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Abstract (for dissemination)	The Semantic Interoperability and Ontologies topical roadmap will tackle the importance of the interoperability and semantics for advancing to a smarter and integrated water management (from resource acquisition, storage, distribution and consumption). The main outcomes are specific analyses and recommendations for policy makers and relevant water stakeholders that can foster Information and Communication Technologies (ICT) for Water and its standardization regarding to semantic interoperability and ontologies. This deliverable is the first one of a series of three topical roadmaps which will help in the analysis of key issues regarding the usage ICT based solutions applied to the different water sectors.
Key words	Semantic Interoperability, Ontologies, Standards, Water Management, ICT

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Executive Summary

Deliverable 2.1 consists in the report of Semantic Interoperability and Ontologies topical roadmap. The report initially provides a revision of the state of the art of the current semantic technologies focusing on Ontologies and existent standards. This analysis of the state of the art has followed a methodology in order to identify relevant documentation, repositories and software providing a set of ontologies that can be used within Water Management community and also a set with the corresponding scientific documentation. It also analyse the contribution regarding semantics and ontologies to each field in ICT for Water Management, this analysis has been used to target some gaps in some specific areas providing a first recommendation in terms of directing research to these fields.

From the revision of the state of the art, challenges and issues regarding the development of semantic technologies have been detected and analysed. These challenges and issues can be classified into two groups: a first one linked with technologic issues and challenges; and a second one regarding the actions that each stakeholder should overcome to help the development of semantic interoperability and ontologies. Another important point in this roadmap corresponds to the analysis of the current dominant solutions to advice of the developments, contributions and trends from different vendors and other entities to the field of semantic interoperability in water management. A list, with a deep description of the considered as the most dominant and important solutions has been provided together with some of the current trends in which the research community is focusing the new development and transference.

Finally in later sections, the roadmap provides a future vision through the statement of recommendations and actions to be taken for every relevant stakeholder, linking each recommendation to the challenge or issue that it can mitigate. As an example, specific recommendations for best funding and research directions as well as recommended actions to be taken for each specific stakeholder. A five year view of the development of semantic tools and ontologies is also provided, targeting the specific stakeholders that should be involved in executing the mentioned actions.

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

Number	Title	Description
1.1	Report with IWO definition and implementation	This report focuses on the definition and implementation of the ICT for Water Observatory (IWO). The IWO defines a methodology to collect, analyse and publish in a knowledge base resources from relevant sources of information related to ICT for Water technologies. This report includes the objectives, methodologies, functionalities and structure the IWO is going to offer and support, conforming the inputs of the literature reviews and commercial developments and technology trends analysis.

Number	Title	Description
1.3	Reports containing Literature reviews 1st release	This report presents the first iteration of ICT for Water literature review, including ICT4Water cluster projects publications, conference papers, journal papers, books and books chapters, and other reports. The objective of this report is to collect all these sources, and classify each document taking in consideration topics and tags. This information will be uploaded to the different platforms that support the IWO when possible.
1.4	Reports containing Literature reviews 2nd release	This report presents the second iteration of ICT for Water literature review, including ICT4Water cluster projects publications, conference papers, journal papers, books and books chapters, and other reports. The objective of this report is to collect all these sources, and classify each document taking in consideration topics and tags. This information will be uploaded to the different platforms that support the IWO when possible

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1. Introduction

The objective of Work Package 2 (WP2) is to analyse the key issues and assimilate information across three major topics: Semantic Interoperability, Smart City Connection and Smart Water Grids. Another objective is to advice about effective implementations of each of the previously noted topics focusing on an holistic approach. The outcomes are specific analyses and recommendations for policy makers and relevant water stakeholders that can foster ICT for Water and its standardization regarding to semantic interoperability and ontologies. This will contribute to identify gaps, barriers and bottlenecks on existing regulation blocking innovations and smart technologies, and also to enhance the implementation, interoperability and economy of scale standardization and business opportunities of the already existing solutions on the project portfolios.

This deliverable (D2.1: Semantic Interoperability and Ontologies topical roadmap) will tackle the importance of the interoperability and semantics for advancing to a smarter and integrated water management (from resource acquisition, storage, distribution and consumption). Furthermore deliverable is the first one of a series of three topical roadmaps, it is focused on analysing key issues regarding to the usage of semantic interoperability and ontologies in existing and coming ICT based water solution. The generation of this roadmap started at the beginning of the project although has been during the first part of the second year when most of the writing has been done. During the first year the work done has been devoted to the interaction with different stakeholders to discuss the different issues relevant to the roadmap (such as Data Policies and Application of the standards among stakeholders). This work has been performed in close collaboration with WP1 in the collection and analysis of state of the art. In fact, one of the starting points for the construction of this deliverable have been the outputs of the WP1 (ICT for Water Observatory[1]) and more concretely deliverables D1.3 and D1.4 ("*Reports containing Literature reviews 1st release*" and *"Reports containing Literature reviews 2nd release*", respectively). Hence, this deliverable has taken advantage of the continuous monitoring of the Water Community technologies, developments and trends. These deliverables have provided a valuable and indispensable background as well as the ICT for Water Observatory, which has been a frequently used tool during the construction of the state of the art (see Section2).

It is expected that this roadmap together with the other two (D2.2 Smart City Connection topical roadmap and D2.3 Smart Water Grids topical roadmap) contribute and inspire future work on WP3 (Overall Roadmap). To this end, during the construction of the current deliverable there have been many interactions with the rest of the partners of the project in order to align, establish and identify common issues and topics.

[1] http://iwo.widest.eu/

The rest of the document is structured as follows: Section 2, provides a review of the state of the art of the current technologies that are suitable for providing interoperability. Main focus is put on ontologies and standards. Section 3, provides a set of challenges and issues regarding Semantic Interoperability and Ontologies in Water Management community. Section 4, provides a revision of the current dominant solutions in the market and trends that can appear in the future. Section 8, summarizes the document by linking the previous sections giving a general overview. In section 5, specific recommendations are placed for each implantation/development research direction. Section 6 targets each interested group of stakeholders and recommended actions are proposed. Section 7 concludes the document summarizing the main ideas and recommendations. Section 8 provides the references consulted during the elaboration of this document. And finally Appendix 1 provides the list of documents used for the State of The Art (Section 2) revision.

2. Review of the State of The Art

In this section, the idea of interoperability within the water community is reviewed and the current tools for semantic interoperability are studied. To this end, a methodology for exploring all the tools available in the literature and specific communities is provided. After this the application of this methodology, the results are presented complemented with brief analysis and conclusions.

Historically, interoperability has led to misunderstandings due to its vast range of its semantics. For instance, the IEEE's Standard Computer Dictionary defines interoperability as ''the ability of two or more systems or components to exchange information and to use the information that has been exchanged'' (Geraci, Katki, McMonegal, Meyer, & Porteous, 1991). IEEE's interoperability definition is very general and short (in terms of specificity) regarding to the number of fields in which ICT has been incorporated. Rightly, interoperability is defined in (Mathews, 2016) as the capability by which all operating elements within interdependent and interconnected systems to be able to operate synchronously to achieve mission success or predetermined goals and objectives continually. Here, synchronous operations infer to an operational requirement for all components or subsystems of interdependent and interconnected systems to be properly oriented, skilfully aligned, and readied across geographic and organizational boundaries and professional disciplines to achieve mission objectives.

As stated in (Mathews, 2016), in the United States, uninteroperability (lack of interoperability) results from the improper resource allocation, poor communications, mismanagement, waste, abuse, negligence, malfeasance, and a permeating pattern of oversight. This last aspect is more permissive of a wasting of public infrastructures, endangering public health, and other things such as eroding confidence of citizens in governmental departments, agencies, and personnel and the long-term reliability of U.S. national water infrastructures. In Europe some of previously mentioned facts are repeated and thus affecting to this lack of interoperability. Section 3 focuses in the analysis of the issues and challenges that interoperability faces in Europe.

Due to the inclusion of ICT capabilities in water management, there have emerged many ways of representing information. On the one hand, there exist custom numerical models (Priazhinskaya, 2009) which are used to represent most of the infrastructures. Those models succeed at representing certain specific fields for the calculation and numerical analysis. However, they fail at representing the reality as it is and thus when one tries to link data from other fields, the generalization becomes a complex issue. Also these models require human-effort for maintenance and actualization according to changes in the water network. Then, the management costs and complexity are also increased. Aligned with these aspects water research community has tended to adopt and develop the "Integrated Water Resource Management (IWRM)" towards moving to interoperability, data harmonization and integrated decision-making. The IWRM concept relies on integrating under a decision support system all decisions available in the water supply and distribution chain (including also numeric models). However, this paradigm is far to integrate the available systems and data models of the water infrastructure. Based on that, there have been many efforts to apply different domain vocabularies by different water information systems (*e.g.* (Ahmedi, Jajaga, & Ahmedi, 2013) and (Chau, 2007)) to better represent the data in the water environment. This later task presents a challenge for the exchange of information in an efficient way, as the syntax and semantics of the relying data can be heterogeneous. This heterogeneity gets worse due to the usage of different systems from different vendors. In this scenario, each vendor tries to prevail his data model (vocabulary) as a standardised. The result is the existence of multiple data models that represent in many different ways the water environment. Thus, these systems act as isolated islands with no connection with the rest of the network. Additionally, in the later years, the reduction of technology prices has also affected the informational complexity exchange. Nowadays, environmental and water sensors are deployed and connected remotely using the Web (Internet of Things). The result: a huge amount of unstructured information spread through the entire web. With regards this available information, water researchers have deployed water devices offering open data services that can be useful for supporting decision making. Focusing on the water decision making procedures, there is also a lack of coordination and integration with other domains as for example, environment, agriculture, smart cities services, to mention a few. This lack of coordination ultimately results in inefficiencies at macro level which arrives at citizen level by slowing the development of services and provoking difficulties for establishing Open Data policies and reducing the capability of connecting with Smart Cities. Therefore, the challenge is **to promote the adoption of common data models to exchange information (syntactic interoperability), advance in the integration of heterogeneous source of information, and contextualise/abstract the information to support the decision making in the water environment (organizational interoperability).**

According to the International Telecommunications Union (ITU), ICT is an enabler for the standardization of information about water distribution networks and a provider of the technology necessary for Internet communication which ultimately can benefit for a more effectively operation in water management community (ITU, 2014). Standardized mark-up languages such as Earth Science Markup Language[2] (ESML), Ecological Metadata Language[3] (EML), WaterML[4], Observations and Measurements[5] (O&M) (see Section 2.2.3), and others provide a structured syntax for communicating data from multiple sources as XML documents. There are also National and International data model initiatives such as INSPIRE (European) and NHD/NHD+ (United States) that promote the usage of standards. These mark-up

[2] http://projects.itsc.uah.edu/esml/

[3] https://knb.ecoinformatics.org/#external//emlparser/docs/index.html

[4] http://www.opengeospatial.org/projects/groups/waterml2.0swg

[5] http://www.opengeospatial.org/standards/om

languages can be used to transmit data in a format that resolves syntactic heterogeneity, but they generally do not place semantic constraints on the meanings of the document contents.

For example, the term "*Pipe*" can be seen from different contexts such as "*a piece of the infrastructure*" or "*a water pressure point*". The term "*Semantic Interoperability*" is targeted as one of the main challenges to the achievement of full interoperability among systems (Sheth, 1999). The term Semantic Interoperability refers to the ability of computer systems to communicate data with a unified meaning (Sheth, 1999). In fact, Semantic Interoperability has been already targeted as a key element within ICT to achieve a substantial efficiency gain in the distribution and use of key resources such as energy and water as well as its securitisation and decarbonisation, according to Expert Consultation on ICT for Water Management[6] (European Commission, 2013). In this consultation that involved 13 participants, including experts from industry, academia and water related associations; the stress was put on the need for the focus on interoperability for further ICT R&D and demonstration activities. Moreover, in 2014 the EC released a first version of ICT for Water Management Roadmap (European Commission, 2015), which already targets Standardisation and Data sharing, Interoperability and Standardisation as principal gaps in the development of ICT in Water Management.

Some authors agree at pointing that one feasible solution for providing Semantic Interoperability is the use of ontologies. Through ontologies one can make information accessible, which otherwise would persist inaccessible (Liu, Brewster, & Shaw, 2013; Wache et al., 2001). This is because an ontology can provide a unified explanation of concepts and relationships used by the application field, make them shareable by different users and allow them to be processed by a machine (Liu et al., 2013). In terms of water domain application this could lead to (i) substantial consumer and energy savings, (ii) peak-period reduction of water and energy distribution loads and (iii) reduction of Greenhouse Gas (GHG) emissions, and (iv) facilitate the decision making process by providing a high-level contextualization. During the Extended Standards Session, London (1st May 2015) it was stated among the stakeholders participating in the session that a clear focus on the "20-20-20" EC targets (Energy consumption, carbon emissions, renewables[7]) is needed.

There are already EU Funded projects that used application specific ontologies for achieving this aforementioned interoperability. For instance, WatERP[8] project devoted many efforts for providing semantic and organizational interoperability trough the usage of ontologies and standards to achieve a holistic water management approach that included governability from source to transportation.

