ISS-EWATUS

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UNIWERSYTET SLASKI	US	Poland
INSTYTUT EKOLOGII TERENOW UPRZEMYSLOWIONYCH	IETU	Poland
Rejonowe Przedsiębiorstwo Wodociągów i Kanalizacji w Sosnowcu Spółka Akcyjna	RPWiK	Poland
LOUGHBOROUGH UNIVERSITY	LU	United Kingdom
BRUNEL UNIVERSITY	BU	United Kingdom
UNIVERSIDAD PABLO DE OLAVIDE	UPO	Spain
CENTRE FOR RESEARCH AND TECHNOLOGY HELLAS	CERTH	Greece
Dimotiki Epixirisi Ydreusis - Apoxeutesis Skiathou	DEYASK	Greece
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STICHTING VU-VUMC	VU/VUmc	Netherlands

Deliverable 4.2

Decision Support System at Urban Level

Work Package 4

Organization Name	Short Name	Country
CENTRE FOR RESEARCH AND TECHNOLOGY HELLAS	**CERTH**	**Greece**
UNIWERSYTET SLASKI	US	Poland
INSTYTUT EKOLOGII TERENOW UPRZEMYSLOWIONYCH	IETU	Poland
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Revisions

Version	Author(s)	Partner	Description of Version	Date Completed
01	Konstantinos Kokkinos	CERTH	Initial draft	18.12.2015
02	Konstantinos Kokkinos	CERTH	Included Design of the System	30.12.2015
02.1	Konstantinos Kokkinos	CERTH	Included DSS Architecture	10.01.2016
02.2	Konstantinos Kokkinos Elpiniki Papageorgiou	CERTH	Work on the Logical Architecture of DSS and forecasting algorithms.	20.01.2016
02.3	Konstantinos Kokkinos	CERTH	Included Usability and Interface testing	28.01.2016
02.4	Konstantinos Kokkinos Elpiniki Papageorgiou	CERTH	Further work on Logical Architecture Overview of urban DSS	12.02.2016
03	Konstantinos Kokkinos	CERTH	Final work on testing and validation preparing the first final draft	17.02.2016
03.1	Elpiniki Papageorgiou	CERTH	Final work on the deliverable making corrections	20.02.2016
03.2	Laspidou Chrysi	CERTH	Release to other partners	22.02.2016
03.3	Wojciech Froelich	US	Make significant changes on the structure of the deliverable and provide comments	25.02.2016
04	Jose L. Salmeron	UPO	Provided the Evolutionary multi-objective optimization algorithm for the Inference Module of the DSS	27.02.2016
05	Elpiniki Papageorgiou	CERTH	Include Froelich's restructure and suggestions and provide a new version of deliverable	5.03.2016

ACRONYMS	Explanations
ADL	Architecture Description Language
AJAX	Asynchronous JavaScript and XML
ANFIS	Adaptive Neuro Fuzzy Inference System
API	Application Programming Interface
ArcGIS	Arc GIS Server by ESRI
ASP.NET	Free web framework for building web sites and web applications using HTML, CSS, and JavaScript.
DSS	Decision Support Systems
EUD	End User Development
EPANET	Computer program that performs extended period simulation of hydraulic and water quality behavior within pressurized pipe networks
FCM	Fuzzy Cognitive Maps
GeoServer	Open Source GIS-Server used.
GUI	Graphical User Interface
IEEE	Institute of Electrical and Electronics Engineers
JSON	JavaScript Object Notation
KML	Keyhole Markup Language
LINQ	Language Integrated Query
NN	Neural Network
OGC	Open GIS Consortium
OpenGIS	Open Geographical Information System
PMAC	Part of the Pressure Monitoring And Control system by Technolog Conmpany
PRV	Pressure Regulation Valve
RESTful	Web services based on REST (representational state transfer)
RP	Rapid Prototyping
RSS	Rich Site Summary
SDLC	System Development Life Cycle
SOS	Sensor Observation Service
SSDD	System Software Design Document
WaterML	Water Modelling Language
VM	Virtual machine
WCS	Web Coverage Service
WDS	Water Distribution System
WFS	Web Feature Service
WMS	Web Map Service

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Executive summary

Our web application is hosted on an IIS (Internet Information Services) VM and is available through the Internet in the following address:

www.issewatus.certh.gr

Figure 1.1: The home page and the login panel of ISS-EWATUS DSS

The purpose of the System/Software Design Document (SSDD) is to provide an overall description of the urban level managerial functionalities of the developed DSS and to specify the hardware and software system detail design.

The SSDD covers the following subject areas relative to the ISS-EWATUS Urban DSS application:

- Primary functional users
- System architecture
- System software design
- System hardware design
- Software Application Design
- Database Design (partially since it has been given a separate deliverable for the DB-design)

In this chapter we make a short discussion only relatively to the functional users of the system. However the rest of the subject areas relative to the ISS-EWATUS Urban DSS description are elaborated in the following chapters of this manuscript.

Furthermore, the DSS we will describe in this manuscript is a major component of a larger integrated system that includes a DSS that studies the consumption of water at the household level, a DSS for making effective pricing policies and a social media platform that integrates the above as the following diagram shows (taken from Deliverable 4.1 of the same project).

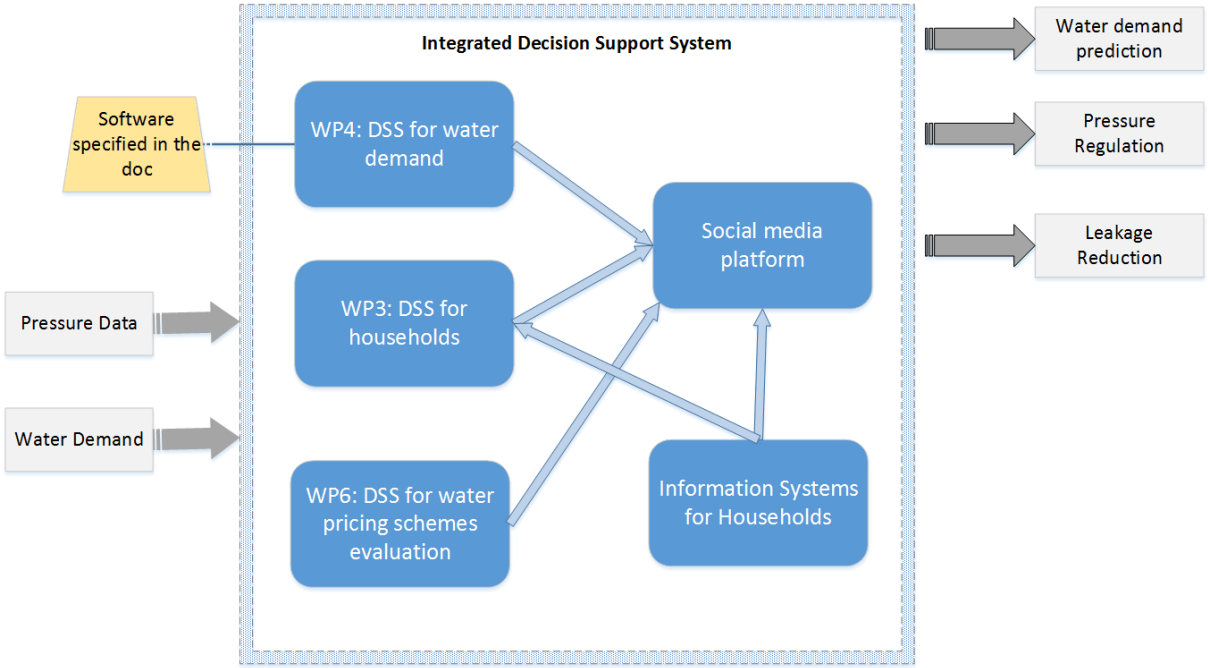

Figure 1.2: *Inner ISS Interactions and the position of the developed DSS module at urban level.*

The following table summarises tasks contributing to this deliverable, their objectives and outcomes with the references to relevant sections of this document.

Tasks	**Objectives**	**Reached (Yes/No)**
Task 4.2: Inference module of decision support system	The suggested algorithms must replace and surpass human decisions of which water supply sources to choose for supply of water at each time. Internal factors, such as water pressure, water demand and flow-rate and external factors must be taken into account.	Yes
Task 4.3: Implementation of forecasting algorithms	Develop water demand forecasting algorithm based on ARIMA, ETS and Holt Winters	Yes
	Develop water demand forecasting algorithm based on Fuzzy Cognitive Maps and Evolutionary Algorithms	Yes
	Develop water demand forecasting algorithm based on Neural Networks	Yes
	Develop water demand forecasting algorithm based on Adaptive Neuro-fuzzy Inference systems	Yes

	Main architectural aspects of the DSS have been defined following the described functional, technical and architectural requirement specifications of D4.1, by identifying the services provided and required by each subsystem and defining the interfaces to be used for communication.	Yes
Task 4.3: Development of the integrated DSS at urban level	Design of Interfaces. The user interface has been developed making the algorithms developed in this WP easily accessible to the end-users.	Yes
	DSS implementation. This work task actually implements the decision support system, using the input from the previous tasks within this work package. All the necessary components have been implemented. Testing and Modification Phase have been accomplished at every stage of the DSS implementation. All developed modules have been already embedded into the DSS.	Yes
	The hydraulic models of the two networks (Skiathos, Sosnowiec) have been built. As a result, the assessment of existing hydraulic conditions within the supply system is obtained.	Yes
Task 4.4: Simulation of water supply network	The forecasts of both water demand and hydraulic model of water distribution are performed.	Yes

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1 Introduction

The developed online Decision Support System (DSS) is a monitoring, forecasting and advisory tool to simulate and control the efficacy of sustainable urban water management practices. This system spans on capturing two different use cases (pilot cities) namely the use case of Sosnowiec, Poland and the use case of the city of Skiathos island, Greece. The DSS gives the ability to experienced users to initiate simulations on water demand practices for each case scenario in a variety of time scales and using a repertoire of intelligent forecasting methodologies on historical data. The results are used for providing input to a hydraulic model for the water distribution network based on the EPANET well known simulation tool in order to induce management practices to be applied to the water user categories within each service area according to selected parameters. The system is able to provide simulation results in thematic maps exactly on the GIS layers that are dynamically created and ultimately create heat maps of water demand for various seasonality oriented parameters.

The primary goal of the development of the aforementioned system is to became an effective tool for the competent authorities, the stakeholders and the policy makers for supporting the decision making process for the water resources management. The uniqueness of such systems is based on the integration of multiple and sometimes interdisciplinary software component that it is made off while at the same time aiming towards the water saving at urban level, the leakage reduction of water distribution networks and the involved energy savings.

The implemented system integrates the monitoring of hardware devices such as the main valves of the water distribution network, the devices that monitor the water pressure at specific critical points of the network etc. Furthermore, through the use of the spatiotemporal database sub-system, we are able to provide an abstract way of concentrating all relevant data into a centralized place with the obvious benefits.

What we have succeeded to provide is to harmonize the water subsystems under study and all the communication languages (coming from the different sub-systems of managing and monitoring) in an interoperable platform that supports the water managers' work to make more effective and efficient decisions regarding the whole chain. To improve decision making, firstly several algorithms have implemented to forecast the water demand of each use case scenario at a daily basis or even at a 10min intervals to make a detailed water demand profile for a city. With the use of these water demand profiles, we make an intelligent and revolutionary algorithm to disaggregate the demand to the level of each household (hydrometer) and to the level of a previously defined geographical area of study. In this way we finally implemented a dynamic interaction between all subsystems with the EPANET model so that to forecast what will be the water pressure profile of the water distribution network under the methodology described above.

In the following sections we describe the main objectives of the system implemented and all the user and functional requirements addressed by the system.

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2 Objectives and Requirements

The implemented software for managing water resources at urban level builds on the lessons of experience. At its core the system has the major objective to adopt a comprehensive policy framework and to address the treatment of water resources at urban level as an economic good, combined with decentralized management and delivery structures, greater reliance on pricing, and fuller participation by stakeholders. More specifically, the system even though it is primarily made for water company experts, it has also implemented the necessary "hooks" to be accessed by the city residents (a subsystem to provide alarms for water distribution failures and leakages). The proposed approach is consistent with the water directives from the European Commission.

The implemented system allows the adoption of a comprehensive framework in order to analyze policies and options and draw decisions about managing urban water resources in cities. In the case scenario where significant problems exist, or are emerging, concerning the scarcity of water, the system provides an efficiency of service regarding the control of water pressure and the future reduction of water leakages in the distribution network.

The complexity of the analysis was multileveled depending on the characteristics of each pilot city, however, the framework can facilitate the consideration of deviations of the already existed systems for monitoring and managing in these pilot cities. The system can also easily be hooked to the appropriate subsystem of the same project regarding the economic objectives, and produce appropriate thematic maps of the projected demand. The analytical framework would provide the underpinnings for formulating public policies on regulations, incentives, public investment plans, and environmental protection and on the interlinkages among them. It would establish the parameters, ground rules, and price signals for decentralized implementation by government agencies and/or the private sector. Also, decentralizing the delivery of water services and adopting pricing that induces efficient use of water are key elements of sound water resource management.

To summarize the basic objectives met by the development of this system we must say that:

1. It provides adaptive management of water resources at urban level.
2. The system characterizes and clarifies certain sources of uncertainty that usually exist in systems of such application range. More specifically, it gives a compact yet understandable way to intercommunicate between proprietary hardware and software and also gives a common ground to analyze data through the spatiotemporal model shared data repository.
3. The system provides the observation and monitoring functionalities as a response to management actions. Furthermore, the dynamic nature of the system allows expert users to initiate and integrate specific management interventions as it was claimed in the document of work.
4. Relatively to the evaluation of the system, and even though this will follow in the next tasks of this work package, the system responds as was expected and therefore, other different potential changes can be developed and tested in future management alternatives. Information and data gathered in future management interventions could be used to validate or invalidate such changes.

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5. The system is open ended in terms of including and assimilating new data and information in a conceptual and numerical representation, embodying the current understanding of how it should function.
6. Flexibility which is an important aspect of a good adaptive management practice has also been taken into account. The changing of policies which are based on the observed impacts in future times and under the global policy making allows the system to conform. That means, the system gets essential feedback which links the latest sensor observations with the next decision-making steps. However, to achieve this, the system requires close collaboration between those who monitor, study and interpret the behavior of the system with those who do the decision-making.

In order to accomplish the desired functionalities for our tool we had to integrate a mixture of different technologies to help us in our goal and manage each one of the corresponding modules. Those modules are listed in Appendix A.

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3 Design of the DSS

3.1 Primary Functional Users

We define what types of users the system can support and for each type we provide their characteristics. By users we mean the individuals who are able to interact directly with the software product at hand:

- **Water Company User –** These are the primary users of our system and have as a main goal to use this tool to practice to water resource management for their urban area under consideration. The system has been implemented to fully handle the areas of the two pilot cities namely the city of Sosnowiec, Poland and the city of the Skiathos Island, Greece. However we must mention that with the appropriate additions in the spatiotemporal database (i.e. specific database tables that needed to define each new use case) as well as minimal code changing the system has been developed to be an open-ended online system and to have the ability to host many other use cases. The role of the water company user which is the primary and most important user type in the system enjoys the following privileges:
    - Can insert/update water data for the registered regions/countries.
    - Can insert information about sensors and valves.
    - Can deploy forecasting algorithms to predict water demand for a case scenario (it may be a one step ahead, a one-day ahead or a series of days ahead).
    - Can manage land zones of interest in the area under study. The water company user has the ability to create, edit, update and delete land zones of interest in the field of study.
    - Can have a managerial role in the insertion of meteorological and socio-economics data in the system. The reason the system is built this way is that firstly there are cases when the meteorological data is not available through the developed web services (for example today's temperatures are not available yet) and secondly there are socio-economics data which are inserted into the system as they become available and the availability time periods may range from days to trimesters according to the time-period of interest and the use case. The ability therefore of the primary user of the system to handle awkward situations like the ones mentioned above is crucial for the system to function at all times.
    - Can have managerial role in handling alarms that are raised by simple users. When we talk in detail about such users we will elaborate on this issue. However the aforementioned alarms refer to cases of water distribution network failures and therefore it is an important submodule of the system.

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- Can deploy the EPANET model submodule after a series steps that involve forecasting of water demand and disaggregation of this water demand to the various land zones of the area, in order to predict the water pressure of the water distribution network.

- **The System Administrator** – The system administrator/developer is the person/team of developers that have implemented the system. This user role can create new water company users and configure the product for assigning access (create and manage access accounts). The same holds for the creation and management of simple/guest users of the system. The system has been developed in such a methodology that, each one of the use case cities may have their own system administrator i.e., the admin that handles all the water company users. Hence two system administrator accounts are made, one for each pilot city. Furthermore, the system administrator has full privileges to handle not only the system but also has access to the host server, the database server and is able to make any changes to all tables of the spatiotemporal database.

- **The Guest User** – The guest user role involves people who primarily register into the framework through the social network portal. These users may have additional privileges than the social network users only if they are residents of the pilot cities under study. More specifically users with these characteristics have the ability to monitor their own hydrometer consumption and also to see all the historical data that refer to their water meter (data that the water company gathers every month or in other cases every trimester). Additionally guest users have the ability to log in and initiate alarms into the system. As we have already described in the functional requirements document (Deliverable 4.1 of ISS-EWATUS) the system handles alarms put by guest users and the handling of alarms is managed by the water company expert user. Alarms may refer to water distribution network failures as well as water meter failures, indications of major leakages of the network etc.

- **Competitor User** – The competitor users is a special category of users who are given a temporary access to the system for the absolute reason to view few of the major functionalities of the system. Competitor users may login to see the main capabilities of the DSS for some example case studies that will be selected as demos.

3.2 Structure of the Local Database

The local Database for the default membership provider runs on a SQL Server 2012 Express instance on the same Virtual Machine that the web application is implemented. It consists of several tables that contain all necessary information and data schemas for the authentication procedures. The tables that the applied membership uses to securely store and validate user credentials, roles and profiles can be seen below (Figure 3.1).

