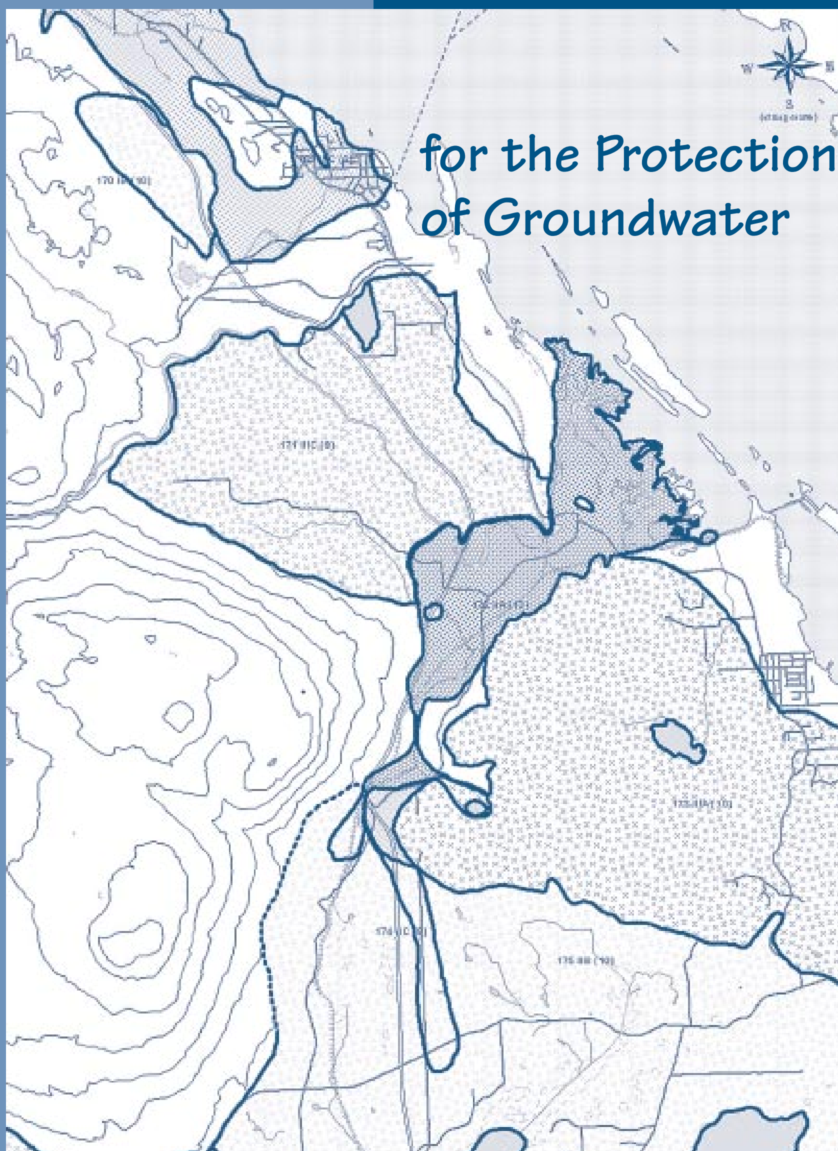
Guide to Using the BC Aquifer Classification Maps for the Protection and Management of Groundwater



Ministry of
Water, Land and
Air Protection

BRITISH COLUMBIA

GUIDE TO USING THE BC AQUIFER CLASSIFICATION MAPS

FOR THE PROTECTION AND MANAGEMENT OF GROUNDWATER

BY:
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SUMMARY

This guide is designed to assist readers in interpreting and using the aquifer classification maps produced by the B.C. Ministry of Water, Land and Air Protection. The maps are products of the BC Aquifer Classification System developed in 1994 to support groundwater management and assessment. This guide explains the aquifer classification system and discusses the assumptions underlying its design, the interpretation of the information presented and the appropriate use of the accompanying maps.

A wide range of individuals will find the guide useful: planners, resource managers, government representatives, geoscience professionals, community groups, those working in industries such as agriculture and resource extraction, and the public. The information is intended to show how the aquifer classification maps can be used to help address particular community concerns about groundwater. By making groundwater information more accessible, the Ministry hopes to demystify some of the more complex aspects of the resource and to raise groundwater awareness generally throughout the province. The guide has five main sections:

The first section provides background information on groundwater resources in British Columbia, and discusses important groundwater management issues in the province. The development and purpose of the BC Aquifer Classification System are explained and key groundwater concepts and definitions, as they relate to the aquifer classification maps, are included.

The second section presents a detailed description of the BC Aquifer Classification System. It is intended to clarify the content, sources and limitations of the data compiled to classify aquifers.

The third section provides a guide to interpreting and finding information on the maps. It includes the sources of information and the methodology used to characterize or map the aquifers and to define and delineate aquifer boundaries.

The fourth section explains how the aquifer classification maps are intended to be used, and then describes some specific uses and possible interpretations of the information contained in the maps. Real-life examples of how the maps have been applied are also presented.

The fifth section presents a sample groundwater management scenario to show how aquifer classification maps help resolve a land use issue. This exercise highlights some of the benefits and limitations in applying aquifer classification maps to planning purposes.

Appendices A and B provide a glossary of groundwater related terms and definitions, and then describes how to access the Groundwater Section web site and databases.

Though the limitations of the maps are often discussed throughout the report to promote appropriate use, the limitations are the exception rather than the rule. The information contained within the maps; will both benefit and support groundwater management and assessment.

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WHAT IS GROUNDWATER? Groundwater is water that occurs in the ground.

WHAT IS AN AQUIFER? Aquifers are saturated geologic units that are permeable and yield water in a usable quantity to a well, spring or stream.

WHO WILL FIND THE AQUIFER CLASSIFICATION MAPS OF USE? People working in (1) regional and local land use planning; (2) water management; (3) property management; (4) environmental health protection; (5) resource extraction; (6) community development; (7) community stewardship; (8) geoscience and well-drilling industry

This guide compliments the aquifer classification maps produced by the B.C. Ministry of Water, Land and Air Protection for use in regional groundwater planning and management. It explains the components of the Aquifer Classification System, outlines the assumptions underlying the map information presented, summarizes the content of an aquifer classification map and describes an example situation in which the maps may be used. The goal is to help map users understand the strengths and limitations of the information contained on the aquifer classification maps so that they can apply that information appropriately to their particular water and land management needs.

The system and maps are designed to be used together and in conjunction with other available information as a screening tool for setting groundwater management priorities. They provide a way of comparing aquifers within a consistent hydrogeological context and prioritizing future actions at various planning levels.

The maps may provide some background information for site-specific projects. However, the maps are not to be used for making site-specific decisions. The classification of an aquifer reflects the aquifer as a whole and at a specific time. Groundwater conditions, such as the degree of vulnerability and water quality, can vary locally and over time respectively. The quality and availability of data used to delineate and classify aquifers varies across the province. This variability in the data sometimes requires subjective decision-making and generalising of information for an entire aquifer.

GROUNDWATER USE AND IMPORTANCE IN BRITISH COLUMBIA

Today more than 750,000 people in British Columbia rely on groundwater. Total use in 1985 was an estimated 630 million litres per day (Association of Professional Engineers of British Columbia, 1985). This accounts for approximately 25% of all groundwater extracted in Canada. Excluding the water supplies of Greater Victoria and Vancouver areas, approximately 25% of the total municipal water demand in the province is supplied by groundwater (BC Environment, 1994).

Groundwater is used to meet the needs of community and domestic water supplies, and for industrial and agricultural purposes. In general, industry uses 55% of the groundwater extracted in the province, the agricultural sector 20%, and municipalities 18%. Rural domestic use makes up the remaining 7% (Hess, 1986). Examples of activities using groundwater include irrigation, livestock watering, pulp and paper processing, fish hatchery production, food processing, mining, chemical and petroleum processing, and park and airport operations.

For many users, groundwater is the only source of water readily available. Except in major metropolitan areas of the province, groundwater use is expected to continue to grow, given that subsurface supplies are often better quality, more accessible and less expensive to develop than surface water. Groundwater's subsurface location offers a degree of natural protection from contamination and storage for future water use. As water demand grows, groundwater will be sought in greater quantity.

No less significant is the role that groundwater plays in maintaining base flows in rivers and streams, which in turn are critical for maintaining fish and wildlife habitat, spawning areas, wetlands and water supplies for aquaculture. Protecting the quality and quantity of groundwater resources is therefore of great public importance.

KEY GROUNDWATER MANAGEMENT ISSUES IN BRITISH COLUMBIA

While groundwater is a valuable water resource in the province, it is hidden from view, and historically had a lower profile than surface water. Being "out of sight, out of mind", coupled with the physical constraints of being underground has long made the resource difficult to manage. Now, however, groundwater-related issues are increasingly becoming a concern for many individuals, organizations and governments. The issues are primarily categorized as groundwater quality and groundwater supply. Key aspects of these issues are discussed below.

Groundwater quality

Incidents of groundwater contamination resulting mainly from fertilizers, septic systems, gasoline stations, waste disposal, mining, industrial processing, and product storage and transportation activities have been recorded across the province (BC Environment, 1994). These incidents, as well as some cases of salt water intrusion, are drawing increasing attention to monitor and protect groundwater (Office of the Auditor General of British Columbia, 1999; BC Environment, 1994; and Canadian Geoscience Council, 1993). This is particularly so in areas without alternative surface water sources.

The need for measures that prevent contamination is especially acute, because the water's underground location and rate of flow mean that contamination can occur and go undetected for a long time. Even if detected, it is difficult and very costly to contain and remove contaminants from an aquifer. As water can be underground for a long time, a contaminated resource is often unavailable for many years – sometimes 1000's of years. Many aquifers in British Columbia occur in sand and gravel formations, exposed at the ground surface and are highly susceptible to contamination from human activities.

Some groundwater quality issues that governments and other organisations in BC are currently trying to address include:

- where to monitor groundwater quality;
- how to protect or improve groundwater quality;
- what land use decisions (such as zoning, population growth or siting of storage and waste facilities) could help protect water quality;
- what codes of practice (such as best management practices for agriculture) could be used to prevent contamination;
- where codes of practices should be applied; and
- which aquifers are more susceptible to contamination than others.

Groundwater supply

The two main groundwater supply issues in the province are (1) well interference between water users and (2) a decreasing groundwater availability, which can also affect base flows in streams. If groundwater withdrawal is greater than its replenishment, then water supplies will be reduced. Reduction of stream base flows can not only draw down licensed water supplies, but also harm fish and wildlife habitat. Evidence of groundwater withdrawal being greater than replenishment has been documented in the Fraser Valley (Gallo, 1996), near Cache Creek (BC Environment, 1994) and along coastal areas in the Gulf Islands (Hodge, 1995 and BC Environment, 1994).

Some of the main groundwater quantity issues being addressed by those involved in water management include:

- identification and study of aquifers to guide future groundwater development;
- identification of streams susceptible to reduced base flows as a result of heavy groundwater use;
- what measures could be adopted to maintain a sustainable supply of groundwater; and
- in areas of surface water conflicts, what groundwater supply alternatives are available.

MINISTRY RESPONSE TO KEY GROUND-WATER ISSUES

To help address the issues of groundwater quality and supply, the Ministry of Water, Land and Air Protection developed the Aquifer Classification System to present groundwater information in a format easily understood and accessible by planners, resource managers and the public (Kreye and Wei, 1994). Historically, groundwater information collected by the Province has mainly 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 to be interpreted and synthesized into more usable and accessible information.

This need for interpreted groundwater information was proposed in a number of reports. The Ministry's discussion paper, *Stewardship of the Water of British Columbia* (BC Environment, 1993) listed a number of proposals to achieve sustained and healthy groundwater use. One proposal suggested enhancing groundwater inventory and data collection and developing a program for classifying and mapping aquifers in the province. The Ministry's report *Water Management Planning*, identified aquifer maps and information on aquifers as being necessary to support planning (B.C. Ministry of Environment, Lands and Parks 1995). A significant response to these reports are the Aquifer Classification System and maps that have been designed to supply a more systematic mapping and assessment of aquifers across the province.

As recently as March 1999, the Auditor General of British Columbia released a report entitled *Protecting Drinking-Water Sources*. In its overview of recommendations, the Auditor General called for *"building an information base for better management of groundwater, through more extensive mapping of aquifers and monitoring of groundwater quality and quantity"*. They stated in their report that *"this work would be valuable"*.

Clearly, the aquifer classification mapping program is a large step in the right direction.

DEVELOPMENT AND PURPOSE OF THE BC AQUIFER CLASSIFICATION SYSTEM

A primary objective of groundwater management is to ensure a sustained potable water supply. To achieve that objective, the Ministry determined that a tool was required to assist resource managers in establishing, for each aquifer, its use and vulnerability to contamination, and an indication of the importance or priority to manage and protect an aquifer. The resulting tool – the BC Aquifer Classification System – systematically identifies and groups aquifers with similar attributes into categories that provide the resource manager with the use and vulnerability information to support their protection and management initiatives.

Development of the classification system began with a literature review to identify classification and mapping systems used by other jurisdictions. The results of this review revealed that no other jurisdiction in Canada was using groundwater classification on a regional or provincial scale. Some classification methods were being applied elsewhere to meet specific objectives or on a site-specific basis but none of these were appropriate to the existing groundwater data and management objectives in British Columbia. In response, a methodology tailored to the existing data here was developed and applied to the Fraser Valley in a pilot study.[1]

The main objectives of the aquifer classification system are to:

- provide a framework to direct detailed aquifer mapping and assessment;
- provide a method of screening and prioritizing management, protection and remedial efforts on a provincial, regional and local level;
- identify the level of management and protection an aquifer requires;
- build an inventory of the aquifers in the province; and
- increase public knowledge and understanding of the groundwater resource.

It is important to note that the system is **not** intended to replace more detailed aquifer assessment required to manage the resource.

[1] An extensive discussion of the initial Aquifer Classification System can be found in Kreye and Wei (1994).

The aquifers have been mapped on 1:20,000 and 1:50,000 scale maps. To date, with both federal, provincial, and local government funding, over 375 aquifers have been delineated, mapped and classified in the Fraser River Basin, the east coast of Vancouver Island and the Shuswap-Okanagan area. Mapping of the remaining areas will be carried out as funding is available. The index map in Figure 1 indicates which areas have been mapped as of June 2002.

The aquifers delineated are those that have a history of use. Potential aquifers not currently in use are not included in the inventory. **Therefore, areas where aquifers are not defined should not be interpreted as lacking groundwater resources.** Untapped groundwater supplies exist in varying amounts throughout British Columbia. New aquifers will be mapped as they are developed.

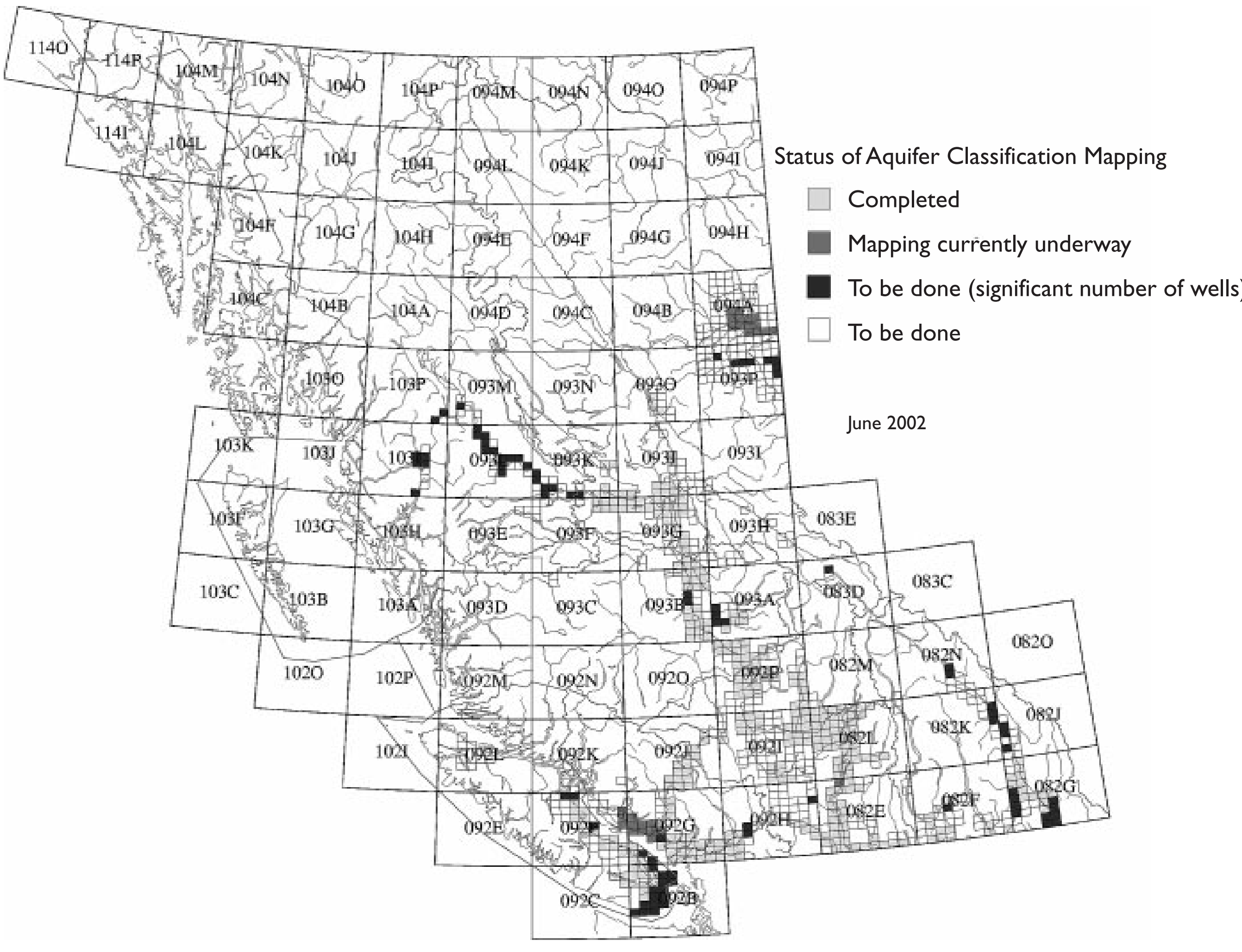


FIGURE 1. Aquifer classification map index (current to June 2002)

THE FUNDAMENTALS OF GROUNDWATER

This section presents some key definitions and basic concepts of groundwater. It is intended for people who do not work with groundwater resources on a regular basis or have any background in hydrogeology.

