BRITISH COLUMBIA'S AQUIFER CLASSIFICATION SYSTEM.

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ABSTRACT
In 1994, the Ministry of Water, Land and Air Protection (then Ministry of Environment, Lands and Parks) developed an aquifer Classification System to provide an inventory of developed aquifers in the Province of British Columbia. Since 1994, 675 aquifers have been delineated, classified and mapped in the province. This map-based inventory of aquifers has provided a valuable priority setting framework to better protect and manage the province's groundwater resources through raising awareness of aquifers to decision-makers and using the information to support regional land use planning. It is estimated that the mapping and classification of known aquifers in British Columbia is 80% complete, with essential completion by 2008.

RÉSUMÉ
En 1994, le Ministère de la protection de l'eau, des terres et de l'air (précédemment Ministère de l'environnement, des terres et des parcs) a développé un système de classification d'aquifère pour fournir un inventaire des aquifères dans la province de Colombie-Britannique. Depuis 1994, 675 aquifères ont été délinées, classifiés et tracés dans la province. Cet inventaire cartographique a fourni un cadre pour protéger et contrôler les ressources des eaux souterraines de la province en prenant conscience des aquifères pour mieux communiquer l'information aux décideurs pour supporter l'aménagement régional du territoire. On l'estime que la cartographie et la classification des aquifères connues en Colombie-Britannique est 80% complet, avec l'accomplissement essentiel en 2008.

1 INTRODUCTION

It is estimated that currently, over 750,000 British Columbians, both in communities and rural areas, use groundwater as a source of drinking water. The largest amounts of groundwater are withdrawn in British Columbia (BC) for agricultural and industrial uses. In some areas, groundwater is the only viable economic source of water supply. Knowledge of the groundwater resources and aquifers is therefore important to support the economic activities of the province.

Historically, groundwater information collected by the Province of British Columbia (BC) has primarily been in the form of raw data (i.e., well records, water chemistry test results) or in site-specific studies. In view of growing groundwater information needs, efficient and effective long-term groundwater management would require this raw data be interpreted and synthesized into more usable and accessible information (Figure 1).

To achieve that objective, the Ministry of Water, Land and Air Protection (formerly Ministry of Environment, Lands and Parks) developed the BC Aquifer Classification System in 1994 with the intent of allowing aquifers in the province to be compared within a consistent context; of providing a framework to direct detailed aquifer characterization and assessment; of building a comprehensive inventory of the aquifers in the province; and of increasing public knowledge and understanding of the aquifers and prioritizing future actions at various planning levels.

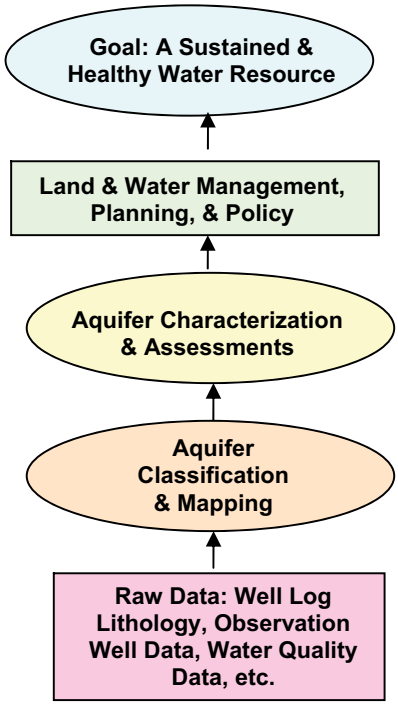

Figure 1. The path from raw data to more useable information to the goal of a sustainable groundwater resource.

This paper describes the BC Aquifer Classification System and identifies the strengths and limitations of the system. Examples of some of the uses of the classification system are discussed and a summary of the inventory of aquifers are presented. Finally, future directions for regional aquifer mapping in BC are discussed.

2 THE SYSTEM

The classification system (Figure 2) has two main components: a classification component which characterizes the aquifer on the basis of level of development (the water supply available relative to the amount of demand placed on the aquifer) of the groundwater resources and vulnerability of the aquifer to contamination; and a ranking value component which assigns a number value to indicate the relative importance of an aquifer. This value helps prioritize aquifers for protection and management.

