NADM-H2O and H2O-GML: Enabling Decision Support by Extending NADM for Groundwater Information Interoperability

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ABSTRACT

This paper reports on extensions made to the North American Data Model or NADM-C1 conceptual model (http://nadm-geo.org/) and to the related NADM-C1 GML schema, for the modeling of groundwater concepts related to water quantity assessment. The extensions are described in detail, and a use case is presented to demonstrate their usefulness in delivering groundwater information from the National Groundwater Database of Canada.

BACKGROUND

Nearly 10 million Canadians rely on groundwater for their fresh water supply and yet the extent of the resource is poorly known. Knowledge about groundwater resources is not only key for water supply but also has ramifications for energy production, industry and community development. As this information is required in many types of decision making it is important to improve access to it, and thereby ensure that the Canadian government's goals in sustainable development are met.

The Groundwater program of the Earth Sciences Sector of Natural Resources Canada has funded a series of projects to improve knowledge of key Canadian aquifers and created a specific project to build an infrastructure to improve access to the resultant information. The National Groundwater Database (http://ntserv.gis.nrcan.gc.ca/gwp/ngwd/exploration) project is implementing a series of tools and procedures to connect heterogeneous data and to distribute them to the community. Full connectivity between the data providers and the data users is enabled via partnerships with other projects, such as with the PATHWAYS project (Brodaric et al., 2005, in this volume), which provides mechanisms for transforming groundwater information into forms useful for decision makers.

Non traditional users are also being reached through partnership with other federal and provincial departments, such as Environment Canada and Health Canada, through the RésEau project. RésEau is building a larger infrastructure for water (surface and groundwater) to create a single access point for all water related information in Canada.

IMPORTANCE OF GROUNDWATER INFORMATION INTEROPERABILITY

A large portion of the data used in groundwater projects comes from provincial sources. The bulk of this data comes from water well databases built incrementally from the well logs collected from various sources (well drillers, municipalities, other agencies). Each agency has its own motive for collecting such data. These are either legal, because the agency is legally bound to keep this information, or operational, because it needs the information to support its activities. The databases have different requirements, hence different structures and nomenclature. Furthermore, the databases are not static, since more and more information is being keyed in as new wells are being dug. Centralizing this information into a single national database is not possible because of practical concerns (we simply don't have the resources to keep this information up to date), technical reasons (addressing a large set of requirements within a single information system), and legalities (the data is owned by the provinces). The bottom line is: the data must stay where they are, and structured as they are. The solution to reach those data lies in interoperability technology.

Interoperability amongst data producers and data consumers is realized by us through the implementation of technologies promoted by the CGDI (Canadian Geospatial Data Infrastructure; http://cgdi.gc.ca/CGDI.cfm). To attain the CGDI vision, Geoconnections, a federal government arm of the CGDI, has for the last 5 years supported significant development efforts to implement Open Geospatial Consortium (OGC) standards. The OGC standards are themselves closely related to the ISO TC/211 standards, emphasising that technologies developed from OGC specifications have solid international credentials.

OGC standards only provide an interoperability framework, which must be adapted to domain specific data such as hydrogeological information. Therefore, for this technology to work, the community of users requiring interoperability must go through a supplemental round of standardisation that is specific for the domain. An important activity in this standardisation effort is the development of a common GML-based interchange format that can be shared (and served) by data providers (OGC, 2004). Several geoscience initiatives have elected to implement GML standards: e.g., XMML (eXploration and Mining Mark-up Language, http://xmml.arrc.csiro.au/), GeoSciML (IUGS Commission for the Management and Application of Geoscience Information, or "CGI"; https://www.seegrid.csiro.au/twiki/bin/view/CGIModel/GeoSciML), and NADM (Boisvert et al., 2004). H2O is the next step: it is a groundwater interchange standard based on NADM, XMML, and GeoSciML.

