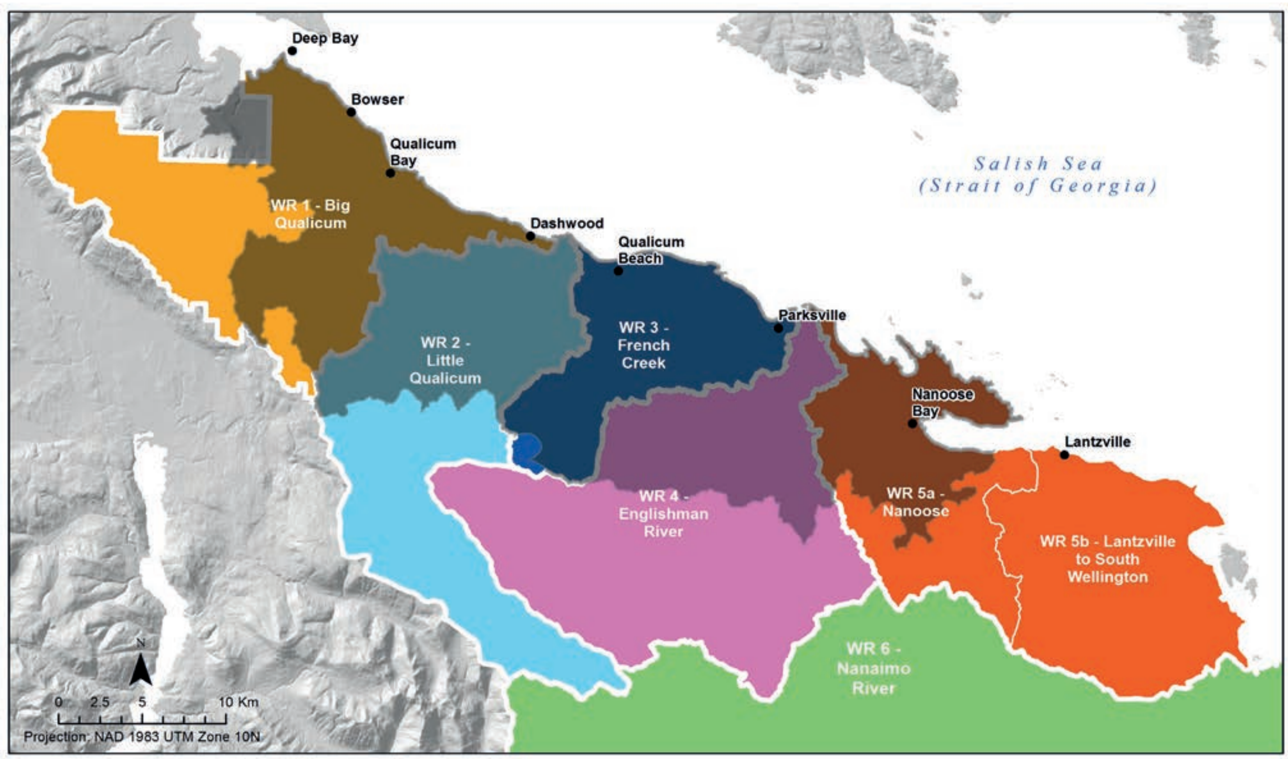
WORKSHOP

Knowledge Transfer and Exchange on Nanaimo Lowland Groundwater

Nanaimo, British Columbia



PARTICIPANT WORKBOOK

February 2018

Réseau québécois sur les eaux souterraines

Ressources naturelles Canada | Natural Resources Canada

Université du Québec à Trois-Rivières

This knowledge transfer workshop pertains to the results of the Nanaimo Lowland Groundwater Study, and has been made possible through funding from the Geological Survey of Canada (GSC). It is the result of a collaborative effort between the Quebec Groundwater Network (Réseau québécois sur les eaux souterraines; RQES), the GSC, the Regional District of Nanaimo (RDN), the BC Ministry of Forests, Lands, and Natural Resource Operations (FLNRO), the BC Ministry of Environment and Climate Change Strategy (MoE), and the Université du Québec à Trois-Rivières (UQTR) Landscape Ecology and Planning Chair. The following individuals in particular have contributed to various aspects of the workshop:

- Daniel Paradis, Geoscience Research Professional, GSC, Nanaimo Lowland Groundwater Study Coordinator
- Yves Michaud, Geoscience Manager, GSC
- Yohann Tremblay, RQES Transfer Agent, workshop preparation and facilitation
- Anne-Marie Decelles, RQES Transfer Agent, workshop preparation and facilitation
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- Mike Wei, Head, Groundwater and Aquifer Science, BC MoE

References to cite

The hydrogeological information presented herein is derived from various documents produced as part of the Nanaimo Lowland Groundwater Study. The principal documents should be cited as follows:

Benoît, N., Paradis, D., Bednarski, J. M., Hamblin, T., and Russel, H. A. J. 2015. Three dimensional hydrostratigraphic model of the Nanoose - Deep Bay Area, Nanaimo Lowland, British Columbia. Geological Survey of Canada Open File 7796, 26 p.

Benoit, N. and Paradis, D. 2015. Three dimensional groundwater flow model of the Nanoose - Deep Bay Area, Nanaimo Lowland, British Columbia. Geological Survey of Canada Open File 7845, 27 p.

Russel, H. A. J., and Benoît, N. 2016. Nanoose Bay - Deep Bay Area, Nanaimo Lowland Groundwater Study Atlas. Geological Survey of Canada Open File 7877, 63 p.

This document is the result of groundwater knowledge transfer based on the Nanaimo Lowland Groundwater Study :

Tremblay, Y., Decelles A. M., Ouellet, M. A., Ruiz, J., Paradis, D. 2018. Knowledge transfer workshop on groundwater, Nanaimo Lowland Groundwater Study, participant workbook. Document prepared by the RQES, with the contribution of the GSC and UQTR, for land-use planning stakeholders.

Workshop organizers

The Quebec Groundwater Network (Réseau québécois sur les eaux souterraines - RQES)

The mission of the RQES is to consolidate and expand collaborations between university research teams and governmental and non-governmental organizations, consultants, educational institutions, and other organizations interested in groundwater, with the aim of mobilizing scientific knowledge on groundwater.

The RQES pursues the following specific objectives:

- Identify end users' needs in terms of new research, concrete applications for groundwater resource management, and training;
- Facilitate the transfer of scientific knowledge to end users in order to support the management and protection of groundwater resources;
- Support the training of qualified personnel in groundwater-related fields to meet current and future requirements of the labor market in research, management, and consulting.

For more information please visit : **rqes.ca**

The Geological Survey of Canada

The GSC is part of the Earth Sciences Sector of Natural Resources Canada. It is Canada's oldest scientific agency and one of its first government organizations. Founded in 1842, the GSC helped to develop a viable Canadian mineral industry by establishing the general geological baseline information upon which the industry could plan detailed investigations. Throughout its long and colourful history, the GSC has played a leading role in exploring the nation.

Today, the GSC is Canada's national organization for geoscientific information and research. Its world-class expertise focuses on the sustainable development of Canada's mineral, energy, and water resources, on the stewardship of Canada's environment, on the management of natural geological and related hazards, and on related technological innovation.

For more information please visit : www.nrcan.gc.ca/earth-sciences/science/geology/gsc/17100

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Agenda

Objectives

This workshop aims to present and contextualize new hydrogeological information produced by the GSC via the Nanaimo Lowland Groundwater Study, and to explore how it can support water management and land-use planning. More specifically, it aims to:

- Highlight the main findings of the Nanaimo Lowland Groundwater Study
- Improve participants' understanding of hydrogeological concepts and aquifer characteristics in the region
- Enable participants to read maps and use the GIS data produced by the Nanaimo Lowland Groundwater Study
- Evaluate the usefulness of hydrogeological information in decision-making

Activities	Workbook Sections
1. Understanding hydrogeological information *(formal presentations + subgroup activity)*	Part 1, p. 11 to 57
2. Discovering and using the hydrogeological geospatial data *(formal presentation + ArcGIS activity in partners)*	Part 2, p. 59 to 93
3. Supporting land-use planning and water management decisions with hydrogeological information *(subgroup activity + ArcGIS activity in partners)*	Part 3, p. 95 to 152
4. Usefulness of hydrogeological information for sustainable water management *(subgroup activity +discussion)*	Part 4, p. 155 to 164

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Part 1

UNDERSTANDING HYDROGEOLOGICAL INFORMATION

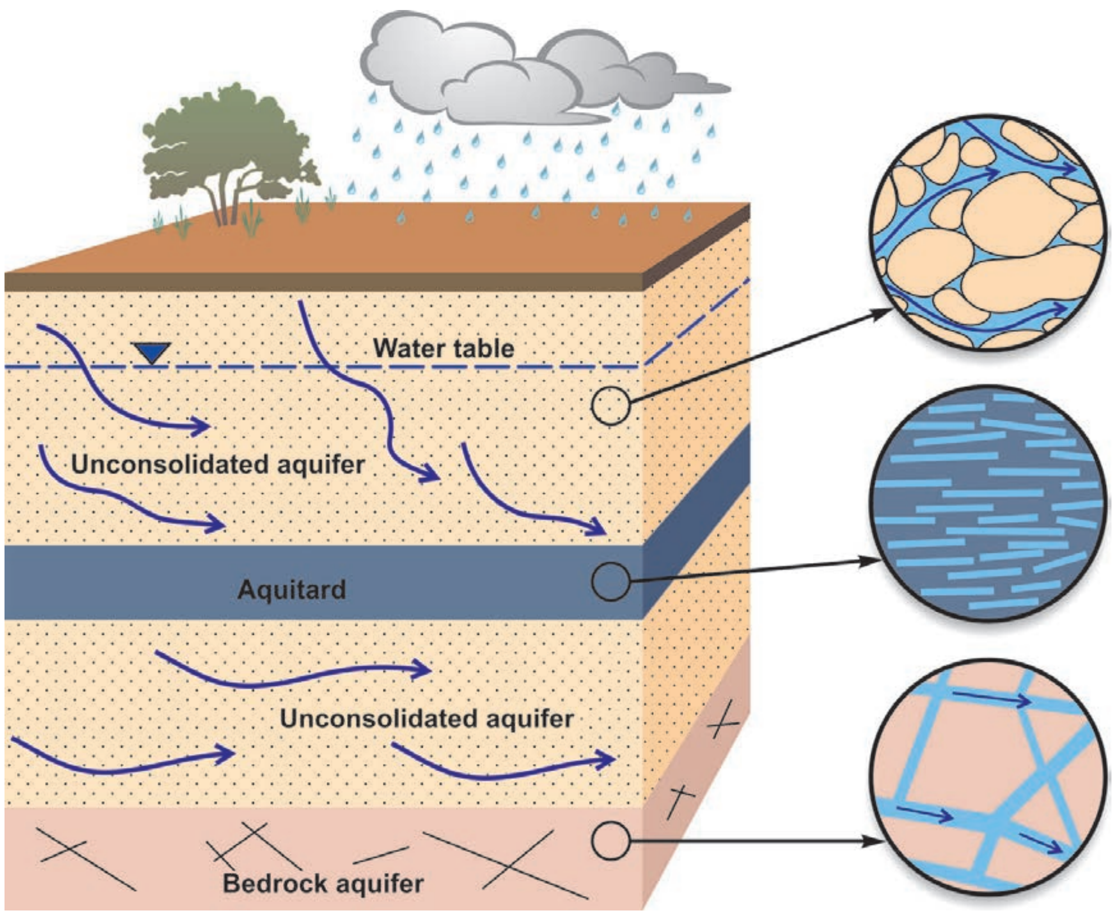
Throughout this workbook section

Terms in **blue** represent key concepts in hydrogeology

The Key Concept Index on **p. 12** refers to page numbers where the definitions can be found

Key concepts index

1.1 Fundamentals of Hydrogeology



GROUNDWATER, AQUIFERS AND AQUITARDS

GROUNDWATER is water present under the ground surface that fills the empty spaces of geological units.

Basic definitions

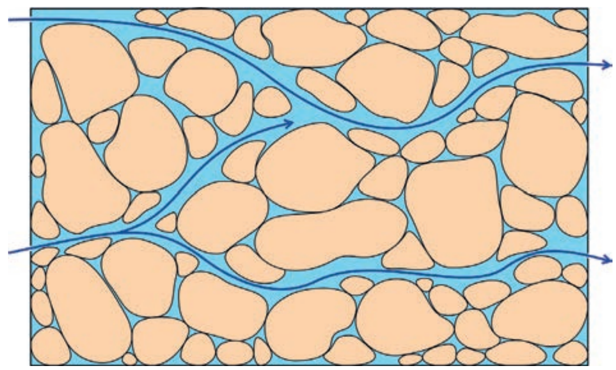
POROSITY is the relative volume (in %) of **pores**, which are the empty spaces inside the solid matrix.

- The higher the porosity, the more space is available for water storage.

HYDRAULIC CONDUCTIVITY is the ability of the geological unit to transmit water.

- The higher the interconnection of pores, the higher the permeability of the geological unit, and the easier the infiltration and flow of water.

Groudwater flowing through interconnected pores



AQUIFERS and **AQUITARDS**, what are they ?

An **AQUIFER** is a geological unit that can contain enough water to yield economically significant quantities of water.

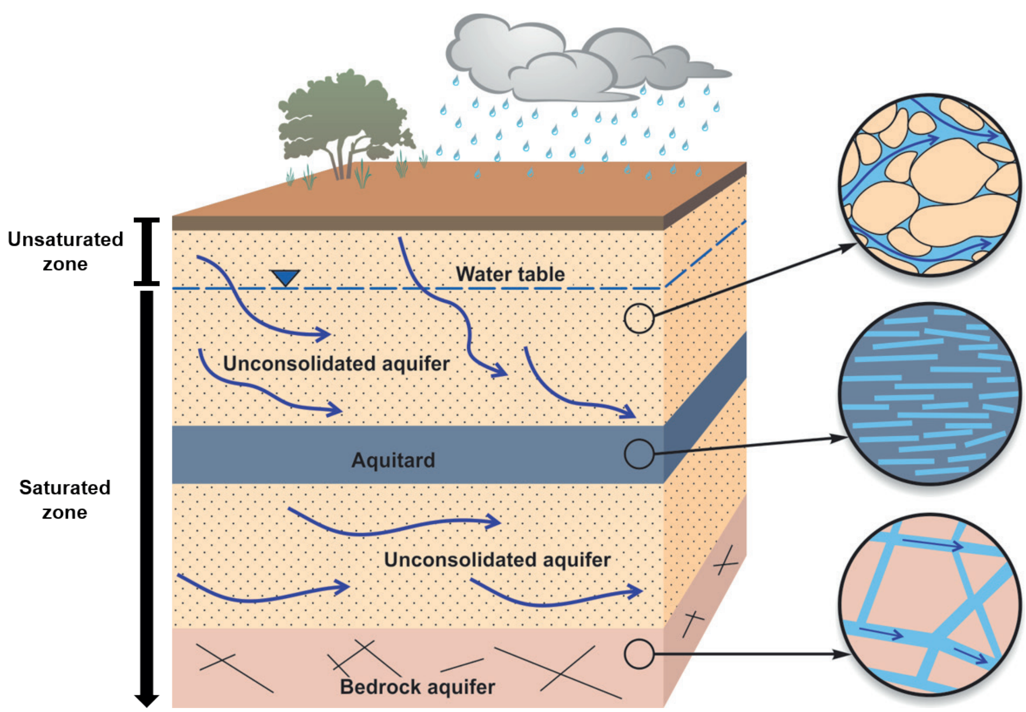
- It's the **container**.

An **AQUITARD** is a geological unit that has such fine-grained or cemented matrices (small and/or unconnected pore spaces) that it forms a **barrier** to groundwater flow. When it overlies an aquifer, it provides an additional level of protection against contamination entering the aquifer from the surface.

How does it work ?

Water infiltrating the soil surface percolates down through the **UNSATURATED ZONE** (or **vadose zone**) to reach the **WATER TABLE**, the level below which the ground is fully saturated with water. Water reaching the **SATURATED ZONE** contributes to the **recharge** of the aquifer.

Like surface water, groundwater flows in aquifers, but much less rapidly than water in rivers.



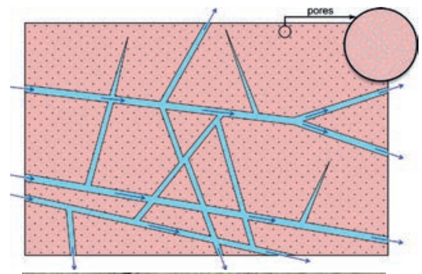
What types of geological environments constitute aquifers ?

Two geological environments constitute aquifers :

- **FRACTURED BEDROCK**, which forms the crust of the upper Earth; and
- **UNCONSOLIDATED DEPOSITS**, composed of sediments originating from bedrock erosion and overlying the bedrock.

Porous bedrock

Fractured bedrock



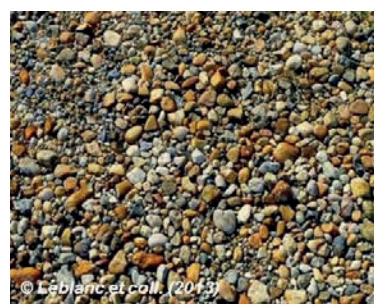
BEDROCK AQUIFER

Pores in bedrock contain groundwater and constitute a large reservoir. However, poor pore interconnection limits water flow, except for in certain rock types, such as sandstone and conglomerates.

Fractures, generally representing a small percentage of groundwater storage by volume compared to pores, allow efficient flow, sometimes suitable to supply single residences.

When drilling wells in this type of aquifer, as many fractures as possible are hoped to be encountered.

Gravel



UNCONSOLIDATED AQUIFER

When unconsolidated deposits are **comprised of coarse particles** (e.g., sand and gravel), they form an **AQUIFER**.

- The larger the pores, the better their interconnection, and the greater the permeability of the aquifer.
- Large amounts of water can be pumped when the saturated thickness is sufficient.

Clay

When unconsolidated deposits are **comprised of fine particles** (e.g., clay and silt), they form an **AQUITARD**.

- The smaller the pores, the more restricted the water flow, and the lower the permeability of deposits.

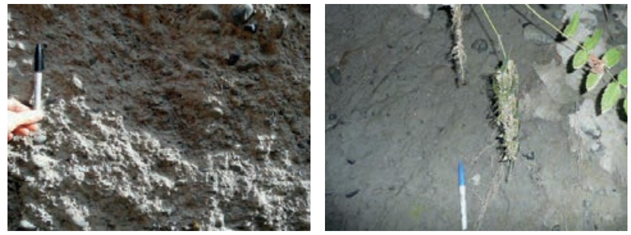
TYPES OF SEDIMENT

GLACIAL TILL

Results from the erosion and transport of rock fragments by glacial flow.

- Composed of unsorted particles of all sizes in a fine-grained matrix, which often forms an **aquitard**.
- When washed of fine particles, however, it can be an **aquifer**.

Glacial Till



GLACIOFLUVIAL SEDIMENTS

Deposited from melting glacial water :

1) in contact with the glacier, thus under ice, over ice, or against an ice wall;

2) in an outwash plain, in front of a glacier; or

3) in a delta, when melting water discharges into a water body, such as a lake or the sea.

- Composed of sand and gravel, forming an **aquifer**.

Glaciofluvial sediments

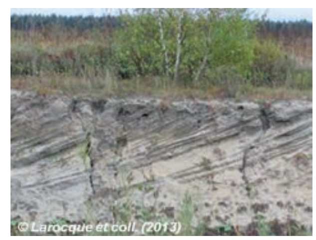
MARINE AND GLACIOMARINE SEDIMENTS

Deposited in the sea, during or after glaciation.

- When deposited in deep water, they are composed of silt and clay, forming an **aquitard**.
- When deposited in shallow water, on the shore or in deltas, they are composed of sand and gravel, forming an **aquifer**.

Marine sediments

Shore sediments



FLUVIAL SEDIMENTS

Deposited by recent streams in flood plains, as alluviums.

- Composed of silt, sand, and gravel, and form **aquifers**.

Alluvium

ORGANIC SEDIMENTS

Constitute wetlands.

- Composed of peat; little is known about their groundwater flow dynamics.

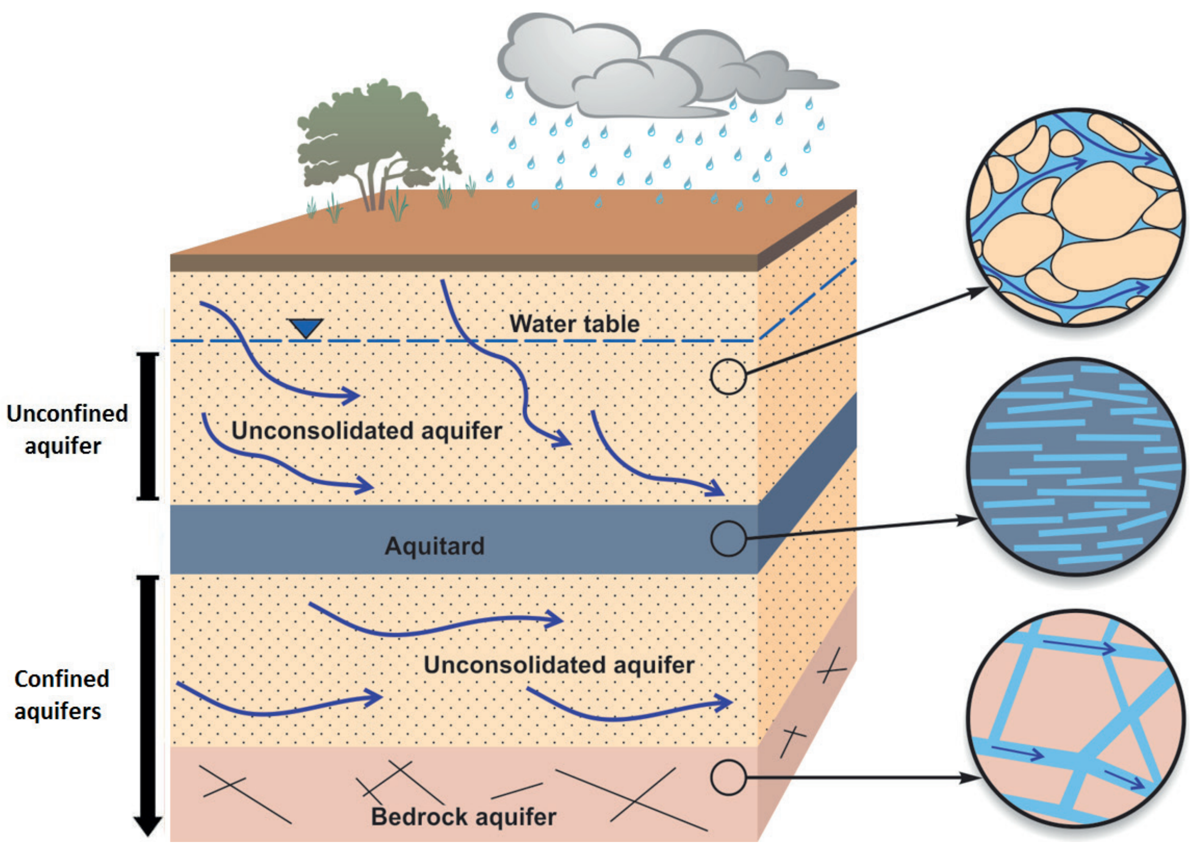
Peat

CONFINEMENT CONDITIONS

A **CONFINED AQUIFER** is « trapped » beneath an aquitard. It is **not directly recharged** by vertical infiltration, and therefore is relatively **well-protected from contamination**. Its recharge area is located further upstream instead, where the impermeable layer is absent. Groundwater in confined aquifers is under pressure.

An **UNCONFINED AQUIFER** is not covered by an aquitard, and is in direct contact with the atmosphere. It can therefore be **directly recharged** by vertical infiltration, but is generally **more vulnerable to contamination**. Groundwater pressure is in equilibrium with atmospheric pressure.

A **SEMI-CONFINED AQUIFER** is an intermediate case in which the overlying geological units are not completely impermeable, due either to their composition or their thickness (i.e., not thick enough to be impermeable). **Recharge** and **protection** from contamination from the surface for these are **moderate**.



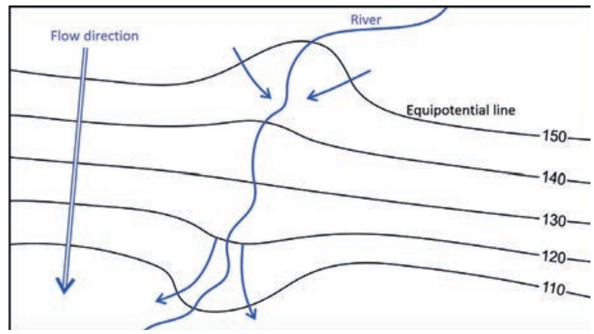
GROUNDWATER FLOW

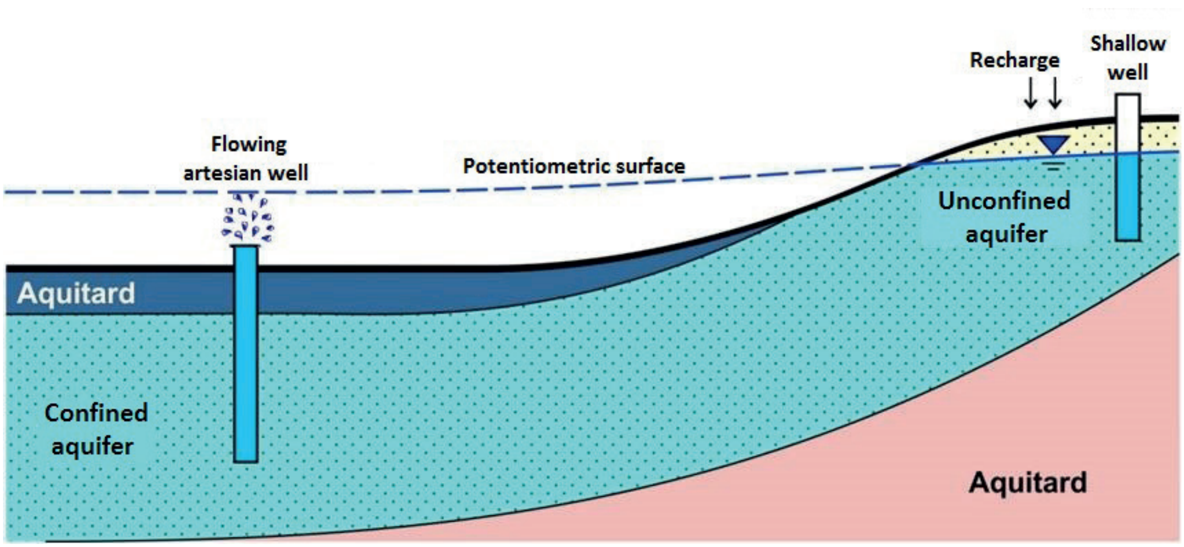
The **POTENTIOMETRIC LEVEL** (or **hydraulic head** or **piezometry**) corresponds to the level of water in a well at which it is at equilibrium with atmospheric pressure.

In an **unconfined aquifer**, this level also corresponds to the **water table** elevation. In a **confined aquifer**, since it is under pressure, it is higher than the top of the aquifer.

The **POTENTIOMETRIC SURFACE** represents groundwater elevation in an aquifer, similarly to topography, which represents the ground surface elevation. It indicates groundwater flow direction, which is from higher to lower hydraulic heads.

Potentiometric surface





RECHARGE AND SEEPAGE

RECHARGE replenishes groundwater by supplying water to aquifers from precipitation infiltrating at the surface.

Recharge rate depends on climatic conditions, land-use and land cover, topography, and physical soil properties. It thus varies spatially.

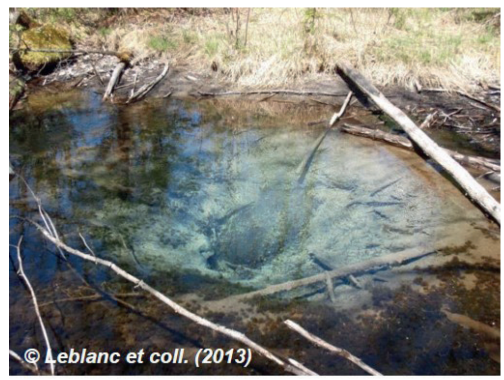
- Dry climate, confinement, steep slope, and a sealed surface are all limiting factors to recharge.

Groundwater **SEEPAGE** corresponds to water emerging from the ground, which occurs when the potentiometric surface is higher than the ground surface.

- Seepage is generally diffuse (i.e., extends over a large surface). Streams, as well as wetlands, often correspond to seepage zones.
- Seepage is sometimes point-source and constitutes natural springs.

During low-flow periods, essentially all water flowing in streams comes from groundwater, which forms the baseflow.

Natural spring

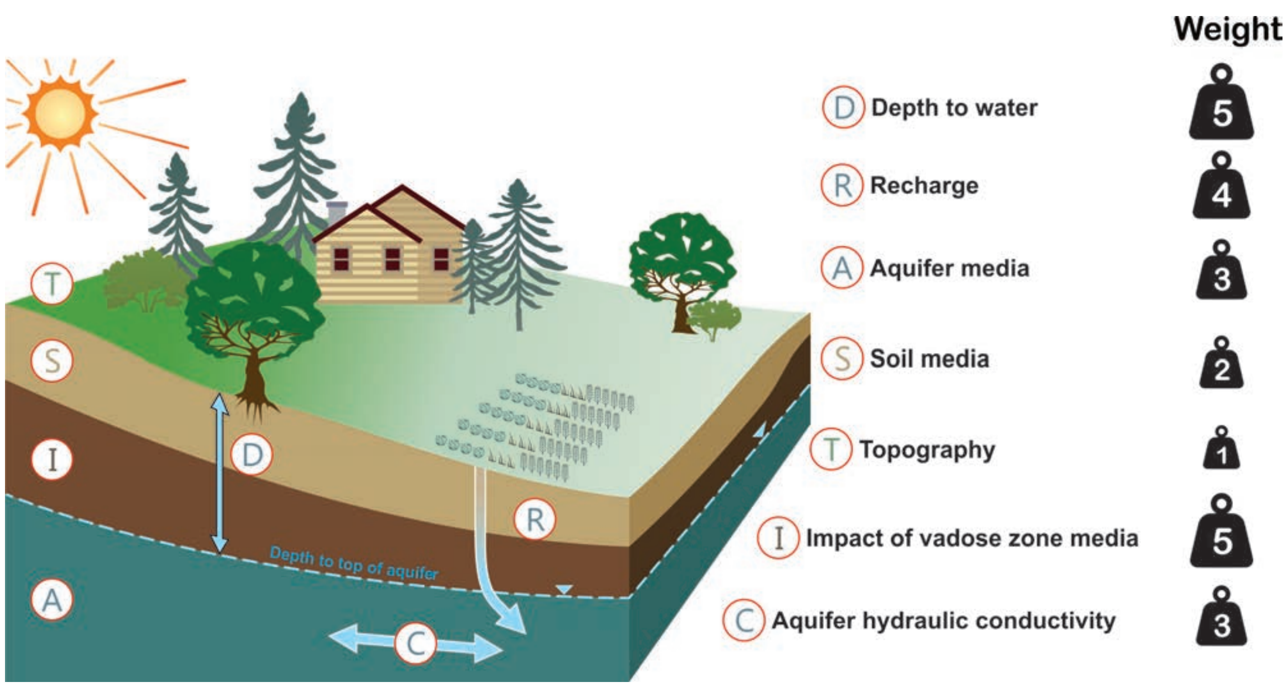


AQUIFER VULNERABILITY

The **DRASTIC** method offers a relative evaluation of intrinsic aquifer **VULNERABILITY**, which is the **susceptibility of groundwater to pollution from contaminants at the soil surface**.

The DRASTIC index varies from 23 to 226, with higher values corresponding to more vulnerable aquifers.

The **calculation** of DRASTIC index takes seven physical and hydrogeological parameters into account :



The **risk of groundwater quality degradation** can be estimated by combining intrinsic aquifer vulnerability, the impact of potentially-contaminating human activities, and the level of development (use) of an aquifer.

The **contamination potential** of a given human activity depends upon several factors, such as the nature and quantity of associated contaminants, the affected area, and the recurrence of contamination.

Using a hydrogeological model to understand groundwater

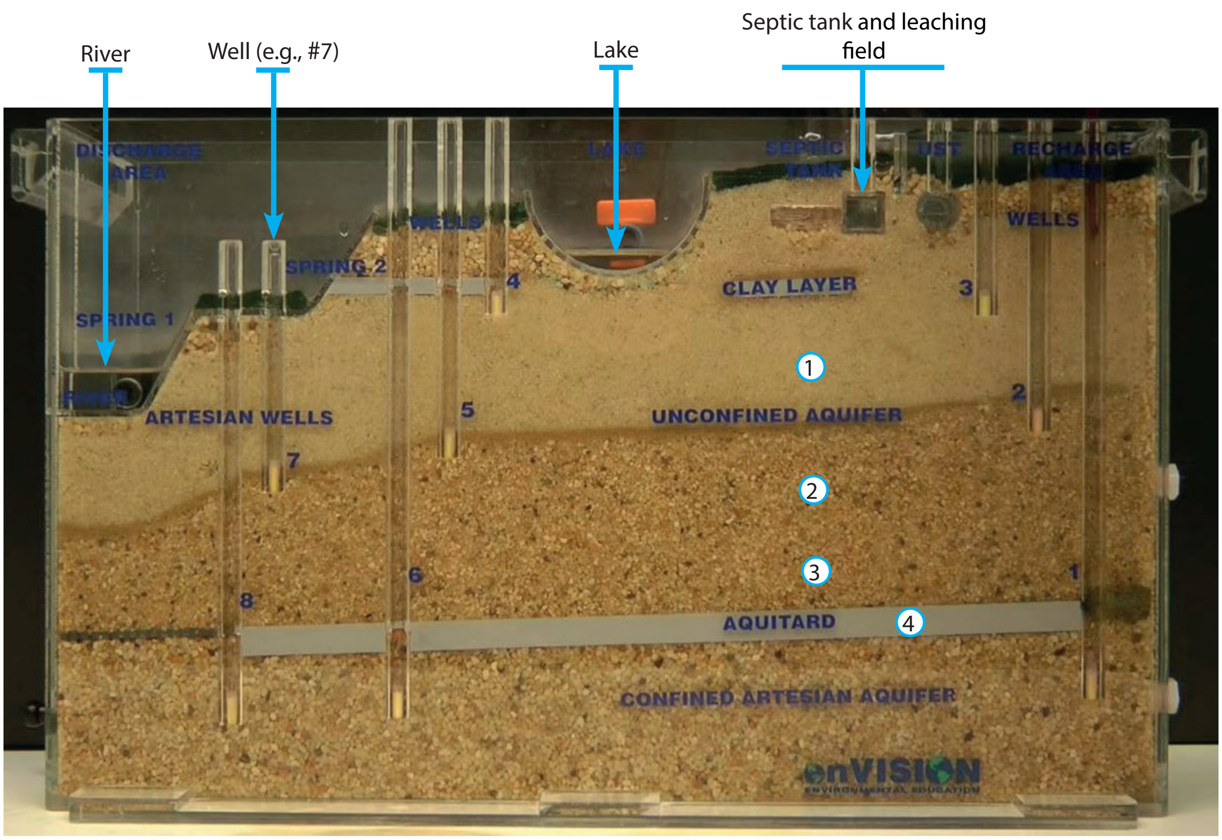
As for surface water, groundwater flows in an aquifer from a more elevated point to a lower one, but generally much more slowly than in rivers. The hydrogeological model illustrated below allows the groundwater pathways in unconsolidated aquifers to be visualized. This hydrogeological model is a miniaturized representation of an underground vertical section, which provides insight into and an illustration of many concepts related to hydrogeology.

Features of the hydrogeological model

The model is approximately 50 cm long, 30 cm high, and 20 cm thick. Aquifers are represented by a vertical sequence of different types of sediment. They correspond to the following hydrogeological contexts :

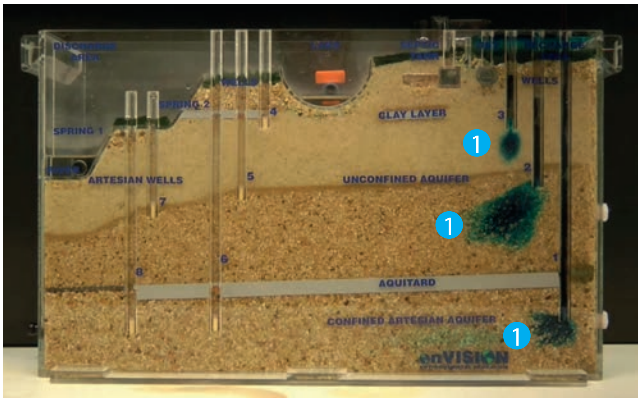
1. Fined-grained sand in the upper part of an unconfined aquifer, in the first layer near the surface;
2. Coarse-grained sand in the lower part of an unconfined aquifer, in the second layer, in the middle of the model;
3. An impermeable layer representing an aquitard, possibly comprised of clay; and
4. Coarse-grained sand in a confined aquifer, in the layer at the base of the model.

The model is filled with water, which occupies the empty spaces between the sediments. A pump allows water to continuously flow through the material. To visualize different groundwater flowing scenarios, the model is designed with eight wells of varying depths, as well as a septic tank and its leaching field. These permit dye to be injected, as well as water to be pumped. The hydrographic network is represented by a lake and a river.



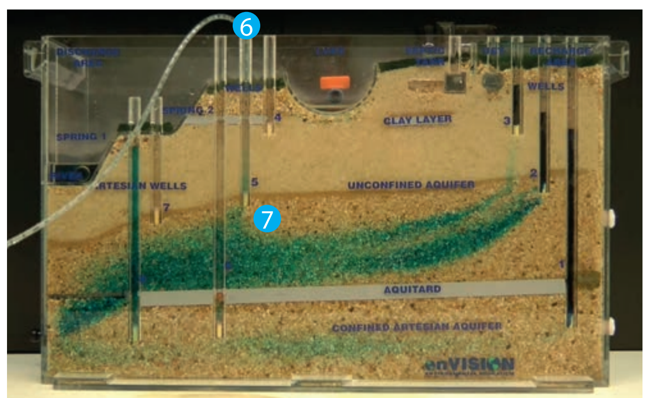
Groundwater flow

1 A tracer (blue dye) is injected via three wells to visualize groundwater flow in the aquifers. Water fills in pores (empty spaces) in the sediment layers.



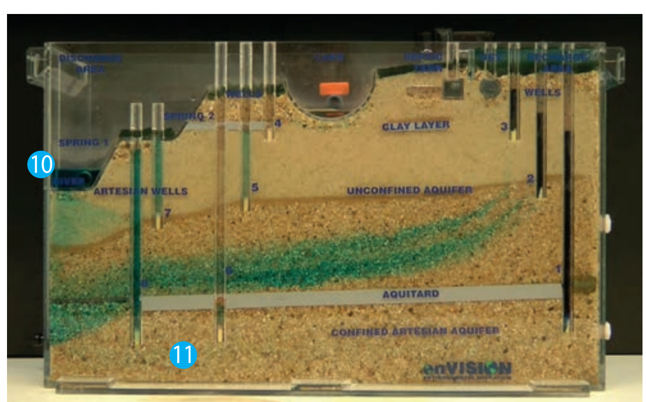
4 Pumping occurs in well #8. Pumped water is dyed, proving that it really comes from upstream. 5 Flow is faster in the lower confined aquifer, indicating a higher hydraulic conductivity.

6 Pumping occurs in well #5. 7 Dyed water is drawn from deeper compared with the previous image.



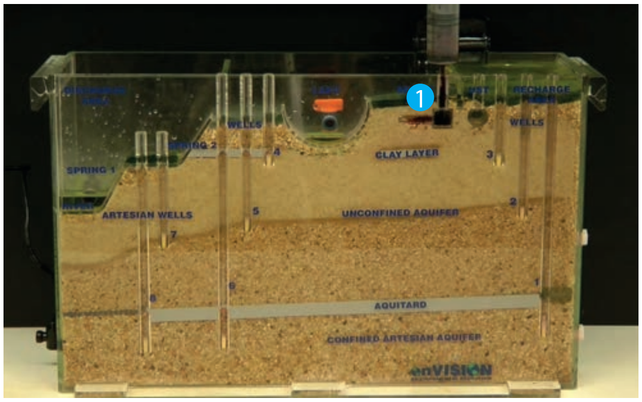
8 Pumping occurs in well #7. 9 Dyed water is also drawn from even deeper compared with the previous image.

10 Groundwater ultimately emerges in the downstream river that in turn gets dyed. 11 Water in the confined aquifer is almost entirely replaced (indicated by its lack of dye).

