WatERP

Water Enhanced Resource Planning

“Where water supply meets demand”

GA number: 318603

WP 1: Water Supply Knowledge Base

1.3: Generic ontology for water supply distribution chain

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Abstract (for dissemination)	Description of the generic ontology that was developed in WatERP project is presented. The novelty of WatERP ontology lies on including man interactions with the natural paths as a mechanism to understand how affect into the water resources management with the objective to match supply with demand, these interactions could range from infrastructures to management decisions. This knowledge representation is supported by a data provenance mechanism in order to define a process towards observation understanding and standardization of the ontology. It includes concepts and standard terms provided by other ones, such as NASA, CUAHSI, OGC and W3C ontologies. Moreover, the WatERP ontology has been constructed following the principles of Linked Open Data Cloud (LODC) where resources can be accessed by a URI and linked to other elements attending with automatic understanding (human-readable).
Key words	Water Ontology, Water Knowledge base, Water Knowledge representation, LODC, data provenance

List of Acronyms

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

CUAHSI- Consortium of Universities for the Advancement of Hydrologic Science

D1.1- Deliverable 1.1 "*Generic taxonomy for water supply distribution chain*"

D1.2- Deliverable 1.2 "*Generic functional model for water supply and usage data*"

D1.3 – Deliverable 1.3 "*Generic Ontology for water supply distribution chain*"

D7.1.1- Deliverable 7.1.1 "*Holistic Auditing*"

DMS- Demand Management System

DSS- Decision Support System

GML- Geography Markup Language

LODC- Linked Open Data Cloud

MAS- Multi-Agent System

NASA- National Aeronautics and Space Administration

NeON- NeOn Methodology for Building Ontology Networks

NIST- National Institute of Standards and Technology

O&M- Observation and Measurement System

OGC- Open Geospatial Consortium

OMP- Open Management Platform

OWL- Ontology Web Language

RDF- Resource Description Framework

SKOS- Simple Knowledge Organization System

SSN- Semantic Sensor Network

SWEET- Semantic Web for Earth and Environmental Terminology

SWKA- Stadtwerke Karlsruhe Gmbh

URI- Uniform Resource Identifier

W3C- World Wide Web Consortium

WaterML2- Water Markup Language (version 2.0)

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

XML- eXtensible Markup Language

Executive Summary

Deliverable 1.3 (D1.3) describes the generic ontology designed for the WatERP project. The work presented in this document has been based on the definition of all needed ontological resources that describes water manager's expertise with the aim of managing water supply and demand. The WatERP ontology has been designed taken into account the taxonomy created for the water supply distribution chain (Deliverable 1.1 "*Generic taxonomy for water supply distribution chain*") and behavioral models about water resource management described in Deliverable 1.2 "*Generic functional model for water supply and usage data*" (D1.2).

The novelty of WatERP ontology over current developments lies in the fact of including man-made infrastructure elements in order to link it to the natural path and represent the interactions among natural and human made entities to understand how affect into the water resources management, these human made modifications of natural path has been defined in WatERP as human-altered paths. So, the WatERP ontology permits to represent semantically the human-altered and natural paths to discover new interrelations (hidden knowledge) that permit to discover new strategies for water resource management.

This knowledge representation is supported by a data provenance mechanism in order to define a process towards observation, understanding and standardization of the ontology including concepts and standard terms provided by others, such as National Aeronautics and Space Administration (NASA), Consortium of Universities for the Advancement of Hydrologic Science (CUAHSI), Open Geospatial Consortium (OGC), and World Wide Web Consortium (W3C) ontologies. Moreover, the WatERP ontology has been constructed following the principles of Linked Open Data Cloud (LODC) contributing to the aim of achieving interconnectivity within WatERP solution. LODC permits resources to be accessed by an URI and linked them to other elements attending with automatic understanding (human-readable). Then, ontological information can be integrated and accessed, the terms of different vocabularies can be mapped, and data fusion supported. All these features contribute to resolve data conflicts by integrating data from different sources into an entity.

The WatERP project proposes an ontology-driven knowledge management with the aim of supporting domain expert users in their decision making process and enhancing the comprehension of the water supply systems upon which it is applied.

The initial information gathering has been used to specify all needed ontological resources, and afterward, ontology construction was performed based on: *(i)* enhancing water management taxonomy elements towards better conceptualization of terms (define equivalency, disjoints and covering axioms); *(ii)* defining relations between hydrological concepts (interaction between natural and human-altered paths) that provides WatERP with the needed mechanism to understand generally (any water resources management system) and specifically (specific case representation) the water supply distribution chain; *(iii)* defining needed data properties (attributes) over hydrological elements in order to differentiate instances and enrich member definition with specific information such as location, date time, full names, standardized names, etc; *(iv)* including classes restriction that introduce into the ontology the expert water domain knowledge in order to use known hydrological expertise towards hidden knowledge discovering as a result of studying non-direct relations between entities; *(v)* defining annotation mechanism to make accessible the ontology to the rest of the world (related with open-environment); *(vi)* applying waterML2.0 for entities definition; *(vii)* using SSN to define relations between the observations.

It should be noted that the ontology presented in this document will be incrementally enhanced and refined throughout the WatERP project. While the intent is to develop generic tools that could be applied in any water supply distribution chain context, the project prototypes will be based on the pilot cases which will provide a real-world confirmation and validity.

Future work to be accomplished is focused on instantiating the ontology according to pilot's information. In order to accomplish this task, a population strategy to feed the ontology will be developed. Aligned with this population strategy, automatic annotation will be included over the instances in order to enhance the comprehension of each individual.

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

Number	Title	Description
D1.1	Generic taxonomy for water supply distribution	This deliverable summarizes the taxonomy of the domain knowledge and the initial version of the ontology, including the scope, purpose and implementation language to be used.
D1.2	Generic functional model for water supply demand and usage data	Report describing the approach that will be used in the WatERP project to represent the processes required to match supply with demand across the water supply distribution chains. It includes processes and decisions involved in the pilot cases.
D2.1	External systems integration requirements	Report summarizing the existing data exchange technologies and standards currently used in the field of water resources management. It presents a description of the specific data flows and systems involved in the WatERP pilot cases. From this, general requirements of interoperability for the project developments were defined, and an initial ICT architecture for the whole solution was presented.
D2.2	Activity plan for work on standards	In this delivery, an activity plan for the WatERP project is devised which shall guide all project standardization

		activities. As a main focus, it is aimed at implementing, testing and extending the WaterML2.0 standard of the Open Geospatial Consortium (OGC).
D3.1	WDW Conceptual design	Description of the architectural design of the water data warehouse used to integrate all data relevant for the WatERP project and the interfaces used for data integration and offered to other work packages
D7.1.1	Holistic Auditing	Document that describes the procedure to be followed for ontology's validation in the different steps of its implementation within the pilots.

Table of contents

List of figures

List of tables

1. Introduction

The primary objective of WatERP project is to match water supply with demand along the water supply and distribution chain. Water can be viewed as a main resource that can be used in a variety of different ways. Water sources throughout the cycle, can vary in form and distribution. Water can be found in the air (humidity), on the surface (streams), below the ground (aquifers), and in seas and oceans (water bodies). However, water undergoes different process (natural and human-engineered) in order to satisfy demand. This set of natural and human-engineered processes needed to satisfy the demand is called water supply distribution chain (Seckler, Amarasinghe, Molden, de Silva, & Barker, 1998). Natural water process (Oki & Kanae, 2006) refers to the continuous movement of water around, through and above the Earth. This process generates a water state transformation (liquid, solid and gas) throughout the natural cycle (Evaporation, Condensation, Precipitation, Infiltration, Run-off and Evapotranspiration). Human-engineered process (Marsalek, Jimenez Cisneros, Karamouz, Malmquist, Avruch, & Chocat, 2007) is defined as infrastructure elements created by human or human-altered (river, channels, pipe networks, etc) to modify (and/or transform) natural water paths in benefit of humans (provide water to cities, irrigation, industry, etc). The activity of planning, developing, distributing and managing the optimum water resource in order satisfy the demand is denoted as water resource management (Grigg, 2005).

The main goal of the WatERP ontology (knowledge-base) is to render information/knowledge on water supplies and demand actors, and the various water resources (natural and human-altered) available for the particular water supply distribution chain under management. The ontology is the mechanisms to manage water resources by means of exploiting the relations between the entities of the water supply distribution chain to discover hidden relationships that permit to understand new paths (linkages) between supply and demand. The discovering of unknown linkage between elements provides the water resource managers with new forms of understanding the water supply and distribution chain.

Knowledge-base also provides the water resource managers with the possibility of exploiting ontological information by using querying languages. This is very important to enhance managers' knowledge about how to manage water resources.

Moreover, the knowledge-base supports WatERP interoperability by using of WaterML2 and LODC technology. The first one provides standardized data exchange procedures and the second one connectivity mechanisms. In addition, semantic meanings contribute to make the ontology knowledge more clearly understandable. The combination of these features will permit to exchange knowledge with other applications and to offer data provenance understanding.

Furthermore, WatERP knowledge-base is designed to be capable of understanding data observations with the aim of selecting better displayable information (data fusion concept).

Existing water (hydrologic and hydrological) and water resource management ontologies were described on D1.1 and D1.2. Summarizing, current ontologies are focusing on natural cycle of water (also called hydrologic cycle or hydrological cycle) instead of the linkage between natural water cycle and human-engineered (or human-altered). Moreover, current ontologies need more expressivity in its developments. That means, current ontologies are not capable of interrelating the concepts between them (are more taxonomies than ontologies). So, current development uses the ontology with the only objective of giving a simplest (or directed) knowledge based on the categorization of the concepts. As a consequence of avoiding the use of ontology relations, reasoning over ontology is not used and then, any ontology inference (e.g. behavior study) is not performed. WatERP ontology by the use of the relations between concepts permits to infer new paths of interconnection and then enhance the water resource management domain knowledge.

Beyond current ontologies, WatERP ontology development permits to *(i)* find semantic inconsistencies and rules that can improve water resources management, *(ii)* align concepts semantically in order to facilitate data understanding and provenance, *(iii)* link to external ontological resources using concept alignment (ontological mappings) and *(iv)* query and pivote ontological resources in order to answer user needs.

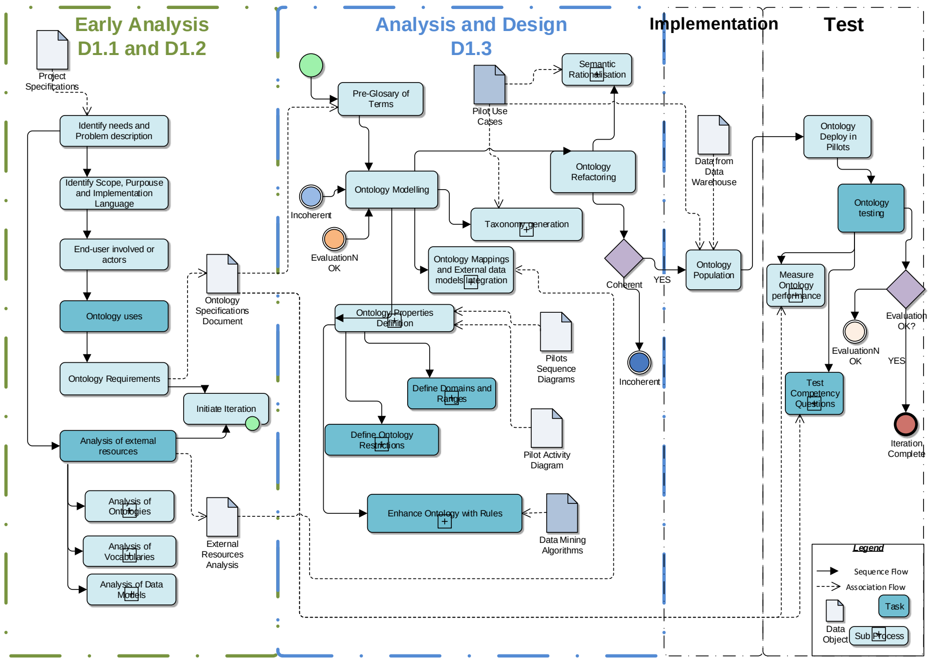

Figure 1 "WatERP methodology aligned with deliverables"

As mentioned in D1.1 (see Section 1.1 of D1.1), ontology construction has been based on a NeOn Methodology for Building Ontology Networks (NeON). This methodology was selected in order to assure that user requirements are satisfied (Suárez-Figueroa, Gómez Pérez, & Fernández López, 2010).

NeON methodology is based on three stages (see Figure 1). First stage, "*Early Analysis*" (D1.1), highlights the implementation of the taxonomy categorizing the generalization of water resource management concepts and the ontology requirements definition that permits to guide ontological development towards user needs. Second stage, "Analysis and design", is reported in the present deliverable and is focused on the work performed to define water resource management knowledge into the WatERP ontological structure. It is important to remark that the ontology created allows the access to the information meanwhile new knowledge is discovered. Third stage, "Implementation and Test", will be based on populating the ontology with pilots information in order to check the ontology validity in a real-scenario.

In the first stage, taxonomy created has been implemented on Ontology Web Language (OWL) rather than Resource Description Framework (RDF) language because of expressivity and needed logics to be implemented (D1.1, section 2.3). Further than current ontology developments (like CUASHI, NASA, etc) the WatERP taxonomy developed provides the needed categorization of terms to make possible the linkage between natural water cycle and human-engineered cycle. Furthermore, created taxonomy has been driven by pilots' information (ACA[1] and SWKA[2]) and state of the art on the water supply distribution chain (current standards and developments) in order to refine the concepts and aligned it with real-life notation (language) and needs. Moreover, in this first stage of the NeON's methodology, logical models over pilots have been defined in D1.2 (see Section 3 of D1.2). Logical models permit extract behavioural patterns and rules over pilots to *(i)* support the creation of specific-ontology or populated ontology and *(ii)* discover generic rules to be included in WatERP ontology and support holistic point of view.

During the second stage of NeON's methodology, called "*Analysis and Design*", the WatERP ontology construction has been performed and is mainly reported in the present deliverable. The "*Analysis and Design*" stage is based on extending primary taxonomy and enriching it with ontological expressivity (relations, axioms, etc). Hence, present document will describe ontology construction (Section 2) starting with taxonomy enrichment (Section 2.1) that means define equivalence and separation (disjoints) between concepts of the hierarchy. Additionally, taxonomy concepts are linked between each other using ontology relations generating the core ontology (Section 2.2). Over this core ontology has been defined data properties or specification of concepts using ontology attributes (Section 2.3). Moreover, core ontology has been enhanced adding ontological restriction that defines entities behaviour (Section 2.4). The ontology definition ends with ontology mappings and external data models integration like CUASHI, Semantic Web for Earth and Environmental Terminology (SWEET), Semantic Sensor Network (SSN) ontology and new tentative standard developed by OGC called HY_Features

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[1] Agencia Catalana del Agua (trans. Catalan Water Agency)

[2] Stadtwerke Karlsruhe Gmbh

(see Section 2.5). In order to prove first results of the ontology construction, a reduced modelling of pilots has been showed in (Section 3). In this last section first consistency test that has been implemented and a reasoner selection to exploit ontological resources efficiently based on ontological modelling are also described.

1.1 Initial Concepts

As introduced, this deliverable is focused on describing WatERP ontology construction. Based on "*Initial Concepts*" introduced on D1.1 (Section 1.2), at this stage WatERP project goes further describing in depth OWL ontological resources implemented and detailing how they are exploited to give proper knowledge to the water resource manager. Initial concepts are needed to better comprehension of defined classes (concepts), relation between concepts (ontology properties or object properties), data properties, axioms and so on.

As it is known, ontology is mainly conformed by classes, relation between classes (properties), attributes (also called data properties) that provide more specification to the class, and individuals of the ontology that represent an instantiation of the ontology by a population process. These concepts can be viewed as mathematical group that is defined by an N-tuples notation (D1.1, section 1.2 "*Initial Concepts*"). As an example, in Figure *2* is described a small ontology that has two concepts (orange colored) that corresponds with "*observations*" (e.g. water temperature, volume, discharge) and "*features of interest*" (e.g. Deddington station, Ebro hydrologic station and HW pumping station). Both concepts are related by an ontology property (blue colored) called "*hasObservation*" that represent the observations that has a feature of interest . Furthermore, "*features of interest*" is specified by an attribute (green colored) called "*region*" (e.g Nile basin, Karlsruhe City and Ebro basin) that represent a geographical space (e.g. station). In addition, "*observation*" concept (or entity) is specified by the "*unit*" attribute (e.g Hm3, m3/s and ºC) that measures the specific observation. Finally, instances (purple colored) for both classes are defined in order to know which kind of observation has a specific feature of interest in a specific region. So, the small ontology is defined by *4* mathematical groups that are related by *2* kinds of transformation functions: *(i)* ontological relation between concepts and *(ii)* attributes defined by an ontological entity.