What is groundwater?

Groundwater is water that occurs in the ground. Groundwater flows in the subsurface part of the land-based portion of the hydrologic cycle (Figure 2). The Hydrologic Cycle describes a continuous circulation of water between the ocean, atmosphere and land. A portion of the water, falling as precipitation, evaporates directly from the land surface back into the atmosphere. Some water reaching the land flows overland into channels and then streams, ultimately discharging into the ocean. Some water infiltrates into the ground and travels as groundwater, either discharging directly into the ocean or back to the land surface into lakes and streams.

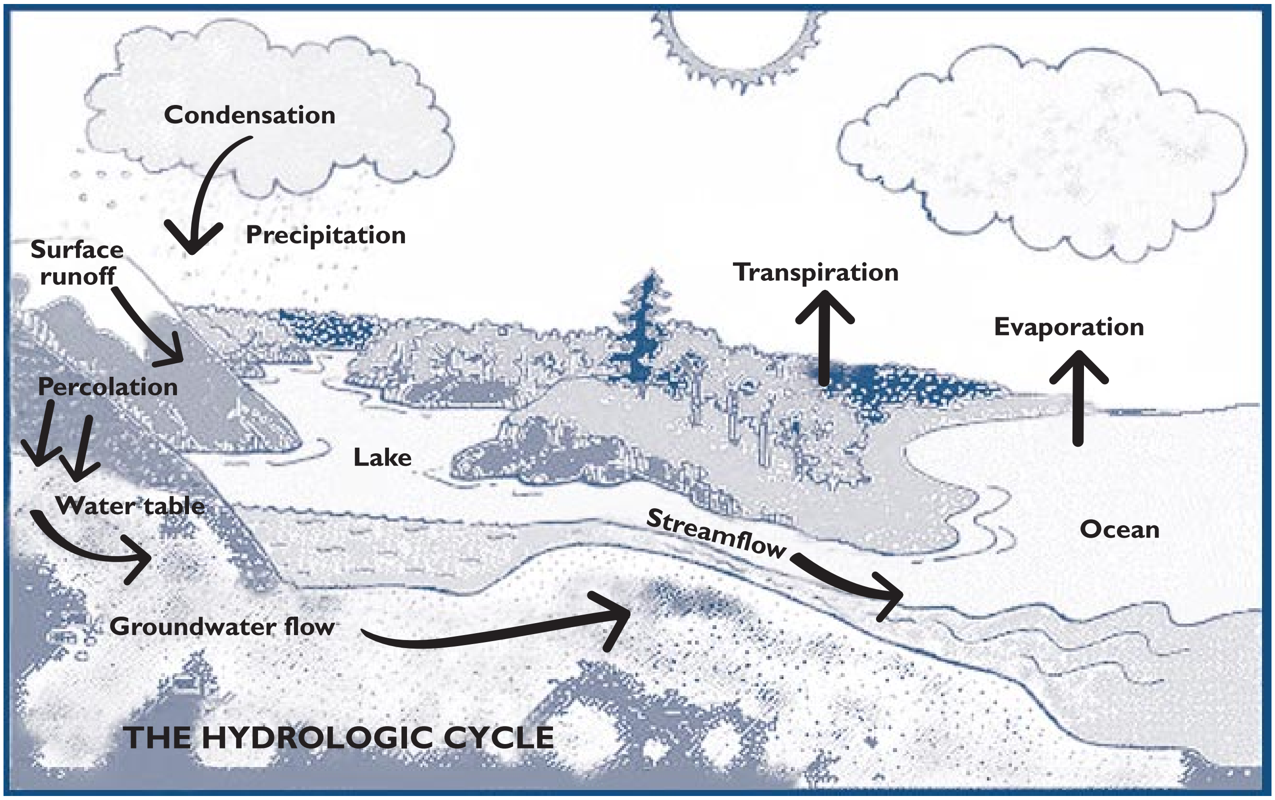


FIGURE 2. *Groundwater and the hydrologic cycle (after Environment Canada, 1990)*

What is an aquifer?

Aquifers are saturated geologic units that are permeable (how easy the geologic unit transmits water) and yield water in a usable quantity to a well, spring or stream (Figure 3). There are different types of aquifers, depending on the geologic materials in which they occur. The Aquifer Classification System refers to unconsolidated aquifers (e.g., those comprised of sand and gravel) and consolidated – or bedrock – aquifers (e.g., those comprised of fractured granite).

Aquitards are less permeable geologic units than aquifers, usually comprised of silt, clay, shale, or dense crystalline rocks (Figure 3). They may be permeable enough to transmit significant quantities of water on a regional scale, but they are incapable of yielding a viable water supply to a production well.

Why is aquifer confinement important?

Aquifers are also described by their degree of confinement (i.e., whether or not they are capped by an aquitard above). Naturally occurring confinement varies in thickness regionally across an individual aquifer or between aquifers. The degree of confinement is a factor used to assess an aquifer's vulnerability to contaminants introduced at the land surface (Figure 3).

Unconfined or **water table aquifers** are those with no overlying confining layer. In general, unconfined aquifers are more vulnerable to contamination than confined or partially confined aquifers.

Confined aquifers are those overlain by a confining layer. The confining layer, which offers a protective "shield" from contamination from the land surface, is typically composed of clay, silt and/or till. As a result, confined aquifers tend to be less vulnerable to contamination than unconfined aquifers.

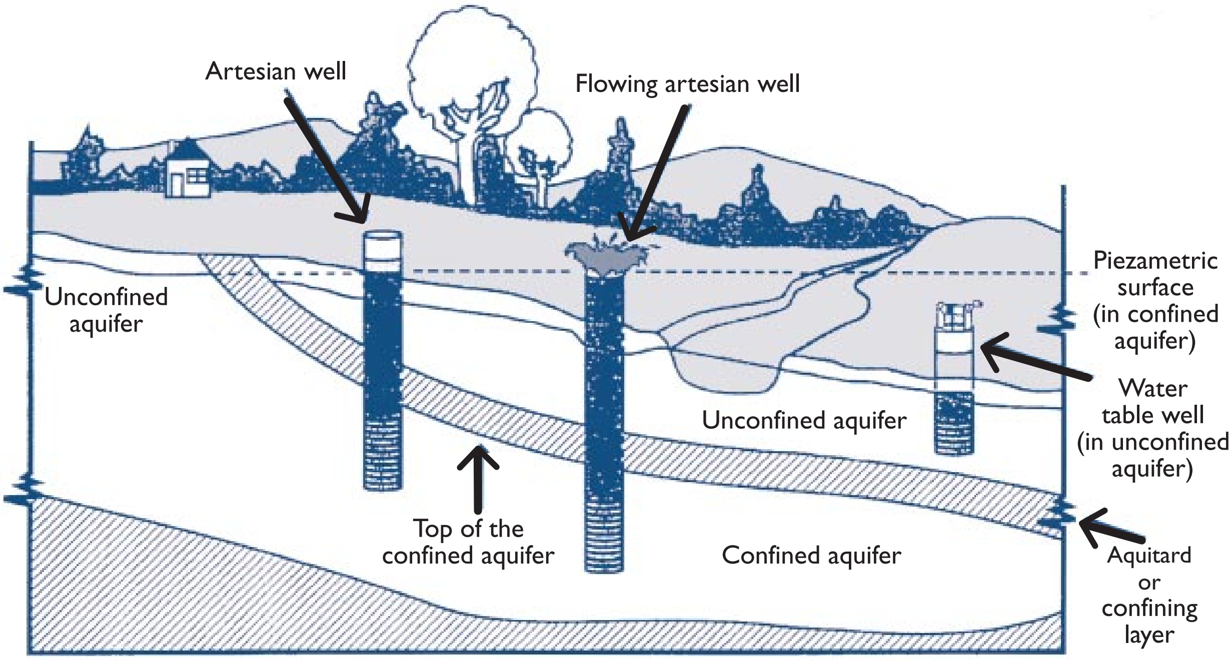


FIGURE 3. Confined and unconfined aquifers and wells (after Environment Canada, 1990)

Partially confined aquifers may be confined over parts of their area and unconfined over others. The unconfined parts are "windows" through which contaminants can reach the aquifer. Partially confined aquifers may also be confined by semi-pervious sediments that do not completely shield the aquifer from contamination from the land surface. In the Aquifer Classification System, confinement is assessed on an aquifer-wide basis. The more detailed information that shows the variation in vulnerability over an aquifer does not appear on the map.

Artesian wells occur when the water level is above the top of the aquifer (i.e., the bottom of the confining layer). If the water level is above the ground surface, water will flow from the well without the aid of pumping. This is referred to as a flowing artesian well.

All geologic materials that underlie the earth's surface can be classified as either consolidated or unconsolidated.

Unconsolidated materials (sediment) are made up of loose granular particles that formed from disintegration of bedrock and then deposited by water, air, gravity or ice. The important unconsolidated materials found in British Columbia include clay, silt, sand and gravel and till. By far the largest amount of groundwater used in British Columbia comes from unconsolidated sediments (mainly sand and/or gravel) that receive water from precipitation or nearby surface watercourses.

Consolidated materials (or **bedrock**) consist of minerals or particles of different sizes and shapes welded together by chemical reactions induced by heat and pressure. The various rock types underlying British Columbia include sedimentary (particles welded together under low temperature and pressure), igneous (cooled from molten materials) and metamorphic rocks (particles welded together under high temperature and pressure). A bedrock aquifer may include different rock types or be confined to a localized zone within a single geologic formation. It follows then, that water wells can be constructed in a single rock type or in several different rock types where the geology is more complex.

The "productivity" of different bedrock aquifers is generally determined by their fracture porosity and permeability. In British Columbia, productivity depends primarily on the existence of a water-bearing fracture zone. The majority of bedrock aquifers in British Columbia are found in shale, sandstone, limestone, basalt and granite rocks. The most productive of these are found in the basalt and granite rocks. Major supplies are also found in highly fractured zones in other rock types.

THE BC AQUIFER CLASSIFICATION SYSTEM

This section presents a detailed description of the BC Aquifer Classification System, as well as the methodologies employed in classifying aquifers and discussions on some of the limitations of the data. This should help the reader to better understand the criteria used to identify, delineate and classify an aquifer. The classification system has two main components:

a) 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 that water) of the groundwater resources and groundwater vulnerability to contamination;

b) a **ranking value component** which assigns a number value to indicate the relative importance of an aquifer. This value helps prioritize aquifers for groundwater protection and management.

The classification and ranking value components are determined for the aquifer as a whole, and not for parts of aquifers. As each aquifer is classified it is added to the Province's aquifer inventory.

Data used for aquifer classification come from various sources, including existing studies, technical reports, water quality information and well logs 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.

The BC Aquifer Classification System is shown schematically in Figure 4.

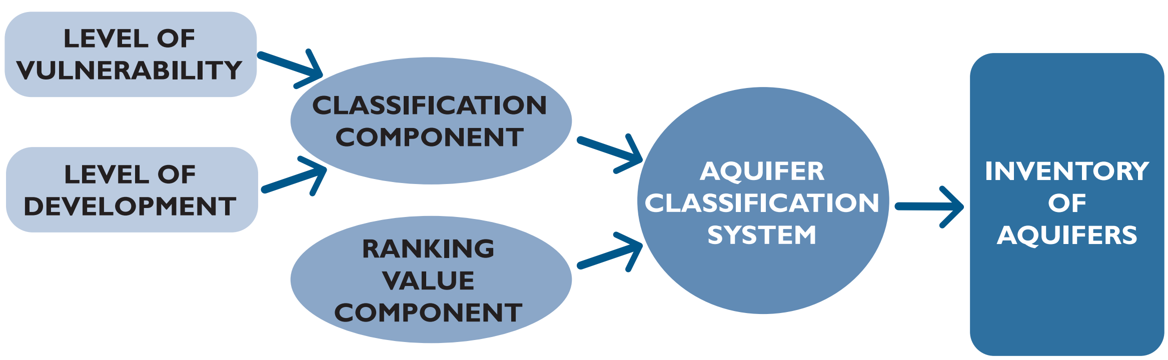


FIGURE 4. The BC Aquifer Classification System

The following sections explain in detail the two components (classification and ranking value) of the aquifer classification system. The classification component is composed of two categories – the level of development and the level of vulnerability. Assigned ranking values are derived from seven criteria: aquifer productivity, aquifer vulnerability to surface contamination, aquifer area, demand on the resource, type of groundwater use, and known documented groundwater concerns related to quality and to quantity. The criteria: demand, productivity and vulnerability, are found in both the classification and ranking components. The other four criteria in the ranking component let the resource manager prioritize between two aquifers with the same classification; but often with different ranking values.

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 Table 1 below.

INCREASING LEVEL OF DEVELOPMENT

HIGH

INCREASING VULNERABILITY

	I Heavy	II Moderate	III Light
A High	**IA:** heavily developed, high vulnerability aquifer	**IIA:** moderately developed, high vulnerability aquifer	**IIIA:** lightly developed, high vulnerability aquifer
B Moderate	**IB:** heavily developed, moderate vulnerability aquifer	**IIB:** moderately developed, moderate vulnerability aquifer	**IIIB:** lightly developed, moderate vulnerability aquifer
C Low	**IC:** heavily developed, low vulnerability aquifer	**IIC:** moderately developed, low vulnerability aquifer	**IIIC:** lightly developed, low vulnerability aquifer

LOW

NOTE: ◄· · · · · · · · · · · · · · · = implied priority

TABLE 1. Aquifer classes

- The nine aquifer classes have an implied priority from a management and protection standpoint, from IA, which is the highest priority, to IIIC, which is the lowest.

- Prioritizing the aquifer classes also depends on the management objective. For example, if assurance of a sustainable water supply were the only issue, then all highly developed I aquifers (i.e., IA, IB, IC) might have higher priority than lower developed III aquifers (i.e., IIIA, IIIB, IIIC). If protection of groundwater quality were the only issue, then all highly vulnerable A aquifers (i.e., IA, IIA, IIIA) might have higher priority than lower vulnerability C aquifers (i.e., IC, IIC, IIIC).

Level of development

The level of development, a relative and subjective term, compares the amount of groundwater withdrawn from an aquifer (demand) to the aquifer's inferred ability to supply groundwater for use (productivity).

- Given the same demand, the level of development of an aquifer of low productivity would be considered higher than an aquifer of higher productivity.

- Three levels of development are designated: heavy I; moderate II; or light, III.

How is level of development assessed?

Ideally, if a water balance (i.e., the balance between the inflow of water from precipitation and snowmelt, and the outflow of water by evapotranspiration, groundwater discharge, water use, and stream flow) has been calculated, then a quantitative estimate of the level of groundwater development can be obtained. Presently, however, water balance is seldom available.

The second option is to determine levels of development subjectively by assessing well density, water use and aquifer productivity (determined from well yield and specific capacity), and sources of recharge. This is the general methodology used to determine levels of development.

Table 2 shows how the demand and productivity factors are combined to determine the development rating. For example, if an aquifer has high productivity but low demand on it, the level of development would be light (III). If an aquifer has both high productivity and high demand, the level of development would be heavy (I) or moderate (II) (depending on the absolute productivity and demand). Where there are two numbers, the decision to select one development rating over another will depend on information available to the mapper. The bold numbers are more conservative assessments of development.

DEMAND	Productivity: Low	Productivity: Moderate	Productivity: High
High	**I**	**I** or II	**I** or II
Moderate	**I** or II	**II**	**II** or III
Low	**II**	**II** or III	**III**

TABLE 2. Assigning level of development (I, II, III) from demand and productivity

How are the different levels of development interpreted?

As stated above, the level of development compares the amount of groundwater withdrawn (demand) from an aquifer to the aquifer's inferred ability to supply groundwater (productivity) for use. 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. Table 3 summarizes the level of attention that should be considered for different levels of development.

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. Three vulnerability categories are used: high, moderate or low. High is assigned the symbol A; moderate, B; and low, C.

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

Level of Development	Interpretation
Heavy I	• Demand for water is high relative to water availability. • Additional development* of this aquifer should be carefully assessed.
Moderate II	• Demand is moderate relative to water availability. • Additional development* of this aquifer should be given careful consideration.
Light III	• Demand is light relative to water availability. • Additional development* should not be a problem, provided productivity can meet the demand.
*Additional development for any level depends on the degree of the demand and the productivity of the aquifer in question. For example, a single domestic well would have far less impact than a municipal production well. And an extensive bedrock aquifer that is only lightly developed (with a few domestic wells constructed in it) may be able to support many more domestic wells, but not a large, high output well for agricultural purposes.	

TABLE 3. Interpretation of the levels of development

- Assessment of vulnerability is not an assessment of the risk of contamination. For example, one aquifer in the city and the other in a pristine area in the country may be of equal vulnerability, but the one in the city is likely at higher risk of contamination.

Given the variety of factors, that govern vulnerability, the variability of vulnerability that may exist within an individual aquifer, and the possible lack of data, professional judgement is often important for a reasonable assessment of vulnerability for an entire aquifer to be made.

How are levels of vulnerability assessed and interpreted?

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.

- The shallower the aquifer and the water table, the higher the vulnerability.

- If there are low-permeability confining layers above an aquifer then the aquifer is considered less vulnerable to contamination.

- Porosity is an important criterion in assessing the vulnerability for bedrock aquifers. Fracture porosity in bedrock aquifers is generally much lower than inter-granular porosity in unconsolidated sand and gravel aquifers. This results in the faster movement of water in the bedrock, everything else being equal, which may increase the vulnerability of the bedrock aquifer.

Table 4 shows how different levels of vulnerability are interpreted.