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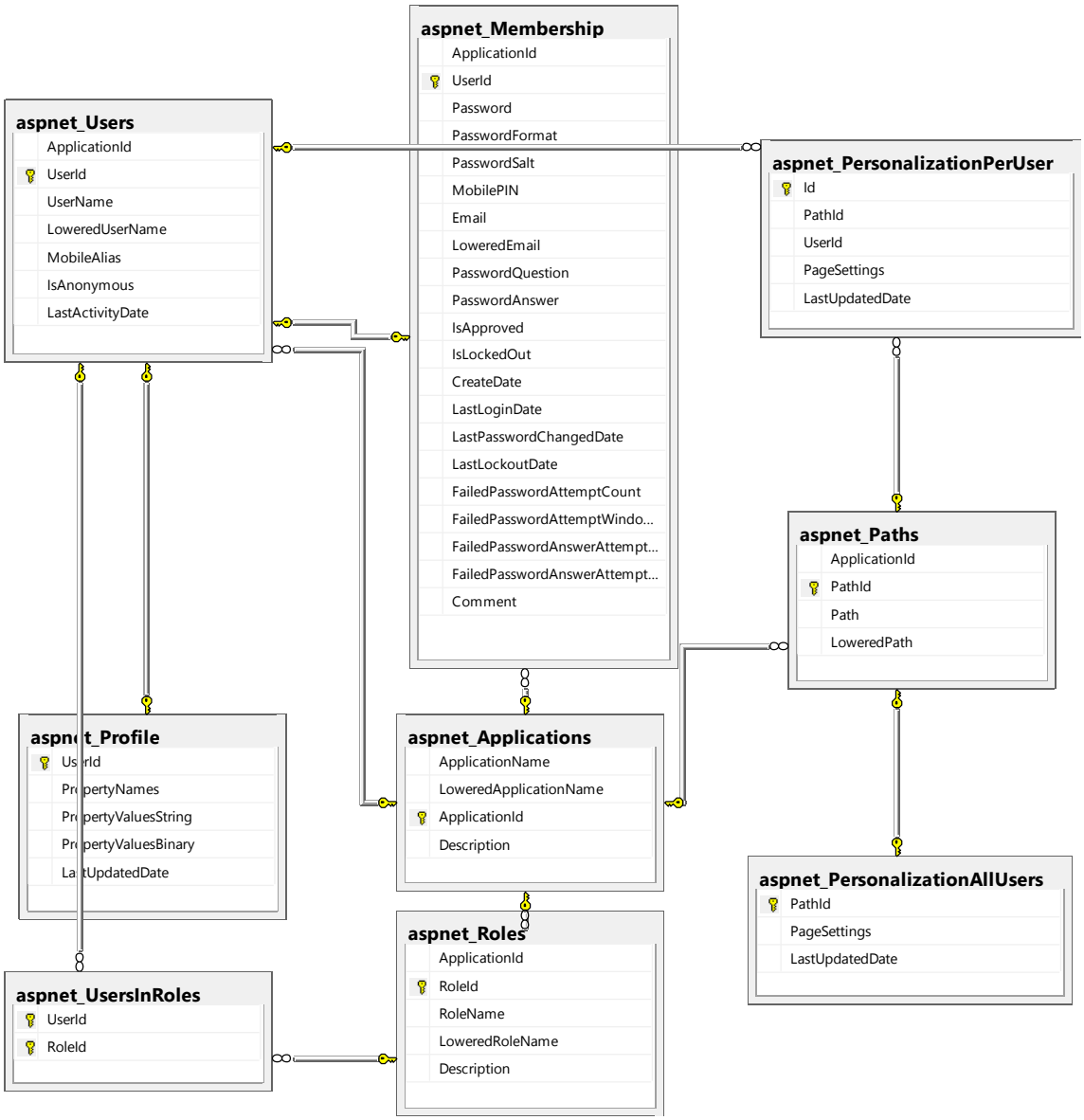

Figure 3.1: Local Database Diagram used from Membership provider

After successful login the system checks the assigned user Role (Poland or Skiathos Admin) and redirects user to the corresponding function.

3.3 Deployment Model

Most of the modern programming languages try to exploit abstraction in order to reduce complexity. That means that when we program rather complex systems it is towards the best of our interest to modularize to the finest/smaller component the work and at a second phase to write code that will be the abstract possible to accommodate all possible situations. The abstraction characteristic primarily focuses on the functional behaviour and the logical composition of software. Also we must say that the new modern programming languages are based in specific paradigms in order to deploy new software. The most prominent that we also use in our system are the multithreading and the concurrent objects. These two types of data types have the special characteristic of using interaction mechanisms such as method calls, message passing, and shared resources in order to share the same

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data repository. In our novel DSS we have developed a number of techniques to enable the compositional development of modular systems such as the spatiotemporal database management and the web services repository and the flexible reuse of these components whenever it is needed. For example, the development of the set of algorithms for the DSS and the set of web services for the case of one of the pilot cities and the reuse of them for the development of the other pilot city or the future inclusion of any other pilot city in our system justifies the reuse development mechanism of concurrent objects.

However the aforementioned techniques suffer from a small deficiency that is, they still overlook how software's deployment influences its behaviour. This is not always the case for concurrent objects and multithreading but in our case we faced the above problem especially when concurrent web services tried to modify data resources during execution. We resolved this issue by introducing virtualization on the methodology to concurrently access the same data and concurrently trying to modify the same data repository through concurrent objects. We had to separate the application model, which requires resources, and the deployment scenario, which reflects the virtualized computing environment and elastically provides resources. The next step that we are going to test during the evaluation phase of this software (i.e. the third year of the project) is the performance and scalability of a service for many different deployment scenarios already at the modeling level

Deployment support provided by methodologies

The deployment of systems development methodologies can be seen and evaluated from several perspectives. Examples of criteria/metrics to perform such an evaluation may include the following:

- Level of use
- Acceptance by the target group of users
- Horizontal and vertical use
- User satisfaction etc.

Note also that the deployment encapsulates the post-implementation stages of the innovations diffusion process where the innovation is actually being used in the organization. Thus from this point of view we cannot have any data yet since our software is at the first stage of such conclusion of its development and the evaluation comes next.

To measure the perceived support that systems development methodologies provide, we based our measurement on the work by Henderson and Cooprider (Henderson and Cooprider , 1990). These authors have developed and tested a functional model for Integrated Software planning. They base their methodology into two major categories: production and co-ordination technology. They believe that "production is the functionality that directly impacts the capacity of an individual(s) to generate planning or design decisions and subsequent artefacts or products."

Having in mind the methodology of these authors we have developed our software to include the following three basic characteristics:

1. The software allows the user to define, describe, or change a definition or description of an object, relationship, or process.
2. The system allows the user to explore, simulate, or evaluate alternate representations or models of objects, relationships, or processes.
3. The way the software was developed, it executes a significant amount of planning or design task, thereby replacing or substituting a human designer or planner.

3.4 Graphical User Interface

All web pages that exist in user folder, and are used as the front-end of our web application conform to a universal stylesheet that defines the overall style and element positioning of the User Interface. These pages derive from a MasterPage file (basically a universal Template) which defines the basic components such as the menu bar, popup windows, footer, content placeholders (where each page holds their separate UI modules) etc. With this type of implementation we achieved a universal look and style for all web pages, easy and secure authentication procedures (so that only logged in and roles registered users can access).

The majority of the project's web pages consist of html elements (ul, labels, text-areas, divs, paragraphs etc.) as front-end source code, along with CSS, JavaScript and JQuery functions and run on Server Side. We must also note that the whole web application project was built using the bootstrap framework (Twitter based front-end framework that consists of html, CSS and JavaScript that helps to build responsive applications).

The initial home page for each user contains a dashboard (Figure 3.2) with all functionalities that are available to each Group / Role of users. Each tab redirects user to a specific web page that handles the required modules.

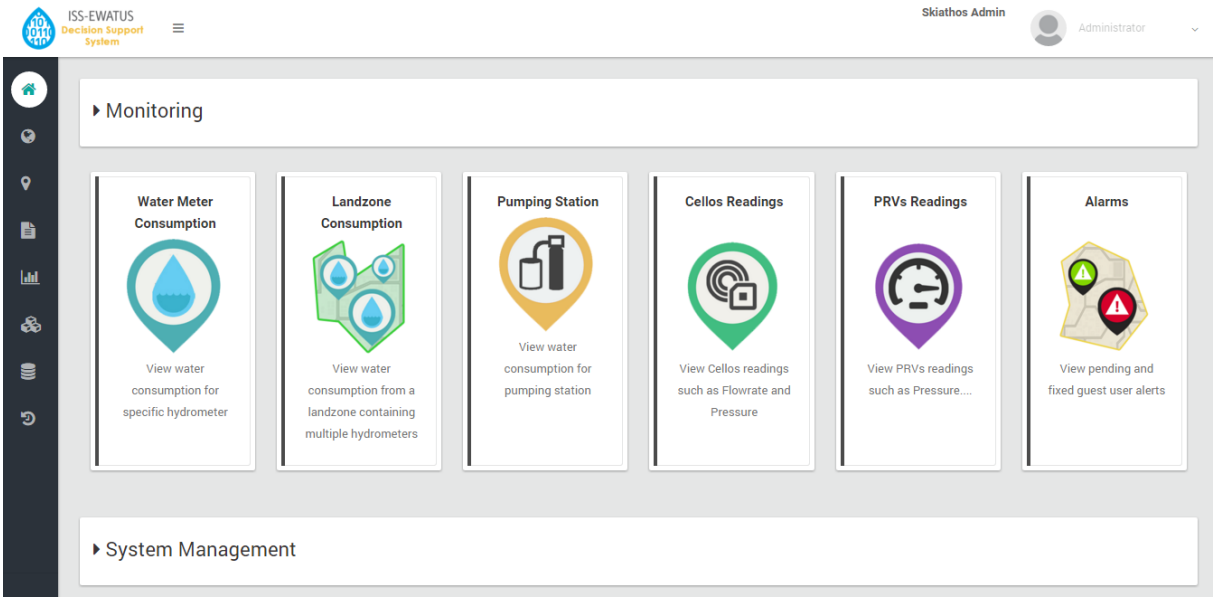

Figure 3.2: User Dashboard

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Our software implements each one of the basic functional requirements in separate web pages that allows users to easily access them (i.e. monitoring of water-meter consumptions, monitoring of pumping stations, database records management, simulation algorithms etc.)

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4 Architecture of the DSS

The system is composed by a set of sub components which are implemented artificial intelligence algorithms and models that can simulate and predict the water demand of an area or district.

The ISS-EWATUS DSS is 3-tier application consisting of 3 layers. This allows us to develop a highly flexible, responsive and modular software. The layers are:

- User Interface - Client Layer (html and aspx web pages)
- Presentation - Application Layer (graphical display of user case action results)
- Data Layer (Connection and Manipulation of data objects)

The ISS-EWAUSS urban-level DSS software tool integrates web technologies (web services, n-tier architecture, client and server side programming, geographical information services, complex forecasting algorithms) to a single web-based application that is user friendly and has the ability to manage and depict all necessary functionalities.

The ISS-EWATUS urban-level DSS is a model-driven DSS implementing a spatiotemporal model methodology which aggregates through online telemetry information about:

- The water demand of a city,
- The water distribution network characteristics of that city,
- The water consumption of each household water pipeline that belongs to the water distribution network,
- The water pressure time-series data for each pressure regulator device that controls the flow of water within the network,
- The meteorological data related to the city as daily time series, and
- Several other data that are implicated into the fluctuation of the population using the water network such as seasonality, tourism, summer temperatures etc.

The software tool focuses on providing the water network and the water company managers a decision support system that can be used to forecast water demand, suggest a near-optimal water pressure regulation scheme on a daily basis and through this water pressure management decrease the overall water leakage in the network.

Compared to traditional DSS, there are two changes brought by this implemented Web-based DSS. First, it is the fact that the underlying architecture of the DSS has moved from main frames, to client–server systems, to Web and network technology-based distributed systems. Consequently, large amounts of data and related decision support tools from multidisciplinary sources, which may be located in a distributed computing environment, have the possibility to be integrated together to support decision-making.

Secondly, differing from traditional DSS, such as data-driven DSS focusing on access to and manipulation of a time-series of data, model-driven DSS focusing on access to and manipulation of a

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domain-related model, and knowledge-driven DSS focusing on high-level knowledge extraction and data mining, our Web-based DSS provides the ability to build a hybrid DSS. That is the ability to synthesize the previous three approaches of design and to make an amalgamation of the different methodologies by keeping the most convenient components. Furthermore, our system is not restricted to just the management of the urban water resources but it can be easily modified to integrate other commodities or any other product that is governed by spatiotemporal analysis and risk management. To analyse and interpret the data from the spatiotemporal database, domain-related analysis tools were needed to provide value-added information. Unfortunately these tools are not ready made components but they had to be implemented from scratch. Furthermore, knowledge discovery tools and data mining tools were built for the case of web DSS access to the host server in order to extract useful knowledge from the information and data to support decision making. More specifically there is a variety of forecasting algorithms spanning from minute one step ahead forecasting to daily basis forecasting and from univariate to multivariate time-series forecasting analysis. Given the multidisciplinary data sources and the related decision support tools and algorithms, the design, specification, and implementation of the DSS was successful.

The system initially consisted of the data and the related tools, which come from multidisciplinary areas such as weather and meteorological data, social economics data, hydrological data, water distribution network hydraulic data, client data and geographical information system data for the client hydrometers. These data and related tools originally were not designed to work together. Also we must note that traditional DSS framework design methods usually lack the ability to structure, organize and set a hierarchical view of the data used and the software components developed in order to specify the software architecture of a Web-based DSS in a formal way. On the other hand, with the assistance of the todays' available Web and network technology, the data and the developed decision support tools from multidisciplinary areas can be located on computers distributed over a network. For example in our case the spatiotemporal database is located in a different server located in Poland where the main host that contains the vast majority of the DSS functionalities is located in a server in Greece. Additionally the connection of the system with the EPANET hydraulic model to predict the water pressure of the network is of the same philosophy since the EPANET is hosted in another separate server. Summarizing our arguments, we claim that in such a distributed environment, our decision to develop a web based DSS application was "a must decision" in order to manage and integrate the data and tools in a seamless way and to tackle the aforementioned problems.

We show that, the system uses layered software architecture to provide a hierarchical view in order to organize and specify the data and the related tools from multidisciplinary sources. In the layered architecture, the data and related tools are viewed as components/services. When it is necessary we use an Architecture Description Language (ADL) which is applied to provide formal specifications for components and component composition (connectors). We need this specification of components and connectors for the design of open interfaces and formal behaviour and to avoid an ambiguous guidance for component and connector analysis and implementation. To implement the layered architecture in a distributed computing environment, a component-based framework is also presented. The framework we created has three major roles: the creation of components, the creation of connectors that connect the components, and the creation of a coordinator that provides the coordination of the components and the orchestration of the web services. The implementation

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of components and connectors in the framework follows the specification of components and connectors at the design stage. We note that a component is a computation or storage server while a connector is a server enabling component composition. On the other hand, a coordinator is a server that manages components and connectors. The following figure (Fig. 4.1) shows the relationship between the layered software architecture and the component-based framework in a Web-based DSS. The layered software architecture creates a formal and hierarchical architecture view for the Web-based DSS while the framework concretizes the layered software architecture in a distributed computing environment. In this figure we show an example of the information layer to provide access to more than one web services which in the framework have their own dedicated connector objects. These objects are used from the coordinator object to synthesize the decision making process according to the use case scenario, the philosophy of the forecasting methodology used for the water demand and the integration of the EPANET model for the water pressure prediction.

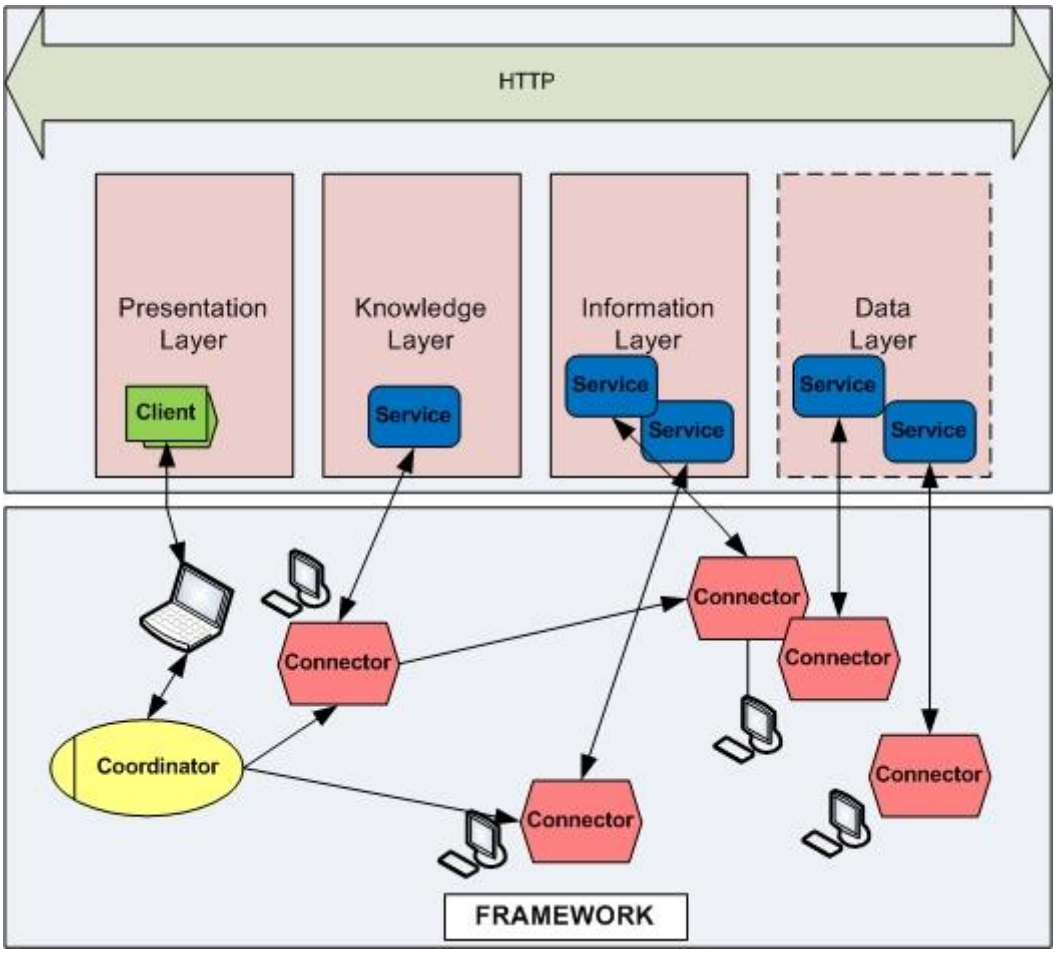

Figure 4.1: *The architecture software view of the DSS implemented and its interconnection to the framework designed to accommodate the variety of web services.*

As the diagram shows, the goal for the DSS and the decision analysis as a whole is to develop relationships explaining the field of study and the engineering processes that describe these relationships and their conversion into knowledge that can be used to make sound decisions for water management. The layered software architecture assists in the design of the DSS implemented by providing a formal and hierarchical view. With the help of the component-based framework, the

urban ISS-EWATUS provides distributed services that can quantitatively describe the intensity, duration, and magnitude of events.

4.1 Logical Architecture Overview – Main functionalities and modules

The ISS-EWATUS DSS project consists of several modules combined under a unique - universal platform that brings all required functionalities to the user.

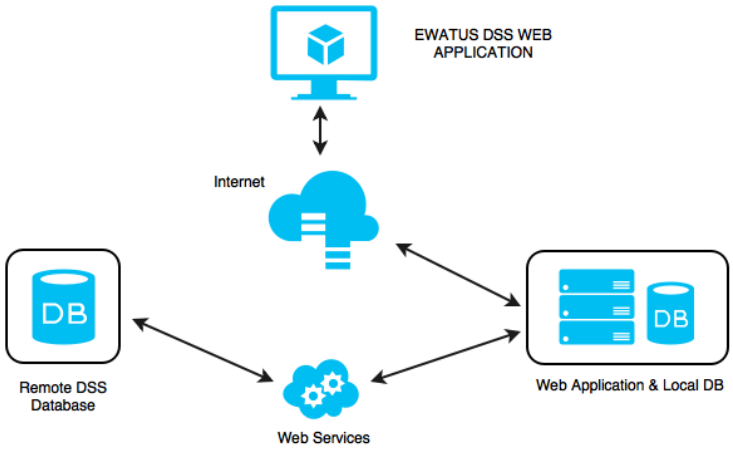

Figure 4.2: System Overview

4.1.1 Monitoring

Users can monitor various devices, observations or water network parameters. We included 6 use cases for monitoring: (a) water consumption from the hydrometers, (b) water pressure data for a specific land-zone or the whole network, (c) water flow, (d) water consumption of a specific land zone, (e) water readings of devices at the urban level controlled solely by the water company (e.g. Cellos, PRV device (Regulo)).

- Water Consumption monitoring: In this sub-category we have succeeded to include all consumer hydrometers for both the use case areas.
- Water pressure data for a specific land-zone or the whole network: There are several types of readings regarding the water pressure in a field of study that we need either to monitor or to even generate for our calculations. More specifically we monitor/store
    - The inlet and outlet (the one provided by the PRV) water pressure of the network at the main pipe coming from the well in Skiathos and at the main pipe for the case of Sosnowiec.
    - The water pressure monitoring at the critical points.
    - The calculation of individual water pressures at the land zones (Skiathos) or at the hydrometers (Sosnowiec) after a spatial disaggregation of the water demand.