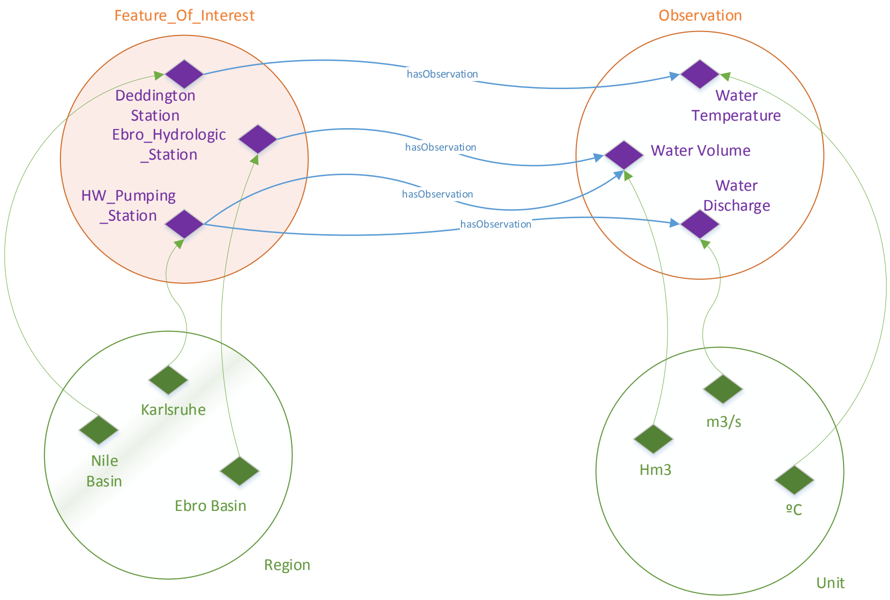

Figure 2"Ontology Concept"

However, this representation of the ontology needs a more detailed elements definition in order to facilitate ontological inference. As an example, the ontology of Figure *2* is enhanced by definition of functionalities over it resources like separation/equivalence between classes (orange coloured), type of property, type of attributes (string, double, etc), restrictions of the classes when the property is used (axioms), etc. Hence, present section is aimed at explaining in deep the specification of ontological resources that are used to exploit one by querying mechanism. Also, the ontological resource definition permits infer new relations between ontological individuals offering to the water resource manager new information about water supply and demand management chain.

1.1.1 Classes Definition

To fully define a class/concept in the ontology, a definition of **equivalences**, **disjoints** and **covering axioms** are needed (Davies, Studer, & Warren, 2006). Two classes are "**equivalent**" (see Formula 1) if both classes express the same meaning. In other words, two classes (C_A, C_B) are equivalents ($\equiv$) if all members of both classes ($I_A = I_B$) are the same.

$$C_A \equiv C_B \Leftrightarrow \forall (I_A = I_B)$$

Formula 1"Equivalent class definition"

Equivalent classes are used in the ontology to say that two concepts are similar. In the ontology, "*disjoint*" concept is used to indicate to the ontology that two elements (classes) are totally different. Two classes (C_A, C_B) are **"disjoint"** (see Formula 2) if the intersection is the void set (ϕ). In other words, two classes are disjoint ($\not\equiv$) if all individuals ($I_A = I_B$) are different between classes.

$$C_A \not\equiv C_B \Leftrightarrow \{\forall I_A \in C_A, I_B \in C_B \mid I_A \neq I_B\} \Rightarrow C_A \sqcap C_B \equiv \phi$$

Formula 2 "Disjoint definition"

Furthermore, during ontology construction sometimes is needed a restriction that force to a member of a class be included into a one of the defined sub-classes. In this case is needed to define covered axioms. A class (C_A) "*is covered by*" (**covered axiom**) it subclasses (C_B, C_c) if the union of the subclasses is the super class (C_A) (see Formula 3). In other words, individuals (members) of super class (C_A) must be a member of one of the subclasses (C_B, C_c).

$$C_A\, is\_covered\_by\, (C_B, C_c) \Leftrightarrow \{\forall I_A \in C_A \mid I_A \in (C_B \sqcup C_C)\} \Rightarrow C_A \equiv C_B \sqcup C_C$$

Formula 3 "Covered axiom definition"

In conclusion, in Figure 3 is shown an example of entities definition. This example is derived from ontology showed in Figure *2*. In the Figure 3, concepts (classes) are orange coloured and members of a concept (individuals) are purple coloured. The graphical representation shows the difference between operators. In case "*(a)"*, normal definition without restriction produce that classes have intersections between them. That means one individual can be a member of two classes. In case "*(b)"*, is shown equivalent class definition where all individuals pertain to the classes that have defined the equivalency. In case "*(c)"*, it is shown the disjoint concept where classes have no member in common (classes totally separated). Finally, in case "*(d)"*, it is shown axiom covered concept where its definition produces a perfect division of the concept/class "*feature of Interest*".

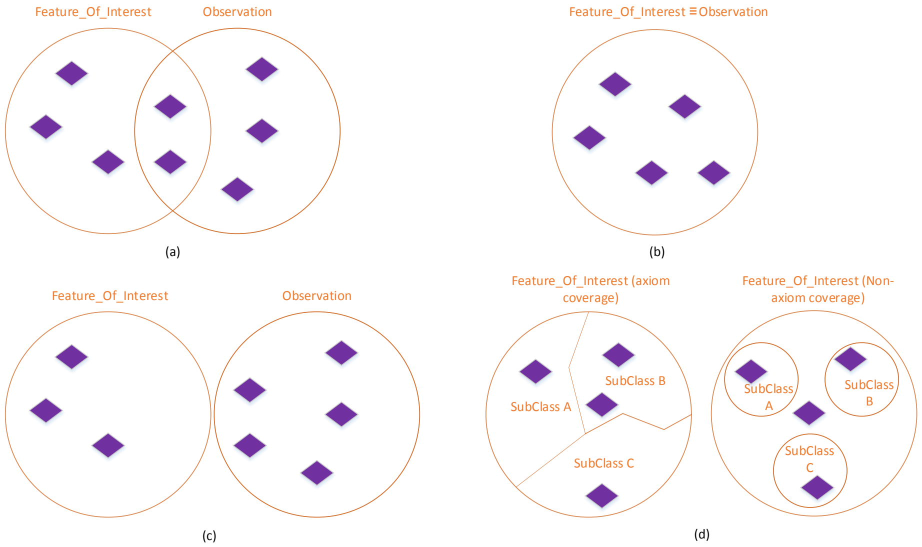

Figure 3"Classes Operation Definition" where (a) represent normal definition (without class definition); (b) equivalence operation; (c) disjoint operation and (d) difference between use vs. not use covered axiom

1.1.2 Relations (Object Properties) Definition

In the ontology, relation or object properties are the mechanisms to interconnect two classes between them. Mathematically, relations can be viewed as a transformation function (Formula 4) that defines how classes are interrelated between them (Staab, Schnurr, Studer, & Sure, 2001).

$$hasObservation(R): Features\_of\_Interest(f) \times Observation(o) \Rightarrow fRo = R(f,o)$$

Formula 4 "Relation or Object Property definition"

Accordingly to the definition, object property is formed by "*domains*" (e.g "*Features_of_interest*") and "*ranges*" ("*Observation*"). The "*domain*" of an ontological relation or object property are the elements to be linked (*math.* "*domain*"). Hence, a "*range*" of an ontological relation is the element which the function is applied (*math.* "image"). Depending on the kind of transformation between "domains" and "ranges", different types of object properties are defined. The object property to be used in the ontology corresponds with functional (*ant.* Inverse functional), transitive, symmetric (ant. antisymmetric) and reflexive (*ant.* Irreflexibe).

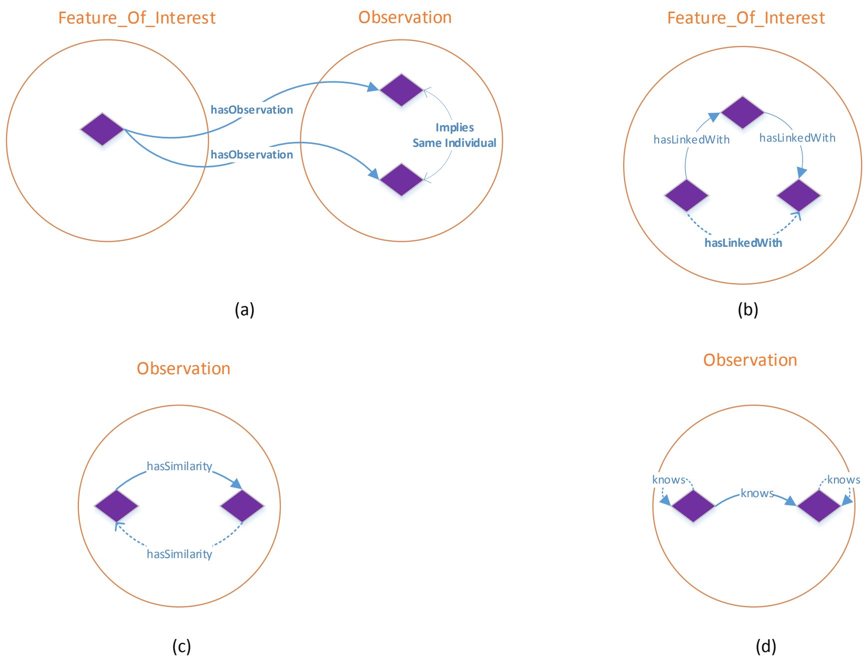

Figure 4 "Ontology properties Concept" where (a) represents functional property, (b) transitive property, (c) symmetric property, and (d) reflexive property

Functional property (Formula 5) is defined as the relation where if a member of domain class ($I_A \in C_A$) is related by transformation function (R) into two members of image/range class ($I_B, I_c \in C_B$) then the two members of the image/range functions are the same (see Figure 4 (a)).

$$\{\forall\, I_A \in C_A; I_B, I_c \in C_B; R: C_A \times C_B \mid I_A R I_B \;\wedge\; I_A R I_C \rightarrow I_B = I_C\}$$

Formula 5 "Functional property definition"

Transitive property (Formula 6) is defined as the relation where members (I_A, I_B, I_c) of a class (one or more) are related by transformation function (R) linking the individuals I_A with I_B and I_B with I_c. Then first of the members (I_A) is linked to the last (I_c) by same transformation function (see Figure 4 (b)).

$$\{\forall\, I_A, I_B, I_c \in C_A; R: C_A \times C_A \mid I_A R I_B \;\wedge\; I_B R I_C \rightarrow I_A R I_C\}$$

Formula 6 "Transitive property definition"

Symmetric property (Formula 7) is defined for members (I_A, I_B) of some concept (C_A). The symmetric property holds that if I_A is related with a transformation function (R) with I_B, then I_B is also related by the same transformation function with I_A (see Figure 4 (c)).

$$\{\forall\, I_A, I_B \in C_A; R: C_A \times C_A \mid I_A R I_B \rightarrow I_B R I_A\}$$

Formula 7 "Symmetric property definition"

Reflexive property (Formula 8) is defined for members (I_A, I_B) of a specific class (C_A). The reflexive property holds that if I_A and I_B are related by a transformation function (R), then I_A and I_B can be related with itself using the same transformation function (see Figure 4 (d)).

$$\{\forall\, I_A, I_B \in C_A; R: C_A \times C_A \mid I_A R I_B \rightarrow I_A R I_A, I_A R I_B, I_B R I_B\}$$

Formula 8 "Reflexive property definition"

To sum up, in Table 1 it is shown the compatibility between properties. This table remarks some rules to be followed in ontology construction in order to create a consistent ontology. Also, it can be remarked that if an ontology relation is defined without using any relation property then it is described as a direct connection.

Property/Property	**Functional**	**Inverse Functional**	**Transitive**	**Symmetric**	**Antisymmetric**	**Reflexive**	**Irreflexive**
Functional	--	*Yes*	*No*	*Yes*	*Yes*	*Yes*	*Yes*
Inverse Functional	*Yes*	--	*No*	*Yes*	*Yes*	*Yes*	*Yes*
Transitive	*No*	*No*	--	*Yes*	*Yes*	*No*	*No*
Symmetric	*Yes*	*Yes*	*Yes*	--	*No*	*Yes*	*Yes*
Antisymmetric	*Yes*	*Yes*	*Yes*	*No*	--	*Yes*	*Yes*
Reflexive	*Yes*	*Yes*	*No*	*Yes*	*Yes*	--	*No*
Irreflexive	*Yes*	*Yes*	*No*	*Yes*	*Yes*	*No*	--

Table 1" Compatibility between properties"

1.1.3 Data Properties Definition

Similar to object properties definition (ontological relations), a data property is defined by a transformation function (Formula 9) that links a class or concept ("*domain*") with a specific OWL variable type ("*image*") such as Double, Integer, String, DateTime, URI, etc (Staab & Studer, Handbook on Ontologies, 2009).

$$Region(R){:}\, Features\_of\_Interest(f)\ \times OWL{:}\, string(s)\ \ \Rightarrow fRs = R(f,s)$$

Formula 9 "Data property concept"

Data properties are really useful to specify a class/concept or object property with values. These elements have similarities with attributes in OWL schema based on an eXtensible Markup Language (XML) file. Data properties can only be defined as functional properties when necessary (see Section 1.1.2).

1.1.4 Restrictions (Axioms)

Another element that plays a key role in the ontology construction is the restriction. A restriction is defined as a "*class of individuals based on the relationships that members of the class participate in*" (Antoniou & van Harmelen, 2004). In other words, a restriction is an anonymous class (and unnamed class) that contains all individuals that satisfy the restriction. Throughout the document, a restriction is defined using the following notation:

$$Class\ \sqsubseteq (\exists, \forall, </\leq\ \ value, >/\geq value, =, \ni)\ Property\ \ [Class/Individual]$$

Formula 10 "Restriction notation"

Restrictions fall into three main categories: *(i)* Quantifier restrictions, *(ii)* Cardinality restrictions, and *(iii)* "*hasValue*" restrictions. A **quantifier restriction** (Figure 5) represents the elements that "*exist*" within that domain (von Fintel, 1994). Quantifier restrictions can be categorized into existential (∃) and universal restrictions (∀). On the one hand, an existential restriction describes classes of individuals that participate in "*at least*" one relationship along a specified property to individuals that are members of a specified class. On the other hand, a universal restriction describes classes of individuals of a specific class that only have relationship with a given property.

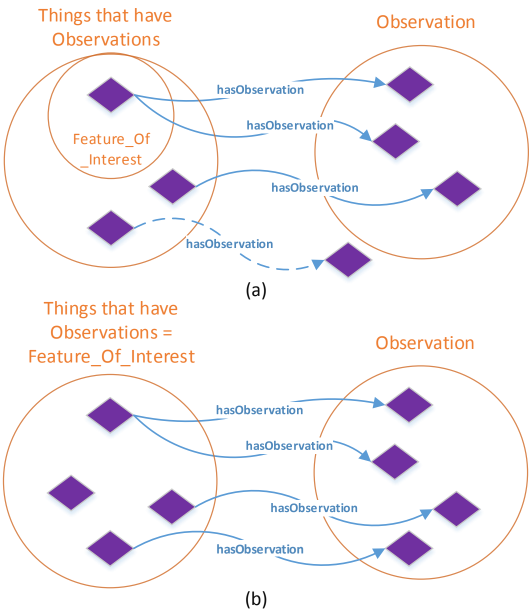

Figure 5 "Comparison between existential and universal restriction": (a) represent existential description, and (b) Universal restriction

A **cardinality restriction** (Figure 6) describes the elements that have "*at least*", "*at most*" or "*exactly*" the number of relations with other individuals or data-type values (Hebeler, Fisher, Blace, & Perez-Lopez, 2009). Cardinality restriction can be categorized as Minimum Cardinality Restriction ("*at least*"), Maximum Cardinality Restriction ("*at most*"), or Cardinality Restriction ("*exactly*"). In a Minimum Cardinality Restriction it is specified the minimum number of relationships that an individual can participate in ($>/\geq value$). In contrast, Maximum Cardinality Restriction is defined by the maximum number of relationships that an individual can participate in ($</\leq value$). In Cardinality Restriction specifies the exact number of relationships that an individual must participate in ($=$).

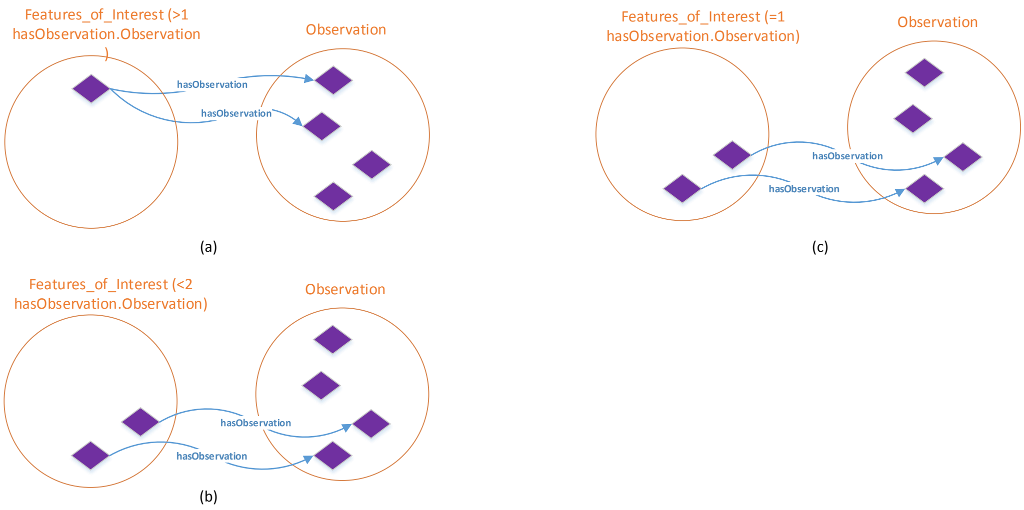

Figure 6 "Comparison between Cardinality restrictions": (a) represents Minimum Cardinality Restriction for features of interest more than (>) 1; (b) Maximum Cardinality Restriction for features of interest less than (<) 2; (c) Cardinality restriction for features of interest equals to (=) 1.