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[6] https://ec.europa.eu/digital-single-market/en/news/ict-water-resources-management-experts-consultation-31012013

[7] http://ec.europa.eu/clima/policies/package/index_en.html

[8] http://waterp-fp7.eu/

The WISDOM EC FP7 project also focused efforts to the development of semantical tools, more precisely, the WISDOM ontology was developed to capture domestic knowledge to allow the integration of consumers within the water value data chain and hence contextualize smart meter and behavioural readings an ontology Both WatERP and WISDOM have their roots in the more general W3C SSN ontology (Compton, Barnaghi, & Bermudez, 2011). Another EC FP7 project that contributes to the use of semantic tools is Waternomics[9]. This project aims to create a Linked Water Dataspace as an emerging information management approach for collecting, standardizing, enriching and linking water usage data coming from sensors. Waternomics proposes an RDF model and a sensor data management infrastructure that facilitates to integrate various data sources for effective decision making.

There are also other EC initiatives that claim for the use of open standards and definition to make possible the addressment of the interoperability challenge in water management *(e.g.* River Basin Standards Interoperability Pilot on the EIP Water Conference 2016[10]).

A first step to provide a future vision of the development and application of Semantic Interoperability tools and Ontologies is to have an exhaustive and complete overview of the currently existing ontologies and standards that have been developed to address the requirements in water management projects. The focus of this section is to perform a review of semantics technologies applied to the water domain. The latter objective is to identify current challenges and issues related to the semantic interoperability aligned with the water stakeholders needs regarding management, citizen services, and systems intercommunication perspectives. To do so, a methodology for exploring the already existing ontologies and standards is proposed together with a full review of the already existing technologies. The methodology proposed follows the ideas presented in (Liu et al., 2013) where an special effort is devoted to the identification of the subject areas covered by the concepts in these ontologies, the types of water management systems they address, and how these ontologies were designed and used.

2.1 Methodology

Water management is a complex application domain which involves several fields of actuation ranging from infrastructure water resource management and/or water quality monitoring, to mention a few. Given the complex environment described, having a complete solution for the exact representation of the domain (that is a valid ontology that represents the whole management domain) is a hard issue as this would require a big effort from expert from different domains to discuss and agree in common conceptualizations. Consequently, it is mandatory to build an overall picture of the subject areas involved in water management and address the problem of finding how the concepts related to those areas should

[9] http://waternomics.eu/

[10] http://www.eip-water.eu/side-meetings-eipwater2016

be represented in water information systems. The methodology followed in this document proposes the following schema:

1. Identification of the subject areas which water management concepts belong to (Section 2.2.1)
2. Identification of the currently existing ontologies that cover the previous identified subject areas (Section 2.2.2)
3. Description and identification of the design and usage of the previously identified ontologies (Section 2.2.2)
4. Identification of the standards which ontologies conform to (Section 2.2.3)

To cover the scientific production that already exists in the specialized literature, the main scientific repositories (Google Scholar[11], Researchgate[12], Sciencedirect[13], arXiv[14]) have been reviewed collecting papers within both the application domain (water management, hydrology, etc.); and the technical domain (artificial intelligence, knowledge representation, etc.). To cover the transference of the scientific concepts and ideas, the specialized forums and repositories for the development of the technology have also been reviewed (Swoogle[15], Watson[16], DAML Ontology Library[17]), collecting ontologies and standards that cover the subject areas identified.

The literature review was carried out in order to identify new or non-implemented technologies and to provide an updated notion of the current research. In (Liu et al., 2013) the inclusion of papers was carried out following a set of rules. In this methodology we adapt those rules to better fit the water management domain:

- The work should present the design, implementation, analysis or evaluation of an ontology or standard based water information system.
- If two or more papers describe the same system, the latest or more comprehensive one was included.
- If the paper does not introduce an ontology or standard based water information system, it should describe information interoperability requirements and challenges for water management.

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[11] http://www.sciencedirect.com/

[12] https://www.researchgate.net

[13] http://www.sciencedirect.com/

[14] http://arxiv.org/

[15] http://swoogle.umbc.edu/

[16] http://watson.kmi.open.ac.uk/WatsonWUI/

[17] http://www.daml.org/ontologies/

As a result, a total of 26 papers were finally selected which conform the scientific background of this document (to see the full list of the papers please check Appendix 1). Each paper was analysed, extracting the main information and tagging and classifying the exposed concepts. Additionally, the main outputs of WP1 were used. On the one hand, the IWO has been used and has become an essential tool for targeting the most relevant literature in each domain (see D1.1 Section 2). On the other hand, in the outcomes of D1.3: Reports containing Literature reviews 1st release (Section 1 page 9) there is a classification of the current available literature, this classification includes the identification of "Water Management subject areas" and specific tags regarding each paper strict domain. With all this knowledge available through IWO and WIDEST deliverables, the subject areas identified in D1.3 have been used for this methodology.

Following the same idea exposed regarding the papers selection procedure, some rules were derived to include ontologies and standards as background for this deliverable:

- Ontologies and standards designed originally for water management and ontologies. This topic also includes standards designed for other domains that can provide appropriate concepts relevant to the water subject areas are included.
- Different approaches to ontologies and standards including formal ontologies, taxonomies, schemas and data models are considered.
- Incomplete ontologies are excluded from the analysis (e.g. ontologies that are currently under development) but they are included as they will be taken under consideration for the future.

The number of relevant ontologies and standards collected are, respectively, 18 and 19.

2.2 Results

The main results after the analysis of the state of the art of ontologies and standards in water management are presented in this section. The methodology schema will be followed and all the results will be presented and explained.

2.2.1 Subject Areas in Water Management

The EU Funded project WIDEST has already identified the main subject areas by tagging and grouping the most relevant literature within the water management community (see D1.3 Reports containing Literature reviews 1st release and D1.4 Reports containing Literature reviews 1st release, Sections 2, 3, 4, 5 and 6). As a result Table 1, summarizes the main water management topics which conform the main subject areas in water management and quantifies the number of documents that each topic. Table 1 tries to sort the knowledge regarding Water Management domain and weight the research relevance of each topic in such domain with the number of documents in each topic.

Water Management Topic	Number of documents (including books, book chapters, journal papers and conference papers)
Water Supply and Distribution	235
Data Management and Smart City Services	191
Quality of Water	55
Sustainable Development, Circular Economy, and Ecosystem Services	24
Wastewater and Storm Water Collection (including Flood Risk Management)	22
Water-Energy Nexus	13
River Basin Management	12
Drinking Water Production	10
Water Reuse and Recycling	8
Wastewater Treatment (including Recovery of Resources)	5
Customer Relationship	4
Management of the Water Cycle in Industry	4
Sea Water	2
Water Scarcity and Droughts	2

Table 1: Summarization of Water Managements Topics and quantification of number of documents of each topic

A total number of 587 documents (including books, book chapter, journal papers, thesis, conference papers and whitepapers) were included in Table 1 according to the outputs of D1.2. All these documents were identified and classified using 14 topics. The topic that accounted for more documents is Water Supply and Distribution with the 40.03% of the total number of documents. The rest of topics are: Data Management and Smart City Services (32.54%), Quality of Water (9.37%), Sustainable Development, Circular Economy, & Ecosystem Services (4.09%), Wastewater and Storm Water Collection (including Flood Risk Management) (3.75%), Water-Energy Nexus (2.21%), River Basin Management (2.04%), Drinking Water Production (1.70%), Water Reuse and Recycling (1.36%), Wastewater Treatment (including Recovery of Resources) (0.85%), Customer Relationship (0.68%), Management of the Water Cycle in Industry (0.68%), Sea Water (0.34%) and Water Scarcity and Droughts (0.34%). This Table reflects that there is a major interest in research for Water Supply and Distribution and Data Management and Smart City Services. This can be explained due to the fact that Water Supply and Distribution affects to day to day customer life and the interest of increasing the water quality for the final costumer and the energy diminution. We can also see Data Management and Smart City Services is a topic which is getting attention; this field integrates Ontologies, Standards and many other data interoperability tools. From the Data Management point of view, this deliverable will focus on providing the current picture of interoperability development and Deliverables D2.2 and D2.3 will focus in Smart City Connection and Smart Water Grids.

The sharp-eyed reader would have noticed that the subject areas described in Table 1 are not exclusive. This means that during ontologies identification and classification, ontologies can correspond to one to many subject areas. In one hand, this can provide more definition capabilities, that is: increase de range of the expressivity of that classification. However it's a clear lack of specificity. To solve this we provide a more specific definition of the ontologies usage in Table 2 in Section 2.2.2.

2.2.2 Identification of the Ontologies Covering Water Management Subject Areas

This section introduces the main ontologies identified based on the literature review described within the Section 2.2.1. Indeed Table 2, classifies each identified ontology by subject. Moreover, other relevant aspects such as representation language [18](RDF, OWL, etc.), the available documentation (URL) and the accessibility are depicted.

Ontology Name	Subject Areas	Representation Language	Downloadable	Documentation
Organisation Ontology	Management of the Water Cycle in Industry Customer Relationship	RDF	Yes	https://www.w3.org/TR/vocab-org/
OTN	Wastewater and Storm Water Collection (including Flood Risk Management) Data Management and Smart City Services	OWL	Yes	http://rewerse.net/deliverables/m18/a1-d4.pdf
Ordnance Survey Hydrology Ontology	Water Supply and Distribution	OWL	Yes	https://github.com/vangelisv/thea/blob/master/testfiles/Hydrology.owl

[18] http://www.cs.man.ac.uk/~stevensr/onto/node14.html

Ontology Name	Subject Areas	Representation Language	Downloadable	Documentation
NNEW weather ontology	Wastewater and Storm Water Collection (including Flood Risk Management) River Basin Management	OWL	Yes	http://www.aixm.aero/gallery/content/public/2010_05_Conference/Day%202%20-%20WX%20-%2003%20-%20wxxmn.pdf
USGS CEGIS	Wastewater and Storm Water Collection (including Flood Risk Management) River Basin Management Water Scarcity and Droughts	OWL	Yes	http://cegis.usgs.gov/ontology.html
Ordnance Survey Buildings and Places Ontology	Data Management and Smart City Services	OWL	No	http://webarchive.nationalarchives.gov.uk/20090216122315/ordnancesurvey.co.uk/oswebsite/ontology/
h-TechSight Technologies	Management of the Water Cycle in Industry	RDF,DAML+OIL	Yes	http://gate.ac.uk/projects/htechsight/Technologies.daml
GWSW TopBas	River Basin Management	OWL	Yes	http://webprotege.stanford.edu/#Edit:projectId=e81a50fe-cf70-4a58-a73f-180fbf05a97c

Ontology Name	Subject Areas	Representation Language	Downloadable	Documentation
SWEET	Wastewater and Storm Water Collection (including Flood Risk Management) River Basin Management Water Scarcity and Droughts Sea Water Sustainable Development, Circular Economy, & Ecosystem Services	OWL	Yes	https://sweet.jpl.nasa.gov/graph
CUAHSI	Quality of Water Sustainable Development, Circular Economy, & Ecosystem Services Drinking Water Production Water Reuse and Recycling Wastewater Treatment (including Recovery of Resources)	OWL	Yes	http://his.cuahsi.org/ontologyfiles.html

Ontology Name	Subject Areas	Representation Language	Downloadable	Documentation
WatERP Ontology	Water Supply and Distribution Data Management and Smart City Services Sustainable Development, Circular Economy, & Ecosystem Services Water-Energy Nexus River Basin Management Water Reuse and Recycling Management of the Water Cycle in Industry Water Scarcity and Droughts	OWL	Yes	http://www.waterp-fp7.eu/Downloads/deliverables/D1.3_Generic_Ontology_for_water_supply_distribution_chain_v1.3.pdf
INWS	Quality of Water	OWL	Yes	http://inwatersense.uni-pr.edu/ontologies/
SemantEco	Quality of Water Sustainable Development, Circular Economy, and Ecosystem Services	N/A	N/A	https://tw.rpi.edu//web/doc/SemantEco-TR
WaWO	Wastewater Treatment (including Recovery of Resources) Water Reuse and Recycling	N/A	No	http://citeseerx.ist.psu.edu/viewdoc/download;jsessionid=6C6894FC750F5CAE9BB9A55572B44D31?doi=10.1.1.28.6725&rep=rep1&type=pdf

Ontology Name	Subject Areas	Representation Language	Downloadable	Documentation
EHMP	Data Management and Smart City Services Quality of Water River Basin Management	OWL	No	http://www.itee.uq.edu.au/eresearch/papers/2010/Hunter_IJAEIS.pdf
DOLCE-ROCKS	Wastewater and Storm Water Collection (including Flood Risk Management) River Basin Management Water Scarcity and Droughts Sea Water Sustainable Development, Circular Economy, & Ecosystem Services	OWL	Yes	https://marinemetadata.org/references/dolcerocksontology
hydrOntology	Wastewater and Storm Water Collection (including Flood Risk Management) River Basin Management Water Scarcity and Droughts Sea Water Sustainable Development, Circular Economy, & Ecosystem Services	OWL	Yes	http://mayor2.dia.fi.upm.es/oeg-upm/index.php/en/ontologies/107-hydrontology/index.html

Ontology Name	Subject Areas	Representation Language	Downloadable	Documentation
HY_Features	Water Supply and Distribution Data Management and Smart City Services Sustainable Development, Circular Economy, & Ecosystem Services Water-Energy Nexus River Basin Management Water Reuse and Recycling Management of the Water Cycle in Industry Water Scarcity and Droughts	OWL/RDF	No	http://www.opengeospatial.org/pressroom/pressreleases/2240

Table 2: Water Management ontologies classification

Table 2 provides a first identification of the ontologies to be studied, providing a classification based on the subject areas form water management identified in Subject Areas in Water Management Section Subject Areas in Water Management. We can apply more filters to classify and identify those ontologies. For example, one can distinguish between those ontologies that are originally designed for water management on those designed for other domains that can provide appropriate concept relevant to the water management subject areas.