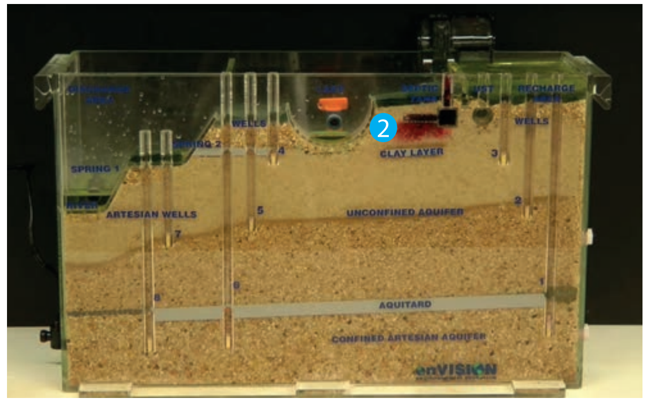


Contaminant migration in aquifers

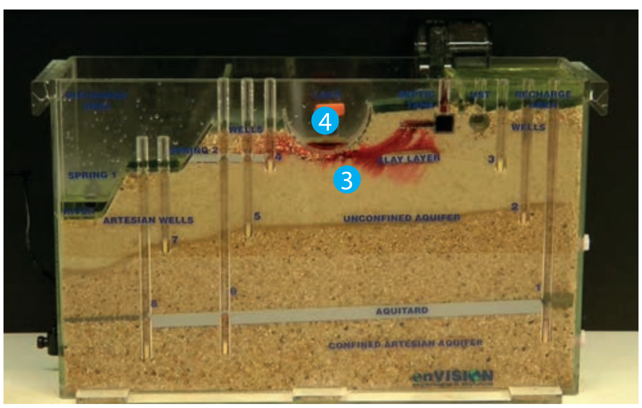
1 A contaminant (red dye) is injected via the septic tank to visualize the migration of a contaminant in the aquifers.



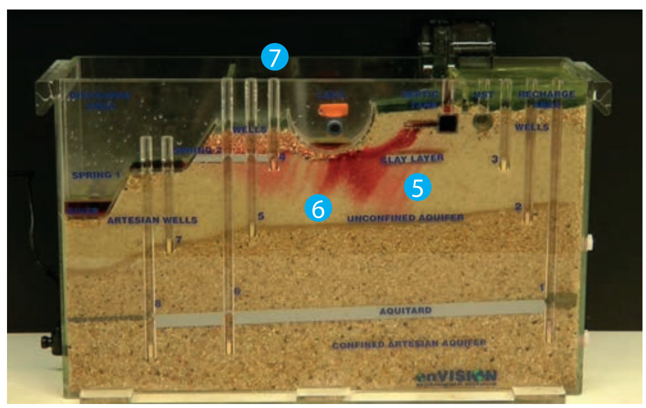
2 From the leaching field, the contaminant migrates downward in the fine-grained sand layer of the unconfined aquifer.



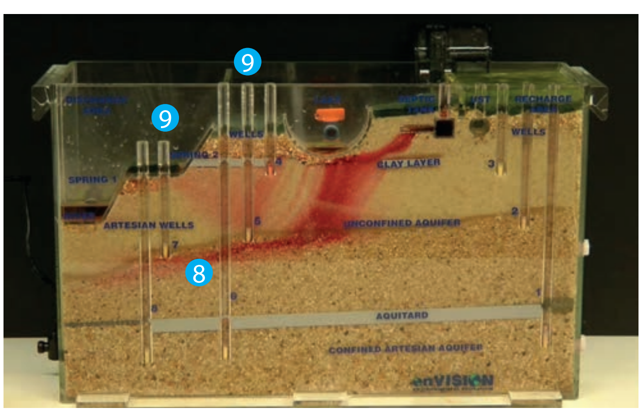
3 The contaminant continues its downward migration, but also extends laterally in the downstream direction. 4 Contaminated groundwater emerges into the lake that in turn gets dyed. 5 The discontinuous clay layer did not completely protect the part of the aquifer right below it.



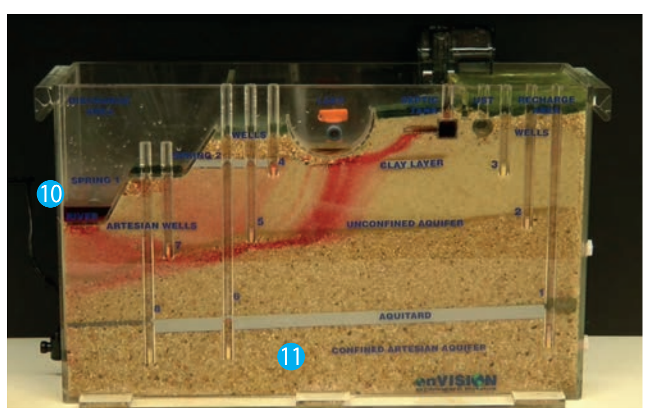
6 More and more groundwater becomes contaminated. 7 Well #4 is now contaminated.



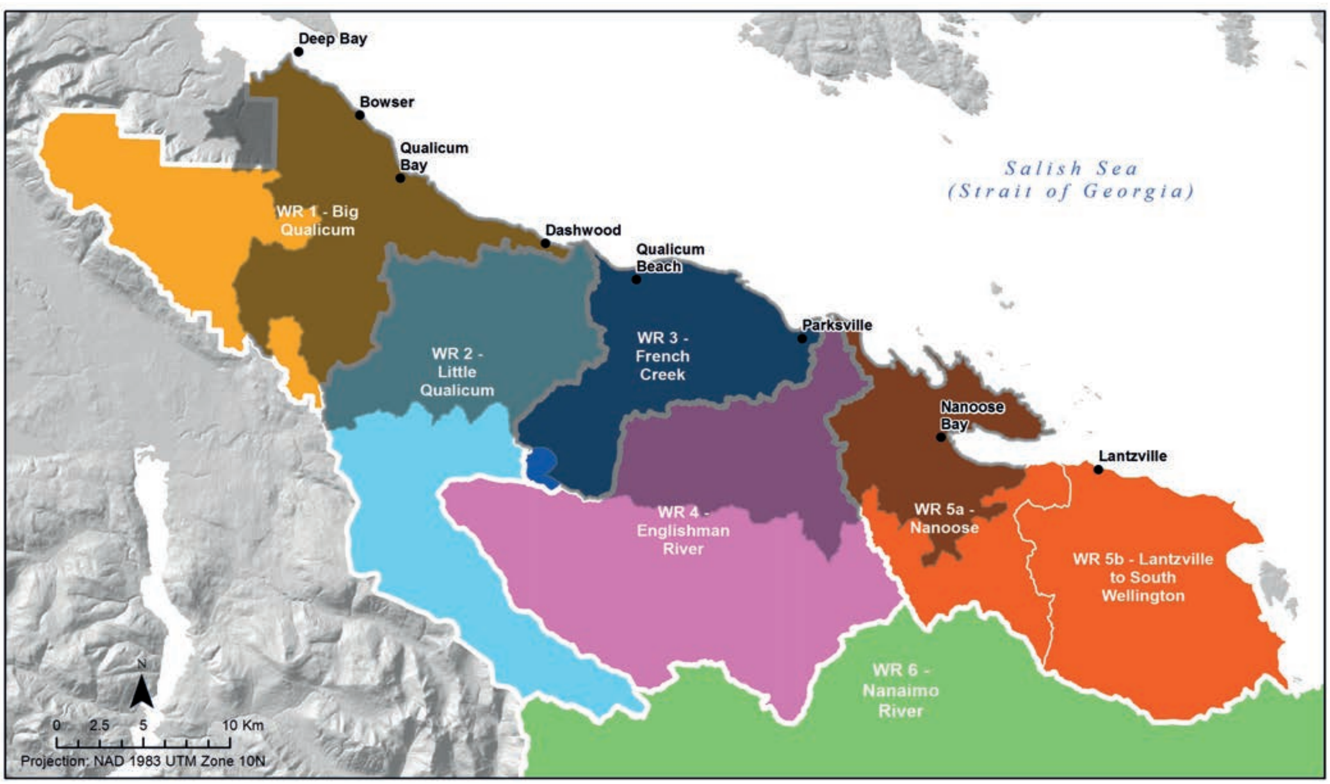
8 When it reaches the coarse-grained sand layer, the contaminated groundwater flows more rapidly because of its higher hydraulic conductivity. 9 Wells #5 and #7 are now contaminated.



10 The contaminated groundwater ultimately emerges in the downstream river that in turn gets dyed. 11 The confined aquifer under the aquitard remains protected from contamination.



1.2 General groundwater characteristics of the Nanaimo Lowland



Nanaimo Lowland Groundwater Study Overview

The Nanaimo Lowland Groundwater Study consisted of a five-year collaborative project on the regional groundwater resources of the Nanaimo Lowland area, of British Columbia (BC), between Nanoose Bay, in the south, and Deep Bay, in the north. The project was initiated by the Regional District of Nanaimo (RDN), the BC Ministry of Forests, Lands, and Natural Resources (MFLNR), and the BC Ministry of Environment (MoE).

The Geological Survey of Canada (GSC) joined the project in 2009 owing to its responsibility to map Canada's major aquifers. This was a major recommendation of a report of the Standing Senate Committee on Energy, the Environment, and Natural Resources, released in 2005. The report *Water in the West: Under Pressure* noted that our limited knowledge of our groundwater resources was a critical issue that needed to be addressed. Sound management of groundwater resources for current and future users can only be based on an understanding of the characteristics of the aquifers and the processes that control groundwater availability. The Nanaimo Lowland is one of 30 key Canadian aquifers identified by the GSC.

The GSC completed the data collection phase of the project in 2014. In a parallel study, contracted by the RDN, the Calgary-based consulting firm Waterline Resources Inc., conducted a literature search of published sources to assemble a report on legacy data (Waterline, 2013), and part of this material has been used for this workbook. Archival data obtained from the MoE Water Well Database has also been integrated with data from other projects.

The information presented herein consists of compiled and interpreted data as well as results regarding the geology, hydrology, and hydrogeology of the study area. It is a summary of the study investigations. For more detailed information, readers are referred to the relevant cited references at the end of this document.

The study results are presented within the context of a basin analysis study that can act as a tool to aid understanding of regional groundwater in support of sound management of the resource. The objective of a basin analysis study is the collection of geoscience data to support the interpretation of the paleogeographic history of the basin. Such a framework provides a predictive framework of the sedimentary history and arrangement of geological units.

Excerpt from: Russell, H.A.J., and Benoit, N., (compilers); Nanoose Bay – Deep Bay Area, Nanaimo Lowland Groundwater Study Atlas, Regional District of Nanaimo, British Columbia; Geological Survey of Canada, Open File 7877.

To support the sustainable groundwater management of the Nanaimo Lowland, a 3D hydrostratigraphic model (HSM) and a groundwater flow model (GFM) were developed for its aquifer system. The main goal of the HSM was to better improve the understanding of the composition, distribution, and stratigraphic architecture of the hydrostratigraphic units. Development of a 3D model provides a basis for integrating knowledge gained throughout the course of the study, and forms a framework for a numerical groundwater flow model. The main objective of the GFM is to improve the understanding of the regional groundwater flow system of the Deep-Nanoose Bay area. This is achieved using a 3D GFM of the study area, calibrated with hydraulic head and baseflow data. Due to the scale of the study area, the complexity of the aquifer system, and the assumptions of the 3D GFM, its main purpose is to provide a regional picture of the groundwater resources, which can be used to constrain local hydrogeological investigations. It provides a framework for more local-scale work that can appropriately address sustainable groundwater management.

Data collection and data sources

A basin analysis approach was applied in the study area to advance understanding of the basin framework, using new data collected as an aid to interpretation of the basin history and, consequently, to provide a predictive guide for future studies and understanding. Development of a sound geological framework that integrates available geological, geophysical, geochemical, and hydrogeological data is central to this approach.

To achieve this, existing data were compiled, including:

- Public water wells database (MoE, 2013). After filtering and validation 708 bedrock wells and 570 surficial wells were used for this project.
- Surficial geological map including stratigraphic columns (12) and a cross-section (Fyles, 1963).

New data collection included:

- Surficial geology mapping that updated the surficial geology and stratigraphy (Bednarski, 2015).
- Bedrock outcrop analysis: 61 outcrops were measured for stratigraphic/sedimentologic interpretation and analyzed for fracture orientation (Hamblin, 2012; Hamblin and McCartney, 2014) and one 215 m long bedrock core was collected for analysis.
- Seismic reflection surveys: 42 km of two-dimensional (2D) seismic reflection surveys were collected along 15 lines using a mini-vibe energy source and a land- streamer geophone array.
- Rotosonic coring: three cores of surficial sediments ranging from 65 to 140 m with lithological descriptions and stratigraphic interpretations supported by geochemical analysis (Knight et al., 2015).
- Borehole geophysics: surveys in five wells (four surficial and one bedrock) that included gamma, induction, temperature, fluid resistivity, magnetic susceptibility and compressional (p-wave) and shear (s-wave) wave logs (Crow et al., 2014).
- Water chemistry data for the Englishman River (Provencher et al, 2013; Provencher, 2014).

These data were assembled and used to support construction of a 3D HSM (Benoit et al., 2015), that was used as the framework for a GFM (Benoit and Paradis, 2015) to advance understanding of regional groundwater flow in aquifer systems of the study area.

Excerpt from: Russell, H.A.J., Benoit, N., and Paradis, D., 2016. 1.3 Data Collection and Data Sources; in Russell, H.A.J., and Benoit, N., (compilers); Nanoose Bay – Deep Bay Area, Nanaimo Lowland Groundwater Study Atlas, Regional District of Nanaimo, British Columbia; Geological Survey of Canada, Open File 7877.

Groundwater use

Between Deep Bay, in the north, and Nanoose Bay, in the south of the study area, the primary source for community water supply is groundwater. The main community water supply systems consist of three improvement districts (local service authorities), one private purveyor, seven regional (RDN) water service areas, and two municipal utilities. Each of these community supply systems relies on a groundwater source. In addition to relying on groundwater, Parksville and the RDN service area on the Nanoose Peninsula use surface water from the Englishman River for their water supply from May through October. There are also some smaller community well operations (for example, that service a mobile home park) that rely on groundwater, as well as a significant number of properties with their own wells.

There are a significant number of unregistered wells in the region because the province has not required the registration of private wells. Estimates indicate that there are about 4900 private wells on properties outside of the municipalities (excluding the properties in community water service areas). These wells are not metered, so usage data is not available.

An estimation of water use from private wells was based on an average demand per land-use type, which was applied to the limited data available in the RDN Water Budget Study (Waterline, 2013). The resulting calculation of the total annual groundwater diversion for human use from private wells, and agriculture and community systems was 22,336,047 m^3.

The major systems' annual water use (2014) are :

Town of Qualicum Beach, serving ~9,350 people: 1,574,962 m^3 groundwater

City of Parksville, serving ~12,685 people: 657,169 m^3 surface water + 1,239,550 m^3 groundwater = 1,896,719 m^3

RDN Nanoose Peninsula, serving ~4,576 people: 218,071 m^3 surface water + 434,390 m^3 groundwater = 652,461 m^3

Excerpt from: Pisani, J., 2016. 1.2 Groundwater Use; in Russell, H.A.J., and Benoit, N., (compilers); Nanoose Bay – Deep Bay Area, Nanaimo Lowland Groundwater Study Atlas, Regional District of Nanaimo, British Columbia; Geological Survey of Canada, Open File 7877.

General study limitations

The maps produced as a result of the Nanaimo Lowland Groundwater Study are regional. It is therefore strongly recommended to avoid local inference of this information, which was generated at the regional level.

Most of the hydrogeological analyses carried out within this project are based on data treatment and processing methods that involve generalizations and simplifications of the complexity of the natural environment.

The data used (e.g., from wells, boreholes, rock outcrops) have a non-uniform distribution across the study area. The uncertainty of the hydrogeological analyses is greater in areas where data is sparse.

The data used come from a variety of sources (e.g. field data, consultant reports, government databases) for which the quality of the data is variable. A large proportion of the data comes from the BC Wells Database, which were filtered and validated to reduce errors in geological and hydrogeological measurements and reported locations. These data are very valuable to show regional trends in the hydrogeological parameters studied.

The values of certain data and the results of subsequent analyses (e.g., potentiometry, recharge, water quality) can show temporal variation at different scales (e.g., daily, seasonal, yearly, climate change).

Hydrogeological regional overview

The study area, along the central east coast of Vancouver Island, is part of the Canadian Cordillera Hydrogeological Region (Sharpe et al., 2014).

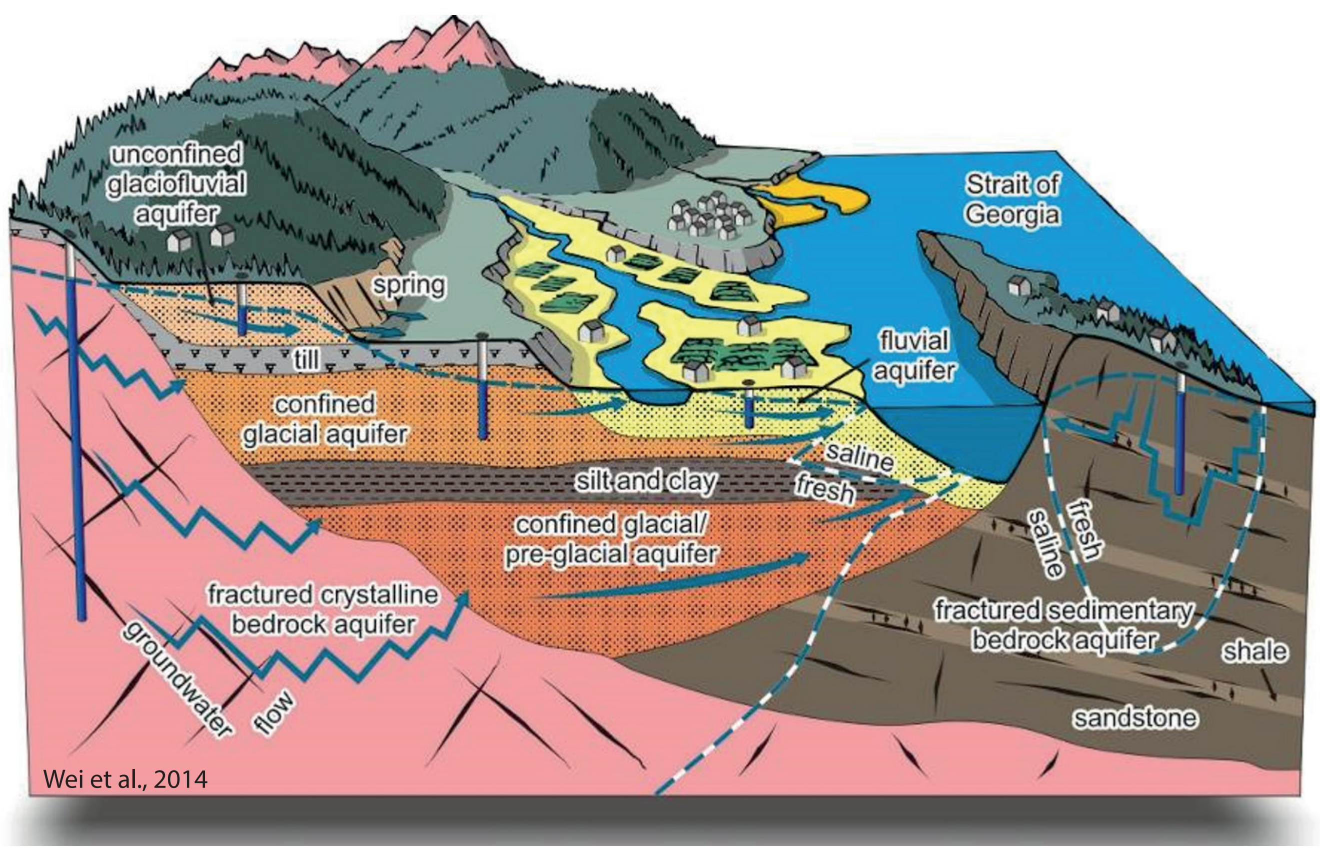
The area is underlain by bedrock of the Nanaimo Group of sedimentary rocks in the lowland and by a mix of crystalline bedrock in the mountainous areas. In bedrock, groundwater typically occurs in fractures and faults. There are two practical implications. First, the permeability of fractured bedrock and the yield from water wells drilled into bedrock tend to be limited. Second, the water storage potential in this type of bedrock is very low, resulting in generally quick responses of the bedrock aquifer to hydraulic and chemical changes. This means recharge from precipitation occurs quickly in fractured bedrock, for example, within a matter of days in the Englishman River watershed.

Unconsolidated aquifers comprising sand and gravel are the main aquifers in the study area. The bedrock surface, land topography, and surficial geology influence the occurrence and characteristics of these aquifers.

The Quadra Sand Aquifer is an important unconsolidated aquifer in the study area that supplies groundwater to residents of the communities of Parksville and Qualicum Beach. Meltwater rivers deposited the sand when glacial ice advanced south along what is now the Strait of Georgia more than 15,000 years ago. It was subsequently covered locally by glacial till, which formed an overlying confining layer. Because the permeability of sand is much greater than the permeability of fractured bedrock, this sand aquifer supports greater well yields and is a target when developing larger groundwater supplies. Other, more recent, sand and gravel deposits formed at the end of the last Ice Age or along alluvial rivers such as the Little Qualicum River, and they are also productive aquifers in the study area.

The study area is located in a coastal hydrologic regime. Much of the precipitation, which is the main source of recharge, falls in the winter months. Monitoring of ambient groundwater levels in BC observation wells within the study area has shown that recharge to the aquifers generally peaks in late winter-early spring.

Excerpt from: Wei, M., 2016. 1.1 Hydrogeological Regional Overview; in Russell, H.A.J., and Benoit, N., (compilers); Nanoose Bay – Deep Bay Area, Nanaimo Lowland Groundwater Study Atlas, Regional District of Nanaimo, British Columbia; Geological Survey of Canada, Open File 7877.



Regional District of Nanaimo (RDN) water regions

There are seven major basins in the RDN, which are comprised of several watersheds and sub-watersheds. These seven areas are referred to as water regions for planning purposes. The Nanaimo Lowland Groundwater Study area intersects five water regions:

The **Big Qualicum Water Region** (WR1) extends from Mud Bay in the north to Qualicum River in the south and from the coast to the Beaufort Mountain Range in the west. The total drainage area is approximately 292 km^2. It includes all of RDN Electoral Area H and small sections of Areas F and G.

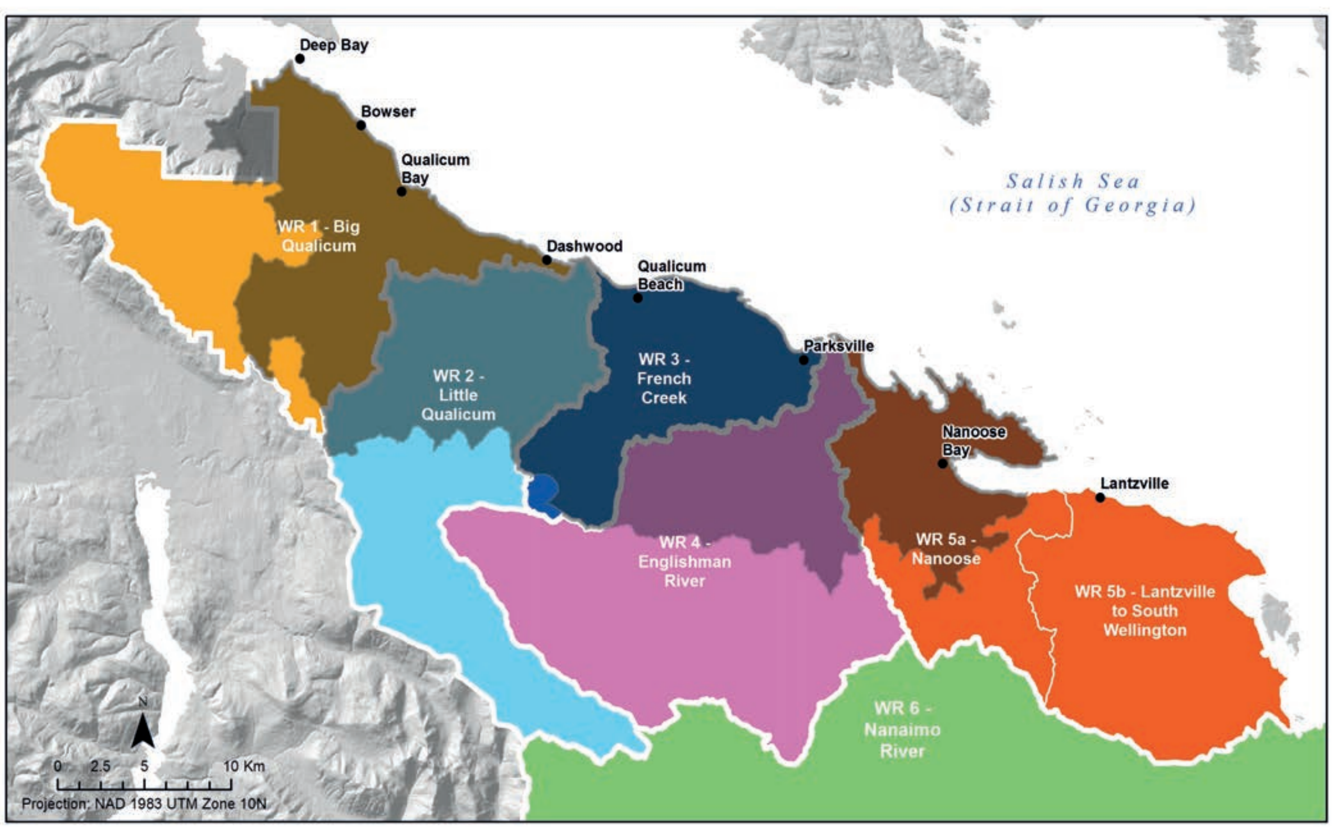
The **Little Qualicum Water Region** (WR2) flows north east from the highest point in the watershed at Labour Day Lake on Mount Arrowsmith towards Cameron Lake and down the Little Qualicum River into the Strait of Georgia just NW of the Town of Qualicum Beach. The total drainage area is approximately 251 km^2. It includes parts of RDN Electoral Areas F, G and H.

The **French Creek Water Region** (WR3) consists of steep forested headlands that drain from the mountains at 1080 meters above sea level, and the more gentle topography of the Nanaimo lowland. The total drainage area is approximately 121 km^2. It includes most of the communities of Parksville, Qualicum Beach, and parts of Electoral Area F (including Hilliers, Coombs and Errington) and Area G (French Creek).

The **Englishman River Water Region** (WR4) flows in an easterly direction from Mount Arrowsmith at 1819 m above sea level and discharges into the Strait of Georgia, north of Craig Bay. The main Englishman and South Englishman rivers originate in Arrowsmith, Hidden and Fishtail lakes. The total drainage area is approximately 324 km^2. The watershed includes parts of Electoral Areas F and G and the City of Parksville.

The **Nanoose Water Region** (WR5a) covers the Nanoose area. The forested headlands are drained by small creeks such as Bonnell and Nanoose Creeks. The water for residents in this region comes from groundwater sources - the bedrock and sand & gravel aquifers that underlie this area. It includes RDN Electoral Area E, which is primarily rural residential and suburban.

Excerpt from: ***http://www.rdn.bc.ca/cms.asp?wpID=3471***



1.3 Regional District of Nainaimo (RDN) and Geological Survey of Canada (GSC) presentations of the Nanaimo Lowland Groundwater Study

Our programs and involvement in the Nanaimo Lowland Groundwater Study

Our highlights and main findings of Nanaimo Lowland Groundwater Study

1.4 Specific groundwater characteristics of a sampled area of the Nanaimo Lowland

Exercises on understanding hydrogeological information

Difficulty level of the questions :

- **E** easy
- **M** moderately difficult
- **D** difficult

Bedrock geology

Definition

When rock is sufficiently fractured, it can constitute an **AQUIFER**, in which wells can be installed. The ability of **FRACTURED BEDROCK** aquifers to release water depends on fracture thickness (openness) and interconnection. Fractures are accentuated by post-depositional tectonic compression and differential erosion following glacier flow. Inversely, some rock units can form an **AQUITARD** when they are fine-grained, cemented, and their fracture network is poorly developed.

AQUIFER, **AQUITARD** page 14
FRACTURED BEDROCK page 15

Methodology

The study and understanding of sedimentary bedrock aquifers incorporate four components:

- Mapping: delineating the 2D distribution of identifiable bedrock lithologies
- Stratigraphy: identifying the layering, interbedding, and lateral extents of potential aquifer and aquitard zones
- Sedimentology: studying the dimensions and internal characteristics and qualities of individual bedrock horizons
- Structural geology: observing the distribution and trends of folds, faults, and fractures

To begin to understand bedrock aquifer characteristics, 61 surface outcrops within and outside of the study area, and one long core (215 m in length), were measured and described. A full assessment of the aquifer potential of the various sedimentary rock units and of the possible contribution of porous- versus fracture-controlled aquifer properties needs additional work that was beyond the scope of this project.

Interpretation for the study area

The Nanaimo Group sedimentary rocks display a prominent pattern of alternating coarse-grained (potential regional-scale aquifer zones) and fine-grained (potential regional-scale aquitard zones) formations. Extensive fracturing is commonly observed, especially at shallow depths, but the extent and orientation of fracturing in the subsurface is currently unknown. The quality of the water in these potential aquifers may be brackish at depth.

The Nanaimo Group comprises a total stratigraphic thickness of up to 4 km, and is subdivided into 11 formations, of which only the lower eight are present in the study area. From bottom to top, these are :

1. Comox Formation, composed of sandstone and conglomerate, the best regional bedrock aquifer potential;
2. Haslam Formation, composed of siltstone and mudstone with minor sandstone interbeds, a regionally extensive aquitard zone;
3. Extension Formation, composed of conglomerate and coarse sandstone, a potential aquifer zone;
4. Pender Formation, composed of siltstone, sandstone, and mudstone, a potential aquitard zone;
5. Protection Formation, composed of sandstone with minor mudstone, an additional potential aquifer zone;
6. Cedar District Formation, composed of mudstone and siltstone with minor sandstone interbeds, a regionally extensive aquitard;
7. De Courcy Formation, composed of sandstone with lesser conglomerate, may have good aquifer characteristics;
8. Northumberland Formation, composed of mudstone and siltstone with minor sandstone interbeds, a potential aquitard zone.

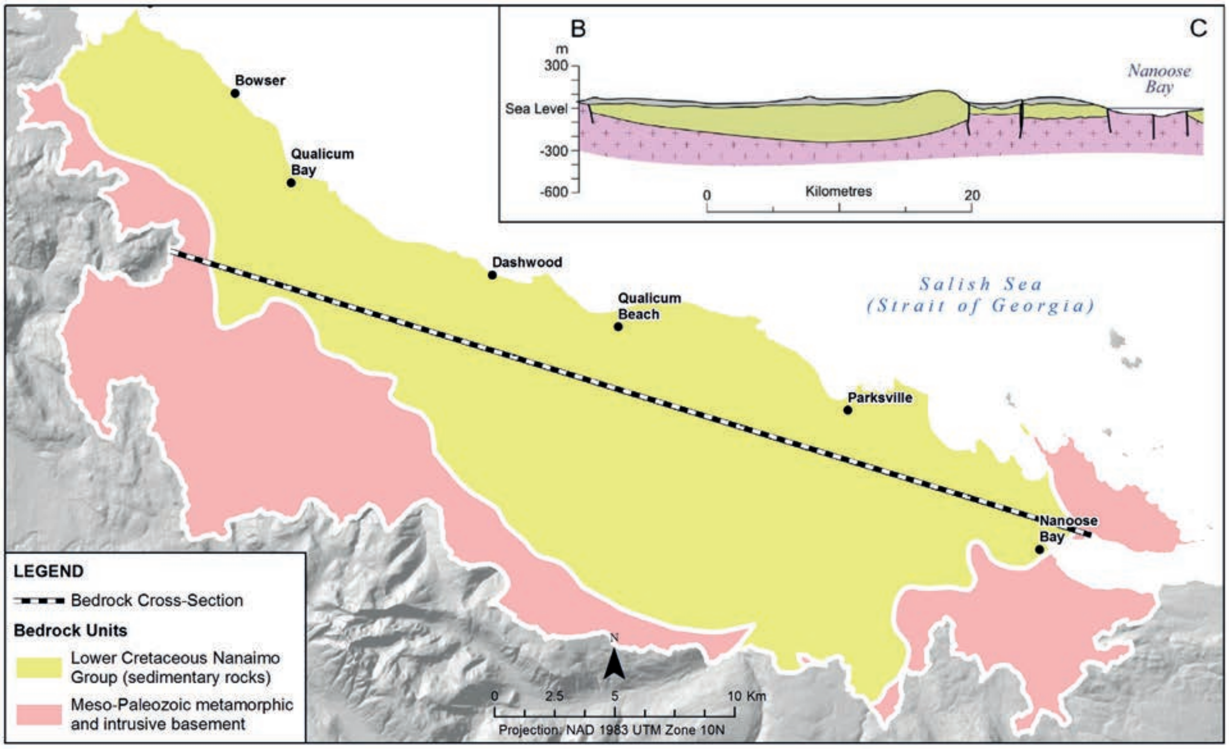
E Only rocks at shallow depths, where extensive fracturing is observed, may constitute aquifers.

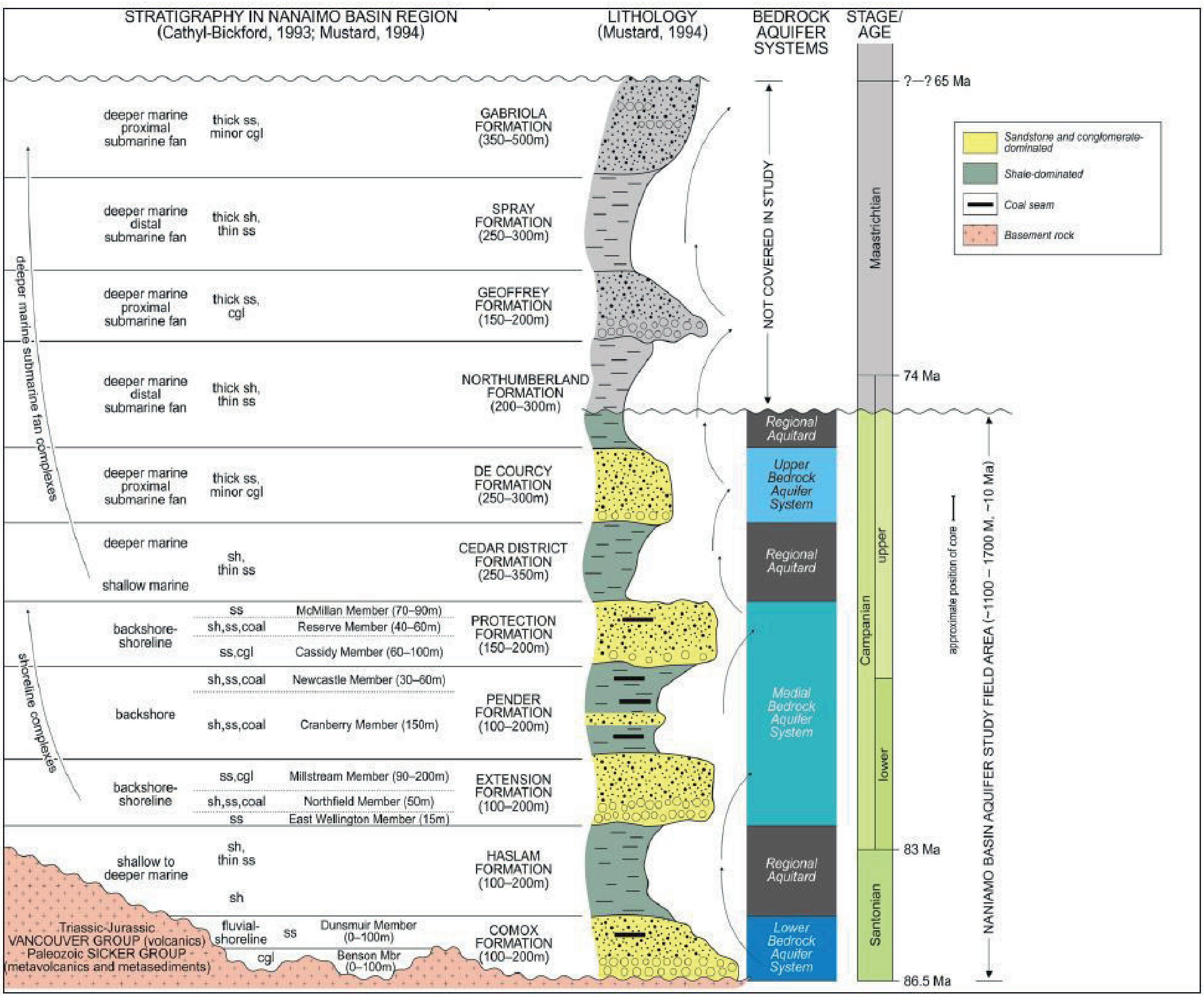
True ☐ False ☐

E Protection Formation is a potential aquifer zone.

True ☐ False ☐

M Which rock formation(s) may constitute potential regionally-extensive aquitard zones?


B
C
m
300
Sea Level
-300
-600
0
Kilometres
20
Nanoose Bay
Bowser
Qualicum Bay
Dashwood
Qualicum Beach
Parksville
Nanoose Bay
Salish Sea (Strait of Georgia)
LEGEND
Bedrock Cross-Section
Bedrock Units
Lower Cretaceous Nanaimo Group (sedimentary rocks)
Meso-Paleozoic metamorphic and intrusive basement
N
0 2.5 5 10 Km
Projection: NAD 1983 UTM Zone 10N


STRATIGRAPHY IN NANAIMO BASIN REGION (Cathyl-Bickford, 1993; Mustard, 1994)
LITHOLOGY (Mustard, 1994)
BEDROCK AQUIFER SYSTEMS
STAGE/ AGE
deeper marine proximal submarine fan
thick ss, minor cgl
GABRIOLA FORMATION (350–500m)
deeper marine distal submarine fan
thick sh, thin ss
SPRAY FORMATION (250–300m)
deeper marine proximal submarine fan
thick ss, cgl
GEOFFREY FORMATION (150–200m)
deeper marine distal submarine fan
thick sh, thin ss
NORTHUMBERLAND FORMATION (200–300m)
deeper marine proximal submarine fan
thick ss, minor cgl
DE COURCY FORMATION (250–300m)
deeper marine
shallow marine
sh, thin ss
CEDAR DISTRICT FORMATION (250–350m)
backshore-shoreline
ss
McMillan Member (70–90m)
sh,ss,coal
Reserve Member (40–60m)
ss,cgl
Cassidy Member (60–100m)
PROTECTION FORMATION (150–200m)
backshore
sh,ss,coal
Newcastle Member (30–60m)
sh,ss,coal
Cranberry Member (150m)
PENDER FORMATION (100–200m)
backshore-shoreline
ss,cgl
Millstream Member (90–200m)
sh,ss,coal
Northfield Member (50m)
ss
East Wellington Member (15m)
EXTENSION FORMATION (100–200m)
shallow to deeper marine
sh, thin ss
sh
HASLAM FORMATION (100–200m)
fluvial-shoreline
ss
Dunsmuir Member (0–100m)
cgl
Benson Mbr (0–100m)
COMOX FORMATION (100–200m)
Triassic-Jurassic VANCOUVER GROUP (volcanics)
Paleozoic SICKER GROUP (metavolcanics and metasediments)
deeper marine submarine fan complexes
shoreline complexes
NOT COVERED IN STUDY
Regional Aquitard
Upper Bedrock Aquifer System
Regional Aquitard
Medial Bedrock Aquifer System
Regional Aquitard
Lower Bedrock Aquifer System
Maastrichtian
Campanian
upper
lower
Santonian
?—? 65 Ma
74 Ma
83 Ma
86.5 Ma
Sandstone and conglomerate-dominated
Shale-dominated
Coal seam
Basement rock
approximate position of core
NANIAMO BASIN AQUIFER STUDY FIELD AREA (~1100 – 1700 M, ~10 Ma)

Surficial geology

Definition

The first step to understanding the stratigraphy of **UNCONSOLIDATED DEPOSITS** at depth is to identify the **TYPES OF SEDIMENT** observed on the ground surface. These deposits are generally closely linked to the past glacial history, with successive episodes of sediment deposition and erosion.

UNCONSOLIDATED DEPOSITS page 15

TYPES OF SEDIMENT page 16

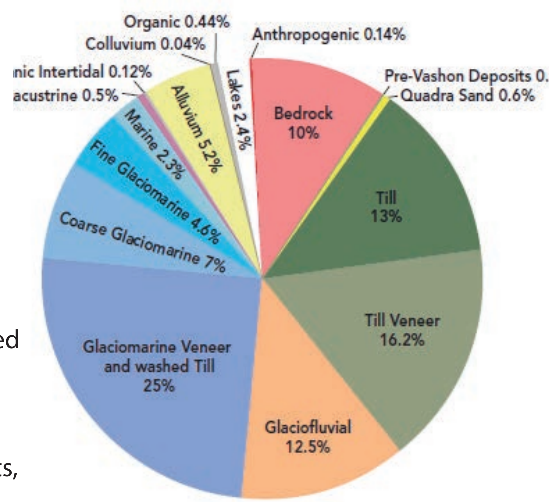
Methodology

The surficial map was generated based on manual delineation of the surficial units by interpretation of aerial photographs, composite satellite images, and a digital elevation model (DEM). Additional stratigraphic information was derived from the BC Water Well Database, BC aggregate resource potential database, soil maps, seismic reflection data, and rotosonic cores collected during the study. Most of the fieldwork and ground verification was along roads, stream banks, and coastal cliffs.

Interpretation for the study area

The thick unconsolidated sediment underlying the study area records a succession of two glacial intervals separated by a period of nonglacial sedimentation, all overlain by postglacial marine and fluvial deposits. There are six main surficial geological units that make up the stratigraphic framework in the study area (from bottom to top, or older to younger) :

1. Mapleguard Sediments - Dashwood Drift, from the Penultimate Glaciation, composed of glacial till and glaciomarine sediments;
2. Cowichan Head Formation, from the Olympia Nonglacial Interval, composed of marine sediments;
3. Quadra Sand, from the Fraser Glaciation, composed of glaciofluvial sediments;
4. Vashon Drift, from the Fraser Glaciation, composed of glacial till and glaciofluvial sediments;
5. Capilano Sediments, from the Fraser Glaciation to the postglacial period, composed of glaciomarine to marine, and glaciofluvial to fluvial sediments;
6. Salish Sediments, from the postglacial period to modern times, composed of fluvial, marine, lacustrine, slope, and organic sediments.



