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A Spatial Data Infrastructure Approach for the Characterization of New Zealand's Groundwater Systems

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Abstract

The future information needs of stakeholders for hydrogeological and hydro-climate data management and assessment in New Zealand may be met with an Open Geospatial Consortium (OGC) standards-compliant publicly accessible web services framework which aims to provide integrated use of groundwater information and environmental observation data in general. The stages of the framework development described in this article are search and discovery as well as data collection and access with (meta)data services, which are developed in a community process. The concept and prototype implementation of OGC-compliant web services for groundwater and hydro-climate data include demonstration data services that present multiple distributed datasets of environmental observations. The results also iterate over the stakeholder community process and the refined profile of OGC services for environmental observation data sharing within the New Zealand Spatial Data Infrastructure (SDI) landscape, including datasets from the National Groundwater Monitoring Program and the New Zealand Climate Database along with datasets from affiliated regional councils at regional- and sub-regional scales. With the definition of the New Zealand observation data profile we show that current state-of-the-art standards do not necessarily need to be improved, but that the community has to agree upon how to use these standards in an iterative process.

1 Introduction

New Zealand's freshwater resources are extremely valuable for the economic and environmental benefits and services that they provide. Large economic value comes from water supplies to agriculture, industry and domestic users (White 2001; White et al. 2001). The many environmental benefits of water resources also include the maintenance of aquatic ecosystems and provision of recreation opportunities (Harding et al. 2004). Currently, both surface water and groundwater resources are under pressure from development, e.g. as demonstrated by an approximate 50% increase in allocation between 1999 and 2006 (Ministry for the Environment 2006). Increasingly, the effects of land use on water quality are being recognized by communities.

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The current understanding of New Zealand's groundwater resources is generally less than is required to meet current and future water resources management challenges (White 2006). Since the publication of "Groundwaters of New Zealand" (Rosen and White 2001), much resource characterization at the sub-regional scale has been completed by regional councils as the responsible authorities, but stakeholder opinions have not been sufficiently recognized. Stakeholder information requirements for the characterization of New Zealand's groundwater resources were previously assessed by Lowry et al. (2003) and William et al. (2009), but might by outdated considering the latest technical and methodological developments. For instance, assessments have been incorporated into regional policies on groundwater quantity and quality, but besides reports and research articles, the actual collected and derived data has often not been published or otherwise made accessible, but is being archived in internal computer systems. This means essential environmental data is not directly available for national or cross-regional water resource management.

At the end of the last century, Albrecht (1999) discussed "offline" Geospatial information standards. Since then these standards transcended to "online" web service technologies with an increasing amount of available, web and cloud based, geospatial resources and modeling functions (Bailey and Chen 2011; Ballagh et al. 2011; Zhao et al. 2012). While offline geospatial content still has its value, the diffusion of this information available as hard copy maps, digital images or Portable Document Format (PDF) files is limited. The internet, as a fast, efficient, and effective information distribution medium, offers sufficient capabilities to provide continuously updated and 'live' information.

Typically, resource management decisions are based on environmental information that has spatial and temporal properties. Web-based geographic information systems (GIS) provide means to process and analyze spatio-temporal data and derive valuable information to inform policy development (Crompvoets et al. 2011; Latre et al. 2013). At the same time, information retrieval has become faster, but datasets remain scattered in both location and formats. Some 60–80% of the time and cost investments in projects involving spatio-temporal data are related to searching, discovering, accessing, understanding, transforming and pre-processing of relevant datasets, before the actual usage (Bandaragoda et al. 2006). The larger the number of datasets and the less structured the datasets are, the worse the situation becomes. Since we are not only looking at single data users but also considering multi-vendor architectures and multi-user applications, a considerable loss of economic and production power due to inefficiency and ineffectiveness is apparent.

Open and easy access to hydro(geo)logical data and information is a key issue for the timely assessment and management of groundwater resources (Klug and Kmoch 2014). Generally, publicly or proprietary distributed data is made available via manual downloads as PDF reports, time series in spreadsheets or comma-separated text files or in other proprietary formats and application programming interfaces (APIs) of commercial software products. Examples include current legacy web portals such as Institute of Geological and Nuclear Science's (GNS) Geothermal and Groundwater database (GGW) and National Groundwater Monitoring Program (NGMP) (Daughney and Reeves 2006) or National Institute of Water and Atmospheric research's (NIWA) Climate and Flow Databases (CLIDB). New Zealand Regional Councils increasingly display regional hydro-climate and water quality information to the citizens on their websites through custom data viewers or download sites, again generally through custom or proprietary non-streamlined formats. Thus, constraints on the standardized and structured access of hydro(geo)-logical and related data and information are a significant impediment to easy re-use for national and cross-regional projects. Constraints include inconsistencies across organizations such as: data format and standardized APIs as well as parameter naming and descriptions.