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- Water Flow Monitoring: Similar to the water pressure the water flow is very important to be monitored since it is the most important factor in predicting it through the forecast algorithms for the next day and also it is primary input to the EPANET model for predicting the water pressure of the network.
- Water consumption of a specific land zone: Similar to the monitoring of water consumption on a hydrometer level, after the creation of land zones of study, each of the land zones behaves as a single "virtual hydrometer". The system allows the water company user to monitor and store the aggregated water consumption in various time scales based on the number of hydrometers that reside in the land zone. The presentation of data is exactly the same as in the first case of single hydrometer monitoring and it will be shown in detail in the software architecture chapter.
- Water readings of devices at the urban level controlled solely by the water company (cellos, PRV device (regulo)): Devices like these are treated similarly to the hydrometers. They are stored in the spatiotemporal database with their X,Y coordinates, thus they appear on the thematic maps on the dashboard of the system and the user can click on them. According to the data sampled by the device, there is an appropriate menu that is shown to the user so he/she can pick the appropriate time series to inspect. For example we can show time series for flow rate data, water pressure data etc.

4.1.2 Administrating land zones

This category corresponds to administrating land zones of the network and has one use case, i.e., to create or update or delete a specific land zone for processing (a sub area of the whole water network). We must note that the existing concepts and practices within the scope of the administration of spatial units and the fulfilment of the objective of producing equally important results in terms of forecasting water demand or predicting water pressure of a sub area of the water distribution network have an extensive use in most software systems that deal with urban water sustainability. Nonetheless, enhancing the land management paradigm is very important for urban case studies where the number of nodes in the water distribution network is of great amount and whenever it is necessary to study and analyse the individual characteristics of specific sub areas of the network. For that reason we have incorporating in our system the functionality for the water company expert user to create land zones of study, to save these land zones in a special database table, to have the ability to update the characteristics of each of the land zones dynamically (for example the dynamic changing of status of the hydrometers residing inside a specific land zone), to delete unneeded land zones and in general to have full administration privileges in data manipulation of these sub-areas. To succeed such a case, we developed a set of graphical interface tools to make the creation, manipulation and administration of the land zones easier for the user.

4.1.3 Administrating Users

This category contains only the administration of users of the system and includes only one use case to do so. We have created three different user roles for the whole DSS:

- The super/admin or the back-end user,
- The water company expert user and
- The resident user.

Users can be added or removed from the system by any back-end user. Resident users are created by the social network portal from which there will be an anchor to the DSS. The resident users will have only information to their personal data (i.e. the historical data of their own hydrometer and the ability to create and upload alarms into the DSS system).

The water company expert user is the main user of the DSS. Indicatively, we have two accounts created: one for the water company expert of Sosnowiec and the other for the water company expert of the Skiathos Island.

Finally the back-end user is the actual developer of the system who has also the ability to either dynamically create new users or to hard-code new users.

*Auxiliary functionalities*This category contains auxiliary functionalities and includes 3 use cases: (a) the creation of reports, (b) the use of map tools and (c) the use of the DSS manual.

- The use case of reports corresponds to producing reports regarding the:
    - Creating and updating land-zones
    - Creating parameters for the forecasting algorithms
    - Creating a water pressure map of a city or a specific land-zone
    - Viewing and printing shapefiles with annotations of a city or a specific land-zone.
    - Creating heat maps for showing the variations in water demand at a city level or at a specific land-zone
    - Showing the map of the city or the map of a specific land-zone
    - Viewing the list of users etc.
    - Reports for summarization of data for both pilot cities related to
        - Water demand (on a daily average basis and on the recorded granularity step (10 min and 15 min)
        - Water pressure data, both inlet and outlet (on a daily average basis and on the recorded granularity step (10 min and 15 min)
        - Resident consumptions (on a monthly basis for Sosnowiec and on a trimester basis for the Skiathos)
- For the case of map tools the system is able to
    - Create graphically a region (a sub-area of the water distribution network) as a polygon
    - Calculate automatically the area of the region at hand
    - Aggregate the hydrometers that reside in the area that was created and either store them in a separate file or create a virtual hydrometer that represents them as a single consumption point

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- The tools include also the functionality of editing, updating and deleting already existed areas previously created.

4.1.4 Geospatial Web Map Service Management

This category includes functionalities for handling the loading and the saving of GIS (shapefiles) geospatial data from/to web map server and includes two use cases: (a) loading maps (land zones) and (b) loading the water network.

For this functionality we use the OpenGIS® Web Map Service Interface Standard (WMS) which conforms to the OGC protocol and provides a simple HTTP interface for requesting geo-registered map images from one or more distributed geospatial databases. For the two aforementioned procedures we create two WMS requests which define the geographic layer(s) and areas of interest to be processed. Previously the maps in a form of shape files are already uploaded to the WMS server used (in our case the Geoserver). The interface we just described also supports the ability to specify whether the returned images should be transparent so that layers from multiple servers can be combined in the case of rather complicated applications. For our case we do not need more than two layer-overlapping in any of the individual procedure that involve rendering of geospatial data.

4.1.5 Web Application Project

EWATUS DSS was developed using the .NET Framework but with all the open source technologies. More specifically, the Web application project was built under .NET Framework V4.0, using the programming language of C# as back-end, html (Hyper Text Markup Language), JavaScript, CSS3 (Cascading Style Sheets) and various open source libraries.

As stated above all our pages contain html UI elements to display any data to user, styled with CSS files, and various open source JavaScript libraries and methods. These pages communicate through our Web Services with the Remote Database to retrieve data or apply any computational functions and algorithms. Below we will analyze the functional requirement of water-meters monitoring, the web pages that are involved, JavaScript functions, 3rd party tools and libraries and web services used in the example of Skiathos.

WaterMeters-Consumptions.aspx

When the user wants to monitor water consumptions for a specific water-meter he is being redirected to the below web page (Figure 4.3).

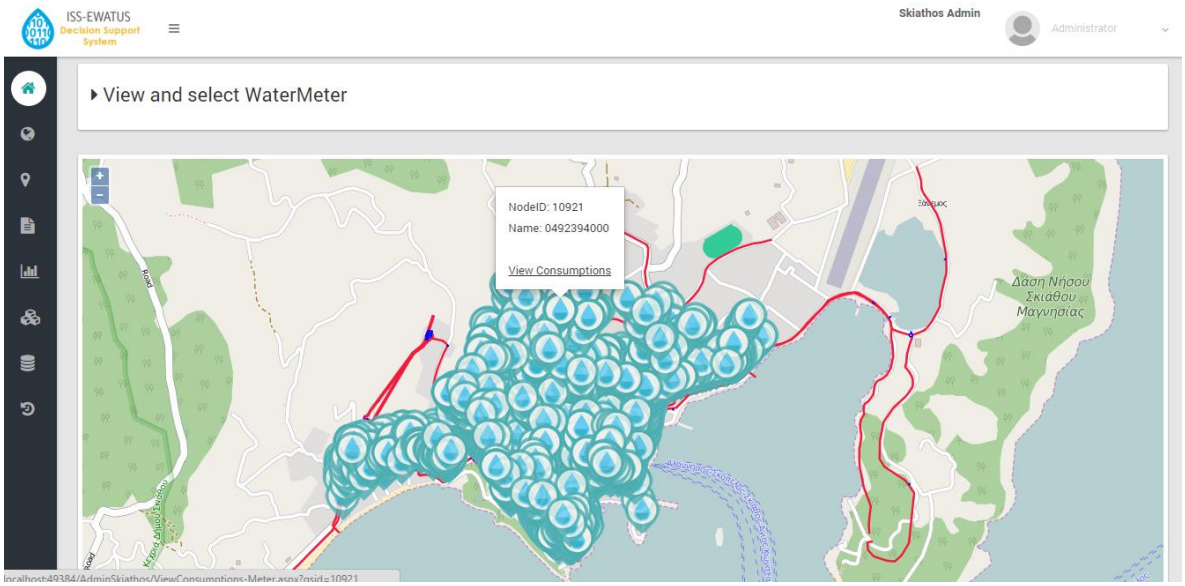

Figure 4.3: Display and select water-meter for consumption analysis

This webpage uses the Open-Layers API to render and display a map (in Street or Aerial view) and consists of 5 tiled layers.

The base map layer can be either an OpenStreet Map layer (Street view option) or a WMS tile layer retrieved for gis.ktimanet.gr. Also we display two additional layers that display some shape files that correspond to the water network topology of Skiathos.

Finally we have the water-meters layer which is displayed on top of all layers and are dynamically generated when the page loads with the help of JavaScript and Web Services. The whole source code is provided to the source code repository of our project.

When the page loads we make a call to the JavaScript function loadnodes_type1(). The AJAX post to our WebService ServiceGeoNodes, in the method "GetAllGeoNodes" includes a JSON serialized variable list that contains the input values the web service method needs in order to work correctly. These variables are the city and type of nodes we want to retrieve.

The Web service method that we use connects to the remote database and queries the data. Then we create a list of C# class objects (GeoNode.cs), compose all necessary values and return them as a JSON serialized string. We choose to use C# class objects and LINQ in order to benefit from latest .NET technologies, data manipulation, ease of access and operational speed from the SQL-Server.

The result is a list containing some GeoNodes Objects that become deserialized on the client side to an array, and then using some Open-Layers functions from the corresponding API we create points based on their coordinates, unique identifiers and names and add them as a vector layer on top of the map. We must note that all points are re-projected to the default EPSG projection system based on their original coordinates in order to display all elements (base layers, tiled shape files layers, water-meters etc.) correctly to the user.

After displaying water-meters to the user, we use a JavaScript event function handler to catch and manipulate user 'clicks' on the map, and display a popup window with necessary information about the element and also a link to view the current consumptions by passing a query string field that contains the unique node ID. By pressing the hyperlink 'View Consumptions' populated for each water-meter we redirect the user to the 'ViewConsumptions-Meter' web page.

This webpage allows user to monitor consumptions for a specific water-meter based on a time period (Figure 4.4).

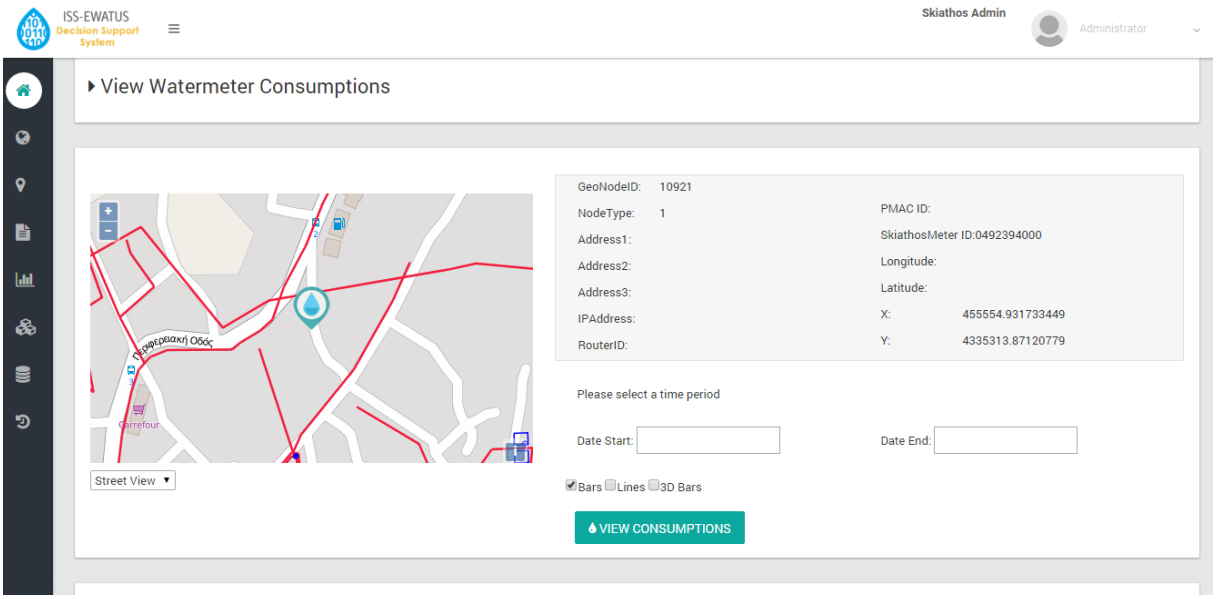

Figure 4.4: View water-meter consumptions

This page uses the same source code for the map rendering and display, with the difference that it generates a single point for the selected hydrometer ("getgeonodeid()") based on the query string of the URL and auto zooms the map to the specific point.

When the page loads it searches using a JavaScript method the URL for query strings (getqueryvariable("qsid")), gets the passed values and then posts asynchronously to WebService's 'ServiceGeonodes.asmx' method 'GetGeoNodeById'. This method takes as input a unique identifier and searches the remote Database for matching records in the table 'GeoNodes'. The result is then passed as a JSON serialized object and it is being displayed on the client side so that user can view all necessary information for the corresponding node.

When the page has finished retrieving all geo-node data the user can input a time period to monitor water consumptions for the selected meter. By pressing the 'View Consumptions' button the system connects to 'ServiceWDSFlowmeters.asmx' web service and calls the 'GetFlowmetersData' method. The input variables for the above method are the geonode id for which we want to monitor data, and also the time period (start and end). The web method analyzes the inputs, constructs the appropriate query and connects to the remote database to get the corresponding records from the database tblDataTableWDSFlowmeters. The result is a JSON serialized object that contains water-meter objects with consumption, reading, datetime and other values.

Upon successful retrieval, on the client side, we use a 3rd party library (Highcharts Javascript Library) to create charts from returned data. We deserialize the data object, create (date, consumption) timeseries lists which and dynamically create the charts as shown below (Figure 4.5).

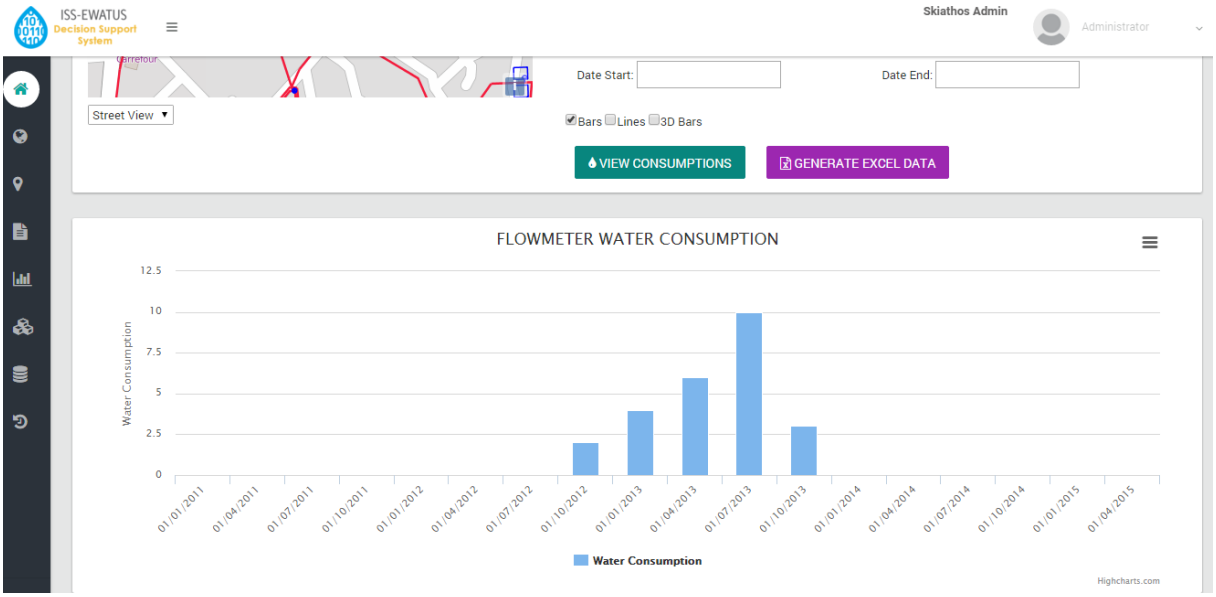

Figure 4.5: Dynamically generated water-meter consumptions

The current chart can then be saved as PDF or Image type file by using the export module of HighCharts library. Also we provide the ability to the user to generate an excel data spreadsheet containing the timeseries dynamically created data with the usage of Closed.XML library. On the client side we make an asynchronous JavaScript post to "Reports.aspx" web service by passing a JSON serialized object of all queried data and creates an excel file with appropriate water-meter consumptions.

4.1.6 Web Services

The core functionalities of the developed DSS derive from the Web Services methods that are consumed in the client side by the user. Each web service contains various public methods, each one serving a specific functionality, grouped together and available for consumption to ISS-EWATUS DSS web application users. These web services can be invoked by SOAP (Simple Object Access Protocol) or by HTTP (POST or GET) or REST. The figure below (Fig. 4.6) shows a UML diagram of the web services and their corresponding methods we use.

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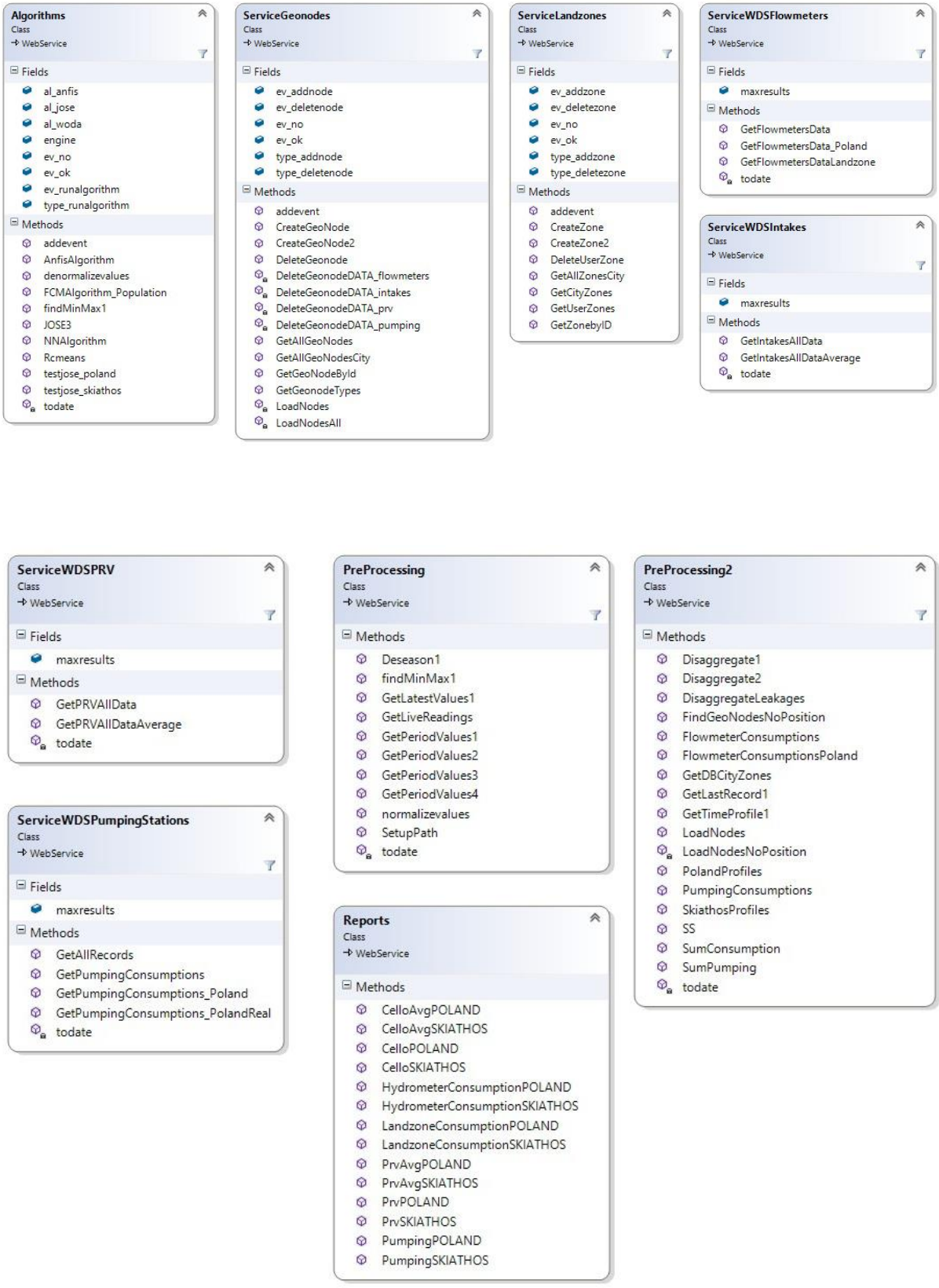

Figure 4.6: ISS-EWATUS DSS Web Services

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All web invokable methods share the following common properties:

- They are written using the programming language C# which encompasses strong typing, imperative, declarative, functional, generic, object oriented and component oriented programming disciplines.
- They all run under the same Namespace
- They are script enabed, meaning that they can be called via scripts, using AJAX.
- They are developed based on project requirements that are highly modular

As stated above, EPANET module should be run at least once every new billing period in order to have updated and current pressure profiles based on period's billing consumptions and pumping station's water network consumption. When the system loads, it automatically checks the database for latest records and alerts the user if he must run EPANET simulation to create and update the simulations' results. The warning message and module redirection can be seen below.

