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Testbed-11 Catalogue Service and Discovery

Engineering Report

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Abstract

This OGC Testbed 11 Engineering Report provides a comprehensive review and comparison in terms of architecture, functionality, and usability of the OGC catalogue service standards CSW 2.0.2 and CSW 3.0. We are especially interested in how well the two standards provide support for open searches and federated distributed searches in current distributed computing paradigms. We also evaluated the support of semantic searches using different strategies, including (1) semantic mediation, a.k.a. ontology-based query expansion (Li et al. 2008; Li et al. 2011), (2) semantic association, which enables current catalogue information models to support semantic search (Li et al. 2014; Li et al. 2015), and (3) complete renovation of the CSW information model to be a triple store and utilize Semantic Web technology (Berner-Lee 2001) to support semantic query and data retrieval. Scenarios to search for hydrological data are developed to evaluate the performance of catalogue searching using the above strategies. Recommendations for adoption of CSW standards as well as tasks in advancing catalogue search and data discovery in future testbeds is also discussed.

Business Value

This Engineering Report (ER) will advance the OGC interoperability program and standardization process in the following aspects:

(1) The thorough review of distributed search, open search, and federated search support by CSW 3.0 to the metadata cataloging will foster the advancement of CSW specification, the widespread adoptions of OGC standards, as well as the interoperability between OGC standards and open search standards currently adopted by several general search engines;

(2) The proposal for semantic enablement of OGC catalogue services will potentially lead to the development of new specifications to provide intelligent searches, both keyword and location-based, by existing and future metadata catalogues.

Keywords

Testbed11

CSW – Catalogue Service for the Web

CSW 3.0./CAT 3.0 – OGC Catalogue Service Specifications 3.0 – General Model

OWL – Web Ontology Language

RDF – Resource Description Framework

SWEET – Semantic Web for Earth and Environmental Terminology

SPARQL – Semantic Web Query Language

Testbed-11 Catalogue Service and Discovery Engineering Report

1 Introduction

1.1 Scope

This OGC ER has two objectives. The first is a systematic comparison between the CSW 2.0.2 and the CSW 3.0 (CSW 3.0 and CAT 3.0 are used interchangeably) in terms of their architecture, and their support for open, distributed, and federated searches. The aim is to highlight the advancement of CSW 3.0 in terms of supporting metadata cataloguing and search in comparison to CSW 2.0.2. The second objective is to discuss potential semantic enhancement to catalogue services. This includes strategies of considering semantic search a mediation layer, or using ontology-based query expansion and reasoning, or using potentially some data mining approach to mine latent semantic associations automatically to support semantic-enabled data discovery from distributed catalogs. This part will hopefully lead to the development of new standards for semantic-enabled catalogue service, making the catalog search more intelligent to serve needs within and beyond the geospatial community.

1.2 Document contributor contact points

All questions regarding this document should be directed to the editor or the contributors:

Name	Organization
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Sheng Wu	Arizona State University

1.3 Future work

Improvements recommended in this document are offered for community discussions on the applicability and adoption of the CSW in real world applications. The community involves all science domains that use geospatial data in their research and applications, including but not limited to: environmental science, disaster analysis, hydrology, geology, polar science community, etc.

1.4 Forward

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. The Open Geospatial Consortium shall not be held responsible for identifying any or all such patent rights.

Recipients of this document are requested to submit, with their comments, notification of any relevant patent claims or other intellectual property rights of which they may be aware that might be infringed by any implementation of the standard set forth in this document, and to provide supporting documentation.

2 References

The following documents are referenced in this document. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. For undated references, the latest edition of the normative document referred to applies.

OGC 06-121r3, OGC® Web Services Common Standard

NOTE This OWS Common Standard contains a list of normative references that are also applicable to this Implementation Standard.

OGC 07-006r1, OGC® Catalog Services Implementation Specification v2.0.2.

OGC 12-168r4, OGC® Catalog Services Specification v3.0 –General Model.

3 Terms and definitions

For the purposes of this report, the definitions specified in Clause 4 of the OWS Common Implementation Standard [OGC 06-121r3], in OGC® Catalog Services Implementation Specification v2.0.2 [OGC 07-006r1] and OGC Catalogue Services Specification v 3.0 – General Model shall apply.

4 Conventions

4.1 Abbreviated terms

CSW	Catalogue Services for the Web
HTTP	Hypertext Transfer Protocol
ISO	International Organization for Standardization
MIME	Multipurpose Internet Mail Extensions
OGC	Open Geospatial Consortium, also referred to as OpenGIS
UML	Unified Markup Language
GEOSS	Global Earth Observation System of Systems

ebRIM	Electronic business Registry Information Model
OWL	Web Ontology Language
RDF	Resource Description Framework
SPARQL	Semantic Web Query Language
SWEET	Semantic Web for Earth and Environmental Terminology
DC	Dublin Core
PURL	Persistent Universal Resource Locator
URI	Universal Resource Identifier

4.2 UML notation

Most diagrams that appear in this standard are presented using the Unified Modeling Language (UML) static structure diagram, as described in Subclause 5.2 of [OGC 06-121r3].

4.3 Used parts of other documents

This document uses significant parts of documents OGC CSW 2.0.2 OGC 07-006r1 and OGC CSW 3.0 12-168r4. To reduce the need to refer to that document, this document copies some of those parts with small modifications. The copied part is cited in the document.

5 OGC IP Engineering Report on Catalogue Service Discovery overview

This OGC Engineering Report on Catalogue Service Discovery compares the differences in the information model and in particular, the support to metadata discovery, between the CSW 2.0.2 and CSW 3.0. A clear advancement of CSW 3.0 is the detailed discussion on implementation and interface definition to support federated distributed search. We also examined different techniques to semantically enable the search and discovery component of the CSW catalogue. Figure 1 demonstrates the research questions being answered through this ER.

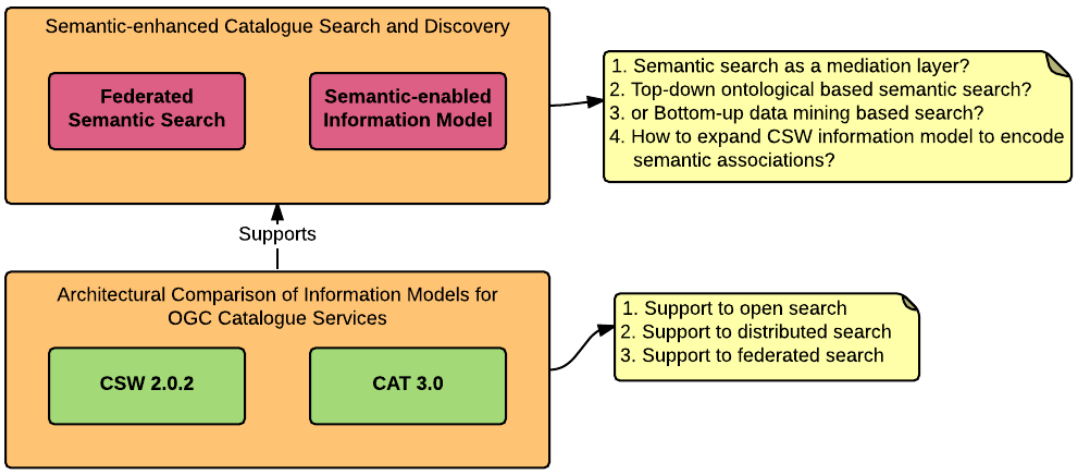

Figure 1. Research question to answer in the catalogue service ER

We first conducted a systematic review and comparison of the two catalogue service standards. The comparison is generally based on the support capacity for open, distributed, and federated searches. These three search types are important for future catalogue implementation because (1) open search is widely supported by general search engines. Thus, enabling open search makes the metadata within the catalogue easily discoverable and shared; and (2) the rapid explosion of the Web makes it possible to connect physically distributed people and more importantly distributed geospatial assets.

Geospatial data is an information resource known to be widely distributed in today's computing paradigms. To support this broad distribution, various catalogue applications have been established. Well known ones include European Union's INSPIRE[1] catalogue, the US data.gov[2] project initiated by the US White House, and the international effort GEOSS (Global Earth Observation System of Systems)[3]. These Web-based catalog services are hosted by different organizations and the metadata contained in them is most always on different topics. To increase the visibility of distributed geospatial data/service resources, there is a need for a federated distributed search mechanism that can coordinate the data discovery process from not only one but many distributed catalogue instances.

Many organizations or applications often require access to distributed catalogues. Each set of these catalogues is used in a federated search. In another words one federated search requires the support from a subset of all distributed catalogs, and different

[1] http://inspire-geoportal.ec.europa.eu/

[2] http://data.gov

[3] http://www.geoportal.org/web/guest/geo_home_stp

federated searches may or may not have overlapping catalogues. This ER discusses CSW 3.0's capacity to support open, distributed, and federated searches in detail.

In addition, we discuss the possible solutions to semantically enable data search and discovery in CSW catalogues. These include the more traditional semantic mediation approach and two new methods for enabling triple storage and semantic query based on semantic association definition and Semantic Web technology. Recommendations for adopting these techniques in the CSW catalogue are made based on the advantages and disadvantage of each techniques, as well as the difficulty in integrating the semantic techniques into existing CSW information models.

6 Status of Work

6.1 CSW 2.0.2: An introduction

CSW 2.0.2 is an OGC standard that supports the publishing of and searching for metadata about data, services, and related information objects. As an implementation standard, OGC 07-006r1 specifies the "interface between clients and catalogue services, through the presentation of abstract and implementation-specific models." Using 07-0061 as a baseline catalogue standard, this section discusses the architecture of CSW 2.0.2 for supporting catalogue searches, its information model, and distributed searching.

6.1.1 Reference Model Architecture

The data publishing and discovery process can be described as follows: the metadata repository is an implementation of a specific CSW information model, such as ebRIM, which provides indexing and storage of descriptive information (metadata) of various geospatial resources. This metadata repository provides a set of query operations (including GetCapabilities, GetRecords, DescribeRecords, etc.), which are compliant with the CSW 2.0.2 standard, to allow an application client to query the metadata from the repository. Once the results are returned, the client can parse the metadata, which often contains the online endpoint to access the geospatial resources. A large portion of these geospatial resources are published as data or processing services, such as the OGC WMS (Web Map Service), OGC WFS (Web Feature Service), and OGC WCS (Web Coverage Service). Figure 2 demonstrates the reference model architecture for OGC catalogue services.

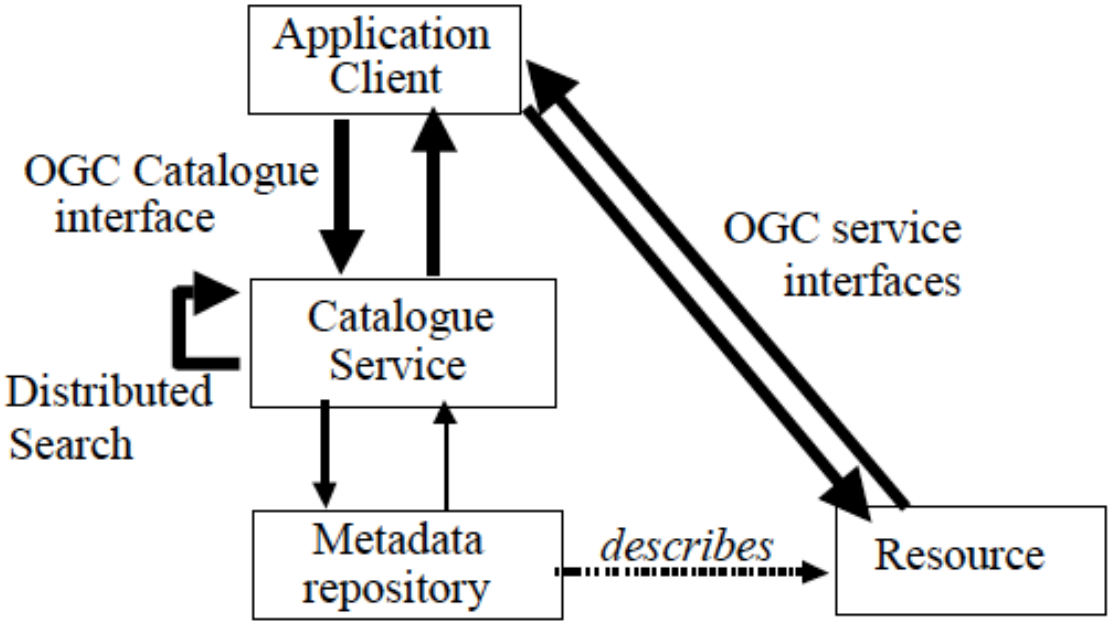

Figure 2. Reference Model Architecture (OGC 07-006r1)

In the 2.0.2 version of CSW standard, distributed search is mentioned. As seen in Figure 2, the catalogue service has an arrow to point to itself, in the aim of supporting distributed search. However, in the description of class definition, information model, and especially the operations, this version of CSW is still mainly focusing on solving the search and discovery in a local environment.

6.1.2 Operations Unique to CSW 2.0.2

A “Session” class is unique to CSW 2.0.2. Figure 2 defines the catalogue UML static model (Figure 3). In this model, there is a “Session” class. This class provides four operations to foster the interaction between server and client. The “initialize” and “close” operations start and end an interactive session. The “status” operation retrieves current status of a *session*, and “cancel” operation terminates an existing session.

The advantage of *session* is to allow the server to record the status of a user operation at the client side to better support a data retrieval process. As long as the session is alive, even if the webpage is accidentally closed, the server would still be able to recover to the previous state. However, the *session* strategy requires the server to store a variety of status information for the client. In a distributed search environment, the synchronization of such status information across different CSW servers will become extremely difficult. The server would also suffer from overloading and its performance will likely be affected. In other words, the efficient communication between server and client has not been well addressed.

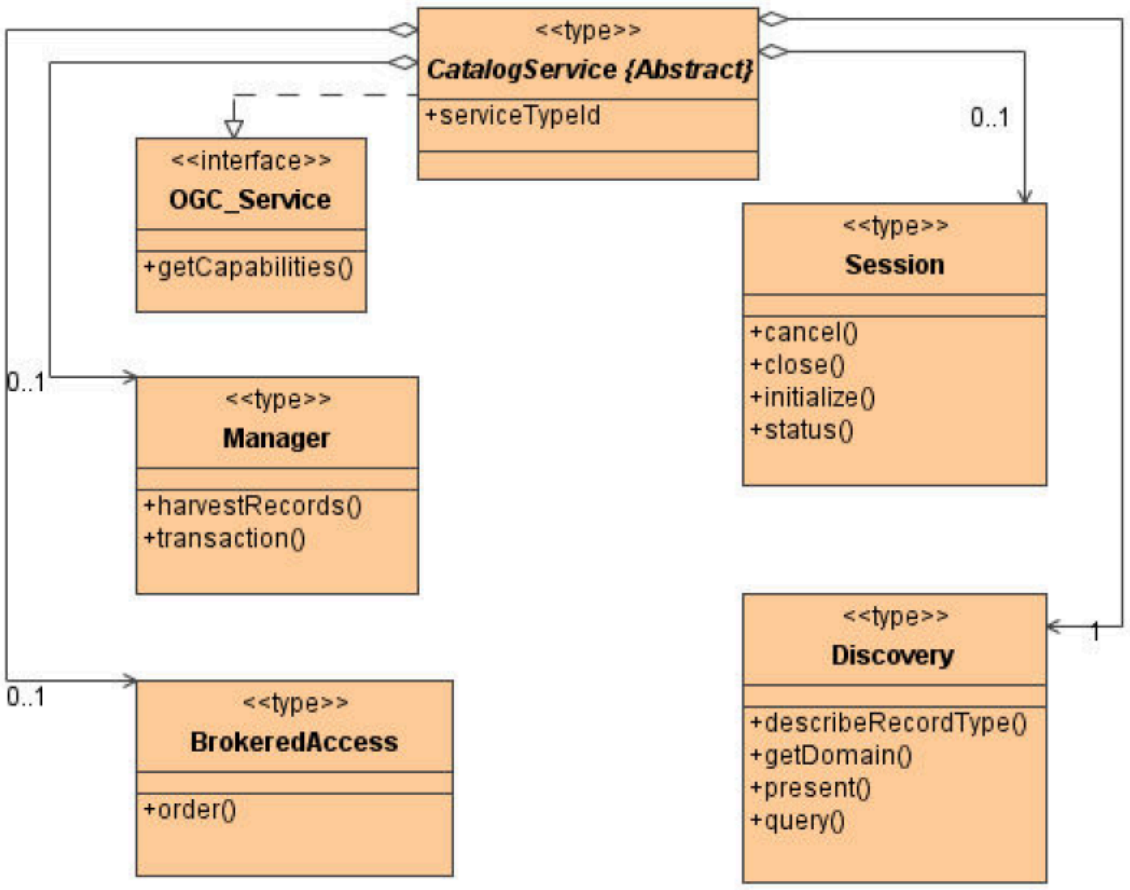

Figure 3. General OGC catalogue UML static model (OGC 07-006r1)

CSW 2.0.2 also provides a full definition of the "Present" operation, which allows the retrieval of a result set that is related to the previous inquired set. For instance, a client can acquire a subset of a previous queried result or obtain more results with the cursor moving to the end of records returned in a previous query.

6.1.3 Support to Distributed Search

In CSW 2.0.2, the required components to enable distributed searching are discussed. First, a multi-tier reference architecture is needed to support cataloging and searching for geospatial data. This architecture diagram is discussed in section 6.1.1. Second, a data model is needed to describe how distributed search can be redirected to different catalogs. Third, the definition of communication messages needs to apply current catalog information model to distributed search context.

Specifically, in "query" operation defined as part of the "Discovery" class, there is an attribute named "queryScope". This parameter has two values, 0 means the search is a local search and 1 means the search is conducted in a distributed catalog environment. In addition, in the "Discovery" message definition, a new structure member *maxLevel* is introduce to control the range of distribution. Suppose all the catalogs are organized as an

interconnected graph, a search is conducted from current catalogue to the sub-catalogs that connect with it. Setting a *maxLevel* to 2 will allow the search of sub-catalogs that directly link to the current catalog, or those that are two steps further from the current catalog. In another words, they are the catalogs that link with the direct sub-catalogs of the current catalog. Setting a maxLevel to -1 will enable a search for all sub-catalogues from the current level. Using the parameter *maxLevel*, the query scope can be controlled.

In CSW 2.0.2, potential problems of distributed catalog search are also discussed and described. In Annex B of the standard, two problematic scenarios are defined. The first problem is when one node X has two parent nodes. In this case, when a search is conducted, i.e., from a node that is the precedent of both the parent nodes, the node X will be searched twice, causing duplication in the result. The second problem is caused by a complex topology of the catalog network. For example, when catalog Y is linked to catalog Z, which is its precedent, catalog Z becomes Y's child node too. In this case, a loop is formed, whereby a search that redirects to Z will fall in a repeated search between Y and Z causing serious issues. Although these problems are discussed, this version of specification did not describe how to solve these problems by extending the definition of the CSW information model.

6.1.4 Usability

The CSW 2.0.2 standard has been widely used in national and international spatial data infrastructure projects. Below we list a sample set of CSW endpoints that were discovered by the NSF PolarHub, a large-scale web crawler for discovering distributed OGC services (Li et al. 2015):

CSW Catalogs	URL
United States Geoscience Information Network Metadata Catalog	http://catalog.usgin.org/geoportal/csw?request=GetCapabilities&service=csw
GEOSS CSR Catalog	http://geossregistries.info/geonetwork/srv/en/csw?Request=GetCapabilities&Service=CSW&Version=2.0.2
ArcGIS Server Geoportal Extension 10 - OGC CSW 2.0.2 ISO AP	http://catalog.chesapeakebay.net/geoportal/csw?Request=GetCapabilities&Service=CSW&Version=2.0.2
ArcGIS Online CSW Interface	http://geoss.esri.com/csw/csw?request=GetCapabilities&service=CSW&version=2.0.2
ArcGIS Server Geoportal Extension 10 - OGC CSW 2.0.2 ISO AP	http://portal.westcoastoceans.org/geoportal/csw?request=GetCapabilities&service=CSW&version=2.0.2
Servicio de catalogaciÃ³n OGC CSW de IDECA	http://metadatos.ideca.gov.co/geoportal/csw?request=GetCapabilities&service=CSW
ArcGIS Server Geoportal Extension	http://data.nconemap.com/geoportal/csw/discovery?request=G

10 - OGC CSW 2.0.2 ISO AP	etCapabilities&service=CSW&version=2.0.2
IARC Data Archive CSW Service	http://climate.iarc.uaf.edu/geonetwork/srv/csw?REQUEST=GetCapabilities&SERVICE=CSW&VERSION=2.0.2
CSW Geospatial Catalogue for NOAA Data Catalog (data.noaa.gov)	https://data.noaa.gov/csw?request=GetCapabilities&service=CSW&version=2.0.2
Welsh Government INSPIRE CSW	http://inspire.wales.gov.uk/metadata/srv/eng/csw?REQUEST=GetCapabilities&service=CSW&version=2.0.2
geocat.ch	http://www.geocat.ch/geonetwork/srv/eng/csw?REQUEST=GetCapabilities&SERVICE=CSW&VERSION=2.0.2
UK Location Catalogue Publishing Service	http://csw.data.gov.uk/geonetwork/srv/csw?REQUEST=GetCapabilities&SERVICE=CSW&VERSION=2.0.2
Copeland Borough Council GeoPortal Discovery Service	http://gistch1.copelandbc.org.uk/geonetwork/srv/csw?REQUEST=GetCapabilities&SERVICE=CSW&VERSION=2.0.2
Catalogue Service Land Steiermark (Geoportal Server 1.2.2) - OGC CSW 2.0.2 ISO API including INSPIRE Network Service Capabilities	http://gis.stmk.gv.at/geoportal/csw/discovery?Request=GetCapabilities&Service=CSW&Version=2.0.2
geocat.ch	http://www.geocat.ch/geonetwork/srv/eng/csw?REQUEST=GetCapabilities&SERVICE=CSW&VERSION=2.0.2
geonetwork GRID	http://129.194.231.213:8080/geonetwork/srv/csw?REQUEST=GetCapabilities&SERVICE=CSW&VERSION=2.0.2
North Dakota GIS Hub Data Portal	http://apps.nd.gov/hubdataportal/srv/en/csw?REQUEST=GetCaities&service=CSW&version=2.0.2
VLIZ Geonetwork	http://geonetwork.vliz.be/geonetwork/srv/en/csw?request=GetCapabilities&service=CSW

Table 1. A list of sample CSW 2.0.2 endpoints

6.2 CSW 3.0

6.2.1 Introduction

The OGC Catalogue Services 3.0 Standards Working Group (OGC CSW 3.0 SWG for short), initiated in March 2008, aimed at developing a new version of the standard to advance existing CSW 2.0.2 definitions for catalog management and search. The new standard CSW 3.0, published on March 18, 2014, was edited by Lorenzo Bigagli, Doug Nebert, Uwe Voges, Panagiotis Vretanos, and Bruce Westcott. The main areas of enhancement in CSW3.0 with regard to CSW 2.0.2 include:

- Restructuring the specification document according to the OGC standard for modular specifications (OGC 08-131r3, also know as Core and Extension model).

- Incorporating the current mass-market technologies for discovery on the Web (namely OpenSearch).

- Providing a better scenario design to support distributed and federated search.

The standard contains the following main content:

- General Model

- Hypertext Transfer Protocol (HTTP) Protocol Binding. In CSW, the GET/KVP encoding is mandatory. The POST/XML encoding is optional. SOAP is supported as a special case of the POST/XML encoding.

- The OpenSearch is mandatory in CSW 3.0, no matter which implementation profile is used in the catalogue instance. The OpenSearch Geospatial and Temporal Extensions (OGC 10-032r2) are also included in CSW 3.0 specification. This document specifies spatial (e.g. point-plus-radius, bounding box, polygons, in EPSG:4326/WGS84 coordinates) and temporal constraints (e.g. time start/end) for searching.

- Additional changes include enhancement to query distribution and conformance classes.

6.2.2 General model

The general model of catalogue service defined in CSW 3.0 is the same as that defined in CSW 2.0.2. Refer to Figure 2.

6.2.3 A new definition in CSW3.0: Conformance class

For conformance, the standard defines a set of requirements for which all catalogue implementations must conform. This is a new feature not included in the CSW 2.0.2 standard. Twelve conformance classes are defined:

- Query language: aiming at using a well-performed syntax to process full text and fielded query.