Standards, tools, and interfaces are being developed by the Open Geospatial Consortium (OGC) for data transfer, processing and visualization in a distributed Spatial Data Infrastructure (Botts et al. 2008; Liang et al. 2005). OGC standards suitable for spatio-temporal observation data include interface standards for web services, e.g. Web Feature Service (WFS, OGC 2010b), Web Coverage Service (WCS, OGC 2010a), but in particular from the OGC Sensor Web Enablement (SWE; OGC 2011b) framework for time-series and environmental observation data, Sensor Observation Service (SOS, OGC 2012a), as well as data encodings: Observations & Measurements (O&M, OGC 2011a) and Water Markup Language (WaterML2.0, OGC (2012c)). These standards are used to publish and use hydro(geo)logical feature and coverage data, time series and metadata (Bröring et al. 2011; OGC 2012b). Jirka et al. (2012) also propose a lightweight station profile for SOS-based observation data delivery. De Andrade et al. (2011) describe how a federation of catalogues through the Catalogue Services for the Web (CSW, OGC 2007a) service interface improves overall access to distributed metadata records. These developments and standards contribute to and correlate with the efforts of the New Zealand Geospatial Office (NZGO) to establish a nationwide SDI including approved international (ISO) and Australian and New Zealand (AS/NZS) standards (Klug and Kmoch 2014).

A common data exchange format is required to transfer hydro(geo)logical data and time series data between users. The Geographical Markup Language (GML, OGC 2007b) provides the foundation for application schemas for feature description, e.g. GeoSciML (Sen and Duffy 2005) and GroundwaterML (Boisvert and Brodaric 2012), and for encodings to exchange hydrological time-series data (WaterML2.0), which have gained attention in the literature (Atkinson et al. 2012; Bermudez and Arctur 2011; Brodaric and Booth 2011). Finally, data sources including their respective metadata sets should be discoverable (e.g. by a web-based keyword search). OGC CSW provides these capabilities. Similar initiatives on a national and international scale that aim to meet these standards include AuScope (Australia), Groundwater Information Network (Canada) and CUAHSI (North America), as well as the activities in the Infrastructure for Spatial Information in Europe (European Commission INSPIRE Directive 2007/2/EC; Portele et al. 2009).

This article describes the development of an OGC standards based Environmental Observation Data Profile (EODP) in New Zealand. We question whether or not the current state-of-the-art standards need to be or can be applied for a common web-enabled framework for distributed (groundwater-related) geospatial feature and observation data discovery and access for monitoring and reporting of general environmental parameters within the New Zealand National Environmental Monitoring Standards (NEMS). The development of the groundwater SDI concept in New Zealand is part of the Smart Aquifer Characterization (SMART) program (Klug et al. 2011) and emerged from continuous community interaction. Input to the design of the groundwater SDI and the observation data profile has come from stakeholder liaison, which has been tested with the two nationally significant databases of the National Groundwater Monitoring Program (NGMP) and the National Climate Database (CLIDB).

2 Materials and Methods

2.1 Stakeholder Liaison

With the initiation of the SMART project in 2011 stakeholder workshops were organized by GNS Science in September 2011 with key stakeholders from five regional councils, the Ministry for Environment and NIWA. Here we identified target users groups and their needs as listed in Table 1.

Table 1 The different target user groups and their needs for groundwater information

Target stakeholders	Example information needs	Role in programme
The public, including Māori, students, interest groups	• Information for process participation and awareness-building • Access to cross-region information • Protection of cultural, recreational, economic, etc. values of water	Participation via feedback mechanisms regarding relevance and usability of research results.
Water managers and regulators, including regional and district authorities	• Easy access to reliable, standardised data for comparison and benchmarking • Cost reduction in water management and monitoring • Protection of cultural, recreational, economic, etc. values of water	Direct involvement as research partners, active data user and data provider, driver of applications in case study areas
Private sector, including farmers, irrigators, tourism operators, construction companies	• More demand-orientated supply of the data from public authorities • Improved services and applications related to spatial datasets, including environmental impact assessment, real estate evaluation	Continuous feedback by means of workshops, consultation and deliverables
Policy makers, including central and regional government, related NGOs, public-private-partnerships	• NZ wide access to geospatial data to support policies and structured impact assessments • Improved environmental monitoring in NZ • Information to support evidence-based policy development and legislative decision making	Continuous feedback by means of workshops, consultation and deliverables
Environmental and scientific institutes, including LINZ, universities, CRIs	• Easy access to reliable, harmonised datasets • Scientific interpretation and analysis of the data	Direct involvement as research partners, active data user and data provider, partner in case study areas

Another workshop at the New Zealand Hydrological Society's annual conference in December 2011 aimed to inform participants (including regional councils, water-related commercial companies, research organizations and universities) about the SMART project and to involve them in the development of a common groundwater portal (Klug et al. 2011). These meetings summarized presently scattered current groundwater information silos and gathered feedback about stakeholder needs in hydrological data access and management.