When this message is displayed, then the user must run new EPANET simulations for the current period in order to be able to generate and use correct flowrate and pressure profiles. In order to run these simulations the DSS must prepare all data and create necessary database records. All these functionalities are handled in RunEpanet.aspx web page.

On page load, the system retrieves and generates landzones for the selected city. Each landzone holds a number of watermeters devices that are retrieved using OpenLayers JavaScript library and TURF.JS. These devices will be used in the next step for the disaggregation of the water network demand to the city's landzones. In order to dynamically retrieve this information first we load all landzone objects from the database, along with their point's coordinates which are represented as GEOJSON objects and finally all watermeter devices that are located in the selected city. Then we render the landzones on top of an OpenLayer map, along with the watermeter posistions and then we use a function that uses TURF.JS library to create and retrieve point objects based on polygons and their shapes. This function basically loops through a JavaScript array variable that holds all landzone objects and checks for watermeter devices that are located in each polygon shape.

When the DSS has finished loading all landzones and their flowmeter devices it displays a message indicating the procedure result and prompting user to continue with the generation and run of epanet simulations. Having already created all landzones and their watermeter devices we can now proceed with the creation and run of Epanet simulations. Although this procedure may take some time, once the DSS and EPANET software has finished the simulations we don't need to create any further simulations for the whole current period. This is achieved with the creation of multiple epanet simulations, based on a range of variables that can cover all possible scenarios for the city we are studying and will be described in details.

The next step is to press the 'Run Epanet Models' button. This button creates an AJAX post request to the web service Preprocessing2 and calls the web method 'CreateEpanetDB'. This method takes as input the current cityid, username and also a serialized list of landzone objects (which is basically the local variable that the DSS created on the client side using OpenLayers and TURF libraries.). These

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inputs are passed along with the POST request and the web service starts with the creation of all necessary EPANET modules

When the user calls the above mentioned Web method a series of functions and modules are called in order to process all data. 'CreateEpanetDB' is the basic function that manages all auxiliary methods and generates database records for the EPANET simulations. First the method deserializes the landzones input text object to a list of landzone class objects. Each landzone object consists of a unique id, its GEOJSON shape and the watermeter devices that are located inside the area polygon. Having generated and assigned all watermeters using openlayers the DSS also checks for missing watermeter devices that don't have valid coordinates and randomly assigns them to landzones.

When the system has finished with the landzones generation the next step is the spatial disaggregation procedure. This is one of the most important functionalities and basically defines the whole system procedure since we are able to generate water demands for specific landzones. The dissagregation procedure is described briefly below (as an analytical description was accomplished at D4.1).

1. We calculate the whole water network demand for a billing period based on pumping station database records. We always use the same billing period from the previous year in order to have complete and correct datasets
2. For all available watermeter devices we are calculating their total billing consumptions for the selected period.
3. Then we are generating the leakage attribute based on the above results with this formula

    - *SDP: Sum of Daily Pumping water demand for the whole billing period*
    - *SKY: Sum of all hydrometers billing consumptions for the whole period*
    - *Leakage Percentage = SDP-SKY / SKY4.*

4. Afterwards we are calculating the theoretical consumption of each watermeter (which includes water losses) based on the formula

    - *DK_Consumption= Consumption * (1+Leakage Percentage)*

5. Finally we are calculating the weight for each watermeter as a percentage based on its theoretical consumption and the total network consumption
    (*Weight= DK_Consumption / SDP*)

When the above function finishes, the system continues with the generation of the landzone consumptions and weights. Based on the watermeter devices that exist in each landzone the web application calculates the whole / summed theoretical water consumption for each landzone and then generates the total weight for each ladzone object.

The next step is to prepare all EPANET Tables. The System clears all previous generated demands, pressure results and other variables in order to regenerate them. The first thing is to create records in the EPANET_QIDs table. By reading the settings for the current city the system automatically

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generates the above records. These records basically define all possible flowrate values that can be found in the PRV device. By declaring some minimum and maximum values, along with some step size we can produce a large amount of possible Flowrates. In this way, the user won't have to run epanet simulations every time he needs to generate flowrate and pressure profiles for the forecasted water demand since the EPANET will run all possible water simulations for the current billing period and store the results for later usage.

The final step of the web method to create all available water demand records. These records are created based on the generated QID values and the disaggregated landzone weights. For each possible QID / PRV value (Flowrate) we are calculating the corresponding landzone water demand and assign them to a Datatable object. At this point we must note that each landzone is assigned a virtual node as a representative for the EPANET simulation models. When all water demands have been created we are using a Bulk SQL query to insert these dataset in the EPANET_demands table. When this procedure finishes we are creating some auxiliary database records and also create a record in the EPANET_triggers table. This last action is responsible for calling / triggering the EPANET software to run the simulations based on the database records we have created on the background. The code used for the web method described above can be found source code repository of the project.

The DSS will display a loading message while generating and writing all appropriate records in the database and upon completion EPANET will start working on the simulations on the server. When all simulations have finished, the EPANET software is configured to store all available results in the remote Database tables (EPANET_Output_Pressure_PRVS and EPANET_Output_Pressure_Nodes). These records are then used by the DSS when necessary in order to generate pressure profiles.

Flowrate and Pressure Profiles

When the DSS has finished with the generation of flowrate profiles and runs all the EPANET simulations, the user can use all available results for the profiles creation. The pressure profile is created after EPANET run. In order to access this functionality we must first run a forecasting algorithm to predict the water demand for the network.

This method handles the creation of flowrate and pressure profiles which are returned as a JSON serialized list of objects to the client side and then are rendered as graphs using Highcharts API. Based on the disaggregation procedure we analyzed above we are generating landzone weights and based on the predicted water demand we calculate the water demand for each landzone. Then we proceed in the generation of flowrate profiles. To achieve this, we are using the latest records from the PRV device. First we are calculating last day's water demand based on the flowrate PRV values. Then we generate weights for each PRV timestep based on the daily demand and the current PRV reading. When we have finished with the time disaggregation we are recreating a flowrate profile by using the PRV timestep weights and the predicted total water network demand.

Finally, based on the predicted flowrate profile values we are retrieving the corresponding PRV pressure values from the EPANET_Pressure_Outputs_PRVs table. The web method returns the serialized results and the web application renders them on clied side.

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These results are dynamically generated as chart figures on client side, along with their distinctive timestep values for easier visualization. Flowrate and pressure profiles can be also saved in excel spreadsheet files as timestep / value arraylists by using the corrresponding functionality.

4.1.7 Forecasting module

Users can run forecasting functionalities. We included 3 forecasting functionalities: (a) forecast the water demand for the whole water network, (b) forecast water demand for a specific land zone and (c) create or update or delete a specific parameter to be included in the water demand forecasting algorithms.

- Forecasting the water demand for the whole water network: There are four different algorithms that have been implemented to forecast water demand for an area or a specific land zone. These algorithms mostly use regression algorithms and soft computing methodologies. We have implemented the Adaptive Neuro Fuzzy Inference System methodology, (ANFIS), a Neural Network methodology, a Fuzzy Cognitive Map (FCM) methodology with Evolutionary algorithms for prediction and variations of regression techniques such as ARIMA, AFRIMA etc. The algorithms have been implemented in different programming languages or scripts thus making their integration to the online system a quite challenging job.
- Forecasting water demand for a specific land zone: Under the same assumptions that hold for the whole study area, we use the forecasting algorithms to forecast water demand for a specific sub-area, or land zone. The methodology is exactly the same, however there is an additional disaggregation technique to project the corresponding water demand profile of a specific land zone using the lumped values that refer to the whole island or district.
- Create or update or delete a specific parameter to be included in the water demand forecasting algorithms: Most of the forecasting algorithms use historical water demand data and various seasonality data in order to predict the water demand for an area in a "one step ahead" methodology i.e. to predict the water demand for the next day. The historical data time span is up to years however today's data are needed in order to predict the next day. There are several obstacles into this approach. First is the fact that the data of current day we would like to run the forecasting algorithm is never fully collected by the system unless we are restricted ourselves to run the algorithm at 12:00 midnight every day. Therefore there is an absolute need to be able to run such algorithms at any time of the day especially for water company experts that work at a specific time schedule. On the other hand, there is a specific set of forecasting algorithms that in order to predict the water demand for the next day they also need several weather data for the next day which are not predicted but simply they must be input by the user of the system. The above arguments make our case strong in terms of human dynamic intervention in running the forecasting algorithms and changing several parameters or updating several data by hand at the time of executing the software component. The system allows such an intervention where the user is prompted to: insert

data (mostly meteorological) that are missing from previous days or put a prediction of meteorological data for the next day, insert/predict socio-economics data for the next day, predict water demand data of time periods of the current day in order to forecast values of the next day etc.

The forecasting water demand module was created based on the cities' available datasets and reuirements. For the DSS we used a variety of prediction algorithms, customized or built based on our needs, and with the help of some auxiliary toolkits and programming environments. These algorithms implementations are located in Algorithms.asmx web service and can be called through any HTTP or REST web request from client side. The code behind each web method handles the communication with all necessary modules and libraries in order to generate appropriate results. Each algorithm has a customized implementation based on the available dataset formats, inputs, configuration variables and outputs in order to achieve better execution times and results.

RCmeans

The algorithm is implemented as an .R script and was modified to be used dynamically through our web service. This script generates a predicted flowrate profile (Timestep / Flowrate values) based on historical PRV dataset.

Inputs: PRV node, period start datetime for learning, cityid and username

The implementation of the script is based on the current season and a clustered dataset consisting of working and non working days Flowrates values. Using a complex SQL query we are generating the correct dataset from the remote database and creating a list of data records objects containing all necessary information.

Calling an R Script through our Web Service is achieved with the usage of R.NET library and a custom installation of R Statistical Software in the same VM that our web application is hosted. The code that initializes the instances, passes all dynamically generated variables and retrieves results is displayed below.

Fuzzy cognitive maps

This algorithm is based on Fuzzy Cognitive Maps implementation of Real Coded Genetic Algorithm in R statistical language for univariate time series prediction of water demand.

Inputs: PRV node, period start datetime for learning, cityid and username

This algorithm generates a predicted water demand value based in aggregated historical PRV flowrate values. By using dynamic SQL queries we are retrieving all necessary flowrate values form the tblDataTableWdsPRV table, then we are created list of flowrate values based on their datetime stamp and finally we are creating normalized daily water demand values by aggregating for each day the Flowrate/hour values to total water demand / day. These results are stored in a complex arraylist of objects and are passed to the R script with the usage of R.Net library. The algorithm executes and

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calculates the predicted water demand value. This result is then disaggregated based on a time profile in order to produce a flowrate profile. The method that is responsible for creating the flowrate predicted profile based on a total water network demand

Based on the current and next day (for which we are generating the predicted total water demand and predicted flowrate profiles) this function retrieves previous week flowrate values for a whole day. These values are then assigned to weights based on their readings and the total daily water network consumption. The result is a list of weights for each timestep which is then used for the time disaggregation in order to create the flowrate profile based on these weights and the total predicted network demand.

This algorithm is based on autoregressive integrated moving average timeseries model implementation in R statistical language for univariate time series analysis.

Inputs: PRV node, period start datetime for learning, cityid and username

This algorithm generates a predicted water demand value based in aggregated historical PRV flowrate values. By using dynamic SQL queries we are retrieving all necessary flowrate values form the tblDataTableWdsPRV table, then we are created list of flowrate values based on their datetime stamp and finally we are creating normalized daily water demand values by aggregating for each day the Flowrate/hour values to total water demand / day. R.net library is initialized and all inputs variables are dynamically passed to the script. Upon execution it uses the same time disaggregation procedure that was described previously to generate a predicted flowrate profile from the predicted total water network demand and return the serialized JSON result to user for rendering.

ANFIS

This is an algorithm implementation of Adaptive Neuro-Fuzzy Inference Systems (ANFIS) using Matlab (Fig 4.28). The connection and execution of this script is achieved using Matlab .COM server toolkit which is installed along with Matlab software on the Web application VM server.

Inputs: JSON serialized input data for learning and forecasting, configuration variables (such as numfs, epochs and step size etc.), cityid and username.

When a user requests to run this algorithm he is displayed with a page that contains some basic steps in order to produce the dataset which will be used as input in the Web Service method. In this page user is displayed the latest database records that contain all necessary variables such as water demand, meteorological data and arrivals. This module helps the user to complete steps 1 and 2 before proceeding in the execution of the algorithm. In these steps user must validate current days readings and also input some predicted values for the next day's variables (Fig 4.7). These are necessary for the execution of ANFIS script. Finally he enters a learning period and by pressing the 'Prepare Dataset' an AJAX post request is made to Preprocessing.asmx web method GetPeriodValues1. This method generates and returns to the client a JSON serialized object of list containing all datarecords from the remote database along with their real and normalized readings.

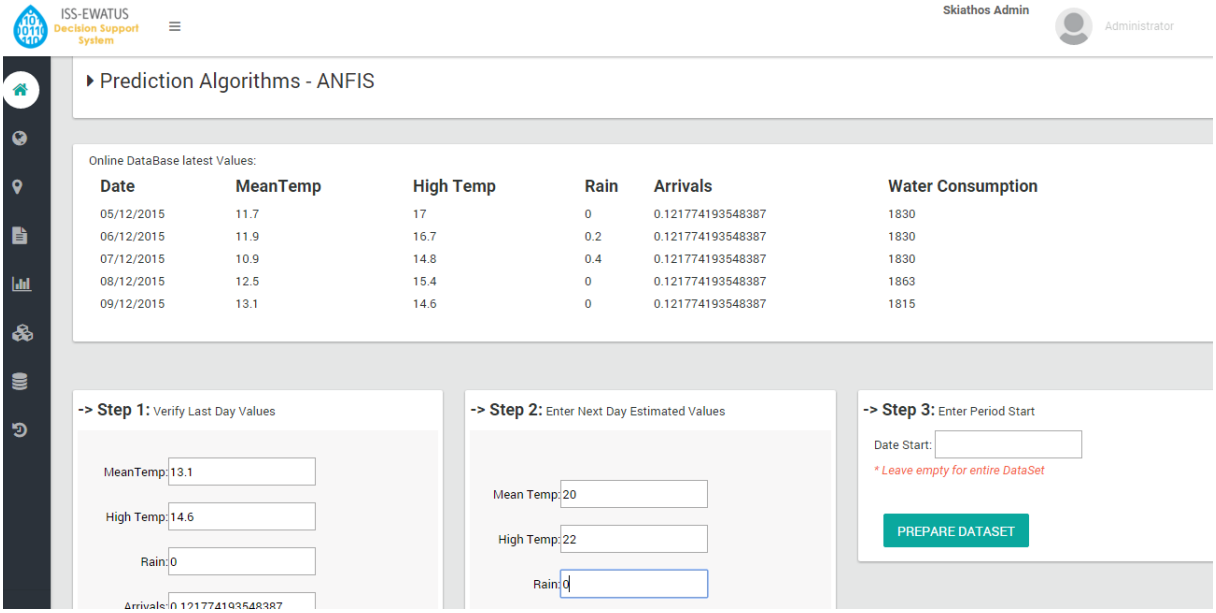

Figure 4.7: Prepare dataset for ANFIS algorithm

When the system has finished with the generation of the dataset a new panel opens to the user. This panel contains all available algorithm parameters that can be changed by the user in order to calibrate the script. When everything is ready user can run the algorithm by pressing the corresponding button. The previously stored javascript dataset variable along with the algorithm parameters are passed in the AJAX post request to Algorithms Web service in order to initiate the matlab enginee, create the dynamic generated variables and execute the script. The result of the whole procedure is finally returned to the user.

FCM

This is a multivariete implemetation of Fuzzy Cognitive Maps based on genetic algorithms using multistep learning genetic algorithm. This algorithm was implemented as a seperate / native library project. Using latest technologies and object oriented programming this forecasting algorithm is connected using native DLL files on code behind through the Web services layer.

Inputs: JSON serialized input data for learning and forecasting, configuration variables (such as population learning size), cityid and username.

Similar to ANFIS algorithm the first step of running this algorithm is to validate current day's values (Fig 4.31). Since the algorithms' implementation for the case of Skiathos takes as inputs multivariete variables (such as water demand, mean temperature, high temperature, rain and touristic arrivals) we must provide a correct dataset for the learning and forecasting data.

For the generation of the data we are calling GetPeriodValues2 web method from Preprocessing Web service. This method takes as inputs the currently user validated variables and the period start datetime to produce a JSON serialized list of data objects.

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Using a complex dynamically generated SQL query we are retrieving all database records from 3 separate tables that contain historical data for pumping station water demand, meteorological data (mean temperature, high temperature and rain) and tourist arrivals. These records are assigned to seperate class objects and are processed to an array list. When finished we are creating current day's user validated readings to another class object and add it to the final list. This last object's readings are basically used for the water demand prediction while all remaining for the learning procedure.

Having generated this list, then next step is to produce their corresponding normalized values and finally return the whole list object in a JSON serialized format that can be used on the client side.

When the preparation of data is finished, a new page is dynamically displayed along with the algorithms parameters. By running the algorithm we are passing previously generated dataset and the code behind handles learning and prediction procedures based on the custom implemented libraries.

Neural Networks forecasting model

This is a custom implementation of multivariate time series prediction with ANNs and Levenberg-Marquardt Algorithm, developed as a native library for the needs of the DSS.

Inputs: JSON serialized input data for learning and forecasting, configuration variables (such as number of iterations, step size and epoch size), cityid and username.

Based on the algorithm inputs and the multivariete implementation for the case of Skiathos user must verify current days variables, enter some estimated variables for next day (which will be used for prediction) and a learning period datetime start. Using similar procedures as described in the above algorithm implementations, the DSS retrieves corresponding data records from multiple records, and generates a list of objects containg real and normalized readings. This object is then passed as input to NNalgorithm web method along with user's selected algorithm parameters and the execution of the Neural Networks methods start.