H2O: just add water (to NADM)

Our GML encoding for groundwater data is derived from the NADM-C1 GML effort (Boisvert et al., 2004), XMML, and the new international effort from IUGS (GeoSciML, 2005; Sen and Duffy, 2005). NADM provides the geoscience framework from which we could derive hydrogeological concepts, and XMML and GeoSciML provides the human artifacts (borehole, observations patterns, etc.). Note that GeoSciML is already a fusion between large portions of NADM-C1 and XMML. H2O is the sum of work carried in several projects within our departments (such as PATHWAYS; Brodaric, et al., 2005) and abroad. If we could put it in a single line, it would read as follows:

```
H2O = NADM + GeoSciML + XMML + NGWD +
    PATHWAYS + RésEau
```

(NGWD is the Canadian National Groundwater Database.)

The H2O model is still a work in progress: it addresses about half of the concepts required to successfully exchange groundwater data. The qualitative aspect is being worked on with our Environment Canada colleagues (through RésEau) while we have concentrated on the quantitative aspect.

Figure 1 shows the main classes we derived from NADM-C1 and XMML/GeoSciML. Most of the top level concepts shown there are drawn from NADM-C1, and a single concept (**`Waterwell`**, a specialisation of **`Borehole`**) is from XMML/GeoSciML. The contribution of XMML/GeoSciML is more in terms of the Observation and Measurement modules (the human artifacts).

We derived **`HydrogeologicUnit`** from **`GeologicUnit`** to provide a home for concepts such as **`Aquifer`** and **`Aquitard`**. We created **`HydrogeologicProperty`** from **`GeologicProperty`**, to provide properties specific to **`HydrogeologicUnit`**. We also had to create a new property under **`GeologicProperty`** called '*porosity*', which is truly a property of the