Vulnerability	Interpretation
High **A**	• Highly vulnerable to contamination from surface sources, **A** aquifers have little natural protection against contamination introduced at the ground surface. • Existing land uses or future additional developments, which may introduce a contaminant to the land surface, should initiate measures to protect against introducing contaminants. • **A** aquifers should be given first priority for the implementation of quality protection measures.
Moderate **B**	• Moderately vulnerable to contamination from surface sources, **B** aquifers have limited natural protection against contamination introduced at the ground surface. Degree of natural protection may vary across an aquifer. • Existing land uses or future additional developments, that could introduce a contaminant to the land surface, should initiate measures to protect against introducing contaminants. • **B** aquifers should be given priority over **C** aquifers when it comes to implementing quality protection measures.
Low **C**	• Generally not considered very vulnerable to contamination from surface sources, **C** aquifers are more protected against contamination introduced at the ground surface. • **C** aquifers have the lowest vulnerability rating and are the least likely to become contaminated. • A rating of **C** does not imply that all **C** aquifers are immune to contamination. All aquifers are vulnerable to contamination to a certain degree, especially if there are "windows" exposing the underlying aquifer or if the land-use activity breaks through the overlying confining layer.

TABLE 4. Interpretation of the different levels of vulnerability

RANKING VALUE COMPONENT

The classification component provides information on the two main criteria affecting groundwater management: level of development and water quality protection. It does not, however, consider other criteria such as type of water use, aquifer size, existing concerns, etc. that are also important in prioritizing management of these aquifers.

The aquifer ranking value component reflects these other criteria in addition to degree of water use and vulnerability. The aquifer ranking value assigned is based on physical aspects of the aquifer (productivity, vulnerability, and aquifer area), the amount and type of water demands on the aquifer, and documented groundwater water quality and quantity concerns. The point value is determined by summing each criterion (Table 5), with the lowest ranking value possible being 5; the highest-ranking value possible is 21. Generally, the greater the ranking value, the greater the priority. A review of the individual points assigned to the ranking value reveals qualitative information of which specific criteria make the aquifer priority higher (e.g., its vulnerability, or the existence of water quality concerns).

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. The IA designation will not identify these differences. The ranking value for the larger IA aquifer with problems would show a higher ranking value because of these issues.

Hydrogeological and water use criteria

Seven hydrogeological and water use criteria are used to determine an aquifer's ranking value:

1. the productivity of an aquifer;
2. the vulnerability of an aquifer to surface contamination;
3. aquifer size (in area);
4. demand for water;
5. type of water use;
6. known or documented water quality concerns (i.e., based on risk to people's health); and
7. known or documented water quantity concerns.

These criteria represent, from the Ministry's point of view, the most pertinent technical factors on which to base aquifer priority. Criteria 1, 2 and 3 are based on physical aquifer characteristics, criteria 4 and 5 refer to water use, and criteria 6 and 7 relate to groundwater concerns.

Table 5 shows the ranking values applied for each criterion.

	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 km^2	5–25 km^2	> 25 km^2	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

TABLE 5. Aquifer ranking values

* N/A = not applicable

How are aquifer ranking values interpreted?

All hydrological and water use criteria are equal weight. Each is assigned a point value that ranges from 1 to 3 according to the magnitude of concern or importance. The exception is quality and quantity concerns, where the point values range from 0 to 3. A zero (0) is assigned if no known or documented concerns exist. Once the individual values have been assigned, all are summed to obtain an overall ranking for the aquifer.

PRODUCTIVITY

Productivity describes the rate of groundwater flow from wells and springs and the abundance of groundwater in an aquifer. Indicators of productivity (e.g., reported well yields, specific capacity of wells, and transmissivity of the aquifer) are used to infer potential water availability of the aquifer.

How is productivity assessed and the ranking values assigned for the different indicators of productivity?

To assess aquifer productivity, the types of existing wells (e.g., irrigation, municipal wells) and probable sources of recharge (e.g., rivers and lakes) are considered and the following indicators observed:

- well yields;
- nature of the aquifer materials;
- specific capacity where available; and
- transmissivity where available.

As Table 6 shows, higher ranking point values are given to higher productivity aquifers.

	Value		
Indicators of Productivity	1	2	3
Nature of Aquifer Materials	silt and fine sand; fractured bedrock	sand (medium)	sand and gravel; coarse sand; gravel
Well Yield	<0.3 L/s (<5 gpm)	0.3 – 3.0 L/s (5 – 50 gpm)	>3.0 L/s (>50 gpm)
Specific Capacity	<0.4 L/s/m (<2 gpm/ft)	0.4 – 4.0 L/s/m (2 – 20 gpm/ft)	>4.0 L/s/m (>20 gpm/ft)
Transmissivity	<0.0005 m^2s (<3,500 gpd/ft)	0.0005 – 0.005 m^2s (3,500 – 35,000 gpd/ft)	>0.005 m^2s (>35,000 gpd/ft)

L/s/m = litres per second per metre; gpm = gallons per minute; gpm/ft = gallons per minute per foot
gpd = gallons per day; gpd/ft = gallons per day per foot; m^2s = metres squared per second

TABLE 6. Productivity ranking values

VULNERABILITY

Vulnerability is the potential for an aquifer to be degraded. The higher the aquifer vulnerability, the greater the potential for degradation and the higher the priority for directing protection and management efforts to that aquifer.

How are the different levels of vulnerability defined?

Vulnerability is subjectively determined according to the following criteria:

- nature, thickness and extent of geologic materials overlying the aquifer;
- depth to the water in an unconfined aquifer (or top of confined aquifers); and
- porosity.

Table 7 further defines these criteria.

Depth to the water table (the shallower the water table, the more vulnerable the aquifer):	Vulnerability Level
Shallow 0 – 15 m	**A**
Moderately shallow 15 – 30 m	**A** or **B***
Moderately deep 30 – 60 m	**B**
Deep > 60 m	**B** or **C***
Permeability (ability of materials to transmit water) of geologic sediments found above the aquifer (the more permeable the geologic sediments, the more vulnerable the aquifer):	**Vulnerability Level**
High permeability sediments: sand and gravel	**A**
Medium permeability sediments: very fine sand, sandy loam, sand and gravel mixed with silt and clay If medium permeability sediments are thin (e.g., < 5 m) vulnerability may be classified as **A**	**B** or **A***
Low permeability sediments: silt, clay, till, shale	**C** or **B***
Thickness and extent of confining sediments (the less areally extensive and the thinner the confining sediments are, the greater the vulnerability):	**Vulnerability Level**
Low degree of confinement: an unconfined aquifer	**A**
Medium degree of confinement: confined by "leaky" sediments; that is, the permeability of the confining layer is 10 times or less than that of the aquifer (e.g., coarse sand versus silty fine sand) or there are "windows" of highly permeable sediments in the confining layer	**B** or **A***
High degree of confinement: confined by thick, areally extensive, low permeability sediments; that is, the permeability of the confining layer is more than 100 times less than that of the aquifer (e.g., sand versus clayey till)	**C**
Porosity of the aquifer (the amount of void spaces relative to the solid material):	**Vulnerability Level**
This is relevant where the aquifer is bedrock and there are no overlying confining sediments protecting it. Porosity of fractured rock is normally very low (less than a few percent). Consequently, water (and any accompanying contaminants) will move relatively quickly through it.	**A** or **B***

* Assigning a specific vulnerability designation can be complex because vulnerability often depends on more than one physical characteristic. These physical characteristics need to be considered together when assigning a designation. For example, a deep (>60m) water table may not always mean an aquifer's vulnerability is low because vulnerability would also depend on the permeability of the overlying sediments. If the overlying sediments are comprised of permeable sand, the vulnerability may be moderate even if the water table is deep.

TABLE 7. Data used to assess vulnerability

Table 8 is an example of the questions a mapper would ask and the decision-making process they would go through when determining the vulnerability and ranking value of a sand and gravel aquifer.

<table>
<tr><th></th><th colspan="4">Is the aquifer Unconfined or Confined?</th></tr>
<tr><td></td><td colspan="2">Unconfined aquifer</td><td colspan="2">Confined aquifer</td></tr>
<tr><td></td><td colspan="2">What is the nature of the material overlying the unconfined aquifer?</td><td colspan="2">What is the nature of the material overlying the confined aquifer and what is the degree of confinement?</td></tr>
<tr><td></td><td colspan="2">What is the depth to the water table?</td><td colspan="2">Are there any high permeable windows or gaps in the confining layer?</td></tr>
<tr><td>Example of geological conditions overlying the aquifer</td><td>Unconfined aquifer with 10 m of gravel overlying the aquifer</td><td>Unconfined aquifer with 40 m of very fine sand overlying the aquifer</td><td>Confined aquifer with windows in the confining layer</td><td>Confined aquifer with extensive confining layer with no windows</td></tr>
<tr><td>Vulnerability category assigned</td><td>A</td><td>B</td><td>B</td><td>C</td></tr>
<tr><td>Ranking value assigned</td><td>3</td><td>2</td><td>2</td><td>1</td></tr>
</table>

TABLE 8. Examples of questions a mapper would ask in determining vulnerability and ranking values of a sand and gravel aquifer

AQUIFER SIZE

Size refers to the areal extent (in square kilometres) of the aquifer. Larger aquifers support, or have the potential to support, a greater number of water users than smaller aquifers. In general, therefore, larger aquifers have more regional importance compared to smaller aquifers. Ranking values are assigned accordingly (Table 9).

- Aquifers smaller than 1 km^2 are not generally delineated.
- For aquifers straddling the international border, size is generally reported only for the portion located within Canada.

What data are used to determine aquifer size, and what ranking values are assigned to different sizes?

The boundaries of an aquifer, which define its areal extent, are delineated with data taken from well logs, technical reports, hydrogeologic studies, air photos and topographic and geologic maps at time of assessment. Digitizing is then used to determine the aquifer size in square kilometres.

Delineated Aquifer Size	Value
< 5 km^2	1
5–25 km^2	2
> 25 km^2	3

TABLE 9. Ranking values assigned to aquifers based on size

DEMAND FOR WATER

Demand, as a component of the level of development, refers to the present groundwater use of the aquifer. The type of use (such as for drinking water or irrigation) indicates the level of demand. Inherent in the demand criterion is an indication of the level of reliance on the resource for supply: a high level of demand indicates greater reliance on the groundwater resource.

- The classification system assumes that all wells mapped on provincial well location maps are in use, unless there is information to indicate otherwise. In reality, many wells in use have not been mapped and some mapped wells have been abandoned. This means that verification of actual demand levels is recommended before any major water-use decisions are made.

- Demand is often based on reported well capacity (the reported amount of water that a well can yield), which is often higher than actual use.

- Major groundwater users generally do not meter water usage and metered supply information is generally not available.

How is demand determined, and what ranking values are assigned to different levels of demand?

Determining demand involves assessing the number, distribution and reported capacity of wells. High capacities may indicate potentially high demand. A larger number of wells or high well density can also imply high demand. Knowledge of type of use (described below) in the local area is also required to interpret groundwater demand.

- Well use and actual withdrawal rates are usually not available. Demand, therefore, must be assessed subjectively based on domestic well density, number and type of production wells, and general knowledge of well use and land use in the area.

Table 10 shows how different levels of demand are assigned ranking value when based on domestic well density alone. If information on high yielding production wells or high water-use consumption practices were available, then the ranking value could increase.

Demand	Number of Domestic Wells per Square Kilometre*	Level of Density of Domestic Wells	Assigned Ranking Value
Light	≤ 4 km^2	Low	1
Moderate	4–20 km^2	Moderate	2
Heavy	> 20 km^2	High and very high	3

* = applies where groundwater is obtained mostly from private wells

TABLE 10. *Demand ranking values*

TYPE OF WATER USE

Type of water use of an aquifer reflects the variability and diversity of the resource as a supply. Categories of water use are non-drinking; drinking (municipal or domestic); and multiple use (both drinking water and other uses such as commercial, industrial and agricultural).

- It is accepted that some uses for groundwater may be more important than other uses. An aquifer that is a drinking water source is generally of greater priority for protection than an aquifer used for irrigation and stock watering only; ranking values are assigned accordingly (Table 11).

- When an aquifer is not used for drinking water because it is of poor quality or it is being developed for a specific industry (e.g., irrigation), its use is considered to be "other."

- When an aquifer supports drinking water use and other uses such as commercial, industrial and agricultural, it is given the highest ranking value.

- The "type of use" is not an indication of water quality.

How is type of use determined, and what ranking values are assigned to the different types?
Type of use is interpreted from water well records and inferred from land use and knowledge of water use in the area.

Table 11 shows how different types of uses are assigned a ranking value.

Different Types of Use	Ranking Value Assigned
Water uses other than for drinking	1
Drinking water: municipal or domestic	2
Multiple uses: drinking water and other uses such as commercial, industrial, and agricultural	3

TABLE 11. Ranking value assigned to different types of use

QUALITY CONCERNS

How are quality concerns defined?
Quality concerns are defined by the presence of contaminants in the aquifer that pose a health risk. Such contaminates may be nitrate, pesticides, volatile organic compounds, fluoride or arsenic.

An aquifer with a reported quality concern generally takes priority for management over an aquifer without a quality concern. Quality concerns are actual concerns found in written reports in the Groundwater Section. They are not potential concerns implied by an aquifer having a high vulnerability rating.

- Contaminants may be naturally occurring (e.g., arsenic) or introduced by human activities (e.g., nitrate).

- Quality concerns that do not pose any health risk (such as elevated levels of iron and manganese) are noted, but do not affect the ranking value.

- The more regional or widespread the quality concern, the higher the ranking value it is given.

What ranking values are assigned to different levels of groundwater quality concerns?

- Quality concerns are classified and ranked according to knowledge and information in the Groundwater Section office. As other information is made available to the office (e.g., chemistry data from Health regions), an aquifer's classification can be revised.

- The Groundwater Section does not monitor for bacteria. This means that knowledge of bacteriological concerns could be underestimated.

Table 12 shows different levels of groundwater quality concerns.

Quality Concerns Documented	Area Affected by Quality Concerns	Ranking Value Assigned
No quality concerns documented	No documented problem	0
Isolated water quality concerns	Detected in a few wells	1
Local quality concerns	Detected in a significant portion of the aquifer (more than a few wells)	2
Regional quality concerns	Detected over much of the aquifer	3

TABLE 12. Ranking value assigned to groundwater quality concerns

QUANTITY CONCERNS

An aquifer with a reported quantity concern takes priority for management over an aquifer without a quantity concern. Quantity concerns are actual concerns reported to the Groundwater Section. They are not potential concerns implied by an aquifer having a heavy demand rating.

How are quantity concerns defined, and what ranking values are assigned to different levels of groundwater quantity concerns?

Quantity concerns are defined by demand exceeding supply. Evidence of demand exceeding supply includes: instances of well interference or aquifer mining, the presence of dry wells, and situations in which primary source aquifers are unable to meet demands on a seasonal or cyclical basis (e.g., fractured bedrock aquifers in parts of the Gulf Islands).

- Quantity concerns are classified and ranked according to knowledge and information in the Groundwater Section office. As other information is made available to the office, an aquifer's classification can be revised. Such information must be reported in the form of a written report or well record and on file in the Groundwater Section office or it must be based on data that has been collected by the Groundwater Section itself through the Observation Well Network. Examples would be records of water level decline in observation wells or reports of wells going dry.

The more regional the quantity concern, the higher the ranking value given (Table 13). If no quantity concerns are evident, then no value is assigned.

Quantity Concerns Documented	Area Affected by Quantity Concerns	Ranking Value Assigned
No quantity concerns documented	No documented problem	0
Isolated water quantity concerns	Found in a few wells	1
Local quantity concerns	Found in a significant portion of the aquifer (more than a few wells)	2
Regional quantity concerns	Found over most of one aquifer or encountered in one or more aquifers	3

TABLE 13. Ranking value assigned to groundwater quantity concerns

UNDERSTANDING THE AQUIFER CLASSIFICATION MAPS

Maps, the products of the BC Aquifer Classification System, are the basis on which decisions, assessments and policies about the groundwater resources of an area can be made. That is why the key elements and information in the aquifer classification maps need to be understood.

Figure 5 shows the standard layout of an aquifer classification map. Each map element is described in further detail in Table 14. An example of an aquifer classification map is provided in the map pocket at the back of this document.

This section discusses the sources of information used to characterize and map the aquifers, the methodology used to define and delineate aquifers, and the means by which information on the maps can be used to detect confined and unconfined aquifers.

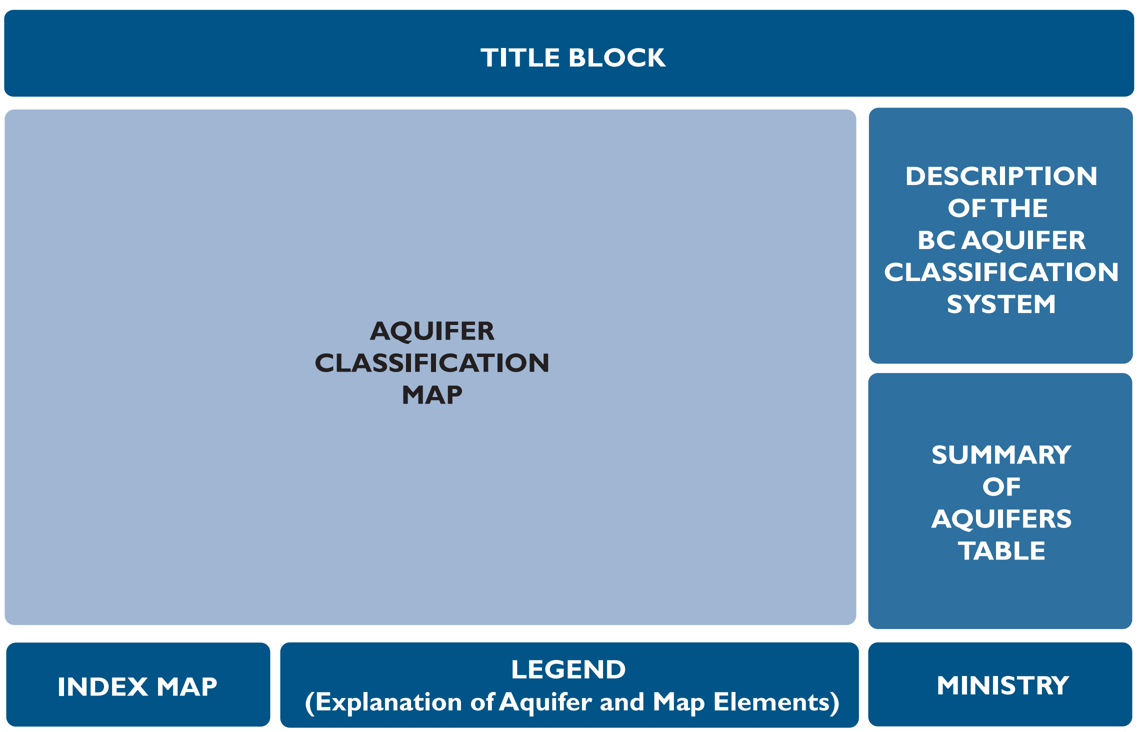


FIGURE 5. Layout for aquifer classification maps

Map Components	Meaning and Relevance
Title Block	Map title identifies the type of mapping (i.e., Aquifer Classification Mapping), the geographic location of the map area, and sometimes, specific aquifer information being displayed.
Aquifer Classification Map	Map of the aquifers and other base map features (e.g., rivers and lakes, roads, topographic contours).
Description of the BC Aquifer Classification System	Discusses the classification system: 1) the classification component (the level of development and vulnerability of the aquifer to contamination) and 2) the ranking value component (a numerical value that indicates the relative importance of an aquifer). Includes brief descriptions of how the aquifers are delineated, the general sources of information used, and the applicability and limitations of the map. Also included is a reference to where more information on the aquifer classification system can be found.
Summary of Aquifers Table	A summary of information for each aquifer, including: the aquifer number, descriptive location, classification, ranking value, aquifer size, productivity, vulnerability, demand, type of water use, and quality and quantity concerns. This information corresponds to each of the aquifers completely defined on the map. Information for aquifer polygons that are only partially in the map are not included in the table; this is a technical limitation of the GIS.
Ministry Title Block and Logo	Identifies the Ministry of Water, Land and Air Protection and the people who mapped the aquifer.
Legend	An explanation of the symbology (for both aquifers and other features) displayed on the map. The information presented can vary, which the legend will reflect accordingly. Attributes commonly defined include aquifer boundaries, aquifer type, aquifer vulnerability, major water and transportation features and land elevation contours.
Index Map	Defines the area of the province covered by the map.

