WatERP

Water Enhanced Resource Planning

“Where water supply meets demand”

GA number: 318603

WP1: Water Supply Knowledge Base

1.2: Generic functional model for water supply and usage data

V1.0 28-March-2013

www.waterp-fp7.eu

Document Information

Project Number	318603	**Acronym**	WatERP
Full title	Water Enhanced Resource Planning "Where water supply meets demand"		
Project URL	**http://www.waterp-fp7.eu**		
Project officer	Grazyna Wojcieszko		

Deliverable	**Number**	1.2	**Title**	Generic functional model for water supply and usage data
Work Package	**Number**	1	**Title**	Water Supply Knowledge Base

Date of delivery	**Contractual**	M06	**Actual**	M06
Nature	Prototype ☑ Report ☐ Dissemination ☐ Other ☐			
Dissemination Level	Public ☑ Consortium☐			

Responsible Author	Catherine Chomat	**Email**	catherine.chomat@inclam.com
Partner	INCLAM	**Phone**	(+34) 934 153 466

Abstract (for dissemination)	Description of the functional models that have been developed for the WatERP project. Functional modeling represents the natural water cycle elements (or paths) in conjunction with the man-made (or "human-altered") infrastructure elements that interact with the natural water cycle and modify the natural flows to benefit humans (via channels, pipe networks, etc). Functional models have been defined for the two pilot cases (Spanish and German). The identification and transformation of functional models into generic information permits enhancing the ontology resources through the definition of entities, relations, axioms and more. Moreover, functional models also support the population process in order to improve alerts generation and recommendation proposition inside WatERP project.
Key words	Water management decision processes, Ontology Enhancement, WaterML2, Functional models

Version Log				
Issue Date	**Version**	**Author**	**Partner**	**Change**
13-02-2013	0.0	Aitor Corchero, Edgar Rubión, Antonio Moya and Carolina Moya	BDIGITAL, INCLAM	Construction of the document structure and start deliverable building up.
14-03-2013	0.1	Catherine Chomat	INCLAM	Draft version
22-03-2013	0.2	Aitor Corchero and Edgar Rubion	BDIGITAL	Draft version
26-03-2013	0.3	Catherine Chomat, Antonio Moya and Carolina Moya	INCLAM	Draft version
27-03-2013	0.4	Aitor Corchero	BDIGITAL	Draft version
28-03-2013	0.5	Aitor Corchero, Gabriel Anzaldi and Catherine Chomat	BDIGITAL, INCLAM	Final version

Glossary of terms

ACA- Agencia Catalana del Agua (trans. Catalan Water Agency)

AMB- Área Metropolitana de Barcelona (trans. Metropolitan Area of Barcelona)

CUAHSI- Consortium of Universities for the Advancement of Hydrologic Science

D1.2- Deliverable 1.2

DSS- Decision Support System

ErhaiSD- Erhai basin System Dynamics

ICT- Information and Communications Technology

LODC- Linked Open Data Cloud

MMI- Marine Metadata Interoperability

NASA- National Aeronautics and Space Administration

OGC- Open Geospatial Consortium

OMP- Open Management Platform

OWL- Ontology Web Language

RWB- Reservoir Water Board

SensorML- Sensor Markup Language

SOS- Sensor Observation Service

SSN Ontology- Semantic Sensor Net Ontology

SWEET- Semantic Web for Earth and Environmental Terminology

SWKA- Stadtwerke Karlsruhe Gmbh

UML- Unified Modeling Language

W3C- World Wide Web Consortium

WaterGAP- Water Global Analysis and Prognosis

WaterML2- Water Markup Language (version 2.0)

WatERP- Water Enhanced Resource Planning "Where water supply meets demand"

WEAP- Water Evaluation and Planning

WP4- Work Package 4

WRSD- Water Resources System Dynamics

XML- eXtensive Markup Language

Executive Summary

Deliverable 1.2 (D1.2) presents the approach that will be used in the Water Enhanced Resource Planning "*Where water supply meets demand*" (WatERP) project to represent water supply distribution chains, the end objective being to enable water supply and demand to be matched across the system in a more integrated and optimal way. More specifically, this report details the processes, decisions and rules that are involved in the WatERP pilot cases in order to enhance and improve the ontology development such that a generic ontology (Work Package 1) that produces productive knowledge about water resources management can be generated. Moreover, the decisions rules and processes identified in the pilots also is supported and taken into account in the development of the Decision Support System (DSS) in Work Package 4 (WP4).

The WatERP project proposes a new modeling approach. In the WatERP project, the use of intelligent and open architecture is proposed, permitting to connect the actors and processes involved in water supply distribution to support, in an integrated manner, the short-term planning and management decisions that take place in water supply distribution systems. Decisions, rules and processes that are represented in the day-by day tasks have been defined using a functional model.

Functional modeling includes the representation of a logical model with associated decisions and rules. In this perspective, the **logical model** describes how the elements interact within the water supply distribution chain. In other words, this model represents the natural water cycle elements (or paths) in conjunction with the man-made (or "*human-altered*") infrastructure elements that interact with the natural water cycle and modify the natural flows to benefit humans (via channels, pipe networks, etc).

This kind of representation and its transformation into generic elements permits enhancing the ontological resources such as properties, data types, rules, axioms and more. In detail, functional modeling represents the involved elements or systems (ontological entities) and the relations between systems categorized in "*flow-level*" and "*management-level*" (ontological properties). Thus, using this modeling language adapted to the WatERP project, support to the ontology development is provided. The ontology enhancement has been done in three ways: *(i)* taxonomical level by identifying concepts/entities; *(ii)* semantic level by enhancing the properties, rules and axioms of the ontology; and *(iii)* population level by associating each individual with the specific ontological resource generating specific scenarios to infer specific knowledge towards alerts discovering and recommendations proposition.

Aligning the functional models with an analysis of currently existing ontologies has permitted to discover: *(i)* the strengths and weaknesses of existing hydrological ontologies from a water resources management point of view, and *(ii)* current efforts and developments that are being made in the hydrology field. Furthermore, current ontology developments and functional models have allowed making a transformation of used hydrologic schemas, as Water Markup Language in version 2 (WaterML2), into ontological resources in order to support the generation and interoperability in an Open Management Platform (OMP).

In spite of the fact that this task (Task 1.3- "*Generic Data Functional Model*") finishes with this current deliverable, further work aligned with other tasks and work packages is proposed. Future works are focused on two main lines: *(i)* enrich ontology with the information of functional models during Task 1.4- "*Generic Water Data Ontology*" and *(ii)* enhance the transformation of non-ontological resources in order to align ontology development and pilots information (and functional models) with the hydrological standards (or further standards) developed by Open Geospatial Consortium (OGC).

In summary, functional modelling representation applied to the WatERP pilots creates a bridge between the hydrological and ICT fields. This means, this kind of modelling permits defined hydrological entities to be related to one another with the aim of linking the model to an ontological source. The **functional modelling serves as a point to enhance the general ontology (WatERP ontology)**. Furthermore, the **functional model permits discovering and knowing the instances related with each scenario, followed by the development of the ontological population process** (specific pilot WatERP ontological scenario).

To understand this document the following deliverables have to be read.

Number	Title	Description
D1.1	Generic Taxonomy for Water Supply Distribution Chain	Report describing the generic water taxonomy that was developed for the WatERP project, based on the system users and needs, problem description, and vocabulary used by domain experts from the water supply management field. Summary of the requirements and taxonomy bases that will enable a coherent, comprehensive and well-defined ontology to be constructed, including the scope, purpose and implementation language to be used.

Table of contents

Table of figures

Table of tables

1. Introduction

One of the main objectives of the WatERP project consists of developing an OMP that facilitates integration in real-time of knowledge inferred from available water supplies and demand, from water sources to users. Moreover, the OMP facilitates interoperability in an open framework of multiple-scalable decisions across geographic and organizational scales (e.g., regulators, bulk water suppliers, water utilities, etc.) so that information provided by each element (step) of the water supply management chain can be exchanged and accessed. Hence, the entire water distribution system can be viewed, understood and improved in an integrated and collaborative manner.

So as to makes interoperable and understandable the elements of the water supply distribution chain, a better understanding of its elements (and operational problems) is necessary. Water supply distribution chains are comprised of natural elements (river channels, ground surfaces and more) as well as man-made or "*human-altered*" elements (reservoirs, canals, and more) which define how the water moves from the sources to the points of usage. All of these elements are monitored and managed using a large amount of different systems to guarantee that water demands are satisfied.

At the operational scale (introduced in Deliverable 1.1 – "*Generic taxonomy for water supply distribution chain*"), many software and modeling packages exist and are currently used to manage water in each of the various steps of the water supply distribution chain. As mentioned, while powerful and providing valuable support to their respective users, these systems are not interconnected. Each step of the water supply distribution chain is managed independently of the others, access to information regarding the upstream and/or downstream processes or needs is usually not available for the decision-makers, and there is a lack of coordination and information sharing resulting in lost opportunities and lower resource efficiencies than if these systems could intercommunicate and data were more readily accessible to the actors involved.

Meanwhile, at the management and planning scale, efforts have been made to develop models and tools to facilitate water supply decisions. Existing models include predictive and estimating models, linear models, nonlinear models, optimization models, as well as stochastic or probabilistic models(Hillyer, 1998). While these tools are extremely valuable, most of these models focus on a specific area of water supply planning, such as demand forecasting, water distribution, reservoir or river system operations. One software tool, the Water Evaluation and Planning (WEAP)[1] model, addresses water supply and demand in an integrated manner. However, although different scenarios can be simulated and compared, this model is a predictive model, can only be run in one direction, from supplies to demand, and is based on a monthly time step such that it cannot support daily operational decisions within water supply distribution chains in a dynamic, interactive manner.

[1] Water Evaluation And Planning (WEAP) web page: http://www.weap21.org/

The WatERP project proposes a new modeling approach. In this project, the use of intelligent and open architecture is proposed, permitting to connect the actors and processes involved in water supply distribution to support, in an integrated manner, the short-term planning and management decisions that take place in water supply distribution systems.

An important part in the WatERP project is the understanding of the water elements and processes that take part in the water supply distribution chain. In this way, the design of the functional model that describes how the WatERP scenarios (pilots) behave is presented in *Section 3*. This specification of the behavior of each pilot is supported by a generalization of the rules, decision processes, and elements involved in water supply management with the aim of enhancing and extending the WatERP ontology that is currently under development to develop generic water management ontology.

With regards to the implementation of the functional model, gaining a deep understanding of the processes involved in the scenarios is an important task. For this, *Section 2* describes the two scenarios that form part of the WatERP project. The two pilots identified for the WatERP project address two different and important problems in the water resource management. On the one hand, in the Spanish pilot, the project tries to overcome the problem of water resources allocation under circumstances of frequent scarcity. On the other hand, in the German pilot, the problem concerns energy efficiency with the hope that energy consumption could be reduced in the water distribution to the consumers.

Furthermore, in order to give support and coherence to the knowledge base, in *Section 4*, the most widely known hydrological (water cycle) ontologies are analyzed through discovery mechanisms to enhance current developments in knowledge modeling and also take advantage of their strengths. Moreover, in order to enhance information exchange (data exchange), a transformation into ontological resources is defined. At this point, the best known language for water data exchange is WaterML2 defined by the OGC. So, in *Section 5*, a transformation into ontological resources of WaterML2 is provided.

As a conclusion, this deliverable is useful to understand the processes, decisions and rules of the WatERP scenarios in order to enhance and improve the ontology development such that a generic ontology that produce productive knowledge about water resources management can be generated.

2. Cases of Study

The WatERP project will be based on two different case study areas in which the OMP and its subcomponents will be tested. The two pilot study areas are very different and consist of the following:

- A <u>Spanish pilot area</u> representing a case in which water scarcity is a frequent problem and where the primary objective is to <u>optimize water resources allocation.</u>

- A German pilot area representing a case in a water-rich environment where water is abundant but where the primary objective is to reduce energy consumption.

It should be noted that while the two pilot problems may appear different in scope, energy and water savings are intimately related. Energy is consumed during water abstraction, storage, treatment and distribution. Meanwhile, water can also be a source of hydropower generation.

The following subsections present a description of the water supply system for each of the pilot cases, as well as a summary of the processes that the ontology will cover, that is, how water supplies are currently managed, in each pilot case, in order to satisfy demands. This information is based on meetings and discussions held with representatives from the Catalan Water Agency (ACA) and Stadtwerke Karlsruhe Gmbh (SWKA), as well as documentation provided by them.

2.1 ACA Pilot

The ACA pilot focuses on the Ter-LLobregat water supply distribution system. This system draws from a number of different water sources and must satisfy a large number of diverse and competing demands within a context of frequent water scarcity. The main challenge that will be addressed in this case consists of **WATER ALLOCATION**: how to best allocate water among the various users, optimizing the resources of the different sources, given limited water supplies.

Water allocation is performed by the ACA taking into account the following points:

- **Every six months**, negotiations are held between ACA and the water users, the outcome of which is the issuance by ACA of a forecast of management of the different supply sources and the distribution of water amounts for each user (Reservoir Water Board meetings).
- **Every month** (every fifteen days or weekly, in situation of drought), actual water usage is compared to the agreed upon water allocation amounts and adjustments are made based on the incurred deviations and updated information regarding water needs and water supplies.
- **Every day**, ACA tracks water supplies and flows and manages the reservoir releases in order to ensure that the daily demands can be met, while also addressing periodic water quality problems in the downstream rivers that could force the water treatment plants to shut down and result in water supply losses (that is, water that would go directly to the sea without having been able to be used).

During extreme events (droughts and floods), ACA might need to manage its water supply infrastructure on an hourly basis. However, during most of the time, the water supply decisions are performed on two different scales, in parallel: on a monthly to seasonal basis, and on a daily basis.

2.1.1 Description of Water Supply System

As shown on *Figure 1*, the Ter-Llobregat water supply system relies principally on two main river sources: the Ter and the Llobregat. While these two rivers are distinct, they are currently connected through a *56* km long water diversion near the city of Barcelona such that the two river systems are now managed as one. It should be noted that while this provides greater flexibility to the water supply system, a balance must always be maintained between the two rivers(ACA, 2013).

In general, natural inflows in these two river basins can satisfy approximately *80%* of the water demand. These flows are regulated by *5* reservoirs. However, reservoir storage capacity is limited and equates to at most a *1 ½* year reserve while droughts typically last two years. These supplies are supplemented by numerous, smaller groundwater sources which are operated at a municipal level(ACA, 2008).

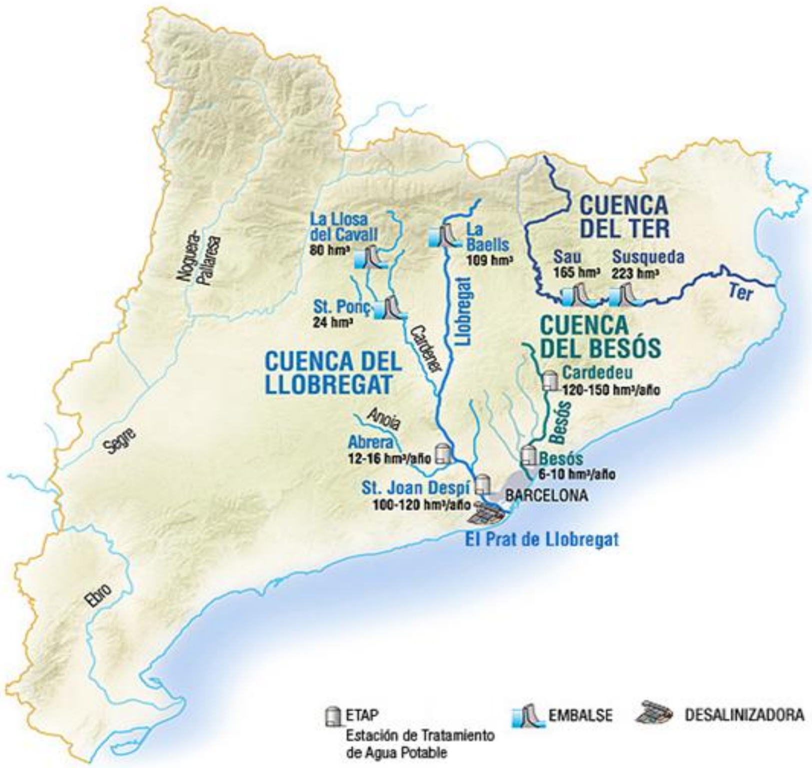

Figure 1 "Map of the Ter-Llobregat water supply system"

When supplies are insufficient, they can be augmented through the use of desalinated water or regenerated water from wastewater treatment plants. Indeed, following a series of *4* big drought episodes, and given the fact that reservoir storage capacity cannot be further increased, two desalination plants (Tordera and Llobregat) were put into service starting in *2009* to provide additional water supply sources. The capacity of the Tordera plant is currently being increased and the establishment of a large water diversion either from the Ebro river or the Rhone is being considered for periods of drought.

Regarding water demand (see *Figure 2*), the primary water use(ACA, 2012) in the Ter-Llobregat river system is drinking water supply (*65%* of total water usage distribution). Serving *5.5* million people, the Metropolitan Area of Barcelona (AMB) represents the highest water demand, although the two rivers also supply water to Girona and its surroundings, as well as portions of the coastal area(ACA, 2008). ACA manages the supply of this water in the upper part of the distribution system, releasing water from the reservoirs when necessary. This water reaches by gravity and within two days, the treatment plants which are located slightly before the Llobregat river outlet (west of Barcelona). Secondary highest water use (*24%*) is agricultural purposes. The remainder of the water uses includes environmental flows (*15%*), hydroelectric power plants, and recreational (*0.4%*). In general, *82%* of the annual surface water resources are used each year(Sala, 2011).

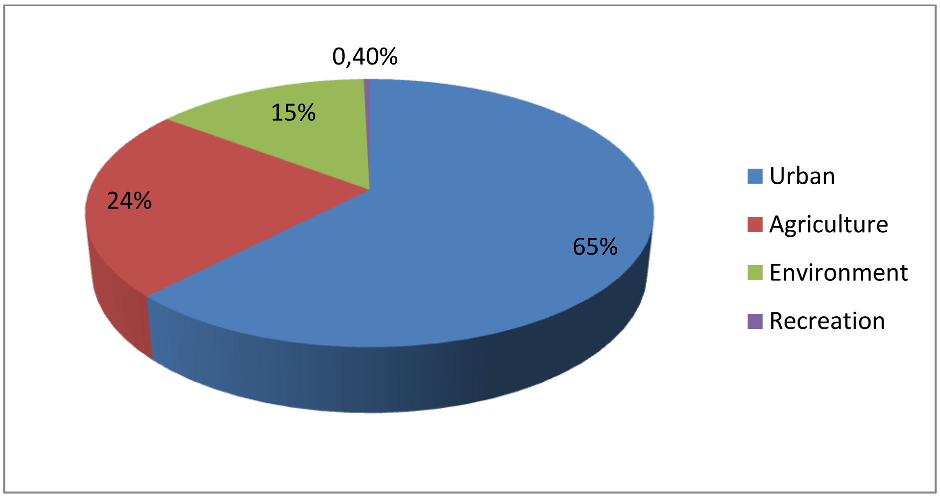

Figure 2 "Water usage distribution in Ter-LLobregat system provided by (ACA, 2012) "

The Ter-Llobregat system is highly vulnerable in terms of guaranteeing supply as the quantity of water available is scant, being close to demand meanwhile the reservoirs can only regulate demand for one year. This vulnerability has become apparent over the various droughts which have occurred in recent years(ACA, 2008).

2.1.2 Water Supply Management

The water management done by the ACA over the Ter-LLobregat water distribution system is presented on *Figure 3*. Water inflows from these rivers (Ter and LLobregat) are stored, to the maximum extent possible, in reservoirs located in the upper portion of the river basins ("*regulated water*"). Rain that falls below these reservoirs enters directly into the river systems and may be used. However, this kind of water is not regulated ("*unregulated water*").

Water from the reservoirs is released to meet different needs. Under normal conditions, the first constraint consists of the maintenance of environmental flows that are required for the river systems. Other factors that define reservoir discharges consist of hydroelectric power generation needs, flood control (prior to a flood, water may need to be removed from a reservoir to ensure that sufficient storage volume is available for the new incoming inflows), and recreational needs. While these water demands are non-consumptive, they affect downstream flows. The remaining water is saved for consumptive water usages (such as domestic and agricultural uses) and released during times when the unregulated flows are not sufficient to meet demand.

Large water users such as agricultural communities, water supply utilities and industries withdraw water either directly from the rivers or from the underlying groundwater aquifers, according to their needs. These amounts are supplemented by regulated water from the reservoirs, according to previously agreed amounts negotiated during the bi-annual Reservoir Water Board (RWB) meetings. Water that is served for potable uses is treated prior to distribution. When these natural water sources are insufficient, desalinated or regenerated water can be produced to augment water supplies.

