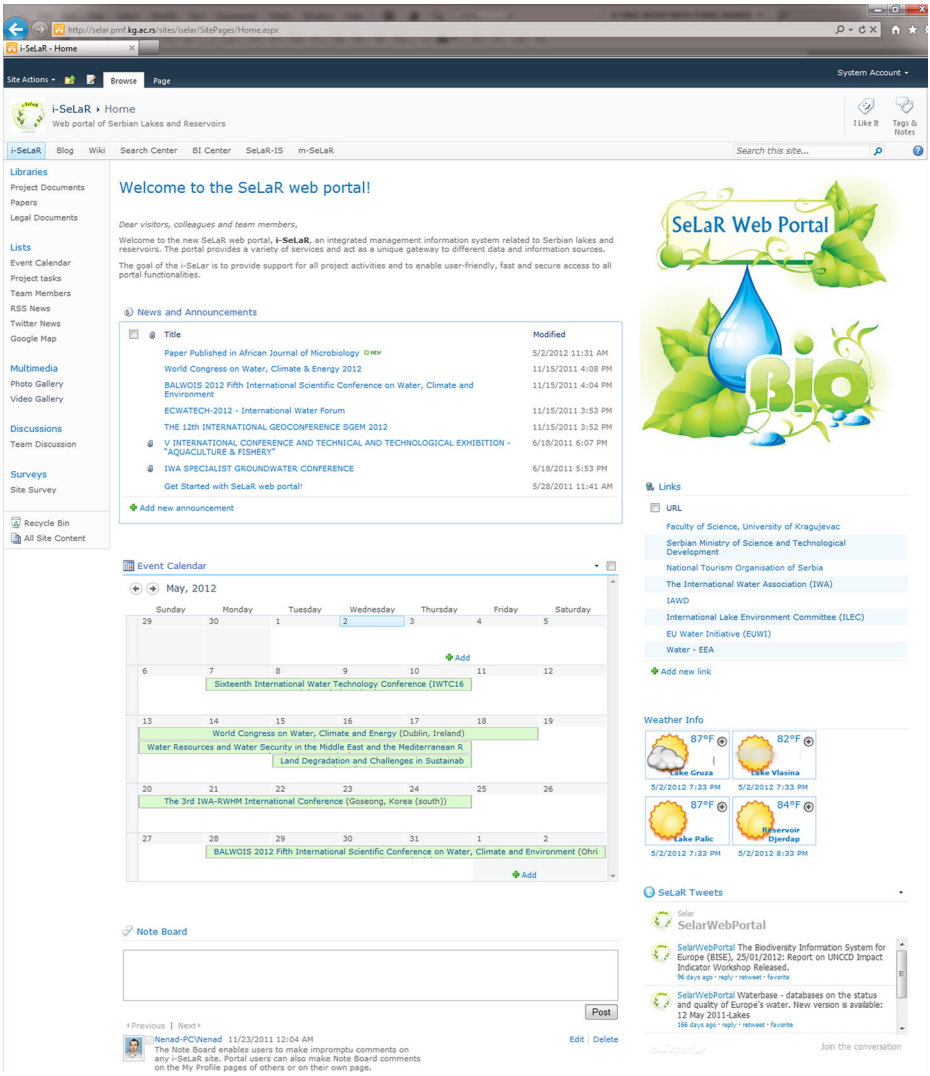

Fig. 3 *i*-SeLaR top-level web portal

- Note board - Provides the ability for users to leave notes on the page for feedback or collaboration purposes that are viewable by other users.
- Tagging – Tools that allows users to tag (or Like) certain pages and to post notes which provide additional details about tagged content. Tags can be showed within user's personal profile (site) or through tag cloud web part.
- Ratings – Users can rate pages or items in certain modules. Ratings allow users to see how useful materials have been for others. Users can rate documents, blog posts, wikis, pictures, videos, etc.
- Personal sites – Each registered user (team member) can have a personal site, where users can organize and manage their work and share information with others. These sites

aggregate news feeds, provide document management features, and show user profile info (interests, tags, posts, colleagues, etc.).

- Multimedia

– Photo gallery – Provides image-specific features for managing pictures: uploading, editing, viewing, sharing, rating, synchronization and downloading.
– Video gallery – Special library for storing and managing audio and video files. It provides item details (i.e. approval status, rating, and size) and playing features with AJAX and Silverlight technologies.