- Common-query language: the syntax being used to be transformable to the BNF (Backus Normal Form) used to describe syntax of languages used in query and other computing environment.

- Classified-as: This is an enhancement of current search support to introduce semantic-based query. Besides the support for keyword-based search, a classified-as operator allows queries based on taxonomy.

- Common-queryables: to support distributed search, different catalog instances need to make available a common set of queryable elements, such as title or abstract.

- Common-returnable: similar to “Common-queryables”, the Common-returnable defines a common set of elements that should be included in the returned documents from different catalogues to support interoperability.

- GetCapabilities: All implementations should provide a means to request structured capability information about the CSW service.

- GetResourceById: All implementations should be able to provide a means to request a record by its ID.

- Query: The CSW instances should support the execution of a query request formed in a KVP or structured format.

- Describe-Records: This is also a requirement for the CSW instances to provide a means to describe the metadata information of a record.

- GetDomain: The catalogue should provide the domain (the value range) of a queryable such that a query can be formulated accordingly.

- Transaction: A transaction operation should allow the actions of adding, updating and deleting records to be performed on a catalog.

- Harvest: The harvest operation allows the retrieval of a resource from another remote catalog.

Figure 4 demonstrates the conceptual architecture of CSW 3.0 and the requests that can be performed between metadata consumer (the user) and the catalog, and between the metadata producer (the data provider) and the catalog.

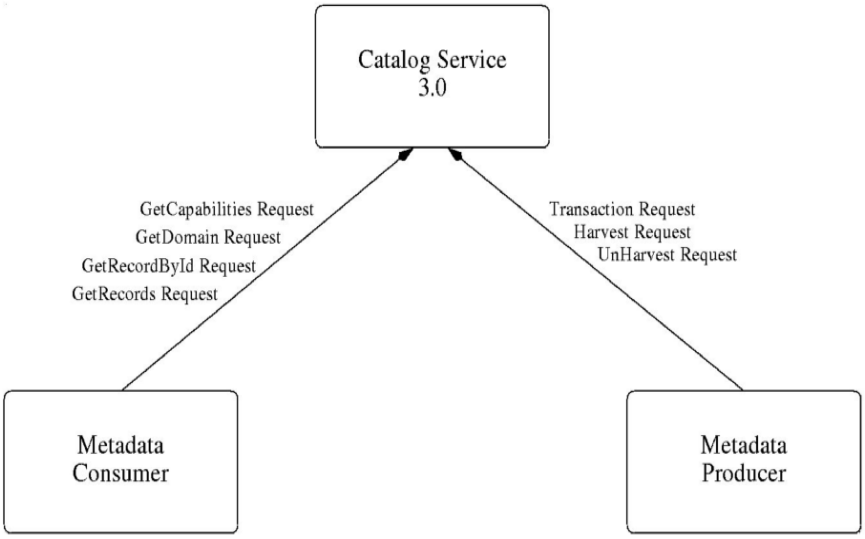

Figure 4. Conceptual architecture of CSW 3.0

6.2.4 Support to OpenSearch

6.2.4.1 Introduction

OpenSearch is a new feature in CSW 3.0 definition. A CSW server should provide a common set of formats conforming to the OpenSearch specification to help search engines and search clients discover geo-resources. By providing links in the Capabilities document to an OpenSearch Description Document of CSW (which include URI and query template), data in the CSW catalog can be accessed by the OpenSearch API. CSW completes the Vertical-Search/Deep-Search job because it is good at understanding the geospatial data. OpenSearch acts as an adapter between the CSW catalog and the common search engines and clients, making CSW searchable by an open API.

OpenSearch Geospatial Extension[4]: The purpose of the OpenSearch-Geo extensions is to provide a standard mechanism to query a resource based on geographic extents, or location name. The geospatial results are based on the GeoRSS standard. Therefore, latitude/longitude order, bounding box parameters are using that defacto standard. Spatial search include query classes: bounding box search, arbitrary geometry search, and proximity search. (geo-extends draft 2).

OpenSearch Temporal Extension: Temporal search includes a Time search and Temporal relation search. Time search can be filtered by time instance of a time period. Temporal relation can be described as After, Before, Begins, During, Ends and so on.

[4] https://portal.opengeospatial.org/files/?artifact_id=56866

OpenSearch Query Interface: The Catalog Service 3.0 SWG recommends that the OGC Technical Committee approve using the Fast Track process for OGC Document Number 10-032 “OpenSearch Query Interface” as an OGC Candidate Standard.

6.2.4.2 PyCSW: an open source tool to support CSW3.0/Open Search

PyCSW is an open source OGC CSW server implementation that allows publishing and sharing of geospatial metadata. This project started in 2010 and is written in Python. PyCSW is light-weighted; this python library can be easily integrated into any python-based application. It also has the ability of hosting multiple CSW with a single installation. PyCSW uses database as backend data storage for metadata management. It supports robust testing and continuous integration.

Figure 5 demonstrates the software architecture diagram of PyCSW. As a pure python library, PyCSW integrates a few other python libraries including pyproj, OWLLib, lxml, Shapely to support the reprojection, XML resolving, and geometric object processing. These libraries altogether foster the core functionality of PyCSW, which allows metadata management, publishing, and storage within backend database. In terms of the database support, a middleware named SQLAlchemy is introduced and it is used to manage several database instances, including PostGreSQL/PostGIS, SQLite, and MySQL. PyCSW also support two interfacing protocols, CGI and WSGI for the communication between a remote client and the server. All the server components are hosted in web servers, such as Apache Tomcat, or IIS. The web server will be responsible for handling remote request and redirect structured response to the client. Both GET/POST requests are supported. OpenSearch is also enabled as an important feature of PyCSW.

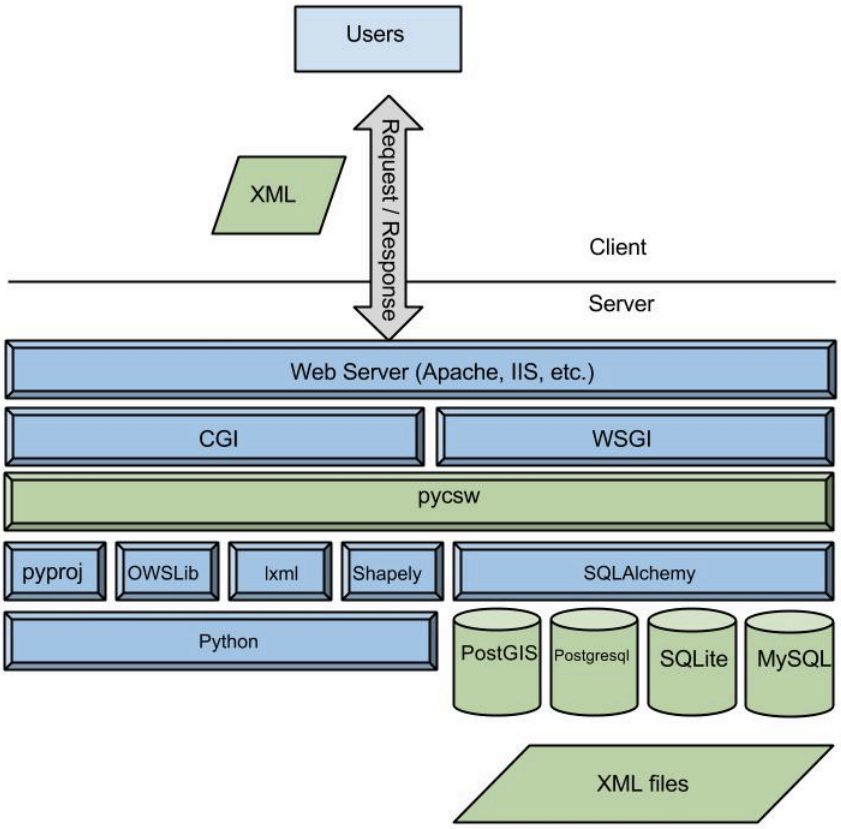

Figure 5. PyCSW architecture diagram (http://geopython.github.io/pycsw-workshop/_images/pycsw-software-architecture.jpg)

6.2.4.3 Testbed 11 deployment of CSW 3.0 server

During testbed 11, the GMU team used PyCSW to deploy a CSW 3.0 server with OpenSearch support. This section introduces the CSW 3.0 instance and its support of different queries and open search.

6.2.4.3.1 Service endpoint

The endpoint of CSW server is hosted at:

- http://www2.csiss.gmu.edu:9009/cat3/csw

6.2.4.3.2 CSW 3.0 GetCapabilities request/response

A **GetCapabilities** request can be formed using the below format:

- http://www2.csiss.gmu.edu:9009/cat3/csw?service=CSW&request=GetCapabilities&AcceptVersions=3.0.0

A response XML for the **GetCapabilities** request is:

```
<csw:Capabilities
   xmlns="http://www.opengis.net/cat/csw/3.0"
   xmlns:csw="http://www.opengis.net/cat/csw/3.0"
   xmlns:fes="http://www.opengis.net/fes/2.0"
   xmlns:gml="http://www.opengis.net/gml/3.2"
   xmlns:ows20="http://www.opengis.net/ows/2.0"
   xmlns:gmd="http://www.isotc211.org/2005/gmd"
   xmlns:xlink="http://www.w3.org/1999/xlink"
   xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
   xmlns:geo="http://a9.com/-/opensearch/extensions/geo/1.0/"
   xmlns:time="http://a9.com/-/opensearch/extensions/time/1.0/" version="3.0.0"
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http://www.opengis.net/gml/3.2 http://schemas.opengis.net/gml/3.2.1/gml.xsd
http://www.w3.org/1999/xlink http://www.w3.org/1999/xlink.xsd">
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                <ows20:Country>USA</ows20:Country>

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    <ows20:OperationsMetadata>
        <ows20:Operation name="GetCapabilities">
            <ows20:DCP>
                <ows20:HTTP>
                    <ows20:Get xlink:href="http://www2.csiss.gmu.edu:9009/cat3/csw?"/>
                </ows20:HTTP>
            </ows20:DCP>
            <ows20:Parameter name="AcceptVersions">
                <ows20:AllowedValues>
                    <ows20:Value>3.0.0</ows20:Value>
                </ows20:AllowedValues>
            </ows20:Parameter>
        </ows20:Operation>
        <ows20:Operation name="GetRecords">
            <ows20:DCP>
                <ows20:HTTP>
                    <ows20:Post xlink:href="http://www2.csiss.gmu.edu:9009/cat3/csw"/>
                    <ows20:Get xlink:href="http://www2.csiss.gmu.edu:9009/cat3/csw?"/>
                </ows20:HTTP>
            </ows20:DCP>
            <ows20:Parameter name="typeName">
                <ows20:AllowedValues>
                    <ows20:Value>csw:Record</ows20:Value>
                    <ows20:Value>gmd:MD_Metadata</ows20:Value>
                    <ows20:Value>rim:RegistryObject</ows20:Value>
                </ows20:AllowedValues>
            </ows20:Parameter>
            <ows20:Parameter name="outputFormat">
                <ows20:AllowedValues>
                    <ows20:Value>application/xml</ows20:Value>
                    <ows20:Value>application/atom+xml</ows20:Value>
                </ows20:AllowedValues>
```

```
        </ows20:Parameter>
        <ows20:Parameter name="outputSchema">
          <ows20:AllowedValues>
            <ows20:Value>http://www.opengis.net/cat/csw/3.0</ows20:Value>
            <ows20:Value>http://www.opengis.net/cat/csw/2.0.2</ows20:Value>
            <ows20:Value>http://www.isotc211.org/2005/gmd</ows20:Value>
            <ows20:Value>urn:oasis:names:tc:ebxml-
regrep:xsd:rim:3.0</ows20:Value>
            <ows20:Value>http://www.w3.org/2005/Atom</ows20:Value>
          </ows20:AllowedValues>
        </ows20:Parameter>
        <ows20:Parameter name="ElementSetName">
          <ows20:AllowedValues>
            <ows20:Value>brief</ows20:Value>
            <ows20:Value>summary</ows20:Value>
            <ows20:Value>full</ows20:Value>
          </ows20:AllowedValues>
        </ows20:Parameter>
        <ows20:Parameter name="constraintlanguage">
          <ows20:AllowedValues>
            <ows20:Value>CQL_TEXT</ows20:Value>
          </ows20:AllowedValues>
        </ows20:Parameter>
        <ows20:Parameter name="q">
          <ows20:AnyValue/>
        </ows20:Parameter>
        <ows20:Parameter name="bbox">
          <ows20:AnyValue/>
        </ows20:Parameter>
        <ows20:Constraint name="OpenSearchDescriptionDocument">
          <ows20:AllowedValues>
            <ows20:Value>
http://www2.csiss.gmu.edu:9009/cat3/opensearch/osdd.xml
</ows20:Value>
          </ows20:AllowedValues>
        </ows20:Constraint>
        <ows20:Constraint name="SupportedISOQueryables">
          <ows20:AllowedValues>
            <ows20:Value>apiso:DistanceValue</ows20:Value>
            <ows20:Value>apiso:Abstract</ows20:Value>
            <ows20:Value>apiso:RevisionDate</ows20:Value>
            <ows20:Value>apiso:Subject</ows20:Value>
            <ows20:Value>apiso:KeywordType</ows20:Value>
            <ows20:Value>apiso:Title</ows20:Value>
            <ows20:Value>apiso:CRS</ows20:Value>
            <ows20:Value>apiso:PublicationDate</ows20:Value>
```

```
            <ows20:Value>apiso:Type</ows20:Value>
            <ows20:Value>apiso:AlternateTitle</ows20:Value>
            <ows20:Value>apiso:BoundingBox</ows20:Value>
            <ows20:Value>apiso:AnyText</ows20:Value>
            <ows20:Value>apiso:ParentIdentifier</ows20:Value>
            <ows20:Value>apiso:Modified</ows20:Value>
            <ows20:Value>apiso:Operation</ows20:Value>
            <ows20:Value>apiso:Format</ows20:Value>
            <ows20:Value>apiso:TempExtent_end</ows20:Value>
            <ows20:Value>apiso:DistanceUOM</ows20:Value>
            <ows20:Value>apiso:OrganisationName</ows20:Value>
            <ows20:Value>apiso:ServiceType</ows20:Value>
            <ows20:Value>apiso:TempExtent_begin</ows20:Value>
            <ows20:Value>apiso:ResourceLanguage</ows20:Value>
            <ows20:Value>apiso:ServiceTypeVersion</ows20:Value>
            <ows20:Value>apiso:OperatesOn</ows20:Value>
            <ows20:Value>apiso:Denominator</ows20:Value>
            <ows20:Value>apiso:HasSecurityConstraints</ows20:Value>
            <ows20:Value>apiso:OperatesOnIdentifier</ows20:Value>
            <ows20:Value>apiso:GeographicDescriptionCode</ows20:Value>
            <ows20:Value>apiso:Language</ows20:Value>
            <ows20:Value>apiso:Identifier</ows20:Value>
            <ows20:Value>apiso:OperatesOnName</ows20:Value>
            <ows20:Value>apiso:TopicCategory</ows20:Value>
            <ows20:Value>apiso:CreationDate</ows20:Value>
            <ows20:Value>apiso:CouplingType</ows20:Value>
        </ows20:AllowedValues>
    </ows20:Constraint>
    <ows20:Constraint name="AdditionalQueryables">
        <ows20:AllowedValues>
            <ows20:Value>apiso:Lineage</ows20:Value>
            <ows20:Value>apiso:Classification</ows20:Value>
            <ows20:Value>apiso:Creator</ows20:Value>
            <ows20:Value>apiso:Relation</ows20:Value>
            <ows20:Value>apiso:OtherConstraints</ows20:Value>
            <ows20:Value>apiso:SpecificationTitle</ows20:Value>
            <ows20:Value>apiso:ResponsiblePartyRole</ows20:Value>
            <ows20:Value>apiso:SpecificationDateType</ows20:Value>
            <ows20:Value>apiso:Degree</ows20:Value>
            <ows20:Value>apiso:Contributor</ows20:Value>
            <ows20:Value>apiso:ConditionApplyingToAccessAndUse</ows20:Value>
            <ows20:Value>apiso:SpecificationDate</ows20:Value>
            <ows20:Value>apiso:AccessConstraints</ows20:Value>
            <ows20:Value>apiso:Publisher</ows20:Value>
        </ows20:AllowedValues>
```

```
        </ows20:Constraint>
        <ows20:Constraint name="SupportedDublinCoreQueryables">
          <ows20:AllowedValues>
            <ows20:Value>dc:contributor</ows20:Value>
            <ows20:Value>dc:source</ows20:Value>
            <ows20:Value>dc:language</ows20:Value>
            <ows20:Value>dc:title</ows20:Value>
            <ows20:Value>dc:subject</ows20:Value>
            <ows20:Value>dc:creator</ows20:Value>
            <ows20:Value>dc:type</ows20:Value>
            <ows20:Value>ows:BoundingBox</ows20:Value>
            <ows20:Value>dct:modified</ows20:Value>
            <ows20:Value>dct:abstract</ows20:Value>
            <ows20:Value>dc:relation</ows20:Value>
            <ows20:Value>dc:date</ows20:Value>
            <ows20:Value>dc:identifier</ows20:Value>
            <ows20:Value>dc:publisher</ows20:Value>
            <ows20:Value>dc:format</ows20:Value>
            <ows20:Value>csw:AnyText</ows20:Value>
            <ows20:Value>dc:rights</ows20:Value>
          </ows20:AllowedValues>
        </ows20:Constraint>
      </ows20:Operation>
      <ows20:Operation name="GetRecordById">
        <ows20:DCP>
          <ows20:HTTP>
            <ows20:Post
xlink:href="http://www2.csiss.gmu.edu:9009/cat3/csw"></ows20:Post>
            <ows20:Get xlink:href="http://www2.csiss.gmu.edu:9009/cat3/csw?"/>
          </ows20:HTTP>
        </ows20:DCP>
        <ows20:Parameter name="ElementSetName">
          <ows20:AllowedValues>
            <ows20:Value>brief</ows20:Value>
            <ows20:Value>summary</ows20:Value>
            <ows20:Value>full</ows20:Value>
          </ows20:AllowedValues>
        </ows20:Parameter>
        <ows20:Parameter name="outputSchema">
          <ows20:AllowedValues>
            <ows20:Value>http://www.opengis.net/cat/csw/3.0</ows20:Value>
            <ows20:Value>http://www.opengis.net/cat/csw/2.0.2</ows20:Value>
            <ows20:Value>http://www.isotc211.org/2005/gmd</ows20:Value>
            <ows20:Value>urn:oasis:names:tc:ebxml-
regrep:xsd:rim:3.0</ows20:Value>
            <ows20:Value>http://www.w3.org/2005/Atom</ows20:Value>
```

```
        </ows20:AllowedValues>
      </ows20:Parameter>
      <ows20:Parameter name="outputFormat">
        <ows20:AllowedValues>
          <ows20:Value>application/xml</ows20:Value>
          <ows20:Value>application/atom+xml</ows20:Value>
        </ows20:AllowedValues>
      </ows20:Parameter>
    </ows20:Operation>
    <!--  OpenSearch support ?  -->
    <ows20:Constraint name="OpenSearch">
      <ows20:AllowedValues>
        <ows20:Value>TRUE</ows20:Value>
      </ows20:AllowedValues>
      <ows20:DefaultValue>TRUE</ows20:DefaultValue>
    </ows20:Constraint>
    <!--  GetCapabilities-XML support ?  -->
    <ows20:Constraint name="GetCapabilities-XML">
      <ows20:AllowedValues>
        <ows20:Value>true</ows20:Value>
      </ows20:AllowedValues>
    </ows20:Constraint>
    <!--  GetRecordById-XML support ?  -->
    <ows20:Constraint name="GetRecordById-XML">
      <ows20:AllowedValues>
        <ows20:Value>true</ows20:Value>
      </ows20:AllowedValues>
    </ows20:Constraint>
    <!--  GetRecords-Basic-XML support ?  -->
    <ows20:Constraint name="GetRecords-Basic-XML">
      <ows20:AllowedValues>
        <ows20:Value>true</ows20:Value>
      </ows20:AllowedValues>
    </ows20:Constraint>
    <!--  GetRecords-Distributed-XML support ?  -->
    <ows20:Constraint name="GetRecords-Distributed-XML">
      <ows20:AllowedValues>
        <ows20:Value>false</ows20:Value>
      </ows20:AllowedValues>
    </ows20:Constraint>
    <!--  GetRecords-Distributed-KVP support ?  -->
    <ows20:Constraint name="GetRecords-Distributed-KVP">
      <ows20:AllowedValues>
        <ows20:Value>false</ows20:Value>
      </ows20:AllowedValues>
```

```
</ows20:Constraint>
<!--  GetRecords-Async-XML support ?  -->
<ows20:Constraint name="GetRecords-Async-XML">
   <ows20:AllowedValues>
      <ows20:Value>false</ows20:Value>
   </ows20:AllowedValues>
</ows20:Constraint>
<!--  GetRecords-Async-KVP support ?  -->
<ows20:Constraint name="GetRecords-Async-KVP">
   <ows20:AllowedValues>
      <ows20:Value>false</ows20:Value>
   </ows20:AllowedValues>
</ows20:Constraint>
<!--  GetDomain-XML support ?  -->
<ows20:Constraint name="GetDomain-XML">
   <ows20:AllowedValues>
      <ows20:Value>false</ows20:Value>
   </ows20:AllowedValues>
</ows20:Constraint>
<!--  GetDomain-KVP support ?  -->
<ows20:Constraint name="GetDomain-KVP">
   <ows20:AllowedValues>
      <ows20:Value>false</ows20:Value>
   </ows20:AllowedValues>
</ows20:Constraint>
<!--  Harvest-Basic-XML support ?  -->
<ows20:Constraint name="Harvest-Basic-XML">
   <ows20:AllowedValues>
      <ows20:Value>false</ows20:Value>
   </ows20:AllowedValues>
</ows20:Constraint>
<!--  Harvest-Basic-KVP support ?  -->
<ows20:Constraint name="Harvest-Basic-KVP">
   <ows20:AllowedValues>
      <ows20:Value>false</ows20:Value>
   </ows20:AllowedValues>
</ows20:Constraint>
<!--  Harvest-Async-XML support ?  -->
<ows20:Constraint name="Harvest-Async-XML">
   <ows20:AllowedValues>
      <ows20:Value>false</ows20:Value>
   </ows20:AllowedValues>
</ows20:Constraint>
<!--  Harvest-Async-KVP support ?  -->
<ows20:Constraint name="Harvest-Async-KVP">
   <ows20:AllowedValues>
```

```
        <ows20:Value>false</ows20:Value>
      </ows20:AllowedValues>
    </ows20:Constraint>
    <!--  Harvest-Periodic-XML support ?  -->
    <ows20:Constraint name="Harvest-Periodic-XML">
      <ows20:AllowedValues>
        <ows20:Value>false</ows20:Value>
      </ows20:AllowedValues>
    </ows20:Constraint>
    <!--  Harvest-Periodic-KVP support ?  -->
    <ows20:Constraint name="Harvest-Periodic-KVP">
      <ows20:AllowedValues>
        <ows20:Value>false</ows20:Value>
      </ows20:AllowedValues>
    </ows20:Constraint>
    <!--   support Transaction ?  -->
    <ows20:Constraint name="Transaction">
      <ows20:AllowedValues>
        <ows20:Value>false</ows20:Value>
      </ows20:AllowedValues>
    </ows20:Constraint>
    <!--  Filter-CQL support ?  -->
    <ows20:Constraint name="Filter-CQL">
      <ows20:AllowedValues>
        <ows20:Value>true</ows20:Value>
      </ows20:AllowedValues>
    </ows20:Constraint>
    <!--  Filter-FES support ?  -->
    <ows20:Constraint name="Filter-FES">
      <ows20:AllowedValues>
        <ows20:Value>true</ows20:Value>
      </ows20:AllowedValues>
    </ows20:Constraint>
    <!--  Filter-FES-XML support ?  -->
    <ows20:Constraint name="Filter-FES-XML">
      <ows20:AllowedValues>
        <ows20:Value>false</ows20:Value>
      </ows20:AllowedValues>
    </ows20:Constraint>
    <!--  Filter-FES-KVP-Advanced support ?  -->
    <ows20:Constraint name="Filter-FES-KVP-Advanced">
      <ows20:AllowedValues>
        <ows20:Value>false</ows20:Value>
      </ows20:AllowedValues>
    </ows20:Constraint>
```

```
      <!--  Filter-KVP support ?  -->
      <ows20:Constraint name="Filter-KVP">
        <ows20:AllowedValues>
          <ows20:Value>true</ows20:Value>
        </ows20:AllowedValues>
      </ows20:Constraint>
      <!--  CSW-Response support ?  -->
      <ows20:Constraint name="CSW-Response">
        <ows20:AllowedValues>
          <ows20:Value>true</ows20:Value>
        </ows20:AllowedValues>
      </ows20:Constraint>
      <!--  ATOM-response support ?  -->
      <ows20:Constraint name="ATOM-response">
        <ows20:AllowedValues>
          <ows20:Value>true</ows20:Value>
        </ows20:AllowedValues>
      </ows20:Constraint>
      <ows20:Constraint name="CoreQueryables">
        <ows20:AllowedValues>
          <ows20:Value>Title</ows20:Value>
          <ows20:Value>Subject</ows20:Value>
          <ows20:Value>Abstract</ows20:Value>
          <ows20:Value>Modified</ows20:Value>
          <ows20:Value>Type</ows20:Value>
          <ows20:Value>Format</ows20:Value>
          <ows20:Value>Identifier</ows20:Value>
          <ows20:Value>Association</ows20:Value>
          <ows20:Value>BoundingBox</ows20:Value>
        </ows20:AllowedValues>
      </ows20:Constraint>
      <ows20:Constraint name="CoreSortables">
        <ows20:AllowedValues>
          <ows20:Value>Title</ows20:Value>
          <ows20:Value>Type</ows20:Value>
          <ows20:Value>Modified</ows20:Value>
        </ows20:AllowedValues>
      </ows20:Constraint>
      <ows20:Constraint name="DefaultSortingAlgorithm">
        <ows20:AllowedValues>
          <ows20:Value>
http://www.sdisuite.de/terraCatalog/documentation/descriprionOfSortalgorithm.html
</ows20:Value>
        </ows20:AllowedValues>
      </ows20:Constraint>
    </ows20:OperationsMetadata>
```

```
<ows20:Languages>
   <ows20:Language>en</ows20:Language>
</ows20:Languages>
<fes:Filter_Capabilities
   xmlns:ows11="http://www.opengis.net/ows/1.1">
   <fes:Conformance>
      <fes:Constraint name="Filter-FES-KVP">
         <ows11:AllowedValues>
            <ows11:Value>q</ows11:Value>
            <ows11:Value>bbox</ows11:Value>
         </ows11:AllowedValues>
      </fes:Constraint>
      <fes:Constraint name="ImplementsMinSpatialFilter">
         <ows11:DefaultValue>true</ows11:DefaultValue>
      </fes:Constraint>
   </fes:Conformance>
   <fes:Spatial_Capabilities>
      <fes:GeometryOperands>
         <fes:GeometryOperand name="gml:Envelope"/>
         <fes:GeometryOperand name="gml:Point"/>
         <fes:GeometryOperand name="gml:LineString"/>
         <fes:GeometryOperand name="gml:Polygon"/>
      </fes:GeometryOperands>
      <fes:SpatialOperators>
         <fes:SpatialOperator name="BBOX"/>
         <fes:SpatialOperator name="Beyond"/>
         <fes:SpatialOperator name="Contains"/>
         <fes:SpatialOperator name="Crosses"/>
         <fes:SpatialOperator name="Disjoint"/>
         <fes:SpatialOperator name="DWithin"/>
         <fes:SpatialOperator name="Equals"/>
         <fes:SpatialOperator name="Intersects"/>
         <fes:SpatialOperator name="Overlaps"/>
         <fes:SpatialOperator name="Touches"/>
         <fes:SpatialOperator name="Within"/>
      </fes:SpatialOperators>
   </fes:Spatial_Capabilities>
   <fes:Extended_Capabilities>
      <fes:AdditionalOperators>
         <fes:Operator name="Between"/>
         <fes:Operator name="EqualTo"/>
         <fes:Operator name="GreaterThan"/>
         <fes:Operator name="GreaterThanEqualTo"/>
         <fes:Operator name="LessThan"/>
         <fes:Operator name="LessThanEqualTo"/>
```

```
            <fes:Operator name="Like"/>
            <fes:Operator name="NotEqualTo"/>
            <fes:Operator name="NullCheck"/>
          </fes:AdditionalOperators>
        </fes:Extended_Capabilities>
    </fes:Filter_Capabilities>
</csw:Capabilities>
```