According to this proposed filter, in the latter group we have ontologies such as the Organization Ontology[19], which is an organizational ontology not devoted directly for water management. However, the linkage between water management and water supply can be a very useful ontology to represent the relation among stakeholders and consumers. In a similar way, we can find infrastructural ontologies such as Ontology for Transportation Systems (OTN) (Lorenz, 2005) and the Ordnance Survey Buildings and Places Ontology. OTN is very similar to the popular Geographic Data Files (GDF), with some extra capabilities. OTN is a general purpose ontology which can be used for all kinds of things besides data storage in the field of transportation networks. OTN includes a meteorological module that can also be very useful for water management. Regarding the Ordnance Survey Buildings and Places Ontology, it was developed through the process of authoring two fairly large (approximately 600 concepts each) and

[19] http://ukgovld.github.io/ukgovldwg/guides/organization.html

expressive (ALCOQ[20]) ontologies within topography, namely Hydrology and Buildings and Places, constructed with the active involvement of domain experts from Ordnance Survey[21]. Since not all domain experts have knowledge engineering skills, using currently available ontology construction tools was not appropriate. Consequently, the knowledge glossary, which included lists of concepts and relationships with corresponding textual descriptions from knowledge sources and structured sentence to define relationships between concepts, was stored in a spreadsheet. The structured sentences were then manually converted to OWL by a team of knowledge engineers.

In the same group of other domains besides water management, we can also include the h-TechSight Technologies ontology The objective of the h-TechSight IST project (coordinated by The University of Surrey in England), is to exploit recent advances in knowledge-based and other systems to harness the potential of the web and turn it into an effective resource to enable businesses to monitor and boost their competitive performance by responding quickly to changes, threats and opportunities, whether local, national or global.

Regarding water management specific ontologies, there are ontologies of domains such ecology or natural resources that can be used for water management, as water is part of these domains. As an instance, SWEET, DOLCE-ROCKS and SemantEco are environmental ontologies. SWEET is a suite of ontologies that are written in the OWL ontology language and are publicly available. SWEET 2.3 is highly modular with 6000 concepts in 200 separate ontologies. You can view the entire concept space from an OWL tool such as Protégé by reading in sweetAll.owl[22]. Alternatively, these ontologies can be viewed individually. SWEET 2.3 consists of nine top-level concepts/ontologies (Representation, Process (microscale), Phenomena (macroscale), Matter, Realm, Human Activities, Property (observation), State (adjective, adverb), and Relation (verb)). SWEET is a middle-level ontology; most users add a domain-specific ontology using the components defined here to satisfy end user needs. DOLCE-ROCKS ontology integrates the DOLCE foundational and two geoscience knowledge representations, the GeoSciML schema and SWEET ontology, to enable cross-domain scientific computing regarding environmental information. SemantEco uses OWL-DL ontology modelling, converted RDF data, and an OWL reasoner web application to determine regulation violations from measurements that exceed chemical thresholds.

HY_Features, hydrOntology, CUAHSI-HIS and Ordnance Survey Hydrology Ontology are specific hydrology ontologies. HY_FEATURES common hydrologic feature model to the state of an adopted Open Geospatial Consortium (OGC) standard for a common and stable identification and referencing of

[20] The expressivity of an Ontology can be classified through its underlying logic properties, in this case ALCOQ (Faddoul, Haarslev, & Muller, 2009) is an extension of Description Logics used in OWL language

[21] https://www.ordnancesurvey.co.uk/

[22] https://sweet.jpl.nasa.gov/download

hydrologic features. It has to be noted that HY_FEATURES is under development by the OGC but it is interesting to take into account as it is being proposed as a standard split into three parts: (i) HY_Features conceptual model (OGC14-111). The normative model is a machine-readable UML artefact published by OGC; (ii) GML[23] implementation schema suitable for data transfer of HY_Features object instances, based on ISO 19136 Annex E encoding rules for Application Schema, and (iii) OWL and RDF representation suitable for defining links between features that implement the HY_Features model, based on ISO 19150 encoding rules. hydrOntology (Blázquez et al., 2007) is an ontology in OWL that follows a top-down development approach. The main goal of hydrOntology is to harmonize heterogeneous information sources coming from several cartographic agencies and other international resources. Initially, this ontology was created as a local ontology that established mappings between different data sources (feature catalogues, gazetteers, etc.) of the Spanish National Geographic Institute (IGN-E)[24]. The purpose of hydrOntology is to serve as a harmonization framework among Spanish cartographic producers. Later, the ontology has evolved into a global domain ontology and it attempts to cover most of the concepts of the hydrographical domain. With respect to CUAHSI-HIS ontology, its purpose is to support the discovery of time-series data collected at a fixed point, including physical, chemical, and biological measurements. The hydrologic ontology is designed for a simple keyword search rather than a multi-dimension search on, for example, property measured, sample medium, and site type. Therefore, these keywords will, at times, include terms, e.g., “air temperature” rather than just “temperature” or “groundwater level” rather than just “water level” to reflect both the property measured and other aspects to make the return of the search meaningful. The ontology does not include certain properties of the time series such as method, speciation, or time support because these were not viewed as being critical to the initial discovery of data. The user will have to sort through these properties in a subsequent search. CUAHSI-HIS was based on WaterML schemas and now is part of the some of the OGC working groups for standards. Ordnance Survey Hydrology Ontology is a hydrology ontology conceptualized by domain experts and implemented by knowledge engineers following the same procedure that the one followed by the Ordnance Survey Buildings and Places Ontology.

WatERP and EHMP ontologies are generic water management ontologies. The WatERP ontology permits to enhance semantically the water domain knowledge by adding metadata information related with water domain decisional, observation and measurement process. WatERP ontology represents infrastructures created by humans that affect to the water cycle. This semantically definition stored in the ontology is able to improve the interoperability by enhancing data provenance (by categorising it measurement process) and data fusing (by understanding the measurement nature). The EHMP ontology has been developed to link area-based Action Plans to specific regions, indicators and parameters. the ontology

[23] Geography Markup Language; see Section 2.2.3

[24] http://www.ign.es/ign/main/index.do?locale=en

also describe the Bing Maps/Google Earth interface that combines ontology-based querying with spatio-temporal querying to integrate the heterogeneous monitoring and management databases and visualize spatial and temporal trends in water quality.

More specific ontologies include the WaWO ontology which is applied to the domain of waste water treatment processes. WaWO is built following the ideas of (Uschold & Gruninger, 1996) and is a hierarchically structured set of terms and a set of axioms for describing the real-world domain of waste water treatment. INWS is a very specific ontology for water quality, in this ontology the SSN ontology was extended to meet the requirements for classifying water bodies into appropriate statuses based on different regulation authorities. The ontology is extended with a module for identifying the possible sources of pollution. The Data Dictionary Urban Water (GWSW) ontology is the central instrument for a better and standardized data for drainage and urban water management. This is a digital collection of unique definitions of the objects, their attributes and their relationships in the field of urban water, with all the relevant additional information (knowledge). The GWSW model allows unambiguous exchange via a BIM (Building Information Model, a standard exchange format) and reuse of information, both within the sector and with other disciplines. And finishing this specific group of ontologies, the USGS CEGIS ontology is part of a project which goal is "Building Ontology for The National[25] Map", and its main objective is to specify geospatial feature semantics for richer data models. New data models and associated knowledge organization systems for The National Map can translate traditional topographic information into a flexible spatiotemporal knowledge base that can serve many different application areas.

2.2.3 Standards for Water Management

Insofar, we described the state of the art of the current available ontologies which can help to address the lack Semantic Interoperability problem; this is: how water management data can be described in a certain context; what does this data means; and how this data is related with other datasets representing other concepts. For example, by means of ontologies we can systematically describe how water levels relate to information such as residential area, pump performance, etc. There are more issues related to Semantic Interoperability that have to be addressed, as for example the necessity for abstraction and perception, time and spatial perception and the lack of knowledge on the huge water related data collected. Some of these problems can be mitigated or even fully solved by means of ontology usage. However, there is still a gap between the current development of interoperability tools and the future solution for interoperability problem. All of these issues and challenges are described in Section 3 and in Section 5 some of the best research trends to solve these problems are revised

It is mandatory to share and make effective and combined use of interdisciplinary data sources, models, and processes lack of interoperability impedes sharing of data and computing resources Standards from

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[25] United States of America

many organizations are the basis for the success of the Internet and the World Wide Web (referred as WWW or W3). An “open” process is necessary to arrive at an “open” standard. For example, the openness that OGC promotes is part of this general progress. Current machines can’t handle syntactic and structural heterogeneity efficiently, so there is still a need for common schemas, grammars and ontologies for data sharing among different systems.

The ISO defines a standard as a document that provides requirements, specifications, guidelines or characteristics that can be used consistently to ensure that materials, products, processes and services are fit for their purpose. In recent history, standards from many organizations have been the basis for the success of the Internet and the World Wide Web, as these standards enabled the interoperability among network systems.

There already exist open geospatial standards and technologies, most of them driven by the OGC who provides solutions for the systems and syntax levels. Among these systems one can find standard for Web Services (WS) such as the Web Map Service (WMS), the Web Feature Service (WFS), the Web Processing Service (WPS), the Sensor Observation Service (SOS), the Sensor Web Enablement (SWE) and the Sensor Planning Service (SPS).

Standard	Provider	Type	Description
Sensor Observation Service (SOS)	OGC	WS	The SOS standard is applicable to use cases in which sensor data needs to be managed in an interoperable way. This standard defines a Web service interface which allows querying observations, sensor metadata, as well as representations of observed features.
Web Map Service (WMS)	OGC	WS	The WMS provides a simple HTTP interface for requesting geo-registered map images from one or more distributed geospatial databases.

Standard	Provider	Type	Description
OpenGIS Web Map Tile Service Implementation Standard (WMTS)	OGC	WS	The Web Map Tile Service (WMTS) is a standard that is built on earlier efforts to develop scalable, high performance services for web based distribution of cartographic maps. WMTS is inspired by the OSGeo Tile Map Service Specification[26]. The team that worked on this standard also considered similar initiatives, such as Google maps and NASA OnEarth. This OGC standard includes both resource (RESTful [27]approach) and procedure oriented architectural styles (KVP [28]and SOAP [29]encoding) in an effort to harmonize this interface standard with the OSGeo specification.
Web Feature Service (WFS)	OGC	WS	The WFS provides an interface allowing requests for geographical features across the web using platform.

[26] http://wiki.osgeo.org/index.php/Tile_Map_Service_Specification

[27] Representational state transfer (REST) is an architectural style of application programming interfaces consisting of a coordinated set of components, connectors, and data elements within a distributed hypermedia system, where the focus is on component roles and a specific set of interactions between data elements rather than implementation details.

[28] Key Value Pair

[29] SOAP (Simple Object Access Protocol) is a protocol specification for exchanging structured information in the implementation of web services in computer networks.

Standard	Provider	Type	Description
Web Coverage Service (WCS)	OGC	WS	The Web Coverage Service (WCS) standard, offers multi-dimensional coverage data for access over the Internet. A WCS provides access to coverage data in forms that are useful for client-side rendering, as input into scientific models, and for other clients. The WCS may be compared to the OGC Web Feature Service (WFS) and the Web Map Service (WMS). As WMS and WFS service instances, a WCS allows clients to choose portions of a server's information holdings based on spatial constraints and other query criteria.
Web Processing Service (WPS)	OGC	WS	The Web Processing Service (WPS) Interface Standard provides rules for standardizing how inputs and outputs (requests and responses) for geospatial processing services, such as polygon overlay. The standard also defines how a client can request the execution of a process, and how the output from the process is handled. It defines an interface that facilitates the publishing of geospatial processes and clients' discovery of and binding to those processes. The data required by the WPS can be delivered across a network or they can be available at the server.
Sensor Web Enablement (SWE)	OGC	WS	The SWE standards enable developers to make all types of sensors, transducers and sensor data repositories discoverable, accessible and useable via the Web.
Sensor Planning Service (SPS)	OGC	WS	The SPS defines interfaces for queries that provide information about the capabilities of a sensor and how to task the sensor.

Standard	Provider	Type	Description
WaterOneFlow	CUAHSI/HIS	WS	WaterOneFlow is a standard mechanism for the transfer of hydrologic data between hydrologic data servers (databases) and users' computers. Web services format the data as XML and the specific variety of XML that is generated by the WaterOneFlow web services is CUAHSI WaterML

Table 3: Water specific schema level standards

Standards presented in Table 3 make use of general schema-level standards; among these standards one can find the WaterML 2.0, the Water Data Transfer Format (WDTF), HY_Features and the GroundWater Markup Language (GWML). All of these standards are water specific and they are presented in Table 4.

Standard	Provider	Type	Description
WaterML 2.0	OGC	Schema	WaterML 2.0 is a standard information model for the representation of water observations data, with the intent of allowing the exchange of such data sets across information systems.
Water Data Transfer Format (WDTF)	Bureau of Meteorology (Australian Government)	Schema	The Water Data Transfer Format is an XML data format for transferring water information.
HY_Features	OGC	Schema + Ontology	The OGC HY_Features implementation standard (under development) defines a standard information model for the identification of hydrologic features independent from geometric. It includes the schema for syntactic representation but includes also the semantics for modelling.
GroundWater Markup Language (GWML)	Groundwater Information Network	Schema	GWML is a GML (Geography Markup Language) application to exchange groundwater related information. It is an extension of another GML application - GeoSciML - designed to exchange.