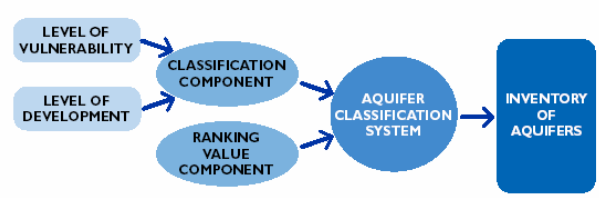

Figure 2. The BC Aquifer Classification System

The classification and ranking value components are determined for the aquifer as a whole, and not for parts of an aquifer. As each aquifer is classified it is added to the Province's aquifer inventory. Data used for aquifer classification come from various sources available to the Ministry at the time an aquifer is being classified. As new data and sources of information become available, the classification and boundary delineation of some aquifers can be reviewed and revised as necessary.

2.1 Classification Component

The classification component categorizes aquifers based on their current level of groundwater development (categories I, II and III for high, moderate and light development, respectively) and vulnerability to contamination (categories A, B and C for high, moderate and low vulnerability, respectively). The combination of the three development and three vulnerability categories results in nine aquifer classes, ranging from IA to IIIC as seen in Figure 3 below. The nine aquifer classes have an implied priority from a management and protection standpoint, from IIIC, which is the lowest priority to IA, which is the highest.

2.1.1 Level of development

The level of development, a relative and subjective term, compares the amount of groundwater withdrawn from an aquifer to the aquifer's inferred ability to supply groundwater for use. Since a water balance is seldom available, it was necessary to infer the level of development for aquifers subjectively by assessing well density, water use, aquifer productivity (from well yield and specific capacity), and sources of recharge (e.g., where an aquifer is situated along a river). Given the same demand, the level of development of an aquifer of low productivity would be considered higher than an aquifer of higher productivity.

Correctly interpreting the level of development is important, since the degree of development indicates the level of care and attention that should be applied in any groundwater management or protection process.

2.1.2 Level of vulnerability

The level of vulnerability of an aquifer is a measure of its vulnerability to a contaminant that is introduced at the land surface. Vulnerability in this system is considered to be intrinsic to the aquifer; that is, it is based on hydrogeology alone and does not consider the existing type of land use or nature of potential contaminants. Contamination from deep sources, such as injection wells or saltwater encroachment from over-pumping, are not considered.

The level of vulnerability of an aquifer is qualitative and based on type, thickness and extent of geologic sediments overlying the aquifer, depth to water (or depth to top of confined aquifers), and type of aquifer material. Porosity is an important criterion in assessing the vulnerability for bedrock aquifers. Given the variety of factors that govern vulnerability, professional judgement is important for a reasonable assessment of an aquifer's vulnerability.

2.2 Ranking Value Component

The aquifer ranking value component is based on seven general physical attributes of an aquifer (productivity, vulnerability, and aquifer area), the amount and type of water demands on the aquifer, and documented groundwater water quality (i.e., based on risk to human health); and quantity concerns. The point value is determined by summing each criterion (Figure 4), with the lowest ranking value possible being 5 and the highest-ranking value possible is 21. Generally, the greater the ranking value, the greater the priority.

As the ranking value includes demand, productivity and vulnerability, a cross-check is provided against the classification designation of aquifers for groundwater protection and management, which is especially useful when two or more aquifers have the same classification. For example, two aquifers may have a IA designation but one aquifer may be regional in extent, while the other is local. The larger (regional) aquifer may also have documented water quality and quantity concerns.

