WatERP

Water Enhanced Resource Planning

“Where water supply meets demand”

GA number: 318603

WP 7: Pilots

7.1.2: Holistic Auditing

V1.0 27-02-2014

www.waterp-fp7.eu

Document Information

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

Deliverable	**Number**	7.1.2	**Title**	Holistic Auditing
Work Package	**Number**	7	**Title**	Pilots

Date of delivery	**Contractual**	17	**Actual**	17
Nature	Prototype ☐ Report ☑ Dissemination ☐ Other ☐			
Dissemination Level	Public ☑ Consortium ☐			

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Abstract (for dissemination)	This deliverable reviews the pilots' data validation methodology and the knowledge base (ontology) validation methodology presented in D7.1.1. Furthermore, an evaluation of the WatERP knowledge base is performed and the results obtained for the different categories (vocabulary, architecture, semantics, application and usability) are compared to other water domain-related ontologies. Finally, several improvements to the knowledge base are discovered and will be implemented in future developments in order to keep the ontology aligned with the pilots' needs and requirements and follow the development standards and best practices.
Key words	Evaluation, Validation, Ontology, Knowledge Base, Vocabulary, Architecture, Semantics, Application, Usability, Pilots

List of Acronyms

ACA – Agència Catalana de l'Aigua (Catalan Water Agency)

CUAHSI - Consortium of Universities for the Advancement of Hydrologic Science, Inc.

DWD – Deutscher Wetterdienst (German National Meteorology Agency)

DX.X – Deliverable X.X

GML - Generalized Markup Language

IT – Information Technology

O&M – Observations & Measurements

OGC – Open Geospatial Consortium

OMP – Open Management Platform

OS – Operative System

OWL – Web Ontology Language

RAM – Random-Access Memory

SPARQL – SPARQL Protocol and RDF Query Language

SSN – Semantic Sensor Network

SWEET – Semantic Web for Earth and Environmental Terminology

SWKA – Stadtwerke Karlsruhe

UPM – Universidad Politécnica de Madrid

URI – Uniform Resource Identifier

URN – Uniform Resource Name

W3C – World Wide Web Consortium

WatERP – Water Enhanced Resource Planning

Executive Summary

Task 7.1 "*Case study holistic auditing*" aims at ensuring the water supply knowledge base built in the framework of Work Package 1 considers the detailed information restored from the pilots, that is, to review the adequate integration of the pilots' characteristics into the created knowledge elements.

In order to reach the objectives, two validation methodologies were defined in deliverable D7.1.1. On the one hand, a methodology to validate the information required from the pilots was defined. A first validation of the pilots' data was performed in deliverable D7.1.1, and the result was that there was some missing information from the pilots. The conclusion was that ACA should provide information about the energy consumption of their site and SWKA should provide information about the meteorological data that is available and used for their usual operation. ACA explained that in the context of the management of the upper part of the water supply chain, the optimization of the hydrological resources is more important than the energy consumption, which is considered as a consequence of the operation itself rather than a critical factor in the decision-making process. As a result, energy consumption will not be considered for the Ter-Llobregat pilot site. SWKA explained that they retrieve and use meteorological information from the *Rheinstetten* meteorological station. Moreover, the access to this information is public and can be downloaded from the official web site of the DWD. This information has been collected and made available for any building block that may need it (e.g. Demand Management System).

On the other hand, also a methodology to evaluate the overall quality of the knowledge base was defined in D7.1.1 in order to ensure that the created elements are a faithful representation of the reality and are aligned with the users' needs. The methodology defined was based on the calculation of several metrics (e.g. vocabulary-related metrics, architecture-related metrics, usability metrics, etc.) with the aim of obtaining a final result as much objective as possible, so that it could be compared against other water-related ontologies.

It was decided to postpone the evaluation over the knowledge base in deliverable D7.1.1 but at this moment the created knowledge base elements have reached a stable version and a proper evaluation can be performed. The main objective of the validation of the WatERP's knowledge base is to verify the current developments are aligned with the pilots' needs and requirements and follow the development standards and best practices established (internal validation). Moreover, the WatERP ontology development was evaluated against some of the most representative water domain ontologies in order to compare the current development status of the WatERP ontology with respect to other ontologies (external validation). As a main conclusion of the knowledge base validation, the WatERP ontology evolves successfully given the score achieved and when compared to other relevant water domain ontologies. However, several improvement opportunities have been discovered including the need of more data properties, the capability of giving answer to several competency questions, the refactoring of ontological resources, the incorporation of new comments and labels, and the enhancement of the ontological population with the information of both pilots.

Finally and in reference to the future work, the effort of Work Package 7 will be focused on *(i)* monitoring and tracking the ontological issues in order to ensure the correct development of the WatERP knowledge base; *(ii)* prepare and plan the next holistic auditing, including the selection of new evaluators, the preparation of the latest WatERP software version and the enhancement of the current procedure towards a more automatic one; and *(iii)* collect new informational requirements from the rest of work packages regarding the pilots. Furthermore, the future work also will be focused on defining and implementing a stress test for the WatERP solution in order to evaluate its performance.

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.
D1.3	Generic ontology for water supply distribution chain	Description of the generic ontology that was developed within WatERP project. This deliverable introduce into the incorporation of human-made interactions inside natural water paths in order to better understanding of the decisions to be adopted. Furthermore, data provenance and Linked Open Data Cloud (LOCD) mechanism are also introduced.
D1.4.1	Extension of the taxonomy and ontology to the pilots	Description of the improvements performed onto the WatERP general ontology and taxonomy based on pilots' data information.
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.

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1. Introduction

The objective of Work Package 7 (WP7) is to test and validate the feasibility of connecting the various components and monitoring systems involved in water distribution networks and technologies within the WatERP Open Management Platform. WP7 plays an active role in the definition and development of the final platform since it checks that the rest of the Work Packages satisfy the requirements for the real-time implementation of the platform over the pilot areas.

Moreover, task 7.1 "*Case study holistic auditing*" aims at ensuring the water supply knowledge base built in the framework of Work Package 1 considers the detailed information restored from the pilots, that is, to review the adequate integration of the pilots' characteristics into the created knowledge elements.

In order to reach the objectives, two validation methodologies were defined in deliverable D7.1.1, which is the first one of the "*Holistic auditing*" deliverable series. On the one hand, a methodology to validate the information required from the pilots was defined. The goal is to check that the pilot sites are able to provide the data needed by the development Work Packages (WP1 to WP6) and also that these data meet the required quality and level of detail.

A first validation of the pilots' data was performed in deliverable D7.1.1, and the result was that all needed information was available except for two specific items. The conclusion was that ACA should provide information about the energy consumption of their site and SWKA should provide information about the meteorological data that is available and used for their usual operation. The resolution of those issues will be explained in *Section 2.1*. Additionally, a review of the defined methodology will be depicted in *Section 2.2* and the results of the application of the reviewed methodology over the pilots' data will be offered in *Section 2.3*.

On the other hand, a methodology to evaluate the overall quality of the knowledge base was defined in D7.1.1 in order to ensure that the created elements are a faithful representation of the reality and are aligned with the users' needs. The defined methodology was based on the calculation of several metrics (e.g. vocabulary-related metrics, architecture-related metrics, usability metrics, etc.) with the aim of obtaining a final result as much objective as possible through the application of mathematical equations so that it could be compared against other relevant ontologies of the water domain.

As opposite to the pilots' data validation, it was decided to postpone the evaluation over the knowledge base in deliverable D7.1.1 (*Section 4.2 in page 25*) since a stable version of the ontology was not available. At the moment of writing deliverable D7.1.1 the ontology construction was at the taxonomy level (deliverables D.1.1 and D1.2), and the ontology as such was not built until M5 (deliverable D1.3)-M12 (deliverable D1.4.1). Although the preliminary versions of the taxonomy, the functional model and the ontology were already available, their status was not mature enough to perform a reliable evaluation. In fact, the created knowledge elements have suffered several modifications since they were created in order to correctly represent the knowledge of the pilots and meet the needs of the work packages (especially Work Package 4 "*Decision Support System*").

At this moment, the created knowledge base elements have reached a stable version and a proper evaluation can be performed. *Section* 3 will be devoted to the knowledge base validation. First, a description of the evaluation procedure will be offered in *Section 3.1*, including the formulas designed to obtain the final score of each one of the tested categories, namely "*Vocabulary layer*" (*Section 3.3*), "*Architecture layer*" (*Section 3.4*), "*Semantics layer*" (*Section 3.5*), "*Application layer*" (*Section 3.6*), and "*Usability layer*" (*Section 3.7*). The ontology created in the WatERP project will be evaluated for each category and compared to several well-known water-related ontologies in order to know the current situation with respect to the current state-of-the-art.

Finally, the conclusions obtained from the evaluations will be depicted in *Section 4.1*, and the future work regarding the holistic auditing of the knowledge base-related features of the project will be outlined in *Section 4.2*.

2. Pilots' data validation

This section is dedicated to the review of the pilots' data validation methodology and results presented in deliverable D7.1.1 "*Holistic Auditing*" in *Sections 2.3* (*page 11*) and *Section 4.1* (*page 23*) respectively.

The pilots' data validation methodology was developed with the aim of ensuring that both pilot sites provide the same kind and amount of information and with the same level of detail. With that objective, a checklist was prepared in order to compare the information supplied by each pilot site. *Table 1* contains the results of the preliminary evaluation performed in deliverable D7.1.1.

Category	Item	Availability	
		ACA	SWKA
Geographical and demographic	Geographical situation and environment	Yes	Yes
	Description of land use	Yes	Yes
	Population coverage/people supplied	Yes	Yes
	Water supply chain roles (e.g. bulk water supplier, water authority, etc.)	Yes	Yes
	Institutional framework (which are the actors involved in which activity, property of each institution, etc.)	Yes	Yes
Institutional and financial framework	Actors involved in which activity	Yes	Yes
	Organization type and legal status of each actor	Yes	Yes
	Institutional hierarchy	Yes	Yes
	Responsibilities matrix	Yes	Yes
	Financial framework	Yes	Yes
Water use	Water use sectors, uses and users	Yes	Yes
Infrastructure	Water supply system diagram	Yes	Yes
	Water sources (including capacity, storage capacity and number of wells)	Yes	Yes
	Treatment plants (including type of treatment)	Yes	Yes
	Desalination plants (including capacity)	Yes	Not app
	Reservoirs/tanks (including volume, area, hydroelectric turbine, etc.)	Yes	Yes
	Pumping stations (including number and capacity)	Not app	Yes
	Pipeline system	Not app	Yes
Data collection	Information about ground water (including sensors/meters, units and frequency)	Yes	Yes
	Information about regulated water (including sensors/meters, units and frequency)	Yes	Yes
	Information produced ground water (including sensors/meters, units and	Yes	Yes

Category	Item	Availability	
		ACA	SWKA
	frequency)		
	Information about flows (including sensors/meters, units and frequency)	Yes	Yes
	Information about water consumption (including sensors/meters, units and frequency)	Yes	Yes
	Information about energy consumption (including sensors/meters, units and frequency)	No	Yes
	Information about meteorology (including sensors/meters, units and frequency)	Yes	No
Systems	Information about the information transmission to the systems	Yes	Yes
	Hydraulic/hydrologic models	Yes	Yes
	Data flow diagram	Yes	Yes
	IT systems architecture and list of software used	Yes	Yes
	Available interfaces to export/import data with specification of storage type (DB, file, etc.), format and access policy	Yes	Yes
Historical data	Water flows (including frequency and availability)	Yes	Yes
	Drinking water supply (including frequency and availability)	Not app	Yes
	Output of water works (including frequency and availability)	Yes	Yes
	Water consumption (including frequency and availability)	Yes	Yes
	Population (including frequency and availability)	Yes	Yes
	Population prediction (including frequency and availability)	Yes	Yes
	Water consumption statistics/trends (including frequency and availability)	Yes	Yes

Table 1: "Results of the preliminary evaluation of pilots' data"

Some data was identified to be missing ("*No*" fields of the table) for both pilots sites and it was stated that an interview with the involved stakeholders would be needed in order to complete this part of the knowledge base. *Section 2.1* depicts how the issues found during the preliminary evaluation were solved.