TABLE 14. *Various sections of the aquifer map template*

HOW AQUIFERS ARE DELINEATED ON THE AQUIFER CLASSIFICATION MAPS

The boundaries of aquifers are drawn as either solid or dashed lines on the aquifer classification maps.

Solid lines are used when there is a reasonable degree of certainty associated with the location of the aquifer boundary. A solid line is often drawn:

- where the valley floor meets the valley walls, marking the areal extent of the floodplain aquifer underneath the valley floor against the less permeable bedrock aquitard underneath the valley walls (Figures 6 and 7);
- along boundaries of surficial or bedrock geology formations, that are known aquifers (Figure 8); or
- at the boundaries of major lakes, rivers and the ocean (Figure 9). Though the aquifer in Figure 9 likely extends under the Fraser River, it is not normally shown as there is no hydrogeological information available under the river and groundwater use does not occur there.

Dashed lines are used when the location of an aquifer boundary is less certain. A dashed line is drawn:

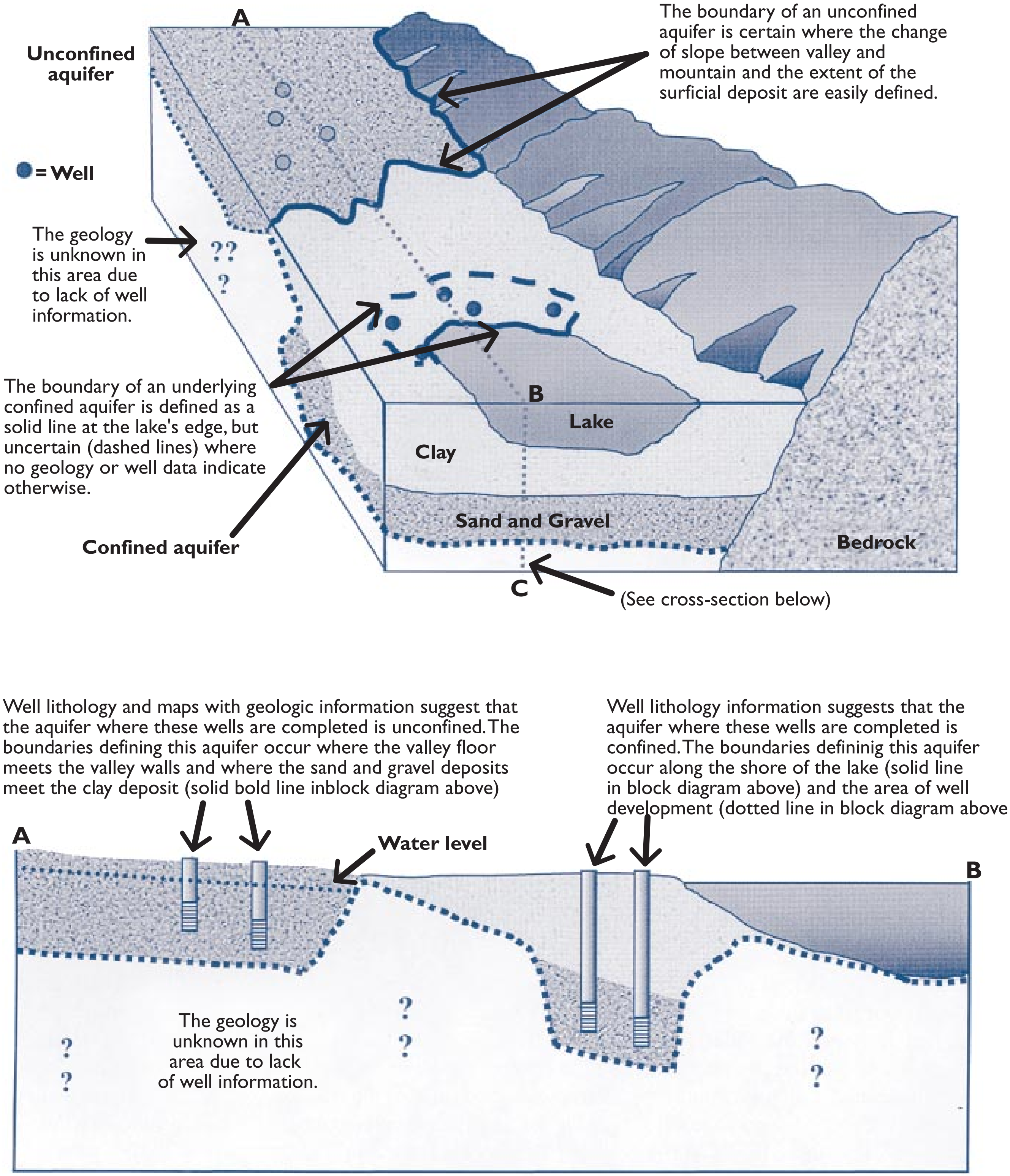
- when the information from well logs does not identify the areal extent of an aquifer (Figure 6);
- along watershed divides (usually for bedrock aquifers) (Figure 10);
- when the surficial geology does not indicate the areal extent of the aquifer (a point that is especially relevant with deeper confined aquifers) (Figure 6); or
- where hydrogeologic mapping is unavailable or the mapping project was restricted to an area defined by an NTS 1:50,000 map sheet (Figure 8)[2].

The location of those boundaries is derived from numerous sources of information, including:

- interpretation from water well logs;
- boundaries of surficial and bedrock geology formations from geology maps;
- hydrogeologic studies and cross-sections;
- the mapped location of geographic boundaries, such as, lakes or rivers; and
- topographic boundaries, such as, abrupt changes in slope.

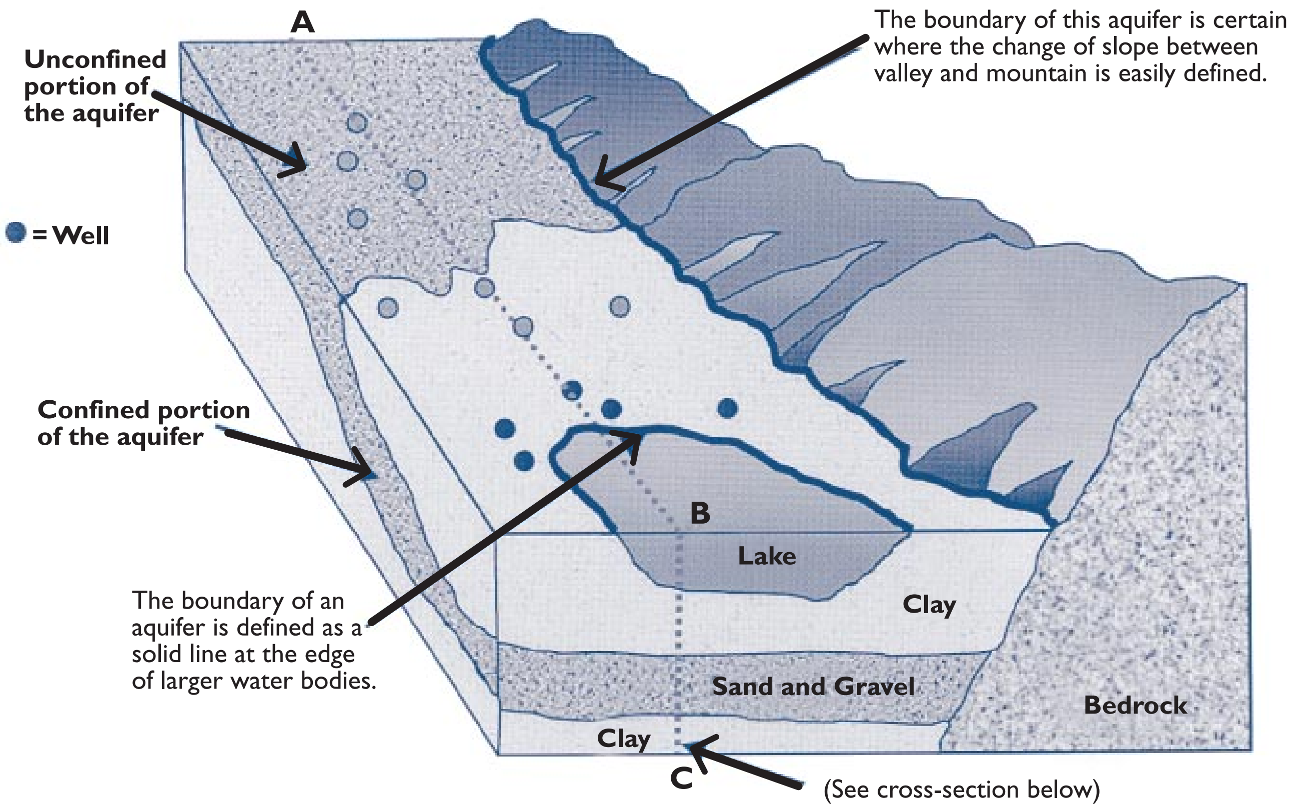
Figure 6 shows an example of an unconfined and a confined aquifer with part of their boundaries delineated. The boundary of the unconfined sand and gravel aquifer is solid where the sand and gravel deposit of the valley floor meets the bedrock of the valley walls. The dashed lines define the boundary of the developed area of the confined sand and gravel aquifer. The solid line of the confined sand and gravel aquifer is delineated according to the boundary of the lakeshore, which it abuts. Figure 7 shows the actual geology if additional wells existed and their lithology were known. The original two aquifers would then become one aquifer and this new aquifer would be classified accordingly.

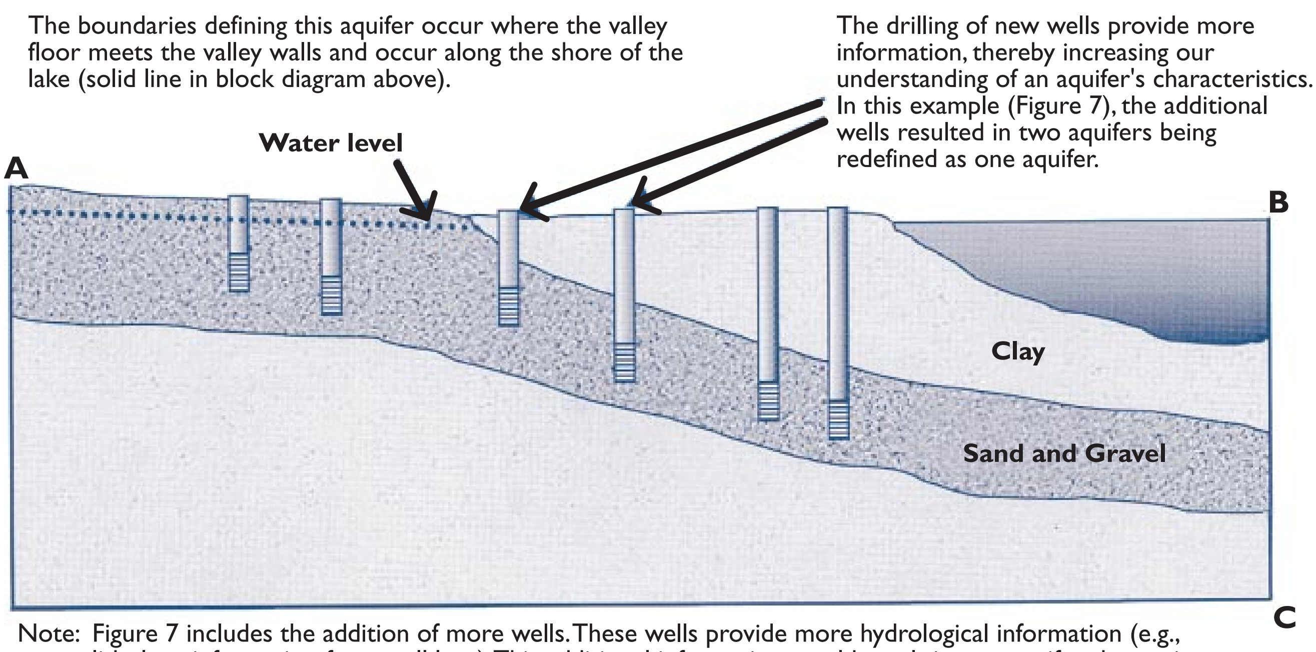
[2] NTS – National Topographic Series. Each NTS 1:50,000 scale map sheet has a name (e.g., Mission is the name of map sheet 92G/1). The NTS number is the number on the map sheet (e.g., 092G01). Every aquifer that has been mapped is geo-referenced to an NTS map sheet name and number.



Note: In Figure 6, two aquifers are delineated because of insufficient data to suggeste that there is one continuous aquifer.

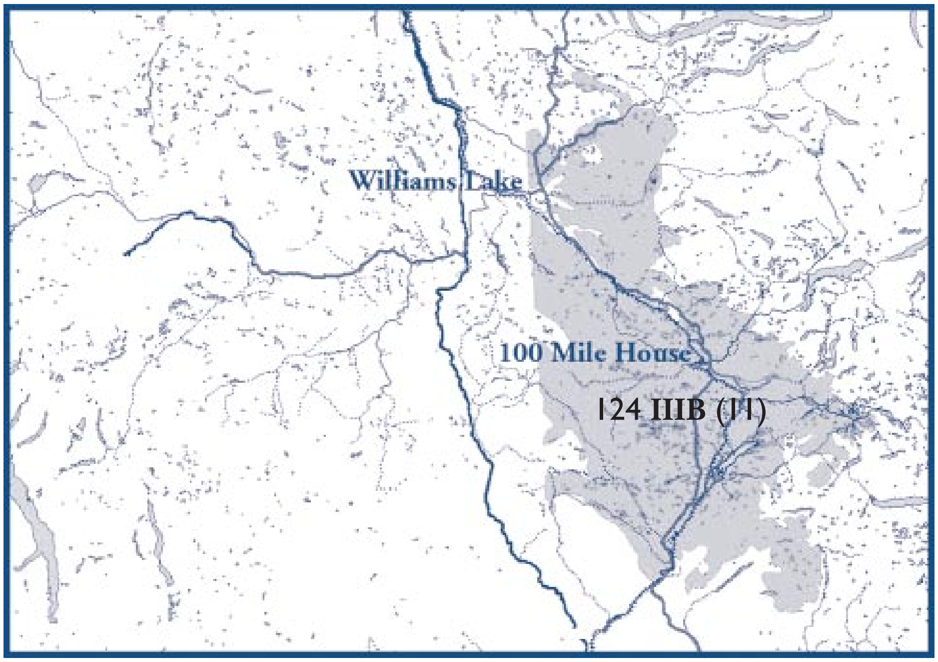
FIGURE 6. Sample aquifer boundaries based on known geology information





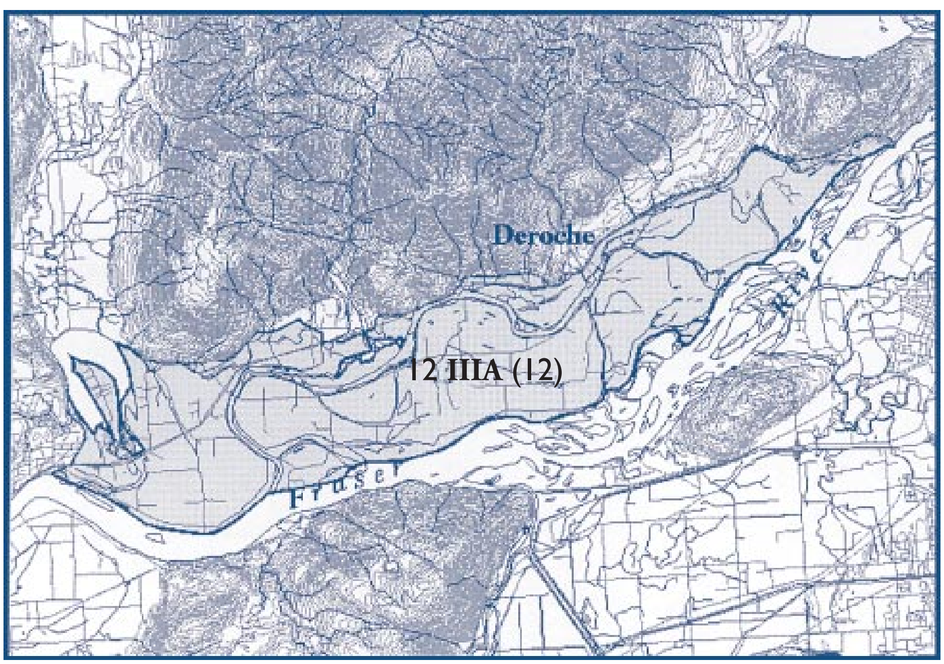
Note: Figure 7 includes the addition of more wells. These wells provide more hydrological information (e.g., lithology information from well logs). This additional information would result in two aquifers becoming one aquifer and its classification would be adjusted accordingly.