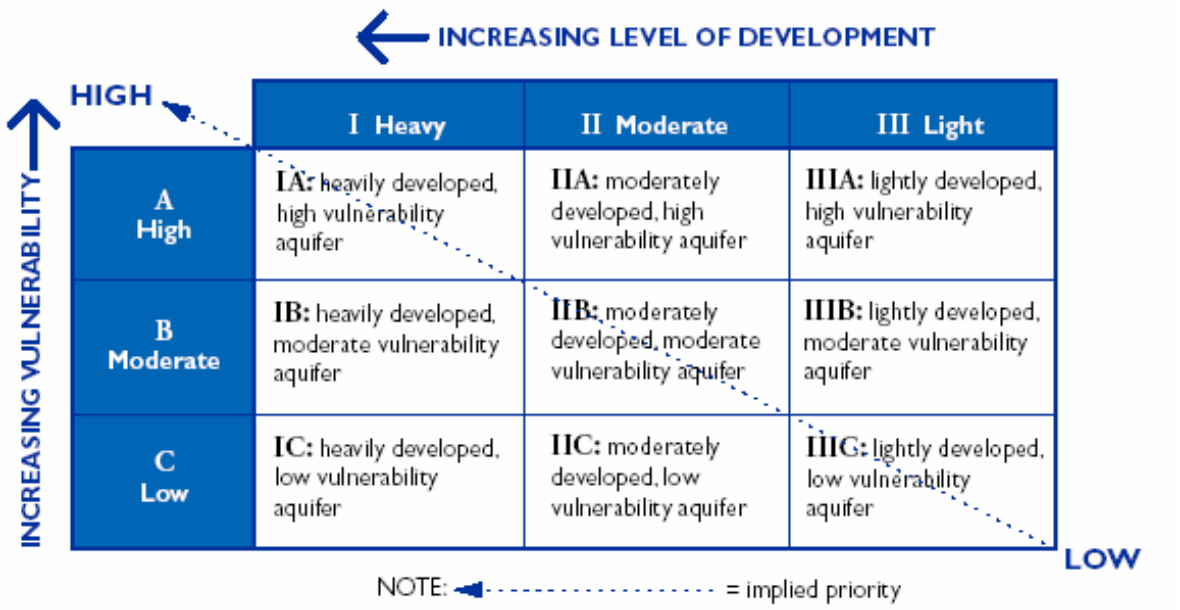

Figure 3. Aquifer classes

	Point Value				
Criteria	**0**	**1**	**2**	**3**	**Rationale**
Productivity	N/A*	Low	Moderate	High	abundance of the resource
Vulnerability	N/A	Low	Moderate	High	potential for water quality degradation
Aquifer Area	N/A	< 5 km²	5–25 km²	> 25 km²	regionality of the resource
Demand for Water	N/A	Low	Moderate	High	level of reliance on the resource for supply
Type of Water Use	N/A	non-drinking water	drinking water	multiple/ drinking water	variability/diversity of the resource for supply
Quality Concerns	unknown/none	isolated	local	regional	actual documented concerns
Quantity Concerns	unknown/none	isolated	local	regional	actual documented concerns

Figure 4. Aquifer ranking values

The IA designation, by itself, does not reveal these other attributes. The ranking value for the larger IA aquifer with problems would show a higher ranking value because of these issues.

2.3 Challenges of delineating aquifers

The primary sources of data for mapping and classifying aquifers are water well records, available hydrogeological reports and geologic mapping. The amount and quality of data available varies both within an individual aquifer and from one aquifer to another. The delineation of some aquifers was relatively straight forward, in other instances, the complexity of the geology, lack of robust hydrologic values (e.g. transmissivity, water budget numbers), required subjective decision making by the mapper.

The delineation of bedrock aquifers often posed greater challenges than unconsolidated sand and gravel aquifers. The type of information available would dictate how the aquifer boundaries were delineated. If only minimal data was available, the delineation of a bedrock aquifer was based on the area of development (area where the wells are located) to establish the boundary that delineates the area of groundwater use. The amount of additional hydrogeologic information available would further define how the developed bedrock aquifers in BC were delineated. This information would include: the known extent of the permeable bedrock geologic unit that makes

up a known aquifer; if there are any major geographical features (e.g., major rivers) dividing the area of development or the permeable bedrock geologic units; or if there are sufficient data to define the local groundwater flow system for an individual aquifer. As this information varied in its availability across the province, the resulting boundaries of different bedrock aquifers were defined by different criteria.

3 STRENGTHS AND LIMITATIONS OF THE BC AQUIFER CLASSIFICATION SYSTEM

3.1 What the System does

Aquifer classification mapping turns data into information for decision makers to use. The map-based products allow others to "see" the aquifers, thereby increasing public knowledge and understanding of the groundwater resource. Figure 5 is a local map of aquifers around the Duncan area on Vancouver Island. The town of Duncan is situated above 3 unconsolidated aquifers (the orange, yellow and green polygons) and surrounded by numerous unconsolidated and bedrock aquifers.

