

A Guide to the Use of Intrinsic Aquifer Vulnerability Mapping



Photo by A. Gilchrist, 2010

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Executive Summary

Over 1 million (25%) of British Columbians rely on groundwater for their daily use, and this number continues to increase¹. Groundwater provides water for drinking, agriculture, industry, and is vital to the functioning of many streams, lakes, and wetlands. Sound water management practices can help protect the quality of groundwater resources for future generations.

To aide in land use decision-making for the protection of groundwater quality, intrinsic aquifer vulnerability maps have been developed for a number of areas of BC with the DRASTIC method, including the Okanagan, Grand Forks, the Fraser Valley, and Vancouver Island. Intrinsic aquifer vulnerability is used describe the relative degree of natural protection of the groundwater from contamination due to the physical characteristics of the land and subsurface^{2,3,4}. Governments, planners, and policy-makers can utilize the maps for various purposes such as to assist in land use decision-making, sustainable development planning, source water protection planning, identifying sensitive areas, prioritizing areas for further monitoring or protection, and educating the public^{3,5,6}. The intrinsic vulnerability maps are conducted at a regional scale and should be used as a screening tool. They are not meant to replace site investigations or to be used for lot scale assessment.

Areas of high intrinsic vulnerability offer less natural protection than areas of low or moderate vulnerability; therefore, land use activities which pose a high hazard should be discouraged from these areas, or require much more stringent hydrogeological assessment and reporting requirements to ensure prevention of contamination is maximized. This combination of intrinsic vulnerability with the hazard threat is one method of groundwater quality risk assessment, which accounts for other factors that influence the potential for contamination in an area rather than just the natural (intrinsic) vulnerability.

This document provides examples of uses of the intrinsic vulnerability maps in land use planning and source water protection, using the South Cowichan area of Vancouver Island as an example. It draws on a number of previously published resources including the BC Well Protection Toolkit²¹, the BC Comprehensive Drinking Water Source-to-Tap Assessment Guideline²², and the BC Groundwater Bylaws Toolkit²³. In this example the intrinsic vulnerability is combined with potential sources of contamination (hazards) to develop a series of levels of hydrogeological reporting requirements for new development permits or zoning applications. The intrinsic vulnerability maps are also combined with previously mapped well capture zones. Monitoring and reporting requirements of existing developments can also be related to the level of intrinsic vulnerability and land-use type for the ongoing protection of groundwater resources in the community.

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The authors would like to thank the BC MoE for their on-going support of intrinsic vulnerability mapping projects throughout BC, including the VIWRVMP, for the purposes of groundwater quality protection. It was the dedication of Vicki Carmichael and Rick Hardy, both of the MoE, who have persevered to make public (on the GeoBC iMap tool) as many of the intrinsic vulnerability studies in BC as possible. GeoBC staff Darren McKellar, Kevin Metcalfe, and Al Sutherland completed the data analysis necessary for the mapping to be included in the provincial databases.

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1 Introduction

Over 1 million (25%) of British Columbians rely on groundwater for their daily use, and this number continues to increase¹. On Vancouver Island for example, about 40% of municipalities utilize groundwater for their water supply, either exclusively or to augment surface supplies. In addition to providing for drinking water, agricultural, and industrial needs¹, groundwater is vital to the functioning of many streams, lakes, and wetlands. Protection of groundwater quality through sound water management and land use practice is critical to ensuring the quality of this resource for years to come. Good water management involves many aspects, including development and implementation of groundwater protection plans, regulation of land use in sensitive areas and education of the public on wise water use and contamination prevention. Land use can have a significant impact on groundwater quality, and is usually regulated at the local government level, therefore including land use management strategies for the protection of groundwater quality at this local level is important.

The BC Government has committed to improving the protection of both groundwater quantity and quality in its Living Water Smart provincial water plan¹. In response to the desire of local governments for tools to address the need for land use decision-making to incorporate the risk to groundwater quality, intrinsic aquifer vulnerability maps have been developed for a number of areas of BC, including the Okanagan, Grand Forks, the Fraser Valley, Gulf Islands and Vancouver Island. Intrinsic aquifer vulnerability is a common term to describe the degree of natural protection of the groundwater from contamination due to the physical characteristics of the land and subsurface^{2,3,4}. These maps show the relative degree of vulnerability over an area and can be an effective tool for assisting decision-making from regional to local levels. Governments, planners, and policy-makers can utilize the maps for various purposes such as to assist in land use decision-making, sustainable development planning, source water protection planning, identifying sensitive areas, prioritizing areas for further monitoring or protection, and educating the public^{3,5,6}.

This document reports on work completed by the Vancouver Island Water Resources Vulnerability Mapping Project (VIWRVMP), which was initiated in 2006 by the Vancouver Island Water Protection Steering Committee as a collaborative project to develop land use decision-making tools to better protect groundwater quality on Vancouver Island. The intrinsic aquifer vulnerability map was completed in two stages. The first stage comprised a pilot study of the Regional District of Nanaimo (RDN), and Cowichan Valley Regional District (CVRD)⁷; whilst the second expanded the mapping to other parts of the Island where necessary data existed⁸.

This report is intended to assist in the interpretation and use of the intrinsic aquifer vulnerability maps both on Vancouver Island and the rest of BC, and draws on examples

from the South Cowichan area of the CVRD. Figure 1 provides a brief outline of this document as well as examples of those who may find the information in this document useful or beneficial. Technical information on the data used and mapping methodology can be found in Liggett and Gilchrist (2010)⁷ for phase 1, and Newton and Gilchrist (2010)⁸ for phase 2.

What will this document tell you?

- Overview of intrinsic aquifer vulnerability mapping method
- How intrinsic vulnerability mapping fits into groundwater quality risk assessment
- Examples of uses of vulnerability maps
 - in source well protection planning
 - for land use decision-making
- Other groundwater protection tools and resources in BC

Who will find this document useful?^{from 9}

- Those working in:
 - regional and local land use and development planning,
 - water protection,
 - environmental health protection,
 - geoscience and well drilling industry,
- water supply systems owners
- Interested public, and
- Teachers and educators

Figure 1 What will this document tell you and who may find it useful.

2 What is intrinsic aquifer vulnerability mapping?

The concept of intrinsic aquifer vulnerability, from here on simply called 'intrinsic vulnerability', is based on the idea that the natural environment can provide some degree of protection against groundwater contamination from the surface^{2,3,4}. Properties of the land and subsurface which can influence contaminant movement include, but are not limited to, the soil and unsaturated zone material, the depth to the water table or aquifer, the amount of recharge to that aquifer, the slope of the land surface, the aquifer material itself, and any preferential pathways such as fractures which contaminants may follow. Intrinsic vulnerability does not include properties of the contaminant or the hazard related to the threat or likelihood of a contaminant release, or the consequences of the contaminant reaching the groundwater system^{3,10}. For example an area of high vulnerability may have a low hazard because it is located in parkland. Such aspects are taken into account during a water quality risk assessment (See Section 5).

2.1 DRASTIC method

Characterization of intrinsic vulnerability can vary from qualitative indexing methods, to process-based, quantitative hydrogeologic assessments with numerical modelling^{11,12,13,14}. For the Vancouver Island study, the DRASTIC method⁵ was used to map the intrinsic vulnerability of the groundwater resource. This is a qualitative, indexing method, and is used to show the relative differences in vulnerability across regional scales. This approach has been used around the world, both with and without modification to the method^{12,15,16,17,18,19,20}. This method was selected for use in BC, including the VIWRVMP, because it provides a regional assessment of vulnerability, is relatively easy to implement, and uses readily available datasets. Technical details of the mapping process for the VIWRVMP are described in references 7 and 8. The main assumptions of this method are that:

- the contaminant is introduced at ground surface;
- the contaminant moves at the same rate as water (e.g. dissolved in the water), vertically through the unsaturated zone driven by precipitation (i.e. not taking into account specifics of a particular contaminant's transport).
- more rapid pathways such as an open well or fracture are not considered; and,
- the size of the mapped area is 100 acres (40.4 hectares) or larger⁵.

The first three assumptions relate to simplifications regarding contaminant movement and pathways. DRASTIC considers protection from the unsaturated zone (geological material overlying the water table or aquifer), so the vulnerability to contaminants that

are introduced below ground (assumption 1 -e.g. from injection wells or underground storage tanks) or that follow preferential pathways (assumption 3 -e.g. open well or fracture) are not accounted since they bypass the natural protection mechanisms offered by these zones. Additionally, each contaminant has its own specific properties which govern its transport through the subsurface (assumption 2). Some contaminants may move slower than water due to reactions with the surrounding soil or geologic material, while others may move at the same rate of water, or even faster (e.g. in the case of contaminants which are denser than water and sink). DRASTIC considers only conservative (i.e. dissolved and moves at same rate of water) contaminants. The final assumption recognizes the density and availability of data which are used and leads to the regional nature of the DRASTIC mapping.

The name DRASTIC represents each of the seven input parameters (Figure 2):

- **D**epth to water table;
- **R**echarge (net);
- **A**quifer Media;
- **S**oil Media;
- **T**opography;
- **I**mpact of the vadose zone;
- **C**onductivity (hydraulic) of the aquifer

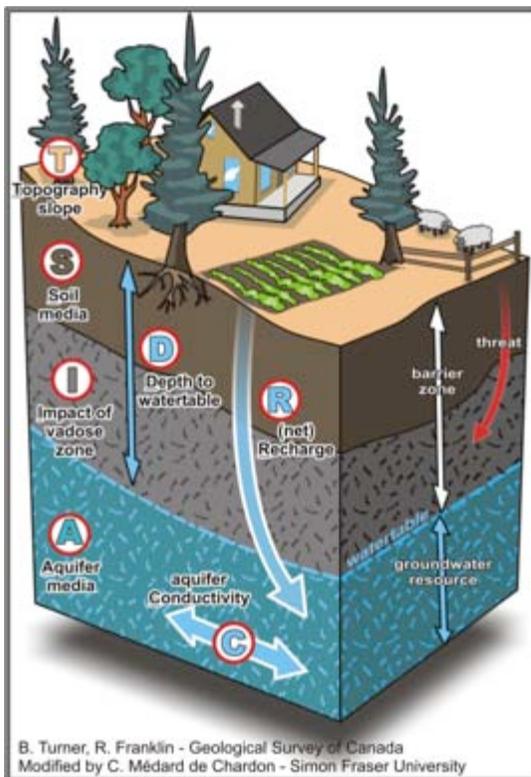
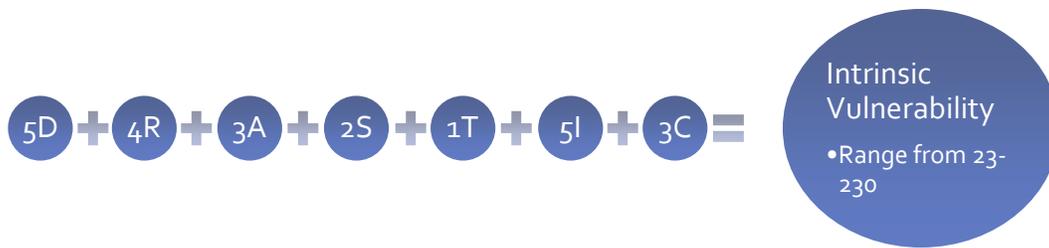


Figure 2: DRASTIC parameters

Each of these seven parameters is mapped, usually from existing datasets, although new field data may also be collected if possible for a particular study area. Attributes of each map are rated from 1 to 10 (lowest to highest vulnerability) according to their relative ability to protect the groundwater system from contamination. For example, a sandy soil is rated as more vulnerable than a clayey soil due to its high permeability, which promotes downwards contaminant movement. Figure 3 summarizes the properties by which each parameter is rated.

Once the map for each parameter is rated from 1 to 10 they are combined to create the final vulnerability index (Figure 3). To do so, each parameter is multiplied by a weighting factor, according to how important that parameter is for overall vulnerability, and all the parameter maps are added together according to:



The final intrinsic vulnerability is represented by a value between 23 and 230. These values can then be classed or grouped in vulnerability categories such as high, medium, and low (Figure 4).

For the Vancouver Island Mapping, the resultant overall vulnerability values ranged from 59 to 218 and were classed into the three categories used to classify the DRASTIC vulnerability in BC as shown in Figure 4. References 7 and 8 outline in detail the methods and data sets used to create the intrinsic vulnerability maps for the Vancouver Island Region. The entire intrinsic vulnerability map for Vancouver Island is shown in Figure 5. Note that for the VIWRVMP the extent of the intrinsic vulnerability map was limited by data availability for the depth to water parameter. For this reason, only those areas within 5 km of available depth to water data (i.e. water well data) were mapped.

Classified (high, medium, and low) or unclassified (numeric vulnerability value) GIS maps in ARCVIEW format can be downloaded from the GeoBC website (see Appendix).

Figure 6 shows the intrinsic vulnerability of the South Cowichan area. Step-by-step instructions on how to create such maps with the online BC iMap tool are outlined in the appendix. The blocky appearance of the intrinsic vulnerability map is due to the larger grid cells (100m) used to map the seven input parameters. This is a reminder of the scale of analysis of the study. The results depict the regional nature of the maps and that they should not be used to determine site-specific vulnerability or detailed site planning at the lot scale.



Figure 3: DRASTIC parameter descriptions and combination to form the final intrinsic vulnerability map

High (>160)

- Material above the water table or aquifer provides the least natural protection from surface contamination.
- These areas are typically unconfined sand and gravel aquifers, which have a low depth to water (or high water table) and high permeability.
- An example of a high vulnerability aquifer on Vancouver Island is Aquifer 186 (Lower Cowichan River A Aquifer) inland from Cowichan Bay, which has a high water table and is a very permeable sand and gravel aquifer (Figure 6).

Moderate (101-160)

- Provide limited natural protection from surface contamination.
- On Vancouver Island these areas are typically:
 - unconfined sand and gravel aquifers which may have deeper water tables or some fine grained sediments (e.g. silts and clays) above them,
 - confined aquifers with discontinuous or thin confining layers, or
 - highly fractured aquifers (e.g. fractured shales or mudstones).
- An example of a moderate vulnerability aquifer on Vancouver Island is the partially confined surficial Aquifer 197 (Cobble Hill Aquifer) south of Cowichan Bay (Figure 6).

Low (<101)

- Provides the highest degree of natural protection but does NOT imply "no vulnerability". These areas simply offer the more natural protection relative to the other areas.
- On Vancouver Island these areas are typically:
 - well confined aquifers,
 - unfractured bedrock with low permeability (hydraulic conductivity), or
 - aquifers with deep water tables.
- An example of a low vulnerability aquifer on Vancouver Island is the bedrock Aquifer 176 just immediately north of Cowichan Bay (Figure 6).

Figure 4: The BC DRASTIC intrinsic aquifer vulnerability classes and examples from the South Cowichan Area.