Following up on stakeholder requirements with first data sharing concepts and prototype implementations in 2012 (e.g. the New Zealand Groundwater Forum and with Horizons Regional Council) lead to a specific data access, transfer and visualization workshop with 36 participants at the Hydrological Society Conference New Zealand in December 2012. These meetings originally addressed questions including: "What kind of databases and tools, standards and services are already in place to characterize New Zealand's groundwater resources?" and "What are the current missing elements preventing proper characterization of New Zealand's groundwaters?" and have been extended to include hydro-climate data sharing across New Zealand to improve fresh water management (surface and groundwater).

Community engagements and stakeholder interest in a general hydro-climate data federation in New Zealand increased and further iterative workshops were held at Horizons Regional Council and another data access workshop at the annual Hydrological Society's conference with 57 attendees in 2013 sought to reconcile the state-of-the-art in hydrological data federation. In 2013 two surveys were issued: one consisting of three simple questions to indicate interest and suggest frequency of further workshops; and the other a large questionnaire to assess technical details in hydro(geo)logical and meteorological data management systems. This questionnaire was divided into four sections: (1) General information about the participants, containing of six questions, each answer with multiple choice and an alternative free text field; (2) Information on spatial datasets and data management practices, containing 24 questions, each answer with multiple choice, 13 of those with an alternative free text fields; (3) Sensor Observation Networks, aiming to obtain information about (live) telemetry and in-situ data logging, containing six questions, each answer with multiple choice, one with alternative free text field; and (4) Web services and visualization requirements, aiming to obtain information about stakeholder practices regarding public data sharing, geoportals, the use of standards and needs related to data exploration and visualization, containing 19 questions, of these 13 being multiple choice with an alternative free text field and the remaining six each having five sub-topics asking for a short statement, product name or technical term. The structure and design of this questionnaire was oriented on the best practices from a similar questionnaire which was used in the European GS Soil project (Klug and Bretz 2012) to assess data, processes and technology around soil data management in Europe within the INSPIRE framework.

In February 2014 a trans-disciplinary workgroup with participants from regional councils, research organizations and a commercial software provider was founded to transcend the hydro-climate data federation into the EODP, which is based on OGC standards, for the integration with New Zealand's SDI landscape. This working group, of which the authors are members, held two workshops in 2014 where documentation and prototype implementations were developed. The SMART project's groundwater portal is one of them. Results were presented at the New Zealand Hydrological Conference in Blenheim in November 2014.

2.2 Groundwater Portal Architecture

The SMART groundwater portal is designed as a client to the emerging New Zealand SDI and consists of a backend web application that runs as a mixed Java/Scala web service on a server.

The user interface is a web-based Hyper Text Markup Language (HTML) 5 and JavaScript frontend to the backend web application and runs in the browser to ensure easy and platform independent access to hydro(geo)logical data.

The portal's data structure has been designed as a client to a Service Oriented Architecture (SOA) that can connect to multiple services and data sources (Hildebrandt and Döllner 2010). Reviews of the INSPIRE process, OGC water-related manuscripts and specifically data structures for New Zealand indicate the following key building blocks.

The backend serves as a data management and processing framework. The backend conducts all OGC service queries and response handling, particularly WFS complex features, CSW metadata and SOS time-series parsing. All responses are subsequently prepared to be visualized by the frontend in dynamically generated views. The aim is not to overload the client browser with heavy data processing tasks and keep the user experience unencumbered. The frontend is merely a visualization and browsing utility, and except for plain web-mapping capabilities, data graphing and simple features access via WFS. The frontend does not connect to any web services other than the backend.

2.3 Metadata and Discovery

Integration of a CSW services is suggested to incorporate metadata based on OGC web services. Common metadata provisioning tools (e.g. GeoNetwork Opensource, the Esri Geoportal Server and 'pycsw') all comply with the CSW 2.0.2 specification and support the ISO metadata and encoding standards ISO 19115 (2003), ISO 19119 (2005) and ISO 19139 (2007). GeoNetwork Opensource and Esri's Geoportal Server provide a fully-fledged all-in-one catalogue solution, including a fully functional and customizable web interface that allows users to explore datasets and view and edit metadata. In contrast, pycsw is less 'resource-hungry' as it only provides access through the CSW protocol. Metadata entry, search and general discovery services can be provided through a geoportal user interface. The CSW response for a GetRecords or GetRecordById request is XML-based and complies with the ISO 19139 application schema, for catalogue service metadata response encoding.