4.1.8 Evolutionary Multi-objective Optimization algorithm

Water that can be pumped and used for urban water consumption can be groundwater, water stored in a reservoir and Spring water. There are restrictions concerning the quantity of water that can be exploited. Concerning a drilling, the pumped water cannot be that much, that the ground water level is not able to recover to its original point. That can be controlled by comparing the time of the operation the and the recovery time. Concerning the reservoir water and the Spring water, the restrictions are set by the availability of each resource.

The first objective is the delivery of the requested water volume. The demand for the highest possible quality of urban water, gives out the second objective, which is the minimization of concentration of each pollutant. The third objective of the multi-objective optimization problem is the minimization of operational costs. The considered scenario involves an arbitrary optimization problem with k objectives, which are, without loss of generality, all to be maximized and all equally important, i.e., no additional knowledge about the problem is available.

Evolutionary algorithms are characterized by a population of solution candidates and the reproduction process enables to combine existing solutions to generate new solutions. Finally, natural selection determines which individuals of the current population participate in the new population. Real-Coded Genetic Algorithm is the population-based algorithm selected to solve this problem. An analytical description of the problem and proposed algorithm is given in Appendix D.

4.1.9 Handling water pressure alerts

This is the case where our implemented system gives the opportunity to resident/users to participate by informing the competent authorities about failures of the water distribution network, leaks in safety valves etc. With this functionality the water company authorities collect information about the current state of the water distribution network real time. The system is implemented to raise an alarm message to the manager that someone has inserted an alarm. Each alarm is attaching an explanation or some notes of what it is about and also is followed by the user's credentials as well as the X,Y coordinates of the area that it refers to. The managers can respond by managing these alarms accordingly to the action taken. Relevant messages/actions can be inserted in the system to inform the current situation. When failures are fixed the status of the alarm changes accordingly. Everything is kept in the records and the log of the system for managerial purposes.

Project's files structure

The project's files structure is the following. Each folder contains several files that are being used by the application in order to work correctly. The most important folders are:

- **App_Code**: This folder holds compiled C# classes objects which are mainly used along with our Web Services to store raw data records into objects, serialize them, manipulate them or display the data to users.
- **AdminPoland**: This folder contains all GUI files (basically html documents) used by our web application only to users that are qualified as Poland administrators.
- **AdminSkiathos**: This folder contains all GUI files (basically html documents) used by our web application only to users that are qualified as Skiathos administrators.
- **WebServices**: This folder stores all necessary asmx (Active Server Method Files) web services. These services were build using C# and basically serve all functionalities of our web application since they contain methods and functions to communicate with remote databases, retrieve data using complex SQL-Queries, create and display data objects, run various algorithms etc.
- **js**: Folder that contains JavaScript libraries and files
- **css**: Folder that contains CSS documents that are responsible for the user interface of our web pages
- **adminjs**: Folder that contains JavaScript libraries used for the administrators' user interface.

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All basic settings are stored in the web.config file and define the connection strings for the remote and local databases (along with authentication credentials), the targeted framework, the authentications forms and memberships and also some 3rd party open-source library references.

4.2 Physical Architecture Overview

EWATUS DSS project consists of two main modules, the Web Application part (Basically the GUI and all User Functionalities) and the Database module (the main storage for our DSS data). Each module lies on a different server in order to achieve a highly modular and easy to maintain project.

EWATUS DSS WEB APPLICATION

Our web application runs on an IIS Virtual Machine that is deployed in a physical server under the CERTH domain. The VM consists of the following properties:

- Windows Server 2012 64bit with IIS
- Microsoft SQL Server 2012 Express
- Processor: Intel Xeon(R) E3 1220
- Memory: 4GB
- HDD: 500GB
- IP: 194.177.202.235

EWATUS REMOTE DATABASE

Our web application data sources that contain all necessary values and structure (such as water demands, geonodes, meteorological data etc.) runs on a IIS Virtual Machine that is deployed in a physical server at Poland. The VM consists of the following properties:

- Windows Server 2012 R2 64bit
- Microsoft SQL Server 2014
- Processor: Intel Xeon(R) E5 2630
- Memory: 8GB
- HDD: 350GB
- IP: 2012.106.179.159

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5 Implementation Details

A Web-based DSS is a complex software system that integrates multidisciplinary data sources and related tools generally developed in different and sometimes diverse programming languages in order to generate value-added information to support decision-making. The experience from the development of previous decision support systems showed that there are three major development methods:

- System Development Life Cycle (SDLC),
- Rapid Prototyping (RP), and
- End-User Development (EUD).

All of them, especially the SDLC and RP, usually use informal box-and-line descriptions to clarify the architecture of a DSS. Such methods bring an informal and ambiguous architecture specification to system analysis. In contrast to those traditional design methods, the idea is to use a hierarchical design method for a Web-based DSS. To achieve however this design we must provide interface descriptions and formal specifications for components and connectors in a Web-based DSS. In this way the layers in the hierarchy can accommodate any kind of information and they will not be bounded to water related information or web services that communicate this information. Thus this kind of web-based DSS design can allow also the organization of multidisciplinary data and related tools.

Like traditional software design methods, most of today's DSS design methods use informal box-and line descriptions that lead to a number of problems. Firstly, the box-and-line diagrams do not provide open access points for the architecture elements and secondly the diagrams cannot be formally analyzed for consistency, completeness, or correctness. To specify the architecture of a software system, we create connectors in our DSS as diagram 1.2 illustrates.

The system described above uses RESTful interoperable web services based on hydrological procedures which perform the connection between different involved systems. When needed the SOS 2.0 web services which are OGC certified are used in transferring data from the proprietary hardware monitor software (namely PMAC) to the spatiotemporal database. After all data is gathered, we use a customized Entity-Relationship model for the spatiotemporal database in such a way that all the hydrological information depends on the concepts defined in the presentation layer of the website. This approach uses the OGC® stack and the WaterML2.

Even though the system is developed mostly for the web based application in HTML and in Javascript programming language we used the Microsoft's ASP.NET Framework as the base layer for the following reasons:

- The host server resides on a virtual Windows Server 2012 therefore is Internet Information Services (IIS-host). The communication between the host and the Microsoft AS.NET Framework environment is more stable for the above reason

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- The development of web services was done using the C# programming language for security reasons. Since the database environment of the spatiotemporal model is Microsoft SQL-Server, it is much easier to program in a language that is used predominately for that.

- Using this framework we were able to use several technologies and modules needed for the project's functional requirements and make them work in the same environment, having complete water DSS web application at urban level.

5.1 Data Transmission

In our system we had to deal with data transmission from the spatiotemporal database in the following 3 use cases: (a) the transmission of the flow rate data, (b) the transmission of water pressure data, and (c) the transmission of the consumer consumption (billed) data. We elaborate for each one of the cases.

- Transmission of the flow rate data. For this case we made two separate web services in order to distinguish data about the flowmeters/hydrometers which are based on the billings and the data coming from the main water distribution network devices such as Cellos, Regulos and the inlet and outlet water pressure after the pressure regulation valve.

- Transmission of water pressure data. Similarly to the previous web service we have implemented a web service to take care of storing and transmitting the water pressure data to and from the spatiotemporal database. The web service has the name WDSP and basically contains two main calls namely `GetPRVAllData` and `GetPRVAllDataAverage` that they perform the following:

    - `GetPRVAllData`: Get all available readings (Flowrate, Outlet, Inlet) data for a specific PRV device, based on a time period.

        - Inputs: Geonode Id, Period Start, Period End
        - Outputs: A JSON serialized List of PRVData C# class objects

    - `GetPRVAllDataAverage`: Calculates all available average daily readings (Flowrate, Outlet, Inlet) for a specific PRV device, based on a time period.

        - Inputs: Geonode Id, Period Start, Period End
        - Outputs: A JSON serialized List of PRVData C# class objects

- Transmission of the consumer consumption data. This service has to deal with the billing data. For the case of Sosnowiec we have two readings per hydrometers per month. However for the case of Skiathos we have only one reading per trimester. This differentiates the treatment of data as to reads and writes relatively to the web service that performs the transmission. Additionally, we are forced to perform different time scale disaggregation procedures for the two pilot cities for the pre-processing of the water demand inputs to the EPANET.

5.2 Geoserver

GeoServer is an open source server for sharing geospatial data. Designed for interoperability, it publishes data from any major spatial data source using open standards. In order to render and display necessary shape files from cities' water networks an instance of GeoServer was installed in the same VM the Web application is deployed. The version we used is the latest stable software version 2.7.1.1

The server was installed to automatically run as a network service by using the port 9090. After installation we created separated Work Spaces for each city's network. By using some administrator provided shape files we initiated separate data store objects based on provided EPSG systems and created WMS (Web Map Service) modules containing tiled layers with shape file objects information, ready to be consumed in our web application.

Through the WMS we specify a number of different request types, two of which are required by the WMS server:

- GetCapabilities - returns parameters about the WMS (such as map image format and WMS version compatibility) and the available layers (map bounding box, coordinate reference systems, URI of the data and whether the layer is mostly opaque or not)
- GetMap - returns a map image. Parameters include: width and height of the map, coordinate reference system, rendering style, image format

Apart from the two basic request types above, other request types may also include:

- GetFeatureInfo - if a layer is marked as "queryable" then you can request data about a coordinate of the map image.
- DescribeLayer - returns the feature types of the specified layer or layers, which can be further described using the requests.
- GetLegendGraphic - returns an image of the map's legend image, giving a visual guide to map elements.

Furthermore we must note that all the above types of requests which are needed for our application are fully serviced by the installed GeoServer. GeoServer is an open-source server which written in Java and even if the programming language is different than the one we are using, it allows us to share, process and edit geospatial data. This server is really designed to accommodate all the interoperability issues we face for the transmission of data from the spatiotemporal database and it is able to publish data from any major spatial data source using open standards. GeoServer has evolved to become an easy method of connecting existing to web-based maps such as Open-Layers used for the maps in Skiathos.

The OGC web map service specification defines an HTTP interface for requesting georeferenced map images from the GeoServer. GeoServer supports the WMS 1.1.1 protocol/version, the most widely used version of WMS, as well as the WMS 1.3.0. On the other hand, WMS provides a standard interface for requesting a geospatial map image. The benefit of this is that, WMS clients can request images from multiple WMS servers, and then combine them into a single view for the user. The

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standard guarantees that, these images can all be overlaid on one another as they actually would be in reality.

6 Testing

6.1 Introduction to Web Application Testing

Testing is one of the most important phases in the software life cycle and in software's growth. It is the best tool both professional and practical to uncover the precision, correctness, fault tolerance, robustness and all the other major characteristics that constitute a good quality software product. Otherwise said, testing leverages the internet computing environments and looks for to imitate real world user visitors for this Web site testing procedure (Kaur et al., 2012; RadhikaBatra, 2014).

The testing for web applications is employed to check the correctness of web based attributes within the web; for instance, how the computer software, hardware, network infrastructure and any other component can perform the tests set for the check. Web testing aims to make certain the quality of web-based applications which are called to verify and confirm the services as well as to check the web support and interactions within the applications in a web structure (Vanitha and Alagarsamy, 2012; Mohsenzadeh, 2013).

Testing needed steps of software progression. In web based software testing procedure, the primary phase test requests are ready by the user and they are delivered to the web-based testing system, so they are obtained by the system when they are agreeing to. In the next phase all check-jobs are organized and dispatched, the software services are offered for checking specific tasks, fundamental sources are consented and test tasks are carried out and also guided. Within the last step, the results of the tests and analytics are gathered and they are provided to users and to developers in order to utilize the web interface (RadhikaBatra, 2014).

6.2 Steps to web application testing

The vast majority of the web sites and the web applications are essentially client/server applications where the web servers perform services to the clients which act as browsers. Consideration should be given to the interactions between html pages, TCP/IP communications, Internet connections, firewalls, applications that run in web pages (such as applets, javascript, plug-in applications), and applications that run on the server side (such as scripts, database interfaces, logging applications, dynamic page generators, active server pages, etc.). Base on the previous comments we must also say that, there is a wide variety of servers and browsers, and also within the same browser there are different versions with small but sometimes significant differences between them. Thus the testing process of web application due to the aforementioned complexity can become a major ongoing effort.

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Before we set up all the steps in order to illustrate the whole testing process we must refer to all the major considerations before to actually start testing any of the procedures or the services of the web application. These considerations include the following:

- What is the maximum possible number of hits that we might experience on the server at the unit of time?
- Considering the above hit counts and the loads that we will experience, what kind of performance is required from the server point of view to respond to these loads, i.e. what should be the appropriate server server response time? Especially for the web services that deal with the database querying and additionally with the fact that these services "talk" to a repote database, what are going to be the database query response times in order the user not to experience any lag?
- Do we need a set of special tools for web loads or maybe web robot downloading tools in order to test the downloading and the uploading performance of the server?
- Who is the target audience?
- What kind of browsers will they be using?
- What kind of connection speeds will these browsers above be using?
- Are they intra- organization (thus with likely high connection speeds and similar browsers) or Internet-wide (thus with a wide variety of connection speeds and browser types)?
- What kind of performance is expected on the client side (e.g., how fast should pages appear, how fast should animations, applets, etc. load and run)?
- Will down time for server and content maintenance/upgrades be allowed? If yes how this will affect the whole system and the decision making process? How much time will be needed as "down-time" for the server to finish the maintenance?
- What kinds of security (firewalls, encryptions, passwords, etc.) will be required and what is it expected to do? How can it be tested?
- How reliable are the site's connections to the internet are and what is required at least by the competent authorities that run the decision support syste? How these connections affect the system at the time of invremental or scheduled backups?
- What processes will be required to manage updates to the web site's content?
- What are the requirements for maintaining, tracking, and controlling page content, graphics, links, etc.?

- Which HTML specification will be adhered to? What variations will be allowed for targeted browsers?
- Will there be any standards or requirements for page appearance and/or graphics throughout a site or parts of a site?
- How will internal and external links be validated and updated? How often? Can testing be done on the production system, or will a separate test system be required? How are browser caching, variations in browser option settings, dial-up connection variabilities, and real-world internet 'traffic congestion' problems to be accounted for in testing?

Having in mind the above considerations we set the categories of testing which are:

- Functionality Testing
- Usability testing
- Interface testing
- Compatibility testing
- Performance testing

Thus the rest of the subsections in this chapter refer to each one of the categories of testing.

6.3 Functionality Testing

In the functionality testing we have to do the checks that are related to links in other web pages (both internal and external), the checks that are related to database connections (especially when the databases are remote), the checks to the forms used in the web pages for submitting or getting information from user and their validation, and finally to do the cookie testing.

6.3.4 Checking of the external and internal links

Relatively to the checking of links we performed the following tests:

- We checked the correcteness of the outgoing links from all the pages from specific domain under test.
- We checked the correcteness of all the internal links.
- We checked the correcteness of the links that are jumping on the same page.
- We tested the links used to send alarms to the administrator from other users and from other web pages.
- We checked if there are any orphan pages.

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- We checked the case of broken links.

6.3.5 Checking of forms

Forms are the integral part of any web site. Forms are used to get information from users and to keep interaction with them. The following issues must be checked when we deal with web pages that contain forms

- First checking all the validations on each field.
- Checking for the default values of fields.
- Wrong inputs to the fields in the forms and how the system will behave on any kind of values that are put in.
- In a purely dynamic system check the options to create forms if any, delete forms, view or modify the forms.

6.3.6 Cookies testing

Cookies are small files stored on the user machine when we use the web application via the browser. These are basically used to maintain the session of the usage, mainly the login sessions is the issue we deal here. We did the appropriate testing of the application by enabling or disabling the cookies in our browser options. The system behaved appropriately. We also tested the encryption mechanism of the cookies before writing them to user machine. We also checked the session cookies (i.e. the cookies which must expire after the session is closed) so basically, we checked for the login sessions and the user stats after the session ended. We finally tested the effect on the application security by deleting the cookies and the system behaved appropriately.

6.3.7 Validation of the HTML/CSS and database testing

The testing for validation of HTML/CSS is very important when we optimize our site for Search engines. In our case scenario this is not the issue since the system is rather a closed system from the point of view that the water company experts only need to know the URL and the correct procedure to reach it.

From the other hand of the residents of the pilot cities using the system this is also covered since there will be an anchor from the social network portal where the resident users mainly will use. Thus a typical check was done towards this aspect with just validating the site for HTML syntax errors. Another major check needs to be done here which is to test if the site is crawlable to different search engines but as we mentioned before this is usually done for public sites and not for web applications that refer to only a few people.

Also relatively to the database testing we must say that data consistency is very important in our web application. For that reason we did the testing that refers to the data integrity and errors while we edit, delete, modify the forms or do any DB related functionality. More specifically, we checked if all the database queries are executing correctly, data is retrieved correctly and also updated correctly.

6.4 Usability testing

The usability testing is the best way to understand how real users experience the website or the web application. Here we are lloking for a well-designed user test from which we can measure actual performance on the most important and mission-critical tasks. If the user cannot figure out how to complete for example a whole prediction process relating to water pressure of the next day in a pilot city, but on the other hand he/she likes a lot the web application then we have a major problem. Thus the usability test refers to how well the users can perform according to how the web site was designed and coded to function relatively to specific tasks. That is, usability testing is a technique used in user-centered interaction design to evaluate a product by testing it on users. This can be seen as an irreplaceable usability practice, since it gives direct input on how real users use the system.

Even though we are at a preliminary phase of releasing the system to the competent authorities for the ultimate test we initially tested the system in a small group of users in the University of Thessaly. This group was mostly formed by students of various prior experiences with computers web applications.

When we conducted the user testing, one of the developers read to the participants (7 people) one task at a time "Find and show on the screen the water meter in Skiathos wof some specific ID and show all thw consumptions of this water meter that are stored in the system". To prevent bias, the developer followed the same "script" when explaining the task to each participant. The results were mostly excellent in almost all the scripts which mean that the design of the web application indicates a system which is user friendly and easy to use. The specific tests examined were the following:

6.4.4 Test for navigation

Navigation means how the user surfs the web pages, how he/she uses different controls like buttons, boxes or how he/she uses the links on the pages to surf different pages. Usability testing includes: Web site should be easy to use. Instructions should be provided clearly. Check if the provided instructions are correct means whether they satisfy purpose. Main menu should be provided on each page. It should be consistent.

6.4.5 Content checking

The content has been checked and it is proved logical and easy to understand. We also checked for spelling errors. We have not used any dark colors in the presentation of the web application since the dark colors have been proved that they annoy the users. We have followed some standards that are used for web page and content building. These are commonly accepted standards and they are the following:

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- Content should be meaningful.
- All the anchor text links should be working properly.
- Images should be placed properly with proper sizes.

6.5 Interface Testing

The main interfaces are the web server and the application server along with the database server interface. Relatively to those we checked all the interactions between these servers and they proved to be executed properly. Errors are handled properly. If database or web server returns any error message for any query by application server then application server catches and displays these error messages appropriately to users.

6.6 Compatibility Testing

Compatibility of any web site or any web application in general is a very important testing aspect. For that reason the compatibility test we executed were the following:

- Browser compatibility
- Operating system compatibility
- Mobile browsing
- Printing options

Browser compatibility: this is one of the most influencing types of web site testing. Some applications are very dependent on browsers. Different browsers have different configurations and settings that the web application should be compatible with. We have checked that the web application coding is cross browser platform compatible. We have checked the correct running of the web application with all the major web browsers (Internet Explorer, Chrome, and Mozilla).

OS compatibility: this test is to check if some functionality of the web application may not be compatible with all operating systems. We have not excausted this type of checking due to limited resources relatively to hardware, but the fact that almost the entire functionality is written in JavaScript makes us confidentent that there will not be any issues of this category.