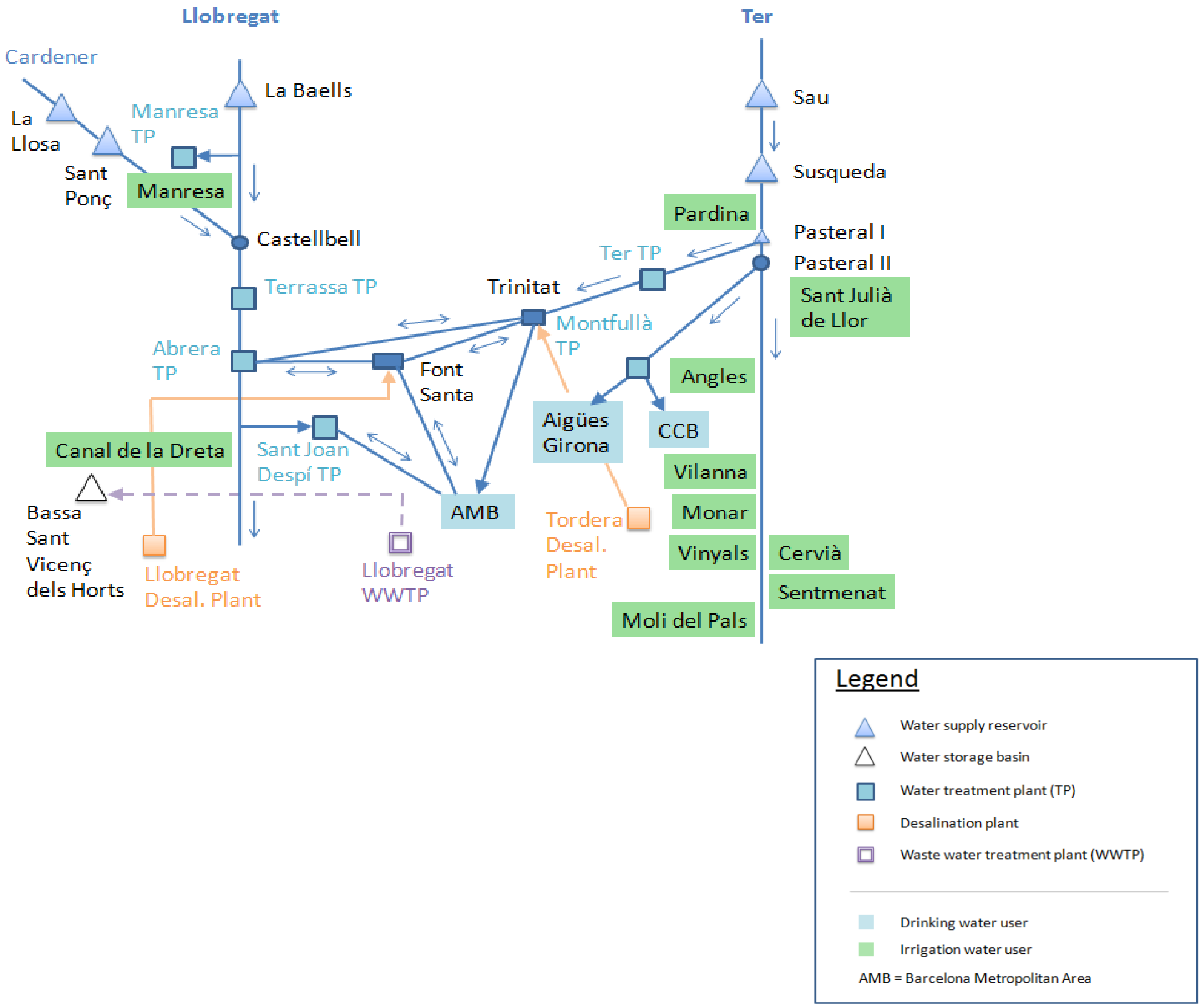

Figure 3 "Schematic representation of the Ter-Llobregat water supply distribution system"

2.1.3 Water Management Decision Processes

Water resources management in the Ter-Llobregat system (*Figure 4*) is governed by a series of distribution rules that are defined between the administration (ACA) and the users (bulk water suppliers, irrigation communities, hydropower producers, and water utilities, among others) during the bi-annual RWB meetings. In these agreements, the maximum volume of regulated water to be allocated to each of the various users is fixed based on the forecasted evolution of the water reserves and an estimation of the expected alternative sources that will be available.

When the state of the water reserves is in an exceptional situation, the RWB agreements are overridden by previously established drought management plans, which define the water usage priorities as well as the management rules that should be followed for the different water sources under conditions of water scarcity.

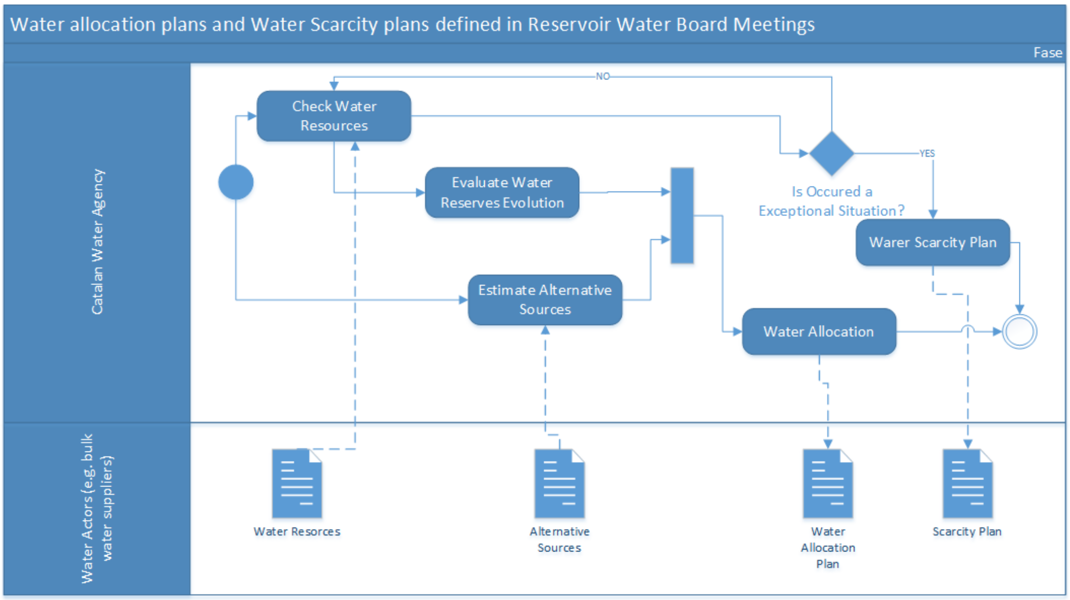

Figure 4 "Process Diagram of Water Allocation and Scarcity Plan definition"

Even though there are rules and norms (*Figure 5*) which defines how the resources and water demands should be managed at all times, these must be continuously adjusted depending on the actual conditions that occur in order to optimize these resources. Factors that can influence from where the water is taken and how it is finally distributed include water treatment plant incidents, the quantity of unregulated inflows that enter in the system (estimated based on weather forecasts), contamination events, and short-term changes in demand (related to consumption differences between weekdays and weekend or holiday days, or resulting from temperature and precipitation fluctuations). These factors which condition the supply, demand and distribution of water require a constant adaptation of the general rules to the actual conditions. Consequently, daily management plays an essential role in the optimization of water resources in the Ter-Llobregat water supply distribution system.

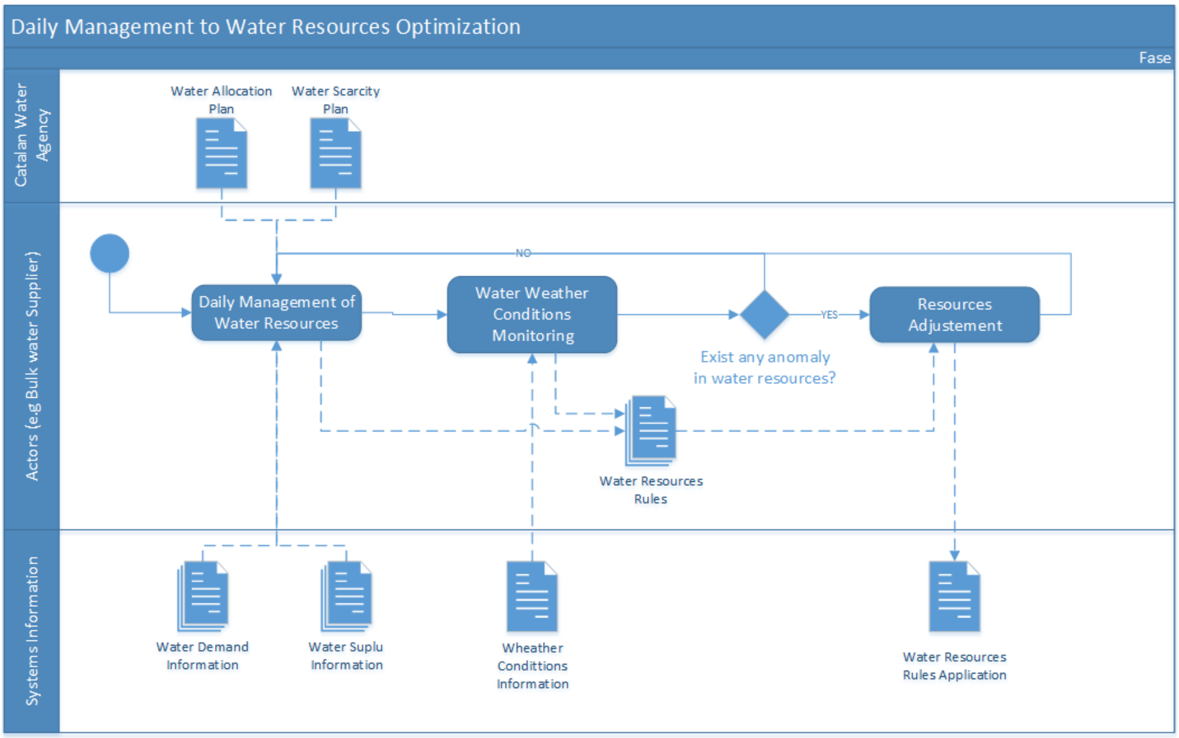

Figure 5 "Daily Management in Water Resource Optimization"

2.1.3.1 Daily management as a tool for optimizing resources and ensuring demand

As noted above, daily water supply management (*Figure 6*) is affected by a number of different factors that alter the conditions established in the general management guidelines and medium to long-term water need forecasts, requiring an adaptation of these guidance values to optimize the water resources.

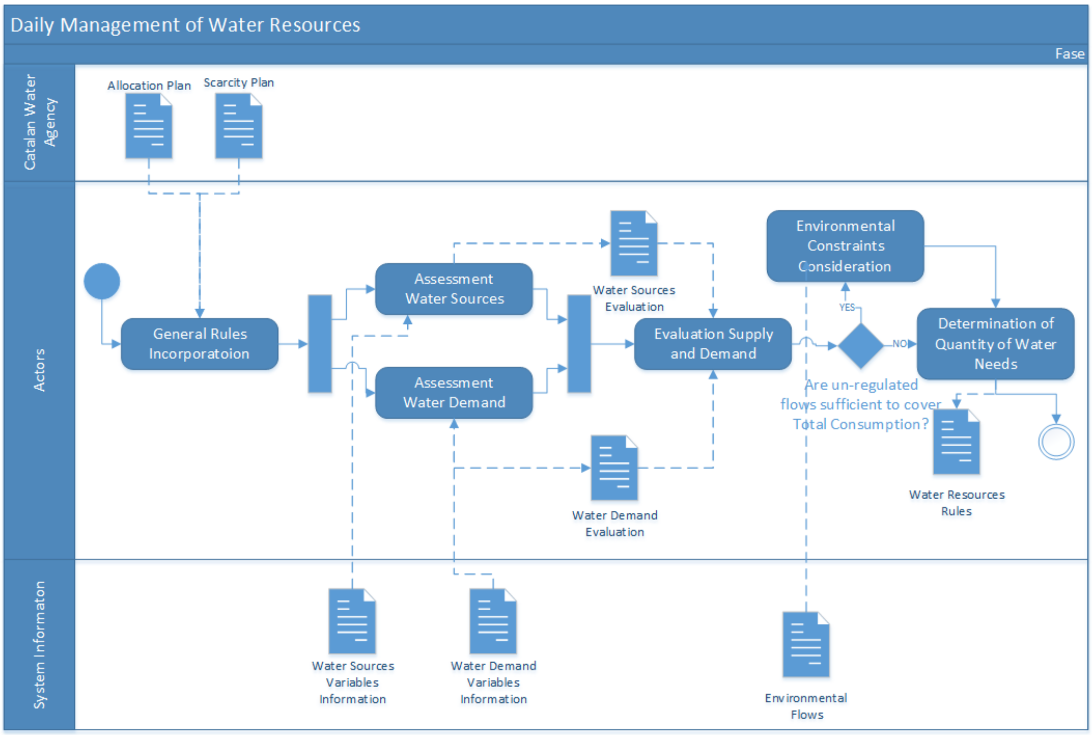

Figure 6 "Detail of Daily Management of Water Resources"

For illustrative purposes, the following figure (*Figure 7*) shows a series of the actual average daily demands of the Llobregat river water treatment plants (blue line) compared to the monthly forecasted value (red line). It can be observed that the actual demand average is very close to the expected demand, but that there are daily fluctuations which, if not taken into account in the management, would result in deficits (unmet demand) or resource losses in certain periods.

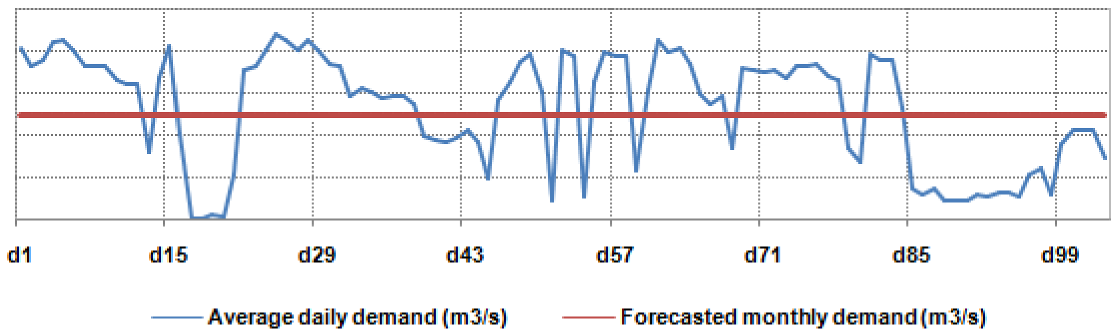

Figure 7 "Comparison of the actual daily demand to the monthly expected value"

The previous analysis focused on demand, although similar analysis could be performed from the supply (resources) management point of view. *Figure 8* again demonstrates the importance of adapting the management to the currently occurring conditions. Indeed, the blue line represents the regulated water that was released each day compared to the anticipated reservoir release needs (red line).

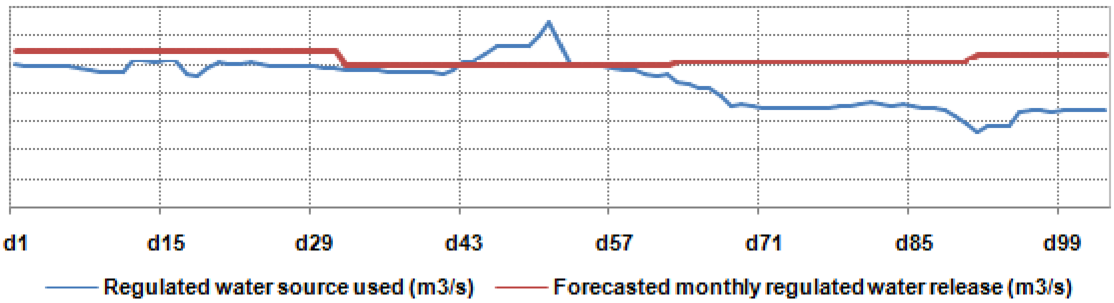

Figure 8 "Comparison of the actual daily regulated water releases to the monthly expected value"

2.1.3.2 Objectives and overall approach of daily management decision making

Daily management consists of overseeing compliance with the general management rules that govern supply and demand and adapting them according to the various factors that alter the previously forecasted medium and long-term conditions in order to optimize resources and guarantee that the demands are satisfied at all times.

For this, the state of the reserves must be assessed each day (*Figure 9*), along with the amount of unregulated and alternative sources that may be available, possible water treatment plant incidents, water production constraints, and actual demand in order to respond to the two following questions, considering the necessary travel time required for the resource to get from its origin to the point of demand:

- What quantify of water must the system provide? -> QUANTITY
- From which source(s) should this water be obtained? -> DISTRIBUTION

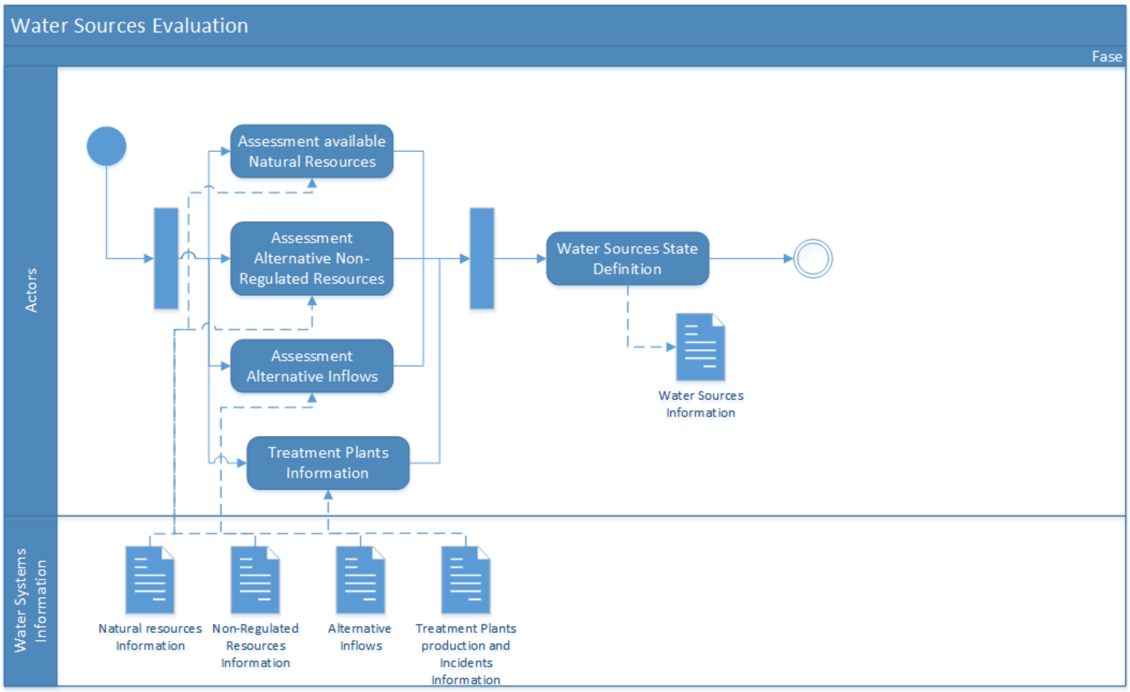

Figure 9 "Water Sources Assessment Process"

Figure 10 illustrates the factors that must be considered during the daily management decision-making processes.

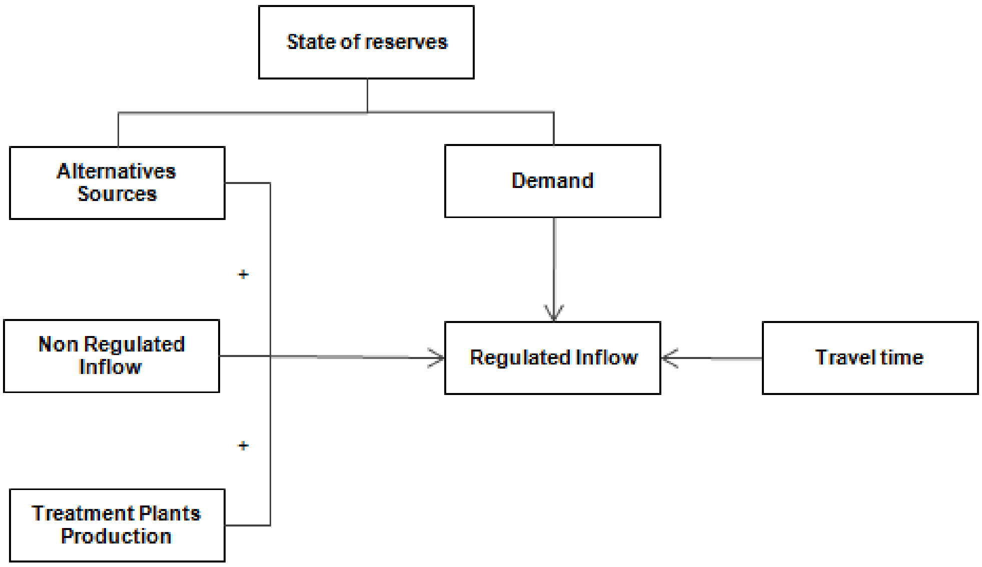

Figure 10 "Variables that must be considered in the daily management decision making processes"

The amount of resource needed depends mainly on the demand (*Figure 11*) and natural inputs (unregulated water inflows). Both existing as well as forecasted within the time frame that is required to bring the resource to its point of possible collection, which, in turn, depends on the location from which the resource is taken and the demand. For example, this could represent the transit time in the river channel from the dam to the point of collection, if the water is released from a reservoir, or to the amount of time required to adapt the processes in a treatment facility to respond to an operational regime change in the case of a desalination plant.