Furthermore some improvements to the categorization and the naming of the items are explained in *Section 2.2*. Finally, the results of the validation are outlined in *Section 2.3*.

2.1 Addressing of the issues found

The conclusions of the preliminary evaluation of the pilots' data performed on *February 2013* and reported in deliverable D7.1.1 "*Holistic Auditing*" in section 4.1 (page 22) stated that some data was identified to be missing for both pilot sites. The issues found were addressed soon after they were detected and the missing data was requested to the involved stakeholders.

Firstly, it was detected that no information regarding energy consumption was reported on behalf of the Ter-Llobregat pilot site. This issue was discussed with the ACA –since they are the partner representing the Spanish site- and although they cannot directly provide energy consumption data, they could supply some information in order to obtain a qualitative estimation of the energy consumption.

In the context of the management of the upper part of the water supply chain, energy consumption is a consequence of the operation itself rather than a critical factor in the decision-making process. In such context the most important is the optimization of the hydrological resources. Therefore, the energy consumption will be marked as "*Not applicable*" for the Ter-Llobregat pilot site.

ACA can provide some consumption average coefficients that could be included in the rule list defined in deliverable D4.1 "*Inference and Simulation Engine Conceptual Design*" in *Section 3.1.4.3* (*page 56*) in order to obtain the order of magnitude of the energetic costs. Furthermore, it would be even possible to perform a detailed study of how the hydropower plants could be affected by the operation, although this level of detail is out of the scope of the WatERP project. With the proposed consumption average coefficients a global value would be supplied and no distinction would be made between the different elements.

The second issue appeared on behalf of the Karlsruhe pilot site, where no meteorological information availability was reported. When asked, SWKA –who is the partner that represents the German site- explained that indeed they do retrieve and use meteorological information from the *Rheinstetten* meteorological station. This station is located at Rheinstetten, which is a town nearby the city of Karlsruhe and is operated by DWD[1] (German National Meteorology Agency). Moreover, this information is publicly available and can be downloaded from the official web site.

A screenshot of the web site[2] from where the information can be obtained is shown in *Figure 1*. The available meteorological information is offered with daily or monthly aggregation, and includes the following variables: relative humidity, vapor pressure, air temperature, wind speed, maximum and minimum temperature, wind gust, accumulated precipitation, sunshine duration and accumulated snow. The links to download the information as a text file are offered below within the same page.

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[1] DWD (Deutscher Wetterdienst) http://www.dwd.de

[2] http://www.dwd.de/bvbw/appmanager/bvbw/dwdwwwDesktop;jsessionid=MKQDTGTYfpHZ0Sxn1yFPBg1kNxlvdXN2V9snvXDP2WyNtJ6Bcqm7!620749260!-612864764?_nfpb=true&_windowLabel=dwdwww_main_book&T82002gsbDocumentPath=Navigation%252FOeffentlichkeit%252FKlima__Umwelt%252FKlimadaten%252Fkldaten__kostenfrei%252Fausgabe__tageswerte__node.html%253F__nnn%253Dtrue&switchLang=en&_pageLabel=_dwdwww_klima_umwelt_klimadaten_deutschland

Once the availability of the information has been checked, the "*Meteorological information*" item marked as "*No*" (not available) can be now switched to "*Yes*" (available). Furthermore, this information has been downloaded and made available to any building block that may need it.

Figure 1: "Screenshot of the DWD web page where the meteorological data for SWKA is available"

2.2 Improvements and corrections

During the review of the pilots' data validation results some errors on the categorization of the items were found and some improvements were detected.

- It was noticed that the "*Water supply chain roles*" and the "*Institutional framework*" items were included in the "*Geographical and demographic*" category but they belong to the "*Institutional and financial framework*" category.
- The "*Water supply chain roles*" item was renamed to "*Water supply chain scheme and roles*", since it also includes the scheme of the water supply process carried out by the water utilities.
- The "*Actors involved in which activity*" item was removed because this information was already included in the "*Institutional framework*" item.
- The "*Organization type and legal status of each actor*" item was renamed to "*Organization type and legal context*", since it is more adjusted to the information it contains. It does not make sense to talk about the "*legal status*" of an actor, but about the legal context of the organization.
- The "*Treatment plants*" item was renamed to "*Fresh water treatment plants*" in order to distinguish it from the "*Desalination plants*" item that, in fact, are also "*Treatment plants*".

- The "*Historical data*" category was renamed to "*Historical data for water supply and demand key variables*", since the items contained in this category are not generic and are related only to water supply and water demand.
- The order of the items under the "*Institutional and financial framework*" and the "*Data collection*" categories were modified in a more logical way in order to improve the readability.

2.3 Results

The conclusion regarding the review of the pilots' data validation is that both pilots fulfill the data requirements of the work packages. As opposite to the results of the preliminary evaluation, no lack of information has been detected and the existing issues have been solved.

Table 2 includes the updated status of the items for each pilot site explained in *Section 2.1* as well as the item categorization and definition modifications explained in *Section 2.2*.

Category	Item	Availability	
		ACA	SWKA
1. Geographical and demographic	1.1. Geographical situation and environment	Yes	Yes
	1.2. Description of land use	Yes	Yes
	1.3. Population coverage/people supplied	Yes	Yes
2. Institutional and financial framework	2.1. Institutional hierarchy	Yes	Yes
	2.2. Organization type and legal context	Yes	Yes
	2.3. Water supply chain scheme and roles (e.g. bulk water supplier, water authority, etc.)	Yes	Yes
	2.4. Institutional framework (which are the actors involved in which activity, etc.)	Yes	Yes
	2.5. Responsibilities matrix	Yes	Yes
	2.6. Financial framework	Yes	Yes
3. Water use	3.1. Water use sectors, uses and users	Yes	Yes
4. Infrastructure	4.1. Water supply system diagram	Yes	Yes
	4.2. Water sources (including capacity, storage capacity and number of wells)	Yes	Yes
	4.3. Fresh water treatment plants (including type of treatment)	Yes	Yes
	4.4. Desalination plants (including capacity)	Yes	Not app
	4.5. Reservoirs/tanks (including volume, area, hydroelectric turbine, etc.)	Yes	Yes
	4.6. Pumping stations (including number and capacity)	Not app	Yes
	4.7. Pipeline system	Not app	Yes
5. Data collection	5.1. Meteorological information (including sensors/meters, units and	Yes	Yes

Category	Item	Availability	
		ACA	SWKA
	frequency)		
	5.2. Information about ground water (including sensors/meters, units and frequency)	Yes	Yes
	5.3. Information about flows (including sensors/meters, units and frequency)	Yes	Yes
	5.4. Information about regulated water (including sensors/meters, units and frequency)	Yes	Yes
	5.5. Information produced ground water (including sensors/meters, units and frequency)	Yes	Yes
	5.6. Information about water consumption (including sensors/meters, units and frequency)	Yes	Yes
	5.7. Information about energy consumption (including sensors/meters, units and frequency)	Not app	Yes
6. Systems	6.1. Information about the information transmission to the systems (e.g. what protocols/technologies are used to collect and transfer the data)	Yes	Yes
	6.2. Hydraulic/hydrologic models	Yes	Yes
	6.3. Data flow diagram	Yes	Yes
	6.4. IT systems architecture and list of software used	Yes	Yes
	6.5. Available interfaces to export/import data with specification of storage type (DB, file, etc.), format and access policy	Yes	Yes
7. Historical data for water supply and demand key variables	7.1. Water flows (including frequency and availability)	Yes	Yes
	7.2. Drinking water supply (including frequency and availability)	Not app	Yes
	7.3. Output of water works (including frequency and availability)	Yes	Yes
	7.4. Water consumption (including frequency and availability)	Yes	Yes
	7.5. Population (including frequency and availability)	Yes	Yes
	7.6. Population prediction (including frequency and availability)	Yes	Yes
	7.7. Water consumption statistics/trends (including frequency and availability)	Yes	Yes

Table 2: "Result of the evaluation of pilots' data"

A review of the availability of each item has been carried out based on the information found in several deliverables and internal working documents available in the WatERP common repository. *Table 3* contains the list of the main source documents/locations where the information regarding each item can be found.

Source document/location	Item(s) covered
"WP5 Pilots Description Annex 1 ACA" internal working document (ACA,	1.1, 1.2, 1.3, 2.1, 2.2, 2.3, 2.4, 2.5,

Source document/location	Item(s) covered
February 2013)	2.6, 3.1, 4.1, 4.2, 4.3, 4.4, 4.5
"WP5 Pilots Description Annex 1 SWKA" internal working document (SWKA, January 2013)	1.1, 1.2, 1.3, 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 3.1, 4.1, 4.2, 4.3, 4.5, 4.6, 4.7
"Water Domain Definitions v2.0" internal working document (INCLAM, April 2013)	2.3, 3.1, 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.7 (SWKA only)
D2.1 "External System Integration Requirements" deliverable document	6.1, 6.2, 6.3, 6.4, 6.5
Several files under the "WP7. Pilots" section of the WatERP DMSF repository	7.1, 7.2 (SWKA only), 7.3, 7.4, 7.5, 7.6, 7.7

Table 3: "WatERP sources used for the evaluation of pilots' data"

3. Knowledge base validation

This section is devoted to the evaluation of the ontology over the WatERP knowledge base in order to discover ontological weaknesses and improvement points that will permit to *(i)* enhance the knowledge base quality by including new relevant ontological resources; *(ii)* align the ontological development with pilot's data needs and requirements; *(iii)* provide needed mechanism to follow the current development standards and best practices; and *(iv)* ensure that the knowledge offered to the platform users is of the required quality. From the testing point of view, the evaluation results have been essential to *(*i) test the ontology from the WatERP pilot's needs and requirements perspective (internal test); and *(ii)* check the WatERP ontology against relevant domain water ontologies in order to standardize the information of the WatERP knowledge base (external test). Therefore, the implemented test over the WatERP knowledge base has permitted to *(i)* discover knowledge base improvement lines through the detection of different issues during the evaluation process; and *(ii)* detect improvement opportunities based on the comparison between the WatERP ontology and other relevant ontologies for the water domain such as CUAHSI[3], HydrOntology[4], W3C-SSN[5], SWEET[6], Surface-Water-Model[7] and InWaterSense[8].

Regarding the WatERP knowledge base, the ontology has suffered many modifications from its initial version caused by the development of other work packages needs, pilots' and knowledge representation needs; and water domain modeling aligned with the current developed standards. Once the WatERP knowledge base development has been stabilized, a formal validation of the WatERP knowledge base can be performed. In spite of the fact that no formal validation was previously done, the ontological evolution has been aligned with the water domain experts' needs and the knowledge base experts' criteria in order to build a suitable domain ontology that permits the generation of the knowledge suitable for the management of the water supply and distribution chain. Thus, the water domain experts and the knowledge base experts have guided the ontological development according to the defined water standards (e.g. OGC, WaterML2) and the pilots' needs by checking with the pilots the informational needs as well as following the ontology development best practices (e.g. reusing other ontologies, mapping ontologies, annotation capabilities, etc.). Furthermore, the WatERP knowledge base has been partially tested in each development step, for example by checking the performance of

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[3] http://his.cuahsi.org/ontologyfiles.html

[4] http://mayor2.dia.fi.upm.es/oeg-upm/index.php/es/ontologies/107-hydrontology

[5] http://www.w3.org/2005/Incubator/ssn/ssnx/ssn

[6] http://sweet.jpl.nasa.gov/ontology

[7] http://loki.cae.drexel.edu/~wbs/ontology/model.htm

[8] http://inwatersense.uni-pr.edu/

SPARQL queries and by gathering water domain experts (e.g. pilots) feedback about the knowledge stored. As an example, on deliverable D1.4.1 "*Extension of the taxonomy and ontology to the pilots*" in *Section 3.1.1 on page 27* an issue related to the categorization of "*phenomenon*" and "*feature of interest*" entities was exposed. Both entities were initially grouped in the same entity, but they were later separated in order to reflect the information provenance and facilitate the maintenance of the knowledge base. Due to this modification, the features of interest are now linked to a phenomenon through the observations that have been already assigned. This modification also enables the water manager to define different observations/phenomena measurements to the same feature of interest, which is aligned with the standard definitions proposed by the OGC Observation & Measurement (O&M).