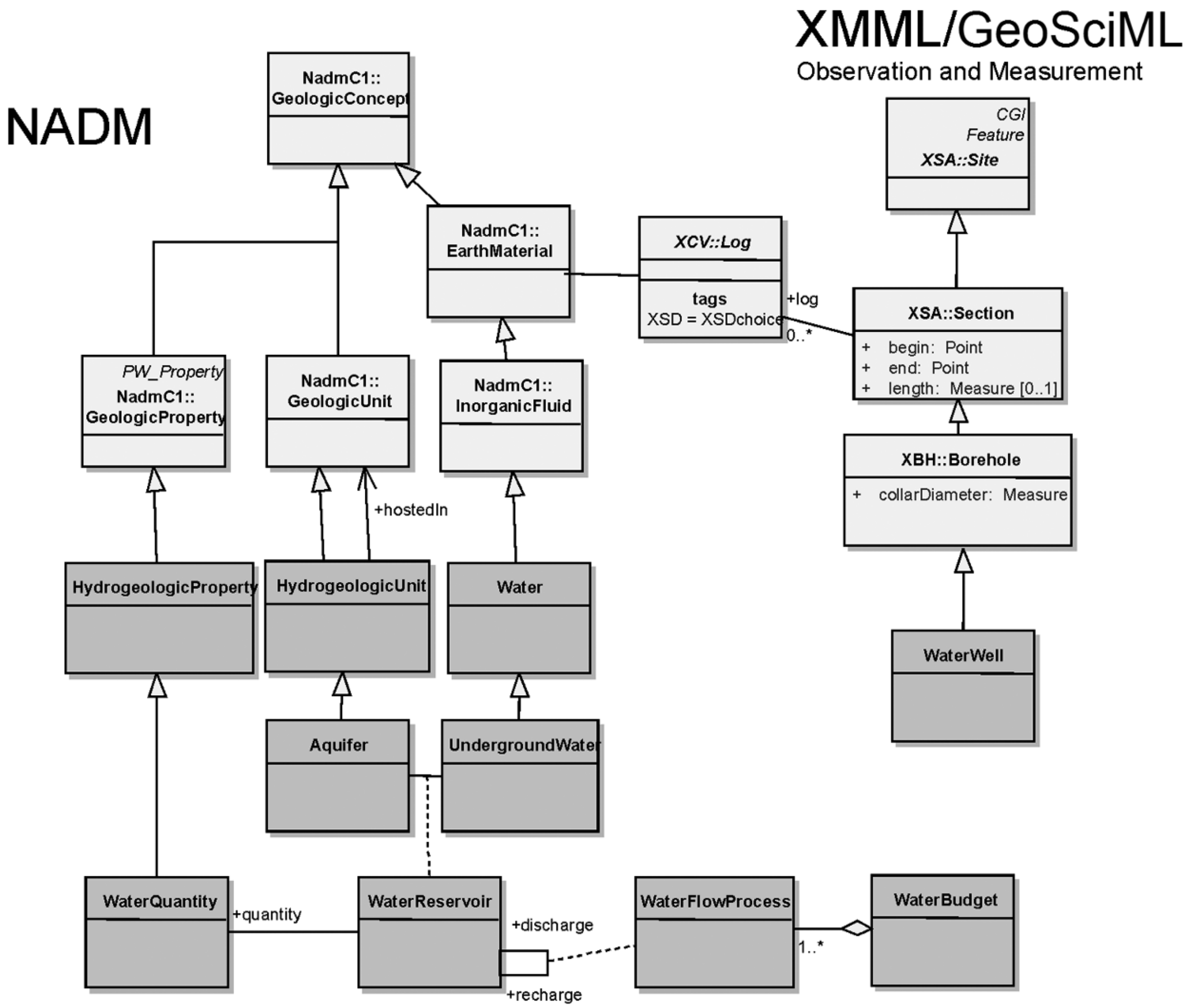

Figure 1. General model of H2O and derivation from NADM-C1 and XMML. The bottom part, shaded gray, represents extensions defined for groundwater.

`EarthMaterial` and not of the **`HydrogeologicUnit`**. The most interesting relation between **`HydrogeologicUnit`** and **`GeologicUnit`** is the '**`hostedIn`**' relation, enforcing the fact that an **`Aquifer`** (a **`HydrogeologicUnit`**) is hosted in **`GeologicUnits`**.

Finally, after much debate about water being a fluid or a mineral (water in the form of ice meets all the requirements of a mineral), we decided it was, for the purposes of exchanging groundwater data, an **`InorganicFluid`**. The relation between water and hydrogeologic unit is done through **`Reservoirs`**, and the flow of water between reservoirs is a water budget, which is at the heart of the quantitative model.

Figure 2 is a more detailed view of the Water Budget structure and related concepts. The **`WaterBudget`** is the aggregation of all inputs and outputs in a given reservoir (discharge and recharge depends on which reservoir you are considering) through a series of flow processes. One might point out that we missed an opportunity to derive those concepts from **`GeologicProcess`**, but most (if not all) of those processes are physical processes that are not restricted to the geological realm.