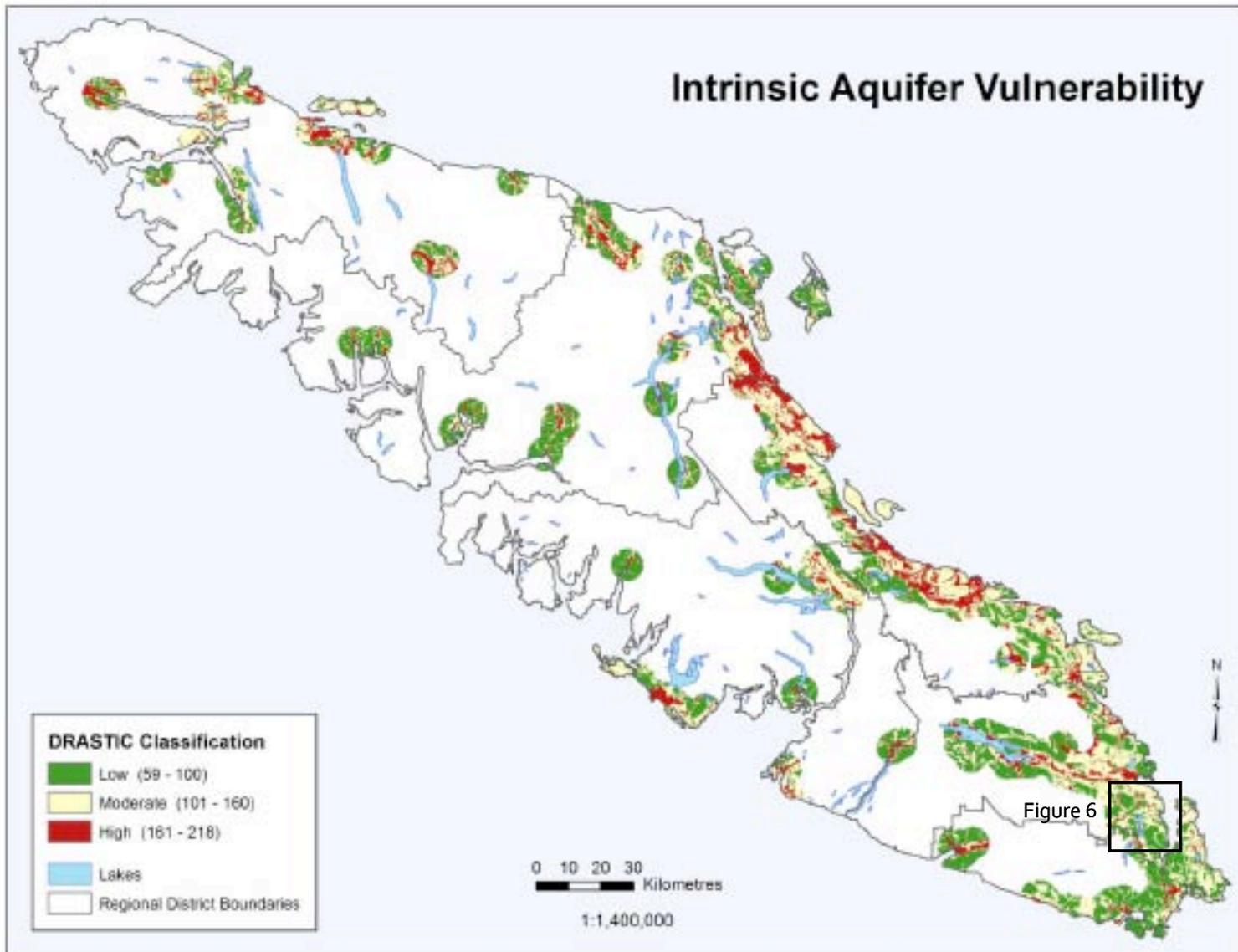


Figure 6: Intrinsic aquifer vulnerability map with DRASTIC for the Vancouver Island from 8.

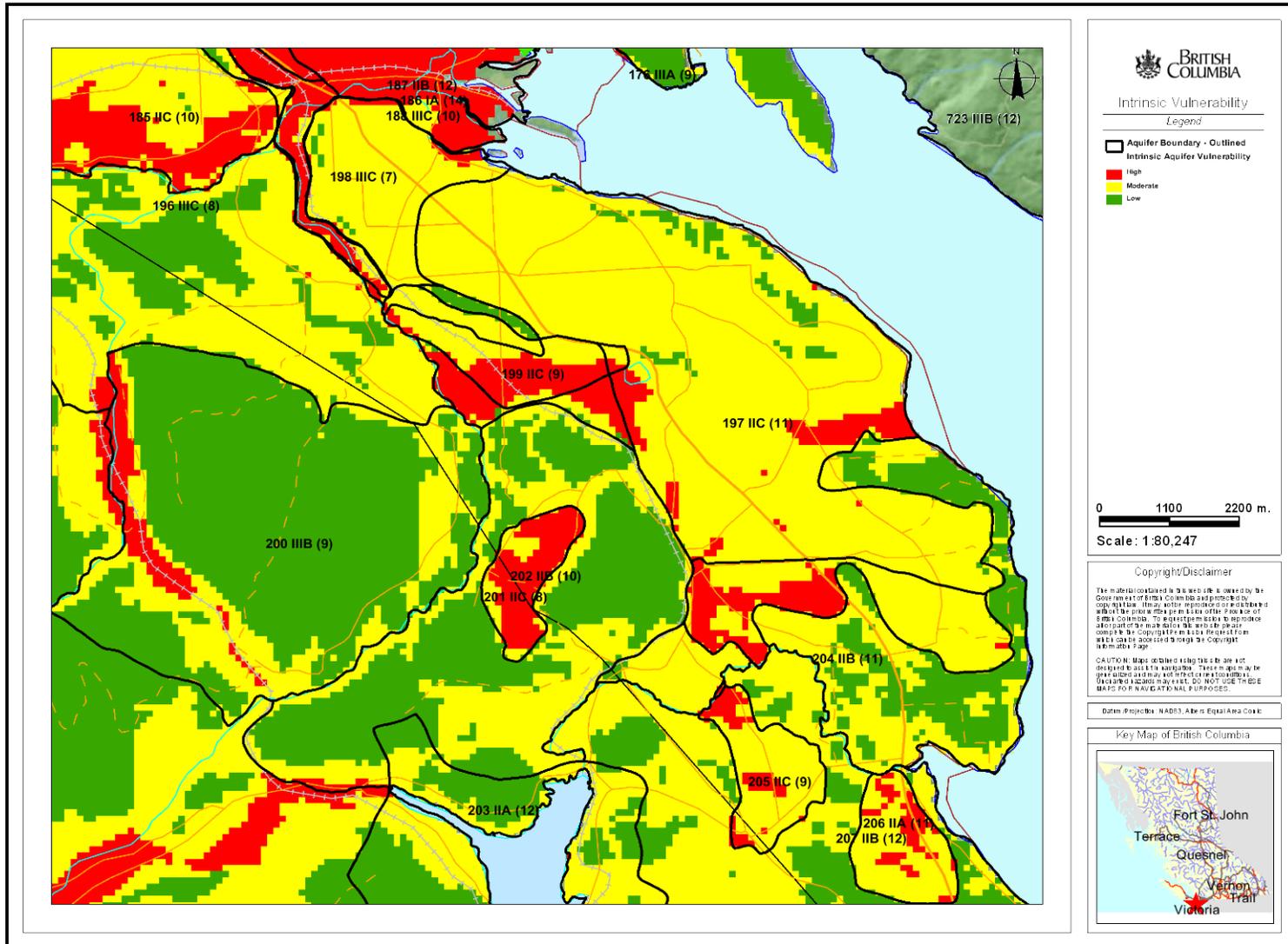


Figure 7a: Intrinsic vulnerability map with DRASTIC for the South Cowichan Area (northern part).

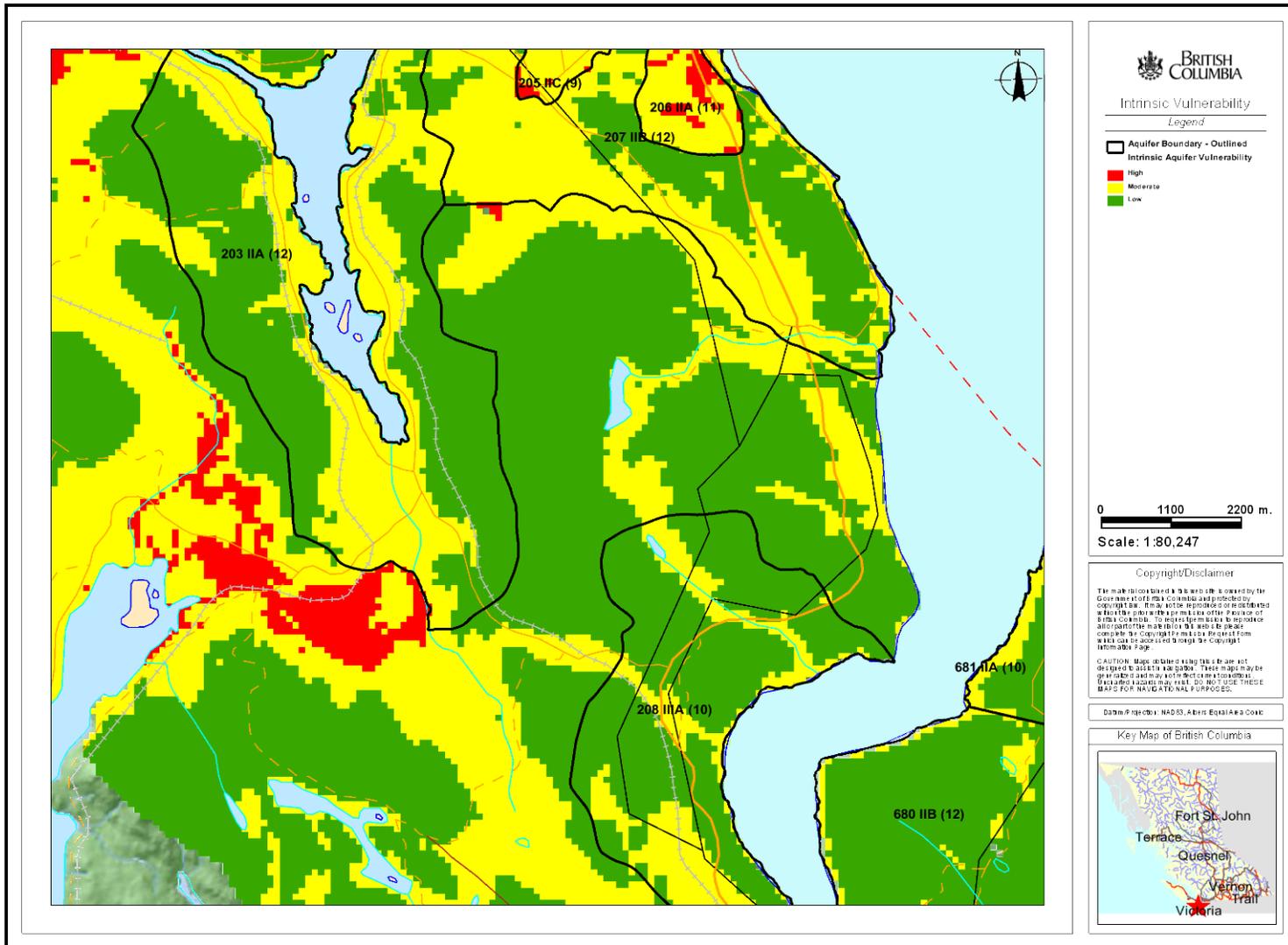


Figure 6b: Intrinsic vulnerability map with DRASTIC for the South Cowichan Area (southern part).

3 Assumptions and limitations of intrinsic vulnerability mapping

There are a number of assumptions and limitations of the uses of the intrinsic vulnerability maps, including those listed in the technical reports to do with the mapping process^{7,8}. Assumptions and limitations of the intrinsic vulnerability maps include:

- the maps are at a regional scale (greater than the property lot level) and are not meant to replace site specific investigations at the lot scale or for detailed site planning;
- the maps apply to the uppermost aquifer only, and do not show areas of vulnerability for deeper or stacked confined aquifers (although these are assumed to be less vulnerable than overlying aquifers);
- the classified maps show three categories of vulnerability and is limited in showing variation in vulnerability within a category, therefore caution should be used in areas close to the boundaries between categories. For example, an area may have vulnerability ranging from 158 to 162, which does not represent a large variation in vulnerability; but part would be classified as moderate vulnerability and the other part as high vulnerability because the category break is at 160);
- only contamination from the surface is considered, therefore the maps do not show vulnerability to such hazards as mines, underground storage tanks, injection wells, short circuiting of contaminants around damaged well seals, etc;
- the maps do not show specific recharge areas for specific aquifers; and
- the DRASTIC method assumes only downwards movement of the contaminant, with the mobility of water (i.e. specific contaminant transport properties are not considered) and does not account for horizontal contaminant movement.

4 Uses of intrinsic vulnerability maps

Intrinsic vulnerability maps can be used for many purposes. Most importantly they are a regional screening tool and can be used as part of:

- groundwater quality risk assessment;
- managing groundwater/source water protection areas;
- guiding development and land use planning;
- prioritizing areas for contaminated sites cleanup and groundwater monitoring;
- developing policy actions related to applications for development permits, zoning or zoning changes, ongoing reporting requirements, onsite regulations on the storage and containment of possible contaminants, emergency response plan requirements, etc.; and,
- educating the public and raising awareness of need for groundwater protection

Currently, intrinsic vulnerability is included specifically in three existing source water and groundwater protection frameworks in BC. These are:

1. the BC Well Protection Toolkit²¹,
2. the Comprehensive Drinking Water Source-to-Tap Assessment Guideline²², and,
3. the Groundwater Bylaws Toolkit²³.

When using the intrinsic vulnerability maps, careful attention should be paid to areas of high vulnerability, since these areas offer the least amount of natural protection to the aquifer. High vulnerability areas generally require more comprehensive groundwater protection measures, especially if located in an area identified as a source water protection zone or an aquifer recharge zone. Excluding or limiting activities which pose a high hazard related to the release of contaminants is desirable, as is requiring detailed site assessments and ongoing emergency spill response plans for development permits. Additionally, understanding why an area has a particular vulnerability is important to the development of the best management strategies for that area.

It is important to note that intrinsic vulnerability maps are only ONE of the tools and considerations that need to be accounted for when making the above assessments and decisions. The maps do not take into account the potential hazards which are present at the land surface, and therefore do not present a complete assessment of the risk to groundwater contamination, which includes the vulnerability, hazard, and consequence of losing the resource (see Section 5). The intrinsic vulnerability maps are also not meant to replace site-specific investigations as they are constructed at a regional scale. However, they do provide useful synoptic information for many purposes, including those listed above.

4.1 Uses of intrinsic vulnerability maps in BC

A number of communities in BC have already mapped intrinsic vulnerability and have utilized the maps in a number of different ways for groundwater protection. The following sections provide a brief outline of some of these studies and how the vulnerability maps have been incorporated into community planning.

Fraser Valley (Langley)^{24, 25, 26}

A number of vulnerability mapping projects have been undertaken in the Fraser Valley.

In 1998 the BC Ministry of Environment used the DRASTIC method, and the Aquifer Vulnerability Index (AVI)⁶ method to determine the intrinsic vulnerability of 169 wells in the Fraser Valley, including the Langley area and the Canadian portion of the Abbotsford-Sumas aquifer²⁴. These methods were compared to each other as well as to nitrate concentrations in each of the wells in order to evaluate if areas of higher vulnerability corresponded to higher levels of nitrates (due to agricultural land use). This vulnerability assessment was performed only for points (wells) and not spatially over the whole area.

In 2005 the AVI method was used to map the intrinsic vulnerability (spatially) as part of a Water Resource Management Strategy (WRMS) for the Township of Langley. The intrinsic vulnerability mapping was completed in earlier phases of the project and it was recommended that the map, together with a numerical groundwater flow model also developed, be used together as a planning and educational tool²⁶. The WRMS is currently in phase 4 of 5, which includes developing action plans, management options, and policy development for groundwater protection based on the previous phases²⁵. As such, a specific example of how the Aquifer Vulnerability Index maps have been used directly is unavailable at this time. At the time of writing, these maps were not available through the BC iMap database.

Currently a new groundwater risk assessment framework is being developed by Simon Fraser University and Natural Resources Canada and was tested in the Langley area as presented in a recent conference abstract²⁷. This risk assessment incorporates the concept of intrinsic vulnerability as well as other components of risk, including hazard threat, consequences of loss, and the social aspects of risk such as the community's ability to prevent and respond to a contamination event.