A **"*hasvalue*" restriction** (Figure 7) describes the set of individuals that have "*at least*" one relationship that links a specified property with a specific individual (Segaran, Evans, & Taylor, 2009). The "*hasvalue*" restriction is denoted by the mathematical symbol "*contain*" (∋).

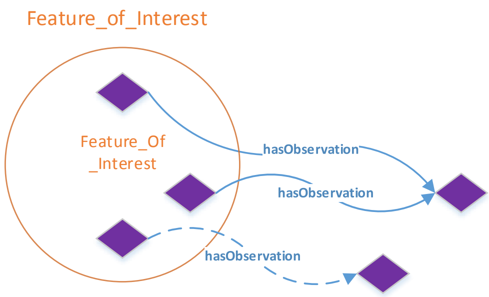

Figure 7 "hasValue restriction concept"

1.2 General WatERP ontology description

The WatERP ontology has been designed to provide water authorities and utilities managers with sufficient knowledge to supports resource management decision-making process for water supply and demand satisfaction. This knowledge will be linked to the Open Management Platform (OMP) the Decision Support Systems (DSS) and Demand Management System (DMS), with the intention of create a mechanism to interact with the user, collect its needs and exchange information using the existing/new knowledge inferred by the ontology. Furthermore, WatERP ontology is specifically designed to be capable of representing the domain of water supply and demand knowledge. The water domain knowledge inside the ontology has been driven by the relations and restrictions producing semantically meaning in direct relations (known relations) and new knowledge through restrictions understanding that produces ontological inference of indirect relations (hidden relations).

As mentioned in D1.2 (Section 4), WatERP ontology has been based on current ontological developments in this field (CUASHI, SWEET and HydrOntology), current standard languages (WaterML2[3]) and tentative standards (HY_FEATURES). However, most of these ontological and schematic resources are focused on water natural cycle. **Beyond this representation, WatERP solution is designed and implemented by linking the natural cycle with the human-engineered modifications of it and by characterizing this linkage based on supply and demand interactions**. To achieve this linkage, a restructuration of current ontological resources has been done. Logical models have been defined in order to create a key mechanism to provide this restructuration. Logical models have been used as a behavioural representation of water resources management. This kind of models represents in a generic form entities, rules and restrictions that are applied in a particular section of the water resource management chain. These models have been used to discover all water supply distribution chain elements to define behaviours and to populate the ontology according to their representation.

The developed ontology (see Figure 8) has been represented in OWL language. Selection of this language has been based on the expressivity, vocabulary, description logics, etc. (D1.1 section 2.3). To sum up, OWL provides the ontology with the needed expressivity (vocabulary) to represent all information and behaviours acquired from water supply and demand distribution chain. Also, OWL permits to enrich ontological resources with annotation and mappings. Mappings provide the capability of linking the WatERP ontology with external resources in order to make more accessible the developed ontology. Moreover, the OWL language allows the ontology to express richer description logics derived from restrictions and axioms through more accurate ontological model with reality.

Developed ontology is described in Figure 8. The figure shows the entities or concepts defined and categorised on D1.1 (D1.1 section 6). In this deliverable, taxonomy has been enhanced by including class/entities properties (disjoint, equivalence, etc), generation of relation between entities, and definition of attributes for the entities. The presented entities (orange coloured) represent the information that models the water resource management chain. These entities are linked using semantic relation (blue coloured). The relationships between concepts represent levels of influence between entities. For example, relationship between "*Water Resources Management*" and "*Feature Of Interest*", using property "*contains*", indicates that a water resource management contains a specific set of Features of Interest. That is, for all elements, that compound water resource management is defined as a set of features of interest (stations, devices, source of data) that details the model defined in water resource management.

---

[3] Water Markup Language (version 2.0)

With the objective of specifying the entities information, some attributes have been defined. The attributes represent concepts that have not sufficient strength to be an entity by themselves but they are necessaries to understand the meaning of an entity. In the WatERP ontology, defined attributes are used to identify a region, specify a result value, a date time, a location of a real-element, a unit of measurement, etc. These attributes also permit to create a “*filter*” over the entities to be applied in the queries in order to retrieve information to water resource managers (application users) via OMP. Moreover, these attributes can be used to specify rules into certain result values, over certain dates, region, etc.

The ontology has been divided into several parts depending on the function to be done (see Figure 8):

1. **Matching between Supply and Demand:** The ontology is capable of matching supply and demand taking into account natural water and human-engineered cycle through water resources relationships that indicate how the water behaves inside the water supply and distribution chain. The matching is implemented in the ontology linking water resources with their corresponding features of interest that measure the variables which affect to the specific part of the water supply distribution chain. The water resources are aligned with real-elements (device, system, informational source, etc) defined as “*Feature of Interest*”. In addition, water resources management are linked to the actors who manage the water supply and distribution chain. This concept is represented in the ontology by the relation “isManagementPartOf” that links the entities “Water Resources Management” and “Actors” (Water Utilities, Regulators and Water Bulk Suppliers).
2. **Observation and Measurement**: This part of the ontology is composed by the observation (element that measures a variable with specific unit), phenomenon to be observed and procedure followed to overcome the observation. It is focused on defining for each real-element the information it can provide to users. This information is related with weather information, water systems information, water demand information, socio-economical information and more (detailed in Deliverable 1.1, section 6.7 and section 6.8). Moreover, this part has been designed following the WaterML2 language and SSN ontology considerations permitting ontology interoperability by defined standard mechanisms. These mechanisms support communication between observations and variables with real-life elements. Furthermore, the “*Phenomenon*”, “*FeaturesOfInterest*” and “*Procedure*” can be grouped in a specific categorization called “*Offerings*”. Finally, it is remarkable that “*Observations*” produces a “*Result*” in form of “*Point*”, “*TimeValuePair*” (date time momentum) and/or a “*TimeSeriesObservation*”.
3. **Actions and Alerts:** This part of the ontology is focused on representing detected alerts and actions performed in the water supply distribution chain in order to provide the water managers with proper information about the performed behaviour of the water resource management performed. The “*Alerts*” have been categorized based on their level of importance into critical and non-critical. Depending on the alert level, some actions are performed. These actions are

linked to the alerts using “solve” relation to indicate dependence between action and alerts. With the matching done between alerts and actions, water managers can know which actions have been applied to solve specific alerts and the ontology can provide them further similar cases.

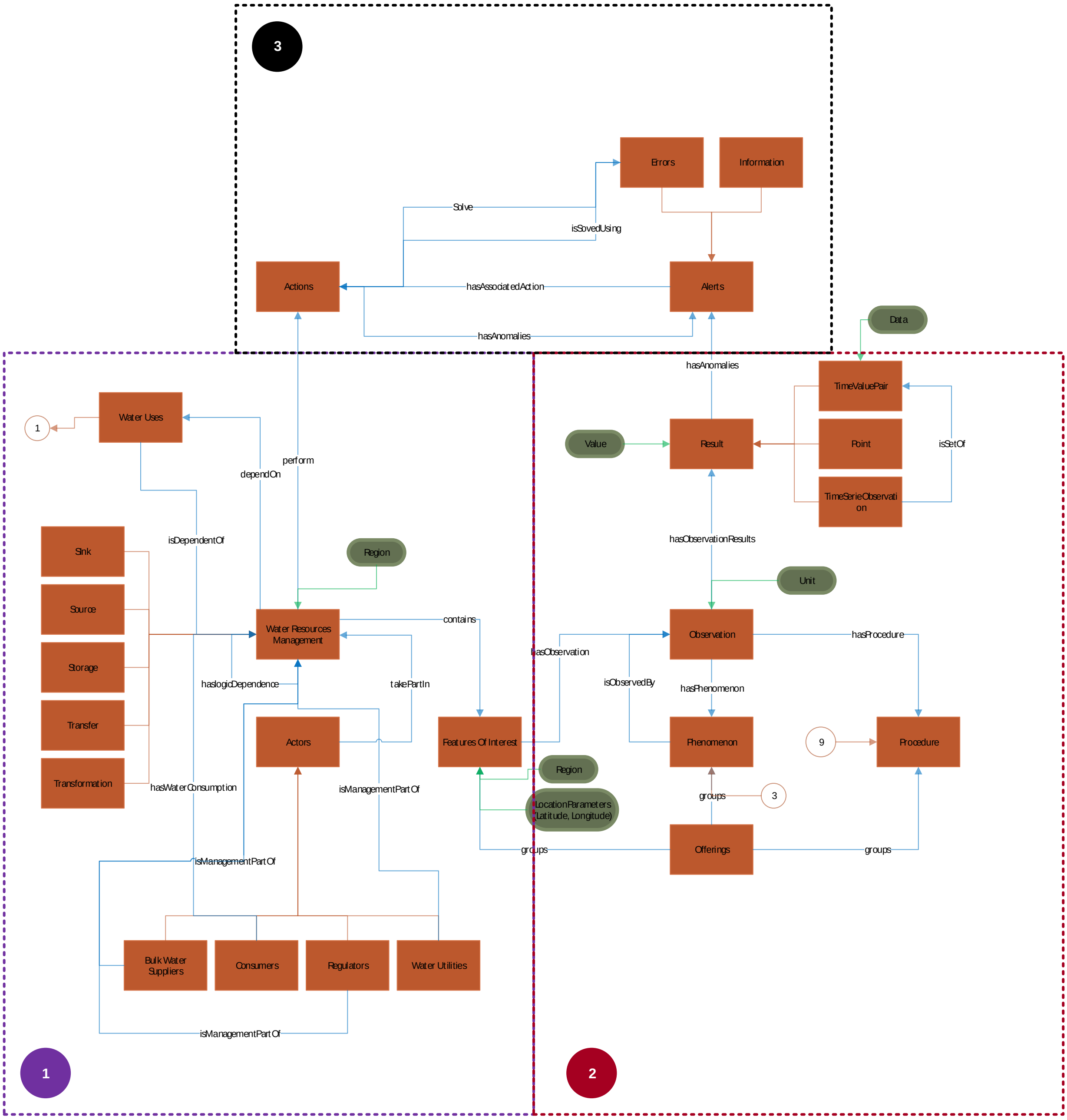

Figure 8 "WatERP Ontology"

2. WatERP Ontology

This section provides a depth description of the designed WatERP ontology. This detailed description of the ontology is done to better understand all ontological resources applied to the WatERP specific water domain. Also, the ontological description provides an understanding of how the elements are interrelated between them in order to support the water resource management process. Following sections describe: *(i)* a definition of the functionalities that enhance entities performance in order to improve new ontological relationships (Section 2.1); *(ii)* properties definition (Section 2.2) in order to understand how knowledge is managed using different flows of information (semantic links); *(iii)* definition of data properties to specify concepts (Section 2.3); *(iv)* definition of the restrictions to provide an exhaustive definition of the ontological relationships that provides the capability of accurate semantic inference (Section 2.4) based on the properties and entities and; *(v)* definition of the proper annotation over concepts and properties (data and object) to make more understandable the ontological resources (inclusion of comments and labels). Also, the annotations provide the ontology with the capability of linkage with external resources such as WaterML2, SSN ontology, CUAHSI ontology and HY_Features schema (Section 2.5).

2.1 Entities Enrichment Mechanism

In WatERP ontology, entities support domain definition with elements that refer to the concepts used in the water supply distribution chain. Beyond the taxonomy of concepts constructed, it is needed to enhance the definition of the classes in order to reinforce knowledge base structure. The enhancement of the ontology has been provided in three main lines: *(i)* Differentiate concepts definition inside WatERP ontology in order to create a consistent knowledge managing (see Section 2.1.1); *(ii)* include synonyms into the ontology in order to enrich the vocabulary where it is desirable (see Section 2.1.2); and *(iii)* define the coverage in the terms needed for the ontology in order to avoid ambiguity in instances definition (see Section 2.1.3).

2.1.1 Disjoint Concepts

“Disjoint concepts” in the ontology is the mechanism to limit the pertinence of the same individual into two different classes. In WatERP ontology, disjoint classes are dependent of taxonomy level. This mechanism is applied to avoid the semantic inconsistence at population stage. Semantic inconsistency at population stage refers to an individual pertaining into two different concepts that are semantically incompatible between them. Furthermore, separating ontology concepts between them produce into the ontology a clear and unique term definition. As a consequence, classes in the ontology (mathematical groups) do not have natural intersection (relations) between them. The intersections (relations) between classes are defined using object properties (ontology relations) that provide the needed mechanism to understand relations between the concepts.

In the WatERP ontology, the disjoint mechanism has been applied by each taxonomy level. That is, definition of terms that form part of the same taxonomical level has been studied. In the study, it has been evaluated whether it is necessary to separate the concepts or on the contrary, instances of a specific entity can be a member of more than one entity at the same time (ontological instantiation). In the first taxonomical level of WatERP ontology, disjoined classes are described mathematically in Formula 11.

$$Actions \not\equiv \{Actors, Alerts, Features\_Of\_Interest, Observations, Offerings, Phenomenon, Procedure, Results, Water\_Resources\_Management, Water\_Uses\}$$

Formula 11 "Disjoint between main WatERP entities"

As an implicit definition from Formula 11, if entity "*Actions*" is disjoined from the classes included into the brackets, each entity in the brackets are disjoined between them and "*Actions*" entity. This procedure is called heritage disjoint.

Using same procedure, disjoined classes have been defined in the second taxonomy level (Figure 12) between sub-concepts that take part in each entity from the first taxonomy order.

$$Errors \in Alerts \not\equiv \{Information\}$$
$$EnvironmentalPhenomena \in Phenomenon \not\equiv \{TechnicalPhenomena, Socio-EconomicalPhenomena\}$$
$$TechnicalPhenomena \in Phenomenon \not\equiv \{(EnvironmentalPhenomena, Socio-EconomicalPhenomena) \sqcup (InfrastructurePhenomena, Socio-EconomicalPhenomena\}$$
$$biologicalParameters \in Procedure \not\equiv \{physicalParameters, chemicalParameters, infrastructureparameters, socio-economicParameters\}$$
$$Point \in Results \not\equiv \{TimeValuePair, TimeSeriesObservation\}$$
$$Agricultural\_Use \in Water\_Uses \not\equiv \{Environmental\_Use, Industrial\_Use, Recreational\_Use, Urban\_Use\}$$

Formula 12 "Second Taxonomical Order Disjoint classes"

An example of disjoint is defined for the sub-concepts of "*Water_Uses*" entity (Agricultural, Industrial, Recreational and Urban uses). They separate different water uses between them in order to clearly identify correspondent water uses that depends on specific elements of water resource management.

Finally, in the WatERP ontology has been applied around 500 disjoint classes in the lower taxonomical levels.

2.1.2 Equivalent Concepts

Equivalence between classes is needed in order to introduce similarity between concepts inside the ontology. In the water supply and distribution chain there are concepts that have the same meaning but in different entities because of the categorization. As an example, in the WatERP ontology the terms "*water_Quality*" and "*Ground_Water_Quality*" are defined as equivalent concepts the term. These concepts refer to the same meaning ("*Water_Quality*") but in different water stages ("*Ground Water*" and "*Surface Water*").

As described, the equivalency methodology is used to enrich the ontology instead of generating more vocabulary that refers to the same concept. Furthermore, the equivalence definition permits to apply restrictions and rules over equivalent classes since they have the same ontological definitions.

In the WatERP ontology, equivalent classes have been obtained taking into account current developments, water engineers' expertise and generalization of pilots' information. Moreover, this enhancement over the ontology has been obtained studying the concepts defined in the taxonomy. As a result, the WatERP ontology presents around 30 equivalent classes which the most representative are shown on Formula 13.

$$
\begin{aligned}
&Evaporation \equiv \left\{Estuary_{Evaporation}, Lake_{Evaporation}, River_{Evaporation}\right\}\\
&Lake \equiv \{Channel\}\\
&Water_{Level} \equiv \left\{Lake_{water_{Level}}, Reservoir_{Water_{Level}}, Stream_{Water_{Level}}, Aquifer_{Water_{Level}}\right\}\\
&Lake \equiv \{Channel\}\\
&Water_{Level} \equiv \{Lake\_water\_Level, Reservoir\_Water\_Level, Stream\_Water\_Level\}\\
&StreamFlow \equiv \{FlowRateStream, DischargeStream, RiverFlow\}\\
&WaterQuality \equiv \left\{Ground_{Water_{Quality}}, StreamWaterQuality\right\}
\end{aligned}
$$

Formula 13 "WatERP ontology equivalent classes"

In Formula 13, it is described the equivalency between multiple classes (classes between brackets). Equivalence between multiple classes is understood as similarity between all the elements that form part of the equivalency. From an ontology point of view, all of equivalent classes share the same ontological resources between themselves and are viewed as a unique ontological class.

