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OGC GroundWaterML 2 – GW2IE FINAL REPORT

Warning

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Contents

i. Abstract

This document describes a conceptual model, logical model, and GML/XML encoding rules for the exchange of groundwater data. In addition, this document provides GML/XML encoding examples for guidance.

ii. Keywords

The following are keywords to be used by search engines and document catalogues.

ogcdoc, OGC document, groundwater, hydrogeology, aquifer, water well, observation, GroundwaterML, GWML2, well construction, UML, GML

iii. Preface

The primary goal of this document is to capture the semantics, schema, and encoding syntax of key groundwater data, in order to enable information systems to interoperate with such data.

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.

iv. Submitting organizations

The following organizations submitted this Document to the Open Geospatial Consortium (OGC):

- Geological Survey of Canada (GSC), Canada
- U.S. Geological Survey (USGS), United States of America
- Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia
- Bureau of Meteorology (BOM), Australia
- Federation University Australia (FedUni), Australia
- Bureau de Recherches Géologiques et Minières (BRGM), France
- Geological Surveys of Germany (GSG), Germany
- Salzburg University (U Salzburg), Austria

The following organizations initiated the Groundwater Interoperability Experiment 2 in which this document was developed:

- Geological Survey of Canada (GSC), Canada
- U.S. Geological Survey (USGS), United States of America
- Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia
- Federation University Australia (FedUni), Australia
- Bureau of Meteorology (BOM), Australia
- European Commission, Directorate General – Joint Research Centre (JRC), European Union
- Polish Association for Spatial Information
- Polish Geological Institute (PGI), Poland
- Geological Surveys of Germany (GSG), Germany
- Salzburg University (U Salzburg), Austria
- Bureau de Recherches Géologiques et Minières (BRGM), France
- British Geological Survey (BGS), U.K.
- International Groundwater Resources Assessment Centre (IGRAC), UNESCO

v. Submitters

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vi. Future Work

Future work involves coordination with ongoing OGC hydrology standards for surface water and time series observations, to demonstrate how these emerging standards can operate together.

1. Scope

This document is a conceptual and encoding specification for the representation of core groundwater data. GroundWaterML2 is implemented as an application schema of the Geography Markup Language (GML) version 3.2.1, and re-uses entities from other GML application schema, most notably the OGC Observations & Measurements standard and the GeoSciML 3.2.0 standard from the International Union of Geological Sciences (IUGS).

GroundWaterML2.1 (GWML2) is designed to enable a variety of data exchange scenarios. These scenarios are captured by its five motivating use cases, including:

(1) a commercial use-case focused on drilling water wells with knowledge of aquifers;
(2) a policy use case concerned with the management of groundwater resources;
(3) an environmental use-case that considers the role of groundwater in natural eco-systems;
(4) a scientific use-case concerned with modeling groundwater systems; and
(5) a technologic use-case concerned with interoperability between diverse information systems and associated data formats.

GWML2 is designed in three stages, each consisting of a schema that builds on the previous stages. The three schemas include:

(1) **Conceptual** (UML): a technology-neutral schema denoting the semantics of the domain;
(2) **Logical** (UML): a GML-specific schema that incorporates the OGC suite of standards; and
(3) **XML** schema (XSD): a GML syntactical encoding of the logical schema.

In addition, this specification describes general and XML-specific encoding requirements, general and XML-specific conformance tests, and XML encoding examples. The specification is designed for future extension into other non-XML encoding syntaxes, which would require each such encoding to describe the related schema, requirements and conformance classes, as well as provide examples.

The GroundWaterML2 Logical and XML schemas are organized into 6 modular packages.

(1) GWML2-Main: core elements such as aquifers, their pores, and fluid bodies.

(2) GWML2-Constituent: the biologic, chemical, and material elements of a fluid body.
(3) GWML2-Flow: groundwater flow within and between containers.
(4) GWML2-Well: water wells, springs, and monitoring sites.
(5) GWML2-WellConstruction: the components used to construct a well.
(6) GWML2-AquiferTest: the elements composing an aquifer test (e.g. pumping test).

Altogether, the schemas and packages represent a precise description of the key features associated with the groundwater domain, as well as their properties and relationships. This provides a semantics and syntax for the correct machine interpretation of the data, which promotes proper use of the data in further analysis. Existing systems can use GWML2 to 'bridge' between existing schema or systems, allowing consistency of the data to be maintained and enabling interoperability.

1.1 Motivation

A significant portion of the global water supply can be attributed to groundwater resources. Effective management of such resources requires the collection, management and delivery of related data, but these are impeded by issues related to data availability, distribution, fragmentation, and heterogeneity: collected data are not all readily available and accessible, available data is distributed across many agencies in different sectors, often thematically fragmented, and similar types of data are diversely structured by the various data providers. This situation holds both within and between political entities, such as countries or states, thereby impairing groundwater management across all jurisdictions. Groundwater data networks are an emerging solution to this problem as they couple data providers through a unified data delivery vehicle, thus reducing or eliminating distribution, fragmentation, and heterogeneity through the incorporation of standards for data access and data content. The relative maturity of OGC data access standards, such as the Web Feature Service (WFS) and Sensor Observation Service (SOS), combined with the rise of water data networks, have created a need for GroundWaterML2 (GWML2), a common groundwater data specification.

1.2 Historical background

Several activities have influenced the development of GWML2:

- GWML1: a GML application schema for groundwater data developed at Natural Resources Canada used to exchange groundwater data within Canada, between Canada and the USA, and in some other international initiatives (Boisvert & Brodaric, 2012).
- GWIE1: an interoperability experiment within the OGC HDWG, in which groundwater data was shared across the USA-Canada border (Brodaric & Booth, 2011).
- INSPIRE Data Specification on Geology: a conceptual model for geology and hydrogeology with regulatory force in the European Union (INSPIRE, 2013), and for which GWML2 is expected to be an encoding candidate.

2. Conformance

This specification has been written to be compliant with the OGC Specification Model – A Standard for Modular Specification (OGC 08-131r3). Extensions of this specification shall themselves be conformant to the OGC Specification Model.

2.1 XML implementation

The XML implementation (encoding) of the conceptual and logical groundwater schemas is described using the XML Schema language and Schematron.

Requirements for **one standardization target type** are considered:

- **data instances**

i.e. XML documents that encode groundwater data. As data *producing* applications should generate conformant data instances, the requirements and tests described in this specification effectively also apply to that target.

Conformance with this specification shall be checked using all the relevant tests specified in Annex A (normative) of this document. The framework, concepts, and methodology for testing, and the criteria to be achieved to claim conformance are specified in ISO 19105: Geographic information — Conformance and Testing. In order to conform to this OGC™ encoding specification, a standardization target shall implement the core conformance class, and choose to implement any one of the other conformance classes (i.e. extensions).

All requirements-classes and conformance-classes described in this document are owned by the standard(s) identified.

2.2 Use of vocabularies

Controlled vocabularies, also known as code-lists, are used in data exchange to identify particular concepts or terms, and sometimes relationships between them. For example, an organization may define a controlled vocabulary for all observed phenomena, such as water quality parameters, that are to be exchanged between parties. Some of these definitions may be related by hierarchies or through other relationships such as equivalence.

GroundWaterML2.1 does not define a set of vocabularies for groundwater data exchange in this version. It is envisaged that specific communities will develop local vocabularies for data exchange within the community. Future work within the Hydrology Domain Working Group could address standardized controlled vocabularies for the groundwater domain. Such vocabularies require a governance structure that allows changes to be made as definitions evolve, possibly using the OGC definition namespace (**http://www.opengis.net/def/groundwaterml/2.1/**), which is governed by the OGC Naming Authority (OGC-NA). The OGC-NA is responsible for processing requests to change or add new definitions to this namespace. The procedures for the OGC-NA are

outlined in OGC document 09-046 (OGC-NA – Procedures) and the structure of URIs is outlined in OGC 09-048 (OGC-NA – Name type specification – definitions).

2.3 Groundwater data

Groundwater data conforming to this specification are encoded in GML-conformant XML documents, for this version of GWML2. It is anticipated that future versions or extensions will develop additional encodings such as JSON or RDF. The standard MIME-type and sub-type for GML data should be used to indicate the encoding choice as specified in *MIME Media Types for GML*, namely

application/gml+xml.

3. References

The following normative documents contain provisions that, through reference in this text, constitute provisions of 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 06-121r9, OGC® Web Services Common Standard

ISO 19103:2005 – Conceptual Schema Language

ISO 8601- Data elements and interchange formats – Information interchange – Representation of dates and times

OGC 10-004r3 Abstract Specification Topic 20 – Observations and Measurements (aka ISO 19156:2011)

OGC 08-015r2 Abstract Specification Topic 2 – Spatial Referencing by Coordinates (aka ISO 19111:2007)

OGC 07-011 Abstract Specification Topic 6 – Schema for Coverage geometry and functions (aka ISO 19123:2005)

OGC 01-011 Abstract Specification Topic 11 – Geographic information — Metadata (aka ISO 19115:2003)

OGC 07-036 Geography Markup Language (aka ISO 19136:2007)

OGC 10-004r1Observations and Measurements v2.0
http://www.opengis.net/doc/AS/Topic20 (also published as ISO/DIS 19156:2010, Geographic information — Observations and Measurements)

OGC 10-025r1 OGC Observations and Measurements - XML Implementation v2.0
http://www.opengis.net/doc/IS/OMXML/2.0

OGC 08-094r1 SWE Common Data Model Encoding Standard v2.0
http://www.opengeospatial.org/standards/swecommon

Schematron: ISO/IEC 19757-3, Information technology — Document Schema Definition Languages (DSDL) — Part 3: Rule-based validation — Schematron
http://standards.iso.org/ittf/PubliclyAvailableStandards/c040833_ISO_IEC_19757-3_2006(E).zip

OGC 08-131r3 The Specification Model — A Standard for Modular specifications
http://www.opengis.net/doc/POL/SPEC

Unified Code for Units of Measure (UCUM) – Version 1.8, July 2009

Unified Modeling Language (UML). Version 2.3. May 2010.

Extensible Markup Language (XML) – Version 1.0 (Fourth Edition), August 2006

XML Schema – Version 1.0 (Second Edition), October 2004

4. Terms and Definitions

This document uses the terms defined in Sub-clause 5.3 of [OGC 06-121r8], which is based on the ISO/IEC Directives, Part 2, Rules for the structure and drafting of International Standards. In particular, the word “shall” (not “must”) is the verb form used to indicate a requirement to be strictly followed to conform to this standard.

For the purposes of this document, the following additional terms and definitions apply.

4.1
coverage
Feature that acts as a function to return values from its range for any direct position within its spatial, temporal or spatiotemporal domain.

[ISO 19123:2005, definition 4.17]

4.2
domain feature
Feature of a type defined within a particular application domain.

NOTE: This may be contrasted with observations and sampling features, which are features of types defined for cross-domain purposes.

[ISO 19156, definition 4.4]

4.3
element <XML>
Basic information item of an XML document containing child elements, attributes and character data.

NOTE: From the XML Information Set — each XML document contains one or more elements, the boundaries of which are either delimited by start-tags and end-tags, or, for empty elements, by an empty-element tag. Each element has a type, identified by name, sometimes called its 'generic identifier' (GI), and may have a set of attribute specifications. Each attribute specification has a name and a value.

[ISO 19136:2007]

4.4
feature
Abstraction of a real-world phenomena.

[ISO 19101:2002, definition 4.11]

4.5
GML application schema
Application schema written in XML Schema in accordance with the rules specified in ISO 19136:2007.

[ISO 19136:2007]

4.6
GML document
XML document with a root element that is one of the elements AbstractFeature, Dictionary or TopoComplex, specified in the GML schema or any element of a substitution group of any of these elements.

[ISO 19136:2007]

4.7
GML schema
Schema components in the XML namespace ―http://www.opengis.net/gml/3.2‖ as specified in ISO 19136:2007.

[ISO 19136:2007]

4.8
measurement
Set of operations having the objective of determining the value of a quantity.

[ISO/TS 19101-2:2008, definition 4.20]

4.9
observation
Act of observing a property.

NOTE: The goal of an observation may be to measure or otherwise determine the value of a property.

[ISO 19156:2011 definition 4.10]

4.10
observation procedure
Method, algorithm or instrument, or system which may be used in making an observation.

[ISO19156, definition 4.11]

4.11
observation result
Estimate of the value of a property determined through a known procedure.

[ISO 19156:2011]

4.12
property <General Feature Model>
Facet or attribute of an object referenced by a name.

EXAMPLE: Abby's car has the color red, where "color red" is a property of the car instance.

4.13
sampled feature
The real-world domain feature of interest, such as a groundwater body, aquifer, river, lake, or sea, which is observed.

[ISO 19156:2011]

4.14
sampling feature
Feature, such as a station, transect, section or specimen, which is involved in making observations of a domain feature.

NOTE: A sampling feature is purely an artefact of the observational strategy, and has no significance independent of the observational campaign.

[ISO 19156:2011, definition 4.16]

4.15
schema <XML Schema>
XML document containing a collection of schema component definitions and declarations within the same target namespace.

Example Schema components of W3C XML Schema are types, elements, attributes, groups, etc.

NOTE: The W3C XML Schema provides an XML interchange format for schema information. A single schema document provides descriptions of components associated with a single XML namespace, but several documents may describe components in the same schema, i.e. the same target namespace.

[ISO 19136:2007]

4.16
sensor
Type of observation procedure that provides the estimated value of an observed property at its output.

Note: A sensor uses a combination of physical, chemical or biological means in order to estimate the underlying observed property. At the end of the measuring chain electronic devices often produce signals to be processed.

[OGC SWE Common 2.0, definition 4.5.]

5. Conventions

5.1 Requirements class
Each normative statement (requirement or recommendation) in this specification is a member of a requirements class. Each requirements class is described in a discrete clause or sub-clause, and summarized using the following template:

Requirements class	**/req/{classM}**
Target type	[artefact or technology type]
Dependency	[identifier for another requirements class]
Requirement	/req/{classM}/{reqN}
Recommendation	/req/{classM}/{recO}
Requirement	/req/{classM}/{reqP}

Requirement /Recommendation	[repeat as necessary]

All requirements in a class must be satisfied. Hence, the requirements class is the unit of re-use and dependency, and the value of a dependency requirement is another requirements class. All requirements in a dependency must also be satisfied by a conforming implementation. A requirements class may consist only of dependencies and introduce no new requirements.

5.2 Requirement

All requirements are normative, and each requirement is presented using the following template:

/req/[classM]/[reqN]	[Normative statement]

where /req/[classM]/[reqN] identifies the requirement or recommendation. The use of this layout convention allows the normative provisions of this specification to be easily located by implementers.

5.3 Conformance class

Conformance to this specification is possible at a number of levels, specified by conformance classes (Annex A). Each conformance class is summarized using the following template:

Conformance class	**/conf/{classM}**
Dependency	[identifier for another conformance class]
Requirements	/req/{classA}
Tests	[reference to clause(s) containing tests]

All tests in a class must be passed. Each conformance class tests conformance to a set of requirements packaged in a requirements class.

W3C Schema (XSD) and ISO Schematron (SCH) files are considered as part of this specification, although available online only, due to concerns about document size. Many requirements are expressed in a single XSD or SCH file although tests are listed individually in the conformance annex (one test for XSD and one test for SCH).

Schematron files explicitly specify which requirements are being tested in the title of the Schematron pattern.

```
<pattern id="origin_elevation">
               <title>Test requirement: /req/gwml2-well-xsd/origin_elevation</title>
               <rule context="gwml2w:GW_Well">
                        <assert
test="count(gwml2w:gwWellReferenceElevation/gwml2w:Elevation[gwml2w:elevationType/@xlink:
href='http://www.opengis.net/req/gwml2-well/origin_elevation']) = 1">A GW_Well needs at
least one origin Elevation</assert>
               </rule>
       </pattern>
```

5.4 Identifiers

Each requirements class, requirement and recommendation is identified by a URI. The identifier supports cross-referencing of class membership, dependencies, and links from each conformance test to the requirements tested. In this specification identifiers are expressed as partial URIs or paths, which can be appended to a base URI that identifies the specification as a whole in order to construct a complete URI for identification in an external context.

The URI for each requirements class has the form

http://www.opengis.net/spec/groundwaterml/2.1/**req/[classM]**.

The URI for each requirement or recommendation has the form

http://www.opengis.net/spec/groundwaterml/2.1/**req/[classM]/[reqN]**.

The URI for each conformance class has the form

http://www.opengis.net/spec/groundwaterml/2.1/**conf/[classM]**.

The URI for each conformance test has the form

http://www.opengis.net/spec/groundwaterml/2.1/**conf/[classM]/[testN]**.

5.5 External package abbreviations

Concepts from schemas defined in some other International Standards are designated with names that start with alpha codes as follow:

GF	ISO 19109:2005 General Feature Model
GFI	ISO 19156:2011 General Feature Model Instances
TM	ISO 19108:2002 Temporal Schema, Temporal Objects

MD	ISO 19115 Metadata
CV	ISO 19123:2005 Schema for Coverage Geometry and Functions
OM	ISO 19156:2011 Observations and Measurements
DQ	ISO 19157:201X Data Quality
WML2	OGC® WaterML 2.0: Part 1- Timeseries
GW	GroundwaterML 2.1

5.6 Abbreviated terms

In this document the following abbreviations and acronyms are used or introduced:

API	Application Program Interface
GeoSciML3.2	GeoScience Mark-up Language version 3.2
GML	OGC Geography Mark-up Language
GWML2	Groundwater Markup Language version 2.1 (this specification)
GWML2-Main	UML Logical Model of the primary GroundWaterML2 elements (namespace http://www.opengis.net/gwml-main/2.1)
GWML2-Flow	UML Logical Model of the elements required to capture groundwater flow (namespace http://www.opengis.net/gwml-flow/2.1)
GWML2-Constituent	UML Logical Model of the groundwater fluid body constituents and their relationships (namespace http://www.opengis.net/gwml-constituent/2.1)
GWML2-Well	UML Logical Model of the features and properties associated with water well (namespace http://www.opengis.net/gwml-well/2.1)
GWML2-WellConstruction	UML Logical Model of the well drilling and construction details (namespace http://www.opengis.net/gwml-wellconstruction/2.1)
GWML2-AquiferTest	UML Logical Model of the features and properties associated with aquifer test (namespace http://www.opengis.net/gwml-aquifertest/2.1)
ISO	International Organization for Standardization
NACSN	North American Commission on Stratigraphic Nomenclature

NADM	North American Geological Data Model
OGC	Open Geospatial Consortium
O&M	OGC Observations and Measurements Conceptual Model
OMXML	Observations and Measurements XML Implementation
SensorML	Sensor Model Language
SOS	Sensor Observation Service
SWE	Sensor Web Enablement
UML	Unified Modeling Language
UTC	Coordinated Universal Time
URI	Universal Resource Identifier
URL	Universal Resource Locator
WML2	WaterML 2.0 – Part 1
XML	Extensible Markup Language
XSD	W3C XML Schema Definition Language

5.7 UML notation

The diagrams that appear in this specification, including the GWML2 Conceptual and Logical schemas, are presented using the Unified Modeling Language (UML), in compliance with ISO/IEC 19505-2.

Note: Within the GWML2 conceptual and logical diagrams, the following color scheme is used to identify packages, except where noted (i.e. Figure 16). This is just for information purposes.

Amber: GWML2 defined within this specification

Green and Purple: from GeoSciML

Blue: from O&M

5.8 Finding requirements and recommendations

This specification is identified as http://www.opengis.net/spec/groundwaterml/2.1. For clarity, each normative statement in this specification is in one and only one place and defined within a requirements class table and identified with a URI, whose root is the specification URI. In this specification, all requirements are associated to tests in the abstract test suite in Annex A. using the URL of the requirement as the reference

identifier. Recommendations are not tested but are assigned URLs and are identified using the 'Recommendation' label in the associated requirements table.

Requirements classes are separated into their own clauses, named, and specified according to inheritance (direct dependencies). The Conformance test classes in the test suite are similarly named to establish an explicit and mnemonic link between requirements classes and conformance test classes.

6. Background

6.1 Technical Basis

This specification builds on a number of standards for encoding XML data, including:

- OMXML (OGC 10-025r1)
- sweCommon (OGC 08-094r1)
- GML ISO 19136:2007 (OGC 07-036)
- ISO 19139 (Metadata)
- W3C XSD

This specification also builds on existing schema, primarily Observations & Measurements (OMXML) and GeoSciML 3.2. It accomplishes this by (a) extending these schemas with groundwater specializations, (b) referring to a class in these schema in order to type a named property, or (c) using a class from the schemas as one of the two participants in a binary relationship.

6.2 Overview of Observations & Measurements

ISO19156 – Observations and Measurements is a generic GML schema for observations. As shown in Figure 1, it defines an observation as "*...an act associated with a discrete time instant or period through which a number, term or other symbol is assigned to a phenomenon. It involves application of a specified procedure, such as a sensor, instrument, algorithm or process chain. The procedure may be applied in-situ, remotely, or ex-situ with respect to the sampling location. The result of an observation is an estimate of the value of a property of some feature."*

6.3 Sampling features

Sampling features in O&M are defined as a "*feature, such as a station, transect, section or specimen, which is involved in making observations concerning a domain feature.*" Sampling features in the groundwater domain are features along which, or upon, observations are made. The most relevant are water wells and boreholes, which effectively host observations along staged intervals; a collection of these intervals and their observations constitutes a log.

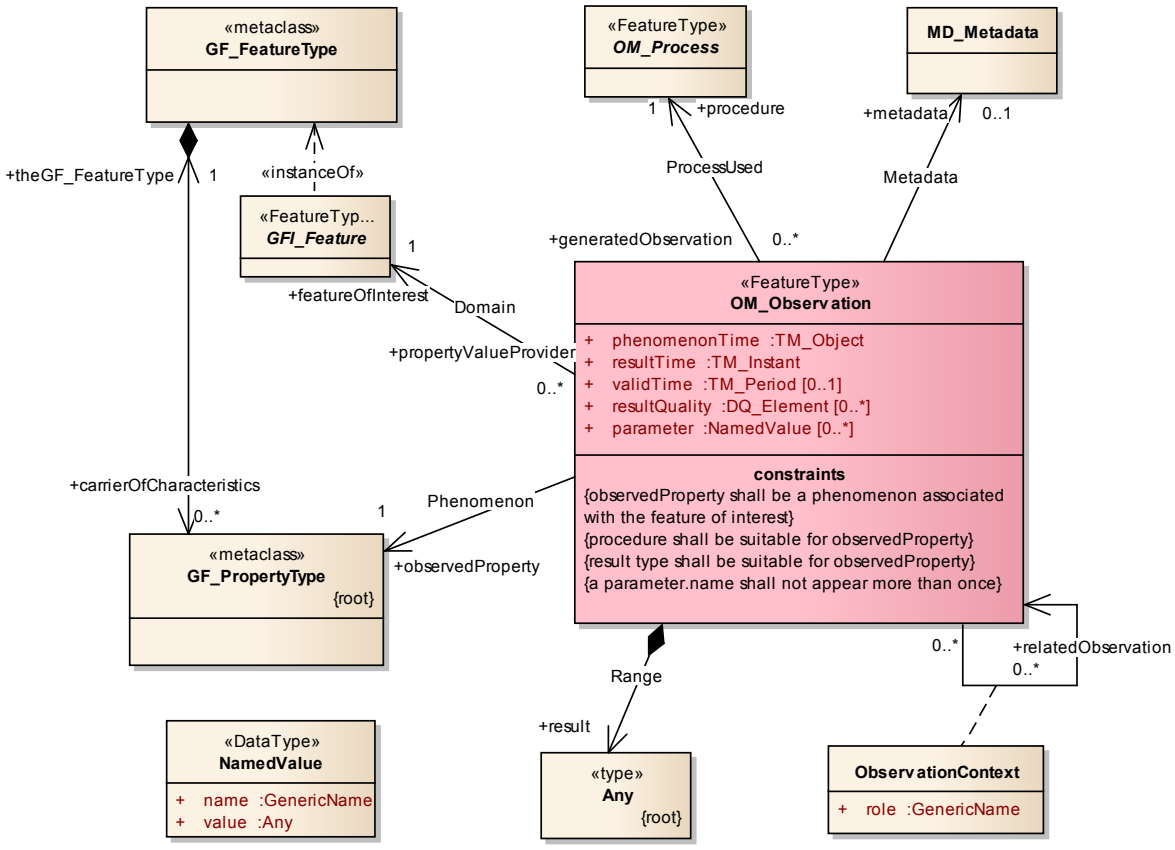

Figure 1: Observation in O&M.

6.4 Overview of GeoSciML 3.2

GeoSciML is a GML schema for core geological entities including geological units, structures, and earth materials. It is particularly relevant to GWML2 because bodies of rock serve as containers for subsurface water bodies. Such rock bodies possess variable hydrogeologic properties according to their material composition and topological organization. Thus, geological units and earth materials are the key GeoSciML entities required by GWML2.

GeoSciML defines a geological unit as "*a body of material in the Earth whose complete and precise extent is inferred to exist (NADM GeologicUnit, Stratigraphic unit in sense of NACSN or International Stratigraphic Code), or a classifier used to characterize parts of the Earth (e.g. lithologic map unit like 'granitic rock' or 'alluvial deposit', surficial units like 'till' or 'old alluvium')*."

GeoSciML defines an earth material as "*naturally occurring substance in the Earth*" and intuitively refers to various types of rocks such as sandstone, granite, and gneiss.

7. Conceptual Model

The GWML2 conceptual model is designed to be technology-neutral, and focused on the semantics of the groundwater domain. It consists of five components, as well as related properties and other entities: hydrogeological units, fluid bodies, voids, fluid flow, and wells. Conceptually, these entities form a simple template for a subsurface water container: the fluid container (a unit or its materials), the fluid itself (fluid body), the spaces in the container occupied by the fluid (void), the flow of fluid within and between containers and their spaces (flow), and the natural and artificial artifacts used to withdraw, inject, or monitor fluid with respect to a container (wells, springs, monitoring sites).

Well construction details are excluded from the conceptual model, but are included in the logical model for two reasons: (1) thematic, inasmuch as well construction was considered on the periphery of groundwater science, but important to resource management, and (2) practical, as it is sufficiently modeled in GWML1 and could thus be directly imported with few changes. This eliminates the need for its re-conceptualization in the GWML2 conceptual model, thereby keeping it parsimonious.

7.1 Hydrogeological Units

These are distinct volumes of earth material that serve as containers for subsurface fluids. The boundaries of a unit are typically discriminated from those of another unit using properties related to the potential or actual ability to contain or move water. The properties can be geological or hydraulic, and typically include influences from the surrounding hydrological environment. More specifically, the conceptual model delineates two types of hydrogeological units, with slightly different orientations: aquifer-related units have boundaries delimited by the hydrogeological properties of the rock body, while groundwater basins have boundaries delimited by distinct flow regimes. Aquifer-related units are subdivided into aquifer systems, which are collections of aquifers, confining beds, and other aquifer systems. Confining beds are units that impede water flow to surrounding units, and supersede notions such as aquitards, aquicludes, and aquifuges, which are not included herein, as it is difficult to differentiate these in practice.

Several significant properties are typically attributed to hydrogeological units, such as porosity, permeability, and conductivity, but these and others are modeled more accurately here as occurring necessarily concurrent with (dependent on) voids or fluid bodies. For example, porosity, in its various forms, requires both the presence of a unit (container) and its voids, as it is typically defined as the proportion of void volume to total unit volume (i.e. volume of solid material plus voids). Likewise, properties such as hydraulic conductivity and yield require the presence of units and fluid bodies, as they are concerned with the rate of movement of a fluid through a unit. Note that permeability and hydraulic conductivity are differentiated here: permeability refers to intrinsic permeability, which measures the ability of a unit to host fluid flow, independent of fluid properties and based solely on the connectivity and size of voids, whereas hydraulic conductivity additionally considers fluid properties.

Likewise, management areas are also relational entities in the sense that they are typically necessarily linked with a unit (or system) and possibly a fluid body. Management areas are earth bodies identified for groundwater management purposes and their boundaries can be delineated by social factors, such as policy or regulation, in addition to physical factors related to hydrogeology or hydrology.

7.2 Fluid Bodies

These are distinct bodies of fluid (liquid or gas) that fill the voids in hydrogeological units. Fluid bodies are made of biologic (e.g. organisms), chemical (e.g. solutes), or material constituents (e.g. sediment). While it is expected that the major constituent of a fluid body will be water, the conceptual model allows for other types of major constituents such as petroleum. Minor constituents are not necessarily fluids, but can be gases, liquids, or solids, and are included in the fluid body in various forms of mixture, such as solution, suspension, emulsion, and precipitates. Fluid bodies can also have other fluid bodies as parts, such as plumes or gas bubbles. Surfaces can be identified on a fluid body, such as a water table, piezometric or potentiometric surface, and some such surfaces can contain divides, which are lines projected to the fluid surface denoting divergence in the direction of flow systems.

7.3 Voids

Voids are the spaces inside a unit (e.g. aquifer) or its material (e.g. the sandstone material of an aquifer), and might contain fluid bodies. Voids are differentiated from porosity, in that porosity is a ratio of void volume to total volume of unit plus voids, while voids are the spaces themselves. It is important to conceptually differentiate voids from units and their containers, in order to represent, for example, the volume of fractures, caves, or pores in a particular unit or portion thereof.

7.4 Flow

Groundwater flow denotes the process by which a fluid enters or exits a container (unit) or its voids, or flows within them. Flow **between** one container or void and another is named *InterFlow*, and flow **within** a container or void is named *IntraFlow*. Recharge is the flow into a groundwater container or void, and discharge is flow out of a groundwater container or void. The reciprocal source or destination entity can be any appropriate container or void such as a river, lake, pipe, dam, canyon, flood plain, etc. A flow system is then a collection of flows ordered in a sequence from recharge to discharge, such that the flow segments of the system make up a connected flow path from source to destination. A water budget is a measure of the balance of recharge and discharge valid for a specific time and relative to a specific groundwater feature, such as a basin, aquifer, management area, or well.

7.5 Wells

Well-related entities include water wells, springs, and monitoring sites. Water wells are man-made constructions for monitoring, withdrawing, or injecting water from/into a hydrogeological unit, while springs are features where water discharges to the surface naturally. Both wells and springs possess important links to the hydrogeological environment, including their host units and materials, as well as the intersecting fluid

body. Monitoring sites are locations where devices are placed to measure various properties of significance to hydrogeology, such as water level, flow rate, water temperature, or chemical composition, or to take samples. As such, monitoring sites are roles played by other features, for example, water wells or springs.

7.6 Conceptual Model Specification

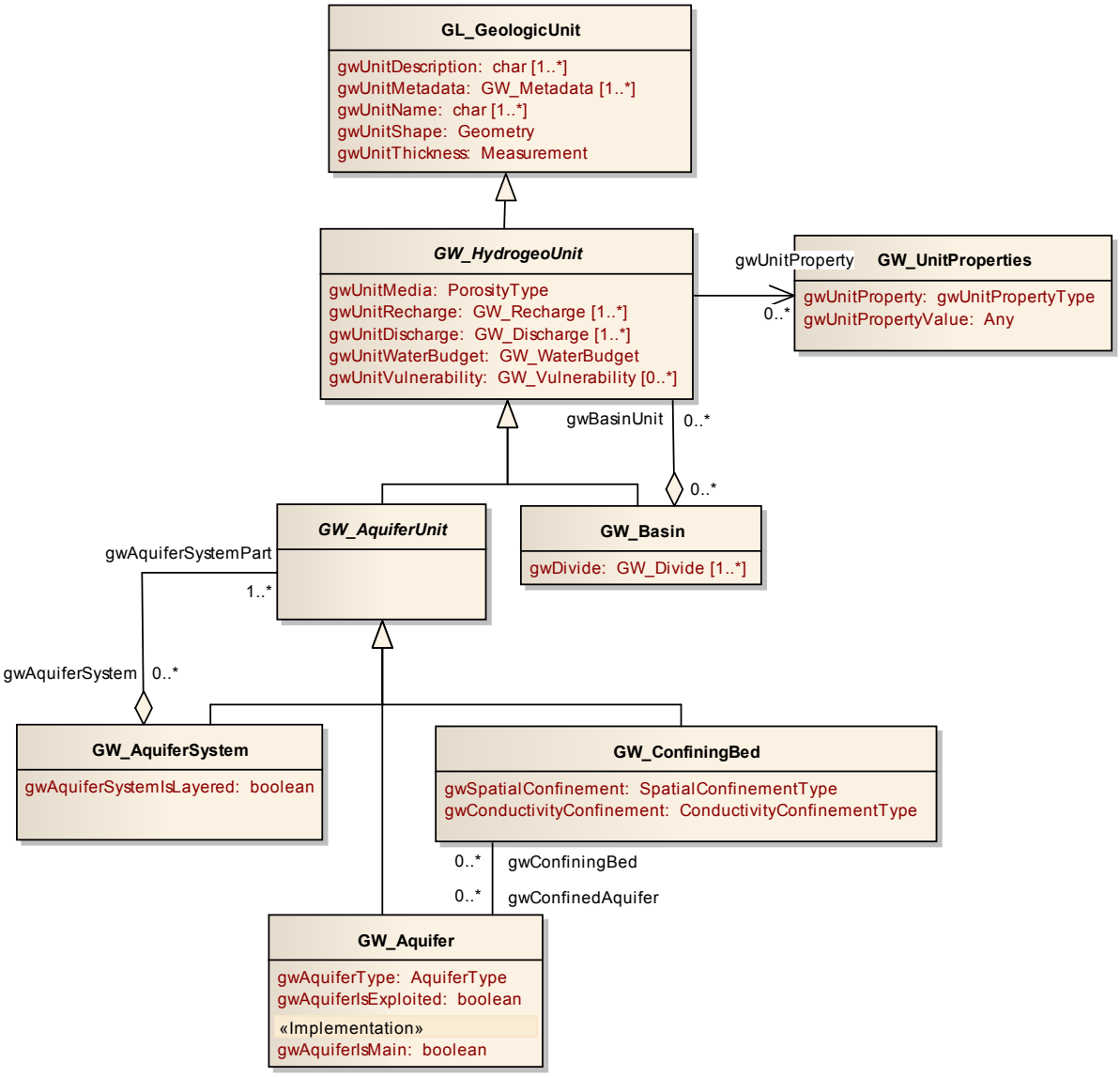

Figure 2: GWML2 CM - Hydrogeological Unit.

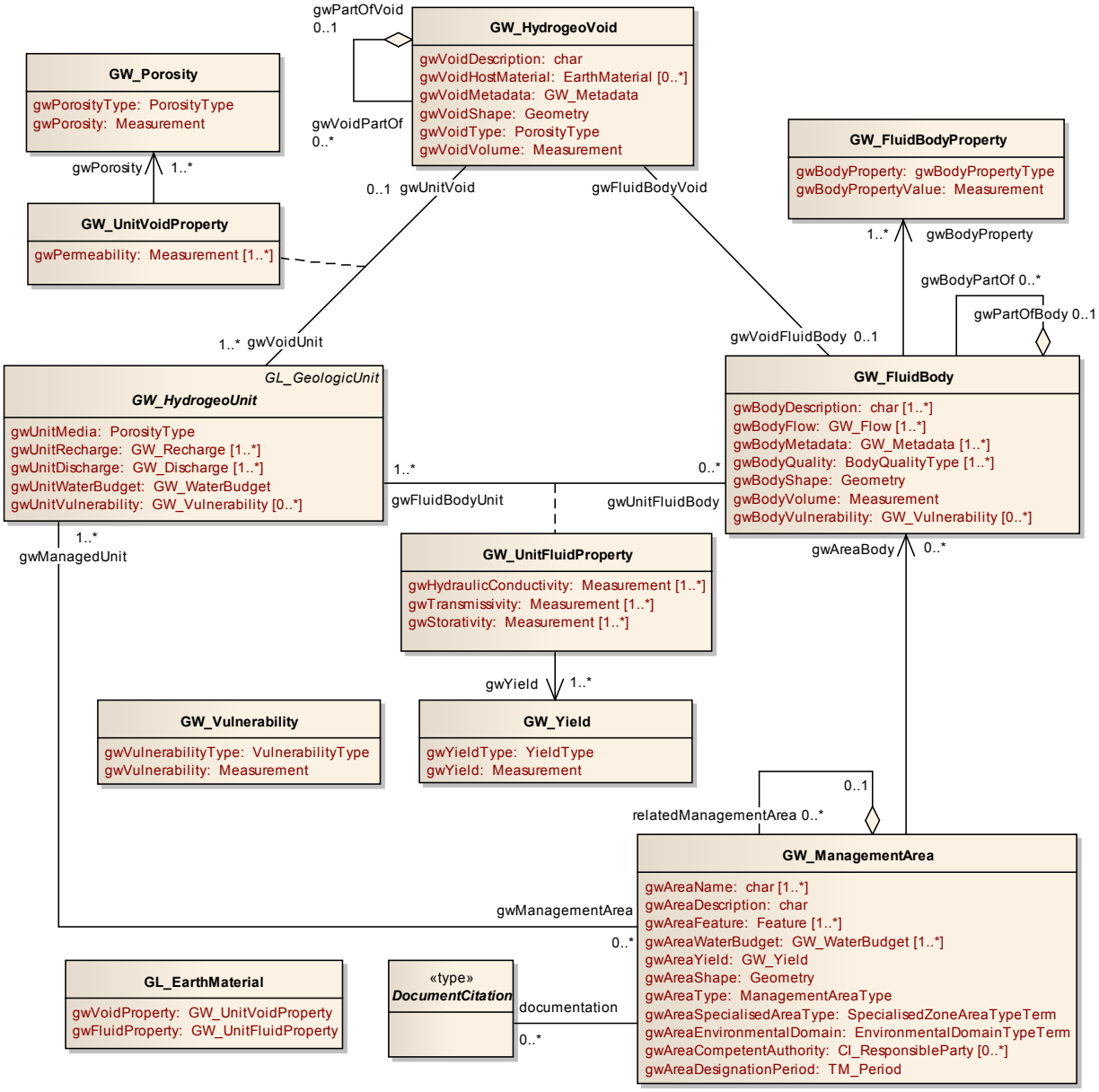

Figure 3: GWML2 CM - Groundwater Properties.