Gulf Islands (North Pender)^{19,28,29}

A modified DRASTIC method, which accounts for fractured rock¹⁹, was used to map the intrinsic vulnerability of the Gulf Islands. The vulnerability map was included in a community atlas released by the Canadian Parks and Wilderness Society²⁸. Additionally, the development of intrinsic vulnerability and hazard maps has been incorporated into the North Pender Island Official Community Plan (OCP)²⁹ in order to develop a groundwater management strategy and protect water resources. A modified

version of the OCP bylaw text is shown in Section 6.11. At the time of writing, the Gulf Islands maps were not available through the BC iMap database

Okanagan Valley (Oliver, Vernon)^{20, 30,31}

An intrinsic vulnerability map with the DRASTIC method²⁰ was used as part of the Smart Growth on the Ground sustainable development process^{30,31}. Water quality was identified as a key priority in a collaborative process to decide community priorities for future development. The intrinsic vulnerability map was used as one of the layers in a land use allocation model to provide scenarios of future development based on the community priorities. Intrinsic vulnerability maps and the land use allocation model was also used in the Vernon area as part of a similar development planning process.

Regional District of Nanaimo^{7,8,32}

The intrinsic vulnerability map from the pilot VIWRVMP⁷ was incorporated into a "Groundwater Assessment and Vulnerability Study"³². This report included a table of potential best management practices for areas of high, moderate and low vulnerability relating to the hazard posed by a selection of sources of contamination from industry, agriculture, the regional district, and miscellaneous. This table is presented in Section 6.1.3 as an example.

Grand Forks³³

An intrinsic aquifer vulnerability map using the DRASTIC method was incorporated into a "State of Understanding of the Hydrogeology of the Grand Forks Aquifer" where the vulnerability map was placed in context with the overall hydrogeology of the Grand Forks Aquifer.

5 Assessing risk to groundwater quality – an integrated framework

Assessing intrinsic vulnerability is only one part of a complete assessment of risk to groundwater quality and groundwater management^{e.g. 22,34,35,36,37}. Low vulnerability does not mean low risk of contamination. For example, a road salt stockpile in an area with low intrinsic vulnerability may have a higher overall risk of contamination than a schoolyard in an area of high intrinsic vulnerability. Therefore, the potential hazard(s), or threat(s) to groundwater quality at the land surface should also be assessed to compliment the intrinsic vulnerability assessment and provide a more complete picture of risk for a region. The DRASTIC vulnerability maps form a fundamental component of a holistic risk assessment.

There are no standardized risk assessment methods for groundwater quality. Generally, evaluating risk has three main components³⁴:

1. The hazard relating to the potential for pollution at the surface,
2. the intrinsic vulnerability to contamination in the event a spill occurs; and,
3. the consequences of a potential contamination event.

An assessment of hazards can include the:

- locating of potential contaminants within the study area,
- listing of the types and quantities of contaminants which may be present,
- understanding of the movement and toxicity of such contaminants, and
- understanding of the likelihood of release or spill of contaminants³⁵.

Risk assessments may be conducted using a variety of data sources including existing data on land use, zoning, previous development permits, or existing contaminated sites from government databases (e.g. GeoBC); aerial photographs or satellite data (e.g. Google Earth); or surveys specifically conducted to gather required information (e.g. mail, phone, door-to-door, windshield)^{from 21}. There is no standardized risk assessment method and the type of assessment conducted and level of detail included will ultimately depend on the community's preferences and intended use of the maps. In all cases these should be conducted by, or at least in consultation with, trained hydrogeologists.

Data compilations of potential sources of contamination, some including quantity, toxicity, mobility, and likelihoods of release, are present in a number of groundwater protection documents. These include Step 3 (Table 3.1, Appendix 3.1) of the BC Well Protection Toolkit²¹, Ontario Source Water Protection Technical Guidance Modules³⁵ and US EPA Office of Drinking Water³⁸. Examples of potential sources of contamination

are shown in Section 6.1.3 in Figures 12 and 13 from the BC Well Protection Toolkit²¹ and RDN Groundwater Assessment and Vulnerability Study³².

The consequence of losing the resource can be determined based on the value of the groundwater and may be represented by how important the aquifer is (e.g. regionally important, locally important, not an important water source)³⁴. The consequence may also be described financially and may include aspects of environmental, societal (e.g. health, future use), and economic consequences of losing the groundwater resource.

Once a full risk assessment has been completed, specific responses or preventative measures such as restriction of certain activities, or detailed requirements for development or operation can then be developed based on the level of risk associated with that area and activity (See example – Section 6).

6 Incorporating groundwater protection into land use decisions

Development of strategies to protect the quality of groundwater resources at both regional and local scales is vital to ensuring the quality of community water resources and drinking water supplies. The intrinsic vulnerability maps can be incorporated into land use decisions by minimising the risk of contamination. This can be achieved in a number of ways, including moving development with a high hazard threat (e.g. pulp mills, gas stations, etc.) away from areas of high vulnerability, and developing requirements for more detailed hydrogeological site assessments and emergency response plans for the development permitting process for land uses which pose a high hazard threat, or which are to be located in a highly vulnerable area. Also, incorporating best management practices for the prevention of groundwater contamination at the surface and instilling emergency response plans is one way to reduce the hazard potential while still allowing certain activities and development.

Below are some recommendations for incorporating the intrinsic vulnerability maps and groundwater protection strategies into land use decisions.

- Development of groundwater quality risk assessments^{e.g. 22,34,35,36,37} with which to identify high risk areas,
- Development of a response matrix in order to guide and manage land use and development requirements using a risk-based approach,³⁴ (see Section 6.1.3)
- Develop strategies and by-laws to not allow or limit new activities or developments which pose a high hazard threat in areas of high intrinsic vulnerability^{e.g. 23};
- Develop ways to regulate existing activities or developments which pose a high hazard threat^{e.g. 23}. These might include:
 - the use of best management practices for the prevention of groundwater contamination according to the type of activity occurring on the surface (e.g. chemical storage and handling requirements, protective barriers etc.),
 - limiting the types and quantities of hazardous materials stored on site and regulate their storage,
 - the development of emergency spill response plans suitable to the activity on the surface in case an incident does occur;
- Mandate that best management practices for storage and handling of industrial, agricultural, and residential chemicals be observed in all areas.

The Groundwater Bylaws Toolkit²³ outlines eight policy and bylaw tools that can be used by local governments to aid in groundwater protection from a land use planning,

policy, and bylaw context. These eight tools, which also include sample bylaw and policy text, are:

1. Groundwater data collection and mapping,
2. Water management and well protection planning,
3. Regional growth strategies,
4. Official community planning,
5. Zoning for groundwater protection,
6. Aquifer protection development permit areas,
7. Aquifer protection development approval information areas, and,
8. Subdivision servicing bylaws.

The intrinsic vulnerability maps can be used in tools 2 through 8. The development of the intrinsic vulnerability maps can be mandated in regional growth strategies and then used at smaller scales such as for prioritizing highly vulnerable areas in official community plans. They can also be used directly in zoning for groundwater protection and aquifer protection development permit and approval information areas where specific types of development that pose a high hazard threat to groundwater are either not allowed in highly vulnerable areas or are required to provide more detailed hydrogeological site assessments, environmental impact reports, best management practices and emergency response plans. The example below illustrates the direct use of the intrinsic vulnerability maps in the context of the Groundwater Bylaws Toolkit. Additional information, including examples of and sample text for bylaws, regulations, and policy can also be found in the toolkit.

6.1 Example for the South Cowichan Area of the Cowichan Valley Regional District

Land use planners and engineers dealing with ongoing and rapid development along the east coast of Vancouver Island will find the DRASTIC mapping useful for a variety of planning purposes. Particularly to assist in the development of risk management plans, but also for long-term community vulnerability analysis to a range of environmental pressures. An example for illustrative purposes has been provided that covers a developing area of the CVRD from Cowichan Bay to Mill Bay. This area is described as the South Cowichan Area and is located in the Cowichan Valley Regional District, about 10 km south of Duncan, BC. It is estimated that about half of the water use in the South Cowichan Area comes from groundwater and demand is likely to increase as population grows³⁹. There are both public (CVRD operated) and private water districts⁴⁰ in the area that supply water to the community where zoning allows for greater density as well as private water wells for larger lots.

There are a number of aquifers in the area which have been mapped with the BC Aquifer Classification system (See Figure 7, Section 7) and consist of both unconsolidated surficial material and consolidated bedrock. The groundwater resources

in this area are highly utilized to meet community needs. For example, the sand and gravel aquifer #197 is the production aquifer for the 10 community supply wells operated by private water districts, societies and the Regional District (Braithwaite Estates Improvement District, the Cobble Hill Improvement District, Millar's Water Supply Society Cowichan Bay Waterworks, Douglas Hill, Lanbourne, Cherry Point Estates, Garnett Creek, Satellite Park and Arbutus Ridge areas according to the CVRD data available at publishing) (Figure 8).

This aquifer (#197) was evaluated as having low vulnerability by the BC Aquifer Classification System (See Section 7); but, was identified as likely being more vulnerable than first thought due to the presence of both an upper unconfined and lower confined water bearing zones in parts of the aquifer, and a lack of confining layer in others^{in 39,40}. The intrinsic vulnerability map with the DRASTIC system classifies most of the aquifer as moderate vulnerability (Figure 9) with some areas mapped as high vulnerability in the southern portion of the aquifer, which correspond to those areas identified as likely being more vulnerability due to a lack of a confining layer. A well head protection plan has been developed by Braithwaite Estates Improvement District the Cobble Hill Improvement District, Millar's Water Supply Society⁴⁰ for their production wells in this aquifer.

The following is an example of how the intrinsic vulnerability maps could be incorporated into land use decision-making in the South Cowichan area moving from a large-scale OCP level (tool #4), to a small-scale aquifer protection development approval information area (tool #7), as well as well protection planning (tool #2). Please note that the well capture zones from the above mentioned well head protection plan⁴⁰ are shown for illustrative purposes only. In all cases it is stressed that the intrinsic vulnerability maps are not meant to replace site specific assessments, and should not be used at the lot scale. The maps are to be used as regional screening tools. Additionally, it is important to recognise that policies and practices such as the examples above be developed in accordance to the community's priorities for development and groundwater management.

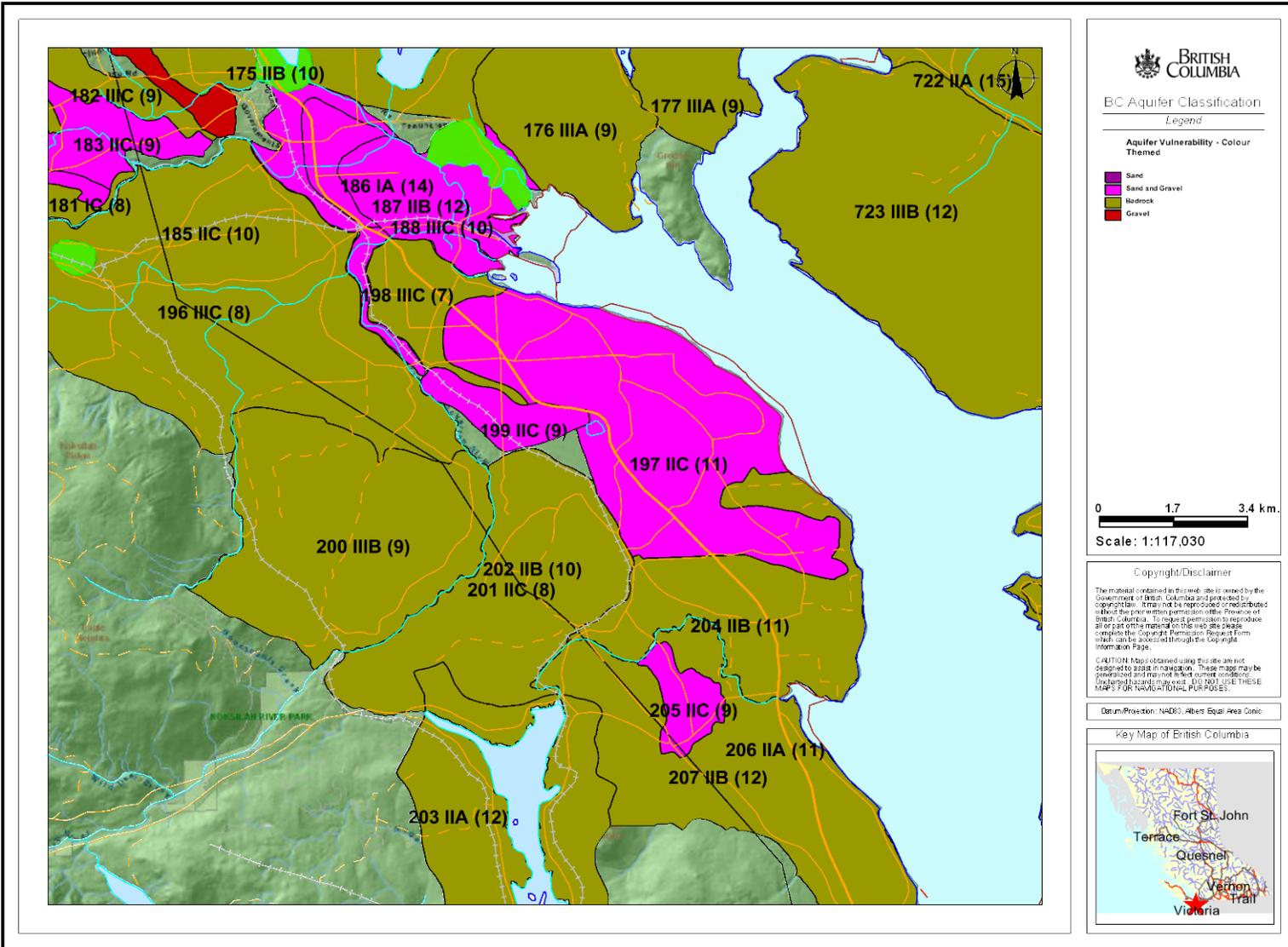


Figure 8: BC mapped aquifers in the Cobble Hill Area. Brown colour is bedrock aquifer material, pink colour is sand and gravel aquifer material. Stars show water supply wells for three water suppliers (BW, CH, Millars). The letter in the BC Aquifer Classification label shows the vulnerability (A=high, B=moderate, C=low)²⁰