Examples of variables that affect the determination of the quantity of water that is needed are:

- **Meteorological conditions** which, in the case of the Mediterranean climate, are sometimes very difficult to predict beyond three or four days
- **Fluctuations in drinking water demand** (affected for example by holidays) or irrigation water needs (which depend on meteorological parameters and crop type)
- **Foreseen as well as unforeseen water treatment plant incidents** or punctual contamination episodes or affectations to the quality of surface water sources

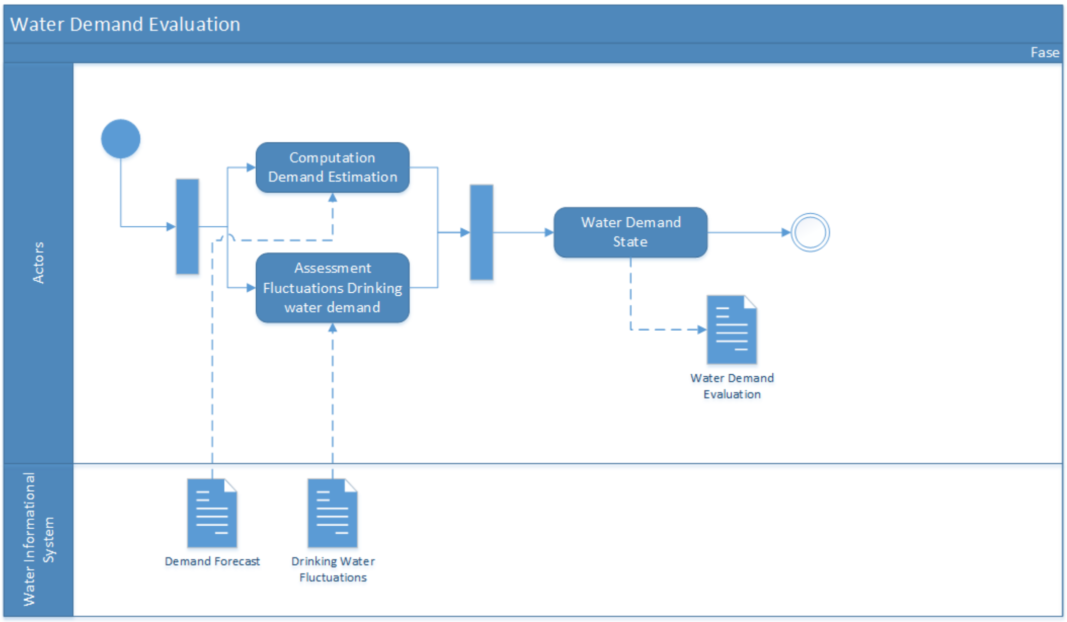

Figure 11 "Water Demand Evaluation Process"

The distribution of the origins and sources from which this water is taken to satisfy the demand is determined by the general rules which set average values and source usage priorities depending on the state of the reserves and depending on the production capacity and the demand that can be covered by each source. That is, demands cannot always be satisfied from any source. Meanwhile, a single source may not have the capacity to meet the entirety of a given demand. *Figure 12* attempts to illustrate these limitations graphically.

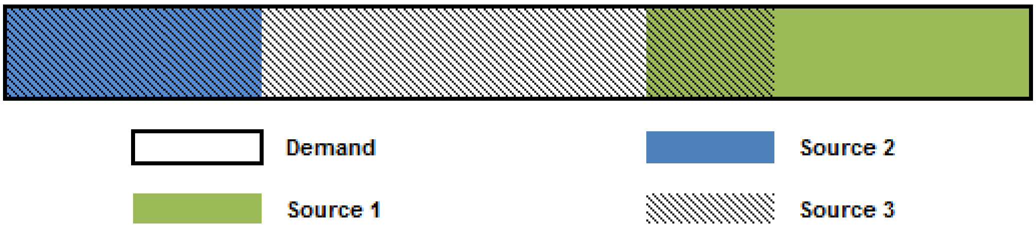

Figure 12 "Example of demand satisfaction distribution when different water sources are involved"

In *Figure 12*, the rectangle represents the entire demand while the green, blue and grey hatching represent the various water sources. It can be observed, for example, how part of the demand can only be satisfied by *source 1* (captive demand), while *source 3* can cover all of the demand that *source 2* can cover as well as part of that of source 1. The supply and demand evaluation process is depicted in *Figure 13*. Greater detail regarding the different steps that are followed in the daily management decision making processes for the Ter-Llobregat water supply management system is presented in *Section 2.1.1*.

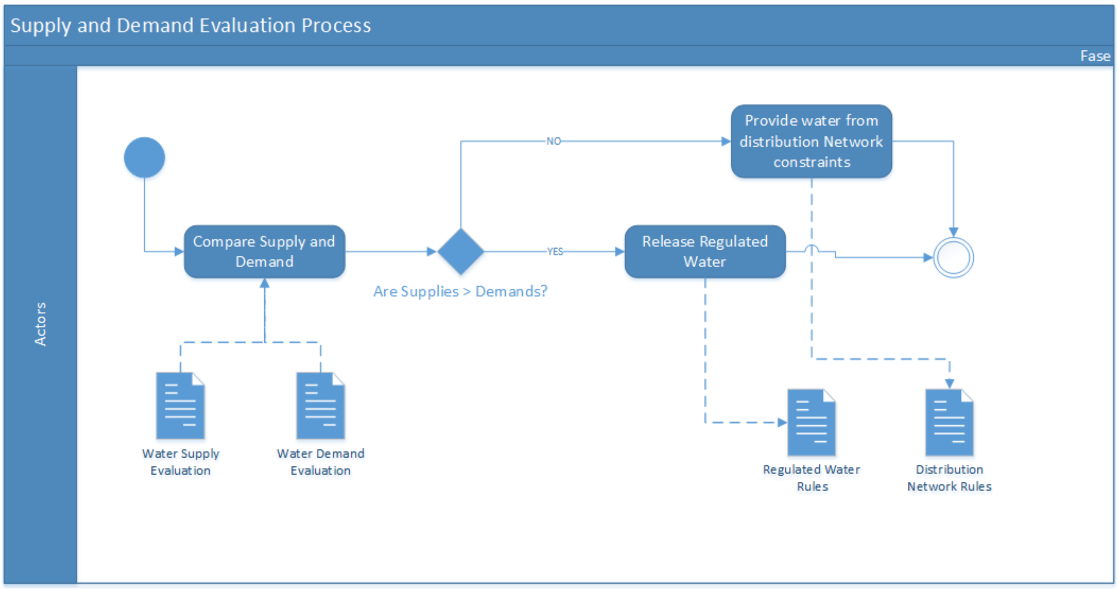

Figure 13 "Supply and Demand Evaluation Process"

2.1.3.3 Water supply distribution constraints

The Ter-Llobregat water supply system is extremely complex. This subsection provides more detail regarding the constraints that influence from where water is taken and where it is used when allocating water among users:

- **Water source consideration**s. The Ter-LLobregat water supply system is comprised of several different water sources. How these sources are used depends on the general rules established during the RWB meetings but also on their respective availability, quality and location relative to the water demands.

- **Water usage consideration**s. The Ter-Llobregat system provides for many different water uses and demands. There is no unique demand, and there are priorities for usage. Under normal conditions, the environmental flow constraints must be satisfied first, followed by the drinking water demands. However, in times of drought, drinking water needs are answered first. Meanwhile, each type of water usage has its own singularities. For example, drinking water must be supplied continuously and cannot be interrupted whereas irrigation has more of a margin and if plants are not watered one day, watering them the next day can be acceptable.
- **Social considerations**. Some areas of the Ter-Llobregat water supply river basin generate more water than others, while areas such as the AMB primarily receive water. Tensions can arise between geographic areas and must be balanced in order to ensure that needs among different locations are considered in a fair and equitable manner. For instance, a balance must always be maintained between the Ter and the Llobregat river basins. In general, the Ter river is naturally more regular than the Llobregat, receives about twice as much natural inflows than the Llobregat, has higher quality water and is less expensive to use. Consequently, the natural tendency would be to use Ter water in precedence over Llobregat water. However, in order to maintain a balance, the two rivers are continuously monitored to ensure that the two systems remain at the same level of water abundance.
- **Economic considerations**. In terms of cost (driven mainly by energy), the least expensive water is that which comes from the Ter and is transferred to the Llobregat basin. It has a higher quality which reduces the cost of treatment and can even generate power at the end point through turbines. The second most economic option is purified water from the Llobregat river. Alternative sources are the most expensive, starting with recycled water, and ultimately the desalinated water from the Tordera and Llobregat plants.
- **Technical considerations**. The distribution system layout presents another set of constraints. Although the Ter-Llobregat connection provides a significant increase in flexibility, water from the various sources cannot always physically reach all of the points of use. In addition, the various abstraction pumps, pipes or diversion canals have certain flow capacities, the treatment plants can only process so much water per unit of time, and the distribution network pipes have both minimum and maximum flow constraints to ensure their proper operation and function. Maintenance must be performed periodically, and incidents can occur at the storage tanks, pollution or rainfall events can affect water quality and treatment plant processes, water levels in the rivers can prevent water to be taken at times, and pipe breaks can occur in the distribution network.

- **Non-consumptive use considerations**. While usages by the hydroelectric power plants or recreational activities is non-consumptive in nature, these flow requirements have an effect on downstream water flows and can condition the other, consumptive, uses.
- **Water availability considerations**. Several different scenarios have been defined for the Ter-Llobregat water supply system management, these being: normal conditions, flood, or drought (water scarcity) conditions. The current scenario will influence both the water source priorities as well as the water usage priorities described above.

All of these considerations and rules must be taken into account in the daily management tasks to ensure that the limited water resources are used in the most efficient manner and so as to satisfy the system's many demands.

2.2 Karlsruhe Pilot

Karlsruhe pilot is managed by SWKA, the water utility in charge of providing water to the city of Karlsruhe in Germany. The Karlsruhe water supply distribution system (see *Figure 14*) uses groundwater as its sole water source, which it draws from four different water works, each comprised of *4* pumps of different sizes. The aquifer reserve is such that it can always meet the demand with usage representing approximately *30%* of the average groundwater recharge and approximately *2%* of the storage capacity of the aquifer. However, the system operation depends upon pumping, which involves energy consumption. In addition, energy is lost at the pump stations but also within the distribution network. The main challenge that will be addressed in this case consists of **INCREASING ENERGY EFFICIENCY**: how to minimize energy consumption while meeting the city's daily water demand.

However, it should be noted that while SWKA is concerned about energy consumption and would like to be able to reduce its energy consumption per unit of water delivered, it is not yet something that is currently considered in the daily operations of the system. In SWKA, water distribution is performed by an operator who controls the four water works along with the filling and emptying of the main reservoir as follows:

- **Every day.** The operator's goal is to fill the main reservoir during the night and empty it during the following day. The main reservoir is not necessary in terms of meeting the necessary demand flow rates but rather, functions as a pressure regulator for the system and as an emergency reserve in case of an unpredicted shutdown of one of the water works.
- **During the day**. The reservoir is emptied at a constant rate. Ideally, to maximize energy efficiency, the tank should be emptied at a rate that keeps the output of the water works as constant as possible. To always ensure the required output of the water works, the operator monitors the capacity of the treatment filters and the water level in the reservoirs of the water works and back flushes the filters when suitable.

2.2.1 Description of Water Supply System

The city of Karlsruhe receives all of its water from groundwater. The local energy and water supply company SWKA provides drinking water for about *400,000* people in the city of Karlsruhe and surrounding area. A small part of the city of Karlsruhe receives its water from another source while some of the drinking water output of the SWKA water works is delivered to other drinking water suppliers, small towns in the surrounding area of Karlsruhe(SWKA, 2013).

For drinking water, SWKA has *4* well fields (water works) located around Karlsruhe (WWHW, WWDW, WWMW and WWRW) that extract groundwater from the aquifer nearest to the surface (see *Figure 14*).

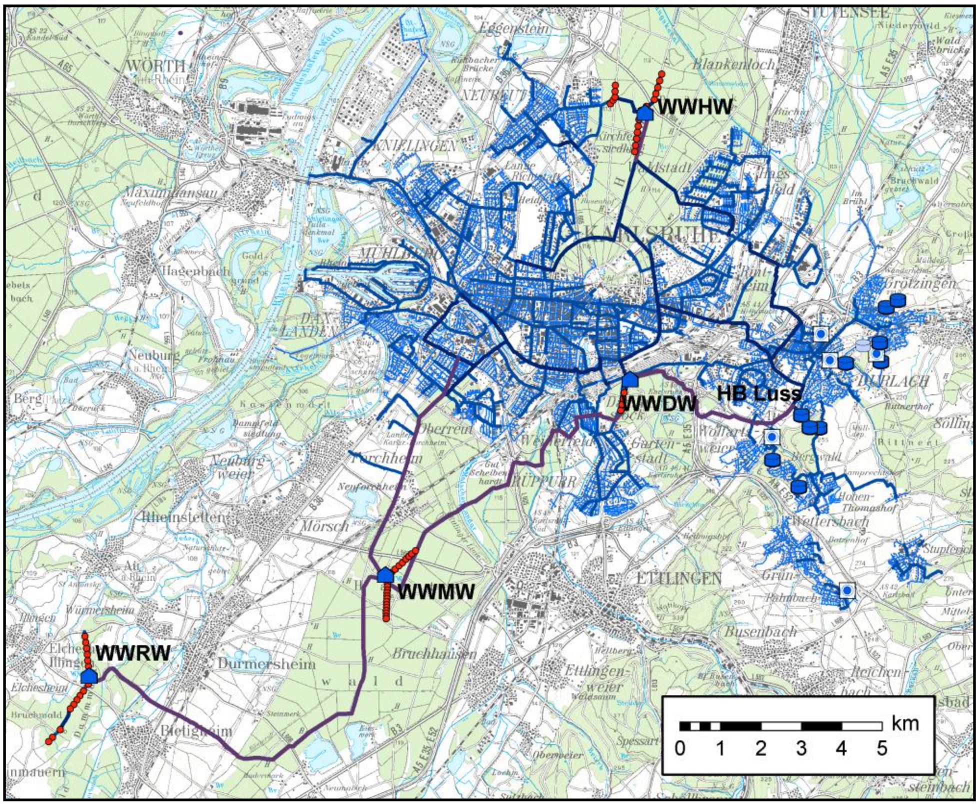

Figure 14 "Map of the Karlsruhe water supply system"

2.2.2 Water Supply Management

Most of the city lies in a plain therefore lies in one pressure zone (representing around *90* to *95%* of the total water demand). All *4* water works feed in this pressure zone, to which a main reservoir (HB Luss) is connected. Located about *50*m above street level, this reservoir stabilizes/controls the water pressure in that main pressure zone. Some smaller parts of Karlsruhe lie in the hills above the plain. For these areas, there is a system of pumping stations and small, higher reservoirs, fed from the main pressure zone, for their water supply. A schematic of the Karlsruhe drinking water supply system is depicted on *Figure 15*. In this scenario, water treatment necessary is the removal of iron and manganese before supplying to the user.

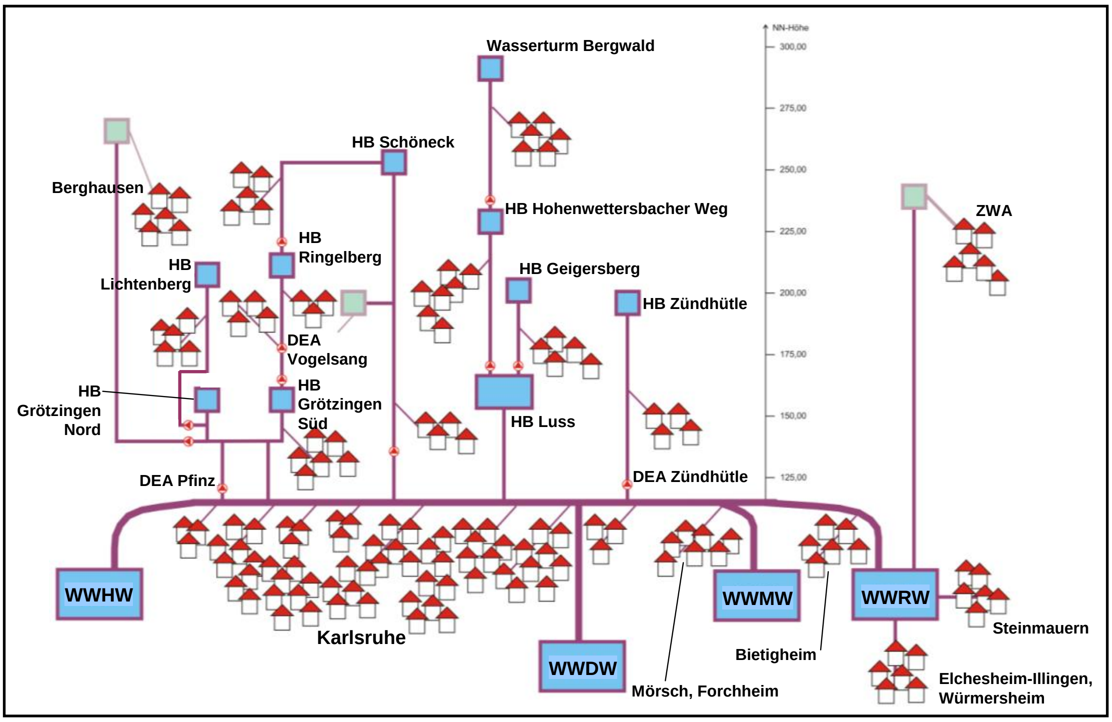

Figure 15 "Schematic representation of the Karlsruhe water supply distribution system"

In general, if water demand in the main pressure zone is lower than the input from the water works, then the reservoirs need to be filled. In the case in which the pressure is higher than the input of water works, the reservoirs must be emptied. The input from the water works is such that the main reservoir is full in the morning and empty late in the evening and gets filled during the night (*Figure 15*).

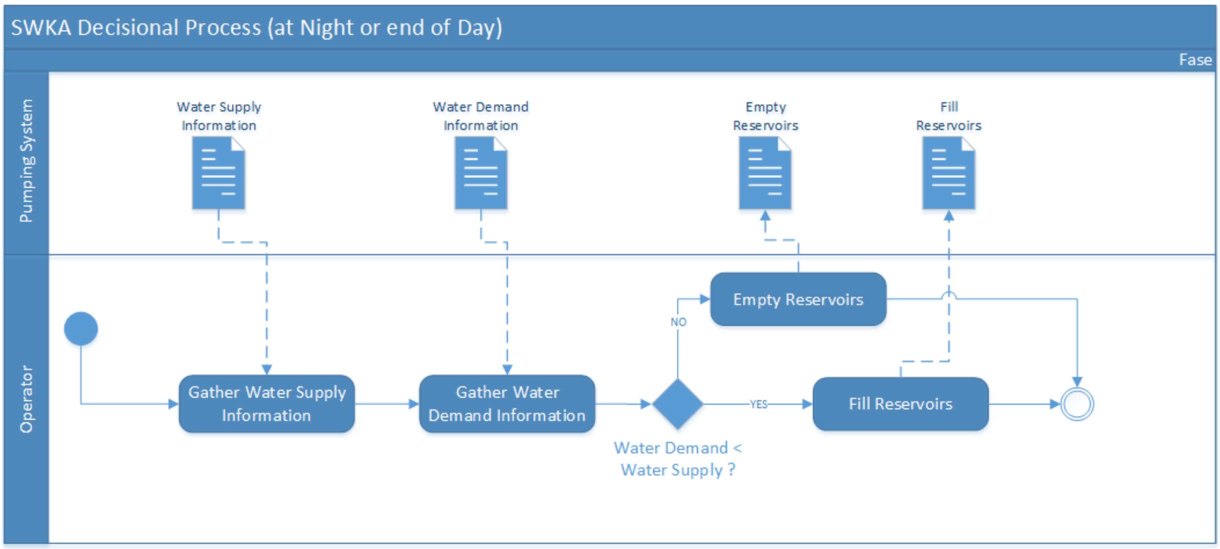

Figure 16 "SWKA Decisional process end of day"

Regarding the higher pressure zones, whenever one of the small reservoirs is empty, the corresponding pumping station starts pumping until the reservoir is full again.