The relative proportions of the main mapped surficial units are illustrated in the pie diagram. Note that important aquifers and aquitards, such as the Quadra Sand and the pre-Vashon sediments respectively, comprise only a small fraction of the material exposed at the surface. Significant groundwater recharge is restricted to alluvium and glaciofluvial deposits, which cover approximately 18% of the total area.

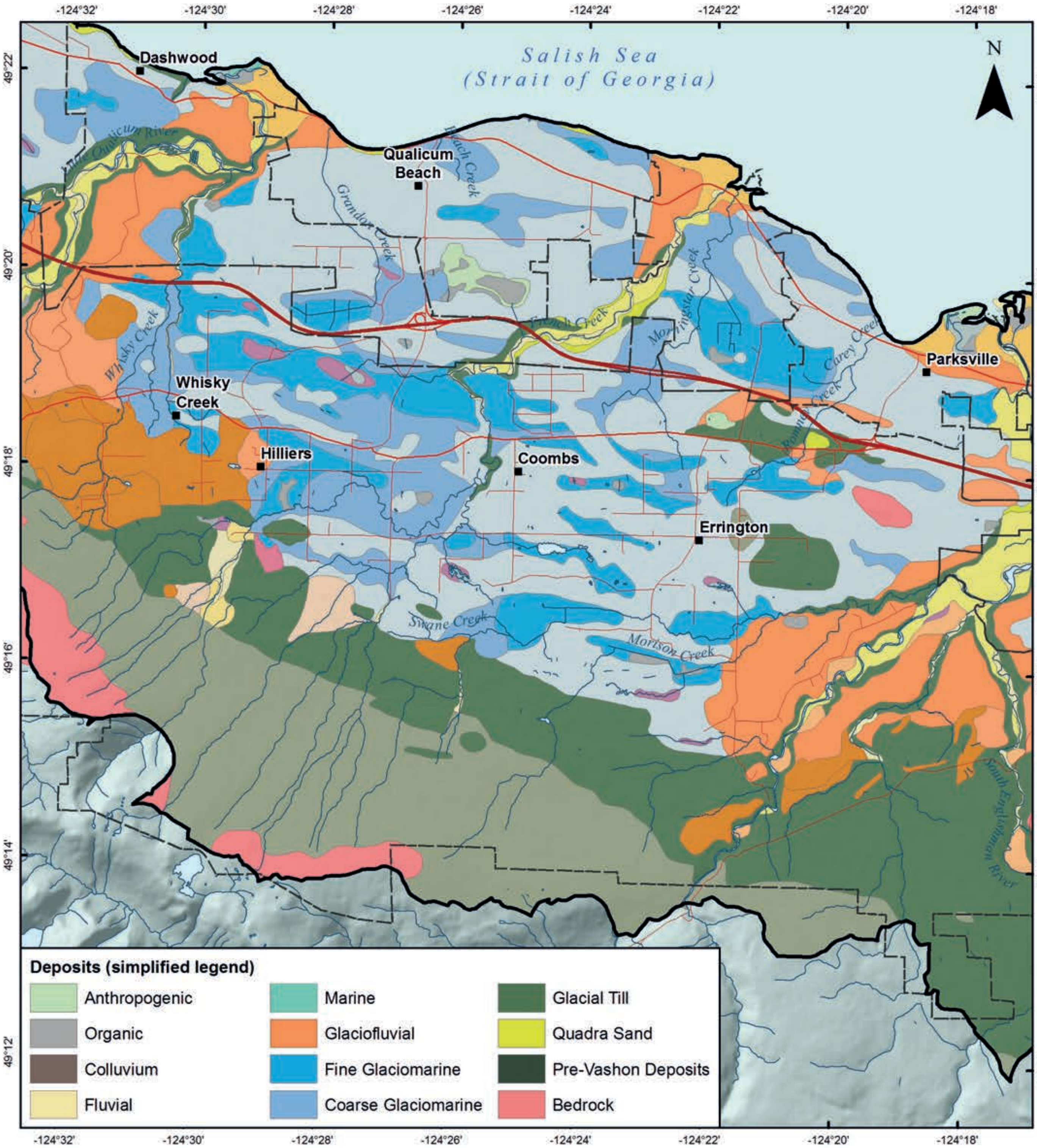
E Glaciomarine sediments are only observed at the surface at lower elevations.

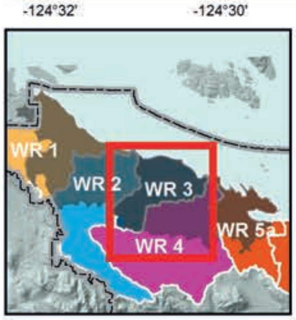
True ☐ False ☐

E Glacial tills are mostly present at the surface at higher elevations.

True ☐ False ☐

M Why is the Quadra Sand unit rarely observed at the surface, even though it is known to be an important aquifer in the study region?





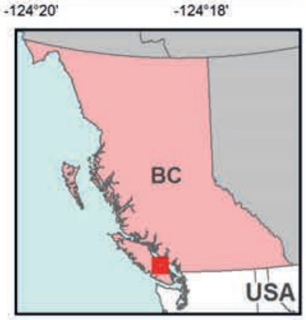
Surficial Geology

NANAIMO LOWLAND, BC

1:100 000

0 2 4 6 8 Km

Projection: NAD 1983 UTM Zone 10N



Sediment thickness

Definition

UNCONSOLIDATED DEPOSITS that are coarse-grained (sand and gravel) and sufficiently thick may constitute an **AQUIFER**. However, if the sediments are fine-grained (clay and silt), and therefore not very permeable, they will instead form an **AQUITARD**. Information on the thickness and texture of unconsolidated deposits may also be useful in domains other than hydrogeology, such as geotechnics, and building construction and infrastructure.

AQUIFER, **AQUITARD** page 14
UNCONSOLIDATED DEPOSITS page 15

Methodology

Bedrock topography was first interpolated from the topographic DEM, outcrop observations, and bedrock-sediment contacts identified in public water well records and seismic surveys. Further validation was obtained through other data collected in the field (i.e., rotosonic core descriptions and borehole geophysical logs). The unconsolidated sediment depth and thickness was then constrained using the topographic DEM and the bedrock topography.

Interpretation for the study area

Sediment deposits of up to 210 m-thick are present in the western part of the study area. Thick deposits have been modelled for two other, smaller areas, near Qualicum Beach and Nanoose Bay. Elsewhere, in particular in the Englishman River, total sediment thickness is lower, rarely exceeding 40 m.

Seismic data and boreholes indicate that thick deposits are more extensive than previously anticipated from the provincial water well record. It should be noted, however, that the interpolation process might also result in an overestimation of the thicknesses, because there are only a few deep boreholes and seismic survey data points to constrain the interpolation at depth.

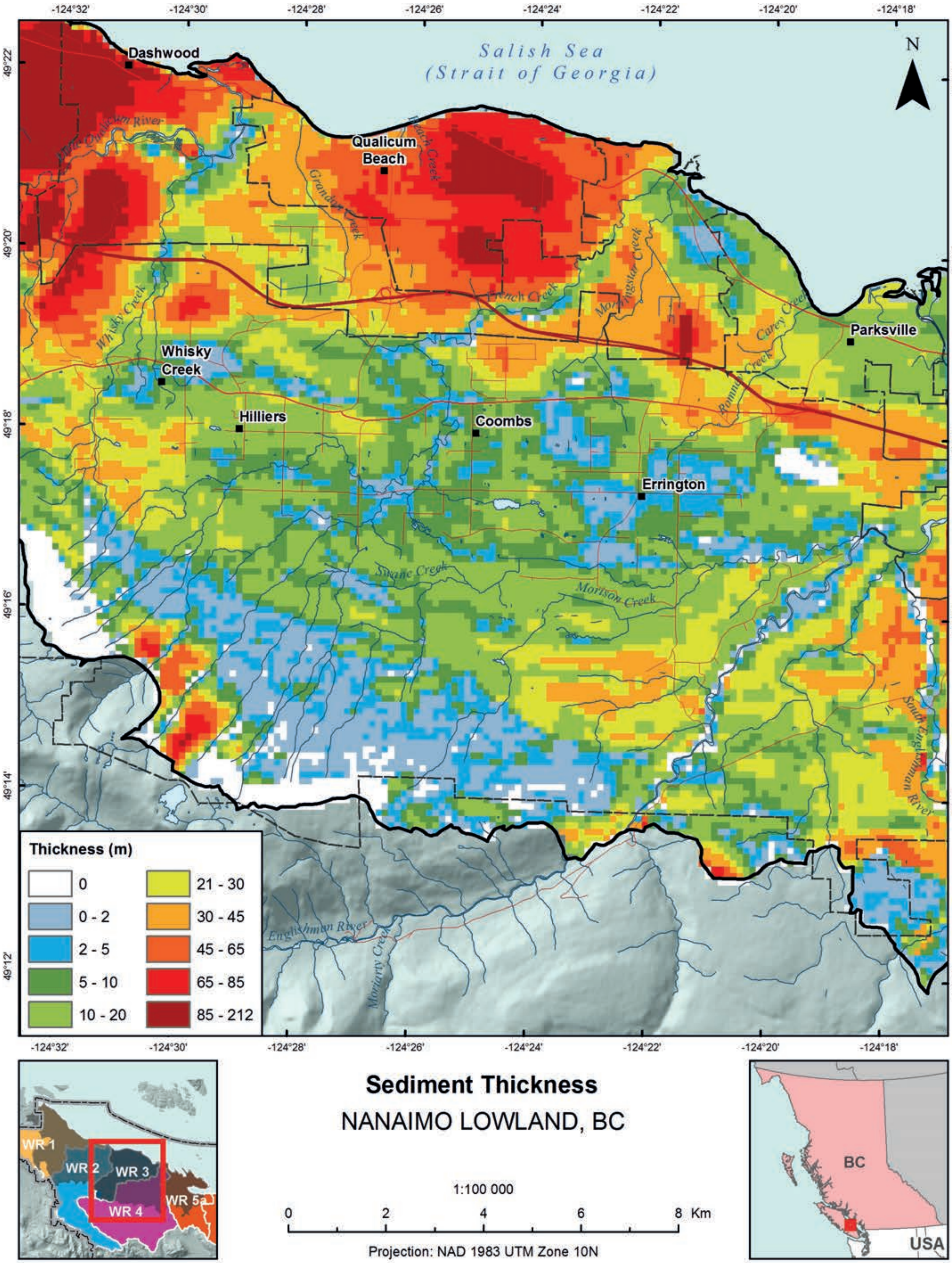
E Dashwood center overlies thick sediment deposits.

True ☐ False ☐

E The thickest unconsolidated deposits are found in the river valley bottoms.

True ☐ False ☐

M Can the sediment thickness map be used to locate unconsolidated sediment aquifers?



Sediment Thickness

NANAIMO LOWLAND, BC

1:100 000

0 2 4 6 8 Km

Projection: NAD 1983 UTM Zone 10N

General hydrostratigraphy

Definition

Hydrostratigraphy is the relationship between geology and the hydrogeological properties of materials (sediments or rocks) that compose an aquifer system. A hydrostratigraphic column shows the relationships between the various geological and hydrogeological units of the study area. The hydrostratigraphy commonly consists of aquifer and aquitard units of various thicknesses and extents.

GLACIAL TILL, **GLACIOFLUVIAL**, **MARINE**, **GLACIOMARINE**, **FLUVIAL SEDIMENTS** page 16

GLACIOFLUVIAL, **FLUVIAL**, and **GLACIOMARINE SEDIMENTS**, such as deltaic deposits, generally form aquifer units. Aquitard units are associated with **GLACIAL TILL** and **MARINE SEDIMENTS**, deposited as fine particles in deep water.

Methodology

The lithostratigraphic column is based on a standard succession that is widely observed in sea cliffs and riverbanks (Fyles, 1963), as well as in the deep rotosonic wells of this study. The sediments were grouped according to their hydrogeological potential, the dominance of the material, and their thickness. Nine hydrostratigraphic units were defined (from top to bottom, or younger to older) : Capilano-Salish (I); Capilano Glaciomarine (II); Vashon-Capilano Coarse (III); Vashon Till (IV); Quadra (V); Cowichan-Dashwood (VI); Dashwood-Mapleguard (VII); Bedrock - Sedimentary (VIII); and Bedrock - Metamorphic (IX).

Interpretation for the study area

Five distinct aquifer units are recognized : the Capilano-Salish (I), the Vashon-Capilano coarse (III), the Quadra (V), the Dashwood-Mapleguard (VII), and the sedimentary bedrock (VIII). The main aquitard units are the Capilano Glaciomarine (II), the Vashon Till (IV), the Cowichan-Dashwood (VI), and the metamorphic and intrusive bedrock (IX).

The surficial aquifers are mostly discontinuous, and are composed of coarse glaciofluvial deposits or deltaic and fluvial sediments. Salish sediments along rivers are mostly recent fluvial deposits that are generally permeable, but of limited extent. Elsewhere, the study area is covered by marine deposits that are relatively impermeable due to their fine-grained size (Capilano Glaciomarine (II)). The thickness of these sediments is highly variable from a few cm to up to 12 m.

The area's most exploited hydrostratigraphic unit for groundwater is Quadra (V), which is present almost everywhere in the study area, except along the main rivers, where it has been eroded by rivers or cut-and-filled by the Vashon till (IV), and in the vicinity of the Englishman River. The upper part of the Quadra unit (V) is coarser and has the best aquifer potential; however, groundwater occupies only a small thickness of the unit.

The Mapleguard proglacial outwash deposits (VII) may be coarser than those of the Quadra (V) and have the potential to be good aquifers; however, the sediment architecture and composition of the unit are not well understood.

The sedimentary bedrock aquifer (VIII) is mostly sandstone and siltstone (Lower Nanaimo Group) in the study area, and generally has only moderate aquifer potential, such as when fractures are present to transmit water. Metamorphic and Intrusion bedrock (IX) is considered to be an aquitard unit, and only a few wells are reported from this formation.

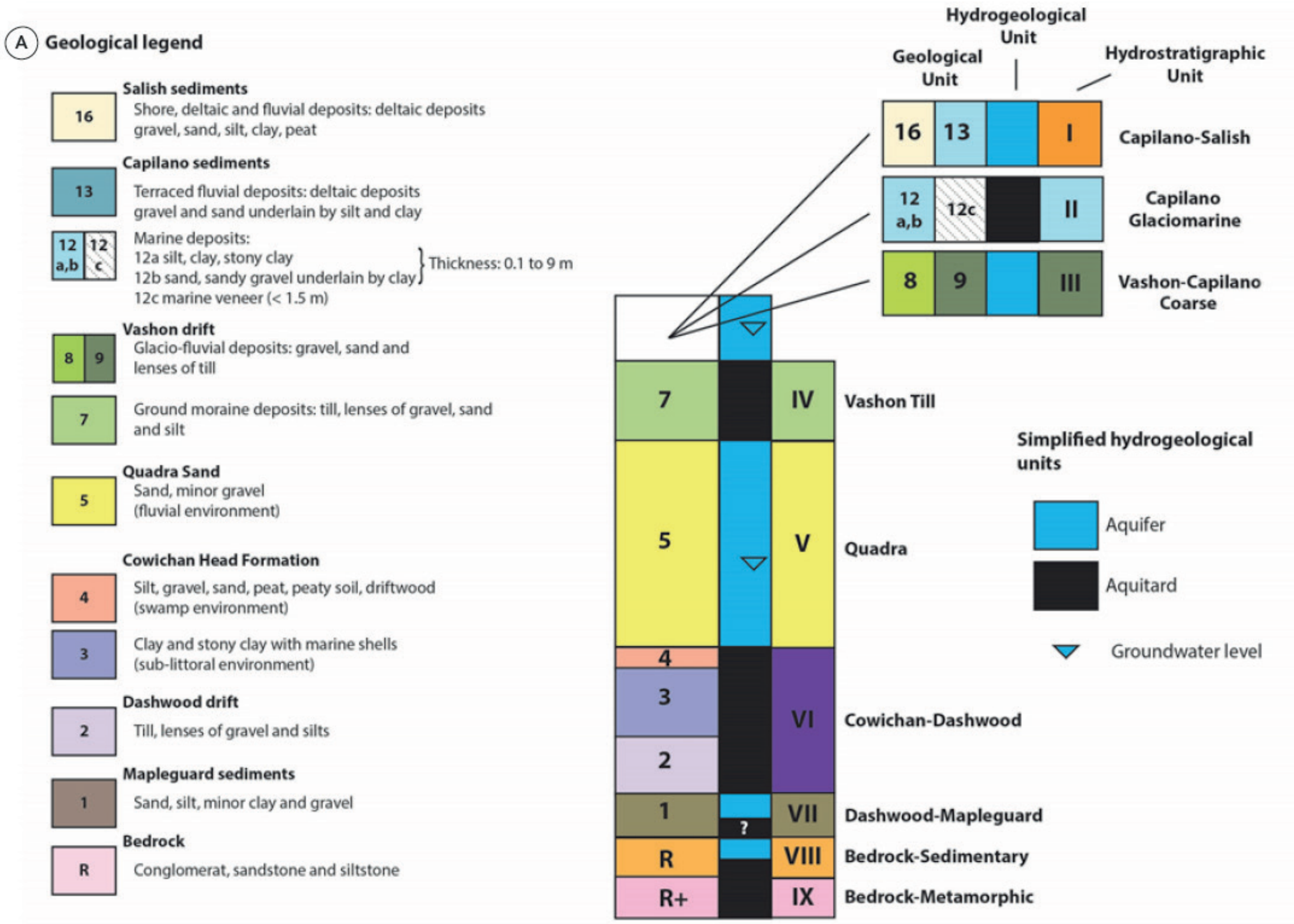
E Groundwater in Quadra Sands may be confined by the Vashon Till unit.

True ☐ False ☐

E Aquifers are probably easily recharged in areas where the Capilano Glaciomarine unit is found.

True ☐ False ☐

M How many distinct unconsolidated aquifers are recognized in the study area, and which are they?


A
Geological legend
Salish sediments
16
Shore, deltaic and fluvial deposits: deltaic deposits gravel, sand, silt, clay, peat
Capilano sediments
13
Terraced fluvial deposits: deltaic deposits gravel and sand underlain by silt and clay
12 a,b
12 c
Marine deposits:
12a silt, clay, stony clay
12b sand, sandy gravel underlain by clay
12c marine veneer (< 1.5 m)
Thickness: 0.1 to 9 m
Vashon drift
8
9
Glacio-fluvial deposits: gravel, sand and lenses of till
7
Ground moraine deposits: till, lenses of gravel, sand and silt
Quadra Sand
5
Sand, minor gravel (fluvial environment)
Cowichan Head Formation
4
Silt, gravel, sand, peat, peaty soil, driftwood (swamp environment)
3
Clay and stony clay with marine shells (sub-littoral environment)
Dashwood drift
2
Till, lenses of gravel and silts
Mapleguard sediments
1
Sand, silt, minor clay and gravel
Bedrock
R
Conglomerat, sandstone and siltstone
Geological Unit
Hydrogeological Unit
Hydrostratigraphic Unit
16 13 I Capilano-Salish
12 a,b 12c II Capilano Glaciomarine
8 9 III Vashon-Capilano Coarse
7 IV Vashon Till
5 V Quadra
4
3
2
VI Cowichan-Dashwood
1 ? VII Dashwood-Mapleguard
R VIII Bedrock-Sedimentary
R+ IX Bedrock-Metamorphic
Simplified hydrogeological units
Aquifer
Aquitard
Groundwater level

Hydrostratigraphic unit thickness and spatial distribution

Definition

3D hydrostratigraphic models (HSMs) define the distribution and thickness of hydrostratigraphic units defined according to their **TYPES OF SEDIMENT** and bedrock. Development of a 3D model provides a basis for integrating knowledge gained during the course of a hydrogeological study, and forms a framework for understanding **GROUNDWATER FLOW** dynamics.

TYPES OF SEDIMENT page 16
GROUNDWATER FLOW page 18

Methodology

Based on available data and the general hydrostratigraphy of the study area, a 3D HSM was constructed for the Nanaimo Lowland using a 3D geographical information system (GIS). All unconsolidated sediment hydrostratigraphic surfaces were constrained using the surface topgraphy (DEM), existing stratigraphic columns and cross-sections, the updated surficial geology map, rotosonic cores, and seismic surveys. When well depths and geological descriptions allowed, hydrostratigraphic information extracted from public water well records were also used to interpolate sediment contact surfaces. The model was then compared to surficial geological mapping and data quality, and corrections were made based on professional judgment.

The data support for the model limits its representation of fine-scale facies changes (horizontal and vertical) and, hence, the geological heterogeneity of the model is only sufficient to support hydrogeological study at the regional level. Data support generally decreases with depth and, in the areas of thickest sediment, the lower units (Dashwood-Mapleguard (VII)) are constrained only by seismic reflection data.

Interpretation for the study area

Capilano-Salish (I) and Capilano glaciomarine (II) are the thinnest units, with a median thickness of 1 and 2 m respectively. These units are widespread over the lowland part of the study area, although with discontinuous cover.

Vashon-Capilano (coarse) (III) and Vashon (till) (IV) occur over most of the study area, and their median thicknesses are 5 and 7 m respectively.

Quadra (V), Cowichan-Dashwood (VI), and Dashwood-Mapleguard (VII) are the thickest units, with median thicknesses of between 16 and 19 m. They are mostly present along the coast, between Deep Bay and Parksville. Elsewhere, south of Parksville and toward the mountains, these units are rarely observed.

The Dashwood-Mapleguard (VII) unit is expected to have a spatial distribution similar to that of the Quadra (V) unit, due to similar depositional processes, but is likely less extensive, given the major erosive intervals that took place after its deposition. Its true extent, however, is uncertain due to the lack of deep boreholes in the area.

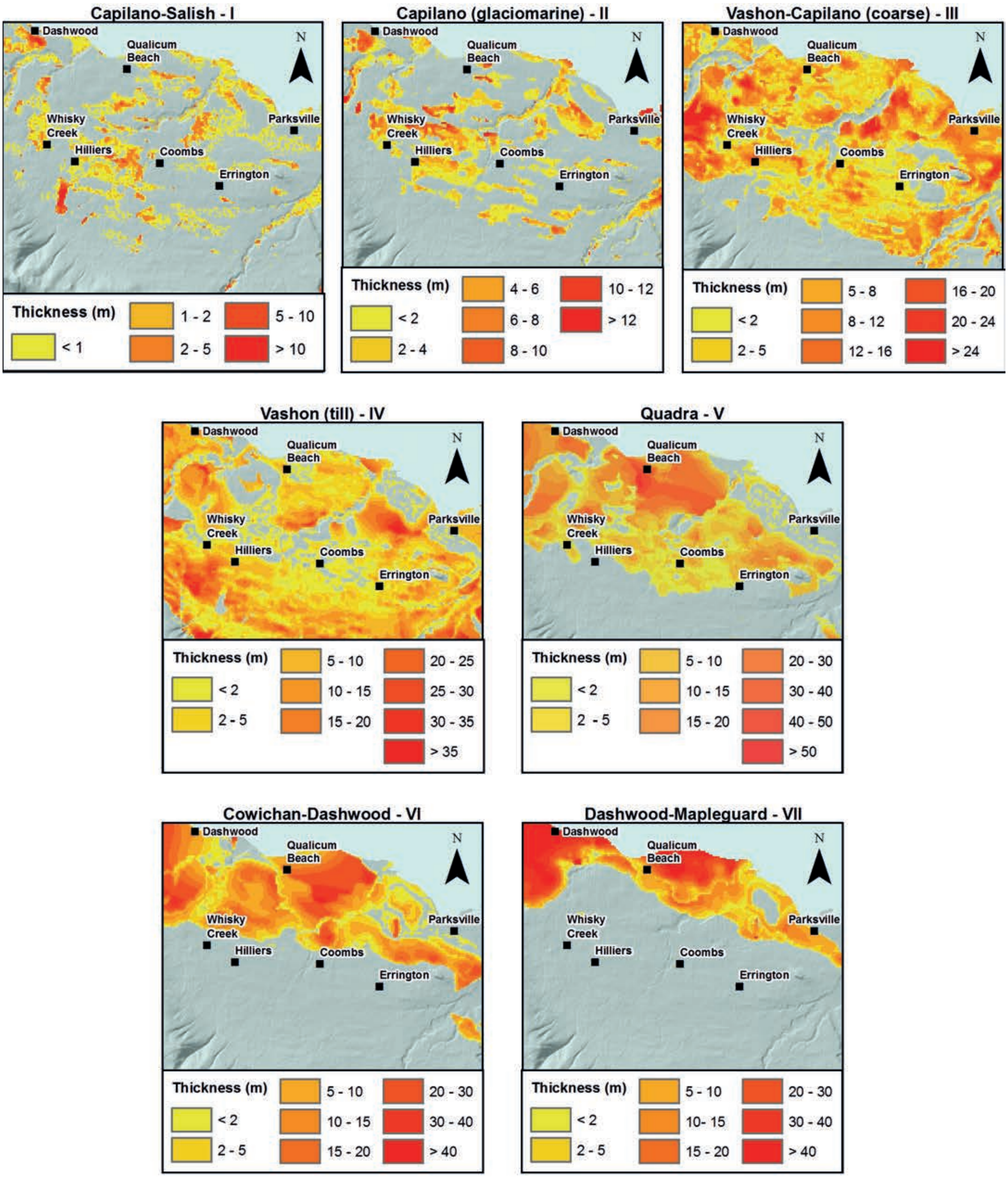
E The Capilano Glaciomarine sediments are generally thick and continuous throughout the study area.

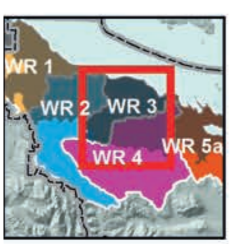
True ☐ False ☐

M Qualicum Beach center overlies three unconsolidated aquifers seperated with two aquitards composed of fine-grained sediments.

True ☐ False ☐

D What limits the certainty of hydrostratigraphic unit extents and thicknesses?





Hydrostratigraphic Unit Thickness and Spatial Distribution

NANAIMO LOWLAND, BC

1:300 000

0 4 8 12 16 20 Km

Projection: NAD 1983 UTM Zone 10N

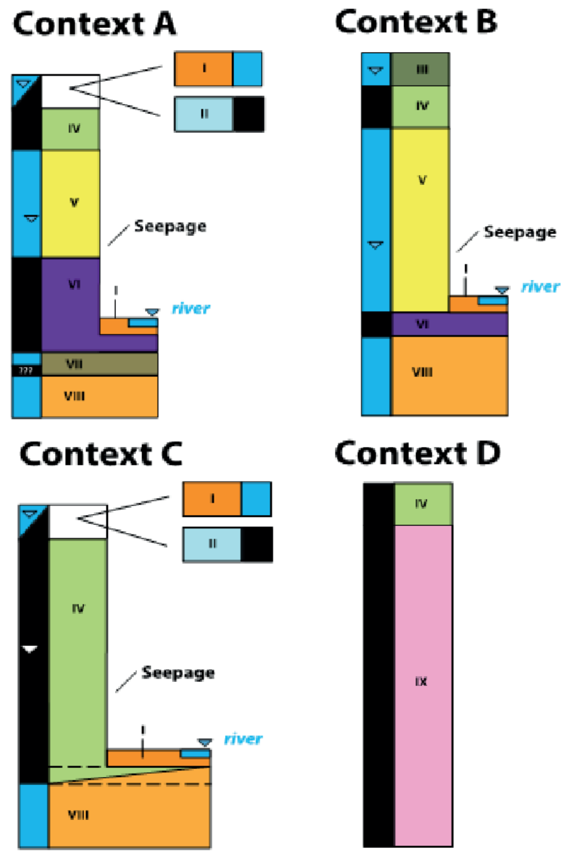
Hydrogeological contexts

Definition

Hydrogeological contexts are defined according to the vertically stacked sequences of hydrostratigraphic units. These contexts influence the flow conditions and groundwater quality, and can provide information of interest for the exploitation and management of groundwater resources.

Methodology

Four distinct contexts were identified based on model layer geometries with similar spatial relationships (see adj. figures). It is assumed that groundwater exchange between hydrostratigraphic units is similar within each context.



Interpretation for the study area

- **Lowland Context (A)**: This is the standard succession, and is applicable to most of the study area. It includes portions of Nile Creek, Qualicum River, Little Qualicum River, and French Creek, all of which flow over the lowland in the eastern part of the study area, as well as a small area of the western part. This context is therefore present on both sides of the Englishman River Context. Most of the hydrostratigraphic units are present within the Lowland Context, except near the main rivers, where the sequence has been eroded by fluvial incision.
- **Cameron-Horne Lakes Context (B)**: Similar to the Lowland Context, except that the surficial unit is composed of large sand and gravel glaciofluvial deposits (Vashon-Capilano coarse (III)). This context is located at the outlets of the Cameron and Horne lakes in the lowland area. The Vashon-Capilano coarse (III) unit can be a large local, shallow aquifer that is expected to be perched over impermeable Vashon till (IV) or in direct contact with the Quadra (V) unit. The Dashwood-Mapleguard (VII) sediments may not be present at this elevation.
- **Englishman River Context (C)**: Its distribution closely matches the limits of the Englishman River watershed, which essentially flows on till and bedrock units. Like other major rivers in the study area, seepage faces can be observed along incised river valley slopes, but with lower discharge, due to the presence of less impermeable material. Capilano-Salish (I) deposits along the Englishman River (especially downstream) could form important riverbank storage and moderate the groundwater-surface water interaction.
- **Mountains Context (D)**: Located on the flanks of the mountainous area, it is essentially composed of till (generally thin) over metamorphic and intrusion bedrock.

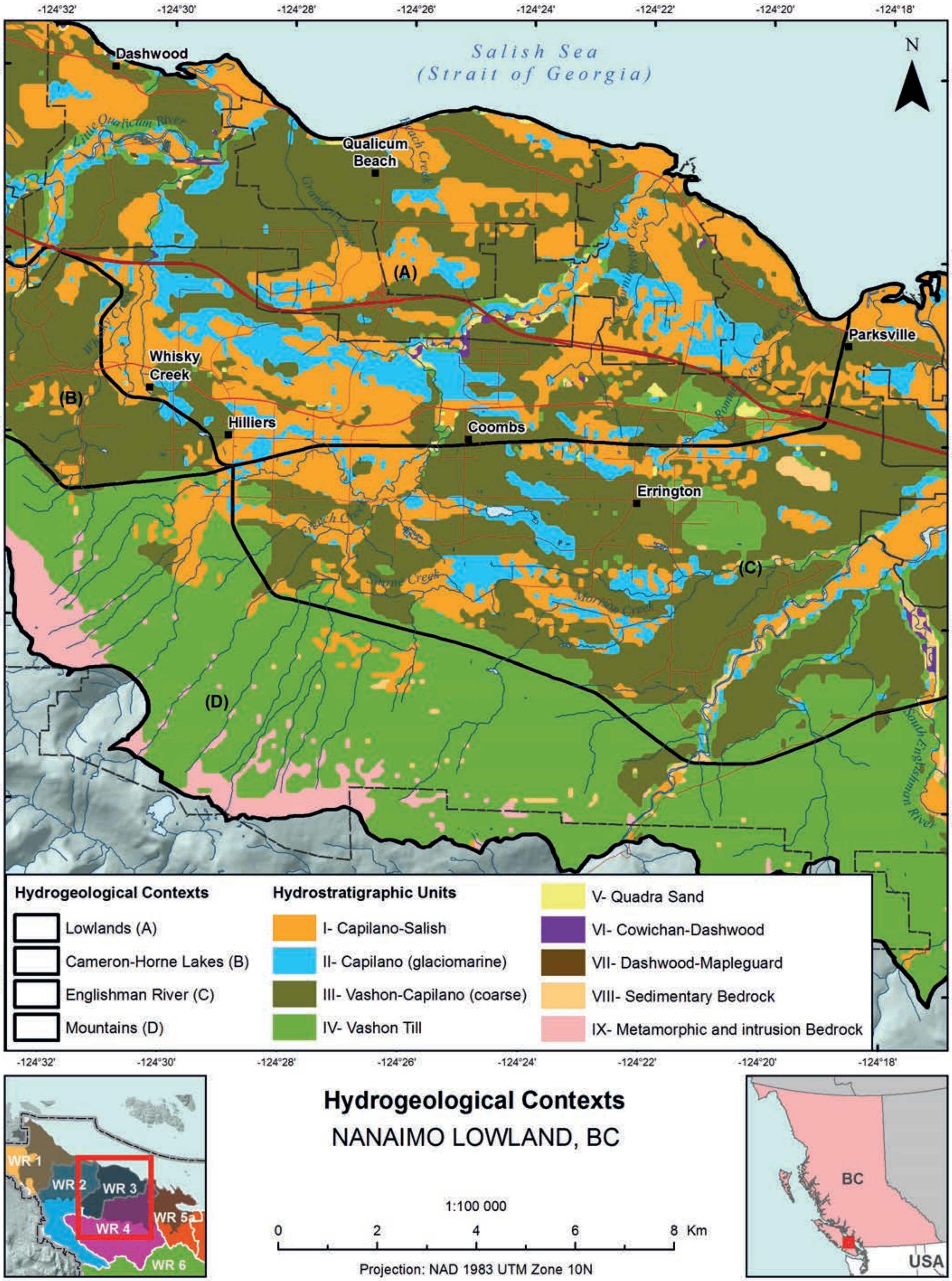
E The Quadra Sand Aquifer is found in all hydrogeological contexts, except the Mountains Context.

True ☐ False ☐

M Permeable units at the ground surface, such as depicted in the Hydrogeological Contexts map, necessarily imply the presence of surficial aquifers.

True ☐ False ☐

M In the Lowland Context, is it preferable for a municipality to supply its population with groundwater from bedrock aquifers or unconsolidated deposits? Why?



Salish Sea
(Strait of Georgia)
N
Dashwood
Little Qualicum River
Qualicum Beach
Beach Creek
Grandon Creek
French Creek
(A)
Whisky Creek
(B)
Hilliers
Coombs
Parksville
Errington
(C)
(D)
Morrison Creek
South Englishman River
Hydrogeological Contexts
Lowlands (A)
Cameron-Horne Lakes (B)
Englishman River (C)
Mountains (D)
Hydrostratigraphic Units
I- Capilano-Salish
II- Capilano (glaciomarine)
III- Vashon-Capilano (coarse)
IV- Vashon Till
V- Quadra Sand
VI- Cowichan-Dashwood
VII- Dashwood-Mapleguard
VIII- Sedimentary Bedrock
IX- Metamorphic and intrusion Bedrock
-124°32'
-124°30'
-124°28'
-124°26'
-124°24'
-124°22'
-124°20'
-124°18'
49°22'
49°20'
49°18'
49°16'
49°14'
49°12'
WR 1
WR 2
WR 3
WR 4
WR 5a
WR 6
Hydrogeological Contexts
NANAIMO LOWLAND, BC
1:100 000
0
2
4
6
8 Km
Projection: NAD 1983 UTM Zone 10N
BC
USA

Quadra Sand aquifer confinement

Definition

Aquifer confinement is related to whether or not an aquifer is overlain by a layer of low permeability materials (aquitard), which isolates the groundwater from the surface. The nature and thickness of sediments or geological units determine the level of confinement of an aquifer, which can range from **UNCONFINED**, to **SEMI-CONFINED** or **CONFINED**. Confinement influences the groundwater flow dynamics and the hydrochemical processes by limiting or facilitating aquifer recharge or its protection from contamination from the surface.

CONFINED, **SEMI-CONFINED**, **UNCONFINED AQUIFER** page 17

Methodology

To determine the confinement conditions of the Quadra Sand aquifer (V), the thicknesses of the four hydrostratigraphic units overlying it were used: Capilano-Salish (I), Capilano glaciomarine (II), Vashon-Capilano (III), and Vashon Till (IV). The criteria used to define the confinement conditions are :

- **Confined aquifer** : more than 5 m of fine sediments (clay or silt);
- **Semi-confined aquifer** : more than 3 m of till, or less than 5 m of fine sediments; and
- **Unconfined aquifer** : coarse sediments (sand or gravel), or less than 3 m of till.

Interpretation for the study area

The Quadra Sand Aquifer (V) is generally confined in the western part of the Nanaimo Lowland, where it is overlain by thick deposits of Vashon Till (IV), which is mostly impermeable.

Semi-confined conditions are exhibited along the coast, between Bowser and Qualicum Bay, and in the downstream part of the French River watershed. In these areas, the Vashon Till (IV) cover is thinner and the overlying coarse Vashon-Capilano sediments (III) are too permeable to entirely protect the aquifer.

Confined and semi-confined aquifer zones are interspersed with areas of unconfined aquifer, where Vashon Till (IV) cover is nonexistent between the Vashon-Capilano sediments (III) and Quadra Sand (V). These conditions appear to explain the relatively large area of unconfined aquifer located south of Deep Bay, west of Qualicum Beach, and northwest of Nanoose Bay.

?

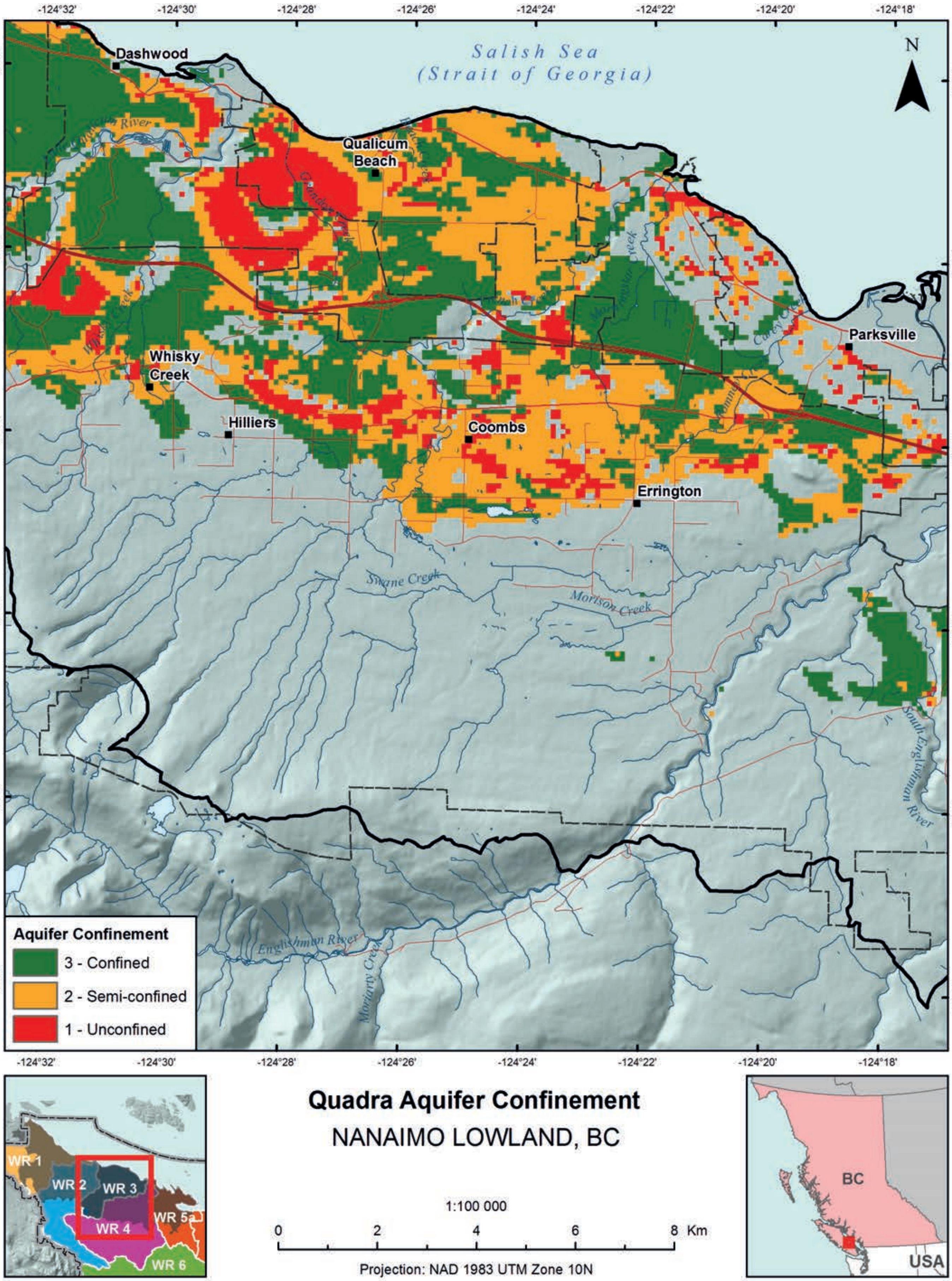
E The area just west of Dashwood is well protected from surface contamination.

True ☐ False ☐

E Semi-confined conditions of the Quadra Sand Aquifer are largely dependant on the presence or absence of Vashon Till cover.

True ☐ False ☐

E What is responsible for the unconfined zone just west of Qualicum Beach?