6.2.4.3.3 CSW 3.0 transaction support

The deployed CSW 3.0 server supports different transaction activities: add, update and delete. For example, an *ADD* request can be sent to the server through HTTP POST to insert a record. A sample ADD request is as follows:

```
<csw:Transaction xmlns:csw="http://www.opengis.net/cat/csw/2.0.2"
xmlns:ows="http://www.opengis.net/ows"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:schemaLocation="http://www.opengis.net/cat/csw/2.0.2
http://schemas.opengis.net/csw/2.0.2/CSW-publication.xsd" service="CSW"
version="2.0.2">
   <csw:Insert>
      <gmd:MD_Metadata xmlns:gmd="http://www.isotc211.org/2005/gmd"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xmlns:gco="http://www.isotc211.org/2005/gco"
xmlns:gml="http://www.opengis.net/gml" xmlns:xlink="http://www.w3.org/1999/xlink"
xsi:schemaLocation="http://www.isotc211.org/2005/gmd
http://schemas.opengis.net/csw/2.0.2/profiles/apiso/1.0.0/apiso.xsd">
         <gmd:fileIdentifier>
            <gco:CharacterString>12345</gco:CharacterString>
         </gmd:fileIdentifier>
         <gmd:hierarchyLevel>
            <gmd:MD_ScopeCode
codeList="http://www.isotc211.org/2005/resources/codeList.xml#MD_ScopeCode"
codeListValue="dataset" />
         </gmd:hierarchyLevel>
         <gmd:contact>
            <gmd:CI_ResponsibleParty>
               <gmd:organisationName>
                  <gco:CharacterString>sample</gco:CharacterString>
               </gmd:organisationName>
               <gmd:role>
                  <gmd:CI_RoleCode
codeList="http://www.isotc211.org/2005/resources/codeList.xml#CI_RoleCode"
codeListValue="publisher" />
               </gmd:role>
```

```
            </gmd:CI_ResponsibleParty>
         </gmd:contact>
         <gmd:dateStamp>
            <gco:Date>2011-05-17</gco:Date>
         </gmd:dateStamp>
         <gmd:identificationInfo>
            <gmd:MD_DataIdentification>
               <gmd:citation>
                  <gmd:CI_Citation>
                     <gmd:title>
                        <gco:CharacterString>sample record</gco:CharacterString>
                     </gmd:title>
                     <gmd:date>
                        <gmd:CI_Date>
                           <gmd:date>
                              <gco:Date>2011-05-17</gco:Date>
                           </gmd:date>
                           <gmd:dateType>
                              <gmd:CI_DateTypeCode
codeList="http://www.isotc211.org/2005/resources/codeList.xml#CI_DateTypeCode"
codeListValue="revision" />
                           </gmd:dateType>
                        </gmd:CI_Date>
                     </gmd:date>
                  </gmd:CI_Citation>
               </gmd:citation>
               <gmd:abstract>
                  <gco:CharacterString>Sample metadata record</gco:CharacterString>
               </gmd:abstract>
               <gmd:language>
                  <gco:CharacterString>eng</gco:CharacterString>
               </gmd:language>
               <gmd:extent>
                  <gmd:EX_Extent>
                     <gmd:geographicElement>
                        <gmd:EX_GeographicBoundingBox>
                           <gmd:westBoundLongitude>
                              <gco:Decimal>-180</gco:Decimal>
                           </gmd:westBoundLongitude>
                           <gmd:eastBoundLongitude>
                              <gco:Decimal>180</gco:Decimal>
                           </gmd:eastBoundLongitude>
                           <gmd:southBoundLatitude>
                              <gco:Decimal>-90</gco:Decimal>
                           </gmd:southBoundLatitude>
```

```
                        <gmd:northBoundLatitude>
                           <gco:Decimal>90</gco:Decimal>
                        </gmd:northBoundLatitude>
                     </gmd:EX_GeographicBoundingBox>
                  </gmd:geographicElement>
               </gmd:EX_Extent>
            </gmd:extent>
         </gmd:MD_DataIdentification>
      </gmd:identificationInfo>
   </gmd:MD_Metadata>
</csw:Insert>
</csw:Transaction>
```

An *UPDATE* request can be sent to the server through HTTP POST to update the metadata information about a data record. A sample UPDATE request is demonstrated below:

```
<csw:Transaction xmlns:csw="http://www.opengis.net/cat/csw/2.0.2"
xmlns:ows="http://www.opengis.net/ows"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:schemaLocation="http://www.opengis.net/cat/csw/2.0.2
http://schemas.opengis.net/csw/2.0.2/CSW-publication.xsd" service="CSW"
version="2.0.2">
   <csw:Update>
      <gmd:MD_Metadata xmlns:gmd="http://www.isotc211.org/2005/gmd"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xmlns:gco="http://www.isotc211.org/2005/gco"
xmlns:gml="http://www.opengis.net/gml" xmlns:xlink="http://www.w3.org/1999/xlink"
xsi:schemaLocation="http://www.isotc211.org/2005/gmd
http://schemas.opengis.net/csw/2.0.2/profiles/apiso/1.0.0/apiso.xsd">
         <gmd:fileIdentifier>
            <gco:CharacterString>12345</gco:CharacterString>
         </gmd:fileIdentifier>
         <gmd:hierarchyLevel>
            <gmd:MD_ScopeCode
codeList="http://www.isotc211.org/2005/resources/codeList.xml#MD_ScopeCode"
codeListValue="dataset" />
         </gmd:hierarchyLevel>
         <gmd:contact>
            <gmd:CI_ResponsibleParty>
               <gmd:organisationName>
                  <gco:CharacterString>sample</gco:CharacterString>
               </gmd:organisationName>
               <gmd:role>
```

```
                <gmd:CI_RoleCode
codeList="http://www.isotc211.org/2005/resources/codeList.xml#CI_RoleCode"
codeListValue="publisher" />
              </gmd:role>
            </gmd:CI_ResponsibleParty>
          </gmd:contact>
          <gmd:dateStamp>
            <gco:Date>2011-05-17</gco:Date>
          </gmd:dateStamp>
          <gmd:identificationInfo>
            <gmd:MD_DataIdentification>
              <gmd:citation>
                <gmd:CI_Citation>
                  <gmd:title>
                    <gco:CharacterString>sample record
UPDATED</gco:CharacterString>
                  </gmd:title>
                  <gmd:date>
                    <gmd:CI_Date>
                      <gmd:date>
                        <gco:Date>2011-05-17</gco:Date>
                      </gmd:date>
                      <gmd:dateType>
                        <gmd:CI_DateTypeCode
codeList="http://www.isotc211.org/2005/resources/codeList.xml#CI_DateTypeCode"
codeListValue="revision" />
                      </gmd:dateType>
                    </gmd:CI_Date>
                  </gmd:date>
                </gmd:CI_Citation>
              </gmd:citation>
              <gmd:abstract>
                <gco:CharacterString>Sample metadata record</gco:CharacterString>
              </gmd:abstract>
              <gmd:language>
                <gco:CharacterString>eng</gco:CharacterString>
              </gmd:language>
              <gmd:extent>
                <gmd:EX_Extent>
                  <gmd:geographicElement>
                    <gmd:EX_GeographicBoundingBox>
                      <gmd:westBoundLongitude>
                        <gco:Decimal>-180</gco:Decimal>
                      </gmd:westBoundLongitude>
                      <gmd:eastBoundLongitude>
```

```
                        <gco:Decimal>180</gco:Decimal>
                      </gmd:eastBoundLongitude>
                      <gmd:southBoundLatitude>
                        <gco:Decimal>-90</gco:Decimal>
                      </gmd:southBoundLatitude>
                      <gmd:northBoundLatitude>
                        <gco:Decimal>90</gco:Decimal>
                      </gmd:northBoundLatitude>
                    </gmd:EX_GeographicBoundingBox>
                  </gmd:geographicElement>
                </gmd:EX_Extent>
              </gmd:extent>
            </gmd:MD_DataIdentification>
          </gmd:identificationInfo>
        </gmd:MD_Metadata>
    </csw:Update>
</csw:Transaction>
```

A *DELETE* request can be sent to the server through HTTP POST to delete an existing record. A sample DELETE request follows:

```
<csw:Transaction xmlns:ogc="http://www.opengis.net/ogc"
xmlns:csw="http://www.opengis.net/cat/csw/2.0.2"
xmlns:ows="http://www.opengis.net/ows"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:schemaLocation="http://www.opengis.net/cat/csw/2.0.2
http://schemas.opengis.net/csw/2.0.2/CSW-publication.xsd" service="CSW"
version="2.0.2">
   <csw:Delete>
      <csw:Constraint version="1.1.0">
         <ogc:Filter>
            <ogc:PropertyIsEqualTo>
               <ogc:PropertyName>apiso:Identifier</ogc:PropertyName>
               <ogc:Literal>12345</ogc:Literal>
            </ogc:PropertyIsEqualTo>
         </ogc:Filter>
      </csw:Constraint>
   </csw:Delete>
</csw:Transaction>
```

6.2.4.3.4 CSW 3.0 Metadata discovery

The KVP requests below provide a few examples to conduct query and retrieve metadata records from the CSW server.

- **Search metadata through OGC CSW 3.0 GetRecords**
  - Request metadata with 'csw:Record' as output metadata schema
    - http://www2.csiss.gmu.edu:9009/cat3/csw?service=CSW&version=3.0.0&request=GetRecords&resultType=results&ElementSetName=full&outputSchema=http://www.opengis.net/cat/csw/2.0.2&typenames=csw:Record&outputFormat=application/xml&startPosition=1&maxRecords=10&constraintlanguage=CQL_TEXT&constraint=csw%3AAnyText%20Like%20%27%25a%25%27
  - Responded XML is:

```
<csw:GetRecordsResponse xmlns:csw="http://www.opengis.net/cat/csw/3.0"
xmlns:dc="http://purl.org/dc/elements/1.1/"
xmlns:rim="urn:oasis:names:tc:ebxml-regrep:xsd:rim:3.0"
xmlns:atom="http://www.w3.org/2005/Atom"
xmlns:xs="http://www.w3.org/2001/XMLSchema"
xmlns:dct="http://purl.org/dc/terms/" xmlns:ows="http://www.opengis.net/ows"
xmlns:ows2="http://www.opengis.net/ows/2.0"
xmlns:apiso="http://www.opengis.net/cat/csw/apiso/1.0"
xmlns:gml="http://www.opengis.net/gml"
xmlns:xlink="http://www.w3.org/1999/xlink"
xmlns:gco="http://www.isotc211.org/2005/gco"
xmlns:gmd="http://www.isotc211.org/2005/gmd"
xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
xmlns:srv="http://www.isotc211.org/2005/srv"
xmlns:ogc="http://www.opengis.net/ogc"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xmlns:os="http://a9.com/-
/spec/opensearch/1.1/"
xmlns:sitemap="http://www.sitemaps.org/schemas/sitemap/0.9"
xmlns:wrs="http://www.opengis.net/cat/wrs/1.0" version="2.0.2"
xsi:schemaLocation="http://www.opengis.net/cat/csw/3.0 ../../../csw/3.0/CSW30-
discovery.xsd">
<csw:SearchStatus timestamp="2015-07-07T15:13:04Z" />
<csw:SearchResults numberOfRecordsReturned="10" nextRecord="11"
numberOfRecordsMatched="12" recordSchema="http://www.opengis.net/cat/csw/3.0"
elementSet="full">
<csw:Record>
<dc:identifier>
urn:geoss:csr:service:urn:uuid:21fa4afd-b60d-47de-8da0-bf35e55e7774
```

```
</dc:identifier>
<dc:title>VASDI Alaska Mapped WMS</dc:title>
<dc:type>service</dc:type>
<dc:subject>service</dc:subject>
<dc:subject>N/A</dc:subject>
<dc:subject>N/A</dc:subject>
<dct:references scheme="WWW:LINK-1.0-http--link">
http://wms.alaskamapped.org/cgi-bin/bdl.cgi?request=GetCapabilities&service=WMS
</dct:references>
<dct:references scheme="WWW:LINK-1.0-http--link">
http://wms.alaskamapped.org/cgi-bin/bdl.cgi?request=GetCapabilities&service=WMS
</dct:references>
<dct:modified>2009-07-20</dct:modified>
<dct:abstract>
Alaska Mapped - Alaska Statewide Digital Mapping Initiative WMS
</dct:abstract>
<dc:date>2009-07-20</dc:date>
<dc:language>eng</dc:language>
<ows2:BoundingBox crs="urn:ogc:def:crs:EPSG::4326" dimensions="2">
<ows2:LowerCorner>-90.0 -180.0</ows2:LowerCorner>
<ows2:UpperCorner>90.0 180.0</ows2:UpperCorner>
</ows2:BoundingBox>
</csw:Record>
<csw:Record>
<dc:identifier>
urn:ogc:ows11:service:urn:uuid:21fa4afd-b60d-47de-8da0-bf35e55e7774
</dc:identifier>
<dc:title>Test</dc:title>
<dc:type/>
<dc:subject>service</dc:subject>
<dc:subject>Flickr</dc:subject>
<dc:subject>Youtube</dc:subject>
<dct:references scheme="None">
http://ows.usersmarts.com/ldscraper/api/types/flickr
</dct:references>
<dct:references scheme="None">
http://ows.usersmarts.com/ldscraper/api/types/flickr/scrape
</dct:references>
<dct:references scheme="None">
```

```
http://ows.usersmarts.com/ldscraper/api/types/youtube
</dct:references>
<dct:references scheme="None">
http://ows.usersmarts.com/ldscraper/api/types/youtube/scrape
</dct:references>
<dct:modified>2015-05-05</dct:modified>
<dct:abstract>Test</dct:abstract>
<dc:date>2015-05-05</dc:date>
<dc:language>eng</dc:language>
<ows2:BoundingBox crs="urn:ogc:def:crs:EPSG::4326" dimensions="2">
<ows2:LowerCorner>-90.0 -180.0</ows2:LowerCorner>
<ows2:UpperCorner>90.0 180.0</ows2:UpperCorner>
</ows2:BoundingBox>
</csw:Record>
<csw:Record>
<dc:identifier>
urn:ogc:ows11:service:urn:uuid:21fa4afd-b60d-47de-8da0-bf22e55e7774
</dc:identifier>
<dc:title>
Geomatys WCS (Constellation-SDI) serving San Francisco and Mozambique coverage
data
</dc:title>
<dc:type/>
<dc:subject>service</dc:subject>
<dc:subject>San Francisco</dc:subject>
<dc:subject>Mozambique</dc:subject>
<dc:subject>TOPOBATHY</dc:subject>
<dc:subject>San Francisco bay</dc:subject>
<dc:subject>SRTM</dc:subject>
<dc:subject>DEM</dc:subject>
<dc:subject>Digital elevation model</dc:subject>
<dc:subject>WCS</dc:subject>
<dct:references scheme="None">
http://ows11.geomatys.com/constellation/WS/wcs/default?REQUEST=GetCapabilities&
SERVICE=WCS&VERSION=2.0.1
</dct:references>
<dct:modified>2015-05-05</dct:modified>
<dct:abstract>
```