In addition to described modules, *i*-SeLaR web portal provides additional tools and features:

- Content management – Content is separated from the presentation, and can be created or updated using just a web browser.
- Customization and personalization – Portals can take multiple forms and be customized visually, allowing for a large degree of personalization to suit the specific needs. Users can filter and sort items by various criteria.
- Sharing – Most of the modules provide sharing capabilities, enabling users to send items via email, RSS or to subscribe to content in order to receive alerts based on subscription rules.
- Search – Each portal provides search capabilities, with options to choose what content will be searchable, and what search scopes can be used.
- Workflows – Certain modules support workflows which combine responsibilities, actions, tasks, and documents into the process. *i*-SeLaR portal supports several workflows such as: approval, disposition approval, collect feedback, and collect signatures.
- Permissions – *i*-SeLaR portals have sophisticated fine-grained authentication and authorization mechanisms. They include support for different authentication providers, roles, anonymous access, hierarchical inheritance (between portal and subportals), and permission levels.

Most of these features are also reused in the subportals.

2.2.2 Blog Subportal

Blog subportal has enhanced authoring and publishing capabilities which enable users to publish different content (text and multimedia). The content can be categorized by topics and by dates. Articles can be commented and linked. Users can subscribe to certain categories and automatically be notified about new articles or other changes. They can document their experiences and findings and share them with others.

2.2.3 Wiki Subportal

Wiki subportal represents a single-point place for knowledge sharing related to water resources and collaborative authoring. Authorized users can edit articles just by using a web browser. Rich-text editor enables flexible and easy content formatting and embedding the multimedia. Articles can be categorized, commented and rated. In addition to various wiki pages, the Wiki subportal stores various documents and photos.

2.2.4 Search Subportal

Search Center is a specialized subportal that provides search services not only across all the sites, but also for external data sources and applications. It is built on the scalable search service application and can address search needs of the small teams, as well as the large organizations. It also utilizes some other SeLaR services such as integration, indexing, and notification. Search scopes (content visibility) can be defined for sites and modules in combination with security configuration.

Search Center also provides some advanced features, such as thumbnail previews, click-through relevance, and automatic metadata tagging. Search can be carried out by many criteria such as by site, author, or language. Search can be exposed through RSS feeds for integration with other systems.

2.2.5 SeLaR-IS (SeLaR Information System) Subportal

i-SeLaR-IS is web-based information system for manipulating data of the SeLaR database (Radojevic et al. 2008; Stefanovic et al. 2012). The SeLaR database stores multi-year data of 168 Serbian lakes and reservoirs. It is the SQL Server database with normalized database schema, optimized for transaction processing. It stores various data: general data about lakes and reservoirs, climate characteristics, physical, chemical and microbiological parameters, etc.

Users can add, modify, delete and retrieve all the data from the SeLaR database just by using a web browser. The information system contains the three segments: forms for manipulating main data, forms for maintaining the base data (codes), and reports. It relies on forms and reporting services. The reports reside on the reporting servers and they are integrated via web services and special web parts for rendering reports.

2.2.6 BI Subportal

BI (Business Intelligence) subportal is designed having in mind all the requirements for the analytical capabilities, performance monitoring, and collaborative decision making (Stefanovic 2014). It is built based on the multi-layered BI semantic model that enables a full range of BI applications, from personal BI, to the team and enterprise-wide BI (Fig. 4).

The Data Layer provides abstraction and it can consume data from various data sources, such as relational databases, text-based files, OData feeds, web services, cloud, and legacy systems. It can use both OLAP and in-memory engine (Vertipaq) for a data warehousing. Additionally, queries can be issued directly against data sources.

The Business Layer enables construction of advanced BI elements such as calculations, named sets, KPIs, hierarchies, and perspectives. It is flexible in terms of querying, so it is possible to use MDX (Multidimensional Expressions), DAX (Data Analysis Expressions), and DMX (Data Mining Extensions).

The Model Layer supports development of both multidimensional and tabular data models, which offers additional flexibility in designing BI solutions.

The Service Layer encompasses specialized BI services used for different analytical purposes: publishing of data connections (which can be consumed by different applications), multidimensional analysis (pivot tables and charts), data mining (forecasting, segmentation, associations, key influences, etc.), performance management (KPI-Key Performance Indicators, scorecards, etc.), and self-service BI.

The User Interface Layer includes a wide range of end-user BI components: BI web parts, KPIs, scorecards, reports, and dashboards.