The formal validation procedure that will be used over the latest stable version of the WatERP knowledge base is explained in *Section 3.1*, where the metrics that will be measured, the automatic programs that will be developed and the experts that will make some of the evaluations are described. Furthermore, this procedure is focused on checking the knowledge base needs, the correctness of the ontological resources' names, time and quality responses, the knowledge generation, the reasoning and ontological consistency, and the expressiveness (see *D7.1.1 on Section 3.2 in page 15*). Hence, the scores calculation for all the defined metrics, the evaluations of the metrics and the automatic programs developed to calculate the objective metrics of the ontology are also depicted.

Based on the detailed evaluation procedure, *Section 3.2* presents the general results of the evaluation where some general considerations are depicted for each one of the evaluated ontologies. Additionally, these general results are detailed in the next subsections with the focus on the WatERP knowledge base results. The WatERP knowledge base results have also been compared with the results of the same evaluation over some other relevant ontologies with the aim of detecting improvement opportunities that could be applied to WatERP's ontology.

Finally, *Section 3.8* summarizes the corrective actions that must be applied to the WatERP knowledge base. These actions are classified by the evaluated categories and have been organized from the criticism's point of view. Furthermore, this list of improvement points permits to evolve the ontology towards the generation of a useful water domain knowledge base for the WatERP platform and potentially other water domain approaches.

3.1 Implemented evaluation procedure

The implemented evaluation procedure described in this section aims to clarify the methodology exposed in deliverable D7.1.1 "*Holistic Auditing*" (*section 3.2, page 15*). As a result, the selection of the ontologies that will be compared with the WatERP ontology, the description of the global scores related to each category defined, the development of specific programs to obtain objective score values, and the selection of the experts that will be involved in the validation process is depicted.

As it was explained in deliverable D7.1.1 "*Holistic auditing*" in *Section 3.2* (*page 16*), the validation procedure is based on the evaluation of the "*Vocabulary*", "*Architecture*", "*Semantics*", "*Application*" and "*Usability*" knowledge base layers (also called evaluation categories). These evaluation categories will facilitate the comparison against other relevant ontologies, since they are referred to essential properties such as the knowledge base syntax, structure, richness, readability, reasoning, querying, and knowledge visualization.

The set of metrics that will be obtained from the evaluation can be divided into two groups: subjective metrics and objective metrics. The first group contains the metrics whose value depends on the evaluator's (e.g. knowledge base expert or water domain expert) criteria, while the second group contains the metrics that are based on specific calculus and such as readability, richness, ontological resource importance, etc. (Tartir & Budak, 2007[9]).

On the one hand, the subjective metrics results (e.g. the "*usability*" or the "*vocabulary*" metrics) have been manually set by knowledge base experts or water domain experts depending on the expertise field required for each metric. The knowledge base experts selected to evaluate the subjective metrics are not involved in the WatERP knowledge base development in order to be impartial. In the case of the water domain experts, the evaluators are people from the pilots' partners who know which are the requirements and the information needs of the WatERP building blocks. Moreover, the combination of different water and knowledge base experts' opinion and criteria permits to obtain an evaluation result as much objective as possible despite the subjective nature of the metrics.

On the other hand, the objective metrics (e.g. "*Application*", "*Semantic*" and "*Architecture*") have been calculated using an automatic program that performs all the needed calculus. The program has been developed in a JAVA environment and is in charge of calculating ontology metrics such as "*consistency*", "*reasoning validation*" or "*richness ratio*". Moreover, the program uses the JENA[10] and the Pellet[11] library in order to perform the metrics calculation. The JENA library has been used to load the ontology and navigate throughout it. Furthermore, Pellet library has been used to check the reasoning part, validate the ontology and check the consistence of all the ontologies.

Once all the identified metrics have been calculated, the global score for each evaluation category is calculated using specific formulas. Based on this ontological rating, a graphical representation of the score of the ontology is done to facilitate the comparison between the different identified water ontologies.

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[9] Tartir, S. & Budak, I. (2007). Ontology Evaluation and Ranking using OntoQA. *Proceeding of the International Conference on Semantic Computing*, 185-192

[10] JENA framework official site: https://jena.apache.org/

[11] Pellet OWL2 reasoner official site: http://clarkparsia.com/pellet/

- The "*Vocabulary*" score is defined as the ratio of the number of "*Pass*" results over the total number of items evaluated in this layer, normalized to the range [0, 3] (Equation 1).

$$Score_{vocabulary} = \frac{|pass|}{N} \times 3; N = total\ number\ of\ items$$

Equation 1: "Vocabulary score calculation"

- The "*Architecture*" score is computed as the average of the scores of the sub-categories, normalized to range [0, 3] (Equation 2).

$$Score_{architecture} = \frac{RR + ARn + Imp + RRc + Rdn + RS}{6} \times 3$$

Equation 2: "Architecture score calculation"

  - The "*Schema relationship richness*" (RR) sub-category score is calculated as the ratio of relationships (P) defined in the schema and the number of subclasses (SC) plus the number of relationships (Equation 3).

$$RR = \frac{|P|}{|SC| + |P|}$$

Equation 3: "Schema relationship richness score calculation"

  - The "*Attribute richness*" (ARn) sub-category score is calculated as the normalization of the average number of attributes (slots) per class (Equation 4). Notice that the result must be normalized[12] since AR is in the range [0, ∞).

$$AR = \frac{|att|}{|C|};\ ARn = \frac{AR}{1 + AR}$$

Equation 4: "Attribute richness score calculation"

  - The "*Class importance*" (Imp) sub-category score is calculated as the average for all classes of the ratio between the number of instances that belong to the sub-tree rooted at *class i* (Ci(I)) and the total number of instances (I) (Equation 5)

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[12] In order to obtain a value Xn in the range [0, 1] from a value X in the range [0, ∞), the following formula is applied:

$$Xn = \frac{X}{1 + X}$$

$$Imp_i = \frac{|C_i(I)|}{|I|};\ Imp = \frac{\sum_{i=1}^{|C|} Imp_i}{|C|}$$

Equation 5: "Class importance score calculation"

- The "*Class relationship richness*" (RRc) sub-category score is calculated as the average for all classes of the ratio between the number of relationships that are being used by instances Ii that belong to Ci (P(Ii,Ij)) and the number of relationships that are defined for Ci at the schema level (P(Ci,Cj)) (Equation 6).

$$RRc_i = \frac{|P(I_i, I_j), I_i \in C_i(I)|}{|P(C_i, C_j)|}; RR_c = \frac{\sum_{i=1}^{|C|} RRc_i}{|C|}$$

Equation 6: "Class relationship richness score calculation"

- The "*Readability*" (Rdn) sub-category score is calculated as the normalization of the sum of the number of attributes that are comments and the number of attributes that are labels in a class (Equation 7). Notice that, analogous to the "*Attribute richness*" calculation, the result must be normalized since Rd is in the range [0, ∞).

$$Rd_i = |A_i, A = rdfs{:}comment| + |A_i, A = rdfs{:}label|; Rd = \frac{\sum_{i=1}^{|C|} Rd_i}{|C|}; Rd_n = \frac{Rd}{1 + Rd}$$

Equation 7: "Readability score calculation"

- The "*Reasoning*" (RS) subclass score value will be 1 if the reasoner does not throw any consistency error and 0 otherwise (Equation 8)

$$RS = 0\ if\ error, 1\ otherwise$$

Equation 8: "Reasoning score calculation"

- The "*Semantics*" score is defined as the ratio of the number of "*Pass*" results over the total number of items evaluated in this layer, normalized to the range [0, 3] (Equation 9)

$$score_{semantics} = \frac{|pass|}{N} \times 3; N = total\ number\ of\ items$$

Equation 9: "Semantics score calculation"

- The "*Application*" score is defined as the ratio of the number of "*Pass*" results over the total number of items evaluated in this layer, normalized to the range [0, 3] (Equation 10)

$$score_{application} = \frac{|pass|}{N} \times 3; N = total\ number\ of\ items$$

Equation 10: "Application score calculation"

- The "*Usability*" score is defined as the average of the scores of all items evaluated by all water domain experts (Equation 11). Each usability item will be scored by at least two water domain experts who will evaluate the knowledge base visualized in a graphical user interface environment. Therefore, the water domain experts will assign a value in the range [0, 1] to each item, considering that 0 means that the item is not good at all and 1 means that the item is perfect from the usability point of view.

$$score_{usability} = \frac{\sum_{i=1}^{n} usabilityItem_i}{n} \times 3; n = number\ of\ experts$$

Equation 11: "Usability score calculation"

Once all the categories have been evaluated, the scores will be presented in a radial graph in order to offer a visual comparison of all the considered ontologies (see Figure 2). The most interesting of this graph is to check how good is the WatERP ontology in each category with respect to the other ontologies. Based on this comparison, some weaknesses could be detected and noted as improvement opportunities.

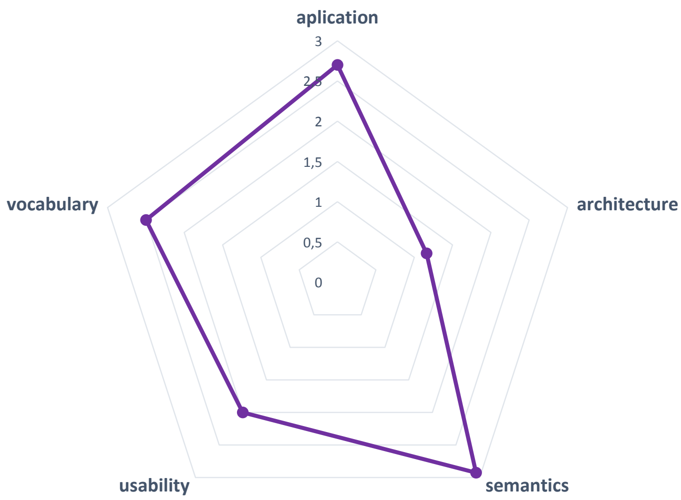

Figure 2: "Example of radial graph to evaluate the ontologies"

3.2 General knowledge base validation

The overall evaluation results for the WatERP ontology will be presented in this section. Those results are essential to compare the knowledge base created in this project to some other well-known ontologies. As it was mentioned before, this evaluation will be used to identify the weaknesses of WatERP's ontology (e.g. information contained is not aligned with pilots' information, the ontology is not aligned with pilots' requirements, the development did not follow the standards and best practices, etc.) that will lead to improvement opportunities.

The WatERP's knowledge base test has been performed using the services available in the First Vertical Integration release and the latest stable version of the software implementation of the knowledge base. The server is located at BDigital's premises and the services are running on Windows Server OS, with 4 GB of RAM memory and a 2 GHz microprocessor. The access to the service is allowed for all the consortium partners according to the accessibility principles established. Furthermore, several ontologies have been tested remotely using its end-point access. The water-domain ontologies that have been evaluated are depicted in Table 4.