Geomatys WCS (Constellation-SDI) serving San Francisco and Mozambique coverage data
</dct:abstract>
<dc:date>2015-05-05</dc:date>
<dc:language>eng</dc:language>
<ows2:BoundingBox crs="urn:ogc:def:crs:EPSG::4326" dimensions="2">
<ows2:LowerCorner>-90.0 -180.0</ows2:LowerCorner>
<ows2:UpperCorner>90.0 180.0</ows2:UpperCorner>
</ows2:BoundingBox>
</csw:Record>
<csw:Record>
<dc:identifier>
urn:ogc:ows11:service:urn:uuid:21fbsbfd-b35d-11de-8da0-bf22e55e7774
</dc:identifier>
<dc:title>IBM Cloudant WFS (OGC Web Feature Service)</dc:title>
<dc:type/>
<dc:subject>service</dc:subject>
<dc:subject>highway</dc:subject>
<dc:subject>Open street map</dc:subject>
<dc:subject>OSM</dc:subject>
<dc:subject>emergency facilities</dc:subject>
<dc:subject>San Francisco</dc:subject>
<dc:subject>WFS</dc:subject>
<dc:subject>Web feature service</dc:subject>
<dct:references
scheme="None">http://ogcwfs.mybluemix.net/wfs/2.5</dct:references>
<dct:modified>2015-05-05</dct:modified>
<dct:abstract>
This service implements the emerging RESTful interface of the Web Feature Service standard. This interface is under development and not yet published outside of the WFS Working Group of the Open Geospatial Consortium. It's brought to you by the Geo team at IBM Cloudant.
</dct:abstract>
<dc:date>2015-05-05</dc:date>
<dc:language>eng</dc:language>
<ows2:BoundingBox crs="urn:ogc:def:crs:EPSG::4326" dimensions="2">
<ows2:LowerCorner>-90.0 -180.0</ows2:LowerCorner>
<ows2:UpperCorner>90.0 180.0</ows2:UpperCorner>
</ows2:BoundingBox>

```
</csw:Record>
<csw:Record>
<dc:identifier>
urn:ogc:ows11:service:urn:uuid:21fa4afd-b60d-12de-8da0-bf22e55e7774
</dc:identifier>
<dc:title>Luciad WCS (OGC Web Coverage Service)</dc:title>
<dc:type/>
<dc:subject>service</dc:subject>
<dc:subject>Monterey bay imagery</dc:subject>
<dc:subject>black marble</dc:subject>
<dc:subject>blue marble</dc:subject>
<dc:subject>San Francisco</dc:subject>
<dc:subject>Mozambique</dc:subject>
<dc:subject>TOPOBATHY</dc:subject>
<dc:subject>San Francisco bay</dc:subject>
<dc:subject>SRTM</dc:subject>
<dc:subject>DEM</dc:subject>
<dc:subject>Digital elevation model</dc:subject>
<dc:subject>Topo50 topographic map</dc:subject>
<dc:subject>WCS</dc:subject>
<dc:subject>Web coverage service</dc:subject>
<dct:references scheme="None">
http://demo.luciad.com:8080/LuciadFusion/wcs?REQUEST=GetCapabilities&SERVICE=WC
S
</dct:references>
<dct:modified>2015-05-05</dct:modified>
<dct:abstract>
The OGC WCS focuses on delivering raster data. This component provides an OGC-
certified implementation of version 1.0.0.
</dct:abstract>
<dc:date>2015-05-05</dc:date>
<dc:language>eng</dc:language>
<ows2:BoundingBox crs="urn:ogc:def:crs:EPSG::4326" dimensions="2">
<ows2:LowerCorner>-90.0 -180.0</ows2:LowerCorner>
<ows2:UpperCorner>90.0 180.0</ows2:UpperCorner>
</ows2:BoundingBox>
</csw:Record>
<csw:Record>
```

```
<dc:identifier>
urn:ogc:ows11:service:urn:uuid:21fa4afd-b35d-11de-8da0-bf22e55e7774
</dc:identifier>
<dc:title>Luciad WFS (OGC Web Feature Service)</dc:title>
<dc:type/>
<dc:subject>service</dc:subject>
<dc:subject>buoy</dc:subject>
<dc:subject>Open street map</dc:subject>
<dc:subject>OSM</dc:subject>
<dc:subject>New Zealand</dc:subject>
<dc:subject>US county</dc:subject>
<dc:subject>US city</dc:subject>
<dc:subject>US river</dc:subject>
<dc:subject>US aviation obstacle</dc:subject>
<dc:subject>San Francisco</dc:subject>
<dc:subject>Mozambique</dc:subject>
<dc:subject>WFS</dc:subject>
<dc:subject>Web feature service</dc:subject>
<dc:subject>Monterey oil spill</dc:subject>
<dc:subject>Monterey sounding</dc:subject>
<dc:subject>US coast</dc:subject>
<dc:subject>Hydro line</dc:subject>
<dc:subject>vent</dc:subject>
<dc:subject>hydrology</dc:subject>
<dct:references scheme="None">
http://demo.luciad.com:8080/LuciadFusion/wfs?REQUEST=GetCapabilities&SERVICE=WF
S
</dct:references>
<dct:modified>2015-05-05</dct:modified>
<dct:abstract>
The OGC WFS focuses on exchanging vector data. This component provides an OGC-
certified implementation of version 1.0.0 and 1.1.0.
</dct:abstract>
<dc:date>2015-05-05</dc:date>
<dc:language>eng</dc:language>
<ows2:BoundingBox crs="urn:ogc:def:crs:EPSG::4326" dimensions="2">
<ows2:LowerCorner>-90.0 -180.0</ows2:LowerCorner>
<ows2:UpperCorner>90.0 180.0</ows2:UpperCorner>
</ows2:BoundingBox>
```

```
</csw:Record>
<csw:Record>
<dc:identifier>
urn:ogc:ows11:service:urn:uuid:21fa4afd-b60d-11de-8da0-bf22e55e7774
</dc:identifier>
<dc:title>Luciad WMS (OGC Web Map Service)</dc:title>
<dc:type/>
<dc:subject>service</dc:subject>
<dc:subject>Monterey bay imagery</dc:subject>
<dc:subject>black marble</dc:subject>
<dc:subject>blue marble</dc:subject>
<dc:subject>buoy</dc:subject>
<dc:subject>Open street map</dc:subject>
<dc:subject>OSM</dc:subject>
<dc:subject>New Zealand</dc:subject>
<dc:subject>US county</dc:subject>
<dc:subject>US city</dc:subject>
<dc:subject>US river</dc:subject>
<dc:subject>US aviation obstacle</dc:subject>
<dc:subject>San Francisco</dc:subject>
<dc:subject>Mozambique</dc:subject>
<dc:subject>TOPOBATHY</dc:subject>
<dc:subject>San Francisco bay</dc:subject>
<dc:subject>SRTM</dc:subject>
<dc:subject>DEM</dc:subject>
<dc:subject>Digital elevation model</dc:subject>
<dc:subject>Topo50 topographic map</dc:subject>
<dc:subject>WMS</dc:subject>
<dc:subject>Web map service</dc:subject>
<dct:references scheme="None">
http://demo.luciad.com:8080/LuciadFusion/wms?REQUEST=GetCapabilities&SERVICE=WM
S
</dct:references>
<dct:modified>2015-05-05</dct:modified>
<dct:abstract>
The OGC WMS focuses on delivering portrayed data. This component provides an
OGC-certified implementation of version 1.1.1 and 1.3.0, and includes support
```

```
for dimensions, the Queryable profile (GetFeatureInfo), and the Styled Layer
Descriptor profile.
</dct:abstract>
<dc:date>2015-05-05</dc:date>
<dc:language>eng</dc:language>
<ows2:BoundingBox crs="urn:ogc:def:crs:EPSG::4326" dimensions="2">
<ows2:LowerCorner>-90.0 -180.0</ows2:LowerCorner>
<ows2:UpperCorner>90.0 180.0</ows2:UpperCorner>
</ows2:BoundingBox>
</csw:Record>
<csw:Record>
<dc:identifier>
urn:ogc:ows11:service:urn:uuid:33fa4afd-b60d-11de-8da0-bf22e55e7774
</dc:identifier>
<dc:title>Luciad WMTS (OGC Web Map Tile Service)</dc:title>
<dc:type/>
<dc:subject>service</dc:subject>
<dc:subject>Monterey bay imagery</dc:subject>
<dc:subject>black marble</dc:subject>
<dc:subject>blue marble</dc:subject>
<dc:subject>Mozambique</dc:subject>
<dc:subject>Maritime map</dc:subject>
<dc:subject>Web map tile service</dc:subject>
<dct:references scheme="None">
http://demo.luciad.com:8080/LuciadFusion/wmts?REQUEST=GetCapabilities&SERVICE=W
MTS
</dct:references>
<dct:modified>2015-05-05</dct:modified>
<dct:abstract>
The OGC WMTS focuses on delivering tiles. This component provides an
implementation of version 1.0.0 of the standard.
</dct:abstract>
<dc:date>2015-05-05</dc:date>
<dc:language>eng</dc:language>
<ows2:BoundingBox crs="urn:ogc:def:crs:EPSG::4326" dimensions="2">
<ows2:LowerCorner>-90.0 -180.0</ows2:LowerCorner>
<ows2:UpperCorner>90.0 180.0</ows2:UpperCorner>
</ows2:BoundingBox>
</csw:Record>
```

```
<csw:Record>
<dc:identifier>
urn:ogc:ows11:service:urn:uuid:21fa3nfd-b60d-11de-8da0-bf22e55e7774
</dc:identifier>
<dc:title>North 52 WPS (OGC Web Processing Service)</dc:title>
<dc:type/>
<dc:subject>service</dc:subject>
<dc:subject>FloodFeatureEnrichment</dc:subject>
<dc:subject>FloodImpactAssessment</dc:subject>
<dc:subject>Flooding</dc:subject>
<dc:subject>Natural disaster</dc:subject>
<dc:subject>GCAM</dc:subject>
<dc:subject>Global Change Assessment Model</dc:subject>
<dc:subject>Flood risk</dc:subject>
<dc:subject>Flood assessment</dc:subject>
<dc:subject>WPS</dc:subject>
<dc:subject>Web processing service</dc:subject>
<dc:subject>geoprocessing</dc:subject>
<dct:references scheme="None">
http://ows.dev.52north.org:8080/wps/WebProcessingService?Request=GetCapabilitie
s&Service=WPS&acceptversions=2.0.0
</dct:references>
<dct:modified>2015-05-05</dct:modified>
<dct:abstract>
Service based on the 52°North implementation of WPS 1.0.0
</dct:abstract>
<dc:date>2015-05-05</dc:date>
<dc:language>eng</dc:language>
<ows2:BoundingBox crs="urn:ogc:def:crs:EPSG::4326" dimensions="2">
<ows2:LowerCorner>-90.0 -180.0</ows2:LowerCorner>
<ows2:UpperCorner>90.0 180.0</ows2:UpperCorner>
</ows2:BoundingBox>
</csw:Record>
<csw:Record>
<dc:identifier>
urn:ogc:ows11:service:urn:uuid:21fa3afa-b60d-21de-8da0-bf22e55e7774
</dc:identifier>
<dc:title>USGS Geoname WFS (OGC Web Feature Service)</dc:title>
```

```
<dc:type/>
<dc:subject>service</dc:subject>
<dc:subject>Geonames</dc:subject>
<dc:subject>Hydrological point</dc:subject>
<dc:subject>Cultural</dc:subject>
<dc:subject>Landform</dc:subject>
<dc:subject>Community</dc:subject>
<dc:subject>Historical</dc:subject>
<dc:subject>Hydrological line</dc:subject>
<dc:subject>Antarctica</dc:subject>
<dc:subject>Transportation</dc:subject>
<dc:subject>Administrative</dc:subject>
<dc:subject>WFS</dc:subject>
<dc:subject>Web feature service</dc:subject>
<dct:references scheme="None">
http://services.nationalmap.gov/arcgis/services/WFS/geonames/MapServer/WFSServe
r?request=GetCapabilities&service=WFS
</dct:references>
<dct:modified>2015-05-05</dct:modified>
<dct:abstract>USGS Geoname WFS (OGC Web Feature Service)</dct:abstract>
<dc:date>2015-05-05</dc:date>
<dc:language>eng</dc:language>
<ows2:BoundingBox crs="urn:ogc:def:crs:EPSG::4326" dimensions="2">
<ows2:LowerCorner>-90.0 -180.0</ows2:LowerCorner>
<ows2:UpperCorner>90.0 180.0</ows2:UpperCorner>
</ows2:BoundingBox>
</csw:Record>
</csw:SearchResults>
</csw:GetRecordsResponse>
```


- Request metadata with 'ebRIM' as output metadata schema
  - http://www2.csiss.gmu.edu:9009/cat3/csw?service=CSW&version=3.0.0&request=GetRecords&resultType=results&ElementSetName=full&outputSchema=urn:oasis:names:tc:ebxml-regrep:xsd:rim:3.0&typenames=rim:RegistryObject&outputFormat=application/xml&startPosition=1&maxRecords=10&constraintlan

guage=CQL_TEXT&constraint=csw%3AAnyText%20Like%20%27%25a%25%27

The response XML can be found at:

```
<csw:GetRecordsResponse xmlns:csw="http://www.opengis.net/cat/csw/3.0"
xmlns:dc="http://purl.org/dc/elements/1.1/"
xmlns:rim="urn:oasis:names:tc:ebxml-regrep:xsd:rim:3.0"
xmlns:atom="http://www.w3.org/2005/Atom"
xmlns:xs="http://www.w3.org/2001/XMLSchema"
xmlns:dct="http://purl.org/dc/terms/" xmlns:ows="http://www.opengis.net/ows"
xmlns:ows2="http://www.opengis.net/ows/2.0"
xmlns:apiso="http://www.opengis.net/cat/csw/apiso/1.0"
xmlns:gml="http://www.opengis.net/gml"
xmlns:xlink="http://www.w3.org/1999/xlink"
xmlns:gco="http://www.isotc211.org/2005/gco"
xmlns:gmd="http://www.isotc211.org/2005/gmd"
xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
xmlns:srv="http://www.isotc211.org/2005/srv"
xmlns:ogc="http://www.opengis.net/ogc"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xmlns:os="http://a9.com/-
/spec/opensearch/1.1/"
xmlns:sitemap="http://www.sitemaps.org/schemas/sitemap/0.9"
xmlns:wrs="http://www.opengis.net/cat/wrs/1.0" version="2.0.2"
xsi:schemaLocation="http://www.opengis.net/cat/csw/3.0 ../../../csw/3.0/CSW30-
discovery.xsd">
<csw:SearchStatus timestamp="2015-07-07T15:18:33Z" />
<csw:SearchResults numberOfRecordsReturned="10" nextRecord="11"
numberOfRecordsMatched="12" recordSchema="urn:oasis:names:tc:ebxml-
regrep:xsd:rim:3.0" elementSet="full">
<rim:ExtrinsicObject xsi:schemaLocation="http://www.opengis.net/cat/wrs/1.0
http://schemas.opengis.net/csw/2.0.2/profiles/ebrim/1.0/csw-ebrim.xsd"
id="urn:geoss:csr:service:urn:uuid:21fa4afd-b60d-47de-8da0-bf35e55e7774"
lid="urn:geoss:csr:service:urn:uuid:21fa4afd-b60d-47de-8da0-bf35e55e7774"
objectType="service" status="urn:oasis:names:tc:ebxml-
regrep:StatusType:Submitted">
<rim:VersionInfo versionName="" />
<rim:ExternalIdentifier registryObject="None" identificationScheme="foo"
id="urn:geoss:csr:service:urn:uuid:21fa4afd-b60d-47de-8da0-bf35e55e7774"
value="urn:geoss:csr:service:urn:uuid:21fa4afd-b60d-47de-8da0-bf35e55e7774" />
<rim:Name>
<rim:LocalizedString value="VASDI Alaska Mapped WMS" />
</rim:Name>
<rim:Description>
<rim:LocalizedString value="Alaska Mapped - Alaska Statewide Digital Mapping
Initiative WMS" />
</rim:Description>
<rim:Slot slotType="urn:ogc:def:dataType:ISO-19107:2003:GM_Envelope">
<rim:ValueList>
<rim:Value>
```

```
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<ows2:LowerCorner>-90.0 -180.0</ows2:LowerCorner>
<ows2:UpperCorner>90.0 180.0</ows2:UpperCorner>
</ows2:BoundingBox>
</rim:Value>
</rim:ValueList>
</rim:Slot>
<rim:Slot name="http://purl.org/dc/elements/1.1/subject">
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<rim:Value>service</rim:Value>
<rim:Value>N/A</rim:Value>
<rim:Value>N/A</rim:Value>
</rim:ValueList>
</rim:Slot>
</rim:ExtrinsicObject>
<rim:ExtrinsicObject xsi:schemaLocation="http://www.opengis.net/cat/wrs/1.0
http://schemas.opengis.net/csw/2.0.2/profiles/ebrim/1.0/csw-ebrim.xsd"
id="urn:ogc:ows11:service:urn:uuid:21fa4afd-b60d-47de-8da0-bf35e55e7774"
lid="urn:ogc:ows11:service:urn:uuid:21fa4afd-b60d-47de-8da0-bf35e55e7774"
objectType="None" status="urn:oasis:names:tc:ebxml-
regrep:StatusType:Submitted">
<rim:VersionInfo versionName="" />
<rim:ExternalIdentifier registryObject="None" identificationScheme="foo"
id="urn:ogc:ows11:service:urn:uuid:21fa4afd-b60d-47de-8da0-bf35e55e7774"
value="urn:ogc:ows11:service:urn:uuid:21fa4afd-b60d-47de-8da0-bf35e55e7774" />
<rim:Name>
<rim:LocalizedString value="Test" />
</rim:Name>
<rim:Description>
<rim:LocalizedString value="Test" />
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<rim:ValueList>
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<ows2:UpperCorner>90.0 180.0</ows2:UpperCorner>
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</rim:ValueList>
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<rim:Slot name="http://purl.org/dc/elements/1.1/subject">
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<rim:Value>Youtube</rim:Value>
</rim:ValueList>
</rim:Slot>
</rim:ExtrinsicObject>
<rim:ExtrinsicObject xsi:schemaLocation="http://www.opengis.net/cat/wrs/1.0
http://schemas.opengis.net/csw/2.0.2/profiles/ebrim/1.0/csw-ebrim.xsd"
id="urn:ogc:ows11:service:urn:uuid:21fa4afd-b60d-47de-8da0-bf22e55e7774"
lid="urn:ogc:ows11:service:urn:uuid:21fa4afd-b60d-47de-8da0-bf22e55e7774"
```

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objectType="None" status="urn:oasis:names:tc:ebxml-
regrep:StatusType:Submitted">
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id="urn:ogc:ows11:service:urn:uuid:21fa4afd-b60d-47de-8da0-bf22e55e7774"
value="urn:ogc:ows11:service:urn:uuid:21fa4afd-b60d-47de-8da0-bf22e55e7774" />
<rim:Name>
<rim:LocalizedString value="Geomatys WCS (Constellation-SDI) serving San
Francisco and Mozambique coverage data" />
</rim:Name>
<rim:Description>
<rim:LocalizedString value="Geomatys WCS (Constellation-SDI) serving San
Francisco and Mozambique coverage data" />
</rim:Description>
<rim:Slot slotType="urn:ogc:def:dataType:ISO-19107:2003:GM_Envelope">
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</ows2:BoundingBox>
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</rim:ValueList>
</rim:Slot>
<rim:Slot name="http://purl.org/dc/elements/1.1/subject">
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<rim:Value>San Francisco</rim:Value>
<rim:Value>Mozambique</rim:Value>
<rim:Value>TOPOBATHY</rim:Value>
<rim:Value>San Francisco bay</rim:Value>
<rim:Value>SRTM</rim:Value>
<rim:Value>DEM</rim:Value>
<rim:Value>Digital elevation model</rim:Value>
<rim:Value>WCS</rim:Value>
</rim:ValueList>
</rim:Slot>
</rim:ExtrinsicObject>
<rim:ExtrinsicObject xsi:schemaLocation="http://www.opengis.net/cat/wrs/1.0
http://schemas.opengis.net/csw/2.0.2/profiles/ebrim/1.0/csw-ebrim.xsd"
id="urn:ogc:ows11:service:urn:uuid:21fbsbfd-b35d-11de-8da0-bf22e55e7774"
lid="urn:ogc:ows11:service:urn:uuid:21fbsbfd-b35d-11de-8da0-bf22e55e7774"
objectType="None" status="urn:oasis:names:tc:ebxml-
regrep:StatusType:Submitted">
<rim:VersionInfo versionName="" />
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id="urn:ogc:ows11:service:urn:uuid:21fbsbfd-b35d-11de-8da0-bf22e55e7774"
value="urn:ogc:ows11:service:urn:uuid:21fbsbfd-b35d-11de-8da0-bf22e55e7774" />
<rim:Name>
<rim:LocalizedString value="IBM Cloudant WFS (OGC Web Feature Service)" />
</rim:Name>
<rim:Description>
```

```
<rim:LocalizedString value="This service implements the emerging RESTful
interface of the Web Feature Service standard. This interface is under
development and not yet published outside of the WFS Working Group of the Open
Geospatial Consortium. It's brought to you by the Geo team at IBM Cloudant." />
</rim:Description>
<rim:Slot slotType="urn:ogc:def:dataType:ISO-19107:2003:GM_Envelope">
<rim:ValueList>
<rim:Value>
<ows2:BoundingBox crs="urn:ogc:def:crs:EPSG::4326" dimensions="2">
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</ows2:BoundingBox>
</rim:Value>
</rim:ValueList>
</rim:Slot>
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<rim:Value>service</rim:Value>
<rim:Value>highway</rim:Value>
<rim:Value>Open street map</rim:Value>
<rim:Value>OSM</rim:Value>
<rim:Value>emergency facilities</rim:Value>
<rim:Value>San Francisco</rim:Value>
<rim:Value>WFS</rim:Value>
<rim:Value>Web feature service</rim:Value>
</rim:ValueList>
</rim:Slot>
</rim:ExtrinsicObject>
<rim:ExtrinsicObject xsi:schemaLocation="http://www.opengis.net/cat/wrs/1.0
http://schemas.opengis.net/csw/2.0.2/profiles/ebrim/1.0/csw-ebrim.xsd"
id="urn:ogc:ows11:service:urn:uuid:21fa4afd-b60d-12de-8da0-bf22e55e7774"
lid="urn:ogc:ows11:service:urn:uuid:21fa4afd-b60d-12de-8da0-bf22e55e7774"
objectType="None" status="urn:oasis:names:tc:ebxml-
regrep:StatusType:Submitted">
<rim:VersionInfo versionName="" />
<rim:ExternalIdentifier registryObject="None" identificationScheme="foo"
id="urn:ogc:ows11:service:urn:uuid:21fa4afd-b60d-12de-8da0-bf22e55e7774"
value="urn:ogc:ows11:service:urn:uuid:21fa4afd-b60d-12de-8da0-bf22e55e7774" />
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<rim:LocalizedString value="Luciad WCS (OGC Web Coverage Service)" />
</rim:Name>
<rim:Description>
<rim:LocalizedString value="The OGC WCS focuses on delivering raster data.
This component provides an OGC-certified implementation of version 1.0.0." />
</rim:Description>
<rim:Slot slotType="urn:ogc:def:dataType:ISO-19107:2003:GM_Envelope">
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<ows2:LowerCorner>-90.0 -180.0</ows2:LowerCorner>
<ows2:UpperCorner>90.0 180.0</ows2:UpperCorner>
</ows2:BoundingBox>
</rim:Value>
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</rim:ValueList>
</rim:Slot>
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<rim:ValueList>
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<rim:Value>black marble</rim:Value>
<rim:Value>blue marble</rim:Value>
<rim:Value>San Francisco</rim:Value>
<rim:Value>Mozambique</rim:Value>
<rim:Value>TOPOBATHY</rim:Value>
<rim:Value>San Francisco bay</rim:Value>
<rim:Value>SRTM</rim:Value>
<rim:Value>DEM</rim:Value>
<rim:Value>Digital elevation model</rim:Value>
<rim:Value>Topo50 topographic map</rim:Value>
<rim:Value>WCS</rim:Value>
<rim:Value>Web coverage service</rim:Value>
</rim:ValueList>
</rim:Slot>
</rim:ExtrinsicObject>
<rim:ExtrinsicObject xsi:schemaLocation="http://www.opengis.net/cat/wrs/1.0
http://schemas.opengis.net/csw/2.0.2/profiles/ebrim/1.0/csw-ebrim.xsd"
id="urn:ogc:ows11:service:urn:uuid:21fa4afd-b35d-11de-8da0-bf22e55e7774"
lid="urn:ogc:ows11:service:urn:uuid:21fa4afd-b35d-11de-8da0-bf22e55e7774"
objectType="None" status="urn:oasis:names:tc:ebxml-
regrep:StatusType:Submitted">
<rim:VersionInfo versionName="" />
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id="urn:ogc:ows11:service:urn:uuid:21fa4afd-b35d-11de-8da0-bf22e55e7774"
value="urn:ogc:ows11:service:urn:uuid:21fa4afd-b35d-11de-8da0-bf22e55e7774" />
<rim:Name>
<rim:LocalizedString value="Luciad WFS (OGC Web Feature Service)" />
</rim:Name>
<rim:Description>
<rim:LocalizedString value="The OGC WFS focuses on exchanging vector data.
This component provides an OGC-certified implementation of version 1.0.0 and
1.1.0." />
</rim:Description>
<rim:Slot slotType="urn:ogc:def:dataType:ISO-19107:2003:GM_Envelope">
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<ows2:UpperCorner>90.0 180.0</ows2:UpperCorner>
</ows2:BoundingBox>
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</rim:ValueList>
</rim:Slot>
<rim:Slot name="http://purl.org/dc/elements/1.1/subject">
<rim:ValueList>
<rim:Value>service</rim:Value>
```

```
<rim:Value>buoy</rim:Value>
<rim:Value>Open street map</rim:Value>
<rim:Value>OSM</rim:Value>
<rim:Value>New Zealand</rim:Value>
<rim:Value>US county</rim:Value>
<rim:Value>US city</rim:Value>
<rim:Value>US river</rim:Value>
<rim:Value>US aviation obstacle</rim:Value>
<rim:Value>San Francisco</rim:Value>
<rim:Value>Mozambique</rim:Value>
<rim:Value>WFS</rim:Value>
<rim:Value>Web feature service</rim:Value>
<rim:Value>Monterey oil spill</rim:Value>
<rim:Value>Monterey sounding</rim:Value>
<rim:Value>US coast</rim:Value>
<rim:Value>Hydro line</rim:Value>
<rim:Value>vent</rim:Value>
<rim:Value>hydrology</rim:Value>
</rim:ValueList>
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</rim:ExtrinsicObject>
<rim:ExtrinsicObject xsi:schemaLocation="http://www.opengis.net/cat/wrs/1.0
http://schemas.opengis.net/csw/2.0.2/profiles/ebrim/1.0/csw-ebrim.xsd"
id="urn:ogc:ows11:service:urn:uuid:21fa4afd-b60d-11de-8da0-bf22e55e7774"
lid="urn:ogc:ows11:service:urn:uuid:21fa4afd-b60d-11de-8da0-bf22e55e7774"
objectType="None" status="urn:oasis:names:tc:ebxml-
regrep:StatusType:Submitted">
<rim:VersionInfo versionName="" />
<rim:ExternalIdentifier registryObject="None" identificationScheme="foo"
id="urn:ogc:ows11:service:urn:uuid:21fa4afd-b60d-11de-8da0-bf22e55e7774"
value="urn:ogc:ows11:service:urn:uuid:21fa4afd-b60d-11de-8da0-bf22e55e7774" />
<rim:Name>
<rim:LocalizedString value="Luciad WMS (OGC Web Map Service)" />
</rim:Name>
<rim:Description>
<rim:LocalizedString value="The OGC WMS focuses on delivering portrayed data.
This component provides an OGC-certified implementation of version 1.1.1 and
1.3.0, and includes support for dimensions, the Queryable profile
(GetFeatureInfo), and the Styled Layer Descriptor profile." />
</rim:Description>
<rim:Slot slotType="urn:ogc:def:dataType:ISO-19107:2003:GM_Envelope">
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<ows2:BoundingBox crs="urn:ogc:def:crs:EPSG::4326" dimensions="2">
<ows2:LowerCorner>-90.0 -180.0</ows2:LowerCorner>
<ows2:UpperCorner>90.0 180.0</ows2:UpperCorner>
</ows2:BoundingBox>
</rim:Value>
</rim:ValueList>
</rim:Slot>
<rim:Slot name="http://purl.org/dc/elements/1.1/subject">
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<rim:Value>service</rim:Value>
```