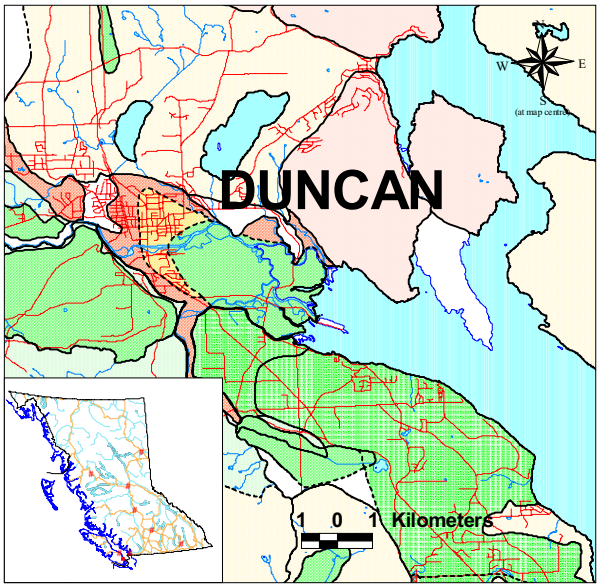

Figure 5. Example of aquifer mapping in the Duncan area of Vancouver Island.

Aquifer classification mapping provides general information and an understanding of aquifers in a given area. It categorizes and prioritizes aquifers for water management, protection and remedial efforts and sets a framework to direct detailed aquifer characterization and assessment. The system has built an inventory of aquifers in BC. The system allows local government to ask where they should be diligent to ensure rural development does not impact groundwater quality or quatity. For example, It allows a health official to know which areas are most susceptible to nitrate contamination in groundwater used for drinking.

3.2 What the System doesn't do

The aquifer classification system does not provide specific information about groundwater availability, direction or rate of flow, recharge or discharge areas nor aquifer capacity. The classification maps do not show variability of properties of an aquifer (e.g., productivity, vulnerability), nor do they reveal interactions with surface water. It is static, a "snap shot" of conditions at the time the aquifer was mapped, it does not show trends over time. The system does not evaluate nor determine risk; it estimates an aquifers inherent vulnerability to contamination.

To minimize mis-interpretation or mis-use of the aquifer classification mapping results, a guidance document was produced (Berardinucci and Ronneseth, 2002) to encourage correct application of the maps and information. The document provides an explanation of the classification system and discusses the assumptions underlying its design, the interpretation of the information presented and the appropriate use of the accompanying maps. It includes the sources of information and the methodology used to characterize or map the aquifers and their boundaries. The guide can be found in a PDF format at:

http://wlapwww.gov.bc.ca/wat/aquifers/index.html

4 AQUIFER CLASSIFICATION MAPPING PROGRESS – AN INVENTORY OF AQUIFERS IN BC

To-date, 675 aquifers have been identified, mapped and classified in BC, 75% are unconsolidated aquifers and 25% are bedrock aquifers. Thirty percent of the aquifers are considered highly vulnerable and 37% have low vulnerability to surface contaminants, and 10% have some documented water quality concerns. Twenty-one percent are considered highly productive and 9% of the aquifers have high demands placed on the water supplies. Only 3% of all aquifers (21 out of 675) delineated are the highest priority IA (i.e., heavily developed and highly vulnerable) aquifers.

The various classification attributes that define BC's aquifers can be displayed in the GIS environment allowing for more flexible analysis of the provinces groundwater resources. For example, Figures 6 and 7 show the aquifers by lithology type and by vulnerability for two different areas of the province.

The British Columbia Aquifer Classification System has successfully classified aquifers from many different hydrogeological regimes. BC is a cordilleran environment, comprised of mountains, valleys, basins, lowlands, plains, plateaus and highland areas. The bedrock aquifers are found in rocks of all ages and types and have undergone most known structural geological processes. The unconsolidated materials are the result of erosional and

depositional processes associated with four major glaciations and accompanying non-glacial periods. BC was affected by both the Cordilleran and Laurentide continental ice-sheets.

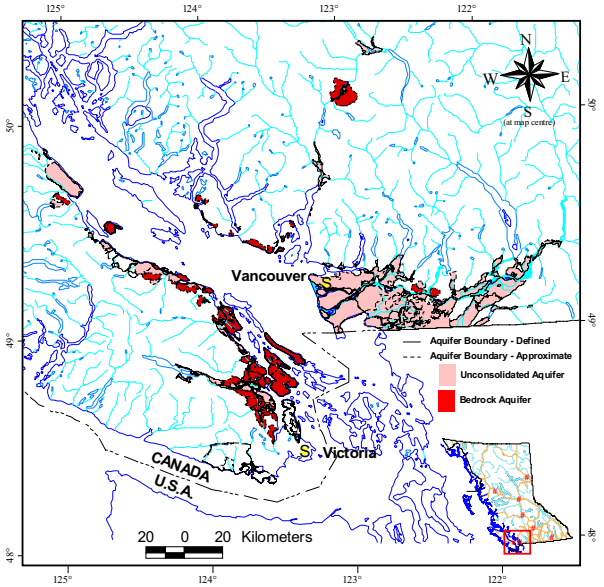

Figure 6. Distribution of Unconsolidated and Bedrock aquifers in south-west BC.