In New Zealand it is becoming common practice that major data providers are also providing their own CSW-service (as opposed to one shared CSW-catalogue for all). On the one hand, this is desirable, because the data provider is in the best position to manage their service content (i.e. has the best knowledge of the data). On the other hand, for a user/client this leads to the challenge of searches across multiple distributed catalogues. This can be tackled with federated searches, meaning the same query is submitted to each known CSW service instance. Hydrological and geographical datasets and data publishing web services (OGC WMS/WFS/SOS) from participating regional councils are registered in such a CSW-capable service as MD_Metadata documents and can be searched.

2.4 Environmental Observation Data Profile (EODP)

The EODP was created to provide unambiguous requirements for OGC web services that serve environmental observation data using the O&M application schema (or its extensions). As an OGC profile, it does not define new interfaces or data models; instead, it identifies the minimum set of existing specifications needed to support the use cases defined by the community of users mentioned above. It is published as a PDF document that conforms to the OGC Modular Specification (OGC 2009) and comprises a set of requirements classes and corresponding conformance tests. The requirements classes govern the deployment of web services: mandatory service types and operations; and the GML application schema they use: required classes, properties and constraints on content.

The EODP has a modular structure comprising a core to which all services must conform, and a set a domain-specific extensions (for example modules for hydrology or pedology) that define additional requirements for those communities. At the time of writing, a core module defining universal behavior has been published and a WaterML 2.0 hydro-climate data extension developed.

The core profile mandates a WFS 2.0 service for discovery of observations of phenomena according to their spatio-temporal location. Responses shall be encoded as O&M 2.0 SF_SpatialSamplingFeature and OM_Observation feature types. However, the result of the observation is withheld, as it only serves as a discovery mechanism. Each OM_Observation functions as an index encompassing all observations with the same metadata (i.e. observed property, procedure, feature of interest) and describing the time frame as phenomenon time within the observation. An additional inherited GML metadata property with a CI_OnlineResource element provides the location of a SOS or WFS that hosts the actual data. Figure 1 shows the conceptual model of a services interplay, where the client interacts with the data services. Identifiers for observed properties for the available observations are pointing to a shared vocabulary service, which provides a full name and description based on the enquired identifier. Thus, a client can request more details about the type of the observed property.

EODP compliant services are being tested with the groundwater quality and groundwater level time series datasets from NGMP and the CLIDB, which have previously only had custom proprietary web interfaces. A data-source specific interface layer is developed to publish these data sets via OGC-compliant web services. Thus, such data sets in turn can be integrated into the portal without copying of datasets and therefore avoiding duplication of large databases. This web service integration is specific for each source dataset, specifically a web-enabled database interface for the NGMP and the CLIDB databases is developed. Both provide OGC SOS 2.0 access to the data and map the domain specific observation data into WaterML2.0/O&M 2.0 data streams. These test services have been implemented using the Geoserver (with app-schema plugin) and Snowflake GO Publisher WFS applications.

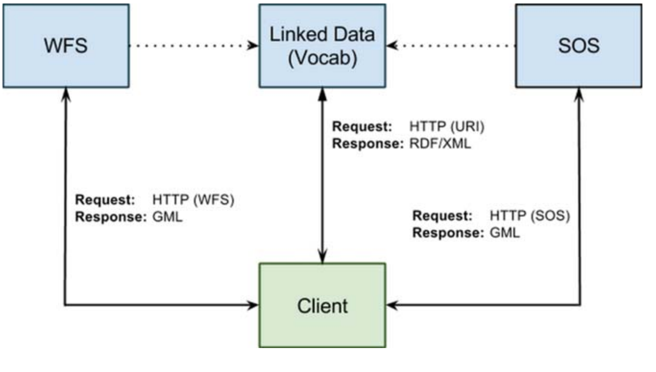

Figure 1 Schematic view of service interaction in EODP Specification Document https://github.com/EODP-NZ/eodp-dev/blob/master/doc/spec-eodp-core-1.0.pdf (Ritchie et al. 2014)

3 Results

3.1 Stakeholder Workshops and Questionnaires

The first "Data Access Workshop" was held in December 2012 collocated with the annual Conference of the New Zealand Hydrological Society. Regional councils, commercial companies and research agencies presented their approaches to data sharing in a one day session. In 2013 a questionnaire was issued to assess technicalities and processes of recent state-of-the-art hydro-climate data management, but also occurring needs in addressing future challenges in particular in fresh water management. This questionnaire was created as an online survey and could be filled out with the browser. The link was sent out via the mailing list of the Hydrological Society including a letter of invitation addressing everyone with interest or work related to hydrology in New Zealand. The mailing list at that time had 473 registered subscriber email addresses. 71 started to fill out the questionnaire, and 17 fully completed it. The majority of the remaining 54 participants did not continue after the first section. In December 2013, a second "Data Access Workshop" was held collocated with the joint annual conferences of the New Zealand Hydrological Society and the Meteorological Society of New Zealand, presenting the outcomes of the former questionnaire and discussing future directions. A small questionnaire with three free-text questions regarding further interest and frequency in these data access workshops was conducted with basic paper sheets and has been submitted by 21 out of 57 officially registered workshops participants. Key statements were about the lack of "leadership" and how the "standards" can solve the actual problems.