2.1.3 Covering Axioms

In WatERP ontology, covering axioms have been used to divide concepts avoiding ambiguities in the population process. This means that covering axioms permit to divide the concepts into its sub-concepts assuring that instance pertains a specific sub-concept where covering axiom acts. In the present ontology, it has been defined the covering axioms in the entities (concepts) where a new sub-division is unexpected. Hence, these mechanisms to enrich the ontology have been used mostly in the concepts covered by the Formula 14.

$$
\begin{aligned}
&Alerts \equiv \{Error \sqcup Information\} \\
&Phenomenon \equiv \{EnvironmentalPhenomena \sqcup InfraestructurePhenomena \sqcup Socio \\
&\qquad - EconomicPhenomena \sqcup TechnicalPhenomena\} \\
&Procedure \equiv \{BiologicalParameters \sqcup chemicalParameters \sqcup InfraestructureParameters \\
&\qquad \sqcup PhysicalParameters \sqcup Socio - EconomicParameters\} \\
&Results \equiv \{Point \sqcup TimeSerieObservation \sqcup TimeValuePair\} \\
&Water\_Resources\_Management \equiv \{Source \sqcup Sink \sqcup Storage \sqcup Transformation \sqcup Transport\} \\
&Water\_Uses \equiv \{Agricultural\_Use \sqcup Environmental\_Use \sqcup Recreational\_Use \sqcup Urban\_Use \\
&\qquad \sqcup Industrial\_Use\}
\end{aligned}
$$

Formula 14 "Covering Axioms in WatERP ontology"

The Formula 14 describes how the concepts of first taxonomy order are equivalent to the union of its sub-concepts (second taxonomy order). In lower taxonomical levels of the ontology, covering axioms have not been applied because the concepts in that levels correspond with parameters and variables used in water field. These variables and parameters can increase in population stage. For this reason, the groups in the lower levels are not strongly defined (using covering axioms) giving the freedom of including new/specific-case variables and parameters into the mentioned groups.

2.2 Object Properties (relations) Definition

Object properties or ontological relationships are in charge of link concepts between them. The linkage is done semantically, so the concepts are joined together following a specific transformation function with a specific set of property/ies (functional, transitive, symmetric, reflexive and its inverse). In WatERP ontology, relationships has been used to *(i)* querying the information semantically in order to provide treated information to the user via the OMP; and *(ii)* generating knowledge meanwhile analyzing ontological resources towards new ontological paths discovering how to enhance water resources managers' vision of the domain.

Hence, object properties are an important mechanism to define and model the water supply distribution chain. Object properties defined have been extracted from the logic modeling (D1.2 in Section 3) and relationships provided by other ontologies like SSN, WaterML2 and HY_Features that support observation and measurement of the variables defined in the water domain.

A summary of the properties defined in the WatERP ontology is offered on Table 2. This table represents the ontological relation with *(i)* property defined) for the specific relation(functional, inverse, transitive, etc, *(ii)* domain that represent the "*origin*" of the relation, *(iii)* range that represents the linkage of the relation, and *(iv)* inverse that represents the inverse relation that specific relation have. Finally, it is important to highlight that each object property of the table is depicted in the following subsections.

Object Property Name	Functional	Inv.Functional	Transitive	Symmetric	Antisymmetric	Reflexive	Irreflexive	Domain	Range	Inverse
isManagementPartOf								Bulk_Water_Suppliers, Water_Utilities,Regulators	Water_Resource_Management	
isSolvedUsing								Errors	Actions	Solve
isSetOf								TimeSeriesObservation	TimeValuePair,TimeSerieObservation	
isObservedBy								Phenomenon	Observations	hasPhenomenon
hasObservationResults								Observations	Results	
isDependentOf								Water_Uses	Water_Resource_Management	dependsOn
hasProcedure								Observations	Procedure	
takePartIn								Actors	Water_Resources_Manageement	
hasFeature								Water_Resources_Management	FeaturesOfInterest	
has Anomalies								$Actions \sqcup Results$	Alerts	
hasLogicDependence								Water_Resources_Management	Water_Resources_Management	
hasObservation								FeaturesOfInterest	Observation	
Groups								Offerings	Procedure,Phenomenon,FeaturesOfInterest	
Solve								Actions	Errors	isSolvedUsing
hasAssociatedAction								Alerts	Actions	
hasWaterConsumption								End_Users	Water_Resources_Management	
dependsOn								Water_Resources_Management	Water_Uses	isDependentOf
hasPhenomenon								Observations	Phenomenon	isObservedBy
Perform								Water_Resources_Management	Actions	

Table 2 "Object Properties defined in WatERP ontology"

2.2.1 Relation "*isManagementPartOf*"

The relationship "*isManagementPartOf*" is defined as the link that joins actors (domain) of the water resource management (range) with its correspondent part of the water supply distribution chain. With this relationship, it is known who is the user that manages a specific part (or whole) of the water resource management. This relationships has been defined as asymmetric and irreflexive so, the reasoner can inference from this relation that an actor can manage more than one different parts of the water resource management.

2.2.2 Relation "*isSolvedUsing*"

The object property "*isSolvedUsing*" is defined as the property that links errors (domain) with the specific action (range) that solves the defined error. Hence, the mentioned relationship links performed action over water resource management chain with the errors (alerts) occurred. This kind of relation is useful to know the actions used to solve errors and then it permits to the user know which is the state of the ontology and performed actions. This property has defined an inverse relation called "*solves*" to represent the actions that solve specific error (see Section 2.2.14). The present relationship is defined as a direct relation that is irreflexive and asymmetric. The relations is irreflexive because an error cannot be solved using another error (semantically incoherent). Hence, the relation is asymmetric because an action cannot be solved using an error (semantically incoherent).

2.2.3 Relation "*isSetOf*"

The ontological relation "*isSetOf*" is the definition of a time series as a consecution of values during a specific time (defined as "*TimePairValues*"). This relation is defined as symmetric and irreflexive because of each time series can be formed by other time series observation.

2.2.4 Relation "*isObservedBy*"

The relation "*isObservedBy*" represents the observations that are related to specific "*Phenomena*" (water quality, water level, etc). This relationship is used to know the type of variable observed in order to link it semantically with the correspondening time series. This property has an inverse relation called "*hasPhenomenon*" (see Section 2.2.18). The current relation has been defined as asymmetric and irreflexive, so a direct link between phenomenon and observation is done. This means that a specific phenomenon can be included in more than one observation.

2.2.5 Relation "*hasObservationResults*"

This relationship joins observation with specific results ("*Points*", "*TimeSeriesObservation*" and "*TimeValuesPairs*"). By the use of this kind of property it is assured that an observation has been represented by some kind of result. This observation has been defined as functional because if a scenario has more than one time series aligned with one observation, then both time series are the same. Using this kind of property assures that an observation is formed by one time series in a specific instant. Furthermore, this relationship is asymmetrical because a result cannot be an observation. Additionally, the property is irreflexive because an observation cannot be the consequence of measuring a specific variable.

2.2.6 Relation "*isDependentOf*"

The relation "*isDependentOf*" links possible water uses (domain) with water resources management (range). This property defines the water usage in the water supply distribution chain (agricultural, industrial, recreational, etc). This property has been defined as irreflexive and asymmetric because the linkage between water resource management and the water uses are done by the inverse property "*dependsOn*" (see Section 2.2.17).

2.2.7 Relation "*hasProcedure*"

"*hasProcedure*" relation specifies the procedure followed in an "*Observations*" when it observes a "*Phenomena*". Hence, this relation links observations (domain) with individuals in the "*procedure*" concept (range). This relationship has been defined as functional. So, the property has the capability of inferring how different procedures measure the same "Observation". That is, the property assures that an observation only has one measurement procedure. It also assures that if more than one procedure is defined, both procedures must to measure the same variable. Furthermore, the property is asymmetric and irreflexive. Asymmetric property is applied because "procedure" cannot be an observation (disjoint class definition). In addition, this object property is irreflexive because an observation cannot be a procedure.

2.2.8 Relation "*takePartIn*"

Relation "*takePartIn*" is used to represent the actors that are involved in the water supply and distribution chain. By this ontological property, specific actors are related to the whole water resource management chain or to specific parts of the chain. The present property has been identified as functional, asymmetric and irreflexive. Functional capabilities assure that a same actor can be involved in different parts of the water supply distribution chain. Furthermore, asymmetric and irreflexive properties have been included to assure that only functional property is applied and thus avoid inconsistencies.

2.2.9 Relation "*hasFeature*"

"*hasFeature*" property defines, for each part of the water supply distribution chain the real-elements that manage the water ("*Feature of Interest*"). So, the water supply distribution chain is formed by a set of features of Interest (stations, data sources, etc) capable of measuring the specific variables involved in management. This object property is defined as direct relationship where any object property functionality has been applied. Asymmetric and Irreflexive capabilities are used in order to assure that the "*hasFeature*" property links "*WaterResourcesManagement*" (domain) with "*FeaturesOfInterest*" (range).

2.2.10 Relation “*hasAnomaly*”

“*hasAnomaly*” relation is included to understand the source of the “*Alerts*” (or anomalies) where a mismanagement occurs. This relationship joins “*Actions*” or “*Results*” with anomalies indicating that both classes can be a source of errors. “*hasAnomaly*” relation is defined as inverse functional in order to associate specific alert with a specific action or result obtained. Furthermore, this property is defined as symmetric because the alerts can be generated also by other actions or results from other observations.

2.2.11 Relation “*hasLogicDependence*”

“*hasLogicDependence*” relation indicates the representation of logical models inside the ontology. This relationship links all sub-categories of water resources management between each other in order to define the logic scenario to be managed. This property is defined as transitive and symmetric to indicate the influence of all the parts in the water resource management chain.

2.2.12 Relation “*hasObservation*”

Relation “*hasObservation*” represents the observations that a feature of interest has. Hence, a specific feature of interest (station, data source, etc) can monitor and control a set of variables that influence a river, lake, pumping station, etc. So, this property is defined to identify which observations can be measured by a specific “*Feature Of Interest*”. This property is defined as an asymmetric and irreflexive because of “*Observations*” only can be measured by specific variables (“*Features Of Interest*”).

2.2.13 Relation “*groups*”

Relation “*groups*” represent the possibility of making “*Offerings*” (set) of “*Observations*”, “*Procedures*” and “*Phenomena*” in order to define a virtual observation as real. The offering joins these mentioned objects with the possibility of saving a set of observations that are used continuously. This relation is defined as functional because the offering can only be defined uniquely in case of similar offering instance exists (with similar instances of observations, procedures and features of interest).

2.2.14 Relation “*solve*”

“*solve*” relation represents the relation held by “Actions” (domain) and “Errors” (range). This property has been defined to know which actions have been used by the users (or other systems) to solve the alerts occurred in the water supply distribution chain. For this object relation has not been defined any capability (a part of asymmetry and irreflexive) because an action can be used to solve different errors.

2.2.15 Relation "*hasAssociatedAction*"

The "*hasAssociatedAction*" relationship represents the kind of actions that have been applied over the alerts when an observation is done. This relationship is defined as transitive because a specific alert can generate a consecutive application of actions.

2.2.16 Relation "*hasWaterConsumption*"

"*hasWaterConsumption*" defines the actors that consumes water inside the water supply distribution chain. Thus, using this property, the ontology can identify which are the end-users for a specific water resources management chain. This property is defined as functional in order to assure that an end-user only consumes water from the same water supply distribution chain.

2.2.17 Relation "*dependsOn*"

"*dependsOn*" relation represents the different usages that can be applied to water. As it is known, inside the water resources management chain, water is abstracted from sources (and depending on its final usage, can be further treated) in order to satisfy the demand of a set of consumers (domestic, agricultural, industrial, recreational, etc). No relevant capability has been defined for this relation. This relation can be understood as a simple relation where water resources manager can produce water for different uses. Furthermore, this relationship has an inverse object property called "*isDependantOf*".

2.2.18 Relation "*hasPhenomenon*"

"*hasPhenomenon*" relation defines a specific observation as a set of "*Phenomena*" to be observed. The only relevant aspect of this property is the usage of inverse property to associate each phenomena with its corresponding observations ("*isObservedBy*" relation). This property has been defined as asymmetric and irreflexive in order to assure that an "Observation" is formed by a set of "Phenomenas".

2.2.19 Relation "*perform*"

"*perform*" relation represents the actions that have been considered in the water resource management chain. So, this relation is used to know what kind of actions have been applied in the specific water supply distribution chain with the aim of knowing which ones have been applied in the specific parts of the water supply distribution chain. This property is defined as normal (asymmetric and irreflexive) in order to assure that in water resource management it has been applied a set of actions that depend of its behaviour.

2.3 Data Properties Definition

In WatERP ontology, data properties have been used to specify entities detailed definition of values that clarify its provenance. Technically, data properties are mostly used in the querying process in order to detail information to user, locate elements geographically, etc.

Data Properties used in the WatERP ontology are summarized on Table 3. This table shows data properties names with its associated capabilities. Associate capabilities can only be functional to generate similarities once the multiple data properties of the same type are defined into an individual of the corresponding ontological concept (domain). Furthermore, data properties define the range as an ontological data type. Data type can be strings, doubles, dateTime, dateTimeStamp,URI and more (Bechhofer, et al., 2004). To avoid overlapping between data properties, some data properties has been defined as disjoined, so each data property is viewed as a group unrelated to the rest of groups. In the case of "*locationParameters*", the disjoint is heritage into it sub-properties data properties ("*LatitudMap*" and "*LongitudeMap*"). In the following subsections, data properties are depicted.

Data Property Name	**Functional**	**Parent**	**Domain**	**Range**
Region			Actos,Water _Resorurces_Management,FeaturesOfInterest	string
locationParameters			FeatureOfInteres,Water_Resources_Management	
LongitudMap		locationParameters	FeatureOfInteres,Water_Resources_Management	double
LatitudeMap		locationParameters	FeatureOfInteres,Water_Resources_Management	Double
idPhenomenon			Phenomeon	String
Value			Results	Double
Date			TimeValuePair,TimeSeriesObservation	dateTimeStamp
Unit			Observations	String

Table 3 "Data properties description"

2.3.1 Data Property "*Region*"

Data property "*Region*" is defined as a string (range) that acts into "*Actors*", "*Water_Resource_Management*" and "*FeaturesOfInterest*" ontological concepts. "*Region*" data property represents a name of the region (City, valley, etc) where actors manage/consume water, location of water_reosurce management and/or location of specific features of interest. This data property has been included into the ontology because of the need of filtering elements by region and/or city and since it facilitates the visualization of water resources management chain and/or elements by a specific zone.

2.3.2 Data Property "*locationParameters*"

"*locationParameters*" data property represents the specific location (latitude and longitude) of "*Water_Resources_Management*" and "*FeatureOfInterest*". This data property has been included in order to locate in a map the elements that compound water supply and distribution chain elements. Furthermore, this data property has been defined based on WaterML2 that is indeed derived from Geography Markup Language (GML) schema to locate elements in a map (related with the OMP).

Hence, "location parameters" is formed by two data properties "*latitudeMap*" and "*longuituedMap*".

1. **"*LatitudeMap*" data property.** As inherit from it name, this data property indicates the latitudinal position in a map. It has been defined as a double (range).
2. **"*LongitudeMap*" data property**. This data property defines the longitudinal position of a specific point in a map. Similar to latitude, this property is defined as a double (range).

2.3.3 Data Property "*idPhenomenon*"

"*idPhenomenon*" data property represents the unique identification of a phenomena in a standardized way. The entity in charge of creating this standardizations is CF Metadata[4]. This organization has created a list of phenomena measured in environmental field. This kind of identifiers are widely used and supported in WaterML2 language and OGC systems (Observation and Measurement System -O&M-). The main reason to include this kind of identifier inside WatERP ontology is the compatibility with current standards in the water measure phenomena.

2.3.4 Data Property "*Value*"

Data property "*Value*" has been included to associate a specific value into a result class ("*Point*", "*TimeSeriesObservation*" and "*TimeValuePair*"). The associated value to be included in a time series ("*TimeSeriesObservation*"), point or time series instant ("*TimeValuePair*") is a double variable. This data property has been included in the WatERP ontology to specify the observations with values. Furthermore via this data property dynamic rules will be constructed in order to detect anomalous behaviours.

2.3.5 Data Property "*Date*"

"*Date*" data property has been included to associate with a value a specific time stamp or time instant (when necessary). Dates are the basis to construct time series and to then apply an analysis into time

[4] Web page of CF Metadata: http://cf-pcmdi.llnl.gov/documents/cf-standard-names

series in order to study water resource management behaviours. “*Date*” data property is only applicable to “*TimeValuePair*” and “*TimeSeriesObservation*” concept and it is defined as a “*DateTimeStamp*” data type. “*DateTimeStamp*” data type represents a time instant into the ontology. A consecution of multiple time instances (multiple instances) of “*timeValuePais*” will built the time series. Furthermore, present data type has not been defined as functional because in case of applying the attribute to “*TimeSerieObservation*”, this data property serves to indicate starting and ending time of defined time series.

2.3.6 Data Property “*Unit*”

“*Unit*” data property is defined as a string. This data property indicates the kind of measure applicable into an “*Observation*” concept. In WatERP ontology, units are used to know how an Observation is measured. Furthermore, “*Unit*” data property gives proper specification about an observation that is applicable to the result and enhances semantically definitions of visualized time series in the OMP.

2.4 Ontology Restrictions

Ontological restrictions are the mechanism to define rules over the member that take part of specific properties. The restrictions can be understood as a static and generic rules defined in the ontology. This statics and generic rules serve as a driver of making inferences from ontological resources (Staab & Studer, Handbook on Ontologies, 2009). By default, ontology restrictions are defined as necessary conditions. A necessary condition (Figure 9) defines the needed number of conditions to be accomplished by a member of a specific class. That is, if an individual is a member of the class (“Named Class”) then it must satisfy the conditions. However, if some individual satisfies these necessary conditions, it cannot be deduced that it is a member of the “*Named Class*”. Necessary conditions are denoted by symbol ⊏ in ontology restriction formula.