```
<rim:Value>Monterey bay imagery</rim:Value>
<rim:Value>black marble</rim:Value>
<rim:Value>blue marble</rim:Value>
<rim:Value>buoy</rim:Value>
<rim:Value>Open street map</rim:Value>
<rim:Value>OSM</rim:Value>
<rim:Value>New Zealand</rim:Value>
<rim:Value>US county</rim:Value>
<rim:Value>US city</rim:Value>
<rim:Value>US river</rim:Value>
<rim:Value>US aviation obstacle</rim:Value>
<rim:Value>San Francisco</rim:Value>
<rim:Value>Mozambique</rim:Value>
<rim:Value>TOPOBATHY</rim:Value>
<rim:Value>San Francisco bay</rim:Value>
<rim:Value>SRTM</rim:Value>
<rim:Value>DEM</rim:Value>
<rim:Value>Digital elevation model</rim:Value>
<rim:Value>Topo50 topographic map</rim:Value>
<rim:Value>WMS</rim:Value>
<rim:Value>Web map service</rim:Value>
</rim:ValueList>
</rim:Slot>
</rim:ExtrinsicObject>
<rim:ExtrinsicObject xsi:schemaLocation="http://www.opengis.net/cat/wrs/1.0
http://schemas.opengis.net/csw/2.0.2/profiles/ebrim/1.0/csw-ebrim.xsd"
id="urn:ogc:ows11:service:urn:uuid:33fa4afd-b60d-11de-8da0-bf22e55e7774"
lid="urn:ogc:ows11:service:urn:uuid:33fa4afd-b60d-11de-8da0-bf22e55e7774"
objectType="None" status="urn:oasis:names:tc:ebxml-
regrep:StatusType:Submitted">
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<rim:ExternalIdentifier registryObject="None" identificationScheme="foo"
id="urn:ogc:ows11:service:urn:uuid:33fa4afd-b60d-11de-8da0-bf22e55e7774"
value="urn:ogc:ows11:service:urn:uuid:33fa4afd-b60d-11de-8da0-bf22e55e7774" />
<rim:Name>
<rim:LocalizedString value="Luciad WMTS (OGC Web Map Tile Service)" />
</rim:Name>
<rim:Description>
<rim:LocalizedString value="The OGC WMTS focuses on delivering tiles. This
component provides an implementation of version 1.0.0 of the standard." />
</rim:Description>
<rim:Slot slotType="urn:ogc:def:dataType:ISO-19107:2003:GM_Envelope">
<rim:ValueList>
<rim:Value>
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<ows2:UpperCorner>90.0 180.0</ows2:UpperCorner>
</ows2:BoundingBox>
</rim:Value>
</rim:ValueList>
</rim:Slot>
<rim:Slot name="http://purl.org/dc/elements/1.1/subject">
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```
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<rim:Value>service</rim:Value>
<rim:Value>Monterey bay imagery</rim:Value>
<rim:Value>black marble</rim:Value>
<rim:Value>blue marble</rim:Value>
<rim:Value>Mozambique</rim:Value>
<rim:Value>Maritime map</rim:Value>
<rim:Value>Web map tile service</rim:Value>
</rim:ValueList>
</rim:Slot>
</rim:ExtrinsicObject>
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http://schemas.opengis.net/csw/2.0.2/profiles/ebrim/1.0/csw-ebrim.xsd"
id="urn:ogc:ows11:service:urn:uuid:21fa3nfd-b60d-11de-8da0-bf22e55e7774"
lid="urn:ogc:ows11:service:urn:uuid:21fa3nfd-b60d-11de-8da0-bf22e55e7774"
objectType="None" status="urn:oasis:names:tc:ebxml-
regrep:StatusType:Submitted">
<rim:VersionInfo versionName="" />
<rim:ExternalIdentifier registryObject="None" identificationScheme="foo"
id="urn:ogc:ows11:service:urn:uuid:21fa3nfd-b60d-11de-8da0-bf22e55e7774"
value="urn:ogc:ows11:service:urn:uuid:21fa3nfd-b60d-11de-8da0-bf22e55e7774" />
<rim:Name>
<rim:LocalizedString value="North 52 WPS (OGC Web Processing Service)" />
</rim:Name>
<rim:Description>
<rim:LocalizedString value="Service based on the 52°North implementation of
WPS 1.0.0" />
</rim:Description>
<rim:Slot slotType="urn:ogc:def:dataType:ISO-19107:2003:GM_Envelope">
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</ows2:BoundingBox>
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</rim:ValueList>
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<rim:ValueList>
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<rim:Value>FloodFeatureEnrichment</rim:Value>
<rim:Value>FloodImpactAssessment</rim:Value>
<rim:Value>Flooding</rim:Value>
<rim:Value>Natural disaster</rim:Value>
<rim:Value>GCAM</rim:Value>
<rim:Value>Global Change Assessment Model</rim:Value>
<rim:Value>Flood risk</rim:Value>
<rim:Value>Flood assessment</rim:Value>
<rim:Value>WPS</rim:Value>
<rim:Value>Web processing service</rim:Value>
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</rim:ValueList>
```

```
</rim:Slot>
</rim:ExtrinsicObject>
<rim:ExtrinsicObject xsi:schemaLocation="http://www.opengis.net/cat/wrs/1.0
http://schemas.opengis.net/csw/2.0.2/profiles/ebrim/1.0/csw-ebrim.xsd"
id="urn:ogc:ows11:service:urn:uuid:21fa3afa-b60d-21de-8da0-bf22e55e7774"
lid="urn:ogc:ows11:service:urn:uuid:21fa3afa-b60d-21de-8da0-bf22e55e7774"
objectType="None" status="urn:oasis:names:tc:ebxml-
regrep:StatusType:Submitted">
<rim:VersionInfo versionName="" />
<rim:ExternalIdentifier registryObject="None" identificationScheme="foo"
id="urn:ogc:ows11:service:urn:uuid:21fa3afa-b60d-21de-8da0-bf22e55e7774"
value="urn:ogc:ows11:service:urn:uuid:21fa3afa-b60d-21de-8da0-bf22e55e7774" />
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<rim:LocalizedString value="USGS Geoname WFS (OGC Web Feature Service)" />
</rim:Name>
<rim:Description>
<rim:LocalizedString value="USGS Geoname WFS (OGC Web Feature Service)" />
</rim:Description>
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<ows2:UpperCorner>90.0 180.0</ows2:UpperCorner>
</ows2:BoundingBox>
</rim:Value>
</rim:ValueList>
</rim:Slot>
<rim:Slot name="http://purl.org/dc/elements/1.1/subject">
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<rim:Value>Hydrological point</rim:Value>
<rim:Value>Cultural</rim:Value>
<rim:Value>Landform</rim:Value>
<rim:Value>Community</rim:Value>
<rim:Value>Historical</rim:Value>
<rim:Value>Hydrological line</rim:Value>
<rim:Value>Antarctica</rim:Value>
<rim:Value>Transportation</rim:Value>
<rim:Value>Administrative</rim:Value>
<rim:Value>WFS</rim:Value>
<rim:Value>Web feature service</rim:Value>
</rim:ValueList>
</rim:Slot>
</rim:ExtrinsicObject>
</csw:SearchResults>
</csw:GetRecordsResponse>
```

- Request metadata with 'ISO 19115-2' as output metadata schema is:

        - http://www2.csiss.gmu.edu:9009/cat3/csw?service=CSW&version=3.0.0&request=GetRecords&resultType=results&ElementSetName=full&outputSchema=http://www.isotc211.org/2005/gmi&typenames=gmi:MI_Metadata&outputFormat=application/xml&startPosition=1&maxRecords=10&constraintlanguage=CQL_TEXT&constraint=csw%3AAnyText%20Like%20%27%25water%25%27
    - Request metadata with the output format of 'ATOM' is:
        - http://www2.csiss.gmu.edu:9009/cat3/csw?service=CSW&version=3.0.0&request=GetRecords&ElementSetName=full&typenames=csw:Record&outputFormat=application/atom%2Bxml&startPosition=1&maxRecords=10&constraintlanguage=CQL_TEXT&constraint=csw%3AAnyText%20Like%20%27%25water%25%27
- **Search metadata through OGC CSW 3.0 GetRecordById**
    - Request metadata with 'csw:Record' as output metadata schema
        - http://www2.csiss.gmu.edu:9009/cat3/csw?service=CSW&version=3.0.0&request=GetRecordById&resultType=results&ElementSetName=full&outputSchema=http://www.opengis.net/cat/csw/2.0.2&typenames=csw:Record&outputFormat=application/xml&id=urn:geoss:csr:service:urn:uuid:21fa4afd-b60d-47de-8da0-bf35e55e7774
    - Request metadata with 'ebRIM' as output metadata schema
        - http://www2.csiss.gmu.edu:9009/cat3/csw?service=CSW&version=3.0.0&request=GetRecordById&resultType=results&ElementSetName=full&outputSchema=urn:oasis:names:tc:ebxml-regrep:xsd:rim:3.0&typenames=rim:RegistryObject&outputFormat=application/xml&id=urn:geoss:csr:service:urn:uuid:21fa4afd-b60d-47de-8da0-bf35e55e7774
    - Request metadata with 'ISO 19115' as output metadata schema
        - http://www2.csiss.gmu.edu:9009/cat3/csw?service=CSW&version=3.0.0&request=GetRecordById&resultType=results&ElementSetName=full&outputSchema=http://www.isotc211.org/2005/gmi&typenames=gmi:MI_Metadata&outputFormat=application/xml&id=urn:geoss:csr:service:urn:uuid:21fa4afd-b60d-47de-8da0-bf35e55e7774
    - Request metadata with the output format of 'ATOM'
        - http://www2.csiss.gmu.edu:9009/cat3/csw?service=CSW&version=3.0.0&request=GetRecordById&resultType=results&ElementSetName=full&outputSchema=http://www.opengis.net/cat/csw/2.0.2&typenames=csw:Record&outputFormat=application/atom%2Bx

ml&id=urn:geoss:csr:service:urn:uuid:21fa4afd-b60d-47de-8da0-bf35e55e7774

The following XML demonstrates the result returned in the format of "application/atom" for the above queries.

```
<?xml version="1.0" encoding="UTF-8"?>
<atom:entry
xmlns:atom="http://www.w3.org/2005/Atom"
xmlns:georss="http://www.georss.org/georss"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xmlns:gml="http://www.opengis.net/gml"
xsi:schemaLocation="http://www.w3.org/2005/Atom
http://www.kbcafe.com/rss/atom.xsd.xml">
<atom:category term="service">service</atom:category>
<atom:category term="N/A">N/A</atom:category>
<atom:category term="N/A">N/A</atom:category>
<atom:id>urn:geoss:csr:service:urn:uuid:21fa4afd-b60d-47de-8da0-
bf35e55e7774</atom:id>
<dc:identifier
xmlns:dc="http://purl.org/dc/elements/1.1/">urn:geoss:csr:service:urn:uuid:21fa
4afd-b60d-47de-8da0-bf35e55e7774
</dc:identifier>
<atom:link href="http://wms.alaskamapped.org/cgi-
bin/bdl.cgi?request=GetCapabilities&amp;service=WMS" type="WWW:LINK-1.0-http--
link" title="None"/>
<atom:link href="http://wms.alaskamapped.org/cgi-
bin/bdl.cgi?request=GetCapabilities&amp;service=WMS" type="WWW:LINK-1.0-http--
link" title="Alaska Mapped - Alaska Statewide Digital Mapping Initiative WMS"/>
<atom:link
href="http://129.174.131.8/csw/csw.py?service=CSW&amp;version=2.0.2&amp;request
=GetRepositoryItem&amp;id=urn:geoss:csr:service:urn:uuid:21fa4afd-b60d-47de-
8da0-bf35e55e7774"/>
<atom:summary>Alaska Mapped - Alaska Statewide Digital Mapping Initiative
WMS</atom:summary>
<atom:title>VASDI Alaska Mapped WMS</atom:title>
<atom:updated>2009-07-20</atom:updated>
<georss:where>
```

```
<gml:Polygon srsName="urn:x-ogc:def:crs:EPSG:6.11:4326">
<gml:exterior>
<gml:LinearRing>
<gml:posList>-90.0 -180.0 90.0 -180.0 90.0 180.0 -90.0 180.0 -90.0 -
180.0</gml:posList>
</gml:LinearRing>
</gml:exterior>
</gml:Polygon>
</georss:where>
</atom:entry>
```

6.2.4.3.5 OpenSearch description document

The endpoint to link to the OpenSearch description document is located at: http://www2.csiss.gmu.edu:9009/cat3/opensearch/osdd.xml

The web browser is not able to view the above XML document because it requires a special configuration for the client to accept viewing the file in opensearchdescription+xml format. A JavaScript code (in the below text block) can be utilized to send the request and download the XML for viewing.

```
//====================
$.ajaxSetup({
   headers: { "Accept": "application/opensearchdescription+xml" }
});
$.ajax({
 url: "http://www2.csiss.gmu.edu:9009/cat3/opensearch/osdd.xml",
 beforeSend: function(xhr) {
   xhr.setRequestHeader("Accept", "application/opensearchdescription+xml");
 },
 success: function(data) {
    console.log(data)
 }
});
//====================
```

The OpenSearch description document can be found below. This XML document describes different ways to send an OpenSearch request.

```
<OpenSearchDescription
xmlns="http://a9.com/-/spec/opensearch/1.1/"
```

```
xmlns:geo="http://a9.com/-/opensearch/extensions/geo/1.0/"
xmlns:time="http://a9.com/-/opensearch/extensions/time/1.0/">
<ShortName>OGC CSW 3.0</ShortName>
<LongName>OGC CSW 3.0</LongName>
<Description>OGC CSW 3.0 OpenSearch implementation for OWS-
11</Description>
<Tags>Catalogue discovery metadata</Tags>
<Image type="image/gif" width="16"
height="16">http://csiss.gmu.edu/csiss_logo_big.gif</Image>
<Developer>Lingjun, Kang</Developer>
<Contact>lkang3@masonlive.gmu.edu</Contact>
<Url type="application/xml" rel="results"
template="http://www2.csiss.gmu.edu:9009/cat3/opensearch?service=CSW&am
p;version=3.0.0&amp;q={searchTerms?}&amp;maxRecords={count?}&amp;startP
osition={startIndex?}&amp;bbox={geo:box?}&amp;time={time:start?}/{time:
end?}&amp;recordIds={geo:uid?}&amp;outputSchema=http://www.opengis.net/
cat/csw/3.0&amp;outputFormat=application/xml"/>
<Url type="application/atom+xml" rel="results"
template="http://www2.csiss.gmu.edu:9009/cat3/opensearch?service=CSW&am
p;version=3.0.0&amp;q={searchTerms?}&amp;maxRecords={count?}&amp;startP
osition={startIndex?}&amp;bbox={geo:box?}&amp;time={time:start?}/{time:
end?}&amp;recordIds={geo:uid?}&amp;outputFormat=application/atom+xml"/>
<Url type="application/json" rel="results"
template="http://www2.csiss.gmu.edu:9009/cat3/opensearch?service=CSW&am
p;version=3.0.0&amp;q={searchTerms?}&amp;maxRecords={count?}&amp;startP
osition={startIndex?}&amp;bbox={geo:box?}&amp;time={time:start?}/{time:
end?}&amp;recordIds={geo:uid?}&amp;outputFormat=application/json"/>
</OpenSearchDescription>
```

6.2.4.3.6 OpenSearch Metadata discovery

Figure 6 demonstrates the metadata discovery template for OpenSearch. Parameter “q” allows the search for any keyword; parameter “bbox” is to enable spatial search by a bounding box parameter; “time” is the temporal filter, a start and end time can be defined to retrieve data record within a give timeframe; and parameter “RecordId” allows the query of data based on its ID information.

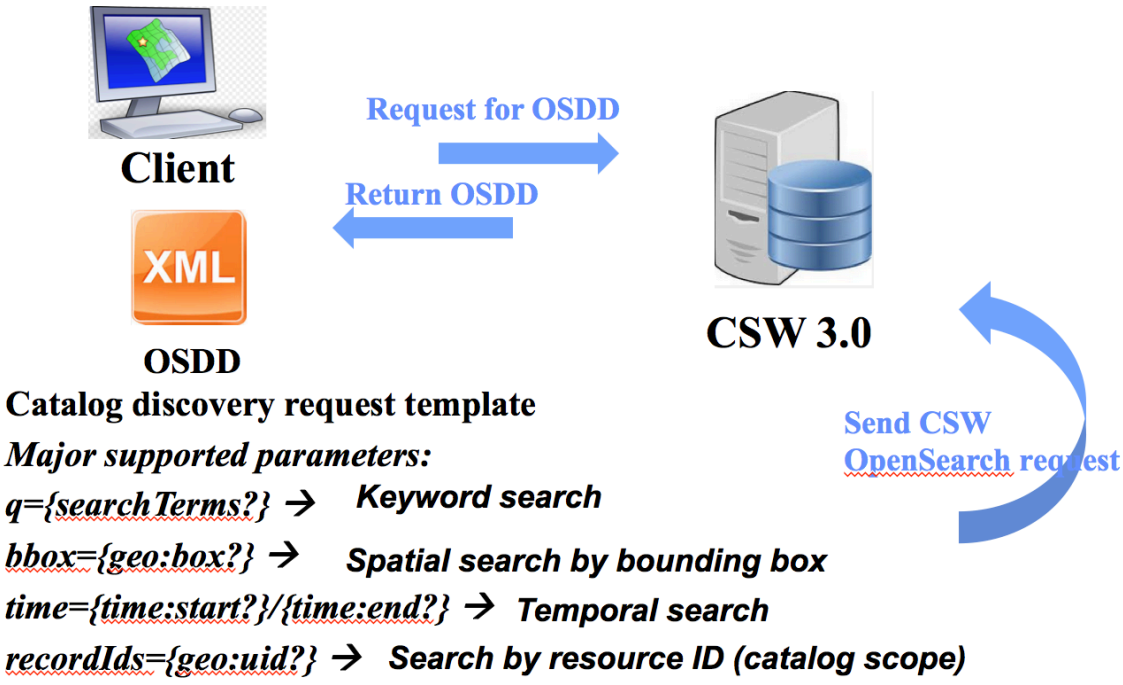

Figure 6. CSW OpenSearch metadata discovery template (GMU, 2015)

The link below shows the URL that requests for metadata with 'RecordId' (dataset identifier being separated by comma) equaling "urn:ogc:ows11:service:urn:uuid:21fa3nfd-b60d-11de-8da0-bf22e55e7774"

http://www2.csiss.gmu.edu:9009/cat3/opensearch?service=CSW&version=3.0.0&recordIds=urn:ogc:ows11:service:urn:uuid:21fa3nfd-b60d-11de-8da0-bf22e55e7774&outputFormat=application/atom%2Bxml

The response XML is:

```
<?xml version="1.0" encoding="UTF-8" ?>
<atom:feed xmlns:atom="http://www.w3.org/2005/Atom"
xmlns:os="http://a9.com/-/spec/opensearch/1.1/"
xmlns:time="http://a9.com/-/opensearch/extensions/time/1.0/"
xmlns:geo="http://a9.com/-/opensearch/extensions/geo/1.0/"
xmlns:dc="http://purl.org/dc/elements/1.1/">
<atom:id>http://129.174.131.8/csw/csw.py</atom:id>
<atom:link rel="search" type="application/opensearchdescription%2Bxml"
href="http://129.174.131.8:9009/cat3/opensearch/osdd.xml" />
<atom:title>OGC CSW 3.0</atom:title>
```

```
<atom:updated>2015-07-07T18:14:15Z</atom:updated>
<atom:author>
<atom:name>n/a</atom:name>
</atom:author>
<os:totalResults>1</os:totalResults>
<os:startIndex>1</os:startIndex>
<os:itemsPerPage>1</os:itemsPerPage>
<atom:entry xmlns:georss="http://www.georss.org/georss"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xmlns:gml="http://www.opengis.net/gml"
xsi:schemaLocation="http://www.w3.org/2005/Atom
http://www.kbcafe.com/rss/atom.xsd.xml">
<atom:category term="service">service</atom:category>
<atom:category
term="FloodFeatureEnrichment">FloodFeatureEnrichment</atom:category>
<atom:category
term="FloodImpactAssessment">FloodImpactAssessment</atom:category>
<atom:category term="Flooding">Flooding</atom:category>
<atom:category term="Natural disaster">Natural disaster</atom:category>
<atom:category term="GCAM">GCAM</atom:category>
<atom:category term="Global Change Assessment Model">Global Change
Assessment Model</atom:category>
<atom:category term="Flood risk">Flood risk</atom:category>
<atom:category term="Flood assessment">Flood assessment</atom:category>
<atom:category term="WPS">WPS</atom:category>
<atom:category term="Web processing service">Web processing
service</atom:category>
<atom:category term="geoprocessing">geoprocessing</atom:category>
<atom:id>urn:ogc:ows11:service:urn:uuid:21fa3nfd-b60d-11de-8da0-
bf22e55e7774</atom:id>
<dc:identifier>urn:ogc:ows11:service:urn:uuid:21fa3nfd-b60d-11de-8da0-
bf22e55e7774</dc:identifier>
<atom:link
href="http://ows.dev.52north.org:8080/wps/WebProcessingService?Request=
GetCapabilities&amp;Service=WPS&amp;acceptversions=2.0.0" type="None"
title="North 52 Web Processing Service" />
<atom:link
href="http://129.174.131.8/csw/csw.py?service=CSW&amp;version=2.0.2&amp
```

```
;request=GetRepositoryItem&amp;amp;id=urn:ogc:ows11:service:urn:uuid:21fa3n
fd-b60d-11de-8da0-bf22e55e7774" />
<atom:summary>Service based on the 52°North implementation of WPS
1.0.0</atom:summary>
<atom:title>North 52 WPS (OGC Web Processing Service)</atom:title>
<atom:updated>2015-05-05</atom:updated>
<georss:where>
<gml:Polygon srsName="urn:x-ogc:def:crs:EPSG:6.11:4326">
<gml:exterior>
<gml:LinearRing>
<gml:posList>-90.0 -180.0 90.0 -180.0 90.0 180.0 -90.0 180.0 -90.0 -
180.0</gml:posList>
</gml:LinearRing>
</gml:exterior>
</gml:Polygon>
</georss:where>
</atom:entry>
</atom:feed>
```


The URL below shows the same request but with a different output format (JSON).

http://www2.csiss.gmu.edu:9009/cat3/opensearch?service=CSW&version=3.0.0&recordIds=NS06agg,5f37e0f8-4fb1-4637-b959-b415058bdb68&outputFormat=application/json

The responded JSON file is:


```
{
"attributes": {
"version": "2.0.2",
"xsi:schemaLocation": "http://www.opengis.net/cat/csw/2.0.2
http://schemas.opengis.net/csw/2.0.2/CSW-discovery.xsd"
},
"tag": "csw:GetRecordsResponse",
"children": [{
"attributes": {
"timestamp": "2015-07-07T18:17:35Z"
},
"tag": "csw:SearchStatus"
}, {
"attributes": {
```

```
"numberOfRecordsMatched": "0",
"nextRecord": "0",
"numberOfRecordsReturned": "0",
"elementSet": "full",
"recordSchema": "http://www.opengis.net/cat/csw/2.0.2"
},
"tag": "csw:SearchResults"
}]
}
```


The request below shows an example of searching for records that contain the keywords "flood assessment" with expected output format of "ATOM"

http://www2.csiss.gmu.edu:9009/cat3/opensearch?service=CSW&version=3.0.0&maxRecords=10&q=Flooding,assessment&startPosition=1&outputFormat=application/atom%2Bxml

The responded XML is:


```
<?xml version="1.0" encoding="UTF-8"?>
<atom:feed
xmlns:atom="http://www.w3.org/2005/Atom"
xmlns:os="http://a9.com/-/spec/opensearch/1.1/"
xmlns:time="http://a9.com/-/opensearch/extensions/time/1.0/"
xmlns:geo="http://a9.com/-/opensearch/extensions/geo/1.0/"
xmlns:dc="http://purl.org/dc/elements/1.1/">
<atom:id>http://129.174.131.8/csw/csw.py</atom:id>
<atom:link rel="search" type="application/opensearchdescription%2Bxml"
href="http://129.174.131.8:9009/cat3/opensearch/osdd.xml"/>
<atom:title>OGC CSW 3.0</atom:title>
<atom:updated>2015-07-09T16:15:34Z</atom:updated>
<atom:author>
<atom:name>n/a</atom:name>
</atom:author>
<os:totalResults>1</os:totalResults>
<os:startIndex>1</os:startIndex>
<os:itemsPerPage>1</os:itemsPerPage>
<atom:entry
```