Quadra Aquifer Confinement

NANAIMO LOWLAND, BC

Groundwater flow

Definition

POTENTIOMETRIC LEVEL (or **hydraulic head** or **piezometry**) corresponds to the water level measured in a well. In an unconfined aquifer, this level also corresponds to the **WATER TABLE** elevation. In a confined aquifer, since it is under pressure, the well water level is above the top of the aquifer. The potentiometric map provides a general idea of the groundwater flow dynamics in the aquifer by indicating flow direction, which goes from higher to lower hydraulic heads.

WATER TABLE page 14
POTENTIOMETRIC LEVEL page 18

Methodology

To help understand and quantify regional groundwater flow in the study area, a numerical groundwater flow model was constructed using the finite element model FEFLOW (Diersch, 2014). The model was calibrated for saturated steady-state conditions, assuming that the model represents average natural past conditions. The calibration process was carried out against 247 well water levels extracted from the provincial database, 21 monitoring wells, and baseflow estimates for four rivers. Because no hydraulic connection is present between the main aquifer units of the region, two distinct groundwater flow systems were defined: one in the Quadra unit (V) and the other in the sedimentary bedrock unit (VIII).

Interpretation for the study area

The potentiometric maps for the two flow systems highlight that the general groundwater generally flows direction is toward the Strait of Georgia, with a component flowing toward the main rivers. The flow component toward the rivers is more important for the Quadra Unit (V) than for the bedrock unit (VIII). This is likely due to the fact that the Quadra unit (V) drains to the river through a seepage face, while the bedrock unit (VIII) is confined below the rivers by the low-permeability Cowichan-Dashwood unit (VI).

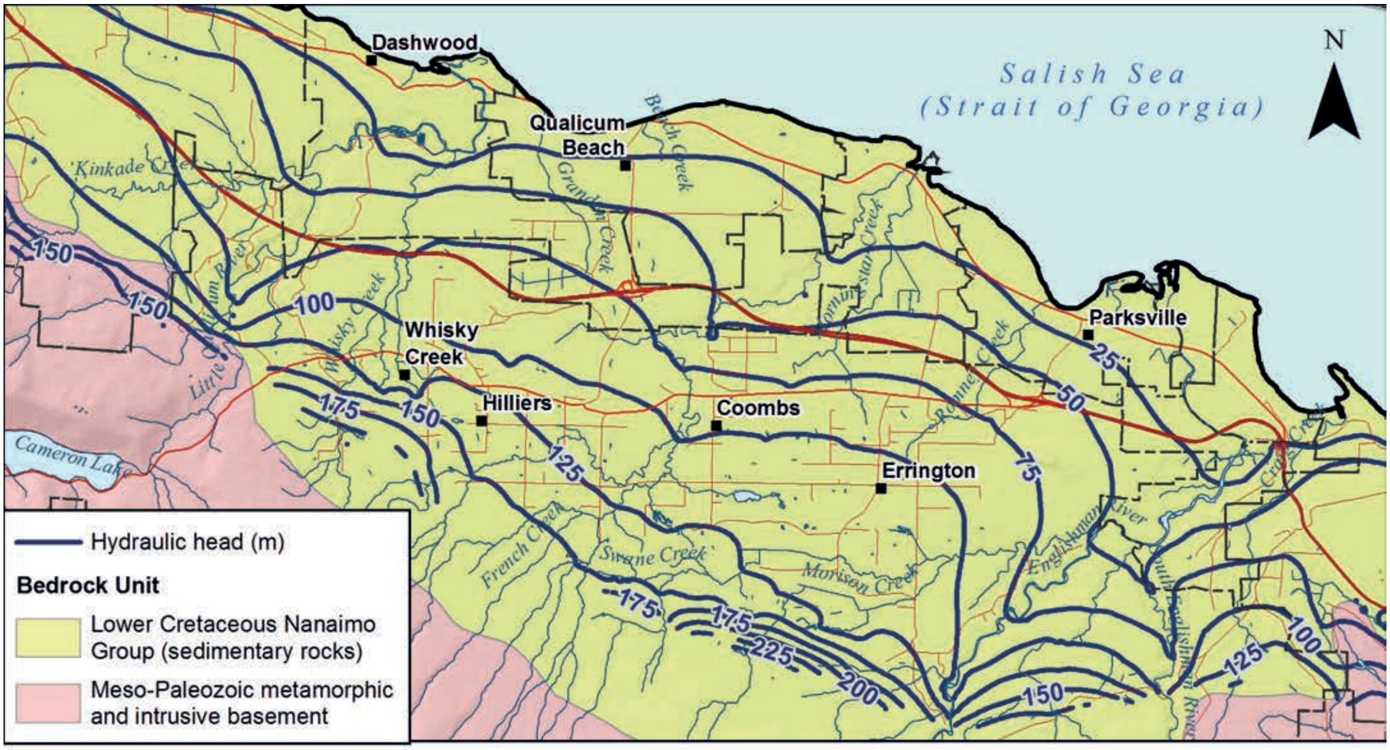
Groundwater flow simulation indicates that groundwater in the Quadra unit (V) is relatively young (< 70 years). In contrast, groundwater age in the sedimentary bedrock (VIII) is generally greater than a few hundred years. This estimation has not been verified by independent water sampling and dating, however.

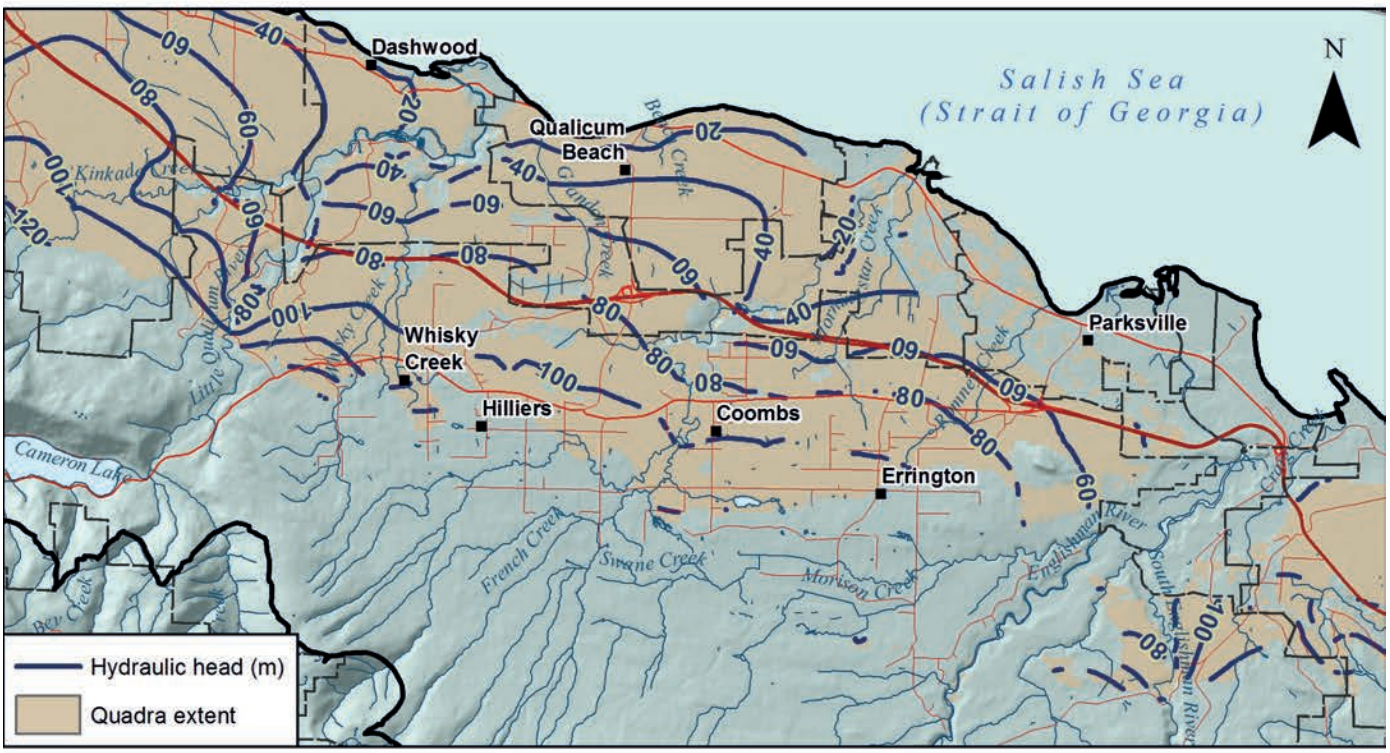
E Groundwater in the Quadra unit (V) flows from Parksville to Errington.

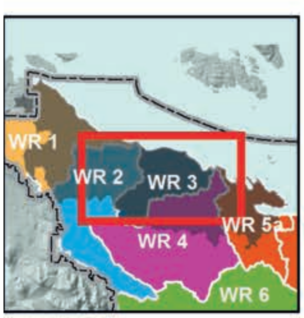
True ☐ False ☐

M Why is the flow component toward rivers greater for the Quadra unit (V) than for the bedrock unit (VIII)?

M What phenomenon is observed when the potentiometric level is above ground level?







Potentiometric Maps

NANAIMO LOWLAND, BC

1:150 000

0 3 6 9 12 Km

Projection: NAD 1983 UTM Zone 10N

Groundwater recharge

Definition

Groundwater **RECHARGE** corresponds to the amount of water supplied to an aquifer by surface infiltration. Recharge estimation is necessary to evaluate groundwater availability, since exploitable and sustainable yields depend on groundwater renewal.

RECHARGE, **SEEPAGE** page 19

Groundwater **SEEPAGE** is water emerging from the ground, as natural springs or as baseflow in streams and wetlands. This occurs when the water table level (or hydraulic head) is higher than the ground surface.

Methodology

Hydrograph separation methods are used for the analysis of daily stream-flow records in a watershed to estimate groundwater recharge. These approaches assume that nearly all groundwater discharges to a river, and that regulation and diversion of stream flow are negligible. Hydrograph separation methods are generally semi-empirical filters that are applied to streamflow records to extract the groundwater component, and specifically the baseflow.

Baseflow was estimated using both the 7-Day Low Flow and the Furey-Gupta methods. The 7-Day Low Flow method assumes that the minimum stream flow recorded for seven consecutive days, when precipitation is the lowest, corresponds to the groundwater contribution to the river that would be observed all year long. The Furey-Gupta method, on the other hand, is a semi-empirical filter that mimics the annual variation in groundwater contribution for days when the observation of baseflow is hindered by other components of stream flow. Given the assumptions inherent to each hydrograph separation method, the recharge values obtained for each watershed by the two methods were considered to be minimum (7-Day Low Flow) and maximum (Furey-Gupta) values respectively for groundwater modelling purposes.

Interpretation for the study area

Recharge values for watersheds located in Hydrogeological Context A (Lowland) vary between 205 and 338 mm/yr for the 7-Day Low Flow method and between 400 and 504 mm/yr for the Furey-Gupta method. These values correspond to groundwater recharge in the Quadra unit (V), which commonly discharges to rivers through seepage flow.

Recharge in Hydrogeological Context C (Englishman River) is between 48 mm/yr (7-Day Low Flow) and 99 mm/yr (Furey-Gupta), consistent with the low permeability of the sediments in this area, mainly till and bedrock.

Analysis of the water budget reveals that 71% of the groundwater discharges to surface water bodies, whereas the remaining 29% discharges along the coast of the Strait of Georgia.

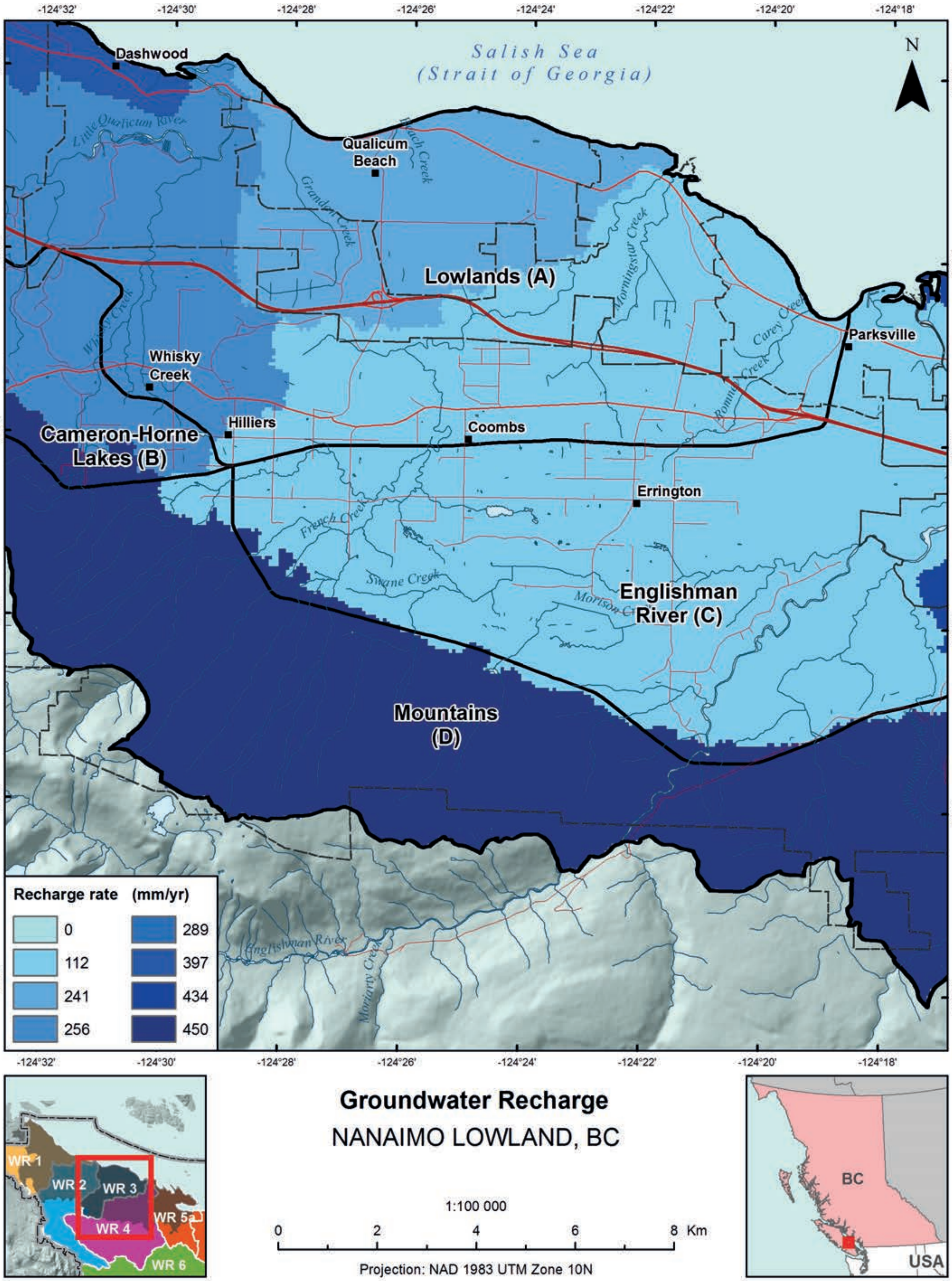
?

M Clays and silts of glaciomarine origin are responsible for limiting recharge in the Englishman River Context.

Vrai ☐ Faux ☐

M Why is recharge highest in the Mountains Context?

M Why is it important to prioritize the protection of groundwater recharge zones?


Salish Sea
(Strait of Georgia)
N
Dashwood
Qualicum Beach
Little Qualicum River
Beach Creek
Grandon Creek
Morningstar Creek
Lowlands (A)
Whisky Creek
Whisky Creek
Hilliers
Coombs
Parksville
Carey Creek
Romney Creek
Cameron-Horne Lakes (B)
Errington
French Creek
Swane Creek
Morison Creek
Englishman River (C)
Mountains (D)
Englishman River
Moriarty Creek
Recharge rate (mm/yr)
0
112
241
256
289
397
434
450
-124°32'
-124°30'
-124°28'
-124°26'
-124°24'
-124°22'
-124°20'
-124°18'
49°22'
49°20'
49°18'
49°16'
49°14'
49°12'
Groundwater Recharge
NANAIMO LOWLAND, BC
1:100 000
0 2 4 6 8 Km
Projection: NAD 1983 UTM Zone 10N
WR 1
WR 2
WR 3
WR 4
WR 5a
WR 6
BC
USA

Aquifer vulnerability

Definition

The intrinsic **VULNERABILITY** of an aquifer is its susceptibility to groundwater pollution from contaminants on the soil surface. Vulnerability mapping integrates a set of aquifer hydrogeological properties, thus combining the regional information into a single index. This index can be used as a tool for decision-making in land-use planning and management, to prevent possible groundwater contamination by potentially polluting anthropogenic activities.

VULNERABILITY, **DRASTIC** page 20

Methodology

DRASTIC is a widely-used method to determine groundwater vulnerability. The term DRASTIC is an acronym derived from the seven parameters to calculate the index : Depth to water, Recharge, Aquifer media, Soil media, Topography, Impact of vadose zone media, and aquifer hydraulic Conductivity. The DRASTIC index varies from 23 to 226 (low to high vulnerabilitity respectively).

The method requires specific mapped data to complete the analysis, most of which it is readily available from government agencies and other sources. A key source of information for this study was the BC Wells Database, which contains well information, including lithological layers, and the depth to water when the well was drilled or dug.

The DRASTIC map represents the vulnerability of the uppermost aquifer only. If there are additional aquifers lower in the sequence, these will be less vulnerable, but in most cases the uppermost aquifer is the most developed and, hence, the target for this study.

The results are not accurate enough to assess local conditions. In many cases, more detailed hydrogeological studies would be required to better characterize and confirm DRASTIC results, especially in areas with limited well data.

Interpretation for the study area

Results of the intrinsic aquifer vulnerability assessment indicate that the confined unconsolidated aquifers are characterized by moderate to low intrinsic vulnerability, due to the presence of a confining layer with low vadose zone permeability, combined with a slightly deeper depth to water. Unconfined unconsolidated aquifers have a higher intrinsic vulnerability, due to their relatively shallow depth to water, and permeable vadose zone and aquifer medium (reflected in the A and C parameters). Consolidated (i.e., bedrock) aquifers generally have moderate to low intrinsic vulnerability, due to their deeper depth to water, low-permeability aquifer medium, conductivity, and vadose zone ratings.

All aquifers were considered to be unconfined in this vulnerability assessment. Some mapped aquifers are known to be confined under a thick and impermeable till overburden (i.e., Quadra Sand Aquifer). In these cases, the DRASTIC map provides a conservative evaluation, and the intrinsic vulnerability is expected to be lower than is indicated by this study.

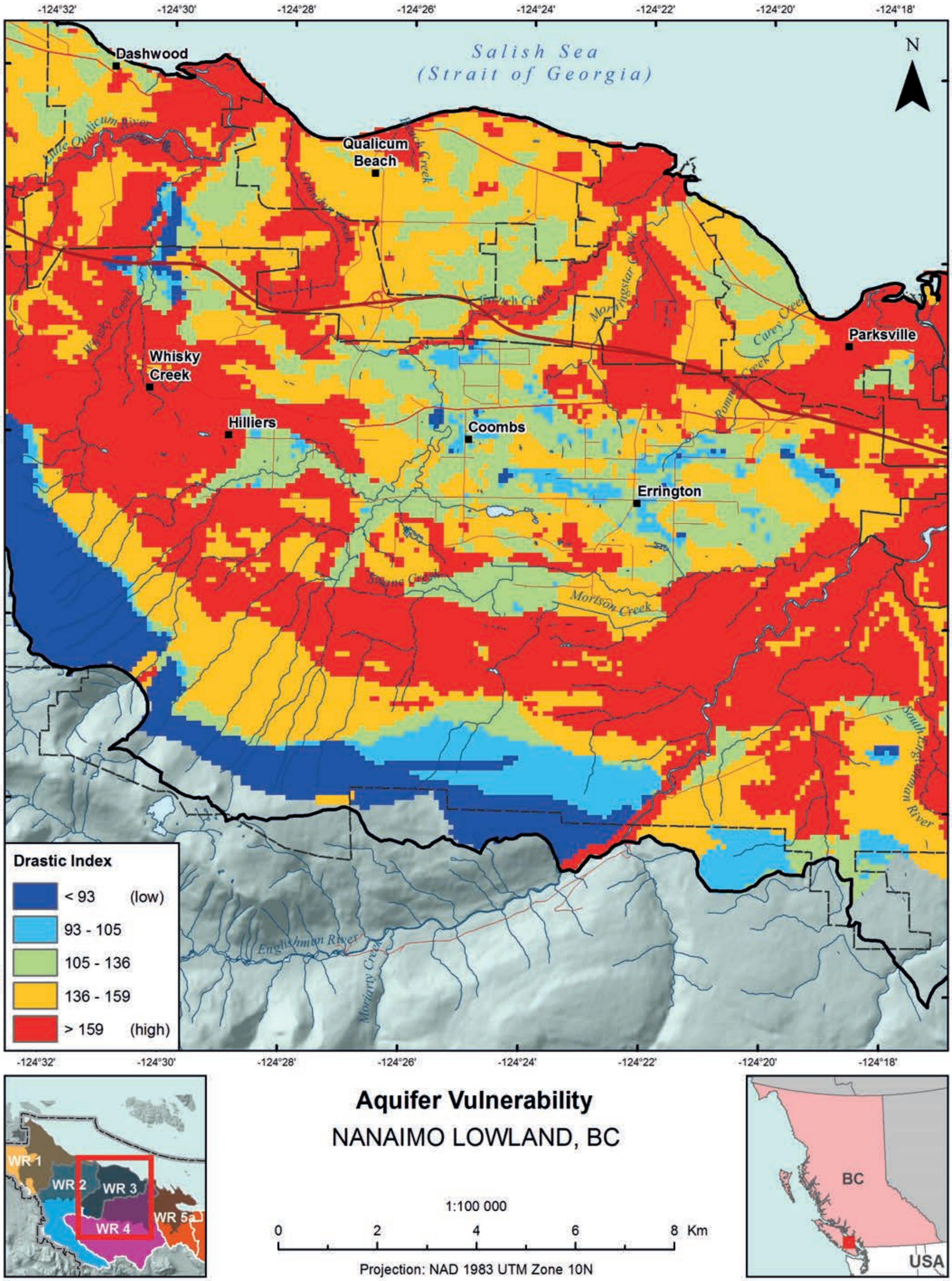
E Unconfined unconsolidated aquifers have a higher intrinsic vulnerability, due to the low permeability of the vadose zone and aquifer medium, as well as the relatively deeper depth to water.

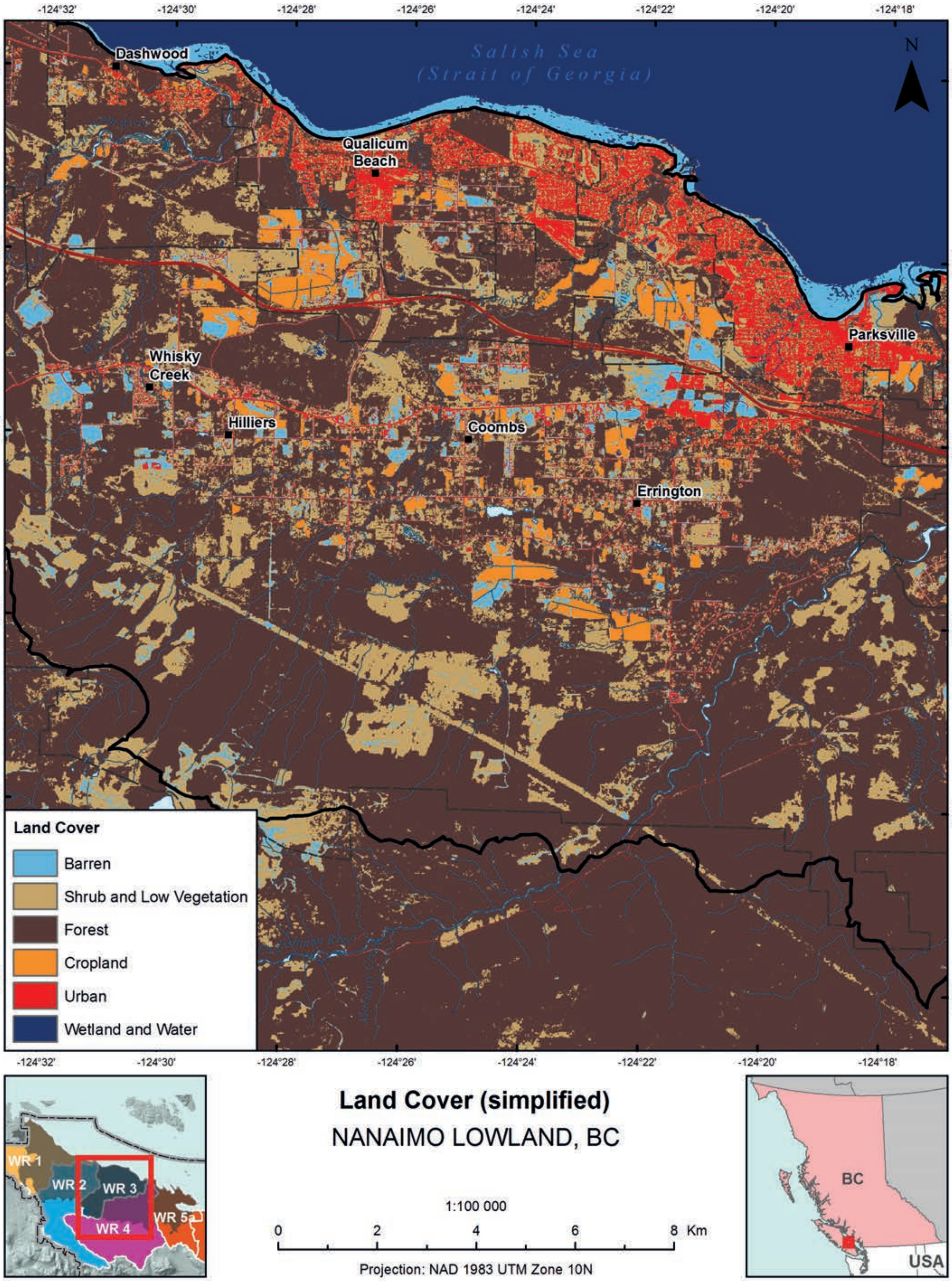
True ☐ False ☐

M This map may be used to determine the vulnerability of a well's recharge zone.

True ☐ False ☐

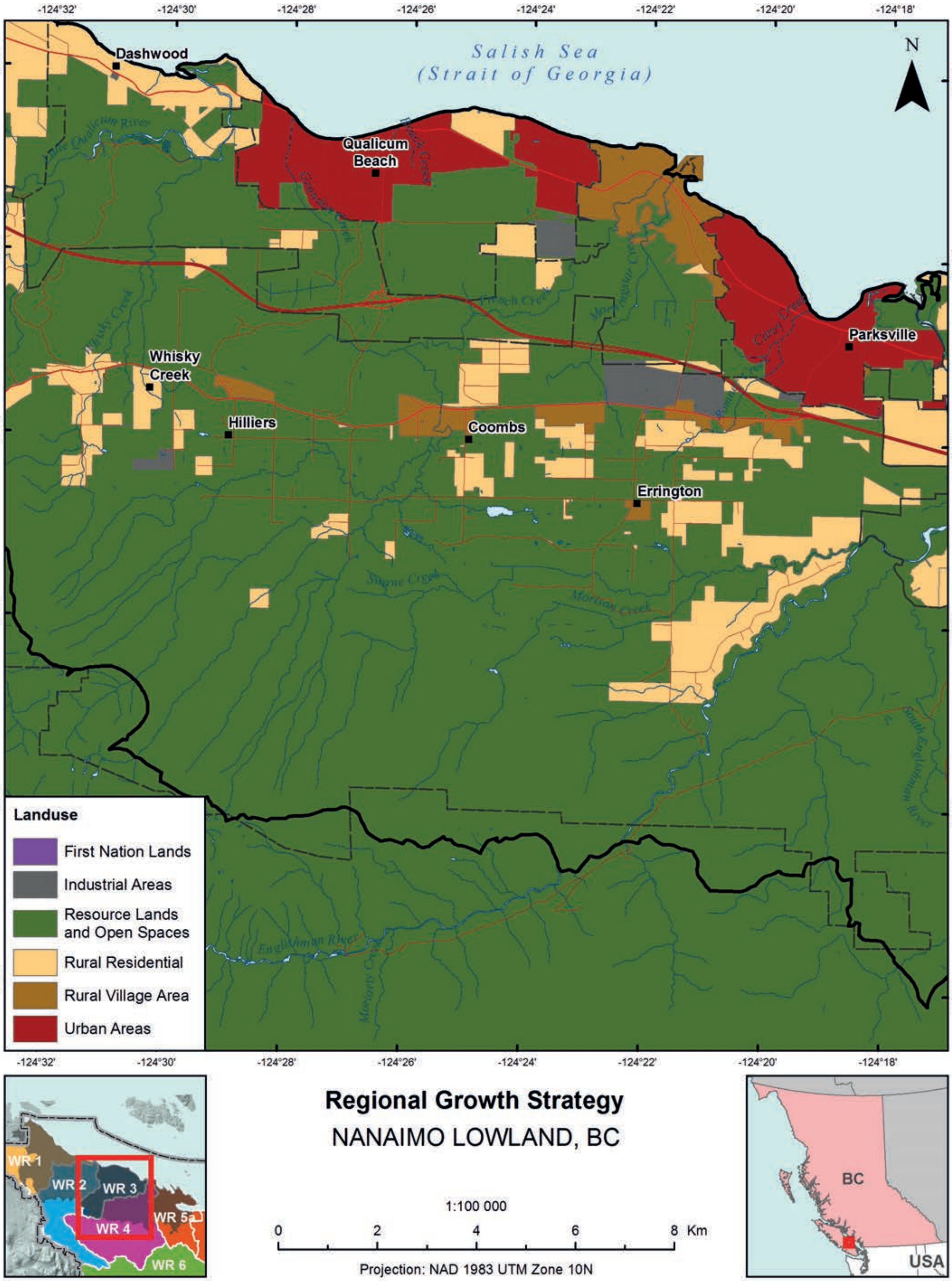
D Why can this vulnerability assessment be considered to be conservative?


Salish Sea
(Strait of Georgia)
N
Dashwood
Qualicum Beach
Whisky Creek
Hilliers
Coombs
Errington
Parksville
Little Qualicum River
Morningstar Creek
Carey Creek
Morison Creek
Englishman River
Moriarty Creek
South Englishman River
-124°32'
-124°30'
-124°28'
-124°26'
-124°24'
-124°22'
-124°20'
-124°18'
49°22'
49°20'
49°18'
49°16'
49°14'
49°12'
Drastic Index
< 93 (low)
93 - 105
105 - 136
136 - 159
> 159 (high)
WR 1
WR 2
WR 3
WR 4
WR 5a
Aquifer Vulnerability
NANAIMO LOWLAND, BC
1:100 000
0 2 4 6 8 Km
Projection: NAD 1983 UTM Zone 10N
BC
USA



Land Cover (simplified)

NANAIMO LOWLAND, BC



Regional Growth Strategy
NANAIMO LOWLAND, BC

Part 2

DISCOVERING AND USING GEOSPATIAL HYDROGEOLOGICAL DATA

Throughout this workbook section

The terms in **orange** are defined in the Glossary of terms used in geomatics on p. 60.

Glossary of terms used in geomatics

ArcCatalog

The ArcCatalog application provides a catalog window for ArcGIS, which is used to organize, manage, and search for various types of geographic information.

ArcGIS

The Geographic information system (GIS) used for this workshop.

ArcMap

The central application used in ArcGIS. ArcMap is where geographic information system (GIS) datasets are displayed and explored, where symbols are assigned, and where map layouts are created for printing or publication. ArcMap is also the application used to create and edit datasets.

ArcToolbox

The ArcMap module that includes the geoprocessing tools.

Geodata

Geodata is information about geographic locations, which is stored in a format that can be used within a geographic information system (GIS). These include geometric data (feature position and shape), attributes (feature characteristics), and metadata (information on the nature of the data). Synonyms include : geospatial data, geographic data, and spatially referenced data.

Feature class

Feature classes are homogeneous collections of common features, each having the same spatial representation, such as points, lines, or polygons, and a common set of attribute columns. An example is a line feature class to represent road centerlines. The four most commonly used feature classes are points, lines, polygons, and annotation (the geodatabase name for map text).

Format (data)

Geodata can have a vector (point, line, or polygon) or raster (image or grid consisting of pixels or cells) format.

Geodatabase

A collection of geographic datasets of various types held in a common file system folder. This data structure is specific to ArcGIS.

Geographic Information System (GIS)

A data management system software for layering different geographic datasets in the form of maps derived from data and models.

Geoprocessing

A framework and set of tools for analysing geographic and related data within a geographic information system (GIS).

Layer

The mechanism used to display geographic datasets. Each layer references a dataset, and specifies how that dataset is portrayed using symbols and text labels.

Layer file

This type of file is specific to ArcGIS, and stores the symbology of a dataset. It does not contain geographic data, only a reference to the data, along with information about how to render the data in ArcMap.

Metadata

Information that describes items in ArcGIS. The metadata of an item records information that is important to know about that item. This might include information about how accurate and recent the item is, restrictions associated with using and sharing the item, and important processes in its life cycle, such as generalizing features.

MXD Project

A map document specific to ArcGIS, in which it is possible to create a map by adding various feature classes and their symbology.

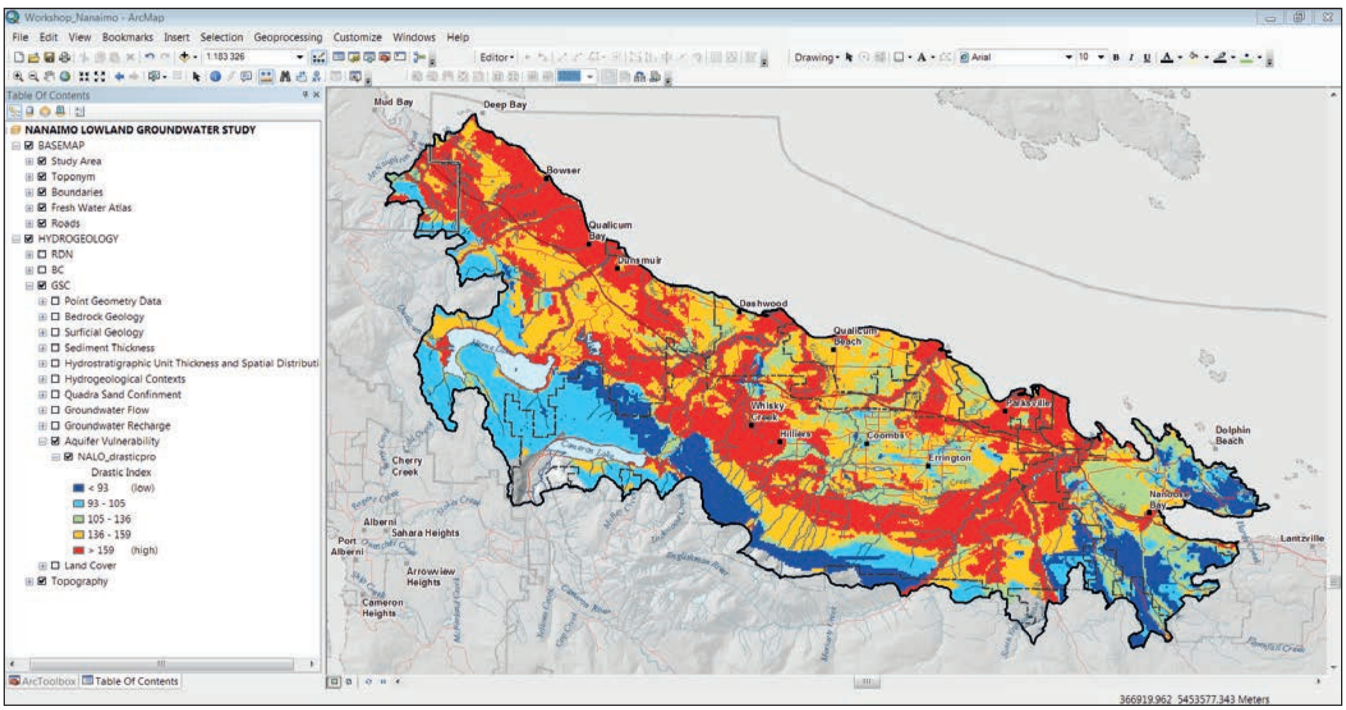
Shapefile

A simple format for storing the geometric location and attribute information of geographic features. Geographic features in a shapefile can be represented by points, lines, or polygons (areas).

Symbology

The use of graphical techniques to represent geographic information on a map. Map symbols for geographic features include visual variables, such as color, size, and shape.

2.1 Geospatial data presentation



Data stored in geodatabases

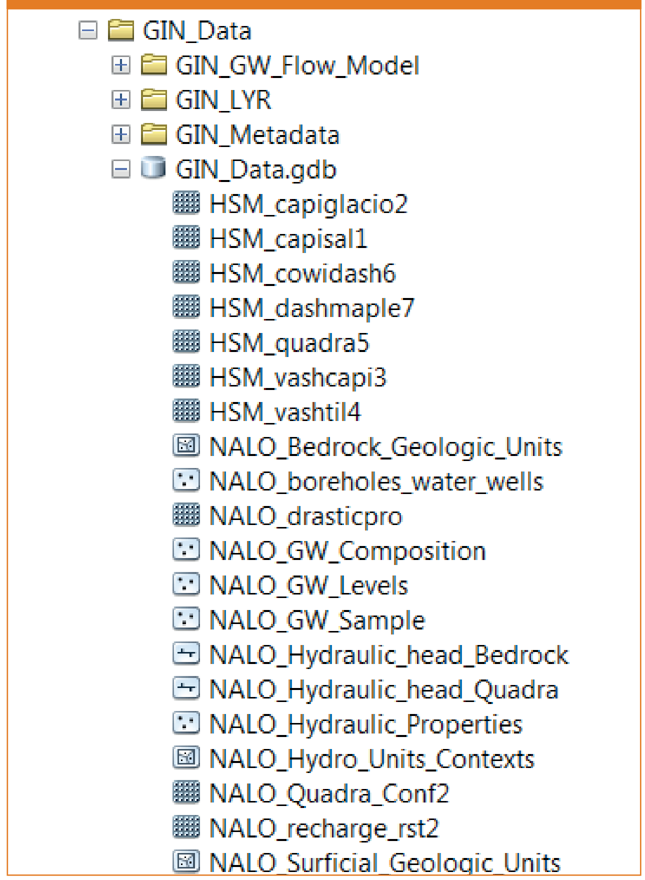
Data from the Groundwater Information Network (GIN)

The Groundwater Information Network (GIN) is developed by the GSC to improve knowledge of groundwater systems, and enhance groundwater management, through increased access to groundwater information. GIN connects a variety of groundwater information from authoritative sources, such as water well databases, water monitoring data, aquifer and geology maps, and related publications. Provincial and territorial collaborators include British Columbia, Alberta, Saskatchewan, Manitoba, Ontario, Québec, Nova Scotia, and Yukon; international collaborators include the US Geological Survey and others. All available information can be accessed through the GIN Portal (http://gin.gw-info.net/service/api_ngwds:gin2/en/gin.html). Geospatial data produced by the GSC's Groundwater Geoscience Program are available for download for the key Canadian aquifers that have been characterized so far.

Your data for this workshop

- Geodata stored in a geodatabase, in the **GIN_Data** folder, within the **GSC_Data** folder :
    - **GIN_Data.gdb** : includes data available from the GIN, including point, line, and polygon feature classes, as well as raster datasets
- Layer files in the **GIN_LYR** folder
- Metadata in html format for each feature class in the **GIN_Metadata** folder
- Groundwater flow model data, developed with FEFLOW, including FEFLOW data in .fem format, metadata in .html format, and images in .png format

Catalog Tree for GIN Data



Other data from the GSC

Datasets produced by the GSC as part of the Nanaimo Lowland Groundwater Study, but not available in the GIN, have been made available for their use in the workshop exercises. These correspond to land cover data and sediment thickness. Other GSC data are made available for location purposes, such as roads, elevation contours, study area boundary, etc. Using the layer files for these feature classes will provide the same rendering as the maps presented in the Nanaimo Lowland Groundwater Study Atlas.

Your data for this workshop

- Geodata stored in a geodatabase, in the **GSC_Other_Data** folder, within the **GSC_Data** folder:
    - **GSC_Other_Data.gdb** : includes line and polygon feature classes, as well as raster datasets corresponding to datasets produced during the Nanaimo Lowland Groundwater Study, but not available in the GIN, as well as basemap elements used to create the Nanaimo Lowland Groundwater Study Atlas
- Layer files in the **GSC_Other_LYR** folder
- There are no metadata for these data

Catalog Tree for Other Data from the GSC

- GSC_Other_Data
    - GSC_Other_Data_LYR
    - GSC_Other_Data.gdb
        - dem_elev_nanaimo
        - dem_hshade_nanaimo
        - Elevation_contours
        - NALO_Land_Cover
        - NALO_Sediment_Thickness
        - Roads
        - Study_area
        - Study_area_ext_mask

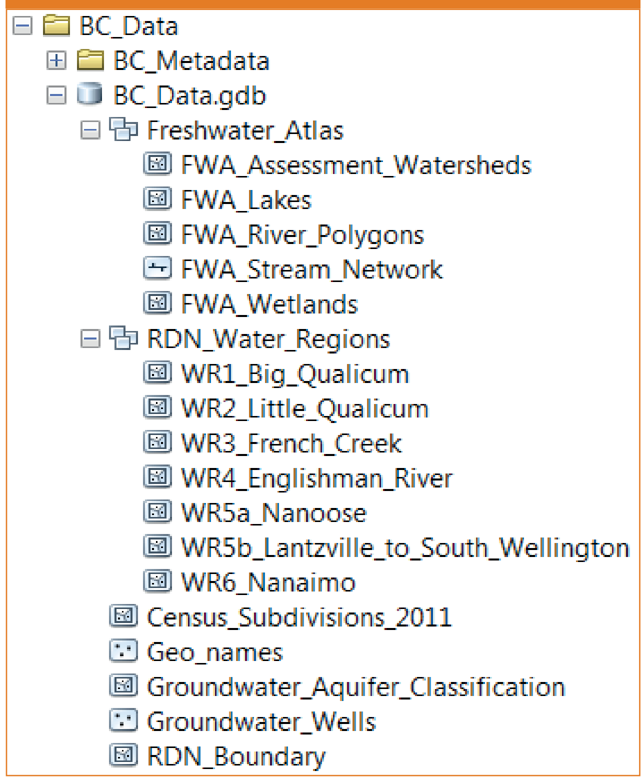
Provincial data

A wide range of provincial geodata is readily available for download via the BC Data Catalogue (https://data.gov.bc.ca/). Water-related data from the BC Water Resources Atlas, such as the mapped groundwater aquifers, as well as the watersheds and surface water network, are particularly useful for the exercises in this workshop. The Water Regions of the RDN are also useful, because they are used for planning purposes.