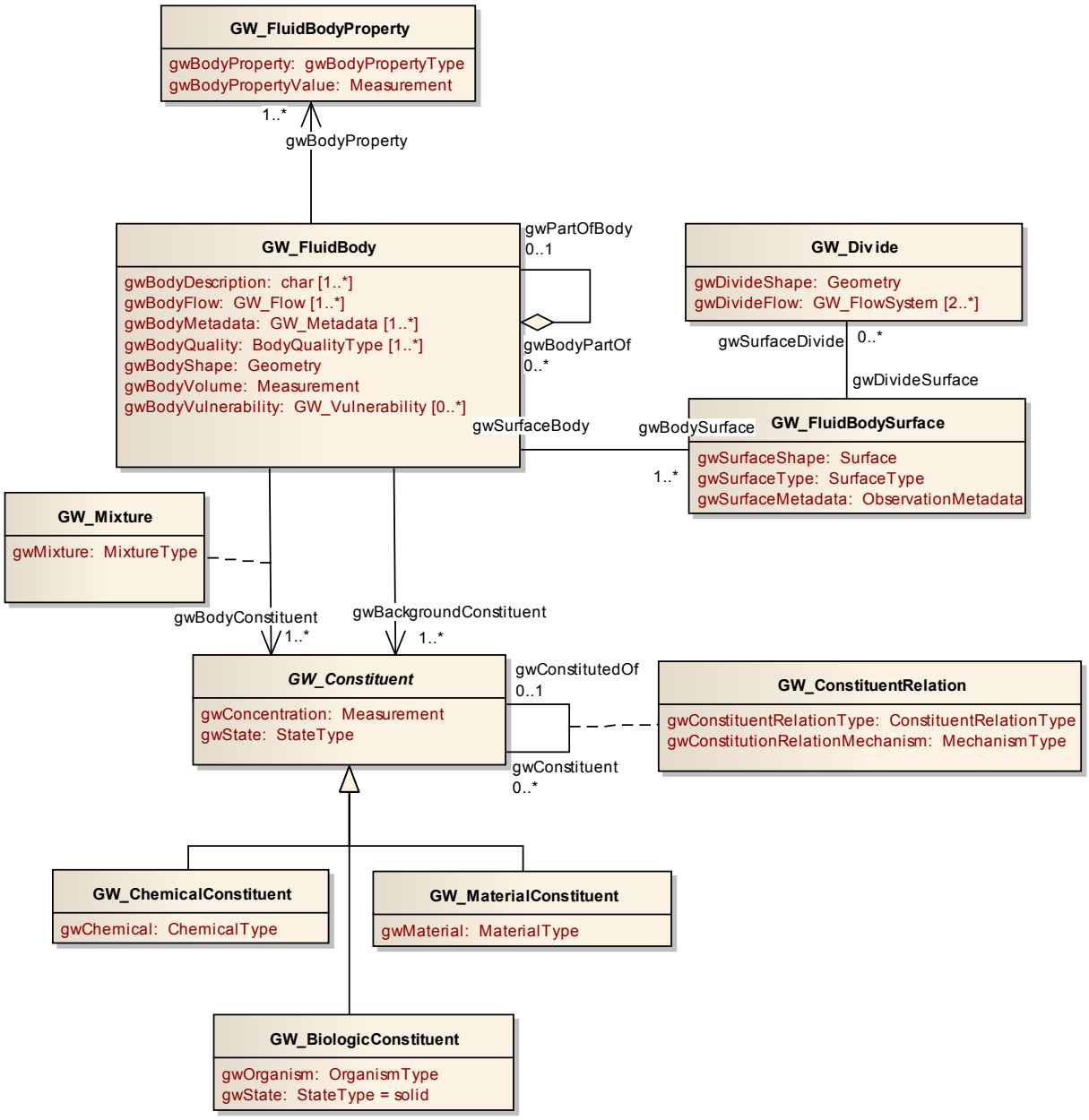

Figure 4: GWML2 CM - Fluid Body.

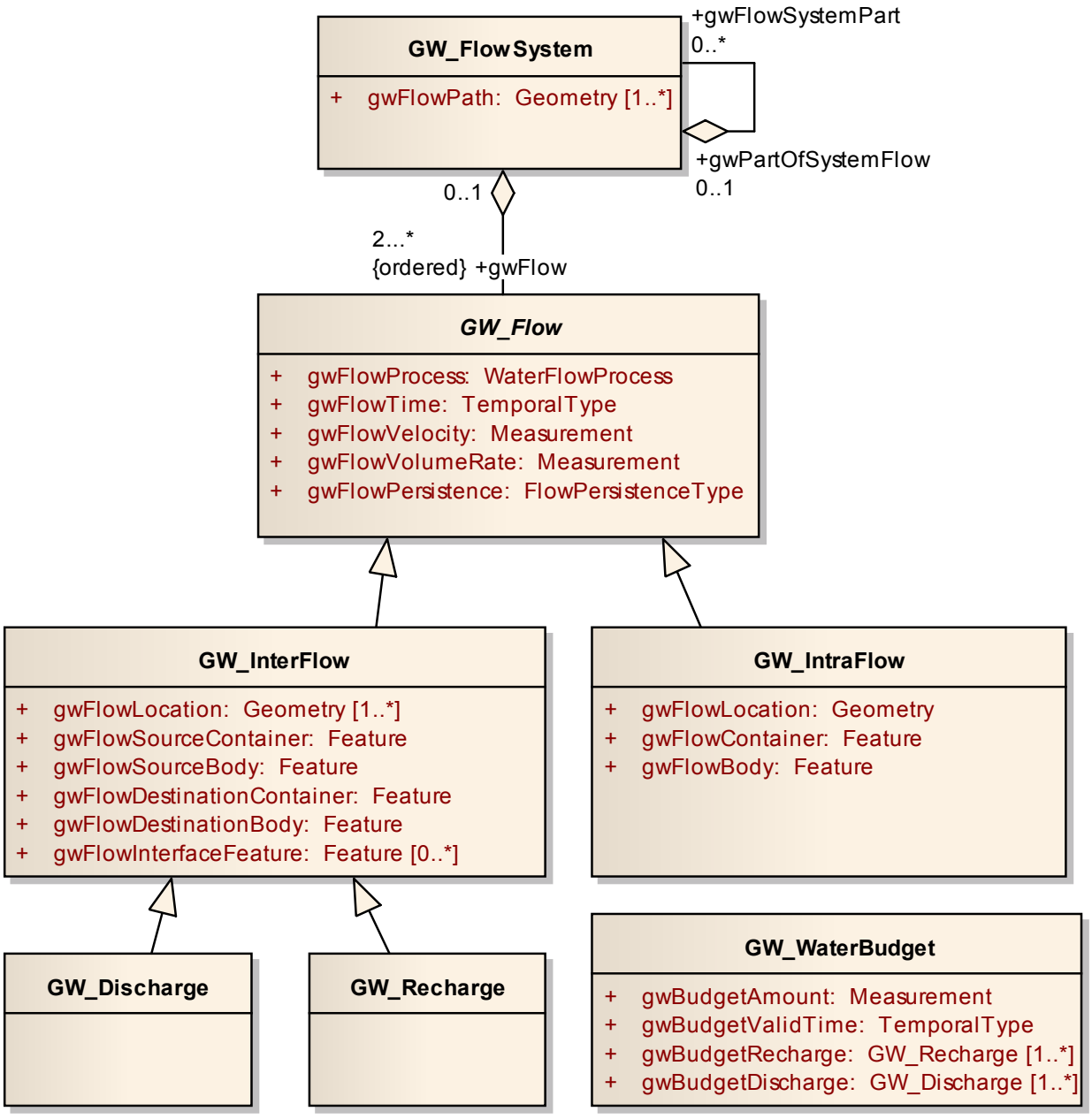

Figure 5: GWML2 CM - Groundwater Flow.

Figure 6: GWML2 CM - Wells.

7.6.1 DocumentCitation

The class DocumentCitation is abstract, and has no attributes, operations or associations. It serves as a placeholder for legislative and reference documentation for a management area. Legislative documentation refers to the legal instrument or document that required the establishment of the management area. Reference documentation might describe the environmental objectives and measures that are to be undertaken in the management area to protect the environment (a reference to a management or action plan), licensing information, and associated maps.

The 'Legislation References' and 'DocumentCitation' classes from the INSPIRE Generic Conceptual Model are possible candidates for DocumentCitation.

Relation	Source	Target	Description
Association	*Entity: GW_ManagementArea* *Role:*	*Entity: DocumentCitation* *Role: documentation*	Relates legislative and reference documentation to a management area.

7.6.2 Elevation

Elevation of a feature in reference to a datum.

Attribute	Type and Multiplicity	Definition
elevation	*Geometry*	Numeric value, coordinate reference system (CRS), and unit of measure (UoM) for the elevation.
elevationAccuracy	*PositionalAccuracyType*	Description of the accuracy of the elevation measurement.
elevationMeasurementMethod	*ElevationMeasurementMethodType*	Method used to measure the elevation, e.g. GPS, Survey, DEM, etc.
elevationType	*elevationTypeTerm*	Type of reference elevation, defined as a feature, e.g. Top of Casing, Ground, etc.

7.6.3 GL_EarthMaterial

Earth materials are substances, e.g. sandstone or granite, that constitute physical bodies, e.g. hydrogeological units. This class enables various hydrogeological properties to be attributed to a specific occurrence of a material, e.g. the sandstone of a specific aquifer.

Attribute	Type and Multiplicity	Definition
gwVoidProperty	*GW_UnitVoidProperty*	The porosity or permeability of a particular earth material that hosts a void.
gwFluidProperty	*GW_UnitFluidProperty*	The hydraulic conductivity, transmissivity, or storativity of an earth material.

7.6.4 GL_GeologicUnit

From GeoSciML:

Conceptually, may represent a body of material in the Earth whose complete and precise extent is inferred to exist (NADM GeologicUnit, Stratigraphic unit in sense of NACSN or International Stratigraphic Code), or a classifier used to characterize parts of the Earth (e.g. lithologic map unit like 'granitic rock' or 'alluvial deposit', surficial units like 'till' or 'old alluvium').

Attribute	Type and Multiplicity	Definition
gwUnitDescription	*char [1..*]*	Description of the unit.
gwUnitMetadata	*GW_Metadata [1..*]*	Metadata for the unit .
gwUnitName	*char [1..*]*	Name of the unit (common local name or formal name).
gwUnitShape	*Geometry*	The geometry of the unit.
gwUnitThickness	*Measurement*	Typical thickness of the unit.

Relation	Source	Target	Description
Generalization	*Entity:* *GW_HydrogeoUnit* *Role:*	*Entity:* *GL_GeologicUnit* *Role:*	A hydrogeological unit is a type of geological unit.

7.6.5 GW_Aquifer

A body of earth material that contains / potentially contains / potentially contained sufficient saturated permeable material to yield significant quantities of water to wells and springs (after Lohman, 1972).

Attribute	Type and Multiplicity	Definition
gwAquiferType	*AquiferType*	Water in an Aquifer is, or is not, under pressure. Based on that, several aquifer types can be distinguished: unconfined, confined, artesian, subartesian, or aquitard (after INSPIRE, 2013).
gwAquiferIsExploited	*boolean*	Denotes whether groundwater from the hydrogeological unit is being exploited by wells or other intakes (after INSPIRE, 2013).
gwAquiferIsMain	*boolean*	Denotes whether the unit is primary in an Aquifer System (after INSPIRE, 2013).

Relation	Source	Target	Description
Association	*Entity: GW_Aquifer* *Role: gwConfinedAquifer*	*Entity: GW_ConfiningBed* *Role: gwConfiningBed*	Relates an aquifer and its confining beds.
Generalization	*Entity: GW_Aquifer* *Role:*	*Entity: GW_AquiferUnit* *Role:*	An aquifer is a type of aquifer-related unit.

7.6.6 GW_AquiferSystem

Aquifer system - a body of permeable and poorly permeable material that functions regionally as a water-yielding unit; it comprises two or more permeable beds separated at least locally by confining beds that impede groundwater movement but do not greatly affect the regional hydraulic continuity of the system; includes both saturated and unsaturated parts of permeable material (after ASCE, 1987).

Attribute	Type and Multiplicity	Definition
gwAquiferSystemIsLayered	*boolean*	True if this aquifer / system is a layered system. (after INSPIRE, 2013).

Relation	Source	Target	Description
Generalization	*Entity: GW_AquiferSystem* *Role:*	*Entity: GW_AquiferUnit* *Role:*	An aquifer system is a type of aquifer-related unit.
Association	*Entity: GW_AquiferSystem* *Role: gwAquiferSystem*	*Entity: GW_AquiferUnit* *Role: gwAquiferSystemPart*	Relates an aquifer system with its parts, which can be other systems, aquifers or confining beds.

7.6.7 GW_AquiferUnit

Denotes aquifer-related hydrogeological units: aquifer systems, aquifers, or confining beds.

Relation	Source	Target	Description
Generalization	*Entity: GW_AquiferUnit* *Role:*	*Entity: GW_HydrogeoUnit* *Role:*	An aquifer unit is a type of hydrogeological unit.
Generalization	*Entity: GW_AquiferSystem* *Role:*	*Entity: GW_AquiferUnit* *Role:*	An aquifer system is a type of aquifer-related unit.
Association	*Entity: GW_AquiferSystem* *Role: gwAquiferSystem*	*Entity: GW_AquiferUnit* *Role: gwAquiferSystemPart*	Relates an aquifer system with its parts, which can be other systems, aquifers or confining beds.
Generalization	*Entity: GW_ConfiningBed*	*Entity: GW_AquiferUnit*	A confining bed is a type of aquifer-related unit.

Relation	Source	Target	Description
	Role:	*Role:*	
Generalization	*Entity: GW_Aquifer* *Role:*	*Entity: GW_AquiferUnit* *Role:*	An aquifer is a type of aquifer-related unit.

7.6.8 GW_Basin

A large hydrogeologically defined body of ground typically consisting of hydraulically connected hydrogeological units, whose waters are flowing to a common or multiple outlets, and which is delimited by a groundwater divide.

Attribute	Type and Multiplicity	Definition
gwDivide	*GW_Divide [1..*]*	“Line on a water table or piezometric surface on either side of which the groundwater flow diverges" (IGH0556).

Relation	Source	Target	Description
Generalization	*Entity: GW_Basin* *Role:*	*Entity: GW_HydrogeoUnit* *Role:*	A basin is a type of hydrogeological unit.
Aggregation	*Entity: GW_Basin* *Role:*	*Entity: GW_HydrogeoUnit* *Role: gwBasinUnit*	Relates hydrogeological units and the basins that contain them, in full or part.

7.6.9 GW_BiologicConstituent

Characterization of the biological composition of the fluid body, both natural and man-made.

Attribute	Type and Multiplicity	Definition
gwOrganism	*OrganismType*	Biological species.
gwState	*StateType solid*	Organisms are always solids.

Relation	Source	Target	Description
Generalization	*Entity: GW_BiologicConstituent* *Role:*	*Entity: GW_Constituent* *Role:*	A biologic constituent is a type of fluid body constituent. There are 3 types of fluid body constituents: chemical (e.g. arsenic), biologic (e.g. organisms), and material (e.g. sediment).

7.6.10 GW_ChemicalConstituent

Characterization of the chemical composition of the fluid body, both natural and man-made.

Attribute	Type and Multiplicity	Definition
gwChemical	*ChemicalType*	Chemical component type, e.g. arsenic.

Relation	Source	Target	Description
Generalization	*Entity: GW_ChemicalConstituent* *Role:*	*Entity: GW_Constituent* *Role:*	A chemical constituent is a type of fluid body constituent. The 3 types of fluid body constituent are: chemical (e.g. arsenic), biologic (e.g. organisms), and material (e.g. sediment).

7.6.11 GW_ConfiningBed

A layer of rock having very low porosity and in consequence hydraulic conductivity that hampers the movement of water into and out of an aquifer (Heath, 1983).

Attribute	Type and Multiplicity	Definition
gwSpatialConfinement	*SpatialConfinementType*	Degree of spatial confinement (typically: "Unconfined-Confined", "Partially Confined").
gwConductivityConfinement	*ConductivityConfinementType*	Degree of hydraulic confinement (e.g. aquiclude).

Relation	Source	Target	Description
Association	*Entity: GW_Aquifer* *Role: gwConfinedAquifer*	*Entity: GW_ConfiningBed* *Role: gwConfiningBed*	Relates an aquifer and its confining beds.
Generalization	*Entity: GW_ConfiningBed* *Role:*	*Entity: GW_AquiferUnit* *Role:*	A confining bed is a type of aquifer-related unit.

7.6.12 GW_Constituent

General (abstract) entity denoting a material, chemical or biological constituent of a fluid body.

Attribute	Type and Multiplicity	Definition
gwConcentration	*Measurement*	The concentration (with uom) of the constituent in the fluid body.
gwState	*StateType*	The physical state of the constituent, i.e. solid, liquid, or gas.

Relation	Source	Target	Description
Association	*Entity: GW_FluidBody* *Role:*	*Entity: GW_Constituent* *Role: gwBackgroundConstitu*	Relates a fluid body to typical background constituent values for that body.

Relation	Source	Target	Description
		ent	
AssociationClass	*Entity: GW_Constituent* *Role: gwConstituent*	*Entity: GW_Constituent* *Role: gwConstitutedOf*	A general binary relation between constituents, in which the relation type can be specified in addition to the causal mechanism that caused the relationship.
Generalization	*Entity: GW_BiologicConstituent* *Role:*	*Entity: GW_Constituent* *Role:*	A biologic constituent is a type of fluid body constituent. There are 3 types of fluid body constituents: chemical (e.g. arsenic), biologic (e.g. organisms), and material (e.g. sediment).
Generalization	*Entity: GW_ChemicalConstituent* *Role:*	*Entity: GW_Constituent* *Role:*	A chemical constituent is a type of fluid body constituent. There are 3 types of fluid body constituents: chemical (e.g. arsenic), biologic (e.g. organisms), and material (e.g. sediment).
Generalization	*Entity: GW_MaterialConstituent* *Role:*	*Entity: GW_Constituent* *Role:*	A material constituent is a type of fluid body constituent. There are 3 types of fluid body constituents: chemical (e.g. arsenic), biologic (e.g. organisms), and material (e.g. sediment).
AssociationClass	*Entity: GW_FluidBody*	*Entity: GW_Constituent*	Relates a fluid body to its chemical, biologic, or material

Relation	Source	Target	Description
	Role:	*Role: gwBodyConstituent*	constituents, and specifies the nature of the mixture of the constituent within the body, e.g. solution, suspension.

7.6.13 GW_ConstituentRelation

Relation between fluid body components, typically caused by a specific mechanism, e.g. coating (from adsorption), constitution (from chemical bonding forming a new material), aggregation (from physical bonding, e.g. pressure), containment (from absorption, digestion).

Attribute	Type and Multiplicity	Definition
gwConstituentRelationType	*ConstituentRelationType*	Specific type of relation between fluid body components, e.g. coating, constitution, aggregation, containment.
gwConstitutionRelationMechanism	*MechanismType*	Mechanisms by which materials (of various states) come into a relationship, e.g. sorption, precipitation, digestion, excretion, etc.

7.6.14 GW_Discharge

An outflow of fluid from a container such as an aquifer, watershed, pipe.

Relation	Source	Target	Description
Generalization	*Entity: GW_Discharge* *Role:*	*Entity: GW_InterFlow* *Role:*	Discharge is a type of interflow in which fluid exits a feature.

7.6.15 GW_Divide

“A line on a water table or piezometric surface, on either side of which the groundwater flow diverges" (IGH0556).

Attribute	Type and Multiplicity	Definition
gwDivideShape	*Geometry*	Shape / position of the divide (line, plane or point) intersecting a fluid body surface.

Attribute	Type and Multiplicity	Definition
gwDivideFlow	*GW_FlowSystem [2..*]*	Flow system on each side of the divide.

Relation	Source	Target	Description
Association	*Entity: GW_Divide* *Role: gwSurfaceDivide*	*Entity: GW_FluidBodySurface* *Role: gwDivideSurface*	Relates a fluid body surface to a line on e.g. a water table or piezometric surface, on either side of which the groundwater flow diverges.

7.6.16 GW_Flow

Process by which the fluid enters or exits a hydrogeological unit or a void, or flows within a unit or a void. Can flow from/to other natural or man-made features such as rivers, filtration stations, etc.

Attribute	Type and Multiplicity	Definition
gwFlowProcess	*WaterFlowProcess*	The process causing the flow, e.g. evapotranspiration, evaporation, transpiration, runoff, baseflow, pumping, infiltration, injection, etc.
gwFlowTime	*TemporalType*	Refers to the duration, instant or interval of the flow (actual time, not observation time). E.g. "yearly", "summer", "2009" or "2009-2011".
gwFlowVelocity	*Measurement*	Measure of water volume per unit of time.
gwFlowVolumeRate	*Measurement*	Measure of water quantity per time period with uom.
gwFlowPersistence	*FlowPersistenceType*	The regularity of flow occurrence, e.g. ephemeral, intermittent, perennial, seasonal. After http://inspire.ec.europa.eu/codeList/WaterPersistenceValue/ (INSPIRE, 2013).

Relation	Source	Target	Description

Relation	Source	Target	Description
Generalization	*Entity: GW_InterFlow* *Role:*	*Entity: GW_Flow* *Role:*	An interflow is a type of directed flow between two features, e.g. flow between two units.
Generalization	*Entity: GW_IntraFlow* *Role:*	*Entity: GW_Flow* *Role:*	An intraflow is a type of flow within a single feature, e.g. flow within a unit.
Aggregation	*Entity: GW_FlowSystem* *Role:*	*Entity: GW_Flow* *Role: gwFlow*	Relates a flow system to the individual flows that comprise the system. Flows are atomic entities that cannot have parts, but which form parts of flow systems.

7.6.17 GW_FlowSystem

Flow path from recharge to discharge location, through hydrogeological units. It is related to a fluid body, and consists of a collection or aggregation of at least two specific flows, as well as possibly other flow systems.

Attribute	Type and Multiplicity	Definition
gwFlowPath	*Geometry [1..*]*	The path of flow of a fluid through a container.

Relation	Source	Target	Description
Association	*Entity: GW_FlowSystem* *Role: gwFlowSystemPart*	*Entity: GW_FlowSystem* *Role: gwPartOfSystemFlow*	Relates a flow system part to a flow system whole.
Aggregation	*Entity: GW_FlowSystem*	*Entity: GW_Flow*	Relates a flow system

Relation	Source	Target	Description
	Role:	*Role: gwFlow*	to the individual flows that comprise the system. Flows are atomic entities that cannot have parts, but which form parts of flow systems.

7.6.18 GW_FluidBody

A distinct body of some fluid (liquid, gas) that fills the voids of a container such as an aquifer, system of aquifers, water well, etc. In hydrogeology this body is usually constituted by groundwater, but the model allows for other types of fillers e.g. petroleum.

Attribute	Type and Multiplicity	Definition
gwBodyDescription	*char [1..*]*	General description of the fluid body
gwBodyFlow	*GW_Flow [1..*]*	Flows associated with the fluid body.
gwBodyMetadata	*GW_Metadata [1..*]*	Metadata about the fluid body.
gwBodyQuality	*BodyQualityType [1..*]*	Categorical assessment of quality of the fluid body as a whole: e.g. saline, brackish, fresh, turbide, sulfurous, mixed, ... 1000-3000mg/l tds, etc. A normative quality description is an assessment based upon some guideline edited by a government or a quality standard.
gwBodyShape	*Geometry*	Shape and position of the fluid body.
gwBodyVolume	*Measurement*	Description of the volume/quantity of a fluid present in a container at a certain time.
gwBodyVulnerability	*GW_Vulnerability [0..*]*	The susceptibility of the fluid body to specific threats such as surface contamination, etc.

Relation	Source	Target	Description
Association	*Entity:*	*Entity: GW_FluidBody*	Relates a void and a fluid body contained by

Relation	Source	Target	Description
	GW_HydrogeoVoid *Role: gwFluidBodyVoid*	*Role: gwVoidFluidBody*	the void. Each void contains at most one fluid body, which can have multiple parts that could be disconnected. Likewise, each fluid body is contained by a single void, which could be an aggregation of disconnected void parts.
Association	*Entity: GW_ManagementArea* *Role:*	*Entity: GW_FluidBody* *Role: gwAreaBody*	Relates a management area to the fluid bodies contained within the area. As with units, the spatial boundaries of management areas do not necessarily coincide with the spatial boundaries of fluid bodies.
Association	*Entity: GW_FluidBodySurface* *Role: gwBodySurface*	*Entity: GW_FluidBody* *Role: gwSurfaceBody*	Relates a fluid body to a surface hosted by the body, e.g. the top of the water table.
Aggregation	*Entity: GW_FluidBody* *Role: gwPartOfBody*	*Entity: GW_FluidBody* *Role: gwBodyPartOf*	Relates a fluid body part to a fluid body whole.
AssociationClass	*Entity: GW_HydrogeoUnit* *Role: gwFluidBodyUnit*	*Entity: GW_FluidBody* *Role: gwUnitFluidBody*	Relates hydrogeological units and the fluid bodies contained by the units.
Association	*Entity: GW_FluidBody* *Role:*	*Entity: GW_FluidBodyProperty*	Relates a fluid body to additional properties such as age, temperature, density, viscosity, turbidity,

Relation	Source	Target	Description
		Role: gwBodyProperty	color, hardness, acidity, etc.
Association	*Entity: GW_FluidBody* *Role:*	*Entity: GW_Constituent* *Role: gwBackgroundConstituent*	Relates a fluid body to typical background constituent values for that body.
AssociationClass	*Entity: GW_FluidBody* *Role:*	*Entity: GW_Constituent* *Role: gwBodyConstituent*	Relates a fluid body to its chemical, biologic, or material constituents, and specifies the nature of the mixture of the constituent within the body, e.g. solution, suspension.

7.6.19 GW_FluidBodyProperty

Additional properties that characterize a fluid body. Can include synoptic values for the whole body or location-specific observations such as age, temperature, density, viscosity, turbidity, color, hardness, acidity, etc.

Attribute	Type and Multiplicity	Definition
gwBodyProperty	*gwBodyPropertyType*	Type of fluid body property, e.g. age, temperature, density, viscosity, turbidity, color, hardness, acidity, etc.
gwBodyPropertyValue	*Measurement*	Value of the fluid body property (with uom).

Relation	Source	Target	Description
Association	*Entity: GW_FluidBody* *Role:*	*Entity: GW_FluidBodyProperty*	Relates a fluid body to additional properties such as age, temperature, density,

Relation	Source	Target	Description
		Role: gwBodyProperty	viscosity, turbidity, color, hardness, acidity, etc.

7.6.20 GW_FluidBodySurface

A surface on a fluid body within a local or regional area, e.g. piezometric, potentiometric, water table, salt wedge, etc.

Attribute	Type and Multiplicity	Definition
gwSurfaceShape	*Surface*	Geometry / position of the surface.
gwSurfaceType	*SurfaceType*	Type of fluid body surface, e.g. piezometric, potentiometric, water table, salt wedge, etc.
gwSurfaceMetadata	*ObservationMetadata*	Date, time, method, etc., of the observation or calculation of the surface.

Relation	Source	Target	Description
Association	*Entity: GW_Divide* *Role: gwSurfaceDivide*	*Entity: GW_FluidBodySurface* *Role: gwDivideSurface*	Relates a fluid body surface to a line on e.g. a water table or piezometric surface, on either side of which the groundwater flow diverges.
Association	*Entity: GW_FluidBodySurface* *Role: gwBodySurface*	*Entity: GW_FluidBody* *Role: gwSurfaceBody*	Relates a fluid body to a surface hosted by the body, e.g. the top of the water table.

7.6.21 GW_HydrogeoUnit

Any soil or rock unit or zone that by virtue of its hydraulic properties has a distinct influence on the storage or movement of groundwater (after ANS, 1980).

Attribute	Type and Multiplicity	Definition
gwUnitMedia	*PorosityType*	Type of material or, by proximity, type of voids (e.g. granular, fracture, karstic, or mixed).
gwUnitRecharge	*GW_Recharge [1..*]*	Volumetric flow rate of water that enters an hydrogeologic unit, at potentially multiple locations.
gwUnitDischarge	*GW_Discharge [1..*]*	Volumetric flow rate of water that goes out of an hydrogeologic unit, at potentially multiple locations.
gwUnitWaterBudget	*GW_WaterBudget*	Sum of water input and output of a hydrogeologic unit, at a particular point in time, with a description of inflows and outflows.
gwUnitVulnerability	*GW_Vulnerability [0..*]*	The susceptibility of the aquifer to specific threats such as various physical events (earthquakes), human processes (depletion), etc.

Relation	Source	Target	Description
Generalization	*Entity: GW_Basin* *Role:*	*Entity: GW_HydrogeoUnit* *Role:*	A basin is a type of hydrogeological unit.
Generalization	*Entity: GW_AquiferUnit* *Role:*	*Entity: GW_HydrogeoUnit* *Role:*	An aquifer unit is a type of hydrogeological unit.
Generalization	*Entity: GW_HydrogeoUnit* *Role:*	*Entity: GL_GeologicUnit* *Role:*	A hydrogeological unit is a type of geological unit.
AssociationClass	*Entity: GW_HydrogeoUnit*	*Entity: GW_HydrogeoVoid*	Relates hydrogeological units with a void hosted by

Relation	Source	Target	Description
	Role: gwVoidUnit	*Role: gwUnitVoid*	the units. A unit hosts one void, which can be an aggregation of multiple voids potentially spatially disconnected. Voids in turn can be hosted by many units, particularly when units are arranged in whole-part relations, such that a void hosted by a part is also hosted by any associated whole, e.g. a void is hosted by both an aquifer and a related aquifer system, or a member and a related formation.
Association	*Entity: GW_HydrogeoUnit* *Role:*	*Entity: GW_UnitProperties* *Role: gwUnitProperty*	Relates a hydrogeological unit to possibly many additional properties.
Aggregation	*Entity: GW_Basin* *Role:*	*Entity: GW_HydrogeoUnit* *Role: gwBasinUnit*	Relates hydrogeological units and the basins that contain them, in full or part.
AssociationClass	*Entity: GW_HydrogeoUnit* *Role: gwFluidBodyUnit*	*Entity: GW_FluidBody* *Role: gwUnitFluidBody*	Relates hydrogeological unts and the fluid bodies contained by the units.
Association	*Entity: GW_ManagementArea* *Role:*	*Entity: GW_HydrogeoUnit* *Role: gwManagedUnit*	Relates a management area to the hydrogeological units contained within it. Because the spatial

Relation	Source	Target	Description
	gwManagementArea		boundaries of management areas can be determined by human concerns, e.g. regulatory, these boundaries do not necessarily align with the spatial boundaries of units, which are determined by physical criteria.

7.6.22 GW_HydrogeoVoid

Voids represent the spaces inside (hosted by) a unit or its material. E.g. the pores in an aquifer, or in the sandstone of an aquifer. Voids can contain fluid bodies. Voids are differentiated from 'porosity' in that porosity is the proportion of void volume to total volume, while voids are the spaces themselves. Voids are required in GWML2, for example, to capture the volume of fractures in an aquifer.

Attribute	Type and Multiplicity	Definition
gwVoidDescription	*char*	General description of the void
gwVoidHostMaterial	*EarthMaterial [0..*]*	The material that hosts the void, if specified. Note voids can be hosted by a unit (an aquifer) or its material (e.g. sandstone).
gwVoidMetadata	*GW_Metadata*	Metadata for the void.
gwVoidShape	*Geometry*	Shape and position of the void.
gwVoidType	*PorosityType*	Type of void e.g. fractured, intergranular, etc.
gwVoidVolume	*Measurement*	Volume of the void.

Relation	Source	Target	Description
Association	*Entity: GW_HydrogeoVoid* *Role: gwFluidBodyVoid*	*Entity: GW_FluidBody* *Role: gwVoidFluidBody*	Relates a void and a fluid body contained by the void. Each void contains at most one fluid body, which can

Relation	Source	Target	Description
			have multiple parts that could be disconnected. Likewise, each fluid body is contained by a single void, which could also be an aggregation of disconnected void parts.
AssociationClass	*Entity: GW_HydrogeoUnit* *Role: gwVoidUnit*	*Entity: GW_HydrogeoVoid* *Role: gwUnitVoid*	Relates hydrogeological units with a void hosted by the units. A unit hosts one void, which can be an aggregation of multiple voids potentially spatially disconnected. Voids in turn can be hosted by many units, particularly when units are arranged in whole-part relations, such that a void hosted by a part is also hosted by any associated whole, e.g. a void is hosted by both an aquifer and a related aquifer system, or a member and a related formation.
Aggregation	*Entity: GW_HydrogeoVoid* *Role: gwPartOfVoid*	*Entity: GW_HydrogeoVoid* *Role: gwVoidPartOf*	Relates a void part to a void whole.

7.6.23 GW_InterFlow

Fluid flow between features through an interface, exiting one feature and entering another. Features into which fluid is flowing are usually units, voids, or fluid bodies, but

can be natural surface water features such as rivers or lakes, or even man-made features such as dams or canals. Likewise for features where water is exiting.

Attribute	Type and Multiplicity	Definition
gwFlowLocation	*Geometry [1..*]*	The location at which water is being transferred from one feature into another.
gwFlowSourceContainer	*Feature*	The feature from which water is flowing.
gwFlowSourceBody	*Feature*	The fluid body from which water is flowing.
gwFlowDestinationContainer	*Feature*	The feature into which water is flowing.
gwFlowDestinationBody	*Feature*	The fluid body into which water is flowing.
gwFlowInterfaceFeature	*Feature [0..*]*	The feature that denotes the interface between, for example, the groundwater and surface, such as a well, spring, seep, etc., or between two aquifers.

Relation	Source	Target	Description
Generalization	*Entity: GW_InterFlow* *Role:*	*Entity: GW_Flow* *Role:*	An interflow is a type of directed flow between two features, e.g. flow between two units.
Generalization	*Entity: GW_Recharge* *Role:*	*Entity: GW_InterFlow* *Role:*	Recharge is a type of interflow in which fluid enters a feature.
Generalization	*Entity: GW_Discharge* *Role:*	*Entity: GW_InterFlow* *Role:*	Discharge is a type of interflow in which fluid exits a feature.

7.6.24 GW_IntraFlow

Fluid flow within a feature such as a unit, void, gw body, or even a man-made feature such as a conduit of some kind.

Attribute	Type and Multiplicity	Definition
gwFlowLocation	*Geometry*	The location where a fluid is flowing within a feature.
gwFlowContainer	*Feature*	The feature in which the fluid is flowing. Typically a unit, void, or gw body, but can also be a man made feature such as some conduit.
gwFlowBody	*Feature*	The fluid body that is flowing.

Relation	Source	Target	Description
Generalization	*Entity: GW_IntraFlow* *Role:*	*Entity: GW_Flow* *Role:*	An intraflow is a type of flow within a single feature, e.g. flow in a unit.

7.6.25 GW_Licence

Licence relating to the drilling of a well, the extraction of groundwater, etc.

Attribute	Type and Multiplicity	Definition
gwLicenceID	*CharacterString*	Licence ID, e.g. a number.
gwPurpose	*CharacterString*	Role of the licence.
gwAssociatedGWVolume	*QuantityRange*	Fluid volume associated with the licence.
gwTimePeriod	*TimeRange*	The period of time for which the licence is valid.

7.6.26 GW_ManagementArea

The GW_ManagementArea represents an area of ground identified for management purposes. The area can be delineated by human factors such as policy or regulation concerns, as well as by domain concerns (in this case hydrogeological or hydrological). The spatial boundaries of a management area do not necessarily align exactly with

associated hydrogeological feature boundaries. GW_ManagementArea has the potential to provide a pattern for a more generic OGC 'trans-domain' feature management class. GW_ManagementArea is equivalent to InspireAM:ManagementRestrictionOrRegulationZone.

Attribute	Type and Multiplicity	Definition
gwAreaName	*char [1..*]*	Name of the management area.
gwAreaDescription	*char*	General description of the management area.
gwAreaFeature	*Feature [1..*]*	Other features that are associated with the management area (watershed, ecological zones, etc) that are not hydrogeological units.
gwAreaWaterBudget	*GW_WaterBudget [1..*]*	Water budget associated with the management area.
gwAreaYield	*GW_Yield*	Yield associated with the management area.
gwAreaShape	*Geometry*	Geometric shape and position of management area.
gwAreaType	*ManagementAreaType*	General classification of the management area (e.g. restricted use zone, irrigation area, consumption area, etc.)
gwAreaSpecialisedAreaType	*SpecialisedZoneAreaTypeTerm*	Additional classification value which further specialises the gwAreaType.
gwAreaEnvironmentalDomain	*EnvironmentalDomainTypeTerm*	Classification of the environment domain(s) for which, through the establishment of the management area, certain environmental objectives are to be reached.
gwAreaCompetentAuthority	*CI_ResponsibleParty [0..*]*	Description of the organization(s) responsible for managing, restricting or regulating measures or activities within the management area.
gwAreaDesignationPeriod	*TM_Period*	Time period specifying when the management area was legally designated or became effective in the real world

Relation	Source	Target	Description

Relation	Source	Target	Description
Association	*Entity: GW_ManagementArea* *Role:*	*Entity: DocumentCitation* *Role: documentation*	Relates legislative and reference documentation to a management area.
Association	*Entity: GW_ManagementArea* *Role:*	*Entity: GW_FluidBody* *Role: gwAreaBody*	Relates a management area to the fluid bodies contained within the area. As with units, the spatial boundaries of management areas do not necessarily coincide with the spatial boundaries of fluid bodies.
Association	*Entity: GW_ManagementArea* *Role:*	*Entity: GW_ManagementArea* *Role: relatedManagementArea*	Relates a management area part to a management area whole.
Association	*Entity: GW_ManagementArea* *Role: gwManagementArea*	*Entity: GW_HydrogeoUnit* *Role: gwManagedUnit*	Relates a management area to the hydrogeological units contained within it. Because the spatial boundaries of management areas can be determined by human concerns, e.g. regulatory, these boundaries do not necessarily align with the spatial boundaries of units, which are determined by physical criteria.