Mobile browsing: This is not one of the requirements for this deliverable. However the web application runs on all the major mobile Operating Systems.

Printing options: Because we have given page-printing options in several cases of the system we made sure that we used printable fonts and the appropriate page alignment and the graphics are getting printed properly.

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6.7 Performance Testing

Web application should sustain to heavy load. Web performance testing must include the following two types of testing:

- Web Load Testing and
- Web Stress Testing

Web load testing: The first thing we did towards this aspect was to test the application performance on different internet connection speeds. In the case web load testing, we have to check the performance of the system when many users are accessing or requesting the same page. However, there is no reason to do such testing because the maximum number of simultaneous users will exceed the number of 10 at any case scenario. We know that in the case scenario that more pilot cities will be included then such a test needs to be performed. However, there is a performance peek that always has to be kept in mind and this is due to the remote database connection and the remote execution of the queries. The way the spatiotemporal database was designed does not give us any other choise but to accept this type of latency.

Stress testing: Generally stress means stretching the system beyond its specification limits. Web stress testing is performed to break the site by giving stress and checked how the system reacts to stress and how the system recovers from crashes. However, there is no reason to do such testing because the maximum number of simultaneous users is limited.

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5 Appendix A – Applied Software Libraries

The main software parts and components of our tool are:

- **ASP.NET –** The base software architecture that we used to build our web application and to manage the users and their authentication into the system.

- **Microsoft SQL SERVER** - We used the MSSQL 2014 for the creation and management of our system's databases that holds our DB system structure and all our data. Note that even though there is a major database part of the integrated system which is the spatiotemporal database, here we refer to the local database that works tightly with the IIS host where the DSS resides. This database helps to keep data locally whenever it is needed and mostly to keep temporarily all intermediate data that have been produced in the midst of some calculation and will be used in the future as input but for the spatiotemporal database and model they are not needed. Note that the version of the database server is different than the version of the database server of the spatiotemporal model. This is not a problem because there is absolute compatibility between the two versions

- **GeoServer** - With the usage of GeoServer we are able to create WMS layers for shape files and display them to users in our web application maps. More specifically, the Web Map Service Interface Standard (WMS) provides a simple way to request and serve geo-registered map images. During pan and zoom operations, WMS requests generate map images through a variety of raster rendering processes. Such image manipulation is generally called re-sampling, interpolation, or down-sampling. GeoServer supports three resampling methods that determine how cell values of a raster are outputted. These sampling methods are the Nearest Neighbor, the Bilinear Interpolation and the Bicubic methods and they are all available on the default Interpolation menu.

- **Web Services** - The main part of our DSS is in this module. By creating and consuming online web services we were able to handle the majority of functionalities that we needed and also create a communication module with our Databases. These are nothing else but a set of modules that perform a specific task but the result of the task i.e. the outcome is communicated through the web via the http protocol. This protocol was originally designed for human-to-machine communication, is utilized for machine-to-machine communication, more specifically for transferring machine readable file formats such as the XML and the JSON. In our case we use the JSON. Thus in practice the web service typically provides an object oriented interface to a database server, utilized for example by another web server, like in our case where the host application is the DSS web application and the data is stored in the spatiotemporal database. Basically our integrated system is offered to the end user as a mushup where the web server consumes several web services at different machines, and compiles the content into one user interface.

- **Open-Layers** – Open-Layers API is an open JavaScript API that we use in order to load, display and render maps on our Web Application. The following diagram shows all the possible

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connections that can be done through the Open-Layers API and how it communicates and complies with the OGC principles.

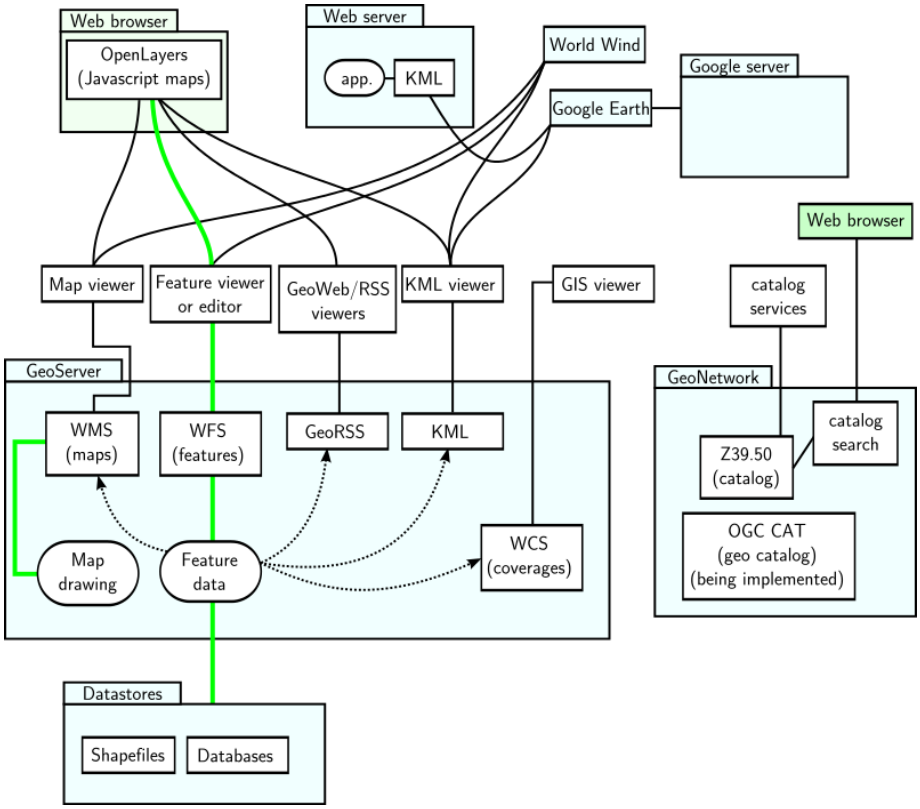

Figure A.1: The set of connections and the protocols that the Open-Layers API can support.

- **EPANET –** EPANET is the most popular water distribution modelling toolkit for running hydraulic simulations. EPANET provides an integrated environment for editing network input data, running hydraulic and water quality simulations, and viewing the results in a variety of formats. EPANET provides a fully equipped and extended period of hydraulic analysis that can handle systems of any size. The package also supports the simulation of spatially and temporally varying water demand, constant or variable speed pumps, and the minor head losses for bends and fittings. The modeling provides information such as flows in pipes, pressures at junctions, propagation of a contaminant, chlorine concentration, water age, and even alternative scenario analysis. This helps to compute pumping energy and cost and then model various types of valves, including shutoffs, check pressure regulating and flow control. Also EPANET's water quality modeling functionality allows users to analyze the movement of a reactive or non-reactive tracer material which spreads through the network over time. It rates the reactive material as is grows, tracks the percentage of flow from the given nodes. The package employs the global reaction rate coefficient which can be modified on a pipe-by-pipe basis. The storage tanks can be modeled as complete mix, plug flow or two-compartment reactors.

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- **Other tools** - Along with the above tools we also used a variety of libraries and technologies, in order to achieve the requirements for the project functionalities. These technologies include:

    - **AJAX (Asynchronous JavaScript and XML)**. AJAX is a set of web development techniques using many web technologies on the client-side to create asynchronous web applications. With Ajax, web applications can send data to and retrieve from a server asynchronously (in the background) without interfering with the display and behavior of the existing page. By decoupling the data interchange layer from the presentation layer, Ajax allows for web pages, and by extension web applications, to change content dynamically without the need to reload the entire page. Despite the name, the use of XML is not required (JSON is often used in the AJAJ variant), and the requests do not need to be asynchronous. This is the case for our web application.

    - **LINQ (Language Integrated Query)**. LINQ is a Microsoft .NET Framework component that adds native data querying capabilities to .NET languages but it has also been expanded to support Java, PHP, JavaScript and ActionScript. LINQ extends the language by the addition of query expressions, which are akin to SQL statements, and can be used to conveniently extract and process data from arrays, enumerable classes, XML, JSON, documents, relational databases in general and third-party data sources. Other uses, which utilize query expressions as a general framework for readably composing arbitrary computations, include the construction of event handlers or monadic parsers. LINQ also defines a set of method names (called standard query operators, or standard sequence operators), along with translation rules used by the compiler to translate fluent-style query expressions into expressions using these method names, lambda expressions and anonymous types.

    - **HighCharts**. Highcharts is a charting library written in pure JavaScript, offering an easy way of adding interactive charts to any web site or web application. Highcharts currently supports line, spline, area, areaspline, column, bar, pie and scatter chart types therefore it covers all the possible charts that are generated in our application.

    - **ClosedXML** (.NET library for the creation of various type files like EXCEL documents). Since there is a need to provide reports and most of these reports contain numeric values, this is one of the most useful functionalities in our system. However, at the same time this is one of the reasons why we had to use the .NET framework and the base of implementing the web application to be the ASP.NET.

    - **NewtonSoft** (.NET library to handle JSON objects), is an open source library that contains a Flexible JSON serializer for converting between .NET objects and JSON LINQ to JSON for manually reading and writing JSON. The main reason why we used

this library is that it is the one with the highest performance in building JSON objects, it is indented and easy-to-read JSON and also very useful for converting JSON to and from XML. Hence it is the best choice especially when we are reading or writing maps closely to a .NET class. Furthermore, there is a very easy to code connection between the LINQ and JSON through NewtonSoft which is good for situations where you we are only interested in getting values from JSON, and we don't have a special class to serialize or deserialize to, or the JSON is radically different from the class we have composed and in this case we need to manually read and write from our objects.

- **R.NET** (an implementation of a .NET library that acts as a communication gateway between .NET and R statistical Language). More specifically R.NET is an in-process interoperability bridge to R from the .NET Framework. R.NET requires .NET Framework 4 and the native R DLLs installed with the R environment. R.NET works on Windows, Linux and Mac-OS. We use this library because a great amount of the forecasting algorithms are implemented in the R-statistical programming language. Therefore this .NET library works as the mediator between our web application and the R-language (environment and compiler) which needs to be installed into the physical server or the virtual server of where the host application is also installed. We can retrieve a single R-Engine object instance, after setting the necessary environmental variables. More specifically, the call `Set Environment Variables`, on Windows/Linux/Mac-OS, looks at the Registry settings set up by the R installer. On Linux/Mac-OS, the path to libR.so (for Linux) must be in the environment variable LD_LIBRARY_PATH before the process start, otherwise the R.NET engine will not properly initialize. While we may evaluate function calls by generating a string and call the Evaluate method, this can be unwieldy for cases where we pass large amounts of data. The following demonstrates how we call a function, reflectively in .NET.

```
// Invoking functions; Previously you may have needed custom
// function definitions
var myFunc = engine.Evaluate("function(x, y) { expand.grid(x=x, y=y) }").AsFunction();
var v1 = engine.CreateIntegerVector(new[] { 1, 2, 3 });
var v2 = engine.CreateCharacterVector(new[] { "a", "b", "c" });
var df = myFunc.Invoke(new SymbolicExpression[] { v1, v2 }).AsDataFrame();
```

Figure A.2: Example of how to invoke in our application R-functions.

- **MATLAB.** We have to use also a web application to MATLAB bridge because the same reason exists like R for a great amount of forecasting algorithms being implemented in MATLAB. We must note that MATLAB is a powerful scientific tool for math manipulation, specifically matrix manipulations, with its own scripting language, where files are .M files. Usually it's used as a standalone program, but can be integrated in two ways using other languages like Java, C and FORTRAN. With the first usage, we declare a new function or component in a native language that

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extends the functionalities of MATLAB, usually to improve the execution speed. This approach uses the MEX system. The second approach uses MATLAB functionalities from an external program, this time a program in the .NET framework. In this schema, the Java language has a special role because, from the version R12 and afterwards MATLAB is Java-based (specifically for the multiplatform GUI functionalities) and you can easily use Java classes in both ways. To use MATLAB from an external program, there are three possible solutions:

- low level C API
- DDE
- COM

Finally we must say that ISS-EWATUS DSS is a web application that runs on a virtual Machine (VM) that was deployed in a dedicated physical server at the CERTH domain, while the Databases run on a SQL Server VM in a dedicated server in Poland.

GEOSERVER

GeoServer is an open source server for sharing geospatial data. Designed for interoperability, it publishes data from any major spatial data source using open standards. In order to render and display necessary shape files from cities' water networks an instance of GeoServer was installed in the same VM the Web application is deployed. The version we used is the latest stable software version 2.7.1.1

The server was installed to automatically run as a network service by using the port 9090. After installation we created separated Work Spaces for each city's network. By using some administrator provided shape files we initiated separate data store objects based on provided EPSG systems and created WMS (Web Map Service) modules containing tiled layers with shape file objects information (Figure A.4), ready to be consumed in our web application.

The consumption and rendering of a WMS service is displayed in Figure A.3. With the usage of the appropriate URL we are calling the GeoServer WMS module which renders and displays on top of an Open-Layers map the corresponding shape object layers by re-projecting the shape EPSG based on the current map coordinate system.

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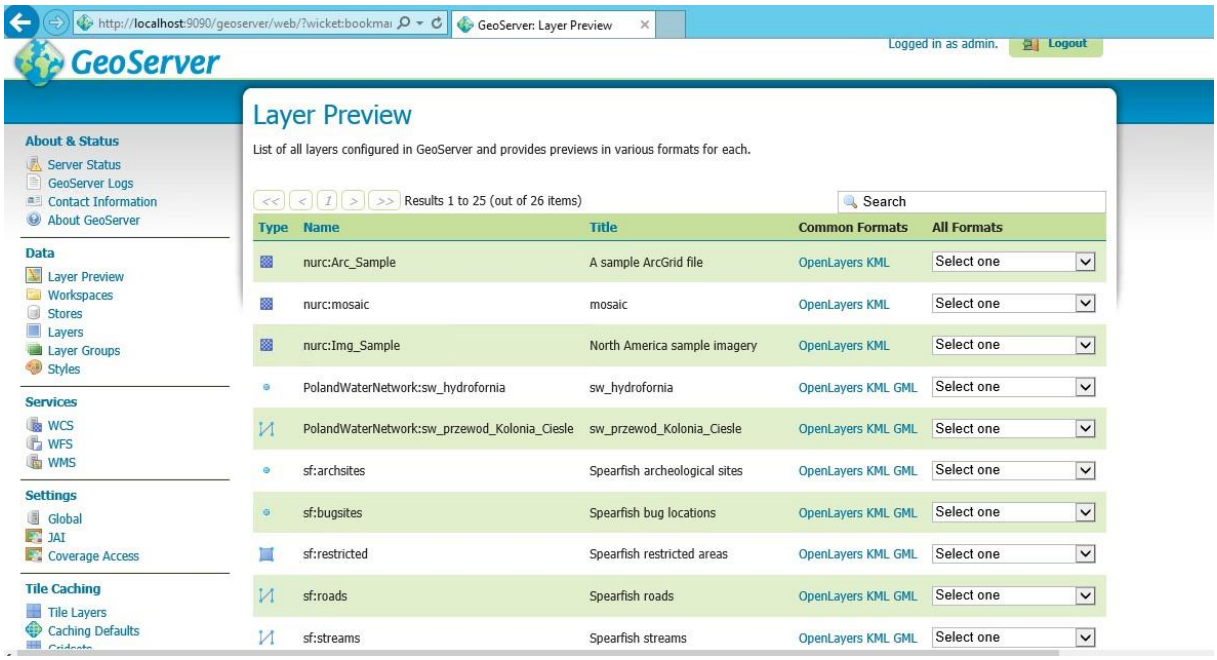

Figure A.3: GeoServer Layers

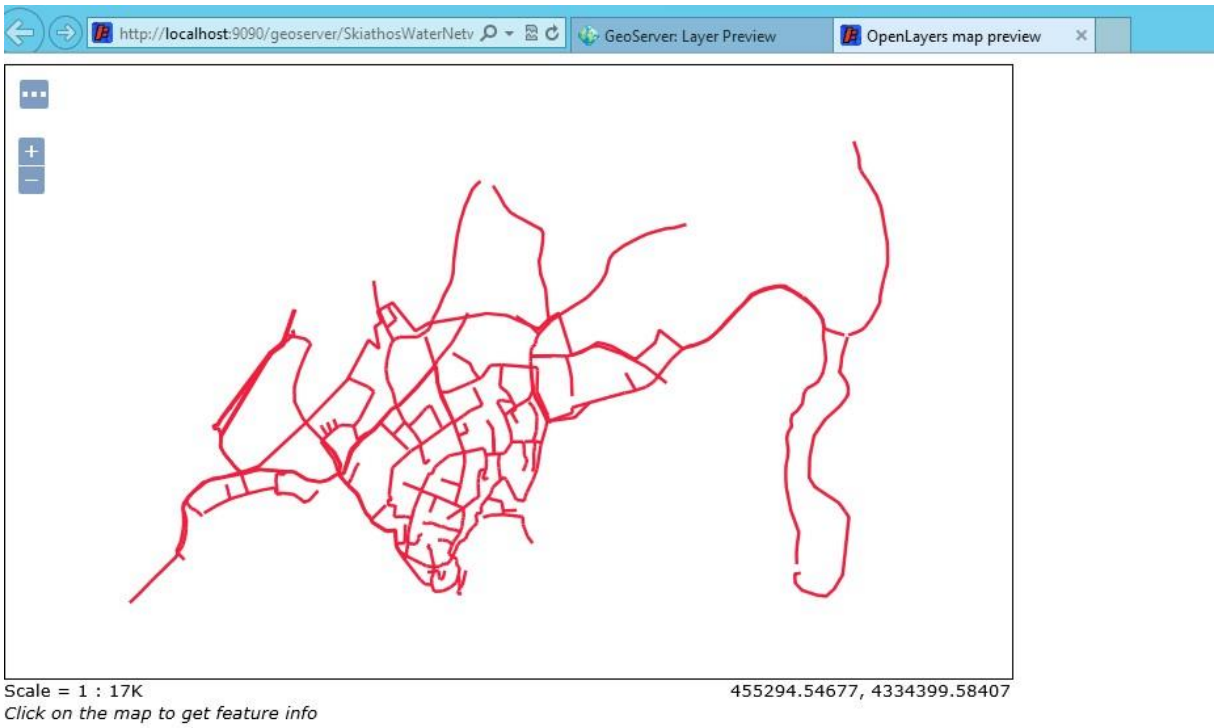

Figure A.4: WMS layer preview for the water network of Skiathos

OPEN-LAYERS

Open-Layers is an open source JavaScript library for displaying map data in web browsers. It provides an API for building rich web-based geographic applications similar to Google Maps and Bing Maps.

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For the developed of EWATUS DSS application we incorporated OpenLayers Version 3 API as the module the render and display all geographical requirements.

The current implementation of Open-Layers module uses the default Web Mercator projection (EPSG:3857) which is the same projection used e.g. for the maps of the OpenStreetMap-project and commercial products such as Bing Maps or Google Maps. In order to achieve this we used a custom developed module and some auxiliary Open-Layers tools and 3rd party libraries to reproject and bind all geographical elements under the same map.

PROJ4JS

Proj4js is an open source JavaScript library to transform point coordinates from one coordinate system to another, including datum transformations.

TURFJS

Open source JavaScript library for advanced geospatial analysis and nodes manipulation

6 Appendix B – Public Web Services

We present and describe the basic web methods that each web service contains, their purpose and how they can be consumed.