Standard	Provider	Type	Description
XHydro	German Federal Waterways and Shipping Administration (WSV)	Schema	XHydro is an XML format for inter-departmental and cost-efficient time-series data exchange for optimised transmission of gauging-station data in the WSV. Key design criteria were neutrality in terms of fields of application, user affiliation, and nationality as well as openness for extensions by additional user-specific data contents.
Climate Science Modelling Language v3.0	British Atmospheric Data Centre	Schema	Climate Science Modelling Language v3.0 is a data model for encoding climate, atmospheric and oceanographic data in terms of geometry-based observation classes such as Points, Profiles, Trajectories and Grids. It is a specialist profile of ISO 19156 Observations and Measurements and there is an accompanying implementation as a GML 3.2.1 Application Schema. Earlier versions of CSML were developed as part of the NERC DataGrid (NDG) projects funded by the Natural Environment Research Council (United Kingdom).
Network Common Data Form (NetCDF)	University Corporation for Atmospheric Research	Schema	NetCDF is a set of software libraries and self-describing, machine-independent data formats that support the creation, access, and sharing of array-oriented scientific data. NetCDF is the format most commonly used for climate model generated data.

Table 4: Water specific schema level standards

The rest of standards described in this document are divided in:

- Specific schema-level devoted for observational data linkage and sensoring data transportation: Observations and Measurements Encoding Standard (O&M) and Sensor Markup Language (SensorML) (Table 5). It also has to be mentioned that the OGC is working in TimeseriesML[30] 1.0, which is a proposed Open Geospatial Consortium encoding standard for the representation of time series observations (and forecast) data.

[30] https://portal.opengeospatial.org/files/60856

- General schema-level standards for geographic and environmental representation: Geography Markup Language (GML), GeoSciML, Earth Science Markup Language (ESML) and Ecological Metadata Language (EML) (Table 6);

Standard	Provider	Type	Description
Sensor Markup Language (SensorML)	OGC	Schema	The primary focus of the Sensor Model Language (SensorML) is to provide a robust and semantically-tied means of defining processes and processing components associated with the measurement and post-measurement transformation of observations. The main objective is to enable interoperability, first at the syntactic level and later at the semantic level (by using ontologies and semantic mediation), so that sensors and processes can be better understood by machines, utilized automatically in complex workflows, and easily shared between intelligent sensor web nodes.
Observations and Measurements Encoding Standard (O&M)	OGC	Schema	The O&M Standard defines XML schemas for observations, and for features involved in sampling when making observations. These provide document models for the exchange of information describing observation acts and their results, both within and between different scientific and technical communities.

Table 5: Specific schema-level devoted for observational data linkage and sensoring data transportation

Standard	Provider	Type	Description
Geography Markup Language (GML)	OGC	Grammar (Schema + Instances)	The GML is an XML grammar for expressing geographical features. GML serves as a modelling language for geographic systems as well as an open interchange format for geographic transactions on the Internet.

Standard	Provider	Type	Description
GeoSciML	IUGS Commission for the Management and Application of Geoscience Information (CGI)	Schema	GeoSciML version 4.0 is a data transfer standard for geological data - from basic map data up to complex relational geological databases.
Earth Science Markup Language (ESML)	NASA & University of Alabama	Schema	The ESML enables data (both structural and semantic) interoperability with applications without enforcing a standard format within the Earth science community.
Ecological Metadata Language (EML)	Ecological Society of America	Schema	The EML is a set of XML schema documents that allow for the structural expression of metadata. It was developed specifically to allow researchers to document a typical data set in the ecological sciences.

Table 6: General schema-level standards for geographic and environmental representation

From previous tables it can be derived that there are some institutions form Europe, United States and Australia working in tools for the standardization of data communication. The OGC, which is an international entity, is leading most of the current applicable tools, and as it will be shown in Section 4 it is leading the dominant solutions for standards. These standards cover transmitting and processing necessities, in the case of Web Services, but also the way information is formatted with the use of Schemas, Grammars and Ontologies. It can be seen that there are some tools for solving syntactic interoperability and in the following Sections a deeper analysis on the technologies and water management topics are covered with the currently developed tools.

2.3 Analysis and Conclusions

From Table 1: Summarization of Water Managements Topics and quantification of number of documents of each topic (Section 2.2.1) we can extract that an initial interest of the water community is to enhance water resource management along the entire chain to preserve water and the environment. Moreover, interested topics are also related to reinforcing the Smart City paradigm towards making accessible water services and make conscious the citizens about the efficient water consumption, adjust water prices, etc. (Smart Water paradigm). Water quality, wastewater treatment are also a key point due to the importance to reduce wastewater treatment, reduce Combined Sewer Overflow (CSO) spills and then reduce the environmental impact in case of CSO spills occurs, to mention a few decision making importance aspects. Finally, circular economy, water-energy nexus and these kind of strategies are currently needed to make integrated the use of water horizontally (industries, processes, water generators) and vertically (European, National and Regional, Local).

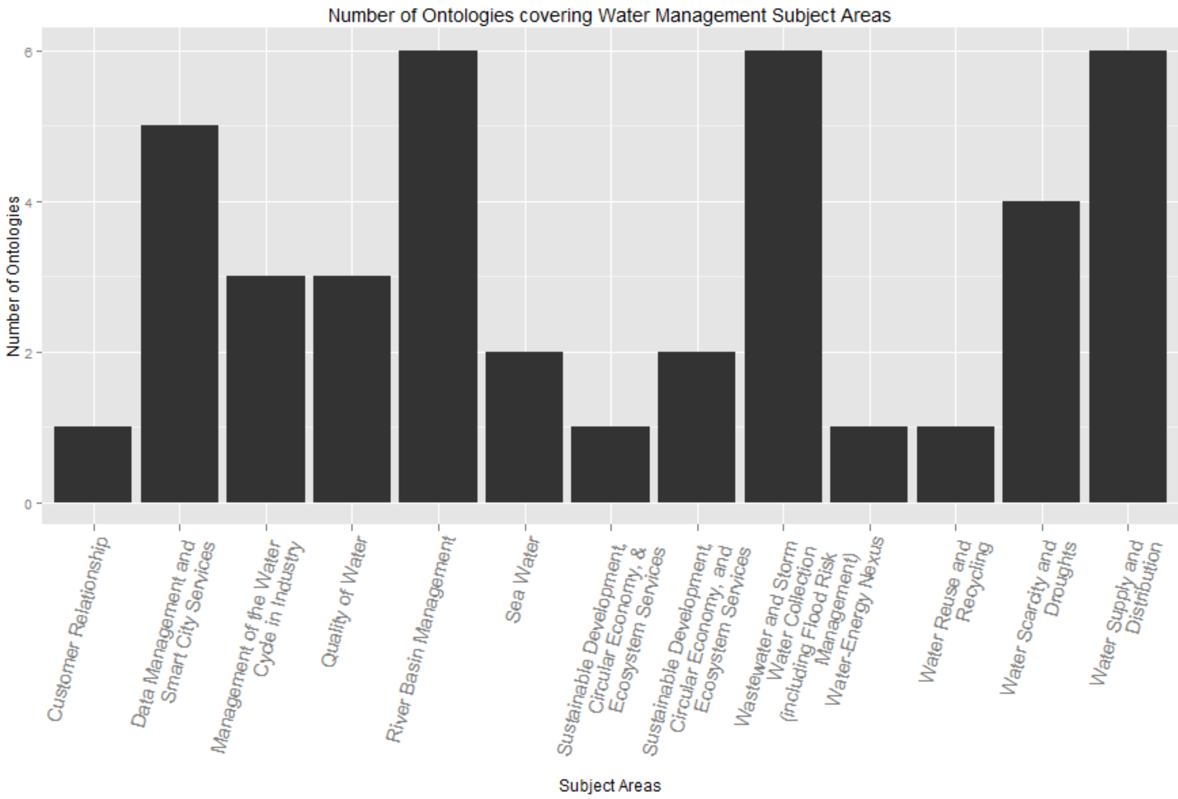

Figure 1: Number of ontologies for each Subject Area

Figure 1 depicts the number of ontologies covering each Water Management Subject Area. It can be noted that the subjects that are covered by more ontologies are Water Supply and Distribution, Wastewater and Storm Water Collection (including Flood Risk Management) and River Basin Management.

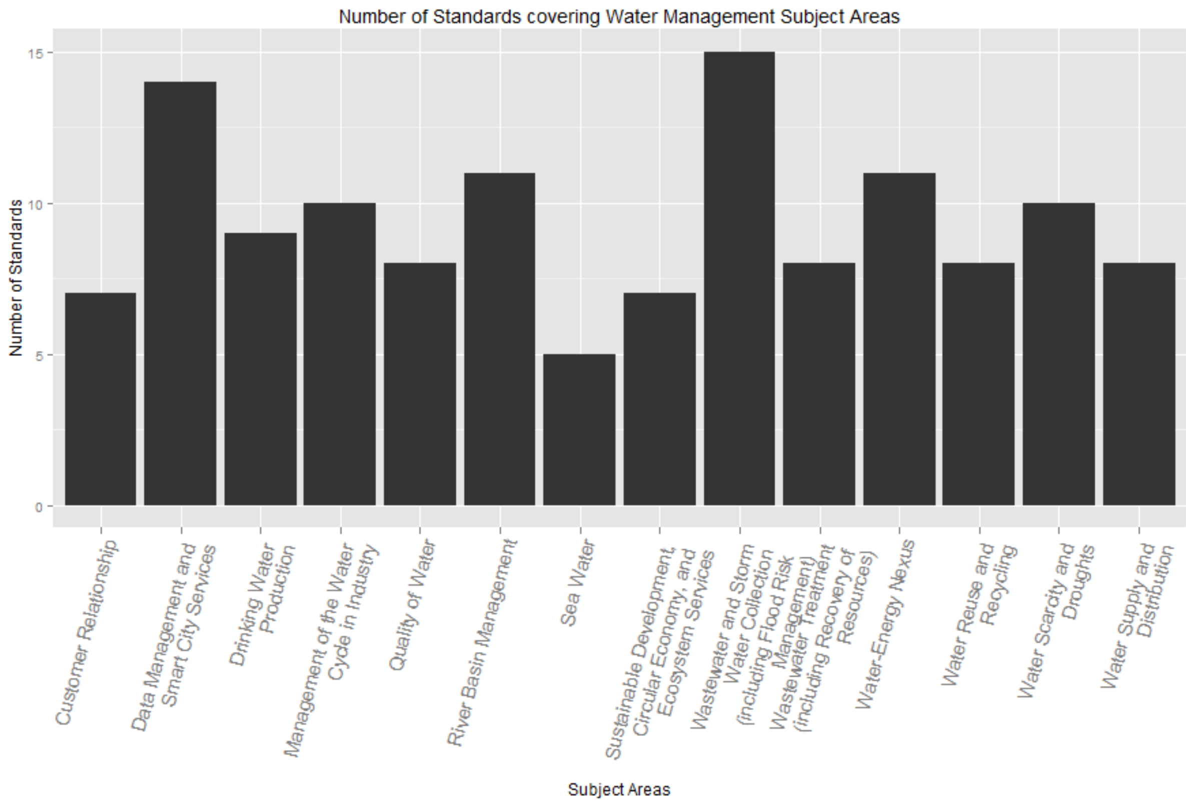

Figure 2: Number of standards for each Subject Area

Figure 2 depicts the number of standards covering each Water Management Subject Area. It can be noted that the subject that is covered by more standards is Wastewater and Storm Water Collection (including Flood Risk Management) followed by Data Management and Smart City Services.

From a technical point of view and following the framework directive INSPIRE for Geospatial[31] information, the technologies introduced in Sections 2.2.2 and 2.2.3 can be divided in different technical fields and aspects:

- **Metadata:** metadata is defined as the data providing information about one or more aspects of the data, it is used to summarize basic information about data which can make tracking and working with specific data easier. Ontologies make use of metadata to add more information during conceptualization process. Also schemas use metedata to structure the information and provide a meaning to the contained information. Some of the already revised standards and ontologies handle metadata within the solution proposed.
- **Network Services:** a network service can be defined as application running at the network application layer and above, that provides data storage, manipulation, presentation,

[31] http://inspire.ec.europa.eu/index.cfm/pageid/48

communication or other capability. Since the *defacto* standarization of Internet Protocol (IP) for almost any data communication process, a network service can be seen as a server connected to the Internet which provides information in a strctured way. This is the case of most of the WS presented in Table 3.

- **Interoperability of Spatial Data Sets and Services:** these kind of applications address the problem of permiting the interchange of information between sets of data and data provinding services. At the current moment, as services and sets are constructed using different standards these kind of applications transform data and metadata from one standard to another. In the case of services, it is used to use an special layer of software between interfaces called *middleware*.
- **Data and Service Sharing:** under this field are included those kind of applications that permit the publication of services and data.

Table 7, provides an enumeration of how many of the technologies reviewed during this state of the art section are useful for each Water Management Topic. This Table has been constructed by relating each Ontology and Standard (Table 2 and Table 16 (Appendix 2) respectively) to some Water Management Topics and Technologies, then each appearance of the technology has been counted.