FIGURE 7. Sample aquifer boundaries if more geology information was available than shown in Figure 6



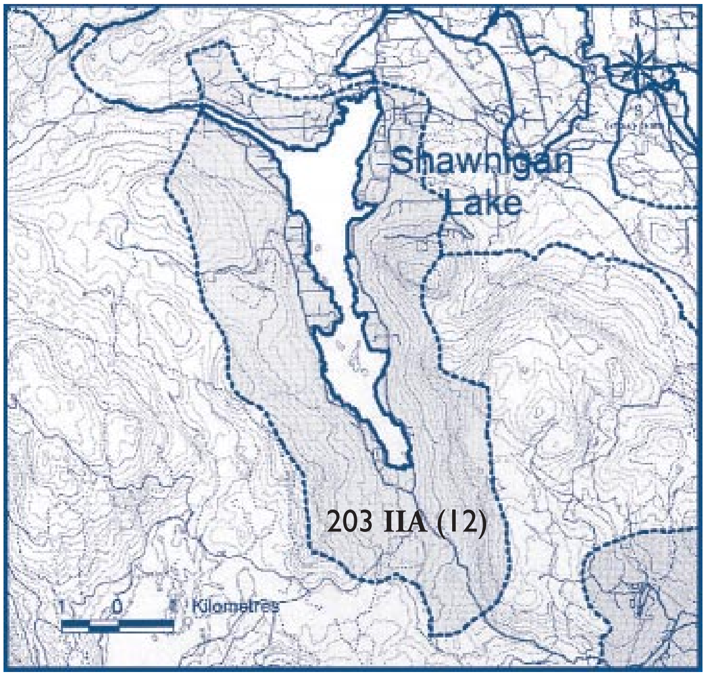
Aquifer 124, located in the 100 Mile House region, is defined by a basaltic bedrock formation. The dashed linear boundaries indicate limit of study area. As data are acquired, the boundary will be extended to encompass the complete basaltic formation.

FIGURE 8. Aquifer boundary defined by geologic formation (basaltic lava flows), study area and extent of available mapping



Aquifer 12, a sand and gravel aquifer, is located east of Hatzic Lake on the north side of the Fraser River. It is defined primarily by geologic boundaries and the boundary with a major water body – the Fraser River. The solid line of the boundary indicates a high degree of certainty about the boundary's location.

FIGURE 9. Aquifer boundary defined by a major river



Aquifer 203, a bedrock aquifer located between Duncan and Victoria, is defined primarily by Shawnigan Lake's drainage basin. The dashed line of the boundary indicates a low degree of certainty about the boundary's location.

FIGURE 10. Bedrock aquifer boundary defined by the watershed divide

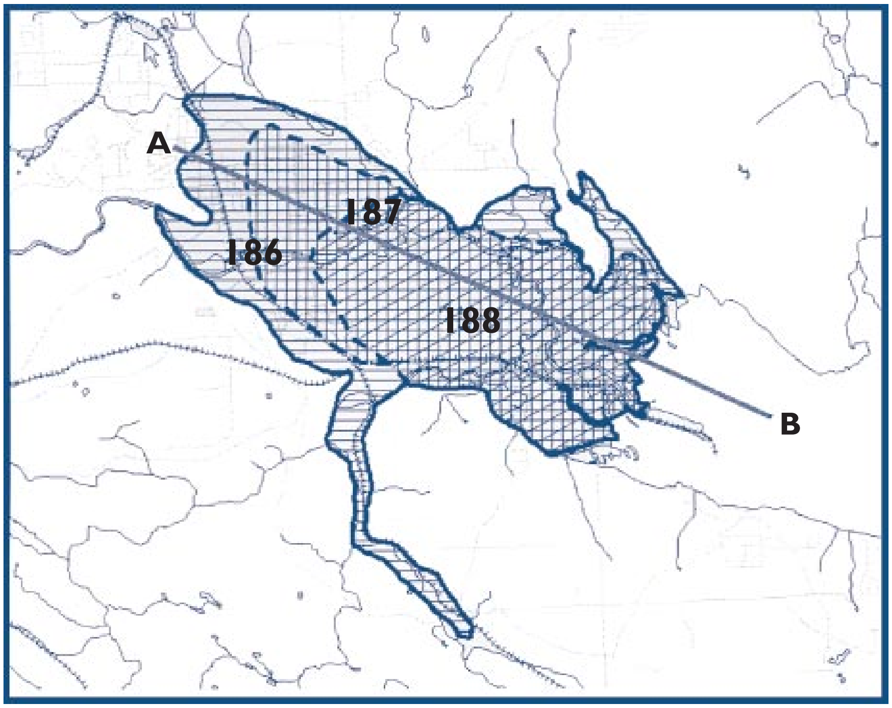
WHAT GENERAL CRITERIA ARE USED TO DELINEATE AN AQUIFER?

Only aquifers that are developed (used) are delineated. A minimum amount of water well data is required to delineate an aquifer. The degree of confidence in delineating and classifying aquifers depend on the quality and amount of information available. For example, delineation and classification of the Abbotsford–Sumas aquifer (#15) has been done to a higher degree of confidence than aquifer #36 adjacent to it, because aquifer #15 has more water well information available.

Before an aquifer is delineated, there first must be sufficient information indicating its existence. This information may be of a hydrological nature (e.g., discharge from springs) or a geological nature (e.g., existence of a permeable formation). Absence of mapped aquifers in an area does not mean an aquifer (as opposed to "mapped aquifer") does not exist there – just that no well records are available to delineate and classify them at that location.

The Geological Survey of Canada has produced 1:250,000 scale mapping showing where potential aquifers may be found in the Fraser River Basin, based on surficial geology (Halliwell, et.al., 1993). Other resources available to identify potential aquifers include surficial geology maps that portray glacio-fluvial or fluvial sand and gravel deposits such as those found in river floodplain areas.

Aquifers may overlap in many areas. That is, one aquifer can occur on top of another. The order of overlap can be inferred from the aquifer vulnerability component (Figure 11). The more vulnerable aquifer will normally be found closer to the surface. On an actual aquifer classification map, an aquifer's vulnerability is normally colour coded with dots: highly vulnerable = red; moderately vulnerable = yellow; and low vulnerability = green. If a highly vulnerable unconfined gravel aquifer was located above a low vulnerability confined sand aquifer; the map reader would see red dots inter-mingling with green dots. Figure 11 below uses lines instead of dots to portray how one aquifer can overlap another.



Three aquifers in the Duncan area overlie one another, with less permeable materials separating them. The uppermost aquifer (#186) is a highly vulnerable one that overlies a moderately vulnerable aquifer (# 187), which in turn overlies a low-vulnerability aquifer (#188). The overlapping aquifers are graphically represented in the accompanying cross-section, A – B.

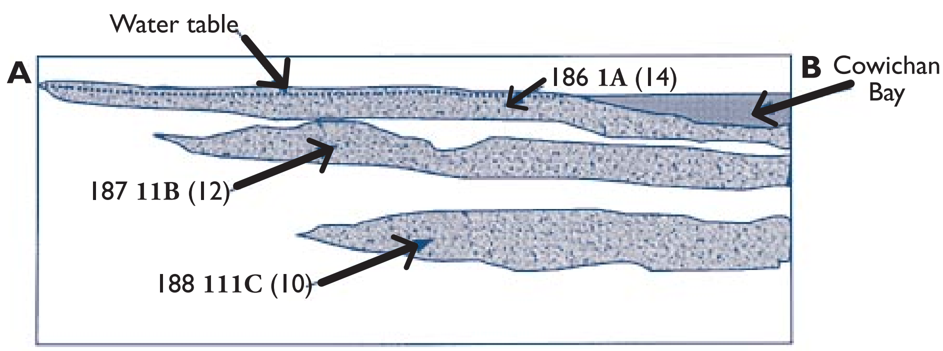


FIGURE 11. The key to identifying which aquifer overlies another is the vulnerability component

HOW SAND AND GRAVEL AQUIFERS ARE DELINEATED

Delineating a sand and gravel aquifer involves answering a series of specific questions:

Is there evidence that a sand and gravel aquifer is present (e.g., are there wells, springs, wetlands, drainage features, favourable geologic deposits and geomorphologic features)?
Are all the wells in an area completed into sand and gravel (this information comes from the lithologic descriptions in the well logs)? Is this sand and gravel traceable from one well to the next? If so, then the geologic formation associated with the sand and gravel deposit can be delineated.

What was the geologic formation or depositional environment – fluvial, glacial or marine?
Each depositional environment results in deposits of different sediment sizes, permeability, thickness and extent. These factors vary the potential for storage and transmission of water. The type of environment in which the sand and gravel were deposited is used to establish the shape and extent of the deposit, the possible boundaries of the aquifer and the relation of the aquifer to other geologic deposits. For example, a shallow well located in a river floodplain may be completed in sand. This sand would be "fluvial", that is, deposited by the river. The boundaries of this aquifer (the sand deposit) would be limited to the edge of the floodplain. A deeper well, in the same flood plain, also completed in sand and gravel, but found beneath the sand deposit and an underlying layer of till would be considered glacio-fluvial, deposited under a different (and earlier) environment than the overlying sand. These two deposits (the sand and the sand and gravel deposit) would be two separate aquifers and the boundary of the deeper glacio-fluvial sand and gravel aquifer may not necessarily be confined to the floodplain.

Does the sand and gravel aquifer occur near the land surface, forming a water table in an unconfined aquifer?
Or is the aquifer located beneath an overlying layer of low permeable clays, silts or tills, forming a confined aquifer? In the majority of cases, aquifers are defined either as unconfined or confined. Exceptions are when an aquifer may be partially confined. The areal extent of an unconfined saturated sand and gravel deposit can be established from well records, surficial geology maps, hydrogeologic reports, topographic maps and air photos. For example, topographic maps and air photos can show abrupt changes in slope and landforms (e.g., where a river valley bottom meets a mountain slope).

Does sufficient information exist to suggest the existence of two or more hydraulically connected geologic formations of saturated sand and gravel deposits?
If sufficient information does **not** exist to differentiate two different aquifers, then only one aquifer would be delineated. For example, colluvial deposits in many parts of BC comprise discontinuous layers / lenses of sand and gravel interspersed with clay. It is not possible to map these individual sand and gravel deposits as individual aquifers, so the entire colluvial deposit (the many sand and gravel lenses along with the clay) may be grouped as one aquifer.

If sufficient information does exist to suggest two or more hydraulically connected deposits formed under different depositional geologic environments, the quality and quantity of the waters found in the different deposits must be assessed. If their chemistry is significantly different, or their ability to store and transmit water is different, then these sand and gravel deposits may be defined as two or more different aquifers.

In either case, knowledge of the geologic environment of the aquifer, well log lithologies, water chemistry analysis, geologic maps and reports, air photos and topographic maps are used to establish the extent of the sand and gravel deposit and the aquifer boundaries.

Is there sufficient information to delineate the boundaries of a confined aquifer?
Boundaries for confined aquifers are often more difficult to delineate than those for unconfined aquifers because the overlying sediments obscure the geomorphology of the confined aquifer. Nevertheless, confined aquifer boundaries can be delineated accurately if sufficient well log lithologies exist. Otherwise they must be approximated from well log lithologies, geology maps and reports, topographic maps and air photos.

Where there is a lack of information, the "area of development" (area where the wells are) can often be used to define the known extent of a confined aquifer's boundaries. The area of development is defined by the location of neighbouring wells that appear to be completed in the same aquifer. An approximate boundary (represented by a dashed line) usually surrounds this area of development, since the ability to extrapolate the aquifer beyond the well field area is limited. Aquifer boundary delineation ranges from relatively accurate (where detailed information is available) to approximate (limited data available).

HOW BEDROCK AQUIFERS ARE DELINEATED

Delineating bedrock aquifers requires a different approach than delineating unconsolidated sand and gravel aquifers because groundwater often occurs in fracture systems that can cut across different bedrock formations. The following questions guide the approach:

Are there sufficient types of information available to delineate a bedrock aquifer?

To delineate a bedrock aquifer in British Columbia, there needs to be some useable information indicating the existence of an aquifer. This information may be of a hydrological (e.g., discharge from springs, productive wells) or geological nature (e.g., existence of a permeable formation). If there is not sufficient information to indicate that an aquifer is present, then the aquifer cannot be delineated.

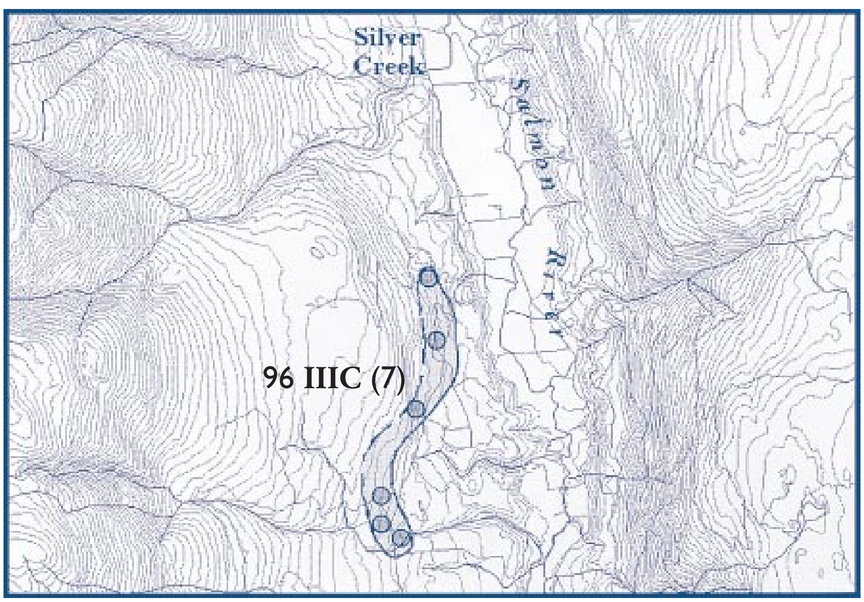
What is the minimum amount of information required to delineate a bedrock aquifer?

When little hydrogeological information is available (other than the knowledge that the wells are constructed in bedrock), mappers use the area of development (area where the wells are located) to establish the boundary that delineates the area of groundwater use (Figure 12). If the area of development has been established, the next step is to evaluate the type of groundwater flow within the bedrock.

What groundwater flow types are most common when delineating a bedrock aquifer?

Understanding how water is stored in, and moves through, the different bedrock types helps the mapper define the bedrock aquifer boundary. The more complete the bedrock groundwater flow information, the more accurate the delineation of a bedrock aquifer will be.

Two types of groundwater flow in bedrock are generally recognised: flow through the pore spaces of the rock, and flow through fractures and channels in the rock. In BC, flow through the pore spaces (the type of flow found in sand and gravel aquifers) is found in some sandstone and vesicular basalt, and in the inter-flow sand and gravel zones sometimes associated with basalt. Fracture flow can be found in all types of bedrock. The fractures or partings in the rock include: faults, joints and



Bedrock aquifer 96, south of Salmon Arm, is defined by the close proximity of a minimum number of wells constructed in the bedrock (area of aquifer development) and the boundary between those wells completed in bedrock and those completed in sand and gravel. The dashed line indicates there was insufficient information to extend the aquifer boundary further upslope. The solid line indicates greater confidence in the boundary based on well and surficial geology information.

FIGURE 12. The area of well development partly defines the boundary of aquifer 96

bedding planes. Channel flow can take the form of solution channels as found in limestone and basalt. Fracture flow is the most common type found in bedrock in British Columbia.

What role does the permeable bedrock geology formation or unit play in defining an aquifer's boundaries?

Groundwater flow occurs in pore spaces, fractures or channels. Assuming that the occurrence and flow of groundwater is associated with a specific rock type (e.g., intergranular flow in sandstone; solution channel flow in karst lime-stone; or interflow zones and discrete fracture flow in basalt formations [Figure 8]), then the aquifer boundary can be extended beyond the area of development. The aquifer's boundary can be set according to the boundaries of the entire permeable bedrock geologic unit that makes up the known aquifer.

What happens when the area of development is comprised of two or more different rock types?

If the area where the wells are located (area of development) involve two or more rock types and if there are great enough differences (e.g., water chemistry or amount of available water) between the rock types, then separate aquifers would be delineated. If there is insufficient information to distinguish between them, the aquifer could be delineated based on the area of development.

Are there any major geographical features dividing the area of development or the permeable bedrock geologic units?

If there are any major geographical features dividing the area of development or the permeable bedrock geologic units, such that two or more flow systems result, then two or more individual aquifers are defined. Figure 9 for example, shows aquifer #12 located on the north side of the Fraser River. Not shown is aquifer #6, across the river. Both are completed in similar geologic environments, but the Fraser River, a major geographical feature, runs between these aquifers, resulting in two separate flow systems.

Are there sufficient data to define the local groundwater flow system for an individual aquifer, thereby extending an aquifer up to the groundwater divide?

If groundwater flows through fractures that cross-cut different geologic formations, using geologic boundaries as aquifer boundaries may not be appropriate. If there are sufficient data to define the local groundwater flow system for an individual aquifer, the aquifer could be extended up to the groundwater divide. The groundwater divide is assumed to coincide with the topographical divide. Therefore, a bedrock aquifer, delineated by its flow system, will often reflect the overlying topography or surface watershed area (Figure 10). This is especially significant in the valley and mountain environments often found in British Columbia.

Where does the information to delineate a bedrock aquifer come from?

The type of bedrock porosity is inferred from the lithologic description in the well logs and from bedrock geology maps. The permeability is inferred from lithology, reported yields, specific capacity and transmissivity values from pump tests. The geology is interpreted from well logs and geologic mapping and information about major geographical features (including major watershed divides) come mainly from topographic maps.

When a groundwater flow system is used to define the boundary of a bedrock aquifer, that system is interpolated from the topography or surface water drainage area. The area delineated usually encompasses the recharge area contributing to the area of development (that is, the area where the bedrock wells are located).