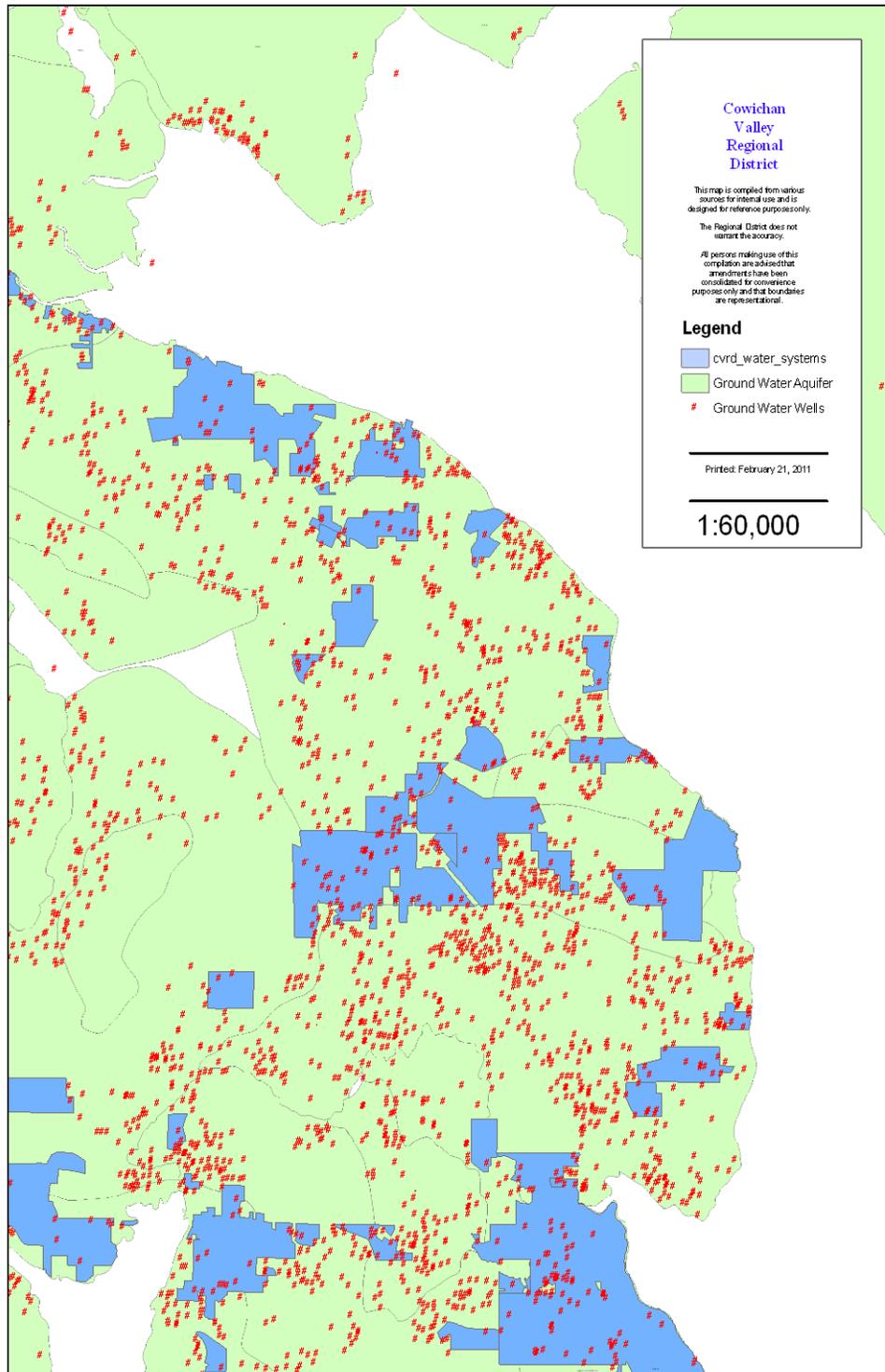


Figure 7: Water wells and groundwater supply systems in the South Cowichan Area

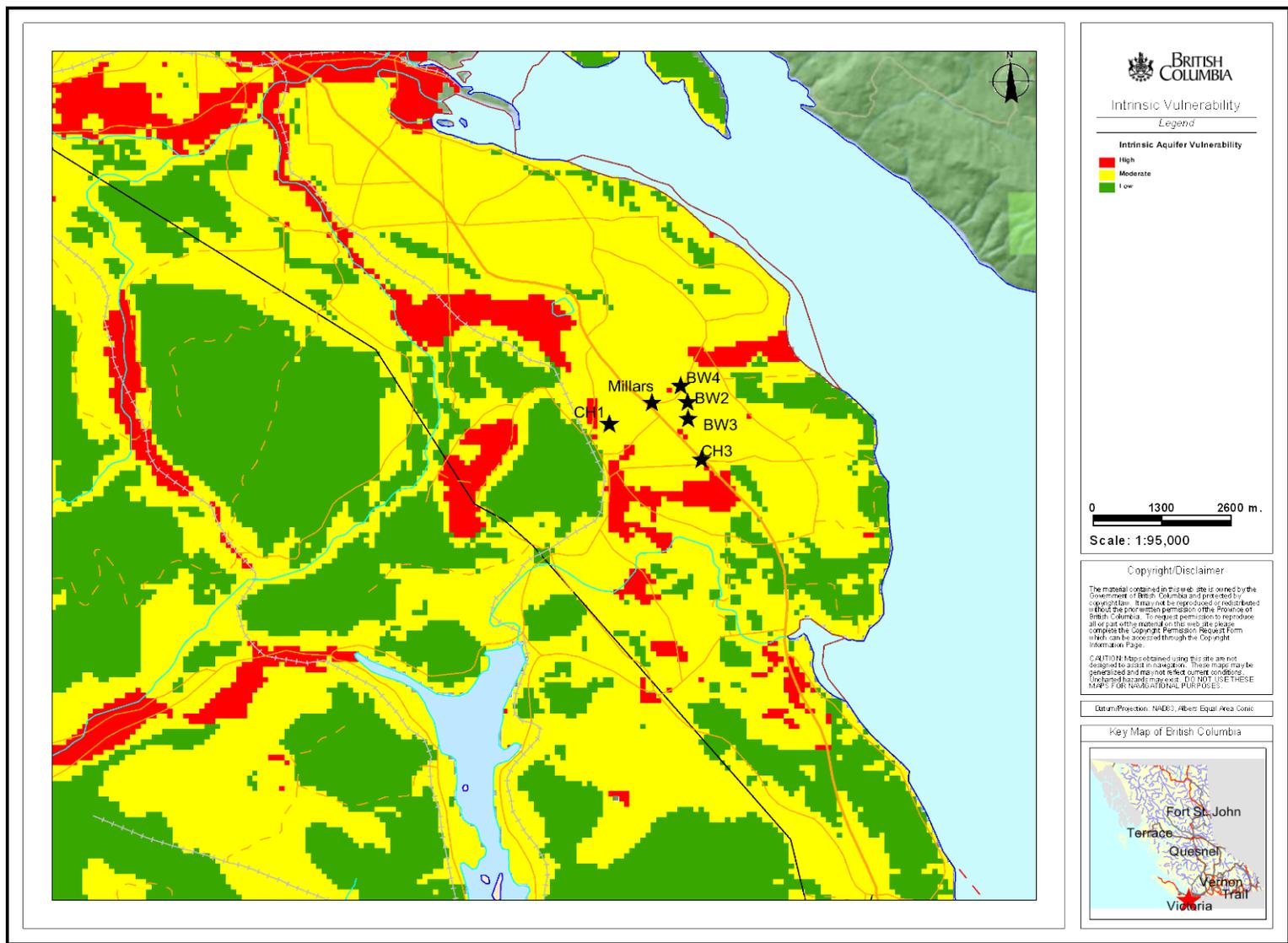


Figure 9: Intrinsic vulnerability (DRASTIC) and the Cobble Hill water supply wells (stars).

6.1.1 Official community planning

The intrinsic vulnerability maps can be incorporated at a large scale into the Official Community Plan (OCP) for local governments. The following shows text that relates to groundwater protection and land use planning from the OCP Bylaw No. 171 from North Pender Island (pg. 55)²⁹ as an example. Modifications are shown in [] for Cowichan Valley Regional District:

Policies

4.1.1 *The {Cowichan Valley Regional District} shall work with other agencies and the community in the implementation of a Groundwater Management Strategy. The Strategy should involve the following elements:*

- a) development of groundwater aquifer vulnerability mapping that identifies intrinsic aquifer susceptibility and land use hazards;*
- b) identification of groundwater recharge areas and development of a sustainable groundwater yield model;*
- c) recommended amendments to policy and regulations that would enhance the protection of groundwater from potential contamination and promote the sustainable use of the groundwater resource;*
- d) assess the potential magnitude of groundwater demand under existing zoning and create a zoning framework to implement necessary changes to secure sustainable water resources; and*
- e) develop a database of all wells [in the area] (existing, abandoned, etc.) that includes the location, age, depth, depth to water and other relevant parameters.*

4.1.2 *Siting regulations and appropriate buffer areas will be established to ensure the protection of wetlands and watercourses.*

4.1.3 *Watersheds, wetlands, creeks and groundwater recharge areas shall be protected through regulation of land use. Vegetation removal in and adjacent to such features may be limited through the implementation of development permit areas.*

4.1.4 *Development which may contaminate or compromise the sustainability of surface or ground water resources shall not be permitted.*

4.1.5 *The [Cowichan Valley Regional District] may consider rezoning large lots with subdivision potential [in] sensitive watershed areas in order to limit development in sensitive areas and to cluster development in other parts of the lot, with no net change in density.*

4.1.6 *The precautionary principle should be applied with respect to the planning, utilization and protection of potable water supplies, so decision makers act with a conservative approach regarding the impacts of land use on water supplies.*

4.1.7 *Groundwater shall not be used as a commercial commodity or for heavy industrial use*

[without impact studies and appropriate permitting].

4.1.8 No piping of water from a source outside of the Bylaw area shall be permitted [without impact studies and appropriate permitting].

Additional sample OCP policies can be found in the Groundwater Bylaws Toolkit²³.

6.1.2 Zoning for groundwater quality protection

While the OCP provides the mandate for making land use decisions with a focus on groundwater protection, the intrinsic vulnerability maps can be used directly beginning with zoning. In general, intrinsic vulnerability maps can be used to direct development away from highly vulnerable areas by limiting the types of land uses occurring in the area or by controlling the density of development²³. Bylaw text may list permitted uses based on the vulnerability or restrictions on uses²³.

6.1.3 Aquifer protection development permit areas and development approval information areas

Aquifer protection development permit areas may be designated based on a number of factors. Examples of these include the intrinsic vulnerability (e.g. high or moderate), if the area is an aquifer recharge zone, or if the area lies within a source water protection zone (see Section 6.1.4). In these cases area or site specific controls may be placed on development²³.

Requirements and guidelines for hydrogeological assessments can be set out as part of the development permit application process, modifications to existing development permits, or re-zoning. The level of hydrogeological assessment required is based on the both the intrinsic vulnerability of the area and the proposed development type or activity. An example of a matrix of assessment requirements is shown in Figure 10. Figure 11 shows examples of the five levels of hydrogeological assessments which can be used to set investigation requirements. These guidelines can be used in the absence of previous region-wide hazard or risk assessments, as the potential risk is assessed within each development application.

Need a short introductory preamble to the table ...

Development Type - Source of contamination (Hazard)	Intrinsic Vulnerability		
	High	Moderate	Low
High	Level 5	Level 4	Level 3
Industrial e.g. Chemical manufacturing, electronics, petroleum, refining and storage, metal treating, food processing, wood, and pulp processing, textile manufacturing			
Commercial e.g. Gas stations, furniture strippers, drum cleaning			
Other e.g. road de-icing, underground pipelines, waste disposal	Level 4	Level 3	Level 2
Moderate			
Industrial e.g. gravel pits			
Commercial e.g. Dry cleaners, junk yards auto repair and body shops, pest control companies, photographic processing, machine shops, auto part stores, lawn and garden/farm stores, paint stores, hardware stores, medical facilities			
Agricultural e.g. Heavy chemical use agricultural (fruits and vegetables), manure storage (lagoons, stockpiles).			
Residential e.g. Urban housing, high density (>5 dwelling units per hectare) using septic systems, trailer parks, sewer mains.	Level 3	Level 2	Level 1
Other e.g. Highways, roads,			
Low			
Commercial e.g. Grocery stores, department stores, office buildings, laundromats, food service, shoe repair, barber and beauty shop	Level 3	Level 2	Level 1
Agricultural e.g. Low chemical use agriculture (forage crops).			
Residential e.g. Moderate and low density (<5 dwelling units per hectare) using septic systems			

Figure 10 Example of level of hydrogeological assessment for development permit applications based on intrinsic vulnerability mapping classifications and proposed development type (source of contamination or hazard). Requirements for each level is described in Figure 11. Sources of contamination are from the BC Well Protection Toolkit²¹.

Level 1	<ul style="list-style-type: none"> •Groundwater contamination assessment report •A desk study is required to identify the concerns and potential risk to groundwater and the environment. A standard format hydrogeological report would most likely result, showing the nature of groundwater resource, pollution risk, and extent of any barriers to pollution flow, either natural or engineered. •If a potential risk has been identified by the desk study, additional information or groundwater monitoring may be required as per a higher level (depends on the risk).
Level 2	<ul style="list-style-type: none"> •Site investigation with monitoring •Limited site investigation is required to collect baseline data. Some soil and water testing required. Definition of groundwater flow system is required. Effectiveness of barriers, either natural or engineered, to be demonstrated. Calculations or modelling results are to be provided in support of conclusions on level of impact. Limited ongoing monitoring required.
Level 3	<ul style="list-style-type: none"> •Demonstrated groundwater protection plan •Extensive site investigation for baseline soil and water data. Definition of groundwater flow system is required. Engineering designs for any artificial barriers to be provided. An effluent/water management plan is required. Calculations or modelling results are to be provided in support of conclusions on level of impact. Demonstrated management skills have to be shown. A groundwater protection plan is required coupled with a monitoring schedule and an annual report.
Level 4	<ul style="list-style-type: none"> •Demonstrated emergency response plan •For moderate vulnerability areas, or where the previous levels of investigation indicate a clear risk to groundwater, a detailed groundwater site investigation is required. •The work should include an ongoing monitoring program, specifics of the potential contaminants (toxicity, quantity, transport behaviour), details on the protection design factors (natural attenuation, physical barriers, etc), a detailed emergency response plan as well as an assessment of the financial capacity of the responsible party to enact the plan.
Level 5	<ul style="list-style-type: none"> •Possible prohibition •For highly vulnerable areas where high hazard activities are proposed, or where there is a high potential risk determined from previous investigations. •All of the previous reporting requirements (Level 1-4) should be completed. •In the event that the risk to groundwater is unacceptable, development or an activity may be banned by the responsible authority.

Figure 11 Example of hydrogeological assessment requirements for development permit applications. Which level of assessment is required is shown in Figure 10. Text is from the New South Wales Groundwater Quality Protection Policy³⁷

While reporting standards exist for assessing existing contaminated sites, geotechnical investigations, well licencing (e.g. Alberta⁴¹, Ontario⁴²), environmental impact assessments (e.g. Manitoba⁴³) these cover a wide range of disciplines, are quite broad, and do not cover specific aspects of reporting for groundwater management. However, the Groundwater Bylaws Toolkit²³ does contain a section on hydrogeological assessments which could be used in conjunction with Figures 10 and 11 for assessing the hydrogeology of the area for management planning and potential risk to contamination. Additional examples of reporting requirements can be found in the Ontario Ministry of Environment's Technical Rules Assessment Report⁴⁴, the Australian Woollahra Municipal Council's "Guide for preparing geotechnical and hydrogeological reports"⁴⁵, and the Victorian EPA "Hydrogeological Assessment (Groundwater Quality) Guidelines"⁴⁶. A number of Australian references are used here and elsewhere in the document due to their efforts in water management related to years of drought and water scarcity.

While Figures 10 and 11 provide a framework for new activities or land uses, existing land uses may have a more profound impact on groundwater quality and are inherently harder to manage. One approach to managing existing land uses involves conducting a regional hazard and risk assessment as described in Section 5 and ongoing reporting, monitoring, use of best management practices, and review. A response matrix was developed for the Regional District of Nanaimo, which includes best management strategies and reporting requirements for certain types of land uses within each intrinsic vulnerability category (Figure 12).

The following table (Figure 12) is an example^{from 32} of an expansion of Figure 10 with specific notation as to the potential sources of contamination in the region, and provides planning guidance and insights as to how they could potentially be managed in each of the vulnerability classes. It should be noted that there is one land use area (transportation corridors) that has not been included in the following example and which will require some level of risk and hazard abatement – with specialized planning.