7.6.27 GW_MaterialConstituent

Suspended or colloidal material in a fluid body, e.g., sediment.

Attribute	Type and Multiplicity	Definition
gwMaterial	*MaterialType*	Name of the suspended or colloid material in the fluid body, e.g. a lithology or mineral name.

Relation	Source	Target	Description
Generalization	*Entity:* *GW_MaterialConstituent* *Role:*	*Entity:* *GW_Constituent* *Role:*	A material constituent is a type of fluid body constituent. There are 3 types of fluid body constituents: chemical (e.g. arsenic), biologic (e.g. organisms), and material (e.g. sediment).

7.6.28 GW_Mixture

The nature of the inclusion of the constituent in the fluid body, e.g. suspension, emulsion, etc.

Attribute	Type and Multiplicity	Definition
gwMixture	*MixtureType*	The manner in which a constituent is within a fluid body, e.g. solution, suspension, emulsion, precipitate, colloidal.

7.6.29 GW_MonitoringSite

Site of observation related to groundwater.

Attribute	Type and Multiplicity	Definition
gwSiteName	*char [0..*]*	Name (or identifier) of the monitoring site.
gwSiteLocation	*Geometry*	Spatial location of the site.
gwSiteReferenceElevation	*Elevation [1..*]*	Reference elevation for all observations at the site, e.g. ground elevation, casing elevation. This can differ from the host feature elevation, or be more specific.

Attribute	Type and Multiplicity	Definition
gwSiteType	*SiteType*	Type of monitoring site, e.g. well, gauging station, etc.
gwMonitoringHost	*Feature*	The feature hosting the site, e.g. a well, spring, lake or stream.

7.6.30 GW_Porosity

Measure of the proportion of the volume occupied by specific voids over the total volume of material including the voids. Voids are differentiated from 'porosity' in that porosity is a proportion, while voids are the spaces themselves. Types of porosity include: primary, secondary, dual, specific, effective, granular, fractured, karstic, etc.

Attribute	Type and Multiplicity	Definition
gwPorosityType	*PorosityType*	Type of porosity (primary, secondary, dual, specific, effective, granular, fractured, karstic, etc.)
gwPorosity	*Measurement*	Measure of the proportion of the volume occupied by specific voids over the total volume of material including the voids.

Relation	Source	Target	Description
Association	*Entity: GW_UnitVoidProperty* *Role:*	*Entity: GW_Porosity* *Role: gwPorosity*	Relates possibly many types of porosity values to a unit and related void combination.

7.6.31 GW_Recharge

Fluid added to an aquifer by various means such as precipitation, injection, etc.

Relation	Source	Target	Description
Generalization	*Entity: GW_Recharge* *Role:*	*Entity: GW_InterFlow* *Role:*	Recharge is a type of interflow in which fluid enters a feature.

7.6.32 GW_Spring

Any natural feature where groundwater flows to the surface of the earth.

Attribute	Type and Multiplicity	Definition
gwSpringName	*CharacterString [0..*]*	Name or ID of the spring.
gwSpringLocation	*Geometry*	Geometry / position of the spring.
gwSpringReferenceElevation	*Elevation [1..*]*	Reference elevation for all observations at the site, e.g. ground elevation, casing elevation.
gwSpringType	*SpringType*	Type of spring e.g. mineral, thermal, saline, etc.
gwSpringCauseType	*SpringCauseType*	The cause of the spring e.g. artesian, geyser, perched, etc.
gwSpringPersistence	*SpringPersistenceType*	The periodicity of the spring e.g. ephemeral, perennial, intermittent, seasonal, etc.
gwSpringGeology	*GL_Feature [0..*]*	Related geology features.
gwSpringUnit	*GW_HydrogeoUnit [1..*]*	The hydrogeological unit(s) hosting the spring.
gwSpringBody	*GW_FluidBody [0..*]*	The fluid body being depleted by the spring.
gwSpringConstruction	*SpringConstruction [0..1]*	Spring construction details, if any.
gwSpringLicence	*GW_Licence [0..*]*	Any licence relating to the spring.

7.6.33 GW_UnitFluidProperty

A measured or calculated physical or hydraulic property that can be inherent in either an aquifer or its material, and some fluid body, e.g. hydraulic conductivity, transmissivity, storativity, permeability, porosity.

Attribute	Type and Multiplicity	Definition
gwHydraulicConductivity	*Measurement [1..*]*	Hydraulic conductivity measures how easily a fluid can move through the voids in a material.
gwTransmissivity	*Measurement [1..*]*	The rate of groundwater flow laterally through an aquifer, determined by hydraulic conductivity and container thickness.

Attribute	Type and Multiplicity	Definition
gwStorativity	*Measurement [1..*]*	Storativity is the volume of water released from storage per unit decline in hydraulic head in the aquifer, per unit area of the aquifer.

Relation	Source	Target	Description
Association	*Entity: GW_UnitFluidProperty* *Role:*	*Entity: GW_Yield* *Role: gwYield*	Relates possibly many types of yield values to a unit and fluid body combination.

7.6.34 GW_UnitProperties

Additional properties of an aquifer not included in the model.

Attribute	Type and Multiplicity	Definition
gwUnitProperty	*gwUnitPropertyType*	The type of hydrogeological unit property, e.g. average well depth.
gwUnitPropertyValue	*Any*	The value of the hydrogeological unit property.

Relation	Source	Target	Description
Association	*Entity: GW_HydrogeoUnit* *Role:*	*Entity: GW_UnitProperties* *Role: gwUnitProperty*	Relates a hydrogeological unit to possibly many additional properties.

7.6.35 GW_UnitVoidProperty

Properties inherent in the relation between a hydrogeological unit and a void: includes the proportion of voids to the unit (porosity) or to the connectivity / size of void openings (intrinsic permeability).

Attribute	Type and Multiplicity	Definition
gwPermeability	*Measurement [1..*]*	Refers to intrinsic permeability: a measure of a material's ability to allow fluid flow that is independent of fluid properties, and based on connectivity of pores and size of their openings. This is not hydraulic conductivity.

Relation	Source	Target	Description
Association	*Entity: GW_UnitVoidProperty* *Role:*	*Entity: GW_Porosity* *Role: gwPorosity*	Relates possibly many types of porosity values to a unit and related void combination.

7.6.36 GW_Vulnerability

The susceptibility of a feature to specific threats such as various physical events (earthquakes), human processes (depletion), etc.

Attribute	Type and Multiplicity	Definition
gwVulnerabilityType	*VulnerabilityType*	The type of vulnerability.
gwVulnerability	*Measurement*	A quantitative estimate of the susceptibility to contamination, e.g. a DRASTIC value. Should be accompanied by metadata about the method of calculation.

7.6.37 GW_WaterBudget

An accounting of the water input and output of a hydrogeological unit, at a particular point in time, with a description of inflows and outflows.

Attribute	Type and Multiplicity	Definition
gwBudgetAmount	*Measurement*	Final quantity (sum) of the budget. If recharge = discharge, the sum is 0.
gwBudgetValidTime	*TemporalType*	Valid time of this budget (e.g., 2010).

Attribute	Type and Multiplicity	Definition
gwBudgetRecharge	*GW_Recharge [1..*]*	Recharge (inflows) considered by the budget.
gwBudgetDischarge	*GW_Discharge [1..*]*	Discharge (outflows) considered in the budget.

7.6.38 GW_Well

A shaft or hole sunk, dug or drilled into the Earth to observe, extract or inject water (after IGH1397).

Attribute	Type and Multiplicity	Definition
gwWellName	*char [0..*]*	Name or ID of the well.
gwWellLocation	*Geometry*	Surface location of the well.
gwWellReferenceElevation	*Elevation [1..*]*	Reference elevation for all observations at the site, e.g. ground elevation, casing elevation.
gwWellContributionZone	*Geometry*	The area or volume surrounding a pumping well or other discharge site that encompasses all areas and features that supply groundwater to the well or discharge site.
gwWellGeology	*GeologyLog [0..*]*	Related borehole, including lithology log.
gwWellUnit	*GW_HydrogeoUnit [1..*]*	The aquifers or confining beds intersecting the well.
gwWellBody	*GW_FluidBody [0..*]*	The fluid body occupying the well.
gwWellPurpose	*WellPurposeType [1..*]*	Purpose of well, e.g. extraction, injection, observation, dewatering, cathodic protection, decontamination, disposal, FlowingShot, Geotechnical, Mineral, MonitoringlevelHead, MonitoringQuality, Oil, OilExploratory, Seismic, WaterExploratory, etc.
gwWellStatus	*WellStatusType*	Status of the well, Can be new, unfinished, reconditioned, deepened, not in use, standby, unknown, abandoned dry, abandoned insufficient, abandoned quality. (gwml1)
gwWellWaterUse	*WellWaterUseType*	E.g. Agricultural, Domestic, Industrial,

Attribute	Type and Multiplicity	Definition
	[1..]*	Recreation.
gwWellTotalLength	*Measurement*	Total length of the well from reference elevation.
gwWellConstructedDepth	*Measurement [0..1]*	Constructed depth of the well.
gwWellStaticWaterDepth	*Measurement*	Depth of the fluid body (e.g. piezometric level).
gwWellYield	*GW_Yield*	Estimated or calculated yield from a well.
gwWellConstruction	*WellConstruction*	Construction details for a well.
gwWellLicence	*GW_Licence [0..*]*	Licence relating to the drilling of the well or to the extraction of groundwater.

7.6.39 GW_Yield

Yield is the rate of fluid withdrawal associated with a unit, well, etc., expressed as m^3.
There are several types of yield, that can be considered: specific yield, sustainable yield, safe yield, aquifer yield, etc.

Attribute	Type and Multiplicity	Definition
gwYieldType	*YieldType*	Type of aquifer yields: e.g. specific yield, safe yield, etc.
gwYield	*Measurement*	Measurement of the yield in units of volume per unit of time.

Relation	Source	Target	Description
Association	*Entity: GW_UnitFluidProperty* *Role:*	*Entity: GW_Yield* *Role: gwYield*	Relates possibly many types of yield values to a unit and fluid body combination.

8. Logical Model

The logical model differs from the conceptual model through the introduction of technology-specific artifacts from the OGC General Reference Model and derived schemas. These include additions such as classes, relations, properties, constraints, and usage principles. Another difference is the incorporation of the well construction package from GWML1.

The logical model is not a syntactical encoding, but is an OGC-compliant schema that is syntax-neutral. Syntactical encodings are derived from the logical model, such as the reference GML encoding described herein.

The addition of OGC constructs to the conceptual model amounts to the integration of several OGC-compliant GML schemas, primarily GeoSciML 3.2 and Observations & Measurements, but also MD_Metadata and others. These are adapted using the following strategies.

(1) HydrogeologicalUnit in GWML2 specializes GeologicUnit from GeoSciML, recognizing that in its most basic sense a hydrogeological unit is a body of rock (a geological unit) exhibiting some hydrogeological properties including possibly fluid storage and transfer.
(2) Water wells and boreholes specialize O&M:SF_SamplingCurve, which allows them to have a shape described by 3D points at the start and end of each segment along the well or borehole. Wells and boreholes differ by purpose and use: boreholes are physical engineering artifacts consisting of a hole and potentially materials fitted inside the hole for some human use, and wells are constructions for the extraction or injection of water from/into the ground, and have specific hydrogeological properties such as water yield and intended use. As a consequence, well and associated borehole lengths can differ for the same well. A well can be seen as a specific role played by a borehole.
(3) Property values are assigned datatypes from O&M: numeric properties are assigned the OM_Measurement datatype, and properties that can be either numeric or categorical are assigned the Observation datatype. Two factors compel these choices: method metadata can be added to each value to describe determination of the value, and each property can be further soft-typed for greater precision. An example of the latter is the porosity property, which in practical situations could refer to any of a wide range of porosity types such as effective porosity, primary porosity, or secondary porosity.
(4) Fluid body constituent values are modeled as observations: for example, a chemical analysis of a groundwater sample might be represented in the following way:
    - Each measured value is the result of an observation.
    - The observedProperty would be e.g. “As_Concentration”
    - The featureOfInterest would be an instance of e.g. GW_ChemicalConstituent with ChemicalTypeTerm = “As” and gwState = “solid”.

This approach is quite flexible: it allows for different mixture types (e.g. suspension, solution, emulsion), states (i.e. liquid, solid, gas), and measurement types (e.g. concentration) for a constituent type (e.g. "As").

(5) Aquifer Tests are completely modelled using O&M, except for the single signature class GW_AquiferTest. This class is a property-less extension of O&M Sampling Feature. The logical model for Aquifer Test is thus the O&M logical model, as illustrated further in Figure 16. Time series generated by aquifer tests are represented using WaterML 2.0 (OGC 10-125r4).
(6) DocumentCitation is replaced by Any type (i.e. the 'documentation' role is assigned a datatype of Any), in order to satisfy the original intention of the DocumentCitation class of enabling re-use of relevant classes from other schemas. This allows, for example, use of classes such as GW_Licence, MD_Metadata, INSPIRE's DocumentCitation or LegislativeReferences for documentation.

The logical model is organized into six application schema packages, as mentioned in Section 1:

(1) GWML2-Main: core items, e.g. aquifers, their pores, fluid bodies, management areas.
(2) GWML2-Constituent: the biologic, chemical, and material elements of a fluid body.
(3) GWML2-Flow: fluid flow within and between containers, and water budgets.
(4) GWML2-Well: water wells, springs, and monitoring sites.
(5) GWML2-WellConstruction: the components used to construct a borehole or well.
(6) GWML2-AquiferTest: aspects associated with an aquifer test.

Because most of the differences between the logical and conceptual models can be inferred directly from the logical model UML diagrams, all diagrams are included below. Complete class descriptions are subsequently included only for additions to the conceptual model, mainly borehole construction elements and geology logs.

8.1 Logical Model Specification

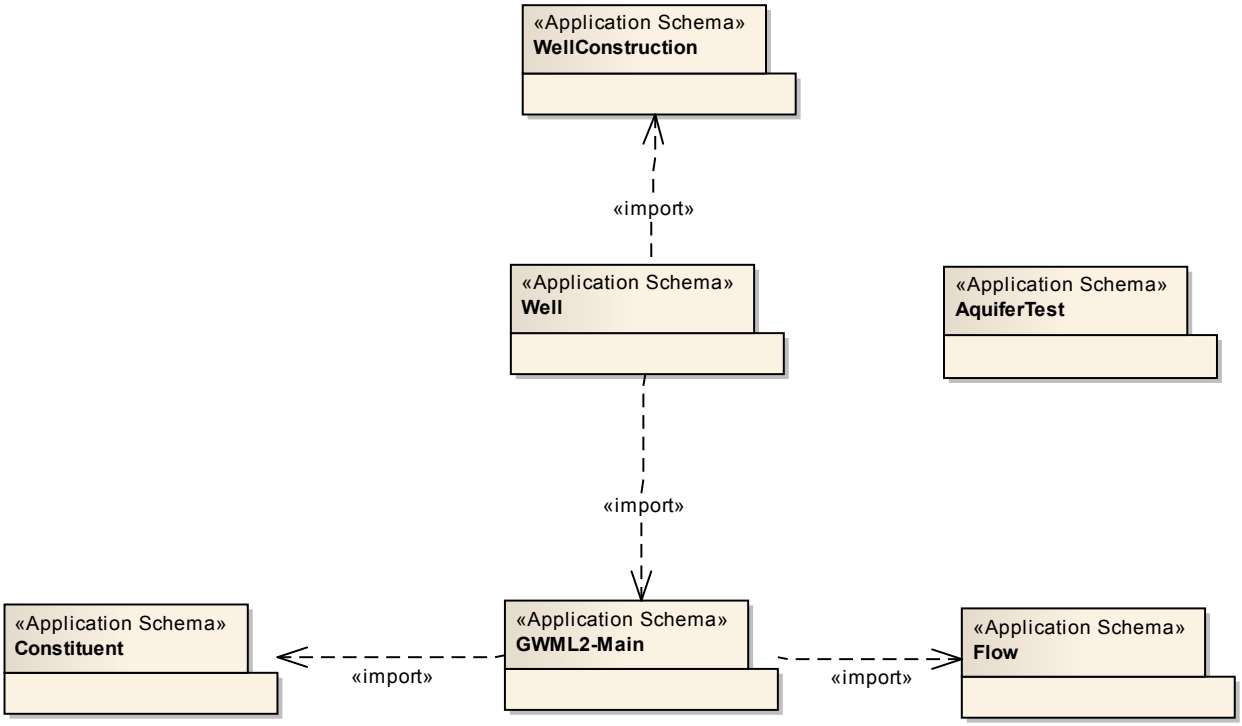

Figure 7: GWML2 LM - Package Dependencies (Internal).

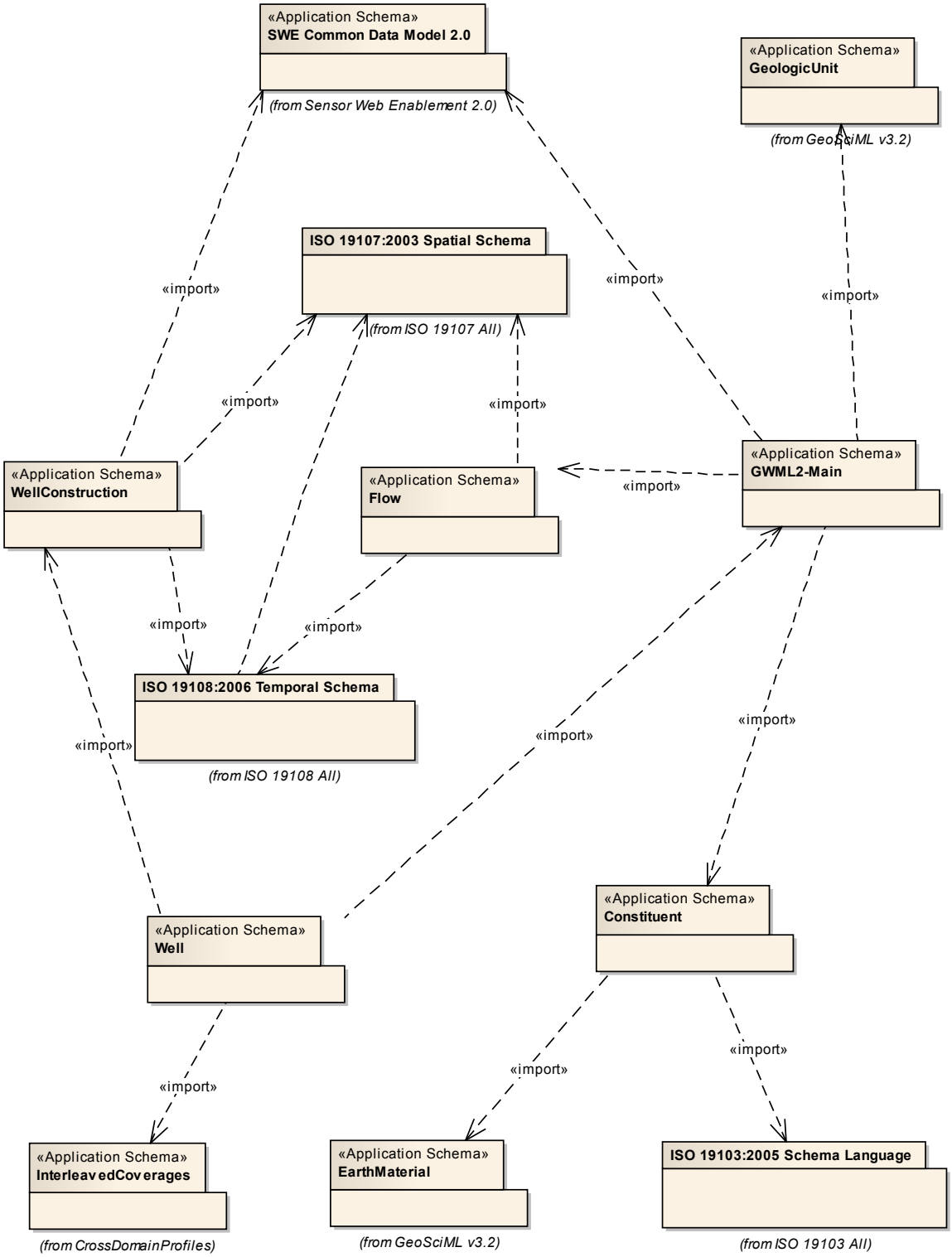

Figure 8: GWML2 LM - Package Dependencies (External -- indirect dependencies not shown).

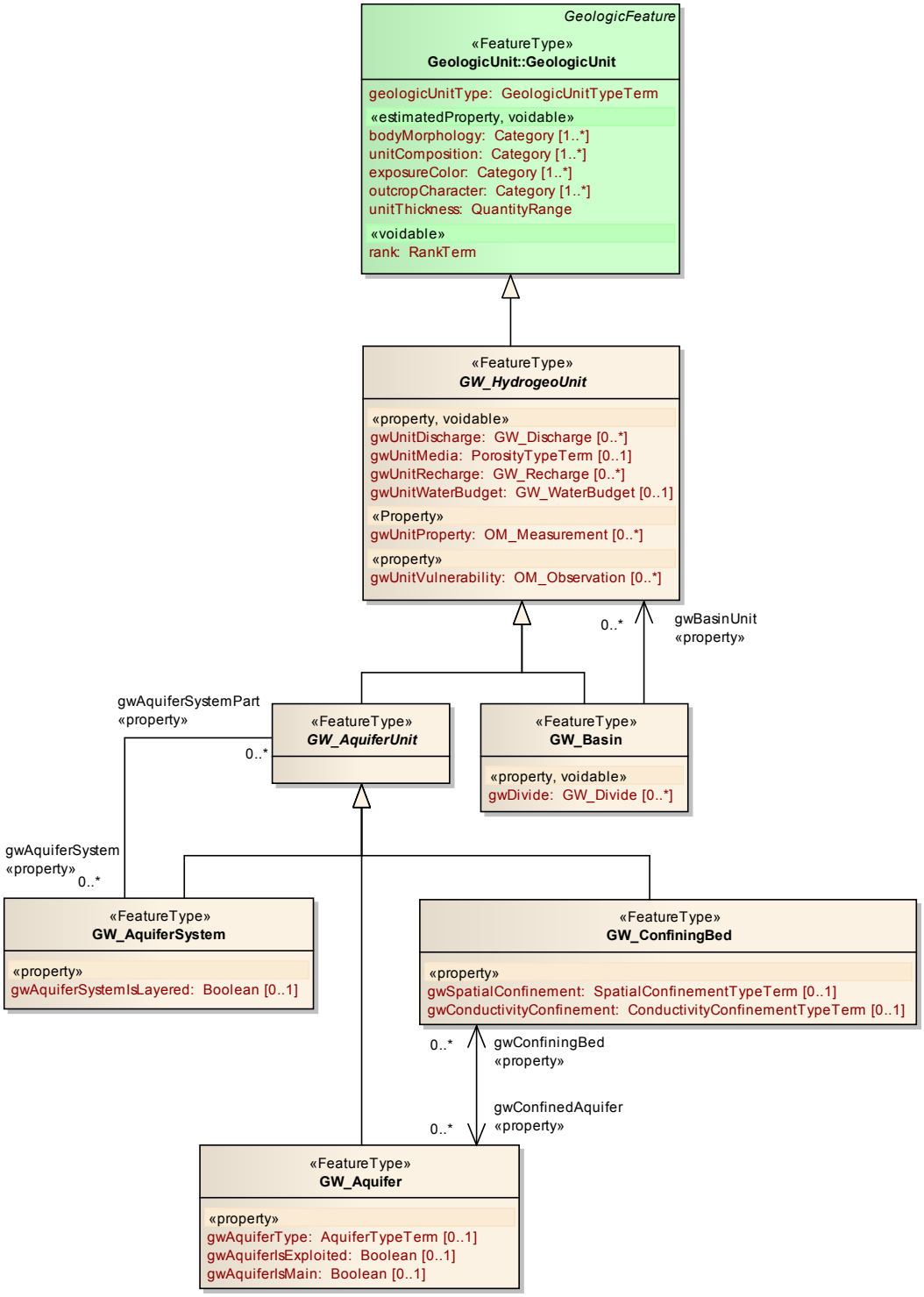

Figure 9: GWML2 LM - Hydrogeological Unit.

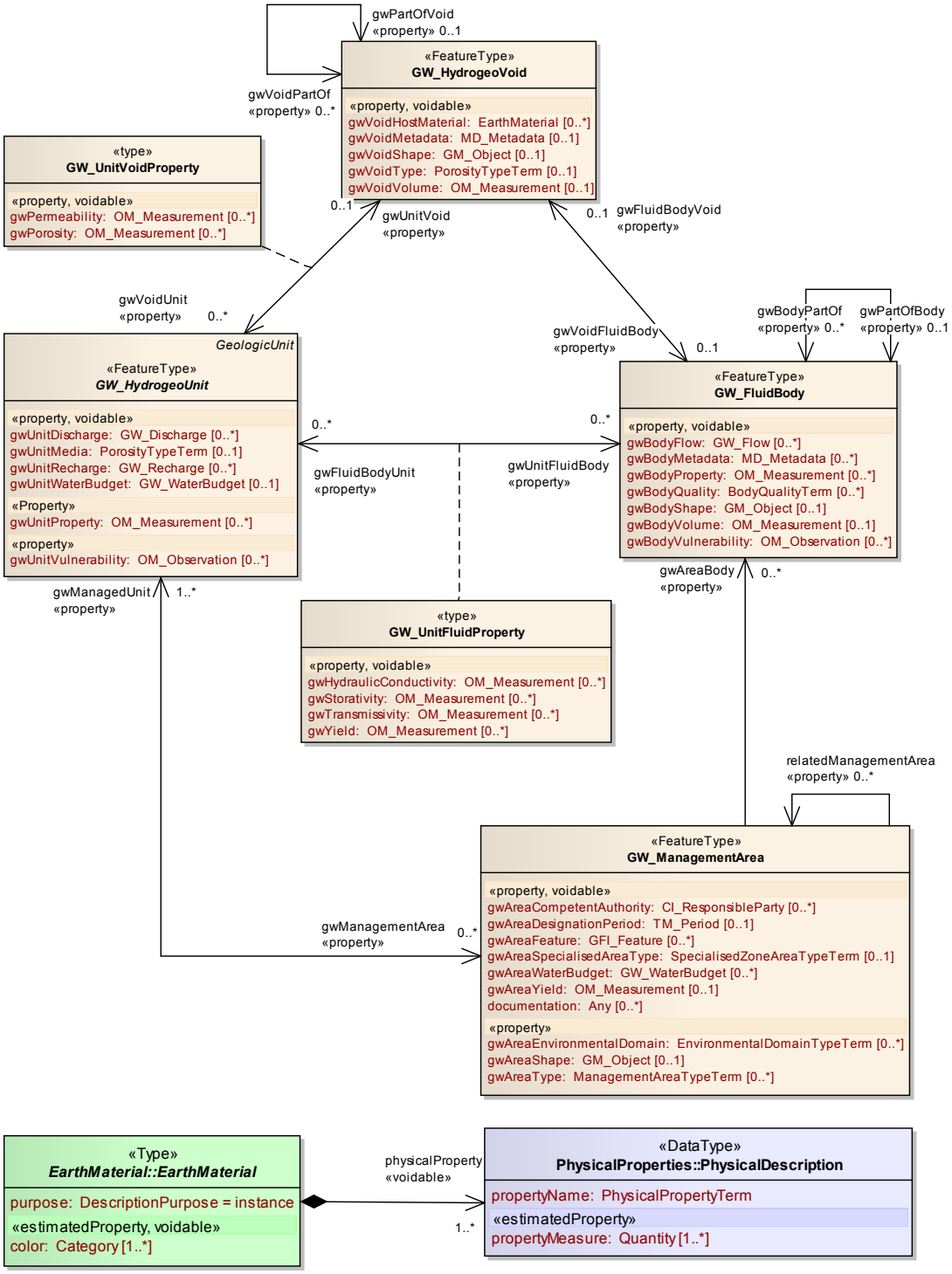

Figure 10: GWML2 LM - Groundwater Properties.

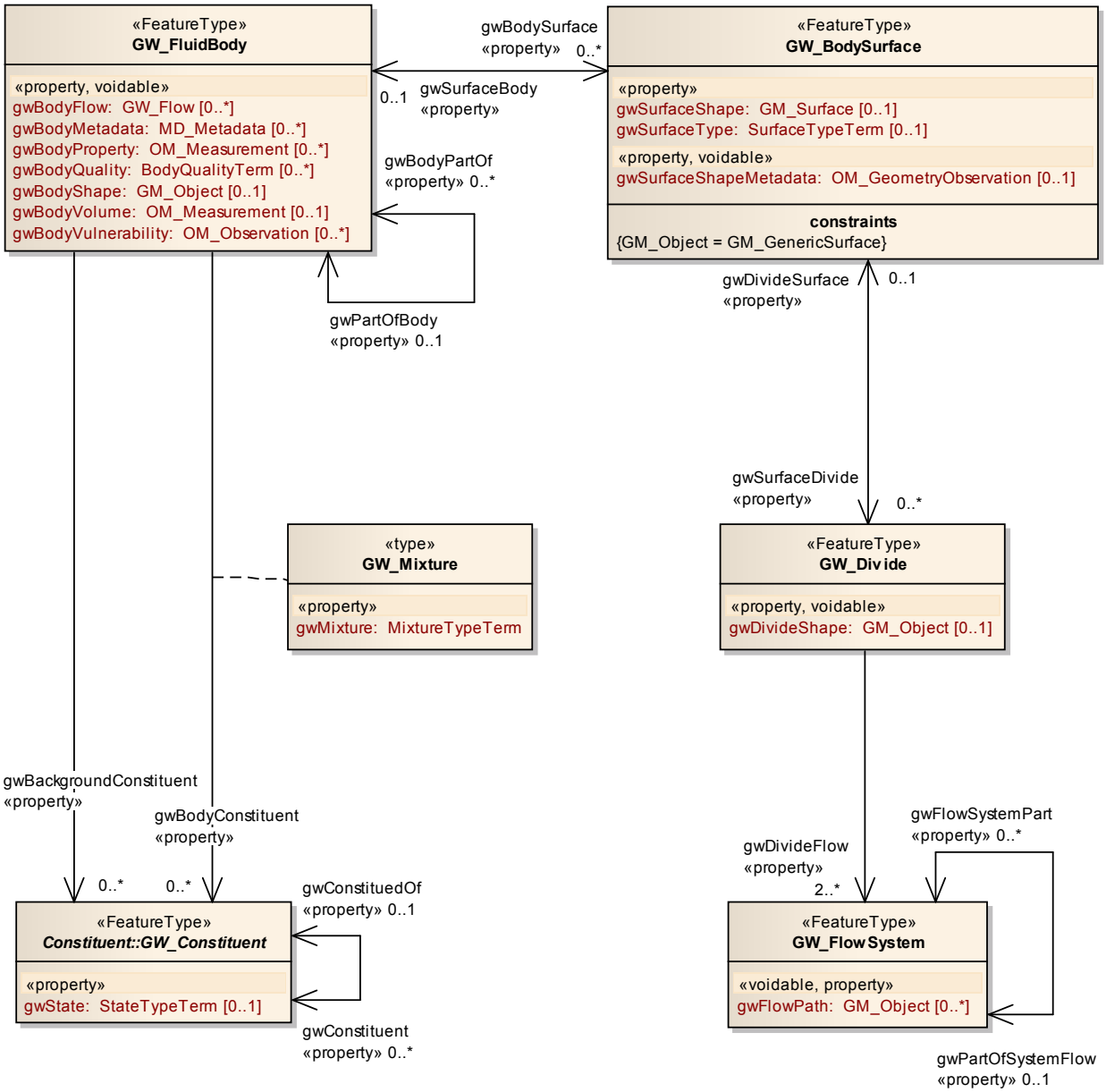

Figure 11: GWML2 LM - Fluid Body.

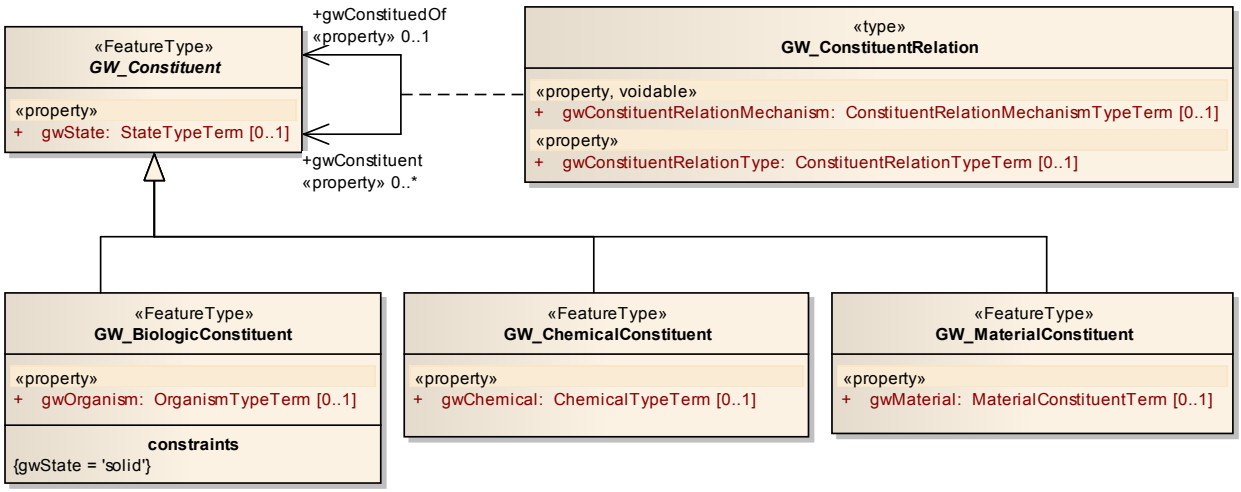

Figure 12: GWML2 LM - GroundWaterML2-Constituent.

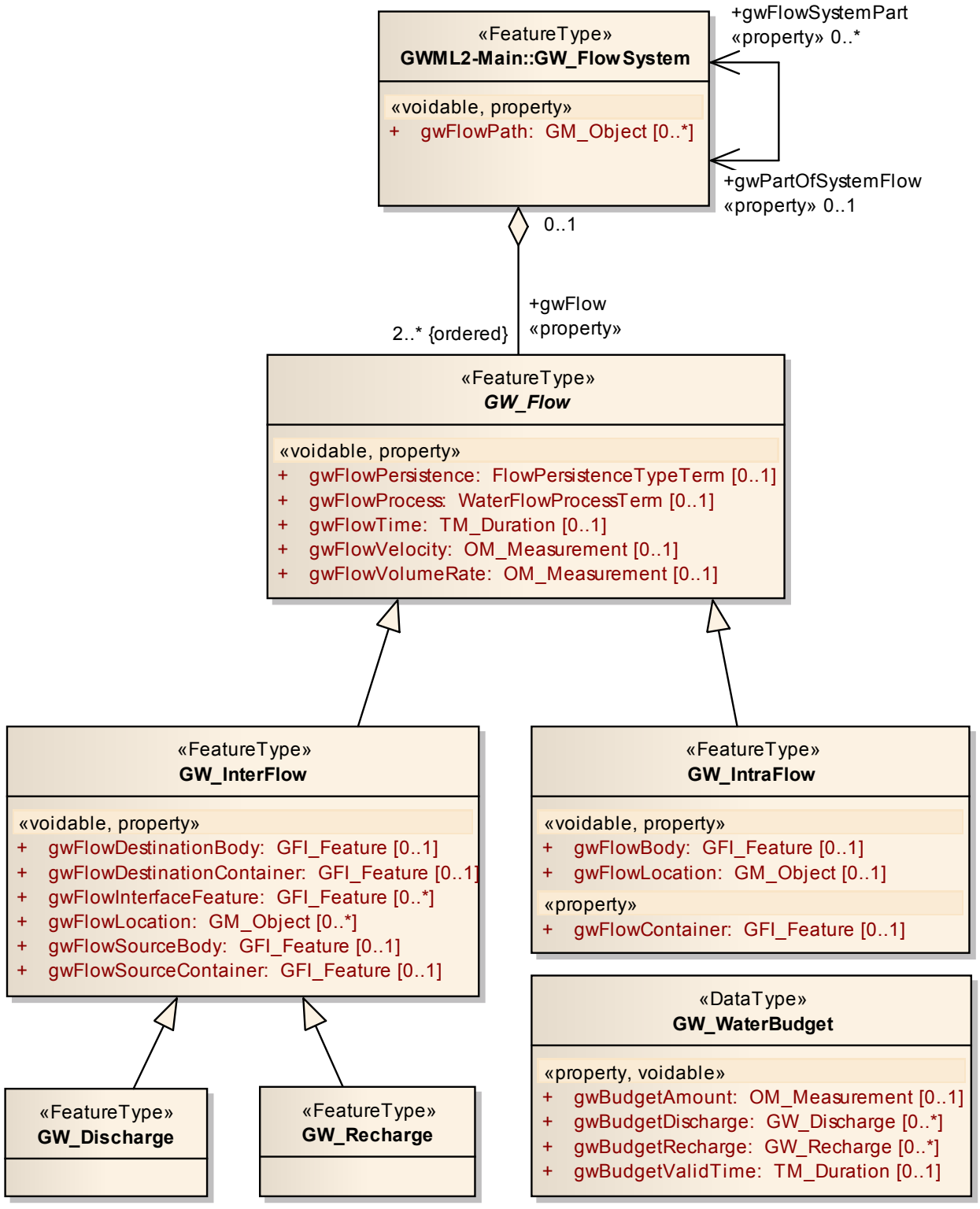

Figure 13: GWML2 LM - Groundwater Flow.