Water Management Topics and Technologies	Data and Service Sharing	Interoperability of Spatial Data Sets and Services	Metadata	Network Services
Customer Relationship	10	3	5	10
Data Management and Smart City Services	18	6	10	18
Drinking Water Production	5	0	5	5
Management of the Water Cycle in Industry	15	3	10	15
Quality of Water	6	0	4	6
River Basin Management	20	6	12	20
Sea Water	14	6	8	14
Sustainable Development	3	0	3	3
Sustainable Development, Circular Economy and Ecosystem Services	8	3	5	8
Wastewater Treatment (including Recovery of Resources)	13	3	10	13
Wastewater and Storm Water Collection (including Flood Risk Management)	20	6	12	20
Water Reuse and Recycling	17	3	12	17
Water Scarcity and Droughts	20	6	12	20
Water Supply and Distribution	18	6	10	18

Water Management Topics and Technologies	Data and Service Sharing	Interoperability of Spatial Data Sets and Services	Metadata	Network Services
Water-Energy Nexus	6	0	4	6

Table 7: Number of technologies per each Water Management Topics and Technologies subject

As seen in Table 7, the average number of Ontologies and Standards is more or less the same (around 12) for each technology, except for Interoperability of Spatial Data Sets and Services which is 6.5. This shows that there's still a gap in this technology regarding Water Management comparing with the rest of technologies. This can be explained because it's a more specific technology, as for example Metadata is a very generic field. However, it plays a relevant role in the development of smart technologies and it would be interesting to increase the number of solutions regarding Interoperability of Spatial Data Sets and Services.

3. Summary and analysis of the major challenges and issues

According to the United Nations (Schuster C., Sandford, 2015), sustainable development worldwide will not be possible without creating a data collection and management system that ensures that accurate, verifiable qualitative and quantitative data are made available, when needed, to all bone fide partners at a level of detail required to be useful and used.

It is widely known (within the water management community) that no one can manage things that are not measured. Globally, reliable data are increasingly viewed as the foundation of sound decision-making and the raw material of meaningful accountability with respect to the management of water. Data must be disaggregated, documented, harmonised, managed, stored, interpreted, and disseminated in a timely manner to inform decisions (Schuster C., Sandford, 2015). This means that core data required to manage water sustainably cannot be seen as secret or guarded as a matter of national or proprietary security. Neither can they simply be seen as data from physical variables; data on water, sanitation, and wastewater use, perceptions, desires, and needs are equally as important for comprehensive water management as data on precipitation, water quantity, and water quality. These data must be useful and relevant, and should not only inform matters related to water use at the community and national level but also inform discourse related to water's role in larger environmental, economic, and social issues that define sustainable development everywhere.

Challenges and issues can be divided in: specific challenges and issues regarding Semantic Interoperability and Ontologies; and general Water ICT challenges and issues. Regarding Water ICT challenges and issues, the EC already explored this topic providing a roadmap which resulted from a cluster meeting of 10 running projects in Brussels, February 2014. That document identified the main challenges, issues and gaps in the usage of ICT for Water Management, as well as a list of emerging topics and technology challenges, which can be seen in Table 8.

Area	Description of main gaps
Efficient water use and reuse	The efficiency can be seen from different perspectives: leakage detection, sustainable reduction of elastic water consumption, increased user awareness, usage of grey water and cascade use of water, etc. Also, more interest has to be put on the optimisation in the use of water in agriculture, as agriculture accounts for almost the 70% water used in the world today[32]. The proper use of ontologies can provide a unified explanation of concepts and relationships used by the application field, make them shareable by different users and allow them to be processed by a machine (Liu et al., 2013).
Reducing Total Cost of Ownership for Water ICT	As an entry barrier for water utilities towards accurately monitoring and understanding water use and demand. Specific emphasis should be placed on strengthening R&D to deliver: a) cost-effective technical solutions addressing water consumption monitoring (e.g. sensing, analysis, engagement), b) technical synergies and business models with energy consumption monitoring, Smart Cities, and smart home ecosystems, and c) an improvement of Water ICT towards leveraging the circular characteristics of water.
Water-energy nexus	Solutions should not just aim at reducing the energy spent for water distribution or water waste processing, but mostly at reducing the total cost of the used energy (that is, not only how much energy it is consumed, but also when and why it is consumed).

[32] http://www.oecd.org/agriculture/wateruseinagriculture.htm

Area	Description of main gaps
Data sharing and privacy management	Special effort should be put into improving legislation and providing common sets of terms and conditions to be used. Including open data clauses in contracts between local authorities and WDN operators may be also an important step forward. Furthermore, there is a need to proactively identify potential privacy risks and propose privacy---preserving solutions (at the technical and policy levels) to facilitate data sharing. Technology entities should also provide the tools to secure the channels and anonymise the data transmitted through all the ICT platform.
Standardisation	Standardisation can be used to increase interoperability, avoid vendor and customer/end---user lock--- in and fight against the obsolescence of the systems that they use (e.g., a few years after deploying a new system they may not be able to access data anymore due to it). Standards need to be considered at several levels: formats, vocabularies, procedures and software/API.
Decision Support Systems (DSS)	There is still much heterogeneity among DSS implementations, with various technologies and algorithms been used in the current status quo, each one focusing on different WDN aspects. The implemented algorithms are not always compared and comparable, and the problem of standardisation is especially relevant here.
Consumer awareness	Consumer awareness has been low so far, with the general population at large still considering water as a perishable resource. Not only citizenship, but also industrial and agricultural customers. As an example the water footprint of most of the products are a big unknown. More effort is required towards developing solutions to improve consumer awareness, induce sustainable changes in consumption behaviour, and improve social perceptions for water

Table 8: Main challenges, issues and gaps in the usage of ICT for Water Management

The following sections summarize the major challenges and issues identified for Semantic Interoperability and Ontologies.

3.1 Specific Challenges for Semantic Interoperability and Ontologies

From previous state of the art analysis (Section 2) the following challenges for fostering the development and adoption of Semantic Interoperability and Ontologies tools have been identified:

Area	Challenges
Securisation	There should exist secure standards that permit the trustable sharing of information among sensors and other type of data management services. Those standards should provide a secure layer that does not affect significantly to the normal performing capabilities. The security and safety issues are important for intelligent sensors because very often they are used for responsible technical applications in varied, high-risk environments. These issues can be considered in the context of connectivity aspects due to the fact that intelligent sensors are elements of wireless sensor networks or can communicate indirectly with other systems in a different way. In (Bialas, 2010) the ISO/IEC 15408 standard is reviewed for intelligent sensors security enhancement. There are already layers of security in WS (HTTPS, SSL, WS-Security to mention a few), but it has to be assured that these security tools arrive to the consumer, as security faults can be a major drawback in the adoption of interoperable open technologies.
Anonymization	There should exist reliable standards and procedures that anonymize data regarding the source and the destination. Underpinning many recent advances (Lane, Xie, Moscibroda, & Zhao, 2012) in sensing applications (e.g., mHealth) is the ability to safely collect and share mobile sensor data. Research has shown that even from seemingly harmless sensors (e.g., accelerometers, gyroscopes, or magnetometers) an ever expanding set of potentially sensitive user behaviour can be inferred. Providing robust anonymity assurances is a principal mechanism for protecting users when data is shared (e.g., with medical professionals or friends).

Area	Challenges
Open Data	All entities involved in water environment should see Open Data as a positive aspect to integrate in their systems. As data becomes available to the whole community; new procedures, algorithms, systems, etc. can be discovered and shared among the research and industry community which ultimately can result in improvements available by the whole water community. Actions can be initiated by legal regulations (like in USA or in Europe) adopting Open Data policies that promote and ensure easy access to data so that they can be used as often and widely as possible. For example in Europe Open Data[33] initiatives are starting to make an impact in respect to both public sector information, and scientific data, while the Research Data Alliance[34] has been established to accelerate and facilitate research data sharing and exchange at the global level. Also open access to different data sources can help to take decisions at a higher level and foster the decision taking.
Open Source	The open-source model, or collaborative development from multiple independent sources, generates an increasingly more diverse scope of design perspective than any one company is capable of developing and sustaining long term. A report by the Standish Group[35] states that adoption of open-source software models has resulted in savings of about $60 billion per year to consumers. The benefits of developing software in a collaborative manner goes beyond the economical aspect, as it has been demonstrated that open source development allows to share knowledge, adapt innovation faster, maintain projects non lucrative, increase the interoperability among software systems, and many other advantages (Lakhani & Von Hippel, 2003).

[33] https://ec.europa.eu/digital-single-market/node/70

[34] http://rd-alliance.org/about.html

[35] www.freesoftwaremagazine.com/community_posts/creating_wealth_free_software

Area	Challenges
Real-time mesaurements	Supported by technological innovations, as for instance the affordability of sensors and its development that permits to place sensors in many parts of the water distribution network, data is under a big expansion in terms of quantity and diversity (e.g., archived, crowd-sourced, high-resolution) (UN Global Pulse, 2012). This poses new challenges and offers new opportunities to turn these data into understandable, usable information in real-time. Consequently, efficient standards and ontologies are required as real-time processing requires light time consuming methodologies in order to provide information to descision makers at the precise moment. Distributed high performance computing infrastructures such as Grids or Clouds appear as promising solutions (Bosin et al.,2011; Fraser et al., 2007; Giuliani et al., 2011).
Big Data support	New remote sensing missions and sensors are producing valuable information to improve the understanding and modeling of the water cycle (Lehmann et al., 2014), some examples are: estimating valuable information on soil moisture and water salinity (Kerr et al., 2010) , groundwater (Rebhan, Aguirre, & Johannessen, 2000), and ice and snow (CryoSat[36]). These are made available by ESA with a Open Data policy[37], however the access to these data sets require a register process. Conversely, NASA's Open Data policy provides free access to data without restrictions, like images, tabular data, etc. since long time ago. Field sensors are also developing rapidly and becoming cheaper. This will certainly improve spatial and temporal coverage of essential information on weather and hydrology in the future. Finally, the use of crowd sourcing (Craglia et al., 2008) has the potential to make use of a large number of contributors of valuable information on the water system (Fienen & Lowry, 2012) for instance on water quality, biodiversity or pollution. Uniform and systematic quality assurance, however, remains a challenge with respect to data provided through crowdsourcing means.

[36] http://www.esa.int/Our_Activities/Observing_the_Earth/CryoSat

[37] https://earth.esa.int/web/guest/-/revised-esa-earth-observation-data-policy-7098

Area	Challenges
IoT support	The Internet of Things (IoT) is a system consisting of networks of sensors, actuators, and smart objects whose purpose is to interconnect “all” things, including everyday and water management assets, in such a way as to make them intelligent, programmable, and more capable of interacting with humansand each other. In Water Management activities include GPS mapping technology and sensors to analyse pumps in the Water Distribution Network, identify water quality, monitor water level reservoirs, and use this information to apply different actions in urban, industrial or agricultural environments. Most standards to date address pieces of the IoT framework (e.g., communications and networking). There is a need for application standards that will enable interoperability between products in the application space. Interoperability is needed to break through the logjam of proprietary solutions to reduce industry fragmentation and build a successful IoT ecosystem. Standards are needed to promote the interoperability of devices both within verticals and within networking and communications environments. Standards are also needed for cross-vertical interoperability (e.g., the exchange of information and services between vertical applications).
Increase the competitiveness of products with lower costs	Standards in the water sector should generally bring new business opportunities and allow a market expansion. It will extremely useful for European SMEs (Small and Medium Enterprises), because it will allows entering a market that was previously in the hands of a few big players (mainly from the US) and will allow establishing ecosystem services by smaller companies.

Area	Challenges
Provide cross-domain alignment	Semantic Interoperability should go further than Water Management domain and also link other domains. This would help to link concepts from different domains such for example energy and water, and link water quality with energy efficiency. This will be a strong requirement for future complex systems such as Smart Cities or Smart Water Grids, where systems manage different assets and properties from different domains. One option for achieving this challenge is to build high-level ontologies that conceptualize concepts from a very general level to more specific. This challenge also includes the exchange of data between neighbouring environments and additional types of cross-domain alignments like forestry or agriculture which requires the development of interoperable tools for modelling these interactions.
Support to adopt the IWRM	As stated in Section 2, water research community has tended to adopt and develop the "Integrated Water Resource Management (IWRM)". The IWRM concept relies on integrating under a decision support system all decisions available in the water supply and distribution chain (including also numeric models). This integration requires the support of semantic interoperability tools and standards that foster the integration of all the components while facilitating the decision taking.

Table 9: Specific Challenges for Semantic Interoperability and Ontologies

3.2 Specific Issues for Semantic Interoperability and Ontologies

According with the research performed in the state of the art revision (Section 2) the following issues have been identified. The following issues are problems that have already been identified or can be major problems in the near future regarding the development and adoption of Semantic Interoperability and Ontologies tools:

Data Policies	Ontologies and standards, particularly methods and technologies appear promising to support and facilitate water-related data discovery, accessibility, visualization, dissemination, and analysis (Lehmann et al., 2014). From a technical point of view, if all data provider modules within an information system are supported by the interoperability standards and frameworks, data could be accessed for everyone. Ontologies and standards have the potential to be part of the answer to bridging the gap between scientists and decision/policy makers by providing tools to access reliable water-related information rapidly, efficiently, and meaningfully. Among the most frequent obstacles to achieving the full interoperability paradigm, however, is the frequent lack of institutional and political wills to publish and share data (GSDI, 2004). Indeed, data providers tend to limit access to data mostly for confidentiality, national security or ‘‘misuse prevention’’ reasons. This inevitably leads to duplication of activities, duplication and fragmentation of data, overlaps between initiatives and projects, lack of coordination, insufficient flow of information, and inadequate resources management.