Your data for this workshop

- Geodata stored in a geodatabase, in the **BC_Data** folder:
  - **BC_Data.gdb** : includes data available within the BC Data Calalog, point, line and polygon feature classes
- Metadata in html format for each feature class in the **BC_Metadata** folder
- There are no layer files for these data

Catalog Tree for Provincial Data



Data from the RDN

Land-use data are available for download via the RDN website (http://www.rdn.bc.ca/spatial-data-files). The purpose of the regional growth strategy is to promote human settlement that is socially, economically and environmentally healthy, and that makes efficient use of public facilities and services, land, and other resources. The intent of land-use designation through the official community plans is to guide the future development of cities or electoral areas, and to provide some certainty to land owners and the community in terms of what uses are supported in certain areas.

Your data for this workshop

- Geodata stored in a geodatabase, in the **RDN_Landuse_Data** folder, within the **RDN_Data** folder:
  - **RDN_Data.gdb** : includes land-use data stored as polygon feature classes
- There are no layer files nor metadata for these data

Catalog Tree for RDN Data

- RDN_Landuse_Data
  - RDN_Data.gdb
    - OCP_Landuse
    - RegionalGrowthStrategy_Landuse

Data from the RDN Water Budget Project

The RDN Water Budget Project is a series of studies commissioned by the RDN to examine the relationship between surface water and groundwater, current water demands, and the long-term impacts of climate change (http://rdnwaterbudget.ca/). The Phase 1 Water Budget assessments provide a preliminary indication of the level of stress on RDN water regions and mapped aquifers. Water Budget calculations are made available for their use in the workshop exercises.

Your data for this workshop

- Geodata stored in a geodatabase, in the **RDN_Water_Budget** folder, within the **RDN_Data** folder:
  - **RDN_HydroGrid.gdb** : includes water budget calculations stored as a polygon feature class, including total annual precipitation, evaporation, runoff, and groundwater recharge
- There are no layer files nor metadata for these data

Catalog Tree for RDN Water Budget Project Data

- RDN_Water_Budget
  - RDN_HydroGrid.gdb
    - HydroGrid

Retrieving hydrogeological information

By geodatabase

Feature classes or datasets by geodatabase			
Geodatabase	**Feature class or dataset name**	**Description**	**Hydrogeological concept**
GIN_Data.gdb	HSM_capiglacio2	*Capilano (glaciomarine) unit thickness*	Hydrostratigraphic unit thickness and spatial distribution
	HSM_capisal1	*Capilano-Salish unit thickness*	Hydrostratigraphic unit thickness and spatial distribution
	HSM_cowidash6	*Cowichan-Dashwood unit thickness*	Hydrostratigraphic unit thickness and spatial distribution
	HSM_dashmaple7	*Dashwood-Mapleguard unit thickness*	Hydrostratigraphic unit thickness and spatial distribution
	HSM_quadra5	*Quadra unit thickness*	Hydrostratigraphic unit thickness and spatial distribution
	HSM_vashcapi3	*Vashon-Capilano unit thickness*	Hydrostratigraphic unit thickness and spatial distribution
	HSM_vashtil4	*Vashon Till unit thickness*	Hydrostratigraphic unit thickness and spatial distribution
	NALO_Bedrock_Geologic_Units	*Bedrock units*	Bedrock geology
	NALO_boreholes_water_wells	*Boreholes and water wells*	NALO point geometry data
	NALO_drasticpro	*DRASTIC vulnerability index*	Aquifer vulnerability
	NALO_GW_Composition	*Hydrochemistry analyses in the Englishman River Basin*	NALO point geometry data
	NALO_GW_Levels	*Provincial Observation Well Network*	NALO point geometry data
	NALO_GW_Sample	*Location points for hydrochemistry analyses in the Englishman River Basin*	NALO point geometry data
	NALO_Hydraulic_head_Bedrock	*Hydraulic head for the bedrock groundwater flow system*	Groundwater flow
	NALO_Hydraulic_head_Quadra	*Hydraulic head for the Quadra Sand Aquifer groundwater flow system*	Groundwater flow
	NALO_Hydraulic_Properties	*Hydraulic properties from existing pump test data*	NALO point geometry data
	NALO_Hydro_Units_Contexts	*Hydrostratigraphic units and hydrogeological contexts*	Hydrogeological contexts
	NALO_Quadra_Conf2	*Quadra Sand Aquifer confinement*	Quadra Aquifer confinement
	NALO_recharge_rst2	*Groundwater recharge*	Groundwater recharge
	NALO_Surficial_Geologic_Units	*Surficial deposits*	Surficial geology

Feature classes or datasets by geodatabase			
Geodatabase	**Feature class or dataset name**	**Description**	**Hydrogeological concept**
GSC_Other_Data.gdb	dem_elevation_nanaimo	*Digital elevation model*	Basemap
	dem_hshade_nanaimo	*Hillshade*	Basemap
	Elevation_contours	*Elevation contours*	Basemap
	NALO_Sediment_Thickness	*Total sediment thickness*	Sediment thickness
	NALO_Land_Cover	*Land cover*	Land-use
	Roads	*Roads*	Basemap
	Study_area	*Study area*	Basemap
	Study_area_mask	*Study area mask*	Basemap
BC_Data.gdb	Census_subdivisions_2011	*Census subdivisions (2011)*	Basemap
	FWA_Assessment_Watersheds	*Fresh Water Atlas Assessment watersheds*	Basemap
	FWA_Lakes	*Fresh Water Atlas lakes*	Basemap
	FWA_River_Polygons	*Fresh Water Atlas river polygons*	Basemap
	FWA_Stream_Network	*Fresh Water Atlas stream network*	Basemap
	FWA_Wetlands	*Fresh Water Atlas wetlands*	Basemap
	Geo_names	*Geographical names*	Basemap
	Groundwater_Aquifer_Classification	*Mapped developed groundwater aquifers*	BC Aquifer Classification
	Groundwater_Wells	*Groundwater wells*	BC Groundwater Wells Database
	RDN_Boundary	*Regional Districts - Legally defined administrative areas*	Basemap
	WR1_Big_Qualicum	*Water Region 1 - Big Qualicum River*	Basemap
	WR2_Little_Qualicum	*Water Region 2 - Little Qualicum River*	Basemap
	WR3_French_Creek	*Water Region 3 - French Creek*	Basemap
	WR4_Englishman_River	*Water Region 4 - Englishman River*	Basemap
	WR5a_Nanoose	*Water Region 5a - Nanoose*	Basemap
	WR5b_Lantzville_to_South_Wellington	*Water Region 5b - Lantzville to South Wellington*	Basemap
	WR6_Nanaimo	*Water Region 6 - Nanaimo River*	Basemap
RDN_Data.gdb	OCP_Landuse	*Official community plans land-use designation*	Land-use
	RegionalGrowthStrategy_Landuse	*Regional growth strategy*	Land-use
RDN_HydroGrid.gdb	HydroGrid	*RDN Water Budget Project calculations*	Water budget

Retrieving hydrogeological information

By hydrogeological concept

Feature classes or datasets by geodatabase			
Hydrogeological concept	**Feature class or dataset name**	**Description**	**Geodatabase**
Bedrock geology	NALO_Bedrock_Geologic_Units	*Bedrock units*	GIN_Data.gdb
Surficial geology	NALO_Surficial_Geologic_Units	*Surficial deposits*	GIN_Data.gdb
Sediment thickness	sed_thick	*Total sediment thickness*	GSC_Other_Data.gdb
Hydrostratigraphic unit thickness and spatial distribution	HSM_capiglacio2	*Capilano (glaciomarine) unit thickness*	GIN_Data.gdb
	HSM_capisal1	*Capilano-Salish unit thickness*	GIN_Data.gdb
	HSM_cowidash6	*Cowichan-Dashwood unit thickness*	GIN_Data.gdb
	HSM_dashmaple7	*Dashwood-Mapleguard unit thickness*	GIN_Data.gdb
	HSM_quadra5	*Quadra unit thickness*	GIN_Data.gdb
	HSM_vashcapi3	*Vashon-Capilano unit thickness*	GIN_Data.gdb
	HSM_vashtil4	*Vashon Till unit thickness*	GIN_Data.gdb
Hydrogeological contexts	NALO_Hydro_Units_Contexts	*Hydrostratigraphic units and hydrogeological contexts*	GIN_Data.gdb
Quadra Aquifer confinement	NALO_Quadra_Conf2	*Quadra Sand Aquifer confinement*	GIN_Data.gdb
Groundwater flow	NALO_Hydraulic_head_Bedrock	*Hydraulic head for the bedrock groundwater flow system*	GIN_Data.gdb
	NALO_Hydraulic_head_Quadra	*Hydraulic head for the Quadra Sand Aquifer groundwater flow system*	GIN_Data.gdb
Groundwater recharge	NALO_recharge_rst2	*Groundwater recharge*	GIN_Data.gdb
Aquifer vulnerability	NALO_drasticpro	*DRASTIC vulnerability index*	GIN_Data.gdb
Water budget	HydroGrid	*RDN Water Budget Project calculations*	RDN_HydroGrid.gdb
BC Aquifer Classification	Groundwater_Aquifer_Classification	*Mapped developed groundwater aquifers*	BC_Data.gdb
BC Groundwater Wells Database	Groundwater_Wells	*Groundwater wells*	BC_Data.gdb
Land-use	NALO_Land_Cover	*Land cover*	GSC_Other_Data.gdb
	OCP_Landuse	*Official community plans land-use designation*	RDN_Data.gdb
	RegionalGrowthStrategy_Landuse	*Regional growth strategy*	RDN_Data.gdb

Feature classes or datasets by geodatabase			
Hydrogeological concept	**Feature class or dataset name**	**Description**	**Geodatabase**
NALO point geometry data	NALO_boreholes_water_wells	*Boreholes and water wells*	GIN_Data.gdb
	NALO_GW_Levels	*Provincial Observation Well Network*	GIN_Data.gdb
	NALO_Hydraulic_Properties	*Hydraulic properties from existing pump test data*	GIN_Data.gdb
	NALO_GW_Sample	*Location points for hydrochemistry analyses in the Englishman River Basin*	GIN_Data.gdb
	NALO_GW_Composition	*Hydrochemistry analyses in the Englishman River Basin*	GIN_Data.gdb
Basemap	dem_elevation_nanaimo	*Digital elevation model*	GSC_Other_Data.gdb
	dem_hshade_nanaimo	*Hillshade*	GSC_Other_Data.gdb
	Elevation_contours	*Elevation contours*	GSC_Other_Data.gdb
	Roads	*Roads*	GSC_Other_Data.gdb
	Study_area	*Study area*	GSC_Other_Data.gdb
	Study_area_mask	*Study area mask*	GSC_Other_Data.gdb
	Census_subdivisions_2011	*Census subdivisions (2011)*	BC_Data.gdb
	FWA_Assessment_Watersheds	*Fresh Water Atlas Assessment watersheds*	BC_Data.gdb
	FWA_Lakes	*Fresh Water Atlas lakes*	BC_Data.gdb
	FWA_River_Polygons	*Fresh Water Atlas river polygons*	BC_Data.gdb
	FWA_Stream_Network	*Fresh Water Atlas stream network*	BC_Data.gdb
	FWA_Wetlands	*Fresh Water Atlas wetlands*	BC_Data.gdb
	Geo_names	*Geographical names*	BC_Data.gdb
	RDN_Boundary	*Regional Districts - Legally defined administrative areas*	BC_Data.gdb
	WR1_Big_Qualicum	*Water Region 1 - Big Qualicum River*	BC_Data.gdb
	WR2_Little_Qualicum	*Water Region 2 - Little Qualicum River*	BC_Data.gdb
	WR3_French_Creek	*Water Region 3 - French Creek*	BC_Data.gdb
	WR4_Englishman_River	*Water Region 4 - Englishman River*	BC_Data.gdb
	WR5a_Nanoose	*Water Region 5a - Nanoose*	BC_Data.gdb
	WR5b_Lantzville_to_South_Wellington	*Water Region 5b - Lantzville to South Wellington*	BC_Data.gdb
	WR6_Nanaimo	*Water Region 6 - Nanaimo River*	BC_Data.gdb

2.2 Interpreting the available data to understand the hydrogeology of my territory of action

In this activity, you are invited to manipulate the geospatial data made available to understand the hydrogeological contexts of your territory.

This exercise is intended to be done in pairs, in the GIS computer lab, using the ArcGIS software. You are invited to explore the aquifers and their characteristics in your area of interest. You are also invited to explore the GSC's geospatial data for several hydrogeological concepts and to try to deepen your understanding of them by answering interpretation questions found in the participant workbook. You will work directly in the participant workbook.

You may ask questions and verify your answers with one of the hydrogeology experts who will circulate in the computer lab throughout the exercises. The workshop facilitators may also guide you through the technical aspects of the software.

Bedrock geology

Description

When rock is sufficiently fractured, it can constitute an aquifer, in which wells can be installed. The ability of fractured bedrock aquifers to release water depends on fracture thickness (openness) and interconnection. Fractures are accentuated by post-depositional tectonic compression and differential erosion following glacial flow. Inversely, some rock units can form an aquitard when they are fine-grained, cemented, and their fracture network is poorly developed.

See **pp. 36-37** for methodology and interpretation for the study area

Geospatial feature classes or datasets concerned

Feature class or dataset name	Description	Contents	Geodatabase
NALO_Bedrock_Geologic_Units	*Bedrock units*	Simplified bedrock geology	GIN_Data.gdb

General interpretation of the dataset(s)

Legend : Bedrock unit	Meaning	General information to be drawn from this concept
Lower Cretaceous Nanaimo Group (sedimentary rocks)	Sedimentary bedrock Aquifers and aquitards	• Four aquifer rock formations, mainly composed of sandstone, with moderate aquifer potential • Four aquitard rock formations, mainly composed of siltstone • Extensive fracturing commonly observed, especially at shallow depths • Extent and orientation of fracturing is currently unknown • Groundwater may be brackish at depth
Meso-Paleozoic metamorphic and intrusive basement	Metamorphic and intrusive bedrock Only aquitard	• An aquitard unit • Data from only a few wells are reported from this formation

Interpretation questions

Where could moderate-potential bedrock aquifers be located in my territory? Is important information missing to confirm the presence of these aquifers?

Where could bedrock aquitards be located in my territory? Is important information missing to confirm the presence of these aquitards?

Related observations in my territory of action:

Surficial geology

Description

The first step to understanding the stratigraphy of unconsolidated deposits at depth is to identify the types of sediment observed on the ground surface. These deposits are generally closely linked to the past glacial history, with successive episodes of sediment deposition and erosion.

See **pp. 38-39** for methodology and interpretation for the study area

Geospatial feature classes or datasets concerned

Feature class or dataset name	Description	Contents	Geodatabase
NALO_Surficial_Geologic_Units	*Surficial deposits*	Spatial distribution of the surficial geology	GIN_Data.gdb

General interpretation of the dataset(s)

Legend : Deposits (simplified legend)	Meaning	General information to be drawn from this concept
Anthropogenic Organic Colluvium	Aquifer or aquitard potential	• Composed of various grain-size particles • May form unconsolidated aquifers or aquitards
Marine Fine Glaciomarine Glacial Till	Aquitard potential	• Composed of low-permeability fine-grained particles or unsorted particles of all sizes in a fine-grained matrix • May form unconsolidated aquitards • May limit groundwater recharge • May enhance aquifer protection from contamination
Fluvial Glaciofluvial Coarse Glaciomarine Quadra Sand	Aquifer potential	• Composed of permeable coarse-grained particles • May form unconsolidated aquifers • May promote groundwater recharge • May limit aquifer protection from contamination
Pre-Vashon Deposits	Aquifer or aquitard potential	• Composed of various grain-size particles • May form unconsolidated aquifers or aquitards
Bedrock	Aquifer or aquitard potential	• Composed of fractured bedrock • May form bedrock aquifers or aquitards

Interpretation questions

Where could unconsolidated aquifers be located in my territory? Is important information missing to confirm the presence of these aquifers?

Where could unconsolidated aquitards be located in my territory? Is important information missing to confirm the presence of these aquitards?

Related observations in my territory of action:

Sediment thickness

Description

Unconsolidated deposits that are coarse-grained (sand and gravel) and sufficiently thick may constitute an aquifer. However, if the sediments are fine-grained (clay and silt), and therefore not very permeable, they will instead form an aquitard. Information on the thickness and texture of unconsolidated deposits may also be useful in domains other than hydrogeology, such as geotechnics, and building construction and infrastructure.

See **pp. 40-41** for methodology and interpretation for the study area

Geospatial feature classes or datasets concerned

Feature class or dataset name	Description	Contents	Geodatabase
sed_thick	*Total sediment thickness*	Estimate of the total unconsolidated deposit thickness, in meters	GSC_Other_Data.gdb

General interpretation of the dataset(s)

Legend : Sediment thickness (m)	Meaning	General information to be drawn from this concept
0 1 - 2 3 - 5	Nul to low thickness 0 to 5 m	• No possible unconsolidated aquifer, because sediments are not thick enough • No confining aquitard, because sediments are not thick enough, but a semi-confining layer is possible if sediments are fine and sufficiently thick (e.g., presence of silt, clay, or > 3 till) • Bedrock aquifer always present under the sediment
6 - 10	Medium thickness 5 to 10 m	• Limited potential unconsolidated aquifer is possible if sediments are coarse and sufficiently thick (e.g., > 5 m sand or gravel) • Confining aquitard is possible if sediments are fine and sufficiently thick (e.g., > 5 m silt or clay) • Bedrock aquifer always present under the sediment
11 - 20 21 - 30	High thickness 10 à 30 m	• High potential unconsolidated aquifer is possible if sediments are coarse and relatively thick (e.g. > 10 m sand or gravel) • Confining aquitard is possible if sediments are fine and sufficiently thick (e.g. > 5 m silt or clay) • Bedrock aquifer always present under the sediment
31 - 45 46 - 65 66 - 85 86 - 212	Very high thickness 30 and more	• Very high potential unconsolidated aquifer is possible if sediments are coarse and very thick (e.g. > 30 m sand or gravel) • Confining aquitard is possible if sediments are fine and sufficiently thick (e.g. > 5 m silt or clay) • Bedrock aquifer always present under the sediment

Interpretation questions

Where could high- and very high-potential unconsolidated aquifers be located in my territory? Is important information missing to confirm the presence of these aquifers?

Where could aquitards be thick enough to cause confined aquifer conditions in my territory? Is important information missing to confirm the presence of these aquitards?

Where are the bedrock aquifers located on my territory?

Related observations in my territory of action:

Hydrostratigraphic unit thickness and spatial distribution

Description

3D hydrostratigraphic models (HSMs) define the distribution and thickness of hydrostratigraphic units defined according to their types of sediment and bedrock. Development of a 3D model provides a basis for integrating knowledge gained during the course of a hydrogeological study, and forms a framework for understanding groundwater flow dynamics.

See **pp. 44-45** for methodology and interpretation for the study area

Geospatial feature classes or datasets concerned

Feature class or dataset name	Description	Contents	Geodatabase
HSM_capiglacio2	*Capilano (glaciomarine) unit thickness*	Thickness estimate (in metres) of Capilano (glaciomarine) (II) sediments	GIN_Data.gdb
HSM_capisal1	*Capilano-Salish unit thickness*	Thickness estimate (in metres) of Capilano-Salish (I) sediments	GIN_Data.gdb
HSM_cowidash6	*Cowichan-Dashwood unit thickness*	Thickness estimate (in metres) of Cowichan-Dashwood (VI) sediments	GIN_Data.gdb
HSM_dashmapl7	*Dashwood-Mapleguard unit thickness*	Thickness estimate (in metres) of Dashwood-Mapleguard (VII) sediments	GIN_Data.gdb
HSM_quadra5	*Quadra unit thickness*	Thickness estimate (in metres) of Quadra (V) sediments	GIN_Data.gdb
HSM_vashcapi3	*Vashon-Capilano unit thickness*	Thickness estimate (in metres) of Vashon-Capilano (III) sediments	GIN_Data.gdb
HSM_vashtil4	*Vashon Till unit thickness*	Thickness estimate (in metres) of Vashon Till (IV) sediments	GIN_Data.gdb

General interpretation of the dataset(s)

Legend : Hydrostratigraphic unit thickness (m)	Meaning	General information to be drawn from this concept
< 2 2 - 5	Low thickness 0 to 5 m	• No unconsolidated aquifer, because permeable sediments are not thick enough • No confining aquitard, because impermeable sediments are not thick enough, but a semi-confining layer is possible if the hydrostratigraphic unit is impermeable
5 - 10	Moderate thickness 5 to 10 m	• Limited-potential unconsolidated aquifer if the hydrostratigraphic unit is permeable • Confining aquitard if the hydrostratigraphic unit is impermeable
10 - 15 15 - 20 20 - 30	High thickness 10 to 30 m	• High-potential unconsolidated aquifer if the hydrostratigraphic unit is permeable • Confining aquitard if the hydrostratigraphic unit is impermeable
30 - 40 40 - 50 > 50	Very high thickness 30 m and more	• Very high-potential unconsolidated aquifer if the hydrostratigraphic unit is permeable • Confining aquitard if the hydrostratigraphic unit is impermeable

Interpretation questions

Where could high- and very high-potential unconsolidated aquifers be located in my territory? Is important information missing to confirm the presence of these aquifers?

Where could aquitards be thick enough to cause confined aquifer conditions in my territory? Is important information missing to confirm the presence of these aquitards?

Related observations in my territory of action:

Hydrogeological contexts

Description

Hydrogeological contexts are defined according to the vertically stacked sequences of hydrostratigraphic units. These contexts influence the flow conditions and groundwater quality, and can provide information of interest for the exploitation and management of groundwater resources.

See **pp. 46-47** for methodology and interpretation for the study area

Geospatial feature classes or datasets concerned

Feature class or dataset name	Description	Contents	Geodatabase
NALO_Hydro_Units_Contexts	*Hydrostratigraphic units and hydrogeological contexts*	Surficial hydrostratigraphic units and hydrogeological context areas	GIN_Data.gdb

General interpretation of the dataset(s)

Legend : Hydrogeological context - Hydrostratigraphic unit	Meaning	General information to be drawn from this concept
Lowlands (A) Cameron-Home Lakes (B) Englishman River (C) Mountains (D)	Hydrogeologic contexts	• Areas of similar vertically stacked sequences of hydrostratigraphic units
I	I - Capilano-Salish (I) Aquifer	• Recent fluvial deposits that are generally permeable
II	II - Capilano (glaciomarine) Aquitard	• Marine sediments that are relatively impermeable due to their fine grain size
III	III - Vashon-Capilano (coarse) Aquifer	• Glaciofluvial deposits of gravel, sand, and lenses of till, which are generally permeable
IV	IV - Vashon Till Aquitard	• Impermeable ground moraine deposits: till, lenses of gravel, sand, and silt
V	V - Quadra Sand Aquifer	• Permeable sands deposited in a fluvial environment
VI	VI - Cowichan-Dashwood Aquitard	• Silt, gravel, sand, and peat deposited in a swampy environment, with clay and stony-clay deposited in a sub-littoral environment - impermeable unit
? VII	VII - Dashwood-Mapleguard Aquifer (upper) and aquitard (lower)	• Permeable proglacial outwash deposits of sand, silt, minor clay, and gravel
VIII	VIII - Sedimentary bedrock Aquifer (upper) and aquitard (lower)	• Mostly sandstone and siltstone, with moderate aquifer potential when fractures are present to transmit water
IX	IX - Metamorphic bedrock Aquitard	• Metamorphic and intrusion bedrock considered to be poorly permeable

Interpretation questions

Which hydrogeological context(s) display aquifer potential in unconsolidated deposits? Are these hydrogeological contexts present in my territory?

Which hydrogeological context(s) display aquifer potential only in bedrock? Are these hydrogeological contexts present in my territory of action?

Related observations in my territory of action:

Quadra Sand Aquifer confinement

Description

Aquifer confinement is related to whether or not an aquifer is overlain by a layer of low-permeability materials (aquitard), which isolates the groundwater from the surface. The nature and thickness of sediments or geological units determine the level of confinement of an aquifer, which can range from unconfined, to semi-confined or confined. Confinement influences the groundwater flow dynamics and the hydrochemical processes by limiting or facilitating aquifer recharge or its protection from contamination from the surface.

See **pp. 48-49** for methodology and interpretation for the study area

Geospatial feature classes or datasets concerned

Feature class or dataset name	Description	Contents	Geodatabase
NALO_Quadra_Conf2	*Quadra Sand Aquifer confinement*	Confinement conditions of the Quadra Sand Aquifer at three different levels: confined, semi-confined, and unconfined	GIN_Data.gdb

General interpretation of the dataset(s)

Legend : Levels of confinement	Meaning	General information to be drawn from this concept
3 - Confined	Confined aquifer	• Low recharge • Low vulnerability • Low water table level variations* • Possibly mineralized and aged groundwater; reduced potential quality**
2 - Semi-confined	Semi-confined aquifer	• Low to medium recharge • Low to medium vulnerability • Medium groundwater level variations* • Possibly less mineralized and aged groundwater; higher potential quality**
1 - Unconfined	Unconfined aquifer	• Medium to high recharge • Medium to high vulnerability • Medium to high groundwater level variations* • Possibly weakly mineralized and young groundwater; probably of good quality**
0	Undetermined confinement	• Absence of the Quadra Sand Aquifer

*Groundwater level fluctuations are also influenced by aquifer hydraulic properties, namely porosity.

**Groundwater mineralization is also greatly influenced by the aquifer type (sediment or bedrock) and mineral composition.

Interpretation questions

Where are confined aquifers located in my territory? What are the impacts on other hydrogeological parameters (recharge, vulnerability, groundwater level, water quality)?

Where are unconfined aquifers located in my territory? What are the impacts on other hydrogeological parameters (recharge, vulnerability, groundwater level, water quality)?

Where are semi-confined aquifers located in my territory? What are the impacts on other hydrogeological parameters (recharge, vulnerability, groundwater level, water quality)?

Related observations in my territory of action:

Groundwater flow

Description

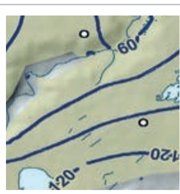
Potentiometric level (or hydraulic head or piezometry) corresponds to the water level measured in a well. In an unconfined aquifer, this level also corresponds to the water table elevation. In a confined aquifer, since it is under pressure, the well water level is above the top of the aquifer. The potentiometric map provides a general idea of the groundwater flow dynamics in the aquifer by indicating flow direction, which goes from higher to lower hydraulic heads.

See **pp. 50-51** for methodology and interpretation for the study area

Geospatial feature classes or datasets concerned

Feature class or dataset name	Description	Contents	Geodatabase
NALO_Hydraulic_head_Bedrock	*Hydraulic head for the bedrock groundwater flow system*	Estimate of the potentiometric level (in meters relative to mean sea level) in the bedrock aquifer	GIN_Data.gdb
NALO_Hydraulic_head_Quadra	*Hydraulic head for the Quadra Sand Aquifer groundwater flow system*	Estimate of the potentiometric level (in meters relative to mean sea level) in the Quadra Sand Aquifer	GIN_Data.gdb

General interpretation of the dataset(s)

Legend : Hydraulic head (m)	Meaning	General information to be drawn from the concept
	Potentiometric level and direction of groundwater flow	• Groundwater flows from higher (upstream) to lower (downstream) potentiometric levels • Generally, groundwater flows toward surface water features (rivers, lakes, or, ultimately, the Strait of Georgia) • Potentiometric contours are often similar to topographic contours, but tempered (flatter) • Groundwater renewal in an aquifer is the result of groundwater flow from upstream zones, as well as recharge from the surface • Potential contamination from upstream zones
	Steep slope of the potentiometric contours	• Rapid groundwater flow if the hydraulic conductivity of the aquifer is high (e.g., sand or gravel) • Short groundwater residence time if the hydraulic conductivity of the aquifer is high (i.e., young water) • Potentially weakly-mineralized groundwater, probably of good quality, if the hydraulic conductivity of the aquifer is high
	Flat slope of the potentiometric contours	• Slow groundwater flow if the hydraulic conductivity of the aquifer is low (e.g., silt or clay) • Long groundwater residence time if the hydraulic conductivity of the aquifer is low (i.e., aged water) • Groundwater possibly mineralized, and possibly of questionable quality, if the hydraulic conductivity of the aquifer is low

Interpretation questions

From and to which area(s) does groundwater generally flow in my territory?

Are there any areas in my territory that present more rapid groundwater flow? What are the potential consequences of this higher flow velocity on the quality of my groundwater?

Are there any areas in my territory that present slower groundwater flow? What are the potential consequences of this slower flow velocity on the quality of my groundwater?

Related observations in my territory of action:

Groundwater recharge

Description

Groundwater recharge corresponds to the amount of water supplied to an aquifer by surface infiltration. Recharge estimation is necessary to evaluate groundwater availability, since exploitable and sustainable yields depend on groundwater renewal.

See **pp. 52-53** for methodology and interpretation for the study area

Groundwater seepage is water emerging from the ground, as natural springs or as baseflow in streams and wetlands. This occurs when the water table level (or hydraulic head) is higher than the ground surface.

Geospatial feature classes or datasets concerned

Feature class or dataset name	Description	Contents	Geodatabase
NALO_recharge_rst2	*Groundwater recharge*	Spatial distribution of recharge rates (mm/yr)	GIN_Data.gdb

General interpretation of the dataset(s)

Legend : Recharge (mm/yr)	Meaning	General information to be drawn from the concept
0	Nul recharge 0 mm/yr	• Surface water (lakes)
112	Low recharge 0 to 150 mm/yr	• Low-permeability unconsolidated deposits on the surface • Slow groundwater renewal in aquifers • Probably low aquifer vulnerability • More mineralized and aged groundwater; reduced potential quality
241 256 289	Medium recharge 150 to 300 mm/yr	• Moderate-permeability unconsolidated deposits on the surface • Moderately rapid groundwater renewal in aquifers • Probably medium aquifer vulnerability • Less mineralized and aged groundwater; higher potential quality
397 434 450	High recharge 300 and more	• High-permeability unconsolidated deposits on the surface • Rapid groundwater renewal in aquifers • Probably high aquifer vulnerability • Weakly mineralized and young groundwater; potential quality comparable to precipitation

Interpretation questions

Where are fast groundwater renewal zones in my territory? What characteristics of the environment are principally responsible?

Where are slow groundwater renewal zones in my territory? What characteristics of the environment are principally responsible?

How different are the recharge rates estimated by the GSC and the RDN Water Budget Project? Where are the differences more pronounced?

Related observations in my territory of action:

Aquifer vulnerability

Description

The intrinsic vulnerability of an aquifer is its susceptibility to groundwater pollution from contaminants on the soil surface. Vulnerability mapping integrates a set of aquifer hydrogeological properties, thus combining the regional information into a single index. This index can be used as a tool for decision-making in land-use planning and management, to prevent possible groundwater contamination by potentially polluting anthropogenic activities.

See **pp. 54-55** for methodology and interpretation for the study area

Geospatial feature classes or datasets concerned

Feature class or dataset name	Description	Contents	Geodatabase
NALO_drasticpro	*DRASTIC vulnerability index*	DRASTIC groundwater vulnerability index for top aquifers	GIN_Data.gdb

General interpretation of the dataset(s)

Legend : DRASTIC Index	Meaning	General information to be drawn from the concept

< 93	Low vulnerability
	93 or lower index
		• Well-protected from direct surface contamination
		• One or more of the following characteristics are present :
		  • (D) High depth to water
		  • (R) Low recharge
		  • (A) Low aquifer permeability
		  • (S) Low soil permeability
		  • (T) Steep slope
		  • (I) Low vadose zone permeability
		  • (C) Low aquifer hydraulic conductivity
		• No evidence of protection from contamination from lateral groundwater flow

93 - 105
105 - 136
136 - 159
	Medium vulnerability
	93 to 159 index
		• Moderately protected from direct surface contamination
		• One or more of the following characteristics are present :
		  • (D) Moderate depth to water
		  • (R) Moderate recharge
		  • (A) Moderately permeable aquifer
		  • (S) Moderately permeable soil
		  • (T) Moderate slope
		  • (I) Moderately permeable vadose zone
		  • (C) Moderate aquifer hydraulic conductivity
		• No evidence of protection from contamination from lateral groundwater flow

> 159	High vulnerability
	159 or more index
		• Weakly protected from direct surface contamination
		• One or more of the following characteristics are present :
		  • (D) Low depth to water
		  • (R) High recharge
		  • (A) Highly permeable aquifer
		  • (S) Highly permeable soil
		  • (T) Low slope
		  • (I) Highly permeable vadose zone
		  • (C) High aquifer hydraulic conductivity
		• No evidence of protection from contamination from lateral groundwater flow

Interpretation questions

Where are highly vulnerable areas in my territory? What characteristics of the environment are principally responsible?

Where are relatively invulnerable areas in my territory? What characteristics of the environment are principally responsible?

Why is the DRASTIC method imperfect to estimate the vulnerability of aquifers in my territory? What other factors should I monitor to determine the risk of groundwater contamination?

Related observations in my territory of action:

2.3 Discussing the hydrogeological information of our territories

Prepare the presentation of your results

Instructions

This activity will enable participants to read orally their understanding of the hydrogeology of their territory. Each team will share and exchange their results with other participants and experts

To help in your presentation, answer the questions below.

According to the hydrogeological data, what does my territory look like?

<u>Name your territory of action</u> :

What is the groundwater flow direction of my territory?

Indicate vulnerable and non vulnerable zones in my territory

What is the main hydrogeological context – hydrostratigraphic unit present on my territory?

Describe the thickness and types of sediments present on your territory.

You know your territory. Were you surprised with the data or was it what you expected? Why?

In your professional practice, how would you ensure protection and sustainable development of groundwater on areas highlighted in your analysis ?

Remaining questions

Instructions:

This is a moment where participants have the opportunity to ask questions to our GSC experts. From what we have seen today, are there any questions you still have about the Nanaimo Lowland Grounwater Study?

Part 3

SUPPORTING LAND-USE PLANNING AND WATER MANAGEMENT DECISIONS WITH HYDROGEOLOGICAL INFORMATION

3.1 Using hydrogeological data for groundwater protection and management in my territory of action

To do this exercise, you will need to choose between one of the three following questions pertaining to groundwater protection and management in the region :

1. Which area(s) appear(s) to be best-suited for the installation of a new community groundwater supply in the Quadra Sand Aquifer ?
2. Which area(s) should take priority for groundwater recharge protection in the Quadra Sand Aquifer ?
3. Where could a new potentially polluting activity be implemented in order to minimize its impact on the Quadra Sand Aquifer groundwater quality ?

The exercise involves three distinct activities :

Activity 1 – Brainstorm useful hydrogeological concepts for groundwater protection and management

This activity's objective is to deliberate on the analysis pathway that you could apply in your territory to respond to the question. Here are a few questions to consider :

- *According to you, what are we looking for?*
- *What are the aquifer characteristics we should seek?*
- *What are the analysis criteria?*
- *What hydrogeological information should we use?*

To perform this activity, you will be separated into groups of a maximum of 10 participants. You will be accompanied by a RQES facilitator who will lead the discussion and will seek your input and solutions. A GSC groundwater expert will also be present to answer to any questions of a scientific nature, and will be invited to comment on the brainstorming results.

An analysis pathway of a hydrogeology expert will then be proposed. It is described in detail in the participant workbook. An overview of this approach will be presented orally, with explanations on the geotreatment procedure. It is this procedure that you will apply in the following activity in the computer lab. We ask that you reserve your comments on this proposed analysis pathway for the third activity.

Activity 2 – Application of a spatial analysis procedure to my territory of action

This activity's objective is to appreciate how groundwater geodata can be used in groundwater protection and management.

This activity will be completed in pairs in the computer lab, using ArcGIS software. You will be asked to apply the geotreatment procedure presented in the previous activity and described in the participant workbook to data from your territory. Workshop facilitators and groundwater experts will be present at all times to answer to your technical questions in geomatics or hydrogeology.

If you finish the activity before the allocated time is up, you are asked to modify some analysis criteria and evaluate their sensitivity on your final results. You could also choose to work on a second question.

It is important to fill in the final questionnaire to prepare the presentation of your results, since it will serve as a basis for the next activity.

Activity 3 – Presentation of exercise results

This activity's objective is to share your results with all workshop participants, and to exchange with the groundwater experts.

At least one pair team who chose each issue will be invited to discuss their results, referring to the final questionnaire that they filled in at the end of the previous activity. The mapped results will be projected on the screen so that everyone can see them.

Question 1

Which area(s) appear(s) to be best-suited for the installation of a new community groundwater supply in the Quadra Sand Aquifer ?

Participant Brainstorming Results

WHAT WE ARE LOOKING FOR	THE ANALYSIS CRITERIA

Expert Analysis Pathway Overview

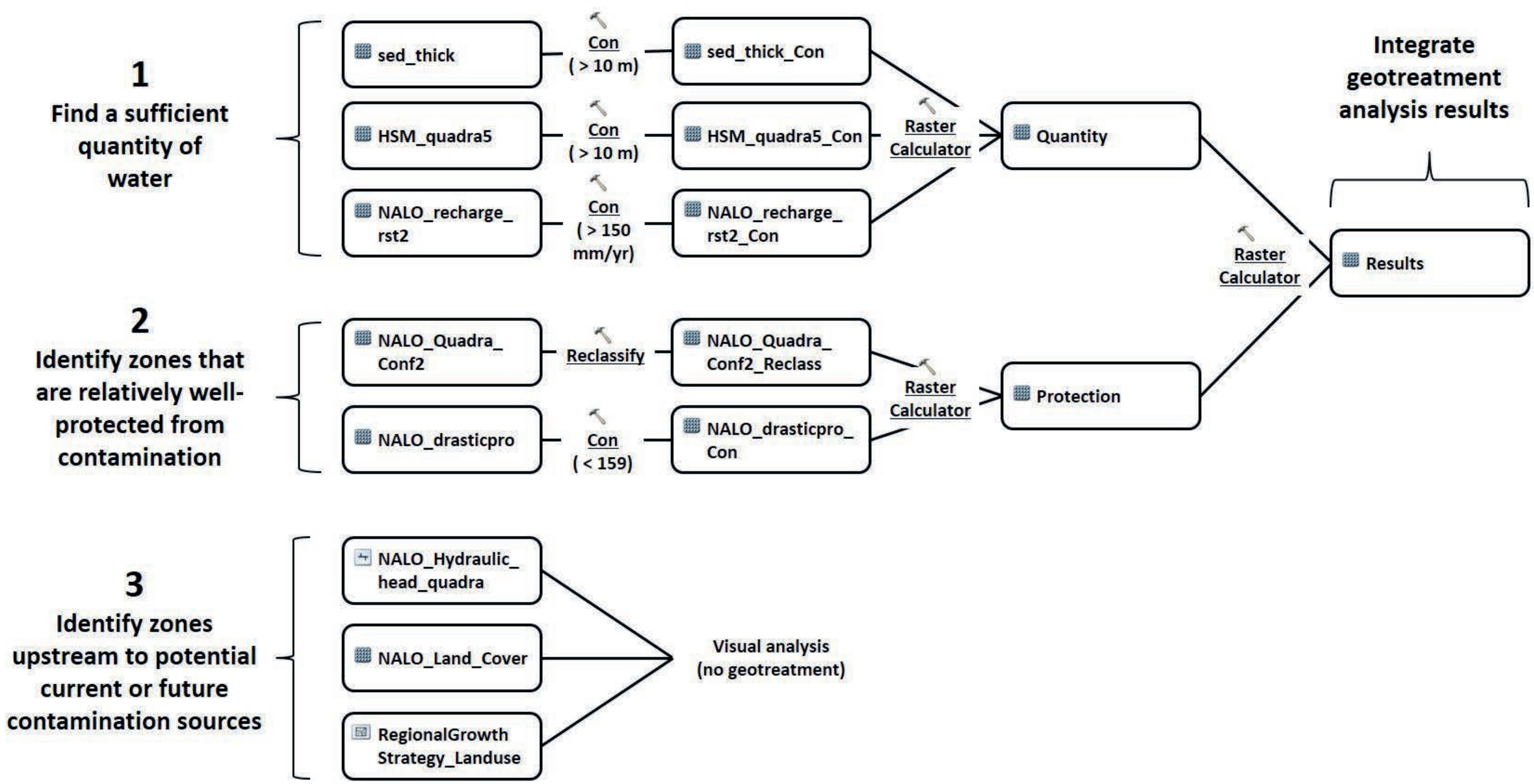
Question

Which area(s) appear(s) to be best-suited for the installation of a new community groundwater supply in the Quadra Sand Aquifer ?