Sources of Contamination		Aquifer Vulnerability			Responsible Parties		
		Low	Moderate	High	Senior Governments	RDN & Municipalities	Individuals & Businesses
Industrial	<i>Liquid wastes</i>	Confined industrial wastewaters disposal allowed (use of impermeable liners)	Confined industrial wastewaters disposal allowed (use of impermeable liners)	No industrial wastewaters disposal is allowed	✓		✓
	<i>Tank and pipeline leakage</i>	Tanks and pipelines are allowed, with groundwater monitoring	Tanks and pipelines are allowed, with groundwater monitoring	No tanks or pipelines are allowed	✓		✓
	<i>Mining activities</i>	Mining activities are allowed with water management plans	Mining activities are allowed with water management plans	No mining activities	✓		✓
	<i>Hazardous products handling and storing</i>	Detailed list of hazardous products handled, stored and used.	Detailed list of hazardous products handled, stored and used.	Industrial activities in a high vulnerability zone are not recommended.			
		Use of highest industry standards for handling and storage (double/triple lining of containers, safe storage program, emergency plans)	Use of highest industry standards for handling and storage (double/triple lining of containers, safe storage program, emergency plans)	Detailed list of type and quantity of hazardous products handled, stored and used.			
		Auto – wreck yards: All vehicles coming to the yards have to be drained of all their fluids (fuels, oils – lubricating and hydraulic, cooling) and batteries be removed and recycled. The BC Vehicle Dismantling and Recycling Industry Environmental Planning Regulation (June 2007) applies.	Auto – wreck yards: All vehicles coming to the yards have to be drained of all their fluids (fuels, oils – lubricating and hydraulic, cooling) and batteries be removed and recycled. The BC Vehicle Dismantling and Recycling Industry Environmental Planning Regulation (June 2007) applies.	Use of highest industry standards for handling and storage (double/triple lining of containers, safe storage program, emergency plans)	✓	✓	✓
		Design and implementation of staff education and training programs on toxicity and risks to the environment	Design and implementation of staff education and training programs on toxicity and risks to the environment	Auto – wreck yards: not allowed.			
	Reporting to reg. agencies every 3 years	Reporting to reg. agencies every 2 years	Reporting to regulatory agencies every year.				
<i>Hazardous products use</i>	Detailed reporting of products used (every 3 years)	Detailed reporting of products used (every 2 years)	Detailed reporting of products used (every year)	✓		✓	
<i>Waste generation and disposal</i>	Detailed description of waste generated (type and volume) and outcome of wastes	Detailed description of waste generated (type and volume) and outcome of wastes	Detailed description of waste (type and volume) and outcome of wastes	✓		✓	

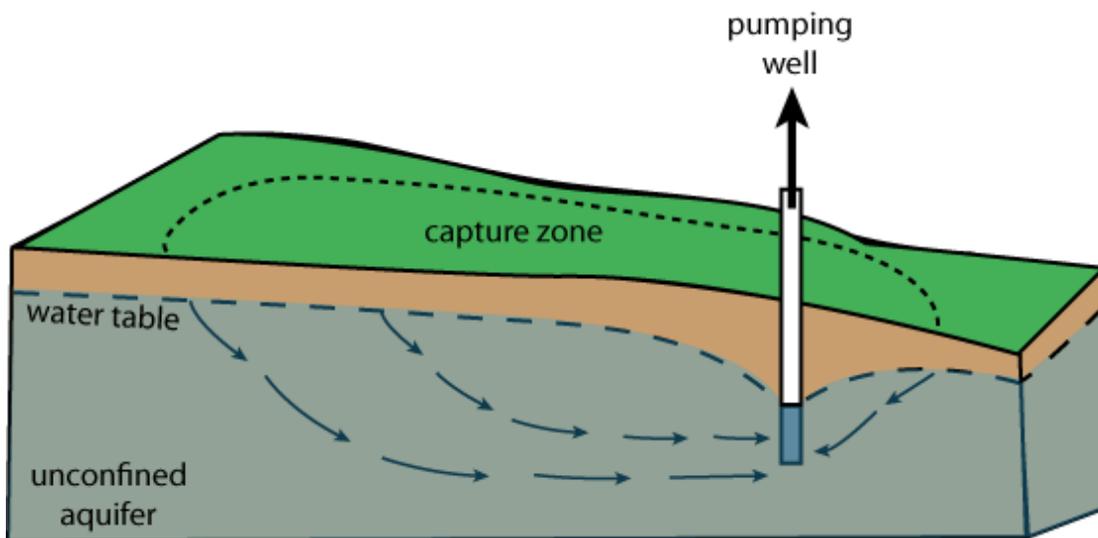
Sources of Contamination		Aquifer Vulnerability			Responsible Parties		
		Low	Moderate	High	Senior Governments	RDN & Municipalities	Individuals & Businesses
Regional District	<i>Sewer leakage</i>	6 year inspections	4 year inspections	2 year inspections	✓	✓	✓
	<i>Liquid wastes</i>	Irrigation, infiltration-percolation, and overland flow allowed	No irrigation or infiltration-percolation allowed, but overland flow is allowed	No irrigation, no infiltration-percolation, no overland flow	✓	✓	✓
	<i>Solid wastes</i>	Landfill permitted	No landfill	No landfill	✓	✓	
Agricultural	<i>Irrigation</i>	Irrigation is allowed- water management and conservation plan recommended	Irrigation is allowed - water management and conservation plan recommended	Irrigation is allowed - water management, monitoring, and conservation plan required	✓	✓	✓
	<i>Animal wastes</i>	Livestock raising is allowed	Livestock raising is allowed	Livestock raising is not allowed	✓	✓	✓
	<i>Fertilizer application</i>	Fertilization is allowed	Fertilization is allowed with groundwater monitoring	Fertilization is not allowed	✓	✓	✓
	<i>Pesticide application</i>	Pesticides are allowed	Pesticides are not allowed	Pesticides are not allowed	✓	✓	✓
Miscellaneous	<i>Spills</i>	Containment is required	Containment is required	Containment is required	✓	✓	✓
	<i>Stockpiles</i>	Containment is required	Containment is required	Containment is required	✓	✓	✓
	<i>Septic tanks and disposal fields</i>	Inspections every 2 years	Inspections every 2 years	Inspections every 2 years Monitoring well installed downgradient of field at property boundary and groundwater quality monitoring every 3 years	✓	✓	✓
	<i>Roadway de-icing</i>	Use of sand recommended. Road de-icing is allowed	Use of sand recommended. Road de-icing is not allowed	Use of sand recommended. Road de-icing is not allowed	✓		
	<i>Cross-contamination of wells</i>	Abandoned wells plugged and new wells properly sealed	Abandoned wells plugged and new wells properly sealed	Abandoned wells plugged and new wells properly sealed	✓		

Figure 12: Example of actions and best management practices from the Regional District of Nanaimo "Groundwater Assessment and Vulnerability Study"³²

6.1.4 Source water well protection planning

The philosophy behind source water well protection planning is the protection and prevention of contamination of the land areas which contribute water to a (community) well. This is a subset of source water protection which can be applied by local governments over larger, watershed scales, and for the protection of both surface water and groundwater supplies.

When a well is pumped it draws in water from the surrounding aquifer and a 'cone of depression' is created in the water table (in an unconfined aquifer) or potentiometric surface (in a confined aquifer) (Figure 13). A capture zone can be defined, which is the land area that contributes water, or recharge, to the well within a certain timeframe (Figure 13). Usually, capture zones are delineated based on the time it takes for water to travel from a certain point to a well. For example, one could delineate 1 year, 5 year, and 10 year zones. Contaminants released within the well capture zone may end up being drawn into the well and contaminating the water supply. Therefore, delineation and mapping of capture zones and source protection areas (the land area around a well in which groundwater protection measures are taken) is an integral part of community source water protection planning²¹. In some areas such as the United States, source water well protections plans are required for community wells.



13: Schematic diagram of a well capture zone and the land surface areas that contribute water to the well

The BC Well Protection Toolkit²¹ describes delineating the capture zone and well protection area in Step 2 of the protection process. Additionally, the Comprehensive Drinking Water Source-to-Tap Assessment Guideline²¹, also describes delineating

capture zones as part of Module 1 – Delineate and Characterize Drinking Water Sources. Following the BC Well Protection Toolkit there are five methods which are most commonly used to delineate the well capture zone (Figure 14).



Figure 14: Well capture zone delineation according to the BC Protection Toolkit²¹.

Combination of the intrinsic vulnerability maps with the mapped well capture zones is outlined in both the BC Well Protection Planning Toolkit and Comprehensive Source-to-Tap Assessment Guideline, along with defining the well protection area, identifying potential contaminants, and the development of management strategies. By including the intrinsic vulnerability, management strategies could be set in which activities which pose a high hazard are regulated either by limiting development or requiring groundwater monitoring, groundwater protection plans, the use of best management practices to prevent contamination, and emergency response plans from existing developments. An example of the combination of the intrinsic vulnerability with well capture zones is shown in Section 6.1.4.

The intrinsic vulnerability maps can also be used in the management of source water protection zones, which include the well capture zones. Here, the intrinsic vulnerability is combined with the well capture zones delineated in the Cobble Hill Well Protection Plan⁴⁰ (Figure 15). These capture zones were delineated with a numerical groundwater flow model using backwards particle tracking: where particles are “released” at the well and tracked backwards through time to determine where they would have started given 1-, 5-, and 10- years to migrate to the well under the flow conditions created by the model⁴⁰. The capture zones have an elliptical shape, elongated in the general direction of modelled groundwater flow, with the well at the down gradient side of the ellipse. The 1-year capture zones lie closest to the wells and water recharging this area will take less than 1 year to reach the well. The 5- and 10-year capture zones are larger and enclose a bigger area around the well, with a majority of the capture zone up-gradient of groundwater flow into the well.

The capture zones of all six water supply wells primarily lie within the moderate intrinsic vulnerability category (Figure 15), although there is some overlap with the high vulnerability category in the 5- and 10- year capture zone of wells CH₁, CH₃, BW₄, and BW₂, and BW₃. Although these areas of high vulnerability are small, the DRASTIC classification does not show gradational changes in vulnerability, so it is possible that other areas within these capture zones are near the moderate/high boundary.

Similar to the examples above (e.g. Figures 10, 11, 12), the capture zones and intrinsic vulnerability map can be used to reduce the risk of groundwater contamination by reducing the hazard of the permitted land uses and activities within the source water protection zone. The permitted level of risk should be much lower inside the source water protection zones, and the level of hydrogeological assessment should be higher. For example, while a gas station may be allowed in a moderately vulnerable aquifer in the rest of the region, it may not be allowed on a moderately vulnerable aquifer in the source water protection zone. Additionally, extra protection measures may be taken around Highway 1, which passes through three of the capture zones and may be a source of contamination from road salt and spills from road accidents.

The development of the levels of action and requirements for each, and the matrix of actions should be developed in consultation with hydrogeologists, local governments, land managers and planners and policymakers to ensure that the levels of action are in the best interests of all parties for groundwater protection.

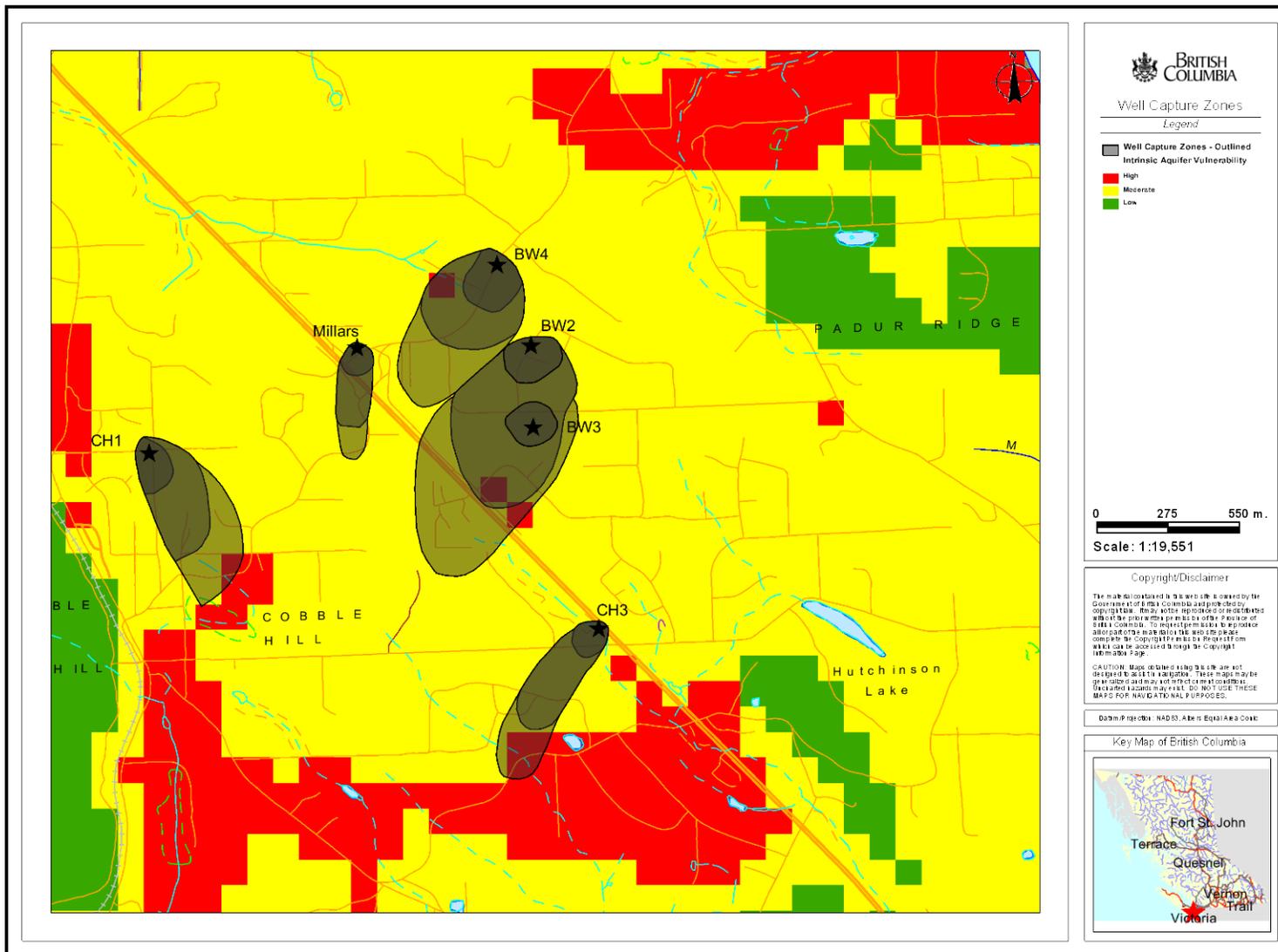


Figure 15: Intrinsic aquifer vulnerability with well capture zones from the Cobble Hill Protection Plan³⁹. Shading in well capture zones shows the 1- (dark), 5-, and 10-year (light) time of travel

7 Groundwater protection in British Columbia

7.1 Current groundwater legislation

While all levels of government in Canada have a role and responsibility in the protection and sustainable use of groundwater, water management and its regulation it is a provincial jurisdiction²³. However, the activities and uses of the land can have a profound effect on the quality of our groundwater resource. Land use regulation is generally a municipal or regional government jurisdiction. Hence the formulation of this document, which is intended to be a primer for local government planners, engineers and consultants. Information on federal government groundwater jurisdiction can be found in *Buried Treasure: Groundwater Permitting and Pricing in Canada*⁴⁷. The *Groundwater Bylaws Toolkit*²³ summarizes the jurisdiction and legislation relating to groundwater in BC. A brief overview of the major groundwater legislation in BC is provided below.

In 2004 the *BC Water Act* (2001)⁴⁸ was amended to include the *Groundwater Protection Regulation*⁴⁹ (GWPR). Up until this time *Water Act* did not include any regulations specifically focused on groundwater. The implementation of the GWPR is a multi-phase process with the first phase relating to the drilling, construction, and maintenance of wells. Phase 2 will follow with additional regulations⁵⁰. A general overview of the GWPR is provided below and more detail can be found on the BC Ministry of Environment's groundwater protection website⁵¹ and in the regulations themselves⁴⁹.