Manage uncertainty	It is clear that the more standard interfaces for information systems are provided the more sources of data can be combined. Hydrological models typically suffer from the uncertainty of their input data being combined in complex ways into their outputs (Abbaspoury, Schulin, Schläppi, & Flühler, 1996). The use of different possible hydrological models is even a source of uncertainty itself[38]. Current web-based modelling frameworks are facing the problem of managing uncertainty with respect to data and models (Bastin et al., 2013). Policy and decisions-makers are increasingly relying on scientific data and model outputs to explore different scenarios and take or develop better-informed decisions/policies (Buytaert, Baez, Bustamante, & Dewulf, 2012). Therefore, having the means to quantify and efficiently communicate uncertainty of data and models appears an essential pre-requisite. Otherwise, providing incomplete information can negatively influence decision-making processes and development of adaptation strategies to in response to the pressing challenges we are currently facing (e.g., climate change, energy supply, water scarcity). To tackle this issue, it is required to enable uncertainty propagation in models and propose an interoperable representation of uncertainty. Currently WaterML2.0 provides tools to work with this uncertainty but more (complete and sound) methods are required to infer valuable information from these potentially inconsistent sources of data.

[38] http://earthzine.org/2010/08/04/18-reasons-for-open-publication-of-geoscience-data/

Application of the standards among stakeholders	It has already been stated that facilitating the exchange and access to water-related data is essential (Beniston et al., 2012) to easily integrate them with other distributed data sources (Lee & Percivall, 2009). So, besides the development of new ontologies and standard there is still work to do regarding the entities that generate the data. The adaptation of the standards in each industry or sectors is a must. In particular, documenting data with adequate metadata and making them searchable through catalogues is a pre-requisite to facilitate data search and discovery. In this respect, the implementation of the INSPIRE Directive will do much to address this situation in Europe, while the development of the GEOSS Data – CORE, a pool of resources with full and open access addressing key environmental domains including water, needs to be fully supported to overcome existing policy differences at the global level. Notwithstanding these important developments, further difficulties affecting data sharing include policies on data commercialization, protection of intellectual property through restrictive copyrights, the existence of linguistic and geopolitical barriers, and the reluctance by older generations to adopt new technologies.
Water governance	The current context for water management is one of complexity and uncertainty, where divergent economic and political interests are at stake, and where cultural and identity discourses play a significant role (Pedregal, Cabello, Hernández-Mora, Limones, & Moral, 2015). In such a context, the effective incorporation of diverse actors and the quality of decision-making processes is of particular importance. Access to information over which deliberation can be arranged is a prerequisite in any participatory process. Information must be relevant to the specific management questions, easily accessible and understandable for all types of stakeholders, adapted to the decision-making context and time frame, and traceable.

Lack of repositories	It has been already targeted that there are two fundamental problems within water management data collection: how to collect such a large mass of information, and how to access the information and retrieve coherent data to process in order to perform easy, fast and reliable decision making. The centrality of such a theme was already asserted by the European Community, which launched since 2003 the WISE project (Water Information System for Europe) as a joint initiative of DG Environment, The European Environment Agency (EEA), Eurostat (ESTAT) and the Joint Research Centre (JRC) in order to implement the data upload, sharing and analysis requirements of the Water Framework Directive 2000/60/CE. As an information system WISE includes all possible WISE nodes, data and viewer providers as well as the common WISE public web site and their interactions. It is not a centralized database but rather a decentralised system at EU level which will have capabilities to interoperate with existing national systems.
Complexity of ontologies and standards	The inherent complexity of ontologies and standards makes its implementation a difficult task (Anzaldi et al., 2014). one of the reasons for this is that some of them are very ambitious, e.g. the INSPIRE standards (ED, 2007) which, in practice, are usually only partially implemented.
Increase the price of products	Due to the necessity of certification products will have an extra cost that will lead to more expensive products. This can be a drawback in the application of standards as the final user is not intended to understand the necessity of a higher price for standardized product. However, this increase can be justified if a better management is clearly targeted. In this later case the user would accept an increase of the price of the product, but it will have to be linked with a better general management infrastructure.
Awareness among stakeholders	There still exists a lack of awareness among stakeholders regarding the use of interoperability and ontologies tools. Actions in that direction should be taken so stakeholders know why they should use interoperability tools and provide standard ways of accessing information and provide a clear picture of the benefits of acquiring open data policies.

Lack of linkage with INSPIRE	The Directive 2007/2/EC of the European Union, adopted in 2007 aims at establishing and Infrastructure for Spatial Information in the European Union (INSPIRE) for environmental policies or policies and activities that have an impact on the environment (European Commission, 2007). The Directive does not require connection of new data, but Member States' existing spatial datasets, should be publicly accessible, harmonized and interoperable through network services, within established implementation roadmap. To ensure that the data infrastructures that already exists are compatible and usable ontologies developed should take into account the models proposed by INSPIRE and that currently are not considered.

Table 10: Specific Issues for Semantic Interoperability and Ontologies

4. Summary and analysis of the dominant solutions and trends

4.1 Dominant Solutions

In the following, we provide details about some projects that can be considered representative of the large suite of community and proprietary solutions that provide tools for semantic interoperability.

4.1.1 52º North

The open source software initiative 52°North[39] is an open international network of partners from research, industry and public administration. Its main purpose is to foster innovation in the field of Geoinformatics through a collaborative R&D process.

The 52°North R&D communities develop new concepts and technologies e.g. for managing near real-time sensor data, integrating geoprocessing technologies into SDIs, making use of GRID- and Cloud technologies. They evaluate new macro trends, such as the Internet of Things, the Semantic Web or Linked Open Data, and find ways to unfold their use in practice.

All 52°North partners have a long and outstanding record in the Geo-IT domain and actively contribute to the development of international standards, e.g. at W3C, ISO, OGC or INSPIRE.

All software developed within this collaborative development process is published under an open source license. 52°North is a trusted and well established entity in the Geoinformatics arena. Its software is widely used in operational IT environments, research labs and education.

52°North - Initiative for Geospatial Open Source Software GmbH is the initiative's administrative office and service center. It functions as initiator and contributor in many of the network's activities. This company maintains the 52N software repositories and provides its partners with an extensive IT and communication infrastructure to support the collaborative software development process. It actively supports the coordination of activities within and amongst the R&D communities.

Also, 52°North GmbH manages the Intellectual Property Rights (IPR) and software licensing for all of the 52°North software. The contributions are published under a Free and Open Source Software License. This gives potential users maximum degrees of freedom to use, adapt and redistribute the software and derivative works in any combination with other software.

Complementary to the 52°North software stack, the 52°North team of IT experts provides support, maintenance, consulting and software development services. It supports the development of high quality software solutions in all fields of geo IT applications.

[39] http://52north.org/

52ºNorth's portfolio includes tools and solutions for:

- managing near real-time sensor data
- web-based and cloud-based geoprocessing
- geostatistical analysis with R and GSTAT
- processing ESA-DDS and GEONETCast data
- OSM-based routing and data analysis
- security access to geospatial web services
- working with linked data and the semantic web
- metadata editing

4.1.1.1 References

The work in 51ºNorth's projects spans one or more communities. The following short list includes current projects.

- AgriCAB: A framework for enhancing EO capacity for Agriculture and Forest Management in Africa as a contribution to GEOSS
- BRIDGES: Bringing together Research and Industry for the Development of Glider Environmental Services
- ConnectinGEO: Coordinating an Observation Network of Networks EnCompassing saTellite and IN-situ to fill the Gaps in European Observations
- EEA SOS Framework: IT consultancy for SOS Integration
- FixO3: Fixed Point Open Ocean Observatory
- GLUES: Global Assessment of Land Use Dynamics and Impacts on Ecosystem Services
- MYGEOSS: Innovative User Feedback App
- NeXOS: Next generation, Cost-effective, Compact, Multifunctional Web Enabled Ocean Sensor Systems Empowering Marine, Maritime and Fisheries Management
- ODIP II: Ocean Data Interoperability Platform
- OGC IMIS IoT Pilot: OGC Incident Management Information Sharing (IMIS) Internet of Things Pilot (IoT) Pilot
- TaMIS: Development of a Dam Surveillance and Information System for the Management of Natural Hazards
- WaterInnEU: Applying European market leadership to river basin networks and spreading of innovation on water ICT models, tools and data

4.1.2 KISTERS Water Resources Management

KISTERS' solutions are devoted to the task of collecting, storing, managing, validating, analyzing and reporting all of their water data. Its aim is to provide a solution for many areas such as: hydrological measuring networks, meteorology, groundwater, flooding, water quality, urban hydrology, waste water, drinking water and dam operation.

KISTERS also develops robust portal solutions that offer organizations many capabilities for public awareness and safety. One such portal is the award-winning Portal for Flemish Water Managers[40].

4.1.2.1 WISKI

The KISTERS product called WISKI (Water Information Systems KISTERS) is a water data management software solution. WISKI automates data collection processes for faster analysis and better decisions, improves data quality, provides visualization tools, and offers an easy way to report and share hydrological data. WISKI is a powerful and flexible software solution that can manage all of your water data.

- Automate Data: Automated real time collection and data importing allows to easily get data from remote sources and visualize it in near real time for fast and accurate analysis.
- Import Data: Automatic import of data from various sources including: SCADA, GOES, CDEC, NWS, USGS, and logger data files.
- Export Data: Export data in multiple formats to enable a simple import into other database applications. It is capable of obtaining the data in a format that fits with the business needs and the requirements of stakeholders and government agencies.
- Edit Data: Availability of data management software to allow water resource staff to revise and edit erroneous data with ease and accuracy.
- Reports: Creation of individualized reports or build customer specific reports based on specific project requirements. WISKI provides a range of standard reports that can be generated immediately.
- Share Data: Data sharing is easy with WISKI Web Services. Several data export solutions are available to provide third party access.

4.1.2.2 Hydstra

Hydstra/TS is a file-based time-series data management system that provides the tools to build and maintain a time-series data archive.

Hydstra/TS, store supporting information such as station information, rating tables, shifts, discharge measurements, cross-sections, logger configurations and data quality codes. Data acquired through SODA, HydroTel, and other third party telemetry systems can be directly stored in Hydstra.

[40] http://www/waterinfo.be

Hydstra supports other methods of data acquisition, such as manual file import, FTP file transfer, and the automatic import of data from publicly accessible websites.

Hydstra stores data in a proprietary file system that is optimized for compression and querying.

About data management, Hydstra provides to:

- Redraw data to correct spikes, flat spots, etc.
- Apply filters to smooth data or remove values outside normal range
- Operate on data in text or graphical mode
- Undo any edit
- Quality code data and add comments
- Recalibrate data to adjust for clock or transducer drift
- Archive data using drag and drop
- Operate on any number of files simultaneously
- Report on the contents of a time-series file
- Quantise data in time and/or value domains
- Resample data with time and event triggers
- Copy and paste between blocks, variables, data files. Paste data points into other Windows text-based applications
- Process logger data files into time series

4.1.3 OGC Hydrologic Applications

The Open Geospatial Consortium (OGC) has promulgated standards used within the GIS software industry that are also based on web services technologies for data sharing.

One of the most widely used of the OGC standards is the Web Feature Service (WFS) which offers direct fine-grained access to geographic information at the feature and feature attribute level. Most GIS applications support WFS 1.0.0 and WFS 1.1.0 servers, but are being updated to incorporate the latest WFS 2.0.0 servers. The other most commonly used OGC standards include Web Mapping Service (WMS), which is used to send map images between computers, and Keyhole Markup Language (KML) used to encode feature data in applications such as Google Maps. The Sensor Observation Service (SOS) version 2.0 standard, defines a web service interface is used to report not only the observations collected by the sensor but also manage and report sensor metadata from heterogeneous sensor systems. Also Web Processing Service (WPS) is very used in many cases for processing geospatial or location data, including data from sensors, as this data must be processed before the information can be used effectively. The WPS Interface Standard provides a standard interface that simplifies the task of making simple or complex computational processing services accessible via web services. Such services include well-known processes found in GIS software as well as specialized processes for spatio-temporal modelling and simulation. While the WPS standard was designed with spatial processing in mind, it can also be used to readily insert non-spatial processing tasks into a web services environment such as Water Management processing tasks.

Although many organizations, institutes and scientific communities have already used this Web Services, one issue that remains is its interoperability with other systems. To address this issue the OGC accepted and endorsed WaterML 2.0 schema (Sheahan & Taylor, 2014) as an encoding standard for publishing time series of hydrological observation data. WaterML 2.0 is an updated version of WaterML that incorporates the OGC O&M standards and the OMXML GML Application Schema. In Europe, scientific communities, organizations and institutes are encouraged to make use of this standard (WaterML 2.0) and establish a system for publishing hydrological observation data in WaterML 2.0 format.

4.1.4 O&M and Sensor Web Enablement related standards in INSPIRE

In Europe a major recent development has been the entering in force of the INSPIRE Directive in May 2007, establishing an infrastructure for spatial information in Europe to support Community environmental policies, and policies or activities which may have an impact on the environment.