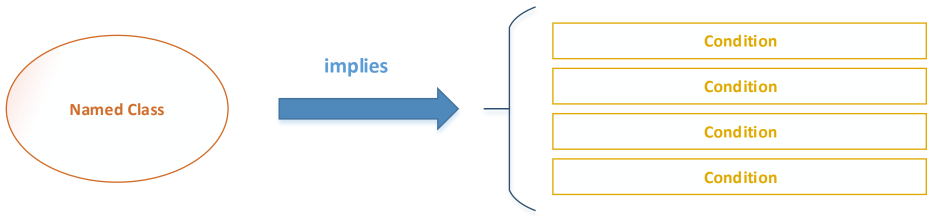

Figure 9 "Necessary ontological restrictions"

In order to enhance inference in some of the classes, necessary and sufficient conditions (Figure 10) permit associate a random and ambiguous member with a specific class. This means, that if an individual is member of “*Named class*” then it must satisfy the conditions. Furthermore, if some individual satisfies the conditions defined then the individual must be a member of “*Named Class*”. Necessary and sufficient conditions are denoted by symbol ⊑ in ontology restriction formula.

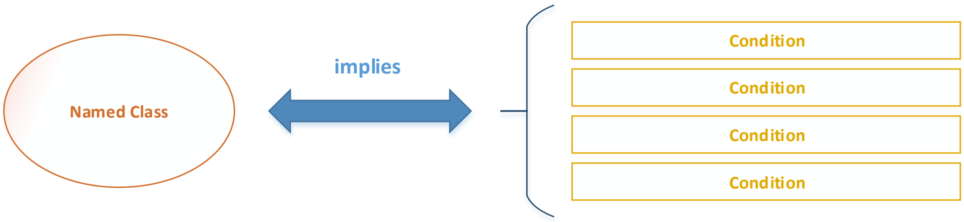

Figure 10 "Necessary and sufficient ontological restrictions"

In WatERP ontology, ontological restrictions have been used to discover new knowledge in the matching between supply and demand by the application of generic rules to be accomplished by each element involved in the water resource management. Furthermore, the use of restrictions permits to understand data provenance and also understand observations in order to select proper information to be provided to the user (data fusion). So, the defined restrictions should permit to associate the elements of the ontology using *(i)* cardinality and quantifier restrictions in order to enhance the relation between classes and *(ii)* application of "*necessary*" and "*necessary and sufficient*" conditions in order to facilitate to the reasoner the inference of individuals inside correct entities in the WatERP ontology. In relation with restriction over present ontology, "*hasValue*" restrictions have not been applied. "*hasValue*" restrictions are not applied because WatERP ontology does not have defined any instance in its generic form. Moreover, in WatERP ontology it is a preference to restrict classes by values and properties instead of specific case. Restriction by "*hasValues*" will be applied in the form of dynamic ontological rules that has DSS provenance based on the analysis and population of each specific scenario.

2.4.1 Restrictions over "*Actions*" Entity

"*Action*" restrictions have been defined as "*necessary and sufficient*" condition that allows to infer as an "Action" the individuals that accomplish the entities conditions. They can be inferred by user interaction and/or expert intuition. As described in Formula 15, "*Action*" entity has defined two conditions. The first condition has been defined as "existential" and links "*Actions*" to "*Alerts*" using "hasAnomaly" relationship. This means that some of the occurred "*Alerts*" in the scenario can be generated by the application of "*Actions*" (erroneous actions). The second condition has been defined as "universal" and links "Actions" to "Errors" using "solve" relationship. This condition represents that errors are solved only by the application of "*Actions*".

$$Action \sqsubseteq \begin{cases} \exists hasAnomalies\ Alerts \\ \forall solve\ Errors \end{cases}$$

Formula 15"Action restriction"

2.4.2 Restrictions over "*Actors*" Entity

"*Actors*" restriction has been defined as a "*necessary*" restriction because "*Actors*" in this ontology is represented as a concept that interacts with "*Water Resources Management*" using the object property "*is part of*". This object property does not have sufficient strength to be a definition of actor if unknown members accomplish all defined restrictions. Present restriction has only been represented by a "*universal*" restriction that describes the way that an actor is involved in water supply distribution chain.

$$Actors \sqsubset \forall takePartIn\ Water\_Resources\_Management$$

Formula 16 "Actors restriction"

As "*Actors*" entity has defined sub-concepts, the Formula 16 is applied as a condition in each of the sub-classes defined. In this specific case, the sub-concepts have also defined specific condition that serve to differentiate one from another. These sub-concepts are: *(i)* "*Bulk_Water_Suppliers*", *(ii)* "*End_Users*", *(iii)* "*Regulators*", and *(iv)* "*Water_Utilities*".

2.4.2.1 "Bulk_Water_Suppliers", "Regulators" and "Water_Utilities" restriction

These entities have included a "*necessary*" restriction because defined conditions refer to the "*interaction*" that these ontological classes have with "Water Resource Management" entity. Defined condition for these entities has been identified as "*existential*". This "*existential*" condition is applied to "*isManagementPartOf*" relation and "*WaterResourceManagement*" concept (Formula 17). This condition is introduced in the WatERP ontology in order to remark management parts of water supply and distribution chain where "*Bulk_Water_Supply*", "*Regulators*" and "*Water_Utilities*" are involved.

$$Bulk\_Water\_Suppliers \sqsubset \exists isManagementPartOf\ Water\_Resource\_Management$$
$$Regulators \sqsubset \exists isManagementPartOf\ Water\_Resource\_Management$$
$$Water\_Utilities \sqsubset \exists isManagementPartOf\ Water\_Resources\_Management$$

Formula 17 "Bulk_Water_Suppliers, Regulators and Water_Utilities restriction"

2.4.2.2 End_Users restriction

"*End_Users*" entity has been enhanced using a "*sufficient and necessary*" condition that defines as a "*End_Users*" any member of "*Actors*" concept that consumes water from any water resource (Formula 18). "*End_Users*" condition has been defined as "*existential*" because not all actors do water consumption over water resources.

$$End\_Userss \sqsubseteq \exists hasWaterConsumption\ Water\_Resources\_Management$$

Formula 18 "End_Users restriction"

2.4.3 Restrictions over "*Alerts*" Entity

In WatERP ontology, "*Alerts*" entity represents a categorization of abnormal behaviours that have occurred during the water resource management. Alerts are based on its level of criticism. A restriction applied to this concept has been defined as a "*necessary*" condition because a restriction over an Alert entity is used to align the alerts with the actions applied in the water resource management. The used condition in "*Alerts*" concept (Formula 19) has been identified as "*universal*" to indicate that all alerts have some "Actions" associated.

$$Alerts \sqsubset \forall hasAssociatedAction\ Actions$$

Formula 19 "Alerts restriction"

This restriction applied to "*Alert*" concept is inherited in its sub-concepts (Errors and Information). Furthermore, "*Errors*" concept has been specified by a "*universal*" restriction indicating that it can be solved using specific actions (Formula 20).

$$Errors \sqsubset \forall isSolvedUsing\ Actions$$

Formula 20 "Error restriction"

2.4.4 Restrictions over "*Features Of Interest*" Entity

In "*FeatureOfInterest*" concept it has been included a "*necessary*" condition to relate this concept with its associated observations. "*Necessary*" condition is defined because double implicitly is not applicable, that is, individuals that have "*Observations*" might not be members of *"Features Of Interest*" concept. The condition applied to this restriction (Formula 21) is identified as "*universal*" to indicate that the use of "*hasObservation*" property is only used with "*Observations*".

$$FeatureOfInterest \sqsubset \forall hasObservation\ Observation$$

Formula 21 "FeaturesOfInterest restrictions"

2.4.5 Restrictions over "*Observations*" Entity

Restrictions applicable to "Observation" concept are related with the possible relation that this entity has. The restriction is defined as "*necessary*" in order to assure that all "*Observation*" members accomplish the identified conditions. In this case, the identified conditions (Formula 22) are three:

- **Results condition** is defined as the possible results that observations acquire over a "*Feature Of Interest*" (station, data source, etc).
- **Phenomenon condition** is used to indicate the kind of variable that the "*Observation*" measures.
- **Process condition** is used to understand the measurement of the "*Observation*" by a specific procedure of measuring.

Both conditions have been defined as "*existential*". However, object properties defined for these conditions are sufficient restricted that there is no difference between "*existential*" and "*universal*" restrictions.

$$Observation \sqsubset \begin{cases} \exists hasObservationResults\ Results \\ \exists hasPhenomenon\ Phenomenon \\ \exists hasProcedure\ Procedure \end{cases}$$

Formula 22 "Observations restriction"

2.4.6 Restrictions over "*Offerings*" Entity

"*Offerings*" is the grouping of "*Features Of Interest*", "*Phenomena*" and "*Procedure*" into a virtual variable name. Then, "*Offerings*" restriction is defined as a "*necessary*" condition in order to assure that this entity is formed by grouping any kind of "*Features Of Interest*", "*Phenomena*" or "*Procedure*" (Formula 23). The object property "groups" condition is identified as "*universal*" to indicate that all offerings group specific kind of variables.

$$Offerings \sqsubset \forall\ groups\ (FeatureOfInterest\ \sqcup Phenomenon\ \sqcup Procedure)$$

Formula 23 "Offerings restriction"

2.4.7 Restrictions over "*Phenomenon*" Entity

"*Phenomenon*" restriction is defined as "*necessary*" condition in order to assure that a "*Phenomenon*" is observed by some "*Observations*" (Formula 24). The condition identified has been defined as "*existential*". However object properties defined for these conditions are sufficient restricted that there is no difference between "*existential*" and "*universal*" restrictions.

$$Phenomenon \sqsubset \exists\ isObservedBy\ Observations$$

Formula 24 "Phenomena restriction"

2.4.8 Restrictions over "*Results*" Entity

"*Results*" concept has been defined as "*necessary*" restriction that indicates anomalous results which generates alerts. The usage of necessary restriction is focused on categorizing the abnormal results in order to know which kind of alert is associated with the result. The condition that links results to the alerts has been defined as universal because all the results linked to this relationship are defined as alert.

$$Results \sqsubset \forall\ hasAnomalies\ Alerts$$

Formula 25 "Results restriction"

These restrictions are inherited by all sub-categories of the class ("*Pair*", "*TimeSeriesObservation*" and "*TimeValuePair*"). However, "*TimeSeriesObservation*" concept has a special mention. It is defined by a specific restriction. The specific restriction describes the time series ("*existential*" condition) as a set of consecutive values in a certain time interval (Formula 26). This concept is defined as a "*necessary*" restriction.

$$TimeSerieObservation \sqsubset \forall\, isSetOf\ TimeValuePair$$

Formula 26 "Time Series Observation restriction"

2.4.9 Restrictions over "*Water Resources Management*" Entity

In WatERP ontology, water resources management is one of the main entities. Restriction applied into this entity has been defined as "*necessary and sufficient*" because the conditions identified permit to generate a complete definition of the water supply distribution chain including interrelation between water resources, considered actions, water uses and the real-elements that monitor the specific variables for each water resource (Formula 27). Relations or conditions applicable to this concept have been summarized as:

- **Water uses generation**. Water resources management depends on the final use of water creating different strategies and treatments depending on the final user ("*existential*" condition).
- **Definition of features of Interest**. In water resource management real-life elements exist permitting to measure each process and to observe the behaviour of the demand. So, the way to interconnect each part of the water resource management with the features of interest is creating an "*existential*" condition that indicates which "*Features Of Interest*" are included in a specific scenario.
- **Logical dependence between elements.** In order to indicate the interconnection between different elements of the water resource management, a logical dependence is defined as a "*universal*" restriction to assure that only elements of water resource management are linked using this object property.
- **Action performance.** In order to know which "*Actions*" are taken into account inside the water supply distribution chain, an "*existential*" condition has been included to indicate that some "*Actions*" have been performed.

$$Water\_Resources\_Management \sqsubset \begin{cases} \exists dependsOn\ Water\_Uses \\ \exists hasFeatures\ FeaturesOfInterest \\ \forall hasLogicDependence\ Water\_Resources\_Management \\ \exists perform\ Actions \end{cases}$$

Formula 27 "Water Resources Management restrictions"

2.4.10 Restrictions over "Water Uses" Entity

In "*Water_Uses*" concept, the defined restriction is identified as "*necessary*". This necessary condition has been defined to include the inverse property of "*dependsOn*" described in the "*Water Resource Management*" concept. So, this restriction permits to identify the water uses of a water resource management ("*existential*" restriction).

$$Water\_Uses \sqsubset \exists\, isDependentOf\ Water\_Resources\_Management$$

Formula 28 "Water Uses restriction"

2.5 Annotations

Annotations are the mechanism to semantically enhance the understanding of the ontology from knowledge engineer point of view. Annotations permit to add to the ontology any type of technical description about the ontological resources, to add meta-data information in an automatic human-readable ontological concept (useful to automatic understanding of the ontology), and it also allows to link the ontology to external resources (mappings) in order to acquire and offer ontological resources to the rest of the world and furthermore, make the ontology more accessible to third parties and also more interoperable.

In the WatERP ontology, annotations have been used to *(i)* improve understanding of ontological resources by the incorporation of description in all parts; *(ii)* define labels in order to make automatically understandable the ontology from the crawling point of view, *(iii)* standardize the ontology by the linkage to representative ontological resources and XML (WaterML2) resources, and *(iv)* link the ontology to external resources for knowledge sharing through external resources.

All these all features have been focused on defining ontological labels, comments and mappings that permit to enrich the ontological resource with meta-data information. The definitions of these ontological pieces are important to audit and to facilitate the edition of the ontology from thirds parties (external knowledge engineers).

2.5.1 Labels

Labels allow the ontology to add meaningful, human readable names to ontology elements such as classes, properties, data properties and individuals. Technically, labels are meta-data information inside the ontology that permits automatic understanding in order to link the ontology in the semantic web.

In the present ontology, labels are used to define a name for the ontological resource with the aim of offer different tools the possibility of reading and understanding the ontology automatically. This mechanical understanding of the ontology has the benefit of offering ontological resources in open web-semantics like Simple Knowledge Organization System (SKOS)[5], DBPedia[6] and/or LODC[7].

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[5] SKOS Web Page: http://www.w3.org/2004/02/skos/

[6] DBPedia Web Page: http://dbpedia.org/About

[7] Linked Data Cloud Web Page: http://linkeddata.org/

Labels in WatERP ontology (Figure 11) have been defined for the entities, object properties and data properties. As the ontology is generic, no individuals are included in this ontological representation. Proper annotations over the instances will be done in the population process. Furthermore, in the population process to feed the ontology, a mechanism of automatic annotation will be developed.

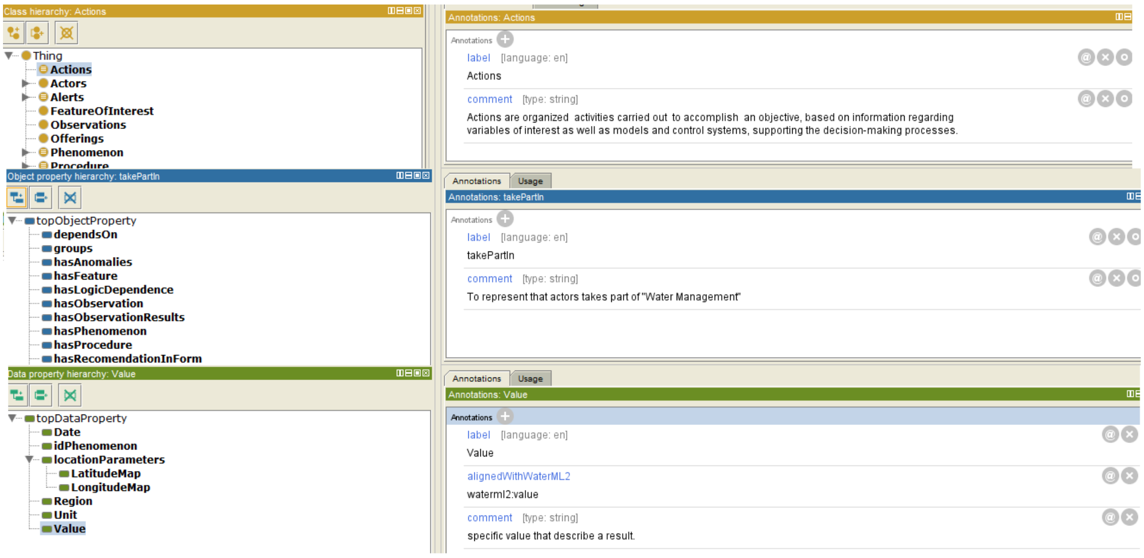

Figure 11"Label definition in WatERP ontology"

2.5.2 Comments

The inclusion of comments into the ontology creates the benefit of a better understanding of ontological resource by the use of natural-language. Comments are defined as a string and support an intrinsic benefit for knowledge engineers in order to edit and use the ontological resources defined in the ontology. Therefore, comments add to the ontology extra information that supports the understanding of the ontological resources defined to modelling the water supply and demand chain.

In WatERP ontology, comments (Figure 12) have been included in ontological entities, object properties and data properties. As the WatERP ontology is generic, some instances have been defined. So, comments are not applicable over this ontological resource. However, specific ontological cases will be driven by a population process so automatic annotation will be developed in this stage to include corresponding comments into the instances.