Ontology	Description	Number of entities	Number of object properties	Number of data properties	Highlights
CUAHSI	This ontology has been developed by the Consortium of Universities of Hydrologic Science with the purpose of discovering collections of time series such as physical, chemical and biological measurements (see *D1.2 on Section 4.1 in page 44*)	413	0	0	This is an important ontology in the water domain
HydrOntology	This is an ontology developed by the Polytechnic University of Madrid (UPM). Its main goal is to represent geographical information and cartography information related to hydrological domain knowledge (see *D1.2 on Section 4.4 in page 50*). The ontology is mapped with several different knowledge models such as IGN-E, Water Framework European Directive, and Alexandra Library	150	34	66	This ontology is highly valuable for its link with open data entities available on the web
W3C-SSN	This ontology is an upper ontology (model ontology) created by the W3C consortium (SSN-XG group). The ontology is aimed at representing the sensors, observations and concepts related to sensor measurement (e.g. unit of measure, procedure, etc.) (see *D1.2 in Section 4.2 on page 46*)	117	142	6	This ontology is a reference regarding the description of sensor process for a transversal domains and then, has been selected has a representative ontology
SWEET	This ontology has been developed by the NASA organization. The ontology has the objective of representing the earth and environmental terminology and processes it in a standardized way (see *D1.2 in Section 4.3 on page 48*). This is an upper ontology.	4417	565	41	This is one of the largest ontologies, given the number of entities and properties

Ontology	Description	Number of entities	Number of object properties	Number of data properties	Highlights
Surface-Water-Model	This ontology aims to represent the most common phenomena defined in the WaterML2 standard	59	0	0	This ontology has been selected because of the use of WaterML2 for the phenomena description
InWaterSense	This ontology has been developed by the University of Prishtina under the "*InWaterSense: Intelligent Wireless Sensor Networks for Monitoring Surface Water Quality*" EU project. The ontology has been based on SSN ontology and adapted towards classifying water bodies in an appropriate status including also the observational data for water quality assurance. Furthermore, the ontology is able to identify the pollution causes using rules inside the ontological knowledge	111	49	37	This is an outcome of another research project and it would be interesting to compare it to the WatERP ontology

Table 4: "Description of the ontologies to be compared"

The results obtained from the knowledge base validation results (see *Figure 3*) state that the WatERP ontology has a competitive level of architecture and semantics when compared to the rest of the selected water domain ontologies. However, the WatERP ontology needs to improve the quality regarding the "*Application*", "*Vocabulary*" and "*Usability*" categories. Referring to the "*Application*" category, the WatERP ontology needs to give an answer to the defined competency questions in order to satisfy the pilots' data requirements and needs. In terms of the "*Vocabulary*" category, it is needed to add more comments to the ontological resources, and add more labels and rewrite some resource names. Regarding the "*Usability*" category, the usage of the WatERP ontology must be intensified as long as the development of the OMP advances in order to represent the needed information in the user interface.

These results will be improved during the WatERP project's evolution with the aim of consolidating the WatERP knowledge base as a rich ontology in the water management domain.

The situation of the rest of relevant ontologies varies from taxonomical definitions such as "*CUAHSI*" and "*Surface-Water-Model*" towards more complex knowledge structures like "*SSN*", "*SWEET*", "*InWaterSense*" and "*HydrOntology*". However, these complex knowledge structures have presented a lack of data properties in the case of the "*InWaterSense*" ontology. Moreover, although "*HydrOntology*" has the benefit of being interconnected to Linked Data Cloud entities, the measurement of features of interest was not considered. Finally it must be remarked that both the "SSN" and the "SWEET" ontologies are abstract ontologies designed with the aim of providing standard entities and properties to more specific domain ontologies.

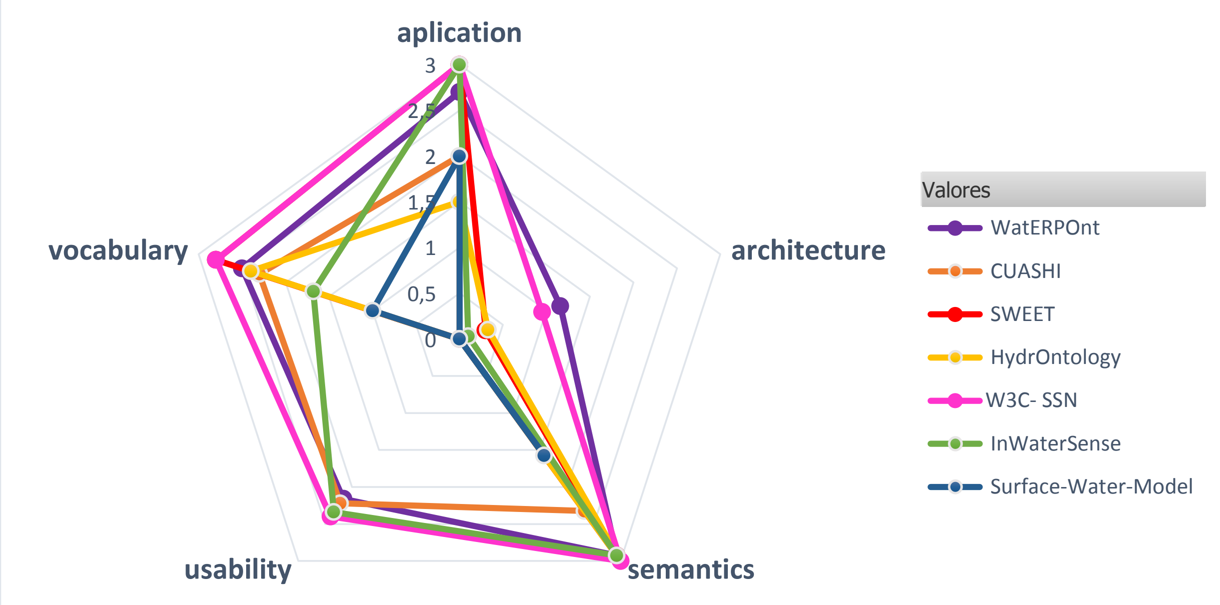

Figure 3: "Knowledge base results"

The next subsections offer a detailed explanation of the individual results for each category. Furthermore, the measurement procedure, the specific results and the issues will be explained for each one of the ontologies. Special emphasis has been given to the WatERP knowledge base improvements during the analysis of the results. The improvement actions that will be implemented on the next versions of the ontology are summarized in the last part of this section.

3.3 Vocabulary layer

This section is focused on the validation of the "*Vocabulary* layer (or category) by using the methodology presented in deliverable D7.1.1 "*Holistic Auditing*" in *Section 3.2.1*. The methodology is based on checking out the syntax of each of the ontological resources that conforms each of the knowledge bases.

The procedure followed to measure this category consists of manually rating each of the syntactical definitions for each of the ontological resources. The measured variables are based on validating: *(i)* the entity name syntax; *(ii)* the property name syntax; *(iii)* the prefixes and suffixes in the name of the ontological resource; *(iv)* the inverse properties defined; *(v)* the definition of the entities and properties (from the annotations' perspective); *(vi)* the comments and labels (in order to assure definitions are clearly understandable); and *(vii)* the definition of ontological resources are aligned with the defined comments and the domain definition.

As a summary of the metrics, the naming criteria evaluates that all entities are named as single nouns and using CamelCase notation (e.g. “*MyNewEntity*”). In the same way, named properties evaluates if all properties are called using a verb and also using mixedCase notation (e.g. “*hasProperty*”). Referring to the descriptive prefixes and suffixes metric, a revision of sub-entities and sub-properties are done in order to verify if all sub-entities (or sub-properties) that belong to the same entity use common and descriptive prefixes and suffixes when possible. Another relevant metric is the inverse property definition that checks the correct naming for all inverse properties defined. Regarding the ontological understanding from the syntactic point of view, the “*Syntax*” metric inspects if all entities and properties have a clear definition. Moreover, this metric is aligned with the verification of the ontological annotations (e.g. comments and labels) from the definition and syntax point of view. In other words, it will be checked that there are no entities without comment and the sense of the comment is appropriate for the entity. Furthermore, the “*Governance*” metric evaluates if the defined ontological resources make sense in the context and the scope of the specific knowledge base domain.

Once the measurement for each vocabulary metric has been done for all ontologies (the WatERP ontology and the rest of relevant domain water ontologies listed in *Table 4*), the general results are presented on

		Metric						
Category	**Item**	**WatERP**	**CUAHSI**	**W3C-SSN**	**NASA-SWEET**	**InWaterSence**	**Surface-Water-Model-Ontology**	**HydrOntology**
Naming criteria	Named entities	Fail (0,7)	Fail (0,6)	Fail (0,7)	Fail (0,6)	Fail (0,7)	Fail (0)	Fail (0,2)
	Named properties	Fail (0,7)	Not rated (0)	Fail (0,6)	Fail (0,8)	Fail (0,7)	Not rated (0)	Fail (0,2)
	Descriptive prefixes and suffixes	Fail (0.8)	Pass (1)	Pass (1)	Pass (1)	Pass (1)	Pass (1)	Fail (0,8)
	Inverse properties	Pass (1)	Not rated (0)	Pass (1)	Fail (0,9)	Pass (1)	Not rated (0)	Fail (0,8)

	Entities and properties definition.	Fail (0.3)	Fail (0)	Fail 0,7)	Fail (0,7)	Fail (0)	Fail (0)	Fail (0)
Syntax	Words and definitions clarity	Fail (0,8)	Fail (0,9)l	Pass (1)	Pass (1)	Not rated (0)	Not rated (0)	Pass (1)
Governance	Term sense	Pass (1)	Pass (1)	Pass (1)	Pass (1)	Pass (1)	Pass (1)	Pass (1)
Vocabulary Metric (See Equation 1)		***2,5***	***2,3***	***2,8***	***2,8***	***1,68***	***1,2***	***2,4***

Table 5. The items have been empirically analyzed since it is not possible to do an automatic vocabulary validation.

		Metric						
Category	**Item**	**WatERP**	**CUAHSI**	**W3C-SSN**	**NASA-SWEET**	**InWaterSence**	**Surface-Water-Model-Ontology**	**HydrOntology**
Naming criteria	Named entities	Fail (0,7)	Fail (0,6)	Fail (0,7)	Fail (0,6)	Fail (0,7)	Fail (0)	Fail (0,2)
	Named properties	Fail (0,7)	Not rated (0)	Fail (0,6)	Fail (0,8)	Fail (0,7)	Not rated (0)	Fail (0,2)
	Descriptive prefixes and suffixes	Fail (0.8)	Pass (1)	Pass (1)	Pass (1)	Pass (1)	Pass (1)	Fail (0,8)
	Inverse properties	Pass (1)	Not rated (0)	Pass (1)	Fail (0,9)	Pass (1)	Not rated (0)	Fail (0,8)
	Entities and properties definition.	Fail (0.3)	Fail (0)	Fail 0,7)	Fail (0,7)	Fail (0)	Fail (0)	Fail (0)
Syntax	Words and definitions clarity	Fail (0,8)	Fail (0,9)l	Pass (1)	Pass (1)	Not rated (0)	Not rated (0)	Pass (1)
Governance	Term	Pass	Pass	Pass	Pass	Pass	Pass	Pass

	sense	(1)	(1)	(1)	(1)	(1)	(1)	(1)
Vocabulary Metric (See Equation 1)		***2,5***	***2,3***	***2,8***	***2,8***	***1,68***	***1,2***	***2,4***

Table 5: "Results of the vocabulary layer analysis for water ontologies"

The most remarkable about the results obtained is the lack of best practices and standard considerations when naming the entities and properties. Moreover, several annotations over the entities and properties are also missing, thus none of the evaluated ontologies is fully documented. However, while most of the ontologies use prefixes and suffixes for the properties or entities, the WatERP knowledge base will have to be improved in future releases in order to include the necessary suffixes and prefixes. Referring to the term sense, the results obtained were successful for all the evaluated ontologies. Regarding the inverse properties' definition, different results were obtained. The WatERP ontology, the W3C-SSN ontology and InWaterSense ontology have defined inverse properties correctly. As a contrary, the NASA-SWEET ontology and the HydrOntology ontology present several inconsistencies regarding inverse properties' definition. Finally, the last evaluated metric was the "*Annotation*". The annotations are clearly defined and with sufficient sense for the W3C-SSN ontology, the NASA-SWEET ontology and the HydrOntology ontology. However, the WatERP ontology and the CUAHSI ontology need to clarify and enhance its annotations.

The results summary offered above is detailed in the following sub-sections where the specific results obtained for each of the identified water domain ontologies are presented.

3.3.1 WatERP

The evaluation performed over the WatERP Knowledge Base identifies that the inverse properties definition and governance metrics are successfully implemented on the knowledge base. That means all inverse properties follow the standards and the defined best practices principles. However, although the definitions of the terms in the WatERP ontology are of good quality from the water domain perspective, several improvements are needed regarding the rest of the metrics.

Referring to the name of the entities and properties ("*Naming Criteria*" metric), neither the properties nor the entities follow the best practices. On the one hand, some entities do not use singular nouns. For example, "*EndUsers*", "*Regulators*", "*WaterUtilities*", "*Winds*", "*Marshes*", "*Streams*", "*Wetlands*", "*DissolvedSolids*", "*CrossSections*" and "*Species*" are in plural form in CamelCase notation. On the other hand, some of the properties are defined in first person instead of third person such as "*consistOf*", "*perform*", "*performActivity*", "*serve*", "*solve*", "takePart" and "takePartIn". Moreover, the "*Exterior*" property is not named using a verb and it will have to be modified.