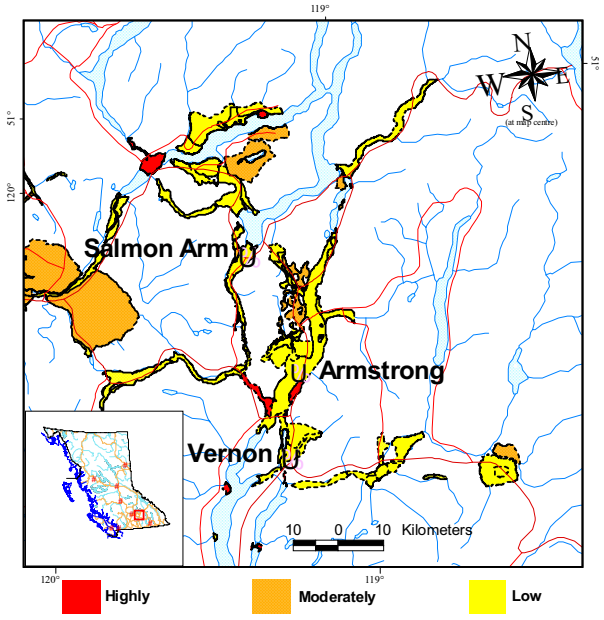

Figure 7. Distribution of vulnerable aquifers in south-central BC.

Bedrock aquifers include a regional plateau lava flow aquifer, found in the central part of the province, where water supplies come from fractures and the "brecciated" or erosional inter-flow zones and is greater than 6500 km^2 in size, down to a local granitic island intrusion aquifer found on south-eastern Vancouver Island where water supplies come from fractures and is 16 km^2 in size.

Unconsolidated aquifer types include aquifers comprised of outwash sands deposited in the advance of the last major glacial advance located around the Georgia Basin of southwest BC to deep confined aquifers in the Prince George area comprised of Tertiary channel sand and gravel deposits. Information on aquifer classification characteristics can be found at the following web site:

http://wlapwww.gov.bc.ca/wat/aquifers/query/aquifers.htm

It is estimated that the mapping and classification of known aquifers in British Columbia is 80% complete, with essential completion by 2008. Figure 8 shows the status of the aquifer mapping as of December 2003. The green areas are areas that have been completed. The red areas are where aquifer mapping was completed in fiscal year 2003/2004. The yellow and white areas remain to be mapped. The yellow areas have sufficient data to map aquifers. The white areas are areas where data is minimal or insufficient to map aquifers.

5 EXAMPLES OF USES OF AQUIFER CLASSIFICIATION INFORMATION

5.1 Who uses the System

A successful outcome of the aquifer classification mapping is the wide variety of groups using the information for inventory purposes, priority setting and development of high level policies for monitoring groundwater quality and quantity. These include: provincial agencies involved in water management, regional and local land use planning groups, people involved in property management, environmental health protection, resource extraction, community development, community stewardship, the educational community, and the geoscience and well drilling industry.

Another successful outcome measure is how the aquifer classification information is being used. The Ministry of Water, Land and Air Protection is establishing at least one observation well and expanding its ambient groundwater quality network to all 21 high priority IA aquifer (Figure 9). The number of highly vulnerable aquifers helped the province develop an Aquifer Awareness Program; providing grants to organizations to place aquifer awareness signage over their vulnerable aquifers. The Ministry is using the inventory of aquifers for more detailed characterization of aquifers and to provide criteria for funding groundwater stewardship and assessment projects.

Information from the aquifer classification mapping has been used for regional water and land-use planning in the Okanagan-Shuswap, Caribou-Chilcotin and Squamish-Whistler areas. The maps have also been used as a screening tool to help target areas for composting, burning and landfill sites.