What we are looking for

1. Find a sufficient quantity of water
2. Identify zones that are relatively well protected from contamination
3. Identify zones upstream to potential current or future contamination sources

Proposed geotreatment procedure using available geodata



1. Find a sufficient quantity of water

Proposed analysis parameters

Analysis parameters	Why ?	Limitations and additional information
Presence of the Quadra Sand hydrostratigraphic unit in sufficient thickness	• A minimum sediment thickness is necessary, since pumping induces a cone of depression on the water table around the well. A thin sediment layer combined with substantial pumping can result in well dewatering.	• Unconsolidated aquifers generally have a high enough hydraulic conductivity to allow adequate well discharge for community water supply systems. Bedrock aquifers often have relatively weak hydraulic conductivity, which barely allows for well discharge of more than is needed for a single residence. • Contrary to bedrock aquifers, which are found throughout the study area, unconsolidated aquifers are less frequent.
High groundwater recharge rate	• To ensure a sustainable groundwater supply, well discharge must be less than recharge.	• The greater the number of people supplied, the greater the recharge in the well capture zone must be. • The well capture zone area depends on well discharge : the greater the discharge, the greater the capture zone area.

Proposed analysis criteria for geodata treatment

Analysis parameters	Hydrogeological concepts	Datasets to use	Description	Criteria
Presence of the Quadra Sand hydrostratigraphic unit in sufficient thickness	Sediment thickness	sed_thick	*Total sediment thickness*	• High thickness : 10 to 30 m • Very high thickness : 30 m and more
	Hydrostratigraphic unit thickness and spatial distribution	HSM_quadra5	*Quadra unit thickness*	• High thickness : 10 to 30 m • Very high thickness : 30 m and more
High groundwater recharge rate	Groundwater recharge	NALO_recharge_rst2	*Groundwater recharge*	• Medium recharge : 150 to 300 mm/yr • High recharge : 300 mm/yr and more

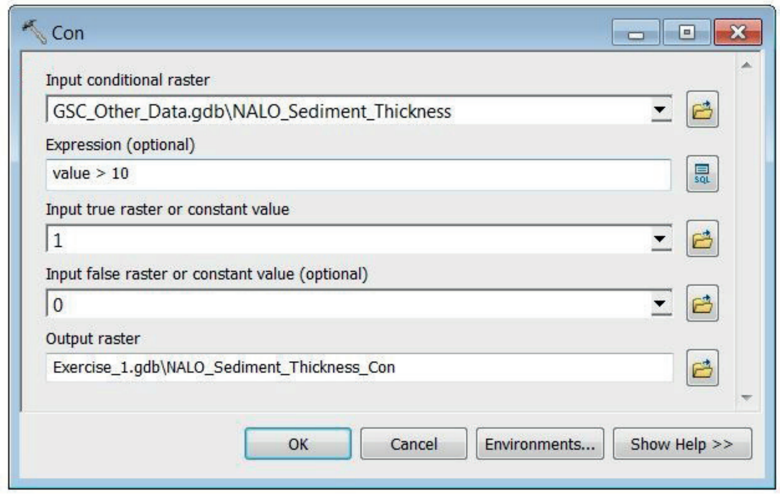
Step by step procedure

SEDIMENT THICKNESS

Execute the adjacent geotreatment to identify cells in **sed_thick** that meet the criteria.

New cells in **sed_thick_Con** with the value of 1 meet the criteria.

Arc Toolbox Spatial Analyst Tools Conditional Con

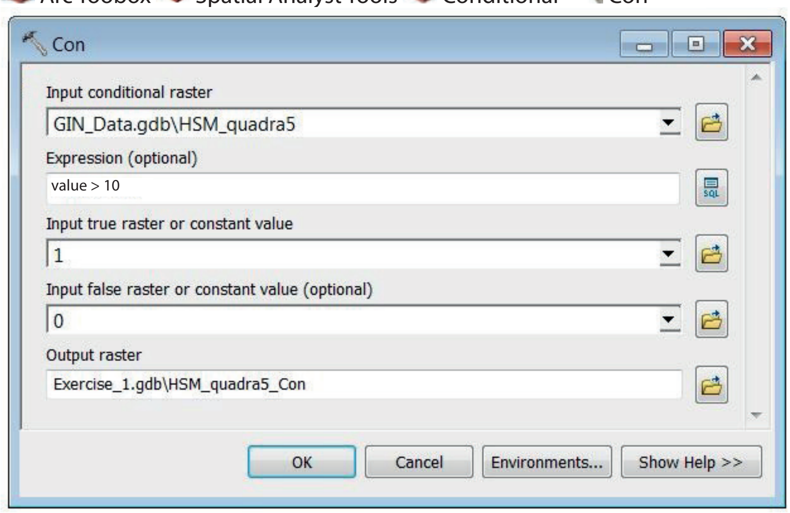


HYDROSTRATIGRAPHIC UNIT THICKNESSES AND SPATIAL DISTRIBUTION

Execute the adjacent geotreatment to identify cells in **HSM_quadra5** that meet the criteria.

New cells in **HSM_quadra5_Con** with the value of 1 meet the criteria.

Arc Toolbox Spatial Analyst Tools Conditional Con

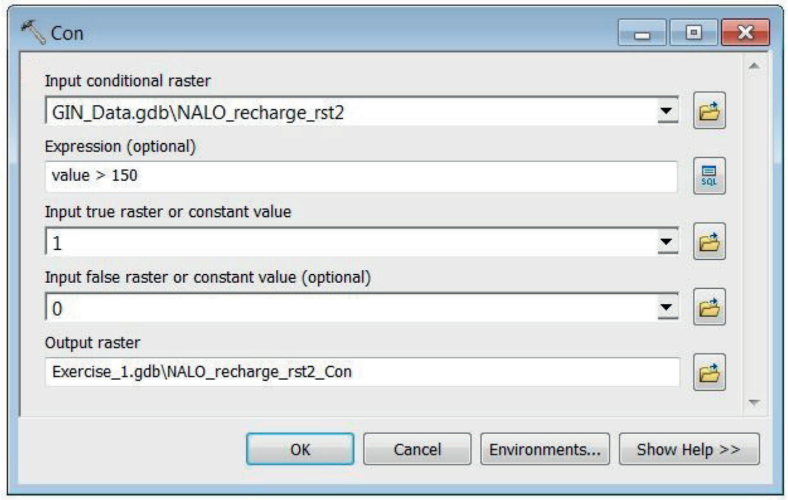


GROUNDWATER RECHARGE

Execute the adjacent geotreatment to identify cells in **NALO_recharge_rst2** that meet the criteria.

New cells in **NALO_recharge_rst2_Con** with the value of 1 meet the criteria.

Arc Toobox Spatial Analyst Tools Conditional Con



INTEGRATION

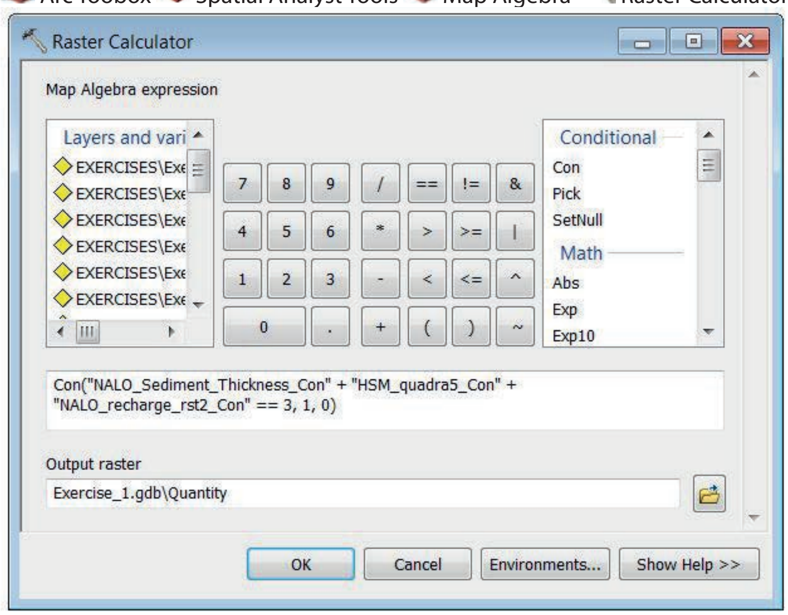
Execute the adjacent geotreatment to combine the results of **sed_thick_Con**, **HSM_quadra5_Con** and **NALO_ recharge_rst2_Con**.

The conditional calculation is written in the Python programming language supported by ArcGIS. It can be described as follows: if the condition before the first comma is true, then the new cell takes the value indicated after the first comma, if not it takes the value indicated after the second comma.

In this case, if the sum of the cells from the three raster datasets is 3, meaning that all criteria to find a sufficient quantity of water are met, then the new cell takes the value of 1. If not, it takes the value of 0.

New cells in **Quantity** with the value of 1 correspond to zones where a sufficient quantity of groundwater would be present.

Arc Toobox Spatial Analyst Tools Map Algebra Raster Calculator



2. Identify zones that are relatively well protected from contamination

Proposed analysis parameters

Analysis parameters	Why ?	Limitations and additional information
Semi-confined or confined aquifers	• It can be more advantageous to exploit confined aquifers, since they are protected from direct surface contamination. However, their recharge rates are significantly lower than unconfined aquifers. • Semi-confined aquifers could also be of interest since they may be a good compromise between protection and recharge.	• Unconfined aquifers benefit from greater recharge, and their groundwater is typically of better quality. However, they are more vulnerable to contamination from the surface. • Unconfined aquifers could be exploited for groundwater, but require greater management effort.
Low-vulnerability aquifers	• If the aquifer is relatively well protected from human activities on the surface, fewer and less intense interventions are necessary to reduce the risk of contamination.	• A highly vulnerable aquifer could be considered, but a lot of attention would need to be paid to contamination sources in the well capture zone. Pumped water may need to be treated. • A vulnerability index is subjective. One needs to be careful when interpreting the results. • DRASTIC vulnerability only considers contaminants infiltrating from the ground surface, without taking into account those which may originate from lateral groundwater flow. • To determine the risk of groundwater quality degradation, considering aquifer vulnerability alone is insufficient: one also needs to consider the combined impacts of human activities that present contamination potential, including the nature and quantity of the contaminant, the area of the affected zone, and the recurrence of contaminant discharge.

Proposed analysis criteria for geodata treatment

Analysis parameters	Hydrogeological concepts	Datasets to use	Description	Criteria
Semi-confined or confined aquifers	Quadra Sand confinement	NALO_Quadra_Conf2	*Quadra Sand Aquifer confinement*	• Confined aquifer • Semi-confined aquifer
Low-vulnerability aquifers	Aquifer vulnerability	NALO_drasticpro	*DRASTIC vulnerability index*	• Low vulnerability : 93 or lower index • Medium vulnerability : 93 to 159 index

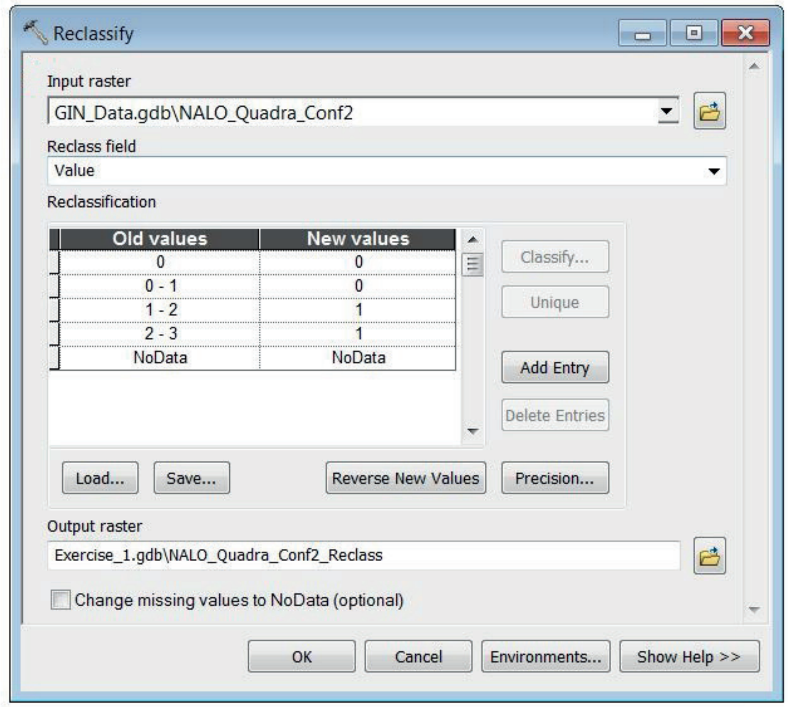
Step by step procedure

QUADRA AQUIFER CONFINEMENT

Execute the adjacent geotreatment to identify cells in **NALO_Quadra_Conf2** that meet the criteria.

New cells in **NALO_Quadra_Conf2_ Reclass** with the value of 1 meet the criteria.

Arc Toobox Spatial Analyst Tools Reclass Reclassify

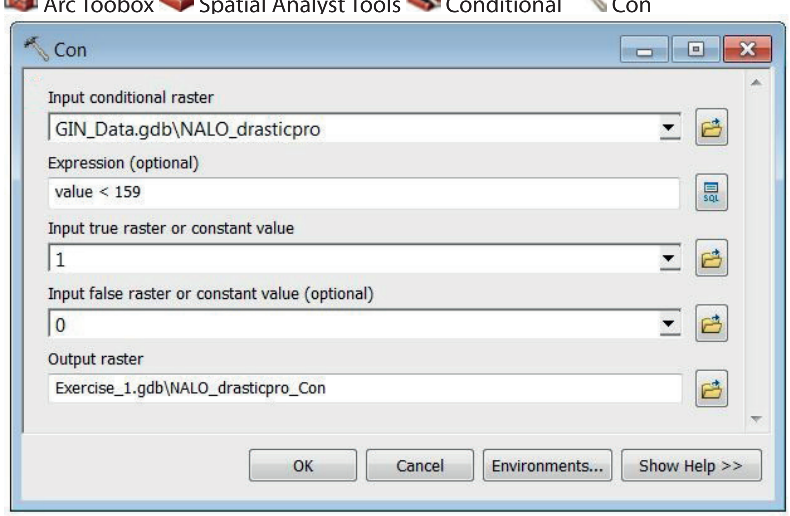


AQUIFER VULNERABILITY

Execute the adjacent geotreatment to identify cells in **NALO_drasticpro** that meet the criteria.

New cells in **NALO_drasticpro_Con** with the value of 1 meet the criteria.

Arc Toobox Spatial Analyst Tools Conditional Con

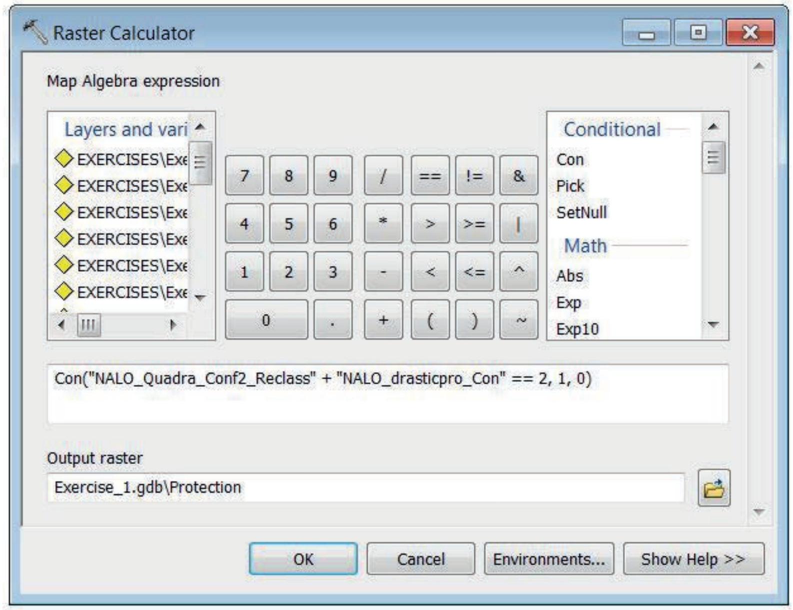


INTEGRATION

Execute the adjacent geotreatment to combine the results of **NALO_Quadra_Conf2_Reclass** and **NALO_drasticpro_Con**.

New cells in **Protection** with the value of 1 correspond to zones where aquifers are relatively well protected from contamination.

Arc Toobox Spatial Analyst Tools Map Algebra Raster Calculator



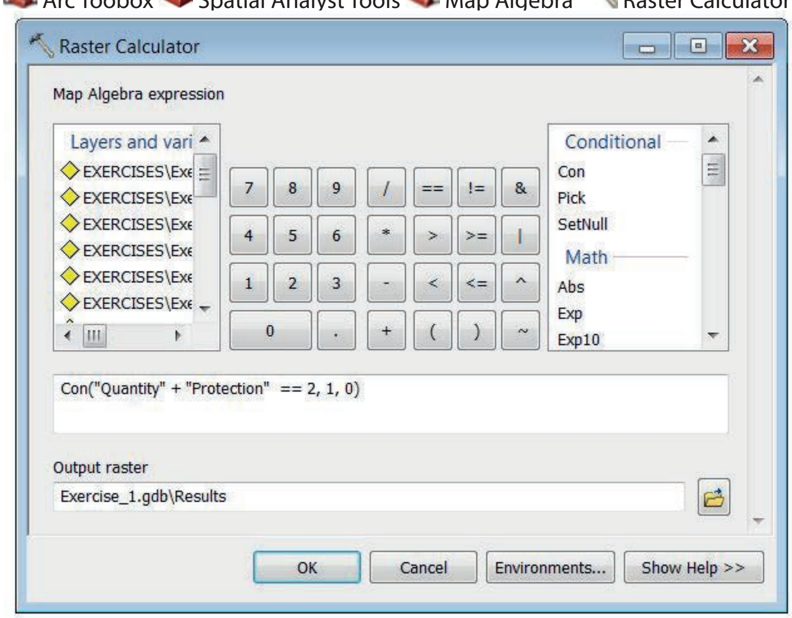
Integrate geotreatment analysis results

Step by step procedure

Execute the adjacent geotreatment to combine the results of **Quantity** and **Protection**.

New cells in **Results** with the value of 1 correspond to zones where groundwater would be present in a sufficient quantity and where aquifers are relatively well protected from contamination. Inversely, new cells with the value of 0 correspond to zones where at least one of the analysis criteria is not met : groundwater quantity would not be sufficient and/or aquifers would be too vulnerable to contamination.

Arc Toobox Spatial Analyst Tools Map Algebra Raster Calculator



3. Identify zones upstream to potential current or future contamination sources

Proposed analysis parameters

Analysis parameters	Why ?	Limitations and additional information
Upstream to potential current or future contamination sources	• To prevent contamination, groundwater reaching the supply well should be recharged in areas where there are no human activities that present a threat to water quality. Flow direction must therefore be considered to identify activities occurring upstream.	• Potentially polluting activities and their impact on water quality must be identified. • The limitations of a regional potentiometric map must be taken into account. For a specific well, a local hydrogeological study should be carried out to more effectively delineate its capture zone and identify threats inside this area.

Proposed criteria for visual analysis

Analysis parameters	Hydrogeological concepts	Datasets to use	Description	Criteria
Upstream to potential current or future contamination sources	Groundwater flow	NALO_Hydraulic_head_Quadra	*Hydraulic head for the Quadra Sand Aquifer groundwater flow system*	• Upstream to potential current or future contamination sources
	Land-use	NALO_Land_Cover RegionalGrowthStrategy_Landuse	*Land cover* *Regional growth strategy*	

Step by step procedure

GROUNDWATER FLOW AND LAND-USE

To identify potential current contamination sources, in the Table of Content in ArcMap, copy and paste the **NALO_Land_Cover** dataset in order to make changes to its legend without modifying the original one. In the new dataset, under the Symbology tab of the Layer Properties window, group values corresponding to human activities that may present a threat to groundwater quality (e.g., cropland, urban, road). Label this new group **Current potential contamination**.

To identify potential future contamination sources, in the Table of Content in ArcMap, copy and paste the **RegionalGrowthStrategy_Landuse** feature class in order to make changes to its legend without modifying the original one. In the new feature class, under the Symbology tab of the Layer Properties window, group values corresponding to human activities that may present a threat to groundwater quality (e.g., industrial areas, urban areas). Label this new group **Future potential contamination**.

In ArcMap, overlay these two new layers on the potentiometric map, **NALO_Hydraulic_head_Quadra**, to visualize zones from **Results** located downstream from **Current** or **Future potential contamination**. These aquifer zones are potentially more at risk to contamination than other zones, and should not take priority for groundwater supply.

Prepare the presentation of your results

Which area(s) appear(s) to be best-suited for the installation of a new community groundwater supply in the Quadra Sand Aquifer ?

Name of your territory of action :

When applying the proposed analysis criteria, describe the results obtained for your territory of action (e.g., location, surface area, hydrogeological characteristics of the selected areas).

Did you modify the proposed analysis criteria of the expert pathway ? If yes, why and how ? Please record in the analysis criteria used on the next page.

Did you integrate other information than those from the GSC study in your analysis criteria (e.g., the BC Well Database, the BC aquifer classification, data from RDN Water Budget Project, etc.) ? If yes, how do they influence the results ? Are there any inconsistencies between the available hydrogeological information ?

In your professional practice, what other information not available during this workshop would you use to answer the question (e.g., distance to urban cores, information on specific human activities or land-uses, etc.) ?

Regarding the regional scale of the available hydrogeological data, are there areas where you would need more local data ?

In your professional practice, how would you ensure the protection and sustainable development of groundwater in the areas highlighted by your analysis ?

Your analysis pathway for your territory of action

What we are looking for	Interpretation key specific to the issue		Geodata treatment			
	Analysis parameters	Why ?	Hydrogeological concepts	Datasets to use	Description	Criteria
Find a sufficient quantity of water			Sediment thickness	sed_thick	*Total sediment thickness*	
			Hydrostratigraphic unit thickness and spatial distribution	HSM_quadra5	*Quadra unit thickness*	
			Groundwater recharge	NALO_recharge_rst2	*Groundwater recharge*	
Identify zones that are relatively well protected from contamination			Aquifer vulnerability	NALO_drasticpro	*DRASTIC vulnerability index*	
			Quadra Aquifer confinement	NALO_Quadra_Conf2	*Quadra Sand Aquifer confinement*	
Identify zones upstream to potential current or future contamination sources			Groundwater flow	NALO_Hydraulic_head_Quadra	*Hydraulic head for the Quadra Sand Aquifer groundwater flow system*	
			Land-use	NALO_Land_Cover RegionalGrowthStrategy_Landuse	*Land cover* *Regional growth strategy*	

In practice, a lot of information on the human environment is integrated when seeking a new community groundwater supply (e.g., : location of the existing water network, distance to urban cores, land owners, land-uses, etc.). To complete this exercise, some information on land-use are made available. However, interpretation keys and analysis criteria are not proposed in the expert pathway. They are left to the participant to choose. The procedure below shows an example of geodata treatment.

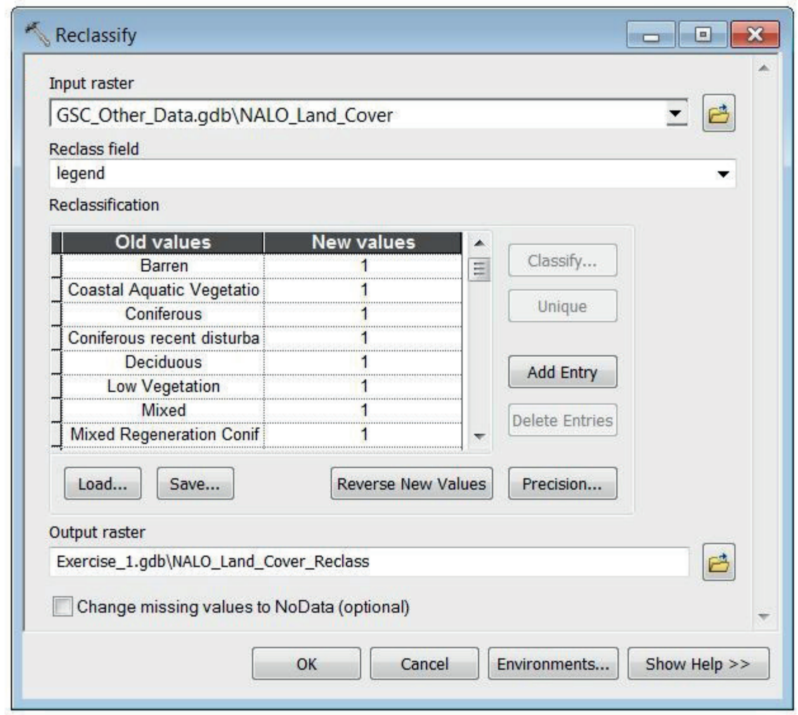
Step by step procedure

LAND COVER

Execute the adjacent geotreatment to identify cells in **NALO_Land_Cover** that meet the criteria you have chosen.

New cells in **NALO_Land_Cover_Reclass** with the value of 1 meet the criteria.

Arc Toobox Spatial Analyst Tools Reclass Reclassify

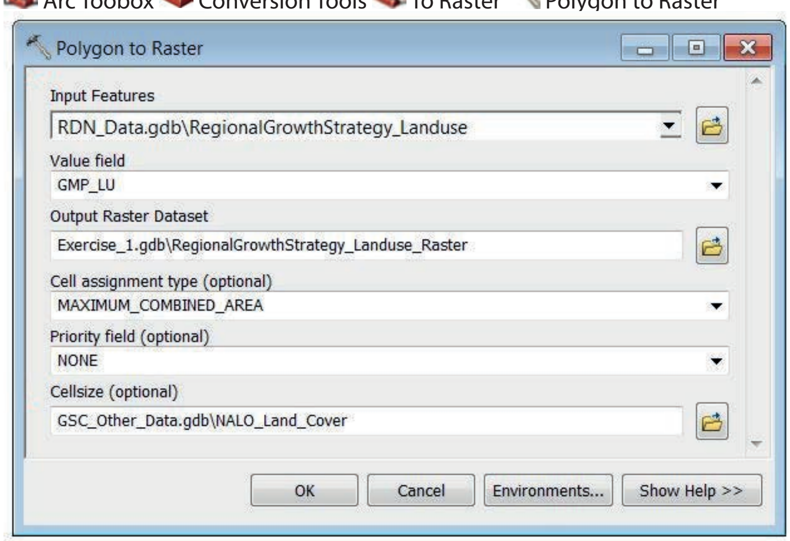


REGIONAL GROWTH STRATEGY

Execute the adjacent geotreatment to convert the **RegionalGrowth Strategy_Landuse** feature class from a vector format to a raster dataset **RegionalGrowth Strategy_Landuse_Raster**.

Make sure to select the correct Value field, Cell assignment type and Cellsize.

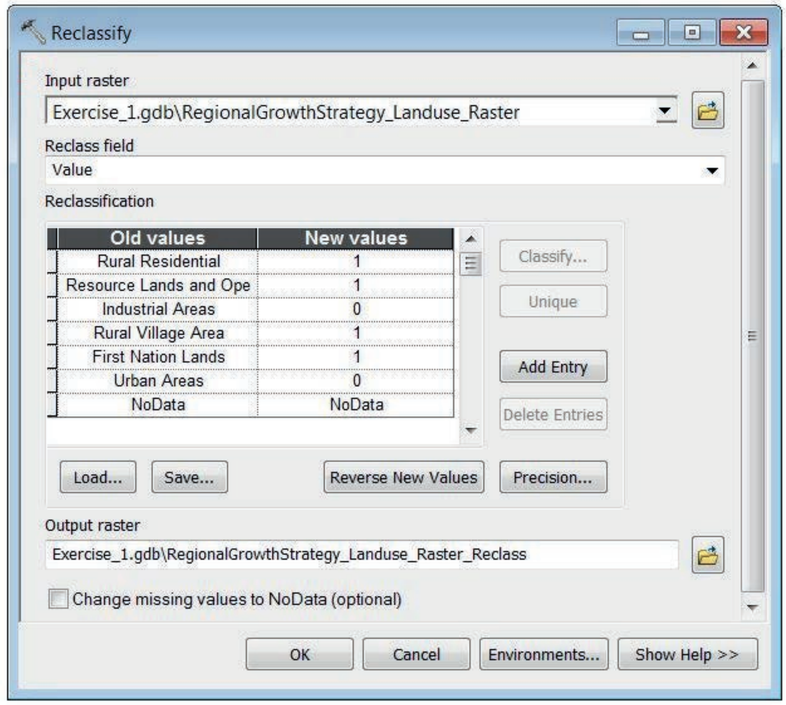
Arc Toobox Conversion Tools To Raster Polygon to Raster



Execute the adjacent geotreatment to identify cells in **RegionalGrowth Strategy_Landuse_Raster** that meet the criteria you have chosen.

New cells in **RegionalGrowthStrategy_ Landuse_Raster_Reclass** with the value of 1 meet the criteria.

Arc Toobox Spatial Analyst Tools Reclass Reclassify

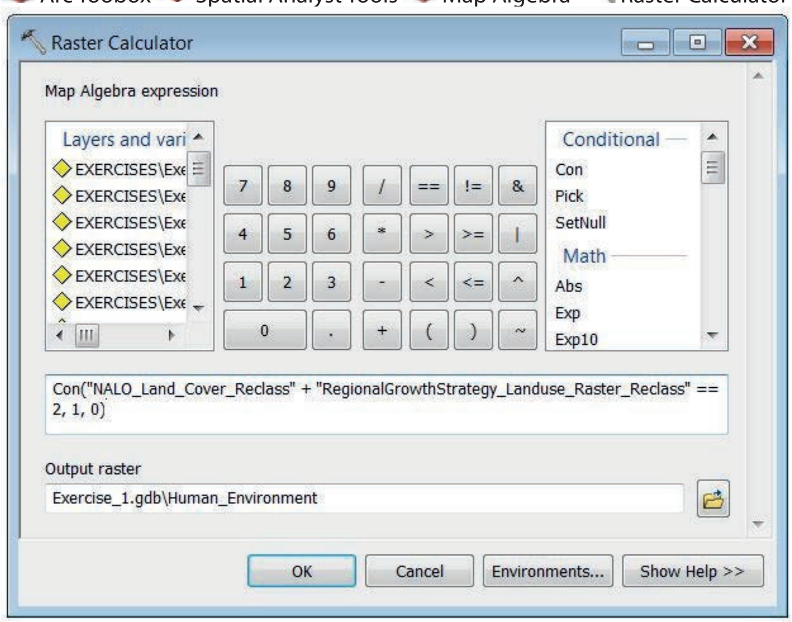


INTEGRATION

Execute the adjacent geotreatment to combine the results of **NALO_Land_Cover_Reclass** and **RegionalGrowthStrategy_Landuse_ Raster_Reclass**.

New cells in **Human_Environment** with the value of 1 correspond to zones where groundwater exploitation would be possible according to the available land-use information.

Arc Toobox Spatial Analyst Tools Map Algebra Raster Calculator

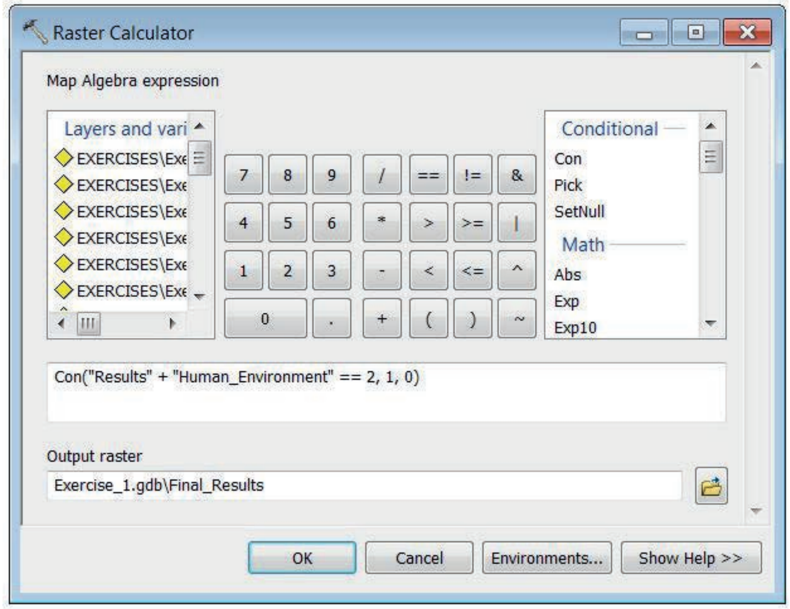


FINAL RESULT

Finally, it is possible to combine the results of **Human_Environment** and **Results** by executing the adjacent geotreatment in order to locate zones where groundwater would be present in a sufficient quantity, where aquifers are relatively well protected from contamination, and where groundwater exploitation would be possible according to the available land-use information.

The **Final_Results** dataset is the final solution to the exercise according to the expert hydrogeological analysis pathway, combined with knowledge on the human environment.

Arc Toobox Spatial Analyst Tools Map Algebra Raster Calculator



To do this exercise, you will need to choose between one of the three following questions pertaining to groundwater protection and management in the region :

1. Which area(s) appear(s) to be best-suited for the installation of a new community groundwater supply in the Quadra Sand Aquifer ?
2. Which area(s) should take priority for groundwater recharge protection in the Quadra Sand Aquifer ?
3. Where could a new potentially polluting activity be implemented in order to minimize its impact on the Quadra Sand Aquifer groundwater quality ?

The exercise involves three distinct activities :

Activity 1 – Brainstorm useful hydrogeological concepts for groundwater protection and management

This activity's objective is to deliberate on the analysis pathway that you could apply in your territory to respond to the question. Here are a few questions to consider :

- *According to you, what are we looking for?*
- *What are the aquifer characteristics we should seek?*
- *What are the analysis criteria?*
- *What hydrogeological information should we use?*

To perform this activity, you will be separated into groups of a maximum of 10 participants. You will be accompanied by a RQES facilitator who will lead the discussion and will seek your input and solutions. A GSC groundwater expert will also be present to answer to any questions of a scientific nature, and will be invited to comment on the brainstorming results.

An analysis pathway of a hydrogeology expert will then be proposed. It is described in detail in the participant workbook. An overview of this approach will be presented orally, with explanations on the geotreatment procedure. It is this procedure that you will apply in the following activity in the computer lab. We ask that you reserve your comments on this proposed analysis pathway for the third activity.

Activity 2 – Application of a spatial analysis procedure to my territory of action

This activity's objective is to appreciate how groundwater geodata can be used in groundwater protection and management.

This activity will be completed in pairs in the computer lab, using ArcGIS software. You will be asked to apply the geotreatment procedure presented in the previous activity and described in the participant workbook to data from your territory. Workshop facilitators and groundwater experts will be present at all times to answer to your technical questions in geomatics or hydrogeology.

If you finish the activity before the allocated time is up, you are asked to modify some analysis criteria and evaluate their sensitivity on your final results. You could also choose to work on a second question.

It is important to fill in the final questionnaire to prepare the presentation of your results, since it will serve as a basis for the next activity.

Activity 3 – Presentation of exercise results

This activity's objective is to share your results with all workshop participants, and to exchange with the groundwater experts.

At least one pair team who chose each issue will be invited to discuss their results, referring to the final questionnaire that they filled in at the end of the previous activity. The mapped results will be projected on the screen so that everyone can see them.

Question 2

Which area(s) should take priority for groundwater recharge protection in the Quadra Sand Aquifer ?

Participant Brainstorming Results

WHAT WE ARE LOOKING FOR	THE ANALYSIS CRITERIA

Expert Analysis Pathway Overview

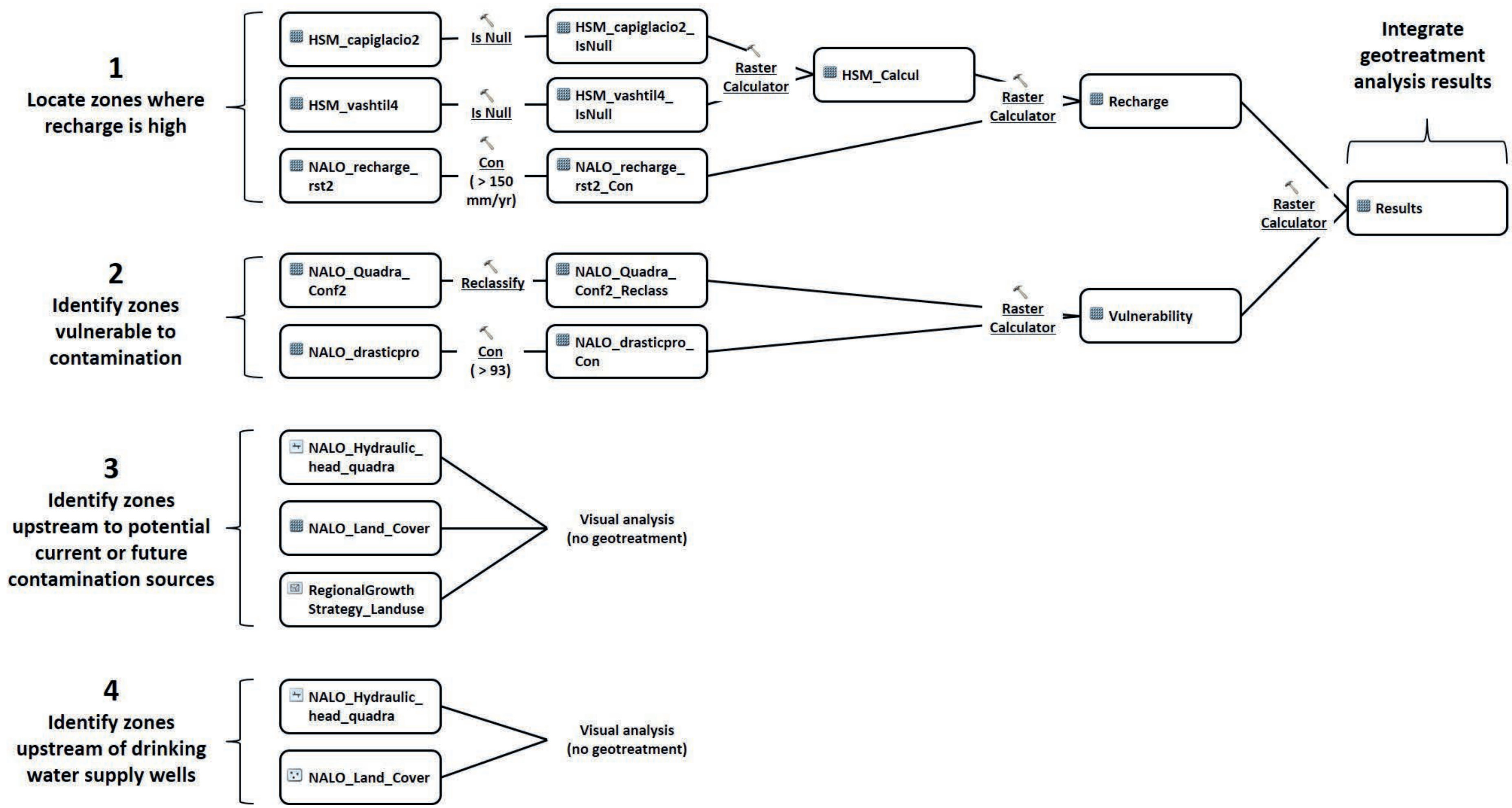
Question

Which area(s) should take priority for groundwater recharge protection in the Quadra Sand Aquifer?

What we are looking for

1. Locate zones where recharge is high
2. Identify zones vulnerable to contamination
3. Identify zones upstream to potential current or future contamination sources
4. Identify zones upstream of drinking water supply wells

Proposed geotreatment procedure using available geodata



1. Locate zones where recharge is high

Proposed analysis parameters

Analysis parameters	Why ?	Limitations and additional information
Permeable sediments at the surface	• High recharge occurs when permeable sediments are at the surface, i.e. when impermeable sediments are absent.	• A bedrock aquifer could also receive substantial recharge when it outcrops or is near the surface under permeable sediment.
High annual recharge rate	• Zones where recharge is important should take priority for protection.	• The annual recharge rate can vary from one year to another, depending on climatic variations or land-use modifications. It also varies seasonally.

Proposed analysis criteria for geodata treatment

Analysis parameters	Hydrogeological concepts	Datasets to use	Description	Criteria
Permeable sediments at the surface	Hydrostratigraphic unit thickness and spatial distribution	HSM_capiglacio2 HSM_vashtil4	*Capilano (glaciomarine) unit thickness* *Vashon Till unit thickness*	• Absence : thickness of 0 m
High annual recharge rate	Groundwater recharge	NALO_recharge_rst2	*Groundwater recharge*	• Medium recharge : 150 to 300 mm/yr • High recharge : 300 mm/yr and more

Step by step procedure

HYDROSTRATIGRAPHIC UNIT THICKNESS AND SPATIAL DISTRIBUTION

Execute the adjacent geotreatment to identify cells in **HSM_capiglacio2** that meet the criteria.