```
xmlns:georss="http://www.georss.org/georss"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xmlns:gml="http://www.opengis.net/gml"
xsi:schemaLocation="http://www.w3.org/2005/Atom
http://www.kbcafe.com/rss/atom.xsd.xml">
<atom:category term="service">service</atom:category>
<atom:category
term="FloodFeatureEnrichment">FloodFeatureEnrichment</atom:category>
<atom:category
term="FloodImpactAssessment">FloodImpactAssessment</atom:category>
<atom:category term="Flooding">Flooding</atom:category>
<atom:category term="Natural disaster">Natural disaster</atom:category>
<atom:category term="GCAM">GCAM</atom:category>
<atom:category term="Global Change Assessment Model">Global Change
Assessment Model</atom:category>
<atom:category term="Flood risk">Flood risk</atom:category>
<atom:category term="Flood assessment">Flood assessment</atom:category>
<atom:category term="WPS">WPS</atom:category>
<atom:category term="Web processing service">Web processing
service</atom:category>
<atom:category term="geoprocessing">geoprocessing</atom:category>
<atom:id>urn:ogc:ows11:service:urn:uuid:21fa3nfd-b60d-11de-8da0-
bf22e55e7774</atom:id>
<dc:identifier>urn:ogc:ows11:service:urn:uuid:21fa3nfd-b60d-11de-8da0-
bf22e55e7774</dc:identifier>
<atom:link
href="http://ows.dev.52north.org:8080/wps/WebProcessingService?Request=
GetCapabilities&amp;Service=WPS&amp;acceptversions=2.0.0" type="None"
title="North 52 Web Processing Service"/>
<atom:link
href="http://129.174.131.8/csw/csw.py?service=CSW&amp;version=2.0.2&amp
;request=GetRepositoryItem&amp;id=urn:ogc:ows11:service:urn:uuid:21fa3n
fd-b60d-11de-8da0-bf22e55e7774"/>
<atom:summary>Service based on the 52°North implementation of WPS
1.0.0</atom:summary>
<atom:title>North 52 WPS (OGC Web Processing Service)</atom:title>
<atom:updated>2015-05-05</atom:updated>
<georss:where>
<gml:Polygon srsName="urn:x-ogc:def:crs:EPSG:6.11:4326">
```

```
<gml:exterior>
<gml:LinearRing>
<gml:posList>-90.0 -180.0 90.0 -180.0 90.0 180.0 -90.0 180.0 -90.0 -
180.0</gml:posList>
</gml:LinearRing>
</gml:exterior>
</gml:Polygon>
</georss:where>
</atom:entry>
</atom:feed>
```

The URL below shows the same request as above. The only difference is that the output format is set to be JSON.

http://www2.csiss.gmu.edu:9009/cat3/opensearch?service=CSW&version=3.0.0&maxRecords=10&q=Flooding,assessment&startPosition=1&outputFormat=application/json

The responded JSON file is:


```
{
    "attributes": {
    "version": "2.0.2",
    "xsi:schemaLocation": "http://www.opengis.net/cat/csw/2.0.2
    http://schemas.opengis.net/csw/2.0.2/CSW-discovery.xsd"
    },
    "tag": "csw:GetRecordsResponse",
    "children": [
    {
    "attributes": {
    "timestamp": "2015-07-09T16:17:42Z"
    },
    "tag": "csw:SearchStatus"
    },
    {
    "attributes": {
    "numberOfRecordsMatched": "1",
    "nextRecord": "0",
    "numberOfRecordsReturned": "1",
```

```
"elementSet": "full",
"recordSchema": "http://www.opengis.net/cat/csw/2.0.2"
},
"tag": "csw:SearchResults",
"children": [
{
"tag": "csw:Record",
"children": [
{
"text": "urn:ogc:ows11:service:urn:uuid:21fa3nfd-b60d-11de-8da0-
bf22e55e7774",
"tag": "dc:identifier"
},
{
"text": "North 52 WPS (OGC Web Processing Service)",
"tag": "dc:title"
},
{
"tag": "dc:type"
},
{
"text": "service",
"tag": "dc:subject"
},
{
"text": "FloodFeatureEnrichment",
"tag": "dc:subject"
},
{
"text": "FloodImpactAssessment",
"tag": "dc:subject"
},
{
"text": "Flooding",
"tag": "dc:subject"
},
{
"text": "Natural disaster",
"tag": "dc:subject"
```

```
},
{
"text": "GCAM",
"tag": "dc:subject"
},
{
"text": "Global Change Assessment Model",
"tag": "dc:subject"
},
{
"text": "Flood risk",
"tag": "dc:subject"
},
{
"text": "Flood assessment",
"tag": "dc:subject"
},
{
"text": "WPS",
"tag": "dc:subject"
},
{
"text": "Web processing service",
"tag": "dc:subject"
},
{
"text": "geoprocessing",
"tag": "dc:subject"
},
{
"text":
"http://ows.dev.52north.org:8080/wps/WebProcessingService?Request=Ge
tCapabilities&Service=WPS&acceptversions=2.0.0",
"tag": "dct:references",
"attributes": {
"scheme": "None"
}
},
```

```
{
"text": "2015-05-05",
"tag": "dct:modified"
},
{
"text": "Service based on the 52\u00b0North implementation of WPS
1.0.0",
"tag": "dct:abstract"
},
{
"text": "2015-05-05",
"tag": "dc:date"
},
{
"text": "eng",
"tag": "dc:language"
},
{
"attributes": {
"crs": "urn:x-ogc:def:crs:EPSG:6.11:4326",
"dimensions": "2"
},
"tag": "ows:BoundingBox",
"children": [
{
"text": "-90.0 -180.0",
"tag": "ows:LowerCorner"
},
{
"text": "90.0 180.0",
"tag": "ows:UpperCorner"
}
]
}
]
}
]
}
]
```

```
}
```

6.2.5 Support to Distributed Search

There are two kinds of distributed searches described in the CSW 3.0 standard —client-controlled and server-controlled. In a client-controlled search, the client maintains a list of CSW endpoints as well as their connection topology. The client sends requests to distributed catalogs and results are aggregated at the client side. Figure 7 demonstrates such a distributed search scenario. The advantage of this search strategy is that all the CSW server information is transparent to the client. The overhead that relies on a third party middleware to manage the communication is eliminated, making communication more efficient. Also, because the client has the control, it can decide freely which server to contact and how the search will be conducted.

However, the choice of performing any kind of search the client prefers also introduces extra workload for the client. First, the client must maintain the whole topology of the distributed CSW servers. It also needs to maintain the availability of each CSW server in its network. When a CSW server is behind a firewall, it will become challenging for the client to access. In addition, each client needs to maintain its own set of server information, making the client fat and burdensome.

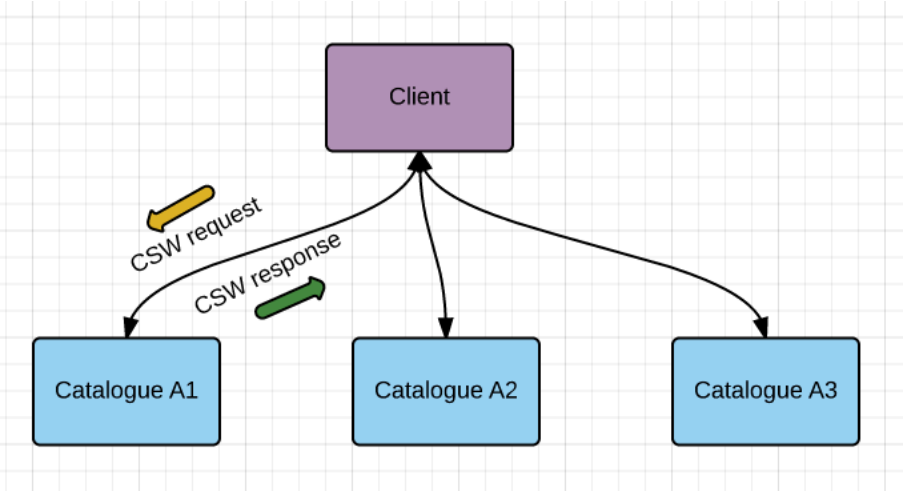

Figure 7. Client-controlled distributed search scenario

The other strategy is to let a ‘root’ catalog coordinate the distributed search between the client and remote catalogues. In this search scenario, as Figure 8 shows, the client only needs to communicate with the root catalog. All the request formulation, the results filtering and aggregation are completed by the root catalog. In this search context, the workload on the client side is very much reduced as it only communicates with the root catalog. All the data query actions are handled by the catalog, which is responsible for federating the remote communications. Another advantage is that there is no need to maintain an entire topology showing how the catalogs are connected. Instead, each

catalog only needs to know who is its child. For instance, the root catalog A1 in the Figure 8 example only needs to know the existence of catalog A2, A3, and A4. And catalog A4 only needs to know the existence of A5.

The disadvantage of using this strategy is that each catalog must have the ability to process search to its child catalogs and is able to return the entire result sets to its parent catalog. Therefore, there an enhanced data search-response structure must exist as part of the catalog information model.

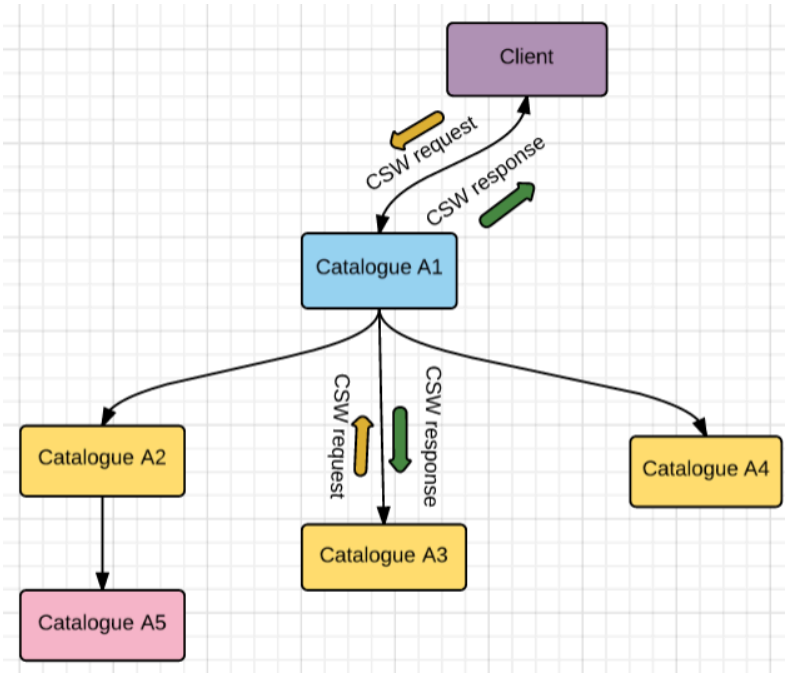

Figure 8. A server-controlled distributed catalog search

Besides these two search scenarios, the CSW 3.0 standard also describes in detail the solutions to problems that may occur in the case of distributed search. First, when there are a large number of catalogs to access, the response time may be long. Second, there may be a loop (a catalog is linked back to its parent catalog) in the catalog topology, causing problems of an endless looped search. To solve these problems, a parameter hopCount is introduced in the “DistributedSearchType” class. Once the hopCount is higher than a certain number, meaning the search is going too deep or it has reached out to too many catalog nodes, no more catalogs will be reached during this search cycle. A third problem is potential duplication in the results. This problem is caused by the situation in which the same records are stored in different catalogs and they are returned from both catalogs after a search request. Defining a unique identifier, or a URI, for each record, solves this problem. Therefore, when a record with the same content is found in different catalogs, it can be automatically filtered out because the record with the same URI has been included in the result set.

6.2.6 Usability

- The OpenSearch support advances interoperability of the CSW catalogue with existing search engines, such as Google and Bing etc.

- OpenSearch is an effective way to enable search and access across different catalogues within a federation. For instance, CEOS (Committee on Earth Observation Satellites) is developing an open search project named CEOS OpenSearch to develop a best open search practice to allow agencies and data centers to easily and independently set up a best-practice-compliant OpenSearch server.

- Through the OpenSearch support in the CSW 3.0 standard, implementation of CSW service instances in compliance with this standard will provide stronger and better support for cross-catalogue data search and discovery.

- However, currently not many CSW servers support the 3.0 version. We conducted a search using the NSF PolarHub on the CSW instances and are only able to find one CSW instance that is a sample server provided by PyCSW, besides the one implemented by GMU during Testbed11.

6.3 Comparison between CSW 2.0.2 and CSW 3.0

As a summary, CSW 3.0 has extended substantially the existing CSW 2.0.2 version in the following aspects:

(1) Supports OpenSearch. This is a completely new feature in CSW 3.0. By providing metadata sharing and search through OpenSearch, better interoperability across different catalog instances, especially the interoperability with catalogs that implement standards beyond OGC, and the interoperability with general search engines, will be significantly enhanced.

(2) Provides a comprehensive picture to support federated distributed search. While support to distributed search is mentioned in CSW 2.0.2, the information model itself does not serve the purpose very well. The potential problems, such as dead loop and long response time, are mentioned, but solutions are not provided. In CSW 3.0, the enhancement to the information model in order to avoid the problems is described in detail. Two different distributed search scenarios are also discussed. Another major change to the information model is that the stateful request/response model in CSW 2.0.2 is removed. In CSW 3.0, all the communication becomes stateless. This change will reduce the load of work at the server side and provide better support to distributed search, in which the interaction across catalogs and clients is more complicated. Through the above analysis, it is determined that CSW 3.0 is more mature than CSW 2.0.0 in terms of supporting distributed search.

6.4 Semantic enablement in catalogue service

Although catalogue services have greatly increased the visibility of distributed geospatial data and services, the search part is still based on full text indexing and keyword search, which lacks semantic support and a better understanding of users' search intention. In recent years, researchers have acknowledged the importance of utilizing Semantic Web technology to enhance search efficiency. There are two families of search mechanisms that aim at implementing semantic-enabled search: semantic mediation and semantic association.

Semantic mediation enhances search performance without touching the backend information model of the CSW catalogue. This approach often utilizes ontology-based query expansion to support semantic search. Adding semantic associations between terminologies and keywords within the metadata of a data record enables saving these associations in a triple store then supporting semantic query in the front end for more intelligent searching. In this section, we discuss these two strategies and how they can potentially improve search performance significantly. Note that we exploit two approaches in terms of providing semantic association support to the existing catalogue search. These two approaches are discussed in Sections 6.4.1.2 and 6.4.1.3, respectively.

6.4.1 Semantic mediation in catalogue search

6.4.1.1 Search architecture design

Figure 9 demonstrates the use of ontology-based query expansion to serve as a semantic mediation layer to support semantic search. As mentioned earlier, such a search scenario does not need to alter the backend information model of a CSW service. Therefore, this loosely coupled architecture has the advantages of being easily deployable. As seen in Figure 9, the semantic mediation component on the left hand side is composed of an ontology and a semantic reasoner. The ontology defines the terminology and their relationships in the sub-disciplines of geospatial domain. The semantic reasoner converts the ontology defined in OWL/RDF into a semantic graph, based on which of the latent associations among different keywords can be identified. A reasoning engine could be Jena (https://jena.apache.org/) or Pellet (https://www.w3.org/2001/sw/wiki/Pellet). They can also be linked to a triple store such as Sesame (http://rdf4j.org/) to make the system more scalable than using a file-based system.

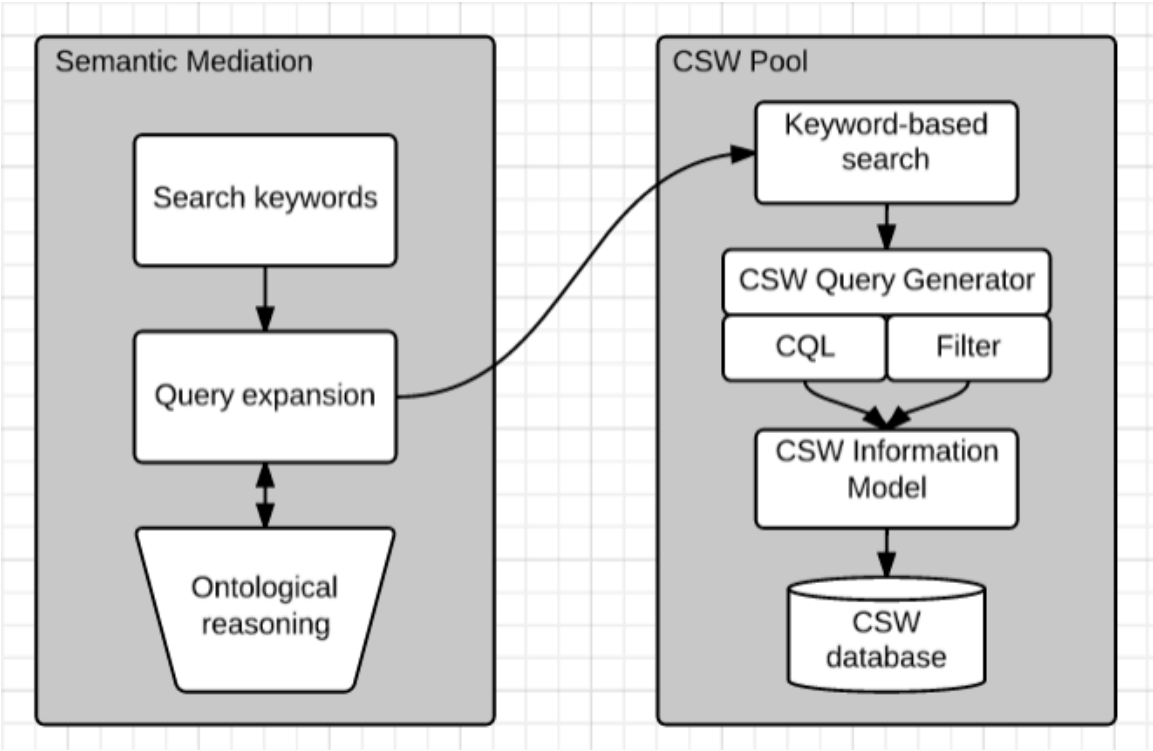

Figure 9. Semantic search as a mediation layer

The CSW pool component on the right of Figure 9 is a regular implementation of either CSW 2.0.2 service or CSW 3.0 service. It uses a database to store metadata records. The database schema should follow the CSW information model. The spatial information in the metadata needs to be spatially indexed. To support keyword-based query, the CSW implements CQL (Common Query Language), a SQL (Structured Query Language)-like query language for keyword matching. Alternatively, a CSW service can implement the OGC Filter specification to form an XML-formatted query to answer users' queries.

The below text shows the differences in grammar between a CQL query and a query based on an OGC filter. The CQL query requests all of the records for which the string "hydrology" appears in the Title and for which the geographical boundingbox lies completely within a certain area:

```
Title LIKE '%hydrology%' AND
WITHIN(ows:BoundingBox,ENVELOPE(3.19,7.26,53.59,50.67))
```

The same query written using OGC filter is:

```
<ogc:Filter>
  <ogc:And>
```

```
    <ogc:PropertyIsLike escape="\" singleChar="_" wildCard="%">
      <ogc:PropertyName>Title</ogc:PropertyName>
      <ogc:Literal>%hydrology%</ogc:Literal>
    </ogc:PropertyIsLike>
    <ogc:BBOX>
      <ogc:PropertyName>ows:BoundingBox</ogc:PropertyName>
      <gml:Envelope>
        <gml:lowerCorner>3.19 50.67</gml:lowerCorner>
        <gml:upperCorner>7.26 53.59</gml:upperCorner>
      </gml:Envelope>
    </ogc:BBOX>
  </ogc:And>
</ogc:Filter>
```

6.4.1.2 Implementation details

To implement this ontology-based semantic mediation framework, we first need to construct a domain ontology to link semantically related keywords and terminology to create a knowledge base that supports semantic reasoning. Li (2010) developed a multi-tier ontology to support such operations. Figure 10 demonstrates the conceptual model for the example domain ontology. The top most tier divides the geospatial domain into different disciplines/application subfields, including hydrology, geology, land use and land cover, etc. Then terminologies in each of these subfields are further divided into five different facets: process, property, substance, phenomena, and earthrealm. In another words, a term based on the content they present belongs to one of the above facets. For instance, “rain” is an instance of “Phenomenon”, “melt” belongs to the class of “Process”, and “particles” belongs to the facet “Substance”. Going down one more layer, is the facets are further divided by “object and relationship space”, where terms belonging to different facets are linked and interconnected together based on the semantic associations between them. For instance, the phenomenon “Weather” has the relation of “influencedBy” with a property concept “Temperature”.

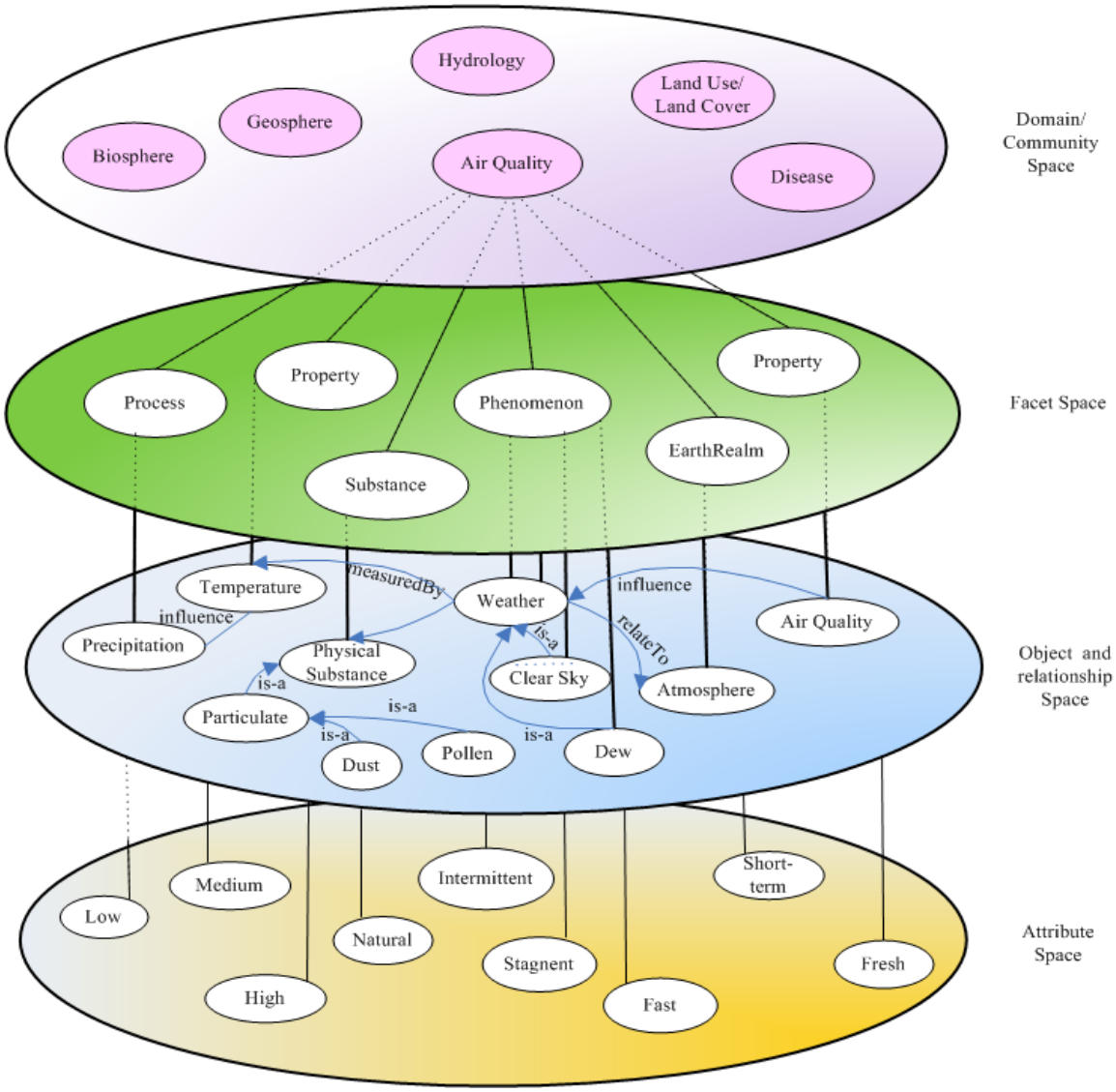

Figure 10. A conceptual model for a domain ontology (Li, 2010)

Based on this conceptual model, an ontology is developed. Figure 11 demonstrates an OWL (Web Ontology Language) segment that shows the hydrology component within the SWEET (Semantic Web for Earth and Environmental Terminology) ontology.