2.2.3 Water Management Decision Processes

As explained in the previous sections, the SWKA water management is focused on distributing water to the users in the city of Karlsruhe. The management decision processes to provide such water is centred around the management of the pumps in the four water works that service the city.

The pumps of the four water works into the distribution network are all controlled manually (*Figure 17*). The control over the pumps is done taking into account the current state and some performance rules (rules related to water works pressure needs).

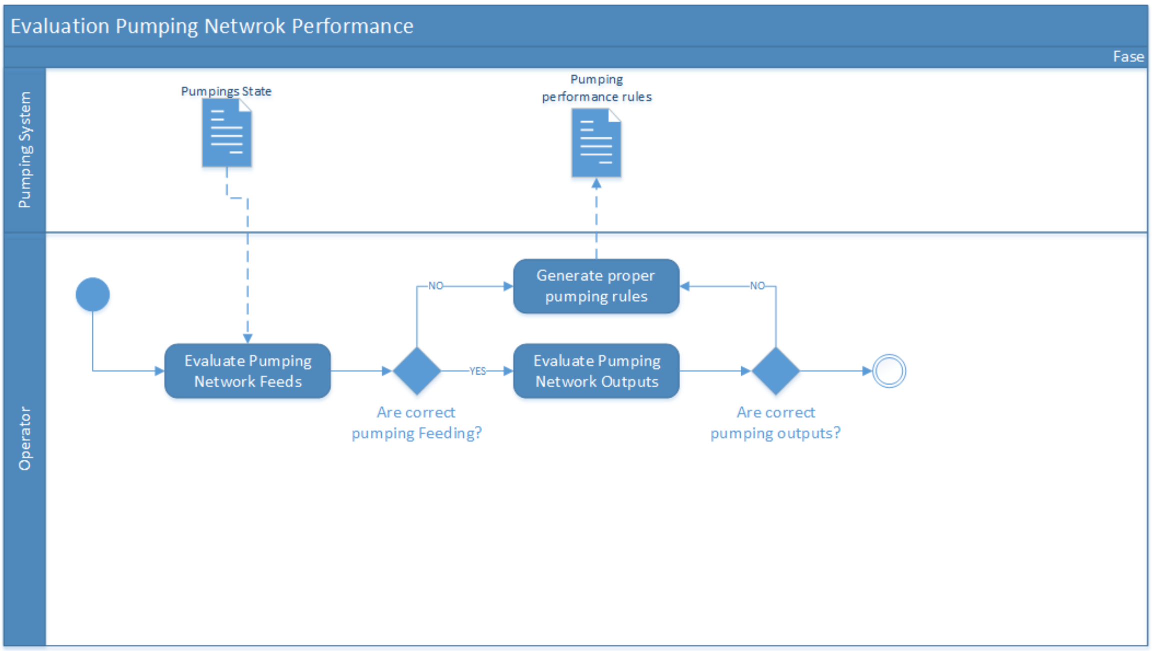

Figure 17 "Decisional process of SWKA pumping performance"

Based on the expert experience of SWKA operators, several rules(SWKA, 2013) are applied in normal conditions in order to maintain the correct performance of the pumps and water works. These rules also are described graphically in the *Figure 18* and *Figure 19*:

- As the WWRW and the WWMW are connected to the same pipeline, only one of the two well fields feeds water into that pipeline at the same time to prevent the pumps from running inefficiently due to high pressure in that pipeline (see *Figure 18*).
- As the water quality of the WWDW is slightly less good than the water quality of the other well fields, this well field only feeds water in the pipeline when either the WWRW or the WWMW also feed water in it (which is always the case, see below) (see *Figure 18*)
- One of the well fields WWRW and WWMW always feeds water into the distribution network to keep the water pressure in the southwest and south of Karlsruhe high enough (see *Figure 18*).

* The WWHW always feeds water into the distribution network to keep the water pressure in the north of Karlsruhe high enough (see *Figure 18*).

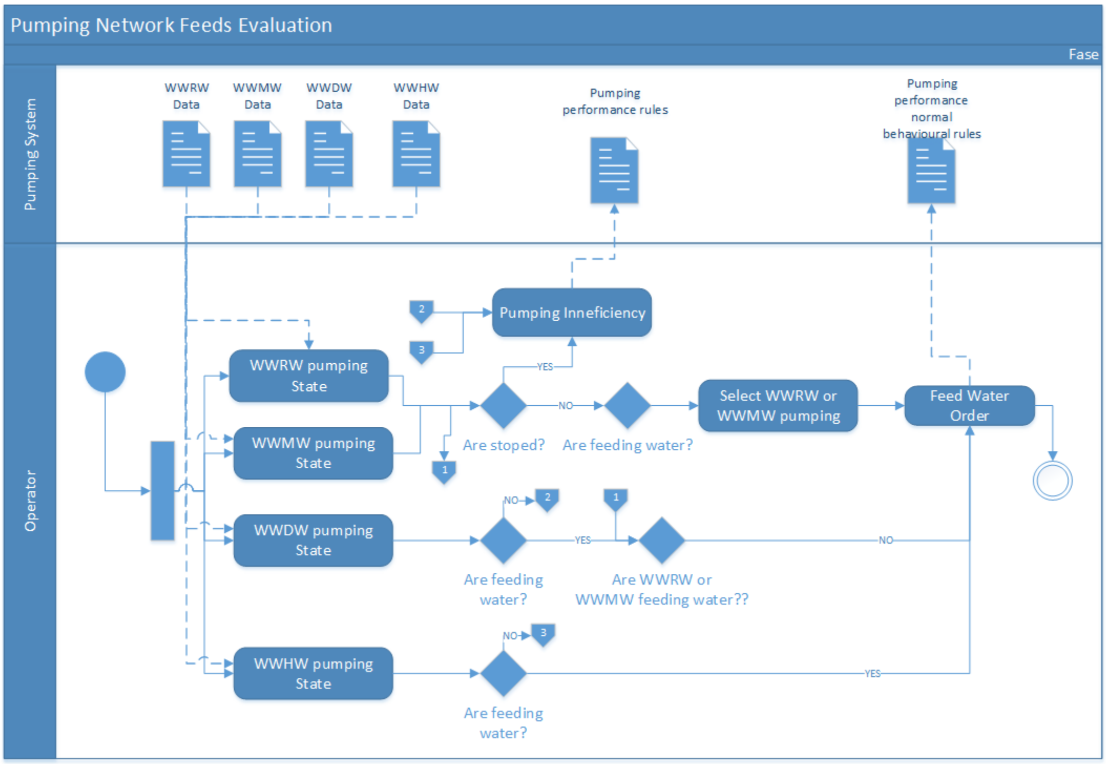

Figure 18 "Evaluation of Fees in SWKA pumping performance"

* The daily output of the WWDW should not exceed *2,000 m^3/d*. For political reasons at present, the daily output of the WWDW should not be below *2,000 m^3/d* (see *Figure 19*).

* The percentages of the daily outputs of the water works WWHW, WWMW and WWRW should be within certain boundaries that ensure that the legally allowed maximum groundwater withdrawal per year is not exceeded (see *Figure 19*).

* The water input from the four water works into the distribution network is such that the HB Luss is filled during the night (when the water demand is low) and emptied during the day (when water demand is high). The water table in the HB Luss should always be between defined minimum and maximum values (see *Figure 19*).

* Regarding the smaller reservoirs, the corresponding pumping station automatically starts working when the water table in the reservoir is at empty or below a certain threshold level and stops working when the water table in the reservoir is at full or above the threshold level. Therefore, the smaller pumping stations and reservoirs do not need to be managed (see *Figure 19*).

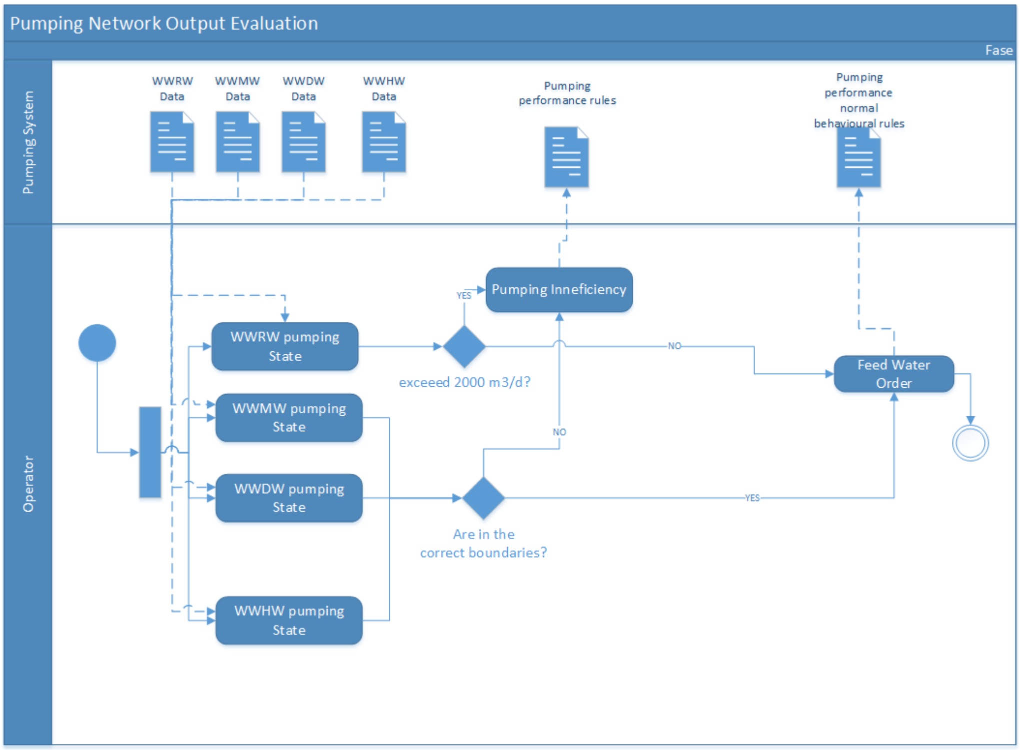

Figure 19 "SWKA Outputs evaluation in pumping performance"

Although not currently done, SWKA would like to enhance the energy efficiency in the distribution network by optimizing the use of the pumps in the water works. Suggested rules that are believed to help improve energy efficiency in the Karlsruhe water supply system include the following:

- The output of each water work should be as constant as possible.
- If the full capacity of the main reservoir HB Luss will, according to the demand prediction, not be needed to keep the output of the water works fully constant during the next day, it does not need to be filled to the maximum during the night but only to the level needed for providing a constant pumping rate.
- During the day (e.g., from *5 am* to *6 pm*), a minimum water table in the main reservoir HB Luss should be met to fulfil its function as an emergency reserve.
- In the evening (e.g., between *8 pm* and *10 pm*), the water table in the main reservoir HB Luss should go below a defined level at least once to ensure a sufficient exchange of water in the reservoir, while not going below another, lower level.
- More efficient pumps should be used more than less efficient pumps.
- Water works located closer to the city should be used more than water works farther away.

3. Proposed Functional Model

This section presents the functional model that is being proposed for the WatERP project. **Functional models** are used in multiple fields of engineering in order to represent how a system behaves. In the water field a functional model is similar to a logical model where system behavior is represented as a set of rules and decisions. Hence, **logical model** describes the interactions that occur between elements throughout water distribution chain. More in detail, this model represents the natural water cycle elements and its interaction (or conjunction) with the man-made ("*human-altered*") infrastructure elements that modify the natural flows for human benefit (via channels, pipe networks, etc).

This logical model was designed based upon a review of previously existing water supply management modeling approaches and the project needs. It is based on the knowledge structuring presented in Deliverable 1.1 – "*Generic Taxonomy for Water Supply Distribution Chain*" and will help discover and improve the rules of the ontology that is currently being developed to support the OMP.

3.1 Existing Water Supply Management Models

Several general simulation assessment models already exist for water supply management. For example, the WEAP model can simulate water demand, supply, flows and storage throughout a defined system under different scenarios of varying policy, hydrology, climate, land use, technology and socio-economic factors(Simonovic, 2002). While valuable, this model is a predictive tool and can only be run in one direction: given specified supply conditions, how can the various demands be satisfied. Although different scenario simulations can be run and compared, questions cannot be asked in the opposite direction: for example, given a specific end use water demand, how much water should be drawn from a given source. Furthermore, the model is based on monthly time steps and while daily values are generated, the model is intended for long-term planning horizons and cannot enter into daily operational details. For instance, for a predicted future peak water usage rate, the model cannot provide insight as to how much water a treatment plant should process or from where water should be obtained given distribution network travel time and connectivity constraints.

Similarly, the Water Global Analysis and Prognosis (WaterGAP) model designed to solve water balancing problems includes a water supply model (Global Hydrology Model) and a water demand model (Global Water Use Model). However, it is designed for long-term global and regional scale analyses and does not allow sufficient spatial resolution to answer specific distribution system operational questions. In addition, such simulation models are limited in terms of their ability to capture the dynamic behaviour of the complex systems that they are modelling and are not capable of reflecting the dynamic feedback relationships that occur among water availability and use.

Other models have been developed using system dynamics in order to enable more dynamic modelling of the system, such as TARGETS and WorldWater at the global scale, or Erhai basin System Dynamics

(ErhaiSD) and Water Resources System Dynamics (WRSD) at the watershed scale(Simonovic, 2002). These models represent the system physical processes and key variables through mathematical relationships, enabling an understanding to be gained regarding the inter-relationships between the different elements and a quantification of the system behaviour. However, although these models can provide insight into the dynamics of water use (how alternative choices would alter the tendency to move towards a certain condition), these models cannot resolve specific operational decisions at the scale of a water distribution system.

3.2 Need for a Holistic, Basin Scale Approach

Water resources management is extremely complex, related not only to the environment but also the numerous human activities that are carried out within this environment. Water availability and usage depend on the timing and manner of its arrival (rainfall intensity, rain or snow, duration, frequency), the physical setting of the region (climate and weather, topography, geology), the engineering structures in place, the environmental constraints (existing ecosystems), the legal regulatory context and institutional policies(Serrat-Capdevila, 2011).

Traditional approaches to water resources management have typically been based on black-box optimization models, handled by technical people and developed for very specific purposes. They do not include interactions with the end users or stakeholders involved and have not been able to include in their computations the variety of important factors that are necessary for decision makers, or in ways that are transparent to the public.

There is consequently a need for more holistic approaches that can address the complex coupled human and physical system interactions at the basin scale. Furthermore, new holistic and integrative approaches must include multi-resolution capacity so that findings and information can be transferred and used across models and users, and should be based on an agreed-upon conceptual model of the system that will help stakeholders and decision-makers understand what are the main issues and challenges at the system level, but also for each stakeholder(Serrat-Capdevila, 2011). However, the tools must be flexible so as to be able to evolve as needs arise or based on feedback obtained from prior decision-making findings. Rather than developing and using them once, decision support systems offer greater benefits when they are dynamically changed over time, as a working tool that can be modified over time as policies or modifications in the engineered system layer (canals, pipes, wells, dams, water allocations, changes in use efficiencies, changes in land use cover, etc.) occur, as well as in response to new or modified understanding of how the system works.

3.3 Proposed Functional Model

As mentioned in the beginning of this section, functional models provide the necessary mechanism to discover and know how a system behaves. This functional model has been represented in its logical form for the both pilots systems described in the *Section 2*. As mentioned, functional models (in water field called logical models) describe on the one hand the elements that comprise its specific systems (natural paths and also human altered paths). On the other hand, these models represent decisions and rules attached with specific definition of the pilots. The representations of functional models are useful for enhancing and defining two important parts of the WatERP project. On the one hand, the rules and behavioral description will permit define the ontological rules between concepts of the ontology (Task 1.4- "*Generic Water Data Ontology*") and also define instance (in a first version) needed for ontological population. On the other hand, the functional models permit the definition of the decisional rules that could be included in the DSS which will be defined during WP4. These rules to be included thanks to functional models also represent rules and decisions done by expert users in order to adapt the normal behavior of the system to the particularities of the pilot management and most usual states of the system (e.g., droughts, floods and more).

Within a water supply system, water demand originates in many different places, and water flows within water supply distribution systems are not necessarily linear. For instance, industrial users can be located in the upper portion of the watershed, but can also be situated in the lower part of the river basin in a more urban environment. Municipalities located in the upper part of the river basin can divert water to a local water treatment plant such that this water does not follow the main water supply distribution chain but rather uses a locally-operated treatment facility, or municipalities can depend upon the primary water supply distribution system. Meanwhile, water supplies can be encountered throughout the water supply distribution chain. Although the largest surface water storage systems are typically located in the upper portions of the water supply network, rainfall falls upon all parts of the river basin, generating new water inflows throughout the system. Finally, and further complicating the flow sequence, water can be reused or recycled throughout the system.

Although water supply networks can be very complex, what is common to each step is that each water supply entity (such as a water treatment plant or a reservoir) has an inflow and an outflow, and these inflows and outflows are a function of supply and demand. If the proposed tool is to replicate the "*expert user*" process, it will need to follow a chain of decisions that will most likely require the simultaneous examination of several different entities. Each entity will have an outflow that should correspond to the demand made by a downstream entity, and an inflow which will be passed on to an upstream entity as the new demand.

While the computations in each entity will be different depending on the type of entity and its respective characteristics, and each entity will involve a different set of data variables to relate inflow to outflow, the elements involved in water supply management can be classified according to the following five categories:

- **SOURCE.** Entity in which system resources are provided.
- **TRANSPORT.** Entity that moves resources from one place to another in the system.

* STORAGE. Entity capable of retaining resources for a period of time for later introducing them back into the system when needed.
* **TRANSFORMATION.** Entity that modifies the properties of resource.
* SINK. Entity in which system resources are subtracted.

Even though differences can occur among entities, in general, entities within a same category will have similar characteristics and functions. These categories are presented in the following table along with the corresponding entities that can be found in a water supply distribution system and some of the associated key variables.

Category	Entities	High Level Variables
SOURCE	Precipitation Sea Transfer	Volume Flow Level
TRANSPORT	River or channel Distribution	Flow Level Width Slope Travel time
STORAGE	Reservoir Aquifer Tank	Volume Level Inflow Outflow Storage capacity
TRANSFORMATION	Treatment Hydropower Desalination	Flow Elevation Quality Price Other quantitative properties
SINK	Environmental use Domestic use Agricultural use Industrial use Recreational use Evaporation losses Unaccounted for water	Volume Flow Water use rate Activity level

Table 1"Water supply management categories, entities and variables"

It should be noted that the variables contained in this table are not intended to represent an exhaustive list but rather illustrate the main parameters considered in these types of water supply elements. Additional detail is provided in Deliverable 1.1 -"*Generic taxonomy for water supply distribution chain*".

3.4 ACA Pilot

In this section, the aim is to represent the functional model of the ACA pilot (Spanish pilot). The functional model is represented graphically in the *Section 3.4.1*, along with a detailed description of the rules and decisional process done over pilot. *Section 3.4.2* presents the users that are involved in the decisional process and *Section 3.4.3* gives a description of the variables (and measures) involved in the decisional process.

3.4.1 Simplified Logical Model

Figure 20 presents a simplified schematic, using a logical model, of the Ter-Llobregat water supply distribution system.