The degree of accuracy in defining and delineating bedrock aquifers is dependent on the quality and amount of information available. Figure 12 illustrates that, if limited information is available, only the area of water well development would be delineated as a bedrock aquifer. As more information becomes available, the aquifer boundary may be extended to the limits of the geologic formation boundaries, or the watershed divide boundary, or some combination of the two (Figures 8 and 10). For a more detailed discussion of mapping bedrock aquifers in British Columbia, see *The Identification and Delineation of Bedrock Aquifers in British Columbia* (Ronneseth and Pinto [in draft]).

The aquifer classification system and maps were designed for setting priorities to groundwater management activities, primarily at the provincial, regional and sub-regional levels. However, there are many other uses for the maps. The first part of this section discusses the appropriate use of the classification system at the provincial, regional, local and site-specific levels. The second part presents real-life examples of how the aquifer classification system and maps have been applied. The third part provides examples of how aquifer classification maps can be used to address specific groundwater quality and supply issues that occur around the province.

THE APPROPRIATE USE OF THE CLASSIFICATION SYSTEM AT DIFFERENT PLANNING AND MANAGEMENT LEVELS

Figure 13 shows how the aquifer classification maps and aquifer inventory can be used at the provincial, regional, local and site-specific planning and management levels.

Map scale influences the appropriate use of the aquifer maps and the aquifer inventory. The smaller aquifers would not be very legible on small-scale regional or provincial maps. Therefore, the aquifer inventory would be more appropriate for regional and provincial issues. Aquifer maps are visually meaningful at mapping scales from 1:10,000 to 1:150,000. Since aquifer boundaries were delineated on 1:20,000 scale maps, mapping scales larger than 1:20,000 could be misleading on the accuracy of an aquifer's boundary. The examples described in the following subsection show where and how the aquifer inventory and the aquifer maps might be applied for initiatives at different levels of planning and management.

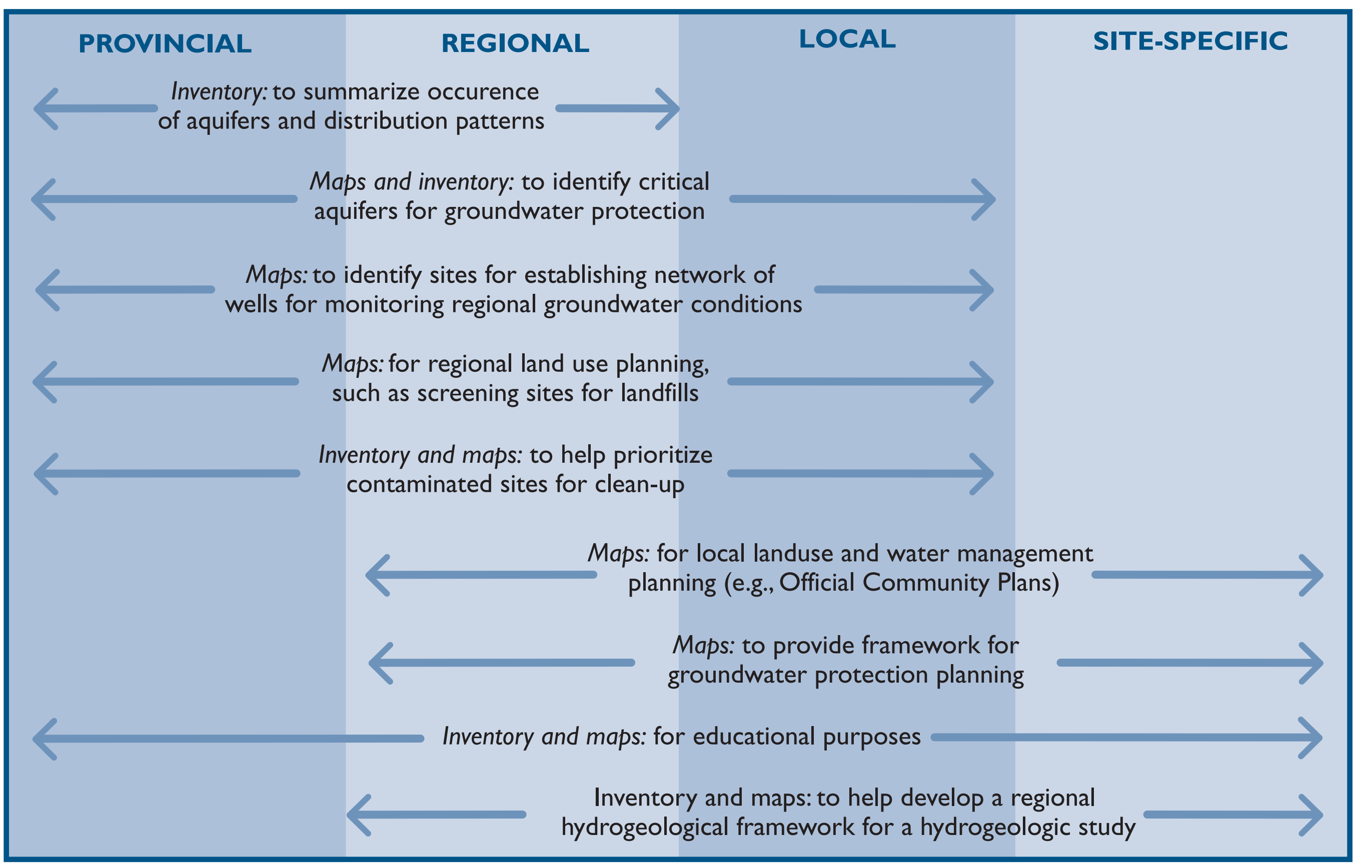


FIGURE 13. Applying the aquifer classification maps and inventory at four different planning and management levels

Provincial level

Users of the aquifer classification maps and inventory include the federal and provincial governments, as well as universities and industries that require a broad provincial summary or coverage of aquifer information.

Appropriate use of the maps and inventory at the provincial level:

- to summarize occurrence and distribution patterns of developed aquifers;
- to identify critical aquifers for groundwater protection and for education purposes; and
- to help set general policy direction in groundwater protection and management for the province.

The aquifer classification designations that would be appropriate to identify for planning and management initiatives at a provincial level include:

- the number of heavily developed and highly vulnerable IA aquifers;
- the number of highly vulnerable A aquifers;
- the aquifers for which a water quality problem is identified;
- those aquifers that, because of their high productivity and low level of development, are potential new sources of drinking water supplies;
- a summary of the total number of aquifers; and
- the number of vulnerable aquifers.

Specific application examples:

- to guide expansion of the Provincial Observation Well Network by supporting a groundwater policy directive that observation wells be established in all IA (heavily developed, highly vulnerable) aquifers;
- to provide groundwater quality and quantity status summaries of the aquifer inventory for the State of the Environment report;
- to identify the water systems that draw water from highly vulnerable aquifers that may need to implement groundwater protection plans; and
- to direct more detailed studies of IA aquifers.

Regional level

Users of the aquifer classification maps and inventory include the provincial and regional district governments.

Appropriate use of the maps and inventory at the regional level:

- as a screening tool (e.g., for cross-referencing vulnerable aquifers with the location of high-risk land uses to identify areas requiring attention);
- to support regional resource inventory and land-use planning processes.

Specific application examples:

- to identify heavily developed and highly vulnerable aquifers and, based on that information, to develop broad policy objectives to protect the groundwater quality and quantity in these aquifers by promoting:
    - best land use and best management practices,
    - development of aquifer protection plans,
    - monitoring of water levels and water quality, and
    - public education.
- to support development of the Land Resource Management Plan (LRMP) process (e.g., Okanagan-Shuswap);
- to contribute an additional layer of aquifer information to the 1:50,000 scale BC Provincial Watershed / Water Body Atlas Project;
- to identify high-risk petroleum service stations (those overlying highly vulnerable aquifers) that may require increased monitoring or upgrading;
- to prioritize areas for contaminated site clean-up, monitoring and inspections by identifying sites over highly vulnerable aquifers;
- to confirm an aquifer's vulnerability status and initiate effective protection of source drinking water supplies; and
- to support the preliminary environmental impact assessments of major projects covering large areas (e.g., pipeline construction).

Local level

Users of aquifer classification maps and inventory include Improvement Districts, the Local Health Authorities, Regional Districts, Municipalities, First Nations Communities and Environmental Non-government Organizations.

Appropriate use of the maps and inventory at the local level:

- to promote the local understanding and awareness of the groundwater resource;
- to support local governing bodies in protecting vulnerable aquifers from degradation;
- to support local governing bodies in carrying out their planning initiatives.

Specific application examples:

- to set a framework for defining capture zones of municipal wells;
- to zone land use, site facilities and plan for growth management;
- to identify critical aquifers for designation as environmentally sensitive Development Permit Areas in Official Community Plans;
- to raise awareness of groundwater and aquifers;
- to prioritize areas for monitoring.

Site-specific level

Users of aquifer classification maps and inventory include local community groups, groundwater consultants and industry.

Appropriate use of the maps and inventory at the site-specific level:

- to promote the understanding and awareness of the groundwater resource;
- to provide a general hydrogeologic framework for background information to assist more detailed site-specific studies;
- to call attention to the groundwater resource in land-use decision-making.

Specific application examples:

- set the hydrogeological context for a site (land-use assessment);
- to promote public awareness that an aquifer exists in the area; and
- to promote advocacy for best aquifer use practices.

Note: These maps should not be used by themselves as a basis for site-specific land-use decisions.

EXAMPLES OF HOW THE CLASSIFICATION MAPS HAVE ALREADY BEEN APPLIED

The aquifer classification maps are already in use by both government agencies and industry. For example:

- The Groundwater Section in the Ministry of Water, Land and Air Protection uses the maps to set work priorities for the Observation Well Network and Ambient Water Quality Network by identifying the most heavily developed and highly vulnerable IA aquifers for monitoring.

- Private consultants, working for a gas utility company have used the maps to assist in the preliminary environmental impact assessment of proposed gas pipeline corridors, noting where vulnerable and highly developed aquifers are located.

- Officers in the Ministry of Water, Land and Air Protection conducting impact assessments have used the maps to identify vulnerable aquifers that may be affected by proposed landfills and larger sewage systems.

- Environmental Health Officers (EHOs) use the aquifer classification maps as educational tools to inform various groups about the total number of aquifers, including those aquifers which are vulnerable, within their jurisdiction. After cross-referencing aquifers with known areas of nitrate contamination, the EHOs inform local nurses so that they can inform their clients. As well, the EHOs refer to the vulnerability component of the maps when reviewing waste management applications, so that they can ensure safeguards are in place for the waste management activities to prevent water quality degradation.

- Public Health Engineers may note the existence of a high vulnerability aquifer in an area where an application for a new drinking water supply has been made. This information is important when decisions are made about well protection plans or the need for further treatment of a water supply.

- In managing the movement and storage of fuels and toxic chemicals, the British Columbia Buildings Corporation management has used the classification maps to evaluate which sites, from a hydrogeological perspective, may require secondary containment or spill response plans.

- The Okanagan-Shuswap Land and Resource Management Plan is an integrated land use plan that provides policy direction to Crown agencies responsible for resource allocation and approval decisions. The aquifer classification maps were one of the layers of information used in this planning process.

HOW THE AQUIFER CLASSIFICATION MAPS HELP ANSWER SOME COMMONLY ASKED QUESTIONS ON WATER QUALITY AND QUANTITY

From the aquifer classification maps, users can find answers to many specific questions about groundwater and its relation to water supply development, potability and water quality impacts. Table 15 offers guidance on what information can be obtained from the aquifer classification maps to address the various groundwater management issues occurring across the province. The table also notes additional information sources that can be used with the maps to provide a more detailed understanding of the local situation. The table is derived in part from conversations with present users of the aquifer classification maps who work in such areas as:

- regional and local land use planning and management
- property management
- environmental health
- gravel resource extraction
- community development
- community stewardship
- geoscience
- well drilling industry

Aquifer classification maps, by themselves, cannot definitively answer most of the site specific water supply or quality questions found in Table 15. The maps do not show whether or not water is available for a specific purpose, or the water quality is suitable at a particular site. What the maps can do is help a user:

- gain hydrogeological background;
- identify aquifers where there might be an increased likelihood of obtaining water supplies – or where that likelihood is small; and
- identifying aquifers that have the potential to be at risk of contamination (e.g., because the aquifer is classed as highly vulnerable or a previous water quality problem has been encountered).

When site-specific decisions are being made, the information provided on the maps must always be supplemented with additional information.

	Questions Related to Key Groundwater Issues in British Columbia	✓ Relevant Information from the Aquifer Classification Maps ➔ (Additional information sources that can be used with the aquifer classification maps[a])	Related Management Questions (not an exhaustive list)
Quantity (Supply)	• Is availability of water a likely concern? • Is there potential for well interference or groundwater mining?	✓ Level of development; productivity; demand; quantity concerns. ➔ Well record information; water use information; water level monitoring locally and from BC Observation Well Network.	• Where should we focus more attention when it comes to zoning and future development so that we can minimize supply conflicts? • Where in the regional district do we need to have more stringent bylaws for ensuring adequate well water supplies?[b] • Where should groundwater level monitoring programs be focused?
	• Is there potential for groundwater/surface water conflicts?	✓ The location of heavily developed IA and IB aquifers relative to surface water bodies; quantity concerns. ➔ Existence of surface water licences; groundwater and surface water level records; and flow measurement of streams.	• Will further well drilling have the potential to affect surface water flows in a stream that is already fully allocated or affect stream base flow levels and adversely affect fish habitat?
	• Where can new or alternative major groundwater supplies be found?	✓ Productivity; level of development; demand; quantity concerns. ➔ Assessment of surficial geology maps; well log information; test drilling; pump tests; aquifer budget calculations.	• What areas have the potential of providing a sustainable water supply for a major user (such as industry, fish hatchery, or municipal supply)?
Quality	• Is there potential for naturally occurring water quality concerns?	✓ Quality concerns ➔ Geological maps; water quality records; water sampling and analysis; groundwater flow velocity and direction.	• Is this natural mineral occurrence usual for this area? • What should we monitor for?
	• What is the potential for groundwater contamination?	✓ Vulnerability; type of groundwater use; water quality concerns. ➔ Land use; water quality records (Local Health Authority/Ministry of Water, Land and Air Protection); well records; surficial geology maps; and soil maps.	• Where should we focus more attention when it comes to existing and future land use practices? • Where should we focus groundwater quality monitoring, given limited time and money constraints? • Where are sensitive fish-bearing streams in relation to high-risk activities over vulnerable aquifers?

[a] At this point, a consulting hydrogeologist should be hired to assess additional sources of information.

[b] Guidelines for ensuring adequate well water supplies for a Certificate of Public Convenience and Necessity (BC Environment, 1999) are available from the Ministry of Water, Land and Air Protection at http://wlapwww.gov.bc.ca/wat/gws/gwdocs/eval_well/toc.html

TABLE 15. *Groundwater quantity, quality and education issues*

	Questions Related to Key Groundwater Issues in British Columbia	✓ Relevant Information from the Aquifer Classification Maps ➔ (Additional information sources that can be used with the aquifer classification maps[a])	Related Management Questions (not an exhaustive list)
Quality	• Is there a possibility of impact from non-point source pollutants?[c]	✓ Quality concerns; vulnerability; water use. ➔ Land-use; information on the use of potential contaminants in an area (eg., fertilizers, septic systems).	• Where do we need to watch closely to make sure land development does not impact on water quality? • Where should best land use management practices be required?
	• What is the potential impact from point source pollutants?	✓ Vulnerability; quality concerns. ➔ Inventory of known point source contaminated sites and potential contaminant sources.	• Where should we focus more attention when it comes to existing land use practices? • Where should we focus more attention when it comes to future land use zoning and development (eg., siting of facilities for storage of animal wastes)? • Where can we site our municipal landfill?
Education	• How can the public become informed on the need for protecting our groundwater resources?	✓ All information presented in map form. ➔ Fact sheets; State of the Environment reports; information on local groundwater information; and potential sources of contamination.	• During consultation for the Official Community Plan, how can the public be shown where their water is coming from? • How can we demonstrate that best management practices are needed over a vulnerable aquifer? • How can we demonstrate well protection planning is necessary for our municipal wells?[d] • What information is available to enhance awareness of the groundwater resource at schools, community events, etc?[e] • What can citizens do to help protect groundwater resources?
	• Where are the aquifers in our area, what type are they, and how big are they?	✓ Aquifer maps	• Is there an aquifer in our area that we need to be concerned about? • Is there an aquifer in our area that is more vulnerable than another and requires more attention?

[c] For more information on non-point source pollutants, refer to the following internet site: http://wlapwww.gov.bc.ca/wat/wq/NPS_web_page/Home/NPS_Home.html

[d] The "Well Protection Toolkit" (Province of BC, 2000) provides guidelines on how a community can develop a well protection plan. The toolkit is available from the Ministry of Water, Land and Air Protection or on the internet: http://wlapwww.gov.bc.ca/wat/gws/well_protection/wellprotect.html

[e] An excellent video on groundwater entitled: www.groundwater.protection is available, for a nominal cost, from the British Columbia Groundwater Association (604-530-8934).

TABLE 15 (cont'd). *Groundwater quantity, quality and education issues*

APPLYING THE AQUIFER CLASSIFICATION MAPS: USING LAND-USE PLANNING AS AN ILLUSTRATIVE EXAMPLE

The following sections suggest ways in which information from the aquifer classification maps might be used to help a planner decide between different land uses. It also highlights some of the benefits and limitations of the maps that should be kept in mind when they are used.

Though the maps are not meant to address specific questions concerning Official Community Plans or Regional Growth Strategies. The different map elements (e.g., vulnerability and level of development) however, do provide information relevant to land-use planning. The following information provides insights and direction in identifying where attention and resources should be placed.

Zoning has traditionally been based on the principle of the "highest and best use" for the land. Today, highest and best use needs to include protection and sustainability of the province's water resources. The aquifer classification maps provide land use planners with groundwater information that can both support planning processes and help protect and sustain the resource. The maps offer a regional perspective on what areas should be given priority for protection or best management practices.