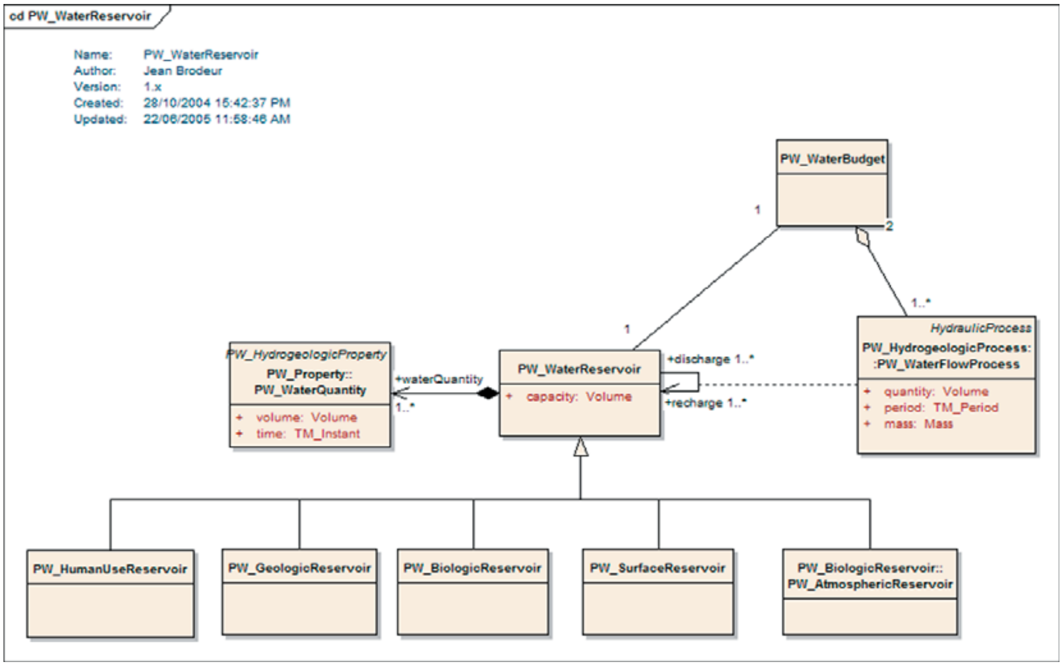

Figure 2. The water budget model. A budget is the sum of all flows that enter and exit a reservoir. The debit or credit is assigned depending on the flow direction (discharge or recharge).

The logic becomes clearer when we go through an example representing an instance of the model of Figure 2. For an introduction to GML, we refer the reader to OGC (2004), Lake et al. (2004), and Boisvert et al. (2004):

```
<?xml version="1.0" encoding="ISO-8859-1"?>
<nadm:Nadm xmlns="http://gwp.nrcan.gc.ca/ngwd"
xmlns:gml="http://www.opengis.net/gml"
xmlns:nadm="http://geology.usgs.gov/dm/NADM/v1.0"
xmlns:xlink="http://www.w3.org/1999/xlink"
xmlns:xmml="http://www.opengis.net/xmml"
xmlns:xsi=http://www.w3.org/2001/XMLSchema-instance>
      <gml:featureMember>
     [1]  <GeologicReservoir gml:id="EskerAbitibi">
            <capacity uom="m3">0.0</capacity>
            <waterReservoirBudget>
     [2]      <WaterBudget gml:id="B1">
                <gml:description>
            Calculation of complete budget of the St-Mathieu esker water budget
                </gml:description>
                <gml:name>Complete budget 2004</gml:name>
     [3]        <waterFlowComponent>
                  <Precipitation gml:id="P1">
                    <quantity uom="m3">21870360</quantity>
                    <gml:timeInterval unit="year">1</gml:timeInterval>
                    <recharge xlink:href="http://gwp.nrcan.gc.ca/ngwd/
                           Reservoirs#Atmosphere"/>
```

```
          </Precipitation>
        </waterFlowComponent>
        <waterFlowComponent>
          <Pumping gml:id="Pu1">
            <gml:name>Pumping from Amos old wells</gml:name>
            <quantity uom="m3">1193795.28</quantity>
            <gml:timeInterval unit="year">1</gml:timeInterval>
            <discharge xlink:href="http://gwp.nrcan.gc.ca/ngwd/
                    Reservoirs#Municipal
            Facilities"/>
          </Pumping>
        </waterFlowComponent>
[more waterFlowComponent removed for readability ]
      </WaterBudget>
    </waterReservoirBudget>
[4] <groundWaterContainer>
      <Aquifer gml:id="EskerAbitibiAquifer">
        <!-- the aquifer is hosted in an Esker -->
[5]     <hostIn xlink:href="#E1"/>
      </Aquifer>
    </groundWaterContainer>
    <groundWaterContent>
[6]   <GroundWater gml:id="E1.W">
          <gml:description>Water contained in the esker, water properties
                  should be added at this point to characterise this
                  particular groundwater</gml:
          description>
      </GroundWater>
    </groundWaterContent>
  </GeologicReservoir>
</gml:featureMember>
<gml:featureMember>
[7] <nadm:GeomorphologicUnit gml:id="E1">
    <gml:description>Large N-S sand and gravel body</gml:description>
    <gml:name>Esker St-Mathieu/Berry</gml:name>
    <nadm:geologicUnitMember>
      <nadm:GeologicUnitPart gml:id="E1.P1">
        <nadm:proportion uom="pct">100</nadm:proportion>
        <nadm:gupMaterial>
          <nadm:UnconsolidatedMaterial gml:id="E1.P1.M1">
            <gml:description>Thick beds of coarse sand and gravel, poorly
                    sorted</gml:
            description>
            <gml:name>sand and gravel</gml:name>
          </nadm:UnconsolidatedMaterial>
        </nadm:gupMaterial>
        <nadm:guRole>composition</nadm:guRole>
      </nadm:GeologicUnitPart>
    </nadm:geologicUnitMember>
  </nadm:GeomorphologicUnit>
</gml:featureMember>
</nadm:Nadm>
```