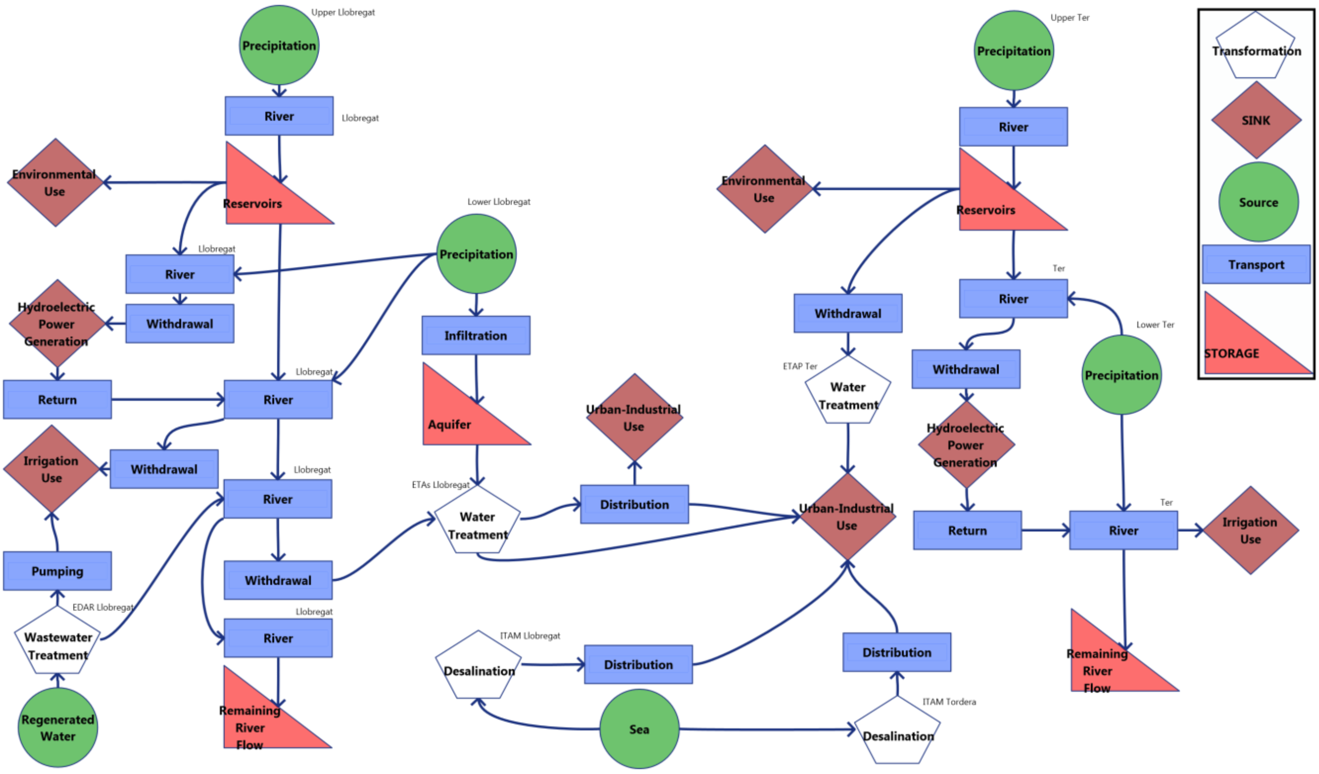

Figure 20 "Simplified logical model of the Ter-Llobregat water supply system"

Having previously explained the objectives, constraints and variables involved in the Catalan Water Agency's daily water management activities (see *Section 2.1.3*), this section presents the daily decision making steps that are followed in the Ter-Llobregat water supply system. At the end of this section, a flow diagram schematically represents the process described below (*Figure 21*).

1. **General rules**. As a starting point, the current scenario of the system must be determined (state of the reserves, balance between the two rivers) in order to understand which of the pre-established rules in the general norms apply at that moment. This first assessment indicates the priorities

and/or restrictions regarding the usage of different water sources, as well as the possible constraints on demand. Based on this framework setting, the current situation can begin to be evaluated.

2. **Assessment of available natural inflows**. Based on the streamflow gauge records, the amount of current unregulated river flows is estimated and future quantities are estimated based on the meteorological forecasts. The objective is to prioritize and maximize the use of these naturally-occurring unregulated flows so as to save the water stored in the reservoirs for times when the river flows are insufficient to meet the demands, and minimize alternative resources usage (e.g., desalination) since its production represents a significant economic cost.
3. **Assessment of available alternative resources**. Evaluation of the availability of alternative sources (from desalination plants or regenerated resources) as potential additional sources.
4. **Computation and estimation of demand**. Current demand is calculated based on real-time records, if available, and/or estimated data (for example, based on river reach water balances) and the short-term demand is estimated from the information provided by the users as well as the expert user experience (reproducing behaviours from similar past situations)
5. **Comparison of supply and demand**. At this point, the total contributions amount (regulated, unregulated and alternative sources) is compared to demand, both for the current moment and the short-term (corresponding to the travel time between the source and usage points):
    a. If the available supplies are superior to the demand, then the regulated water releases and alternative source supply contributions should be reduced.
    b. If the available supplies fail to satisfy demand, more resources must be introduced into the system, from sources that correspond to the location of the demand, distribution network constraints, and the general rules that are in force. It should be noted that in this case, the balance between the Ter and Llobregat rivers must be examined to ensure that the state of water usage in the two systems remains even.
6. **Environmental constraints consideration**. It is possible that given a situation in which the unregulated flows were sufficient to cover the total consumptive demand, that only considering this need, that no regulated water releases would be required. However, in such cases, the environmental flows, which vary according to river reach sections, must be considered. Depending on the scenario in which the system is in, the time of year, and the flows that remain in the rivers after the water abstractions are made, it is possible that a minimum regulated flow release may be required in order to ensure that the environmental flow requirements are respected at all times.

7. **Determination of the quantity and source for additional water needs**. Once the above aspects are analysed, the amount of additional water required to meet demand is determined, as well as from where this water should be obtained.

Figure 21 presents in a schematic form, the flow sequence of decisions and steps involved in ensuring that the water supply and demand are matched in the Ter-Llobregat system, each day.

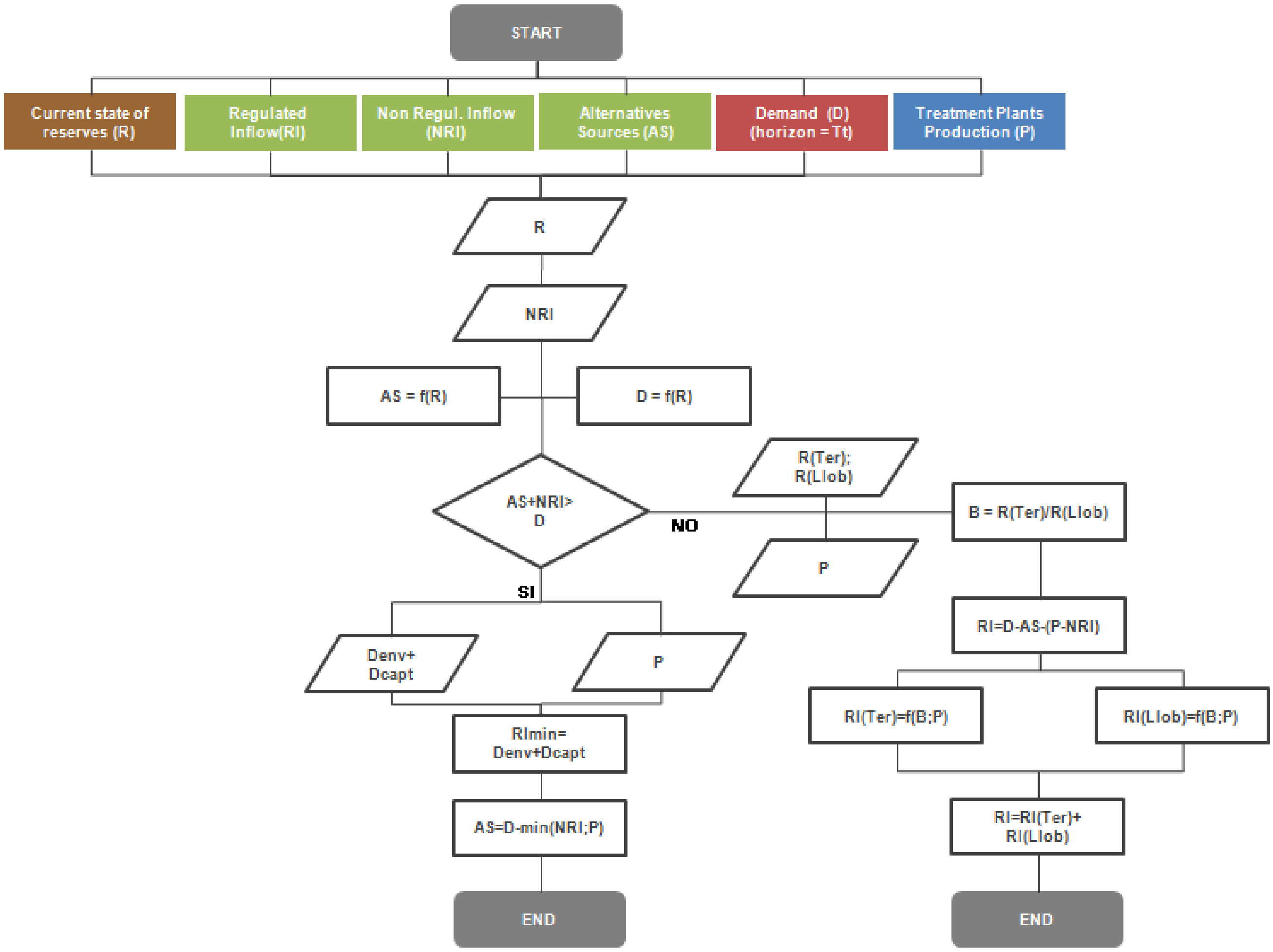

Figure 21 "Flowchart of the daily management of the Ter-Llobregat water supply system"

3.4.1 Spatial and Temporal Scales

The Ter-Llobregat water supply system involves two different management time scales. On the medium to long term, ACA makes 6-month agreements with the various users regarding the maximum volume that ACA can guarantee each user, based on forecasted water reserve estimates. However, at the operational short-term scale, the reservoirs and the distribution system are managed on a daily basis (see *Table 2*).

Spatial scale	Temporal scale
Upper part of the distribution system	Seasonal - monthly and daily

Table 2 "Spatial and temporal scales in the Spanish pilot case"

3.4.2 Potential System Users

The following table presents the potential WatERP system users for the Spanish pilot case (see *Table 3*). These potential users have been discovered taking into account the water management organizations (ACA and disaggregated organizations to manage water at different levels) and the water uses described in *Section 2.1*.

Users	Yes/No
Authorities	Yes
Utilities	Yes
Agricultural communities	Yes
Industries	Yes
Hydroelectric power producers	Yes
Municipalities	Yes
General Public	Yes
Recreational users	Yes

Table 3 "Potential WatERP system users in the Spanish pilot case"

3.4.3 Available Data

Available data in the Ter-Llobregat pilot case relevant to water supply management is presented on *Table 4*. The available data are organized according to the proposed logical model categories and the system that store the information (source of the information).

Category	Variable	Unit	Frequency	Source
SOURCE	Precipitation	mm	daily	SIX
	Runoff	hm3	15 days	Excel
	Desalinated water production	m3/s	daily	SIX
	Transfer flow (Ter->Llob)	m3/s	daily	SIX
TRANSPORT	River flow	m3/s	daily	SIX
STORAGE	River water level	m	daily	SIX
	River flow	m3/s	daily	SIX
	Reservoir water level	m	daily	SIX
	Reservoir water volume	hm3	daily	SIX
	Reservoir inflow	m3/s	daily	Excel
	Reservoir outflow	m3/s	daily	SIX
	Groundwater level	m	daily	SIX
	Groundwater volume	m3	monthly	GAC model
TRANSFORMATION	Treatment plant inflow	hm3	daily or weekly	SIX
			monthly	Excel
SINK	Irrigation diversion water level	m	daily	SIX
	Irrigation diversion rate	m3/s	daily	SIX
	Irrigation water use	hm3	15 days	Excel
	Domestic + industrial water use	hm3	15 days	Excel
	Environmental water use	hm3	15 days	Excel
	Recreational water use	hm3	15 days	Excel

Table 4 "Available data in the Spanish pilot case"

3.5 Karlsruhe Pilot

Similar to the ACA pilot, in the case of the Karlsruhe pilot, a functional model is presented in *Section 3.5.1*. This functional representation of the scenario is accompanied by the decisions and rules that an expert user makes in day-to-day situations (see *Section 3.5.2*), the users involved in the decision making process over the German pilot (see *Section 3.5.3*), and the available data that supports the optimal decisions and rules (see *Section 3.5.4*)

3.5.1 Simplified Logical Model

Figure 22 presents a simplified schematic, using a logical model, of the Karlsruhe water supply distribution system.

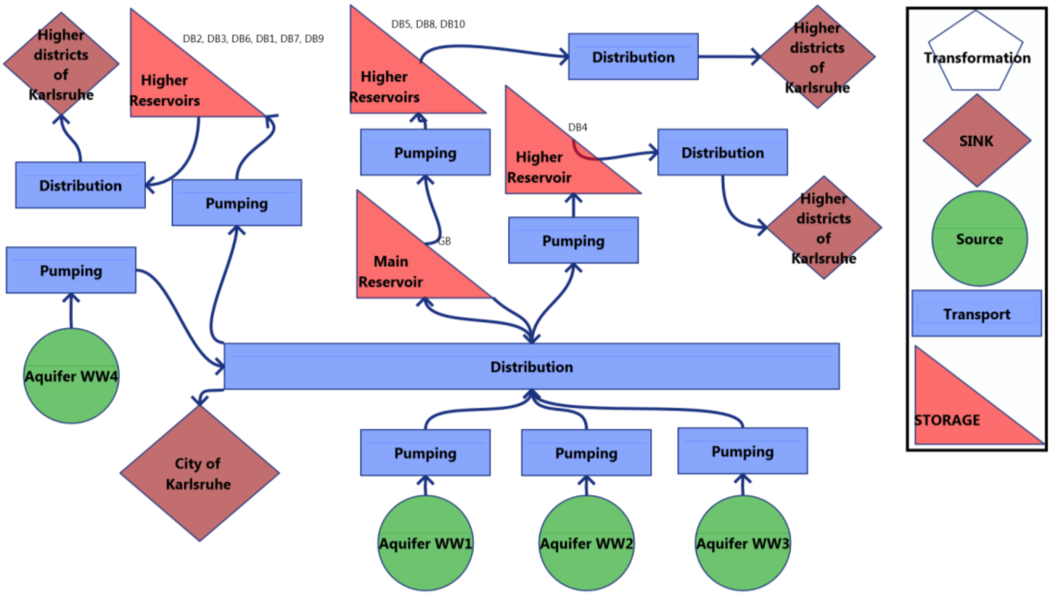

Figure 22 "Simplified logical model of the Karlsruhe water supply system"

Given the fact that energy consumption is not currently considered by the operators of the Karlsruhe water works, it is not possible to summarize the expert user decision processes that take place relative to this problematic. However, according to SWKA, minimizing energy consumption and losses within the water supply distribution chain would require combining a numerical hydraulic model of the distribution network with an optimization algorithm. The developed optimization model could then be used not only to calculate the ideal pumping schedule for the next day, but also to evaluate a possible change in the infrastructure of the distribution network (e.g., different, rpm-controlled pumps).

While improving pumping efficiency can result in important energy consumption reductions, selecting the optimal pumps according to the expected performance requirements and then maintaining their optimal performance is very difficult to achieve and requires dynamic optimization of the pump scheduling to maintain the greatest efficiency level possible under changing diurnal and seasonal water demand patterns(Bunn, S.M. and Reynolds, L., 2009). Efforts have been made during recent years to develop pump efficiency improvement techniques using real-time dynamic optimization technologies and data-mining techniques and several products have been generated, although their usage is not widely disseminated. Several commercial products have been developed by Derceto Ltd such as *Derceto*, an online pump schedule optimisation tool and which has been used in combination with EPANet[2] in Wellington Regional Council's Wainuiomata-Waterloo water distribution network in Australia

[2] EpaNET Software Web Page: http://www.epa.gov/nrmrl/wswrd/dw/epanet.html

and Aquadapt™[3], an automated pump-scheduling system which has been successfully applied in four different locations in the United States(Bunn, S.M. and Reynolds, L., 2009).

Although energy consumption is not optimized yet, several decisions and rules are implemented in order to maintain a correct performance of the SWKA system. *Figure 23* represents the main rules obtained from SWKA scenario aligned with the water distribution over the city of Karlsruhe (see also *Section 2.2.2*).

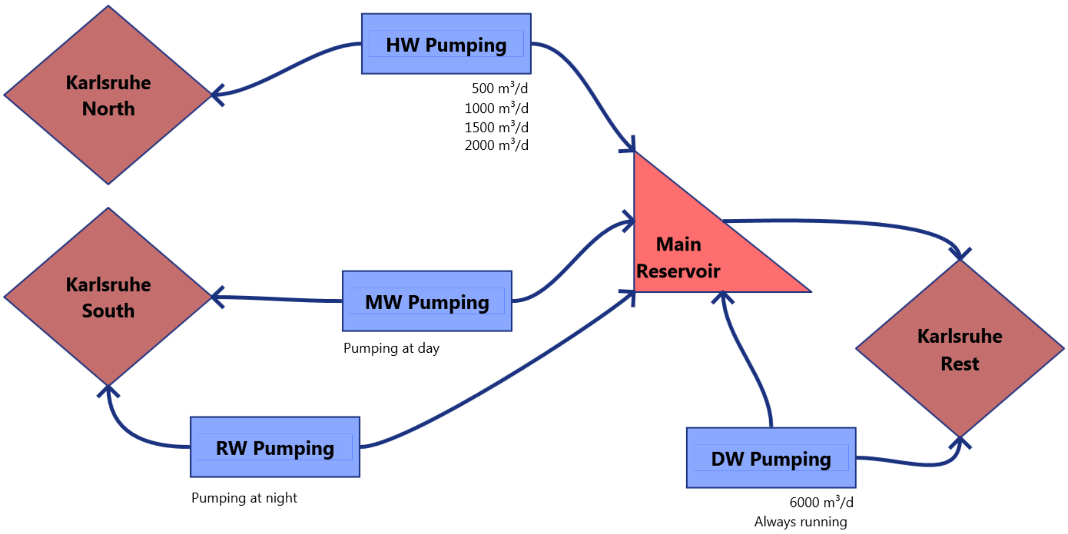

Figure 23 "Entities of SWKA model"

3.5.2 Spatial and Temporal Scales

The temporal scale involved in the Karlsruhe water supply operations (see *Table 5*) is hourly to daily.

Spatial scale	Temporal scale
Lower part of the distribution system	Daily to hourly

Table 5 "Spatial and temporal scales in the German pilot case"

3.5.3 Potential System Users

In the Karlsruhe water supply system users involved in the decisional process are presented in *Table 6*. The potential users have been identified from the information presented in the *Section 2.2*.

[3] Decreto Aquadapt Web Page: http://www.derceto.com/Products-Services?page_id=12

Users	Yes/No
Authorities	No
Utilities	Yes
Agricultural communities	No
Industries	No
Hydroelectric power producers	No
Municipalities	No
General Public	Yes

Table 6 "Potential WatERP system users in the German pilot case"

3.5.4 Available Data

Available data in the Karlsruhe pilot case relevant to water supply management and organized according to the proposed logical model categories is presented in Table 7. Also presented in the table are the systems that provide the data (source information).

Category	Variable	Unit	Frequency	Source
SOURCE	Groundwater level (60 extraction wells)	m	1-minute	GW-Base 8.0
	Groundwater level (200 monitoring wells)	m	weekly	GW-Base 8.0
	Groundwater pumping rates	m^3/h	1-minute	FDWH
	Energy consumption (sum for each water work)	A	3-minute	FDWH
TRANSPORT	Pumping flow rates (towards supply network and for filling smaller reservoirs)	m^3/h	1-minute	FDWH
	Electric current to each pump in distribution network	V	1-minute	FDWH
	Pressure within water distribution network (15 different locations)	Pa	1-minute	FDWH
	Flows within the water distribution network (computed)	m^3/h	3-minute, 15-minute and 1-hr	FDWH
	Cumulative value of flows within the water distribution network (computed)	m^3	3-minute, 15-minute and 1-hr	FDWH
STORAGE	Reservoir water level	m	1-minute	FDWH
	Reservoir inflow	m^3/h	1-minute	FDWH
	Reservoir outflow	m^3/h	1-minute	FDWH

TRANSFORMATION	Outflow of each groundwater well to the treatment	m^3/h	1-minute	FDWH
	Flow through each treatment filter	m^3/h	1-minute	FDWH
SINK	Water consumption (computed)	m^3	daily	FDWH
	Water consumption at the building level (manual totalizers)	m^3		SAP system
	Water consumption by external distribution networks (manual totalizers)	m^3		SAP system

Table 7 "Available data in the German pilot case"

4. Analysis of Water Ontologies

In this present section, an analysis of current ontologies used in the water field is performed. The ontologies selected for the analysis are those which attempt to represent the knowledge of hydrologic cycles. For this analysis, ontologies related to the hydrologic cycle have been selected because of the lack of ontologies that represent the water supply distribution chain. Furthermore, this analysis covers ontologies that have been created by representative organizations such as the OGC, National Aeronautics and Space Administration (NASA) or World Wide Web Consortium (W3C). These ontologies are widely linked (mappings) or used by scientists and knowledge engineers in order to standardize concepts between different fields (or used in a unique way). Ontologies developed by representative water organizations and researchers such as Consortium of Universities for the Advancement of Hydrologic Science (CUAHSI) (Open Geospatial Consortium Inc., 2010) and Towntology & hydrOntology (Vilches-Blázquez, Bernabé Poveda, Suárez-Figueroa, & Rodríquez Pascual, 2007) have also been included. It should be noted that ontologies that are related to model construction in the water field were not included because water modeling is not the scope and objective of this project. The WatERP ontology tries to collect water supply management related information in order to make sense and knowledge. Knowledge is generated in the form of alerts and recommendations over the process studied (e.g., water demand, water supply, phenomena, observations, etc).