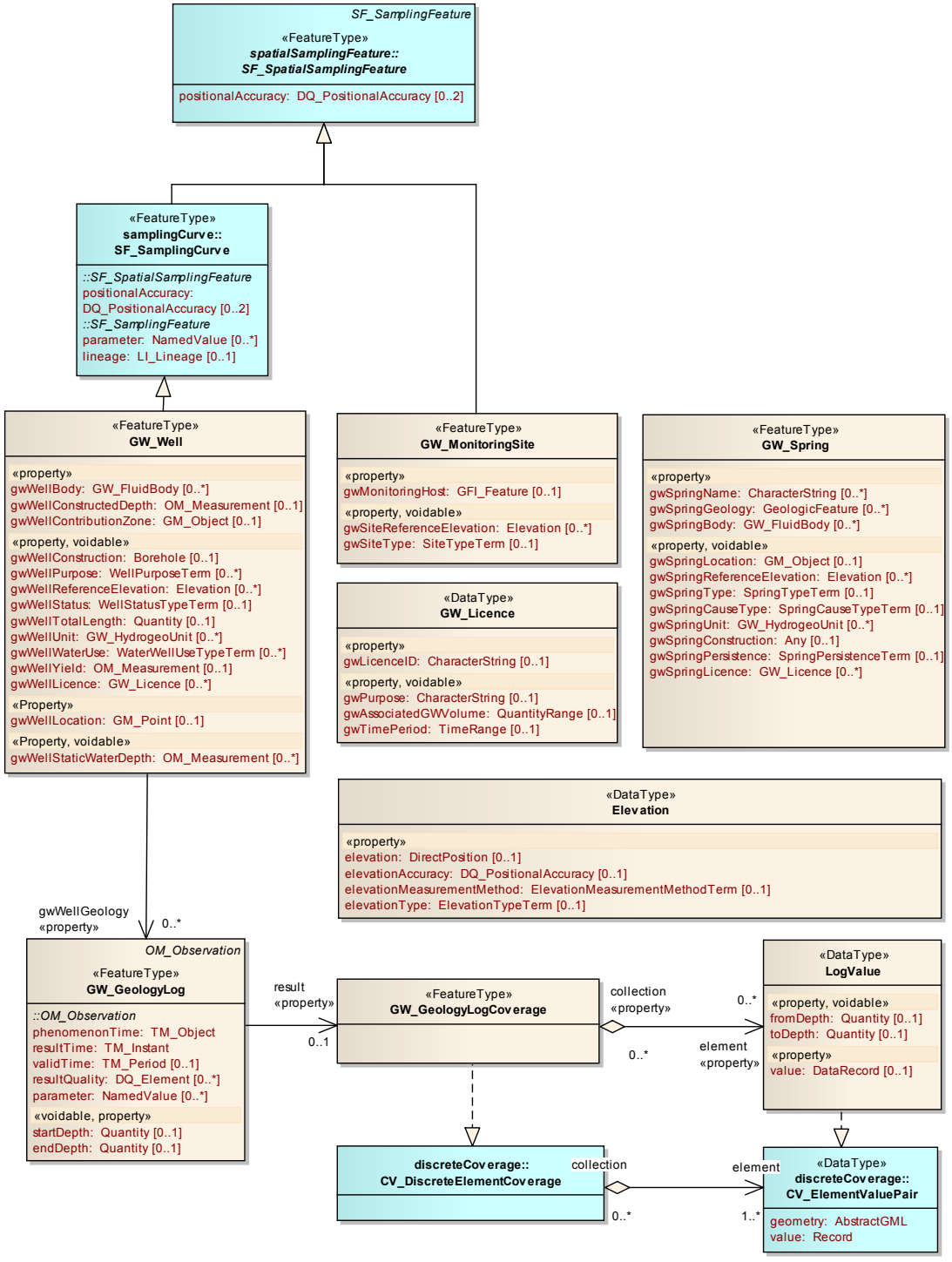

Figure 14: GWML2 LM - Well.

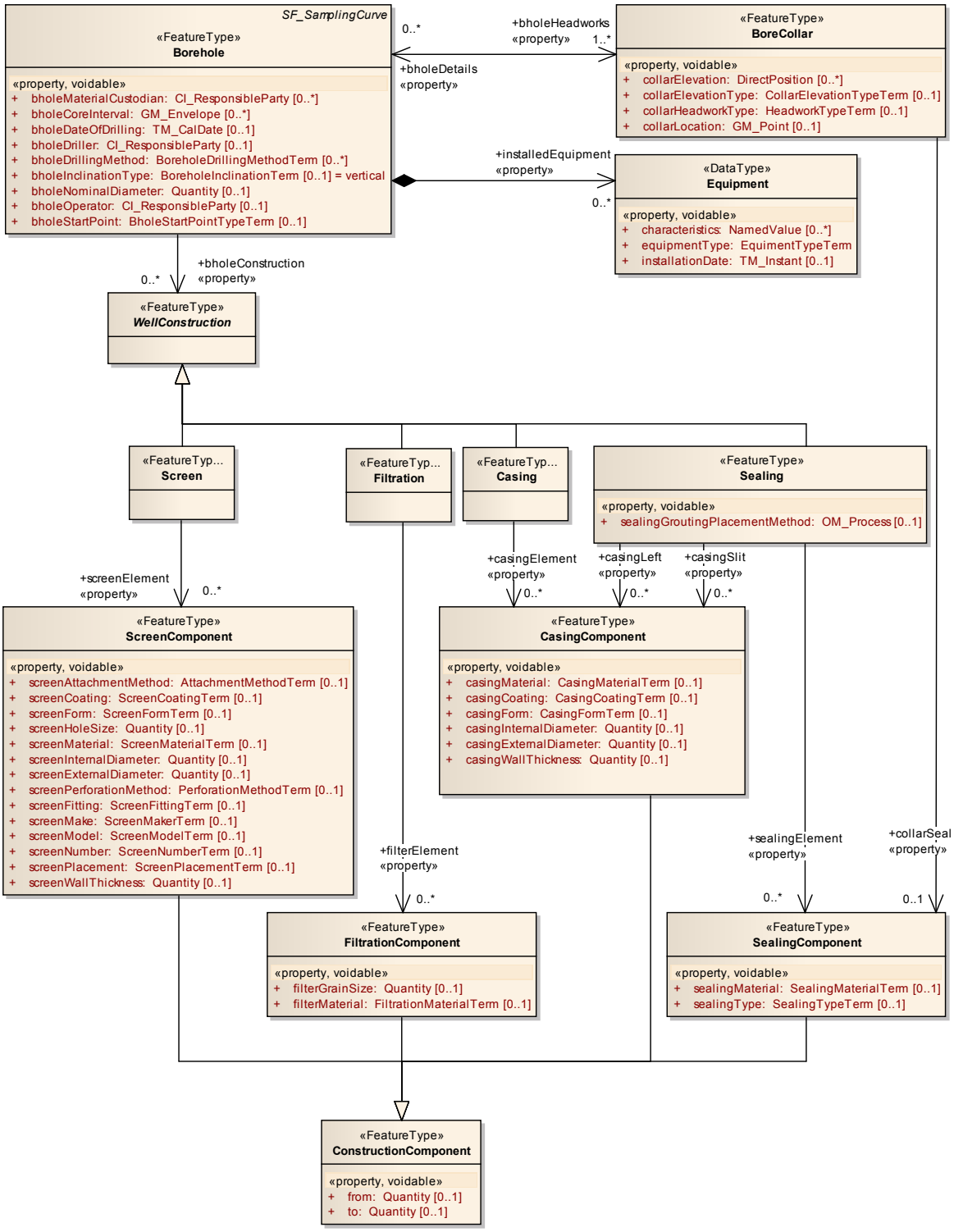

Figure 15: GWML2 LM - WellConstruction.

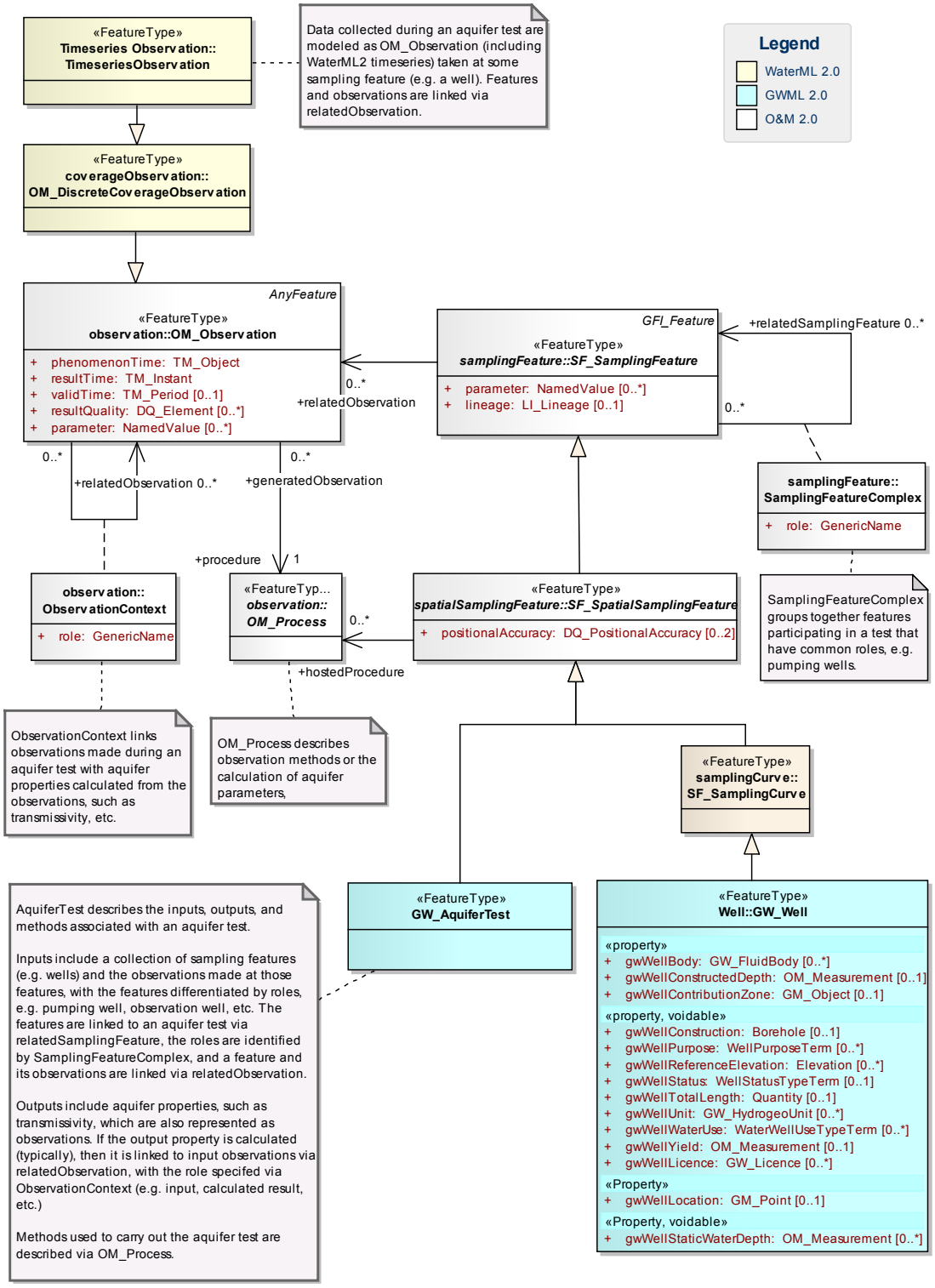

Figure 16: GWML2 LM - Aquifer Test.

8.1.1 BoreCollar

Topmost component of a borehole construction.

Attribute	Type and Multiplicity	Definition
collarElevation	*DirectPosition [0..*]*	The elevation of the bore collar with CRS and UOM.
collarElevationType	*CollarElevationTypeTerm [0..1]*	Type of reference elevation, defined as a feature, e.g. Top of Casing, Ground, etc.
collarHeadworkType	*HeadworkTypeTerm [0..1]*	Type of assembly bolted to the production casing to control the well, and to provide access and protection (e.g. from flooding, vandalism). Example: raised tube, covers, manhole, 'Gattick Cover' flush, concrete ring, etc. (after Fretwell, et al., 2006).
collarLocation	*GM_Point [0..1]*	The geographical location of the collar.

Relation	Source	Target	Description
Association	*Entity: Borehole* *Role: bholeDetails*	*Entity: BoreCollar* *Role: bholeHeadworks*	Relation between a borehole and its collar, which represents the top construction component of the borehole.
Association	*Entity: BoreCollar* *Role:*	*Entity: SealingComponent* *Role: collarSeal*	Relation between a bore collar and its sealing parts.

8.1.2 Borehole

General term for a hole drilled in the ground for various purposes such extraction of a core, release of fluid, etc.

Attribute	Type and Multiplicity	Definition
bholeMaterialCustodian	*CI_ResponsibleParty [0..*]*	The custodian of the drill core or samples recovered from the borehole.

Attribute	Type and Multiplicity	Definition
bholeCoreInterval	*GM_Envelope [0..*]*	The geometries for the intervals from which core is extracted along the borehole.
bholeDateOfDrilling	*TM_CalDate [0..1]*	Date of drilling.
bholeDriller	*CI_ResponsibleParty [0..1]*	The organisation responsible for drilling the borehole (as opposed to commissioning the borehole).
bholeDrillingMethod	*BoreholeDrillingMethodTerm [0..*]*	Method of drilling.
bholeInclinationType	*BoreholeInclinationTerm [0..1] vertical*	Type of borehole inclination, e.g. vertical or horizontal.
bholeNominalDiameter	*Quantity [0..1]*	Diameter of the borehole.
bholeOperator	*CI_ResponsibleParty [0..1]*	Organisation responsible for commissioning the borehole (as opposed to drilling the borehole).
bholeStartPoint	*BholeStartPointTypeTerm [0..1]*	Describes the location of the start of the borehole, e.g. ground surface.

Relation	Source	Target	Description
Association	*Entity: Borehole* *Role:*	*Entity: Equipment* *Role: installedEquipment*	Relation designating the equipment installed in a borehole.
Association	*Entity: Borehole* *Role:*	*Entity: WellConstruction* *Role: bholeConstruction*	Relation between a borehole and its construction components.
Association	*Entity: Borehole*	*Entity: BoreCollar*	Relation between a borehole and its collar, which represents the

Relation	Source	Target	Description
	Role: bholeDetails	*Role: bholeHeadworks*	top construction component of the borehole.
Generalization	*Entity: Borehole* *Role:*	*Entity: SF_SamplingCurve* *Role:*	A borehole is a type of Sampling Curve.

8.1.3 Casing

Collection of linings of the borehole.

Relation	Source	Target	Description
Generalization	*Entity: Casing* *Role:*	*Entity: WellConstruction* *Role:*	A casing is a type of well construction entity.
Association	*Entity: Casing* *Role:*	*Entity: CasingComponent* *Role: casingElement*	Relation between a casing and its parts.

8.1.4 CasingComponent

A single part of a borehole casing.

Attribute	Type and Multiplicity	Definition
casingMaterial	*CasingMaterialTerm [0..1]*	Material in which the casing is made. E.g. metal, steel, iron, concrete, wood, brick, plastic, teflon, PVC, ABS, fibreglass, etc.
casingCoating	*CasingCoatingTerm [0..1]*	Coating applied to the casing. E.g. galvanized, stainless, mild, low carbon, copper bearing, black, etc.
casingForm	*CasingFormTerm [0..1]*	Form of material used in the casing. E.g.

Attribute	Type and Multiplicity	Definition
		curbing, cribbing, corrugated, culvert, hose, etc.
casingInternalDiameter	*Quantity [0..1]*	Internal diameter of the casing.
casingExternalDiameter	*Quantity [0..1]*	External diameter of the casing.
casingWallThickness	*Quantity [0..1]*	Thickness of the wall of the casing.

Relation	Source	Target	Description
Generalization	*Entity: CasingComponent* *Role:*	*Entity: ConstructionComponent* *Role:*	A casing part is a type of construction component.
Association	*Entity: Sealing* *Role:*	*Entity: CasingComponent* *Role: casingSlit*	Casing slit opposing water bearing zones before plugging.
Association	*Entity: Casing* *Role:*	*Entity: CasingComponent* *Role: casingElement*	Relation between a casing and its parts.
Association	*Entity: Sealing* *Role:*	*Entity: CasingComponent* *Role: casingLeft*	Casing left after plugging.

8.1.5 ConstructionComponent

Elements used in borehole construction.

Attribute	Type and Multiplicity	Definition
from	*Quantity [0..1]*	Position of the top (nearest to the borehole start) of the component.
to	*Quantity [0..1]*	Position of the bottom (farthest to the borehole start) of the component.

Relation	Source	Target	Description
Generalization	*Entity: CasingComponent* *Role:*	*Entity: ConstructionComponent* *Role:*	A casing part is a type of construction component.
Generalization	*Entity: ScreenComponent* *Role:*	*Entity: ConstructionComponent* *Role:*	A screen part is a type of construction component.
Generalization	*Entity: FiltrationComponent* *Role:*	*Entity: ConstructionComponent* *Role:*	A filtration part is a type of construction component.
Generalization	*Entity: SealingComponent* *Role:*	*Entity: ConstructionComponent* *Role:*	A seal part is a type of construction component.

8.1.6 Equipment

Equipment installed in a borehole (like a pump or any other device).

Attribute	Type and Multiplicity	Definition

Attribute	Type and Multiplicity	Definition
characteristics	*NamedValue [0..*]*	General characteristics of the equipment.
equipmentType	*EquimentTypeTerm*	Type of equipment.
installationDate	*TM_Instant [0..1]*	Date of installation of the equipment.

Relation	Source	Target	Description
Association	*Entity: Borehole* *Role:*	*Entity: Equipment* *Role: installedEquipment*	Relation designating the equipment installed in a borehole.

8.1.7 Filtration

Collection of filtration components used to filter a fluid body in a well.

Relation	Source	Target	Description
Association	*Entity: Filtration* *Role:*	*Entity: FiltrationComponent* *Role: filterElement*	Relation between a filtration device and its parts.
Generalization	*Entity: Filtration* *Role:*	*Entity: WellConstruction* *Role:*	A filtration device is a type of well construction entity.

8.1.8 FiltrationComponent

Material used to filter the fluid in a borehole or well.

Attribute	Type and Multiplicity	Definition
filterGrainSize	*Quantity [0..1]*	Size of the particles of the filtration material.
filterMaterial	*FiltrationMaterialTerm [0..1]*	Material used in the filtration device. E.g. gravel, pit run, silica sand, washed sand, crushed rock,

Attribute	Type and Multiplicity	Definition
		etc.

Relation	Source	Target	Description
Association	*Entity: Filtration* *Role:*	*Entity: FiltrationComponent* *Role: filterElement*	Relation between a filtration device and its parts.
Generalization	*Entity: FiltrationComponent* *Role:*	*Entity: ConstructionComponent* *Role:*	A filtration part is a type of construction component.

8.1.9 GW_GeologyLog

Specialization of the OM_Observation containing the log start and end depth for coverages.

For Stratigraphic logs the observedProperty will be a GeoSciML:GeologicUnit/name.

For Lithologic logs the observedProperty will be a GeoSciML:GeologicUnit/composition/CompositionPart/material.

Attribute	Type and Multiplicity	Definition
startDepth	*Quantity [0..1]*	The start of the log measured as a depth from the reference elevation.
endDepth	*Quantity [0..1]*	The end of the log measured as a depth from the reference elevation.

Relation	Source	Target	Description
Generalization	*Entity: GW_GeologyLog* *Role:*	*Entity: OM_Observation*	A geology log is a type of observation.

Relation	Source	Target	Description
		Role:	
Association	*Entity: GW_GeologyLog* *Role:*	*Entity: GW_GeologyLogCoverage* *Role: result*	Relates a geology log with a particular collection of values (the result) that represent the group of measurements taken in intervals along the length of the log.
Association	*Entity: GW_Well* *Role:*	*Entity: GW_GeologyLog* *Role: gwWellGeology*	Relates a GeologyLog with a well.

8.1.10 GW_GeologyLogCoverage

A particular collection of values that represent the group of measurements taken in intervals along the length of the log. Overrides DiscreteElementCoverage to enable LogValues to be elements of the collection (GeologyLogCoverage).

Relation	Source	Target	Description
Realization	*Entity: GW_GeologyLogCoverage* *Role:*	*Entity: CV_DiscreteElementCoverage* *Role:*	A GeologyLogCoverage is a realization of a DiscreteElementCoverage.
Association	*Entity: GW_GeologyLogCoverage* *Role: collection*	*Entity: LogValue* *Role: element*	Relates a collection with the values that are part of the collection and that represent the measurements taken in intervals along the length of the log.
Association	*Entity: GW_GeologyLog*	*Entity: GW_GeologyLogCover*	Relates a geology log with a particular collection of values

Relation	Source	Target	Description
	Role:	*age* *Role: result*	(the result) that represent the group of measurements taken in intervals along the length of the log.

8.1.11 LogValue

The value of the log property at a depth interval along the log.

Attribute	Type and Multiplicity	Definition
fromDepth	*Quantity [0..1]*	Start depth of the interval along a log.
toDepth	*Quantity [0..1]*	End depth of the interval along a log.
value	*DataRecord [0..1]*	Value of the log property.

Relation	Source	Target	Description
Association	*Entity: GW_GeologyLogCoverage* *Role: collection*	*Entity: LogValue* *Role: element*	Relates a collection with the values that are part of the collection and that represent the measurements taken in intervals along the length of the log.
Realization	*Entity: LogValue* *Role:*	*Entity: CV_ElementValuePair* *Role:*	A LogValue is a realization of a CV_ElementValuePair from O&M.

8.1.12 Screen

Collection of components of the water pump screen.

Relation	Source	Target	Description
Generalization	*Entity: Screen* *Role:*	*Entity: WellConstruction*	A screen is a type of well construction

Relation	Source	Target	Description
		Role:	entity.
Association	*Entity: Screen* *Role:*	*Entity: ScreenComponent* *Role: screenElement*	Relation between a screen and its parts.

8.1.13 ScreenComponent

Component of the well lining where water enters the well.

Attribute	Type and Multiplicity	Definition
screenAttachmentMethod	*AttachmentMethodTerm [0..1]*	Screen attachment method. E.g. telescoped, on casing, on riser pipe, neoprene (K) packer, Lead packer, etc.
screenCoating	*ScreenCoatingTerm [0..1]*	Thin outer layer applied to the screen. E.g. galvanized, stainless, copper bearing, low carbon, black, porous, etc.
screenForm	*ScreenFormTerm [0..1]*	Form of the screen. E.g. slotted casing, perforated casing, bridge slot casing, wire wrap or continuous slot, wire mesh, shutter or louvered, well point, tube, etc.
screenHoleSize	*Quantity [0..1]*	Size of the slots or perforations of the screen.
screenMaterial	*ScreenMaterialTerm [0..1]*	Material that makes up the screen. E.g. metal, steel, iron, copper, brass, bronze, everdur, Armco metal, veriperm, stone, plastic, PVC, ABS, Fibreglass, etc.
screenInternalDiameter	*Quantity [0..1]*	Internal screen diameter.
screenExternalDiameter	*Quantity [0..1]*	External screen diameter.
screenPerforationMethod	*PerforationMethodTerm [0..1]*	Method used for perforating the screen. E.g. drill, grinder, axe / chisel, machine, saw, torch, other, etc.

Attribute	Type and Multiplicity	Definition
screenFitting	*ScreenFittingTerm [0..1]*	The screen fitting (from the bottom). E.g. bail, open, plug, tail pipe, washdown, etc.
screenMake	*ScreenMakerTerm [0..1]*	Make of the screen.
screenModel	*ScreenModelTerm [0..1]*	Model of the screen
screenNumber	*ScreenNumberTerm [0..1]*	Screen number corresponds to hole size and is given in 0.001 inch. The value is expressed as an alphanumeric code.
screenPlacement	*ScreenPlacementTerm [0..1]*	Screen placement method. E.g. bail down, pull back, jetted, washed down, etc.
screenWallThickness	*Quantity [0..1]*	Thickness of the screen wall.

Relation	Source	Target	Description
Generalization	*Entity: ScreenComponent* *Role:*	*Entity: ConstructionComponent* *Role:*	A screen part is a type of construction component.
Association	*Entity: Screen* *Role:*	*Entity: ScreenComponent* *Role: screenElement*	Relation between a screen and its parts.

8.1.14 Sealing

Collection of materials that prevent undesirable elements from entering the borehole.

Attribute	Type and Multiplicity	Definition
sealingGroutingPlacementMethod	*OM_Process [0..1]*	Method of placing the sealing grouting.

Relation	Source	Target	Description
Association	*Entity: Sealing* *Role:*	*Entity: CasingComponent* *Role: casingSlit*	Casing slit opposing water bearing zones before plugging.
Generalization	*Entity: Sealing* *Role:*	*Entity: WellConstruction* *Role:*	A sealing is a type of well construction entity.
Association	*Entity: Sealing* *Role:*	*Entity: CasingComponent* *Role: casingLeft*	Casing left after plugging.
Association	*Entity: Sealing* *Role:*	*Entity: SealingComponent* *Role: sealingElement*	Relation between a seal and its parts.

8.1.15 SealingComponent

A material used for sealing the construction of a borehole or well.

Attribute	Type and Multiplicity	Definition
sealingMaterial	*SealingMaterialTerm [0..1]*	Material used in the sealing component of a water well. E.g. formation packer, welded ring, shale trap, drive shoe, driven casing, etc.
sealingType	*SealingTypeTerm [0..1]*	Type of sealing. E.g. annular sealing, plugging, etc.

Relation	Source	Target	Description

Relation	Source	Target	Description
Generalization	*Entity: SealingComponent* *Role:*	*Entity: ConstructionComponent* *Role:*	A seal part is a type of construction component.
Association	*Entity: BoreCollar* *Role:*	*Entity: SealingComponent* *Role: collarSeal*	Relation between a bore collar and its sealing parts.
Association	*Entity: Sealing* *Role:*	*Entity: SealingComponent* *Role: sealingElement*	Relation between a seal and its parts.

8.1.16 WellConstruction

Construction components of the well. These are particularly important when assessing results of pump tests.

Relation	Source	Target	Description
Generalization	*Entity: Casing* *Role:*	*Entity: WellConstruction* *Role:*	A casing is a type of well construction entity.
Association	*Entity: Borehole* *Role:*	*Entity: WellConstruction* *Role: bholeConstruction*	Relation between a borehole and its construction components.
Generalization	*Entity: Screen* *Role:*	*Entity: WellConstruction*	A screen is a type of well construction entity.

Relation	Source	Target	Description
		Role:	
Generalization	*Entity: Filtration* *Role:*	*Entity: WellConstruction* *Role:*	A filtration device is a type of well construction entity.
Generalization	*Entity: Sealing* *Role:*	*Entity: WellConstruction* *Role:*	A sealing is a type of well construction entity.

9. Requirements Classes (normative)

This section describes requirement classes for any target implementation conforming to GWML2. Target implementations must meet related conformance class tests for at least one **concrete** requirements class (in Sections 9.2 and greater). The core requirement class (Section 9.1) is **abstract,** therefore solely meeting the core requirements is insufficient to claim compliance with GWML2. Note, this section documents only those requirements that cannot be read directly from the UML logical model—**the logical model denotes the first suite of canonical requirements, which are supplemented by those below**.

9.1 Abstract requirements classes: GWML2 core logical model

This core requirement class describes requirements that must be met by all target implementations that claim compliance with GWML2 (this specification). It also sets common requirements for all extensions of this specification. Since this requirement class is abstract, a conformant target implementation SHALL also implement at least one concrete requirements class from Sections 9.2 and greater.

Requirements class	**/req/gwml2-core**
Target type	Encoding of logical models
Name	GWML2 core logical model
Dependency	urn:iso:dis:iso:19156:clause:6.2.2
Dependency	urn:iso:dis:iso:19156:clause:7
Dependency	http://www.opengis.net/doc/IS/GML/3.2/clause/2.4

Dependency	O&M Abstract model, OGC 10-004r3, clause D.3.4
Dependency	http://www.opengis.net/spec/SWE/2.0/req/core/core-concepts-used
Requirement	/req/gwml2-core/encoding
Requirement	/req/gwml2-core/quantities-uom
Recommendation	/req/gwml2-core/codelist
Requirement	/req/gwml2-core/codelistURI
Requirement	/req/gwml2-core/identifier
Requirement	/req/gwml2-core/feature

The properties, constraints, cardinalities and associations documented in the UML will be honored by all the target implementations.

/req/gwml2-core/encoding	All target implementations SHALL conform to the appropriate GroundWaterML2 Logical Model UML as defined at http://www.opengis.net/def/groundwaterml/2.1/ftc and represented in Section 8.

9.1.1 Quantities

The Quantities and Measurements units of measure shall be taken from a standard vocabulary governed by an appropriate community.

/req/gwml2-core/quantities-uom	Quantities and measurements SHALL have explicit units of measure specified using the URI for an individual from a class governed as an external ontology.

9.1.2 Code lists

All properties that require formal vocabularies are modelled in UML as classes having the stereotype <<CodeList>>. The list of valid terms should be taken from a standard vocabulary governed by an appropriate community.

/req/gwml2-core/codelist	Classes of stereotype <<CodeList>> SHOULD be specified using the URI for an individual from a class governed as an external ontology

9.1.3 Code lists URI

The URI used to identify vocabulary terms SHALL be resolvable using Linked Open Data Principles, where a URI identifier can resolve to multiple representations (or formats) for the term using HTTP content, MIME-type and language negotiation mechanisms.

/req/gwml2-core/codelistURI	URI used for vocabulary terms SHALL be resolvable using Linked Open Data principles.

9.1.4 Identifier

Features that use an HTTP URI as their identifier SHALL be resolvable following Linked Open Data principles.

/req/gwml2-core/identifier	HTTP URI used as identifiers SHALL be resolvable following Linked Open Data principles.

9.1.5 Feature

A valid instance document SHALL contain at least one valid GWML 2.1 feature

/req/gwml2-core/feature	A valid GWML 2.1 document SHALL contain at least one valid GWML 2.1 feature.

9.2 Requirement class: GWML2-Main

Requirements class	**/req/gwml2-main-uml**
Target type	Encoding of logical model
Name	Main logical model
Dependency	/req/gwml2-core
Dependency	ISO-19115
Dependency	GeoSciML GeologicUnit 3.2
Dependency	GeoSciML EarthMaterial 3.2
Dependency	/req/gwml2-flow-uml
Dependency	/req/gwml2-constituent-uml
Requirement	/req/gwml2-main/observed-unit-fluid-property-foi
Requirement	/req/gwml2-main/observed-unit-void-property-foi
Requirement	/req/gwml2-main/managementArea

9.2.1 Feature of interest for Association classes

OM_Observation is extensively used to represent property values wherever metadata supporting the result is deemed useful. As stated in ISO19156/OGC 10-004r3, the OM_Observation's feature of interest should be the bearer of the observed property (10-004r3, clause 7.2.2.7). All properties in GWML 2.1 that use OM_Observation in the model are carried by Features; the relationship between the observation and the bearer of properties is obvious, except for two cases: **GW_UnitFluidProperty (**Figure 17**)** and **GW_UnitVoidProperty (**Figure 18).

GW_FluidProperty is an association class linking a GW_HydroGeoUnit and a GW_FluidBody and carries properties that are inherently related to the association of a geological unit and the fluid occupying its voids. Not being a feature, this class cannot be the feature of interest of the properties it bears.

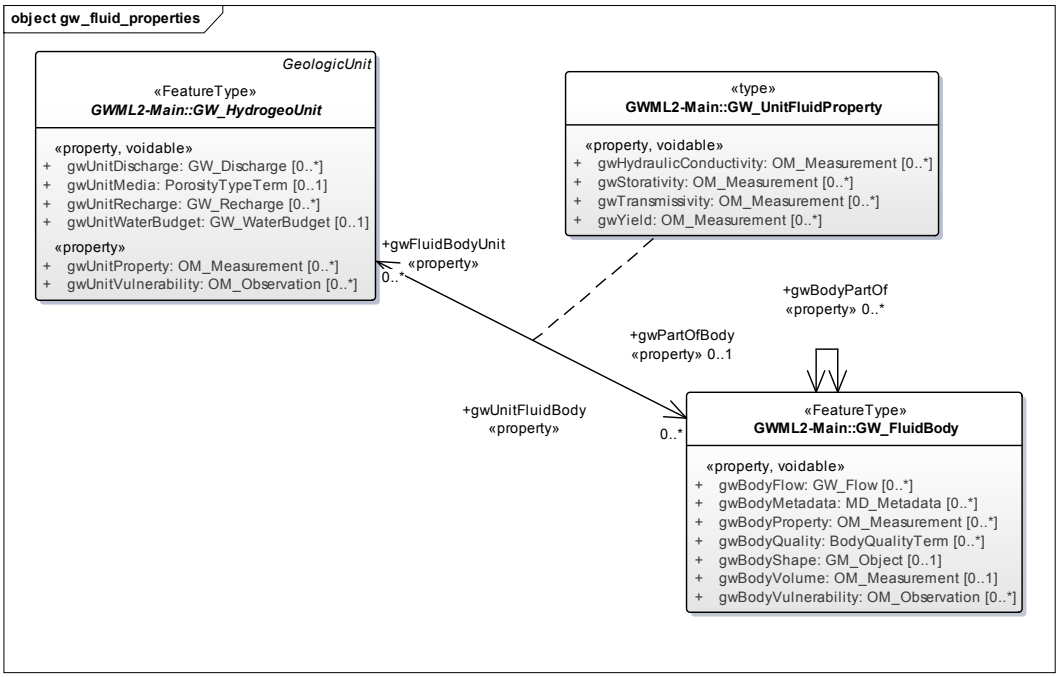

Figure 17: Observation as property values of GW_UnitFluidProperties.

Traditionally, those properties (gwHydraulicConductivity, gwStorativity, gwTransmissivity and gwYield) are assigned by convenience to the hydrogeological unit (GW_HydrogeoUnit) because the fluid as a body of groundwater that is rarely identified. It is therefore proposed that the feature of interest of all the values of GW_UnitFluidProperty SHALL be the instance at the gwFluidBodyUnit end of the association.

/req/gwml2-main/observed-unit-fluid-property-foi	The feature of interest of OM_Measurement values for GW_UnitFluidProperty properties (gwHydraulicConductivity, gwStorativity, gwTransmissivity and gwYield) SHALL be the GW_HydrogeoUnit instance at the gwFluidBodyUnit end of the GW_UnitFluidProperty association.

GW_UnitVoidProperty is an association class linking a GW_HydroGeoUnit and a GW_HydrogeoVoid that carries properties that are inherently related to the association of a geological unit and the voids (Figure 18).

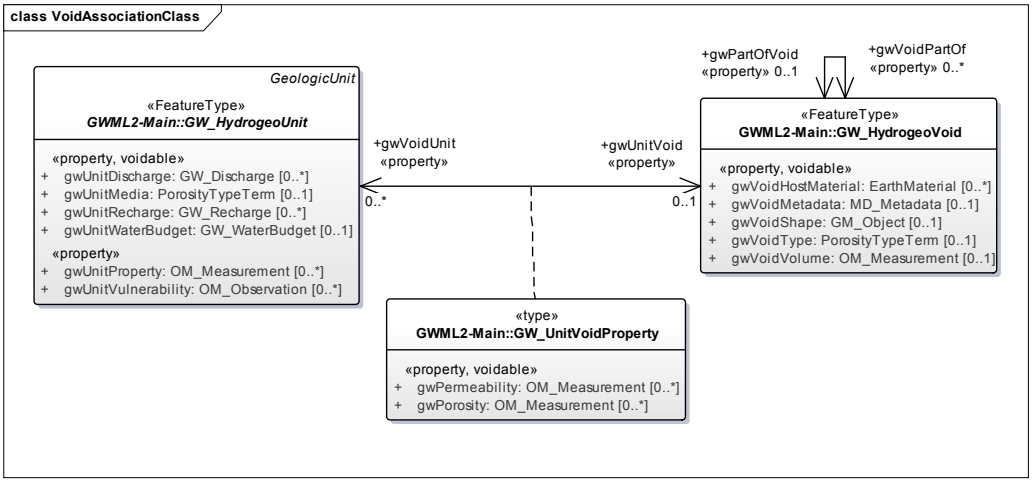

Figure 18 : Association class between a GW_HydrogeoUnit and GW_HydrogeoVoid.

Void properties are traditionally assigned to the hydrogeologic unit, while they are in reality a measurement of the relation between a unit and its voids. For convenience, the feature of interest of the OM_Measurement values of the properties SHALL link to the feature at the gwVoidUnit end of the association.

/req/gwml2-main/observed-unit-void-property-foi	The feature of interest of OM_Measurement values for GW_UnitVoidProperty properties (gwPermeability and gwPorosity) SHALL be the GW_HydrogeoUnit instance at the gwVoidUnit end of the GW_UnitVoidProperty association.

/req/gwml2-main/managementArea	GW_Management's gwAreaFeature SHALL not be one of the subtypes of 'GW_HydrogeoUnit'

9.3 Requirement class: GWML2-Constituent

Requirements class	**/req/gwml2-constituent**
Target type	Encoding of logical model
Name	Constituent logical model
Dependency	/req/gwml2-core
Dependency	ISO-19115
Recommendation	/req/gwml2-constituent/sampled-fluid-body

Analytical results are modelled as OM_Observation having GW_Constituent as features of interest (see Figure 19). A typical analytical procedure involves a sampling feature (such as a SF_Specimen) and a series of OM_Observations reporting on some properties of the feature of interest.