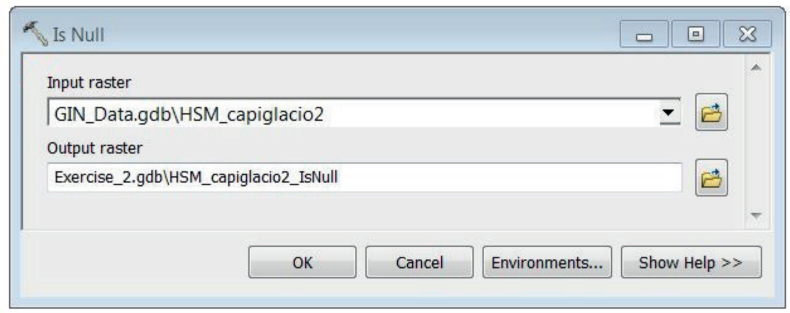
The dataset only contains cells with defined values greater than 0 m. Where the sediment thickness is 0 m, cells do not have a defined value (no data). The Is Null tool attributes a value of 1 to cells with no data and a value of 0 to cells with a defined value.

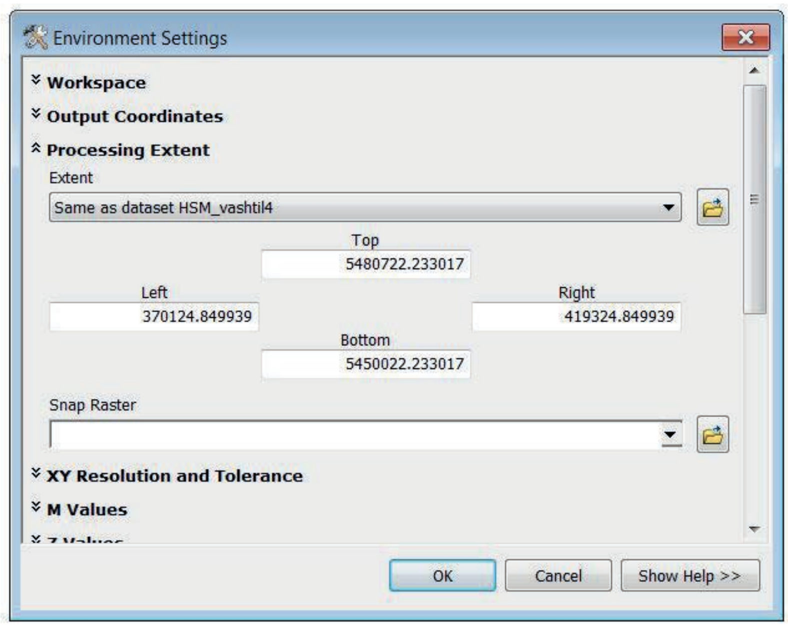
Because the dataset extent is smaller than the whole study area, a larger extent must be set during the geotreatment. The below procedure uses the extent of the **HSM_vashtil4** dataset :

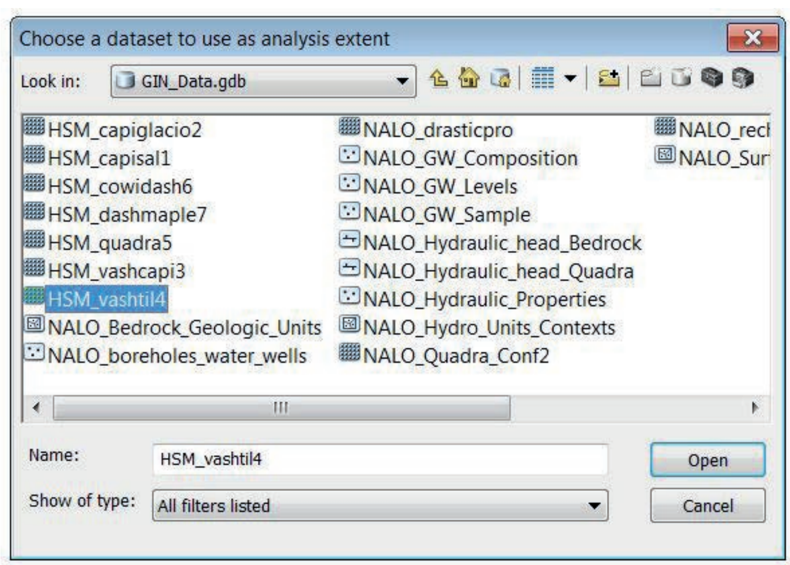
- In the Is Null tool window, Click on the Environments... button.
- In the Environment Settings window, click on Processing Extent.
- Click on the folder icon next to the drop-down menu Extent.
- Navigate to the **GIN_Data.gdb** geodatabase and select the **HSM_vashtil4** dataset.
- Click Open, then Ok to validate the settings and return to the Is Null tool window.

New cells in **HSM_capiglacio2_IsNull** with the value of 1 meet the criteria.

Arc Toolbox Spatial Analyst Tools Math Logical Is Null



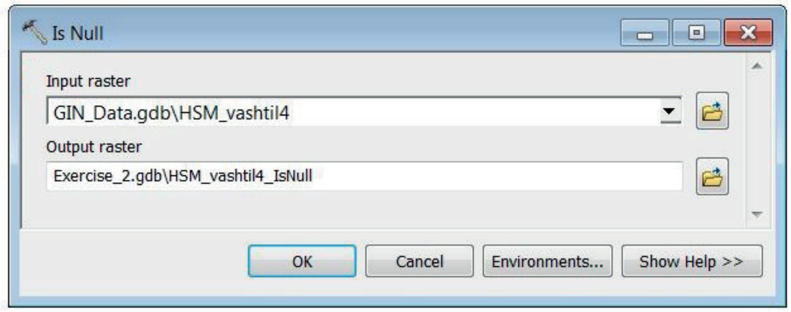




Execute the adjacent geotreatment to identify cells in **HSM_vashtil4** that meet the criteria.

New cells in **HSM_vashtil4_IsNull** with the value of 1 meet the criteria.

Arc Toobox Spatial Analyst Tools Math Logical Is Null



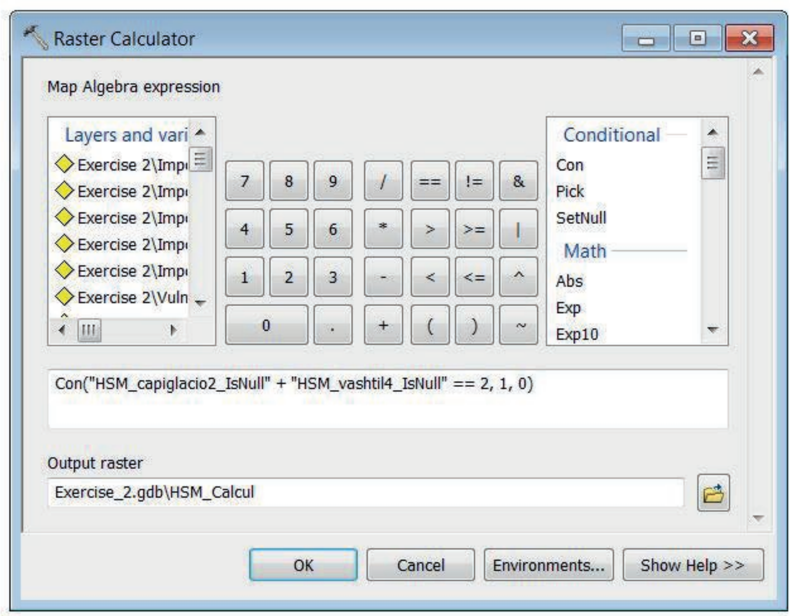
Execute the adjacent geotreatment to combine the results of **HSM_capiglacio2_IsNull** and **HSM_vashtil4_IsNull**.

The conditional calculation is written in the Python programming language supported by ArcGIS. It can be described as follows : if the condition before the first comma is true, then the new cell takes the value indicated after the first comma. If not, it takes the value indicated after the second comma.

In this case, if the sum of the cells from the two raster datasets is 2, meaning that the sediment thickness is 0 m for the two datasets, then the new cell takes the value of 1. If not, it takes the value of 0.

New cells in **HSM_Calcul** with the value of 1 correspond to zones where impermeable sediments are absent, thus permeable sediments are present at the surface.

Arc Toobox Spatial Analyst Tools Map Algebra Raster Calculator

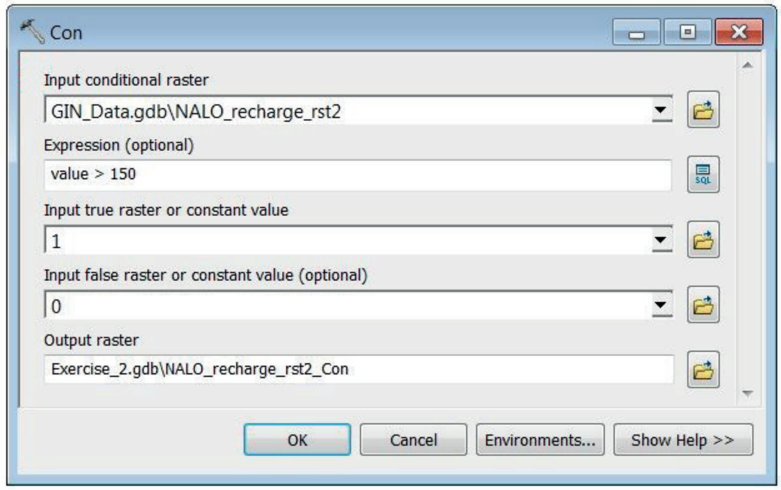


GROUNDWATER RECHARGE

Execute the adjacent geotreatment to identify cells in **NALO_recharge_rst2** that meet the criteria.

New cells in **NALO_recharge_rst2_Con** with the value of 1 meet the criteria.

Arc Toobox Spatial Analyst Tools Conditional Con



INTEGRATION

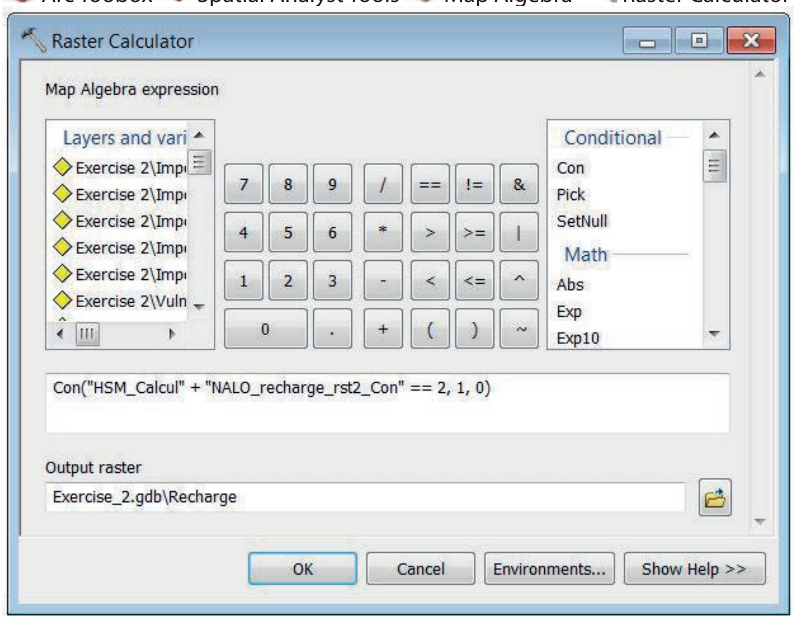
Execute the adjacent geotreatment to combine the results of **HSM_Calcul** and **NALO_recharge_rst2_Con**.

The conditional calculation is written in the Python programming language supported by ArcGIS. It can be described as follows: if the condition before the first comma is true, then the new cell takes the value indicated after the first comma. If not, it takes the value indicated after the second comma.

In this case, if the sum of the cells from the two raster datasets is 2, meaning that all criteria to locate zones where recharge is high are met, then the new cell takes the value of 1, If not, it takes the value of 0.

New cells in **Recharge** with the value of 1 correspond to zones where recharge is high.

Arc Toobox Spatial Analyst Tools Map Algebra Raster Calculator



2. Identify zones vulnerable to contamination

Proposed analysis parameters

Analysis parameters	Why ?	Limitations and additional information
Unconfined aquifers	• Unconfined aquifers are not protected from direct surface contamination.	• Recharge is usually significant in unconfined aquifers.
Vulnerable aquifers	• One should focus on protecting aquifers sensitive to direct surface contamination rather than those already naturally protected.	• A vulnerability index is subjective. One needs to be careful when interpreting the results. • DRASTIC vulnerability only considers contaminants infiltrating from the ground surface, without taking into account what could originate from lateral groundwater flow. • To consider the risk of groundwater quality degradation, aquifer vulnerability alone is insufficient: one also needs to combine impacts of human activities that present a potential for contamination, including the nature and quantity of the contaminant, the area of affected zone, and the recurrence of contaminant discharge.

Proposed analysis criteria for geodata treatment

Analysis parameters	Hydrogeological concepts	Datasets to use	Description	Criteria
Unconfined aquifers	Quadra Aquifer confinement	NALO_Quadra_Conf2	*Quadra Sand Aquifer confinement*	• Unconfined aquifer
Vulnerable aquifers	Aquifer vulnerability	NALO_drasticpro	*DRASTIC vulnerability index*	• Medium vulnerability : 93 to 159 index • High vulnerability : 159 or more index

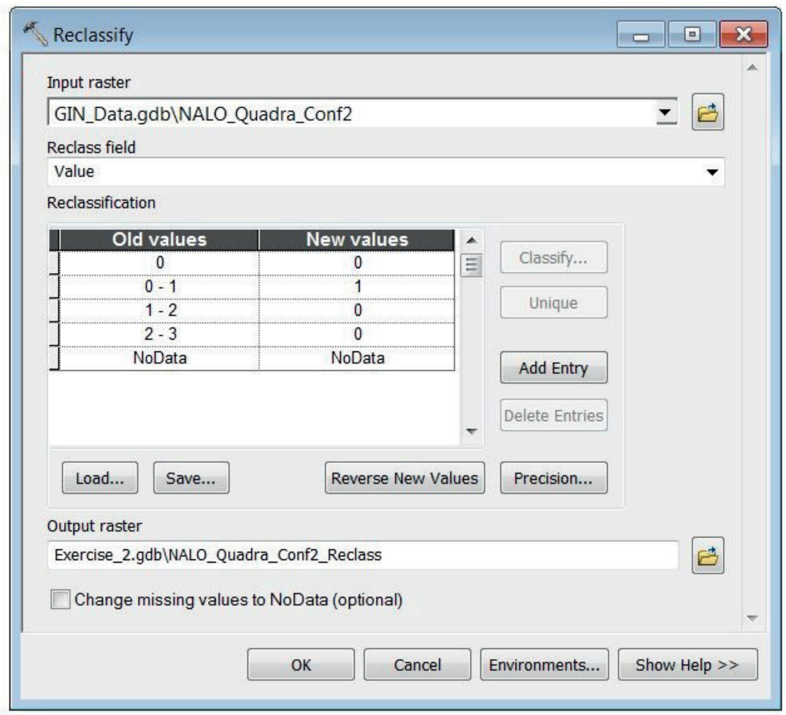
Step by step procedure

QUADRA AQUIFER CONFINEMENT

Execute the adjacent geotreatment to identify cells in **NALO_Quadra_Conf2** that meet the criteria.

New cells in **NALO_Quadra_Conf2_Reclass** with the value of 1 meet the criteria.

Arc Toobox Spatial Analyst Tools Reclass Reclassify

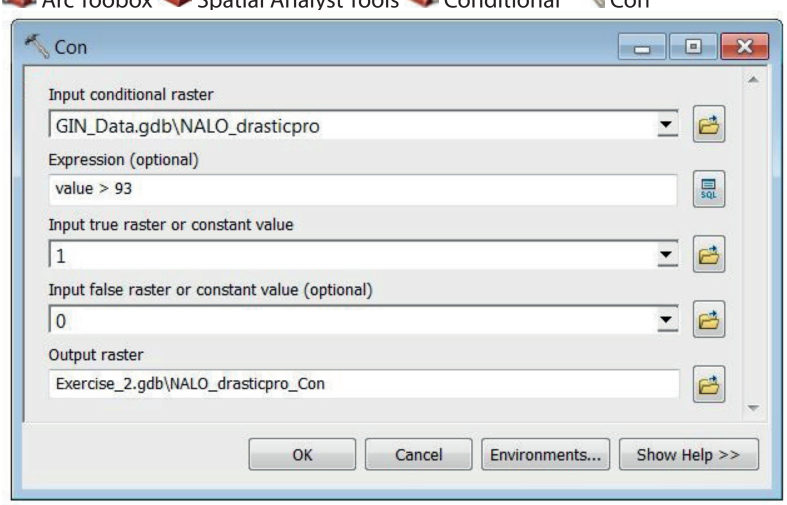


AQUIFER VULNERABILITY

Execute the adjacent geotreatment to identify cells in **NALO_drasticpro** that meet the criteria.

New cells in **NALO_drasticpro_Con** with the value of 1 meet the criteria.

Arc Toobox Spatial Analyst Tools Conditional Con

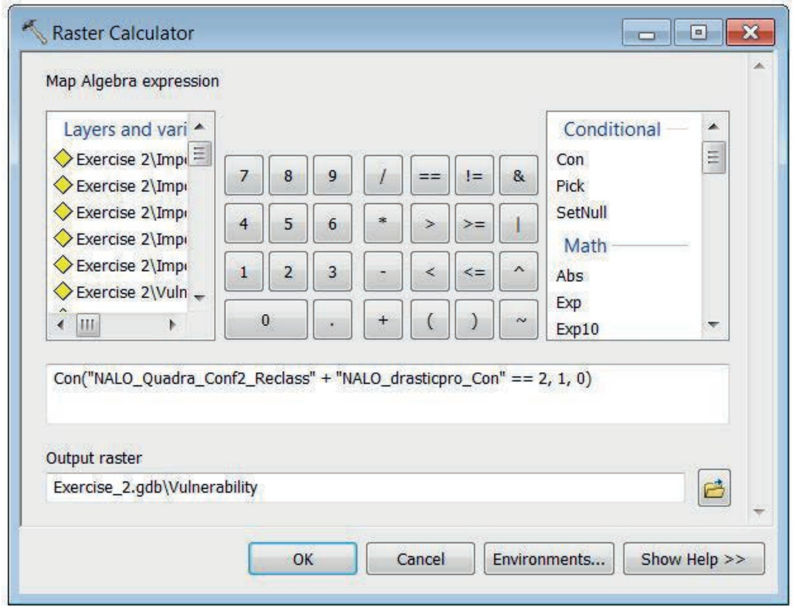


INTEGRATION

Execute the adjacent geotreatment to combine the results of **NALO_Quadra_Conf2_Reclass** and **NALO_drasticpro_Con**.

New cells in **Vulnerability** with the value of 1 correspond to zones where recharge is high.

Arc Toobox Spatial Analyst Tools Map Algebra Raster Calculator



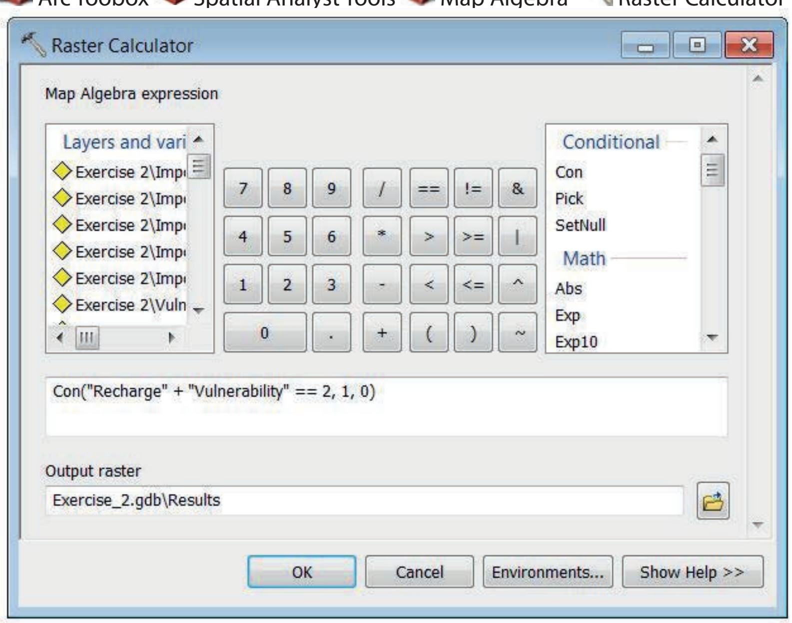
Integrate geotreatment analysis results

Step by step procedure

Execute the adjacent geotreatment to combine the results of **Recharge** and **Vulnerability**.

New cells in **Results** with the value of 1 correspond to zones where groundwater recharge is high and aquifers are vulnerable to contamination. Inversely, new cells with the value of 0 correspond to zones where at least one of the analysis criteria is not met: groundwater recharge is not high and/or aquifers are vulnerable to contamination.

Arc Toobox Spatial Analyst Tools Map Algebra Raster Calculator



3. Identify zones upstream to potential current or future contamination sources

Proposed analysis parameters

Analysis parameters	Why ?	Limitations and additional information
Upstream to potential current or future contamination sources	• To prevent contamination, groundwater reaching the protected aquifer should be recharged where there are no human activities that may present a threat to water quality. Flow direction must therefore be considered to identify activities occurring upstream.	• Potentially polluting activities and their impact on water quality must be identified.

Proposed criteria for visual analysis

Analysis parameters	Hydrogeological concepts	Datasets to use	Description	Criteria
Upstream to potential current or future contamination sources	Groundwater flow	NALO_Hydraulic_head_Quadra	*Hydraulic head for the Quadra Sand Aquifer groundwater flow system*	• Upstream to potential current or future contamination sources
	Land-use	NALO_Land_Cover RegionalGrowthStrategy_Landuse	*Land cover* *Regional growth strategy*	

Step by step procedure

GROUNDWATER FLOW AND LAND-USE

To identify potential current contamination sources, in the Table of Content in ArcMap, copy and paste the **NALO_Land_Cover** dataset in order to make changes to its legend without modifying the original one. In the new dataset, under the Symbology tab of the Layer Properties window, group values corresponding to human activities that may present a threat to groundwater quality (e.g., cropland, urban, road). Label this new group **Current potential contamination**.

To identify potential future contamination sources, in the Table of Content in ArcMap, copy and paste the **RegionalGrowthStrategy_Landuse** feature class in order to make changes to its legend without modifying the original one. In the new feature class, under the Symbology tab of the Layer Properties window, group values corresponding to human activities that may present a threat to groundwater quality (e.g., industrial areas, urban areas). Label this new group **Future potential contamination**.

In ArcMap, overlay the new layers on the potentiometric map, **NALO_Hydraulic_head_Quadra**, to visualize zones from **Results** located downstream from **Current** or **Future potential contamination**. These recharge zones are potentially more at risk to contamination than other zones and take priority for protection.

4. Identify zones upstream of drinking water supply wells

Proposed analysis parameters

Analysis parameters	Why ?	Limitations and additional information
Upstream of drinking water supply wells	• To promote the protection of exploited aquifers and to prevent the contamination of groundwater supply wells, protected recharge zones should be located upstream of drinking water supply wells.	• The higher the well density, the more severe the effects of contamination would be due to the large number of consumers affected. The benefits of protecting the recharge zones of exploited aquifers is therefore high. • Community supply wells should be identified, since contamination of only one of these would affect many consumers, therefore increasing the severity of the contamination event.

Proposed criteria for visual analysis

Analysis parameters	Hydrogeological concepts	Datasets to use	Description	Criteria
Upstream of drinking water supply wells	Groundwater flow	NALO_Hydraulic_head_Quadra	*Hydraulic head for the Quadra Sand Aquifer groundwater flow system*	• Upstream of drinking water supply wells
	BC Groundwater Wells Database	Groundwater_Wells	*Groundwater wells*	

Step by step procedure

GROUNDWATER FLOW AND BC GROUNDWATER WELLS DATABASE

To identify drinking water supply wells, in the Table of Content in ArcMap, copy and paste the **Groundwater_Wells** feature class in order to make changes to the display of the layer without modifying the original one. In the new feature class, execute the following query under the Definition Query tab of the Layer Properties window. This query can be copied from the text file **Query** in the **Exercises** folder.

WLLSNM = 'Commercial and Industrial' OR WLLSNM = 'Private Domestic' OR WLLSNM = 'Water Supply System'

In ArcMap, overlay the new layer on the potentiometric map, **NALO_Hydraulic_head_Quadra**, to visualize zones from **Results** located upstream of a substantial number of drinking water supply wells. These recharge zones should take priority for protection.

Prepare the presentation of your results

Which area(s) should take priority for groundwater recharge protection in the Quadra Sand Aquifer ?

Name of your territory of action :

When applying the proposed analysis criteria, describe the results obtained for your territory of action (e.g., location, surface area, hydrogeological characteristics of the selected areas).

Did you modify the proposed analysis criteria of the expert pathway ? If yes, why and how ? Please record in the analysis criteria used on the next page.

Did you integrate other information than those from the GSC study in your analysis criteria (e.g., the BC Well Database, the BC aquifer classification, data from RDN Water Budget Project, etc.) ? If yes, how do they influence the results ? Are there any inconsistencies between the available hydrogeological information ?

In your professional practice, what other information not available during this workshop would you use to answer the question (e.g., natural habitat of interest, conservation zones, information on specific human activities or land-uses, etc.) ?

Regarding the regional scale of the available hydrogeological data, are there areas where you would need more local data ?

In your professional practice, how would you ensure the protection and sustainable development of groundwater in the areas highlighted by your analysis ?

Your analysis pathway for your territory of action

What we are looking for	Interpretation key specific to the issue		Geodata treatment			
	Analysis parameters	Why ?	Hydrogeological concepts	Datasets to use	Description	Criteria
Locate zones where recharge is high			Hydrogeological contexts	NALO_Hydro_Units_ Contexts	*Hydrostratigraphic units and hydrogeological contexts*	
			Groundwater recharge	NALO_recharge_rst2	*Groundwater recharge*	
Identify zones vulnerable to contamination			Quadra Aquifer confinement	NALO_Quadra_Conf2	*Quadra Sand Aquifer confinement*	
			Aquifer vulnerability	NALO_drasticpro	*DRASTIC vulnerability index*	
Identify zones upstream to potential current or future contamination sources			Groundwater flow	NALO_Hydraulic_head_ Quadra	*Hydraulic head for the Quadra Sand Aquifer groundwater flow system*	
			Land-use	NALO_Land_Cover RegionalGrowthStrategy_ Landuse	*Land cover* *Regional growth strategy*	
Identify zones upstream of drinking water supply wells			Groundwater flow	NALO_Hydraulic_head_ Quadra	*Hydraulic head for the Quadra Sand Aquifer groundwater flow system*	
			BC Groundwater Wells Database	Groundwater_Wells	*Groundwater wells*	

In practice, a lot of information on the human environment is integrated when identifying areas to take priority for groundwater recharge protection (e.g., conservation zones, land owners, land-use, etc.). To complete this exercise, some information on land-use is made available. However, interpretation keys and analysis criteria are not proposed in the expert pathway. They are instead left to the participant to choose. The procedure below shows an example of geodata treatment.

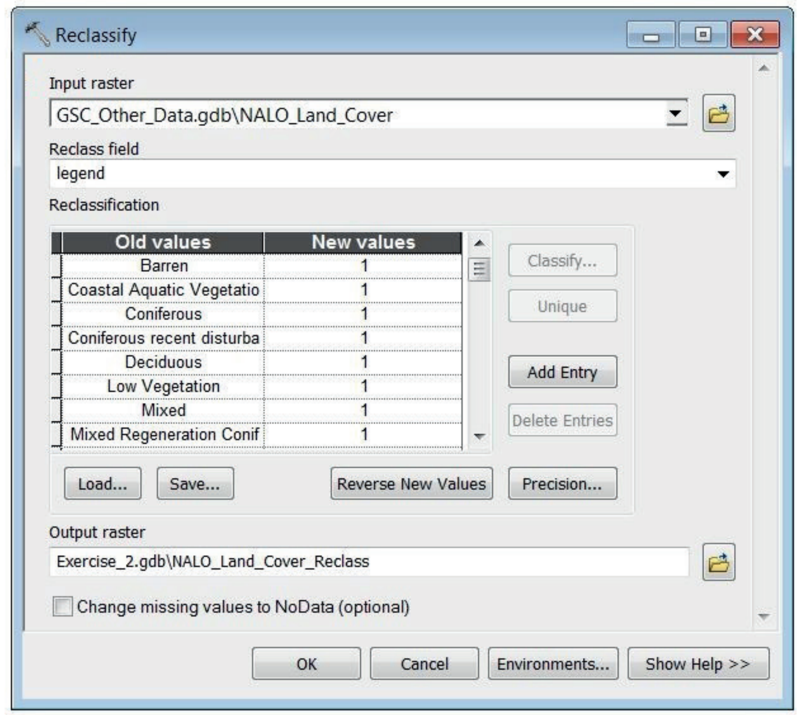
Step by step procedure

LAND COVER

Execute the adjacent geotreatment to identify cells in **NALO_Land_Cover** that meet the criteria you have chosen.

New cells in **NALO_Land_Cover_Reclass** with the value of 1 meet the criteria.

Arc Toobox Spatial Analyst Tools Reclass Reclassify

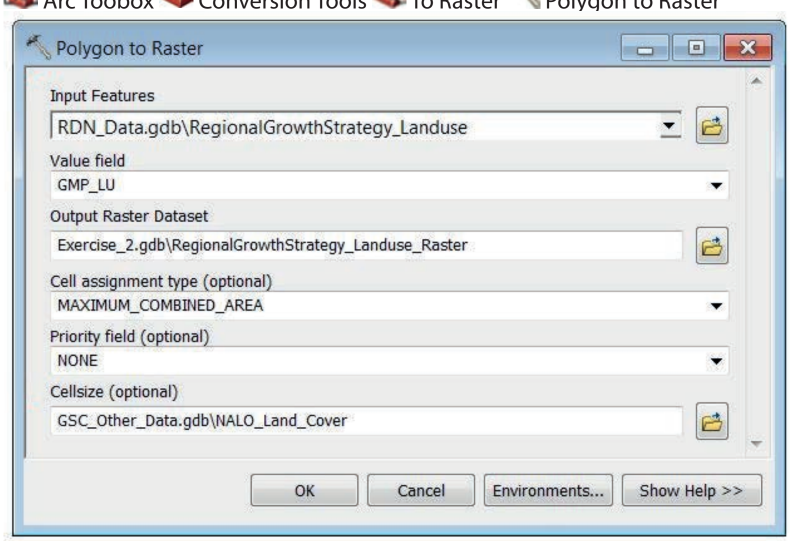


REGIONAL GROWTH STRATEGY

Execute the adjacent geotreatment to convert the **RegionalGrowth Strategy_Landuse** feature class from a vector format to a raster dataset **RegionalGrowth Strategy_Landuse_Raster**.

Make sure to select the correct Value field, Cell assignment type and Cellsize.

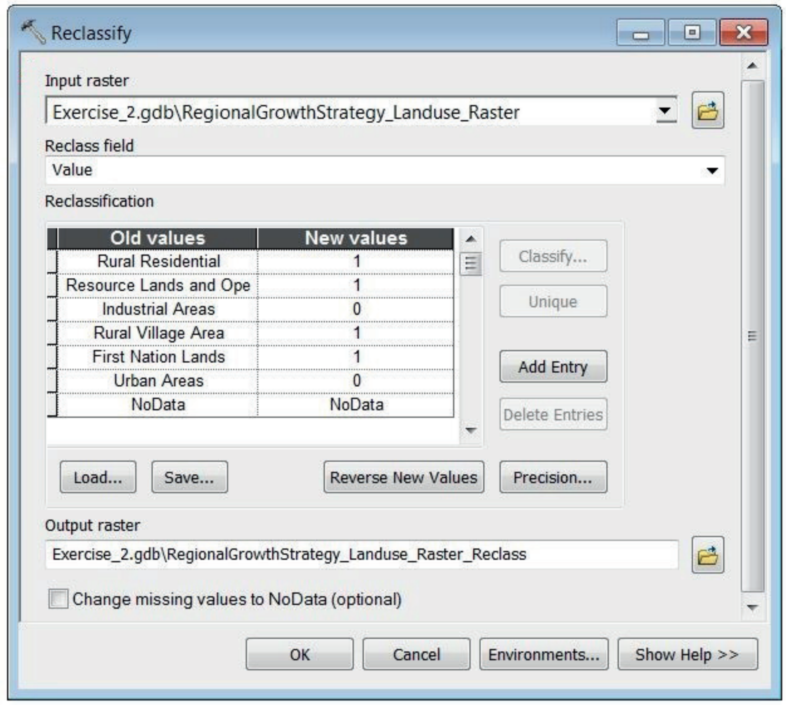
Arc Toobox Conversion Tools To Raster Polygon to Raster



Execute the adjacent geotreatment to identify cells in **RegionalGrowth Strategy_Landuse_Raster** that meet the criteria you have chosen.

New cells in **RegionalGrowthStrategy_ Landuse_Raster_Reclass** with the value of 1 meet the criteria.

Arc Toobox Spatial Analyst Tools Reclass Reclassify

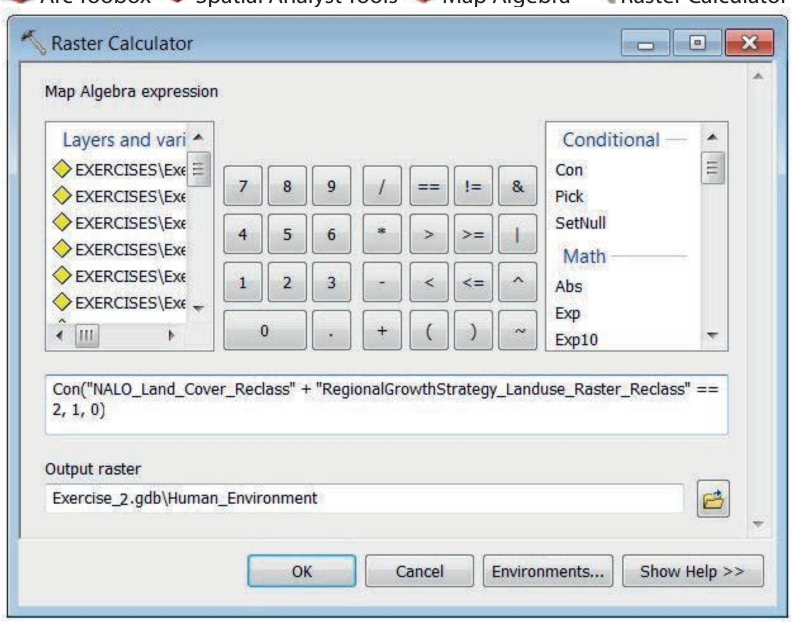


INTEGRATION

Execute the adjacent geotreatment to combine the results of **NALO_Land_Cover_Reclass** and **RegionalGrowthStrategy_Landuse_ Raster_Reclass**.

New cells in **Human_Environment** with the value of 1 correspond to zones where groundwater recharge protection would be possible according to available land-use information.

Arc Toobox Spatial Analyst Tools Map Algebra Raster Calculator

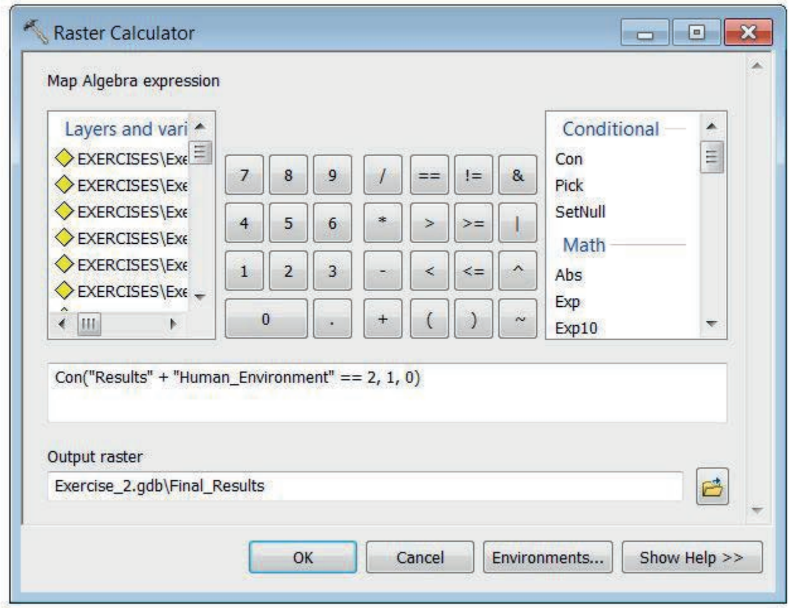


FINAL RESULT

Finally, it is possible to combine the results of **Human_Environment** and **Results** by executing the adjacent geotreatment in order to locate zones where recharge is high, aquifers are vulnerable to contamination, and groundwater recharge protection would be possible according to available land-use information.

The **Final_Results** dataset is the final solution to the exercise according to the expert hydrogeological analysis pathway, combined with the integration of knowledge on the human environment.

Arc Toobox Spatial Analyst Tools Map Algebra Raster Calculator



To do this exercise, you will need to choose between one of the three following questions pertaining to groundwater protection and management in the region :

1. Which area(s) appear(s) to be best-suited for the installation of a new community groundwater supply in the Quadra Sand Aquifer ?
2. Which area(s) should take priority for groundwater recharge protection in the Quadra Sand Aquifer ?
3. Where could a new potentially polluting activity be implemented in order to minimize its impact on the Quadra Sand Aquifer groundwater quality ?

The exercise involves three distinct activities :

Activity 1 – Brainstorm useful hydrogeological concepts for groundwater protection and management

This activity's objective is to deliberate on the analysis pathway that you could apply in your territory to respond to the question. Here are a few questions to consider :

- *According to you, what are we looking for?*
- *What are the aquifer characteristics we should seek?*
- *What are the analysis criteria?*
- *What hydrogeological information should we use?*

To perform this activity, you will be separated into groups of a maximum of 10 participants. You will be accompanied by a RQES facilitator who will lead the discussion and will seek your input and solutions. A GSC groundwater expert will also be present to answer to any questions of a scientific nature, and will be invited to comment on the brainstorming results.

An analysis pathway of a hydrogeology expert will then be proposed. It is described in detail in the participant workbook. An overview of this approach will be presented orally, with explanations on the geotreatment procedure. It is this procedure that you will apply in the following activity in the computer lab. We ask that you reserve your comments on this proposed analysis pathway for the third activity.

Activity 2 – Application of a spatial analysis procedure to my territory of action

This activity's objective is to appreciate how groundwater geodata can be used in groundwater protection and management.

This activity will be completed in pairs in the computer lab, using ArcGIS software. You will be asked to apply the geotreatment procedure presented in the previous activity and described in the participant workbook to data from your territory. Workshop facilitators and groundwater experts will be present at all times to answer to your technical questions in geomatics or hydrogeology.

If you finish the activity before the allocated time is up, you are asked to modify some analysis criteria and evaluate their sensitivity on your final results. You could also choose to work on a second question.

It is important to fill in the final questionnaire to prepare the presentation of your results, since it will serve as a basis for the next activity.

Activity 3 – Presentation of exercise results

This activity's objective is to share your results with all workshop participants, and to exchange with the groundwater experts.

At least one pair team who chose each issue will be invited to discuss their results, referring to the final questionnaire that they filled in at the end of the previous activity. The mapped results will be projected on the screen so that everyone can see them.

Question 3

Where could a new potentially polluting activity be implemented in order to minimize its impact on the Quadra Sand Aquifer groundwater quality ?

Participant Brainstorming Results

WHAT WE ARE LOOKING FOR	THE ANALYSIS CRITERIA

Expert Analysis Pathway Overview

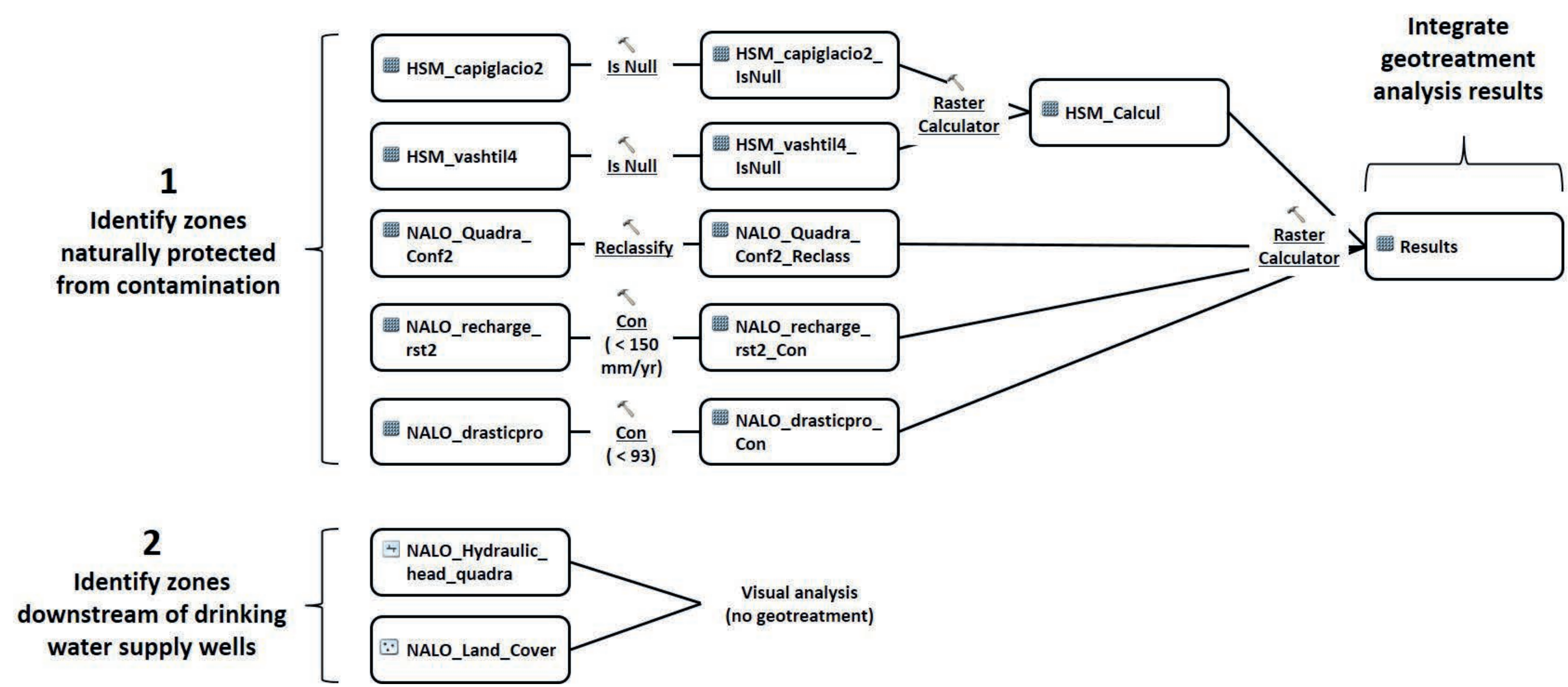
Question

Where could a new potentially polluting activity be implemented in order to minimize its impact on the Quadra Sand Aquifer groundwater quality?