INTERPRETING AQUIFER VULNERABILITY WITHIN THE CONTEXT OF LAND-USE PLANNING

How can a planner use the aquifer classification maps to interpret the vulnerability and development level of aquifers? What are the implications of the aquifer and its ranking value to planning?

When it comes to zoning and land use actions that may affect groundwater quality, a general rule of thumb is that the more vulnerable the aquifer, the more attention it should receive.

When two aquifers are under review, one classified as having high vulnerability and the other classified as having low vulnerability, it can be said with a relatively high level of confidence that more attention should be given to the former. For example, it is obvious that a landfill should be sited over a low vulnerability aquifer. Between a highly vulnerable and a moderately vulnerable aquifer the same decision might not be so clear and the resultant action may depend on other specific issues at hand. The reason is that the hydrogeological information defining an aquifer's vulnerability varies in quality and quantity between aquifers. Furthermore, each classification is subjective and is designated for the aquifer as a whole and does not identify variations that may occur across it. It is possible, that there are areas within the moderately vulnerable aquifer that are highly vulnerable. In using these maps to screen potential sites for high-risk land-uses, the planner may want to focus on low vulnerability aquifers and eliminate moderate and high vulnerability aquifers if possible to be conservative.

Specific points to consider for each of the different vulnerability classes.

- **Highly vulnerable aquifers (A):** Areas overlying highly vulnerable aquifers require planners to consider activities that minimize the risk of contamination (e.g., zoning for a park rather than for industry) or to require safeguards to protect the resource. If, however, high-risk land use already exists over a highly vulnerable aquifer, then preventative measures and more stringent standards for operation should be considered (e.g., ensuring that stockpiled manure has proper storage cover and that a leachate collection system has been installed).

- **Moderately vulnerable aquifers (B):** Areas overlying moderately vulnerable aquifers may or may not be suitable for land uses that pose a high risk of groundwater contamination. Since an aquifer classified as moderately vulnerable may contain areas of both low and high vulnerability, no zoning change for a higher risk use over a B aquifer should be considered until the level of vulnerability for that specific site has been assessed.

- **Low-vulnerable aquifers (C):** Areas overlying low vulnerability aquifers are more likely to be considered for land uses that are high risk to groundwater (e.g., some industrial operations) than areas overlying A or B aquifers. As some C aquifers may still have areas vulnerable to contamination, a site-specific investigation is always recommended. It is also possible to introduce contamination into a "naturally protected" low vulnerability aquifer through improperly abandoned wells. To reduce the chance of this happening, proper well abandonment procedures should be promoted.

- **Non-data areas:** Blank areas on the aquifer classification maps (showing no aquifer polygons with their representative colour shading) mean simply that no aquifer data were available at the time of mapping. In a few instances, there are developed aquifers in the blank areas and unfortunately the information was not readily available to delineate and classify them. Generally, however, there is negligible or no groundwater use reported in the blank areas. In interpreting these areas for development, the planner must independently determine whether these areas are vulnerable to contamination.

  Sometimes, for areas where no aquifer classification mapping exists, groundwater potential can be inferred from surficial geology maps. Experience shows that areas directly underlain by glacio-fluvial and fluvial deposits comprising sand and/or gravel contain groundwater. These deposits are often the most vulnerable because they occur at the land surface.

  Blank map areas can be considered for siting higher-risk activities, but only on the condition that site-specific assessments be undertaken to confirm that no vulnerable aquifers underlie the areas in question, and that they are not recharge areas for more distant aquifers.

INTERPRETING LEVEL OF AQUIFER DEVELOPMENT WITHIN THE CONTEXT OF LAND-USE PLANNING

The definition of an aquifer's level of development is based on a combination of supply and demand factors. Like vulnerability, it is a subjective assessment derived from available information. As a result, care should be exercised in using level of development as a screening tool.

In most cases, a heavily developed aquifer will have a lower ratio of supply to demand than a moderately developed aquifer. However, a more detailed water availability assessment of a heavily developed aquifer could show additional water supplies are available for use. The existing classifications are likely to change as future human activity continues to expand and put increasing pressures on the aquifers.

In planning land use, it is necessary to look at an aquifer's productivity, the demand placed on it, and the areal extent (size) of the aquifer to assess the impact of increased water withdrawal on the aquifer from the proposed land uses. For example, land use causing increased water withdrawal may be supported if current demand on the aquifer is less than the aquifer's ability to replenish or recharge itself, regardless of the productivity of the aquifer. The productivity and the size of the aquifer, however, will dictate the type of land use that is suitable: while highly productive aquifers may have sufficient supplies for irrigation or industry, low productivity aquifers may only have sufficient supplies for domestic wells.

It is important to remember that though the aquifer classification maps provide an indication of the aquifer's productivity, they cannot determine actual water availability for a proposed development. If significant amounts of water were required for a particular land use, a consulting hydrogeologist would have to be hired to undertake test drilling and pump testing to confirm availability. Though the maps cannot answer the following questions, when making zoning decisions for a particular land use, planners should ask:

- In the aquifer being explored, are there sufficient water supplies available for use? The answer to this question would require a pump test.

- Can water be extracted from the ground at the rate required? The answer to this question would also require a pump test.

- Is the quantity of water being extracted sustainable, that is, will the demand be less than the aquifer's ability to naturally recharge itself? The answer to this question would require the aquifer to be monitored.

- Is there potential for well interference or negative impacts on surface water? The answer to this question would require an assessment of the aquifer.

Heavily developed aquifers (I): An aquifer defined as being heavily developed indicates existing high demands on the groundwater resource. However, this does not mean that more water could not be extracted. Rather, it is an indication that the aquifer should be assessed to determine whether new wells could be constructed without affecting the ability of existing wells to withdraw water. An aquifer can be de-watered (or mined) if too many wells extract water faster than the aquifer can be recharged. It indicates that more stringent standards for proof of water availability are required before a land use activity that requires additional water supplies is allowed. When assessing an aquifer's capacity to accommodate particular land uses, the aquifer's heavy level of development indicates the planner should consider in more detail the aquifer's capacity to store and yield water. It also indicates the need to monitor the water level.

Moderately developed aquifers (II): Moderately developed aquifers should be able to support more groundwater withdrawals than heavily developed aquifers. However, the proposed withdrawals must be appropriate to the productivity of the aquifer. For example, a low-productivity bedrock aquifer with low demand can be considered to be moderately developed, and an appropriate land use would be one that requires less groundwater to be viable (e.g., residential development with larger-size lots) than one that requires greater water supplies (e.g., irrigation).

Lightly Developed aquifers (III): Lightly developed aquifers should be able to accommodate greater demand on their water supplies then either of the previous two categories of aquifer development. However, the ability to increase demand depends on the aquifer's productivity. An areally extensive aquifer may have little demand placed on it and therefore be classified as lightly developed. However, if its capacity to yield water is limited (e.g., a bedrock aquifer with low productivity), then that may limit the type of development. The additional development may also change the classification from lightly to moderately developed.

Interpreting each aquifer's classification by vulnerability and level of development must be done on a case-by-case basis. The following two examples show why.

- A highly productive unconsolidated aquifer, extensive in size and with a low demand placed on it, may support a substantial increase in water withdrawal.

- A low productivity bedrock aquifer with a heavy demand already placed on it is unlikely to support any significant increased demand.

An aquifer classified as moderately or heavily developed and is moderately productive requires more assessment to establish its potential for a substantial increase in groundwater withdrawals. The amount and type of increase depends on how large the aquifer is and the rate at which water can be extracted. This combination of total available water in storage and the capacity of the aquifer to yield that water can dictate the appropriate land use.

Table 16 summarizes the nine different aquifer classification combinations of development and vulnerability, and describes briefly their implications for land use decisions. It should be noted that these are generalizations and exceptions exist.

The numbers in parentheses indicate the number of aquifers in British Columbia classified as of April 2000.

IA Aquifers	IIA Aquifers	IIIA Aquifers
• **IA** unconsolidated aquifers (14) are generally highly productive (11) with high demands (13) placed on them. • If a **IA** unconsolidated aquifer is large enough or productive enough, it may be able to support additional water withdrawals. • The province's single **IA** bedrock aquifer (high demand – low productivity) in Belcarra east of Vancouver, would have less potential for yielding additional supplies at high flow rates due to limited permeability. • **IA** aquifers require particular care and attention when it comes to land use activities that could affect water quality. Seven **IA** aquifers have documented quantity-related problems. • Recommend monitoring of water level and water quality to ensure aquifer is not over used or impacted by human activities.	• **IIA** unconsolidated aquifers (30) are moderately (16) to highly (14) productive with moderate (25) demands placed on them. • These unconsolidated aquifers should be able to support additional withdrawals depending on aquifer size and the amount of additional demands. • **IIA** bedrock aquifers (5) have generally low (5) productivity with moderate (4) demands placed on them and are less capable of yielding additional supplies than a **IIA** unconsolidated aquifer. • **IIA** aquifers require particular care and attention regarding land-use activities that could affect water quality. Nine **IIA** aquifers have documented quality-related problems and one **IIA** aquifer has a documented quantity-related problem.	• **IIIA** unconsolidated aquifers (57) are generally moderately (34) to highly (15) productive with low (56) demands placed on them. • These unconsolidated aquifers should be able to support additional withdrawals depending on aquifer size and the amount of additional demands. • There is a greater potential for increasing the water withdrawal from a **IIIA** unconsolidated aquifer than a **IA** aquifer. • **IIIA** bedrock aquifers (4) are generally low (3) in productivity with low (4) demands placed on them and are probably capable of yielding additional supplies at low rates. • **IIIA** aquifers require particular care and attention when it comes to land use activities that could affect water quality. Two **IIIA** aquifers have documented quality-related problems.
IB Aquifers	**IIB Aquifers**	**IIIB Aquifers**
• **IB** unconsolidated aquifers (4) are moderately (2) to highly (2) productive with moderate (2) and high (2) demands placed on them. • These unconsolidated aquifers may be able to support additional withdrawals depending on aquifer size and the amount of additional demands. • The province's single **IB** bedrock aquifer at Chemainus, BC (high demand – moderate productivity) may have less potential for yielding additional supplies at high rates due to limited permeability. • **IB** aquifers are moderately vulnerable to contamination. Until a site-specific study is undertaken, care and attention are needed when it comes to land use activities that could affect water quality. Two **IB** aquifers have documented quantity-related problems. • Recommend monitoring of water level and water quality to ensure aquifer is not over used or impacted by human activities.	• **IIB** unconsolidated aquifers (27) are generally moderately (16) to highly (8) productive with moderate (23) demands placed on them. • These unconsolidated aquifers may be able to support additional withdrawals depending on aquifer size and the amount of additional demands. • The bedrock aquifers (21) have moderate (5) to low (16) productivity with moderate (18) demands placed on them. • These bedrock aquifers may be able to support additional withdrawals if aquifer is extensive enough or if water is pumped from wells at low rates. • **IIB** aquifers are moderately vulnerable to contamination. Until a site-specific study is undertaken, care and attention are needed when it comes to land use activities that could affect water quality. • Eight **IIB** aquifers have documented quality-related problems and three IIB aquifers have documented quantity-related problems.	• **IIIB** unconsolidated aquifers (21) are generally moderately (18) productive with generally low (20) demands placed on them. • These unconsolidated aquifers should be able to support additional withdrawals depending on aquifer size and the amount of additional demands. • The **IIIB** bedrock aquifers (20) are generally low (16) in productivity with low (20) demands placed on them. • These bedrock aquifers are moderately vulnerable to contamination. Until a site-specific study is undertaken, care and attention are needed when it comes to land use activities that could affect water quality. Four **IIIB** aquifers have documented quality-related problems and one **IIIB** aquifer has a documented quantity-related problem.

TABLE 16. *General comments on the different aquifer classes and land use planning*

The numbers in parentheses indicate the number of aquifers in British Columbia classified as of April 2000.

IC Aquifers	IIC Aquifers	IIIC Aquifers
• **IC** unconsolidated aquifers (8) are generally moderately (4) to highly (3) productive with high (8) demands placed on them. • These unconsolidated aquifers are less likely to support additional withdrawals than **IIIC** unconsolidated aquifers. Developing a water budget for these aquifers is recommended. • The province's single **IC** bedrock aquifer (high demand-low productivity) west of Duncan on Vancouver Island is less likely to yield additional supplies at high sustainable rates due to low permeability. • **IC** aquifers are generally considered to have low vulnerability to contamination. However, a site-specific study is still needed before introducing major land use activities that could affect water quality. • One quality-related and one quantity-related problem have been documented in **IC** aquifers. • Recommend monitoring of water level and water quality to ensure aquifer is not over used or impacted by human activities.	• **IIC** unconsolidated aquifers (45) are generally moderately (37) productive with moderate (43) demands placed on them. • These unconsolidated aquifers may be able to support additional withdrawals depending on aquifer size and the rate and amount of the additional demands. • The bedrock aquifers (12) have moderate (3) to low (9) productivity with moderate (8) and low (4) demands placed on them. • To support additional withdrawals, these bedrock aquifers must be extensive enough or when demand is found to be less than the productivity. • When productivity is low and the demand is moderate, increasing demand must consider the limited permeability of the bedrock, which is usually far less than that found in unconsolidated aquifers. • **IIC** aquifers are generally considered to have low vulnerability to contamination. However, a site-specific study is still needed before introducing major land use activities that could affect water quality. Three quality-related and two quantity-related problems have been documented in **IIC** aquifers.	• **IIIC** unconsolidated aquifers (64) are generally moderately (51) to highly (9) productive with low (56) to moderate (8) demands placed on them. • These unconsolidated aquifers should be able to support additional withdrawals depending on aquifer size and the amount of additional demands. • The bedrock aquifers (26) are low (18) to moderate (8) in productivity with low (23) demands placed on them. • These bedrock aquifers may be able to support additional withdrawals depending on aquifer size and the nature of the demand. • Increasing demand needs to reflect the yield capability of the bedrock, which is usually far less than that found in unconsolidated aquifers. • **IIIC** aquifers are generally considered to have low vulnerability to contamination. However, a site-specific study is still needed before introducing major land use activities that could affect water quality. Only one quantity-related problem has been documented in **IIIC** aquifers.

TABLE 16 (cont'd). *General comments on the different aquifer classes and land use planning*

INTERPRETING THE AQUIFER RANKING VALUE WITHIN THE CONTEXT OF LAND-USE PLANNING

Assigning ranking values makes it possible to compare and prioritize aquifers at local, regional and provincial scales. This is particularly useful where aquifers have similar classifications. At a local scale, if two IA aquifers are being considered and one has a ranking value of 12 and the other 20, the latter is the one that can be assumed to have greater importance. The IA aquifer with a ranking value of 20 would likely have higher productivity, more varied water use, greater vulnerability, or quality/quantity concerns. The criteria (productivity, vulnerability, size of aquifer, demand, type of use, and quality and quantity concerns) used to produce the ranking value can contribute to the understanding the issues in an aquifer.

SOME BASIC ASSUMPTIONS ABOUT THE AQUIFER CLASSIFICATION SYSTEM

Several important assumptions should be kept in mind when using the maps and the information they contain for land use planning:

- Because the aquifers were subjectively classified, they must be treated subjectively. For example, though one aquifer can be said to be more vulnerable than another, how much more vulnerable cannot be determined from the maps. The same can be said with an aquifer's level of development.

- On each map, aquifers were classified based on information available at the time that the aquifer was delineated. In addition, the available information may not have been as "robust" as the mapper would have preferred. Though unlikely, it is possible that some aquifers may have to be reclassified in the future as more information becomes available. (This means that no aquifer classification should be assumed to be the "last word" and that any land use decision using the maps should recognize that fact.)

- Each classification is for the aquifer as a whole, and vulnerability, demand for water and productivity may vary across an individual aquifer. For this reason, a site-specific assessment (reviewing other available land and water information) is always necessary when decisions about specific land-use activities are being made.

- How the productivity of an aquifer has been interpreted on the maps can vary, and this variability must be taken into account when the information is to be used in a land use decision. There is a very high degree of confidence that a sand and gravel aquifer classified as highly productive will be more productive than a bedrock aquifer classified as having low productivity. And it is even probable that a sand and gravel aquifer classified as highly productive will be more productive than a sand and gravel aquifer classified as moderately productive.

However, there can be exceptions. For example, if all wells in an aquifer were developed, without well screens, for domestic purposes only and the wells had reported yields in the 0.5 to 1.5 litres per second (8 – 24 gpm) range (more than sufficient for domestic purposes), then the productivity would have been classified as moderate. If well screens had been used, then the wells would be more efficient and likely to produce higher yields. As a result, the productivity of the aquifer would have been classified as high.

Thus, when an aquifer classification map denotes a moderately productive aquifer, it should not be ruled out as a potential source of water. Again, reviewing other additional land and water information is always required before any important land use decision is made.

Since variability in both information and geology exists for aquifers in every region, consult with the Ministry of Water, Land and Air Protection or a professional hydrogeologist to obtain a better understanding of whether any of the above issues are a consideration in the planning project in your land use area.

INFORMATION THE AQUIFER CLASSIFICATION MAPS WILL NOT PROVIDE

The aquifer classification maps offer a considerable amount of information, but they do not include (nor were they intended to) a "one-stop" source for local land use planning.

For example, what the maps will not tell us:

- **Site-specific information**: For instance, using aquifer classification maps to determine lot size for septic tank installation is not recommended, as the resolution of the data used to define an aquifer is too broad to be applied to an area of such limited size.

- **Risk information**: The maps do not evaluate or determine risk. They estimate an aquifer's inherent vulnerability to contamination, but it is human activity above a vulnerable aquifer that contributes to an aquifer's risk of contamination.

- **Actual land use**: Present land use information is not available on the aquifer classification maps.

- **Other hydrogeological information**: The maps do not portray hydrogeological information such as direction of groundwater flow or the amount of recharge and the existence of discharge areas.

COMMON QUESTIONS ABOUT APPLYING THE AQUIFER CLASSIFICATION MAPS

The following questions and answers offer some additional insights to how the classification system can be applied in land use decision-making. (Users should remember that exceptions always exist which is why more detailed assessments are appropriate.)

Is one type of aquifer more productive than another?