In reference to the use of descriptive prefixes and suffixes, some of the necessary suffixes and prefixes have been found on several entities. However, the incorporation of suffixes and prefixes to some other entities will improve its understanding. For example it is the case of the "*HeatFlux*" entity, where it is recommended to add the "*Energy*" word as a suffix.

Regarding the presence of a comment for each ontological resource, several entities need to include a definition for a better ontological understanding. In the current version of the knowledge base, only the main elements have defined a comment and a label. Furthermore, the following entities still a clear description: "*Activity*", "*DecisionalAlert*", "*ThresholdAlert*", "*Cluster*", "*AtmosphericHydrology*", "*Winds*", "*GroundwaterHydeology*", "*Acquifer*", "*Infiltration*", "*Reservoir*", "*SurfaceHydrology*", "*Appliance*", "*Basin*", "*Channel*", "*Desalination*", "*Distribution*", "*Pump*", "*WaterWork*", "*Esturary*", "*Hydropower*", "*Lake*", "*Land*", "*Soil*", "*Vegetation*", "*Marshes*", "*Ocean*", "*Tide*", "*River*", "*Sea*", "*Streams*", "*Tank*", "*Transfer*", "*WaterTreatmentPlant*", "*Wetlands*", "*ChemicalPresence*", "*Color*", "*Humidity*", "*AbsoluteHumidity*", "*DewPoint*", "*SpecificHumidity*", "*Density*", "*DOX*", "*Economic*", "*Energy*", "*Evaporation*", "*Geometry*", "*Envelope*", "*LinearRing*", "*LineString*", "*Point*", "*Polygon*", "*Material*", "*Momentum*", "*Precipitation*", "*Quality*", "*Radiation*", "*IncidentRadiation*", "*Absorved*", "*Reflected*", "*Scattered*", "*Transmitted*", "*Radiance*", "*TMBand*", "*Rainfall*", "*CrossSections*", "*Height*", "*Length*", "*Slope*", "*Weight*", "*Width*", "*Temperature*", "*WindChill*", "*Transpiration*", "*Volume*", "*Flow*", "*Outflow*", "*Designed*", "*Estimated*", "*Measurement*", "*Simulated*", "*State*" and "*UserClass*". Furthermore, some properties also need a description. These properties are: "*hasState*", "*consistOf*", "*exterior*", "*hasLocation*", "*hasModel*", "*hasOffering*", "*hasRiver*", "*hasUserClass*", "*iscompoundPhenomenon*", "*isCompositedPhenomenon*", "*isMultiPhenomenon*", "*isSingledPhenomenon*", "*isConstrainedPhenomenon*", "*isConstrainedList*", "*isSingleConstrainedPhenomenon*", "*isGroupedBy*", "*isLogicalDependent*", "*isManagedBy*", "*isModelOf*", "*isObservedByFOI*", "*isObservedByPhenomenon*", "*isOfferingOf*", "*isPartOf*", "*isProducedBy*", "*isRiverOf*", "*isWaterWorkOf*", "*perform*", "*performActivity*", "*serve*" and "*takePart*".

For the ontological resources that have defined an annotation (e.g. comment or label), the "*Governance*" results (which is the meaning of the comments and labels) reflect that most of the ontological resources have a good score. However, some ontological resources like "*EquivalentDepth*", "*hasAssociatedAction*" and "*hasObservationResults*" need a revision, since the defined comments and labels do not correspond to the entity/property.

As a summary, the WatERP ontology presents several issues in the "*Vocabulary*" category, ranging from the use of standardized names for the entities and properties to the description of the entities (e.g. comments and labels). The issues identified will be addressed in the next future versions of the WatERP knowledge base, and they will be re-evaluated and documented in the next "*Holistic Auditing*" deliverable (*D7.1.3* scheduled on *M27*).

3.3.2 CUAHSI

The CUAHSI ontology evaluation reveals that the prefixes and suffixes applied to the name of the entities are used appropriately. Furthermore, the CUAHSI ontology uses terms that are closely related and relevant for the water domain. However, the rest of the measured metrics have revealed some weaknesses regarding the vocabulary category, especially in the taxonomical definition.

There are multiple entities that do not use the CamelCase notation. Some of them start with lowercase such as "*aquaticBiology*", "*atmospherivHydrology*", "*biologicalParameters*", "*estuary*", "*lake*", and "*land*" for instance. Moreover, other entities are named using single marks that can cause problems when querying (e.g. "*'Fish Habitat'*", "*'Fish Substrate'*", "*'Habitat Type'*", "*'Haul Length'*", etc.). In reference to the definition of the entities' name, this ontology uses plural names definition instead of singular ones. This is the case of the "*'General Species'*", "*Winds*", "*'Heat Fluxes'*", "*biologicalParameters*" entities among others.

Regarding the definition of the object and data properties, CUAHSI ontology has not defined any of them. As a consequence, this metric cannot be measured. Similarly, neither the name of the properties or the inverse properties can be rated.

Another key metric that could not be rated is the properties' definition, since they do not exist in the CUAHSI ontology. Moreover, different entities contain the same comment as reflected in "*Net*" and "*Reflected*" sub-entities of the "*'Terrestrial Rad', Long Wave'*" and "*Net*", and "*Downward*" sub-entities of the "*'Total Rad, Short +'*".

3.3.3 W3C-SSN

As it was previously mentioned, the W3C-SSN ontology is a representative and standardized ontology regarding the sensor observation and measurement. However, the ontology is not totally standardized.

In reference to the named entities and properties, on the one hand, the entities names are defined with single nouns and special characters, and they also avoid the use of the CamelCase notation (e.g. "*'Formal Entity'*", "*'Insieme {it}'*", "*'Social attribute'*", "*'detection limit'*", "*'Sensor Output'*"). On the other hand, most of the property names avoid the use of mixedCase notation. Instead, they contain spaces and use single quotation marks in the names. Properties such as "*'acts for'*", "*'is constraint for'*", "*'expresses concept'*" are not aligned with mixedCase notation. Moreover, the evaluation has also revealed that some of the properties are named avoiding verb tenses such as "*'qualitiy of observation'*", "*'far from'*", "*'for property'*" and "*'on platform'*".

Regarding the use of prefixes and suffixes in the names, they are appropriately used in the ontology, highlighting the child entities when needed. In the same line, the definition of the inverse properties were checked and validated according to the standards and best practices principles.

Referring to the entities and properties definition, most of the entities and properties contain comments and labels (annotations) to facilitate the understanding of the ontology. However, there are several properties and entities that do not contain any annotation. This is the case of the "*'hasInput'*", "*'hasOuput'*", "*'end time'*", "*'hasValue'*", "*'start time'*", "*'is event included in'*", "*'is action included in'*", "*'is object included in'*", "*'is agent included in'*", "*'is time included in'*", "*'is characterized by'*" and "'*observedBy*'" object properties and "*Community*", "'*Workflow execution*'", "*Narrative*", "*DesignedSubstance*", "'*Functional substance*'", "'*Chemical object*'", "'*Biological object*'", "*DesginedSubstance*", "*SpatioTemporalRegion*" and "*Insieme*" entities. Another desired characteristic related to the annotations is that they must be clear and concise. The W3C-SSN ontology has defined all the entities clearly and this helps the reader to understand the ontological resources easily.

3.3.4 NASA-SWEET

The NASA-SWEET ontology has been designed with a similar objective to the W3C-SSN. Both ontologies are upper knowledge bases that define standardized in the scope of the water and the sensor frameworks respectively. The NASA-SWEET ontology is focused on representing standard procedures and entities related to the environmental science. The vocabulary evaluation of this ontology concludes that the entities are totally aligned with the ontology domain. In spite of this, the ontology developed by the NASA has several issues related to the naming conventions.

The notation used by the NASA-SWEET is not aligned with the best practices when naming the ontological resources. In general, the ontology follows the CamelCase notation, but some entities are wrongly named. For example, there are entities which use a plural noun such as "*Acoustics*". Moreover, some other entities use special characters and blank spaces in the name. Examples of this case are "'*Gorund Water Flow*'", "'*Ground Water Level*'", "'*detection limit*'", and "'*Energy Content*'". Regarding the properties, all of them use the mixedCase notation. Instead, some properties do not use verb tenses in the name of the properties. This is the case of "*categoryOf*", "*coordinate_1*", "*transparent*", "*from*", "*reduction*" and "*minimumOf*". Moreover, there are properties which are named using verb tenses but do not use the third person in the verb (e.g "*reduce*", "*feed*", "*descompose*").

Another relevant aspect of the evaluation is the testing of the use of prefixes and suffixes in order to clarify the hierarchical organization of the entities and sub-entities (if present). In this case, the NASA-SWEET is aligned with the best practices, since the prefixes and suffixes are used appropriately in the ontology.

The conclusion regarding the inverse properties' analysis is that it would be needed to define the inverse property for the "*impacts*" (e.g. "*impactedBy*") and "*produces*" (e.g. "*is produced by*") object properties.

To conclude the vocabulary evaluation, the annotations definition for the ontological resources has not been fully achieved. The NASA-SWEET ontology should define more comments and labels for the entities and object properties in order to facilitate the understanding of the entities.

3.3.5 InWaterSence

Most of the entities in the "*InWaterSence*" ontology follow the CamelCase notation in the naming criteria, as opposite to the inverse definition and notation. Furthermore, the defined elements also correspond to the ontology scope. Nevertheless, several improvements have been identified with special mention to the lack of annotations in the definition of the ontological resources.

Focusing on the issues found, there are a few entities that do not follow the CamelCase notation. There are some entities that use single quotation marks and blank spaces such as "*'Sensing Device'*", "*'Sensor Input'*", "*'Feature of Interest'*", and "*'Unit of measure'*". The use of special characters in the name of the entities is not recommended, since it can cause problems during ontological querying and navigation. Additionally, several entities are named using plural nouns instead of single ones (e.g. "*Oxygenation_confitions*" and "*Thermal_conditions*").

Referring to the properties naming, the majority of the properties follow the mixedCase notation, but not all of them. Some examples are "*'made observation'*", "*'has location'*" and "*'has property'*". Additionally, there are properties that do not use a verb in its name. This is the case of "*'observation result time'*", "*'feature of interest'*" and "*unitOfMeasure*". The use of descriptive prefixes and suffixes in the ontology is appropriate (a clear example is the Sensor entity and its children).

Finally, the evaluation of the ontology states that there are no definitions for the entities and properties. Hence, this is a weakness of the "*InWaterSence*" ontology. Consequently, the clarity and the sense of the ontological annotations (e.g. comments and labels sense) cannot be validated.

3.3.6 Surface-Water-Model-Ontology

The Surface-Water-Model ontology represents the OGC phenomena in a taxonomical level. As the elements are based on OGC schemas, the ontology accomplishes the domain scope and the validity of the terms.

However, the Surface-Water-Model-Ontology does not accomplish the naming best practices. The entities do not follow the CamelCase notation, since it was chosen to use a URIS-like notation. This means the concept names are defined using OGC URN scheme to identify resources in the context of OGC Web Services. The name of the ontological properties could not be rated, since the Surface-Water-Model-Ontology ontology is actually a taxonomy and, consequently, it does not contain any property.

Similarly, the inverse property evaluation cannot be performed since there are object or data properties in the ontological definition. Furthermore, this ontology has no annotations defined in the entities. As a conclusion, the present ontology is not aligned with the current standards and best practices.

3.3.7 HydrOntology

The evaluation of the HydroOntology knowledge base has proved that the ontological elements have sense and are totally aligned with the domain where the ontology acts.

However, the HydrOntology knowledge base does not follow the best practices regarding the naming of the properties and entities in the ontology. The entities are not named using the CamelCase notation and they use single quotation marks and blank spaces (e.g. "*'Corriente subterránea'*", "*'Llanura de inundación'*"). In the same line, the properties do not follow the best practices regarding mixedCase notation and the names of all properties are written using lowercase, blank spaces, and underscores. As a contrary, prefixes and suffixes are used (e.g. "*'Aguas corrientes'*" entity and its sub-entities) according to the standards.