What we are looking for

1. Identify zones naturally protected from contamination
2. Identify zones downstream of drinking water supply wells

Proposed geotreatment procedure using available geodata



1. Identify zones naturally protected from contamination

Proposed analysis parameters

Analysis parameters	Why ?	Limitations and additional information
Impermeable sediment at the surface	• Impermeable sediment at the surface prevents the infiltration of contaminants.	• Impermeable sediment acts as an aquitard, forming a barrier to groundwater flow and confining the underlying aquifer.
Confined aquifers	• Confined aquifers are protected from direct surface contamination. • Groundwater quality in confined aquifers may already be lower, which diminishes the subsequent severity of a potential contamination event.	• Confined aquifers are not protected from contamination coming from lateral groundwater flow.
Low annual recharge rate	• Recharge must be low to limit the quantity of infiltrating water that may mobilize contamination at the surface.	• Land cover has a significant impact on infiltration (e.g., paving in urban areas versus cropland or forest). • A sloping terrain favours surface runoff instead of groundwater recharge.
Invulnerable aquifers	• Low-vulnerability aquifers are well protected from direct surface contamination.	• A vulnerability index is subjective. One needs to be careful when interpreting the results. • DRASTIC vulnerability only considers contaminants infiltrating from the ground surface, without taking into account contamination which may originate from lateral groundwater flow. • To consider the risk of groundwater quality degradation, aquifer vulnerability is insufficient: one also needs to combine impacts of human activities that present a contamination potential, including the nature and quantity of the contaminant, the area of affected zone, and the recurrence of contaminant discharge.

Proposed analysis criteria for geodata treatment

Analysis parameters	Hydrogeological concepts	Datasets to use	Description	Criteria
Impermeable sediment at the surface	Hydrostratigraphic unit thickness and spatial distribution	HSM_capiglacio2 HSM_vashtil4	*Capilano (glaciomarine) unit thickness* *Vashon Till unit thickness*	• Presence : thickness > 0 m
Confined aquifers	Quadra Aquifer confinement	NALO_Quadra_Conf2	*Quadra Sand Aquifer confinement*	• Confined aquifer
Low annual recharge rate	Groundwater recharge	NALO_recharge_rst2	*Groundwater recharge*	• Nul recharge : 0 mm/yr • Low recharge : 0 to 150 mm/yr
Invulnerable aquifers	Aquifer vulnerability	NALO_drasticpro	*DRASTIC vulnerability index*	• Low vulnerability : 93 or lower index

Step by step procedure

HYDROSTRATIGRAPHIC UNIT THICKNESS AND SPATIAL DISTRIBUTION

Execute the adjacent geotreatment to identify cells in **HSM_capiglacio2** that meet the criteria.

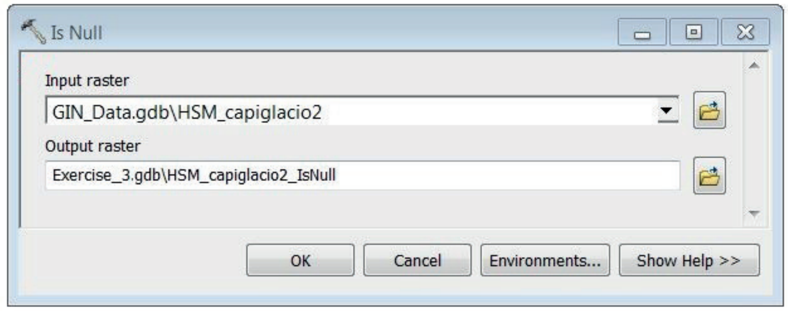
The dataset only contains cells with defined values greater than 0 m. Where the sediment thickness is 0 m, cells do not have a defined value (no data). The Is Null tool attributes a value of 1 to cells with no data and a value of 0 to cells with a defined value.

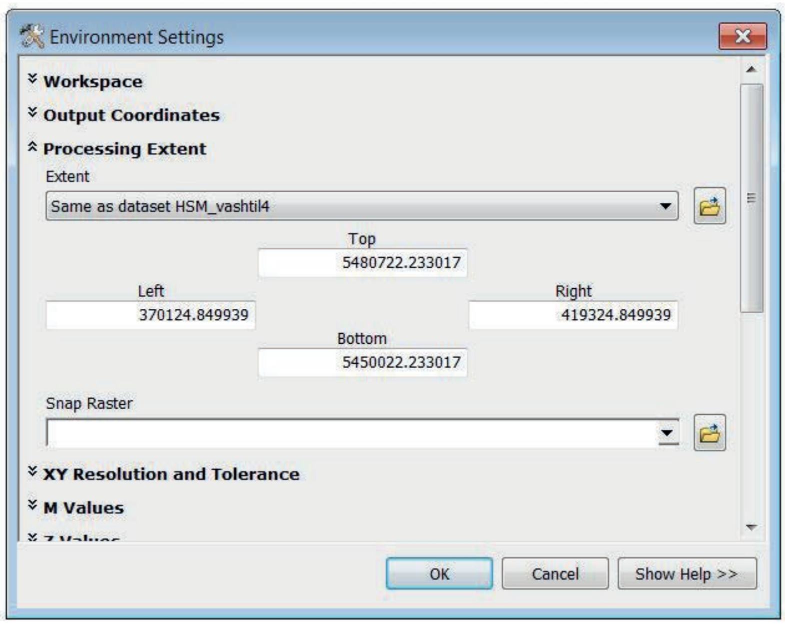
Because the dataset extent is smaller than the whole study area, a larger extent must be set during the geotreatment. The below procedure uses the extent of the **HSM_vashtil4** dataset :

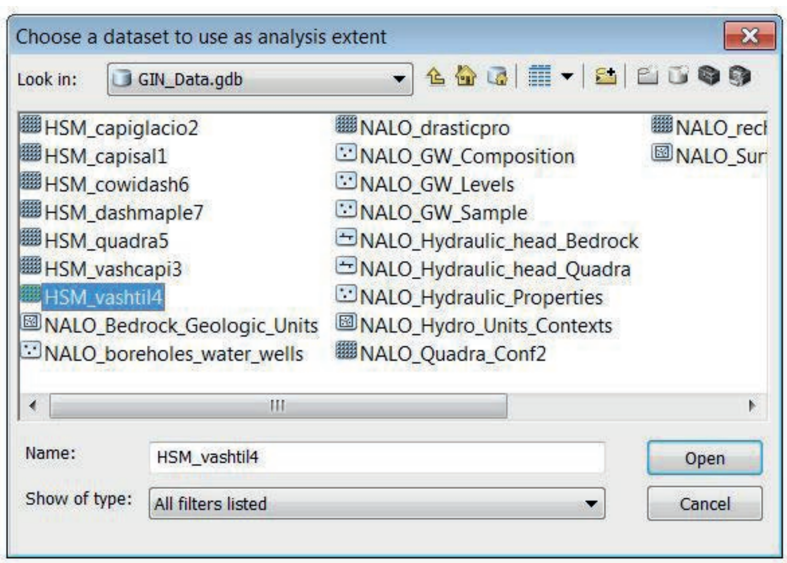
- In the Is Null tool window, Click on the Environments... button.
- In the Environment Settings window, click on Processing Extent.
- Click on the folder icon next to the drop-down menu Extent.
- Navigate to the **GIN_Data.gdb** geodatabase and select the **HSM_vashtil4** dataset.
- Click Open, then Ok to validate the settings and return to the Is Null tool window.

New cells in **HSM_capiglacio2_IsNull** with the value of 0 meet the criteria.

Arc Toolbox Spatial Analyst Tools Math Logical Is Null



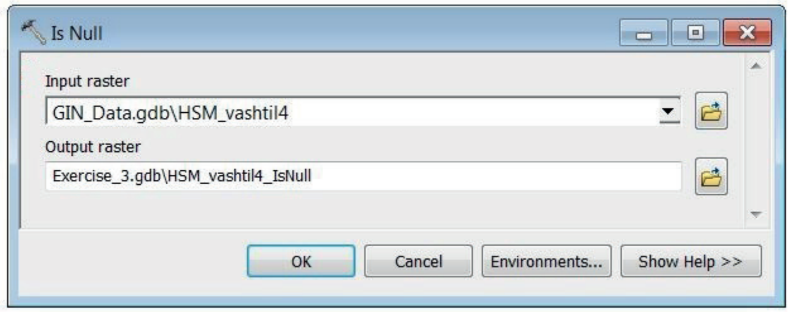




Execute the adjacent geotreatment to identify cells in **HSM_vashtil4** that meet the criteria.

New cells in **HSM_vashtil4_IsNull** with the value of 0 meet the criteria.

Arc Toolbox Spatial Analyst Tools Math Logical Is Null



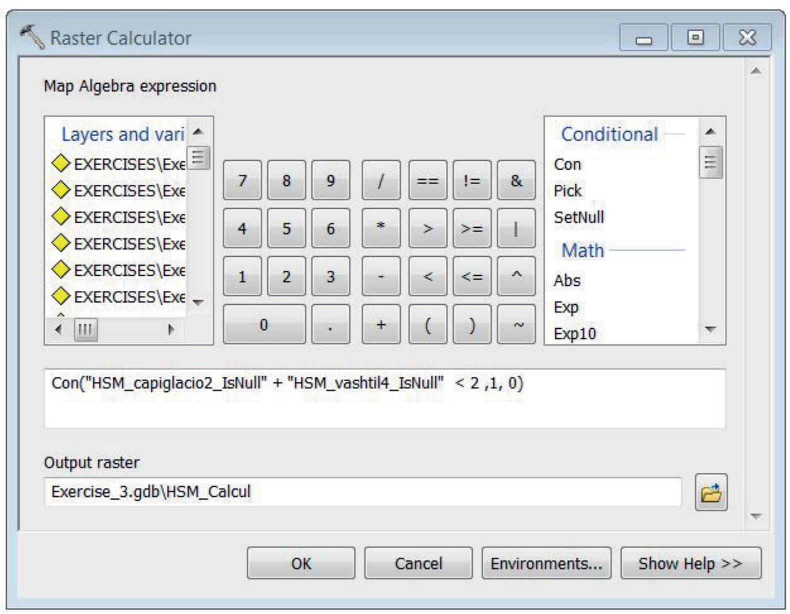
Execute the adjacent geotreatment to combine the results of **HSM_capiglacio2_IsNull** and **HSM_vashtil4_IsNull**.

The conditional calculation is written in the Python programming language supported by ArcGIS. It can be described as follows : if the condition before the first comma is true, then the new cell takes the value indicated after the first comma. If not, it takes the value indicated after the second comma.

In this case, if the sum of the cells from the two raster datasets is smaller than 2, meaning that the cell value for at least one of the two datasets is one, then the new cell takes the value of 1. If not, it takes the value of 0.

New cells in **HSM_Calcul** with the value of 1 correspond to zones where impermeable sediments are present at the surface.

Arc Toolbox Spatial Analyst Tools Map Algebra Raster Calculator

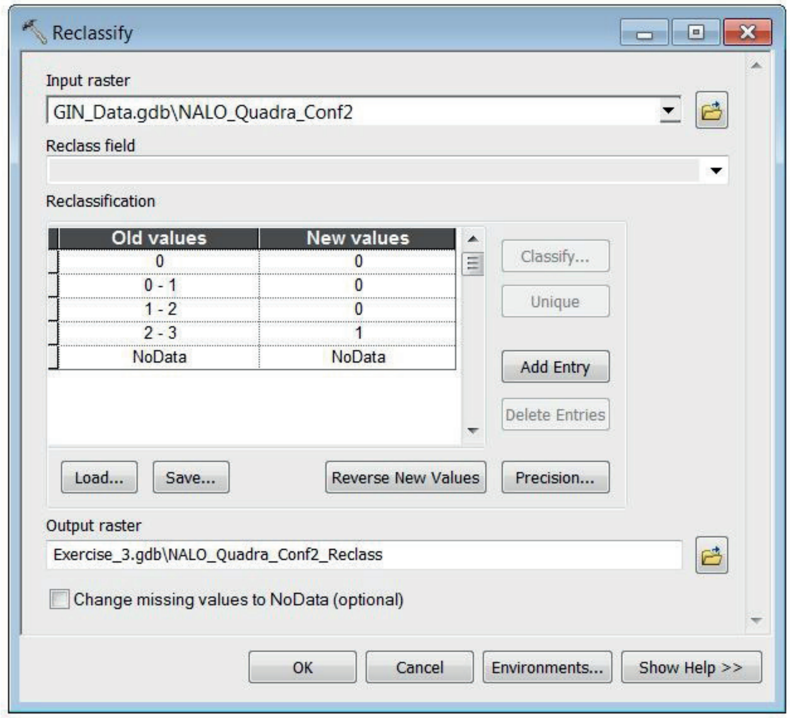


QUADRA AQUIFER CONFINEMENT

Execute the adjacent geotreatment to identify cells in **NALO_Quadra_Conf2** that meet the criteria.

New cells in **NALO_Quadra_Conf2_Reclass** with the value of 1 meet the criteria.

Arc Toobox Spatial Analyst Tools Reclass Reclassify

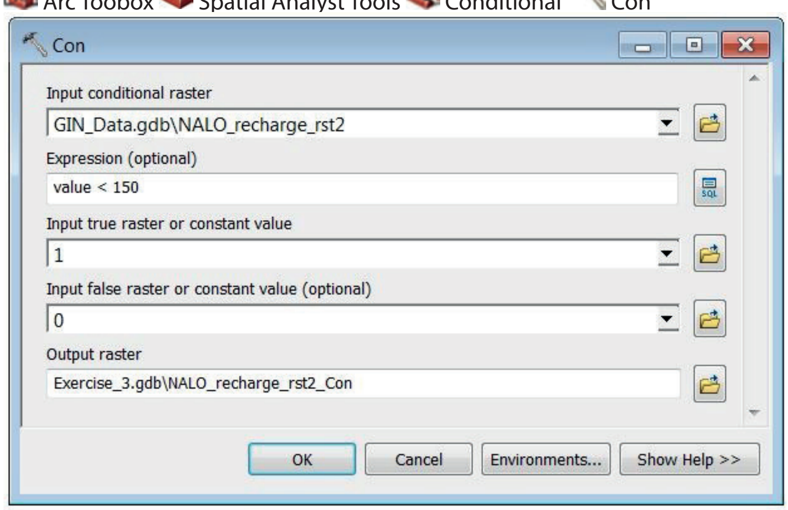


GROUNDWATER RECHARGE

Execute the adjacent geotreatment to identify cells in **NALO_recharge_rst2** that meet the criteria.

New cells in **NALO_recharge_rst2_Con** with the value of 1 meet the criteria.

Arc Toobox Spatial Analyst Tools Conditional Con

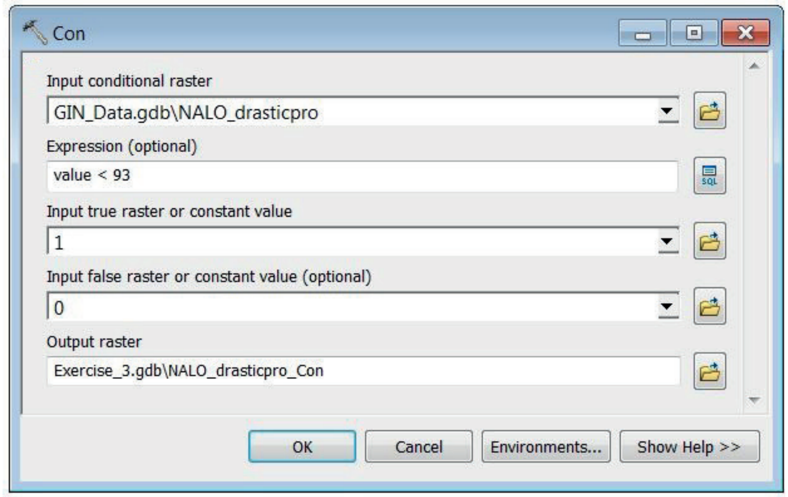


AQUIFER VULNERABILITY

Execute the adjacent geotreatment to identify cells in **NALO_drasticpro** that meet the criteria.

New cells in **NALO_drasticpro_Con** with the value of 1 meet the criteria.

Arc Toobox Spatial Analyst Tools Conditional Con



INTEGRATION

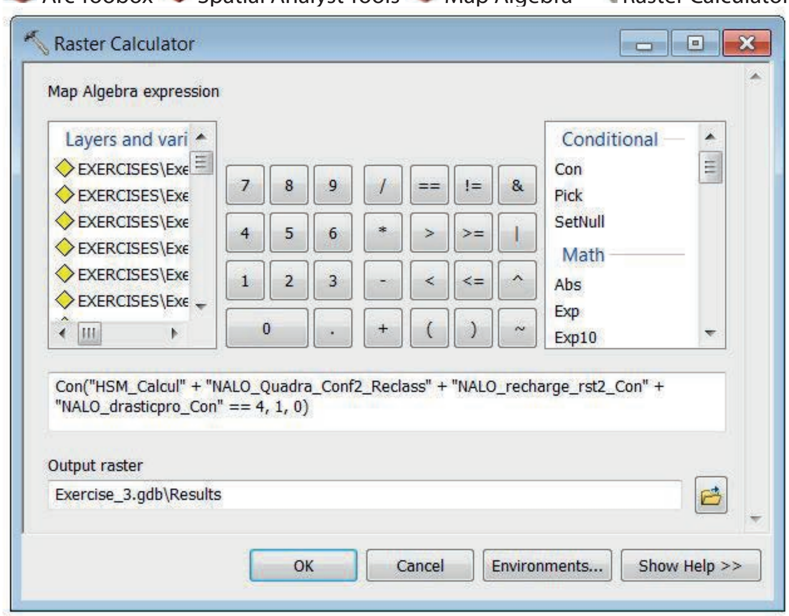
Execute the adjacent geotreatment to combine the results of **HSM_Calcul**, **NALO_Quadra_Conf2_Reclass**, **NALO_recharge_rst2_Con** and **NALO_drasticpro_Con**.

The conditional calculation is written in the Python programming language supported by ArcGIS. It can be described as follows: if the condition before the first comma is true, then the new cell takes the value indicated after the first comma. If not, it takes the value indicated after the second comma.

In this case, if the sum of the cells from the four raster datasets is 4, meaning that all criteria to identify zones naturally protected from contamination are met, then the new cell takes the value of 1. If not, it takes the value of 0.

New cells in **Results** with the value of 1 correspond to zones where groundwater is naturally protected from contamination.

Arc Toobox Spatial Analyst Tools Map Algebra Raster Calculator



2. Identify zones downstream of drinking water supply wells

Proposed analysis parameters

Analysis parameters	Why ?	Limitations and additional information
Downstream of drinking water supply wells	• To prevent contamination of groundwater supply wells, potentially polluting activities should be located downstream of drinking water supply wells.	• The higher the well density, the more severe the contamination event would be due to the great number of consumers affected. • Community supply wells should be identified since contamination of only one of these would affect many consumers, therefore increasing the severity of the contamination event.

Proposed criteria for visual analysis

Analysis parameters	Hydrogeological concepts	Datasets to use	Description	Criteria
Downstream of drinking water supply wells	Groundwater flow	NALO_Hydraulic_head_Quadra	*Hydraulic head for the Quadra Sand Aquifer groundwater flow system*	• Downstream of drinking water supply wells
	BC Groundwater Wells Database	Groundwater_Wells	*Groundwater wells*	

Step by step procedure

GROUNDWATER FLOW AND BC GROUNDWATER WELLS DATABASE

To identify drinking water supply wells, in the Table of Content in ArcMap, copy and paste the **Groundwater_Wells** feature class in order to make changes to the display of the layer without modifying the original one. In the new feature class, execute the following query under the Definition Query tab of the Layer Properties window. This query can be copied from the text file **Query** in the **Exercises** folder.

WLLSNM = 'Commercial and Industrial' OR WLLSNM = 'Private Domestic' OR WLLSNM = 'Water Supply System'

In ArcMap, overlay the new layer on the potentiometric map, **NALO_Hydraulic_head_Quadra**, to visualize zones from **Results** located upstream of a substantial number of drinking water supply wells. These zones should be avoided for the implementation of a new potentially polluting activity.

Prepare the presentation of your results

Where could a new potentially polluting activity be implemented in order to minimize its impact on the Quadra Sand Aquifer groundwater quality?

Name of your territory of action :

When applying the proposed analysis criteria, describe the results obtained for your territory of action (e.g., location, surface area, hydrogeological characteristics of the selected areas).

Did you modify the proposed analysis criteria of the expert pathway ? If yes, why and how ? Please record in the analysis criteria used on the next page.

Did you integrate other information than those from the GSC study in your analysis criteria (e.g., the BC Well Database, the BC aquifer classification, data from RDN Water Budget Project, etc.) ? If yes, how do they influence the results ? Are there any inconsistencies between the available hydrogeological information ?

In your professional practice, what other information not available during this workshop would you use to answer the question (e.g., land-use, information on specific human activities, etc.) ?

Regarding the regional scale of the available hydrogeological data, are there areas where you would need more local data ?

In your professional practice, how would you ensure the protection and sustainable development of groundwater in the areas highlighted by your analysis ?

Your analysis pathway for your territory of action

What we are looking for	Interpretation key specific to the issue		Geodata treatment			
	Analysis parameters	Why ?	Hydrogeological concepts	Datasets to use	Description	Criteria
Identify zones naturally protected from contamination			Hydrogeological contexts	NALO_Hydro_Units_Contexts	*Hydrostratigraphic units and hydrogeological contexts*	
			Quadra Aquifer confinement	NALO_Quadra_Conf2	*Quadra Sand Aquifer confinement*	
			Groundwater recharge	NALO_recharge_rst2	*Groundwater recharge*	
			Aquifer vulnerability	NALO_drasticpro	*DRASTIC vulnerability index*	
Identify zones downstream of drinking water supply wells			Groundwater flow	NALO_Hydraulic_head_Quadra	*Hydraulic head for the Quadra Sand Aquifer groundwater flow system*	
			BC Groundwater Wells Database	Groundwater_Wells	*Groundwater wells*	

Integration of knowledge on the human environment

In practice, a lot of information on the human environment is integrated when identifying areas in which to implement a new potentially polluting activity, so as to minimize the impact on groundwater quality (e.g., already existent polluting activities, land owners, land-use, etc.). To complete this exercise, some information on land-use is made available. However, interpretation keys and analysis criteria are not proposed in the expert pathway. They are instead left to the participant to choose. The procedure below shows an example of geodata treatment.

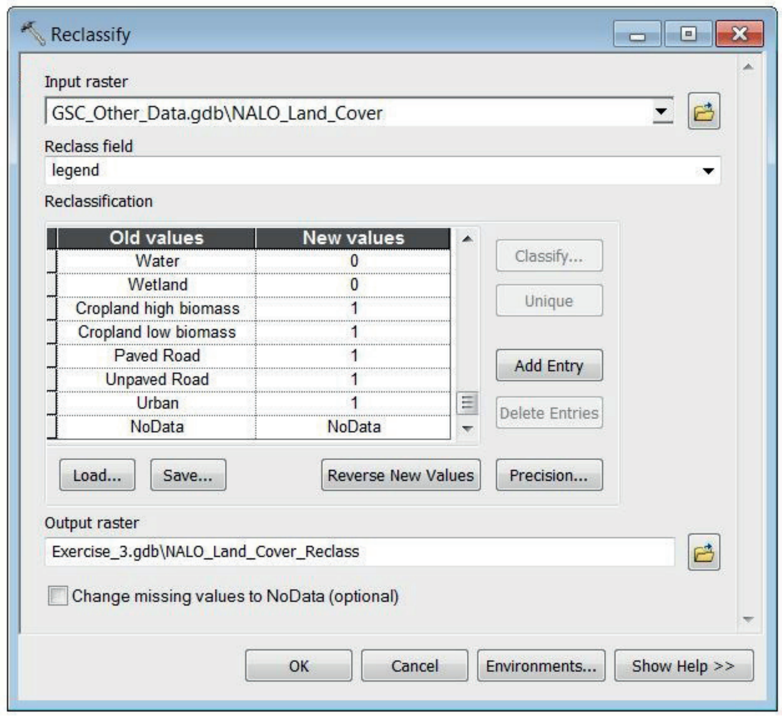
Step by step procedure

LAND COVER

Execute the adjacent geotreatment to identify cells in **NALO_Land_Cover** that meet the criteria you have chosen.

New cells in **NALO_Land_Cover_Reclass** with the value of 1 meet the criteria.

Arc Toobox Spatial Analyst Tools Reclass Reclassify

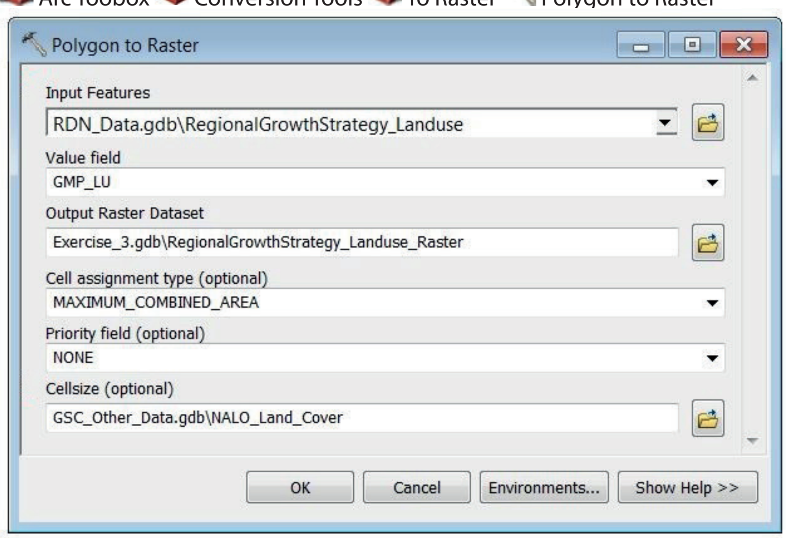


REGIONAL GROWTH STRATEGY

Execute the adjacent geotreatment to convert the **RegionalGrowth Strategy_Landuse** feature class from a vector format to a raster dataset **RegionalGrowth Strategy_Landuse_Raster**.

Make sure to select the correct <u>Value field</u>, <u>Cell assignment type</u> and <u>Cellsize</u>.

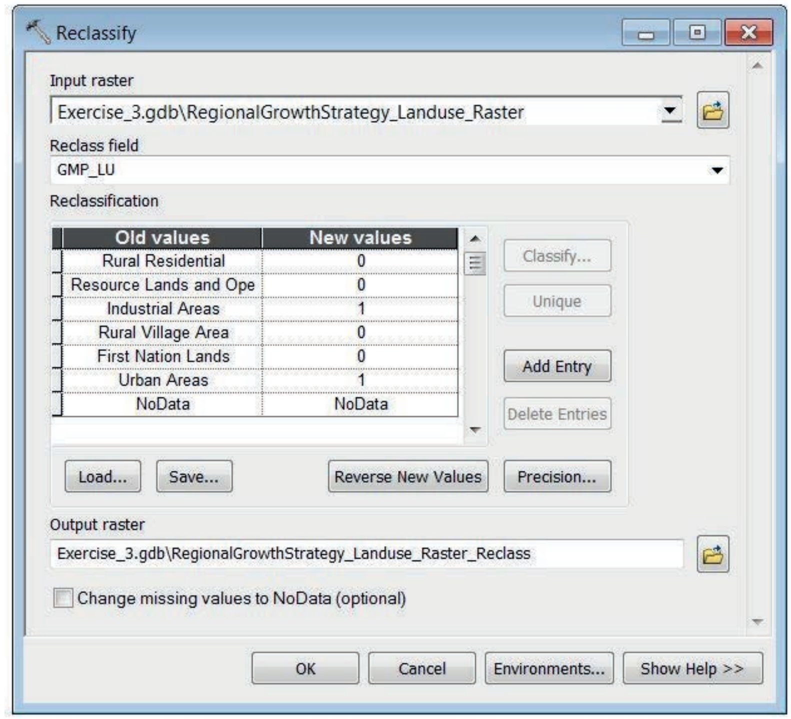
Arc Toobox Conversion Tools To Raster Polygon to Raster



Execute the adjacent geotreatment to identify cells in **RegionalGrowth Strategy_Landuse_Raster** that meet the criteria you have chosen.

New cells in **RegionalGrowthStrategy_ Landuse_Raster_Reclass** with the value of 1 meet the criteria.

Arc Toobox Spatial Analyst Tools Reclass Reclassify

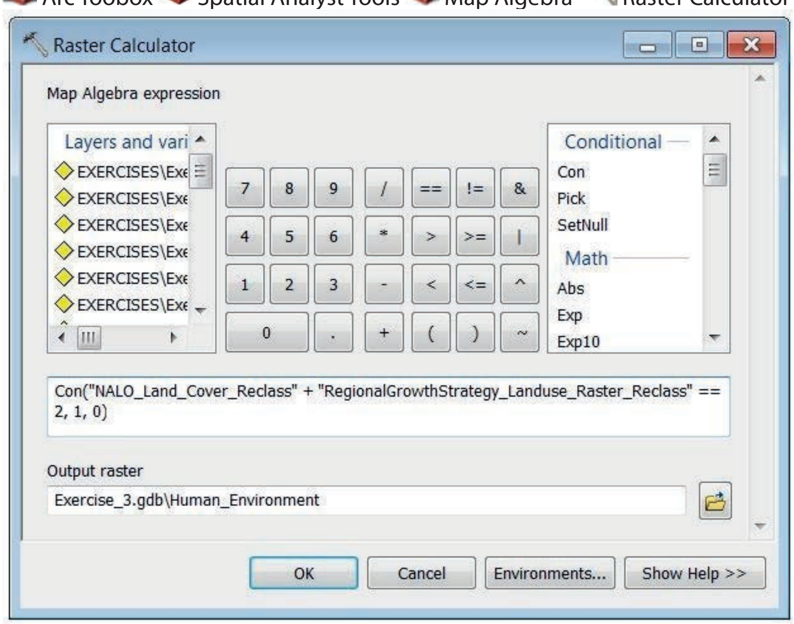


INTEGRATION

Execute the adjacent geotreatment to combine the results of **NALO_Land_Cover_Reclass** and **RegionalGrowthStrategy_Landuse_ Raster_Reclass**.

New cells in **Human_Environment** with the value of 1 correspond to zones where implementation of a new potentially polluting activity would be possible according to available land-use information.

Arc Toobox Spatial Analyst Tools Map Algebra Raster Calculator

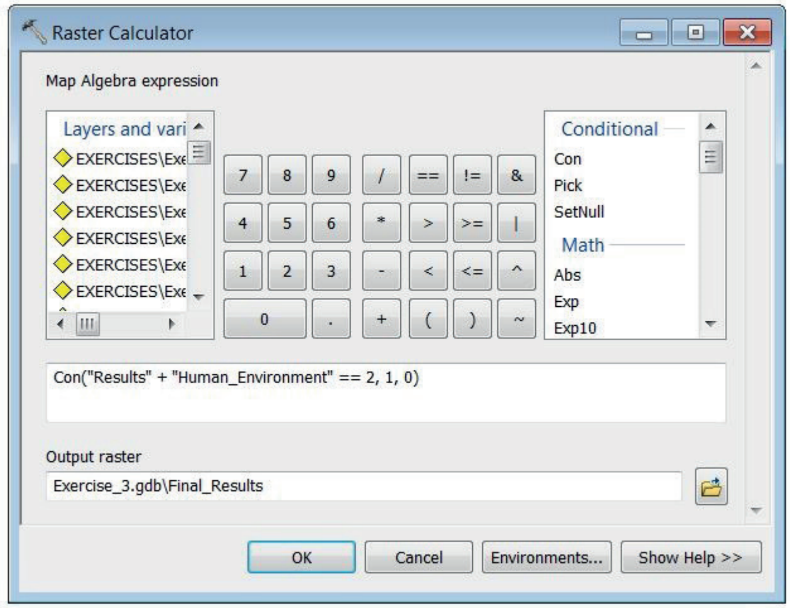


FINAL RESULT

Finally, it is possible to combine the results of **Human_Environment** and **Results** by executing the adjacent geotreatment in order to locate zones where groundwater is naturally protected from contamination and where it would be possible to implement a polluting activity according to available land-use information.

The **Final_Results** dataset is the final solution to the exercise according to the expert hydrogeological analysis pathway, combined with the integration of knowledge on the human environment.

Arc Toobox Spatial Analyst Tools Map Algebra Raster Calculator



Part 4

USEFULNESS OF HYDROGEOLOGICAL INFORMATION FOR SUSTAINABLE WATER MANAGEMENT

4.1 Current uses of hydrogeological information

Identify your current uses of hydrogeological information.

Instructions:

In your professional roles and responsibilities related to water management or land-use planning, you have to use hydrogeological information. Taking into account the hydrogeological information produced by the GSC and any other sources of hydrogeological information, identify the uses you make of the information and the types of information that you mobilize or that you could mobilize.

You are provided a template comprised of three columns to organize this information by type of organization (e.g., ministry, district, municipality).

Here are some made-up examples to help get you started.

No°	ORGANIZATION	CURRENT USES	USEFUL OR USABLE INFORMATION
1	Ministry	Evaluate the quantity of water	Recharge
2	Municipality	Authorize a new residential development	DRASTIC

Type of organization:

USES OF HYDROGEOLOGICAL INFORMATION IN OUR DECISIONS

N°	USES WHAT DECISIONS ?	HYDROGEOLOGICAL INFORMATION USED AND USABLE

4.2 Usefulness of hydrogeological information in your decision-making

Criteria of useful information

Research has been dedicated to identifying the criteria that make information useful and usable for managers and decision-makers. Three main criteria have been found to result: relevance, credibility, and legitimacy of the information.

Credibility involves the scientific adequacy of the technical evidence and arguments. Relevance deals with the whether the information actually contributes to the needs of decision-makers. Legitimacy reflects the perception that the information and technology production have been respectful of stakeholders' divergent values and beliefs, unbiased in its conduct, and fair in its treatment of views and interests (Cash et al., 2003). From these broad criteria, seven key requirements were elaborated to further assess the usefulness of any given information.

Seven key requirements:

1. The information **meets our needs**. It fills in missing information needed for our decisions. It is directly related to our needs.

   Score 5 – e.g., I have the right kind and amount of information to make my decision; none is lacking; the content is appropriate.

2. The information is available at the **right time**. It comes in response to a current request.

   Score 5 - e.g., I have all the information needed to make my decision; none is missing; none are still in the process of being obtained or produced.

3. Information is produced on a **spatial scale** relevant to the given decision-making. The scale is adequate for the decision I must make.

   Score 5 – e.g., I have to make a decision at the municipal level; the information is detailed enough for me to do.

4. The information is **easily accessible**. I know exactly where to get the information and it is in an appropriate format.

   Score 5 – e.g., I do not waste time accessing information; I know where it is, how to acquire it, and how to consult it; It is in a format that I can easily use (e.g., GIS).

5. The information is **easy to understand**.

   Score 5- e.g., I easily understand the information that is available and required for my decision-making, and am able to use it.

6. The information appropriately includes or excludes confidential data, and can be easily **transferred** to other users.

   Score 5 – e.g., In the information I use for my decisions, there are no issues related to data privacy.

7. I consider this data to be **accurate and reliable**. I trust the information.

   Score 5 – E.g., I have full confidence in the quality of the information I use; I never question its validity.

Evaluate the usefulness of hydrogeological information in your decision-making

Instructions:

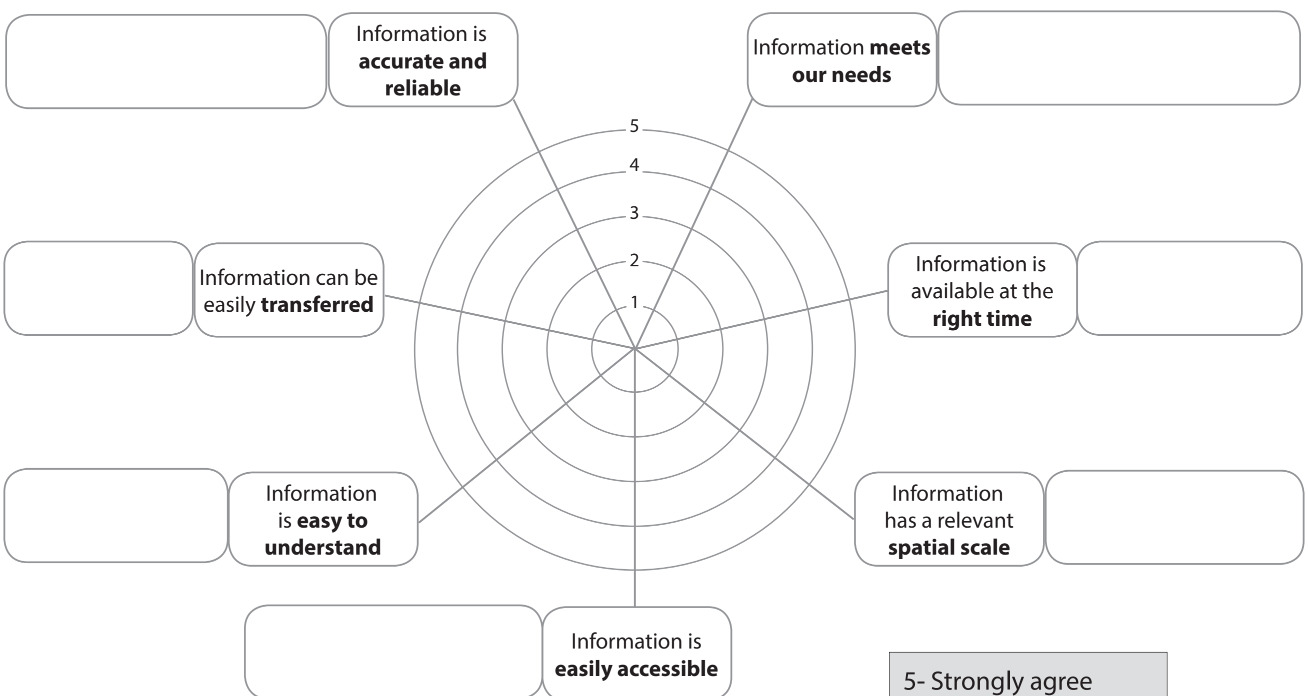
This activity can be carried out either individually or in groups. In the latter case, please work with colleagues from your organization. For each of the uses, please evaluate the usefulness of the knowledge by rating it on a scale from 1 to 5 (1= Strongly disagree and 5= Strongly agree). You may include information you currently use as well as information you might use in the near future (e.g., GSC information).

If many of your current uses are similar, you can evaluate them together. Otherwise, make an evaluation for each use, and for each decision. The decision number should correspond to the decision number used in the template of the previous activity.

Please write comments in the boxes to justify your evaluation of each requirement. These comments will appear in the results book you will receive after the workshop.

Organization:

Decision #:



5- Strongly agree
4- Agree
3- Neutral
2- Disagree
1- Strongly disagree

Strengths and weaknesses of the hydrogeological information

Instructions:

In order to obtain an overview of the strengths and weaknesses of the hydrogeological information, each group of participants will put a red sticker for each score of 1 or 2 and a green sticker for each score of 4 or 5 for each of the seven key requirements.

STRENGTHS AND WEAKNESSES OF THE HYDROGEOLOGICAL INFORMATION

	Ministry	District	Municipality	Other
Information meets our **needs**				
Information is available at the **right time**				
Information has a relevant **spatial scale**				
Information is **easily accessible**				
Information is **easy to understand**				
Information can be easily **transferred**				
Information is **accurate and reliable**				

4.3 Improving usefulness of hydrogeological information in your decision-making

How to improve the usefulness of this information?

Instructions:

You have evaluated the usefulness of the information for your decision-making, and know its strengths and weaknesses.

What do you think could be done to improve the usefulness of hydrogeological information for decision-making?

- Is there a need for new information? What additional information is needed?
- Is there a need for an information exchange platform?
- Is there a need for training on the use of information?

In a group discussion, please raise your hand if you have an idea, and one of the facilitators will write down your idea.

We will then proceed to vote for each idea. Is this idea an important need, a somewhat important need, or an unimportant need with regards to improving the usefulness of hydrogeological information?

Ideas to improve the usefulness of hydrogeological information for decision-making

Idea 1:____

Idea 2:____

Idea 3:____

Idea 4:____

Idea 5:____

Idea 6:____

Important

Somewhat important

Non important

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My personal notes

Contributors to the Nanaimo Lowland Groundwater Study :

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