Sand and gravel aquifers are generally more productive than bedrock aquifers, and experience shows that if a sand and gravel aquifer is productive, viable and located closely to where humans live and work, then the aquifer will be developed. The aquifer maps allow the user to identify nearby aquifers that have the greatest potential for providing alternative water supplies (e.g., a highly productive, lightly developed aquifer sand and gravel aquifer).

How much water is available for use?

The aquifer classification maps cannot answer this question. The maps can only compare one aquifer with another and indicate the potential for groundwater availability. If both an unconsolidated sand and gravel aquifer and a bedrock aquifer were the same size, greater amounts of accessible groundwater would be found in the unconsolidated aquifer. The unconsolidated aquifer would also be able to yield this water in much greater quantities than the bedrock aquifer (that is, there is a greater capacity to move a greater amount of water at a given moment). The significance of this is that unconsolidated aquifers are more likely to meet the requirements of larger water users, including community water supplies, industrial and agricultural (irrigation) needs. Bedrock aquifers generally yield less water and are normally capable of meeting lesser needs, such as domestic requirements. As stated earlier there are exceptions to this rule.

What is the current demand placed on this aquifer's water supply, and is that demand greater than, equal to or less than the amount being withdrawn?

Another way this question might be asked: Is the amount of water being pumped out of the ground greater than the aquifer's ability to naturally recharge from precipitation and surface bodies of water (i.e., streams, rivers, lakes)? Again the aquifer maps cannot specifically answer these questions. The maps can only provide, in relative terms, information about the demand placed on any given aquifer. If demand is high, there may not be additional water available for use; if demand is low, there could be. What is known is that in general a highly productive unconsolidated aquifer will have a far greater capacity to support a large-volume water user than a low productivity bedrock aquifer will.

How can the aquifer maps help resource managers and others protect groundwater supplies from human activities not normally associated with on-site activities?

One example where past groundwater contamination in British Columbia has occurred is the spillage of bulk chemicals during transfer. The most dramatic have been spills resulting from accidents on both road and rail. The classification maps provide managers and planners with interpreted groundwater information that can be used to support emergency spill response planning. The interpreted information includes:

- the location of an aquifer's boundaries;
- the importance of the aquifer (its level of development); and
- the aquifer's vulnerability to contamination.

This information allows the map user to identify where a contaminant spill is likely to impact vulnerable aquifers and therefore where to focus preventative measures. As well, the maps can be used to identify nearby aquifers that have the greatest potential to be alternative water supplies.

How can we prioritize the aquifers in our regional district for proper management?

Each aquifer should be considered in its two component parts – level of development and vulnerability. Aquifers designated with high levels of development (I or II) indicate their current importance as a water supply source. Aquifers designated as vulnerable (A or B) indicate their susceptibility to contamination. Assuming land uses have not changed significantly since these aquifers were mapped and classified, all four of those aquifer classes would normally be given higher priority than the III and C aquifers. Solutions to manage and safeguard them can range from non-regulatory methods, such as public education and water quality monitoring, to bylaws to protect them from being over-developed or put at risk from surface contamination.

Are there sufficient groundwater supplies to allow the density of a residential subdivision to be increased?

The maps cannot answer this question. A more detailed assessment of water availability by a hydrogeologist would be required. The maps may, however, indicate the likelihood that increasing lot density could be an issue. A highly productive IIIC sand and gravel aquifer is much more likely to support additional water withdrawals than a low productivity IB bedrock aquifer.

How much attention should be given to aquifers when considering zoning a parcel of land for the bulk storage of petroleum products?

The aquifer maps show the relative vulnerability of the aquifers. The high vulnerability A and B aquifers will be more susceptible to contamination than the low vulnerability C aquifers; though precautions must always be taken with higher risk substances, regardless of where they are stored. When the aquifer is highly developed, indicating its importance as a water supply, there is even further incentive to take precautions. Requirements for site risk assessments should be established and appropriate protective measures undertaken (if required) before permitting takes place.

Current land uses and how those uses are put into practice is also important information. Planners should know which land uses pose the greatest risk to the water supply. For example, a gas station on a highly vulnerable aquifer should require extra precautions. A gas station with a newly installed, double-walled underground gasoline storage tank is of less concern than a very old, underground gasoline storage tank.

Any high-risk land use near an important community water supply should be carefully assessed. Even a low vulnerability aquifer is at risk from human activities if an improperly abandoned well penetrates the low permeability layer overlying the aquifer and creates a direct conduit for a contaminant to enter the aquifer.

The aquifer maps are just one part of the puzzle in evaluating the groundwater resource and the risks to this resource.

Can aquifer boundaries be regarded as fixed limits within which to define areas of action?

Boundaries should not be regarded as fixed limits. They are delineated on the maps based on information at the time of assessment, and some boundaries may change as new information becomes available. Thus caution should be exercised when decisions are being made for areas close to aquifer boundaries – especially dashed boundaries. For example, land located immediately outside the delineated boundary of a vulnerable aquifer may, on further evaluation, also be found to be vulnerable, and so the boundary would be extended.

Do small aquifers make viable water supplies?

Though aquifers less than 1 km^2 are generally not mapped, many such aquifers do exist and have viable water supplies capable of meeting certain (e.g., domestic) water requirements. Consult Ministry of Water, Land and Air Protection or hire a professional hydrogeologist to review existing information before major land use changes are implemented.

How beneficial is present land use information when considered in conjunction with the aquifer classification maps?

Land use information can help a planner decide where to focus attention in further or additional site-specific analysis. For example, a moderately vulnerable (B) aquifer may be given a higher priority for monitoring over a highly vulnerable (A) aquifer if it is determined that the land use overlying the B aquifer shows a higher risk for contamination.

CLOSING REMARKS

British Columbia is blessed with many major aquifers that are capable of yielding large quantities of water to serve domestic, municipal, industrial and agricultural needs. In most cases, the natural chemical quality of the groundwater in the province is very good. Ensuring it stays that way means protecting it from the overuse and contamination that can accompany population growth and increased industrial and agricultural production. By far the easiest and most cost-effective groundwater protection actions are **preventative** in nature.

One of the first steps in managing and protecting groundwater is to understand the physical nature of the resource. Knowing where the aquifers are, the nature of their use, is a key to sensible development. Knowing the groundwater's vulnerability to potential contamination is key to effective protection. The Aquifer Classification System and maps provide just this information, offering planners, resource managers and stakeholders a means of optimizing water resource decisions related to land use and resource protection.

How can your jurisdiction develop and implement a groundwater protection plan?

1. Use the Aquifer Classification System and maps to identify what aquifers exist and where, and how they have been classified (in terms of vulnerability, level of development productivity, etc.). The maps can also be used to help raise public awareness of the local groundwater resource.

2. Use of the maps to identify aquifers that require more detailed assessment, including hydrogeologic mapping and identification of recharge and discharge areas. Consider developing operational policies for making hydrogeologic assessments of individual aquifers. For instance, water quality surveys, vulnerability mapping (Piteau Associates and Turner Groundwater Consultants. 1993a and 1993b) and monitoring programs could be initiated for high-vulnerability aquifers that have a moderate to heavy level of development (IA, IIA). These types of surveys or programs will assist in properly siting land-use activities and assessing any land-use impacts on water quality.

3. Obtain other data and information such as current water and land uses and projected population growth.

4. Estimate the costs both for preventative measures to protect your groundwater supplies versus for clean-up should the supplies become contaminated. This may show the economic advantage of groundwater protection.

5. Identify alternative water supplies and the probable costs required in bringing them online.

6. Investigate whether existing or past water quality concerns exist and what costs are associated with addressing them. (Knowing this information will make it easier to develop and promote your own groundwater protection initiatives.)

7. Study the different types of non-regulatory and regulatory measures that can be implemented to safeguard future groundwater resources. Information on regulatory and non-regulatory measures for groundwater protection can be found in the *Well Protection Toolkit* (Province of British Columbia, 2000) and *Groundwater Quality Protection Practices* (Golder Associates Ltd., 1995).

8. Formulate a protection plan by:

   - forming a "community planning team" to guide the development of a well protection plan;
   - mapping community wells and their capture zones;
   - mapping potential sources of contamination;
   - managing activities in the aquifer to prevent pollution and to reduce pollution risk;
   - developing a contingency plan against contaminant disasters; and monitoring, reporting and evaluating;
   - refer to the *Well Protection Toolkit* (Province of British Columbia, 2000) for a six-step process to well protection planning.

People involved with the groundwater resource are just starting to become familiar with and using the aquifer classification maps. This guidance document, designed to assist readers in interpreting and using these maps, is ever evolving as we gain more experience. To improve this guidance document, any feedback on the guide's clarity or ambiguity would be appreciated. Having groundwater information presented in a useful and understandable format will provide the tools to better protect and manage the groundwater resource.

Knowing how and where the aquifer classification maps have assisted you in your activities with the groundwater resource would also be beneficial to us. This information will assist in identifying uses and applications of the aquifer classification maps in assisting local agencies to protect this hidden but valuable resource.

Please send any comments regarding the maps or the guidance document to:

BC Ministry of Water, Land and Air Protection
Water Protection Section
PO Box 9340 Stn Prov Govt
Victoria, British Columbia
V8W 9M1

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APPENDIX A: GLOSSARY

Aquifer: A saturated geologic unit that yields water in a usable quantity to wells and springs. Geologic materials can be consolidated or unconsolidated. Therefore, the aquifer classification system refers to "unconsolidated aquifers" and "consolidated or bedrock aquifers".

Aquifer Classification: Categorizes aquifers according to their specific level of groundwater development and vulnerability to contamination, placing them into one of nine possible aquifer classes.

Aquitard: Less-permeable geologic unit than aquifers. They may be permeable enough to transmit significant quantities of water at a regional scale, but not enough to yield economic quantities of water to wells.

Artesian well: A well in which the water level rises above the top of an aquifer. (See flowing artesian well.)

Base Flow: The part of the stream flow that is derived from inflow of groundwater to the stream. The flow in a stream during the dry season is usually made up entirely of base flow.

Confined aquifer: A confined aquifer is an aquifer bounded both below and above by geologic units of considerably lower permeability than that existing in the aquifer itself. The groundwater in a confined aquifer can be under pressure that is significantly greater than that existing in the atmosphere. A confined aquifer is generally less vulnerable to contamination from the land surface than an unconfined aquifer because it is protected to some degree by the aquitard overlying it.

Consolidated materials (or bedrock): Geologic materials consisting of mineral particles of different sizes and shapes that have been welded into a rock by heat, pressure or chemical reactions.

Demand: Demand refers to the present level of ground-water use. Demand is one of the seven criteria used to rank the relative importance of an aquifer. Demand may be light, moderate or heavy.

Discharge area: The land area where groundwater flows back towards the land surface. Features that are common to discharge areas are springs, wetlands and shallow water tables.

Flowing artesian well: A well in which the water level rises above the ground surface and flows out under natural head pressure.

Geomorphology: Geomorphology is the science dealing with the origin and evolution of land forms.

Hydrogeologic mapping: Mapping groundwater and groundwater related features. A contour map of the water table, a map outlining the aquifer boundary and thickness, or a map showing the rate and direction of groundwater flow in an aquifer are examples of hydrogeologic maps.

Hydrogeology: The study of the flow of water and chemicals through the geological formations.

Hydrogeologic cycle: The continual circulation of water between the ocean, atmosphere, and land.

Level of groundwater development: Determined according to the amount of groundwater withdrawn from an aquifer (demand) relative to the aquifer's ability to supply groundwater for use (productivity).

Non-point Source Contamination: Contamination where the source is diffuse (e.g., urban runoff).

NTS map name and number: The name of the map sheet on all National Topographic Series (NTS) map sheets (e.g., Mission is the name of map sheet 92G/1). The NTS number is the number on the 1:50,000-scale map sheet (e.g., 092G1). Each aquifer is geo-referenced to an NTS map sheet name and number.

Permeability: The capacity of a porous rock, sediment, or soil for transmitting a fluid; it is a measure of the relative ease of fluid flow. Permeability is usually expressed in metres squared (m^2) or feet squared (ft^2). It is closely related to the hydraulic conductivity.

Perched groundwater system: Exists where a confining layer that occurs in more permeable material causes the groundwater to perch above the main saturated zone. Such a system produces its own water table called a "perched water table" above the main water table.

Productivity: Productivity describes an aquifer's ability to yield water and is inferred from aquifer transmissivity values, specific capacity of wells, well yields, description of aquifer materials and sources of recharge (e.g., rivers or lakes), or a combination of all of these factors. Productivity is one of the seven criteria used to rank the relative importance of an aquifer.

Pumping test: A test that is conducted to determine aquifer or well characteristics. A pumping test is usually conducted to determine the transmissivity and storativity characteristics of an aquifer and the capacity of a well supply.

Quality concerns: Quality concerns are actual documented concerns on file with the Groundwater Section. Quality concerns is one of the seven criteria used to rank the relative importance of an aquifer. The concerns may be isolated, local or regional in extent. It is possible to have no quality concerns documented.

Quantity concerns: One of the seven criteria used to rank the relative importance of an aquifer. Quantity concerns are actual documented concerns on file with the Groundwater Section. The concerns may be isolated, local or regional in extent. It is possible to have no quality concerns documented.

Ranking value: The sum of the point values for each of the following physical criteria: productivity, size, vulnerability, demand, type of use and documented quality and quantity concerns.

Recharge area: Land area where water infiltrates into the ground and replenishes the aquifer.

Transmissivity: The rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient. Transmissivity of an aquifer is the hydraulic conductivity of the aquifer multiplied by the aquifer thickness. Transmissivity is expressed as metres squared per second (m^2/s), feet squared per day (ft^2/d), or gallons per day per foot (gpd/ft).

Unconfined aquifers: An aquifer where its upper boundary is defined by the water table. Where no aquitards overlie the aquifer, the aquifer is said to be "unconfined." Unconfined aquifers are generally more vulnerable to impacts from human activities at the land surface, particularly if the water table is shallow.

Unconsolidated sediments: Material that has disintegrated (e.g., gravel, sand, silt, clay, and till) from consolidated rocks.

Unsaturated, or vadose, zone: The zone between the land surface and the water table. The pore spaces or interstices may contain water at less than atmospheric pressure, and also air and other gases. Perched groundwater bodies (local saturated zones) may exist in the unsaturated zone.

Vulnerability: Vulnerability of an aquifer to contamination is based on type, thickness and extent of geologic materials above the aquifer, depth to water table (or to top of confined aquifer) and type of aquifer materials. Vulnerability is one of the seven criteria used to rank the relative importance of an aquifer. Vulnerability may be high, medium or low. Land use activities are not considered in determining an aquifer's vulnerability.

Water table: The top of the unconfined aquifer; water level where the pressure is equal to that of the atmosphere; water level in a shallow well.

Water table wells: Wells constructed in unconfined aquifers, where the well water level is that of the water table.

Well interference: When the area of influence, or the cone of depression around a water well comes into contact with or overlaps that of a neighbouring well pumping from the same aquifer and thereby causes additional drawdown or drawdown interference in the wells.

Well tag number: A unique identification number assigned to a particular well in the WELL database.

APPENDIX B: ACCESSING THE GROUNDWATER SECTION WEB SITE AND DATABASES

The B.C. Ministry of Water Land and Air Protection 's groundwater web site is located at:
http://wlapwww.gov.bc.ca/wat/gws/gwis.html

The Ministry updates the water well database once a month. At this site, you will also find:

- query access to the Ministry's well databases;
- access to groundwater-related publications;
- access to free groundwater software, a data capture system to provide water well drillers with an easy to use customizable database;
- a listing of groundwater consultants in British Columbia;
- a discussion on groundwater issues in British Columbia;
- a discussion of the British Columbia Environmental Assessment Act and those sections that are concerned with groundwater;
- information on the provincial observation well network;
- a reference library;
- a list of charges and fees for maps and services;
- Ministry staff contact information;
- the water quality limits for the different elements that can be found in water;
- a set of guidelines *The Well Protection Toolkit* for the six-step approach on how a community or water purveyor can develop and put into place a well protection plan to prevent contamination of their well water supply;
- well testing guidelines; and
- links to other groundwater web sites.

The BC Aquifer Classification System Database is located at:
http://wlapwww.gov.bc.ca/wat/aquifers/index.html

The aquifer classification system database can be queried for the following fields: aquifer number, aquifer name, National Topographic System (NTS) number, NTS map name, descriptive location, adjoining map sheet, materials, litho-stratigraphic unit, classification, ranking value, size, productivity, vulnerability, demand, type of water use, quality concerns and quantity concerns .

The results of a query can be output in database or spreadsheet format and links exist to more help with querying and descriptions of all of the search criteria as well as database and technical support contacts.

Aquifer image portfolio

A sketch map of most of the individual aquifers can also be viewed at
http://wlapwww.gov.bc.ca/wat/aquifers/aqmaps/viewmaps.html

If you know the aquifer number click "**Choose by Aquifer Number**". If you don't know it, you can find it by querying the aquifer database at the web site noted above. Clicking the "**Help on using this screen**" link located at the bottom of the "**Query the Aquifer Database**" page will help you query the aquifer database.

Well information

Well information can be found in two locations: 1) the WELL database; and 2) Waterbot.

Water well data made available through the Computerised Groundwater Data System was transferred to a new VAX system on October 16, 1995, and renamed the WELL database. WELL and Waterbot are two ways of accessing the same well record database. Querying both will offer identical information.

- WELL
  The WELL database allows you to make queries for and by a number of search criteria: land district, range, township, district lot, section, lot, plan,

street name, well tag number, lithology, observation well number, British Columbia Geographic System (BCGS) map sheet, and island. A link to help with querying is included. Results can be sorted and the number of wells found in a certain area can be calculated.

- Waterbot
  Waterbot allows you to query the database beginning from the selection of a map sheet based on either the (BCGS) or the National Topographic System (NTS). Search criteria include: well tag number with output in a standard format developed in conjunction with the British Columbia Ground Water Association, street name, BCGS number for a summary of water wells or lithologies, legal land descriptions and particular geographic areas. Search results can be saved in spreadsheet or database format.

Note that accessing the Aquifer Classification System is particularly useful for obtaining information for regional planning and management. For compiling original data for purposes such as determining average well depth or for examining well lithologies, the water well database is more useful.

At this time, the well records are not linked to the aquifers delineated through the Aquifer Classification System. It is not possible to query the well records or the aquifers for all the well records that are found in the area of any given aquifer.