ServiceGeoNodes.asmx

** Web service for GeoNodes Database objects and records management.*

- **GetAllGeoNodesCity**: Retrieve all GeoNodes for a specific city
  - Inputs: City Id
  - Outputs: A JSON serialized list of Geonodes arrays
- **GetAllGeoNodes**: Get all nodes for a specific city and specific geonode type (1=watermeters, 3=cellos, 7=pumping station, 8=prv, 10=critical points)
  - Inputs: City Id, Geonode Type
  - Outputs: A JSON serialized list of Geonodes C# class objects
- **GetGeoNodeByID**: Get all information for a specific Geographical Node
  - Inputs: Geonode Id
  - Outputs: A JSON serialized Geonode C# class Object
- **GetGeonodeTypes**: Get all available geonode types

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- Inputs: No input needed
- Outputs: Returns a JSON serialized list of GeoNodeType C# class objects

- **CreateGeoNode**: Creates a new geonode record along with its corresponding information for the city of Skiathos
  - Inputs: User, city id, type, familyid, pmacid, skiathosid, address, ipaddress, routerip, latitude, longitude, X, Y, elevation, parentid
  - Outputs: A message indicating if the procedure was sucessfull.
- **CreateGeoNode2**: Creates a new geonode record along with its corresponding information for the city of Poland
  - Inputs: User, city id, geonode type, familyid, pmacid, polandid, address, ipaddress, routerip, latitude, longitude, X, Y, elevation, parentid
  - Outputs: A message indicating if the procedure was sucessfull
- **DeleteGeoNode**: Deletes a Geonode from the database
  - Inputs: Node Id, User, City Id
  - Outputs: A message indicating if the procedure was sucessfull
- **addevent**: Creates a new log event stored in the database, based on user interaction
  - Inputs: User, city id, event, type, result
  - Outputs: A message indicating if the procedure was sucessfull

SystemGetResults.asmx

** Web service for System Log Events*

- **ViewSystemLog**: Retrieve all log events for a specific city
  - Inputs: City Id
  - Outputs: A JSON serialized List of database records arrays

ServiceLandzones.asmx

** Web service for Landzones management*

- **CreateZone**: Creates a new Landzone database object using the GUI of Open Layers and our web application
  - Inputs: User, city id, area code, area name, description, shape, epanet node, EPSG type
  - Outputs: A message indicating if the procedure was sucessfull
- **CreateZone2**: Creates a new Landzone database object by entering raw data inputs
  - Inputs: User, city id, area code, area name, description, shape, epanet node, EPSG type
  - Outputs: A message indicating if the procedure was sucessfull
- **GetUserZones**: Get all landzones created from a specific user
  - Inputs: User
  - Outputs: A JSON serialized List of Landzones as String Array

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- **GetCityZones**: Get all available landzones for a specific city
  - Inputs: City Id
  - Outputs: A JSON serialized List of Landzones as String Array
- **GetZoneById**: Get all data information for a specific landzone identifier
  - Inputs: Landzone Id
  - Outputs: A JSON serialized Landzone C# class object
- **GetAllZonesCity**: Get all available landzones for a specific city
  - Inputs: City Id
  - Outputs: A JSON serialized list of Landzone C# class objects
- **DeleteUserZone**: Removes the selected landzone (that the same user has previously created) from the database
  - Inputs: Landzone Id, User, City Id
  - Outputs: A message indicating if the procedure was sucessfull
- **addevent**: Creates a new log event stored in the database, based on user interaction
  - Inputs: User, city id, event, type, result
  - Outputs: A message indicating if the procedure was sucessfull

ServiceWDSFlowmeters.asmx

** Web service for watermeters (geonodes of type=1) and landzone readings / water consumption*

- **GetFlowmetersData**: Get water consumption data for a specific watermeter device (located in Skiathos), based on a time period. In Skiathos we have readings every 3months.
  - Inputs: Geonode Id, Period Start, Period End
  - Outputs: A JSON serialized List of FlowmeterData C# class objects
- **GetFlowmetersDataPoland**: Get water consumption data for a specific watermeter device (located in Poland), based on a time period. In Poland we have readings every 1 month.
  - Inputs: Geonode Id, Period Start, Period End
  - Outputs: A JSON serialized List of FlowmeterData_Poland C# class objects
- **GetFlowmetersDataLandzone**: Calculate the total water consumption of all watermeters located in a specific landzone, based on a time period.
  - Inputs: Landzone Geonodes' Ids, Period Start, Period End
  - Outputs: A JSON serialized List of FlowmeterData C# class objects

ServiceWDSIntakes.asmx

** Web service for critical points (geonodes of type=10) available readings such as FlowRate, Volume and Pressure*

- **GetIntakesAllData**: Get all available readings (Flowrate, Volume, Pressure) data for a specific intake device, based on a time period.
  - Inputs: Geonode Id, Period Start, Period End
  - Outputs: A JSON serialized List of IntakeData C# class objects
- **GetIntakesAllDataAverage**: Calculates all available average daily readings (Flowrate, Volume, Pressure) for a specific intake device, based on a time period.

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- Inputs: Geonode Id, Period Start, Period End
- Outputs: A JSON serialized List of IntakeData C# class objects

ServiceWDSPRV.asmx

** Web service for Pressure Regulator Valve (geonodes of type=8) available readings*

- **GetPRVAllData**: Get all available readings (Flowrate, Outlet, Inlet) data for a specific PRV device, based on a time period.
  - Inputs: Geonode Id, Period Start, Period End
  - Outputs: A JSON serialized List of PRVData C# class objects
- **GetPRVAllDataAverage**: Calculates all available average daily readings (Flowrate, Outlet, Inlet) for a specific PRV device, based on a time period.
  - Inputs: Geonode Id, Period Start, Period End
  - Outputs: A JSON serialized List of PRVData C# class objects

ServiceWDSPumpingStations.asmx

** Web service for PRV readings*

- **GetAllRecords**: Get all available readings (Flowrate, Volume, Pressure) data for a specific Pumping station device, based on a time period.
  - Inputs: Geonode Id, Period Start, Period End
  - Outputs: A JSON serialized List of data records
- **GetPumpingConsumptions**: Get all available readings (Flowrate, Volume, Pressure) data for a specific Pumping station device located in Skiathos, based on a time period.
  - Inputs: Geonode Id, Period Start, Period End
  - Outputs: A JSON serialized List of PumpingData C# class objects
- **GetPumpingConsumptions_Poland**: Calculate all available daily average readings (Flowrate, Volume, Pressure) data for a specific Pumping station device located in Poland, based on a time period.
  - Inputs: Geonode Id, Period Start, Period End
  - Outputs: A JSON serialized List of PumpingData_Poland C# class objects
- **GetPumpingConsumptions_PolandReal**: Get all available readings (Flowrate, Volume, Pressure) data for a specific Pumping station device located in Poland, based on a time period.
  - Inputs: Geonode Id, Period Start, Period End
  - Outputs: A JSON serialized List of PumpingData_Poland C# class objects

ServiceAlarms.asmx

** Web service for user alerts*

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- **GetAlarms**: Get all alerts for a specific city and of specific status type (fixed or pending).
    - Inputs: City id, Fixed status
    - Outputs: A JSON serialized list of Alarm C# class objects
- **GetAlarm**: Get all available ifos for a specific Alert database object.
    - Inputs: Alarm Id
    - Outputs: A JSON parsed Alarm C# class object
- **UpdateAlarm**: Update the status and basic information for a specific alert
    - Inputs: Alarm id, user email, user comments, admin comments, fixed status, user, city id
    - Outputs: A message indicating if the procedure was sucessfull
- **InsertAlarm**: Inserts a new alert record for a specific city in the database
    - Inputs: City id, longitude, latitude, user email, user comments
    - Outputs: A message indicating if the procedure was sucessfull
- **addevent**: Creates a new log event stored in the database, based on user interaction
    - Inputs: User, city id, event, type, result
    - Outputs: A message indicating if the procedure was sucessfull

Reports.asmx

** Web service for creation and rendering of EXCEL spreadsheets containing data from user created charts*

- **LandzoneConsumption**: Create excel data report for a specific landzone in Skiathos or Poland
    - Inputs: Landzone name, JSON serialized database records
    - Outputs: An excel data report
- **HydrometerConsumptionSKIATHOS**: Create excel data report for a specific watermeter in Skiathos
    - Inputs: Watermeter Geonode Id, name, JSON serialized database records
    - Outputs: An excel data report
- **PumpingSKIATHOS**: Create excel data report for pumping station data in Skiathos
    - Inputs: Pumping station id, JSON serialized database records
    - Outputs: An excel data report
- **CelloSKIATHOS**: Create excel data report for a specific intake / cello device in Skiathos
    - Inputs: Geonode Id, PMAC id, name, JSON serialized database records
    - Outputs: An excel data report
- **CelloAvgSKIATHOS**: Create excel data report for a specific intake / cello in Skiathos containg average daily calculated data
    - Inputs: Geonode Id, PMAC id, name, JSON serialized database records
    - Outputs: An excel data report
- **PrvSKIATHOS**: Create excel data report for a specific PRV device in Skiathos
    - Inputs: Geonode Id, PMAC id, name, JSON serialized database records
    - Outputs: An excel data report
- **PrvAvg**: Create excel data report for a specific PRV device in Skiathos or Poland containing average daily calculated data

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- Inputs: Geonode Id, PMAC id, name, JSON serialized database records
- Outputs: An excel data report

- **LandzoneConsumption**: Create excel data report for a specific landzone in Skiathos or Poland
  - Inputs: Landzone name, JSON serialized database records
  - Outputs: An excel data report
- **HydrometerConsumptionPOLAND**: Create excel data report for a specific watermeter in Poland
  - Inputs: Watermeter Geonode Id, name, JSON serialized database records
  - Outputs: An excel data report
- **PumpingPOLAND**: Create excel data report for pumping station data in Poland
  - Inputs: Pumping station id, JSON serialized database records
  - Outputs: An excel data report
- **CelloPOLAND**: Create excel data report for a specific intake / cello device in Poland
  - Inputs: Geonode Id, PMAC id, name, JSON serialized database records
  - Outputs: An excel data report
- **CelloAvgPOLAND**: Create excel data report for a specific intake / cello in Poland containg average daily calculated data
  - Inputs: Geonode Id, PMAC id, name, JSON serialized database records
  - Outputs: An excel data report
- **PrvPOLAND**: Create excel data report for a specific PRV device in Poland
  - Inputs: Geonode Id, PMAC id, name, JSON serialized database records
  - Outputs: An excel data report
- **PrvAvgPOLAND**: Create excel data report for a specific PRV device in Poland containing average daily calculated data
  - Inputs: Geonode Id, PMAC id, name, JSON serialized database records
  - Outputs: An excel data report

Algorithms.asmx

** Web service for running prediction algorithms and simulations for the water network*

- **Rcmeans**: Runs an Rscript prediction algorithm for Sosnowiec water network with the usage of R.NET library
  - Inputs: Geonode Id, Data Period start, City Id, User
  - Outputs: a JSON serialized RmeansData list of objects (Predicted profile)
- **ARFIMA**: Runs an Rscript prediction algorithm for Sosnowiec water network with the usage of R.NET library
  - Inputs: Geonode Id, Data Period start, City Id, User
  - Outputs: a JSON serialized RmeansData list of objects (Predicted profile)
- **FCM**: Runs an R-script prediction algorithm for Sosnowiec water network with the usage of R.NET library
  - Inputs: A JSON serialized array of the latest 27 data records containg corresponding DataBase values
  - Outputs: Predicted water demand value

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- **AnfisAlgorithm**: Runs Adaptine Neuro-Fuzzy Inference System prediction module with the usage of Matlab .COM server component
    - Inputs: JSON serialized arraylist of objects containing all records with data, Nummfs parameter, MfType parameter, NumEpochs parameter, Steps parameter, City id, User
    - Outputs: Predicted water demand value
- **FCMAlgorithm_Population**: Runs a Fuzzy Cognitive Maps prediction algorithm based on Genetic Algorithms with the usage of a custom created .NET library
    - Inputs: JSON serialized arraylist of objects containing all records with data, sigma parameter, error parameter
    - Outputs: Predicted water demand value
- **NNAlgorithm**: Runs Neural Network prediction algorithm with the usage of a custom created .NET library
    - Inputs: JSON serialized arraylist of objects containing all records with data, iterations parameter, steps parameter, epochs parameter, city id, user
    - Outputs: Predicted water demand value
- **addevent**: Creates a new log event stored in the database, based on user interaction
    - Inputs: User, city id, event, type, result
    - Outputs: A message indicating if the procedure was sucessfull

PreProcessing.asmx

** Web service for data calculation and preparation*

- **GetLatestValues1**: Get latest Database records for a specific node
    - Inputs: Geonode id, city id
    - Outputs: A JSON serialized list of the latest database queried records as C# class objects
- **GetPeriodValues1**: Used in Anfis module, for preprocessing and generating data that we will use in the forecasting dataset
    - Inputs: Geonode id, city id, current days values (water demand, mean temperature, high temperature, rain,arrivals), predicted next day values (mean temperature, high temperature, rain,arrivals), data normalization procedure, period start
    - Outputs: A JSON serialized list of the latest database queried records, processed and generated as C# class objects
- **GetPeriodValues2**: Used in FCM module, for preprocessing and generating data that we will use in the forecasting dataset
    - Inputs: Geonode id, city id, current days values (water demand, mean temperature, high temperature, rain,arrivals), data normalization procedure, period start
    - Outputs: A JSON serialized list of the latest database queried records, processed and generated as C# class objects
- **GetPeriodValues4**: Used in NNs module, for preprocessing and generating data that we will use in the forecasting dataset

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- Inputs: Geonode id, city id, current days values (water demand, mean temperature, high temperature, rain,arrivals), predicted next day values (mean temperature, high temperature, rain,arrivals), data normalization procedure, period start
- Outputs: A JSON serialized list of the latest database queried records, processed and generated as C# class objects

- **GetPeriodValues3**: Used in Poland's FCM forecasting script module, for preprocessing and generating data that we will use in the forecasting dataset
  - Inputs: Geonode id, city id, current days values (water demand, mean temperature, high temperature, rain,arrivals), data normalization procedure, period start
  - Outputs: A JSON serialized list of the latest database queried records, processed and generated as C# class objects

PreProcessing2.asmx

** Web service mainly used for generating water prediction profiles, dissagregation procedures and also Epanet models*

- **SkiathosProfiles**: Generate Water demand profile for the city of skiathos
  - Inputs: predicted water demand, landzones
  - Outputs: A JSON serialized list of the dissagregated Landzone records as C# class objects
- **PolandProfiles**: Generate Water Demand profile for the city of Sosnowiec
  - Inputs: daily flowrate profile, city id, user
  - Outputs: A JSON serialized list of the dissagregated Landzone records as C# class objects
- **CreatePolandEpanetDB**: This method is responsible for the creation and initialization of the Epanet simulations for Sosnowiec. With the help of some additional WebService functions the DSS clears all previous tables and recreates them by adding new and updated data to be used in Epanet Software simulations.
  - Inputs: city and user
  - Outputs: A message indicating if the procedure was successful
- **CreateSkiathosEpanetDB**: This method is responsible for the creation and initialization of the Epanet simulations for Skiathos. With the help of some additional WebService functions the DSS clears all previous tables and recreates them by adding new and updated data to be used in Epanet Software simulations.
  - Inputs: city, user and list of landzone objects
  - Outputs: A message indicating if the procedure was successful

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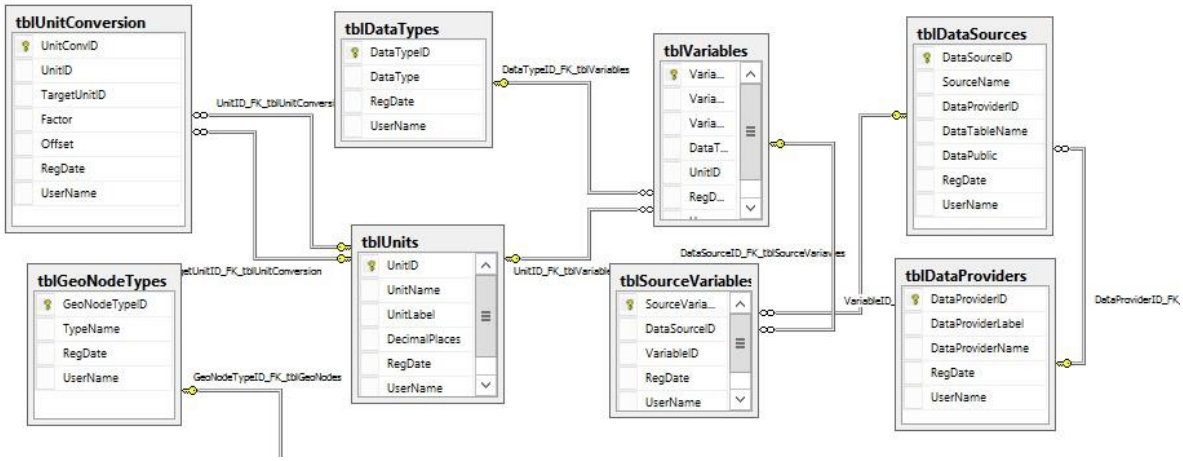
7 Appendix C – Remote Database

All data available through the Web Application are dynamically generated by remotely connecting to a SQL Server DataBase named 'EWATUSDBa'. This database contains all necessary tables, data structures and variables our system uses in order to function properly. Data connections are accomplished by using Remote Server's public IP, port 2003 and user credentials supplied from the administrator. The database scheme is displayed in Figure C.1



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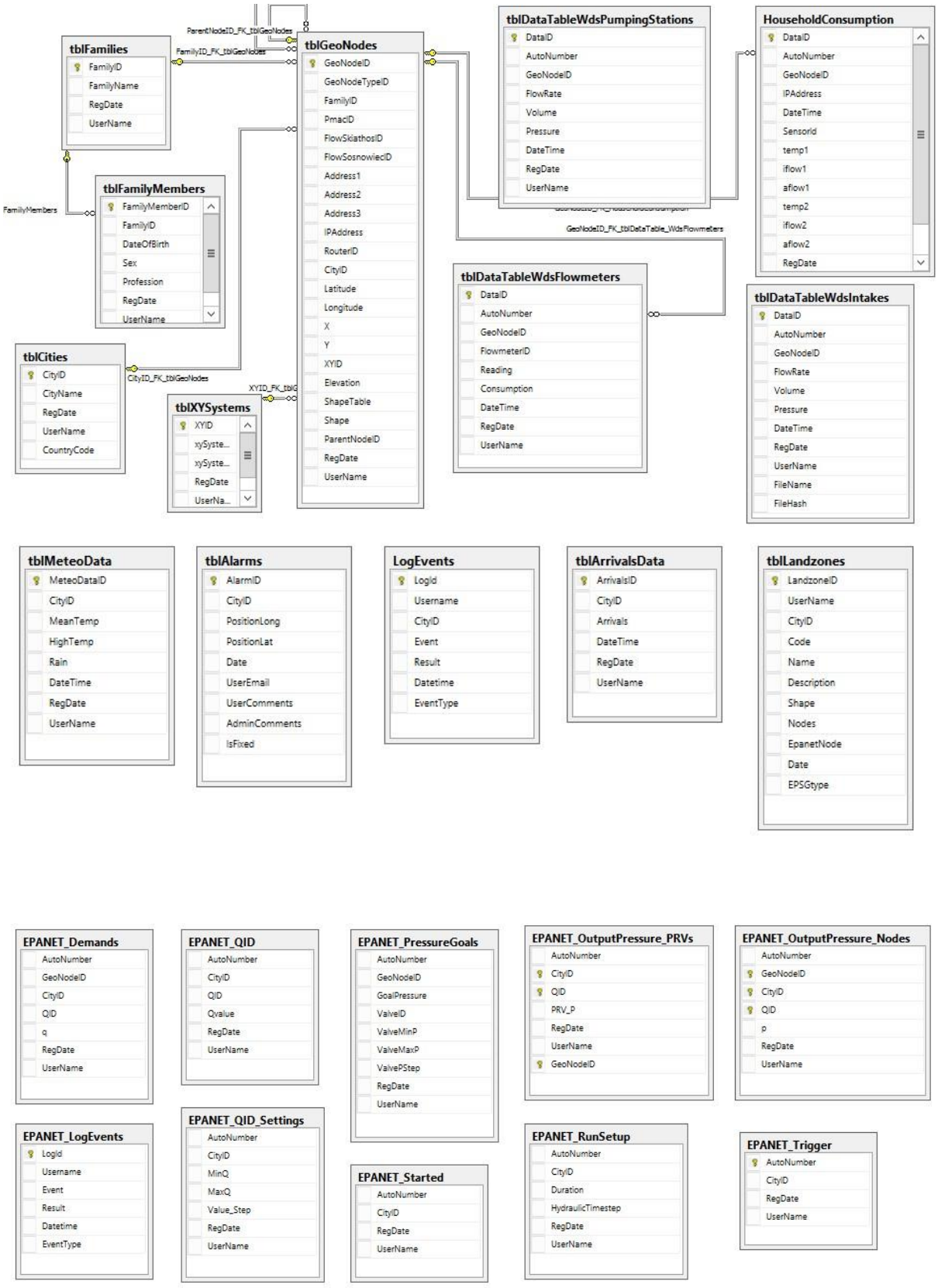