The GWPR applies to all water supply wells (domestic and non-domestic such as municipal wells or irrigation wells), groundwater monitoring wells, recharge and injection wells, dewatering or drainage wells, remediation wells and geotechnical wells. New wells must be drilled and completed by qualified well drillers and the well pump must be installed by a qualified well pump installer. New wells must be constructed with appropriate surface sealing, well cap, well casing stick-up, graded surface away from the wellhead, a well identification plate, and controlled or stopped artesian flow. It is the well owner's responsibility (private owner, municipality, etc.) to:

- cap any existing wells and ensure wells remain capped with secure, vermin-proof caps;
- maintain the well identification plate and obtain a new one if plate is damaged or lost;
- protect the well, including not putting junk (e.g. garbage, pesticides, chemicals, animal or human waste, etc.) down the well, maintaining the wellhead and surface sealing, protect the well from physical damage, and operates the well to prevent saltwater intrusion or contaminant movement into the well; and,

- wells not used for 5 years must be properly deactivated, and wells not used for 10 years must be properly closed.

A sample of other legislation, which also influences how groundwater resources are managed and protected, include:

- *Fisheries Act*⁵² (federal) – regulates protection of fish habitat which may require protection of groundwater baseflow into water bodies²³.
- *Canadian Environmental Protection Act*⁵³ (federal) – regulates the release of toxic substances into the environment, which also includes groundwater.
- *Drinking Water Protection Act*⁵⁴ (provincial) - regulates water supply systems and contains regulations for prevention of drinking water contamination, which also includes groundwater source areas. It allows for a local authority or water supplier to undertake a drinking water protection plan to reduce drinking water health hazards.
- *Environmental Management Act*⁵⁵ (provincial) – regulates environmental assessments of contaminated sites. Various regulations and codes of practise under this act such as the Waste Discharge Regulation, Municipal Sewage regulation and the Vehicle Dismantling and Recycling Industry Environmental Planning Regulation have implications for the quality of groundwater.
- *Environmental Assessment Act*⁵⁶ (provincial) – regulates groundwater withdrawals of greater than 75 litres or more per second (one well or combined wells). Environmental Assessment may be required for such projects. Additionally, impacts to groundwater from projects (e.g. mine) are assessed through the environmental assessment process.
- *Municipal By-Laws* (municipal) – any additional regulations such those due to source water protection plans, stormwater management, land use planning and zoning, development applications, emergency response planning, pesticide use or agricultural activities, etc. which may also incorporate groundwater vulnerability and risk. The Groundwater Bylaws Toolkit²³ provides an extensive list of possible municipal bylaws which may incorporate groundwater protection measures.

7.2 BC Aquifer Classification System

In 1994, the BC Ministry of Water, Land and Air Protection developed the British Columbia Aquifer Classification System as a means of synthesizing raw groundwater data (e.g. well records, water chemistry, geology) into a format which could be easily understood by planners, managers and the public⁵⁷ and used for groundwater protection and management. The system delineates the spatial extent of individual aquifers and then classifies them into one of nine classes based on a level of vulnerability, as well as a level of development and priority for each aquifer.

To date, more than 900 aquifers have been mapped in BC and on Vancouver Island, about 200 aquifers were identified and classified between 1995 and 2007. The BC Aquifer Classification System is dynamic, and will change over time as more groundwater information becomes available. New aquifers will be mapped and the boundaries of existing aquifers may change as detailed site characterization is undertaken.

The BC Aquifer Classification Maps are currently available for viewing and downloading on GeoBC and the BC Water Resources Atlas. Specific details regarding the system can be found in Kreye and Wei (1994)⁵⁷ and in the "Guide to Using the BC Aquifer Classification Maps for the Protection and Management of Groundwater"⁹.

There are several similarities and differences between the DRASTIC method used in the current study and the BC Aquifer Classification System (Figure 16). This may result in one area being classed as a different vulnerability due to the differences in methodology. Since the DRASTIC system accounts for spatially variable parameters within an aquifer (e.g. depth to water, soil type, topography, unsaturated zone material), the DRASTIC intrinsic vulnerability category will generally provide a more reliable and accurate estimate of the vulnerability of the groundwater resource from potential contaminants applied on the ground surface than the vulnerability category assigned by the BC Aquifer Classification System, which is applied over the entire aquifer. However, as DRASTIC evaluates the vulnerability for the aquifer closest to the surface the BC Aquifer Classification system may be used to estimate vulnerability for any underlying aquifers. The DRASTIC methodology is also more objective than the BC Aquifer Classification System as ratings of the individual parameters follow set tables.

A comparison of the BC Aquifer Classification System and the DRASTIC method is shown in Figure 17 for the South Cowichan area (Previously discussed in Section 6) and illustrates differences in methodology. For example, the DRASTIC method shows variation in vulnerability ranging from low to high within Aquifer #197, which is mapped as low vulnerability (C) with the BC Aquifer Classification system. In this case the DRASTIC method not only shows spatial variability within the mapped aquifer, but also indicates a moderate vulnerability over most of the aquifer and a high vulnerability in the southern part of the aquifer. Using the DRASTIC intrinsic vulnerability in this case is not only conservative, but also follows subsequent investigations which have pointed to a more complex and vulnerable aquifer system^{39,40}.

Conversely, Aquifer 203 is classified as high vulnerability (A) yet DRASTIC shows low to moderate vulnerability. In this case the aquifer is a bedrock aquifer with shallow static water levels (depth to water in a well). It is these water levels that lead to a high vulnerability class in the BC Aquifer Classification System. However, static levels in wells intercepting confined bedrock aquifers often reflect a potentiometric surface that can be much higher than the top of the aquifer. The DRASTIC methodology accounts for this difference in the determination of the depth to water surface by using the depth

to top of aquifer instead. This is explained in greater detail in Liggett and Gilchrist (2010)⁷. This alternative methodology may explain the difference in vulnerability rating.

A conservative approach, where the BC Aquifer Classification and the DRASTIC method are in disagreement, might be to use the highest vulnerability category between the two methods; however, due to the more rigorous methodology used mapping vulnerability with DRASTIC, it should be assumed that DRASTIC is providing the more defensible determination of groundwater vulnerability. The general descriptions of the properties of the low, moderate, and high vulnerability categories (Figure 3) is true for both the DRASTIC system and the BC Aquifer Classification System.

BC Aquifer Classification System vs. DRASTIC	
<p>Similarities</p> <ul style="list-style-type: none"> • Regional-scale screening tools for aquifer assessment. • Vulnerability assessment based on same characteristics such as depth to water (D), soil type (S), the permeability of the region above the water table or aquifer (I), and the permeability of the aquifer itself (C). In both methods depth to water is an important parameter • Same management strategies can be applied to same vulnerability classification. 	<p>Differences</p> <ul style="list-style-type: none"> • The BC Aquifer Classification system delineates the shape and extent of aquifers in plan view while DRASTIC does not attempt to do this. • The BC Aquifer Classification system assigns a single vulnerability value to an entire aquifer polygon, whereas DRASTIC provides spatial variability within mapped and unmapped aquifer polygons due to changes in depth to water, soil type, topography, or unsaturated zone material. • DRASTIC includes three additional parameters: aquifer media type (A), topography (T) and recharge (R). • DRASTIC shows the vulnerability to the uppermost aquifer only, whereas the BC Aquifer Classification can show the vulnerability of overlying aquifers. • DRASTIC can estimate vulnerability in unmapped aquifer areas as aquifer boundaries are not considered part of the analysis • BC Aquifer Classification includes level of development, and importance of aquifer, in addition to aquifer vulnerability to contamination. • Vancouver Island DRASTIC maps cover some areas outside the mapped BC Aquifer Classification polygons.

Figure 16: BC Aquifer Classification System^{57,9} and DRASTIC^{6,7,8}

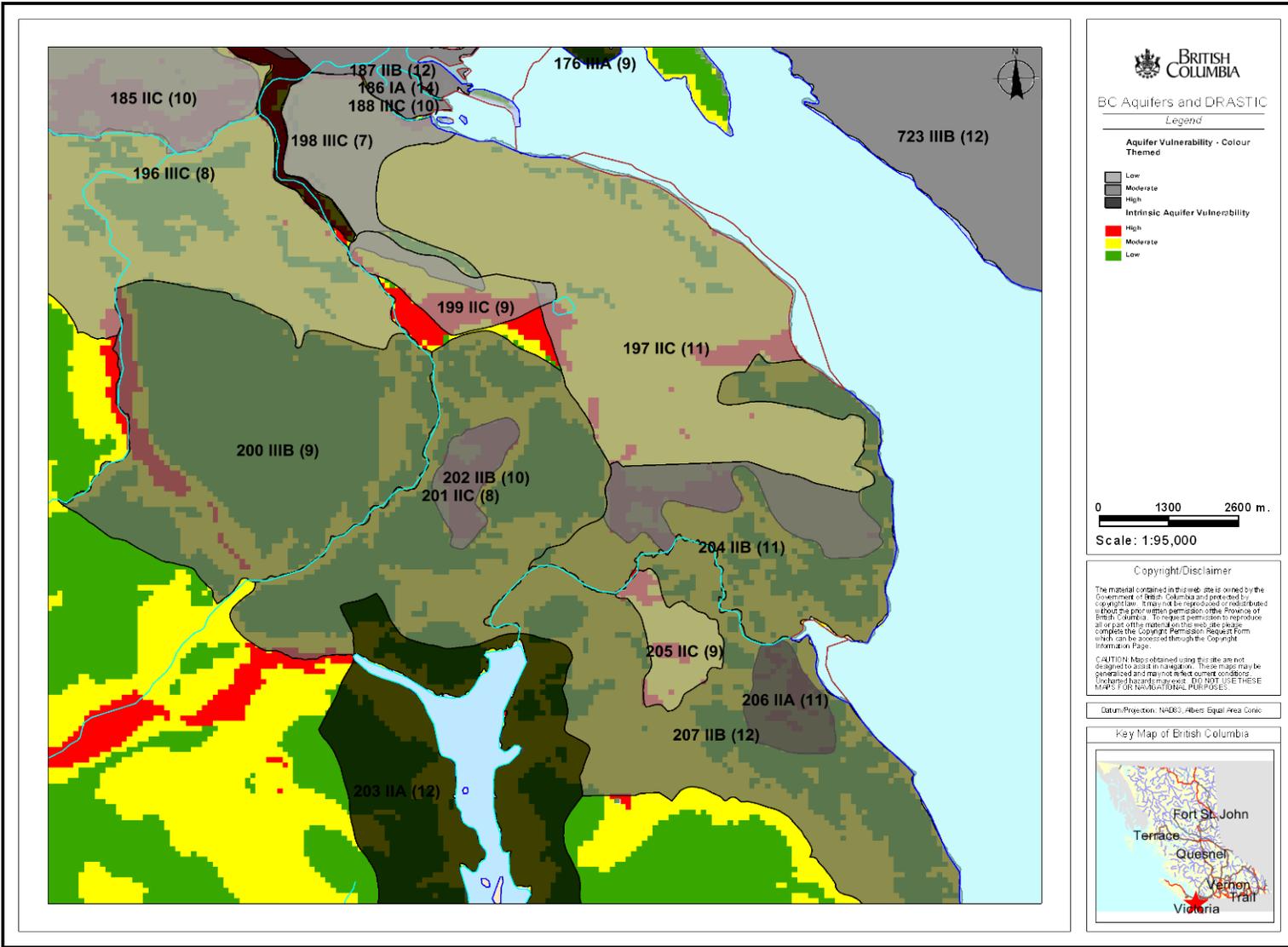
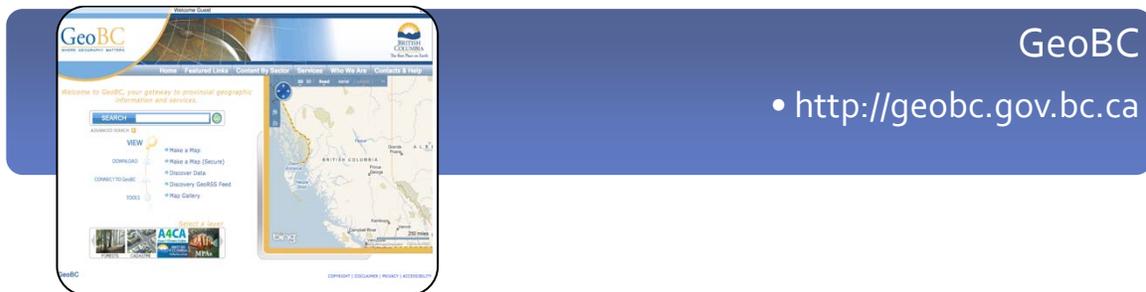


Figure 17: Intrinsic aquifer vulnerability with BC Aquifer Classification (greyscale) and DRASTIC intrinsic vulnerability (colour) for the Cobble Hill Area.

7.3 Available groundwater resources

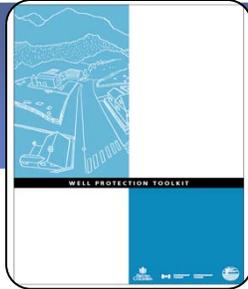
A number of toolkits and guidelines specific to groundwater protection in BC are available and are listed below. Additionally, there are numerous online repositories available for viewing, mapping, and downloading data related to groundwater resources in BC.



GeoBC is an online data repository of provincial geographical information for viewing, downloading, analysing, and creating maps. Available information ranges from base maps to hydrological, marine, geology, land status, parks, wildlife, climate, forestry, satellite imagery, and physical infrastructure data among many others. Users can view and create maps online using the free iMap tool. Data are available for download, some for free such as the intrinsic vulnerability map, while others require a fee.

Groundwater information can be found under the "Freshwater and Marine" layer and includes the DRASTIC intrinsic vulnerability map for Vancouver Island, aquifers in the BC Aquifer Classification System, water wells, well capture zones, water quality data, and water licences in addition to many other hydrological and hydrogeological data. A layer is also included which links the intrinsic vulnerability maps with the corresponding reports in EcoCat that describe the methodology used to make the maps.

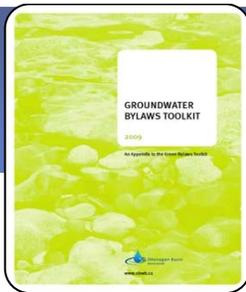
Figure 6 was created with the online iMap tool and a brief outline of how to find groundwater related information and make a map is found in the appendix.



BC Well Protection Toolkit

- http://www.env.gov.bc.ca/wsd/plan_protect_sustain/groundwater/wells/well_protection/wellprotect.html

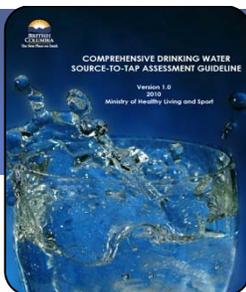
The BC Well Protection Toolkit was created to raise awareness to the issue of groundwater protection and good water well management. It also provides a practical approach to how communities and water supply system owners can develop well protection plans.



Groundwater Bylaws Toolkit

- http://www.obwb.ca/groundwater_bylaws_toolkit/

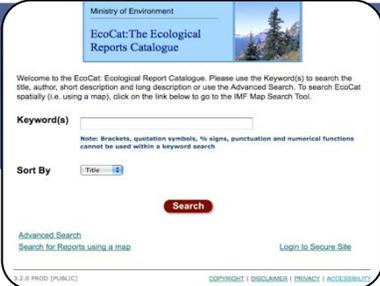
The Groundwater Bylaws Toolkit was developed by the Okanagan Basin Water Board and partners as an appendix to the Green Bylaws Toolkit. The aim is to provide guidance to local governments for protecting the quality and quantity of groundwater and includes sections on the basic principals of hydrogeology, groundwater data management, and jurisdiction for managing groundwater. There are also eight policy and bylaw tools outlined, with sample bylaw text, that local governments may use to develop their own groundwater protection regulations. These categories include: groundwater data collection and mapping, water management and well protection planning, regional growth strategies, official community planning, zoning for groundwater protection, aquifer protection development permit areas, aquifer protection development approval information areas, and subdivision servicing bylaws.