As a result of the stakeholder interactions a variety of tools, applications and databases to manage hydrogeological and hydrological data used by New Zealand's regional councils, research institutes and consultancies became apparent (Table 2). The Data Tamer™ application suite from the Hilltop software company is very popular among regional councils to manage and work with hydrological time series data. Hilltop software, the successor of TIDEDA™, is now used by almost 80% of the regional councils. The demand for public distribution of hydrological time series data (in near real time) is increasing. Hilltop implements a prototypical version of the OGC standards SOS 2.0, WFS 1.0.0 and WaterML2.0 for hydrological time series, claiming to support the OGC SOS Profile for Hydrology. As of the end of 2014, Hilltop did not support the SOS DescribeSensor operation, which is part of the SOS 2.0 core requirements and not the SOS 2.0 GetDataAvailability operation, which has been defined by the SOS Hydrology Profile. Hydstra™ (hydrological data management) and HydroTel™ (telemetry solution) are connected to the Kisters Wiski™ and KIWIS™ products but are not interoperable themselves. Regional councils are currently evaluating software (including commercial, free and open source) for geospatial data to publish the publicly-available parts of their data via OGC web services. Regarding sensor information and integration, there is a great variety of sensor-based information around New Zealand, including pump tests, water sample analysis, and flow recording. Based on stakeholder feedback, HydroTel™ is the most commonly-used sensor network system for hydrological data, incorporating data loggers and real-time (wireless) upstream data transmission.

3.2 NGMP and CLIDB as EODP Service Implementation Prototypes

Following up on the continuous stakeholder engagement, a workgroup was formed to formalize the emerging standards for hydro-climate and general observation data federation in New Zealand and develop the New Zealand Environmental Observation Data Profile (EODP) into a standardization document. The profile refines existing information and web service

Table 2 Overview of main hydro(geo)logical data management systems in use in New Zealand

Tool	Description
Tideda™	DOS/Windows-based database and reporting application for hydrology-related time series data, uses special file formats, prequel to Hilltop, now maintained by NIWA (NIWA 2013).
Hilltop Data Tamer™	Windows-based database and reporting application suite for hydrology-related time series data, uses special file formats, server system which provides REST-style XML access and can import HydroTel™ data. OGC support is planned (Rodgers 2013).
Hydstra™	Database and reporting application for hydrologic time series data. This Australian-based company was acquired by German-based company Kisters around 2003 that promotes Wiski which provides data migration paths (Kisters 2013a).
Kisters Wiski™	Fully-fledged data management and reporting system for hydrological data and time series, Kisters is currently working on WaterML2.0 and took part in the OGC surface water interoperability experiment ((Kisters 2013c), (Kisters 2013b) OGC news).
HydroTel™	Telemetry/sensor system from New Zealand-based iQuest company, which was acquired by Kisters in 2007 (IQUEST 2013). Kisters and HydroTel interoperability tests are described in (IQUEST 2011).
Oracle™ and Spatial/Locator™	Many regional councils and agencies use an Oracle database with and without its spatial extensions and implement independent data models to store hydrogeological and hydrological data including information related to bores, wells, springs and hydro-climate data, e.g. the Geothermal and Groundwater Database (GGW) including the National Groundwater Monitoring Programme (NGMP) (GNS Science 2013), EW bore database (Waikato Regional Council 2013) and NIWA Climate Databases (NIWA 2015)

specifications published by the OGC, and vocabulary data standards defined by the World Wide Web Consortium (W3C) (Ma et al. 2011). The only scenario supported directly by this document is data discovery where the services and their responses act as indexes – providing the minimum required information to locate observation data for a phenomenon in space and time. This will be supported by WFS. Other scenarios, mainly focused on data delivery, will be addressed by the domain specific extensions to this profile, e.g. a WaterML 2.0 profile for hydro-climate time-series data delivery. These will be supported by a SOS and/or a WFS (Ritchie et al. 2014). Both, the databases of the NGMP as well as CLIDB, have their own domain specific database schemas as well as dedicated custom web interfaces for data access. To make these databases interoperable, two versions of the open source 52°North Sensor Observation Service have been modified to connect to each of the databases. The abstraction data model for its native database schema and its data access objects (DAOs) have been rewritten to fit the specific data models of NGMP and CLIDB and map their respective data models into the OGC SOS/O&M data model.