This document describes a water budget for an aquifer in the Abitibi area of Québec, Canada (preliminary data from Riverin, in preparation). Points of interest are marked by a number in the left column. The line marked as [1] is the beginning of the description of a Reservoir (a **`GeologicReservoir`**) for which a budget has been calculated. The **`WaterBudget`** at [2] contains the list of all the **`waterFlowComponents`**. Each waterflow component [3] contains a specific process (Precipitation, Pumping, etc), the direction of the flow (**`discharge`** or **`recharge`**), and the reservoir the water comes from or goes to. The destination (or the origin) of the water is useful if we need to balance several budgets, like surface-groundwater interaction. The groundwater container (the unit that acts as the reservoir) is described in [4] (an **`Aquifer`** is a groundwater reservoir) and note in [5] that this **`Aquifer`** is hosted in a **`GeomorphologicalUnit`** that is described further down at [7] (and pointed to by an **`xlink:href`**, which is the mechanism employed in GML to point to other sections of the document or to elements in another document). In [6], we define the water that is contained in the aquifer. This looks superfluous at this point, but you might see this as a placeholder where water properties can be attached. Finally, in [7], the host unit (referred in [5]) is described with its components according to NADM-C1 model (Boisvert et al., 2004).

USE CASE

In this section we describe a use case that demonstrates the usefulness of interoperability for groundwater and related domains. In the use case, the water level in an aquifer is required to assess the sustainability of housing developments in certain communities where groundwater is the sole or principal source of water. Combining this information with other socioeconomic variables and providing local government with decision making tools then allows calculations to be made about current and future trends for water supply and demand. Using groundwater information in this way is the goal of the PATHWAYS project (http://sdki.nrcan.gc.ca/path/index_e.php).

The simplest use case would allow PATHWAYS modelling tools to access the water level information stored in various provincial water well databases, without any prior knowledge of how the data are actually structured or how to access them. The process, demonstrated to some extent during the DMT'05 presentation (Brodaric, et al., 2005), requires a series of intermediate pieces of software to handle the request from one step to the next. Figure 3 is a sketch of the process.

- First, a tool designed by the PATHWAYS project team (the Phoenix browser) sends a request to the National Groundwater Database (NGWD) for a specific theme (Water Level) using a common schema: H2O. The request is made using the Web Feature Service standard protocol (OGC, 2002);
- NGWD receives the request and determines which database holds this information. Once it locates the provincial service that might have this information, it translates the H2O request into a schema the provincial service can understand (it might be an OGC standard, or it might not);
- NGWD sends the translated request to the provincial database, which proceeds to extract the information. This may involve another translation step that turns the web based query into a database query– e.g., XML into a SQL statement;
- The information from the province is streamed back to NGWD in either XML, HTML, or another specified format. NGWD performs the reverse translation to turn this into the H2O public schema and sends it over to PATHWAYS, which is unaware of the provincial schema; and
- PATHWAYS receives the H2O document and turns it into the internal format required by the modelling tool.