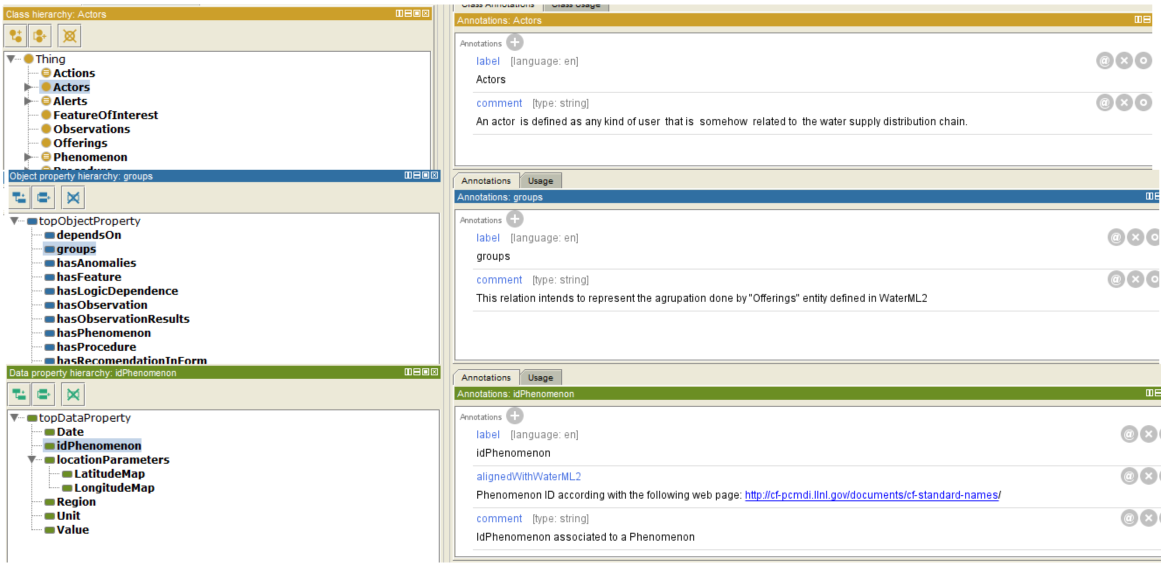

Figure 12 "Comment definition in WatERP ontology"

2.5.3 Ontological Mappings

Ontological mappings are the mechanism to link the ontological resources with to external ontologies or ontological resources. Mappings offer the benefit of *(i)* standardize the concepts defined in the ontology by the linkage between representative organization such as NASA, National Institute of Standards and Technology (NIST), etc; *(ii)* share ontological resources with the aim of enhancing other ontological resources; and *(iii)* improve understanding of data provenance by linking the ontology to the rest of the semantic world.

In WatERP ontology, mappings have been considered taking into account the most representative hydrological ontologies developed (CUAHSI and SWEET). Moreover, observation measurement ontology like SSN has been taken into account in order to align WatERP observations with a standardized mechanism. Also, the ontology has been mapped with hydrological XML schemas (HY_FEATURES) and hydrological exchange data languages (WaterML2) with the benefit of *(i)* follow the consideration in hydrological observation given by the OGC; and *(ii)* align WatERP ontological development with domain knowledge developments and standardized data language sharing developed by OGC.

2.5.3.1 CUAHSI mappings

CUAHSI ontology (Open Geospatial Consortium Inc., 2010) is the most representative hydrological ontology that has been included into OGC standards to model hydrological concepts. This ontology defines the hydrological water cycle from natural paths point of view. In the WatERP ontology, the mappings with this ontology are focused on acquiring natural water paths and its most representative variables are used in order to create the mechanism to include the human-engineered water paths. So, the mappings elaborated for CUAHSI ontology permits to include into the WatERP ontology the needed variables and basic categorization of the elements.

Technically, CUAHSI mappings have been defined as ontological entities resources because of CUAHSI ontology has a lack of definition of object properties resources. In order to provide a linkage and meta-information about the mapping, a new tag into WatERP ontology has been defined. The CUAHSI mapping tag defined is called "*alignedWithCUAHSI*". This "*mark*" (Figure 13) must also include *(i)* a named ontological description with CUAHSI resource; and *(ii)* a URI to access the linked resource in order to complete the mapping.

Figure 13 "CUAHSI mapping"

2.5.3.2 SWEET mappings

SWEET ontology has been designed by NASA (Raskin & Pan, 2003). This ontology conceptualize environmental and earth processes in a standardized way. The benefit of mapping WatERP ontology with this ontology is based on enhancing the definition of water resource management including a standardized definition of hydrological process. Furthermore, the application of this mapping permits to interconnect with other fields the WatERP water supply distribution chain.

Inside WatERP ontology, SWEET linkage has been done using "*alignedWithSWEET*" tag (Figure 14). This meta-data has been included into the WatERP entity "*Water_Resource_Management*" in order to link the WatERP vision of water resource management to the SWEET vision of hydrological cycle. So, the mapping produces link WatERP vision of water resource management (interaction between natural water path and human-engineered water paths) as a kind of hydrological cycle defined by a representative organization (NASA).

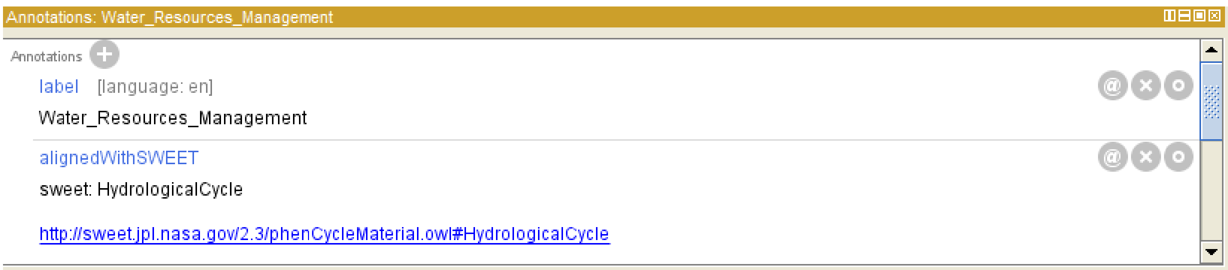

Figure 14 "SWEET mapping"

2.5.3.3 SSN mappings

W3C-SSN ontology (Compton, et al., 2012) is a representative knowledge-base that has been designed with the aim of creating a standardized mechanism to describe an observation process from a system. In the WatERP ontology, SSN ontology has been adapted in regards with OGC recommendations about O&M system. Thanks to this adaptation and mappings definition, a mechanism to obtain the corresponding time series from elements that manages the water supply and distribution chain, is defined. SSN mappings are identified by the "*alignedWithSSN*" tag (Figure 15). Hence, mappings have been applied into WatERP entities (e.g "*Features Of Interest*", "Observations", "*Results*", "*Phenomenon*", etc) and relations (e.g "*hasObservation*") with the aim of describing the essence of the SSN ontology.

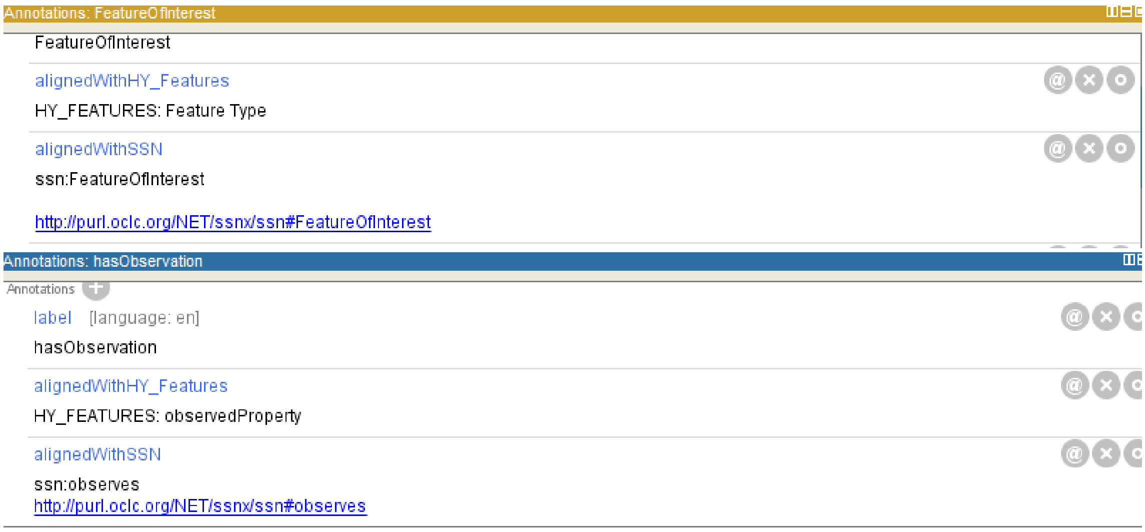

Figure 15 "SSN mappings"

2.5.3.4 WaterML2 mappings

WaterML2 (Open Geospatial Consortium Inc, 2007) is the hydrological language used to exchange hydrological information between systems. This language has been defined as a standard by the OGC and it has been included into the OGC systems to monitor environmental and water cycle. In order to align the ontology with the standards and support the communication in all WatERP infrastructures, a mapping with waterML2 schema has been defined. This mapping has been implemented using "*alignedWithWaterML2*" tag. The meta-data included under this tag is the name of the WaterML2 schema and class that is linked to the WatERP ontological resource. The ontological resources that have been mapped (Figure 16) with the ontology are related with entities (e.g "*Procedure*" and "*Results*"), and data properties (e.g "*date*", "*idPhenomenon*", "*unit*", "*value*", etc).

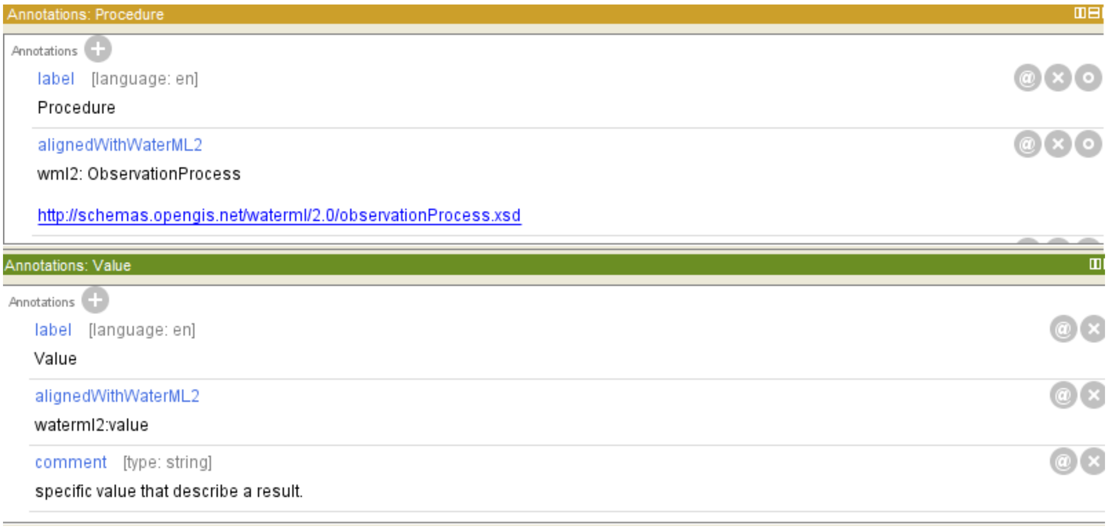

Figure 16 "WaterML2 mapping"

2.5.3.5 HY_FEATURES mappings

HY_FEATURES (Open Geospatial Consortium, 2012) is the result of current efforts done by the OGC in order to define a standard ontology for the water domain. The current status of this ontology is a draft and so, only a schema of the resources has been defined. The concept of this ontology is similar of the adopted in CUAHSI ontology, that is, it models natural paths of the water cycle. As CUAHSI ontology, HY_FEATURES has also included chemical, biological and physical aspects in other to depict the interaction with the environment. The improvements of HY_FEATURES over CUAHSI has been summarized as *(i)* definition of proper semantics relation between hydrologic features (called HY_FEATURE); *(ii)* create a mechanism to domain-specific instances (e.g "*GF_FeaturesType*"); *(iii)* definition of meta-data concept inside the ontology (annotation); and *(iv)* usage of Linked Data principles (identification of resources by URIs).

WatERP knowledge-base development improves HY_FEATURES ontology by *(i)* modeling natural water paths with human-engineered; *(ii)* using meta-data information (annotation) in order to standardize and make more readable the ontology; *(iii)* using of Linked Data principles (URIs resource identification) in order to make accessible the ontology and then, generate interaction with semantic world; *(iv)* developing a mechanism that supports ontology inference over the water ontological resources in the water supply and distribution chain; and *(iv)* using knowledge discovering mechanism and mappings in order to elaborate a strategy for data provenance.

In spite of the difference with HY_FEATURES, in the WatERP ontology it has been implemented the corresponding mapping with this ontology in order to adapt current developments in hydrological field towards the actual and future standardization mechanisms. So, the mappings with this hydrological ontology have been done using "*alignWithHY_FEATURES*" tag (Figure 17). This tag has been applied in WatERP entities (e.g “*Features Of Interest*”, “*Observations*”, etc) and ontological relations (e.g “*hasObservation*”).

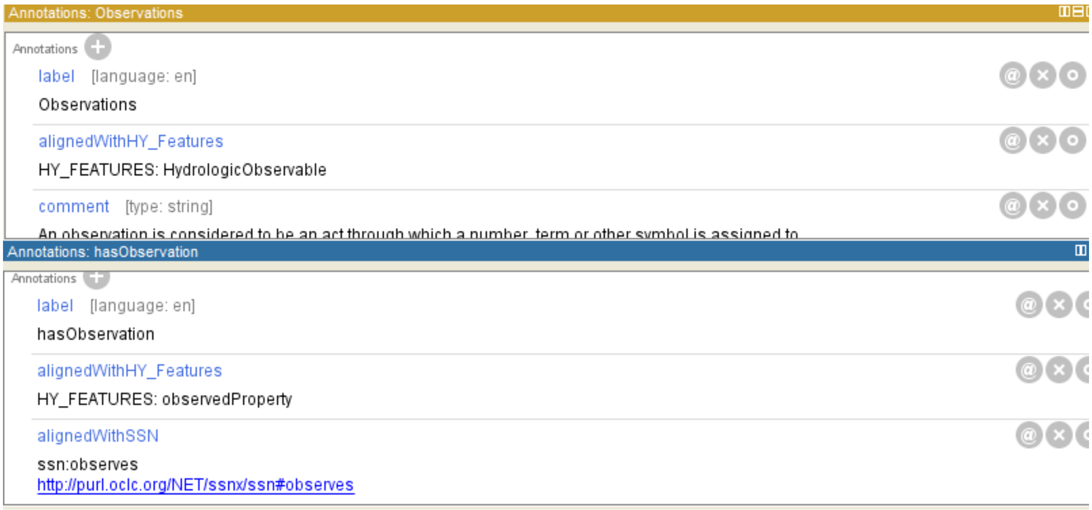

Figure 17 "HY_FEATURES mapping"

3. WatERP Ontology Implementation

Ontology implementation permits to establish the bases to extract meaningful knowledge from the WatERP ontology. Knowledge is transmitted to the user through OMP and then the user is able to interact with the knowledge base. In this process of knowledge-extracting, reasoning mechanism over the ontology is a key aspect. Indeed, reasoning is focused on analyzing the ontological resources towards inference generation. However, ontological reasoning also includes the querying aspect over ontological inferences/resources in order to fully accomplish the knowledge generation. This reasoning process over the ontology is generated by the reasoner. Therefore, reasoner selection permits to define how to exploit ontological resources taking into account the ontological language expressiveness used (e.g. $\mathcal{SHOIQ}$). Then, a strategy to select a reasoner (Section 3.1) should be elaborated in order to give to the user accurate knowledge.

Based on reasoner selection, ontological resources and definitions should be analyzed and refined in order to make the ontology consistent for a selected reasoner (Section 3.2). A consistency analysis permits to make a fast test of the ontology describing the facts inferred. Once, the generic ontology has been completely defined, an example of ontology instantiation is presented in order to depict the scenario where decisions will be made (Section 3.3).

3.1 Reasoner Selection

In WatERP ontology, the reasoner is an artificial intelligence mechanism that understands expert-knowledge implemented to (i) obtain new knowledge based on hidden relations between ontological entities, (ii) permit to query the ontological knowledge across navigating by the entities using the relations between them.

To accomplish these tasks, entities, object/data properties, annotations and restrictions that represent the expert-user knowledge are used by the reasoner. All ontological definitions are translated into logics. So, the reasoner is strongly related with the expressivity (kind of logics) that it can understand. As logics are more understandable, more richer can be the ontology definitions and more specific can be the inferred knowledge. Derived logics from the ontology are refined using reasoning properties such as soundness property (it only proofs the logics that are valid in respect to the semantics) and completeness property (it studies the consequences of a set of sentences that can be derived from a deduction). Additionally, logics are a starting point to use learning techniques such as satisfiability (e.g. tableau) and optimization (e.g. consequence-based) algorithms that generates a knowledge hierarchy (knowledge map). This knowledge map is used to infer proper knowledge over the instances of the ontology by (i) direct relations derived from ontological definitions, (ii) new relations inferred from the learning of the ontological relations properties, (iii) new individuals classification using the restrictions defined in the ontology, and (iv) new equivalences definition based on the entities specification.