The analysis over the standard ontologies (see *Table 8*) covers *(i)* a brief general description of the organization that created each ontology; *(ii)* a description of the ontology including aspects such as implementation language, description logic used, size (viewing as a number of concepts, properties and axioms) and a brief summary of aspects defined inside the ontology; *(iii)* an identification of the main benefits and weaknesses of each ontology from the WatERP and knowledge engineer point of view; and *(iv)* a brief description of the projects and/or organization for which the ontology was designed.

Finally, *Table 8* provides a summary of the ontologies analyzed according to the main categorization aspects.

Ontology Features	CUAHSI	SSN	SWEET	Towntology & hydrOntology
Size	6500 concepts	41 concepts and 39 properties	200 Ontologies and 6000 concepts	150 concepts, 34 relations, 66 attributes and 256 axioms
Language Used	OWL	OWL2	OWL2	OWL
Description Logic	$\mathcal{ACL}$	$\mathcal{SHI}$	$\mathcal{SHOI}$	$\mathcal{SHIN}$
Ontologies Imported	Sub-ontologies that are developed in CUAHSI framework	DUL		
Ontologies Mapped		SKOS and Marine Data Interoperability Ontology		

Table 8 "Summary of Ontologies Analyzed"

4.1 CUAHSI Ontology

The Hydrologic Ontology for Discovery was developed by the CUAHSI. CUAHSI is a research organization representing more than *100* U.S. universities and international water science-related organizations. CUAHSI's mission consists of enabling the water science community to advance understanding of the central role water plays with respect to life, Earth, and society.

The ontology was designed with the single purpose of data discovery in mind. This means an adoption of a keyword structure that can organize data variables along thematic classifications going from general concepts to finer concepts. CUAHSI ontology is implemented in a multi-file Ontology Web Language (OWL) and is composed of around *6,500* concepts. The ontology analyzed follows an $\mathcal{ACL}$ description logic family.

The ontology (*Figure 24*) has been subdivided in *3* layers called Navigation, Compound and Core/Leaf. The top level called "*Navigation*" (most general layer) is the ontology backbone that hosts the root concept "*HydroSphere*". The "Hydrosphere" concept provides a first classification including elements taking account location or place ('Where' divisions) such as land, atmosphere, surface, groundwater, etc. Also, the "*Hydrosphere*" concept classifies concepts related to elements or resources ('*what*' divisions) such as water/soil quality and more.

The next layer is the "*Compound*" layer which focuses on the nature of the resources rather than location (more emphasis on "*what*" rather than "*where*"). In this level, concepts such as "*Physical parameters*", "*biological parameters*", etc; are defined.

The last layer of the ontology is the "*Core*" or "*Leaf*" layer which consists of all of the concepts at the end of any branch in the ontology. It has by this definition only one concept for each end of a branch, and represents a concept that is quite specific, i.e., specific enough that it can be used to tag (or register) a variable name with it.

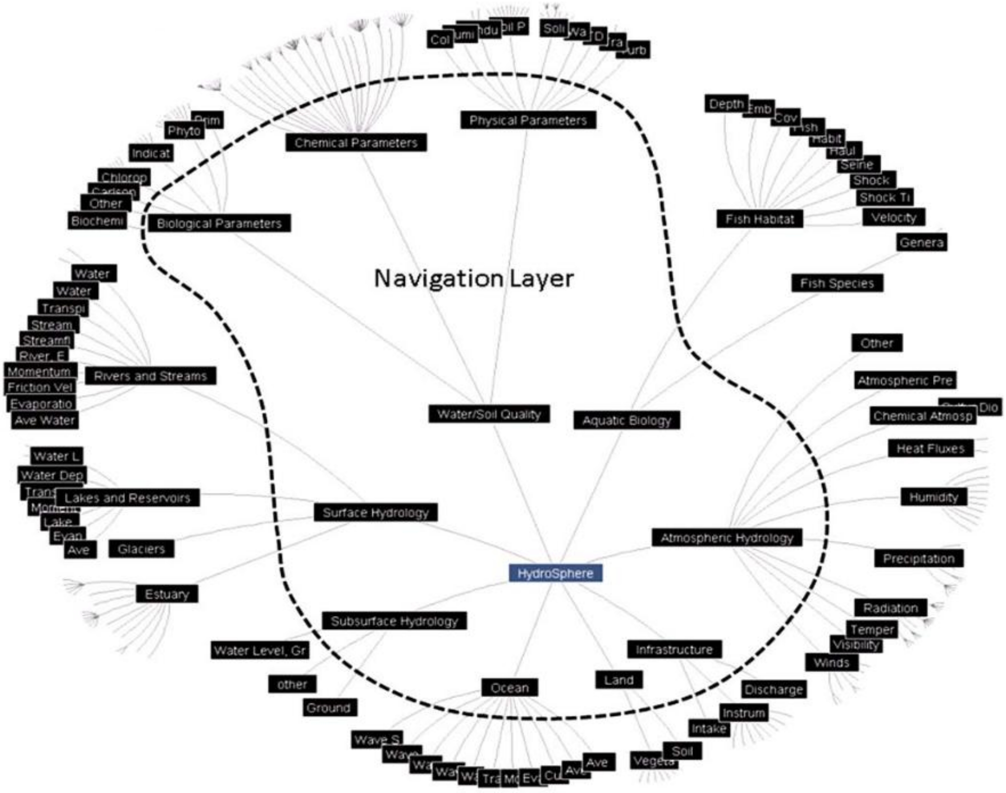

Figure 24 "Hyperbolic Star Tree visualization of the top layer of the Hydrologic Ontology for Discovery"

The ontology was developed when CUAHSI had to compile a national water information catalogue. The catalogue had to incorporate information from numerous and disparate water databases, so CUAHSI realized that an ontology was needed to clarify and standardize concepts and keywords. This is the most common problem in water information sharing - the need for understanding and interoperability. Consequently, CUAHSI developed the "*Hydrologic Ontology for Discovery*" in order to support the discovery of time-series data collected at a fixed point, including physical, chemical, and biological measurements. These time-series could then be served on WaterML (Water Markup Language) which defines an information exchange schema that attempts to be interoperable. WaterML2 which is the current OGC standard for water information interoperability and which was developed as a continuation of WaterML, will serve as a base for the WatERP ontology.

The main weakness of the CUAHSI ontology (*Table 9*) is that it was developed only to discover data and covers only the hydrologic aspects of the water information cycle. Also the ontology does not have properties defined so it has low expressiveness and all the connections are parent to child such that no knowledge can be inferred. Finally, there is no disjoint defined between classes so an instance could be located in two classes and this is a source of inconsistency.

Benefits	Weakness
Defined by CUAHSI consortium	It does not have enough expressiveness because it does not have properties
Complete and detailed entities	All the connections are parent to child thus no knowledge coud be inferred
Strongly interconnected with WaterML	There is not disjoint defined between classes so an instance could be located in two classes and this is a source of inconsistency
	Ontology used to discover information and to provide the basic semantic.

Table 9 "Analysis of CUAHSI Ontology"

It should be remarked that the CUAHSI ontology has been included into the OGC as a tentative standard in the architecture of the environmental field.

4.2 Semantic Sensor Net (SSN) Ontology

The SSN Ontology (Compton, et al., 2012) has been developed by a group of the W3C called Network Incubator Group. This group has the aim of explore activities on emerging Web-related concepts, guidelines or activities.

The SSN Ontology (*Figure 25*) is focused on describing *(i)* the capabilities and properties of sensors, *(ii)* the act of sensing and *(iii)* the results provided by observation processes. The ontology has been implemented and developed in OWL2 language. With regards to the ontology expressiveness, the ontology follows the $\mathcal{SHI}$ family description. The SSN ontology has been divided into *10* modules and consists of *41* concepts and *39* properties. As showed in *Figure 25*, the ontology has been constructed over a central node called "*Stimulus-Sensor-Observation (SSO) pattern*". This module is in charge of the process of sensor behavior and information collection. This module is interconnected with: *(i)* the "*Device" and "System*" module to represent physical sensor/system that initiates the process of sensing; *(ii)* the "*Process*" and "*Operating Restriction*" module to describe more in detail the process of sensing (e.g., indicate if the process is an input/output or whether the process has some operating restriction); *(iii)* "*Data*" to categorize observations values; *(iv) the* "*Measuring Capability*" and "*Constraint Block*" module in order to associate to a sensor (or sensing process) a measurement capability. Also, this module associates measures the conditions needed in the observation process (and feature of interest observed).

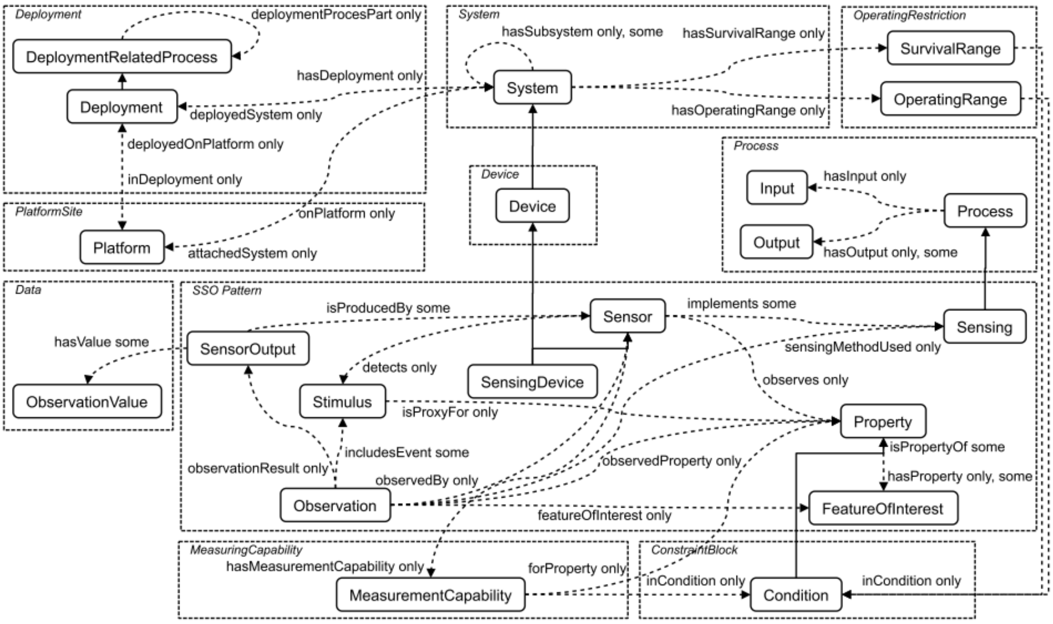

Figure 25 "SSN Ontology Schema (Compton, et al., 2012)"

The analyzed ontology tries to overcome gaps that occur nowadays in semantic sensor web (Corcho & García-Castro, 2010) with regards to: *(i)* data provenance through definition of models, methods, measures and metrological definition (e.g., precision, measurement range, etc); *(ii)* data discovery and the improvement of abstraction and perceptions through the linkage with Linked Open Data Cloud (LODC) and other standards ontologies such as DUL, SKOS thesaurus and Marine Metadata Interoperability[4] (MMI) Ontology.

The SSN ontology has the benefit of providing strong entities and definition supported by other representative ontologies. Also, the SSN ontology has been developed with the idea of working with the Open Geospatial Consortium. This ontology links concepts and properties with corresponding fields in Sensor Markup Language (SensorML) language defined for exchange information with OGC elements (Observation and Measurement Service). As another benefit, the SSN ontology permits an enrichment of the ontology during its use. This means that the restrictions over observations values, properties sensed etc; is done at the same time as ontology specification (or population process including as new axioms).

In contrast, the SSN ontology has as a weakness the fact that the measurement entity is not linked with any organization, consortium or ontology that provides standardized measurements for the sensors. Rather, the linkage done by the ontology in the measurement aspect is related to the definitions of the entities Precision, Response Time, Sensitivity, etc. Furthermore, the ontology does not have the

[4] https://marinemetadata.org/node

concept “Phenomena” that has been included into the latest version of the WaterML2 language. The phenomena in the WaterML2 language describe the process to be observed (e.g., Water Temperature, Water Rate). The phenomena concept also gives more description to the process of sensing (observation and features of interest).

Benefits	Weakness
Supported by representative organism W3C, OGC and Kno.e.sis	Lack of measurement standardizations. Useful a linkage with NIST and/or SWEET.
Aligned with OGC standards (SensorML modelling)	“Phenomena” concept is not clarified (aligned with “Property” concept that forms an “Observation”).
Enrichment of the ontology in use-time	
Enhancement of Data Provenance	
Mappings with DUL, SKOS and Marine Data Interoperability Ontology to improve data abstractions	

Table 10 "Analysis of SSN Ontology"

Finally, the SSN ontology is used by representative organizations such as Open Geospatial Consortium (OGC), Kno.e.sis Center and World Wide Web Consortium (W3C). Moreover, the ontology also has been used in European Projects such as SENSEI (FP7-215923) and SPITFIRE (FP7-258885).

4.3 SWEET Ontology

The Semantic Web for Earth and Environmental Terminology (SWEET)[5] Ontology (Raskin & Pan, 2003) has been developed by NASA’s Jet Propulsion lab for Earth system science. This group has the aim of explore activities related to emerging Web-related concepts, guidelines or activities.

The aim of the analyzed ontology is to minimize the existing gap in the semantic understanding of the Earth science (Raskin & Pan, 2003). *Figure 26* depicts the understanding of the integrated Earth system and its components. The ontology has been implemented and developed in OWL language. With regards to the ontology expressiveness, the ontology follows the $\mathcal{SHOI}$ family description logic. The SWEET ontology is highly modular with *6,000* concepts in *200* separate ontologies. As showed on *Figure 26*, the ontology has been constructed over eight top-level ontologies: *(i)* Representation; *(ii)* Process; *(iii)* Phenomena; *(iv)* Realm; *(v)* State; *(vi)* Matter; *(vii)* Human activities; and *(viii)* Quantity.

---

[5] http://sweet.jpl.nasa.gov/

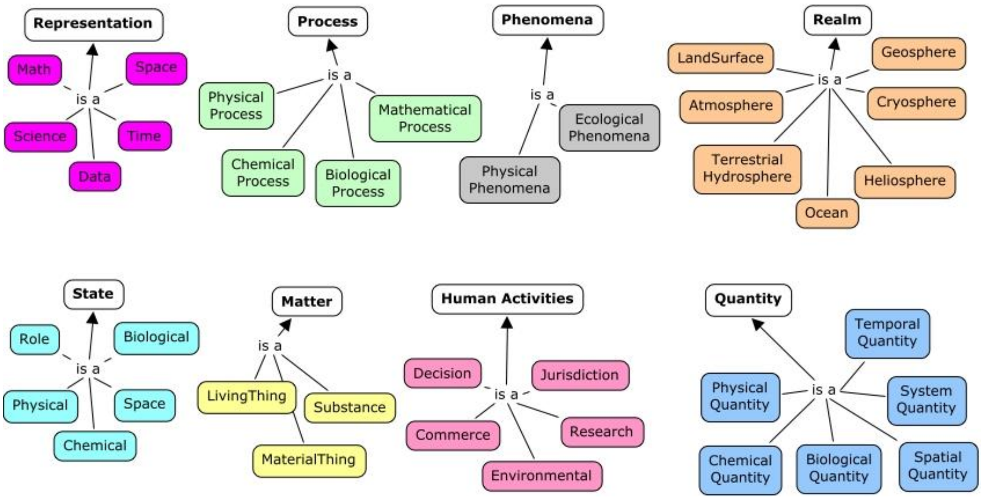

Figure 26 "SWEET Ontologies Architecture"

The benefits that the SWEET ontology can provide are detailed below and summarized in *Table 11*. A remarkable benefit is the organization of the SWEET ontology. NASA, a relevant association in the technological world, was involved in its development. Given its reputation, this organization provides some assurance regarding the content of the ontology. Furthermore, the ontology has been developed following an orthogonal design, which helps in quick retrieval of knowledge and is therefore more efficient. Moreover, the orthogonality ensures more benefits like re-usability. Another point to remark is that the ontology content structuring has been based upon the inherent knowledge of the discipline, rather than on how the domain knowledge is used. Thanks to this, the ontology is general and is not specific to a concrete project. Also, due to its generality, the SWEET ontology is more reusable. It may also be noted that the hydrographic cycle is defined to a high level and involves a categorization of cycles (see *Figure 27*). As a last remark, this ontology is frequently used to represent scientific concepts.

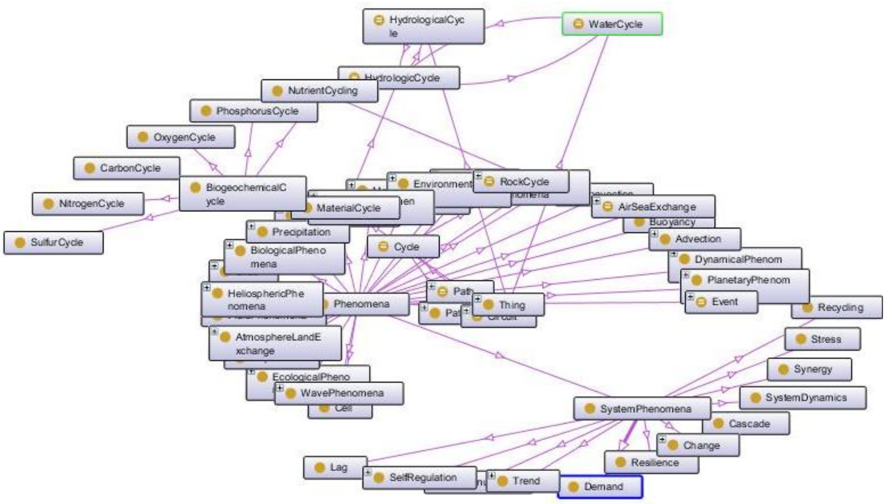

Figure 27 "SWEET-Hydrological Cycle Overview"

On the other hand, the SWEET ontology has several weaknesses from the ontological point of view and with respect to the WatERP project needs. First, the concepts or terms used in the ontology are populated with instances. Due to this instantiation, the ontology is heavy and has high memory consumption. Another detected weakness is that the ontology is ambiguous and its content is depicted at a high level. That is, the detail level is minimal in scope with respect to the hydrographic cycle. Finally, the ontology cannot handle sensor observations.

Benefits	Weakness
Defined by a relevant association	Heavy ontology
Orthogonal design	Ambiguous and high level ontology
Based upon the inherent knowledge of the discipline	Sensors are not characterized
Hydrographic cycle is defined	
Widely used to represent scientific concepts	

Table 11"SWEET Ontology Analysis"

The SWEET ontology is used by several projects and/or associations. For instance, the MMI project has included it into the repositories. The main reason to include it is to promote the exchange, integration and use of marine data through enhanced data publishing, discovery, documentation and accessibility. Another project is GEON[6] (GEOsciences Network) which is an open collaborative project that is developing cyber infrastructure for integrating *3* and *4* dimensional earth science data. Finally, the IRI (International Research Institute for Climate and Society) uses a science-based approach to enhance society's capacity to understand, anticipate and manage the impacts of climate. All of these aim to improve human welfare and the environment, especially in developed countries.

4.4 Towntology & hydrOntology

The Towntology & hydrOntology (Vilches-Blázquez, Ramos, López-Pellicer, Corcho, & Nogueras-Iso, 2009) are two linked ontologies which have been developed by a semantic group of the Universidad Politécnica de Madrid. The semantic group of the Universidad Politécnica de Madrid is one of the major references in ontological design and development. They have created ontology development methodologies (METHONDOLOGY and NeoN). Moreover, they have been modeling knowledge domains such as Chemistry, Science, Knowledge Management, e-Commerce, etc.

Towntology & hydrOntology (see *Figure 28*) is focused on characterizing aspects of city planning, including aspects of water infrastructures and hydrographic phenomena in urban landscapes. Initially, these ontologies were developed to support Urban Civil Engineers in urban design and planning. However, hydrOntology has become an ontology of global domain that tries to cover concepts of the hydrographic domain. This ontology has been developed in OWL language. With regards to ontology

[6] http://www.geongrid.org/index.php

expressivity, the hydrOntology follows $\mathcal{SHIN}$ description logic family. The hydroOntology has been written in Spanish language. It is comprised of *3* main entities that cover a total of *150* concepts related to the hydrological field. These *150* concepts have defined *34* relations (properties), *66* attributes and *256* axioms. As mentioned, the ontology has been built based on three main classes: *(i)* "*Cuenca fluvial*" (trans. "*River Basin*") defined as the drainage area that feeds a river; *(ii)* "*Fenómeno hidrografico*" (trans. "*Hydrographic Phenomena*") that is defined as an abstraction of a set of water that a country or region is conformed and structurally configured; *(iii)* "*Morfología*" (trans. "*Morphology*") that is an aggregation of objects aligned with the change that water entities undergo.