Furthermore, some inverse properties have not been defined although they were necessary. For example, property "*es_transvasada*" is the inverse of "*transvasa*" but they have not been defined as the inverse property of each other. Similar case occurs with "*es_distribuida*" and "*distribuye*".

With regards to the annotations and the definition of the properties and entities, the evaluation has concluded that the ontology was written in Spanish only, and it is recommended to incorporate some other languages in order to improve its understanding (e.g. English). In spite of this, most of the ontological entities include a comment explaining its meaning. Moreover, no annotation has been included in any of the elements although they are highly recommended, especially in entities like "*'Llanura de inundación'*" or "*Barranquilo*". Finally, the existing definitions are clear and help the reader to understand the meaning of the entities and properties.

3.4 Architecture layer

The main goal of the architecture category is to characterize the ontological model from the structure (e.g. richness, readability, etc.) and reasoning (e.g. ontological consistency) point of view.

In order to perform the evaluation of the metrics and the category test, a JAVA program was developed using the JENA model and the Pellet reasoner over the knowledge base (Jena Model). The main purpose of the created evaluation software is to load a JENA model in memory and compute all the metrics navigating through the ontology. The navigation includes the calculation of the number of entities, the number of properties by each entity, the number of comments and labels, etc. Furthermore, the consistency of the ontology has been checked using Pellet reasoning (OWL reasoning). This kind of reasoning has been possible because of the OWL definition of the ontology and the reasoning recommendations exposed in deliverable D1.3 "*Generic ontology for water supply distribution chain*" on *Section 3* (*page 50*).

The results obtained (see *Table 6*) demonstrate that the WatERP ontology has the highest rating in this category, followed by the W3C-SSN ontology. The cause the high rating of the WatERP ontology lies on the inclusion of entities from the W3C-SSN ontology that have been enriched with attributes of other ontologies such as CUAHSI, SWEET and GML (GeoSPARQL ontology). Furthermore, the WatERP knowledge base has also been enriched with attributes and entities from WaterML2, and decisional aspects regarding water domain, demand knowledge, etc. However, it will be needed to increase the population of the ontology in order to clarify the entity importance and usage. Another improvement applicable to all the ontologies is the readability of the ontological resource, that is, the definition of comments and labels in the ontologies to enhance the ontological resource understanding.

		Metric						
Category	**Item Description**	**WatERP**	**CUAHSI**	**SWEET**	**HydrOntology**	**W3C-SSN**	**In Water Sense**	**Surface Water Model**
Structure	Schema Relationship Richness	*0,22*	*0,0*	*0,05*	*0,08*	*0,35*	*0,08*	*0,00*
	Attribute Richness	*0,09*	*0,0*	*0,005*	*0,15*	*0,023*	*0,006*	*0,0*
	Entity Importance	*0,019*	*0,0*	*0,28*	*0,0*	*0,0*	*0,039*	*0,0*
	Entity Relationship Richness	*0,62*	*0,0*	*0,08*	*0,0*	*0,0*	*0,0*	*0,0*
	Readability	*0,36*	*0,0*	*0,15*	*0,44*	*0,53*	*0,0*	*0,0*
Reasoning	Ontology consistency	*1,0*	*1,0*	*1,0*	*1,0*	*1,0*	*1,0*	*1,0*
Architecture Metric (See Equation 2)		***1,16***	***0***	***0,3***	***0,328***	***0,95***	***0,1***	***0***

Table 6: "Results of the architecture layer analysis for water ontologies"

Specifically, the metrics calculated for the WatERP knowledge base reveals that this ontology has the highest relationship richness. This means the WatERP ontology is able to connect the entities defined by the objects' properties so that new knowledge can be generated using a reasoner such as Pellet. Furthermore, the entity relationship richness (that measures the variety of instances that pertain to the entities) has also achieved a high score. This result demonstrates that the knowledge source is distributed. However, the entity importance reveals that the ontology is not fully populated (around *2%*) and during the next versions of the WatERP ontology a further emphasis in the population is needed.

The score obtained for the attribute richness indicates that an improvement will be needed. Therefore, it will be needed to include more attributes based on the work packages needs, WaterML2 schema and other relevant standardization attributes. Another aspect that must be improved is the readability, where more comments and labels must be defined in the lower part of the WatERP ontology.

Regarding the rest of the ontologies, "*CUASHI"* and "*Surface-Water Model*" results reveal that both ontologies only have defined a taxonomical structure and do not have the relationships between entities and, what is more important, the data properties that permit to enrich the ontological resources with specific information. The results over "*HydrOntology*" show that the ontology is actually a model and it does not have enough instances compared to the ontological schema. A similar problem appears with "*SWEET*", "*SSN*" and "*InWaterSense*". In the case of "*SWEET*" and "*SSN*" the problem is not critical since both ontologies are considered upper ontologies (e.g. ontologies that serve as a model for domain specific ontologies). Furthermore, the "*InWaterSense*" ontology has low attribute richness and low schema relationship richness that is a consequence of the low number of attributes compared to the total amount of ontological resources. In the case of the "*W3C-SSN*" ontology, the results show that it is an ontology model (upper ontology) with high object properties and data properties richness, and with a good comprehension (e.g. readability) level.

As a conclusion, the WatERP ontology needs to be improved in terms of *(i)* ontological population in order to clarify which ontological resources are not widely used; *(ii)* attributes (data properties) definition in order to enrich the ontological resource with more information; and *(iii)* readability by the definition of comments and labels for the ontological resources.

3.5 Semantics layer

The semantic category aims to evaluate the defined ontological semantics through the examination of the ontological axioms, assertions and reasoning inference over the different identified ontologies. The purpose of this layer is to assure that the inferred knowledge is valid and coherent with the information introduced into the ontology.

The semantic category has been tested by loading each of the ontologies in the ontological editor (e.g. Protégé) with the Pellet reasoning capabilities over OWL ontologies. Once the ontology has been loaded and the reasoner has been launched, the metrics have been reviewed by different knowledge base experts. Based on the knowledge base experts' criteria, the final results have been set as the mean of the experts' score.

The overall results obtained (see *Table 7*) reveal that most of the ontologies have achieved a good score in this category. Hence, most of the ontologies have well-defined semantics. The ontologies that need more definition and ontological structuration are "*CUAHSI*" and "*Surface Water Model*". Only a taxonomic structure has been defined for both ontologies, thus there is nothing for the reasoner to infer.

	Metric						
Item Description	**WatERP**	**CUAHSI**	**SWEET**	**HydrOntology**	**W3C-SSN**	**In Water Sense**	**Surface Water Model**
Consistency	Pass (1)	Pass (1)	Pass (1)	Pass (1)	Pass (1)	Pass (1)	Pass (1)

Expressiveness	Pass (1)	Fail (0,5)	Pass (1)	Pass (1)	Pass (1)	Pass (1)	Fail (0,5)
Granularity	Pass (1)	Fail (0,6)	Pass (0,9)	Pass (1)	Pass (1)	Pass (0,9)	Fail (0,1)
Comprehensiveness	Pass (0,9)	Pass (1)	Pass (1)	Pass (1)	Pass (1)	Pass (1)	Fail (0,5)
Semantic Metric (See Equation 9)	**2,93**	**2,33**	**2,93**	**3,00**	**3,00**	**2,93**	**1,58**

Table 7: "Results of the semantics layer analysis for water ontologies"

In the context of the WatERP ontology, the results show that this ontology has achieved good scores in all sub-categories. In terms of "*Consistency*", the reasoner discovered additional axioms based on the definitions of the ontological resources (see *Figure 4*). All of these axioms are correct and produce new explicit knowledge inside the WatERP knowledge base (see *Figure 4*). In reference to the "*Expressiveness*", the WatERP knowledge base is defined by $\mathcal{SROIQ}(\mathcal{D})$ expressivity which indicates that the ontology is represented by a hierarchical structure, inverse properties, and nominal and qualified cardinality (see *D1.1 in Section 2.3 on page 26*). Regarding the "*Granularity*", the last version of the ontology has a suitable categorization of the water resources since the problem with the "*Feature of Interest*" and "*Phenomena*" was solved (see *D1.4.1 on section 3.1.1 in page 27*). The "*Comprehensiveness*" high rating is due to the initial population of both pilots (ACA and SWKA) in the ontology.

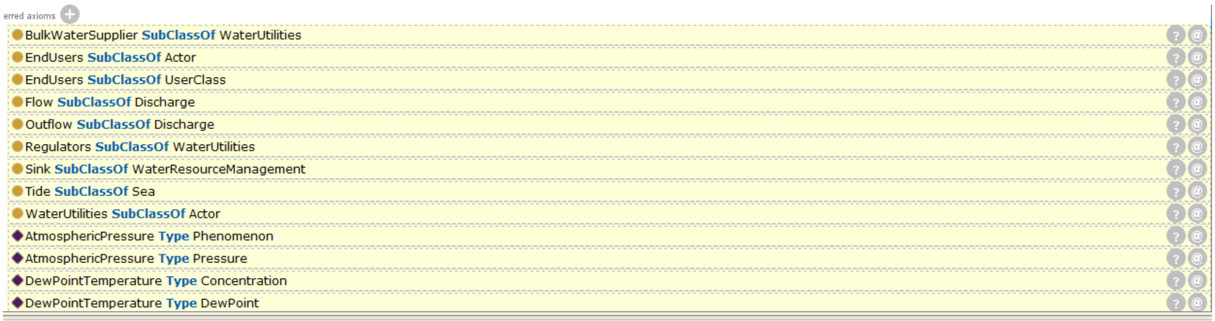

Figure 4: "Inferred axioms"

Regarding the rest of the ontologies, the evaluation shows that "*CUAHSI*" ontology and "*Surface-Water-Ontology*" are defined by a $\mathcal{AL}$ description logic expressiveness that asserts that both ontologies have only defined a taxonomical structure. Then, none of these ontologies has enough semantic content to infer appropriate knowledge. Furthermore, the "*CUAHSI*" ontology has the inconvenience that the entity

“*Features Of Interest*” defines the variables to be measured (“*Phenomena*”) as a subcategory. This categorization produces rigidity in the ontological structure and does not facilitate its maintenance when new instances are included. In the case of the “*Water-Surface-Ontology*” ontology, the comprehensiveness and granularity is not adequate, since the phenomena representation contains duplicate ontological resources like the “*Phenomena*” entity and its specific instances. Furthermore, in the “*InWaterSense*” ontology, the “*MeasurementSite*” could have been defined as a sub-entity of “*Feature*” in order to align it with the GML ontology that is included in this specific knowledge base.

As a conclusion of this category, the WatERP ontology is coherent and has a powerful reasoning engine. However, several improvements are needed in order to allow the correct incorporation of new information needed by the different work packages (e.g. demand management, decision support system, open management platform, etc.).

3.6 Application layer

The application category aims to evaluate the applicability of the ontology in its specific domain. In the case of the WatERP project, the application category is in charge of testing the querying over the ontologies using different types of SPARQL queries.

The process to test the ontology has been based on the development of a JAVA program that uses the JENA library, the Pellet reasoner and the SPARQL query language in order to perform a set of defined queries over the identified ontologies. This set of queries are divided into simple queries (e.g. using direct knowledge only), medium queries (e.g. using simple knowledge inference only) and complex queries (e.g. using several inferred mechanism and external mappings). Furthermore, for the knowledge bases that do not have defined individuals, the queries have been performed using examples that use these specific ontologies (see *Table 8*).

Knowledge Base	URL of the Abox Ontology
WatERP	ACA population and SWKA population
CUAHSI	http://svn.sdsc.edu/repo/WATER/CUAHSI/OntologyOwl/StarTree_Current/ontology/ajax.owl
SWEET	http://sweet.jpl.nasa.gov/ontology/ http://www.semantic-systems-biology.org/biogateway/querying
HydrOntology	http://mayor2.dia.fi.upm.es/oeg-upm/files/hydrontology/hydrOntology_GeoLinkedData.owl
W3C-SSN	http://www.w3.org/2005/Incubator/ssn/ssnx/weather-station/station
InWaterSense	http://inwatersense.uni-pr.edu/ontologies/rivers_sampledata.owl http://inwatersense.uni-pr.edu/ontologies/drinking_sampledata.owl
SurfaceWaterModel	https://marinemetadata.org/files/mmi/examples/mmihostedwork/ontologieswork/ogcowlharmo

	nization/om.owl

Table 8: "Abox ontologies tested during the application layer"

As a general result for this category (see *Table 9*) most of the SPARQL queries were successfully executed. In the case of the "*HydrOntology*" knowledge base, the query test could not be executed because of the lack of instances in the ontology. In the case of the "*CUAHSI*" and the "*Surface-Water-Model*" only the simplest queries could be executed successfully, because only direct knowledge could be obtained since there are no objects or data properties. Furthermore, in the case of the WatERP knowledge base, the queries could be successfully executed. However, several issues were found at a competency questions level (see *Section 3.7*). In rest of the cases, all the queries were executed according to the domain knowledge and the defined competency questions.