Table 3 displays how the data access semantics have been mapped. The NGMP-SOS and the CLIDB-SOS can now deliver time-series and observation data into the SDI.

To comply with EODP, the CLIDB stations have been exported into a spatially enabled PostgreSQL database and published via the commercial software Snowflake GO Publisher WFS service as Spatial Sampling Features including related observations. Herein the result values in the observations are withheld, as the WFS is only intended for discovery but not of actual time-series delivery. A similar approach has been conducted with the NGMP sites, except that as WFS server the open source software Geoserver has been trialed. A difference in the behavior and functionality was the support of time within WFS complex features queries. Snowflake allowed querying the Sampling Features for related observations by TimePeriods, but not TimeInstants. The opposite behavior was true for Geoserver.

3.3 *The Groundwater Portal as SDI Client*

Based on the latest available international and national standards and the identified existing gaps in New Zealand, a service-oriented modular based concept has been realized in the SMART groundwater portal (http://portal.smart-project.info/) as shown in Figure 2. Multiple interfaces provide the means to deliver, use and visualize hydro(geo)logical data. The main processing, transport and mediation happens within the 'Data Interface and Services Layer', which is part of the backend application running on the web server. Existing data providers can be registered and connected to the infrastructure via standardized OGC web services.

The web interface, also referred to as 'frontend' or user interface, is the part of the service that is visible to the user. This interface presents the data from the 'Data Interface and Services Layer' and includes web applications providing data viewing capabilities, like traditional 2D web maps with sampling feature locations and related time-series data graphs and attribute tables, as shown in Figure 3.

Furthermore, the interface includes utilities to query, search, and discover registered datasets. Data is also directly accessible via the explicit OGC web service interfaces for use with GIS and other hydrological software applications that support OGC web services. Likewise, datasets and related metadata can be queried through the portal's CSW interface (see Figure 2), which will distribute CSW GetRecords search queries across the major geoportals in New Zealand, including LINZ Data Service (LINZ 2015), geodata.govt.nz, NIWA Environmental Information Browser (NIWA 2015a), Landcare LRIS Portal and Department of Conservation (DOC) Geoportal and collate the search results with reference back to their original catalogue.

4 Discussion

We started with the setup of a groundwater portal architecture in New Zealand. From previous experiences in the European eContentPlus projects NatureSDIplus and GS Soil we knew that stakeholder involvement is of utmost importance to tailor the design, functionalities and usability of the portal to the end user needs. While the process of dealing with nature conservation and soil datasets in Europe was straightforward and implemented without the involvement of different disciplines, the stakeholder involvement in New Zealand led to an increase of interested parties from separate disciplines, e.g. meteorology. This necessitated thinking about connections with related hydro(geo)logical datasets and the multi-purpose use of geospatial information. This migration from a discipline-oriented approach guided us towards a national

Table 3 The mapping of local domain data model semantics into OGC SOS2.0 and O&M2.0

SOS2.0/O&M2.0	NGMP	CLIDB
SOS_/OM_ObservedProperty	"Parameter", a numerical identifier of the associated entity, which has a name and a description, e.g. 1679 – "Static Water Level" – "Distance to standing water level"	"Measure", an abbreviation (aka LADA Code) as identifier of the measured phenomenon as well as its temporal spacing, e.g. "223HOURLY" – "hourly rainfall"
SOS_/OM_Procedure	"Parameter" only, each "parameter" has an "equipment" associated with it of how it was measured, e.g. "Heron Dipper", for simplicity the actual device is only described via SensorML_Components	"Station", CLIDB only separates between "Measure" and "Station", "Procedure" is mapped to "Station" according to "OGC SOS Lightweight Station Profile", the different sensors (rain gauge, anemometer etc.), are described as SensorML_Components
SOS_/OM_FeatureOfInterest	"Feature", the site feature entity where the measurements/samples have been taken, incl. name, identifier and spatial coordinates	"Station", the CLIDB station entity contains name, identifier as well as spatial coordinates
SOS_Offering (SOS 2.0 requires a 1:1 association between Procedure and Offering)	"Parameter", the offering collections are modelled as spatially distributed measurements of the same observed property	"Station", for CLIDB the offering is the collection of all observations for each single station
Result Values	OM_MeasurementType, for EODP and SOS Hydrology Profile WaterML2.0 encoding is also supported	Intended default encoding is SWE_DataArrayType, for EODP and SOS Hydrology Profile WaterML2.0 encoding is also supported