Figure C.1 EWATUSDBa Database diagram

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Each data table holds the data required by our DSS system to create object models, retrieve queried data, run forecasting algorithms, create water network profiles and run smoothly all auxiliary modules. Below we briefly describe the most important tables our system uses.

tblGeoNodes: Contains all geographical nodes objects for the whole system. Each node is defined by a GeoNodeTypeId field which indicates what type the node is (for example watermeter, critical point, pumping station etc.), the CityId in which it belongs, its geographical position both in WGS84 system and also into the country's specific EPSG type and finally some further auxiliary fields.

tblCities: Contains the objects for the cities that are involved in the DSS Web application

tblGeoNodeTypes: Contains all available geographical node's types

tblLandzones: Contains all the user created Landzones. Each zone is assigned to a city and is defined by an area code, a name, a shape object of points (a polygon that basically renders the landzone), an EpanetNode (a GeoNode which is used in Epanet Water Simulations) and finally some further auxiliary fields.

tblDataTableWDSFlowmeters: This table contains data for the cities' watermeters consumptions. Each record is defined by a specific GeonodeID (which is of type 1), the reading and consumption fields containing the water consumption values, the DateTime for the consumption period and finally some further auxiliary fields.

tblDataTableWDSPRV: This table contains data for cities' PRV devices. Each record is defined by a specific GeonodeID (which is of type 8), outlet, inlet, flowrate fields containing corresponding values, the DateTime stamp for the readings and finally some further auxiliary fields.

tblDataTableWDSPumpingStations: This table contains data for cities' Pumping station devices. Each record is defined by a specific GeonodeID (which is of type 7), flowrate, volume and pressure fields containing corresponding values, the DateTime stamp for the readings and finally some further auxiliary fields.

tblDataTableWDSIntakes: This table contains data for cities' cellos and critical point devices. Each record is defined by a specific GeonodeID (which is of type 10 or 3), flowrate, volume and pressure fields containing corresponding values, the DateTime stamp for the readings and finally some further auxiliary fields.

tblAlarms: Contains alarm object infos. Each alarm is defined by a specific CityId, its position in WGS84 geographical coordinate system, its status, description, user infos, admin comments and finally some further auxiliary fields.

tblMeteoData: This table contains city's meteorological historical data. Each record consists of the CityId, mean temperature, high temperature and rain readings, a date stamp declaring the date the readings are referring to and finally some further auxiliary fields. Currently only the City of Skiathos has these type of data.

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tblArrivalsData: This table contains city's data referring to tourists arrivals. Currently only the City of Skiathos uses these type of data.

LogEvents: Contains data information for the Web Application modules Users' interactions.

Epanet_Demands: Contains water demand data for each landzone, based on the provided total network consumption and spatially disaggregated demands. This table is used by the Epanet software to create and runs water simulations for each city, based on the input data.

Epanet_QID: This table contains data declaring all possible flowrates and daily water demands for the cities that Epanet uses for the simulations. Based on these values the DSS generates and writes all corresponding landzones demands for the simulations.

Epanet_PressureGoals: Contains information about desired pressure in the water distribution system used by EPANET to optimize the pressure at the system inflow.

Epanet_QID_Settings: Contains settings for each city that are used in the generation of QIDs table values.

Epanet_RunSetup: This table holds data that are used by the Epanet software to calibrate the simulation models' settings.

Epanet_Output_Pressure_PRVs: This table contains all Epanet's simulations results for the PRV of each city.

Epanet_Output_Pressure_Nodes: This table contains all Epanet's simulations results for the Nodes of each city.

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8 Appendix D – Evolutionary multiobjective algorithm for Task 4.2 – Inference Module of urban DSS

An evolutionary multi-objective optimization algorithm was proposed for Task4.2 concerning the Inference Module of the DSS. A description of the problem and proposed algorithm is given.

Water that can be pumped and used for urban water consumption can be

a) groundwater (fig. D.1),

b) water stored in a reservoir (fig. D.2) and

c) Spring water (fig. D.3).

There are restrictions concerning the quantity of water that can be exploited. Concerning a drilling, the pumped water cannot be that much, that the ground water level is not able to recover to its original point.

That can be controlled by comparing the time of the operation the pump ($T_{drill-i-pump}$) and the recovery time ($T_{drill-i-rec}$).

Concerning the reservoir water and the spring water, the restrictions are set by the availability of each resource. For example there may be a limit to the lower water level in a reservoir or a minimum demand of environmental flow downstream a spring water flow. In Table D. 1, the quantity related variables and constraints are presented.

a) b)

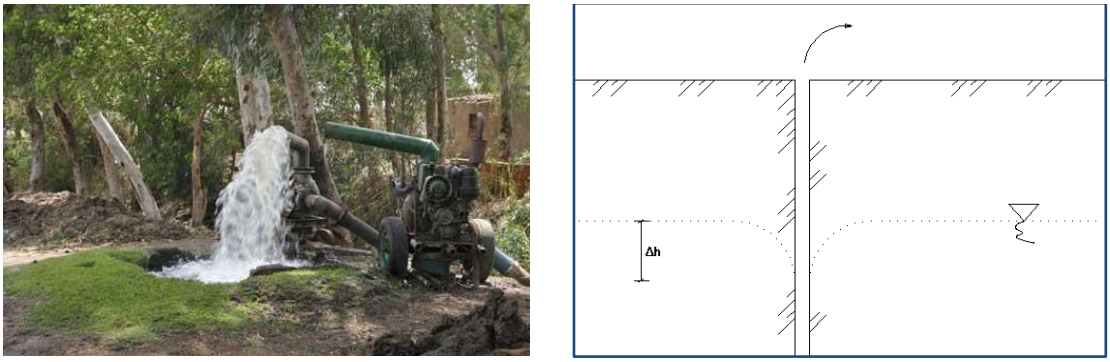

Figure D.1. a) qroundwater drilling, b) schematic presentation of a drilling

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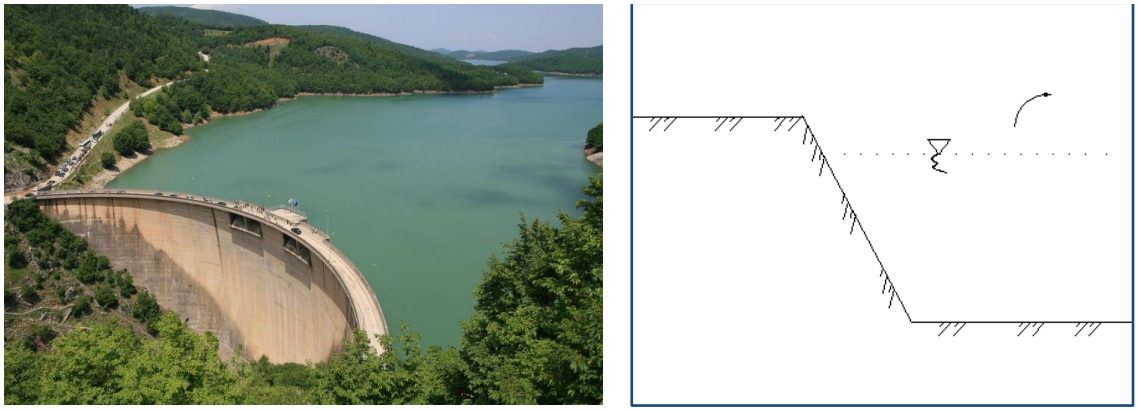

Figure D.2. a) reservoir b) schematic presentation of a reservoir

Figure D.3. Spring water

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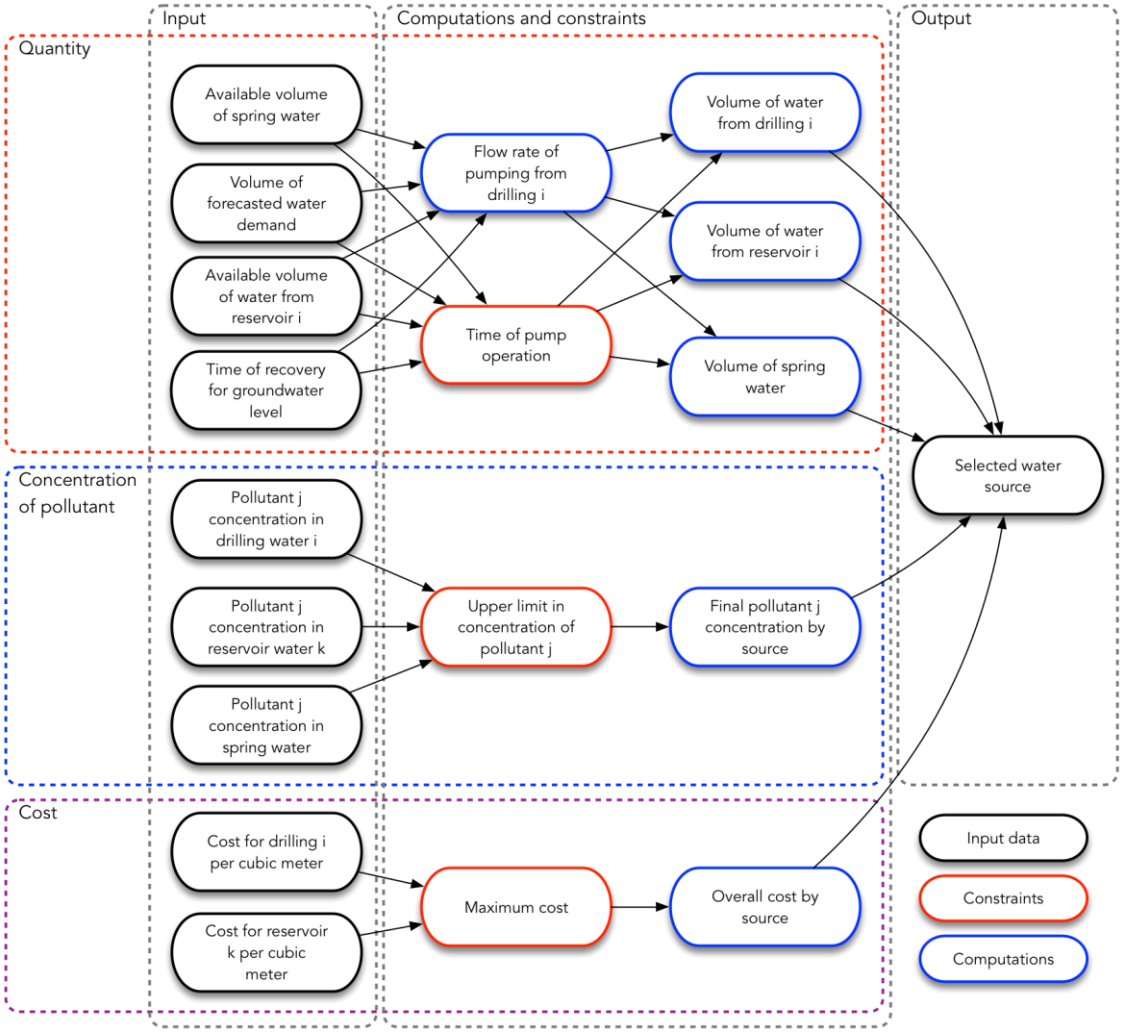

Figure D.4. Overview of the optimization problem

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Table D.1. Quantity related variables

Variable	Description	Source/Computation
V_{wd}	Volume of total water demand	Forecasted
$V_{dril-i-rec}$	Time of recovery of the groundwater level	Measured by the water utility
$V_{dril-i-pump}$	Time of pump operation	Set by the water utility
$V_{res-i-av}$	Available volume of water from reservoir i	
V_{spr-av}	Available volume of water from spring water i	
V_{dril-i}	Volume of water from drilling i	DSS outcome
Q_{dril-i}	Flow rate of the pumping	DSS outcome $Q_{dril-i} = \frac{V_{dril-i}}{T_{dril-i}}$
V_{res-i}	Volume of water from reservoir i	DSS outcome
V_{spr}	Volume of water from spring water	

The constraints are the following

$$\begin{aligned} V_{wd} &= \sum_{i=1}^{n} V_{dril-i} + \sum_{i=1}^{n} V_{res-i} + V_{spr} \\ T_{dril-i} &\geq T_{dril-i-rec} \\ V_{res-i} &\leq V_{res-i-av} \\ V_{spr} &\leq V_{spr-av} \end{aligned}$$

Quite often, water resources are characterized by high concentrations of a pollutant or an unwanted substance (P_j). A typical example of this is high salinity at underground water, when the aquifer is located at a coastal area. This is reinforced, by the degradation of the aquifer water level.

The demand for the highest possible quality of urban water, gives out the first objective, which is the minimization of concentration of each pollutant (C_j).

Table D.2. Quality related variables

Variable	Description	Source/Computation
$C_{j,dril-i}$	Concentration of pollutant j in drilling water i	Measured by water utility
$C_{j,res-i}$	Concentration of pollutant j in reservoir i	
$C_{j,spr}$	Concentration of pollutant j in spring water	
$C_{j,up}$	Upper limit in concentration of pollutant j	Ruled by government

The quality related constraints are the following

$$C_j = \left(\frac{1}{V_{wd}}\right) \cdot \sum_{i=1}^{n} C_{j,drill-i} \cdot V_{dril-i} + \sum_{i=1}^{n} C_{j,res-i} \cdot V_{res-i} + \sum_{i=1}^{n} C_{j,spr-i} \cdot V_{spr-i}$$
$$C_j \leq C_{j,up}$$

The third objective of the multi-objective optimization problem is the minimization of operational costs.

The costs come out as functions of the pumping energy needed, the level differences and the distances between the water resource and the utility tank, and the pump specifications (see Table D.3).

Table D.3. Cost related variables

Variable	Description	Source/Computation
m_{dril-i}	Cost per cubic meter for drilling i	Estimated by the water utility
m_{res-i}	Cost per cubic meter for reservoir i	Estimated by the water utility
M_{max}	Maximum cost	Setting by the water utility

According to this, the third optimization problem is

$$M = \sum_{i=1}^{n} m_{dril-i} \cdot V_{dril-i} + \sum_{i=1}^{n} m_{res-i} \cdot V_{res-i} + m_{spr} \cdot V_{spr}$$
$$M \leq M_{max} \leq C_{j,up}$$

The considered scenario involves an arbitrary optimization problem with k objectives, which are, without loss of generality, all to be maximized and all equally important, i.e., no additional knowledge about the problem is available.

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We assume that a solution to this problem can be described in terms of a decision vector $(x_1, x_2, \ldots, x_n)$ in the decision space X. A function $f : X \to Y$ evaluates the quality of a specific solution by assigning it an objective vector $(y_1, y_2, \ldots, y_k)$ in the objective space Y.

Now, let us suppose that the objective space is a subset of the real numbers, i.e., $Y \subseteq \mathbb{R}$, and that the goal of the optimization is to maximize the single objective. In such a single-objective optimization problem, a solution $x^1 \in X$ is better than another solution $x^2 \in X$ if $y^1 > y^2$ where $y^1 = f(x^1)$ and $y^2 = f(x^2)$. Although several optimal solutions may exist in decision space, they are all mapped to the same objective vector, i.e., there exists only a single optimum in objective space.

In the case of a vector-valued evaluation function f with $Y \subseteq \mathbb{R}^k$ and $k > 1$, the situation of comparing two solutions x^1 and x^2 is more complex. Following the well-known concept of Pareto dominance, an objective vector y^1 is said to dominate another objective vectors $y^2 (y^1 \succ y^2)$ if no component of y^1 is smaller than the corresponding component of y^2 and at least one component is greater. Accordingly, we can say that a solution x^1 is better to another solution x^2, i.e., x^1 dominates $x^2 (x^1 \succ x^2)$, if $f(x^1)$ dominates $f(x^2)$. Here, optimal solutions, i.e., solutions not dominated by any other solution, may be mapped to different objective vectors. Indeed, there may exist several optimal objective vectors representing different trade-offs between the objectives.

The set of optimal solutions in the decision space X is in general denoted as the Pareto set $X^* \subseteq X$, and we will denote its image in objective space as Pareto front $Y^* = f(X^*) \subseteq Y$. With many multiobjective optimization problems, knowledge about this set helps the decision maker in choosing the best compromise solution. For instance, when designing computer systems, engineers often perform a so-called design space exploration to learn more about the Pareto set. Thereby, the design space is reduced to the set of optimal trade-offs: a first step in selecting an appropriate implementation.

Although there are different ways to approach a multiobjective optimization problem, e.g., by aggregation of the objectives into a single one, most work in the area of evolutionary multiobjective optimization has concentrated on the approximation of the Pareto set. Therefore, we will assume in the following that the goal of the optimization is to find or approximate the Pareto set. Accordingly, the outcome of an Evolutionary Multiobjective Optimization Algorithm is considered to be a set of mutually non-dominated solutions, or Pareto set approximation for short.

Evolutionary algorithms are characterized by a population of solution candidates and the reproduction process enables to combine existing solutions to generate new solutions. Finally, natural selection determines which individuals of the current population participate in the new population. Real-Coded Genetic Algorithm is the population-based algorithm selected. The algorithm is detailed as follows

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```
Data: Input data
Result: Optimized water sources
Choose initial random population;
Evaluate each chromosome's fitness;
while Termination is false do
    Select best-ranking chromosome to reproduce;
    Mate pairs at random;
    Prune chromosome population;
    Crossover operator;
    Mutation operator;
    Evaluate each chromosome's fitness;
    Check termination criteria;
end
Select best-fitness chromosome
```

For the purpose of the task 4.2, we decided to calculate the fitness function as a weighted one. We are going to use weighted-sum aggregation, where the weights represent the parameters which are changed during the evolution process. The algorithm for the fitness computation is the following.

```
Data: Input data
Result: Candidate's fitness
Evaluate f(x);
if Constraints are ok then
    return fitness;
else
    return bad score
end
```

Note that the function for the fitness score is computed as

$$f(x) = \sum_{i=1}^{n} w_{dril-i} \cdot V_{dril-i} + \sum_{j=1}^{m} w_{res-i} \cdot V_{res-i} + w_{spr} \cdot V_{spr}$$

where the chromosome is composed by

$0 \leq \sum_{i=1}^{n} w_{dril-i} \leq 1$

Each one is the parameter for the relative value of the water volume for each drill

$0 \leq \sum_{j=1}^{m} w_{res-i} \leq 1$

Each one is the parameter for the relative value of the water volume for each reservoir

$0 \leq w_{spr} \leq 1$

This is the parameter for the relative value of the water volume of spring water.