```
<rdf:RDF xmlns:owl="http://www.w3.org/2002/07/owl#"
xmlns:sys="http://sweet.jpl.nasa.gov/2.3/phenSystem.owl"
xmlns:com="http://sweet.jpl.nasa.gov/2.3/reprSciComponent.owl"
xmlns:trans="http://sweet.jpl.nasa.gov/2.3/phenFluidTransport.owl"
xmlns:realm="http://sweet.jpl.nasa.gov/2.3/realmHydro.owl"
xmlns:planet="http://sweet.jpl.nasa.gov/2.3/realm.owl"
xmlns:phen="http://sweet.jpl.nasa.gov/2.3/phen.owl"
```

```
xmlns:impa="http://sweet.jpl.nasa.gov/2.3/stateRoleImpact.owl"
xmlns:rela="http://sweet.jpl.nasa.gov/2.3/rela.owl"
xmlns:screla="http://sweet.jpl.nasa.gov/2.3/relaSci.owl"
xmlns:crela="http://sweet.jpl.nasa.gov/2.3/relaChemical.owl"
xmlns:geom="http://sweet.jpl.nasa.gov/2.3/phenGeolGeomorphology.owl"
xmlns:fluid="http://sweet.jpl.nasa.gov/2.3/phenFluidDynamics.owl"
xmlns:surf="http://sweet.jpl.nasa.gov/2.3/phenHydro.owl"
xmlns:comp="http://sweet.jpl.nasa.gov/2.3/matrCompound.owl"
xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
xmlns:xsd="http://www.w3.org/2001/XMLSchema#"
xml:base="http://sweet.jpl.nasa.gov/2.3/phenHydro.owl">
<owl:Ontology rdf:about="" owl:versionInfo="2.3">
<rdfs:label>SWEET Ontology</rdfs:label>
<owl:imports
rdf:resource="http://sweet.jpl.nasa.gov/2.3/matrCompound.owl"/>
<owl:imports
rdf:resource="http://sweet.jpl.nasa.gov/2.3/stateRoleImpact.owl"/>
<owl:imports
rdf:resource="http://sweet.jpl.nasa.gov/2.3/phenFluidTransport.owl"/>
<owl:imports
rdf:resource="http://sweet.jpl.nasa.gov/2.3/relaChemical.owl"/>
<owl:imports rdf:resource="http://sweet.jpl.nasa.gov/2.3/relaSci.owl"/>
<owl:imports rdf:resource="http://sweet.jpl.nasa.gov/2.3/rela.owl"/>
<owl:imports
rdf:resource="http://sweet.jpl.nasa.gov/2.3/realmHydro.owl"/>
<owl:imports
rdf:resource="http://sweet.jpl.nasa.gov/2.3/phenFluidDynamics.owl"/>
<owl:imports rdf:resource="http://sweet.jpl.nasa.gov/2.3/realm.owl"/>
<owl:imports rdf:resource="http://sweet.jpl.nasa.gov/2.3/phen.owl"/>
<owl:imports
rdf:resource="http://sweet.jpl.nasa.gov/2.3/phenGeolGeomorphology.owl"/
>
<owl:imports
rdf:resource="http://sweet.jpl.nasa.gov/2.3/phenSystem.owl"/>
<owl:imports
rdf:resource="http://sweet.jpl.nasa.gov/2.3/reprSciComponent.owl"/>
</owl:Ontology>
<!-- Phenomena -->
```

```
<owl:Class rdf:about="#HydrospherePhenomena">
<rdfs:subClassOf
rdf:resource="http://sweet.jpl.nasa.gov/2.3/phen.owl#PlanetaryPhenomena
"/>
<rdfs:subClassOf>
<owl:Restriction>
<owl:onProperty
rdf:resource="http://sweet.jpl.nasa.gov/2.3/rela.owl#hasRealm"/>
<owl:allValuesFrom
rdf:resource="http://sweet.jpl.nasa.gov/2.3/realm.owl#Hydrosphere"/>
</owl:Restriction>
</rdfs:subClassOf>
</owl:Class>
<owl:Class rdf:about="#Drainage">
<rdfs:subClassOf
rdf:resource="http://sweet.jpl.nasa.gov/2.3/phenSystem.owl#Removal"/>
</owl:Class>
<owl:Class rdf:about="#Discharge">
<rdfs:subClassOf rdf:resource="#WaterFlow"/>
</owl:Class>
<owl:Class rdf:about="#BaseFlow">
<rdfs:subClassOf rdf:resource="#Streamflow"/>
</owl:Class>
<owl:Class rdf:about="#FlashFlood">
<rdfs:subClassOf rdf:resource="#Flood"/>
<rdfs:subClassOf
rdf:resource="http://sweet.jpl.nasa.gov/2.3/phen.owl#ExtremeEvent"/>
</owl:Class>
<owl:Class rdf:about="#SnowCover">
<rdfs:subClassOf rdf:resource="#HydrospherePhenomena"/>
</owl:Class>
<owl:Class rdf:about="#Flood">
<rdfs:subClassOf rdf:resource="#HydrospherePhenomena"/>
<rdfs:subClassOf
rdf:resource="http://sweet.jpl.nasa.gov/2.3/phenSystem.owl#Inundation"/
>
<rdfs:subClassOf>
<owl:Restriction>
```

```
<owl:onProperty
rdf:resource="http://sweet.jpl.nasa.gov/2.3/relaSci.owl#hasImpact"/>
<owl:hasValue
rdf:resource="http://sweet.jpl.nasa.gov/2.3/stateRoleImpact.owl#Hazard"
/>
</owl:Restriction>
</rdfs:subClassOf>
</owl:Class>
<owl:Class rdf:about="#Drain">
<rdfs:subClassOf rdf:resource="#WaterFlow"/>
</owl:Class>
<owl:Class rdf:about="#OpenChannelFlow">
<rdfs:subClassOf rdf:resource="#WaterFlow"/>
<rdfs:comment xml:lang="en">
Flow of a fluid with its surface exposed to the atmosphere.
</rdfs:comment>
</owl:Class>
<owl:Class rdf:about="#Outflow">
<rdfs:subClassOf rdf:resource="#WaterFlow"/>
</owl:Class>
<owl:Class rdf:about="#OverlandFlow">
<rdfs:subClassOf rdf:resource="#Runoff"/>
</owl:Class>
<owl:Class rdf:about="#Runoff">
<rdfs:subClassOf rdf:resource="#WaterFlow"/>
<rdfs:comment>
Runoff is a term used to describe the flow of water, from rain,
snowmelt, or other sources, over the land surface, and is a major
component of the water cycle. Runoff that occurs on surfaces before
reaching a channel is also called a nonpoint source. If a nonpoint
source contains man-made contaminants, the runoff is called nonpoint
source pollution. A land area that produces runoff draining to a common
point is called a watershed. When runoff flows along the ground, it can
pick up soil contaminants such as petroleum, pesticides (in particular
herbicides and insecticides), or fertilizers that become discharge or
nonpoint source pollution.
</rdfs:comment>
</owl:Class>
<owl:Class rdf:about="#Snowslide">
```

```
<rdfs:subClassOf
rdf:resource="http://sweet.jpl.nasa.gov/2.3/phenGeolGeomorphology.owl#A
valanche"/>
</owl:Class>
<owl:Class rdf:about="#Streamflow">
<rdfs:subClassOf rdf:resource="#WaterFlow"/>
<rdfs:comment>
Streamflow, or channel runoff, is the flow of water in streams, rivers,
and other channels, and is a major element of the water cycle. It is
one component of the runoff of water from the land to waterbodies, the
other component being surface runoff. Water flowing in channels comes
from surface runoff from adjacent hillslopes, from groundwater flow out
of the ground, and from water discharged from pipes. The discharge of
water flowing in a channel is measured using stream gauges or can be
estimated by the Manning equation. The record of flow over time is
called a hydrograph. Flooding occurs when the volume of water exceeds
the capacity of the channel.
</rdfs:comment>
</owl:Class>
<owl:Class rdf:about="#StreamDischarge">
<rdfs:subClassOf rdf:resource="#Discharge"/>
</owl:Class>
<owl:Class rdf:about="#Torrent">
<rdfs:subClassOf rdf:resource="#Discharge"/>
</owl:Class>
<owl:Class rdf:about="#Debouche">
<rdfs:subClassOf rdf:resource="#StreamDischarge"/>
</owl:Class>
<owl:Class rdf:about="#WaterFlow">
<rdfs:subClassOf
rdf:resource="http://sweet.jpl.nasa.gov/2.3/phenFluidDynamics.owl#Flow"
/>
<rdfs:subClassOf>
<owl:Restriction>
<owl:onProperty
rdf:resource="http://sweet.jpl.nasa.gov/2.3/relaChemical.owl#hasSubstan
ce"/>
```

```
<owl:hasValue
rdf:resource="http://sweet.jpl.nasa.gov/2.3/matrCompound.owl#Water"/>
</owl:Restriction>
</rdfs:subClassOf>
</owl:Class>
<owl:Class rdf:about="#HydrothermalAlteration">
<rdfs:subClassOf rdf:resource="#HydrospherePhenomena"/>
</owl:Class>
<owl:Class rdf:about="#GroundwaterStorage">
<rdfs:subClassOf rdf:resource="#HydrospherePhenomena"/>
<rdfs:subClassOf
rdf:resource="http://sweet.jpl.nasa.gov/2.3/reprSciComponent.owl#Storag
e"/>
</owl:Class>
<owl:Class rdf:about="#Infiltration">
<rdfs:subClassOf rdf:resource="#LandWaterCirculation"/>
</owl:Class>
<owl:Class rdf:about="#Intrusion">
<rdfs:subClassOf rdf:resource="#LandWaterCirculation"/>
</owl:Class>
<owl:Class rdf:about="#LandWaterCirculation">
<rdfs:subClassOf rdf:resource="#HydrospherePhenomena"/>
<rdfs:subClassOf>
<owl:Restriction>
<owl:allValuesFrom
rdf:resource="http://sweet.jpl.nasa.gov/2.3/realmHydro.owl#UndergroundW
ater"/>
<owl:onProperty
rdf:resource="http://sweet.jpl.nasa.gov/2.3/rela.owl#hasRealm"/>
</owl:Restriction>
</rdfs:subClassOf>
<rdfs:subClassOf>
<owl:Restriction>
<owl:allValuesFrom
rdf:resource="http://sweet.jpl.nasa.gov/2.3/phenFluidTransport.owl#Tran
sport"/>
<owl:onProperty
rdf:resource="http://sweet.jpl.nasa.gov/2.3/rela.owl#hasPhenomena"/>
</owl:Restriction>
```

```
</rdfs:subClassOf>
</owl:Class>
<owl:Class rdf:about="#RadionucleiRetardation">
<rdfs:subClassOf rdf:resource="#HydrospherePhenomena"/>
<rdfs:comment xml:lang="en">
The process or processes that cause the time required for a given
radionuclide to move between two locations to be greater than the
groundwater travel time, because of physical and chemical interactions
between the radionuclide and the geohydrologic unit through which the
radionuclide travels.
</rdfs:comment>
</owl:Class>
<owl:Class rdf:about="#Recharge">
<rdfs:subClassOf
rdf:resource="http://sweet.jpl.nasa.gov/2.3/phenFluidTransport.owl#Tran
sport"/>
<rdfs:subClassOf>
<owl:Restriction>
<owl:allValuesFrom
rdf:resource="http://sweet.jpl.nasa.gov/2.3/realmHydro.owl#Aquifer"/>
<owl:onProperty
rdf:resource="http://sweet.jpl.nasa.gov/2.3/rela.owl#hasRealm"/>
</owl:Restriction>
</rdfs:subClassOf>
</owl:Class>
<owl:Class rdf:about="#DeepPercolation">
<rdfs:subClassOf rdf:resource="#Percolation"/>
</owl:Class>
<owl:Class rdf:about="#Percolation">
<rdfs:subClassOf
rdf:resource="http://sweet.jpl.nasa.gov/2.3/phenFluidTransport.owl#Tran
sport"/>
<owl:equivalentClass rdf:resource="#Percolate"/>
<rdfs:comment xml:lang="en">
Percolation concerns the movement and filtering of fluids through
porous materials.
</rdfs:comment>
</owl:Class>
```

```
<owl:Class rdf:about="#Percolate"/>
</rdf:RDF>
```

Figure 11. A hydrology component of the SWEET ontology

As seen, a number of "hydrology" terms, such as "Runoff", "Waterflow", and "Drainage" are defined. In addition to the classes, a number of associations are also defined. These include "isSubClassOf", "hasRealm", "hasPhenomenon", "hasImpact" and "hasSubstance." Using these relationships, the terms are interconnected to create triples. For instance, the below triples defines that flood is a type of extreme event and it has serious impact as a hazard.

http://sweet.jpl.nasa.gov/2.3/phenHydro.owl#Flood *isSubClassOf*
http://sweet.jpl.nasa.gov/2.3/phen.owl#ExtremeEvent

http://sweet.jpl.nasa.gov/2.3/phenHydro.owl#Flood *hasImpact*
http://sweet.jpl.nasa.gov/2.3/stateRoleImpact.owl#Hazard

These triples are formalized knowledge that is encoded in a machine understandable RDF (Resource Description Framework) language to foster semantic queries. The language SPARQL is often used to create the semantic query request. For instance, the SPARQL query for expanding the query in which "hydrology" is entered as the search keyword can be expressed as outlined below. Note that the SWEET ontology is used as the backbone knowledge base for semantic reasoning. Q1 is to retrieve all the terms that are defined as subclasses of "hydrology." Q2 is to search for all terms that are related to the keywords "hydrology" through any property defined in the ontology.

SPARQL Q1:

```
PREFIX rdf:  <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX xsd:  <http://www.w3.org/2001/XMLSchema#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX owl:  <http://www.w3.org/2002/07/owl#>
PREFIX PhenomenaNS: <http://localhost/ontology/phenomena.owl#>
PREFIX PropertyNS: <http://localhost/ontology/property.owl#>
PREFIX SubstanceNS: <http://localhost/ontology/substance.owl#>
PREFIX EarthRealmNS: <http://localhost/ontology/earthrealm.owl#>
PREFIX ProcessNS: <http://localhost/ontology/process.owl#>
SELECT *
 WHERE {
?someHydroClass rdfs:subClassOf #hydrology
}
```

SPARQL Q2:

```
PREFIX rdf:  <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
```

```
   PREFIX xsd:  <http://www.w3.org/2001/XMLSchema#>
   PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
   PREFIX owl:  <http://www.w3.org/2002/07/owl#>
   PREFIX PhenomenaNS: <http://localhost/ontology/phenomena.owl#>
   PREFIX PropertyNS: <http://localhost/ontology/property.owl#>
   PREFIX SubstanceNS: <http://localhost/ontology/substance.owl#>
   PREFIX EarthRealmNS: <http://localhost/ontology/earthrealm.owl#>
   PREFIX ProcessNS: <http://localhost/ontology/process.owl#>
   SELECT *
   WHERE {
   someHydroClass owl:onProperty ?p2 .
   someHydroClass rdf:type owl:Restriction .
   someHydroClass ?pre ?range .
   FILTER (?pre != owl:onProperty)
   FILTER (?pre != rdf:type)
   FILTER (?pre != rdfs:subClassOf)
}
```

After the query expansion, relevant keywords can be pulled from the ontology. The new keyword set can then be forwarded to CSW server for metadata search.

6.4.1.3 Search examples

Based on this logic, the data discovery workflow enabled by the ontology-guided semantic mediation within a CSW catalog can be performed as follows:

When the user provides a keyword, it will not be sent directly to the CSW server. Instead, the keyword will first go through the semantic mediation layer, where the query keyword “hydrology” will be expanded to a set of keywords that are relevant to “hydrology” or having similar meanings. For instance, “waterflow”, “runoff”, “watershed” may be returned as relevant keywords to “hydrology”. Then using this expanded set of keywords, a new search request can be generated. For instance, the example below shows the new CSW request after semantic mediation.

```
<ogc:Filter>
  <ogc:And>
    <ogc:Or>
        <ogc:PropertyIsLike escape="\" singleChar="_" wildCard="%">
                <ogc:PropertyName>Title</ogc:PropertyName>
                <ogc:Literal>%hydrology%</ogc:Literal>
        </ogc:PropertyIsLike>
        <ogc:PropertyIsLike escape="\" singleChar="_" wildCard="%">
                <ogc:PropertyName>Title</ogc:PropertyName>
                <ogc:Literal>%waterflow%</ogc:Literal>
        </ogc:PropertyIsLike>
```

```
      <ogc:PropertyIsLike escape="\" singleChar="_" wildCard="%">
             <ogc:PropertyName>Title</ogc:PropertyName>
             <ogc:Literal>%runoff%</ogc:Literal>
      </ogc:PropertyIsLike>
      <ogc:PropertyIsLike escape="\" singleChar="_" wildCard="%">
             <ogc:PropertyName>Title</ogc:PropertyName>
             <ogc:Literal>%watershed%</ogc:Literal>
      </ogc:PropertyIsLike>
    </ogc:Or>
   <ogc:BBOX>
     <ogc:PropertyName>ows:BoundingBox</ogc:PropertyName>
     <gml:Envelope>
       <gml:lowerCorner>3.19 50.67</gml:lowerCorner>
       <gml:upperCorner>7.26 53.59</gml:upperCorner>
     </gml:Envelope>
   </ogc:BBOX>
  </ogc:And>
</ogc:Filter>
```

Alternatively, three separate CSW search requests can be sent to the server with each semantically related keyword as an individual request.

Request 1.1: Search for "**hydrology**" related metadata record. This is the same as the original request without keyword expansion.

```
<ogc:Filter>
  <ogc:And>
    <ogc:PropertyIsLike escape="\" singleChar="_" wildCard="%">
      <ogc:PropertyName>Title</ogc:PropertyName>
      <ogc:Literal>%hydrology%</ogc:Literal>
    </ogc:PropertyIsLike>
    <ogc:BBOX>
      <ogc:PropertyName>ows:BoundingBox</ogc:PropertyName>
      <gml:Envelope>
        <gml:lowerCorner>3.19 50.67</gml:lowerCorner>
        <gml:upperCorner>7.26 53.59</gml:upperCorner>
      </gml:Envelope>
    </ogc:BBOX>
  </ogc:And>
</ogc:Filter>
```

Request 1.2: Search for "**waterflow**" related metadata record. The result-set is considered a subset of the entire request.

```
<ogc:Filter>
  <ogc:And>
    <ogc:PropertyIsLike escape="\" singleChar="_" wildCard="%">
      <ogc:PropertyName>Title</ogc:PropertyName>
      <ogc:Literal>%waterflow%</ogc:Literal>
    </ogc:PropertyIsLike>
    <ogc:BBOX>
      <ogc:PropertyName>ows:BoundingBox</ogc:PropertyName>
      <gml:Envelope>
        <gml:lowerCorner>3.19 50.67</gml:lowerCorner>
        <gml:upperCorner>7.26 53.59</gml:upperCorner>
      </gml:Envelope>
    </ogc:BBOX>
  </ogc:And>
</ogc:Filter>
```

Request 1.3: Search for "**runoff**" related metadata record. The result-set is considered a subset of the entire request.

```
<ogc:Filter>
  <ogc:And>
    <ogc:PropertyIsLike escape="\" singleChar="_" wildCard="%">
      <ogc:PropertyName>Title</ogc:PropertyName>
      <ogc:Literal>%runoff%</ogc:Literal>
    </ogc:PropertyIsLike>
    <ogc:BBOX>
      <ogc:PropertyName>ows:BoundingBox</ogc:PropertyName>
      <gml:Envelope>
        <gml:lowerCorner>3.19 50.67</gml:lowerCorner>
        <gml:upperCorner>7.26 53.59</gml:upperCorner>
      </gml:Envelope>
    </ogc:BBOX>
  </ogc:And>
</ogc:Filter>
```

Request 1.4: Search for "**watershed**" related metadata record. The result-set is considered a subset of the entire request.

```
<ogc:Filter>
  <ogc:And>
    <ogc:PropertyIsLike escape="\" singleChar="_" wildCard="%">
      <ogc:PropertyName>Title</ogc:PropertyName>
      <ogc:Literal>%watershed%</ogc:Literal>
```

```
    </ogc:PropertyIsLike>
    <ogc:BBOX>
      <ogc:PropertyName>ows:BoundingBox</ogc:PropertyName>
      <gml:Envelope>
        <gml:lowerCorner>3.19 50.67</gml:lowerCorner>
        <gml:upperCorner>7.26 53.59</gml:upperCorner>
      </gml:Envelope>
    </ogc:BBOX>
  </ogc:And>
</ogc:Filter>
```

6.4.2 Semantically enabled CSW information and search model

The previous section introduces semantic enablement of the CSW data discovery process through a more traditional way – semantic mediation. This approach improves the search performance without the need of altering the backend information model. In other words, the metadata information is still organized in a traditional way within the catalog, rather than being semantically organized. In this section, we will try out a new solution to enable semantic search by extending the current CSW information model with the addition of semantic annotation and semantic associations of and between the metadata records. We will present the proposed solution from three aspects: semantic association identification, semantic representation, and semantic query.

6.4.2.1 Extending CSW information model with semantic associations

Figure 12 demonstrates the semantic enablement of the current CSW information model. First, the metadata encoded in ISO (International Standardization Organization) is mapped to different groups representing different search contexts to be defined. These search contexts include “content”, “spatial”, “temporal”, “lineage” and other properties. The semantic associations among keywords and terms can then be defined by conducting latent semantic analysis (Li et al. 2015). The ebRIM-based CSW catalogue information model can be leveraged to manage the inter-term and inter-data relationship built from the knowledge mining process. The “Association” class in the information model will be extended to store such semantic association. In addition, ClassificationScheme and ClassificationNode classes defined in ebRIM can be used to store the information of a classification scheme tree for each of the search contexts.

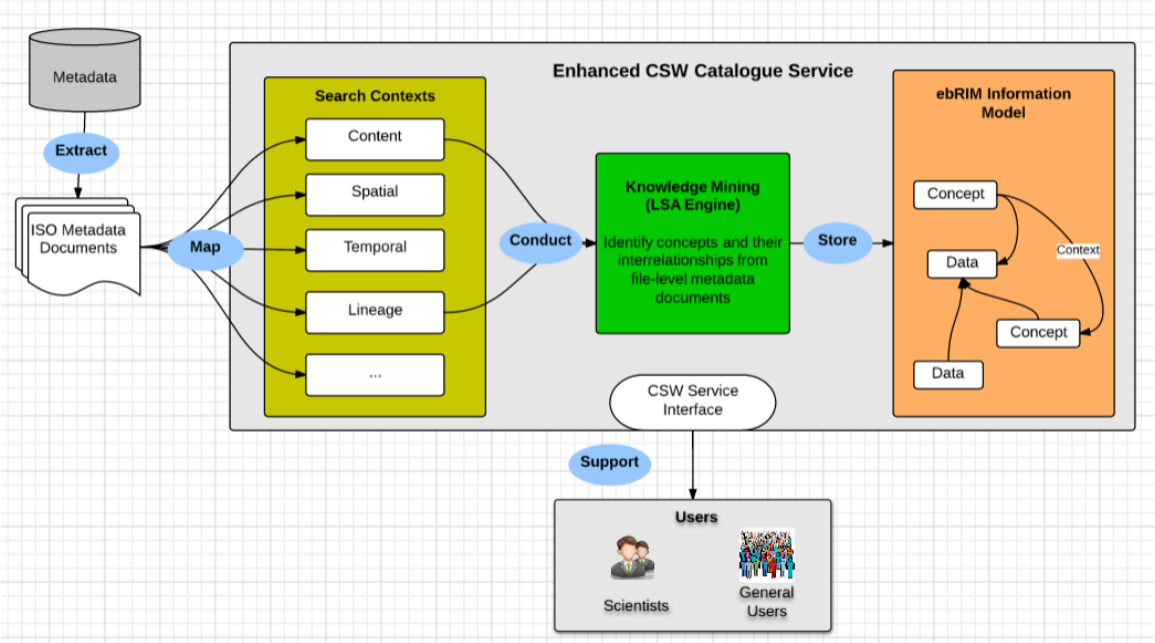

Figure 12. Proposed semantic mapping between ISO metadata record to semantic metadata in a CSW server

6.4.2.2 An extended OGC query for semantic data search

The OGC CSW specification defines a standard but extensible interface for discovering and querying metadata about geospatial resources over HTTP. Through the OGC CSW interface, users define their data search criteria using OGC Filter Encoding (OGC 09-026r1). To enable semantic search for discovering semantically related dataset, the standard OGC Filter Encoding and its Extensions package can be enhanced by introducing a new search operator "*DataIsRelated*". This new operator can take two input parameters. The first parameter is either an identifier of a data record or a concept term; the second specifies the data search context. This new operation will return a list of metadata records relevant to the given data or the given concept term under a specified search context. This new operator can be combined with other operators, such as spatial relations and value comparisons, predefined in the OGC Filter Encoding specification to achieve more complicated search capabilities. Figure 13 shows an example OGC CSW query* that leverages the new "*DataIsRelated*" operator to find data records relevant to a data object (identified by identified id93872) in terms of lineage and whose content is related to "hydrology".