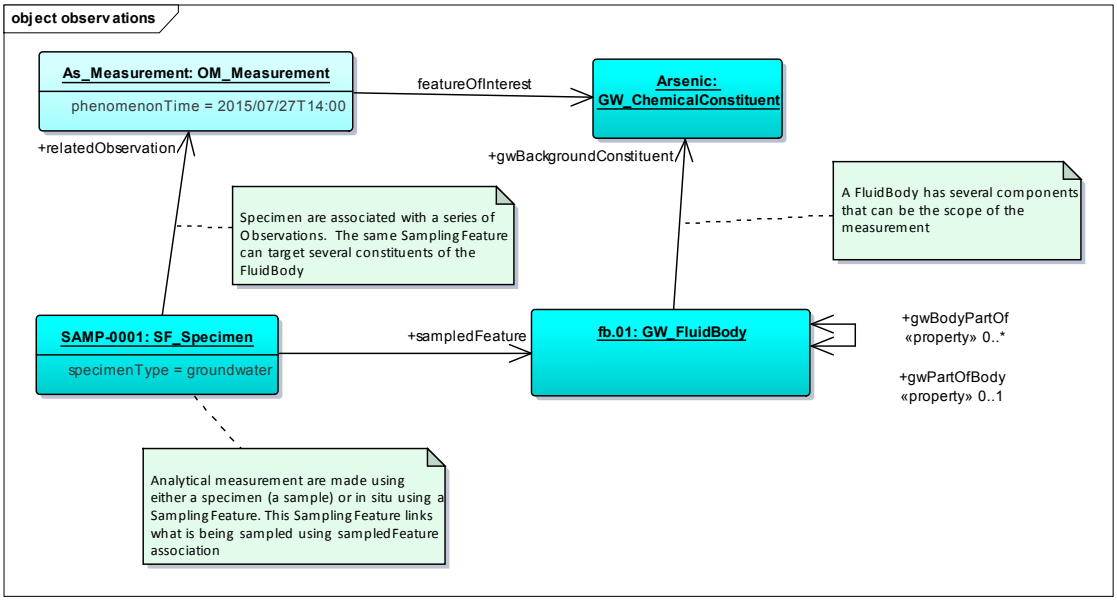

Figure 19: The pattern for analytical results.

By referring to the real world identifiable feature using the sampleFeature property and using the observation featureOfInterest to constituent of the fluid body, this pattern permits a detailed description of composition of various part of the fluid body.

/req/gwml2-constituent/sampled-fluid-body	Sampling feature SHOULD reference a real world identifiable feature through sampledFeature while individual observations should refer to the constituent that has been measured.

9.4 Requirement class: GWML2-Flow

Requirements class	**/req/gwml2-flow**
Target type	Encoding of logical model
Name	Flow logical model
Dependency	/req/gwml2-core
Dependency	/req/gwml2-constituent

9.5 Requirement class: GWML2-Well

This clause describes groundwater abstraction and monitoring through artificial (water wells, monitoring stations) and natural (springs) features. Artificial features are modelled as O&M sampling features (by ISO-19156 definition) as they are used as support for observations.

9.5.1 Water wells

Requirements class	**/req/gwml2-well**
Target type	Encoding of logical model
Name	Water well logical model

Dependency	/req/gwml2-main
Dependency	/req/gwml2-construction
Requirement	/req/gwml2-well/waterwell-elevationCRS
Requirement	/req/gwml2-well/waterwell-shape
Requirement	/req/gwml2-well/waterwell-observation-spatial-reference
Requirement	/req/gwml2-well/waterwell-observation-fromparam
Requirement	/req/gwml2-well/waterwell-observation-toparam
Requirement	/req/gwml2-well/waterwell-sf-spatial-reference
Requirement	/req/gwml2-well/waterwell-sf-fromparam
Requirement	/req/gwml2-well/waterwell-sf-toparam
Requirement	/req/gwml2-well/well-geology
Requirement	/req/gwml2-well/log-coverage
Requirement	/req/gwml2-well/log-geometry-origin
Requirement	/req/gwml2-well/log-depth
Requirement	/req/gwml2-well/log-depth-order
Requirement	/req/gwml2-well/monitoring-elevationCRS

The shape of the well is a 3D curve, in absolute coordinates, that represents the path of the hole in the ground. However, it is common practice to position observations, construction artefacts, and properties of the surrounding materials along this 3D path using a 1D coordinate system relative to the beginning of the hole. Although most wells are often assumed to be straight vertical bores, this standard allows for the generic case, where the well path is not a straight line, and therefore any such property or element needs to refer to the well path to calculate its absolute position.

This standard also provides alternative representations for commonly used origin elevations, such as the location of the well on the surface of the earth, the location and elevation of the well collar, the reference elevation for down hole properties, etc. Note that the reference elevation and the well path are distinct reference elements but it is best practice to ensure that the reference elevation point intersect the path. Because of the variety of practices and because the reference elevation can actually change over time (replaced headwork, subsidence, etc.) it is not always possible to have a definitive reference elevation.

Several GW_Well features need to be located relative to the well path:

- GW_GeologyLog LogValue
- Construction elements
- Any related Observation
- Any related SamplingFeature

The following set of requirements defines how to report these values.

The elevation CRS must be a relevant EPSG vertical (1 dimension) CRS. Example: EPSG:5100 (Mean Sea Level : http://epsg.io/5100-datum).

/req/gwml2-well/waterwell-elevationCRS	GW_Well:gwWellReferenceElevation/Elevation:elevation CRS SHALL have a vertical datum.

9.5.2 Well shape

/req/gwml2-well/waterwell-shape	GW_Well:shape SHALL be a 3D geometry that represents the complete well that includes any elements above the ground

9.5.3 Relative position

The relative positions of all elements positioned relative to the 3D shape shall be calculated from the origin point of that shape, which is the first vertex of the shape.

The relative position is the linear distance along the bore path, expressed as a positive value, using the uom inferred from the CRS of the shape z axis (metres or feet in the vast majority of cases). Different GW_Well elements may have different ways to encode the relative positions.

9.5.3.1 Observations

Any Observation that needs to be positioned along the well path must provide a reference geometry (a GM_Curve) and a position along that curve. In a case where the path is the path of the well or a borehole, the reference geometry is expected to be the shape of the well or the borehole, but it is not required. For instance, the relative location can be a "virtual path" somewhat related to a well or a group of wells.

/req/gwml2-well/waterwell-observation-spatial-reference	The reference geometry of an Observation SHALL be encoded in a om:NamedValue with the name http://www.opengis.net/req/ **gwml2-well/waterwell-observation-spatial-reference** and a value of type GM_Curve.

The relative position shall be encoded in a specially named NamedValue.

/req/gwml2-well/waterwell-observation-fromparam	The boundary of the interval closest to the well path origin, the "from" distance, SHALL be encoded in a om:NamedValue with the name-http://www.opengis.net/req/gwml2-well/waterwell-observation-fromparam and a value of type swe:Quantity
/req/gwml2-well/waterwell-observation-toparam	The boundary of the interval farthest from the well path origin, the "to" distance, SHALL be encoded in a om:NamedValue with the name http://www.opengis.net/req/gwml2-well/waterwell-observation-toparam and a value of type swe:Quantity

9.5.3.2 Related SamplingFeature

Any sampling feature that must be positioned along the linear path shall encode the reference GM_Curve and the relative position using sams:parameter

/req/gwml2-well/waterwell-sf-	The reference geometry of an Observation SHALL be encoded in a

spatial-reference	sams:NamedValue with the name http://www.opengis.net/**req/gwml2-well/waterwell-sf-spatial-reference** and a value of type GM_Curve.

The relative position shall be encoded in specially labelled NamedValue.

/req/gwml2-well/waterwell-sf-fromparam	The boundary of the interval, closest to the well path origin, the "from" distance, SHALL be encoded in a om:NamedValue with the name http://www.opengis.net/req/gwml2-well/waterwell-sf-fromparam and a value of type swe:Quantity
/req/gwml2-well/waterwell-sf-toparam	The boundary of the interval farthest from the well path origin, the "to" distance, SHALL be encoded in a om:NamedValue with the name-http://www.opengis.net/req/gwml2-well/waterwell-sf-toparam and a value of type swe:Quantity

9.5.4 Geology Log

GW_GeologyLog is an OM_Observation, with a start and end depth, that shall capture downhole geological observations (including geophysical and geochemical) using the gwml:gwWellGeology property rather than other OM_Observation properties.

/req/gwml2-well/well-geology	gwWellGeology SHALL associate GW_Well and any GW_GeologyLog

The geologic log is encoded as a GW_GeologyLogCoverage.

/req/gwml2-well/log-coverage	The value of om:result of GW_GeologyLog SHALL be a GW_GeologyLogCoverage

The GW_GeologyLogCoverage/LogValue is positioned at the origin of the support feature, which is a SF_SamplingCurve.

/req/gwml2-well/log-geometry-origin	The origin of the GW_GeologyLogCoverage/LogValue location SHALL be the first vertex of the GW_Well shape

Depth shall be expressed as linear distance from the first vertex of the GM_Curve. When the featureOfInterest is a GW_Well, the origin is implicitly gwWellLocation + Elevation.

/req/gwml2-well/log-depth	The fromDepth and toDepth of a LogValue SHALL be the linear distance along the path from featureOfInterest's linear geometry

The fromDepth must be nearest the reference elevation.

/req/gwml2-well/log-depth-order	The fromDepth of a LogValue SHALL be the closest along the path to gw_WellReferenceElevation while the toDepth shall be the

	farthest.

9.5.5 Monitoring Sites

Elevation CRS must be a relevant EPSG vertical (1 dimension) CRS. Example EPSG:5100 (Mean Sea Level : http://epsg.io/5100-datum).

/req/gwml2-well/monitoring-elevationCRS	The elevation CRS SHALL be an appropriate vertical datum.

9.6 Requirement class: GWML2-WellConstruction

Requirements class	**/req/gwml2-construction**
Target type	Encoding of logical model
Name	Construction logical model
Dependency	/req/gwml2-core
Requirement	/req/gwml2-construction/collar-elevationCRS
Requirement	/req/gwml2-construction/construction-origin-elevation
Requirement	/req/gwml2-construction/borehole-shape
Requirement	/req/gwml2-construction/log-depth
Requirement	/req/gwml2-construction/log-depth-order

9.6.1 Borehole

BoreCollar:collarElevation CRS must be a relevant vertical (1 dimension) CRS. Example EPSG:5100 (Mean Sea Level : http://epsg.io/5100-datum).

/req/gwml2-construction/collar-elevationCRS	Borehole:bholeHeadworks/BoreCollar:collarElevation CRS SHALL be a relevant vertical datum.

9.6.2 Construction

Borehole must identify a BoreCollar that must be used as the reference location. The reference BoreCollar shall have a collarElevationType equal to http://www.opengis.net/**req/gwml2-construction/construction-origin-elevation**.

Note that this BoreCollar need not be a physical feature, but would normally coincide with one. In a typical instance, we would find 2 or more collars, one or more real physical features, and another one as the reference collar that might or might not match one of the physical collars.

/req/gwml2-construction/construction-origin-elevation	Each Borehole SHALL have one bholeHeadworks/BoreCollar:collarElevationType @xlink:href = “http://www.opengis.net/req/gwml2-construction/construction-origin-elevation

The Borehole shape SHALL be a 3D geometry that represents the complete well that includes any construction elements above the ground.

/req/gwml2-construction/borehole-shape	Borehole:shape SHALL be a 3D geometry that represents the complete borehole that includes any Construction Component above the ground.

Depth shall be expressed as linear distance from the Borehole shape's first vertex.

/req/gwml2-construction/log-depth	The "from" and "to" of a Construction Component SHALL be the linear distance along the shape of the borehole.

The 'from' value must be closer to the Borehole origin than the 'to' value.

/req/gwml2-construction/log-depth-order	The 'from' value of a Construction Component SHALL be the closest along the path to first vertex of the Borehole shape while the 'to' value SHALL be the farthest.

9.7 Requirement class: Vertical Well (profile)

Requirements class	**/req/gwml2-vertical-well**
Target type	Model encoding
Name	Vertical well logical model
Dependency	/req/gwml2-well
Requirement	/req/gwml2-vertical-well/waterwell-shape
Requirement	/req/gwml2-vertical-well/end-vertex

A vertical well is a special case where the shape of the well is a straight vertical line. The rationale to create a special profile is to inform the data consumer that calculation of relative position into absolute position can be greatly simplified. Vertical wells are very common and several groundwater applications expect them to be vertical. GW_Well:shape shall have only 2 vertices.

/req/gwml2-vertical-well/waterwell-shape	GW_Well:shape SHALL have only 2 vertices

The second vertex shall have the same x and y as the first vertex.

/req/gwml2-vertical-well/end-vertex	The planar position (x,y) of the second vertex SHALL be the same as the first vertex

9.8 Requirement Class: GeologyLog (profile)

This requirement class describes the recommended pattern to encode a GeologyLog.

Requirements class	**/req/gwml2-well-log**

Target type	Encoding of logical model
Name	Geologic Unit logs
Dependency	**/req/gwml2-well**
Dependency	http://www.opengis.net/spec/SWE/2.0/req/uml-record-components
Recommendation	/req/gwml2-well-geologicLog/log-definition

Geological logs are modelled as GML discrete coverages (CV_DiscreteElementCoverage) of elements of type LogValue. Each Log Value is composed of a pair of properties to locate the element along the Well path (fromDepth and toDepth) and a **SWE DataRecord** that contains an arbitrary set of fields to report properties of interest along the path (see Figure 20).

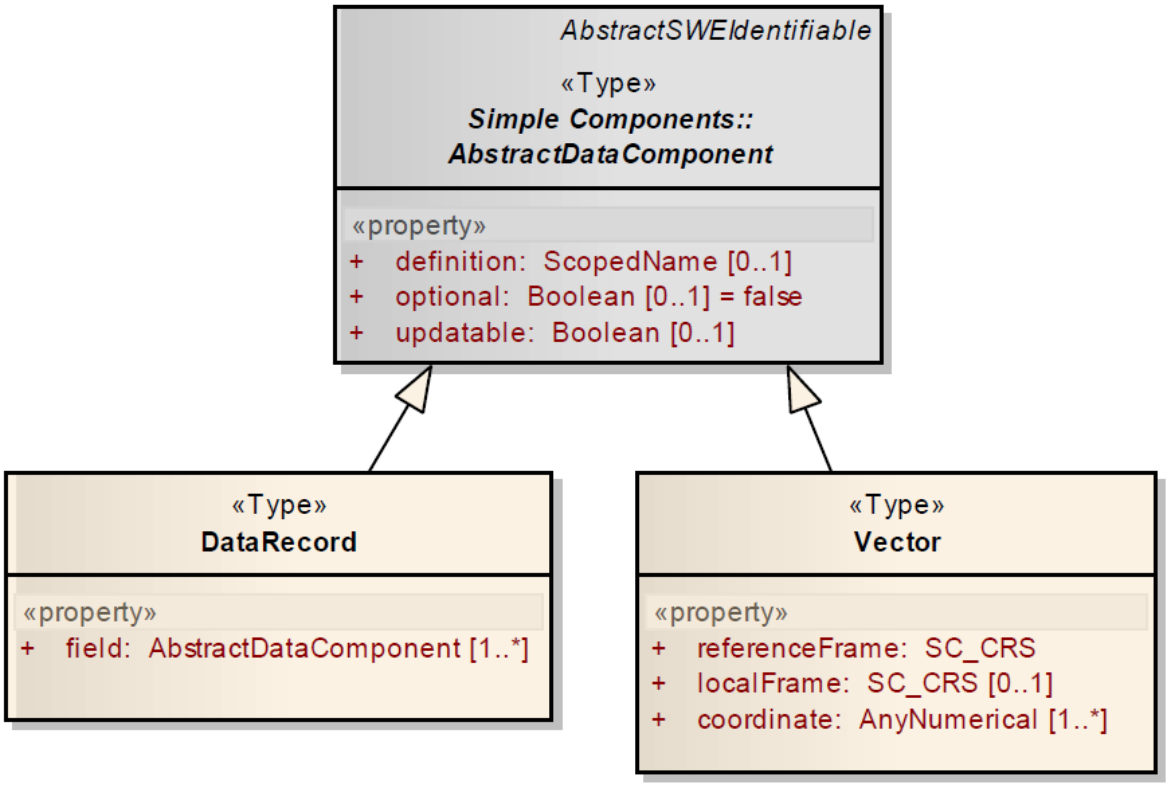

Figure 20 : SWE Data Record.

SWE (Clause 7.3 of OGC 08-094r1) describes the requirements to encode a DataRecord. A community that defined a common Geologic Log encoding should agree on a definition and scoped name for the DataRecord, and definitions of the individual fields composing the record.

For example, a community that wants to use GeoSciML vocabulary to encode a geology log can agree on a field type (eg: SWE Category) and a definition (a URI) to flag that field in the DataRecord as having controlled content. Another community might chose to constrain the complete DataRecord by agreeing on the scoped name of the DataRecord itself.

/req/gwml2-well-geologicLog/log-definition	The Log Value of a Geologic Log SHOULD use a community controlled definition for the DataRecord and / or the fields that compose it.

9.9 Requirement class: Aquifer test (profile)

Requirements class	**/req/gwml2-aquifer-test**
Target type	Encoding of logical model
Name	Aquifer test
Dependency	/req/gwml2-core
Dependency	Observations and Measurements
Dependency	http://www.opengis.net/spec/waterml/2.0/req/uml-timeseries-observation
Dependency	http://www.opengis.net/spec/SWE/2.0/req/uml-record-components
Requirement	/req/gwml2-aquifer-test/sampledfeature
Requirement	/req/gwml2-aquifer-test/testfeature
Requirement	/req/gwml2-aquifer-test/observationfeature
Recommendation	/req/gwml2-aquifer-test/testparameter
Recommendation	/req/gwml2-aquifer-test/observation
Requirement	/req/gwml2-aquifer-test/observation-role
Recommendation	/req/gwml2-aquifer-test/observedProperty
Requirement	/req/gwml2-aquifer-test/timeseries
Requirement	/req/gwml2-aquifer-test/timeseries-datarecord

Aquifer hydraulic parameters are routinely evaluated by a series of tests that involves pumping or injecting water at known rates and by observing the changes in the water table. Other tests might involve injecting a tracer (radio element or dye) at some location and follow its progression at observation points. From these observations, various methods have been developed to compute aquifer properties. To adequately report an aquifer test, the data about initial conditions, test parameters, sampling features, measured and calculated observation must be packaged and put into context.

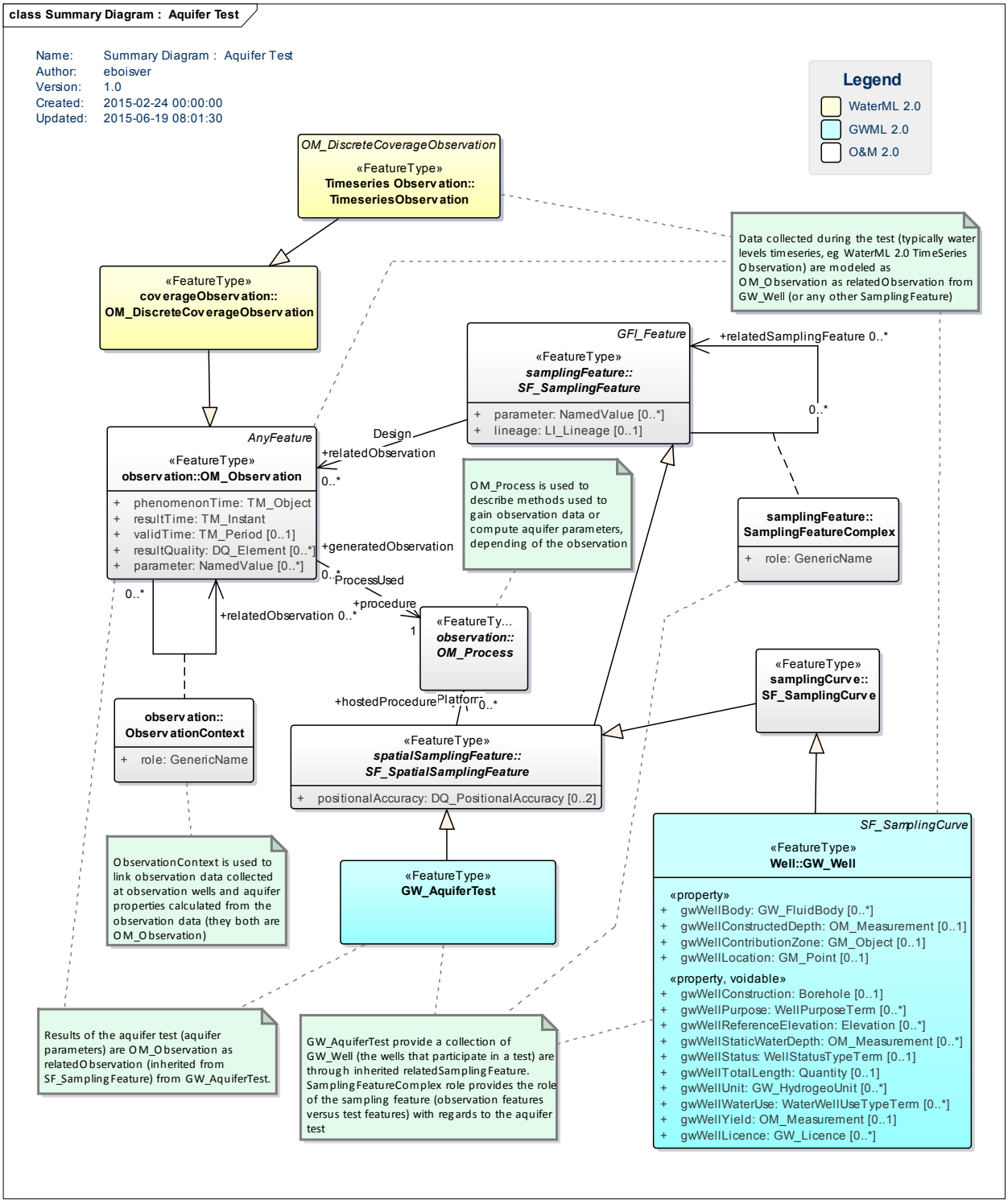

Figure 21: Summary diagram for aquifer tests, a profile of Observations and Measurements.

Figure 21 shows the elements required to encode an aquifer test. An AquiferTest assesses an Aquifer using a method (e.g., Packer test) that is encoded as an OM_Process. The test

is performed at a test site (the GW_AquiferTest defines a geometry corresponding to the test location) and consists of sampling features (usually the GW_Well) that are associated to the GW_AquiferTest through relatedSamplingFeature. Each sampling feature has a role in the test (observation or test features). Some sampling features are sites where test activities are performed (referred to as "test feature"), such as pumping water out of a bore. Other features are sites where more passive observations are made, such as measuring the impact of pumping made at the test sampling feature on the water table. From this activity, a series of observation are made, typically time series along the timespan of the test. Then from these observations, a method is used to infer some aquifer properties (such as transmissivity, storativity or yield). The findings are then documented in a report that can be attached to GW_AquiferTest using generic metadata properties.

A typical AquiferTest might be sketched as follows in Figure 22:

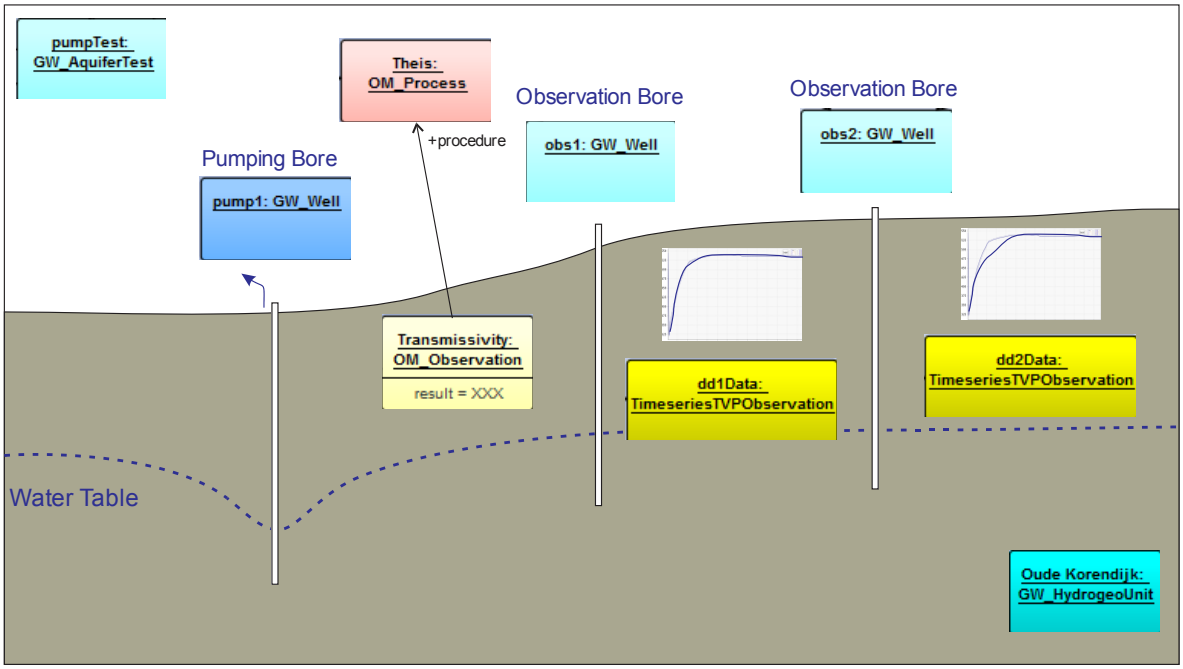

Figure 22: Typical setup of a pumping test.

9.9.1 Aquifer Test O&M mapping

Observation and Measurement (O&M 2.0: OGC 10-004r3), along with its GWML extensions, contains all the elements needed to model an aquifer test. Indeed, a complete aquifer test can be built around SF_SamplingFeature and OM_Observation, with one addition: GW_AquiferTest, a subtype SF_SpatialSamplingFeature (Figure 23), acts to distinguish aquifer tests from other sampling features and to package observations and sampling features.

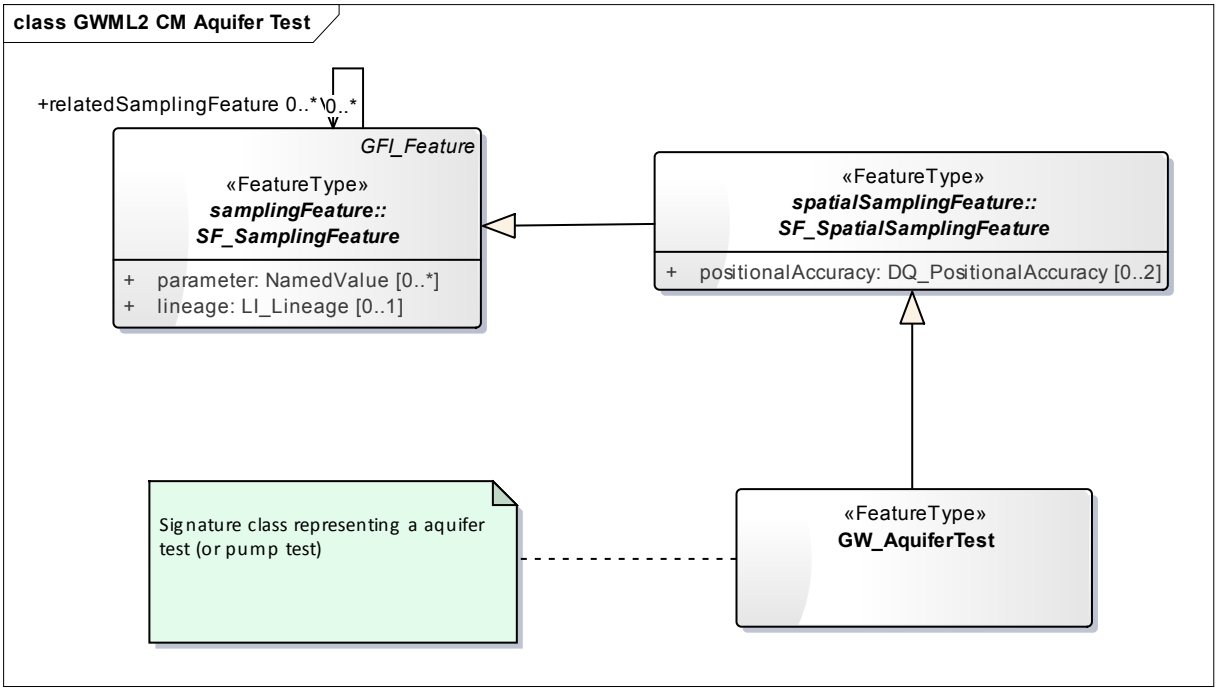

Figure 23: GW_AquiferTest model.

9.9.2 GW_AquiferTest

GW_AquiferTest is a: "Signature class" representing an aquifer test (or pump test). GW_AquiferTest properties are inherited from SF_SpatialSamplingFeature and its parent classes.

9.9.3 SF_SamplingFeature properties

9.9.3.1 sampledFeature

Links to the real world feature being assessed by the aquifer test (generally a **GW_AquiferUnit**,). O&M does not constrain **SF_SamplingFeature** to any particular feature type, but this specification requires that the **sampledFeature** shall be a subtype of a **GW_HydrogeoUnit**.

/req/gwml2-aquifer-test/sampledfeature	The sampledFeature of a GW_AquiferTest SHALL be an instance of a subtype of GW_HydrogeoUnit.

9.9.3.2 relatedSamplingFeature

The related sampling feature property identifies all the sampling features participating in the aquifer test. The role of each feature is assigned by the **SF_SamplingFeatureComplex:role** property. The role of the sampling feature is scoped by the test. Therefore, the same sampling feature can have different roles in different tests, but also within the same test (by having multiple **SF_SamplingFeatureComplex** referring to the same **SF_SamplingFeature**). Single bore tests are examples where the

observation bore and the test bore are the same feature. This specification proposes a list of core roles to identify the observation features and test features.

The test feature is the "active" sampling feature where the test is performed (e.g. the well that is pumped or injected).

/req/gwml2-aquifer-test/testfeature	SF_SamplingFeatureComplex:role for the sampling feature where the test is performed SHALL have the value http://resource.gwml.org/def/role/testFeature

The observation feature is the "passive" feature where observations are made. It is the feature at which the effects of the test are measured.

/req/gwml2-aquifer-test/observationfeature	SF_SampleFeatureComplex:role for the sampling feature where the observations are made SHALL have the value http://resource.gwml.org/def/role/observationFeature

A single sampling feature can be the target of several SF_**SamplingFeatureComplex**. A data provider can add more than one SF_**SamplingFeatureComplex** to accommodate other roles (see Figure 24).

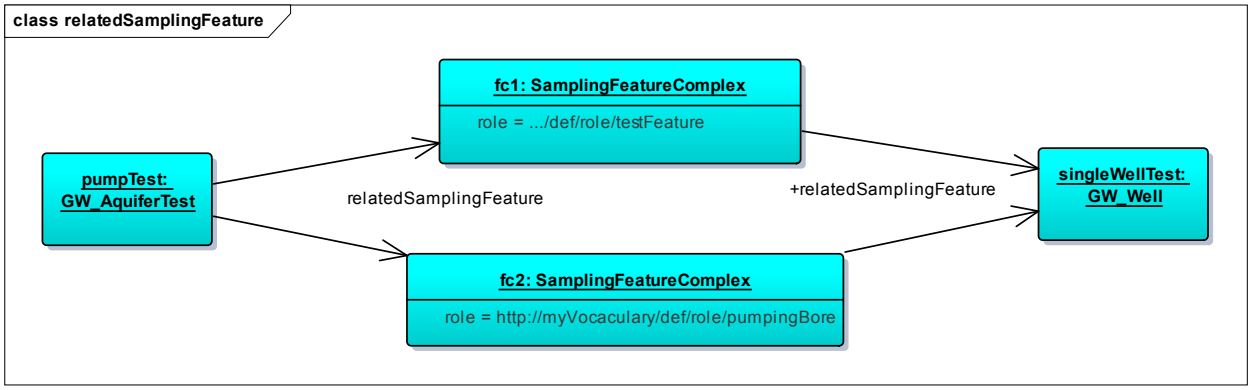

Figure 24: Multiple roles for the same well using two SF_SamplingFeatureComplexes.

9.9.3.3 parameter

Test parameters, such as pumping rates during the test are not considered as being an observation, but as test parameters. To document test parameters, there are two options:

- Using **SF_SpatialSamplingFeature:hostedProcedure** of type OM_Process that can encode all possible details of a test using SensorML (OGC 12-000), MD_Metadata (ISO-19115) or any other suitable model or
- Use **parameter** of type **SF_SamplingFeature:parameter:NamedValue** using agreed value types for well-known test parameters.

Altough the formal mechanism to report test parameters is through **OM_Process**, this specification recommends reporting community defined values in simple parameter key-value pairs (KVP) using **sf:NamedValue**.

/req/gwml2-aquifer-test/testparameter	When present SF_SamplingFeature:parameter:NamedValue SHALL be encoded using community defined values

9.9.3.4 relatedObservation

All related observations, including the observations made at the test feature sites and observation derived from those observations should be available as related observations (**sf:relatedObservation**).

/req/gwml2-aquifer-test/observation	All observations relevant to an aquifer test SHOULD be available as relatedObservation

From the raw observations measured during a test, new observations can be inferred or calculated. The raw observations (related from the observation Features) and the derived observations (the result of the test) SHALL be related to each other using om:ObservationContext. The role of the observation context defines which observation derives or supports the other one. 'supportObservation' and 'derivedObservation' roles can be considered complementary: if A is supportObservation of B, then B is the derivedObservation of A.

/req/gwml2-aquifer-test/observation-role	Raw observations from the observation sampling feature SHALL be link to the test result observations using the roles defined in Table 1

Table 1: ObservationContext roles.

Role	URI	Direction
Support observation	http://resource.gwml.org/def/role/supportObservation	Observation linking to other observation used to calculate, derive or infer a new values
Derived observation	http://resource.gwml.org/def/role/derivedObservation	Observation linking to another observation that has calculated, inferred or derived values

9.9.3.5 hostedProcedure

A hostedProcedure is used to document such things as methods to identify or localise the sampling feature, but its use is not constrained to anything specific. The hostedProcedure property, of type OM_Process, may be used to accommodate detailed aquifer test parameters if needed by the data provider.

The O&M specification does not prescribe any model to encode OM_Process, but suggests:

> *ISO 19115-2 provides MI_Instrument, LE_Processing and LE_Algorithm, which could all be modelled as specializations of OM_Process. OGC SensorML [16] provides a model which is suitable for many observation procedures*
>
> OGC 10-0043 / ISO-19156, clause 7.2.3, p. 14

For instance, a pump (used to pump water from the borehole) can be modelled as a SensorML sml:PhysicalSystem.

9.9.3.6 shape

SF_SpatialSamplingFeature does not constrain the geometry type (Point, Curve, Polygon, etc), therefore any geometry can represent a test. In most situations, the geometry of the test is the test area, the zone of influence around the pumping test or even the volume of rock affected or in scope for the test.

This standard also does not constrain the geometry type. Communities that wish to constrain the geometry type should create a profile of this standard.

9.9.4 OM_Observation

OM_Observations are used to represent values of properties observed or computed in the context of this test. There are at least two categories of observations generated through an aquifer test:

- Raw observations, normally taken at the observationFeatures,
- Derived observations, calculated from the raw observations.

These two kinds of observations differ by their respective feature of interest. For the former (raw data) the feature of interest is the sampling feature from which observations are made (e.g. observation bore). In the latter case, the feature of interest is the GW_AquiferTest itself. Observations can be linked together using related observations (**om:relatedObservation/om:ObservationContext**), which provide a role (**om:ObservationContext/om:role**) for the targeted observation. Figure 25 shows an example of "raw" observations (Drawdown1 and Drawdown2) measured at two observation wells (obs1 and obs2). The same figure also shows a derived observation (transmissivity) having the aquifer test itself as its feature of interest. The derived observation provides a link back to supporting observation used to compute the derived values.

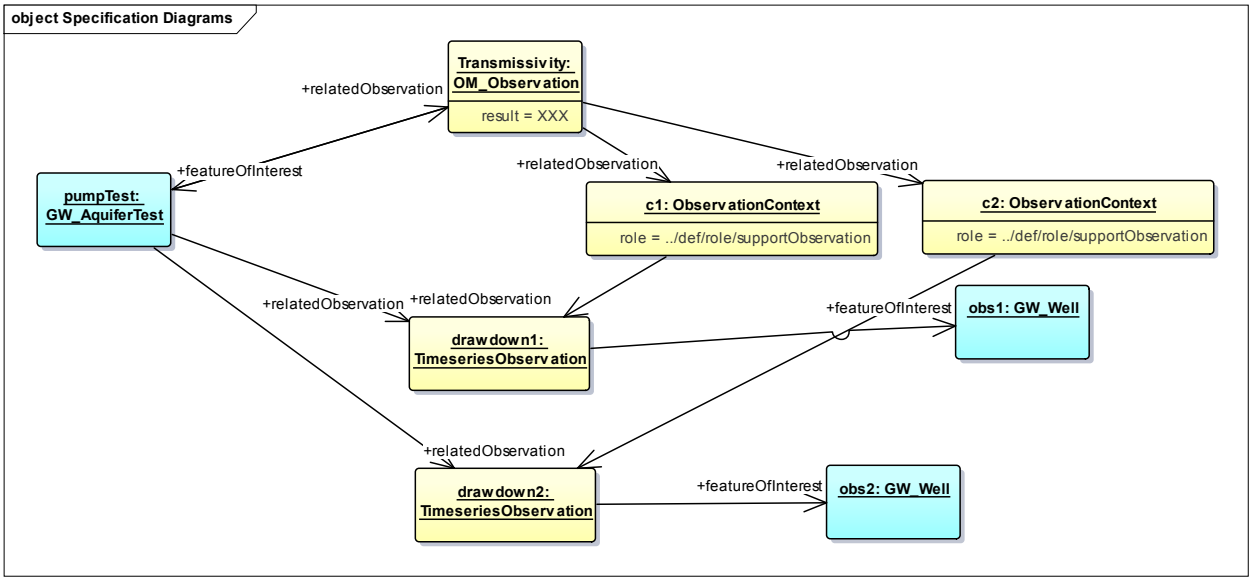

Figure 25: Relationships between observations and features of interest.

Observations made during the test and computed observations are modelled as OM_Observations.

9.9.4.1 phenomenonTime, resultTime and validTime

As specified in Observation and Measurement; **phenomenonTime** reflects the time that the result applies to the property; the **resultTime** is the time at which the value has been obtained or became available and **validTime** is the time during which the value is usable. Depending on the type of observation (raw or computed), those time might be different (see Table 2).

Table 2: Types of observations and times.