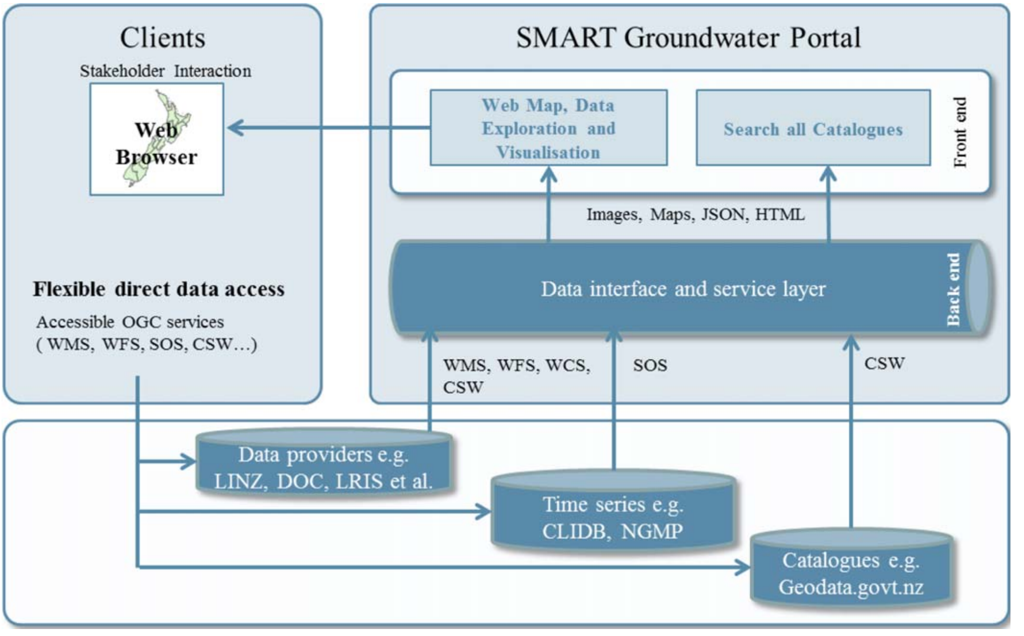

Figure 2 Groundwater Portal architecture overview, SDI services and stakeholder interaction

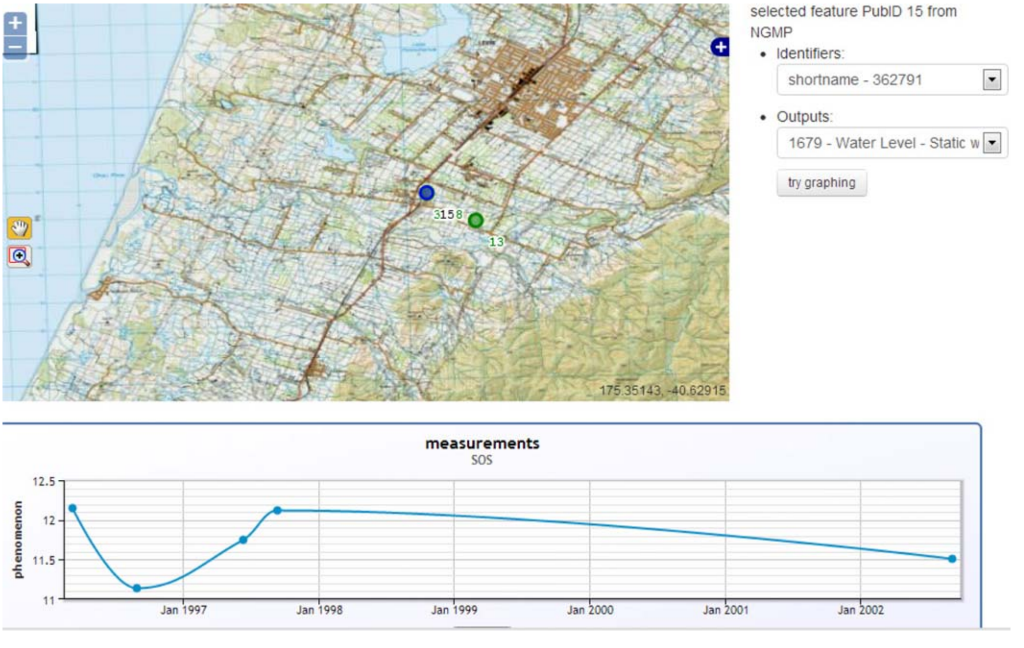

Figure 3 A view of groundwater observation data in the Horowhenua area in the Manawatu-Wanganui region as accessed from the portal via the NGMP-SOS service

level discussion on how international standards can be used in the context of the National Environmental Monitoring Standards (NEMS) in New Zealand. Thus, the EODP working group was founded and developed a profile framing rather than re-inventing existing standards. The EODP profile was subsequently tested with the NGMP and CLIDB databases developed at GNS and NIWA, respectively.