	Metric						
Item Description	**WatERP**	**CUAHSI**	**SWEET**	**HydrOntology**	**W3C-SSN**	**In Water Sense**	**Surface Water Model**
Ontology Querying	Pass (1)	Pass (0'33)	Pass (1)	Fail (0)	Pass (1)	Pass (1)	Pass (0,33)
Competency Questions	Pass (0,8)	Pass (1)	Pass (1)	Pass (1)	Pass (1)	Pass (1)	Pass (1)
Application Metric (See Equation 10)	**2,70**	**2,00**	**3,00**	**1,50**	**3,00**	**3,00**	**2,00**

Table 9: "Results of the application layer analysis for water ontologies"

Focusing on the WatERP knowledge base, the results show that the ontology is being developed aligned with the competency questions raised with the basis of the pilots' needs. Furthermore, the population of the ontology is also focused on giving answer to these.

Regarding ACA, there are two competency questions that cannot be answered by the current knowledge base (see *Table 10*). The first one is related to the economic costs associated to specific features of interest. The problem is that there are no instances related to these questions. The second question is related to water quality constraints, and it could be answered if the relevant object properties and restrictions were defined in the knowledge base.

ACA Competency Question	**Implemented**
What is the current level of reserves?	

Are any new inflows expected to enter the system? If so, how much?	
Are there non-regulated inflows in the lower part of the basin? If so, how much?	
Are there any available alternative sources (e.g., desalinated water)? Costs? Production capacity?	
Are there any water quality constraints (temperature, pollution)?	
What are the current demand levels? Future forecasts? Water use priorities?	
What is the current drinking water use? Source options? Future needs?	
What is the current industrial water use level? Supply options?	
What is the current irrigation water need? Usage? Forecasted needs?	
What is the minimum hydropower operation flow requirement?	

Table 10: "ACA competency questions"

In the case of SWKA there is only one competency question that cannot be answered by the current version (see *Table 11*). It is related to water quality constraints, and it will be needed to define the proper object properties and the ontological restrictions in order to give an answer.

SWKA Competency Question	Implemented
What is the water level in the main reservoir?	
Is there a water quality constraint?	
What is the current water use?	
What is the current pumping rate out of the water works?	
What is the current inflow rate into the main reservoir? Outflow?	
What is the current energy consumption?	
What is the efficiency of the system (regarding the water allocation in reference to the used energy)?	

Table 11: "SWKA competency questions"

Regarding the rest of the evaluated ontologies, the results of the tested queries has been satisfactory in most of the cases. However, some issues appeared. In the case of the "*CUAHSI"* and the "*Water-Surface-Model*" ontologies, only the direct (e.g. explicit) knowledge queries could be executed due to its ontological expressiveness. Furthermore, in the case of the "*HydrOntology*" knowledge base none of the queries could be performed, since this ontology does not contain any instance and no knowledge can be obtained.

As a conclusion for this layer, the WatERP knowledge base needs to include the necessary elements to give an answer to the following competency questions:

- "*Is there a water quality constraint?*" and "*Are there any water quality constraints (temperature, pollution)?*"
    - One possibility to give answer to those questions is to include a restriction that groups the needed constraints to water quality measures
- "*Are there any available alternative sources (e.g., desalinated water)? Costs? Production capacity?*"
    - The answer to those questions will be possible with the definition of the instances that represent relative costs and production capacity related to the features of interest of both pilots

3.7 Usability layer

The usability layer aims to define the quality measurements that are required in order to ensure that the evaluated ontologies follow a set of usability standards.

The evaluation process is empirical, and is carried out with the help of the tools that use the ontologies. All categories are evaluated for with each tool and the possible results are: *Pass*, *Fail* and *Not rated*. The considered categories are: *(i)* visibility and system state; *(ii)* errors; *(iii)* error recovery; *(iv)* responsiveness; and *(v)* feedback. A detailed description of those categories is explained in deliverable *D7.1.1 "Holistic Auditing" in section 3.2.1* (*page 21*). Notice that the "*Standards*" category presented in deliverable D7.1.1 has been discarded since it has already been evaluated in the "*Vocabulary*" layer.

Table 12 shows the results of the evaluation for each of the ontologies. As a summary, all ontologies satisfy the usability requirements except for the "*Error Recovery*" category that has not been evaluated since no errors occurred during the test. Finally, it is important to remark that the "*NASA-SWEET*", the "*Surface-Water-Model-Ontology*" and the "*HydrOntology*" ontologies could not be tested because no tool suitable to manage them was found.

	Ontologies						
Category	**WatERP**	**CUAHSI**	**W3C-SSN**	**NASA-SWEET**	**InWaterSense**	**Surface-Water-Model-Ontology**	**HydrOntology**
Visibility and system state	Pass (0,6)	Pass (0,9)	Pass (1)	Not rated (0)	Pass (0,9)	Not rated (0)	Not rated (0)
Errors	Pass (1)	Pass (1)	Pass (1)	Not rated (0)	Pass (1)	Not rated (0)	Not rated (0)
Error Recovery	Not rated (0)	Not Rated (0)	Not rated (0)	Not rated (0)	Not rated (0)	Not rated (0)	Not rated (0)
Responsiveness	Pass	Pass	Pass	Not rated	Pass	Not rated	Not rated

	(1)	(0,8)	(1)	(0)	(1)	(0)	(0)
Feedback	Pass (1)	Pass (1)	Pass (1)	Not rated (0)	Pass (1)	Not rated (0)	Not rated (0)
Usability Metric (See Equation 11)	***2,16***	***2,22***	***2,4***	***0***	***2.34***	***0***	***0***

Table 12: "Usability layer evaluation items"

A detailed explanation of the results shown in *Table 12* is presented in the next sub-sections.

3.7.1 WatERP

Both the WatERP ontology and its application (OMP, see *Figure 5*) are still in development stage, thus not all features could be reviewed in this deliverable. Those functionalities have caused several *Fail* ratings that will not be present once the development is finished. Regarding "*Visibility and system rate*", all visualization elements displayed are coherent with the information stored in the ontology. The logical models are displayed as diagrams and the different types of water resources are identifiable. Moreover, the application allows the navigation through the water resources discovering their features of interest, observations and, finally, the data stored in them. However, this interface can be improved in order to make it more intuitive by showing extra information.

As it was explained before, no errors occurred during the test, thus the "*Error Recovery*" category could not be evaluated, including the clarity of language and the understanding of the error messages.

Regarding the "*Responsiveness*" category, which evaluates that the response time is appropriate for the querying and for the knowledge inference, the performance of the WatERP ontology was satisfactory. On the one hand, the queries performed during the test were answered in less than a second. The querying aimed at recovering the available logical models (ACA and SWKA) which are composed by the water resource entities, the type of water resources, the relationship between them, and the features of interest that belong to a water resource. On the other hand, the inference could not be evaluated during the test because currently the OMP has not yet implemented these functionalities. Finally, in reference to the "*Feedback*" category, the OMP returned the expected data for the actions issued.

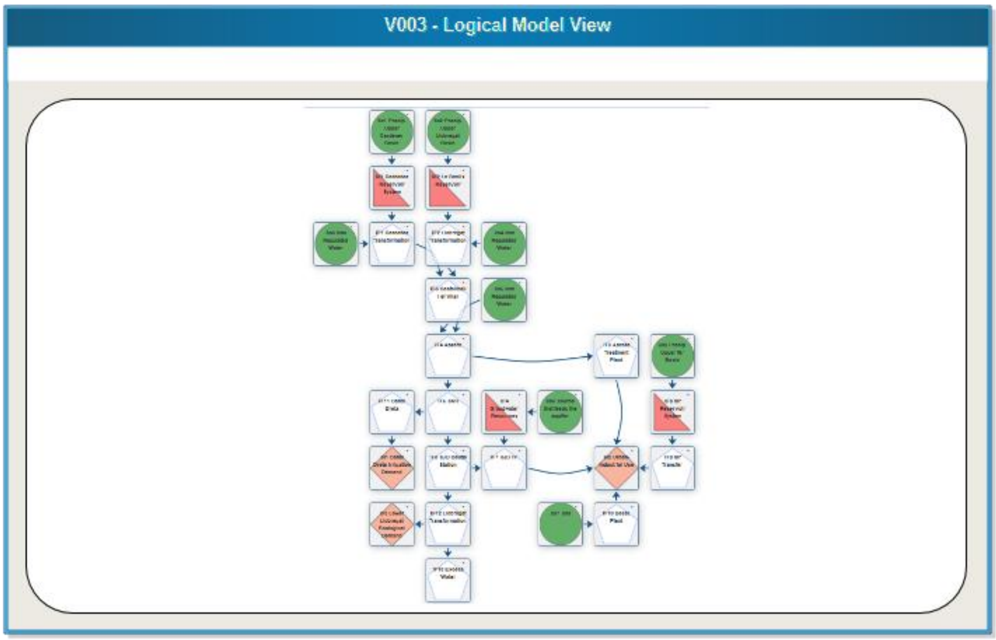

Figure 5: "WatERP OMP graphical user interface"

3.7.2 CUAHSI

The utility layer was evaluated over the CUAHSI ontology using the HydroDesktop[13] tool (see *Figure 6*), which allows finding, retrieving, analyzing and using hydrological data from the CUAHSI-HIS system by managing the metadata and the ontology services. Regarding the "*Visibility and system state*" category, the tool and the ontology fulfill the minimum requirements from the visual point of view. The sensors are displayed on maps and they are geographically referenced. Moreover, the navigability between sensors and their measures is easy. No errors occurred during the evaluation of HydroDesktop. For this reason, the error messages were not evaluated. With regards to the "*Responsiveness*" category, it happens that the first time that the data are accessed it is necessary to download them, although the download time and the response time once they have been downloaded are acceptable on HydroDesktop tool. In both cases the time was less than one second, which allows working in a comfortable manner, that is, without important lags during navigation. Finally, the "*Feedback*" category was evaluated and the system behaved according to the actions issued, thus the feedback evaluation was positive.