Furthermore, in the WatERP ontology it is also important the A-box reasoning which means querying the ontology in order to "*navigate*" throughout the knowledge-base to provided demanded information by the user and display it by the OMP. Additionally, A-box reasoning permit to exploit new knowledge about matching supply and demand by the application of temporal inferences over the ontology and/or it uses existent inferences to exploit known relation between water resources, observation, phenomena and current state of the water resource management chain. Since interoperability is one of the most important objectives of WatERP, relations between the ontology and the systems that directly use the ontology have to be built in an open environment. Used reasoning tools must be compatible with the most used open standards (e.g. OWLAPI, JENA and/or NeoN toolkit), open licensing and programming languages. From an ontological engineering point of view, the reasoner also should permit consistency checking. Consistency checking serves as a driver to construct the ontology and proper justifications that support the understanding of the mechanism that the reasoner has used to infer hierarchical ontology decisional tree.

Nowadays, there are a wide number of reasoners in the ontological engineering environment (Abburu, 2012)(Dentler, Cornet, ten Teije, & de Keizer, 2011)(Kang, Li, & Krishnaswamy, 2012). A set of the most used are described in Table 4. Accomplishing WatERP ontology needs, the selected reasoner is Pellet (Sirin & Parsia, 2004). The main reason for this decision is the ontological WatERP expressivity ($\mathcal{SHROIQ}(\mathcal{D})$), the possibility of including dynamic rules (SWRL) and A-Box reasoning (SPARQL). Moreover, Pellet reasoner also provides support with the most used libraries of ontological exploitation such as OWLAPI (Horridge & Bechhofer, 2011) and JENA[8]. A minor but also important reason is the coverage with our ontological development environment that is mostly based on JAVA.

Features/Reasoner	ELK reasoner (Kazakov, Krötzsch, & Simancík, 2011)	CEL (Baader, Lutz, & Suntisrivaraporn, 2006)	FaCT++ (Tsarkov & Horrocks, 2006)	HermiT (Glimm, Horrocks, Motik, & Stoilos, 2010)	Pellet (Sirin & Parsia, 2004)	RacerPro (Haarslev, Hidde, Möller, & Wessel, 2011)	Snorocket (Lawley & Bousquet, 2010)	TrOWL (Thomas, Pan, & Ren, 2010)
Methodology	*Consequence-based algorithm*	*Completion Rules*	*Tableau Based*	*Hypertableau Based*	*Tableau Based*	*Tableau Based*	*Completion Rules*	*Completion Rules*
Soundness	*YES*	*YES*	*YES*	*YES*	*YES*	*YES*	*YES*	*YES*
Completeness	*YES*	*YES*	*YES*	*YES*	*YES*	*YES*	*YES*	*YES*
Expressivity	$\mathcal{EL}$	$\mathcal{EL}+$	$\mathcal{SROIQ}(\mathcal{D})$	$\mathcal{SROIQ}(\mathcal{D})$	$\mathcal{SROIQ}(\mathcal{D})$	$\mathcal{EL}+$	$\mathcal{EL}+$	$\mathcal{SROIQ}$
Rule-Support	*YES (Own Format)*	*NO*	*NO*	*YES (SWRL)*	*YES (SWRL)*	*YES (SWRL)*	*NO*	*NO*
Justifications	*NO*	*YES*	*NO*	*NO*	*YES*	*YES*	*NO*	*NO*
Consistency checking	*YES*	*NO*	*YES*	*YES*	*YES*	*YES*	*NO*	*YES*
A-Box Reasoning	*NO*	*YES*	*YES*	*YES*	*YES (SPARQL)*	*YES (SPARQL,nRQL)*	*NO*	*YES (SPARQL)*
Licensing	*Apache License 2.0*	*Apache License 2.0*	*GLGPL*	*GLGPL*	*DULI: AGPL*	*Pay License Closed Source*	*Apache License 2*	*DULI: AGPL*
NeoN support	*NO*	*NO*	*NO*	*YES*	*YES*	*NO*	*NO*	*NO*
Protegé Support	*YES*	*YES*	*YES*	*YES*	*YES*	*YES*	*YES*	*YES*
OWLAPI support	*YES*	*YES*	*YES*	*YES*	*YES*	*YES*	*YES*	*YES*
JENA Support	*PARTIALLY*	*NO*	*NO*	*NO*	*YES*	*NO*	*NO*	*YES*
Implementation Language	*JAVA*	*LISP*	*C++*	*JAVA*	*JAVA*	*LISP*	*JAVA*	*JAVA*

Table 4 "Reasoning selection based on (Dentler, Cornet, ten Teije, & de Keizer, 2011)(Abburu, 2012)"

3.2 Consistency Check

The selected reasoner permits to check the ontology consistence before generating the hierarchical structure and facilitates the ontology construction to the ontological engineer. During WatERP ontology construction, the consistency check permits to refine the restrictions in order to adequate the ontological resources and its relations to the domain reality.

[8] JENA documentation: http://jena.apache.org/documentation/rdf/

Current state of the WatERP ontology is consistent (Figure 18). That is, all relations, restrictions and rules defined in the ontology permits to create a satisfiable state where all classes are classified and related based on the logics defined in the general ontology. Satisfiable state is reached when a hierarchical decision tree classify all classes under its corresponded branch in the tree avoiding inconsistencies and non-categorized elements (elements under "*Nothing class*").

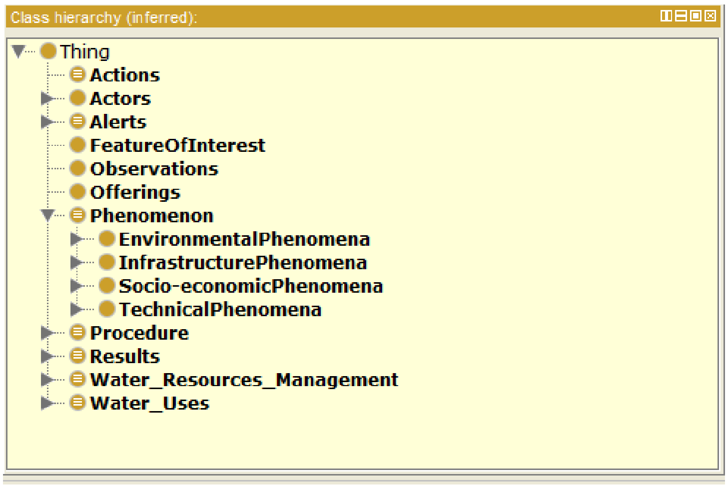

Figure 18 "WatERP ontology consistency check"

However, consistency proof does not assure that the logics defined in the WatERP ontology are adequate for the domain. In order to check the WatERP ontology functionality, a test over the ontology will be developed during the next months in order to incrementally enhance the present ontology with water management domain and pilots reality (Deliverable 7.1.1 "*Holistic Auditing*"). This test measures ontological metrics such as scalability, depth consistency, taxonomical structure, relations etc. Moreover, this test will check ontological functionality using the competence questions defined in D1.1.

3.3 First Implementations

This part is focused on showing a first implementation of pilot's logics models described in the D1.2 into the ontology. Fully implementation of the scenarios including more detailed information will be presented in the Deliverable 1.4.1 "Extension of taxonomy and ontology to the pilots". The mentioned deliverable is iterative so the ontology and its population process will be incrementally enhanced in order to accomplish pilot's needs. The ontology instantiation performed in this deliverable has been based on the information gathering from pilots and its logic model definition. Hence, each water resource identified in the pilots has been categorized based on its behaviour in sink, source, storage and transformation element. Relation between water resources categories for each pilot has been performed by the use of "*logical dependence*" that represents water flow inside each pilot. Finally, the ontology also considers the dependency between each element of the pilots and then first points in the way of manage water resources.

3.3.1 ACA

The first implementation over ACA pilot corresponds to user history that represents the water supply distribution chain for the system formed by LLobregat and Cardener Rivers (Figure 19). This system contains a set of different elements (image boxes) that should be monitored in regards with water resource management decision-making process. By each element that compounds the LLobregat-Cardener system, a relation is defined (image line between boxes) in order to represent the influence between elements. In the instantiation is showed all the sources elements such as rainfalls, aquifer and water transfers from the Ter river (e.g Precipitation in the Upper Cardener Basin, Precipitation in the Upper LLobregat Basin, Non regulated water from LLobregat, etc). Some of these sources elements (e.g. Precipitation in the Upper Cardener Basin and Precipitation in the Upper LLobregat Basin) are linked with storage elements that correspond with a reservoir or reservoir system (the Cardener reservoirs system encompasses La LLosa del Caball and Sant Ponç Reservoirs). Some of the storages elements (e.g. Cardener reservoir System and La Baells reservoir) and sources elements (e.g. non-regulated water from lower Cardener basin, non regulated water from the LLobregat sub-basin between the reservoir downstream and Castellbell gage station and non-regulated water from Llobregat sub-basin between Castellbell-Arbrera gauge station) flow through the transformation entities. As its name indicates, transformation entities produce a transformation, like adding water from different sources, abstracting water from the river for different purposes (satisfying the irrigation demand, feeding the treatment plants, etc). Furthermore, transformation entities might be linked to the sinks elements (such as Canal de la Dreta Irrigation Channel) or other transformations (e.g. Cardener transformation is linked to Castellbell Transformation, Abrera gauge station transformation is linked to Abrera Treatment Plant).

The design of this ontological instantiation based on the logical model is useful to make decisions about how to manage the water inside Ter-LLobregat supply distribution chain. Hence, this representation shows how to match supply (sources) and demand (sinks) as efficiently as possible.

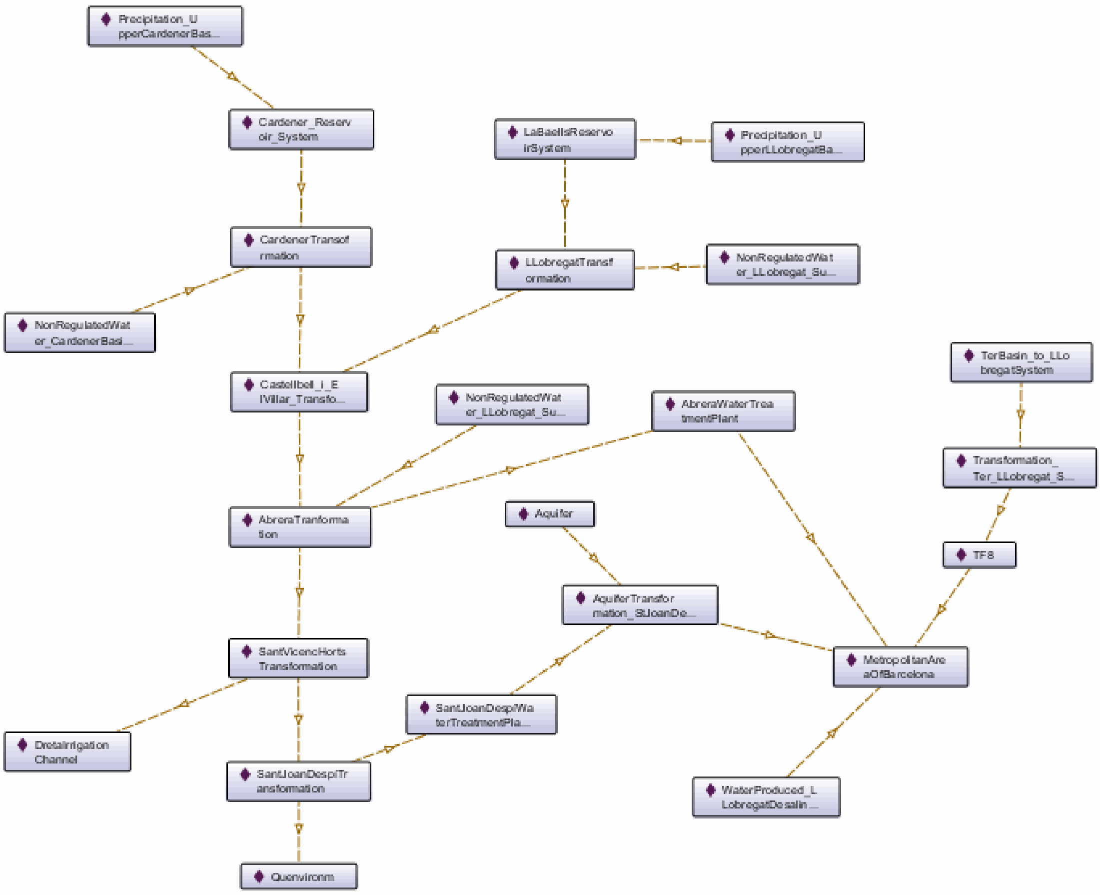

Figure 19 "ACA elements instantiation"

3.3.2 SWKA

The instantiation defined for SWKA pilot represents the zones in which the Karlsruhe supply network is divided. Hence, the Figure 20 describes how water is abstracted from the aquifers to supply the Karlsruhe areas by transporting the water through the network.

Instances that take part of this representation describe most common urban distribution system. The main aim of this pilot is to reduce energy consumption when water is abstracted and distributed to satisfy Karlsruhe demand. Therefore, this representation has modelled water sources (e.g. Aquifer Hasrdtwald, Aquifer, Mörscher, Aquifer Rheinwald and Aquifer Durlacher) that represent the groundwater aquifers from the city (all the drinking water in Karlsruhe comes from aquifers). All water sources feed the storage elements with water. Storage elements (e.g. tank of Hasrdtwald, tank of Mörscher, tank of Rheinwald and tank of Durlacher) in the city of Karlsruhe are represented by tanks that are connected with the main reservoir (the main reservoirs that ensure the water supply in the city). This main reservoir is in charge of distributing the water to the city by transformation elements.

Transformation elements (e.g. HW pumping, MW pumping, RW pumping and DW pumping) are represented by pumping stations that carry water form tanks to specific zones. At the end of the process, sink elements are located. These elements represent the three areas in which the distribution network is sub-divided (Karlsruhe North, Karlsruhe South and Karlsruhe city).

This instantiation is simpler than the ACA pilot. However, this represented scenario is complex enough to provide recommendations and actions based on SWKA user history. This is, to propose schedules for pumps in order to improve energy efficiency and water leaks detection by supplying and demanding comparison all along the distribution pumping network.

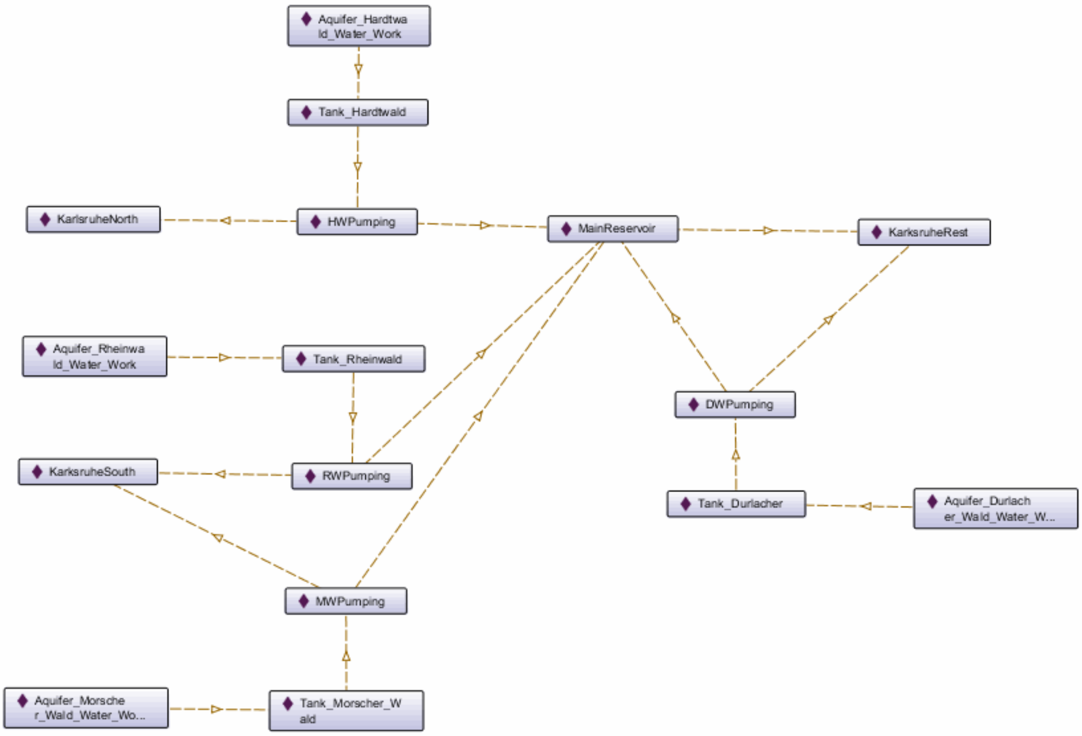

Figure 20 "SWKA elements instantiation"

4. Conclusions and Future Work

This section summarizes conclusions and results (Section 4.1) obtained from the work developed in the "*Task 1.4- Generic Water data ontology*". This task was started on month 6 (M6) of the project and a first version of the ontology is presented in current month (M8). As mentioned during the deliverable, the knowledge-base development is an iterative process where currently it has been completed a first "*implementation*" and "*population/instantiation*" stage is going to be started.

The future work (Section 4.2) related with this document will be focused on establishing the state of the ontology by testing it, elaborating an ontological population strategy and enhancing the ontology according to testing processes, incremental developments over the pilots and additional needs that can appear in the pilots.