While in Europe both mentioned eContentPlus projects contributed to the INSPIRE Implementation Rules, in New Zealand a national process was stimulated. at due time. While achieving only a limited number of filled questionnaires in New Zealand, the national conversation and standardization process might have been encouraged by the questionnaires. In Europe more than 300 questionnaires have been returned from a large soil community. A comparably small hydro-meteorological community in New Zealand was reluctant to fill in questionnaires but was continuously engaged to share experiences in a parallel community effort. Thus, in contrast to the "paid lip service" in stakeholder engagement mentioned by Voinov and Bousquet (2010), this exercise is still an active bottom-up approach leading to significant progress towards the exchange of interoperable datasets.

A prototype of a web-enabled integrated spatial visualization of groundwater resources has been developed according to OGC and international best practices in continuous consultation with New Zealand stakeholders. The components of this development are discussed with the community and recommendations for methodological and technical improvements are listed hereafter.

From several stakeholder meetings, we recognized the importance of integrated transdisciplinary knowledge capitalization with respect to groundwater-related data. It has also been acknowledged that tools and data resources for hydrogeological and hydrological assessments are not yet well integrated, hampering effective and efficient use. With some of the datasets identified by stakeholder liaisons, we demonstrated the value of making multiple distributed datasets available through a single web-based point of access. Consecutive workshops and presentations of implementing prototypes created the necessity of framing existing standards, file formats and internet technologies into a (re-)useable agreed-on set. Formerly disconnected and distributed datasets could be discovered and combined with a harmonized representation and distributed within one data portal. To permit a direct access to groundwater data, a user can directly access the data sources via WFS and SOS without the need of labor-intensive pre-processing and harmonization of datasets. Increased interest throughout the environmental data community in New Zealand sparked the foundation of a joint cross-agency working group to formalize available standards for data services into a refined agreed upon behavior into the EODP specification. Once OGC-enabled data services are readily available they can be re-used in a multi-purpose context. This would enable multifunctional and multi-user public use cases through provided services that are accessible and free-of-charge. Preferably the users would connect interoperable applications to the OGC-enabled web services as envisioned in Klug and Kmoch (2015). The EODP formalization solves a perceived issue with a "step-by-step" discovery of environmental observation data and time-series data in particular. For a comprehensive web service orchestration, the tools mentioned in Table 2 mostly lack the use of internationally established standards. During the stakeholder interactions we noted that for New Zealand OGC and EODP support is now planned for many of the tools to web enable the hydro(geo)-logical data management systems currently in use in New Zealand.

Despite expeditious progress, more single datasets from the regional councils' and research institutes' data repositories need to be accessible online in an agreed on target schema as described. Service implementations are hard for service software providers to implement all of the capabilities. Especially regarding the filtering problem in this case, as the foundational

GML temporal data model is complicated due to so many options being offered. Stakeholder interaction needs to be maintained to further discuss and test these new developments. Nevertheless, the present developments are already of benefit for consistent and transparent decision support in catchment-wide approaches and for analysis at the national level. Thus, the work presented here is a blueprint that needs to be implemented more robustly.

The stakeholder interaction has also demonstrated the value of personal communication and guidance as part of the process to discuss political and technical issues in large-scale data sharing. On a political level, organizations in New Zealand are starting to adopt open data policies, while being careful what information to share with whom.

5 Conclusions and Outlook

Many OGC and ISO standard documents provide the technical and conceptual information to prototype a spatial data infrastructure connecting many distributed data sources for integrated data access. Without the discourse of an EODP process, this design connecting many services and providing a single point of access for knowledge inventory capitalizing on information might have not been elaborated as it is now. In the beginning of the SMART groundwater portal developments we lacked connection to other domains; however, the discussion and exchange of implementation rules of existing standards led to a higher level integration of environmental datasets now bridging the exchange of meteorological and groundwater related datasets as demonstrated with the two exemplified use cases in this article. This process also shows that experiences gained from other (European) projects cannot necessarily be transferred across domains and nations.

Although this development exercise does not change the general approach in using international standards, it did identify a number of innovative data management implications not previously considered in New Zealand. The new potentials of searching, discovering, and accessing data with this framework model lie within information distribution and information sharing with a clearly commonly defined set of implementation rules. With the refinement of the New Zealand observation data profile we show in our contribution that current state-of-the-art standards do not necessarily need to be improved, but that the community has to agree upon a set of rules as to how to use these standards, instead of developing new formats and interfaces or hiding such complexities behind portals with proprietary or custom data access. It integrates research activities and thus yields more knowledge by allowing for the recombination and correlation of spatial datasets and their n-dimensional representation. This has not been previously done and highlights the importance of a single point of access for geospatial data to the emerging distributed data sources to efficiently discover access and explore for instance groundwater-related datasets. As a product, a generic observation data profile for New Zealand is being developed together with a community with interests beyond groundwater.

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