Many variations of this scenario might exist. If the province follows OGC WFS standards, much less work is required by NGWD to translate it, because WFS is using GML (Boisvert et al., 2004). If the province follows the H2O public schema, NGWD does no translation at all. On the other hand, if the service is based on any other technology, a specific solution must be devised for this particular service. In any case, the goal of NGWD is to shield PATHWAYS from those details also that it is exposed only to data accessed using H2O and WFS.

CONCLUSION

NADM-C1 GML provided a good starting point for our groundwater data interchange format, called H2O. In H2O we leveraged the fact that hydrogeology is essentially an extension of geology (at least for its quantitative aspects), allowing us to reuse many of the concepts in NADM-C1. We showed how H2O is developed from NADM-C1, how it is structured, and how it is implemented in the National Groundwater Database. Future work involves extending H2O to include water quality concepts, so that it can be used as an interchange format for both water quantity and quality information.

ACKNOWLEDGMENTS

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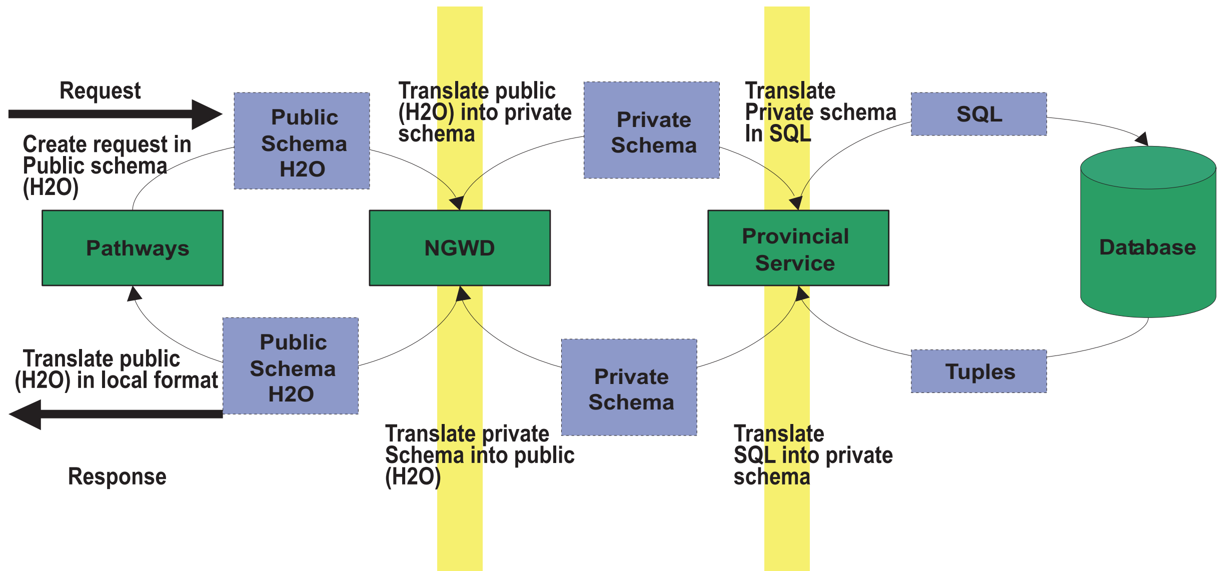

Figure 3. General view of the components involved in the DMT '05 demonstration of interoperability between PATHWAYS and the National Groundwater Database.

edge Integration program of the Earth Science Sector of Natural Resources Canada, and the ResEau project of Environment Canada (ESS contribution number 20060072).

A special thought for the people of Louisiana, in light of the terrible events that occurred a few months after they welcomed us to Baton Rouge.

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