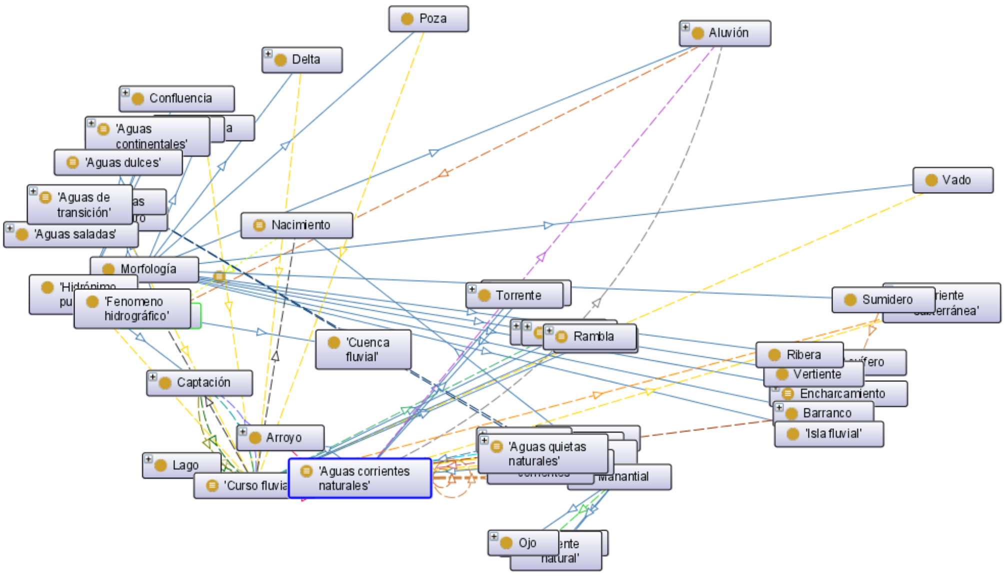

Figure 28 "hydrOntology overview"

The analyzed ontology has the benefits of modeling urban infrastructure in order to represent water supply, distribution and treatment elements. With regards to this aspect, environmental concepts (rivers, lakes, etc) have been linked with artificial concepts related to water supply (piping, sewer system, etc). Another benefit is the rich expressivity supported by the ontology. In this ontology, properties have been defined (functional, transitive, inverse, etc), as well as axioms (closure axioms, concept definition, etc) and restrictions (nominal restrictions based on property usage). Furthermore, the elements and concepts has been defined using definition from representational organisms such as National Spanish

Institute of Geographic[7] (IGN-E), Defence geospatial Information Working Group (DGIWG) and Water Framework Directive[8] (WFD).

On the other hand, hydroOntology's weakness is that it focuses on developing state of the ontology that is not fully completed. With regards to this aspect, the ontology has been focused on a small part of the water supply distribution chain. Also, the ontology has been based on national (Spanish) scenario where all needed elements for this specific case have been defined. Finally, as the authors mention in (Vilches-Blázquez, Bernabé Poveda, Suárez-Figueroa, & Rodríquez Pascual, 2007), the ontology needs an improvement over ontological resources such as properties, rules and axioms. This enhancement of ontological elements is related to the need for more ontological mappings. In this aspect, ontology mappings must be done including different knowledge sources such as Digital Alexandria Library or UNESCO thesaurus.

Benefits	Weakness
Alignment between hydrologic and Civil Engineering field.	Ontology is not fully developed.
Modeling of Urban infrastructure for water supply, distribution and clean-up.	Based on national (Spanish) scenario (Ebro river Basin)
Concepts and entities are provided by representative organisms (IGN-E, EuroGlobalMap, DGIWG group, WFD)	Short ontology and it not cover all supply chain.
Rich ontological expressiveness	Needs an improvement over ontological resources.
	Needs and enhancement of mapping with other data sources.

Table 12"Analysis of HydrOntology"

Finally, the ontology has been done under the Towntology project framework. This project is supported by the COST[9] (European Co-operation in the field of Scientific and Technical Research) in the domain of Urban Civil Engineering.

[7] Instituto Geográfico Nacional-Español (trans. "National Spanish Institute of Geographic"):http://www.ign.es/ign/main/index.do

[8] Water Framework Directive: http://ec.europa.eu/environment/water/water-framework/index_en.html

[9] COST web page: http://www.cost.eu/about_cost

5. Transformation of non-ontological resources into conceptual models and rules

In this part of the document an introduction to the transformation of WaterML2 (see Deliverable 2.1) language into an ontological resource (OWL concepts or mapping into it) is explained. As a brief description, the WaterML2 language is an eXtensive Markup Language (XML) used to exchange hydrological data. This schema has been defined by OGC as a solution that tries to harmonize previously existing standards for water observation data. A detailed overview of the WaterML2 schema can be found in (Open Geospatial Consortium Inc, 2007) and (Open Geospatial Consortium Inc., 2010).

Figure 29 shows an example of how WaterML2 performs an observation using a class diagram (UML[10]). The example refers to an observation done over "*Nile*" and "*SouthEast River*" (blue colored). Over these examples, a specific "*Observations*" has been done taking into account "*FeaturesOfInterest*" defined in the rivers. The result has been a "*Sampling Point*" or time instant ("*CV_DiscreteTimeInstantCoverage*") that covers the specifications defined ("*Observation*" and "*FeatureOfInterest*") for the element queried.

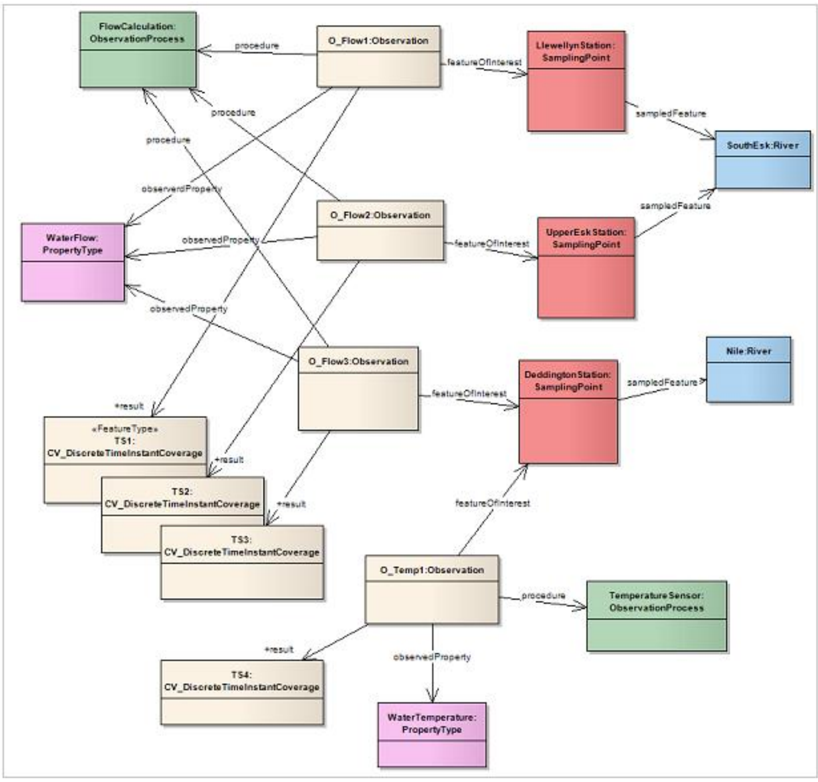

Figure 29 "WaterML2 Graphical Example (Open Geospatial Consortium Inc., 2010)"

[10] Unified Modelling Language (UML).

Figure 29 depicts the most important parts of WaterML2. However, not all relevant information is described. WaterML2 schema are encapsulated and used in Sensor Observation Service (SOS) schema ("*REQUEST*" or "*GET*" process) designed by OGC. Moreover, WaterML2 language is involved when the system generates the response to the user ("*RESPONSE*" process), as a mechanism to share observed water data.

Figure 30 depicts the SOS REQUEST process. In this specific example, most of the parameters that can be included in a SOS request are shown. Thus, when a SOS makes a petition of information (e.g., water time series), it can be structured by:

- **Procedure** that in the example is represented by a sensor (can be also an instrument, algorithm or process).
- **Offerings** that represent a logical name to a group of phenomena. In this specific example the offering is called "*FORECAST*" and refers to each forecasted phenomena described in the SOS system. So, the use of offerings facilitates data acquisition (if more forecast elements are included the user do not need change the petition) by the user thanks to petition encapsulation under "*FORECAST*" offering.
- **ObservedProperty** that describes the phenomena that is observed (e.g., "*um:ogc:def:phenomenon:OGC:1.0.30:obs:rain*")
- **Temporal Filter** that defined a temporal scale to describe the time interval of the values to be obtained.
- **Features of Interest** represent the element to be observed. This element is common in hydrologic observations and include points (gauging stations, test sites, etc), linear features (streams, river channels), or polygon features (catchments, watersheds).
- **Spatial Filter** represents an area of interest used as a spatial filter for narrowing a search of data.

```xml
<sos:GetObservation service="SOS" version="2.0.0" xmlns:sos="http://www.opengis.net/sos/2.0"
xmlns:fes="http://www.opengis.net/fes/2.0" xmlns:gml="http://www.opengis.net/gml/3.2"
xmlns:swe="http://www.opengis.net/swe/2.0" xmlns:swes="http://www.opengis.net/swes/2.0"
xmlns:xlink="http://www.w3.org/1999/xlink" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:schemaLocation="http://www.opengis.net/sos/2.0http://schemas.opengis.net/sos/2.0/sos.xsd">

<sos:procedure>urn:ogc:object:feature:Sensor:CHE:15111</sos:procedure>
<sos:offering>FORECAST</sos:offering>
<sos:observedProperty>urn:ogc:def:phenomenon:OGC:1.0.30:obs:rain</sos:observedProperty>
<sos:temporalFilter>
        <fes:During>
                <fes:ValueReference>phenomenonTime</fes:ValueReference>
                <gml:TimePeriod gml:id="tp_1">
                        <gml:beginPosition>2009-10-01T17:44:15.000+02:00</gml:beginPosition>
                        <gml:endPosition>2009-11-01T17:50:15.000+02:00</gml:endPosition>
                </gml:TimePeriod>
        </fes:During>
</sos:temporalFilter>
<sos:featureOfInterest>16921</sos:featureOfInterest>
<sos:spatialFilter>
        <fes:BBOX>
                <fes:ValueReference>
                        om:featureOfInterest/sams:SF_SpatialSamplingFeature/sams:shape
                </fes:ValueReference>
                <gml:Envelope srsName="http://www.opengis.net/def/crs/EPSG/0/4326">
                        <gml:lowerCorner>0 0</gml:lowerCorner>
                        <gml:upperCorner>60 60</gml:upperCorner>
                </gml:Envelope>
        </fes:BBOX>
</sos:spatialFilter>
<sos:responseFormat>text/xml;subtype="WML2"</sos:responseFormat>

</sos:GetObservation>
```

Figure 30 "WaterML2 Request format"

A real response from water data observed is showed on *Figure 31*. The response is done based on the procedure ("*urn:ogc:object:feature:Sensor:CHE:15111*") defined in the request process. The response given by the system to the user is codified in WaterML2 (*Figure 31*) and provides the value points referred to the specific request done. In the WaterML2 response file, the information included specifies the procedure observed ("*urn:ogc:object:feature:Sensor:CHE:15111*") with the observations for that procedure ("*urn:ogc:def:phenomenon:OGC:1.0.30:obs:waterlevel*") and data values referred to the procedure and observation defined. Data values are represented over a Time Period that also includes the unit of measure (e.g "*cm*"). Data values are given in "Points" format that includes "*TimeValuePair*" values (time and value) such as "*0.81*" (value in "*cm*") and "*2009-10-01T15:45:00.000Z*" (time).

Taking into account two examples viewed and the sensoring definition given in the SSN ontology (Compton, et al., 2012) and the OGC, the entities selected to be included into the WatERP ontology are: *(i)* **"*SampledFeature*"** or "Real-life Elements" that represents the real element to be monitored; *(ii)* **"*Feature of Interest*"** that defines the location and the specific structure to be monitored (e.g., location or specific station); *(iii)* **"*Observation*"** indicates the measurement of specific phenomena for a specific "*feature of Interest*" by a "*Procedure*"; *(iv)* **"*Phenomenon*"** defines the property that is measured; *(v)* **"*Procedure*"** describes how an "*Observation*" is performed (also can indicate how a sensor works); and *(vi)* **"*Offerings*"** defines a grouping of "*Features of Interest*", "*Procedures*" and/or "*Phenomena*" using a common name in order to give more accessibility to the information.


```xml
<om:procedure xlink:href="urn:CHE:id:procedure:urn:ogc:object:feature:Sensor:CHE:15111"
xlink:title="urn:ogc:object:feature:Sensor:CHE:15111"/>
<om:observedProperty
xlink:href="urn:ogc:def:phenomenon:OGC:urn:ogc:def:phenomenon:OGC:1.0.30:
obs:waterlevel"
xlink:title="urn:ogc:def:phenomenon:OGC:1.0.30:obs:waterlevel"/>
<wml2:Timeseries gml:id="time_series_dom_extend">

<wml2:domainExtent xlink:href="ts_1360688304259_dom_extend">
        <gml:TimePeriod gml:id="ts_1360688304259_dom_extend_period">
        </gml:TimePeriod>
</wml2:domainExtent>
<wml2:defaultTimeValuePair>
        <wml2:TimeValuePair>
                <wml2:unitOfMeasure uom="cm"/>
        </wml2:TimeValuePair>
</wml2:defaultTimeValuePair>

<wml2:point>
<wml2:TimeValuePair>
        <wml2:time>2009-10-01T15:45:00.000Z</wml2:time>
        <wml2:value>0.8100000023841858</wml2:value>
</wml2:TimeValuePair>
</wml2:point>
<wml2:point>
<wml2:TimeValuePair>
        <wml2:time>2009-10-01T16:00:00.000Z</wml2:time>
        <wml2:value>0.800000011920929</wml2:value>
</wml2:TimeValuePair>
</wml2:point>
```


Figure 31 "WaterML2 Response"

In order to render the ontological conversion more understandable, an example of how WaterML2 has been converted into ontological resources for both examples is showed in *Figure 32*. In this specific figure, entities discovered from the WaterML2 example including also OGC recommendations are shown. Moreover in this image, identified entities and WaterML2 information have been linked to ontological properties in order to provide a semantic layer to the information transmitted by the WaterML2 language.

In conclusion, this approach to convert WaterML2 language into ontological resources is an approach that has been included in the WatERP knowledge base. In order to clarify the linkage between WaterML2 information and the WatERP ontology, an explicit mapping will be done. An explicit mapping refers to the linkage between ontological entities (WatERP ontology) and tags of the WaterML2 (XML) schema.

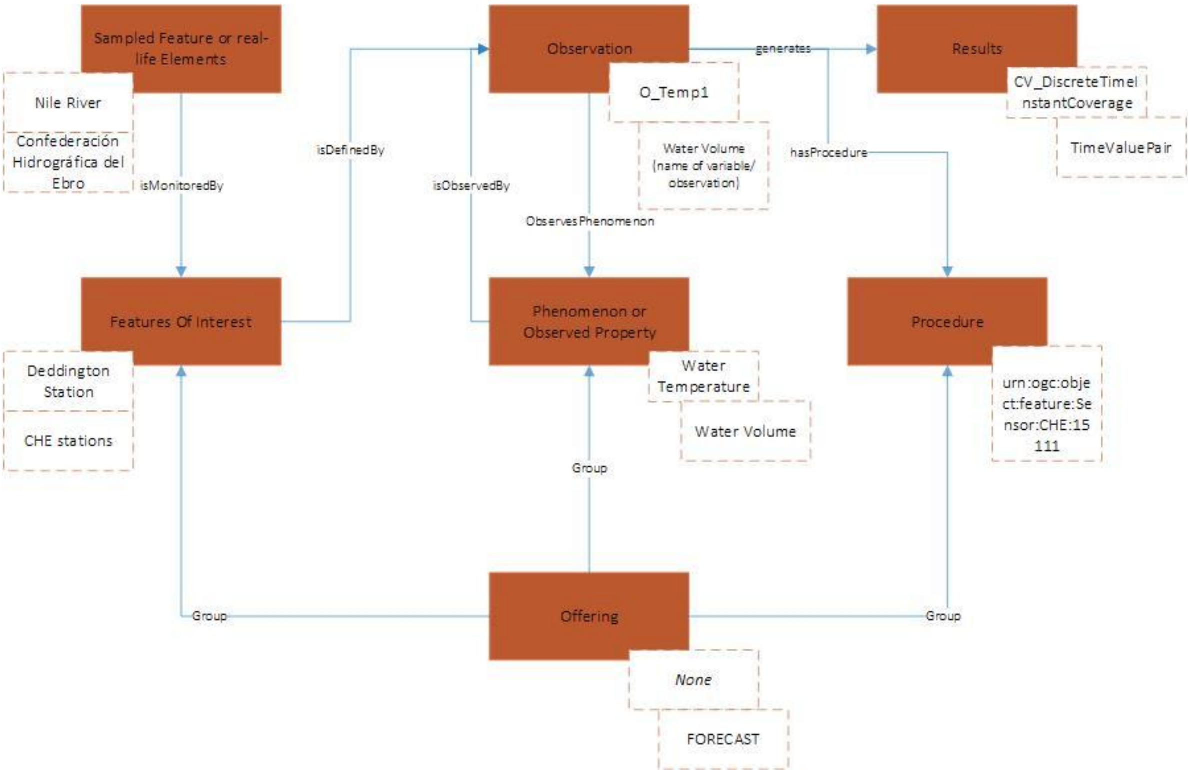

Figure 32 "Ontological resources for WaterML2"

6. Conclusions, Recommendations and Future Work

In designing the logical model for the WatERP project, a main challenge has been to discover the processes, rules and decisions that are present in the WatERP pilots. These scenarios have been categorized based on the problematic of water allocation under water scarcity (Spanish pilot) and of improving energy efficiency during water distribution (German pilot). In order to provide a better understanding of the pilots and their respective decisional needs, a description of the pilots has been provided in this document. These pilot descriptions also provide a better understanding of the processes and decisions involved in water supply management, at the more general (generic) level.

For the WatERP project, the pilots will provide the necessary detail to construct, define and design the functional model. As mentioned in the document, functional modelling is based upon decision logics, rules and processes, which for its development, will be aligned with the WatERP pilots (Spanish and German). However, these representations provide a starting point to enhance and expand the ontology towards the development of a generic ontology that will support water resources management in any scenario, and rendered accessible through an open environment (OMP).

This section provides a description of the main conclusions (*Section 3*) reached regarding functional modelling and strategies to enhance the ontology, based on the work performed to date. Although this deliverable marks the completion of this task (Task 1.3 of WatERP called "*Generic water data functional model*"), this document also presents the future research (*Section 6.2*), developments and ontology enhancement lines that could be followed during the ontology development stage (Task 1.4 called "*Generic water data Ontology*").

6.1 Conclusions

As mentioned, a significant challenge in the WatERP project consists of categorizing the identified scenarios from the pilot cases in order to extrapolate them to a generic level that encompasses all of the processes, variables and decisions that can be incurred in any water supply distribution system. In order to accomplish this task, the functional model plays an important role. In the water domain chain, a **functional model** includes the representation of a logical model with associated decisions and rules. In this perspective, the **logical model** describes how the elements interact around the water supply distribution chain. In other words, this model represents the natural water cycle elements (or paths) in conjunction with the man-made (or "*human-altered*") infrastructure elements that interact with the natural water cycle and modify the natural flows to benefit humans (via channels, pipe networks, etc).

Aligned with the representation of the functional model and it transformation into generic elements that can be included as ontological resources, the ontology analysis has been useful to discover: *(i)* the strengths and weaknesses of existing hydrological ontologies from a water resources management point of view, and *(ii)* current efforts and developments that are being made in the hydrology field.

Aligned with this second aspect, special interest in their degree of maturity and completeness has been identified for the CUAHSI and SWEET Ontology. With regards to the CUAHSI Ontology[11], this knowledge base has focused on representing **timeseries** and the associated phenomena to be observed. Special attention to this ontology requires the mechanism to collect and exchange time series compatible with the WaterML2 standard. However, the CUAHSI ontology lacks ontological expressiveness. With regards to the SWEET Ontology[12], concepts (and processes) are related to **earth sciences**. While this ontology has a section for hydrological processes and specifically to model the water cycle, it has a relatively small level of detail for the specific needs of the WatERP pilots and is also very focused on existing data exchange and relationships.

In spite of their limitations, these existing ontologies have been helpful for defining the WatERP logical model. Specifically, the strengths of these ontologies in sharing information and modeling natural cycles have been used. However, the main improvement that is being made over these existing ontologies, in the context of the WatERP project consists in combining the natural water cycle with the "human-engineered" systems that monitor, control and manage water resources throughout water supply distribution chains.

Upon examination of the WatERP scenarios (Spanish and German) functional modeling, some difficulties have appeared with regard to *(i)* the high complexity of the scenarios from a hydrological point of view; and *(ii)* the necessity to merge the hydrology and Information and Communications Technology (ICT) fields using common representational modeling language. At this point, UML language has been discarded due to its difficulty of understanding outside the ICT field.