Type of Observation	phenomenonTime	resultTime	validTime
Raw	Duration of the test	End of the test	Period during which the condition are the same, so the same test would produce the same values
Derived	Duration of the test	When calculation are done (publication)	Depends on the parameters or test

9.9.4.2 observedProperty

This property describes the phenomenon being observed (e.g., groundwater level). The observed property is normally a reference to a property inherent in the feature of interest ("*the real word feature is the subject of the observation and carries the observed property,* OGC-10-004r3, clause 7.2.2.7). But because of subtle variations in the

semantics of such properties (such as specific Yield versus maximum Yield versus sustainable Yield, etc.), the **observedProperty** meaning should be formally defined by a community. The value of **observedProperty** becomes a reference to that definition (expressed in SWE, SKOS or OWL for example).

ObservedProperty can also be a compound property (a collection of **observedProperty**). Again, because of the close tie to use cases, compound properties should be defined by a community.

/req/gwml2-aquifer-test/observedProperty	The observedProperty SHOULD be a reference to a community managed vocabulary.

9.9.4.3 result

The result property reports the product of the observation process. In many cases, the aquifer test will produce a time series, such as drawdown data over time. When the result is a time series, it shall be modelled as a TimeSeriesML 1.0 (OGC 10-042r1).

/req/gwml2-aquifer-test/timeseries	Observation producing time series SHALL be modelled as WaterML 2.0 Time Series (OGC 10-126)

Derived (or computed) observations will often produce compound values. It is possible to report each result component as distinct observations, but GWML2 shall use the more efficient alternative of wrapping compound results into **swe:DataRecord.**

/req/gwml2-aquifer-test/timeseries-datarecord	Derived or computed observations SHALL be encoded as swe:DataRecord

9.9.5 Aquifer test overview

Figure 26 provides an example of the mapping of AquiferTest to O&M.

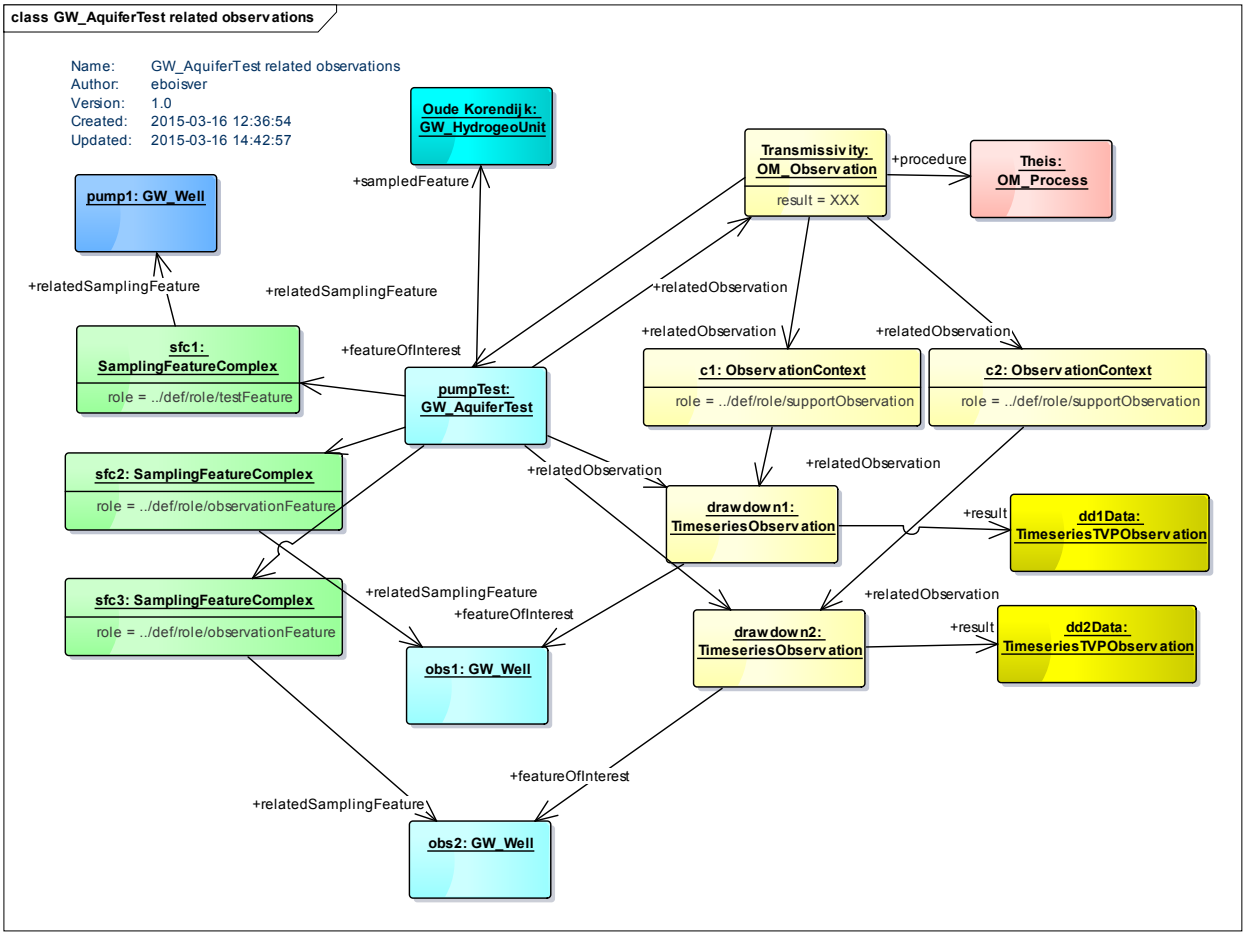

Figure 26: Typical pump test instance: 1 sampling feature and 2 observation features.

10. XML Implementation (normative)

10.1 GWML2-XSD

Groundwater features and their properties will be encoded in XML using standard GML encoding rules (Annex E of OGC Geography Markup Language v3.2 (ISO 19136:2007).

In examples, HTTP URIs that are used as resolvable resources (e.g. for vocabularies) are encoded using the DTD entity resource.gwml.org to avoid binding the examples to a specific URI. Full instance documents will have an entity declaration in the xml header in the form.

XML snippets will use the following prefixes:

gwml2	http://www.opengis.net/gwml-main/2.1

gwml2c	http://www.opengis.net/gwml-constituent/2.1
gwml2f	http://www.opengis.net/gwml-flow/2.1
gwml2w	http://www.opengis.net/gwml-well/2.1
gwml2at	http://www.opengis.net/gwml-aquifertest/2.1
gwml2wc	http://www.opengis.net/gwml-wellconstruction/2.1
gml	http://www.opengis.net/gml/3.2
cv	http://www.opengis.net/cv/0.2/gml32
om	http://www.opengis.net/om/2.0
sam	http://www.opengis.net/sampling/2.0
sams	http://www.opengis.net/samplingSpatial/2.0
spec	http://www.opengis.net/samplingSpecimen/2.0
swe	http://www.opengis.net/swe/2.0
gco	http://www.isotc211.org/2005/gco
gmd	http://www.isotc211.org/2005/gmd
gsmlgu	http://xmlns.geosciml.org/GeologicUnit/3.2
gsmlem	http://xmlns.geosciml.org/EarthMaterial/3.2
gsmlpp	http://xmlns.geosciml.org/PhysicalProperties/3.2
xlink	http://www.w3.org/1999/xlink
wfs	http://www.opengis.net/wfs/2.0

Requirements class	**/req/xsd-xml-rules**
Target type	XML data document
Name	GML/XML encoding
Dependency	ISO-19118

Dependency	ISO/IEC 19757-3:2006 (Schematron)
Dependency	http://www.w3.org/TR/xmlschema-2
Dependency	http://www.opengis.net/doc/IS/GML/3.2/clause/2.4
Dependency	http://www.opengis.net/spec/SWE/2.0/req/xsd-simple-components
Dependency	urn:iso:dis:iso:8601:2004:clause:4
Dependency	req/gwml2-core
Dependency	http://www.ietf.org/rfc/rfc2616
Dependency	http://www.opengis.net/spec/GML/3.3/req/definitions
Requirement	/req/xsd-xml-rules/W3C_XSD
Requirement	/req/xsd-xml-rules/ISO-schematron
Requirement	**/req/xsd-xml-rules/iso8601-time**
Requirement	/req/xsd-xml-rules/time-zone
Requirement	/req/xsd-xml-rules/swe-types
Requirement	/req/xsd-xml-rules/identifier
Recommendation	/req/xsd-xml-rules/byrefproperty
Recommendation	/req/xsd-xml-rules/xlink-title
Recommendation	/req/xsd-xml-rules/vocabulary-reference

ISO-19136_2007 provides a mapping between UML classifiers and XSD entities. All XSD types and elements must be created following those mapping rules. This specification considers the XSD files (the schema files) to be normative (they contain the official interpretation of 19136 conversion of the UML classifiers into XML).

/req/xsd-xml-rules/W3C_XSD	All elements and attributes in a namespace SHALL validate according to W3C XSD rules encoded in the xsd file associated with this namespace and its dependencies.

Other rules, that can't be expressed in XSD, are provided as schematron rules. As the XSD files, schematron rules files are considered normative.

/req/xsd-xml-rules/ISO-schematron	All elements and attributes covered by this specification SHALL pass schematron validation rules in http://schemas.opengis.net/gwml/2.0/xml-rules.sch

The date-time formats will conform to ISO standards. Although this is already a GML 3.2 encoding rule (clause 14.2.2.7), this format shall also be used in any string that does not attempt to validate the date time structure.

/req/xsd-xml-rules/iso8601-time	All date-time elements SHALL be encoded using ISO8601 extended time format

Note that this precludes the use of time-coordinate systems such as UNIX time. This is specified in order to be maximally consistent with WML2 requirements. The time zone will be included in the time element.

/req/xsd-xml-rules/time-zone	The value of each time element SHALL include a time zone definition using a signed 4-digit character or a 'Z' to represent Zulu or Greenwich Mean Time (GMT). This is defined by the following regular expression: (Z|[+-]HH:MM)

Greenwich Mean Time (GMT or Zulu)

```
<om:phenomenonTime>
	<gml:TimeInstant gml:id="ab.ww.402557.wl.1.ti.1">
		<gml:timePosition>1981-09-12T00:00:00Z</gml:timePosition>
	</gml:TimeInstant>
</om:phenomenonTime>
```

Time Zone (example is Newfoundland time zone -3:30)

```
<om:phenomenonTime>
	<gml:TimeInstant gml:id="nf.ww.34212.wl.1.ti.1">
		<gml:timePosition>1981-09-12T00:00:00-03:30</gml:timePosition>
	</gml:TimeInstant>
</om:phenomenonTime>
```

Some SWE Common types are restricted to avoid ambiguity.

/req/xsd-xml-rules/swe-types	When using the SWE Common types, the following elements SHALL not be used: swe:quality (AbstractSimpleComponentType), swe:nilValues (AbstractSimpleComponentType), swe:constraint (QuantityType, QuantityRangeType, CategoryType). The attributes 'optional' and 'updatable' from the base type 'AbstractDataComponent' SHALL also not be used.

10.1.1 Identifier

A feature that can be accessed through Linked Data using a resolvable HTTP URI must use this HTTP URI as its global unique identifier. In GML, this shall be encoded using `gml:identifier` and code space = "http://www.ietf.org/rfc/rfc2616". In other words, the gml:identifier shall point to a representation of itself.

/req/xsd-xml-rules/identifier	A resolvable resource SHALL expose its resolvable HTTP URI as a gml:identifier AND use http://www.ietf.org/rfc/rfc2616 for the codeSpace value.

Example of a feature that exposes its resolvable HTTP URI as a globally unique identifier.

```
(…)
<gwml2w:GW_Well gml:id="ca.ab.gov.wells.402557">
   <gml:description>Water well from Alberta water well database</gml:description>
        <gml:identifier codeSpace="http://www.ietf.org/rfc/rfc2616">http://ngwd-
bdnes.cits.nrcan.gc.ca/Reference/uri-
cgi/feature/gsc/waterwell/ca.ab.gov.wells.402557</gml:identifier>
        <gml:name codeSpace="urn:cgi:featureType:CA.AB:WaterWell">402557</gml:name>
        <gml:name codeSpace="urn:x-gin">ca.ab.waterWell.402557</gml:name>
(…)
```

10.1.2 By-Reference properties

Properties can be constrained to be by-reference only, or either inline or by-reference. For a by-reference property that refers to an external feature, the reference shall be resolvable over the web. The reference shall be either a resolvable HTTP URI that might also match the feature's globally unique identifier (see **/req/gwml2-core/identifier)** or an HTTP request (for instance, a WFS GetFeature with the stored query "urn:ogc:def:query:OGC-WFS::GetFeatureById") to the a representation of the feature in GML.

/req/xsd-xml-rules/byrefproperty	A reference to an external feature SHOULD be resolvable to a GML representation of the feature

```
  (…)

<gwml2:gwAquiferSystemPart
xlink:href="http://environment.data.gov.au/groundwater/feature/hydrogeologicalu
nit/hgu.nsw.5" xlink:title="Stuarts Point - Lower Quaternary Sands"/>

(…)
```

Note that elements under GWML2 namespaces can be mixed with other namespaces. For example, this specification does not have a dependency to WFS, but GWML can be serialised in a WFS document, along with features from other domains. Failure to validate such a document does not necessarily mean that the GWML XML requirements are not met, as other external indirect instances might fail. Therefore, this requirement class only addresses instances of GWML in an XML document.

All property by reference using xlink:href should provide a human readable label in xlink:title.

/req/xsd-xml-rules/xlink-title	If an xlink:href is used to reference a controlled vocabulary item, the xlink:title attribute SHOULD encode a text label of the referenced item.

Example of a casing material showing the use of xlink:href (**/req/xsd-xml-rules/vocabulary-references)** and xlink:title (**/req/xsd-xml-rules/xlink-title**):

```
<gwml2wc:casingMaterial
xlink:href="http://www.sandre.eaufrance.fr/?urn=urn:sandre:donnees:154::CdElement:5:::r
eferentiel:3.1:xml" xlink:title="PVC"/>
```

Vocabulary references for all classes of stereotype «CodeList» are implemented as gml:Reference using xlink:href and ought to be a resolvable URI in the form of an HTTP URL.

/req/xsd-xml-rules/vocabulary-reference	A resolvable HTTP URL SHOULD be used in an xlink:href when specifying references to vocabulary (CodeList) items.

10.2 Requirement class: GWML2-Main XML encoding

Requirements class	**/req/gwml2-main-xsd**
Target type	XML data document
Name	Main xml encoding
Dependency	/req/xsd-xml-rules
Dependency	GeoSciML/GeologicUnit
Dependency	ISO-19115
Dependency	/req/gwml2-main-uml
Requirement	/req/gwml2-main-xsd/xsd
Requirement	**/req/**gwml2-main-xsd**/observed-unit-fluid-property-foi**
Requirement	**/req/**gwml2-main-xsd**/observed-unit-void-property-foi**
Requirement	**/req/**gwml2-main-xsd**/managementArea**

All xml elements under namespace http://www.opengis.net/gwml-main/2.1 must validate against the schema located at http://schemas.opengis.net/gwml/2.1/gwml2-main.xsd.

/req/gwml2-main-xsd/xsd	All the elements and types under namespace “http://www.opengis.net/gwml-main/2.1” SHALL validate with schema located at http://schemas.opengis.net/gwml/2.1/gwml2-main.xsd

OM_Measure values, used as property values in GW_UnitFluidProperty must identify the instance of GW_HydrogeoUnit at the gwFluidBodyUnit end of the association between this feature and the GW_FluidProperty.

/req/gwml2-main-xsd/observed-unit-fluid-property-foi	All OM_Measurement:featureOfInterest for OM_Measurement properties of one coherent GW_UnitFluidProperty instance SHALL reference the same feature as GW_UnitFluidProperty/gwFluidBodyUnit.

```
<?xml version="1.0" encoding="UTF-8"?>
<gwml2:GW_Aquifer gml:id="aq.1">
```

```
	<gsmlgu:geologicUnitType
xlink:href="http://www.opengis.net/def/gwml/2.0/geologicunitype/aquifer_unit"
xlink:title="Aquifer" xsi:type="gwml2:AquiferPropertyType"/>
	<!-- (...) -->
	<gwml2:gwUnitFluidBody>
		<gwml2:GW_UnitFluidProperty>
			<gwml2:gwYield>
				<om:OM_Observation gml:id="aq.1.fp.1">
					<om:phenomenonTime>
						<gml:TimeInstant gml:id="aq.1.fp.1.ti.1">

	<gml:timePosition>2015/7/28T12:00:00Z</gml:timePosition>
						</gml:TimeInstant>
					</om:phenomenonTime>
				<!-- (...) -->
					<om:featureOfInterest xlink:href="#aq.1"
xlink:title="aquifer 1"/>
				<!-- (...) -->
				</om:OM_Observation>
			</gwml2:gwYield>
			<gwml2:gwUnitFluidBody xlink:href="http://resource.org/id/fluid-
body/fb1" xlink:title="fluid body f1"/>
			<gwml2:gwFluidBodyUnit xlink:href="#aq.1" xlink:title="aquifer
1"/>
		</gwml2:GW_UnitFluidProperty>
	</gwml2:gwUnitFluidBody>
</gwml2:GW_Aquifer>
```

OM_Measure values, used as property values in GW_UnitVoidProperty must identify the instance of GW_HydrogeoUnit at the gwVoidUnit end of the association between this feature and the GW_VoidProperty.

/req/gwml2-main-xsd/observed-unit-void-property-foi	All OM_Measurement:featureOfInterest for OM_Measurement properties of one coherent GW_UnitVoidProperty instance SHALL reference the same feature as GW_UnitVoidProperty/gwVoidUnit.

```
<?xml version="1.0" encoding="UTF-8"?>
<gwml2:GW_AquiferSystem gml:id="as.1">
	<!-- (...) -->
	<gwml2:gwUnitVoid>
		<gwml2:GW_UnitVoidProperty gml:id="v1">
			<gwml2:gwPorosity>
				<om:OM_Observation gml:id="aq.1.fp.1">
					<om:phenomenonTime>
						<gml:TimeInstant gml:id="aq.1.fp.1.ti.1">

	<gml:timePosition>2015/7/28T12:00:00Z</gml:timePosition>
						</gml:TimeInstant>
					</om:phenomenonTime>
					<!-- (...) -->
					<om:featureOfInterest xlink:href="#as.1"
xlink:title="Aquifer System 1"/>
					<!-- (...) -->
```

```
                        </om:OM_Observation>
                    </gwml2:gwPorosity>
                    <gwml2:gwUnitVoid
xlink:href="http://www.opengis.net/def/nil/OGC/0/unknown" xlink:title="Unknown"/>
                    <gwml2:gwUnitVoid xlink:href="#as.1" xlink:title="Aquifer System
1"/>
                </gwml2:GW_UnitVoidProperty>
            </gwml2:gwUnitVoid>
</gwml2:GW_AquiferSystem>
```

/req/xsd-main/managementArea	GW_ManagementArea/gwAreaFeature SHALL not refer to features of type 'GW_Aquifer', 'GW_AquiferSystem', 'GW_Basin' or 'GW_ConfiningBed'

10.3 Requirement class: GWML2-Constituent XML encoding

Requirements class	**/req/gwml2-constituent-xsd**
Target type	XML data document
Name	Constituent xml encoding
Dependency	/req/xsd-xml-rules
Dependency	/req/gwml2-constituent
Requirement	**/req/gwml2-constituent-xsd** /xsd

All xml elements under namespace http://www.opengis.net/gwml-constituent/2.1 must validate with the schema located at http://schemas.opengis.net/gwml/2.1/gwml2-constituent.xsd.

/req/gwml2-constituent-xsd /xsd	All the elements and types under namespace "http://www.opengis.net/gwml-constituent/2.1" SHALL validate with schema located at http://schemas.opengis.net/gwml/2.1/gwml2-constituent.xsd

10.4 Requirement class: GWML2-Flow XML encoding

Requirements class	**/req/gwml2--flow-xsd**
Target type	XML data document
Dependency	/req/xsd-xml-rules
Dependency	/req/gwml2-flow
Requirement	/req/gwml2--flow-xsd /xsd

All xml elements under namespace http://www.opengis.net/gwml-flow/2.1 must validate with the schema located at http://schemas.opengis.net/gwml/2.1/gwml2-flow.xsd.

/req/gwml2-flow-xsd /xsd	All the elements and types under namespace "http://www.opengis.net/gwml-flow/2.1" SHALL validate with schema located at http://schemas.opengis.net/gwml/2.1/gwml2-flow.xsd

10.5 Requirement class: GWML2-Well XML encoding

Requirements class	/req/gwml2-well-xsd
Target type	XML data document
Dependency	/req/xsd-xml-rules
Dependency	/req/gwml2-construction-xsd
Dependency	/req/gwml2-well
Requirement	req/gwml2-well-xsd-/xsd
Requirement	/req/gwml2-well-xsd/origin-elevation
Requirement	/req/gwml2-well-xsd/waterwell-elevationCRS
Requirement	**/req/**gwml2-well-xsd**/waterwell-CRS-uom**
Requirement	/req/gwml2-well-xsd/waterwell-shapeCRS
Requirement	/req/gwml2-well-xsd/obs-relative-pos-spatial-reference
Requirement	/req/gwml2-well-xsd/waterwell-observation-fromparam
Requirement	/req/gwml2-well-xsd/waterwell-observation-toparam
Requirement	/req/gwml2-well-xsd/waterwell-sf-spatial-reference
Requirement	/req/gwml2-well-xsd/waterwell-sf-fromparam
Requirement	/req/gwml2-well-xsd/waterwell-sf-toparam
Requirement	/req/gwml2-well-xsd/well-geology
Requirement	/req/gwml2-well-xsd/log-coverage
Requirement	/req/gwml2-well-xsd/log-depth-order
Requirement	/req/gwml2-well-xsd/monitoring-elevationCRS
Requirement	/req/gwml2-well-xsd**/monitoring-elevation-uom**

All xml elements under namespace http://www.opengis.net/gwml-well/2.1 must validate with the schema located at http://schemas.opengis.net/gwml/2.1/gwml2-well.xsd.

/req/gwml2-well-xsd/xsd	All the elements and types under namespace “http://www.opengis.net/gwml-well/2.1” SHALL validate with schema located at http://schemas.opengis.net/gwml/2.1/gwml2-well.xsd

Well must provide an origin elevation as a reference for relative positions along the borehole path.

/req/gwml2-well-xsd/origin-elevation	There SHALL be a gwWellReferenceElevation: Elevation:elevationType with a xlink:href equal to “http://www.opengis.net/req/gwml2-well/origin_elevation”

Elevation geometries must have a relevant vertical 1D srsName.

/req/gwml2-well-xsd/waterwell-elevationCRS	gwWellReferenceElevation:Elevation:elevation @srsName SHALL contain a 1D vertical SRS

/req/gwml2-well-xsd/waterwell-CRS-uom	gwWellReferenceElevation:Elevation:elevation @srsName datum units and coordinate reference system SHALL be the same as the /req/xsd-gwml-well/waterwell-shapeCRS units and coordinate reference system of the vertical axis

Examples of reference elevations (measured using different methods); note, one of them is designated as the origin ('reference') elevation for relative positions:

```
<gwml2w:gwWellReferenceElevation>
	<gwml2w:Elevation>
		<gwml2w:elevation srsDimension="1"
srsName="http://www.opengis.net/def/crs/EPSG/0/5711" uomLabels="m
AHD">139.06</gwml2w:elevation>
		<gwml2w:elevationAccuracy
xlink:href="http://www.opengis.net/def/nil/OGC/0/unknown" xlink:title="unknown"/>
		<gwml2w:elevationType
xlink:href="http://www.bom.gov.au/water/groundwater/ngis/elevation-type/natural-ground-
surface" xlink:title="natural ground surface"/>
		<gwml2w:elevationMeasurementMethod
xlink:href="http://www.bom.gov.au/water/groundwater/ngis/elevation-method/dem"
xlink:title="Digital Elevation Model"/>
	</gwml2w:Elevation>
</gwml2w:gwWellReferenceElevation>
<gwml2w:gwWellReferenceElevation>
	<gwml2w:Elevation>
		<gwml2w:elevation srsDimension="1"
srsName="http://www.opengis.net/def/crs/EPSG/0/5711" uomLabels="m
AHD">139.06</gwml2w:elevation>
		<gwml2w:elevationAccuracy
xlink:href="http://www.opengis.net/def/nil/OGC/0/unknown" xlink:title="unknown"/>
		<gwml2w:elevationType
xlink:href="http://www.bom.gov.au/water/groundwater/ngis/elevation-type/reference-
elevation" xlink:title="reference elevation"/>
		<gwml2w:elevationMeasurementMethod
xlink:href="http://www.bom.gov.au/water/groundwater/ngis/elevation-method/dem"
xlink:title="Digital Elevation Model"/>
	</gwml2w:Elevation>
</gwml2w:gwWellReferenceElevation>
```

10.5.1 Well shape

The CRS of the shape must be a 3D CRS that is coherent with the planar CRS of gwWellLocation and the elevation CRS of origin Elevation.

/req/gwml2-well-xsd/waterwell-shapeCRS	GW_Well:shape @srsName SHALL contain a 3D SRS.

Example of a well shape represented as a vertical line, using a relevant srsName:

```
<sams:shape>
	<gml:Curve gml:id="ab.ww.402557.shape.1" srsDimension="3"
srsName="urn:ogc:def:crs:EPSG:4955">
		<gml:segments>
			<gml:LineStringSegment>
				<gml:posList>49.671622 -114.625045 0.00 49.671622 -
114.625045 11.58</gml:posList>
			</gml:LineStringSegment>
		</gml:segments>
	</gml:Curve>
</sams:shape>
```

10.5.1.1 Observations

Any observation that is positioned relative to a geometry, such as well or borehole path, SHALL identify the geometry as a spatial reference.

/req/gwml2-well-xsd/obs-relative-pos-spatial-reference	Any OM_Observation that is positioned relative to a GM_Curve SHALL provide this geometry using a om:NamedValue with the name http://www.opengis.net/req/gwml2-well/waterwell-observation-spatial-refenrece and a value of type gml:GM_Curve

The relative position of the observation must be encoded in the om:parameter using a specific encoding.

/req/gwml2-well-xsd/waterwell-observation-fromparam	The closest boundary of the interval, the “from” distance, SHALL be encoded in a om:NamedValue with the name http://www.opengis.net/req/gwml2-well/waterwell-observation-fromParam and a value of type swe:Quantity
/req/gwml2-well-xsd/waterwell-observation-toparam	The farthest boundary of the interval, the “to” distance, SHALL be encoded in a om:NamedValue with the name http://www.opengis.net/req/gwml2-well/waterwell-observation-toParam and a value of type swe:Quantity

Example of Observation positioned along the path of a bore:

```
<om:OM_Observation gml:id="feduni.borehole.observation.51409.44574.32328">
	<gml:identifier
codeSpace="http://www.ietf.org/rfc/rfc2616">http://groundwater.victoria.com.au/feature/
observation/feduni.borehole.observation.51409.44574.32328</gml:identifier>
	<om:phenomenonTime>
		<gml:TimeInstant gml:id="feduni.borehole.observation.time.51409.44574">
			<gml:timePosition>1997-07-14+12:00:00</gml:timePosition>
		</gml:TimeInstant>
	</om:phenomenonTime>
	<om:resultTime xlink:href="#feduni.borehole.observation.time.51409.44574"/>
	<om:procedure xlink:title="PUM"/>
	<om:parameter>
		<om:NamedValue>
			<om:name xlink:href="http://www.opengis.net/req/gwml2-well/waterwell-
observation-fromParam" xlink:title="from"/>
			<om:value xsi:type="swe:QuantityPropertyType">
				<swe:Quantity>
```

```
                                        <swe:uom
xlink:href="http://qudt.org/vocab/unit#Meter" xlink:title="metre"/>
                                        <swe:value>10.5</swe:value>
                                </swe:Quantity>
                        </om:value>
                </om:NamedValue>
        </om:parameter>
        <om:parameter>
                <om:NamedValue>
                        <om:name xlink:href="http://www.opengis.net/req/gwml2-well/waterwell-
observation-toParam" xlink:title="to"/>
                        <om:value xsi:type="swe:QuantityPropertyType">
                                <swe:Quantity>
                                        <swe:uom
xlink:href="http://qudt.org/vocab/unit#Meter" xlink:title="metre"/>
                                        <swe:value>10.6</swe:value>
                                </swe:Quantity>
                        </om:value>
                </om:NamedValue>
        </om:parameter>
<om:parameter>
                                <om:NamedValue>
                                        <om:name
xlink:href="http://www.opengis.net/req/gw_well/waterwell-observation-spatial-reference"
xlink:title="geometry"/>
                                        <om:value xsi:type="gml:GeometryPropertyType"
xlink:href="# feduni.borehole.51409.shape.1"/>
                                </om:NamedValue>
                        </om:parameter>
        <om:observedProperty
xlink:href="http://environment.data.gov.au/def/property/pH_water" xlink:title="pH"/>
        <om:featureOfInterest xlink:href="#feduni.borehole.51409"/>
        (…)
</om:OM_Observation>
```

10.5.1.2 Related Sampling Feature positioned along well path

Any sampling feature that is positioned along the well path shall encode a relative position in sams:parameters.

/req/gwml2-well-xsd/waterwell-sf-spatial-reference	A SF_SamplingFeature that is positioned relative to a psth SHALL provide the geometry in a om:NamedValue with the name http://www.opengis.net/req/gwml2-well-xsdl/waterwell_sf_soatial-reference and a value of type gml:GM_Curve

If included, the relative positions along the GW_Well shall be encoded using NamedValue.

/req/gwml2-well-xsd/waterwell-sf-fromparam	The closest boundary of the interval , the “from” distance, SHALL be encoded in a om:NamedValue with the name http://www.opengis.net/req/gwml2-well-xsd/waterwell-sf-fromParam and a value of type swe:Quantity
/req/gwml2-well-xsd/waterwell-sf-	The farthest boundary of the interval , the “to” distance, SHALL be

toparam	encoded in a om:NamedValue with the name http://www.opengis.net/req/gwml2-well-xsd/waterwell-sf-toParam and a value of type swe:Quantity

Example of a related sampling feature (the parent feature is a GW_Well):

```
<sam:relatedSamplingFeature>
       <sam:SamplingFeatureComplex>
              <sam:role xlink:href="http://www.opengis.net/def/gwml/role/waterSample"
xlink:title="Water sample"/>
              <sam:relatedSamplingFeature>
                     <spec:SF_Specimen gml:id="spc.1">
                            (…)

                            <sam:parameter>
                                   <om:NamedValue>
                                          <om:name
xlink:href="http://www.opengis.net/req/gwml2-well-xsd /waterwell-sf-fromParam"
xlink:title="from"/>
                                          <om:value
xsi:type="swe:QuantityPropertyType">
                                                 <swe:Quantity>
                                                        <swe:uom
xlink:href="http://www.opengis.net/def/uom/UCUM/0/m" xlink:title="metre" code="m"/>
                                                        <swe:value>8.12</swe:value>
                                                 </swe:Quantity>
                                          </om:value>
                                   </om:NamedValue>
                            </sam:parameter>
                            <sam:parameter>
                                   <om:NamedValue>
                                          <om:name
xlink:href="http://www.opengis.net/req/gwml2-well-xsd/waterwell-sf-toParam"
xlink:title="to"/>
                                          <om:value
xsi:type="swe:QuantityPropertyType">
                                                 <swe:Quantity>
                                                        < swe:uom
xlink:href="http://www.opengis.net/def/uom/UCUM/0/m" xlink:title="metre" code="m"/>
                                                        <swe:value>8.4</swe:value>
                                                 </swe:Quantity>
                                          </om:value>
                                   </om:NamedValue>
                            </sam:parameter>
<sam:parameter>
                                   <om:NamedValue>
                                          <om:name
xlink:href="http://www.opengis.net/req/gwml2-well--xsd/waterwell-sf-spatial-reference"
xlink:title="to"/>
                                          <om:value
xsi:type="gml:GeometryPropertyType" xlink:href="#well.path.1" />
                                   </om:NamedValue>
                            </sam:parameter>

       (…)
                     </spec:SF_Specimen>
              </sam:relatedSamplingFeature>
       </sam:SamplingFeatureComplex>
</sam:relatedSamplingFeature>
```

10.5.1.3 Geology Log

This specification forbids the use of relatedObservation to link a GW_Well to a GW_GeologyLog, the property gwWellGeology must be used.

/req/gwml2-well-xsd/well-geology	GW_Well SHALL not be associated with GW_GeologyLog using om:relatedObservation

The geologic log is encoded as a GW_GeologyLogCoverage.

/req/gwml2-well-xsd/log-coverage	The XML element om:result of GW_GeologyLog SHALL have a data type GW_GeologyLogCoverage

The fromDepth value must be less than or equal to the toDepth value.

/req/gwml2-well-xsd/log-depth-order	For any given value where both fromDepth and toDepth are non-null, the value of gww:fromDepth/swe:Quantity/swe:Value SHALL be less than or equal to gww:toDepth/swe:Quantity/swe:Value

```
<gwml2w:GW_GeologyLogCoverage
gml:id="borehole.INDIANA.USGS.403836085374401.lithology.coverage">
        <gwml2w:element>
                <gwml2w:LogValue>
                        <gwml2w:fromDepth>
                                <swe:Quantity>
                                        <swe:uom
xlink:href="http://qudt.org/vocab/unit#Foot" xlink:title="foot" code="ft"/>
                                        <swe:value>0</swe:value>
                                </swe:Quantity>
                        </gwml2w:fromDepth>
                        <gwml2w:toDepth>
                                <swe:Quantity>
                                        <swe:uom
xlink:href="http://qudt.org/vocab/unit#Foot" xlink:title="foot" code="ft"/>
                                        <swe:value>9</swe:value>
                                </swe:Quantity>
                        </gwml2w:toDepth>
                        <gwml2w:value>
                                <swe:DataRecord
definition="http://www.opengis.net/def/gwml/2.1/datarecord/earthMaterial">
                                        <swe:field name="major_lithology">
                                                <swe:Category
definition="http://www.opengis.net/def/gwml/2.0/observedProperty/earthMaterial">

        <swe:identifier>http://cida.usgs.gov/groundwater/def/lithology/CLAY</swe:identif
ier>
                                                        <swe:value>CLAY</swe:value>
                                                </swe:Category>
                                        </swe:field>
```

```
                                        <swe:field name="lithology-description">
                                            <swe:Category
definition="http://www.opengis.net/def/gwml/2.0/observedProperty/earthMaterial">
                                                <swe:value>BROWN</swe:value>
                                            </swe:Category>
                                        </swe:field>
                                    </swe:DataRecord>
                                </gwml2w:value>
                            </gwml2w:LogValue>
                        </gwml2w:element>
</gwml2w:GW_GeologyLogCoverage>
```

10.5.2 Monitoring Sites

Monitoring site elevation geometry must have a relevant vertical 1D srsName.

/req/gwml2-well-xsd/monitoring-elevationCRS	GW_MonitoringSite:gwSiteReferenceElevation/Elevation:elevation @srsName SHALL contain a vertical SRS.

/req/gwml2-well-xsd/monitoring-elevation-uom	GW_MonitoringSite:gwSiteReferenceElevation/Elevation:elevation @srsName datum units and coordinate system SHALL be the same as the **/req/gwml2-well-xsd/monitoring-elevationCRS** units and coordinate system vertical axis

```
<gwml2w:gwSiteReferenceElevation>
        <gwml2w:Elevation>
                <gwml2w:elevation srsName="http://www.opengis.net/def/crs/EPSG/0/5711"
uomLabels="m AHD" srsDimension="1">523.27</gwml2w:elevation>
                <gwml2w:elevationAccuracy
xlink:href="http://www.opengis.net/def/nil/OGC/0/unknown" xlink:title="unknown"/>
                <gwml2w:elevationType xlink:title="Relative Level Natural Surface"/>
       <gwml2w:elevationMeasurementMethod
   xlink:href="http://www.opengis.net/def/nil/OGC/0/unknown" nilReason="unknown"
   xlink:title="unknown"/>
        </gwml2w:Elevation>
</gwml2w:gwSiteReferenceElevation>
```

10.6 Requirement class: GWML2-WellConstruction XML encoding

Requirements class	**/req/gwml2-construction-xsd**
Target type	XML data document
Dependency	/req/xsd-xml-rules
Dependency	/req/gwml2-construction
Requirement	/req/gwml2-construction-xsd/xsd
Requirement	/req/gwml2-construction-xsd/collar-elevationCRS
Requirement	/req/gwml2-construction-xsd/depth-order

All xml elements under namespace http://www.opengis.net/gwml-construction/2.1 must validate with the schema located at http://schemas.opengis.net/gwml/2.1/gwml2-wellconstruction.xsd.

/req/gwml2-construction-xsd/xsd	All the elements and types under namespace "http://www.opengis.net/gwml-construction/2.1" SHALL validate with the schema located at http://schemas.opengis.net/gwml/2.1/gwml2-wellconstruction.xsd

BoreCollar:collarElevation must have a relevant vertical 1D srsName.

/req/gwml2-construction-xsd/xsd	BoreCollar:collarElevations SHALL had a relevant vertical srsName

/req/gwml2-construction-xsd/depth-order	Each Borehole SHALL have one bholeHeadworks/BoreCollar:collarElevationType @xlink:href = "http://www.opengis.net/req/gwml2-construction/construction_origin_elevation

Example Borehole BoreCollar and collarElevationType encodings:

```
</gwml2wc:Borehole>
       <gwml2wc:bholeHeadworks>
      <gwml2wc:BoreCollar gml:id="borehole.construction.nsw.10019168.collar">
                        <gwml2wc:collarElevation axisLabels="m AHD" srsDimension="1"
srsName="http://www.opengis.net/def/crs/EPSG/0/5711"
uomLabels="metre">139.06</gwml2wc:collarElevation>
                  <gwml2wc:collarElevationType
xlink:href="http://www.opengis.net/req/gwml2-
construction/construction_origin_elevation"/>
                        <gwml2wc:collarHeadworkType
xlink:href="http://www.opengis.net/def/nil/OGC/0/missing" xlink:title="missing"/>
                        <gwml2wc:collarLocation>
                              <gml:Point
gml:id="borehole.construction.nsw.10019168.location" srsDimension="2"
srsName="http://www.opengis.net/def/crs/EPSG/0/4283">
                                    <gml:pos>-35.50485492957156
146.2265360498699</gml:pos>
                              </gml:Point>
                        </gwml2wc:collarLocation>
                        <gwml2wc:bholeDetails
xlink:href="http://environment.data.gov.au/groundwater/feature/borehole/nsw.10019168"/>
      </gwml2wc:BoreCollar>
       </gwml2wc:bholeHeadworks>
</gwml2wc:Borehole>
```

Construction element "from" value must be less than or equal to the "to" value.