INSPIRE is based on the infrastructures for spatial information established and operated by the 28 Member States of the European Union. The Directive addresses 34 spatial data themes needed for environmental applications, with key components specified through technical implementing rules. This makes INSPIRE a unique example of a legislative “regional” approach (European Commission, 2007).

Included in these 34 spatial themes, there are hydrographic elements, including marine areas and all other water bodies and items related to them, including river basins and sub-basins. Where appropriate, according to the definitions set out in Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 (European Community, 2000) establishing a framework for Community action in the field of water policy and in the form of networks which is also known as Water Framework directive (WFD).

The theme Hydrography is a basic reference component and, therefore, of interest for many users and uses. For mapping purposes (to provide a map background for orientation and to understand place relationships), it includes the representation of all main hydrographic elements – both natural and artificial. To fulfil reporting requirements of EC water-related directives it includes the river and channel network; surface water bodies within river basin districts are categorised as rivers, lakes, transitional waters or coastal waters, or as artificial surface water bodies or heavily modified surface water bodies. Furthermore, a topologically-sound river network is necessary for GIS-based spatial analysis and modelling. Geographically, the theme Hydrography covers all inland water and marine areas covered by river basin districts as defined by WFD.

According to (Network Services Drafting Team, 2007), the ISO 19156:2011 standard on Observations and Measurements (O&M) was designed for basic spatial information, including measured, modelled or simulated data, and thus shall be used in INSPIRE to cover these requirements. The following INSPIRE themes have identified O&M as integrally relevant to their thematic domain and are including elements of O&M into their data specifications (Network Services Drafting Team, 2007):

- Geology
- Oceanographic geographical features
- Atmospheric conditions and Meteorological geographical features
- Environmental monitoring facilities
- Soil

In addition to these themes, several further INSPIRE themes have been identified to which observational information, while not at the core of the data specification, is relevant. These themes are (Network Services Drafting Team, 2007):

- <u>Area management/restriction/regulation zones and reporting units:</u> Not mentioned but relevant for reporting on aggregated levels
- <u>Human Health and Safety:</u> provision of health determinants
- <u>Land cover:</u> Observations form the basis for land cover information
- <u>Natural risk zones:</u> Not in model, but use case states: Monitoring data:
    - Type of monitoring instrumentation
    - Location of sampling measurements
    - Type and record of measurements"
- <u>Production and industrial facilities:</u> Relevant for provision of emissions data for E-PRTR
- <u>Statistical units & Population distribution, demography:</u> StatisticalDataValue looks a bit like OM_Observation, SU would also make sense
- <u>Utility and governmental services:</u> Currently stated that "Non-geographic data (e.g. information on flow in m^3/s) is also out of scope of this specification"
- <u>Habitats and biotopes & Species distribution:</u> Observation form the basis for these themes, link to primary observations

While the O&M standard provides a generic framework for the provision of measurement data, there are many ways of utilizing the core structures. In order to assure compatibility across thematic tailoring versions of the O&M standards, the X-TWG OM has provided guidelines as to how this standard is to be used within INSPIRE. These guidelines should be taken into account in all INSPIRE themes integrating or referencing to the O&M standard.

In addition to the use of the Observations and Measurements standard, further elements of the OGC Sensor Web Enablement Suite (SWE) have been identified as useful for the encoding and provision of observational data. While further SWE specifications may be nominated for use in INSPIRE, at the present we have identified the following:

- Sensor Observation Service (SOS): service created for the provision of observational data;

- SensorML: Standard for the provision of procedural information;
- SWE Common: Includes result encoding options.

4.2 Trends

The current trends in the field of Semantic Interoperability and Ontologies have been identified in Table 11. On the one hand, the development of a Semantic Broker is discussed in recommended actions for the future and regarding SDIs, it has been already discussed how they can contribute to cope with Interoperability issues.

Trend	Description
Semantic Broker	A semantic broker is a computer service that automatically provides semantic mapper services. A semantic broker is frequently part of a semantic middleware system that leverages semantic equivalence statements. To qualify as a semantic broker product a system must be able to automatically extract data from a message and use semantic equivalence statements to transform this into another namespace. (Çelik & Elçi, 2013)
Spatial Data Infrastructure (SDI)	A SDI is a data infrastructure implementing a framework of geographic data, metadata, users and tools that are interactively connected in order to use spatial data in an efficient and flexible way. Another definition is "the technology, policies, standards, human resources, and related activities necessary to acquire, process, distribute, use, maintain, and preserve spatial data". A further definition is given in Kuhn (Steiniger & Hunter, 2011): "An SDI is a coordinated series of agreements on technology standards, institutional arrangements, and policies that enable the discovery and use of geospatial information by users and for purposes other than those it was created for."

Table 11: Trends in Semantic Interoperability and Ontologies

5. Specific recommendations for the best funding and research directions

In Table 12, there is an identification of the Funding and research directions, as well as a description linked with the recommendations to follow to foster the development of Semantic Interoperability and Ontologies.

Funding or research direction	Description	Recommendations
Smart City and Water Management semantic connection	The development of advanced systems such as Smart Cities will require a high data transmission and coordination capability. That's why it is very important that in systems which are based on the utilization of many subsystems (Systems of Systems – SoS). Using standardized interfaces and languages for the communication among water infrastructures with the rest of systems (e.g. Power-line infrastructures) or with central computing centres within the Smart City, is a key point in the development of all components of the system.	• Work in the standardization of a high level ontology for Water Management in urban areas • Align Smart City interoperability tools with Water Management concepts • Foster the inclusion of semantic tools able to interact with other systems within the Smart City paradigm • Provide regulatory advices for the implantation of semantic tools in water infrastructures

Funding or research direction	**Description**	**Recommendations**
Ontologies for Smart Water Grid	Application of Ontologies in the Smart Water Grid paradigm (SWG). The future application of the SWG will involve Smart Meters, Smart Valves and Pumps, Analytical Tools, etc. in a two direction stream of information: from user to infrastructure and *vice versa*. It will be crucial to provide an Open Data schema which will cope with the necessity of sharing information between different components from different vendors.	• Develop Ontologies capable of representing knowledge within Smart Water Grid paradigm • Provide reasoning mechanism for SWG ontologies that provide information for decision making

Table 12: Recommendations for the best funding and research directions

6. Recommended actions to be taken for each of the targeted stakeholders to implant the innovations

A varied set of target groups and actors are considered in the context of the application of ICT for Water Management (European Commission, 2015). These include:

- Water entities, including those that treat water and/or waste-water, water supply and distribution system (WDS) operators, etc.
- Governments and other types of policy-making or influential organisations, including:
    - Municipalities
    - Water authorities/regulators (e.g., River Basin Authorities, OFWAT in the UK)
    - Environmental authorities
    - Non-Governmental Organisations (NGOs)
- Customers
    - Individual customers
    - Groups of customers (e.g., blocks of flats, suburbs, hotels, etc.)
    - Industry end-users
    - Agriculture end-users

One of the first recommendations for implanting the innovations is the coordination and synergies among these different stakeholders. It has been highlighted as one of the main challenges (European Commission, 2015) and, at the same time, opportunities in the sector. The rest of recommendations are listed in Table 13.

Stakeholders	Recommended Actions	Challenges and Issues addressed
Governments and other types of policy-making	• Policies to enforce companies for the use of ontologies over natural resources • Provide open models and open data through interoperable platforms • Invest in the development of technologies such as ontologies, grammars, schemas through coordinated projects	• Open Data • Increase the competitiveness of products with lower costs • Provide cross-domain alignment • Data Policies • Application of the standards among stakeholders • Awareness among stakeholders • Water governance
Water entities	• Incorporate ontologies in products and also in internal procedures and processes • Integrate ontologies and standards to new and existing products to help to identify technologies and assure interoperability among systems • Investigate the application of technologies in processes for water providers and utilities • Provide tools for an easier understanding of ontologies • Provide an open repository where all ontologies are available and described with examples of use • Implant secure standards to guarantee the anonymity and security of customer data	• Securisation • Anonymization • Open Data • IoT support • Big Data support • Manage uncertainty • Application of the standards among stakeholders • Lack of repositories • Increase the price of products

Stakeholders	Recommended Actions	Challenges and Issues addressed
Customers	• Ontologies and the concept of semantic interoperability should arrive to customers by means of standardized products that can be used through all the water cycle • Provide standardized tools that conceptualize the water usage through services and applications • Provide agreements so that the consumer can trust the usage of the provided applications. That means that the consumer is not afraid about its data being used for third part entities	• Securisation • Anonymization • Increase the price of products

Table 13: Recommended actions to be taken for each stakeholder

7. Conclusions and Recommendations

The following Table 14 summarizes the actions to be taken within a stage of action. The stages are tied to short-term actions (to be taken within the following year), mid-term actions (to be taken within the next 2-3 years) and long-term actions (to be taken within the next 5 years). Also these actions are tied to some stakeholders, as not all recommendations should be taken for each stakeholder.

Stakeholders Involved	Actions Recommended	Stage
• Municipalities • Water authorities/regulators • Environmental authorities • Water entities • Individual customers • Groups of customers (e.g., blocks of flats, suburbs, hotels, etc.) • Industry end-users • Agriculture end-users	Identify the most attractive fields for the application of Semantic Interoperability technologies such as Ontologies	Short-term
• Municipalities • Water authorities/regulators • Environmental authorities • Water entities	Take advantage of the potential of application in real application environments of the advanced technologies of interoperability of IoT through the chain of value in Water Management environments.	Short-term
• Municipalities • Water authorities/regulators • Environmental authorities • Water entities	Select and integrate the best technologies in each class among all the range of suitable standards and ontologies ensuring the interoperability at data and communication level. This has to facilitate the integration of data at user level in the water value chain.	Mid-term

Stakeholders Involved	Actions Recommended	Stage
• Municipalities • Water authorities/regulators • Environmental authorities • Water entities	Foster the transference of knowledge and experience acquired for all the stakeholders through all the research and development stage.	Mid-term
• Municipalities • Water authorities/regulators • Environmental authorities • Water entities	Propose a procedure to integrate all IoT elements in a SoS architecture for Water Management that permits to add value to all participants in water management value chain. This architecture will follow the requisites of a system based in standards and no entity will have a central role.	Mid-term
• Municipalities • Water authorities/regulators • Environmental authorities • Water entities	Provide a central element based in a Broker infrastructure for Water Management. This element will support the management of water in different environments. One of the main contributions will be a model and data format based on Standards and Ontologies. This Broker will be adaptable to all different scenarios and use settings.	Mid-term

Stakeholders Involved	Actions Recommended	Stage
• Municipalities • Water authorities/regulators • Environmental authorities • Water entities	Integral management of water resources through the integration of data delivered by IoT devices between different Domains. The Broker will be a central part of the final system and will permit to each of the participant in the Water Management cycle contribute and control its part of the chain value.	Long-term
• Municipalities • Water authorities/regulators • Environmental authorities • Water entities • Individual customers • Groups of customers (e.g., blocks of flats, suburbs, hotels, etc.) • Industry end-users • Agriculture end-users	Take advantage of new ICT opportunities for water sector. Accordingly with the development and increase of environmental regulations in Europe it is also expected a higher pressure in policies at global level	Long-term

Table 14: Stakeholders involved in each future action and its stage of application

8. General summary

The current Deliverable is the Semantic Interoperability and Ontologies topical roadmap which intention is to analyse the current state of semantic technologies within Water Management community, identify the barriers and challenges of the adoption of such technologies and provide a vision for the future while providing relevant recommendations for involved stakeholders in the field.

This document provides an analysis of the state of the art of Ontologies and Standards regarding the Water Management domain. Thus, this document analyse and present some barriers in terms of the adoption of such technologies. Hence, this berries and recommendations have been obtained by analysing the interest of the community (water, research/scientific, industrial) combined with the ontology study. During this analysis, the identified topics have been matched with the ontologies identified in order to demonstrate the areas with major semantic interoperability impact. Similar approach has been followed in the standards case, analysing which topic is more suitable for each standard. At the end, main highlighted aspect is the identification of Water Management topics that are more covered regarding the use of ontologies and standards.

Later, in Section 3 an analysis of the gaps identified during the state of the art (Section 2) is provided, and Table 8: Main challenges, issues and gaps in the usage of ICT for Water Management provides a first quick view of the current necessities in the field. Later in this document, issues and challenges are identified in Table 9: Specific Challenges for Semantic Interoperability and Ontologies and Table 10: Specific Issues for Semantic Interoperability and Ontologies. These challenges and issues can be divided into two groups: a first group which is focused in technological barriers and challenges regarding the development and adoption of ontologies and standards; and a second group of regulatory/educational challenges and issues that all stakeholders can contribute to overcome. These challenges and issues have been used later in the document to identify possible actions and recommendations for the future.

In Section 4, an analysis of the main solutions present in Water Management community is provided. Included in this analysis there exist proposals of the OGC, which clearly is leading the development of tools for overcoming semantical and syntactical problems and standardizing schemas, services and standards. Also, there exist proposals for linking INSPIRE directive with water management, although this linkages has to be strengthen and also regulatory assessment should be provided form governmental institutions. Also the trends that will help to cope with the barriers have been identified and presented in, especially semantic brokers which seem to be a suitable tool for future development of semantic capabilities in next generation systems (Smart Water Grids and Smart City).