In order to solve the problems addressed in the WatERP project, a functional modeling language has been developed. Functional modeling represents the involved elements or systems (ontological entities) and the relations between systems categorized in "flow-level" and "management-level" (ontological properties). Thus, using this modeling language adapted to the WatERP project, support to the ontology development is provided. The ontology enhancement has been done in two ways: *(i)* taxonomical level by identifying concepts/entities; and *(ii)* semantic level by enhance the properties, rules and axioms of the ontology.

In summary, functional modelling representation applied to the WatERP pilots creates a bridge between hydrological and ICT filed. This means, this kind of modelling permits defined hydrological entities to be related to one another with the aim of linking the model to an ontological source. The functional modelling serves as a point to enhance the general ontology (WatERP ontology). Furthermore, the functional model permits discovering and knowing the instances related with each scenario, followed by the development of the ontological population process (specific pilot WatERP ontological scenario).

---

[11] CUAHSI Ontology link: https://svn.sdsc.edu/repo/WATER/CUAHSI/OntologyOwl/StarTree_Current/ontology/

[12] SWEET Ontology link: http://sweet.jpl.nasa.gov/ontology/

6.2 Future Research

Despite the fact that Task 1.3 concludes with this present deliverable, the project continues with the knowledge base development. Future work will be focused on continuing with the ontology development including functional modeling aspects, and also translating the main non-ontological resources (schemas) into the ontology.

With regards to the ontological enhancement by the inclusion of functional models, the next steps consist of adding the relations between entities discovered in the functional models into the taxonomy. This means, starting with the creation of the fist version of the ontology. Related with the ontological properties definition, special attention is needed in the definition of ontology properties related to the human-engineered hydrological cycle components. In addition, more efforts are needed regarding: *(i)* the time-frame of the decision-making processes definition when the model is extrapolated to generic case; and *(ii)* enhancing the categories that are associated with the "*human-altered*" hydrological cycle elements depending on the specific perception. The perception concept refers to the situation of different entity behaviors depending on the manager's point of view, time-frame or location.

With regards to the translation of non-ontological resources (structured schemas) into the ontology, short-term work will be focused on including WaterML2 relations into the taxonomy. Along this line, ontological entities related to the WaterML2 schema have been included in the taxonomy. In a more mid(long)-term, the incorporation of "*HY_Features*" into the ontology (currently in draft version) will be studied. The "*HY_Features*" (Open Geospatial Consortium, 2012) is a development promoted by the World Metereological Organization (WMO) and the Open Geospatial Consortium (OGC). From (Open Geospatial Consortium, 2012) the scope of this class is: "*The HY_Features model is intended to provide a hydrology domain-specific instance of the GF_GeneralFeatureType metaclass, the HY_HydroFeature. The class is intended to provide a realization of the GFI_DomainFeature, as currently required by the ISO 19156 Observation and Measurements model (O&M). Specifically, this is expected to provide a model for use in applications of WaterML 2.0 Implementation Profile of O&M. Further clarification regarding the role of the OGC in governance, integration and binding of individual domain models and related controlled vocabularies is required in order to address how the model may be used by the stakeholder community*". So, the "*HY_Features*" will be useful in the WatERP project in order to provide a standardized mechanism for interoperability in accordance with the evolution of the OGC-SOS system (called Observation and Measurement) and hydrological field.

As a conclusion, further developments and actions will be linked with the Ontology development in each iteration (Work Package 1), Water Data Warehouse design (Work package 3), Decision Support System (Work Package 4), and Open Management Platform design (Work Package 6).

7. References

ACA. (2012). Comissió ordinària de desembassament - Octubre 2012, water supply management Excel spreadsheets, Ter and Llobregat river flow data, and daily water consumption records.

ACA. (2008). Water in Catalonia. Diagnosis and Proposed Actions.

ACA. (2013). WP5 Pilots Description Annex 1 ACA.

Bunn, S.M. and Reynolds, L. (2009). The energy-efficiency benefits of pump scheduling optimization for potable water supplies. *IBM Journal of Research and Development* , Vol. 53, No. 3, Paper 5.

Compton, M., Barnaghi, P., Bermudez, L., García-Castro, R., Corcho, O., Cox, S., et al. (2012). The SSN ontology of the W3C semantic sensor network incubator group. *Elseiver , 17* (0), 25-32.

Corcho, O., & García-Castro, R. (2010). Five Challenges for the Semantic Sensor Web. *Journal on Semantic Web , 1* (1-2), 121-125.

Este, L. I. (2011). LA Lore Ipsiunm. *Lorem Journal* , 30-34.

Harou, J.J. et al. (2010). An open-source model platform for water management that links models to a generic user-interface and data-manager. *International Environmental Modelling and Software Society, 2010 International Congress on Environmental Modelling and Software Modelling for Environment's Sake, Fifth Biennial Meeting, Ottawa, Canada* .

Hillyer, T. a. (1998). Water Supply Handbook: A Handbook on Water Supply Planning and Resource Management. *U.S. Army Corps of Engineers, Water Resources Support Center, Institute for Water Resources, Alexandria, Virginia* .

Open Geospatial Consortium. (2012). *HY_Features: a Common Hydrologic Feature Model Discussion Paper.* OGC.

Open Geospatial Consortium Inc. (2007). *CUASHI WaterML.* Open Geospatial Consortium.

Open Geospatial Consortium Inc. (2010). *Harmonizing Standards for Water Observation Data.* Open Geospatial Consortium.

Raskin, R., & Pan, M. (2003). Semantic Web for Earth and Environmental Terminology.

Sala, L. (2011). Leading Issues in Water Supply Sustainability in Catalonia. *Consorci Costa Brava, Girona Forum for Collaborative Research, Girona, 30 September 2011* .

Serrat-Capdevila, A. V. (2011). Decision Support Systems in Water Resources Planning and Management: Stakeholder Participation and the Sustainable Path to Science-Based Decision Making. *Efficient Decision Support Systems: Practice and Challenges - from Current to Future / Book 1* , ISBN 978-953-307-165-7, Intech - Open Access Publisher.

Simonovic, S. P. (2002). World water dynamics: global modeling of water resources. *Journal of Environmental Management* , 00, 1-19.

SWKA. (2013). Land use and drinking water supply system maps, Karlsruhe drinking water balance data, water distribution network management rules, Flexibile Data Warehouse parameters list, reservoirs, water works and consumption data.

SWKA. (2013). WP5 Pilots Description Annex 1 Karlsruhe.

Vilches-Blázquez, L. M., Bernabé Poveda, M. Á., Suárez-Figueroa, M. C., & Rodríquez Pascual, A. F. (2007). Towntology & hydrOntology: Relationship between Urban and Hydrographic Features in the Geographic Information Domain. *In Ontologies for Urban Development (Studies in Computational Intelligence) , 61*, 73-84.

Vilches-Blázquez, L. M., Ramos, J. Á., López-Pellicer, F. J., Corcho, O., & Nogueras-Iso, J. (2009). An approach to comparing different ontologies in the context of hydrographical information. *Lectures notes in Geoinformation and Cartography (LN&C) in Information Fusion and Geographical Information Systems* , 193-207.

8. Appendix A: Proposed User History for the Spanish Pilot

Given the available data from ACA and the problem to be addressed, the following question is proposed to be solved by the DSS in order to test the feasibility of the tools developed in the project:

A - How much water must be released from the reservoir system for consumptive water use?

This question focuses on how much water is needed to meet the demand and if the unregulated water resources are sufficient in supplying this volume, or if additional (regulated) water will be needed from the reservoirs. It is assumed that alternative water supply production is not necessary. The solution can be done in several different conditions, such as normal, drought... but the case is focused on satisfying the demand with the supply (rather than managing floods or other situations).

An important decision is the time frame of the process, not for the software process, but for the usefulness of the decisions adopted. This time frame could be seasonal (6 months or one hydrological year) and the time-step could be daily (this is important because we need to have enough data to run the complete process).

The main process must be something like:

1. Calculate the hydrologic inflow by running a rainfall-runoff model, starting from the meteorological forecast.
2. The inflow can feed two types of water supply sources: regulated (captured by reservoirs) or unregulated (direct runoff into the river). The distribution of the expected inflows among these two categories must be determined for each catchment area.
3. The amount of water that must be released by the reservoirs for consumptive water use (without considering hydroelectric power or environmental flow needs) is the difference between the demand and the unregulated flow.

Algorithm for regulated-unregulated water use:

```
1.- Before:

1.1.- USER: Set the possible different demand status of the system
          Drought
          Normal
          Abundance
          Other...


1.2.- USER: Define for each demand status and each demand point its conditions for supplying
demand
  For Each Demand Point
          For Each Demand Status
                  Total percentage of demand that must be served as mandatory
                  Temporal restrictions to demand supply
                  Part that should be supplied with regulated water
                  Define the importance in the supply chain of the current point
```

Other...
End For
End For

2.- Process:

2.1.- Define initial conditions
USER: set current status (this could be done manually or inserting rules to do that automatically).
USER: set time-frame (or always seasonal?)

2.2.- Compute algorithm inputs
OMP-MAS: Get meteorological forecast
OMP-MAS: Get initial basin conditions (reservoirs status, soil status, river status...)
DSS: Run rainfall-runoff model
DMS: Get all demand points within the given time-frame

2.3.- Compute the supply-demand status over time
For Each DAY in time-frame
DSS: Feed regulated water in reservoirs
DSS: Feed unregulated water in rivers or channels
DSS: Apply water dynamic (movement through the transport entities)
For Each Demand Point
DSS: Get its demand supply parameters (regarding demand status)
DSS: Supply demand based in supply parameters
DSS: Compute current supply, demand and other useful information
End For
End For

3.- Analyze the outputs and get recommendations
DSS: Has all the demand been satisfied?
DSS: In which place(s) has it not been met?

In greater detail:

The aim of the algorithm is to compute the supply/demand balance under certain conditions, and generate advice to the expert user regarding the fulfilment of the demands.

The first step for this is to define the different “demands” and how to manage each demand point in the basin (step 1). This could be done at least one time to define the behaviour of each element of the system based on the current basin state.

Once this is done, the expert user must define the current basin state (step 2.1). This could be done directly inserting the state or through a collection of rules to infer it (this is the best way if it is defined concretely).

To start the simulation of the evolution of the resources over time, the first step is to get the complete supply and demand in the time-frame (step 2.2).

For the water sources, it is necessary to calculate the runoff (based mainly but not only on the forecasted rain) and the reservoirs state (how much regulated water is in the system at the beginning of the time-frame).

For the demand, the DMS has to obtain the forecasted demand for each demand point of the system for the entire time-frame.

After that, the time simulation begins, and in each time-step (day), the DSS must compute the state of the system at the end of that time-step. To do this, the first process is to feed the incoming water into the reservoirs (regulated water) or into the correct place in rivers or channels (unregulated water). One we have the water inputs in the correct place, the demand must be met at each demand point based on the system constraints and rules (if the system has enough water).

At the end of the time-frame, once the system has computed the time series at each demand point, representing the water supply and how the demand has been met, it is necessary to analyze these time-series (step 3) to obtain recommendations about how to improve the management of the water. These recommendations pertain to where is the maximum demand?, when is the maximum demand?, can we satisfy all of the demand?, how can we improve the water management? and of course, how much regulated water is needed to satisfy the demand if the unregulated water sources are not sufficient to meet this demand?.

The data required for this decision are:

Table A1: Required input data

From DSS	From DMS
• Current river flows • Weather forecast for selected time horizon (daily rainfall)	• Expected water demand in each catchment area (daily volume)

Based on the input, the DSS will then return the following to the expert user:

Table A2: System output

SystemOutput	Information	Decision
Average rainfall per catchment area (average daily rainfall)	✓	
Expected surface water inflows to each catchment area (total daily inflow)	✓	
Of this, the expected unregulated water flows available in each catchment area (daily flow and volume)	✓	
Quantity of unmet demand in each catchment area (daily flow and volume)	✓	
Quantity of water that must be released by the reservoirs, as the sum of the previous item (daily volume)		✓

Once the amount of water that must be released is known, the following question consists in deciding:

B - How much water should be released from each reservoir?

This question consists in determining from where this water should be obtained, i.e., from which reservoir(s) the water should be taken, and how much. Based on a DAILY time step.

This type of decision can be made according to different criteria, and consequently with a different collection of rules:

1. Determine the environmental flow requirements at each water withdrawal point.
2. Determine the optimal hydropower needs (minimum and maximum flows).
3. Calculate the amount of water demand that cannot be met at each withdrawal point and downstream of each reservoir.
4. Determine the limitations of the transport, treatment and distribution infrastructure (maximum and minimum flows, for example the minimum required technical flow for a given pipe section or treatment plant).
5. Determine the water source priority order according to current reservoir water levels, downstream water needs, and infrastructure constraints (try to maximize the total final volume in all reservoirs, verify that the Ter and Llobregat river systems are in balance with regard to water availability, etc.)
6. Based on all of the above, calculate how much water should be released from each reservoir.

The necessary information is based on that generated for question A, but with the following additional information needs.

Table B1: Required input data

From DSS	From DMS
• Environmental flow requirements (min flow) • Unregulated water flows in each catchment (*from A*) • Current reservoir releases • Current reservoir water level • Current status of the transmission network (distribution network storage and flows) • Topology and characteristics of transmission network (min. and max. flow constraints, travel time) • Hydropower optimal flow range requirement for each plant (min and max flow)	• Expected water demand at each water withdrawal point (average daily rate)

Based on the input, the DSS will then return the following to the expert user:

Table B2: System output

SystemOutput	Information	Decision
Water flows at each water usage withdrawal point (average daily flow)	✓	
Environmental flow requirements immediately downstream of each water withdrawal point (average daily flow)	✓	
Available water at each water withdrawal point, as the difference between the above two items (average daily flow)	✓	
The unmet water demand at each water withdrawal point (average daily flow)	✓	
The total unmet water demand downstream of each reservoir (average daily flow)	✓	
Current storage in each reservoir (daily average volume and percentage full)	✓	
Maximum release rate for each reservoir (daily flow rate)	✓	
Quantity of water that should be released from each reservoir (daily volume)		✓
Quantity of hydropower generated (daily energy production)	✓	

9. Appendix B: Proposed User History for the German Pilot

There are several ways in which energy usage could be reduced in the Karlsruhe water distribution system:

- Reducing water consumption (however this is already naturally occurring)
- Redistributing the water consumption through politics (land-use planning) or water pricing incentives (for instance, reflecting the energy usage within the water tariff structure, or penalizing water consumption in areas that require greater energy consumption)
- Minimizing pressure in the distribution network (defined primarily by the water level in the main reservoir)
- Minimizing water velocity in the distribution network pipes

The hope in this project from SWKA is that the WatERP Open Management Platform could help increase energy efficiency by reducing energy consumption in its drinking water distribution. Ideally, the DSS would offer suggestions as to how to operate the pumps in the water works towards the distribution network, generating, each day, for the following day's expected water demand, the optimal pumping schedule that would minimize total energy consumption.

However, solving such a problem is not an easy task as it would require the use of an optimization algorithm, which at this time, does not exist for SWKA's distribution system. Therefore, given the currently available data from SWKA, the problem to be addressed, and the project approach which consists of using expert systems to emulate the decision-making processes, the following questions are proposed to be solved by the DSS in order to test the feasibility of the tools developed in the project, intending to approximate as closely as possible the problematic described above:

A. Recommended pumping schedule based on historical energy consumption records?

The aim of the algorithm is to improve over time pumping performance along the supply network. This makes use of the knowledge of an expert user, data mining techniques and the information obtained during successive iterations.

For this, three parameters will be considered: demand, pumping schedule, and energy. A pumping schedule is defined for a given demand, and results in certain energy expenditure.

It should be noted that this question requires a connection to SWKA's existing EPANet water distribution piping network model in order to determine, for a given pumping scenario, the associated energy consumption. It should also be remarked that to this date, EPANet model runs are not normally saved. However, if the model were run for a series of different daily demand curves and the resulting energy consumption amounts were recorded along with the pumping schedule, data could then be inferred from this information to help guide future decisions.

Alternatively, the energy consumption might be able to be estimated from the electric current which is measured and recorded for (almost) each pump that supplies water to the distribution network. This data is available for the last two years.

Algorithm for pump scheduling:

```
Before:
1 - Set environment:
    pumps to manage
    reservoir to manage
    cluster/s to manage
    temporal frame

2 - For each DAY:
3 -         DMS: Get demand forecast for next day
4 -         DSS: Compare with past demands
                    IF match/s THEN
5 -                          DSS: Propose pump schedule of minimum energy consumption
6 -                          USER: Modify/Accept current pump schedule
                    ELSE
7 -                          USER: Define current pump schedule
                    END IF
8 -         MODEL (EPANet): Get energy consumption for current pumping strategy (unless
            this can be estimated from the pumps electric current records)
9 -         OMP - DSS: Save this state [Strategy, Energy cost, Demand]
End For
```

In greater detail:

The first step is to set environment (1). It is important to note that the process can be performed simultaneously at different temporal and spatial frames; this first step is to decide where we are going to carry out the rest of the process.

The algorithm defines an interaction at each time step chosen (2). Could be any, but it is necessary to have enough information to complete the process (DSS, model data...). In this example, a daily time step is used.

In each loop of the process (each time step) the DMS has to estimate the demand for the next time step (3) in the cluster/s defined.

With the estimated demand, the DSS has to look for similar demands (4) in the past (this could be done with expert user criteria, pattern recognition algorithms, manual selection...), and if there are, the DSS would return the pumping schedule with minimum energy expenditure.

At this moment, there are two paths. If there are not matches, the expert user has to define a pumping schedule for the next time step (7). If there are matches, the system has to propose to the user that pumping management (5), and the user can modify it or simply accept (6).

Once we have defined the future demand and the pumping schedule, the system is able to run the model (8) to obtain the energy expenditure for this configuration: [demand, pumping schedule, energy] and save the current information for next iterations (9). This last parameter is important, because is the way to quantify how good the solution is.

The data required for this decision are:

Table A1: Required input data

From DSS	From DMS
• Past water demand – energy consumption records	• Aggregate (total daily city-wide) water demand for the next day • Expected peak demand during the next day

Based on the above input, the DSS will then return the following to the expert user:

Table A2: System output

System Output	Information	Decision
Optimal pumping schedule with regard to energy minimization which, based on the available historical records, would fit the expected next day water demand curve		✓
Demand forecast for next day	✓	
Past demand that matches		✓
User modified pump schedule	✓	

This decision could be expanded in the future to answer the question:

B. What is the optimal management of the pumps to provide this water in the most energy efficient manner?

In order to solve this question, a set of rules would need to be defined to provide recommendations regarding the optimal pumping schedule that would satisfy the water demand while minimizing energy consumption. However, it should be noted that these rules, if backed by an optimization model, would be much more powerful.

According to SWKA, the city of Berlin has developed and implemented an optimization model in its distribution system. However, it is the only city which has implemented such a system so far in Germany, and no optimization model currently exists for Karlsruhe.

C. Identification of potential areas for energy saving

Aside from the objective of saving energy associated with pumping, the WatERP Open Management Platform could help identify opportunities for saving energy more generally, by combining different types of information over which the DSS could ask questions. For example, comparing energy consumption levels to distribution zone elevations, considering where certain types of water usages are located, and relating energy to water consumption.

For example, the DSS could follow a set of rules with logic similar to:

1. What day of last year had the highest peak flow demand?
2. On that day, what was the peak demand rate? The total daily demand volume?
3. Where did the highest pressure occur within the network? Highest flow rate within distribution pipe network?
4. Calculate, for that day, the drinking water consumption of the different pressure zones (based on the outflows from the waterworks and pumping stations as well as the inflows and outflows from the reservoirs)
5. Calculate the drinking water consumption associated with each water work
6. What was the energy consumption for each water work?
7. Using EPANet, how much energy was lost in the system that day at the city-wide scale? Per distribution zone?

The data required for this decision are:

Table C1: Required input data

From DSS	From DMS
• Outflows from each water work and from pumping stations that day • Inflows and outflows from each reservoir that day	• Day of highest peak water demand during past year • Peak water demand rate and total demand volume for that day

Based on the above input, the DSS will then return the following to the expert user:

Table C2: System output

System Output	Information	Decision
Location of highest pressure in distribution network	✓	
Location of highest flow in distribution network	✓	
Energy consumed by each water work (daily aggregate)	✓	
Amount of energy losses incurred within the distribution system (both at the city-wide level, as well as by distribution area)	✓	
Areas of possible energy saving		✓

Many similar decisions could be asked by varying different water supply distribution characteristics, the idea being to try and determine where energy savings could be obtained. Such types of question scenarios would not solve the water operator’s immediate decision needs, but could shed light into understanding better the drivers behind both water and energy consumption and from this newly generated information, decisions could be made for future savings.