/req/xsd-gwml-construction/depth-order	For any given value where both "from" and "to" are non-null, the value of bh:from/swe:Quantity/swe:Value SHALL be less or equal to

	bh:to/swe:Quantity/swe:Value

10.7 Requirement class: GWML2-Well-Vertical XML encoding (profile)

Requirements class	/req/gwml2-vertical-well-xsd
Target type	XML data document
Dependency	/req/gwml2well-xsd
Dependency	/req/gwml2-vertical-well
Requirement	/req/gwml2-vertical-well-xsd/waterwell-shape
Requirement	/req/gwml2-vertical-well-xsd/endvertex

Vertical wells are represented as simple gml:Curve, made of a single Segment having only 2 coordinates.

/req/gwml2-vertical-well-xsd/waterwell-shape	The sams:shape value of a vertical GW_Well SHALL be of type gml:Curve, consisting of a single segment of type LineStringSegment, containing 2 3D vertices

Example of a 3D vertical curve:

```
<sams:shape>
                <gml:Curve gml:id="ab.ww.402557.shape.1" srsDimension="3"
srsName="http://www.opengis.net/def/crs/EPSG/0/4955">
                        <gml:segments>
                                <gml:LineStringSegment>
                                        <gml:posList>49.671622 -114.625045 0.00 49.671622
-114.625045 11.58</gml:posList>
                                </gml:LineStringSegment>
                        </gml:segments>
                </gml:Curve>
        </sams:shape>
```

The first vertex (v0) of the LineStringSegment must have the same planar coordinate as the last vertex (v1).

/req/gwml2-vertical-well-xsd/endvertex	The first vertex of the LineStringSegment SHALL have the same planar (x,y) coordinate as the last vertex.

10.8 Requirement class: GeologicLog XML encoding

This requirement class specifies the requirements for encoding Geologic Logs

Requirements class	/req/gwml2-well-log-xsd
Target type	XML data document
Dependency	/req/gwml2-well-log-xsd
Dependency	http://www.opengis.net/spec/SWE/2.0/req/xsd-record-components
Recommendation	/req/xsd-gwml-well-log/log-definition

Log values are encoded as swe:DataRecord, which is an encoding of ISO 11404 Record. It is a composite datatype made of 1 to many fields that are defined along with the instance (not by the XSD). DataRecord allows any collection of fields of any SWE AbstractDataComponent.

The DataRecord definition URI defines the structure of the data record and the semantics of the fields. This specification recommends that the definition be controlled by a community with specific use cases to address.

/req/xsd-gwml-well-log/log-definition	The definition of a DataRecord and the fields that compose it SHOULD have a defining URI governed by an appropriate community

Example of a complete gwWellGeology/GW_GeologyLog for geologic units illustrating how swe:DataRecord/definition specifies the field and DataRecord content for the log.

```
<gwml2w:gwWellGeology>
	<gwml2w:GW_GeologyLog gml:id="borehole.qld.14483A.1.1.stratigraphy">
		<gml:identifier
codeSpace="http://www.ietf.org/rfc/rfc2616">http://environment.data.gov.au/groundwater/
feature/stratigraphy-log.qld.14483A.1.1</gml:identifier>
		<om:phenomenonTime
xlink:href="http://www.opengis.net/def/nil/OGC/0/unknown" xlink:title="unknown"/>
		<om:resultTime xlink:href="http://www.opengis.net/def/nil/OGC/0/unknown"
xlink:title="unknown"/>
		<om:procedure xlink:href="http://www.opengis.net/def/nil/OGC/0/unknown"
xlink:title="unknown"/>
		<om:observedProperty xlink:href="http://
resource.gwml.org/def/gwml/2.0/observedProperty/hydrostratigraphy"
xlink:title="hydrostratigraphy"/>
		<om:featureOfInterest
xlink:href="http://environment.data.gov.au/groundwater/feature/borehole/qld.14483A"/>
		<om:result>
			<gwml2w:GW_GeologyLogCoverage
gml:id="borehole.qld.14483A.1.1.stratigraphy.coverage">
				<gwml2w:element>
					<gwml2w:LogValue>
						<gwml2w:fromDepth>
							<swe:Quantity>
								<swe:uom
xlink:href="http://qudt.org/vocab/unit#Meter" xlink:title="metre" code="m"/>
								<swe:value>0.00</swe:value>
							</swe:Quantity>
						</gwml2w:fromDepth>
						<gwml2w:toDepth>
							<swe:Quantity>
								<swe:uom
xlink:href="http://qudt.org/vocab/unit#Meter" xlink:title="metre" code="m"/>
								<swe:value>14.02</swe:value>
							</swe:Quantity>
						</gwml2w:toDepth>
						<gwml2w:value>
							<swe:DataRecord
definition="http://resource.gwml.org/def/gwml/2.0/datarecord/geologicUnit">
```

```
                                                    <swe:field name="geologic
unit">
                                                        <swe:Category
definition="http://resource.gwml.org/def/gwml/2.0/observedProperty/hydrostratigraphy">

        <swe:identifier>http://environment.data.gov.au/groundwater/feature/hydrogeologic
unit/hgu.1079</swe:identifier>

        <swe:description>Lockyer Creek alluvium</swe:description>
                                                            <swe:codeSpace
xlink:href="http://www.bom.gov.au/water/groundwater/hydrogeologicunit"/>

        <swe:value>Lockyer Creek alluvium</swe:value>
                                                        </swe:Category>
                                                    </swe:field>
                                                </swe:DataRecord>
                                            </gwml2w:value>
                                        </gwml2w:LogValue>
                                    </gwml2w:element>
            <gwml2w:element>{more gwml2w:elements here}</gwml2w:element>
                        </gwml2w:GW_GeologyLogCoverage>
                </om:result>
                <gwml2w:startDepth>
                        <swe:Quantity>
                                <swe:uom xlink:href="http://qudt.org/vocab/unit#Meter"
xlink:title="metre" code="m"/>
                                <swe:value>0</swe:value>
                        </swe:Quantity>
                </gwml2w:startDepth>
                <gwml2w:endDepth>
                        <swe:Quantity>
                                <swe:uom xlink:href="http://qudt.org/vocab/unit#Meter"
xlink:title="metre" code="m"/>
                                <swe:value>57</swe:value>
                        </swe:Quantity>
                </gwml2w:endDepth>
        </gwml2w:GW_GeologyLog>
</gwml2w:gwWellGeology>
```

10.9 Requirement class: Aquifer test XML encoding

Requirements class	**req/gwml2-aquifer-test-xsd**
Target type	XML data document
Dependency	/req/xsd-xml-rules
Dependency	/req/gwml-aquifer-test
Dependency	http://www.opengis.net/spec/SWE/2.0/req/xsd-record-components
Requirement	/req/gwml2-aquifer-test/xsd
Requirement	**/req/gwml2-aquifer-test-xsd/sampledfeature**
Requirement	**/req/gwml2-aquifer-test-xsd/testfeature**
Requirement	**/req/gwml2-aquifer-test-xsd/observationfeature**
Requirement	**/req/gwml2-aquifer-test-xsd/observation-role**
Requirement	**/req/gwml2-aquifer-test-xsd/timeseries**
Requirement	**/req/gwml2-aquifer-test/timeseries-datarecord**

All xml elements under namespace http://www.opengis.net/gwml-aquifertest/2.1 must validate with the schema located at http://schemas.opengis.net/gwml/2.1/gwml2-aquifertest.xsd.

/req/gwml2-aquifer-test/xsd	All the elements and types under namespace "http://www.opengis.net/gwml-aquifertest/2.1" SHALL validate with schema located at http://schemas.opengis.net/gwml/2.1/gwml2-aquifertest.xsd

XML encoding conforms to O&M XML encoding (10-025r1), sweCommon (08-094r1) and WaterML 2.0 encoding (10-126 r4). This extension introduces a single new class with no new property or association.

Note that, while O&M (OGC 10-004r3) proposes subtypes of (abstract) **SF_SpatialSamplingFeature**, based on their geometries (SF_SamplingPoint, SF_SamplingCurve, etc.), the XML encoding does not materialise any classes for these sub types, but maps (OGC 10-025r1) them all to a concrete **SF_SpatialSamplingFeature**. The sub types are "soft types" and reported using sam:type property. This property is an XML encoding artefact from 10-025r1 and is not described in the conceptual model (10-004r3).

```
<gwml2at:GW_AquiferTest xmlns:gwml2at="http://www.opengis.net/gwml-aquifertest/2.1"
xmlns:sf="http://www.opengis.net/samplingSpatial/2.0"
xmlns:swe="http://www.opengis.net/swe/2.0"  xmlns:om="http://www.opengis.net/om/2.0"
xmlns:gmd="http://www.isotc211.org/2005/gmd" xmlns:gml="http://www.opengis.net/gml/3.2"
xmlns:sam="http://www.opengis.net/sampling/2.0" gml:id="pump.wit.63"
xmlns:xlink="http://www.w3.org/1999/xlink" xmlns:xsi="http://www.w3.org/2001/XMLSchema-
instance"
xsi:schemaLocation="http://www.opengis.net/gwml-aquifertest/2.1 http://ngwd-
bdnes.cits.nrcan.gc.ca/service/gwml/schemas/2.1/gwml2-aquifertest.xsd
http://www.opengis.net/samplingSpatial/2.0
http://schemas.opengis.net/samplingSpatial/2.0/spatialSamplingFeature.xsd">

       <gml:description>Multiple well pumping test using Thiems's method.  Data from
The Netherland (from Kruseman &amp;amp; deRitter, 2000).  Pumping test done in Oude
Korendijk documented by Wit (1963).</gml:description>
       <gml:identifier codeSpace=" http://www.ietf.org/rfc/rfc2616
">http://opengis.org/example/pumpingTest/wit63</gml:identifier>
       <gml:name codeSpace="urn:gwml2:example:name">wik63</gml:name>
       <gml:location>
              <gml:LocationString>Oude Korendijk</gml:LocationString>
       </gml:location>
       <sam:type xlink:href="http://www.opengis.net/def/samplingFeatureType/OGC-
OM/2.0/SF_SamplingSurface"/>
       <sam:sampledFeature
xlink:href="http://opengis.org/example/aquifer/OudeKorendijk" xlink:title="Oude
Korendijk aquifer"/>
(…)
</gwml2at:GW_AquiferTest>
```

GW_AquiferTest, as a subtype of **SF_SpatialSamplingFeature**, inherits sam:type property.

The sampled feature of GW_AquiferTest SHALL be a reference to an instance of a GW_HydrogeoUnit

/req/gwml2-aquifer-test-xsd/sampledfeature	The sam:sampledFeature SHALL have a xlink:href to an instance of GW_HydrogeoUnit.

SF_SamplingFeatures that are test features, as defined in 9.9.3.2, shall be associated with the GW_AquiferTest using a SF_SamplingFeatureComplex, with the role's xlink:href set to http://resource.gwml.org/def/role/testFeature

/req/gwml2-aquifer-test-xsd/testfeature	SF_SamplingFeatureComplex roles that associates GW_AquiferTest with test features SHALL have it's xlink:href set to http://resource.gwml.org/def/role/testFeature

```
<sam:relatedSamplingFeature>
            <sam:SamplingFeatureComplex>
            <!-- this one is the pumping well -->
                  <sam:role
xlink:href="http://resource.gwml.org/def/role/testFeature" xlink:title="Well
that is being pumped"/>
                  <sam:relatedSamplingFeature
xlink:href="http://example.gw.com/samplingFeature/WellWit63"/>
            </sam:SamplingFeatureComplex>
      </sam:relatedSamplingFeature>
```

SF_SamplingFeatures that are observation features, as defined in 9.9.3.2, shall be associated with the GW_AquiferTest using a SF_SamplingFeatureComplex, with the role's xlink:href set to http://resource.gwml.org/def/role/observationFeature

/req/gwml2-aquifer-test-xsd/observationfeature	SF_SamplingFeatureComplex roles that associates GW_AquiferTest with test features SHALL have it's xlink:href set to http://resource.gwml.org/def/role/observationFeature

```
<sam:relatedSamplingFeature>
            <sam:SamplingFeatureComplex>
                  <sam:role
xlink:href="http://resource.gwml.org/def/role/observationFeature"
xlink:title="Well at which the observation is made"/>
                  <sam:relatedSamplingFeature
xlink:href="http://example.gw.com/samplingFeature/WellWit63h215"/>
            </sam:SamplingFeatureComplex>
      </sam:relatedSamplingFeature>
```

OM_Observations are linked together using ObservationComplex in the specific case when new observations are derived from support observations. This specification imposes URI for those specifics roles.

/req/gwml2-aquifer-test-xsd/observation-role	Raw observations from the observation sampling feature SHALL be link to the test result observations using the roles defined in 9.9.3.4

```
<sam:relatedObservation>
            <om:OM_Observation gml:id="obs.wik63.1">
                  <om:relatedObservation>
                        <om:ObservationContext>
                              <om:role
xlink:href="http://resource.gwml.org/def/role/supportObservation"
xlink:title="supporting Observation"/>
                              <!--LINK TO TRANSMISSIVITY IN GWML2 -->
                              <om:relatedObservation
xlink:href="http://example.gw.com/observations/00001" xlink:title="Accepted
Transmissivity for aquifer"/>
                        </om:ObservationContext>
                  </om:relatedObservation>
                  <om:phenomenonTime>
                        <gml:TimePeriod gml:id="tp.wik63.1">
                              <gml:beginPosition>1963-07-
01T13:00:00Z</gml:beginPosition>
                              <gml:endPosition>1963-07-
02T02:50:00Z</gml:endPosition>
                        </gml:TimePeriod>
                  </om:phenomenonTime>
                  <om:resultTime>
                        <gml:TimeInstant gml:id="ti.wik63.1">
                              <!-- result valid at the end of the test -->
                              <gml:timePosition>1963-07-
02T02:50:00Z</gml:timePosition>
                        </gml:TimeInstant>
                  </om:resultTime>
                  <om:procedure
xlink:href="http://resource.gwml.org/def/method/Thiem" xlink:title="Thiem
method"/>
                  <!-- this is one option to pump test related properties,
the other option is to have the procedure above to point to a full SensorML
description of the test -->

                  <!-- links to a combo of typical pumptest results -->
                  <om:observedProperty
xlink:href="http://resource.gwml.org/def/property/pumpTestProperties"
xlink:title="Pump test results"/>
                  <om:featureOfInterest xlink:href="#pump.wit.63"
xlink:title="Wit 63 Pump test"/>
                  <om:result>
                        <swe:DataRecord
definition="http://resource.gwml.org/def/property/pumpTestProperties"
id="le.1">
```

```
                                <!-- Since pump test can result in many
parameters, they are grouped in a record -->
                                <swe:field name="transmissivity">
                                        <swe:Quantity
definition="http://resource.gwml.org/def/phenomenon/groundwaterTransmissivity"
>
                                                <swe:uom code="m^2/d"/>
                                                <swe:value>385</swe:value>
                                        </swe:Quantity>
                                </swe:field>
                        </swe:DataRecord>
                </om:result>
        </om:OM_Observation>
</sam:relatedObservation>
```

Observation results that are time series must be encoded with WaterML 2.0.

/req/gwml2-aquifer-test-xsd/timeseries	OM_Observation results that are timeseries SHALL be encoded as wml2:MeasurementTimeSeries (OGC 10-126)

Derived (or computed) observation results SHALL be encoded using swe:DataRecord XML encoding.

/req/gwml2-aquifer-test/timeseries-datarecord	Derived or computed observations SHALL be encoded as swe:DataRecord as defined in 08-094r1 (http://www.opengis.net/spec/SWE/2.0/req/xsd-record-components)

```
<om:result>
                <swe:DataRecord
definition="http://resource.gwml.org/def/property/pumpTestProperties"
id="le.1">
                        <swe:field name="transmissivity">
                                <swe:Quantity
definition="http://resource.gwml.org/def/phenomenon/groundwaterTransmissivity"
>
                                        <swe:uom code="m^2/d"/>
                                        <swe:value>385</swe:value>
                                </swe:Quantity>
                        </swe:field>
                </swe:DataRecord>
</om:result>
```

Annex A: Conformance Class Abstract Test Suite (Normative)

A.1 Introduction

This test suite contains 7 conformance classes, including one abstract conformance class. Each test relates to one or more specific requirements, which are explicitly indicated in the description of the test.

A.2 Conformance classes – UML packages

A.2.1 Conformance class: GWML 2.0 core logical model (Abstract)

Conformance Class	/conf/gwml2-core	
Requirements	/req/gwml2-core	
Dependency	Urn:iso:dis:iso:19156:clause:A.1.1	
Test	**/conf/gwml2-core/encoding**	
	Requirement	/req/gwml2-core/encoding
	Test purpose	Ensure that all mandatory classes and properties are encoded
	Test method	Verify that the target implementation has all mandatory classes and properties implemented. If mandatory class or property are missing, the test fails
	Test type	Capability
Test	**/conf/gwml2-core/quantities-uom**	
	Requirement	/req/gwml2-core/quantities-uom
	Test purpose	Ensure that all properties of type swe:Quantity or om:OM_Measurement contain an xlink:href with a URI to a valid unit of measurement
	Test method	Visually inspect the target implementation and validate that all properties of type Quantity or Measurement report a unit of measurement
	Test type	Capability
Test	**/conf/gwml2-core/codelist**	
	Requirement	/req/gwml2-core/codelist
	Test purpose	Ensure that vocabularies used in the target implementation are managed in an external system
	Test method	Visually inspect the target implementation and validate that all properties that are identified as vocabularies use values that are managed in a subsystem independent from the target implementation

	Test type	Capability
Test	**/conf/gwml2-core/codelistURI**	
	Requirement	/req/gwml2-core/codelistURI
	Test purpose	Ensure that URI used as vocabulary terms are resolvable using Linked Open Data principle
	Test method	Use a tool such as cURL to get the resource from the web. The server SHALL return a 303 or a 307 (HTTP 1.1) status response with one or more URL pointing to alternative format/languages.
	Test type	Capability
Test	**/conf/gwml2-core/identifier**	
	Requirement	/req/gwml2-core/identifier
	Test purpose	Ensure that the HTTP URI used as a globally unique identifier actually resolves to an instance of the feature using Linked Open Data principles
	Test method	For each feature that has a HTTP URI as a globally unique identifier, resolve the URI and inspect the result to see if it matches the same instance. Note, this conformance class does not imply any specific format, nor a single format
	Test type	Capability
Test	**/conf/gwml2-core/feature**	
	Requirement	/req/gwml2-core/feature
	Test purpose	Ensure that an instance of GWML 2.1 contains at least one valid GWML 2.1 element
	Test method	Inspect the instance and check that a GWML 2.1 element is correctly encoded.
	Test type	Capability

A.2.2 Conformance class: GWML 2.0 main logical model

Conformance Class	/conf/gwml2-main-uml	
Requirements	req/gwml2-main-uml	
Dependency	/conf/gwml2-core	
Dependency	/conf/gwml2-constituent	
Dependency	/conf/gwml2-flow	
Test	/conf/gwml2-main/observed-unit-fluid-property-foi	
	Requirement	/req/gwml2-main/observed-unit-fluid-property-foi
	Test purpose	Ensure that GW_UnitFluidProperty properties have featureOfInterest referring to the GW_HydrogeoUnit that owns the association with GW_FluidBody
	Test method	Check that each OM_Measurement instance that uses a property value for gwHydraulicConductivity, gwStorativity, gwTransmissivity or gwYield has a featureOfInterest that matches the gwFluidBodyUnit property
	Test type	Capability
Test	/conf/gwml2-main/observed-unit-void-property-foi	
	Requirement	/req/gwml2-main/observed-unit-void-property-foi
	Test purpose	Ensure that GW_UnitVoidProperty properties have featureOfInterest referring to the GW_HydrogeoUnit that owns the association with GW_HydrogeoVoid
	Test method	Check that each OM_Measurement instance that uses a property value for gwPermeability or gwPorosity has a featureOfInterest that matches the gwVoidUnit property
	Test type	Capability

A.2.3 Conformance class: GWML 2.0 constituent logical model

Conformance Class	**/conf/gwml2-constituent**
Requirements	/req/**gwml2-constituent**
Dependency	/conf/gwml2-core

A.2.4 Conformance class: GWML 2.0 flow logical model

Conformance Class	**/conf/gwml2_flow**
Requirements	/req/**gwml2-flow**
Dependency	/conf/gwml2-core

A.2.5 Conformance class: GWML 2.0 Well logical model

Conformance Class	**/conf/gwml2-well**	
Requirements	/req/**gwml2-well**	
Dependency	/conf/gwml2-main-uml	
Test	**/conf/gwml2-well/waterwell-elevationCRS**	
	Requirement	/req/gwml2-well/waterwell-elevationCRS
	Test purpose	Ensure that the all Elevation elevation geometry has a 1D CRS where the units and reference system matches vertical axis of the well shape's CRS
	Test method	Check, for each well, Elevation instance and check the elevation geometry CRS identifier. Check that this identifier is a valid EPSG code in the EPSG database (http://epsg.io)
	Test type	Capability
Test	**/conf/gwml2-well/waterwell-shape**	
	Requirement	/req/gwml2-well/waterwell-shape
	Test purpose	Ensure that the shape is a 3D GM_Curve
	Test method	Check that the shape geometry has 3 coordinates and that it has a valid 3D CRS
	Test type	Capability
Test	**/conf/gwml2-well/waterwell-shapeCRS**	
	Requirement	/req/gwml2-well/waterwell-shapeCRS

	Test purpose	Ensure that the coordinate system of the shape, that is derived from the well position and the origin elevation, is a coherent and accepted CRS
	Test method	Check in the EPSG database that a CRS made of the planar CRS of the gwWellLocation and the Elevation::elevation CRS, that correspond to /req/gwml2-well/origin_elevation, exists. Check that this is indeed the CRS reported by the geometry
	Test type	Capability
Test	**/conf/gwml2-well/waterwell-observation-spatial-reference**	
	Requirement	/req/gwml2-well/waterwell-observation-spatial-reference
	Test purpose	Ensure that the reference geometry is encoded correctly in the NamedParameter of OM_Observation and is of the correct type
	Test method	For each Observation that is positioned relative to bore path, check that the value of om:parameter has an instance of om::NamedParameter with two components; the name must be the string "**gwml2-well/waterwell-observation-spatial-reference**" and the value type is GM_Curve
	Test type	Capability
Test	**/conf/gwml2-well/waterwell-observation-fromparam**	
	Requirement	/req/gwml2-well/waterwell-observation-fromparam
	Test purpose	Ensure that the "from" distance is encoded correctly in the NamedParameter of OM_Observation
	Test method	For each Observation that is positioned relative to bore path, check that the value of om:parameter has an instance of om::NamedParameter with two components; the name must be the string "http://www.opengis.net/req/gwml2-well/waterwell-observation-fromparam " and the distance from the origin must be an instance of swe:Quantity, properly encoded according to /conf/gwml2-core/quantities-uom
	Test type	Capability
Test	**/conf/gwml2-well/waterwell-observation-toparam**	
	Requirement	/req/gwml2-well/waterwell-observation-toparam
	Test purpose	Ensure that the "to" distance is encoded correctly in the NamedParameter of OM_Observation
	Test method	For each Observation that is positioned relative to bore path, check that the value of om:parameter has an instance of om::NamedParameter with two components. the name must be the string "http://www.opengis.net/req/gwml2-well/waterwell-observation-toparam" and the distance from the origin must a instance of swe:Quantity, properly encoded according to /conf/gwml2-core/quantities-uom
	Test type	Capability
Test	**/conf/gwml2-well/waterwell-sf-spatial-reference**	
	Requirement	/req/gwml2-well/waterwell-sf-spatial-reference

	Test purpose	Ensure that the reference geometry is encoded correctly in the NamedParameter of SF_SamplingFeature and is of type GM_Curve
	Test method	For each SamplingFeature that is positioned relative to bore path, check that the value of sams:parameter has an instance of sams::NamedParameter with two components; the name must be the string "http://www.opengis.net/**req/gwml2-well/waterwell-sf-spatial-reference**" and the value must be a GM_Curve
	Test type	Capability
Test	**/conf/gwml2-well/waterwell-sf-fromparam**	
	Requirement	/req/gwml2-well/waterwell-sf-fromparam
	Test purpose	Ensure that the "from" distance is encoded correctly in the NamedParameter of SF_SamplingFeature
	Test method	For each SamplingFeature that is positioned relative to bore path, check that the value of om:parameter has an instance of sams::NamedParameter with two components; the name must be the string "http://www.opengis.net/**req/gwml2-well/waterwell-sf-fromparam** " and the distance from the origin must a instance of swe:Quantity, properly encoded according to /conf/gwml2-core/quantities-uom
	Test type	Capability
Test	**/conf/gwml2-well/waterwell-sf-toparam**	
	Requirement	/req/gwml2-well/waterwell-sf-toparam
	Test purpose	Ensure that the "to" distance is encoded correctly in the NamedParameter of SF_SamplingFeature
	Test method	For each sampling feature that is positioned relative to bore path, check that the value of om:parameter has an instance of sams:NamedParameter with two components. the name must be the string "http://www.opengis.net/**req/gwml2-well/waterwell-sf-toparam** " and the distance from the origin must a instance of swe:Quantity, properly encoded according to /conf/gwml2-core/quantities-uom
	Test type	Capability
Test	**/conf/gwml2-well/well-geology**	
	Requirement	/req/gwml2-well/well-geology
	Test purpose	Ensure that an association between a GW_Well and a GW_GeologyLog is only made using a gwWellGeology.
	Test method	Check that there are no occurrences of GW_Well/om:relatedObservation/GW_GeologyLog
	Test type	Capability
Test	**/conf/gwml2-well/log-coverage**	
	Requirement	/req/gwml2-well/log-coverage
	Test purpose	Ensure that the om:result of GeologyLog is an instance of GW_GeologyLogCoverage

	Test method	Check the om:result of GeologyLog and check if it's an instance of GW_GeologyLogCoverage or any of its subtypes.
	Test type	Capability
Test	**/conf/gwml2-well/geometry-origin**	
	Requirement	/req/gwml2-well/log-geometry-origin
	Test purpose	Ensure the LogValue are positioned relative to the first vertex of the SF_SamplingCurve of the feature identified by the GW_GeologyLog's feature if interest
	Test method	Compare coherence with source data
	Test type	Capability
Test	**/conf/gwml2-well/log-depth**	
	Requirement	/req/gwml2-well/log-depth
	Test purpose	Ensure the LogValue depth (fromDepth or toDepth) is the linear distance from the origin of the GM_Curve
	Test method	Compare with the source data that the distance is correctly calculated
	Test type	Capability
Test	**/conf/gwml2-well/log-depth-order**	
	Requirement	/req/gwml2-well/log-depth-order
	Test purpose	Ensure the fromDepth and toDepth are ordered correctly
	Test method	Check for each LogValue, where both fromDepth and toDepth are not nil, that the fromDepth is less or equal to toDepth.
	Test type	Capability
Test	**/conf/gwml2-well/monitoring-elevationCRS**	
	Requirement	/req/gwml2-well/monitoring-elevationCRS
	Test purpose	Ensure the reference elevation geometries have a 1D CRS and its units and CRS match the vertical axis of the shape of the site
	Test method	Check in the EPSG database that CRS of Elevation::elevation exists and is an elevation CRS.
	Test type	Capability

A.2.6 Conformance class GWML 2.0 Construction logical model

Conformance Class	**/conf/gwml2-construction**

Requirements	/req/**gwml2-construction**	
Test	**/conf/gwml2-construction/collar-elevationCRS**	
	Requirement	/req/gwml2-construction/collar-elevationCRS
	Test purpose	Ensure that the collar elevation geometry has a 1D CRS and its units and reference system matches the vertical axis of the borehole shape's CRS.
	Test method	Check in the EPSG database that CRS of collarElevation exists and is an elevation CRS.
	Test type	Capability
Test	**/conf/gwml2-construction/borehole-shape**	
	Requirement	/req/gwml2-construction/borehole-shape
	Test purpose	Ensure that the geometry that describes the borehole path represents the complete length of the bore in such as way that all construction elements (above in below the ground) can be located along the path.
	Test method	Check that the starting point is prior or at the location of the topmost element and the end point is beyond or at the location of the bottommost element.
	Test type	Capability
Test	**/conf/gwml2-construction/log-depth**	
	Requirement	/req/gwml2-construction/log-depth
	Test purpose	Ensure that construction component are positioned linearly from the first vertex of the bore shape, along its path
	Test method	Check that each construction components has a "from" and "to" value is between 0 (zero) and the length of Borehole::shape. If a value is unknown, a "nil" value can be used
	Test type	Capability
Test	**/conf/gwml2-construction/log-depth-order**	
	Requirement	/req/gwml2-well/log-depth-order
	Test purpose	Ensure that ConstructionComponent's "from" value is always less (closer to origin) than "to" value
	Test method	When both "from" and "to" are non nil, check that "from" is less than or equal to "to" value
	Test type	Capability

A.2.7 Conformance class: GWML 2.0 Vertical Well logical model

Conformance Class	/conf/gwml2-vertical-well
Requirements	/req/gwml2-vertical-well

Dependency	/conf/gwml2-well	
Test	**/conf/gwml2-vertical-well/waterwell-shape**	
	Requirement	/req/gwml2-vertical-well/waterwell-shape
	Test purpose	Ensure that the shape of a vertical well is made of only one segment (two vertices)
	Test method	Check that GW_Well::shape geometry has 6 and only 6 coordinates
	Test type	Capability
Test	**/conf/gwml2-vertical-well/endvertex**	
	Requirement	/req/gwml2-vertical-well/end-vertex
	Test purpose	Ensure that the shape of the GW_Well is vertical
	Test method	Considering that the GW_Well:shape is composed of two 3D points, [x0,y0,z0] and [x1,y1,z1]. Check coordinates x1 == x0 and y1 == y0
	Test type	Capability

A.2.8 Conformance class: GWML 2.0 Geologic logs

Conformance Class	**/conf/gwml2-well-gu**
Requirements	/req/gwml2-well-log
Dependency	/conf/gwml2-well

A.2.9 Conformance class : GWML 2.1 Aquifer Test

Conformance Class	**/conf/gwml2-aquifer-test**	
Requirements	/req/gwml2-aquifer-test	
Dependency	/conf/gwml2-core	
Dependency	http://www.opengis.net/spec/waterml/2.0/conf/uml-timeseries-observation	
Dependency	http://www.opengis.net/spec/SWE/2.0/conf/uml-record-components	
Test	**/conf/gwml2-aquifer-test/sampledfeature**	
	Requirement	**/req/gwml2-aquifer-test/sampledfeature**
	Test purpose	Ensure that aquifer tests are about hydrogeological units

	Test method	Check that the sampledFeaure of the test refers to an instance of GW_HydrogeoUnit.
	Test type	Capability
Test	**/conf/gwml2-aquifer-test/testfeature**	
	Requirement	**/req/gwml2-aquifer-test/testfeature**
	Test purpose	Ensure that the sampling features use to perform the test itself are correctly identified
	Test method	Check that the role of the SF_SamplingFeatureComplex is “http://resource.gwml.org/def/role/testFeature”
	Test type	Capability
Test	**/conf/gwml2-aquifer-test/observationfeature**	
	Requirement	**/req/gwml2-aquifer-test/observationfeature**
	Test purpose	Ensure that the sampling features use to monitor the test itself are correctly identified
	Test method	Check that the role of the SF_SamplingFeatureComplex is “http://resource.gwml.org/def/role/observationFeature”
	Test type	Capability
Test	**/conf/gwml2-aquifer-test/observation-role**	
	Requirement	**/req/gwml2-aquifer-test/observation-role**
	Test purpose	Ensure that observations gained from observation features are linked to derived observations
	Test method	Check that the value type use the correct URI when any of the roles are listed in 9.9.3.3
	Test type	Capability
Test	**/conf/gwml2-aquifer-test/testparameter**	
	Requirement	**/req/gwml2-aquifer-test/testparameter**
	Test purpose	Ensure that the well know procedures listed in clause 9.9.3.3 are are unambiguously encoded as NamedValue by using the URI defined in this section
	Test method	Check that the value type use the correct URI when any of the procedures listed in 9.9.3.3
	Test type	Capability
Test	**/conf/gwml2-aquifer-test/timeseries**	
	Requirement	**/req/gwml2-aquifer-test/timeseries**
	Test purpose	Ensure that results that represent values taken over time are encoded using WaterML 2.0 (OGC 10-126)

	Test method	Check the encoding of the result and check it fits conformance classes of WaterML 2.0
	Test type	Capability
Test	**/conf/gwml2-aquifer-test/timeseries-datarecord**	
	Requirement	**/req/gwml2-aquifer-test/timeseries-daterecord**
	Test purpose	Ensure that derived observation results are encoded using a swe:DataRecord
	Test method	Check the encoding of derived observation and check they comply to swe:DataRecord
	Test type	Capability

A.3 Conformance classes – XML encoding

A.3.1 Conformance classes: xml-rules

Conformance Class	**/conf/xsd-xml-rules**	
Requirements	/req/xsd-xml-rules	
Dependency	08-131r3 Req 39	
Dependency	08-131r3 Req 40	
Dependency	http://www.opengis.net/spec/SWE/2.0/conf/xsd-simple-components	
Dependency	1.1.1 http://www.w3.org/TR/xmlschema-2	
Dependency	1.1.2 http://www.opengis.net/doc/IS/GML/3.2/clause/2.4	
Dependency	1.1.3 urn:iso:dis:iso:8601:2004:clause:4	
Test	/conf/xsd-xml-rules/W3C_XSD	
	Requirement	/req/xsd-xml-rules/W3C_XSD
	Test purpose	Ensure that the xml element are valid with XSD
	Test method	Use a XSD validation tool and check that validation does not return any error
	Test type	Capability
Test	/conf/xsd-xml-rules/W3C_XSD	
	Requirement	/req/xsd-xml-rules/ISO-schematron
	Requirement	/req/xsd-xml-rules/unit-of-measure
	Requirement	/req/xsd-xml-rules/swe-types

	Requirement	/req/xsd-xml-rules/xlink-title
	Test purpose	Validate the XML document using the schematron document http://schemas.opengis.net/gwml/2.1/xml-rules.sch. Passes if no errors are reported for '*unit-of-measure*' test. Fails otherwise.
	Test method	Use a schematron validation tool and check that validation does not return any error
	Test type	Capability
Test	/conf/xsd-xml-rules/**iso8601-time**	
	Requirement	/req/xsd-xml-rules/iso8601-time
	Test purpose	Ensure that all instance of date time, even in free text string, use the iso8601 encoding
	Test method	Inspect instance where date-time instance appears and check if they are encoded as iso8601
	Test type	Capability
Test	/conf/xsd-xml-rules/**time-zone**	
	Requirement	/req/xsd-xml-rules/time-zone
	Test purpose	Ensure that all time are flagged with time zone
	Test method	Inspect occurrence of date-time and check if it has a 4 digit character or a Z (Zulu). If absent, test fails
	Test type	Capability
Test	/conf/xsd-xml-rules/**identifier**	
	Requirement	/req/xsd-xml-rules/identifier
	Test purpose	Ensure that gml:identifiers with codeSpace == `http://www.ietf.org/rfc/rfc2616` have a http URI that resolves
	Test method	Check that HTTP URI, when invoked returns an HTTP code between 200 and 203, or 300 and 305
	Test type	Capability
Test	/conf/xsd-xml-rules/**byrefproperty**	
	Requirement	/req/xsd-xml-rules/byrefproperty
	Test purpose	Ensure that a xlink:href to an external resource can resolve (as one of the processable format)
	Test method	Check that HTTP URI, when invoked returns an HTTP code between 200 and 203, or 300 and 305
	Test type	Capability

A.3.2 Conformance classes : GWML2-Main xml encoding

Conformance Class	**/conf/xsd-main**	
Requirements	/req/gwml2-main-xsd	
Dependency	/conf/gwml2-flow-xsd	
Dependency	/conf/gwml2-constituent-xsd	
Dependency	1.1.4 http://www.opengis.net/spec/OMXML/2.0/conf/observation	
Dependency	1.1.5 http://www.opengis.net/spec/OMXML/2.0/conf/sampling	
Test	/conf/**gwml2-main-xsd/xsd**	
	Requirement	/req/gwml2-main-xsd/xsd
	Test purpose	Ensure that all elements under the namespace http://www.opengis.net/gwml-main/2.1 validate with the schema located at http://schemas.opengis.net/gwml/2.1/gwml2-main.xsd
	Test method	Use an XSD validator to validate the XML instance against the schema located at http://schemas.opengis.net/gwml/2.1/gwml2-main.xsd and check that no errors are generated for elements under the namespace http://www.opengis.net/gwml-main/2.1 or its dependencies. Pass if no errors reported. Fail otherwise
	Test type	Capability
Test	/conf/**gwml2-main-xsd/sch**	
	Requirement	/req/gwml2-main-xsd
	Test purpose	Ensure that instance document validate agains schematron rules
	Test method	Use a schematron validator and test the instance document against http://schemas.opengis.net/gwml/2.1/gwml2-main.sch. The test fails if any schematron rules are broken
	Test type	Capability

A.3.3 Conformance classes : GWML2-Constituent xml encoding

Conformance Class	**/conf/xsd-constituent**	
Dependency	/conf/xsd-xml-rule	
Requirements	**/req/gwml2-constituent-xsd**	
Test	/conf/gwml2-constituent-xsd	
	Requirement	/req/gwml2-constituent-xsd**/xsd**
	Test purpose	Ensure that all element under the namespace http://www.opengis.net/gwml-constituent/2.1 validates with schema located at http://schemas.opengis.net/gwml/2.1/gwml2-constituent.xsd