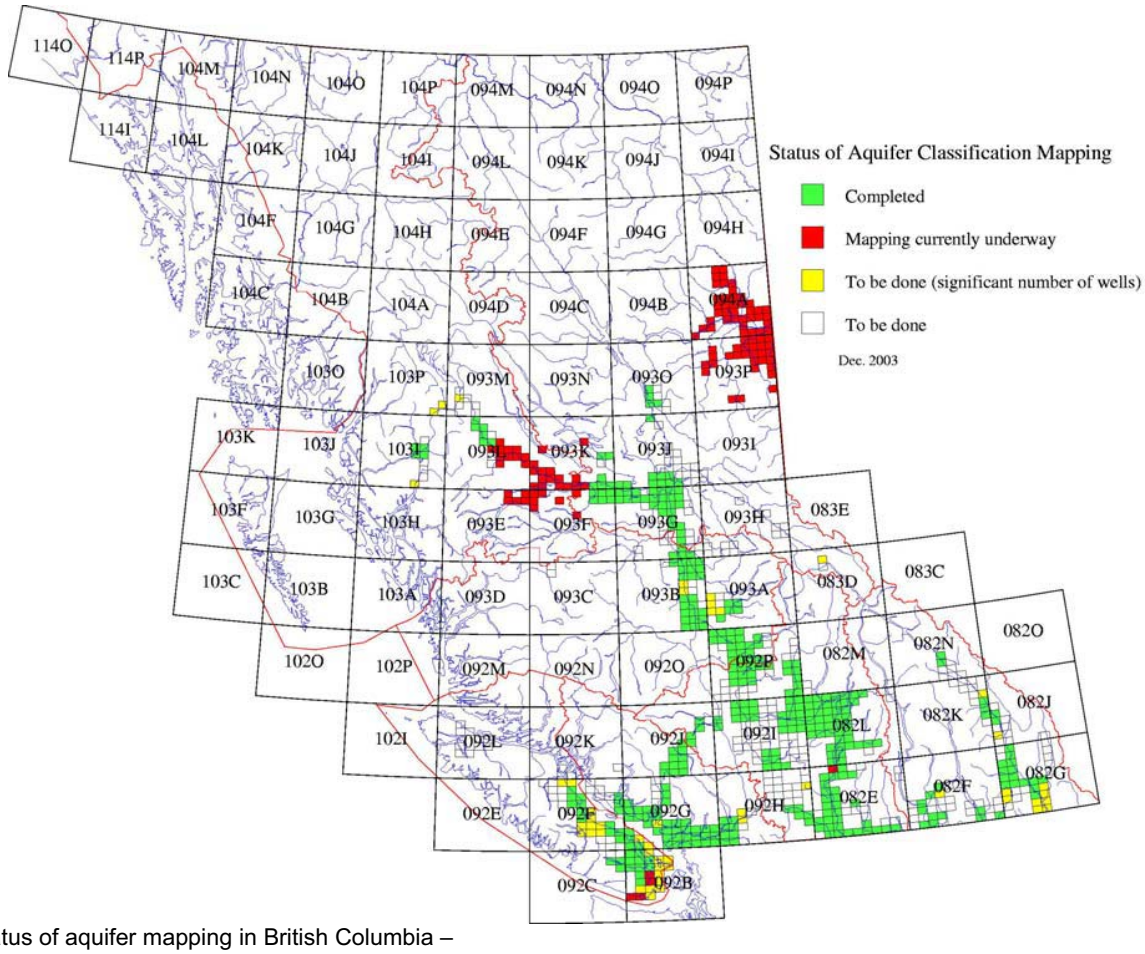

Figure 8. Status of aquifer mapping in British Columbia – as of December 2003

Some local governments have considered designating aquifer areas as Development Permit Areas to ensure hydrogeologic impact assessments are done prior to approval for building. Local health officers use the aquifer classification maps and information to provide a “red flag” when higher risk activities may threaten drinking water supplies in vulnerable aquifers. Another potential use is to identify community drinking water systems utilizing highly vulnerable aquifers for drinking water source assessments. Communities throughout BC now have an information source that allows them to see where their aquifers are and to help identify potential community concerns about groundwater.

6 CONCLUSION AND FUTURE DIRECTIONS

Since the implementation of the classification system, there have been both expected and unexpected results. The demand for the information was far greater than expected. It was accessed by a myriad of other user groups beyond the target group of hydrogeologists, planners and water managers. A guidance document was produced to encourage correct use of the maps and information and to identify the limitations of the mapping. The advances in web based mapping greatly expanded both its use and the demand for the product. The phrase “Build and they will come!” definitely applies to providing groundwater information in a format useful to the user.