[13] http://his.cuahsi.org/hydrodesktop.html

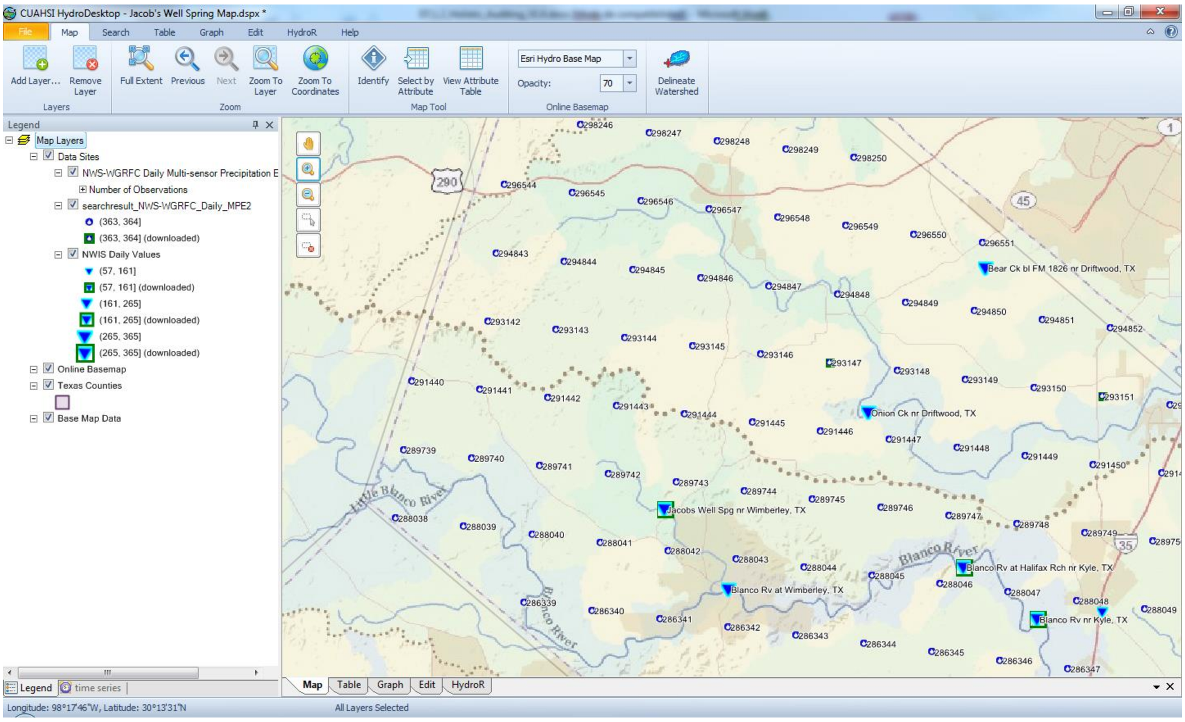

Figure 6: "HydroDesktop graphical user interface"

3.7.3 W3C-SSN

MesoWest[14] (see *Figure 7*), which is a web application which allows accessing the weather observations for all states of USA, was used in order to evaluate the W3C-SSN ontology. Regarding the "*Visibility and system state*" category, the information displayed as well as the elements visualized were appropriate. The sensors are presented on a map and they are geographically referenced. Moreover, there are two ways to access the information of the sensors; moving over them or clicking on them. If we move over a sensor, a summary of the most important information will be displayed. Instead, if we click on a sensor we will obtained a detailed and extended version of the information. No errors occurred during the test, thus the understandability of the messages could not be rated. Regarding the "*Responsiveness*" category, the response time of MesoWest was minimum, despite it is working with large volumes of information. About the "*Feedback*" category, the behavior of the system was coherent all the time, thus no feedback issues were detected.

[14] http://mesowest.utah.edu/index.html

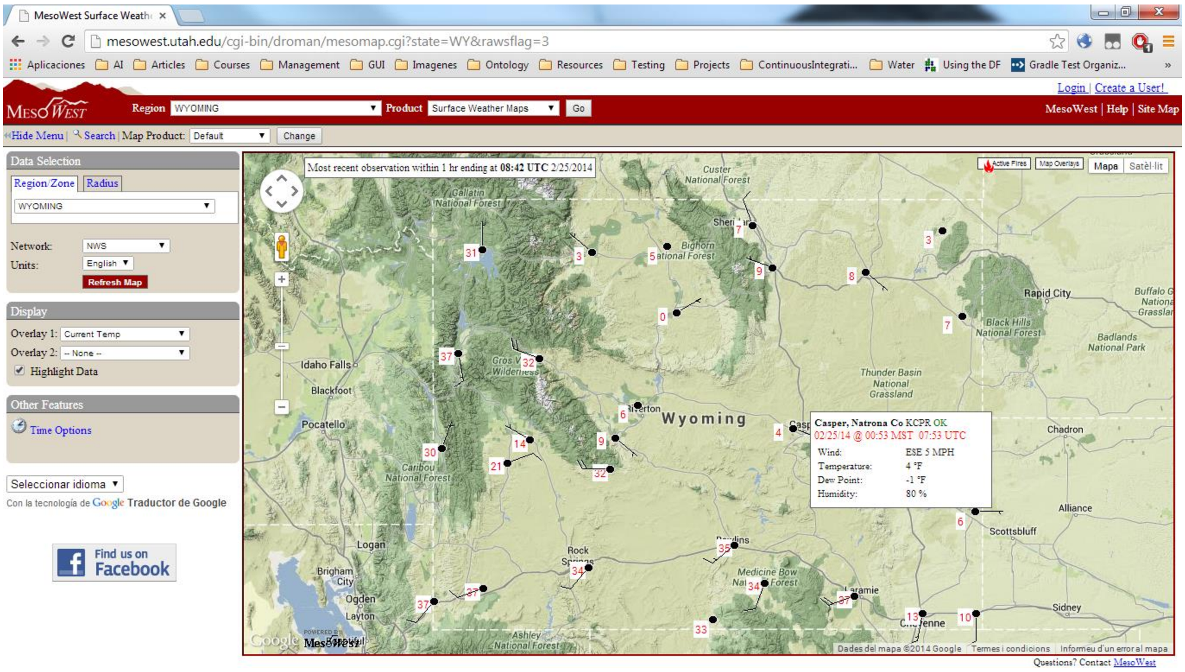

Figure 7: "MesoWest graphical user interface"

3.7.4 InWaterSense

To validate the InWaterSense ontology, the tool[15] implemented on the same project where the ontology was developed was used. It is important to remark that the project is not yet finished and therefore not all functionalities and items can be tested. Referring to the visualization of the elements, it is adequate in order to present the information to the user. Moreover, the information is displayed organized in a logical and understandable way. Regarding the errors, the use cases that are allowed by the application limit the possibility of an error occurrence. Thus, no error was raised during validation and the clarity and understandability of the error messages could not be verified. With regards to the "*Responsiveness*" category, the application responds in less than a second allowing a smooth navigation through the information. Finally, the feedback given by the application is consistent with the expected information, thus no problems were detected on the "*Feedback*" category.

3.8 WatERP ontology improvements

This section summarizes the actions to be performed over the WatERP ontology in order to address the issues appeared during the evaluation. In the previous sections it was verified that the WatERP knowledge base is aligned with the pilots' needs and it is being developed using the standards and

[15] http://inwatersense.uni-pr.edu/portal

following the best practices. It was also verified that it is capable of performing domain reasoning and knowledge inference and as well as its usability when integrated in external tools (e.g. OMP).

Furthermore, the comparison between the WatERP knowledge base and other water management-related ontologies reveals that the developed ontology uses the information of the upper ontologies to enrich its information and construct a coherent, multi-layered and decisional-based water supply and distribution knowledge base. Moreover, the WatERP knowledge base is generic enough to be used as an upper ontology for the water domain knowledge management.

In spite of the previous, several improvements must be done in further developments of the knowledge base (see *Table 13*). These improvement opportunities are mainly focused on enhancing the ontological naming convention towards knowledge base standards and improving the ontological architecture by incorporating more ontological and readability resources aligned with the improvements performed on the rest of work packages. Moreover, an enhanced population model over the ontology will permit to tune the knowledge base towards a more representative entities and relationships. Additionally, a priority rating (LOW, NORMAL or HIGH) has been assigned to each of the issues found in the WatERP knowledge base. Using this last value, the knowledge base will be improved by implementing the most critical issues first.

	WatERP Ontology improvement opportunities		
Category	**Title**	**Description**	**Priority**
Vocabulary	**Refactor Readability**	Refactor the current comments and labels in order to accomplish and improve the ontological resource description.	NORMAL
	Refactor Ontological Resources	Refactor ontological resources in order to align them with the current best practices and standards from ontological development point of view.	NORMAL
Architecture	**Ontological Population**	Enhance the ontological population in order to improve ontological knowledge inference.	HIGH
	Attributes definition	Define more attributes related with the needed information from WaterML2 file, HY_FEATURES information and pilot's information.	HIGH
	Readability improvement	Add into the ontology comments and labels in order to facilitate the reader understanding.	NORMAL
Application	**Ontological Enhancement**	Include into the WatERP ontology more information related with each of the work	NORMAL

		packages (demand management, decision support system, open management platform, etc.) and current standards.	
	Ontological Competency Questions	Include in the ontology needed ontological resources in order to answer the following competency questions: i) "*Is there a water quality constraint?*" ii) "*Are there any water quality constraints (temperature, pollution, etc)?*" iii) "*Are there any available alternative sources (e.g., desalinated water)? Costs? Production capacity?*"	HIGH

Table 13: "WatERP Ontology Improvement opportunities"

As a conclusion of this section, further developments of the WatERP ontology will be done taking into account the list of issues in order to incorporate the improvements into the next document regarding the knowledge base, which is deliverable D1.4.2 "*Extension of the taxonomy and ontology to the pilots*".

4. Conclusions and future work

4.1 Conclusions

The main objectives of the "*Holistic auditing*" of the WatERP project is twofold: *(i)* ensure that the information provided by the demonstration objects (e.g. pilots) are adequate and aligned with the development performed in the rest of work packages; and *(ii)* ensure that development of the knowledge base is aligned with the users' needs and requirements and follows the development standards and best practices.

Regarding the validation of the pilots' information, this deliverable has focused on the verification of the resolution of the issues appeared during the previous validation which were documented in deliverable D7.1.1 "*Holistic auditing*", as well as a review of the checklist used to perform the validation. On the one hand, the missing information issues were addressed. Energy consumption data was missing for the Ter-Llobregat pilot site, and it was decided to mark this information as "*Not applicable*", since it was agreed that it is not relevant enough in the context of upper stream resources' management, where the optimization of the hydraulic efficiency prevails. Instead, meteorological information was missing for the Karlsruhe pilot site, and SWKA explained that they do receive and use the meteorological from a meteorological station nearby the city of Karlsruhe.

On the other hand, a review of the checklist used to validate the pilots' data has been done. An error on the categorization of some items has been found and solved, and some improvements have been applied to the table in order to clarify the meaning of each of the items and enhance the readability of the items by changing the order to a more logical one. Finally, an additional table with a comprehensive list of the documents generated by the consortium where the description of each of the items can be found has been built with the aim of making the pilots' data table a more useful resource for the rest of the work packages.

The main conclusion regarding the pilot's data validation is that both pilots **satisfy the data requirements needed for the correct development of the rest of work packages**.

In reference to the knowledge base validation, the present deliverable has exposed the implementation of the evaluation methodology developed in the previous deliverable D7.1.1. The main objective of the validation of the WatERP's knowledge base is to verify the current developments are aligned with the pilots' needs and requirements and follow the development standards and best practices established (internal validation). Moreover, the WatERP ontology development was evaluated against some of the most representative water domain ontologies in order to compare the current development status of the WatERP ontology with respect to other ontologies (external validation). As a main conclusion of the knowledge base validation, the **WatERP ontology evolves successfully given the score achieved and when compared to other relevant water domain ontologies.** However, several improvement opportunities have been discovered including the need of more data properties, the capability of giving answer to several competency questions, the refactoring of ontological resources, the incorporation of new comments and labels, and the enhancement of the ontological population with the information of both pilots. These issues will be taken into account in the upcoming knowledge base developments and they will be reported in the next deliverable D1.4.2 "*Extension of the taxonomy and ontology to the pilots*".

4.2 Future Work

The future work regarding Task 7.1 "*Case study holistic auditing*" that will be documented in D7.1.3 "*Holistic auditing*" will be focused on the monitoring and tracking of the resolution of the issues appeared with regards to the knowledge base, the design and planning of a stress test for the WatERP platform, and the preparation of the next holistic auditing procedure.

The following tasks are foreseen:

i) **Monitoring and tracking of the knowledge base issues.** The monitoring and tracking of the issues appeared will include new testing programs in order to ensure that all detected improvement opportunities have been taken into account and that the solution is of the expected quality.

ii) **Design and planning of a stress test for the platform.** The creation of a stress test for the WatERP platform will include the corresponding test strategy to ensure that the WatERP platform can handle the load expected in an operational environment and is aligned with the current usability standards and metrics. The design of the stress test will include: *(a)* definition of the metrics needed to evaluate each of the features of the WatERP platform; *(b)* metrics to evaluate the performance of the WatERP platform; and *(c)* visualization and usability tests.

iii) **Next holistic auditing procedure.** The preparation of the next holistic auditing will be focused on: *(a)* enhancing the current procedure in order to adequate it to the new knowledge base (e.g. create new queries, test sesame connection, etc.); *(b)* look for appropriate knowledge engineers and water domain experts in order to perform the test; *(c)* retrieve the last stable version of the ontology to be tested; and *(d)* collect the data requirements regarding the pilots for each work package in order to ensure that all data needs are satisfied.