```
<?xml version="1.0" encoding="ISO-8859-1"?>
<GetRecords service="CSW" version="2.0.2" maxRecords="500"
startPosition="1" resultType="results" outputFormat="application/xml"
outputSchema="http://www.opengis.net/cat/csw/2.0.2"
xmlns="http://www.opengis.net/cat/csw/2.0.2"
```

```
xmlns:ogc="http://www.opengis.net/ogc"
xmlns:cnd="http://daac.ornl.gov/catalog/connected-data"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:schemaLocation="http://www.opengis.net/cat/csw/2.0.2
../../../csw/2.0.2/CSW-discovery.xsd">
  <Query typeNames="Record">
    <ElementSetName>brief</ElementSetName>
    <Constraint version="1.1.0">
      <ogc:Filter>
        <ogc:And>
          <cnd:DataIsRelated>
            <cnd:RelationContext>Content</cnd:RelationContext>
            <cnd:Concept>hydrology</cnd:Concept>
          </cnd:DataIsRelated>
          <cnd:DataIsRelated>
            <cnd:RelationContext>Lineage</cnd:RelationContext>
            <cnd:DataObject>id93872</cnd:DataObject>
          </cnd:DataIsRelated>
        </ogc:And>
      </ogc:Filter>
    </Constraint>
  </Query>
</GetRecords>
```

Figure 13. Example OGC CSW Query for semantic data search (aspatial)

Figure 14 demonstrates another enhanced CSW query that combines semantic search based on the semantic association definition and the spatial filter. This query tries to identify all hydrology related datasets. These datasets should cover a requested spatial area, defined by bounding box “3.19 50.67; 7.26 53.59”.

```
<?xml version="1.0" encoding="ISO-8859-1"?>
<GetRecords service="CSW" version="2.0.2" maxRecords="500"
startPosition="1" resultType="results" outputFormat="application/xml"
outputSchema="http://www.opengis.net/cat/csw/2.0.2"
    xmlns="http://www.opengis.net/cat/csw/2.0.2"
    xmlns:ogc="http://www.opengis.net/ogc"
    xmlns:cnd="http://daac.ornl.gov/catalog/connected-data"
    xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:schemaLocation="http://www.opengis.net/cat/csw/2.0.2
../../../csw/2.0.2/CSW-discovery.xsd">
    <Query typeNames="Record">
        <ElementSetName>brief</ElementSetName>
        <Constraint version="1.1.0">
            <ogc:Filter>
                <ogc:And>
```

```
                    <cnd:DataIsRelated>

<cnd:RelationContext>Content</cnd:RelationContext>
                        <cnd:Concept>hydrology</cnd:Concept>
                    </cnd:DataIsRelated>
                    <ogc:BBOX>

<ogc:PropertyName>ows:BoundingBox</ogc:PropertyName>
                    <gml:Envelope>
                            <gml:lowerCorner>3.19
50.67</gml:lowerCorner>
                            <gml:upperCorner>7.26
53.59</gml:upperCorner>
                        </gml:Envelope>
                    </ogc:BBOX>
                </ogc:And>
            </ogc:Filter>
        </Constraint>
    </Query>
</GetRecords>
```

Figure 14. Example OGC CSW Query for semantic data search (spatial)

6.4.3 Semantic Web-enabled CSW catalogue search

The above two semantic enablement approaches attempt to provide semantic search support with mild modification to the CSW data and search model. Because Semantic Web technology has become increasingly popular, we also exploit possible solutions to convert CSW storage to a triple store and offer SPARQL query endpoint for semantic data discovery in this ER.

6.4.3.1 Service metadata description with OWL/RDF and URI support

To describe service metadata in Dublin Core or other formats of Semantic Web language, such as OWL (Web Ontology Language), we first need to semantically map the metadata slots in different standards to the OWL format. Taking the conversion from DC to OWL as an example, a list of ontologies, classes, properties, including class properties, data properties and annotation properties need to be defined. Among which, the following ontologies need to be integrated. Their prefixes are defined in Table 1. In these ontologies, the ones from the organization PURL (Persistent Uniform Resource Locators) define DC metadata related tags and annotations.

Prefix	Value
dc	http://purl.org/dc/elements/1.1/
dcam	http://purl.org/dc/dcam/
dcmitype	http://purl.org/dc/dcmitype/
dcterms	http://purl.org/dc/terms/
owl	http://www.w3.org/2002/07/owl#
rdf	http://www.w3.org/1999/02/22-rdf-syntax-ns#
rdfs	http://www.w3.org/2000/01/rdf-schema#
skos	http://www.w3.org/2004/02/skos/core#
xsd	http://www.w3.org/2001/XMLSchema#

Table 1. Ontologies for defining DC metadata in OWL to support semantic-enabled CSW

Figure 15 demonstrates the class definitions for DC metadata within an ontology editor Protégé. Two of the most relevant classes defined in the ontology are “Data” and “Service”, which represent the major data types that a CSW catalog will host. The annotation properties including “subject”, “title”, “type”, “source”, etc. can also be used to map DC metadata into the OWL encoding format. Using this new OWL scheme, a *GetRecord* request should be written as:

http://www.example.com/cat3/opensearch?service=CSW&version=3.0.0&recordIds=urn:ogc:ows11:service:urn:uuid:21fa3nfd-b60d-11de-8da0-bf22e55e7774&outputFormat=application/owl

where outputFormat should use “application/owl” to request a OWL-based service metadata.

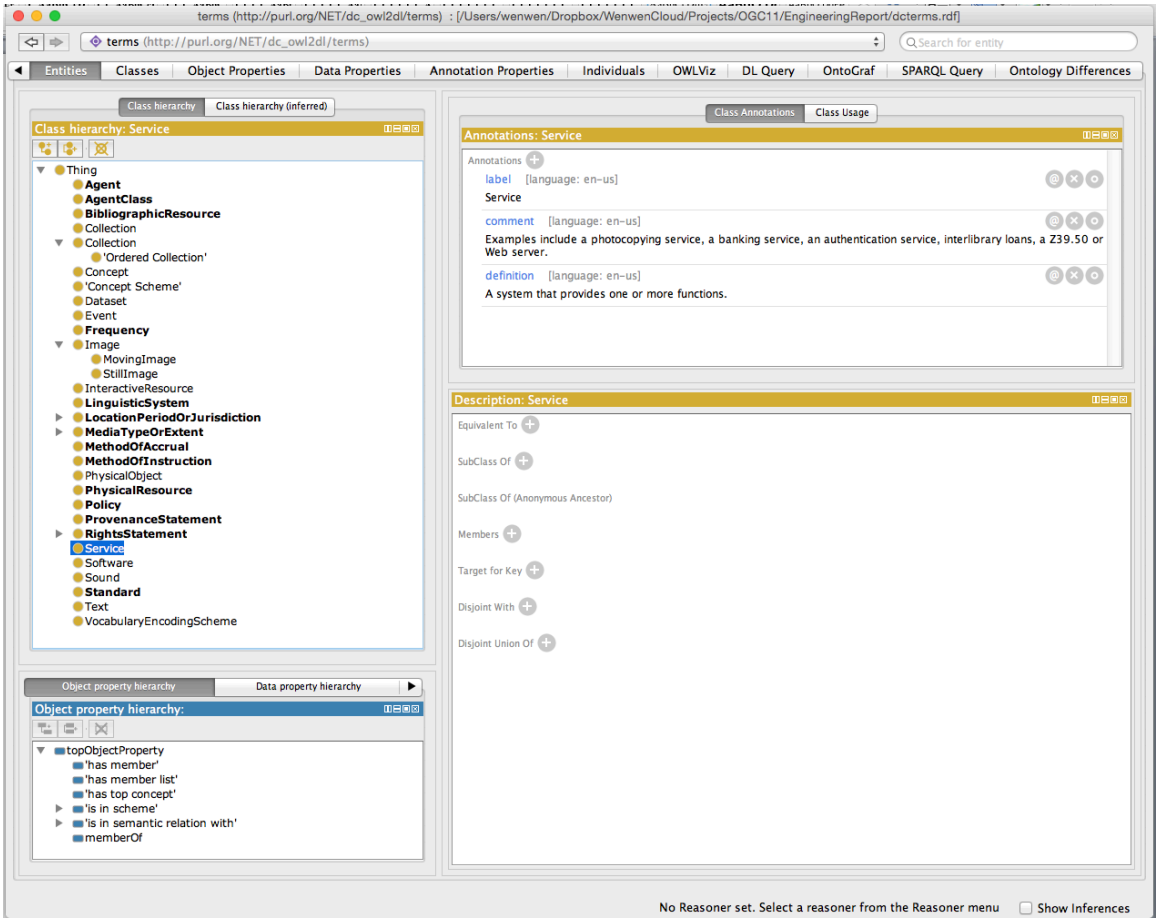

Figure 15. OWL profile for defining Dublin Core metadata

The response file describing the metadata in OWL format is demonstrated below:

<rdf:RDF xmlns="http://purl.org/NET/dc_owl2dl/terms#"
xmlns:dc="http://purl.org/dc/elements/1.1/" xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"xmlns:terms="http://purl.org/NET/dc_owl2dl/terms#"
xmlns:dcmitype="http://purl.org/dc/dcmitype/"
xmlns:owl="http://www.w3.org/2002/07/owl#"
xmlns:xsd="http://www.w3.org/2001/XMLSchema#"xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#" xmlns:dcam="http://purl.org/dc/dcam/"
xmlns:skos="http://www.w3.org/2004/02/skos/core#"
xmlns:dcterms="http://purl.org/dc/terms/"xml:base="http://purl.org/NET/dc_owl2dl/terms">
<owl:Ontology rdf:about="http://purl.org/NET/dc_owl2dl/terms">
<rdfs:label xml:lang="en">DCMI metadata terms</rdfs:label>
<dcterms:modified>2009-09-07</dcterms:modified>

<rdfs:comment xml:lang="en">
OWL 2 DL ontology for Dublin Core metadata terms from the http://purl.org/dc/terms/ namespace; this version is grounded in the DC elements ontology and only uses annotation properties.
</rdfs:comment>
<dcterms:license rdf:resource="http://creativecommons.org/licenses/by-sa/3.0/"/>
<owl:imports rdf:resource="http://purl.org/NET/dc_owl2dl/dcam"/>
<owl:imports rdf:resource="http://purl.org/NET/dc_owl2dl/dcmitype"/>
<owl:imports rdf:resource="http://purl.org/NET/dc_owl2dl/elements"/>
<dcterms:creator rdf:resource="http://simon-reinhardt.de/#me"/>
</owl:Ontology>
<owl:NamedIndividual
rdf:about="http://purl.org/NET/dc_owl2dl/terms#floodservice">
<LowerCorner rdf:datatype="http://purl.org/dc/terms/Point">-90.0 -
180.0</LowerCorner>
<UpperCorner rdf:datatype="http://purl.org/dc/terms/Point">90.0
180.0</UpperCorner>
<crs rdf:datatype="http://www.w3.org/2000/01/rdf-
schema#Literal">urn:ogc:def:crs:EPSG::4326</crs>
<dc:identifier>
urn:ogc:ows11:service:urn:uuid:21fa3nfd-b60d-11de-8da0-bf22e55e7774
</dc:identifier>
<dc:subject>Global Change Assessment Model</dc:subject>
<dc:subject>FloodImpactAssessment</dc:subject>
<dc:title>North 52 WPS (OGC Web Processing Service)</dc:title>
<dc:subject>Natural disaster</dc:subject>
<dc:subject>Flood risk</dc:subject>
<dc:subject>FloodFeatureEnrichment</dc:subject>
<dc:subject>Flooding</dc:subject>
<dc:subject>service</dc:subject>
<rdfs:seeAlso>
http://ows.dev.52north.org:8080/wps/WebProcessingService?Request=GetCapabilities&
Service=WPS&acceptversions=2.0.0
</rdfs:seeAlso>
<dc:subject>GCAM</dc:subject>
<dc:subject>Flood assessment</dc:subject>
</owl:NamedIndividual>
</rdf:RDF>

6.4.3.2 SPARQL/GEOSPARQL enabled semantic query interface of CSW

The triples describing metadata related information should be stored in a triple store, such as Sesame for efficient knowledge processing. Once the metadata arrives, the CSW server needs to identify its metadata standard, and then apply the corresponding OWL mapping profile to extract and record relevant information in the triple store in the backend. Then the CSW front end, besides supporting the existing KVP GET and XML-based POST request, can support retrieval of metadata from the backend triple store if a SPARQL endpoint is also be provided for semantically searching the data. At the same time, the metadata could also be inserted into a traditional catalog database, i.e. one that implements ebRIM information model. Figure 16 demonstrates the recommended CSW registration/search workflow to support semantic registration and query.

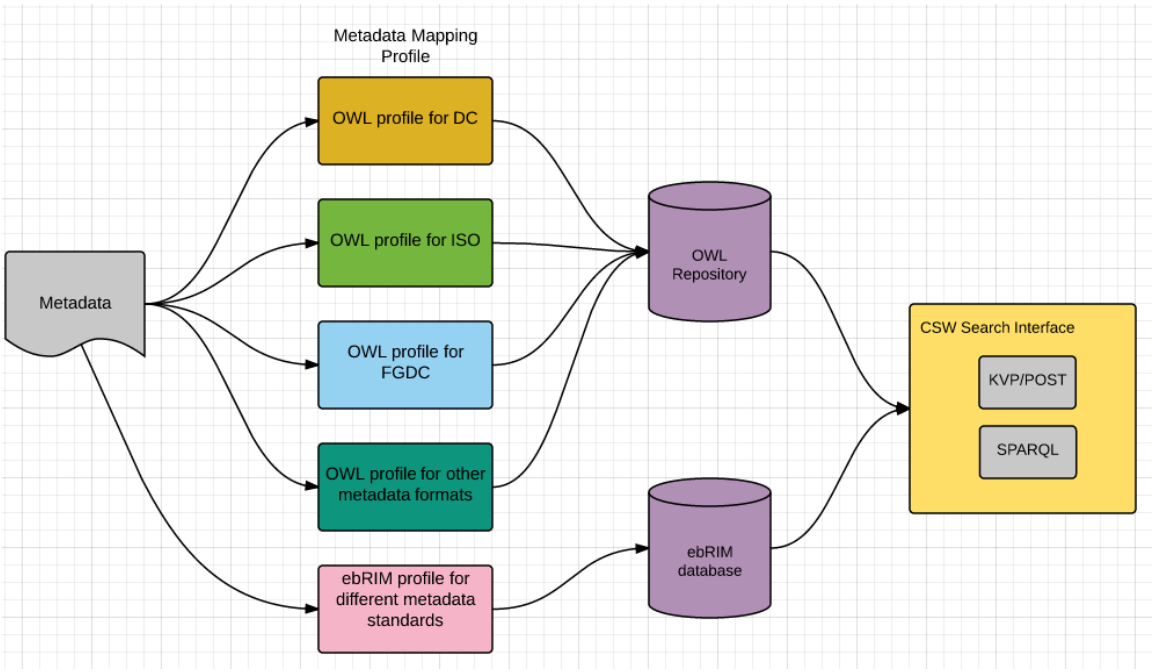

Figure 16. New CSW workflow to support semantic registration and query

An example SPARQL GetRecordByID request to retrieve the metadata can be expressed as:

PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX dc: <http://purl.org/dc/elements/1.1/>
SELECT ?metadata ?property ?value

```
    WHERE
{
    ?metadata ?property ?value .
    ?metadata dc:identifier ?id .
            FILTER (str(?id) = "urn:ogc:ows11:service:urn:uuid:21fa3nfd-b60d-11de-
8da0-bf22e55e7774")
}
```

The above SPARQL query aims at identifying the metadata record which has a unique identifier "urn:ogc:ows11:service:urn:uuid:21fa3nfd-b60d-11de-8da0-bf22e55e7774" and returns all of its properties and values. Figure 17 demonstrates the results in a table format. Future work can be done to encapsulate this resultset into an OWL format as that shown in Figure 16. In this way, a semantic catalog and semantic query can be fully implemented to support CSW cataloging and searching.

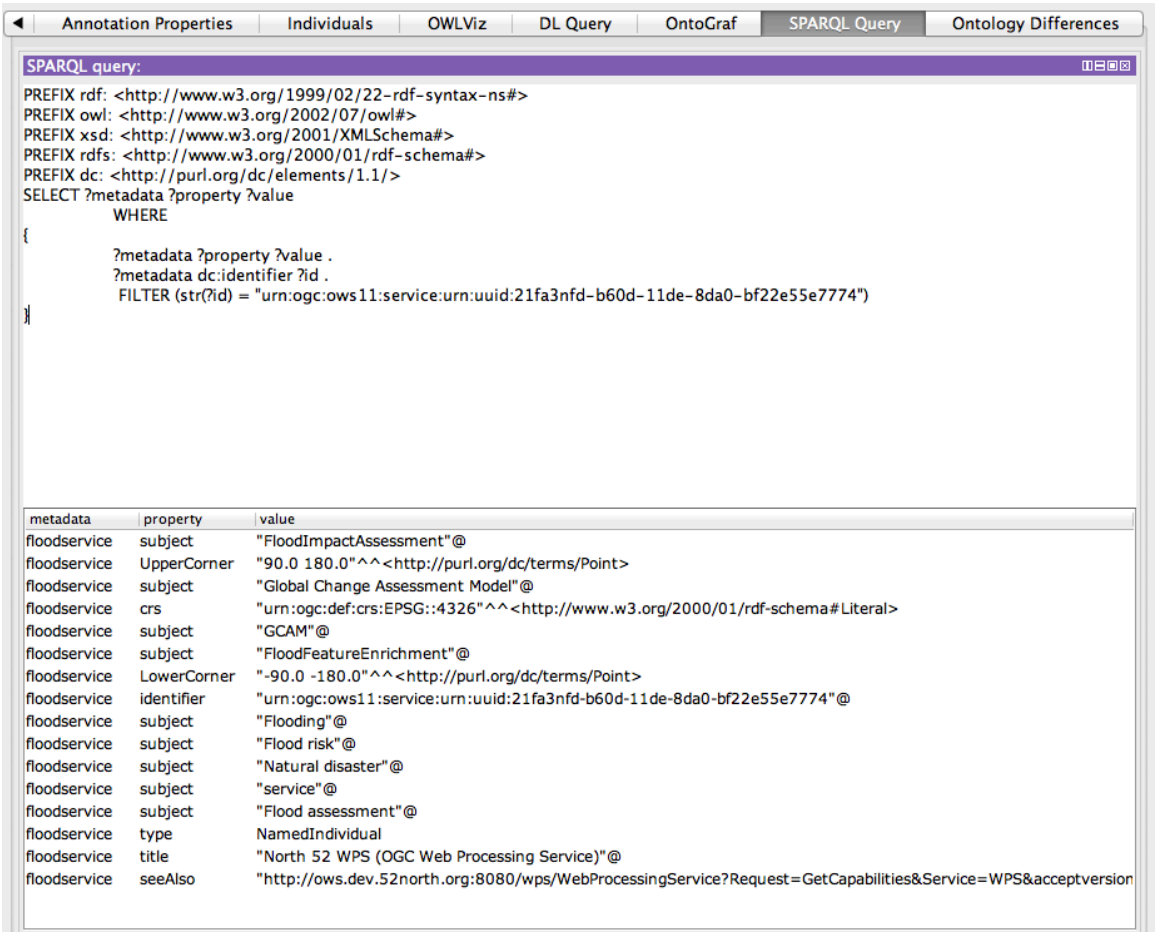

Figure 17. SPARQL query for CSW "GetRecordById" request

6.5 Summary of work and recommendations

This ER focuses on conducting a thorough review and analysis of the status of work for the OGC CSW standards.

A systematic comparison between the CSW 2.0.2 and the latest CSW 3.0 in terms of their architecture, their support to open search, distributed search, and federated search is conducted. The aim is to highlight the advancement of CSW 3.0 from the point of view of providing metadata cataloguing and search to CSW 2.0.2. Through ER work, the editors identify two major advantages of CSW 3.0 over CSW 2.0.2: First, the CSW 3.0 introduces a new feature to support OpenSearch. This is a completely new feature. By providing metadata sharing and search through OpenSearch, better interoperability across different catalog instances, especially the interoperability with catalogs that implements standards beyond OGC, and the interoperability with general search engines, will be significantly enhanced. Second, the CSW 3.0 standard draws a comprehensive picture to support federated distributed search. While support for distributed search is mentioned in CSW 2.0.2, the information model itself cannot serve the purpose very well. The potential problems, such as dead loop and long response time, are mentioned, but solutions are not provided. In CSW 3.0, the enhancement to the information model in order to avoid the problems is described in details.

Different distributed search scenarios are also discussed. Another major change of the information model is that the stateful request/response model in CSW 2.0.2 is removed. In CSW 3.0, all the communication becomes stateless. This change will reduce the load of work at the server side, and will provide better support to distributed search, in which the interaction across catalogs and clients is more complicated. Through the above analysis, it is convincing that CSW 3.0 is more mature than CSW 2.0.0 in terms of supporting distributed search. However, by using our NSF-ASU web crawler PolarHub, every few CSW 3.0 instances were found. Therefore, we strongly recommend that:

Recommendation 1: the catalog provider implements CSW3.0 as their catalogue standards due to CSW 3.0's advance support for OpenSearch, distributed search and federated search.

Part II discusses potential semantic enablement strategy to make the catalogue more intelligent and can support semantic search that is beyond pure keyword matching. Three semantic search strategies are discussed and proposed. The first semantic search strategy utilizes external domain ontology and a knowledge reasoner to support the semantic mediation. Nothing on the CSW catalogue side needs to be changed. The second semantic search strategy utilizes knowledge mining to discover the latent semantic associations among keywords and terminologies, and then use the extended CSW catalogue information model to store the semantic associations. This strategy started to involve the alternation of CSW architecture and implementation, but just to a mild extent. The third strategy is to completely renovate the CSW information model to convert it to a triple store and provides support to semantic query using the Semantic Web Query Language (SPARQL). These three semantic enablement strategies all have advantages

and disadvantages: as the degree of alternation to the CSW information model goes higher, we can express more semantics within the CSW catalogue. But at the same time, the difficulty and complexity in implementing a CSW server will greatly increase as well. This complexity raises a question of how well the community would be willing to adopt the new standard. Based on this analysis, we make the following recommendation:

Recommendation 2: OGC solicit efforts from the technical community in future testbed activities to prototype and test the proposed semantic enablement strategies in this ER for CSW catalog search and discovery.

Annex A: Revision history

Date	Release	Editor	Primary clauses modified	Description
03/09/2015		Wenwen Li		Outline
04/15/205		Wenwen Li, Sheng Wu		Open search section done for CSW 3.0
06/10/2015		Wenwen Li, Sheng Wu	Section 6.1	Section on CSW 2.0.2 is completed
07/01/2015		Wenwen Li, Sheng Wu	Section 6.2	Section on CSW 3.0.0 is completed
07/05/2015		Wenwen Li, Sheng Wu	Section 6.2	Section on comparison of CSW 2.0.2 and CSW 3.0.3 is completed
07/10/2015		Wenwen Li	Section 6.4.1	Section on semantic mediation of catalogue search is completed
07/15/2015		Wenwen Li	Section 6.4.2	Section on semantic association to improve catalogue search is completed
07/17/2015	0.9	Wenwen Li		First complete draft of the ER

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