Despite its limitations and simplicity, the information the maps provide will both benefit and support groundwater management and assessment. Knowing where the aquifers are, understanding their physical nature, the demands placed on them and their vulnerability to contamination is central to sensible sustainable development. By far the easiest and most cost-effective groundwater protection actions are preventative in nature. The Aquifer Classification System and maps begin to provide this information and offer planners, resource managers and stakeholders information on aquifers for consideration for their decision making.

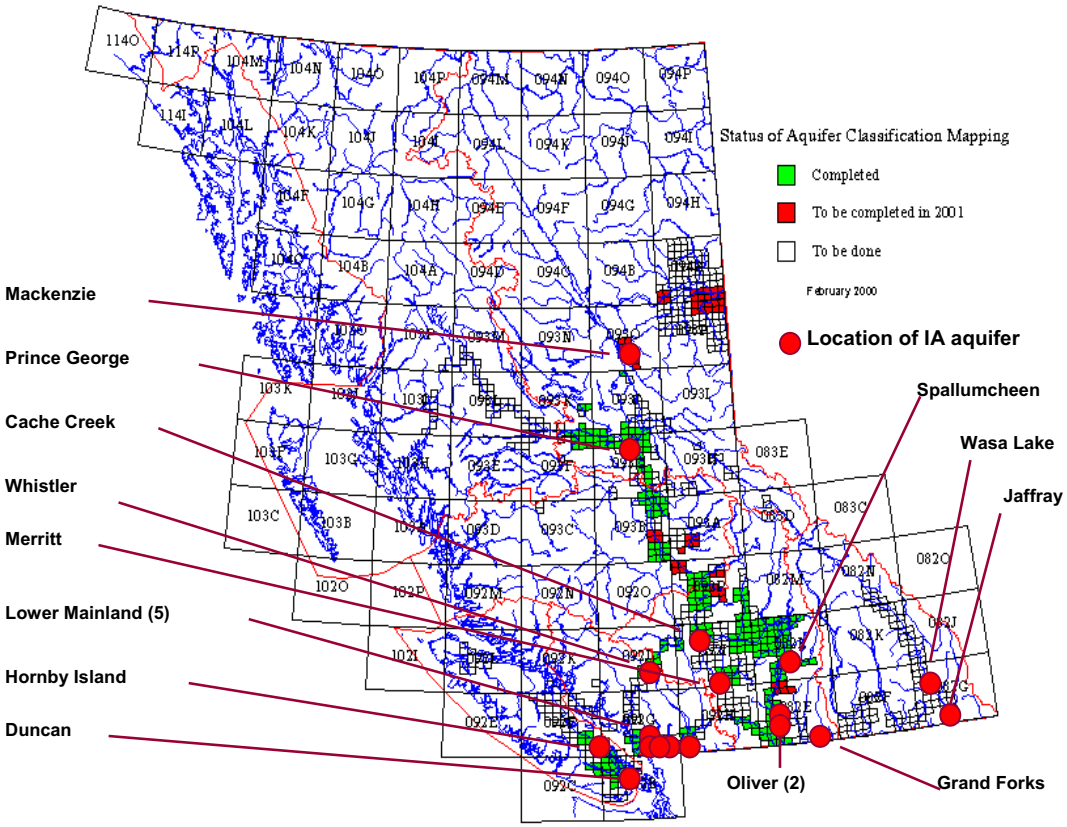

Figure 9. Location of IA aquifers in BC

The Ministry is expected to continue to support aquifer classification mapping over the next few years. On a priority basis, future mapping areas will take place in the areas of the greatest groundwater development and where the Province can partner with local governments. Since new information and new data continue to become available, a protocol is being developed to efficiently update existing aquifer boundaries and classifications as required and to map the new areas as future groundwater development takes place.

As a result of the aquifer classification mapping program, more detailed aquifer characterization mapping is starting to take place in the higher priority aquifers. The aquifer at Grand Forks was the first area to undergo more detailed aquifer characterization (Wei et al. 2004) and the Province has recently entered into a partnership with the Geological Survey of Canada to start assessing and characterizing some of the 60 plus aquifers found within the Okanagan Basin in south central BC. The aquifer classification mapping program and the more detailed aquifer characterization mapping have already proven to be effective tools in changing raw hydrogeological data into useable information suitable for the effective management and protection of the groundwater resources of BC.

7 ACKNOWLEDGEMENTS

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