4.1 Conclusion

The knowledge base developed in the WatERP project is capable of encompassing hydrological elements (natural and human engineered elements) with all factors and entities that the actors of the water supply and distribution chain must consider in order to acquire WatERP main goals: *(i)* improve coordination among actors, *(ii)* foster behavioral change, *(iii)* reduce water and energy consumption, *(iv)* optimize resource flows and *(v)* improve water governance in line with the Water Framework Directive (WFD).

As a result of the above considerations, the WatERP ontology has been constructed using NeoN methodology. The resultant ontology is able to represent and organize the knowledge of the water resource management chain in order to give support in general decisions (e.g. water allocation in all chain) without losing attention to specific knowledge in each stage of the water management chain. So, developed ontology is a mechanism to provide water organizations with the vision of the knowledge they have and the needed knowledge for future resource management.

Furthermore, the ontology has been developed taking into account LODC principles in order to make accessible the water ontological resources to the rest of the WatERP architecture and third parties that can use WatERP ontology as a driver to enhance water resource management. LODC principles are completed by ontological annotations that permit to enrich the ontology capacity of understanding the environment and data provenance. Moreover, ontological annotations permit to make more understandable (human-readable) the ontology by automatic semantic tools such as crawlers. This capacity gives the ontology the benefit of reusability of ontological resources in other related domains. In addition, WatERP ontology includes linkages (mappings) in order to standardize its ontological resources and provides the capacity of abstraction and perception in time of querying and information visualization (A-box reasoning). Data fusion concept has also been included into the ontology in order to associate different measures from different data sets that correspond with the same entity. This understanding of the measure has been provided by the representation of the process of "Observation & Measurement" that permits to link semantically all concepts that are represented in the water supply distribution chain.

In summary, the description of data properties, object properties, entities behaviour, restriction definition, reasoner selection and consistency check have been portrayed in this document. Due to ontological resource description, the WatERP ontology has been defined based on user needs, problem description and other relevant standards used in the water resource management (OGC, CUAHSI, SSN, etc). So, the WatERP ontology accomplishes marked principles of standardization, in alignment with water resource management domain and open interoperability with other systems.

4.2 Future Work

Technically, knowledge-base presented in this document will be incrementally enhanced and refined throughout the WatERP project. However, at this point, the ontology development will be focused on defining a population strategy in order to create specific scenarios for the pilots that serve to test the validity of the domain knowledge. The strategy to automatic populate the ontology will consist of feeding the ontology with instances and automatic needed annotations.

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6. Appendix A: WatERP Ontology

The complete definition of the ontology has been attached in a file called "*WatERPOntology.owl*".

As mentioned in this deliverable, ontology has been represented in a OWL file. To open/editing the ontology an Integrated Development Environment (IDE) is needed. In the WatERP project, the selected IDE for ontology development has been Protégé. Installation process of Protégé has been included in the D1.1 in section "*Appendix A*" titled as "*Taxonomy*".

Once Protégé has been installed, to open the ontology it is needed to execute the software and click on "*Open OWL Ontology*" button (Figure 21). If no page is shown, to open an ontology it is needed to click on "File>Open" and then, the file selection window must be opened.

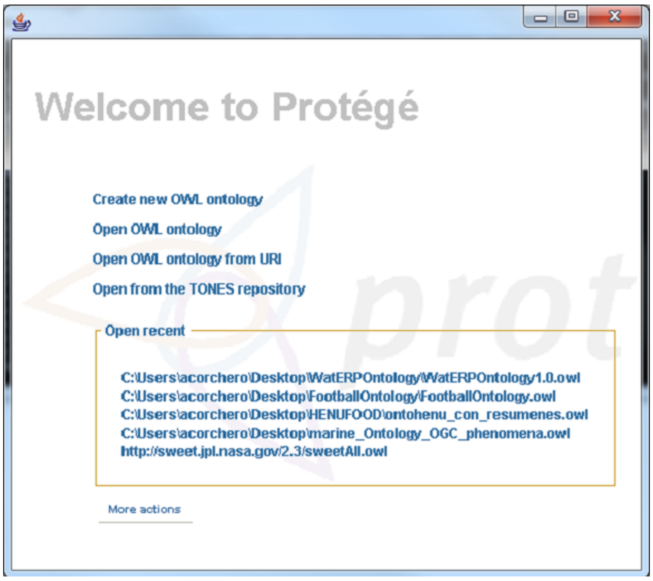

Figure 21 "Protégé main window"

Before clicking the mentioned button, a file selector window must be opened (Figure 22). At this point, it is needed to find the ontology file inside the file system ("WatERPOntology.owl") and pulse "*Open*" (in the figure called "*Abrir*"[9]).

[9] "*Abrir*" in Spanish language means "*Open*".

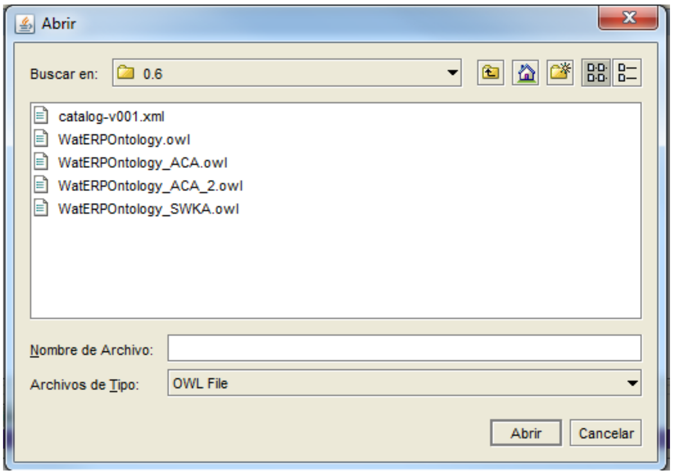

Figure 22 "Open WatERP Ontology"

Once the ontology has been opened, the ontology must be initialized (Figure 23) in Protégé IDE. Initial ontology page ("*Active Ontology*" tab) shows an ontology description, ontology version information (also including previous version information) and ontology URI.

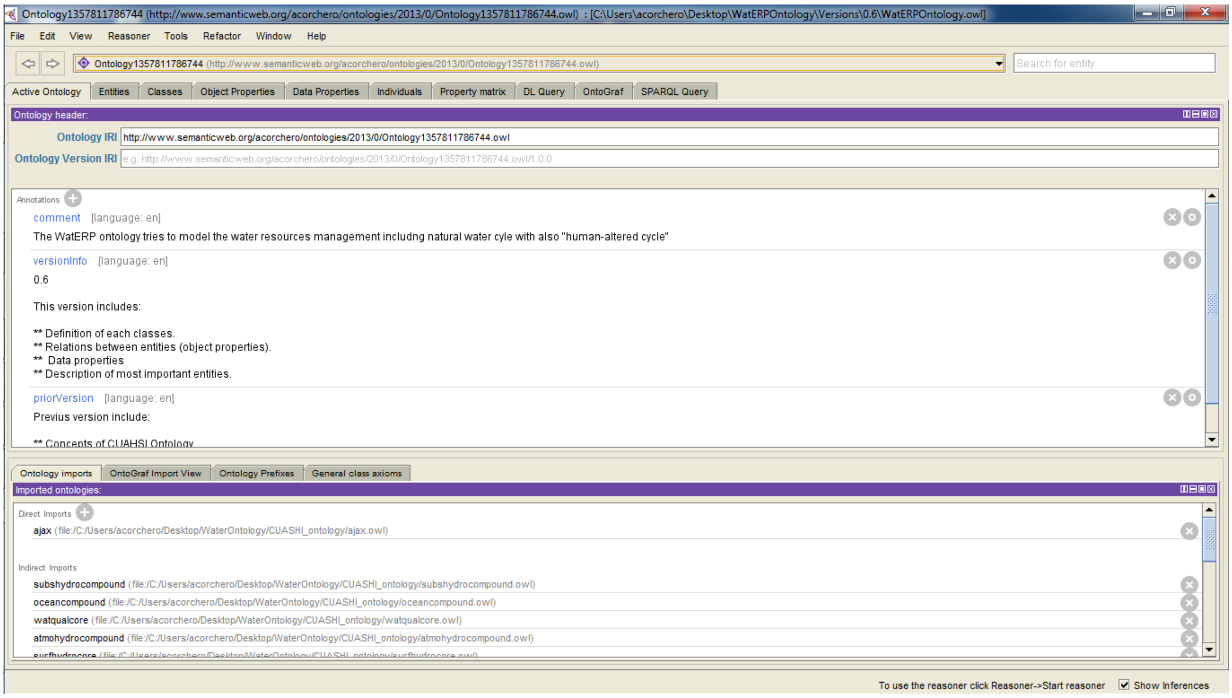

Figure 23 "WatERP ontology-Active Ontology tab"

"*Entities*" tab shows a representation of the taxonomy with a deeply definition of the concepts (Figure 24). In this tab the restrictions and annotation done over ontological entities are represented.

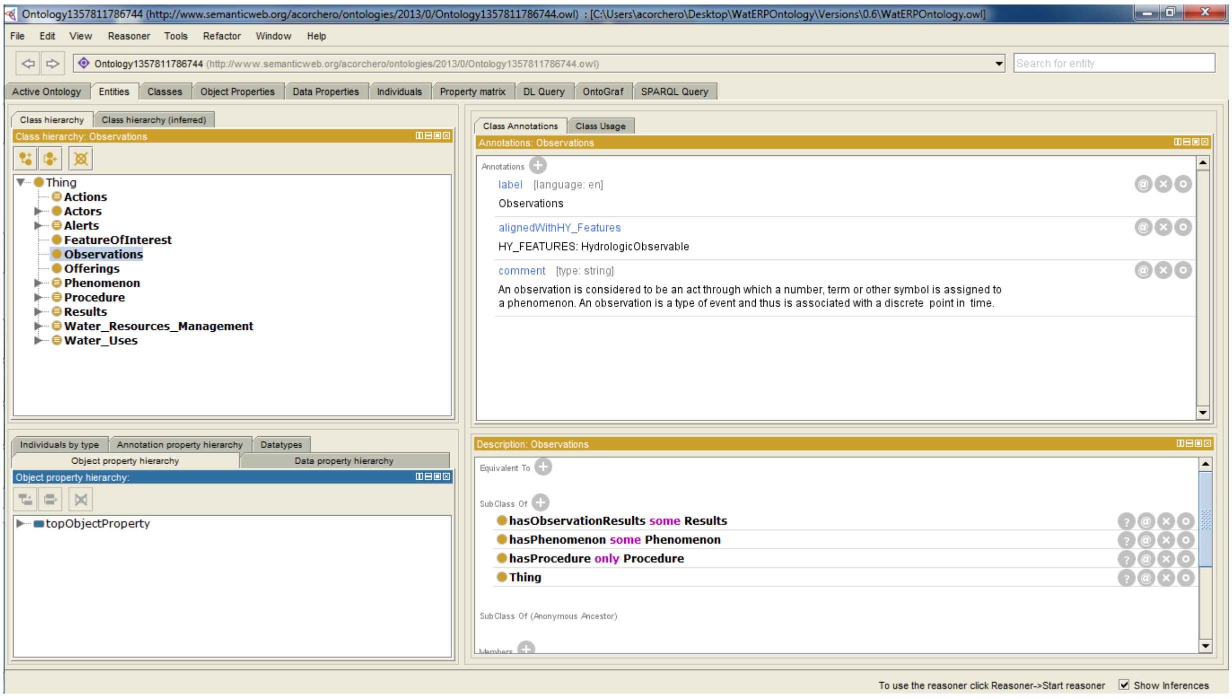

Figure 24 "WatERP ontology-Entities tab"

"*Object properties*" tab (Figure 25) shows the relations between entities defined for the current version of the WatERP ontology. Moreover, this tab also includes object properties annotations (comments, labels, mappings, etc).

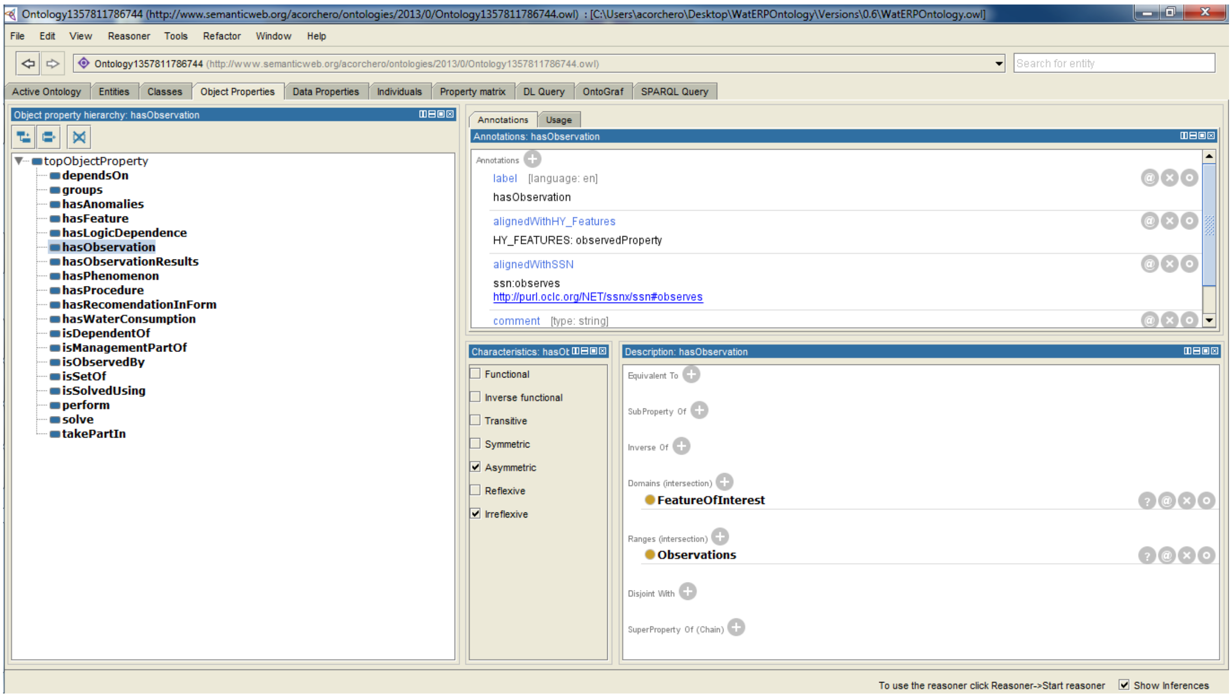

Figure 25 "WatERP ontology- Object property tab"

"*Data properties*" tab shows attributes defined in the ontology (Figure 26). As well as described in above tabs, in this tab one the annotations defined over data properties are also shown.

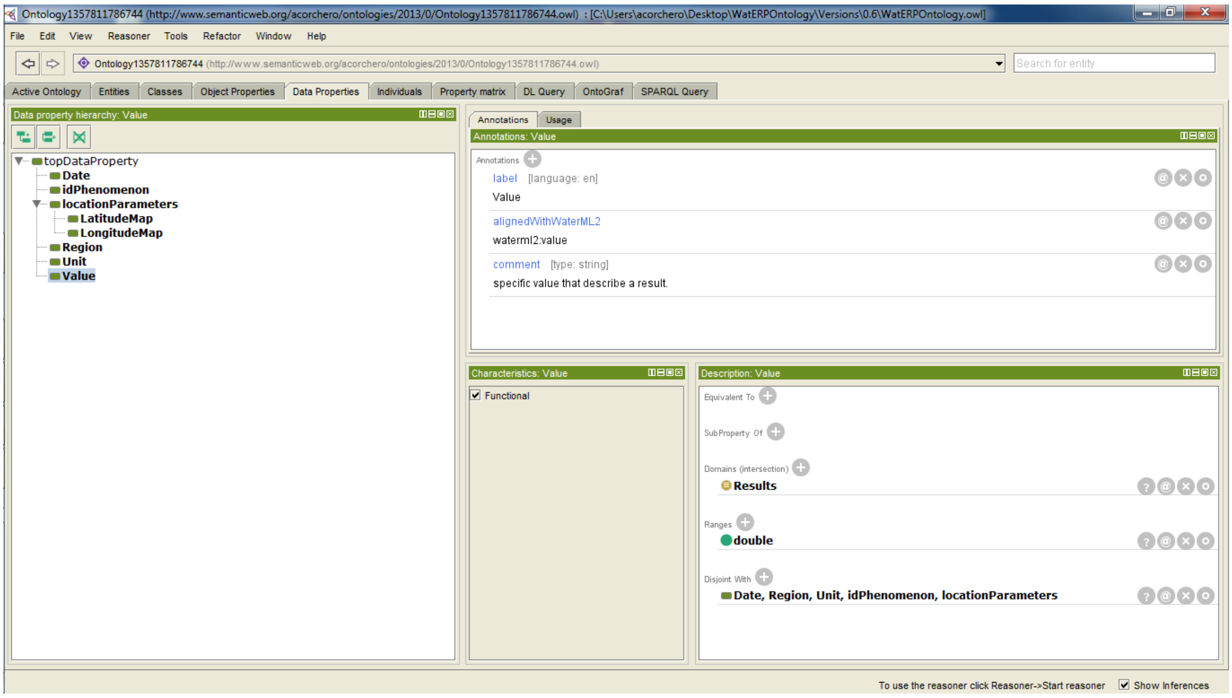

Figure 26 "WatERP ontology-Data Properties tab"