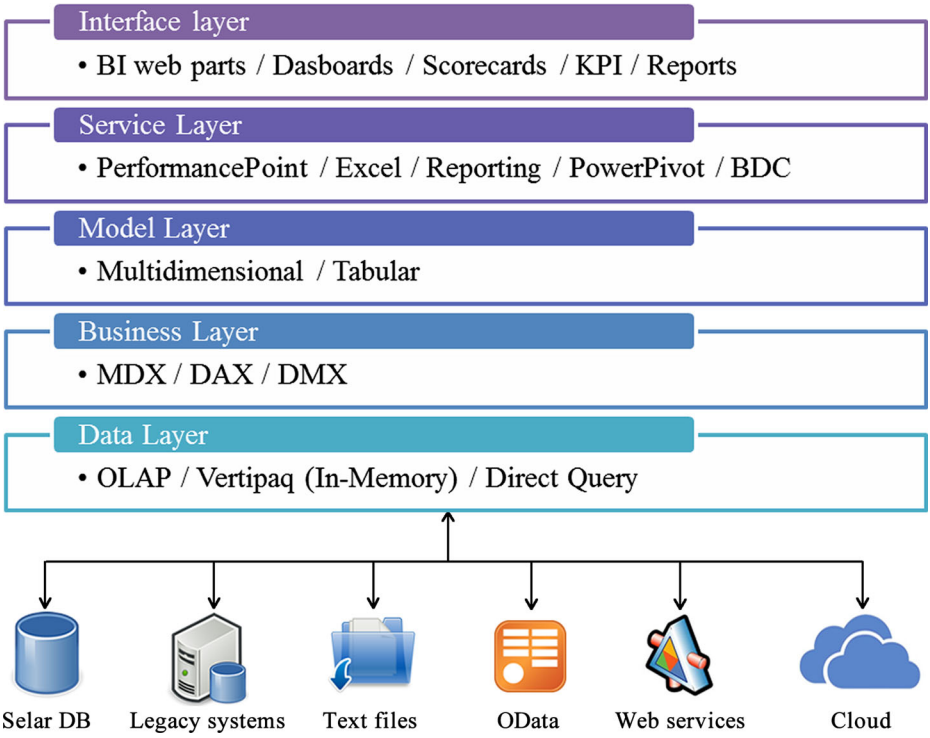

Fig. 4 *i*-SeLaR BI semantic model

BI portal integrates SeLaR data marts (OLAP cubes) and data mining models specially designed for advanced data analysis. Combined with various reporting formats, it provides rich analytical environment that can derive valuable information and knowledge related to lakes and reservoirs (Radojevic et al. 2012). BI portal also hosts the SeLaR legacy client application used for accessing the SeLaR database and for calculating various water quality parameters and indexes.

2.2.7 mSeLaR (Mobile SeLaR)

This is a special version (view) of *i*-SeLaR portal that provides users with mobile devices, such as smart phones and tablets, to access certain sites and modules from these devices. It presents pages in a form that is usable on mobile and handheld devices. This way, SeLaR users can enter data, access information or receive notifications any time and from any place, which further improves collaboration, decision making and content authoring.

3 Discussion

Management of water resources require all participants to work more collaboratively. This trend necessitates a corresponding change in the software systems which they use. Most of the existing information systems are isolated, monolithic and difficult to modularize, extend and maintain. Also, they typically cover only a limited number of processes. The best way would

be to integrate and mix these systems into a single and comprehensive water management software solution.

The presented *i*-SeLaR water management system provides a novel approach to design and utilization of cutting-edge web information systems for managing water resources. The main benefits can be categorized into three groups:

1. Alignment – applications can be composed in a way to accommodate requirements of all participants involved in management, monitoring, analysis and research of water resources.
2. Agility – solutions can be built, assembled, extended and deployed more rapidly and cost-effectively.
3. Adaptability – composite applications are easier to change or reconfigure when requirements change.

i-SeLaR software system is designed upon innovative application model and enables composition at several layers: data, services, processes and user interface.

The starting point was the existing SeLaR information system which is the result of a multiyear research project financed by Serbian Ministry of Science and Technology (Radojevic et al. 2008). The SeLaR is a special purpose client-server information system dedicated to Serbian lakes and reservoirs. Its main component is the database (approximately 1GB in size) which stores various data related to these water resources. The goal was to integrate this database with a new application model, and also to provide additional services and features that would support more organizations, users and processes.