The rest of the roadmap is devoted to the identification of actions to be taken in the future. Section 5 targets some of the best research directions to be funded, which can help in the development of semantic tools for Water Management community. These trends have been grouped and described in Table 11: Trends in Semantic Interoperability and Ontologies. Later in Section 6 recommended actions for each stakeholder are provided, these recommendations are linked to the challenges and issues that each action helps to solve while each stakeholder that is involved in the execution of the action is also identified in Table 12: Recommendations for the best funding and research directions. The roadmap concludes in Section 7 providing a 5 year vision of the actions to be taken in the future for each stakeholder (see Table 14: Stakeholders involved in each future action and its stage of application).

9. References

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1. Appendix: List of ontologies revised

Title	Type of Work	Topics	Year	Reference
An Ontology Framework for Water Quality Management	design, implementation	Quality of Water	2011	(Ahmedi et al., 2013)
The SSN Ontology of the W3C Semantic Sensor Network	design, implementation	General	2012	(Compton et al., 2011)
A Semantic Portal for Next Generation Environmental Monitoring	design, implementation	Quality of Water	2011	(Wang et al., 2011)
Ontology-Driven Complex Event Processing	analysis	General	2011	(Yu, Taylor, & Sherman, 2011)
OntoWEDSS: an ontology-underpinned decision-support system for wastewater management	design, implementation	Wastewater Treatment (including Recovery of Resources)	2004	(Ceccaroni, Cortes, & Sanchez-Marre, 2004)
Knowledge representation in the semantic web for Earth and environmental terminology (SWEET)	analysis	Water Supply and Distribution	2005	(Raskin & Pan, 2005)
SEPSen: Semantic event processing at the sensor nodes for energy efficient wireless sensor networks	design, implementation	Wastewater Treatment (including Recovery of Resources)	2012	(Kasi, Hinze, Legg, & Jones, 2012)
Structuring Multidisciplinary Knowledge for Model Based Water Management: The HarmoniQuA Approach	design, implementation	Data Management and Smart City Services	2004	(Scholten, Refsgaard, & Kassahun, 2004)
Ontology-Based Correlation Of Resource Management Actions With Water Quality Data In South-East Queensland	analysis	Quality of Water	2010	(J Hunter et al., 2010)
An ontology-based knowledge management system for flow and water quality modeling	design, analysis	Quality of Water	2006	(Chau, 2007)
An Ontology-based Knowledge Management System for Industry Clusters	design, analysis	Management of the Water Cycle in Industry	2007	(Sureephong, Chakpitak, Ouzrout, & Bouras, 2008)

Title	Type of Work	Topics	Year	Reference
Using Ontologies to Relate Resource Management Actions to Environmental Monitoring Data in South East Queensland	design, implementation, analysis	Quality of Water	2011	(Jane Hunter, Becker, Alabri, Ingen, & Abal, 2012)
Ontologies and Decision Support for Failure Mitigation in Intelligent Water Distribution Networks	analysis	Water Supply and Distribution	2012	(Lin, Sedigh, & Hurson, 2011)
Good Modelling Practice in water management	design, implementation	Data Management and Smart City Services	2000	(Scholten & Waveren, 2000)
Knowledge Management For More Sustainable Water Systems	analysis	Water Supply and Distribution	2010	(Mounce, Brewster, Ashley, & Hurley, 2010)
GroundWater Markup Language (GWML) – enabling groundwater data interoperability in spatial data infrastructures	design, implementation	Water Supply and Distribution	2012	(Boisvert & Brodaric, 2012)
Going with the Flow: Sustainable Water Management as Ontological Cleaving	analysis	General	2013	(Lavau, 2013)
Domain ontologies for data sharing–an example from environmental monitoring using field GIS	analysis	General	2002	(Pundt & Bishr, 2002)
Role Of Ontologies In Creating Hydrologic Metadata	analysis	Hydrology	2003	(Bermudez & Piasecki, 2014)
A Process-Centric Ontological Approach for Integrating Geo-Sensor Data	design, implementation	Water Supply and Distribution	2010	(Devaraju & Kuhn, 2010)
An integrated system for publishing environmental observations data			2009	(Horsburgh et al., 2009)
Federated Critical Infrastructure Simulators: Towards Ontologies For Support Of Collaboration	design, implementation, analysis	Water Supply and Distribution	2011	(Grolinger, Capretz, Shypanski, & Gill, 2011)
Functional Ontologies and Their Application to Hydrologic Modeling: Development of an Integrated Semantic and Procedural Knowledge Model and Reasoning Engine	design, implementation, analysis	General	2008	(Byrd, 2013)

Title	Type of Work	Topics	Year	Reference
DOLCE ROCKS: Integrating Geoscience Ontologies with DOLCE	design, implementation, analysis	Water Supply and Distribution	2008	(Brodaric & Probst, 2008)

Table 15: List of ontologies revised

2. Appendix: Relation between Standards, Water Management Topics and Technologies

Standard Name	Subject Areas	Technology
Sensor Observation Service (SOS)	Water Supply and Distribution;Data Management and Smart City Services;Quality of Water; Wastewater and Storm Water Collection (including Flood Risk Management);Water-Energy Nexus;River Basin Management;Water Reuse and Recycling;Customer Relationship;Management of the Water Cycle in Industry;Water Scarcity and Droughts	Network Services;Data and Service Sharing
Web Map Service (WMS)	Water Supply and Distribution;Data Management and Smart City Services;Wastewater and Storm Water Collection (including Flood Risk Management);River Basin Management;Sea Water;Water Scarcity and Droughts	Network Services;Interoperability of Spatial Data Sets and Services; Data and Service Sharing
Web Feature Service (WFS)	Water Supply and Distribution;Data Management and Smart City Services;Wastewater and Storm Water Collection (including Flood Risk Management);River Basin Management;Sea Water;Water Scarcity and Droughts	Network Services;Interoperability of Spatial Data Sets and Services;Data and Service Sharing
Sensor Web Enablement (SWE)	Water Supply and Distribution;Data Management and Smart City Services;Quality of Water;Wastewater and Storm Water Collection (including Flood Risk Management);Water-Energy Nexus;River Basin Management;Water Reuse and Recycling;Customer Relationship;Management of the Water Cycle in Industry;Water Scarcity and Droughts	Network Services;Data and Service Sharing

Standard Name	Subject Areas	Technology
Sensor Planning Service (SPS)	Water Supply and Distribution;Data Management and Smart City Services;Quality of Water;Wastewater and Storm Water Collection (including Flood Risk Management);Water-Energy Nexus;River Basin Management;Water Reuse and Recycling;Customer Relationship;Management of the Water Cycle in Industry;Water Scarcity and Droughts	Network Services;Data and Service Sharing
WaterOneFlow	Water Supply and Distribution;Data Management and Smart City Services;Sustainable Development;Wastewater and Storm Water Collection (including Flood Risk Management);River Basin Management;Drinking Water Production;Water Reuse and Recycling;Wastewater Treatment (including Recovery of Resources);Management of the Water Cycle in Industry;Sea Water;Water Scarcity and Droughts	Metadata;Network Services;Data and Service Sharing
WaterML 2.0	Water Supply and Distribution;Data Management and Smart City Services;Quality of Water; Sustainable Development, Circular Economy and Ecosystem Services;Wastewater and Storm Water Collection (including Flood Risk Management);Water-Energy Nexus;River Basin Management;Drinking Water Production;Water Reuse and Recycling;Wastewater Treatment (including Recovery of Resources);Customer Relationship;Management of the Water Cycle in Industry;Sea Water;Water Scarcity and Droughts	Metadata;Network Services;Data and Service Sharing

Standard Name	Subject Areas	Technology
Water Data Transfer Format (WDTF)	Water Supply and Distribution;Data Management and Smart City Services;Quality of Water;Sustainable Development, Circular Economy and Ecosystem Services;Wastewater and Storm Water Collection (including Flood Risk Management); Water-Energy Nexus; River Basin Management; Drinking Water Production; Water Reuse and Recycling; Wastewater Treatment (including Recovery of Resources); Customer Relationship; Management of the Water Cycle in Industry; Sea Water; Water Scarcity and Droughts	Metadata;Network Services;Data and Service Sharing
HY_Features	Water Supply and Distribution;Data Management and Smart City Services;Sustainable Development;Wastewater and Storm Water Collection (including Flood Risk Management);River Basin Management;Drinking Water Production;Water Reuse and Recycling;Wastewater Treatment (including Recovery of Resources);Management of the Water Cycle in Industry;Sea Water;Water Scarcity and Droughts	Metadata;Network Services;Data and Service Sharing
GroundWater Markup Language (GWML)	Data Management and Smart City Services;Sustainable Development, Circular Economy and Ecosystem Services;Wastewater and Storm Water Collection (including Flood Risk Management);River Basin Management;Water Reuse and Recycling;Wastewater Treatment (including Recovery of Resources);Management of the Water Cycle in Industry;Water Scarcity and Droughts	Metadata;Network Services;Data and Service Sharing

Standard Name	Subject Areas	Technology
XHydro	Water Supply and Distribution;Data Management and Smart City Services;Sustainable Development;Wastewater and Storm Water Collection (including Flood Risk Management);River Basin Management;Drinking Water Production;Water Reuse and Recycling;Wastewater Treatment (including Recovery of Resources);Management of the Water Cycle in Industry;Sea Water;Water Scarcity and Droughts	Metadata;Network Services;Data and Service Sharing
Climate Science Modelling Language v3.0	Water Supply and Distribution;Wastewater and Storm Water Collection (including Flood Risk Management);River Basin Management;Water Reuse and Recycling;Wastewater Treatment (including Recovery of Resources);Sea Water;Water Scarcity and Droughts	Metadata;Network Services;Data and Service Sharing
Sensor Markup Language (SensorML)	Water Supply and Distribution;Data Management and Smart City Services;Quality of Water;Wastewater and Storm Water Collection (including Flood Risk Management);Water-Energy Nexus;River Basin Management;Water Reuse and Recycling;Customer Relationship;Management of the Water Cycle in Industry;Water Scarcity and Droughts	Metadata;Network Services;Data and Service Sharing
Observations and Measurements Encoding Standard (O&M)	Water Supply and Distribution;Data Management and Smart City Services;Quality of Water;Wastewater and Storm Water Collection (including Flood Risk Management);Water-Energy Nexus;River Basin Management;Water Reuse and Recycling;Customer Relationship;Management of the Water Cycle in Industry;Water Scarcity and Droughts	Metadata;Network Services;Data and Service Sharing

Standard Name	Subject Areas	Technology
Geography Markup Language (GML)	Water Supply and Distribution;Data Management and Smart City Services;Sustainable Development, Circular Economy and Ecosystem Services;Wastewater and Storm Water Collection (including Flood Risk Management);River Basin Management;Water Reuse and Recycling;Wastewater Treatment (including Recovery of Resources);Customer Relationship;Management of the Water Cycle in Industry;Sea Water;Water Scarcity and Droughts	Network Services;Interoperability of Spatial Data Sets and Services;Data and Service Sharing
GeoSciML	Water Supply and Distribution;Data Management and Smart City Services;Sustainable Development, Circular Economy and Ecosystem Services;Wastewater and Storm Water Collection (including Flood Risk Management);River Basin Management;Water Reuse and Recycling;Wastewater Treatment (including Recovery of Resources);Customer Relationship;Management of the Water Cycle in Industry;Sea Water;Water Scarcity and Droughts	Network Services;Interoperability of Spatial Data Sets and Services;Data and Service Sharing
Earth Science Markup Language (ESML)	Water Supply and Distribution;Data Management and Smart City Services;Sustainable Development, Circular Economy and Ecosystem Services;Wastewater and Storm Water Collection (including Flood Risk Management);River Basin Management;Water Reuse and Recycling;Wastewater Treatment (including Recovery of Resources);Customer Relationship;Management of the Water Cycle in Industry;Sea Water;Water Scarcity and Droughts	Metadata;Network Services;Data and Service Sharing

Standard Name	Subject Areas	Technology
Ecological Metadata Language (EML)	Water Supply and Distribution;Wastewater and Storm Water Collection (including Flood Risk Management);River Basin Management;Water Reuse and Recycling;Wastewater Treatment (including Recovery of Resources);Sea Water;Water Scarcity and Droughts	Metadata;Network Services;Data and Service Sharing
OpenGIS Web Map Tile Service Implementation Standard (WMTS)	Water Supply and Distribution;Data Management and Smart City Services;Sustainable Development, Circular Economy and Ecosystem Services;Wastewater and Storm Water Collection (including Flood Risk Management);River Basin Management;Water Reuse and Recycling;Wastewater Treatment (including Recovery of Resources);Customer Relationship;Management of the Water Cycle in Industry;Sea Water;Water Scarcity and Droughts	Network Services;Interoperability of Spatial Data Sets and Services;Data and Service Sharing
Web Coverage Service (WCS)	Water Supply and Distribution;Data Management and Smart City Services;Wastewater and Storm Water Collection (including Flood Risk Management);River Basin Management;Sea Water;Water Scarcity and Droughts	Network Services; Interoperability of Spatial Data Sets and Services; Data and Service Sharing
Network Common Data Form (NetCDF)	Data Management and Smart City Services;Sustainable Development, Circular Economy and Ecosystem Services;Wastewater and Storm Water Collection (including Flood Risk Management);River Basin Management;Water Reuse and Recycling;Wastewater Treatment (including Recovery of Resources);Management of the Water Cycle in Industry;Water Scarcity and Droughts	Metadata;Network Services;Data and Service Sharing

Table 16: Relation between Standards, Water Management Topics and Technologies