Comprehensive Drinking Water Source-to-Tap Assessment Guideline

- <http://www.health.gov.bc.ca/protect/source.html#water2>

The Source-to-Tap Assessment Guideline was developed in 2010 by the BC Ministry of Healthy Living and Sport as a regulatory requirement of the *Drinking Water Protection Act*, and to provide a tool to understand, identify, and manage risks to drinking water systems. Assessment of drinking water systems using groundwater from wells and springs are included. Characterizing the intrinsic vulnerability (including using DRASTIC, AVI, and the BC Aquifer Classification System) falls under Module 1: Delineate and Characterize Drinking Water Sources.



The screenshot shows the EcoCat website interface. At the top, it says "Ministry of Environment" and "EcoCat: The Ecological Reports Catalogue". Below this is a search bar with the label "Keyword(s)" and a "Search" button. There are also links for "Advanced Search" and "Login to Secure Site".

EcoCat

- <http://www.env.gov.bc.ca/ecocat>

The Ecological Reports Catalogue (EcoCat) is a provincially managed database of free digital reports and publications relating to groundwater, reservoirs, floodplain mapping, aquatic and terrestrial species and habitats, and vegetation. Technical documentation for the intrinsic vulnerability maps can be found here (e.g. references 7 and 8 for Vancouver Island).



The screenshot shows the BC WELLS Database website interface. It features a search bar at the top and a list of related links on the left. The main content area displays the title "WELLS - Ground Water Wells and Aquifer Database" and provides information about the database, including a telephone number and a website link.

BC WELLS Database

- http://www.env.gov.bc.ca/wsd/data_searches/wells/index.html

The BC WELLS database is a provincial database of water wells provided voluntarily by water well drillers, well owners, and groundwater specialists. This database may include specific well details such as depth, lithology, location, well diameter, casing information, owner information, well type, construction information, date drilled, and water depth. The WELLS database can be accessed via the link above and some of the well information (e.g. well location, well type) is also available in map format in GeoBC.



BC Observation Well Network

- http://www.env.gov.bc.ca/wsd/data_searches/obswell/

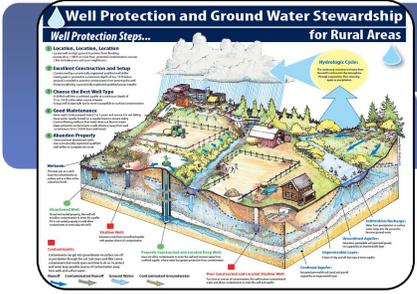
As of May 2011 there were 138 active wells in the provincial observation water well network. These wells cover major developed aquifers and groundwater areas and are used to monitor groundwater by measuring groundwater hydrographs, while some are also used to measure groundwater quality. The measured water levels and hydrographs are available from the site above.



BC Environmental Monitoring System

- <http://www.env.gov.bc.ca/emswr/>

The BC Environmental Monitoring System has a web reporting application (EMS WR) for read-only access to water quality data including physical, chemical, and biological analyses from wells around the province. Analyses are also performed on the quality of air, solid waste discharges and ambient monitoring sites throughout the province.



Groundwater Brochures and Forms

www.env.gov.bc.ca/wsd/plan_protect_sustain/groundwater/brochures_forms.html

A series of brochures and forms relating to groundwater have been developed by the BC Ministry of Environment. Some of these include well protection and ground water stewardship for rural areas, water quality fact sheets, and B.C.'s groundwater protection regulation – what private well owners should know.

8 Conclusions

Intrinsic aquifer vulnerability maps have been developed for different areas of British Columbia and are useful in both source water protection planning and broader groundwater protection frameworks. The vulnerability maps can assist local governments, planners, and policy-makers in land use decision-making and sustainable development planning, by identifying sensitive areas, prioritizing areas for further monitoring or protection, and educating the public. These maps are may also be integrated into more complete assessments of groundwater risk, and can be used as an additional layer in management strategies for source water protection areas. Incorporating these maps into groundwater protection frameworks, together with adhering to those groundwater practices outlined in the frameworks, will help protect the quality of groundwater resources for many years to come.

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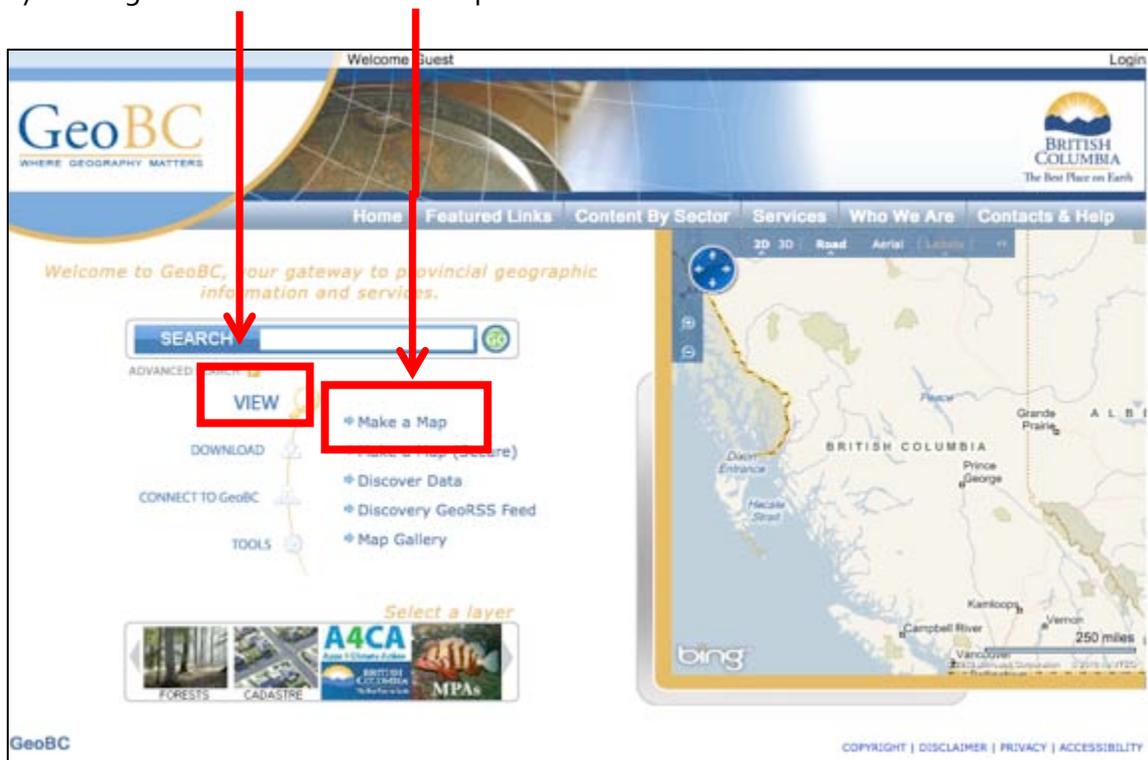
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Appendix

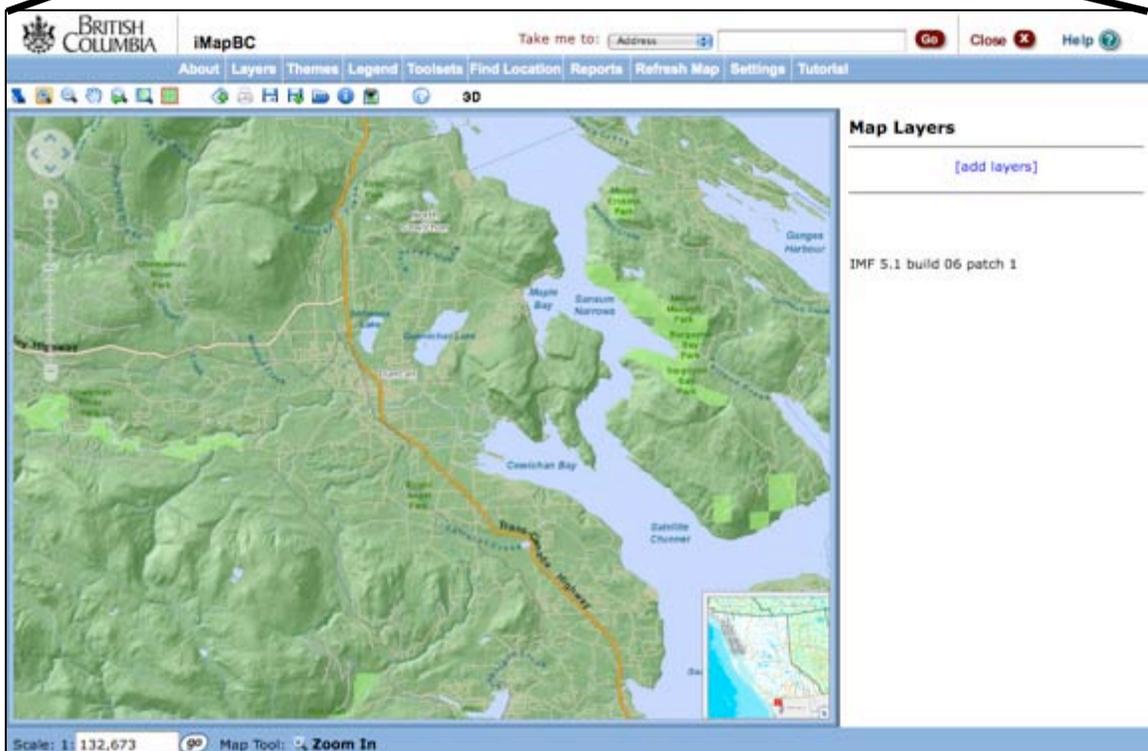
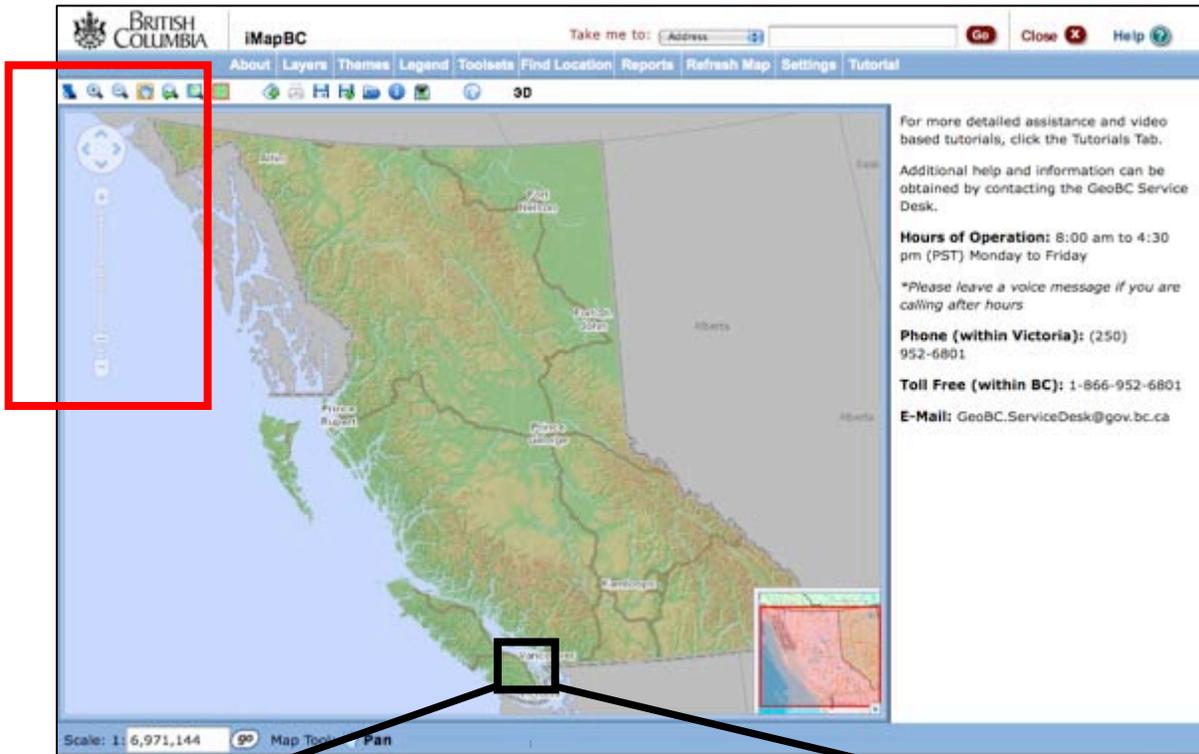
Map creation in iMap BC

Detailed information, tutorials, and help on the iMap system can be accessed from the system itself or at <http://archive.ilmb.gov.bc.ca/imf/HelpSystem/>. The following provides a brief overview of the mapping tool with a focus on finding groundwater related information. Datasets can be downloaded either through the iMap application (see step 3) or through the “download” option on the main GeoBC website (see below).

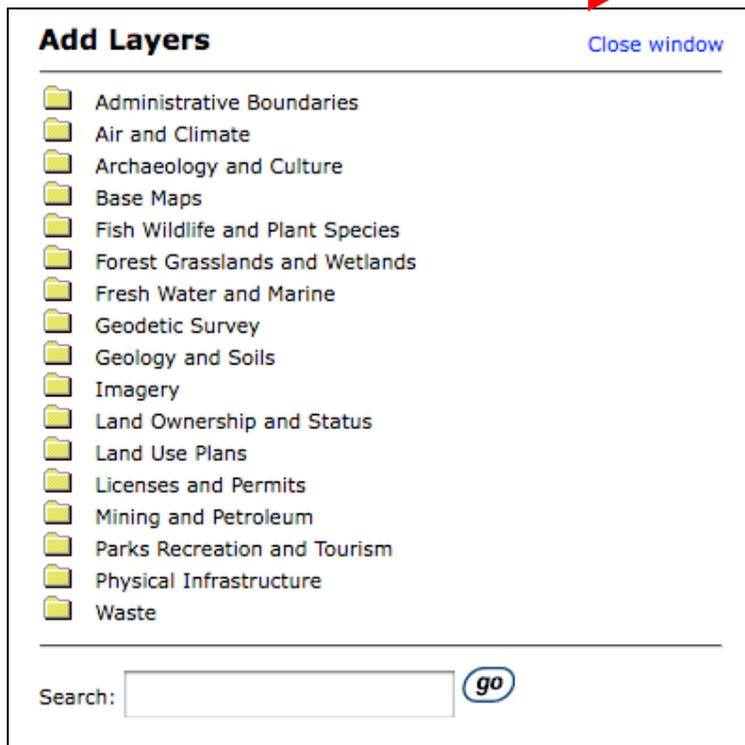
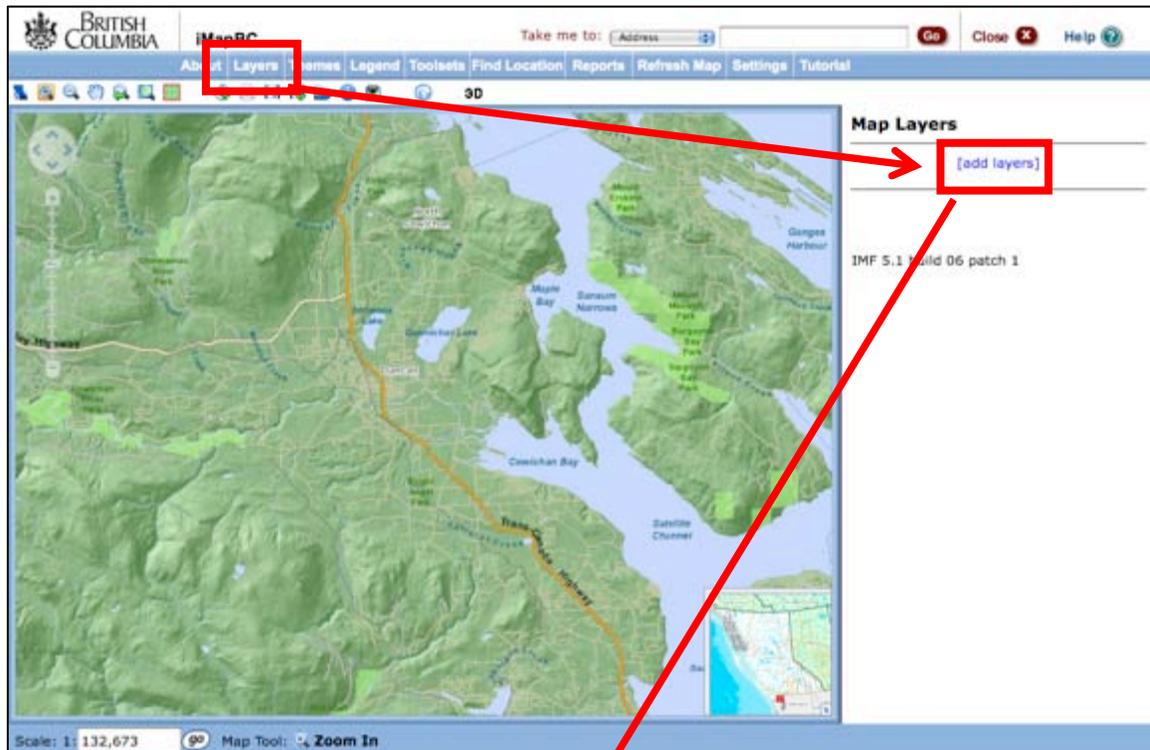
Step 1: Launch the iMap application from the GeoBC website (<http://geobc.gov.bc.ca/>) by clicking on “view” → “make a map”:



Step 2: Navigate to area of interest using zoom and pan tools in the upper left of the screen:



Step 3: Add groundwater-related layers. Click the “Layers” tab in the blue navigation bar at the top of the page, this will show the Map Layers view in the pane to the right of the map. Click on “add layers” to bring up the layers menu:



Groundwater data, including the intrinsic vulnerability maps can be found in the “Fresh Water and Marine” folder:

Add Layers Close window

-  Click this folder to show all of the folders
-  Fresh Water and Marine
 - Aquifer Chloride 
 - Aquifer GWQ Impact NPS 
 - Aquifer Intrinsic Vulnerability 
 - Aquifer Hardness 
 - Aquifer Nitrate Nitrogen 
 - Aquifer Specific Conductance 
 - Aquifer Total Alkalinity 
 - Aquifer Total Dissolved Solid 
 - BC Hydrometric Stations 
 - Dams 
 - EAUBC Ecological Drainage Units 
 - EAUBC Freshwater Ecoregions 
 - EAUBC Lakes 
 - EAUBC Rivers 
 - Floodplain Mapping in British Columbia 
 - Hydrology - Low Flow Zones 
 - Observation Wells 
 - WDIC - BC Watershed Atlas (50k) 
 - Water Management Service Regions 
 - Well Capture Zones 
 - Wells by Aquifer Material 
 - Wells by Construction Method 
 - Wells by Use 
 - Aquifer Boundary - Outlined
 - Aquifer Demand - Colour Themed
 - Aquifer Productivity - Colour Themed
 - Aquifer Vulnerability - Colour Themed
 - Artesian Wells
 - Drinking Water Extraction Points - BC Health Authority
 - Drinking Water Supply System
 - Flood Protection Appurtenant Works
 - Flood Protection Structural Works
 - Hydrologic Zones
 - Hydrology - 100 Year Peak Flow
 - Hydrology - 10 Year Peak Flow
 - Hydrology - Annual Runoff
 - Hydrometric Watershed Boundary - Outlined
 - Natural Aquifer Data Ground Water Quality Stations
 - Non-TRIM Hydrography
 - Points of Diversion
 - Reservoirs - Permits over Crown Land
 - Water Allocation Restrictions
 - Water Licence Points of Diversion - Drinking Water Sources
 - Water Licence Points of Diversion - Springs
 - Water Licence Points of Diversion - Water Utilities
 - Water Licensed Works Linear Features by Colour
 - Water Licensed Works Linear Features by FCODE
 - Water Licensed Works Point Features
 - Water Quality Objectives Reports Index
 - Water Reserves
 - Water Wells
 - Well Lithologies

Search: 

This menu can be used to plot many datasets related to both surface and groundwater in BC. This includes the aquifers mapped with the BC Aquifer Classification (“Aquifer Boundary”, “Aquifer Demand”, “Aquifer Productivity”, and “Aquifer Vulnerability”), the intrinsic vulnerability, where mapped, with the DRASTIC method (“Aquifer Intrinsic Vulnerability”), water wells, and well capture zones, amongst many other datasets. At the time of writing, intrinsic vulnerability maps with the DRASTIC method were available for areas around Grand Forks, Oliver, Vernon, and Vancouver Island.

The small yellow icon  indicates multiple map layers are available, and clicking on it will expand the category to show individual datasets. For example, the Aquifer Intrinsic Vulnerability Category includes two datasets. The actual intrinsic vulnerability layer, and the report index layer”.



Clicking directly on the individual datasets (in blue) will bring up a window with the metadata for that layer as well as a button to download the dataset if desired for use in a desktop GIS:



For this exercise we will check the boxes to the left, beside the “Aquifer Intrinsic Vulnerability” and the “Well Capture Zones”.



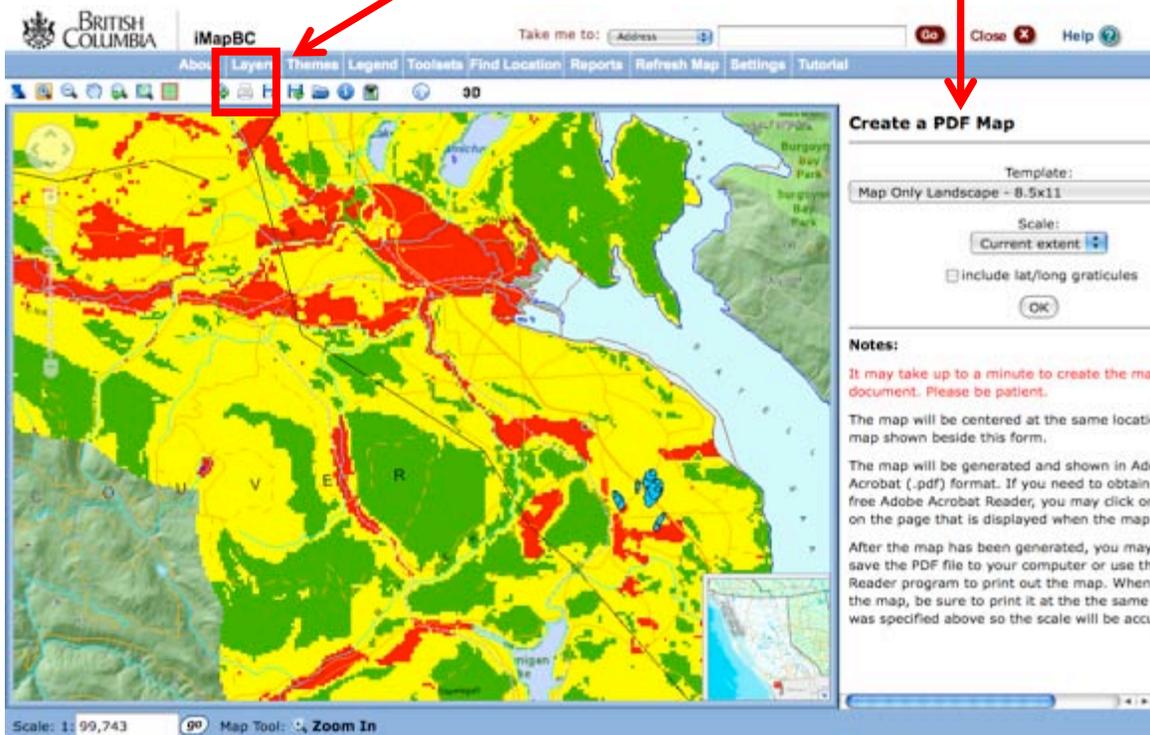
Step 4: Zoom and position map to desired extent. If required, click the  icon to zoom in to the extent of the map layers:

Add base map layers if desired. Click on “add” in the Map Layers Window. In the layers dialogue click “base maps”. Change the order of the map layers by clicking “change order” in the Map Layers window.

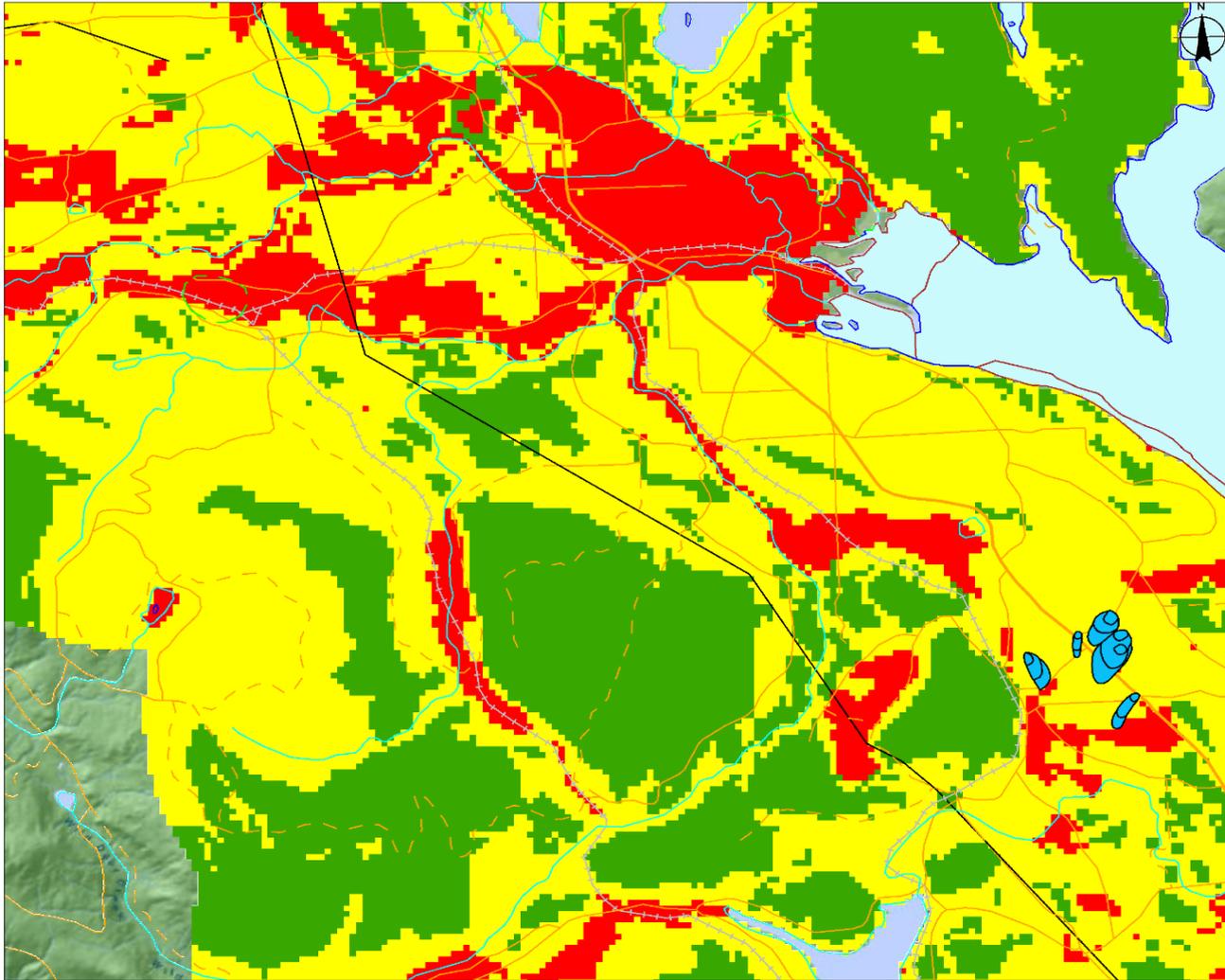
Adjust colour scheme if desired by clicking on the  icon.

View legend clicking on the “legend” tab at the top of the map window. Adjust which layers show up in the legend by clicking on “settings” in the Map Legend panel on the right.

Step 5: Print map by clicking on the  icon to bring up the "Create PDF Map" in the panel on the right.



Select map template (Default landscape includes map and legend), scale, and name and click "ok" to produce PDF map:



Example of iMap BC

Legend

- Well Capture Zones - Colour Filled
- Intrinsic Aquifer Vulnerability
- High
- Moderate
- Low



Scale: 1:99,743

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Datum/Projection: NAD83, Albers Equal Area Conic

Key Map of British Columbia



Glossary

Most terms below are from the glossary of BC Ministry of Environment's – "Groundwater Resources of British Columbia" (http://www.env.gov.bc.ca/wsd/plan_protect_sustain/groundwater/gwbc/) and reference 9.

AQUIFER — A saturated geologic unit that yields water in usable quantity to wells and springs. Geologic materials can be consolidated (fractured rock) or unconsolidated (sand and gravel). (See also confined aquifers and unconfined aquifers.)

AQUIFER VULNERABILITY MAPPING — Mapping the vulnerability of an aquifer to contamination from sources. Vulnerability mapping does not consider the type of land use above an aquifer, only the intrinsic vulnerability of the aquifer, typically based on the type, thickness, and extent of geologic materials overlying an aquifer, depth to water, and type of aquifer materials.

CAPTURE ZONE — The land area that contributes groundwater to or recharges a pumping well.

CONTAMINATION — The impairment of natural water quality by chemical or bacterial pollution as a result of human activities. The degree of contamination allowed before an actual hazard to public health is created will depend upon the intended end use, or uses of the water.

CONFINED AQUIFER — Confined is synonymous with artesian. A confined aquifer or an artesian aquifer is an aquifer bounded both below and above by beds of considerably lower permeability than that existing in the aquifer itself. The ground water in a confined aquifer is under pressure that is significantly greater than that existing in the atmosphere.

GROUNDWATER — Water that occurs in the ground. Specifically, water in the zone of saturation, that is under a pressure equal to or greater than atmospheric pressure.

HYDRAULIC CONDUCTIVITY — Hydraulic conductivity is a measure of the ability of a fluid to flow through a porous medium determined by the size and shape of the pore spaces in the medium and their degree of interconnection and also by the viscosity of the fluid. Hydraulic conductivity can be expressed as the volume of fluid that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow.

HYDRAULIC GRADIENT — The slope of the groundwater level or water table.

INTRINSIC AQUIFER VULNERABILITY — A measure of how vulnerable an aquifer is to contamination based on the natural characteristics of the aquifer and overlying material.

NATURAL ATTENUATION – reduction in mass or concentration of a compound in groundwater over time or distance from the source of constituents of concern due to naturally occurring physical, chemical, and biological processes, such as; biodegradation, dispersion, dilution, adsorption, and volatilization. (from the American Society for Testing and Materials (ASTM))

PERMEABILITY — The property of a porous rock, sediment or soil for transmitting a fluid, it is a test of the relative ease of fluid flow in a porous medium.

RECHARGE AREA— An area where water infiltrates into the ground and joins the zone of saturation. In the recharge area, there is a downward component of hydraulic head.

SATURATED ZONE — The subsurface zone in which all voids are ideally filled with water under pressure greater than atmospheric.

UNCONFINED AQUIFER — An aquifer where its upper boundary is defined by the water table. Where no aquitards (or confining layers) overlie the aquifer is said to be unconfined.

UNSATURATED ZONE — The zone between the land surface and the water table. The pore spaces, interstices, contain water at less than atmospheric pressure, and also air and other gases. Perched ground water bodies (local saturated zones) may exist in the unsaturated zone (also referred to as vadose zone).

WATER TABLE — That surface below which rock, gravel, sand or other material is saturated. It is the top surface of a body of unconfined ground water at which the pressure is atmospheric.