The new application model and software solution are architected and designed in such a way to provide the following advancements in terms of:

- Manageability – more efficient development, deployment and management of the applications.
- Functionality – different features which support collaboration, content management, search, forms, monitoring and analytics.
- Integration – integration is possible at different levels (data, processes, and user interface).
- Security – authentication, authorization, roles, delegations, encryption, and logging.
- Performance and availability – resource optimization, monitoring, and web farms.
- Flexibility – application and interface customization, as well as system scalability.
- Interoperability – the system can aggregate different services and data, and also provide internal services and data to external systems.
- Analytics – the semantic BI model provide building and managing analytical systems, organize data, and discover new insights.
- Usability – uniform and easy to use web interface.
- Mobile access – support for mobile devices such as tablets and smart phones.

In order to achieve improved manageability, higher availability, and greater flexibility, *i*-SeLaR web system is virtualized. Although it can be deployed regularly on physical servers, the virtualization approach offers several advantages:

- Reduced infrastructure costs through server consolidation;
- Increased utilization of server resources;
- Deployment flexibility, reliability, and scalability;
- Simplified manageability and security.

Virtualization support together with service architecture of *i*-SeLaR web system enable realization of various deployment scenarios tailored to specific business needs – ranging from small, single server installation, up to more complex web farm solutions. Even certain services (roles) can be configured and virtualized separately (i.e. database, web server, query and indexing, and search roles).

The presented *i*-SeLaR architecture is multi-layered and seamlessly combines various services and technologies that enable creation of integrated and feature-rich solutions for water resource management. *i*-SeLaR architecture is also service-oriented which enables composition of flexible, powerful and customized solutions according to specific needs of water organizations and researchers. Service applications are specialized and independent services which can be shared across web applications or even across servers. They can be mapped to web applications, allowing for a more scalable and streamlined configuration.

On the other hand, the multilayered *i*-SeLaR BI semantic model enables composition of scalable, flexible and rich analytical services and applications. This model encompasses the entire BI cycle, from data access, to end user analytics. Scalability and high performance is achieved through both OLAP and in-memory tabular data store. Small and large data can be combined from almost any data source, with flexibility of choosing the concrete technologies for data storage and querying. This enables encapsulation of sophisticated business logic and advanced analytical constructs. BI services can support various analytical scenarios that suit specific business requirements.

The presented *i*-SeLaR web portal is modular, which means that each module can be customized and personalized, and existing or new modules can be combined thus assembling composite applications that suit the user's specific needs. This modular structure enables customization and design of composite applications which combine data, documents, and business process in a more creative and useful way, by assembling, connecting, and configuring the basic building blocks of functionality available in SeLaR web system.

i-SeLaR web system has been successfully used for several years by faculty members, researchers, students, city water supply organizations, as well as institutions of public health and water quality. The results demonstrate numerous tangible and intangible benefits.

Tangible benefits include significant cost reduction in terms of less spending on hardware resources, licensing, travel, printing, customization, maintenance, integration and communication.

On the other hand, intangible benefits include more efficient collaboration, better project management, time savings, proactive actions, more informed decision making, etc. Analytical tools and artifacts such as data mining and multidimensional models, KPIs, scorecards and reports enable users to monitor water quality, find hidden patterns and relations, make predictions, identify problems and find root causes. The ultimate benefits are better management of water resources, derived new and valuable knowledge, and higher water quality.

4 Conclusion

i-SeLaR is a complex web system developed and designed for management of Serbian lakes and reservoirs. The goal was to create a unique software solution that unifies all the relevant actors (scientists, technicians, specialists, government representatives, etc.), processes (planning, data collection, collaboration, document management, performance monitoring, etc.), data sources (databases, documents, spreadsheets, web feeds and services, etc.) and applications (data manipulation, analytics, water quality models, etc.).

SeLaR database stores a significant amount of multi-year data about Serbian lakes and reservoirs which can be used for all kinds of data analysis. *i*-SeLaR web portal provides a single point of access to a variety of services and tools, and acts as a unique gateway to different data sources and services. It is a flexible, customizable, and extensible software environment that can support various organizational scenarios.

The modular design and plugin-based architecture enable flexibility in terms of the infrastructure and platform (i.e. operating system choice or database editions), available services (wide range of services that can be added/activated as needed), scalability (it can run on a desktop computer, server cluster or it can be scaled to the cloud) and integration (at different levels).

The web system itself is based on the specific service-oriented architecture which supports integration at five levels:

- User interface integration – web portals.
- People integration – collaboration and social networking services and tools.
- Process integration – workflows, execution and monitoring.
- Application integration – web service provisioning, consuming, and service proxies.
- Data integration – external data, content management, metadata and master data management.

i-SeLaR web system provides all the services, applications, and tools for a new way of data exchange, knowledge sharing and collaborative decision making, which should ultimately result in more efficient management and sustainable development of water resources.

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