	Test method	Use a XSD validator to validate the XML instance against schema located at http://schemas.opengis.net/gwml/2.1/gwml2-constituent.xsd and check that no error are generate for elements under namespace http://www.opengis.net/gwml-constituent/2.1 or its dependencies. Pass if no errors reported. Fail otherwise
	Test type	Capability

A.3.4 Conformance classes : GWML2-flow xml encoding

Conformance Class	**/conf/xsd-flow**	
Dependency	/conf/xsd-xml-rule	
Requirements	**/req/gwml2-flow-xsd**	
Test	/conf/**gwml2-flow-xsd/xsd**	
	Requirement	**/req/gwml2-flow-xsd/xsd**
	Test purpose	Ensure that all element under the namespace http://www.opengis.net/gwml-flow/2.1 validates with schema located at http://schemas.opengis.net/gwml/2.1/gwml2-flow.xsd
	Test method	Use a XSD validator to validate the XML instance against schema located at http://schemas.opengis.net/gwml/2.1/gwml2-flow.xsd and check that no error are generate for elements under namespace http://www.opengis.net/gwml-flow/2.1 or its dependencies. Pass if no errors reported. Fail otherwise
	Test type	Capability

A.3.5 Conformance classes: GWML2-well xml encoding

Conformance Class	**/conf/xsd-well**	
Dependency	/conf/xsd-xml-rule	
Dependency	**/conf/gwml2-construction-xsd**	
Requirements	**/req/gwml2-well-xsd**	
Test	/conf/gwml2-well-xsd/xsd/	
	Requirement	**/req/gwml2-well-xsd/xsd**
	Test purpose	Ensure that the GW_Well instances conform to the rules expressed in the schema
	Test method	Use a XSD validator to validate instances. If the validator reports an error on a GWML 2.1 element, then the test fails
	Test type	Capability
Test	/conf/gwml2-well-xsd/sch/	
	Requirement	**/req/gwml2-well-xsd**

	Test purpose	Ensure that instance document validates agains schematron rules
	Test method	Use a schematron validator and test the instance document against http://schemas.opengis.net/gwml/2.1/gwml2-well.sch. The test fails if any schematron rules are broken
	Test type	Capability
Test	/conf/gwml2-well-xsd/waterwell-elevationCRS	
	Requirement	/req/gwml2-well-xsd/waterwell-elevationCRS
	Test purpose	Ensure that all Elevations have a relevant 1D vertical srsName
	Test method	Check the value of :GW_Well/sam:gwWellReferenceElevation/Elevation/elevation/@srsName against the EPSG database or CRS specification to ensure it represents a 1D vertical SRS
	Test type	Capability
Test	/conf/xsd-gwml-well/waterwell-elevationCRS-uom	
	Requirement	**/req/xsd-gwml-well/waterwell-shape-CRS-uom**
	Test purpose	Ensure that the elevation is expressed using the same units of measure and coordinate system as the geometry
	Test method	Check the CRS of the elevation and compare the uom and coordinate systems. If they are not compatible, the test fails.
	Test type	Capability
Test	/conf/gwml2-well-xsd/waterwell-elevationCRS	
	Requirement	**/req/**gwml2-well-xsd**/waterwell-shape-CRS**
	Test purpose	Ensure that the shape's coordinate system is sharing the same elevation CRS than the than the original Elevation
	Test method	Check the value of GW_Well/sam:shape/*/@srsName against EPSG database or CRS specification to Ensure that it's elevation reference system (z) matches the CRS used in the Elevations used in Elevation
	Test type	Capability
Test	**/req/gwml2-well-xsd /monitoring-elevationCRS**	
	Requirement	**/req/xsd-gwml-well/ monitoring-elevationCRS**
	Test purpose	Ensure that the monitoring site elevation has relevant 1D vertical CRS
	Test method	Check the value of GW_Well/gwSiteReferenceElevation/Elevation/elevation/@srsName against EPSG database or CRS specification to Ensure it represents a 1D vertical SRS
	Test type	Capability

A.3.6 Conformance classes : GWML2-construction xml encoding

Conformance Class	**/conf/gwml2-construction-xsd**	
Requirements	**/req/gwml2-construction-xsd**	
Dependency	/conf/xsd-xml-rule	
Test	/conf/**gwml2-construction-xsd /xsd**	
	Requirement	/req/xsd-gwml-construction-xsd
	Test purpose	Ensure that all elements under the namespace http://www.opengis.net/gwml-construction/2.1 validate with the schema located at http://schemas.opengis.net/gwml/2.1/gwml2-wellconstruction.xsd
	Test method	Use an XSD validator to validate the XML instance against the schema located at http://schemas.opengis.net/gwml/2.1/gwml2-well.xsd and check that no errors are generated for elements under the namespace http://www.opengis.net/gwml-construction/2.1 or its dependencies. Pass if no errors reported. Fail otherwise.
	Test type	Capability
Test	/conf/**gwml2-construction-xsd /sch**	
	Requirement	/req/xsd-gwml-construction-sch
	Test purpose	Ensure that instance document validate agains schematron rules
	Test method	Use a schematron validator and test the instance document against http://schemas.opengis.net/gwml/2.1/gwml2-construction.sch. The test fails if any schematron rules are broken
	Test type	Capability
Test	/conf/**gwml2-construction-xsschematron**	
	Requirement	/req/xsd-gwml-construction/depth-order
	Test purpose	Ensure that instance document validates with rules expressed in schematron file.
	Test method	Validate the XML document using the Schematron document http://schema.opengis.net/gwml/2.1/gwml2-construction.sch. Conformance passes if no error, fails otherwise.
	Test type	Capability
Test	**/conf/gwml2-construction-xs/collar-elevationCRS**	
	Requirement	**/req/xsd-gwml-construction/collar-elevationCRS**

	Test purpose	Ensure that collar elevation uses a relevant 1D vertical CRS
	Test method	Check the values of BoreCollar/collarElevation/@srsName against EPSG database or CRS specification to Ensure it represents a 1D vertical SRS
	Test type	Capability

A.3.7 Conformance classes: GWML2-vertical well xml encoding

Conformance Class	**/conf/xsd-gwml-vertical-well**	
Requirements	/req/ **gwml2-vertical-well-xsd**	
Dependency	/conf/xsd-xml-rule	
Dependency	/conf/gwml2-well-xsdl	
Test	/conf/**gwml2-vertical-well-xsd l/waterwell-shape**	
	Requirement	**/req/xsd-gwml-vertical-well/waterwell-shape**
	Requirement	**/req/ gwml2-vertical-well-xsd /endvertex**
	Requirement	**/req/ gwml2-vertical-well-xsd /depth-order**
	Test purpose	Ensure that instance document validate with rules expressed in schematron file.
	Test method	Validate the XML document using the Schematron document http://schema.opengis.net/gwml/2.0/gwml2-well-vertical.sch. Conformance passes if no error, fails otherwise.
	Test type	Capability

A.3.8 Conformance classes : GWML2-Aquifertest xml encoding

Conformance Class	**/conf/xsd-aquifertest**	
Dependency	/conf/xsd-xml-rule	
Requirements	**/req/gwml2-aquifer-test-xsd**	
Test	/conf/**gwml2-aquifer-test-xsd /xsd**	
	Requirement	/req/gwml2-aquifer-test-xsd /xsd
	Test purpose	Ensure that all elements under the namespace http://www.opengis.net/gwml-aquifertestt/2.1 validate with the schema located at http://schemas.opengis.net/gwml/2.1/gwml2-aquifertest.xsd
	Test method	Use an XSD validator to validate the XML instance against the schema located at http://schemas.opengis.net/gwml/2.1/gwml2-aquifertest.xsd and check that no errors are generated for elements under the namespace http://www.opengis.net/gwml-aquifertest/2.1 or its dependencies.

		Pass if no errors reported. Fail otherwise
	Test type	Capability
Test	/conf/**gwml2-aquifer-test-xsd/sch**	
	Requirement	/req/gwml2-aquifer-test-xsd
	Test purpose	Ensure the instance document validates agains the schematron rules
	Test method	Use a schematron validator and test the instance document against http://schemas.opengis.net/gwml/2.1/gwml2-aquifertest.sch. The test fails if any schematron rules are broken
	Test type	Capability
Test	**/conf/gwml2-aquifer-test-xsd/testfeature**	
	Requirement	**/req/gwml2-aquifer-test-xsd/testfeature**
	Test purpose	Ensure that test features are associated with the aquifer test using the correct role
	Test method	For all sampling features that are test features, check that the SF_SamplingFeatureComplex::role is set to http://resource.gwml.org/def/role/testFeature
	Test type	Capability
Test	**/conf/gwml2-aquifer-test-xsd/observationfeature**	
	Requirement	**/req/gwml2-aquifer-test-xsd/observationfeature**
	Test purpose	Ensure that observation features are associated with the aquifer test using the correct role
	Test method	For all sampling features that are observation features, check that the SF_SamplingFeatureComplex role is set to http://resource.gwml.org/def/role/observationFeature
	Test type	Capability
Test	**/conf/gwml2-aquifer-test-xsd/observation-role**	
	Requirement	**/req/gwml2-aquifer-test-xsd/observation-role**
	Test purpose	Ensure that the observations that are part of a chain, or support and derived observations, are linked together with OM_ObservationContext using the proper role
	Test method	For all observations that are part of a chain of transformation, check that the OM_ObservationContext has it's role xlink:href set to one of the values defined in 9.9.3.4
	Test type	Capability
Test	**/conf/gwml2-aquifer-test-xsd/timeseries**	
	Requirement	**/req/gwml2-aquifer-test-xsd/timeseries**

	Test purpose	Ensure that Observation results that are time series are encoded in WaterML 2.0
	Test method	Inspect instance documents and verify that any time series results are encoded in valid WaterML 2.0 (OGC 10-126)
	Test type	Capability
Test	**/conf/gwml2-aquifer-test/timeseries-datarecord**	
	Requirement	**/req/gwml2-aquifer-test/timeseries-datarecord**
	Test purpose	Ensure that the final aquifer test result, encoded as OM_Observation, delivers the result using a swe:DataRecord
	Test method	Scan the document for Observations that are the final outcome of the test, and check that the results are encoded according to http://www.opengis.net/spec/SWE/2.0/req/xsd-record-components
	Test type	Capability

Annex B: Use-Cases and Implementation Results (informative)

Five use-cases were developed by the GW2IE to determine GWML2 requirements and to test implementation results. While the use-cases describe a variety of actions to be taken, this interoperability experiment focusses on delivering the data that would enable such actions. XML instance documents referred to in the results can be found at: https://xp-dev.com/svn/gwml2/Documents/instance/.

1. Commercial Use Case	
Summary	The commercial scenario involves serving data to allow water wells and springs to be found on a map, identified, and related information used to estimate the cost to complete a water supply well. For example, a consultant or water well driller could use a web client to investigate the local geology and inspect wells located near the target area. By investigating the rock materials and water levels at each well in the web client, the consultant could infer the distance and materials to the water table, as well as the expected yield, and the driller could estimate the cost of drilling. The public is also impacted in this scenario, as they are able to assess online water well records and make independent estimates. This not only informs them about drilling potential, but it might also influence property purchases. Objective: serving water well and aquifer data so it can be used for commercial purposes such as to inform drilling.
Users/actors	Public, Consultants, Drillers
Information types	□ water wells: ○ *general*: id, source, location, elevation, length, water level, well purpose ○ *logs*: depth interval, lithologies, porosity, hydraulic conductivity □ springs, etc. □ aquifers:

	○ *general*: name, area, ○ *geology*: formations, lithologies ○ *properties*: confinement, media, water storage, sediment thickness, aquifer thickness, porosity, conductivity ○ *water balance*: aquifer recharge, aquifer discharge ○ *water use*: yield, usage type, quality ○ *risk*: physical vulnerability, threats
Actions	□ A member of the public finds wells near their home. □ A consultant examines the well-logs and aquifer info and determines there is groundwater potential. □ A driller uses the well-logs and aquifer info to estimate depth to water for price estimate.

Results

Seven organizations served primarily Hydrogeological Units and Wells via WFS, complemented by some related WMS (see Table 3). The bulk of the core data held by the participants was adequately mapped to GWML2 and streamed via the web services, thus meeting the basic requirements of this use-case. The source data varied widely in terms of the breadth of information available for a feature, particularly for aquifer properties and water well construction details. Several issues and proposed solutions are noted in Table 4.

Table 3: Use-Case 1 contributions.

Participant	*Web Services*	*Features*	*Technologies*	*Example XML Instances (File Name)*
NRCan	WMS, WFS	GW_HydrogeoUnit, GW_Well	Custom WFS, MapServer WMS	GW_Aquifer_GSC_uc1.xml GW_Well_GSC_uc1.xml
BRGM	WMS, WFS	GW_HydrogeoUnit, GW_Well	Constellation WFS	GW_Aquifer_BRGM-uc1.xml GW_AquiferSystem_BRGM-uc1.xml

				GW_Well_BRGM-uc1.xml
CSIRO-BOM	WFS	GW_AquiferSystem, GW_Well, GW_Aquifer, Borehole	Geoserver 2.5 PostGIS 9.3	GW_AquiferSystem_BoM_uc1.xml GW_Well_BoM_uc1_qld-40217816.xml GW_Well_BoM_uc1_nsw-10042141.xml GW_Well_BoM_uc1_nsw-10019168.xml GW_Aquifer_BoM_uc1_hgu-act-100000.xml Borehole_BoM_uc1_nsw-10019460.xml
FedUni	WFS WMS	GW_Aquifer, GW_FluidBody, GW_Spring, GW_Discharge, GW_Recharge, OM_Observation, GW_Well Borehole	MySQL 5.6, PostGIS 9.3, Geoserver 2.5, Mapserver 6.x	GW_Aquifer_FedUni-uc1.xml GW_FluidBody_FedUni-uc3.xml GW_Spring_FedUni_uc1.xml GW_Discharge_FedUni_uc1.xml GW_Recharge OM_Observation_FedUni_uc1.xml GW_Well_FedUni_uc1.xml Borehole_FedUni-uc1.xml
GNS / UZ	WFS, WMS	GW_Well, GW_Spring, GW_MonitoringSite	Geoserver 2.7+app-schema, Tomcat 7, PostgreSQL9.x / shape-files and property files	GW_Well_GNS_uc1.xml, GW_Spring_GNS_uc1.xml, GW_MonitoringSite_GNS_uc1.xml
USGS	WMS, WFS	GW_HydrogeoUnit, GW_Well	GeoServer WMS, Custom WFS	GW_Well_USGS_uc4-mapping.xml, GW_AquiferSystem_USGS_uc4-mapping.xml

Table 4: Use-Case 1 issues.

Issue #	*Participant*	*Issue Summary*	*Proposed Solution*	*Timeline*

1.1	GSC BoM	for GW_Flow, gwFlowVolumeRate is OM_Measurement: that constrains the result to be a gml:Measurement , so a single value with a uom. We have ranges in the database	Change all OM_Measurements in the model, to OM_Observations	Later version
1.2	BoM	OM_Observation featureOfInterest can be the samplingFeature (GW_Well) or the sampledFeature (GW_Aquifer). For some observed properties (e.g. pH) the former doesn't make sense, so need to be able to distinguish the two.	Modify O&M to have ultimate featureOfInterest (0..n) and samplingStrategy (0..n) for intermediate sampling features.	OGC SWG
1.3	USGS	Screen hole size only has one dimension and does not account for non-circular holes, i.e. slits	Expand to two fields: screenHoleLength, screenHoleWidth	

2. Policy Use Case	
Summary	The Water Framework Directive 20000/60/EC (WFD) requires all EU member states to achieve and preserve good status for all European waters, including groundwater. The process to achieve WFD requirements includes definition and delineation of water bodies within management units, environmental monitoring, status assessment and finally developing river basin management plans.

	This use case describes the steps and interactions necessary for delivering data required to assess groundwater bodies and thus meet the related EU reporting obligation. The activity includes: collection and evaluation of the geological and hydrogeological characteristics, as well as quantitative and qualitative monitoring of defined chemical and physical indicators and finally overall status assessment of a groundwater body. Delineation of WFD groundwater bodies, in many cases, is not done accordingly to their natural boundaries but usually follows administrative units. In order to better demonstrate interoperability the use case description should cover a cross border scenario, to show synchronization of the collected information by two different member water authorities. This integrating approach facilitates a coordinated assessment and planning of potential future measures. Objective: The provision of WFD required data and information on the trans-boundary groundwater body.
Users/actors	Member state water authorities.
Information types	WFD River Basin District: o general: id, national code, parent river basin districts, name and area measurement WFD_Ground Water Body (GWB) o general: id (RBC-code), national code, name, location, protected area association o pressures: pressure types o impacts: impact types o other impact: further pressure description, other impact description o trend reversal: reversal trend, free text o trend upward: upward trend, free text o hydrogeological characteristics: GW layer, area, depth, thickness, depth range, geological formation, capacity, link surface water, link eco system o quantitative status: quantitative status value, comment

	○ chemical status (qualitative): chemical status value, comment ○ protected area status (optional): protected area code (unique), type of protection, Type of association, status value.
Actions	Step 1: Discovering and collecting initial information on hydrogeological, geological, chemical and physical data about each groundwater body. Step 2: Preprocessing, syntactical and semantically transformation of the input information. Step 3: Assessment of required output. Step 4: Delivering of groundwater module for WFD reports.

Results

This use-case was scaled back during implementation. The main result is the inclusion of GW_ManagementArea in GWML2. The use case was originally designed with a European focus on WFD (as above), but was subsequently tested by BoM and GNSS to ensure it met more generic groundwater management area requirements (Table 5). In general, a management area feature was required in GWML2 because that the spatial boundaries of managed areas do not necessarily align exactly with associated hydrogeological unit boundaries, as they can be delineated by human factors such as policy or regulatory concerns.

In INSPIRE, managed areas are supported by the 'Area management/restriction/regulation zones and reporting units' theme. Consequently, the INSPIRE 'Geology' theme, in its 'Hydrogeology' package, proposes that 'WFDGroundWaterBody'serve as a hydrogeologically managed area by specializing 'ManagementRestrictionOrRegulationZone'. These considerations served as inputs to the design of GW_ManagementArea.

Documentation instituting or enforcing the management area is represented by DocumentCitation in the conceptual model, and implemented in the logical model and XML schema as Any type, enabling any class such as MD_Metadata, GW_Licence etc., to be used.

Regarding alignment of WFD reporting and GWML2:

- A first action was development of GW_ManagementArea.
- A second action was to map the pre-INSPIRE data reporting structure onto the INSPIRE themes ('Area management/restriction/regulation zones and reporting units', 'Environmental Monitoring Facilities', …). This was done at the EU level (JRC, EEA).
- A third action is to specialize GW_ManagementArea specifically to support WFD reporting. To achieve this, an INSPIRExWFD pilot is being discussed with JRC (Table 6).

Table 5: Use-Case 2 contributions.

Participant	*Web Services*	*Features*	*Technologies*	*Example XML Instances (File Name)*
CSIRO-BOM	NA	GW_ManagementArea		GW_ManagementArea_BoM_uc2.xml
GNS / UZ	WFS	GW_ManagementArea	Geoserver 2.7+app-schema	GW_ManagementArea_GNS_uc2.xml including a water budget

Table 6: Use-Case 2 issues.

Issue #	*Participant*	*Issue Summary*	*Proposed Solution*	*Timeline*
2.1	JRC / BRGM - GSG	Needs a dedicated action to involve relevant EU parties	INSPIRExWFD pilot	Later version
2.2	BRGM – CSIRO – GSC	Pointing to documentation is really open in the current model	A 'Recommendation' example could be provided based on the EU experience	Later version
2.3	BoM-CSIRO	<gwml2:gwAreaYield> Documentation has "Type of yields (of the aquifer or management area): e.g. specific yield, safe yield, license yield etc. but excludes well yield. TBD" The cardinality (0..1) and data type (OM_Measurement) appear to contradict this. What is gwml2:gwAreaYield used for and how	Change cardinality to (0..n), data type. Use O&M:observedProperty to specify the yield type.	Cardinality changed 26/8/2015

		do we distinguish the various yield types?		
2.4	BoM-CSIRO	Relationship between <gwml2:gwAreaWaterBudget> and <gwml2:gwAreaYield> is unclear. Need to be able to populate values of 'unallocated groundwater' (% and/or ML), 'current entitlement' (% and/or ML), 'entitlement limit' (ML).	Further testing is required to ensure appropriate properties can be captured.	

3. Environmental Use Case	
Summary	The role of groundwater in sustaining environmental values is of growing importance, particularly in arid countries such as Australia. Groundwater dependent ecosystems (GDE) include rivers, lakes, wetlands, estuaries, seeps, springs, phreatophytic vegetation, cavernicolous ecology and stygofauna. The key parameters are the depth to water table, consistency of groundwater levels, groundwater fluxes to surface water, groundwater chemistry and groundwater biology. In many parts of Australia, it is recognized that GDEs are vulnerable to the pressures on groundwater resources from activities such as mining, agriculture, urban and commercial developments. Within the Great Artesian Basin, the potential impacts of coal-seam gas extraction on groundwater and GDEs is of particular concern. An initial attempt at creating a national inventory of GDEs has recently been published as an interactive GDE Atlas on the Australian Bureau of Meteorology website http://www.bom.gov.au/water/groundwater/gde/map.shtml. In some states, such as Victoria, proposed changes to legislation will provide a risk management framework to provide: □ Protection of high-value GDEs when setting or adjusting permissible consumptive volumes, □ The highest level of protection will be given to GDEs

	with high environmental values and a high risk of being affected by changes in groundwater levels, - GDEs with high environmental values that rely on regional and intermediate scale groundwater flow systems will be considered in groundwater management planning, and - GDEs with high environmental values that rely on the surface expression of local scale groundwater flow systems will be assessed on a site-by-site basis in the licensing regime. Objective: Serving the appropriate groundwater information to allow environmental managers, water managers and legislators to assess the risks to GDEs.
User communities/actors	Water authorities, government departments, research organizations.

Information types	- *Groundwater discharge feature:* point discharge (springs), line discharge (stream baseflow), areal discharge (seep, wetland, diffuse, biological)
	  - *general:* id, type, name, location, length, area
	  - *environmental value:* status
	- Groundwater levels (phreatic and potentiometric)
	- Groundwater chemistry: sample ID, date, method, field analyses (pH, EC, DO, etc.), laboratory analyses (major ions, minor ions, elements, etc.), isotopes, tracers.
	- Groundwater biology: microbiology, stygofauna

Actions	- A water authority assessing a groundwater license application finds the nearest GDEs to investigate their types and environmental values. - A government department assesses the history of groundwater fluctuations around a GDE with high environmental values. - A research organization investigates the groundwater heads, gradients and chemistry to determine the groundwater capture zone around a GDE at two points in time

Results

Two organizations served a number of components via WFS, complemented by some related WMS and SOS (see Table 7). FedUni was able to map the bulk of the required data for this use case using core data held in their Visualizing Victoria's Groundwater (VVG) database. This included observation (OM_Observation), specimen (SF_Specimen), constituent (GW_Constituent), well (GW_Well) and aquifer (GW_Aquifer) data. The GW_Discharge, GW_Recharge and GW_Interflow features were tested using a single case study, since the data were not captured in the VVG database. GNS / UZ was able to map groundwater chemistry data from the New Zealand National Groundwater Monitoring Programme (NGMP), linked to from the sampling features / monitoring sites of NGMP. While OM_Observations are served via a SOS 2.0 implementation, the linkage from the WFS Complex Features' related observations to the SOS was envisioned via om:Parameter and NamedValue.

Data was streamed via the web services, thus meeting the basic requirements of this use-case. Neither organization was able to complete the mapping for all the required Actions but between the two all required components were covered. Encountered issues are noted in Table 8.

Table 7: Use-Case 3 contributions.

Participant	*Web Services*	*Features*	*Technologies*	*Example XML Instances (File Name)*
FedUni	WFS WMS	GW_Aquifer, GW_FluidBody, GW_Spring, GW_Discharge, OM_Observation, GW_Well GW_Recharge SF_Specimen GW_Interflow GW_Constituent	MySQL 5.6, PostGIS 9.3, Geoserver 2.5, Mapserver 6.x	GW_Aquifer_FedUni-uc1.xml GW_Spring_FedUni_uc1.xml GW_Well_FedUni_uc1.xml GW_Constituent-FedUni-uc3.xml GW_FluidBody_FedUni-uc3.xml GW_InterFlow_FedUni_uc3.xml GW_Discharge_FedUni_uc1.xml GW_Recharge_FedUni_uc1.xml OM_Observation_FedUni_uc3.xml SF_Specimen_FedUni_uc3.xml
GNS / UZ	WFS, SOS	GW_Well, GW_Spring, GW_MonitoringSite, OM_Observation	Geoserver 2.7+app-schema, 52North SOS 4.0.0,	GW_Well_GNS_uc1.xml, GW_Spring_GNS_uc1.xml, GW_MonitoringSite_GNS_uc1.xml

Table 8: Use-Case 3 issues.

Issue #	*Participant*	*Issue Summary*	*Proposed Solution*	*Timeline*
3.1	GNS / UZ	Linking from GWML2 features to the SOS service	Xlink:href GetObservationById, OM:Parameter	Later version
3.2	CSIRO/FedUni	The featureOfInterest for the observations was mapped to the GW_Well (i.e. the samplingFeature), but it should be the ultimate featureOfInterest (e.g. the GW_FluidBody)	Modify OMXML to have both featureOfInterest and sampledFeature properties.	GWML2 SWG

4. Scientific Use Case

Summary	This use case involves the delivery of information required to help determine the flow of groundwater within a particular terrain, likely for input into a computational flow modeling software, and model results. It involves the delivery of hydrogeologic and geophysical properties associated with hydrogeologic units (such as key aquifer properties), the delivery of observations related to those units, well characteristics (driller's log), information about the related water bodies and in some cases water use information. Objective: - Delivery of data for use in groundwater flow modeling software (e.g. MODFLOW, FEFLOW or ASPAR) - Data necessary for groundwater flow

	models: (May decide to incorporate only some of these data types) ▪ Data to complete Soil-Water Balance Model (hydrology & terrestrial info: precipitation, temperature, land cover, land use, evapotransporation, runoff) ▪ Water body characteristics & observations (stream flow, gw levels, sw levels) ▪ Water use (pumping rates, diversion schedules) ▪ Geophysical analysis (well construction, rock lithology and fractures, permeability and porosity, and water quality) - Delivery of groundwater flow model output o Coverage of heads & fluxes o Time series of flow and/or water level at points (wells & springs)
User communities/actors	- Groundwater modelers - Hydrogeologists
Actions	- Discovering, searching, displaying, analyzing and downloading characteristics for all groundwater bodies in a study area - Collecting geological, hydrogeological, physical and use/consumption data about each groundwater body - Completing a soil-water balance - Completing spatial and temporal analyses - Calculating heads & fluxes in space and time - Calculating timeseries of flow or water level at points where data was collected (wells & springs) - Visualization of gw flow and storage in time and space

Results

Two participant organizations successfully mapped well data into GWML2, with a few minor exceptions (see Table 9), and served them via WFS. The USGS found that the hole size of screen openings could not be fully described, as only one dimension is captured in GWML2, whereas the USGS stores two dimensions in order to accommodate a variety of hole shapes. Additionally, the specific capacity of a well is not accommodated in the model. A solution was suggested to address this issue in Table 10. Furthermore, the lack of a common lithological vocabulary is a barrier for interoperable exchange of well geology information. Efforts to ingest GWML2 well data directly into modelling software are ongoing, and preliminary results indicate compatibility.

Table 9: Use-Case 4 contributions.

Participant	*Web Services*	*Features*	*Technologies*	*Example XML Instances (File Name)*
USGS	WMS, WFS, SOS	GW_HydrogeoUnit, GW_Well,GroundWaterLevel	GeoServer WMS Custom WFS, Custom SOS	GW_Well_USGS_uc4-mapping.xml, GW_AquiferSystem_USGS_uc4-mapping.xml
GNS/UZ	WFS, SOS, WPS	GW_Well, GW_MonitoringSite, GW_ManagementArea	Geoserver 2.7+app-schema, 52North SOS 4.0.0, 52North WPS 3.2.0,Tomcat 7	GW_ManagementArea_GNS_uc2.xml includes a water budget

Table 10: Use-Case 4 issues.

Issue #	*Participant*	*Issue Summary*	*Proposed Solution*	*Timeline*
4.1	USGS	Screen hole size has one dimension and does not account for non-circular holes, i.e. slits.	Expand to two fields: screenHoleLength, screenHoleWidth.	

4.2	GNS /UZ	Mapping GWML2 features and time-series into domain modelling tools is preliminary	Manual program codes, specific implementations necessary.	
4.3	USGS	Mapping GWML2 features and time-series into domain modelling tools is preliminary	Common vocabularies and specific implementations needed.	
4.4	USGS	Specific capacity values of wells missing	Accommodate in pump test, well or aquifer test packages	
4.5	USGS	Common standard vocabulary needed for lithology terms	Develop or nominate a standard geology vocabulary service for use as a best practice for lithology terms	

5. Technologic Use Case

Summary	Due to various technical and jurisdictional requirements, it is not possible, nor sought, to impose a single physical model on agencies managing groundwater related data. Data will instead be likely translated to a common standard (GWML2), developed herein, for data exchange. This requires a translation between data sources and the standard. The objective of this use case is to document mappings between GWML2 and some pertinent existing models: INSPIRE, GWML1 and HY_FEATURES. Though no formalism to represent the mapping has been chosen at this point, the main deliverable is documentation, either human or machine readable, that could potentially be used in an interoperability project. The mapping should be evaluated with regard to completeness, complexity, etc.
User communities/actors	□ Potential schema providers: o INSPIRE Hydrogeology conceptual model

	in the Geology theme (EU) o GWML1 (NRCan) o HY_Features (WMO)
Information types	Minimally: □ Aquifer (including lithologic and hydrogeological properties) □ Groundwater Body □ Water Well, including water level
Actions	□ Identify a mapping documentation. □ Identify a mapping evaluation method. □ Develop mappings to GWML2.

Results

During the scoping and requirements phase of GWML2 development, key elements from existing models were identified for potential inclusion in GWML2. This led to a consolidated entity list, which contains a list of the entities as well as their definitions. A subset of this list was then selected to be the scope for GWML2—thus GWML's scope explicitly includes elements from the other information models. The origin of those elements was retained via the entity list, thus providing an informal start to the mappings between GWML2 and the other information models.

Although a complete mapping to three information models was originally intended, i.e. to GWML1, INSPIRE Hydrogeology, and HY_FEATURES, the work mainly focused on the INSPIRE mapping, with varying progress on the remainder. Mappings were also developed between GWML2 and some entities from the Australian NGIS database (Table 11).

The INSPIRE mapping is expressed in a structured Excel spreadsheet, developed over several revisions, and is available online at the GW2IE twiki – ModelComparison page. See "Comparison_INSPIRE_GWML2" files where CM refers to the GWML2 Conceptual Model and LM to the GWML2 Logical Model. A drawback to this relatively informal mapping is the inability to use it directly in data translation workflows. The NGIS mappings are expressed as GWML2 instances whose elements refer to their NGIS

sources.

The mappings identified equivalences and difference in feature types, their attributes and associations. Key differences with the evolving GWML2 often caused modification of GWML2, in an iterative approach.

This mapping exercise raises the question of how to achieve INSPIRE compatibility. Other schemas, such as GeoSciML V4, are considering refactoring to ensure that core components are compatible with INSPIRE (Table 12). Should GWML2 consider this also?

Table 11: Use-Case 5 contributions.

Participant	*Mapping*
NRCan	GWML1 - incomplete
BRGM - GSG	INSPIRE Hydrogeology
CSIRO	HY_FEATURES
CSIRO	NGIS (GW_FluidBody-NGIS_uc5-mapping.xml, GW_HydrogeoUnit_NGIS_uc5-mapping.xml, GW_Well_NGIS_uc5-mapping.xml)

Table 12: Use-Case 5 issues.

Issue #	*Participant*	*Issue Summary*	*Proposed Solution*	*Timeline*
5.1	BRGM – NRCan	GWML2 –INSPIRE mapping: revisit formalism to be more machine readable.	Open. Would be easier if we had 2 ontologies to map.	
5.2	BRGM – NRCan	GWML2 –INSPIRE : how to ensure compatibility	As per GeoSciML4 ?	SWG ?
5.3	CSIRO	HY_FEATURES mapping incomplete	Mapping to be discussed at HydroDWG	September2015

Annex C: Remaining Issues (informative)

Remaining issues listed here include all issues reported in the uses-cases, as well as other general issues encountered during GWML2 development.

Issue #	*Participant*	*Issue Summary*	*Proposed Solution*	*Timeline*
1.1	GSC BoM	for GW_Flow, gwFlowVolumeRate is OM_Measurement: that constrains the result to be a gml:Measurement , so a single value with a uom. We have ranges in the database	Change all OM_Measurements in the model, to OM_Observations	GWML2 SWG
1.2	BoM	OM_Observation featureOfInterest can be the samplingFeature (GW_Well) or the sampledFeature (GW_Aquifer). For some observed properties (e.g. pH) the former doesn't make sense, so need to be able to distinguish the two. See discussion below.	Modify O&M to have ultimate featureOfInterest (0..n) and samplingStrategy (0..n) for intermediate sampling features.	O&M SWG No action required
1.3	USGS	Screen hole size only has one dimension and does not account for non-circular holes, i.e. slits	Expand to two fields: screenHoleLength, screenHoleWidth	GWML2 SWG
2.1	JRC / BRGM - GSG	Needs a dedicated action to involve relevant EU parties	INSPIREXWFD pilot	Later version
2.2	BRGM – CSIRO – GSC	Pointing to documentation is really open in the current model	A 'Recommendation' example could be provided based on the EU experience	Later version
2.3	BoM-CSIRO	<gwml2:gwAreaYield> Documentation has "Type of yields (of the aquifer or management area): e.g. specific yield, safe yield, license yield etc. but excludes well yield. TBD" The cardinality (0..1) and data type (OM_Measurement)	Change cardinality to (0..n), data type. Use O&M:observedProperty to specify the yield type.	Cardinality changed 26/8/2015

		appear to contradict this. What is gwml2:gwAreaYield used for and how do we distinguish the various yield types?		
2.4	BoM-CSIRO	Relationship between <gwml2:gwAreaWaterBudget> and <gwml2:gwAreaYield> is unclear. Need to be able to populate values of 'unallocated groundwater' (% and/or ML), 'current entitlement' (% and/or ML), 'entitlement limit' (ML).	Further testing is required to ensure appropriate properties can be captured.	Further testing required
3.1	GNS / UZ	Linking from GWML2 features to SOS service where the actual observations and time-series are store	Xlink:href GetObservationById, OM:Parameter	Later version
3.2	CSIRO/FedUni	The featureOfInterest for the observations was mapped to the GW_Well (i.e. the samplingFeature), but it should be the ultimate featureOfInterest (e.g. the GW_FluidBody)	Modify OMXML to have both featureOfInterest and sampledFeature properties.	O&M SWG As above
4.1	USGS	Screen hole size has one dimension and does not account for non-circular holes, i.e. slits.	Expand to two fields: screenHoleLength, screenHoleWidth.	As above
4.2	GNS /UZ	Mapping from GWML2 features and time-series into domain modelling tools is still in early stages.	Manual program codes, specific implementations necessary.	Further testing required
4.3	USGS	Mapping from GWML2 features and time-series into domain modelling tools is still in early stages.	Common vocabularies and specific implementations needed.	Further testing required
4.4	USGS	Specific capacity values of wells missing	Accommodate in pump test, well or aquifer test packages	Check with Eric/Sylvain

4.5	USGS	Common standard vocabulary needed for lithology terms	Develop or nominate a standard lithology vocabulary / service as a best practice	Later version With recommendation in spec to use standard vocab
5.1	BRGM – NRCan	GWML2 –INSPIRE mapping: revisit formalism to be more machine readable.	Open. Would be easier if we had 2 ontologies to map.	As above
5.2	BRGM – NRCan	GWML2 –INSPIRE : how to ensure compatibility	As per GeoSciML4 ?	As above
5.3	CSIRO	HY_FEATURES mapping incomplete	Mapping to be discussed at HydroDWG	September2015 Resolved in Orleans (gw removed)

Issue 1.2 Discussion:

The Observations & Measurements specification proposes two patterns for featureOfInterest:

(1) the feature of interest can either refer to the real world object that is being observed, or
(2) to a sampling feature (SF_SamplingFeature) that acts as a proxy for the real world feature (which is then accessible through the sampling feature's sampledFeature property).

Because the property featureOfInterest has cardinality 1..1, a data provider must choose one of these approaches. Problems occur when a sampling feature is chosen: while many observations can refer to the same domain feature, it is impossible to navigate back to the sampling feature. Solutions have been proposed using OM_Process to document the relationship between the observation and the sampling feature, but they are cumbersome and require much encoding. Consequently, the JSON (OGC 15-100) and RDF encodings for O&M include an extra samplingRegime property that is absent from the GML encoding. A change request should be issued to correct this in GML. In GWML2, there is no restriction on featureOfInterest—it can refer to a real world feature or a sampling feature.

Annex D: Revision history

Date	Release	Author	Paragraph modified	Description
2014-05-20	0.1.0	Bruce Simons	All	Initial internal version
2014-06-04	0.2.0	Boyan Brodaric	All	More complete internal version
2014-08-04	0.3.0	Sylvain Grellet	All	XML instance examples added
2014-08-11	0.3.1	Boyan Brodaric	All	Minor wording changes
2014-08-26	0.3.2	Eric Boisvert	All	Minor wording changes
2015-07-21	0.4	Boyan Brodaric	All	All revised except 9, 10, and Annex A.
2015-08-09	0.4.1	Pater Dahlhaus	All	Minor wording changes
2015-08-21	0.4.2	Jessica Lucido	All	Minor wording changes
2015-08-25	0.4.3	Bruce Simons	All	Minor edits
2015-08-25	0.4.4	Alexander Kmoch	All	Minor edits
2015-09-01	2.1	Boyan Brodaric	All	Final edits
2016-03-21	2.1	Scott Simmons	All	Preparation for publication

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